BEFORE THE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI
IN
ORIGINAL APPLICATION NO. 588 of 2025

IN THE MATTER OF:

SANJAY SHARAN ……. APPLICANT

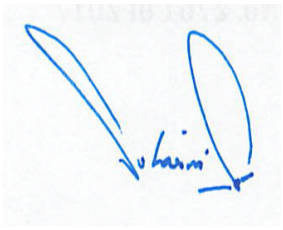
VERSUS

UNION OF INDIA & ORS. ……RESPONDENTS

INDEX

S. No.	PARTICULARS	PAGE NO.
1.	Reply Affidavit on behalf of Respondent No.2 Ministry of Environment, Forest & Climate Change (MoEF&CC)	1-5
2.	**Annexure-R2/1 -** A Copy of the order of the Hon'ble NGT dated 20.11.2025	6-7
3.	**Annexure- R2/2 -** A Copy of the order of the Hon'ble Supreme Court dated 02.04.2025 in M.C Mehta v Union of India W.P (C) No.13029/1985	8-24
4.	**Annexure-R2/3 -** A Copy of reply affidavit filed by MoEF&CC in M.C Mehta v Union of India W.P (C) No.13029/1985	25-570
5.	**Annexure-R2/4 (Colly) –** Copies of orders dated 17.11.2017, 08.04.2019 and 29.07.2020 passed by Hon'ble Supreme Court in M.C Mehta v Union of India W.P (C) No.13029/1985	571-608

THROUGH



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New Delhi
Date – 08.01.2026

BEFORE THE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI
IN
ORIGINAL APPLICATION NO. 588 of 2025

IN THE MATTER OF:

SANJAY SHARAN ..... APPLICANT

VERSUS

UNION OF INDIA & ORS. .....RESPONDENTS

REPLY AFFIDAVIT ON BEHALF OF RESPONDENT No. 2, THE MINISTRY OF ENVIRONMENT, FORESTS & CLIMATE CHANGE.

I, V. Pazhaniyandi, S/o Shri Velayudhan Pillai, aged about 46 years, presently working as Director in the Ministry of Environment, Forest and Climate Change (MoEF&CC), Government of India having its office at New Delhi, do hereby solemnly affirm and declare as under:

1. That I am duly authorized by the Ministry of Environment, Forest and Climate Change, respondent no. 2 to swear this affidavit and I am conversant with the facts and circumstances of the present case and am thereby competent to depose as under:

2. That the applicant has preferred the present application seeking the quashing of Notification No. GSR 465(E) dated 11.07.2025 issued by the Ministry of Environment, Forest and Climate Change (MoEF&CC).

NOTARY R.V. SINGH Advocate Regn. No. 2282 Commission Expire on 24-10-2027 Area-Delhi GOVT. OF INDIA

3. That, the present affidavit is filed in respectful compliance of the order of this Hon'ble Tribunal dated 20.11.2025. That vide aforesaid order this Hon'ble Tribunal was pleased to *inter-alia* direct as follows;

> *".....Learned counsel appearing for the MoEF&CC on advance notice has submitted that the same issue is under consideration before the Hon'ble Supreme Court in W.P. (C) No. 13029/1985, MC Mehta v. UOI & Ors.-In Re: Power Plants, wherein the MoEF&CC has filed a detailed affidavit justifying the extension of date for complying with SO2 norms. She submits that along with the affidavit the impugned notification has been placed on record and the Ministry will be justifying the issuance of the impugned notification before the Hon'ble Supreme Court. She is permitted to place on record the affidavit of the MoEF&CC filed before the Hon'ble Supreme Court along with the relevant orders of the Hon'ble Supreme Court by supplying an advance copy to the counsel for the Applicant within three weeks....."*

A copy of order dated 20.11.2025 is annexed as **Annexure- I**.

4. In this regard, it is respectfully submitted that Hon'ble Supreme Court vide its order dated 02.04.2025 passed the following direction as under:

R.V. SINGH
Advocate
Regn.No.2282
Commission
Expire on
24-10-2027
Area-Delhi
GOVT. OF INDIA

***Para 2**. The learned Amicus Curiae has today flagged the issue of 11 Thermal Power Plants, which are located within 300 kilometers of Delhi. We are concerned with the compliance regarding SO2 emission standards. There are two issues. The first is whether categorization of the Thermal Power Plants within the distance of 300 kilometers from Delhi can be changed. For that purpose, amendment to Schedule I of the Environment (Protection) Rules, 1986 will be required. The second issue is about the timelines for compliance with the SO2 emission standards.*

***Para 3**. The question is whether the timelines up to 31st December, 2029 as stated in Schedule I can be reduced. On the aspect of classification and on the aspect of reducing the timelines, we will need a response of the Ministry of Environment, Forest and Climate Change, Government of India.*

A copy of order dated 02.04.2025 is annexed as **Annexure II**.

5. That pursuant to the directions of the Hon'ble Supreme Court, the answering respondent filed a reply affidavit on 12.08.2025, wherein it was respectfully submitted that the notification dated 11.07.2025 was issued after carrying out due diligence and upon consideration of the scientific reports and technical analyses undertaken by the Central Pollution Control Board (CPCB), the National Institute of Advanced Studies (NIAS), IIT

NOTARY R.V. SINGH Advocate Regn.No.2282 Commission Expire on 24-10-2027 Area-Delhi GOVT. OF INDIA

Delhi, and CSIR–NEERI. The said reports, inter alia, evaluated the prevailing ambient SO_2 levels vis-à-vis the National Ambient Air Quality Standards (NAAQS) and conducted a cost-benefit assessment of installing Flue Gas Desulfurization (FGD) systems. It was further submitted that the impugned notification incorporates the precautionary principle, mandates enhancement of stack heights in accordance with the notification dated 30.08.1990 in all Thermal Power Plants where installation of FGD is not recommended, and makes installation of FGD systems mandatory in all Category-A Thermal Power Plants. A copy of the reply affidavit filed before the Hon'ble Supreme Court is annexed as **Annexure–III.**

6. It is further most respectfully submitted that the matter with respect to compliance with various emission norms by the thermal power plants in the country, and the timelines for such compliance have been monitored by the Hon'ble Supreme Court from time to time in the matter of ***W.P. (C) 13029/1985 'M.C. Mehta v. Union of India'***. A few of such orders are placed on record for the perusal of this Hon'ble Tribunal. A true copy of order dated 17.11.2017, 08.04.2019 and 29.07.2020 are annexed hereto for the perusal of this Hon'ble Court as **Annexure -IV (Colly).**

7. That in view of the above, it is most respectfully prayed that this Hon'ble Tribunal may be pleased to take this affidavit on record and pass such

NOTARY R.V. SINGH Advocate Regn.No.2282 Commission Expire on 24-10-2027 Area-Delhi GOVT. OF INDIA

order(s)/directions as may be deemed just and proper in the facts and circumstances of the case

DEPONENT

(PAZHANIYANDI. V.)
निदेशक (री.पी.)/Director (CP)
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
M/o Environment,Forest and Climate Change
भारत सरकार, नई दिल्ली
Govt. of India, New Delhi

VERIFICATION:

15 JAN 2026

Verified at on this the day of 2026 that the contents of this reply affidavit based on official record(s) maintained and information available in the office are correct to my knowledge and belief. No part of it is false and nothing has been concealed there from.

I identified the deponent/executant who has signed in my presence

DEPONENT

(PAZHANIYANDI. V.)
निदेशक (री.पी.)/Director (CP)
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
M/o Environment,Forest and Climate Change
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Govt. of India, New Delhi

NOTARY
R.V. SINGH
Advocate
Regn.No.2282
Commission
Expire on
24-10-2027
Area-Delhi
GOVT. OF INDIA

CERTIFIED THAT THE DEPONENT
Shri/Smt/Km. V. Pazhaniyandi
S/o.W/o.D/o Sh. R/o
Identified by Shri/Smt. Sadhna Mishra Adv
has solemnly affirmed before me at Delhi
on 15 JAN 2026 at 2 Nos.
that the contents of the affidavit which have been read over & explained to him/her are true & correct to his/her knowledge

Notary Public, Delhi

15 JAN 2026

Item No. 05 Court No. 1

BEFORE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI

Original Application No. 588/2025

Sanjay Sharan Applicant

Versus

MoEF&CC & Ors. Respondent(s)

Date of hearing: 20.11.2025

CORAM: HON'BLE MR. JUSTICE PRAKASH SHRIVASTAVA, CHAIRPERSON
HON'BLE DR. A. SENTHIL VEL, EXPERT MEMBER

Applicant: Mr. Sanjay Upadhyay, Senior Advocate with Ms. Mansi Bachani, Mr. Mohd. Faisal, Mr. M.K. Saxena & Ms. Satvika Krishnan, Advs.

Respondent: Ms. Suhasini Sen, Ms. Supraja V. & Ms. Masooma Rizvi, Advs. for MoEF & CC

ORDER

1. By way of this Original Application (OA), the Applicant is seeking quashing of the Notification No. GSR 465(E) dated 11.07.2025 issued by the MoEF&CC. The stand of the Senior Counsel for the Applicant is that Hon'ble Supreme Court by order dated 08.08.2025 passed in W.P. (C) No. 750/2025 in the case of *Sanjay Sharan v. UOI & Ors.*, while dismissing the writ petition relegated the petitioner to take recourse either before the NGT or jurisdictional High Court. He submits that in pursuance to the said order, present OA has been filed.

2. Learned counsel appearing for the MoEF&CC on advance notice has submitted that the same issue is under consideration before the Hon'ble Supreme Court in W.P. (C) No. 13029/1985, *MC Mehta v. UOI & Ors.*-In Re: Power Plants, wherein the MoEF&CC has filed a detailed affidavit justifying the extension of date for complying with SO_2 norms. She submits that along

with the affidavit the impugned notification has been placed on record and the Ministry will be justifying the issuance of the impugned notification before the Hon'ble Supreme Court. She is permitted to place on record the affidavit of the MoEF&CC filed before the Hon'ble Supreme Court along with the relevant orders of the Hon'ble Supreme Court by supplying an advance copy to the counsel for the Applicant within three weeks.

3. List on 21.01.2026.

Prakash Shrivastava, CP

Dr. A. Senthil Vel, EM

November 20, 2025
Original Application No. 588/2025
A

ANNEXURE R2/2

ITEM NO.41 COURT NO.4 SECTION PIL-W

S U P R E M E C O U R T O F I N D I A
RECORD OF PROCEEDINGS

WRIT PETITION(S)(CIVIL) NO(S). 13029/1985

M.C. MEHTA Petitioner(s)

VERSUS

UNION OF INDIA & ORS. Respondent(s)

[TO BE TAKEN UP AT 12:00 NOON]..... IN RE: MUNICIPAL SOLID WASTE AND IN RE: PAYMENT OF COMPENSATION AND IN RE: POWER PLANTS NAME OF THE FOLLOWING ADVOCATES MAY BE TREATED TO HAVE BEEN SHOWN IN THE LIST: MR. HARISH N. SALVE, SR. ADVOCATE (A.C.) MS. APARAJITA SINGH, SR. ADVOCATE (A.C.) MS. UTTARA BABBAR, SR. ADVOCATE (A.C.) MR. A.D.N. RAO, SR. ADVOCATE (A.C.) MS. SHIBANI GHOSH, ADVOCATE (A.C.) MR. SIDDHARTHA CHOWDHURY, ADVOCATE (A.C.) MR. G.S. MAKKER, MR. AMRISH KUMAR, MR. M.K. MARORIA, MR. SANJAY KR. VISEN, MR. SUDEEP KUMAR, MR. KARAN SHARMA, MR. SANDEEP KR. JHA, MR. JYOTI MENDIRATTA, MR. RAHUL KHURANA, MR. PRANAV SACHDEVA, ADVOCATES

Date : 02-04-2025 This petition was called on for hearing today.

CORAM :
HON'BLE MR. JUSTICE ABHAY S. OKA
HON'BLE MR. JUSTICE UJJAL BHUYAN

Ms. Aparajita Singh, Sr. Adv. (A.C)
Ms. Uttara Babbar, Sr. Adv. (A.C)
Ms. Shibani Ghosh, Adv.

For Petitioner(s): Applicant-in-person, AOR

Petitioner-in-person

For Respondent(s): Mrs. Aishwarya Bhati, A.S.G.
Mrs. Ruchi Kohli, Sr. Adv.
Mr. Mukesh Kumar Maroria, AOR
Mrs. Suhasini Sen, Adv.
Mr. Rajesh Kr. Singh, Adv.
Mr. Subhranshu Padhi, Adv.
Mr. Jagdish Chandra Solanki, Adv.
Mr. Gaurang Bhushan, Adv.

Dr. Menaka Guruswamy, Sr. Adv.
Mr. Wasim S. Qadri, Sr. Adv.
Mr. Utkarsh Pratap, Adv.
Ms. Arunima Das, Adv.
Mr. Devesh Maurya, Adv.
Mr. Ravi Kumar, Adv.

Mr. Aditya Sondhi, Sr. Adv.
Ms. Jyoti Mendiratta, AOR
Ms. Ananya Basudha, Adv.
Mr. Rijjuk Sarkar, Adv.
Mr. Ravender Pal Singh, Adv.

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Mrs. Ruchi Kohli, Sr. Adv.
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Mr. Ejaz Maqbool, AOR

Mr. Prashant Kumar, AOR

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Mr. B.K. Satija, A.A.G.
Mr. Rakesh Kumar Mudgal, A.A.G.
Mr. Akshay Amritanshu, AOR
Mr. Rahul Khurana, Adv.
Mr. Nikunj Gupta, Adv.
Ms. Drishti Saraf, Adv.
Ms. Pragya Upadhyay, Adv.
Ms. Aakanksha, Adv.
Ms. Ishika Gupta, Adv.
Mr. Sarthak Arya, Adv.

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Mr. Radha Shyam Jena, AOR

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Mr. Rakesh K. Sharma, AOR

Ms. Sujeeta Srivastava, AOR

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Mr. Alim Anvar, Adv.
Mr. Santhosh K, Adv.

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Mr. Abhishek, AOR

Mr. Alok Gupta, AOR

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Mr. R. P. Gupta, AOR

Mr. P. Parmeswaran, AOR

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Ms. Baby Devi Bonia, Adv.
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Mr. Shubhranshu Padhi, Adv.
Mr. Gaurang Bhushan, Adv.
Mr. Raghav Sharma, Adv.
Ms. Kanu Agrawal, Adv.
Mr. Bhuvan Kapoor, Adv.
Mr. Varun Chugh, Adv.
Mr. Krishna Kant Dubey, Adv.
Ms. Indira Bhakar, Adv.
Mr. Jagdish Chandra, Adv.
Mr. Shreekant Neelappa Terdal, AOR

Mr. Avi Singh, Sr. Adv.
Mr. Shiven Varma, Adv.
Mr. Saurabh Agrawal, AOR
Mr. Kirti Raj, Adv.
Ms. Komal Mundhra, Adv.

Mr. Devansh Srivastava, AOR

Mr. Shekhar Kumar, AOR

M/S. S. Narain & Co., AOR

Ms. Aswathi M.k., AOR

Mr. Neeraj Shekhar, AOR
Mrs. Kshama Sharma, Adv.
Mr. Rajesh Kumar Maurya, Adv.

Ms. Lubna Naaz, AOR

Mr. Parminder Singh Bhullar, AOR

Mr. Chandrakant Sukumar Sarkar, Adv.
Mr. Mukesh Kumar Singh, Adv.
Mr. Narendra Kumar Goyal, Adv.
Mr. Naveen Yadav, Adv.
Mr. C M Dwivedi, Adv.
Mr. Ikshit Singhal, Adv.
For M/S. Mukesh Kumar Singh And Co., AOR

Mr. Alok Gupta, AOR

Mr. K. V. Mohan, AOR

Mr. Yash S. Vijay, AOR

M/S. Lex Regis Law Offices, AOR

Ms. Jaikriti S. Jadeja, AOR

Mr. Rajan Narain, AOR

Mr. Gaurav, AOR

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Mr. Mohit Paul, AOR

Mr. Shalen Bhardwaj, Adv.
Mr. Virender Kumar, Adv.
Ms. Garima Kumar, Adv.
Mr. Ashok Kumar Panigrahi, Adv.
Ms. Lakshmi, Adv.
Mr. Nischal Kumar Neeraj, AOR

Ms. Aastha Mehta, Adv.
Ms. Deepanwita Priyanka, AOR
Ms. Prerana Mohapatra, Adv.
Ms. Prina Sharma, Adv.
Mr. Deepak Singh, Adv.

Ms. Ankita Sharma, AOR
Mr. Arjun D Singh, Adv.

Mr. Kumar Dushyant Singh, AOR

Mr. A. Venayagam Balan, AOR

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Mr. Chitrangda Rastravara, Adv.
Ms. Shivika Mehra, Adv.
Mr. Madhav Sinhal, Adv.
Mr. Chitvan Singhal, Adv.
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Ms. Suhasini Sain, Adv.

Mr. Shubhranshu Padhi, Adv.
Mr. Rajesh Kr. Singh, Adv.
Mr. Gaurang Bhushan, Adv.
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Mr. Nishit Agrawal, AOR

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Mr. Anando Mukherjee, AOR

Ms. Sanjivani Aggarwal, Adv.
Ms. Jyoti Aggarwal, Adv.
Mr. Pradeep Aggarwal, Adv.
Ms. Filza Moonis, AOR

Mr. Divyanshu Kumar Srivastava, AOR

Mr. Rajiv Yadav, AOR

Ms. Madhumita Bhattacharjee, AOR

Mr. Ayush Sharma, AOR

Mr. Gopal Jha, AOR

Mr. Pradeep Misra, AOR
Mr. Daleep Dhyani, Adv.
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Mr. Surjeet Singh, Adv.
Mr. Chanakya Baruah, Adv.
Ms. Saloni, Adv.
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Mr. Pulkit Agarwal, AOR

Mr. S S Bandyopadhyay, Adv.
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Mr. Abhaya Nath Das, Adv.
Ms. Anjana Sharma, Adv.
Ms. Swagoti Batchas, Adv.
Mr. Om Prakash, Adv.
Ms. Swati Mishra, Adv.
Mr. Abhay Singh, Adv.
Mr. Kishor Kumar Mishra, Adv.

Dr. Aditya Mishra, Adv.
Mr. Satish Kumar, AOR

Ms. Ameyavikrama Thanvi, AOR

Ms. K. Enatoli Sema, AOR
Mr. Amit Kumar Singh, Adv.
Ms. Chubalemla Chang, Adv.
Mr. Prang Newmai, Adv.

Mr. Anas Tanwir, AOR

Ms. Puja Sharma, AOR

Mr. Shishir Deshpande, AOR

Mr. D. Kumanan, AOR

Ms. Rakhi Ray, AOR

Ms. Ishita Jain, AOR

Mr. Manish Kumar Gupta, AOR

Mr. Sravan Kumar Karanam, AOR
Mr. Abhiram Bannur, Adv.
Mr. P. Venkatraju, Adv.

UPON hearing the counsel the Court made the following

O R D E R

IN RE: POWER PLANTS

1. We have heard Ms. Aparajita Singh, learned Senior Advocate appointed as Amicus Curiae on the issue of power plants and Ms. Aishwarya Bhati, learned ASG representing the CAQM as well as the Union of India.

2. The learned Amicus Curiae has today flagged the issue of 11 Thermal Power Plants which are located within 300 kilometers of Delhi. We are concerned with the compliance regarding SO_2 emission standards. There are two issues. The first is whether categorization of the Thermal Power Plants within the distance of 300 kilometers from

Delhi can be changed. For that purpose, amendment to Schedule I of the Environment (Protection) Rules, 1986 will be required. The second issue is about the timelines for compliance with the SO_2 emission standards. Out of the 11 Thermal Power Plant units, we find that the units at Dadri NCTPP, NTPC, Uttar Pradesh and Mahatma Gandhi TPS, Jhajjhar Power, Haryana, there is a compliance. In the case of power plants at Indira Gandhi STPP, NTPC, Haryana and Harduaganj TPS, UPRVUNL, Uttar Pradesh, there is a partial compliance. As regards power plant at Rajpura TPP, NPL-L&T, Punjab, it is mentioned that FGD is installed in both the units, but the system is presently not operational in these units.

3. The question is whether the timelines up to 31st December, 2029 as stated in Schedule I can be reduced. On the aspect of classification and on the aspect of reducing the timelines, we will need a response of the Ministry of Environment, Forest and Climate Change, Government of India. While we do so, we have to also ensure that the timelines are not repeatedly extended. Therefore, it will be appropriate if a notice is issued to the non-compliant Thermal Power Plants so that effective directions can be issued against them. Accordingly, issue notice to the following Thermal Power Plants, returnable on 29th April, 2025:

1.	**Indira Gandhi STPP, NTPC, Haryana;**

2.	Panipat TPS, HPGCL, Haryana;
3.	Rajiv Gandhi TPS, HPGCL, Haryana;
4.	Yamuna Nagar TPS, HPGCL, Haryana;
5.	Rajpura TPP, NPL-L&T, Punjab;
6.	Talwandi Asbo TPP, TSPL-Vedanta, Punjab;
7.	GH TPS (Lehra Mohabbat), PSPCL;
8.	Ropar TPS, PSPCL, Punjab; and
9.	Harduaganj TPS, UPRVUNL, Uttar Pradesh

The Union of India to furnish addresses of the aforementioned Thermal Power Plants. A copy of this order shall accompany the Notice.

4. In the meanwhile, we direct the Ministry of Environment, Forest and Climate Change to file its response in terms of what we have observed in this Order and in terms of the Note submitted by the learned Amicus Curiae for today's hearing. The said response shall be filed at least three days before the returnable date.

5. List on 29th April, 2025 at 12:00 noon.

IN RE: SUBSISTENCE ALLOWANCE

6. We have perused the affidavit filed by the Delhi Government in compliance with the order dated 28th February, 2025. The learned senior counsel representing the National Campaign Committee (NCC) and the learned senior counsel appearing for the Centre for Holistic Development, have several issues about the affidavit of the Delhi Government. We direct both the entities to file their counter dealing with the affidavit filed by the Delhi Government and also

place material on record giving names of the construction workers who actually worked during GRAP-IV period. They must also set out in what manner the verification has been carried out to ascertain whether the workers had worked during the relevant period. Time of three weeks is granted to them to file their counter.

7. The Delhi Government will also address this Court on the question whether the verified workers can be denied amount payable on the ground that their bank accounts are not linked with Aadhaar. This aspect will be considered on 29th April, 2025 at 12:00 noon.

IN RE: SOLID WASTE MANAGEMENT

8. This issue will be considered on 8th April, 2025 at 12:30 p.m.

(ASHISH KONDLE)
ASTT. REGISTRAR-cum-PS

(AVGV RAMU)
COURT MASTER (NSH)

ANNEXURE R2/3

IN THE SUPREME COURT OF INDIA

CIVIL ORIGINAL JURISDICTION

WRIT PETITION (CIVIL) NO. 13029 OF 1985

IN THE MATTER OF:

M.C MEHTA ...PETITIONER

VERSUS

UNION OF INDIA & ORS. ...RESPONDENTS

INDEX

S.NO	PARTICULARS	PAGE NOS.
1.	REPLY AFFIDAVIT ON BEHALF OF MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE, OF THIS HON'BLE COURT.	1 - 11
2.	ANNEXURE-I COPY OF HON'BLE COURT ORDER DATED 02.04.2025	12-28
3.	ANNEXURE-II COPY OF CPCB REPORT	29-548
4.	ANNEXURE-III COPY OF NOTIFICATION DATED 11.07.2025.	549-555

G.S. Makker

Counsel for Union of India

PLACE: NEW DELHI

DATE:

IN THE SUPREME COURT OF INDIA
CIVIL ORIGINAL JURISDICTION
WRIT PETITION (CIVIL) NO. 13029 OF 1985

IN THE MATTER OF:

M C MEHTA ...PETITIONER

VERSUS

UNION OF INDIA & ORS. ...RESPONDENTS

REPLY AFFIDAVIT ON BEHALF OF MINISTRY OF ENVIRONMENT, FOREST AND CLIAMTE CHANGE, IN COMPLIANCE OF THIS HON'BLE COURT ORDER DATED 02.04.2025.

I, V. Pazhaniyandi, S/o Shri Velayudhan Pillai, aged 46 years, presently posted as Director in Ministry of Environment, Forests & Climate Change, Government of India having its office at New Delhi, do hereby solemnly affirm and declare as under:

NOTARY R.V. SINGH Advocate Regn.No.2202 Commission Expiry on 24.10.2027 Area-Delhi GOVT. OF INDIA

1. That, I am well acquainted with the facts and circumstances of the present case and competent to swear this affidavit in the instant Writ Petition.

2. That, the present affidavit is filed in respectful compliance of the order of this Hon'ble Court dated 02.04.2025. That vide aforesaid order this Hon'ble Court was pleased to *inter-alia* direct as follows:

> ***Para 2.*** *The learned Amicus Curiae has today flagged the issue of 11 Thermal Power Plants, which are located within 300 kilometers of*

Delhi. We are concerned with the compliance regarding SO2 emission standards. There are two issues. The first is whether categorization of the Thermal Power Plants within the distance of 300 kilometers from Delhi can be changed. For that purpose, amendment to Schedule I of the Environment (Protection) Rules, 1986 will be required. The second issue is about the timelines for compliance with the SO2 emission standards.

Para 3. *The question is whether the timelines up to 31st December, 2029 as stated in Schedule I can be reduced. On the aspect of classification and on the aspect of reducing the timelines, we will need a response of the Ministry of Environment, Forest and Climate Change, Government of India.*

A copy of the Hon'ble Court order dated 02.04.2025 is annexed at **ANNEXURE- I.**

3. That in March 2021, MoEF&CC vide amendment notification dated 31.03.2021 prescribed the categorisation of TPPs into Category A, B, and C, based on TPPs' location, with extended time limits for compliance up to December 2022, December 2023, and December 2024, respectively. In September 2022, MoEF&CC vide amendment notification dated 05.09.2022 extended the time limits for SO2 emission limit compliance for Category A, B, and C plants by 2 years i.e. up to December 2024, December 2025, and December 2026, respectively. In December 2024,

NOTARY R.K. Singh Regd. No. 2007 Commission Expires on 24-10-2027 New Delhi GOVT. OF INDIA

MoEF&CC vide amendment notification dated 30.12.2024 further extended the time limits for SO2 emission limit compliance for Category A, B, and C plants by 3 years i.e. up to December 2027, December 2028, and December 2029, respectively.

4. That it is submitted that the extension of timelines to meet SO_2 emission norms was sought by power utilities and Ministry of Power due to multiple factors, including the site-specific and complex nature of installation, limited domestic manufacturing before 2015, dependency on imports for critical components, long installation timelines (36–40 months after award), vendor constraints, high capital investment, and increased electricity costs.

5. That it is respectfully submitted that various studies were conducted by leading research institutions, including IIT-Delhi, CSIR-NEERI and National Institute of Advanced Studies (NIAS) Bengaluru, to assess the need, efficacy, and impact of Flue Gas Desulphurization (FGD) in the Indian context.

That IIT-Delhi (2024) conducted a study titled "Study to survey ambient atmospheric SO_2 concentration in different category of cities based on their vicinity to Thermal Power Plant (TPPs)". It concluded that there is no major impact on SO_2 concentration in the atmosphere due to the presence of TPPs. Further, the installation of FGD in TPP also has no significant

impact on ambient SO_2 concentration. The data analysis also shows that there are other major sources of SO_2 emissions as well in these cities/towns. Installation of FGDs pose risks of increased CO_2 emissions, water use, and secondary pollution. The report recommended to develop balanced strategies that effectively address both air quality and climate goals.

7. That CSIR-NEERI (2024), Nagpur conducted research study titled "Analysis of Historical Ambient Air Quality Data along with Emission from coal-based Thermal Power Plants for Developing a Decision Support System". NEERI concluded that the ambient SO2 concentration in all the monitoring stations is well below the prescribed norm of daily average SO_2 concentration of 80 microgram / normal metre cube. This is despite the fact that most of the TPPs have not installed FGDs. Installation of FGDs in TPPs leads to higher capital investment, increased power consumption, increased consumer tariff, and higher water and carbon footprint without environmental benefits.

8. That NIAS (2024) conducted a research study titled "Economic, Environmental and Climate Impacts of FGDs in Thermal Power Plants in India". NIAS concluded that the average sulphur content of Indian coals is considerably low and as per the case study of two large TPPs conducted by NIAS, the annual average ambient SOx concentrations measured in Continuous Ambient Air Quality Monitoring System (CAAQMS) is less

than one-third of NAAQS. On the contrary, installation of FGDs will increase the Auxiliary Power Consumption. Hence, it is concluded that FGDs are not required in TPPs using low-sulphur content coal. In addition one of the key findings of NIAS was that stack heights as prescribed vide notification 30.08.1990 ensures the effective dispersion of SO2 over a large area under the climatic conditions in India so that the ground-level (ambient) concentrations of SO2 comply with the National Ambient Air Quality (NAAQ) Standards. This design basis has proved to be effective all over India since all available data indicates that the ambient SO2 levels around TPPs are compliant with the current NAAQ standard for SO2 (80 µg/m3 on a 24-hour basis and 50 µg/m3 on an annual basis),

9. That the Government of India conducted stakeholder consultations with Industries, Ministry of Power, Central Pollution Control Board, scientific institutions and other stakeholders regarding these emission standards and its timeline. Further, CPCB was requested to examine the issue in totality, assess the available study reports, other relevant materials and other related factors and make a recommendation on applicability of these standards and its timeline.

NOTARY R.V. SINGH Advocate Regn.No.-2282 Commission Expire on 24-10-2027 Area-Delhi GOVT. OF INDIA

10. That the Central Pollution Control Board, after detailed analysis, has submitted its recommendation on 10.07.2025 based on its study on National Ambient Air Quality Standards of Sulphur dioxide across most of

the regions of the country; resource conservation in terms of avoiding additional consumption of water, auxiliary power, and limestone; increase in carbon footprint or Carbon dioxide emission into the atmosphere due to operation of control measures being deployed, and mining and transportation of limestone required for these control measures; the techno-economic feasibility of implementation of such control measures in all coal or lignite based Thermal Power Plants; and also applying the precautionary principle for control and abatement of air pollution in densely populated areas and other air pollution sensitive areas. A copy of the CPCB report is annexed as **Annexure-II.**

11. That it is also mentioned in the CPCB's report that the annual Ambient Air Quality levels of SO_2 were recorded below 25 $\mu g/m^3$ i.e. half the prescribed annual NAAQS of 50 $\mu g/m^3$ at 409 out of 430 cities during 2022, and 472 out of 492 cities during 2023. It is also mentioned that the annual Ambient Air Quality levels of SO_2 has been found exceeding the NAAQS in only 02 cities (Kolar in Karnataka and Imphal in Manipur) out of 430 cities during 2022, and 01 city (Kolar, Karnataka) out of 492 cities during 2023. Whereas, in 4 cities during 2022 and in 1 city during 2023, the Ambient Air Quality levels of SO_2 were recorded between 40 - 50 $\mu g/m^3$, which included Pune in Maharashtra, Kohima in Nagaland, and Chengalpattu, Kanchipuram in Tamilnadu (during 2022), and Imphal in Manipur (during

2023). It is relevant to mention that none of the above-mentioned cities i.e. the cities with annual Ambient Air Quality levels of SO_2 more than 40 $\mu g/m^3$, are located within 10 km from coal/lignite fired TPPs.

12. CPCB report suggested that TPPs falling under Category C may be considered for non-applicability of SO_2 emission standards notified vide notification dated 07.12.2015, as these TPPs are neither located in closed proximity to the metropolitan cities nor in proximity of air pollution sensitive areas such as non-attainment cities and critically polluted areas, and the Ambient Air Quality levels of SO_2 around such TPPs are also reported to be well below the prescribed NAAQS. Category C units should ensure compliance of stack height criteria for dispersion so that air quality of less densely habitated areas is also not compromised. This would also help in tapping the opportunity of resource conservation in terms of avoiding additional consumption of water, auxiliary power, and limestone; increase in carbon footprint/CO_2 emission into the atmosphere due to FGD operation, and mining & transportation of limestone required for FGD.

That it is humbly submitted that based on CPCB's recommendations, the Government of India revised the SO_2 emission standards for coal and lignite-based TPPs, which were duly notified on 11.07.2025 through an amendment to Schedule I under the Environment (Protection) Rules, 1986. A copy of the notification is annexed as **Annexure-III.**

NOTARY R.V. SINGH Advocate Regn. No. 2282 Commission Expire on 24-10-2027 New Delhi GOVT OF INDIA

14. That the notification mandates control of SO_2 emissions in all **Category A TPPs** i.e., the TPPs located within 10 km of the Delhi-NCR or cities with million plus population, by 31.12.2027. The installation of FGDs in **Category B TPPs** i.e., the TPPs located within 10 km of Critically Polluted Areas or non-attainment cities will be decided based on the recommendations of Expert Appraisal Committee (EAC). Therefore, the control of Sulphur Dioxide emissions from stack in Category A or Category B TPPs (based on the outcome of appraisal by EAC) will provide the greatest benefit in abatement of pollution to the cities having the highest need for reducing PM pollution. **Category C** TPPs are considered for non-applicability of SO_2 emission standards notified vide notification dated 07.12.2015 as these TPPs are not located in close proximity to the metropolitan cities or air pollution sensitive areas such as non-attainment cities or critically polluted areas. In addition, the Ambient Air Quality levels of SO2 around such TPPs are also reported to be well below the prescribed NAAQS. These TPPs continue to be under a mandate to comply with the stack emission standards for PM pollution which were tightened significantly vide notification dated 07.12.2015. In all cases where SO2 emission standards are not being made applicable shall ensure compliance of stack height criteria notified vide notification number GSR 742 (E) dated the 30th August, 1990 governing SO2 emissions from TPPs.

NOTARY R.V. SINGH Advocate Regn. No. 4362 Commission Expires on 10-12-2018 GOVT. OF INDIA

15. That the recent report of the NIAS highlights the cost of FGD installation as Rs. 1.20 crores per MW for wet FGDs. As per Central Electricity Authority (CEA), the wet limestone based FGD installation cost is estimated about Rs. 0.80 to 1.25 crores per MW. The O&M cost for wet limestone based FGD units is estimated to be Rs 5 to 6 Lakhs per MW annually which translates to O&M cost of Rs 25-30 crores per annum for a typical 500 MW unit. The aforesaid cost would burden the consumer by an additional cost of 50 – 70 paise per unit.

16. That average time taken for installation of FGDs, after award, is 36-40 months. Thus, from the planning to installation, around 5-6 years will be required for installation of FGDs. Considering the limited remaining operational life in older units, Sulphur Dioxide emission norms have not been made applicable to units retiring by 31.12.2030.

17. That considering the above, the revised policy takes into account the areas where the air quality could be a cause of concern. Thus, the Category A locations are mandated with strict norms; Category B locations shall be adjudged based on site specific environmental conditions and Category C is mandated to address pollution through stack height norms. Even in B category Power plants, stack height norms shall apply if SO2 concentration levels do not require the installation of FGD after due appraisal by sectoral EAC.

NOTARY R.V. SINGH Advocate Regn.No.2282 Commission Expire on 21.01.2027 Area-Delhi GOVT. OF INDIA

18. This policy shall also be applicable to thermal power plants located within a 300 km radius of the Delhi NCR region. For the 14 units categorized under Category A TPPs in this area, compliance shall be ensured by 31.12.2027; out of these, 10 units have already installed Flue Gas Desulfurization (FGD) systems. The 35 units of Category C TPPs located in 300 km of Delhi NCR region shall ensure compliance with the stack height criteria notified vide Notification No: GSR 742(E) dated 30th August 1990 by 31.12.2029.

19. That the revised policy is, thus, a balanced, pragmatic, scientifically justified shift toward more targeted, cost-effective, and environment-coherent regulation. It takes into account the concentration of Sulphur Dioxide in ambient air being well below the prescribed daily average standards; recognizes the limited role of Sulphur Dioxide in driving PM2.5 health impacts; weighs the disproportionate resource and environmental costs; additional cost burden on consumers due to the FGD mandate.

20. In view of the above, it is humbly prayed that the notification dated 11.7.2025 has been published after carrying out requisite due diligence and taking into account the scientific report of Central Pollution Control Board which inter-alia takes into account the scientific and technical analysis carried out by NIAS ; IIT Delhi and CSIR NEERI as well as the prevailing ambient SO2 levels as against the prevailing norms for NAAQS as well as the relative cost -benefit of installing air pollution control devices such

as FGD . The notification incorporates precautionary principles and makes it mandatory to enhance stack height as per the notification dated 30.08.1990 in all TPPs where FGD installation is not recommended while making it mandatory in all Category A Thermal Power Plants .

DEPONENT
(पलनियांडी. वी.)
(PAZHANIYANDI. V.)
निदेशक (सी.पी.)/Director (CP)
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
M/o Environment,Forest and Climate Change
भारत सरकार, नई दिल्ली
Govt. of India, New Delhi

VERIFICATION:

Verified at New Delhi on the of August, 2025 that the contents of the above affidavit are true and correct to the best of my knowledge and belief and nothing material has been suppressed or concealed therein

NOTARY
R.V. SINGH
Advocate
Regn. No. 2232
Commission
Expire on
24-10-2027
Area-Delhi
GOVT. OF INDIA

I identified the deponent/executant who has signed in my presence

DEPONENT
(पलनियांडी. वी.)
(PAZHANIYANDI. V.)
निदेशक (सी.पी.)/Director (CP)
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
M/o Environment Forest and Climate Change
भारत सरकार, नई दिल्ली
Govt. of India, New Delhi

Solemnly affirmed before me, read over & explained to the deponent

Notary Public, DELHI

12 AUG 2025

ITEM NO.41 COURT NO.4 SECTION PIL-W

(12)

225

S U P R E M E C O U R T O F I N D I A
RECORD OF PROCEEDINGS

WRIT PETITION(S)(CIVIL) NO(S). 13029/1985

M.C. MEHTA Petitioner(s)

VERSUS

UNION OF INDIA & ORS. Respondent(s)

[TO BE TAKEN UP AT 12:00 NOON]..... IN RE: MUNICIPAL SOLID WASTE AND IN RE: PAYMENT OF COMPENSATION AND IN RE: POWER PLANTS NAME OF THE FOLLOWING ADVOCATES MAY BE TREATED TO HAVE BEEN SHOWN IN THE LIST: MR. HARISH N. SALVE, SR. ADVOCATE (A.C.) MS. APARAJITA SINGH, SR. ADVOCATE (A.C.) MS. UTTARA BABBAR, SR. ADVOCATE (A.C.) MR. A.D.N. RAO, SR. ADVOCATE (A.C.) MS. SHIBANI GHOSH, ADVOCATE (A.C.) MR. SIDDHARTHA CHOWDHURY, ADVOCATE (A.C.) MR. G.S. MAKKER, MR. AMRISH KUMAR, MR. M.K. MARORIA, MR. SANJAY KR. VISEN, MR. SUDEEP KUMAR, MR. KARAN SHARMA, MR. SANDEEP KR. JHA, MR. JYOTI MENDIRATTA, MR. RAHUL KHURANA, MR. PRANAV SACHDEVA, ADVOCATES

Date : 02-04-2025 This petition was called on for hearing today.

CORAM :
HON'BLE MR. JUSTICE ABHAY S. OKA
HON'BLE MR. JUSTICE UJJAL BHUYAN

Ms. Aparajita Singh, Sr. Adv. (A.C)
Ms. Uttara Babbar, Sr. Adv. (A.C)
Ms. Shibani Ghosh, Adv.

For Petitioner(s): Applicant-in-person, AOR

Petitioner-in-person

For Respondent(s): Mrs. Aishwarya Bhati, A.S.G.
Mrs. Ruchi Kohli, Sr. Adv.
Mr. Mukesh Kumar Maroria, AOR
Mrs. Suhasini Sen, Adv.
Mr. Rajesh Kr. Singh, Adv.
Mr. Subhranshu Padhi, Adv.
Mr. Jagdish Chandra Solanki, Adv.
Mr. Gaurang Bhushan, Adv.

Dr. Menaka Guruswamy, Sr. Adv.
Mr. Wasim S. Qadri, Sr. Adv.
Mr. Utkarsh Pratap, Adv.
Ms. Arunima Das, Adv.
Mr. Devesh Maurya, Adv.
Mr. Ravi Kumar, Adv.

Signature Not Verified
Digitally signed by ASHISH KONDLE
Date: 2025.04.05 15:37:24 IST
Reason:

(13)

Mr. Aditya Sondhi, Sr. Adv.
Ms. Jyoti Mendiratta, AOR
Ms. Ananya Basudha, Adv.
Mr. Rijjuk Sarkar, Adv.
Mr. Ravender Pal Singh, Adv.

Ms. Sheyl Trehan, Sr. Adv.
Mr. Shivendra Singh, AOR

Mr. Praveen Swarup, AOR

Mr. Rajesh Kumar Chaurasia, AOR

Mrs. Aishwarya Bhati, A.S.G.
Ms. Archana Dave Pathak, A.S.G.
Mr. Wasim Quadri, Sr. Adv.
Mr. Swarupama Chaturvedi, Sr. Adv.
Mrs. Ruchi Kohli, Sr. Adv.
Mr. Gurmeet Singh Makker, AOR

Mr. P. K. Jain, AOR

Mr. Ramesh Babu M. R., AOR

Mr. Pavan Kumar, AOR

M/S. S. Narain & Co., AOR

Mr. Chirag M. Shroff, AOR

Mr. Ejaz Maqbool, AOR

Mr. Prashant Kumar, AOR

Mr. Lokesh Sinhal, Sr. A.A.G.
Mr. B.K. Satija, A.A.G.
Mr. Rakesh Kumar Mudgal, A.A.G.
Mr. Akshay Amritanshu, AOR
Mr. Rahul Khurana, Adv.
Mr. Nikunj Gupta, Adv.
Ms. Drishti Saraf, Adv.
Ms. Pragya Upadhyay, Adv.
Ms. Aakanksha, Adv.
Ms. Ishika Gupta, Adv.
Mr. Sarthak Arya, Adv.

Mr. E. C. Agrawala, AOR

Ms. Hemantika Wahi, AOR

Ms. Binu Tamta, AOR

Mr. Radha Shyam Jena, AOR

Mr. Pradeep Kumar Bakshi, AOR

Mr. Ashok Mathur, AOR

Mr. V. K. Verma, AOR

Mr. Ajit Pudussery, AOR

Mrs. Bina Gupta, AOR

Mr. Rakesh K. Sharma, AOR

Ms. Sujeeta Srivastava, AOR

Mr. Anil Kumar Jha, AOR

Mr. Mukesh K. Giri, AOR
Mr. Mandaar Mukesh Giri, Adv.

M/S. Parekh & Co., AOR

Mr. Sudhir Mendiratta, AOR

Mrs. Anil Katiyar, AOR

Mr. Hardeep Singh Anand, AOR

Mr. Sandeep Narain, AOR

Mr. Nishe Rajen Shonker, AOR
Mrs. Anu K Joy, Adv.
Mr. Alim Anvar, Adv.
Mr. Santhosh K, Adv.

Mr. Sushil Kumar Singh, AOR

Mrs. Rani Chhabra, AOR

Mr. G. Prakash, AOR

Ms. Nandini Gidwaney, AOR

Mr. Shri Narain, AOR

Mr. Umesh Kumar Khaitan, AOR

Ms. Shalini Kaul, AOR

Mr. K. R. Sasiprabhu, AOR

Mrs. K. Sarada Devi, AOR

(15)

228

Mr. Sanjay Kumar Visen, AOR

Mrs. Priya Puri, AOR

Ms. Manjula Gupta, AOR

Mr. T. V. Ratnam, AOR

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(23)

236

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(28)

238

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UPON hearing the counsel the Court made the following

O R D E R

IN RE: POWER PLANTS

1. We have heard Ms. Aparajita Singh, learned Senior Advocate appointed as Amicus Curiae on the issue of power plants and Ms. Aishwarya Bhati, learned ASG representing the CAQM as well as the Union of India.

2. The learned Amicus Curiae has today flagged the issue of 11 Thermal Power Plants which are located within 300 kilometers of Delhi. We are concerned with the compliance regarding SO_2 emission standards. There are two issues. The first is whether categorization of the Thermal Power Plants within the distance of 300 kilometers from

Delhi can be changed. For that purpose, amendment to Schedule I of the Environment (Protection) Rules, 1986 will be required. The second issue is about the timelines for compliance with the SO_2 emission standards. Out of the 11 Thermal Power Plant units, we find that the units at Dadri NCTPP, NTPC, Uttar Pradesh and Mahatma Gandhi TPS, Jhajjhar Power, Haryana, there is a compliance. In the case of power plants at Indira Gandhi STPP, NTPC, Haryana and Harduaganj TPS, UPRVUNL, Uttar Pradesh, there is a partial compliance. As regards power plant at Rajpura TPP, NPL-L&T, Punjab, it is mentioned that FGD is installed in both the units, but the system is presently not operational in these units.

3. The question is whether the timelines up to 31st December, 2029 as stated in Schedule I can be reduced. On the aspect of classification and on the aspect of reducing the timelines, we will need a response of the Ministry of Environment, Forest and Climate Change, Government of India. While we do so, we have to also ensure that the timelines are not repeatedly extended. Therefore, it will be appropriate if a notice is issued to the non-compliant Thermal Power Plants so that effective directions can be issued against them. Accordingly, issue notice to the following Thermal Power Plants, returnable on 29th April, 2025:

1.	Indira Gandhi STPP, NTPC, Haryana;

2.	Panipat TPS, HPGCL, Haryana;
3.	Rajiv Gandhi TPS, HPGCL, Haryana;
4.	Yamuna Nagar TPS, HPGCL, Haryana;
5.	Rajpura TPP, NPL-L&T, Punjab;
6.	Talwandi Asbo TPP, TSPL-Vedanta, Punjab;
7.	GH TPS (Lehra Mohabbat), PSPCL;
8.	Ropar TPS, PSPCL, Punjab; and
9.	Harduaganj TPS, UPRVUNL, Uttar Pradesh

The Union of India to furnish addresses of the aforementioned Thermal Power Plants. A copy of this order shall accompany the Notice.

4. In the meanwhile, we direct the Ministry of Environment, Forest and Climate Change to file its response in terms of what we have observed in this Order and in terms of the Note submitted by the learned Amicus Curiae for today's hearing. The said response shall be filed at least three days before the returnable date.

5. List on 29th April, 2025 at 12:00 noon.

IN RE: SUBSISTENCE ALLOWANCE

6. We have perused the affidavit filed by the Delhi Government in compliance with the order dated 28th February, 2025. The learned senior counsel representing the National Campaign Committee (NCC) and the learned senior counsel appearing for the Centre for Holistic Development, have several issues about the affidavit of the Delhi Government. We direct both the entities to file their counter dealing with the affidavit filed by the Delhi Government and also

(28)

place material on record giving names of the construction workers who actually worked during GRAP-IV period. They must also set out in what manner the verification has been carried out to ascertain whether the workers had worked during the relevant period. Time of three weeks is granted to them to file their counter.

7. The Delhi Government will also address this Court on the question whether the verified workers can be denied amount payable on the ground that their bank accounts are not linked with Aadhaar. This aspect will be considered on 29th April, 2025 at 12:00 noon.

IN RE: SOLID WASTE MANAGEMENT

8. This issue will be considered on 8th April, 2025 at 12:30 p.m.

(ASHISH KONDLE)
ASTT. REGISTRAR-cum-PS

(AVGV RAMU)
COURT MASTER (NSH)

"True Copy"

"Report on Review of Implementation of SO_2 Emission Standards in Coal or Lignite based Thermal Power Plants"

Central Pollution Control Board
(Ministry of Environment, Forest & Climate Change, Government of India)
Delhi – 110 032

July 2025

Contents

Sl. No.	Title	Page No.
1.	Background	4
2.	Energy Generation and Coal & Lignite Consumption in the Country – An Overview	4
3.	The Development of Standards for Coal or Lignite Based Thermal Power Plants	6
4.	Best available techniques (BAT) for control of emissions from TPPS	9
5.	Status of FGD implementation in TPPs	10
6.	Concerns Associated with SO_2 Emissions	10
7.	Legal matters associated with SO_2 emissions in NCR	11
8.	SO_2 Emission Standards in Other Industrial Sectors in India	11
9.	Highlights of Findings in Recent Three Study Reports of IIT, Delhi, CSIR-NEERI and NIAS Regarding FGD Installation	12
10.	Sources of SO_2 emissions and ambient SO_2 concentration across cities in the country	15
11.	Conversion of SO_2 to secondary particulates	15
12.	Key points observed by the Committee	19
13.	Proposed way forward	20

List of Abbreviations

AERMOD	American Meteorological Society-Environmental Protection Agency Regulatory Model
APC	Auxiliary Power Consumption
AQM	Air Quality Management
AQMN	Air Quality Monitoring Network
BHEL	Bharat Heavy Electricals Limited
CAAQMS	Continuous Ambient Air Quality Monitoring Stations
CEA	Central Electricity Authority
CO_2	Carbon-dioxide
CPCB	Central Pollution Control Board
CREP	Corporate Responsibility for Environmental Protection
CSIR	Council of Scientific & Industrial Research
EAC	Expert Appraisal Committee
EPCA	Environment Pollution (Prevention and Control) Authority
ESP	Electrostatic Precipitator
EDGAR-HTAPv2	Emissions Database for Global Atmospheric Research-Hemispheric Transport of Air Pollution Version-2
FGD	Flue-gas Desulphurization
GLC	Ground Level Concentration
GRAP	Graded Response Action Plan
IIT	Indian Institute of Technology
IITM	Indian Institute of Tropical Meteorology
IPC	Implementation of Pollution Control
LCA	Life Cycle Assessment
MoEF&CC	Ministry of Environment, Forest & Climate Change
MoP	Ministry of Power
MW	Mega Watt
NAAQS	National Ambient Air Quality Standard
NEERI	National Environmental Engineering Research Institute
NITI	National Institution for Transforming India
NIAS	National Institute of Advanced Studies
NOx	Oxides of Nitrogen
NTPC	National Thermal Power Corporation
PM	Particulate Matter
PSA	Principle Scientific Advisor
SO_2	Sulphur-dioxide
SPCB	State Pollution Control Board
TPPs	Thermal Power Plants
WRF-Chem	Weather Research and Forecasting - model coupled with Chemistry

1. Background

The MoEF&CC vide letter F. No. Q-15017/40/2007-CPW dated 21.01.2025 directed Central Pollution Control Board (CPCB) to examine the concerned reports, publications, database available regarding implementation of Flue-gas Desulphurization (FGD) systems in coal or lignite based TPPs including studies on health impact, and to submit appropriate recommendation in the matter.

In view of the above, a Committee under the chairmanship of the Member Secretary, CPCB, having Divisional Heads of AQM, AQMN, and IPC-II Divisions as members, was constituted vide Office Order dated 14.02.2025 with mandate to examine the studies/reports of CSIR-NEERI, IIT Delhi, NIAS, various reports and publications on TPPs including studies on health impact, if any, and database on emissions from TPPs and its impact on the ambient air quality.

The Committee under the chairmanship of the Member Secretary, CPCB, held its meetings in the matter on 06.03.2025 and 11.03.2025, and decided to further constitute a Sub-group comprising of officials from AQM, AQMN and IPC-II Division for in-depth discussion in the matter to present a detailed analysis before the Committee. Following studies and data has been examined for preparation of the report:

- Development and notification of standards for TPPs issued from time to time;
- Three studies/reports of CSIR-NEERI, IIT Delhi, and NIAS;
- Data of National Ambient Air Quality Monitoring Stations;
- Simulation modelling of emission from source of Thermal Power Plant for different scenarios/matrix

A draft report prepared by the Sub-group was discussed in the meeting of the Committee held on 09.07 2025, and based on the detailed deliberations held in the Committee meeting; the final report of the Committee has been prepared.

2. Energy Generation and Coal & Lignite Consumption in the Country – An Overview

As per available information (https://iced.niti.gov.in/energy/fuel-sources/coal/consumption), the domestic coal & lignite consumption in the "Power Sector" in the country has increased from 335.3 Million Tonnes to **894.94 Million Tonnes** during year 2005-06 to **2023-24** (Figure - 01). Besides, India's coal import has also increased over the time and reached to **268.24 Million Tonnes** in the year 2023-24, which results in **1,274.65 Million Tonnes** of overall coal and lignite consumption in the country during year 2023-24 by all the sectors, including TPPs.

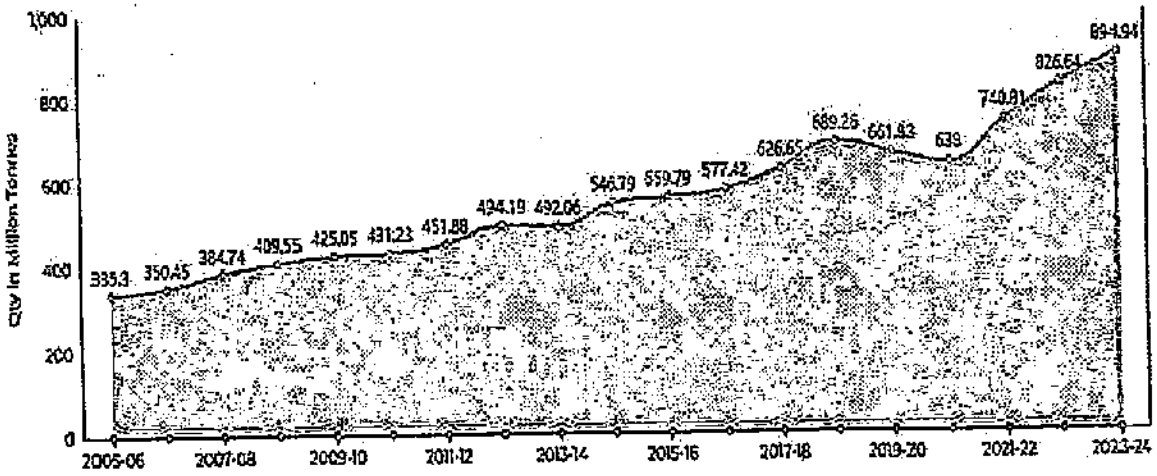

Figure 01: Domestic coal & lignite consumption trend in the Power Sector

As per the categorisation of thermal power plants done by the Task Force constituted by CPCB, comprising of representatives from MoEF&CC, MoP, CEA, and CPCB, in accordance with MoEF&CC's notification dated 31.03.2021, 600 units have been categorized into Category A, B, and C, based on TPPs' location. Plants located within 10 km radius of NCR or cities having million plus population are categorized as Category 'A'; plants located within 10 km radius of non-attainment cities and critically polluted areas are categorized as Category 'B' and plants other than those included in Category 'A' and 'B' are categorized as Category 'C'. Category wise number of units and their installed capacities are given in Table-01 as below:

Table 01: Category wise Distribution of Units of TPPs

Category	No. of Units	Installed capacity (in MW)
Category A	66	20,557
Category B	72	24,057
Category C	462	1,66,885.5
Total	600	2,11,519.5

Government of India has proposed in November, 2023 for setting up of an additional minimum 80,000 MW coal-based thermal power capacity by year 2031-32. Against this target, a total coal-based capacity of 9,350 MW has already been commissioned in 2023-24 & 2024-25 and currently, 29,900 MW of thermal capacity is under construction. In year 2024-25, contracts for 22,640 MW thermal capacity have been awarded, out of which about 5,600 MW is now under construction. Further, 33,580 MW of coal-based capacity has been identified which is at various stages of planning in the country.

3. The Development of Standards for Coal or Lignite Based Thermal Power Plants

Initially, MoEF&CC (erstwhile MoEF) notified stack emission standards for **Particulate Matter (PM)** parameter vide Notification No. S.O. 8(E) dated **03.01.1989** under the Environment (Protection) Act, 1986, requiring TPPs to install Electrostatic Precipitators (ESPs) to reduce emission (**Annexure-1**). Further, MoEF&CC notified stack height regulation for TPPs vide Notification No. G.S.R. 742(E) dated **30.08.1990 (Annexure-2)**. The said notification outlined **stack height regulations** based on the plant's capacity and Sulphur content in the fuel, ensuring proper dispersion of the pollutants (**SO_2 and NOx**) through adequately large stacks.

Charter on Corporate Responsibility for Environmental Protection (**CREP**) Action Points for 17 Categories of industries was issued by CPCB/MoEF in **March 2003**, which comprised action point for **development of SO_2 and NOx emission standards** for coal/lignite fired TPPs by December 2003. CREP action points also included proposal for development of SO_2 and NOx emission standards for other industrial sectors such as Cement, Copper, Fertilizer, Oil Refineries, Zinc. The need for development of SO_2 and NOx emission standards was felt during that time considering the estimations regarding quantum rise in coal/fuel consumption in the country in future with rising population and development-based demand of resources with the time, along with the technological advancement in pollution control devices being implemented globally with the objective of providing clean air/environment to the public.

A **National Task Force** with one of the objectives to develop emission standards for SO_2 and NO_x parameters from coal/lignite-fired TPPs in India was constituted by the MoEF, Govt. of India, initially in **2003**, which was reconstituted further in **2009** and **2014**. The National Task Force, which comprised of representatives from MoEF (now known as MoEF&CC), Ministry of Power (MoP), CPCB, Central Electricity Authority (CEA), NTPC, various State Pollution Control Boards (SPCBs) and other stakeholders submitted its recommendations to MoEF&CC in 2015. Similarly, National Task Forces were also constituted by MoEF for other 17 category of industrial sectors with one of the objectives to develop emission standards for SO_2 and NO_x parameters.

The revision/development of emission standards (and water consumption limit) for coal/lignite-fired TPPs was proposed in Annual Action Plan (AAP) 2014-15 of CPCB. The proposed emission standards and water consumption limit for coal/lignite-fired TPPs were discussed in the meeting taken by the Secretary, MoEF&CC on **11.03.2015** with the Ministry of Power, NTPC and Central Electricity Authority (CEA). The minutes of the same were issued by MoEF&CC on 18.03.2015, and Ministry of Power, NTPC and CEA were asked to send their comments on the same, if any. No comments were provided by the Ministry of Power, NTPC, and CEA on the proposed limits. Accordingly, following the due procedure, the MoEF&CC issued notification dated **07.12.2015 (Annexure-3)**. Later, several comments were received on the said notification from NTPC, which were addressed by MoEF&CC through various amendment notifications/corrigendum issued from time to time.

MoEF&CC, Govt. of India vide its notification dated 07.12.2015 stipulated emission standards for coal/lignite-fired TPPs, which included revised emission standards for Particulate Matter (PM), and newly introduced emission standards for Sulphur dioxide (SO_2), Oxides of Nitrogen (NOx), and Mercury (Hg) parameters. As per the notification, coal/lignite-fired TPPs were initially required to comply with the stipulated emission standards within two years from the date of issuing notification i.e. by 07.12.2017. The emission standards notified for coal/lignite-fired TPPs vide Notification S.O. 3305(E) dated 07.12.2015 (amended on 19.10.2020) is tabulated in Table No. 02:

Table 02: Emission Standards for Coal/lignite-fired TPPs

Parameters	Units installed up to 31.12.2003	Units installed during 01.01.2004 to 31.12.2016	Units to be installed from 01.01.2017
Particulate Matter (PM)	100 mg/Nm^3	50 mg/Nm^3	30 mg/Nm^3
Sulphur dioxide (SO_2)	600 mg/Nm^3 (< 500MW units) 200 mg/Nm^3 (≥ 500MW units)		100 mg/Nm^3
Oxides of Nitrogen (NO_x)	600 mg/Nm^3	450 mg/Nm^3	100 mg/Nm^3 (under review)
Mercury (Hg)	0.03 mg/Nm^3 (≥ 500MW units)	0.03 mg/Nm^3	0.03 mg/Nm^3

MoEF&CC vide Notification S.O. 3305(E) dated 07.12.2015 (amended vide G.S.R. 593(E) dated 28.06.2018) notified the specific water consumption limits for TPPs as below:

- Existing cooling tower-based plants shall reduce specific water consumption up to maximum of 3.5 m^3/MWh within a period of two years from the date of publication of this notification.
- Specific water consumption shall not exceed maximum of 3.0 m^3/MWh for new plants installed after the 1st January, 2017 and these plants shall also achieve zero wastewater discharge.
- Specific water consumption limits mentioned above shall not be applicable to the Thermal Power Plants using sea water.

The stack heights criteria in coal/lignite fired TPPs based on earlier notification and subsequent latest amendment notifications is tabulated in Table no. 03:

Table 03: Stack Height Criteria in TPPs

Parameter	Existing Standards (G.S.R. 742(E) dated **30.08.1990**)	New Standards (post FGD) Notification G.S.R. 593 dated **28.06.2018**)
Stack height (meters)	H = **275 meter** (≥ 500 MW units) H = **220 meter** (210 MW to < 500 MW units) H = 14 Q^0.3 meter (< 210 MW) (Where Q is emission rate of SO_2 in kg/hr)	H = 6.902 (Q x 0.277)^0.555 meter (Minimum 100 meter for ≥ 100 MW units) (Minimum 30 meter for < 100 MW units) (Where Q is emission rate of SO_2 in kg/hr, total of the all units' connected to stack)

The coal/lignite-fired TPPs were required to implement suitable technology, namely, wet Flue Gas De-sulphurisation (FGD) - Lime Stone based; Seawater based FGD, Dry-Sorbent Injection (DSI) or using low-sulphur coal to control SO_2 emission. Whereas, ESP retrofitting was required to meet revised PM standards, and for NOx emission control, the implementation of combustion modification/tuning or primary control measures were required. However, the implementation of new emission standards in coal/lignite-fired TPPs especially using FGD technology got delayed due to various techno-economic constraints faced by coal/lignite-fired TPPs, including availability of resources, logistics and limitation on supplies of pollution control components, increased costs and more than estimated time required for FGD equipment installation, which were further affected by the disruptions caused by COVID-19 pandemic.

The timelines for implementation of revised/new emission standards were extended through the Directions under section 5 of E (P) Act, 1986 issued by CPCB to TPPs in **December 2017** based on MoEF&CC's instructions to CPCB considering the recommendations of MoP. The unit-wise extended time limits for TPPs ranged from March 2018 to December 2022.

In March 2021, MoEF&CC vide amendment notification dated **31.03.2021** prescribed the categorisation of TPPs into Category A, B, and C, based on TPPs' location, with extended time limits up to December 2022, December 2023, and December 2024, respectively.

In September 2022, MoEF&CC vide amendment notification dated **05.09.2022** extended the time limits for **SO_2 emission limit** compliance for Category A, B, and C plants by 2 years i.e. up to December 2024, December 2025, and December 2026, respectively. However, the time limits for compliance of other emission parameters (PM, NOx, Hg) were kept same as prescribed in amendment notification dated 31.03.2021.

In December 2024, MoEF&CC vide amendment notification dated **30.12.2024** further extended the time limits for **SO_2 emission limit** compliance for Category A, B, and C plants by 3 years i.e. up to December 2027, December 2028, and December 2029, respectively.

The category-wise time limits for compliance with the emission parameters other than SO_2 (PM, NOx, Hg), and SO_2 emission for non-retiring thermal power plants are given in Table no. 04.

Table 04: Timeline for compliance of environmental standards

Category	Timelines for compliance	
	Other than SO_2 emission parameter (PM, NOx, Hg) (as per Notification dated **31.03.2021**)	SO_2 emission (as per Notification dated **30.12.2024**)
Category A (Plants within 10 km radius of NCR or cities having million plus population)	Up to 31.12.2022	Up to 31.12.2027
Category B (Plants within 10 km radius of non-attainment cities and critically polluted areas)	Up to 31.12.2023	Up to 31.12.2028
Category C (Other than those included in Category A and B)	Up to 31.12.2024	Up to 31.12.2029

4. Best available techniques (BAT) for control of emissions from TPPs

The coal/lignite fired TPPs are mainly emitting Particulate Matter (PM), Oxides of Nitrogen (NOx), Sulphur Dioxide (SO_2), and Mercury (Hg) pollutant into the atmosphere. The high ash content in the domestic coal/lignite leads to significant emission of PM. Whereas, the presence of Sulphur content in coal/lignite leads to SO_2 emission into the atmosphere. The emission of NOx into the atmosphere mainly depends on the Nitrogen content in coal and the combustion conditions in the boiler. The coal available from coal mines located in the country (domestic coal) have high ash content i.e. up to 40%, whereas, the imported coal has the ash content generally up to 7.5%. Further, the Sulphur content in domestic coal is reported to be less (i.e. up to 0.5%) in comparison with the imported coal (up to 0.75%) [*Source: EPCA report no. 87*].

The best available technique (BAT) to control the emission of PM from TPPs into atmosphere is installation of high-efficiency Electrostatic Precipitator (ESP) or hybrid ESP (with bag filters). Whereas, the emissions of NOx are mainly controlled through primary control measures such as combustion tuning, installation of low NOx burners (LNB), Over Fire Air (OFA), etc. In case of control of SO_2 emissions from TPPs, the best available technologies are wet Flue Gas De-sulphurisation (FGD) - Lime Stone based, Seawater based FGD, Dry-Sorbent Injection (DSI) or use of low-sulphur coal, followed by dispersion of flue gas through high stacks. The dispersion of SO_2 emissions from coal/lignite fired TPPs through their high stacks has been effectively practiced in the country over the years.

5. Status of FGD implementation in TPPs

The status of implementation of FGD in coal/lignite fired TPPs as sourced from CEA is given in Table 05 as below:

Table 05: Status of FGD implementation in TPP units

FGD implementation status	Units	Capacity
CFBC Boiler (FGD installation not needed)	**53**	5,926 MW
FGD installed	**49**	25,590 MW
Retired	**10**	1,434 MW
FGD under implementation / FGD contracts awarded	211	91,880 MW
Under various stages of FGD tendering process (Bids opened, NIT issued, Tender specifications made)	180	58,997 MW
Under pre-tendering process (Feasibility study completed/in process/to be started)	97	27,693 MW
Grand Total	600	2,11,519.5 MW

Total 537 Units [2,04,160 Mega Watt (MW)] have been identified for installation of FGDs in TPPs. Out of these, FGD installation has been completed in 49 Units (25,590 MW). Whereas, FGD contracts awarded / under implementation in 211 Units (91,880 MW); 180 Units (58,997 MW) are under various stages of tendering process; and 97 Units (27,693 MW) are only under pre-tendering process. Out of 49 units which have installed FGD, 14 units are under Category 'A', 4 units are under Category 'B', and 31 units are under Category 'C'.

6. Concerns Associated with SO_2 Emissions

SO_2 is formed from combustion of fuel containing Sulphur. Sulphur is prevalent in raw materials such as crude oil, coal, and ore that contains common metals like aluminium, copper, zinc, lead etc. The SO_2 reacts with other gases in the atmosphere to form sulphates that can cause harm to human health. Health effects of SO_2 include respiratory illness, visibility impairment, acid rain and aesthetic damage. Sulphur oxides are emitted in significant quantities from thermal power plants, smelting process of sulphide ores to produce copper, lead and zinc and also from petroleum refining processes. Sulphate particles, can be transported over long distances and deposited far from the sources. SO_2 can result in respiratory illness, particularly in children and the elderly, and it can also aggravate existing heart and lung diseases. [*Source: National Ambient Air Quality Status, 2007 - CPCB*]. Further, the NAAQS were notified in 2009 for 12 air pollutants, including SO_2 to protect public health and environment.

7. Legal matters associated with SO_2 emissions in NCR

Hon'ble Supreme Court of India vide order dated 02.05.2017 in the matter of Writ Petition (Civil) No. 13029/1985 titled as M.C. Mehta Vs. UOI & Ors., based on the report No. 72 of Environment Pollution (Prevention and Control) Authority (EPCA) directed Union of India and CPCB to fix emission standards for SO_2 and NOx parameters for 34 industrial sectors, namely; Sugar, Thermal Power Plants (notified but not effective till that time), Cotton Textile, Composite woollen mills, Dye and Dye Intermediate, Electroplating industries, Cement Plants, Stone crushing units, Coke ovens, Synthetic rubber, Pulp and paper, Distilleries, Leather industry, Calcium carbide, Carbon black, Copper, lead and Zinc smelter, Nitric acid, Sulphuric acid plant, Iron and steel, Natural rubber, Asbestos, Caustic soda, Re-heating furnaces, Foundries, Small boilers, Aluminium plants, Petro-chemical, Pesticides, Tannery, Inorganic chemical, Glass industry, Lime kiln and Ceramic.

Further vide order dated 24.10.2017, ban on use of Furnace Oil and Pet-coke in the States of U.P., Haryana and Rajasthan was placed in view of the environmental hazards due to their use considering high Sulphur content in these fuels. The recommendation of EPCA in its Report No. 87 dated 11.07.2018 submitted before Hon'ble Supreme Court of India are stated as below:

"EPCA in its report No 76 of November 9, 2017 had stated that it is not in favour of coal for combustion. It had recommended that standards for SOx and NOx be mandated so that pollution can be brought under control from these polluting sources of fuel. It had recommended a ban on pet coke and furnace oil as mitigating pollution from these extremely high sulphur fuels would be expensive and not complied with. The notified standards would provide industry options to install pollution control equipment or to move to cleaner natural gas." .....

8. SO_2 Emission Standards in Other Industrial Sectors in India

MoEF&CC vide notification No. G.S.R. 96(E) dated 29.01.2018 notified SO_2 and NOx emissions standards for industrial boilers used in industries, namely (1) Sugar (2) Cotton Textiles (3) Composite Woollen Mills (4) Synthetic Rubber (5) Pulp and Paper (6) Distilleries (7) Leather Industries (8) Calcium Carbide (9) Carbon Black (10) Natural Rubber (11) Asbestos (12) Caustic Soda (13) Small Boilers (14) Aluminium Plants (15) Tannery (16) Inorganic Chemical and other such industries using boilers.

Further, MoEF&CC vide notification No. G.S.R. 263(E) dated 22.03.2018 notified SO_2 and NOx emissions standards for other industrial sectors, namely Ceramic, Foundry Industries (Furnaces based on Fuel), Glass, Lime Kiln, Reheating furnace.

Besides, MoEF&CC has also prescribed SO_2 emission standards for other industrial sectors such as Sulphuric Acid Plants, Petroleum Oil Refineries, Petrochemicals (Basic and Intermediates), Pesticide Industry, Integrated Iron & Steel Plants, Cement Plants, Copper-Lead

or Zinc Smelting Plants, Calcined Petroleum Coke (CPC) units etc. through various notifications issued from time to time.

9. Highlights of Findings in Recent Three Study Reports of IIT, Delhi, CSIR-NEERI and NIAS Regarding FGD Installation

A) Report of IIT Delhi (Sponsored by Ministry of Power/CEA)

1. "*Study to survey ambient atmospheric SO_2 concentrations in different category of cities based on their vicinity to thermal power plants (TPPs)*" (**Annexure-4**) was conducted across three categories of cities (during the period from February 2023 to February 2024):
    a) Category-1 - Cities without coal-based TPPs (New Delhi, Hyderabad, Lucknow)
    b) Category-2 - Cities with coal-based TPPs without FGDs (Kolkata, Nagpur, Kota, Shahdol)
    c) Category-3 - Cities with coal-based TPPs with FGDs (Ghaziabad, Gautam Buddha Nagar, Khargone)
2. Study assessed SO_2 concentration in ambient air quality and the impact of TPPs on local air quality. Results indicated that all surveyed locations were within the National Ambient Air Quality Standards (NAAQS) for SO_2 (80 $\mu g/m^3$) based on 24 hours average measurements.

3. Daily mean SO_2 concentrations ranged from 2.48 $\mu g/m^3$ to 9.26 $\mu g/m^3$ in Category-1 cities; 3.12 $\mu g/m^3$ to 6.48 $\mu g/m^3$ in Category-2 cities; and 4.24 $\mu g/m^3$ to 12.51 $\mu g/m^3$ in Category-3 cities.

4. Contribution of sulphate aerosols (SO_4) from SO_2 emissions of coal-based TPPs to ambient PM2.5 and PM10 concentrations varies significantly across different city categories and seasons. Averaging across all cities and phases, contributions ranged from 0.96% (0.44 $\mu g/m^3$) to 5.21% (3.30 $\mu g/m^3$) for PM2.5 and from 0.57% (0.49 $\mu g/m^3$) to 3.67% (3.60 $\mu g/m^3$) for PM10.

5. As per estimations, installing FGD systems with an 87.5% SO_2 removal efficiency in all coal-based TPPs across India would:
    a) Reduce PM2.5 concentrations by up to 4.56% (2.89 $\mu g/m^3$) and PM10 concentrations by up to 3.21% (3.15 $\mu g/m^3$) across all surveyed cities and seasons. These findings indicate that while SO_2 emissions from TPP contribute to ambient PM levels, their impact is relatively minor.
    b) Reduce annual SO_2 emissions by 4.88 MT per year, but this would result in an increase of 14.4 MT per year in CO_2 emissions from mining, transportation, reagent operations, and increased Auxiliary Power Consumption (APC).

6. In India, acid rain is mitigated by alkaline substances like ammonia (NH_3) from agricultural activities and carbonate minerals in dust, which neutralize Sulphuric acid.

7. FGD technologies will increase CO_2 emissions, water consumption, and secondary pollution due to the mining and transportation of limestone/gypsum.

8. Recommendations:
   a. Consider halting FGD installation in TPPs that have not yet begun and revisit this decision after conducting a follow-up study to comprehensively evaluate the LCA of implementing FGD technology in coal-based TPPs across India.
   b. Gradually phase out older and less efficient coal-based TPPs and transition to a sustainable energy future, ensuring the country's energy security.

B) Report of CSIR-NEERI (Sponsored by NITI Aayog)

1. Report prepared by CSIR-NEERI on "*Analysis of Historical Ambient Air Quality Data along with Emission from coal-based Thermal Power Plants for Developing a Decision Support System*" (**Annexure-5**).

2. The analysis suggests that the ambient SO_2 concentration in all the CAAQMS stations is well below the prescribed daily average standard of 80 µg/m³. SO_2 concentration in ambient air measured from 464 CAAQMS spread across India were analysed, and it was found that out of 464 sites, 57 sites had no data, and only 13 sites have the highest SO_2 levels beyond the prescribed limit of 80 µg/m³ only in the 4th quartile, which is 3% of the CAAQMS data:
   a) Gaya, Patna, Muzaffarpur (Bihar), Ankaleshwar, Gandhinagar, Ahmedabad (Gujarat), Betul, Mandideep, Singrauli (Madhya Pradesh), Pune – 2 sites (Maharashtra), Bhiwadi (Rajasthan), Salem (Tamilnadu).

3. A total of 5792 PM samples spread in urban centers, coal mining areas and TPPs were analyzed. It was found that the maximum Sulphur content was 20 µg/m3 in all these PM samples, which includes outliers. A statistical analysis consisting of the removal of outliers reveals the highest elemental Sulphur content of 8 µg/m³ in PM. Even if all Sulphur is considered as particulate Sulphate, the increase in PM load would be 24 µg/m³ (32 S : 96 SO_4=)

4. The CSIR-NEERI report has concluded/recommended that:

   a. Conversion of gaseous SO_2 to particulate sulphate is having very low impact. If the PM equivalent to transformed particulate sulphate is captured at the source itself by improved control technology (High efficiency ESPs), the demand for FGD will not arise.

b. Installation of FGDs in TPPs will lead to higher capital investment, increased power consumption, increased consumer tariff, and higher water and carbon footprint without environmental benefits.

C) Report of NIAS (Sponsored by Office of PSA to Govt. of India)

1. Report prepared by NIAS on *"Economic, Environmental, and Climate Impacts of FGDs in Thermal Power Plants in India"* (**Annexure-6**).

2. The analysis suggests that installing FGDs in all TPPs by 2030 will increase the Auxiliary Power Consumption (APC) of the TPPs thereby adding approximately 69 million tons of CO_2 emissions to the atmosphere (2025-30) while reducing SO_2 emissions by ~17 million tons.

3. Installing wet FGDs in TPPs reduces their energy efficiency and increases freshwater consumption. Inland TPPs consume approximately 3.79 billion cubic meters of freshwater per year. NIAS estimates that freshwater consumption by TPPs will increase by about 9.6% in 2030 if FGDs are installed in all inland TPPs.

4. PM pollution is the major problem attributed to TPPs using high-ash Indian coal, which can be addressed quickly and cost-effectively by retrofitting indigenous High-efficiency ESPs in all TPPs. Controlling PM emissions from TPP stacks at this level will make the maximum impact on air pollution from TPPs even without FGDs.

5. M/s BHEL has retrofitted High-efficiency ESPs even in older TPPs with space constraints. Installation of such ESPs will cost only Rs. 25 Lakhs per MW compared to Rs. 120 Lakhs per MW for wet FGDs based on parts having some imported components.

6. The NIAS report has concluded/recommended that:

   a. The Environmental (Protection) Rules, 2015, prescribing SO_2 emission standards for all coal/lignite fired TPPs, shall be amended to limit the SO_2 stack emission standards only for coal/lignite-fired TPPs using imported coal and/or High (> 0.5%) Sulphur coal, considering low Sulphur content in domestic coal.

   b. Since 32 of the 65 TPPs within 10 km of NCR or cities with million plus population have either installed or awarded work for installation of FGDs, the impacts of FGDs in terms of PM pollution reduction in these cities must be assessed before any future FGDs are awarded. Further awarding of FGDs in TPPs other than those located within 10 km of NCR or cities with million plus population shall be avoided.

   c. Using coal washed at the pithead will not only reduce air pollution from TPPs & coal transportation but will also enhance ESP performance as well as boiler efficiency thereby reducing CO_2 emissions. Using washed coal will also reduce water consumption in TPPs. The washeries must be designed & operated to ensure

- that the ash content of rejects is +62% so that they are unfit for any end-use other than backfilling the coal mine void.

10. Sources of SO_2 emissions and ambient SO_2 concentration across cities in the country

Energy sector, industries, hotels & restaurants, and domestic fuel combustion are the major sources of SO_2 emissions in the country. Ambient Air Quality levels of SO_2 remain within the National Ambient Air Quality Standards (NAAQS) i.e. 50 $\mu g/m^3$ (annual average) across most of the regions of the country. However, there are variations across the cities in terms of contribution of SO_2. A summary of Ambient Air Quality levels of SO_2 (annual average) across the country during 2022 and 2023 is given in Table 06 as below:

Table 06: Ambient Air Quality levels of SO_2 in India during 2022 and 2023

SO_2 concentration range (in $\mu g/m^3$)	2022	2023
0 - 10	258	313
10 - 25	151	159
25 - 40	15	18
40 - 50	4	1
50+	**2**	**1**
Total cities	430	492

It is also noted that the Ambient Air Quality levels of SO_2 were recorded below 25 $\mu g/m^3$ i.e. half the prescribed NAAQS of 50 $\mu g/m^3$ at 409 out 430 cities during 2022, and 472 out of 492 cities during 2023.

It is also noted that the Ambient Air Quality levels of SO_2 has been found exceeding the NAAQS in only 02 cities (Kolar in Karnataka and Imphal in Manipur) out of 430 cities during 2022, and 01 city (Kolar, Karnataka) out of 492 cities during 2023. Whereas, in 4 cities during 2022 and in 1 city during 2023, the Ambient Air Quality levels of SO_2 were recorded between 40 - 50 $\mu g/m^3$, which included Pune in Maharashtra, Kohima in Nagaland, and Chengalpattu, Kanchipuram in Tamilnadu (during 2022), and Imphal in Manipur (during 2023). It is relevant to mention that none of the above-mentioned cities i.e. the cities with Ambient Air Quality levels of SO_2 more than 40 $\mu g/m^3$, are located within 10 km from coal/lignite fired TPPs.

11. Conversion of SO_2 to secondary particulates

Once emitted, SO_2 can react with various oxidants in the atmosphere to form sulphate particles, either as H_2SO_4 droplets, or as neutralized particles such as ammonium sulphate. However, SO_3, H_2SO_4, and their various hydrated forms have very short life time in the atmosphere and are rapidly converted to particulate phase species. Particulate Matter (PM) is a concern in a

large number of cities in India, with 192 cities out of 406 cities exceeding the NAAQS for $PM_{2.5}$ and 389 cities out of 505 cities exceeding the NAAQS for PM_{10} during 2023.

In order to establish the contribution of coal-fired thermal power plant to sulphate levels (secondary particulates), Indian Institute of Tropical Meteorology (IITM), Pune was requested to run simulations to assess the SO_2 and sulphate concentrations due to thermal power plants independently under the given scenarios of plant's geographical location, capacity, emission levels and control measures. IITM, Pune was approached for this exercise considering the technical expertise and experience of the institute in application of WRF-Chem model, especially for regulatory purpose (i.e. providing in Delhi-NCR which is subsequently used for invocation of actions listed under GRAP).

There are mainly two dispersion models that accounts for secondary particulate matter formation through a process that involves the transformation of primary pollutants, such as Sulphur dioxide and Oxides of Nitrogen, into particulate matter i.e. AERMOD (American Meteorological Society-Environmental Protection Agency Regulatory Model) and WRF-Chem (Weather Research and Forecasting (WRF) model coupled with Chemistry). While the former is used for short-range model typically used for distances up to 50 km, the latter is long range transport model. In order to assess the long-range impact of SO_2 emissions in terms of secondary particulate contribution, use of WRF-Chem was essential.

Four inland and four coastal locations were identified as point sources, corresponding to locations of actual thermal power plants, spread across the country. The simulations were run for two categories of TPP unit capacities (i.e. more than 500 MW and less than 500 MW) and scenarios considering with and without FGD. 90% reduction efficiency for SO_2 by FGD has been considered for SO_2 emission rate in simulation exercise. The matrixes considered for emission dispersion modelling to assess maximum Ground Level Concentration (GLC) are given in Table 07 as below:

Table 07: Cases considered for emission dispersion modelling to assess max. GLC

Case	Unit capacity	Type	Stack height	SO_2 emission rate
1	660 MW	TPP without FGD	275 m stack height	1000 g/sec
2	660 MW	TPP with FGD	150 m stack height	100 g/sec*
3	250 MW	TPP without FGD	220 m stack height	370 g/sec
4	250 MW	TPP with FGD	100 m stack height	37 g/sec*

**Considering 90% reduction in emission rate from installation of FGD.*

Thus, four simulations were run for each of the specified locations using WRF-Chem model, with the duration as 20th - 29th October, 2023. 'Emissions Database for Global Atmospheric Research-Hemispheric Transport of Air Pollution Version-2 (EDGAR-HTAPv2)' Emission data set has been used for this study for anthropogenic emission inventories, and the existing

SO_2 emissions in EDGAR-HTAPv2 Emission dataset are removed from all other anthropogenic sectors. The new emissions of SO_2 from eight power plants are added, while emissions of other pollutants are kept as in EDGAR-HTAPv2 dataset.

The results show variation between the coastal and the inland locations in the simulated concentration of SO_2 and Sulphate and the maximum distance as tabulated below in Tables 8 and 9:

Table 08: Case 1: TPP unit having capacity more than 500 MW (660 MW)

	Plant location	Mean SO_2 concentration (upper limit) in $\mu g/m^3$	Sulphate concentration (upper limit) in $\mu g/m^3$	Distance of Max SO_2 concentration in (Km)	Distance of Max Sulphate concentration (Km)
TPP unit without FGD with stack height of 275 m (SO_2 emission rate of 1000 gm/sec)					
Coastal	Ratnagiri	10	0.45	10-20	10-100
	North Chennai-II	5	0.4	5-7.5	>100
	Haldia Energy Limited	5	0.4	5-10	10-30
	Mundra TPS	9	0.4	15-20	30-75
Inland	Panipat TPS	10	0.35	5-10	30-50
	Satpura	9	0.4	5-15	30-50
	Rayalseema TPS	8	0.3	<5	5-10
	Korba Power Limited	6	0.35	5-7.5	10-15
TPP unit with FGD with stack height of 150 m (SO_2 emission rate of 100 gm/sec)					
Coastal	Ratnagiri	2.2	0.06	10-20	0-100
	North Chennai-II	1	0.02	5-7.5	0-100
	Haldia Energy Limited	1	0.12	5-10	0-20
	Mundra TPS	1	0.1	10-30	50-100
Inland	Panipat TPS	2	0.04	5-10	5-10
	Satpura	1	0.08	5-15	30-40
	Rayalseema TPS	1	0.02	5-7.5	0-100

	Korba Power Limited	1.6	0.02	5-7.5	0-100

Table 09: Case 2: TPP unit having capacity less than 500 MW (250 MW)

	Plant location	Mean SO_2 concentration (upper limit) in $\mu g/m^3$	Sulphate concentration (upper limit) in $\mu g/m^3$	Distance of Max SO_2 concentration (in Km)	Distance of Max Sulphate concentration(in Km)
TPP unit without FGD with stack height of 220 m (SO_2 emission rate of 370 gm/sec)					
Coastal	Ratnagiri	3	0.35	10-20	50-100
	North Chennai-II	2.5	0.05	5-10	0-100
	Haldia Energy Limited	1	0.35	0-100	20-40
	Mundra TPS	2.5	0.13	10-20	50-100
Inland	Panipat TPS	6	0.2	7.5-15	30-50
	Satpura	-	0.05	-	0-100
	Rayalseema TPS	3	0.05	5-7.5	0-100
	Korba Power Limited	3.5	0.22	5-10	30-75
TPP unit with FGD with stack height of 100 m (SO_2 emission rate of 37 gm/sec)					
Coastal	Ratnagiri	1.4	0.1	10-20	10-20
	North Chennai-II	0.8	0.01	5-15	0-100
	Haldia Energy Limited	0.6	0.035	5-10	5-30
	Mundra TPS	0.6	0.06	10-20	15-30
Inland	Panipat TPS	1.4	0.01	5-10	0-100
	Satpura	0.4	0.07	5-10	7.5-10
	Rayalseema TPS	0.6	0.01	5-10	0-100
	Korba Power Limited	1.2	0.04	5-7.5	15-30

The estimations done by IITM, Pune for sulphates were also found in line with findings of one specific study conducted by IIT Kanpur for a power plant in Punjab (M/s Talwandi Sabo Power Ltd.) wherein monthly mean sulphate contribution due to the TPP at a receptor located at a distance of 12 km from the plant was found to be 0.5 $\mu g/m^3$.

12. Key points observed by the Committee

I. Report of IIT-Delhi highlighted the matter of increase in CO_2 emission, water consumption, auxiliary power consumption and secondary pollution due to the mining and transportation of limestone/gypsum required for FGD. Report of IIT-Delhi suggested revisiting the cases of FGD installation and conducting a follow-up study to comprehensively evaluate the LCA of implementing FGD technology in coal-based TPPs across India.

II. Report of CSIR-NEERI highlighted the matter of higher capital investment, increased power consumption, water consumption and carbon footprints due to installation of FGD operation.

III. Report of NIAS mentions that installing wet FGDs in TPPs increases freshwater consumption and inland TPPs consume approximately 3.79 billion cubic meters of freshwater per year. In addition, NIAS estimated that freshwater consumption will increase by about 9.6% in 2030 in TPPs if FGDs are installed in all inland TPPs. NIAS further mentioned that Auxiliary Power Consumption of TPPs will increase with installation of FGD and result in additional CO_2 emission into the atmosphere. Report of NIAS suggested that further awarding of FGDs in TPPs other than those located within 10 km of NCR or cities with million plus population shall be avoided.

IV. The cost of installation of FGD in TPPs as mentioned in Ministry of Power's representation O.M. dated 03.05.2022 was reported to be Rs. 0.39 crores per MW initially which increased over the time to Rs. 1.14 crores per MW. The recent report of the NIAS highlights the cost of FGD installation as Rs. 1.20 crores per MW for wet FGDs. As per Central Electricity Authority (CEA), the wet limestone based FGD installation cost is estimated about Rs. 0.80 to 1.25 crores per MW.

V. The O&M cost for wet limestone based FGD units is estimated to Rs. 5 to 6 Lakhs per MW annually. For a typical 500 MW unit, the O&M cost for wet limestone based FGD unit is approximately Rs. 25 to 30 Crores per annum.

VI. Ambient Air Quality levels of SO_2 recorded under National Ambient Air Quality Programme are within the NAAQS i.e. 50 $\mu g/m^3$ (annual average) across most of the regions of the country. Further, none of the cities with Ambient Air Quality levels of SO_2 more than 40 $\mu g/m^3$, are located nearby coal/lignite fired TPPs. Further it is also observed that as per the study of IIT Delhi in three categories of cities, maximum daily mean SO_2 concentrations was reported up to 12.51 $\mu g/m^3$ only.

VII. As per the study of IIT Delhi, ccontribution of sulphate aerosols (SO_4) from SO emissions of coal-based TPPs to ambient PM2.5 and PM10 concentrations varies significantly across different city categories and seasons. However, findings indicate that their impact is relatively minor. These findings are substantiated by the CSIR-NEERI study according to which, a total of 5792 PM samples spread in urban centers, coal mining areas and TPPs were analyzed. It was found that the maximum Sulphur content in all these PM samples was 20 $\mu g/m^3$, which includes outliers. A statistical analysis consisting of the removal of outliers reveals the highest elemental Sulphur content of 8 $\mu g/m^3$ in PM.

VIII. Simulations run by IITM, Pune to assess SO_2 concentration and Sulphate in ambient air due to TPPs showed mean SO_2 concentration (upper limit) 10 $\mu g/m^3$ and Sulphate concentration (upper limit) 0.45 $\mu g/m^3$ which may be considered as miniscule, as the concentration of SO_2 were recorded below 25 $\mu g/m^3$ i.e. half the prescribed NAAQS of 50 $\mu g/m^3$ at 409 out 430 cities during 2022, and 472 out of 492 cities during 2023. This could be considered as insignificant in terms of contribution of Sulphate concentration due to TPPs.

IX. As per information available from CEA, it is estimated that there will be an increase in electricity cost about Rs. 0.50 to 0.70 per unit for plants installing wet limestone based FGD. As this cost is to be passed through to the public by means of increased tariff, this would impact the public not only in terms of increased cost of electricity but also in terms of rise in cost of goods and services.

13. Recommendations

With due consideration of the compliance of National Ambient Air Quality Standards (NAAQS) of SO_2 across most of the regions of the country; resource conservation in terms of avoiding additional consumption of water, auxiliary power, and limestone; increase in carbon footprint/CO_2 emission into the atmosphere due to FGD operation, and mining & transportation of limestone required for FGD; the techno-economic feasibility of implementation of FGD in all coal/lignite-fired TPPs; and also applying the precautionary principle for controlling air pollution in densely populated areas and other air pollution sensitive areas, it is recommended that enforcement of the SO_2 emission standards may be implemented in the coal/lignite-fired TPPs in the following manner:

a) The SO_2 emission standards notified vide notification dated 07.12.2015 shall continue to remain mandatory for Category 'A' TPPs.

b) Applicability of SO_2 emission standards notified vide notification dated 07.12.2015 may be examined on a case-to-case basis by the concerned Expert Appraisal Committee (EAC) in MoEF&CC for Category 'B' TPPs.

c) The SO_2 emission standards notified vide notification dated 07.12.2015 may not be applied in the units which declare to retire by December 31, 2030.

d) Remaining TPPs {not included in (a), (b) & (c)} may be considered for non-applicability of SO_2 emission standards notified vide notification dated 07.12.2015 as such TPPs are not located in closed proximity to the metropolitan cities or air pollution sensitive areas such as non-attainment cities and critically polluted areas, and the Ambient Air Quality levels of SO_2 around such TPPs are also reported to be well below the prescribed NAAQS.

e) In such cases where SO_2 emission standards are not being made applicable after due diligence then those cases shall ensure compliance of stack height criteria notified vide notification dated 30.08.1990 governing SO_2 emissions from TPPs.

*****

Member	**Member**	**Member**	**Expert Member**
(Prasoon Gargava) Divisional Head, IPC-II Division	**(Pankaj Agrawal)** Divisional Head, AQM Division	**(Aditya Sharma)** Divisional Head, AQMN Division	**(Nazimuddin)** Divisional Head, IPC-I & WQM-I Division

Chairman of the Committee

(Bharat Kumar Sharma)
Member Secretary, CPCB

The Gazette of India

EXTRAORDINARY

PART II—Section 3—Sub-Section (ii)

NEW DELHI, TUESDAY, JANUARY 3, 1989 / PAUSA 13, 1910

MINISTRY OF ENVIRONMENT & FORESTS

(Department of Environment, Forests & Wildlife)

NOTIFICATION

New Delhi, the 3rd January, 1989

S.O. 8(E)—In exercise of the powers conferred by Section 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986: namely:—

1. (1) These rules may be called the Environment (Protection) Act, 1986 (29 of 1986) First Amendment Rules, 1989.

(2) They shall come into force on the date of their publication in the Official Gazette

2. In Schedule I to the principal Rules, after serial number 24 and the entries relating thereto, the following serial numbers and entries shall be inserted, namely:—

1	2	3	4
"25	Thermal Power Plants	*Particulate Matter Emission - generation capacity 210 MW or more -generation capacity less than 210 MW	 150 milligramme per normal cubic meter 350 milligramme per normal cubic meter
26	Natural Rubber Industry		Concentrations in the effluents not to exceed milligramme per litre (except) for pH
	-Discharge into Inland surface waters	Colour & Odour pH BOD COD Oil & Grease Sulphides Total Kjeldahl Nitrogen Dissolved Phosphate (as P) Suspended solids Dissolved Solids(inorganic)	Absent 6.0–9.0 50 250 10 2 100 5 100 2100

		Ammonical Nitrogen as (N) Free Ammonia (as NH_3)	50 5
	-Disposal on land for irrigation	Colour & Odour pH BOD COD Oil & Grease Suspended solids Dissolved solids	Absent 6.0–8.0 100 250 10 200 2100

*Depending upon the requirement of local situation, such as protected area, the State Pollution Control Boards and other implementing agencies under the Environment (Protection) Act, 1986, may prescribed a limit of 150 milligramme per normal cubic meter, irrespective of the generation capacity of the plant.

[No. 1(21)/86-PL]
K.P. GEETHAKRISHNAN, Secy.

Principal rules published *vide* number S.O. 844(E), dated the 19th November, 1986. Amending rules published vide S.O. 82(E) dated the 16th February, 1987, S.O. 393(E), dated the 16th April, 1987, S.O. 443(E) dated the 28th April, 1987, S.O. 64(E), dated the 18th January, 1988 and G.S.R. 919(E) dated the 12th September, 1988.

" True Copy "

Sr. No.	Industry	Parameter	Standards
1	2	3	4
	(c) Induction Furnace		
	Capacity: All sizes	Particulate Matter	150
	Note : In respect of Arc Furnaces and Induction Furnaces provision has to be made for collecting the fumes before discharging the emissions through the stack.		
33.	THERMAL POWER PLANTS	STACK HEIGHT/LIMIT IN METERS*	
		Power generation capacity :	
		- 500 MW and above	275
		- 200 MW/210 MW and above to less than 500 MW	220
		- Less than 200 MW/210 MW	H-14(Q)$^{0.3}$ where Q is emission rate of SO_2 in *kg/hr. and *H Stack height in metres.
		Steam generation capacity:	
		- Less than 2 ton/hr.	½ times the neighbouring building height or 9 metres (whichever is more)
		- More than 2 ton/hr. to 5 ton/hr.	12
		- More than 5 ton/hr. to 10 ton/hr.	15
		- More than 10 ton./hr.	18
		- More than 15 ton/hr. to 20 ton/hr.	*21
		- More than 20 ton/hr. to 25 ton/hr	24
		- More than 25 ton/hr. to 30 ton/hr.	27
		- More than 30 ton/hr.	30 or using formula H-14(Q)$^{0.3}$ (whichever is more) Q is emission rate of SO_2 in kg/hr and *H-Stack height in meters.

* Correction have been made as per Corrigendum Notification no. S.O. 8(E) dt. 31.12.1990.

रजिस्ट्री सं० डी० एल०-33004/99 REGD. NO. D. L.-33004/99

भारत का राजपत्र
The Gazette of India

असाधारण
EXTRAORDINARY
भाग II—खण्ड 3—उप-खण्ड (ii)
PART II—Section 3—Sub-section (ii)
प्राधिकार से प्रकाशित
PUBLISHED BY AUTHORITY

सं. 2620] नई दिल्ली, मंगलवार, दिसम्बर 8, 2015/अग्रहायण 17, 1937
No. 2620] NEW DELHI, TUESDAY, DECEMBER 8, 2015/AGRAHAYANA 17, 1937

पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय

अधिसूचना

नई दिल्ली, 7 दिसम्बर, 2015

का.आ. 3305(अ).— केंद्रीय सरकार, पर्यावरण (संरक्षण) अधिनियम, 1986 (1986 का 29) की धारा 6 और धारा 25 द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए पर्यावरण (संरक्षण) नियम, 1986 का और संशोधन करने के लिए निम्नलिखित नियम बनाती है, अर्थात् :—

1.(1) इन नियमों का संक्षिप्त नाम पर्यावरण (संरक्षण) संशोधन नियम, 2015 है।

(2) ये उनके राजपत्र में प्रकाशन की तारीख को प्रवृत्त होंगे।

2. पर्यावरण (संरक्षण) नियम, 1986 की अनुसूची 1 में,—

(क) क्रम सं. 5 और उससे संबंधित प्रविष्टियों के स्थान पर निम्नलिखित क्रम सं. और प्रविष्टियां अंत:स्थापित की जाएंगी, अर्थात् :—

क्रम सं.	उद्योग	मापदंड	मानक
1	2	3	4
5क	ताप विद्युत संयंत्र (जल उपभोग सीमा)	जल उपभोग	I. एक बार शीतलन (ओटीसी) के माध्यम से सभी संयंत्र शीतलन टावरों (सीटी) को प्रतिष्ठापित करेंगे और अधिसूचना की तारीख से दो वर्ष की अवधि के भीतर अधिकतम 3.5m^3/MWh के विनिर्दिष्ट जल उपभोग को हासिल करेंगे।

			II. सभी विद्यमान सीटी-आधारित संयंत्र 3.5m³/MWh इस अधिसूचना के प्रकाशन की तारीख से दो वर्ष के भीतर अधिकतम 3.5m³/MWh तक के विनिर्दिष्ट जल उपभोग को कम करेंगे। III. जनवरी, 2017 के पश्चात् प्रतिष्ठापित किए जाने वाले नए संयंत्र अधिकतम 2.5 m³/MWh तक के विनिर्दिष्ट जल उपभोग को पूरा करेंगे और शून्य जल द्रव्य को हासिल करेंगे।

(ख) क्रम सं. 25 और उससे संबंधित प्रविष्टियों के पश्चात् निम्नलिखित क्रम सं. और प्रविष्टियां रखी जाएंगी, अर्थात् :—

क्रम सं.	उद्योग	मापदंड	मानक
1	2	3	4
		विवक्त पदार्थ	100 mg/Nm³
		सल्फर डायोक्साइड(SO_2)	600 mg/Nm³ (500 मेगावाट से कम क्षमता की इकाईयों से लघु इकाईयां) 200 mg/Nm³ (500 मेगावाट और उससे अधिक क्षमता की इकाईयां)
		नाइट्रोजन के आक्साइड (NOx)	300 mg/Nm³
		पारा (Hg)	0.03 mg/Nm³ (500 मेगावाट और उससे अधिक क्षमता की इकाईयां)
		1 जनवरी, 2003 के पश्चात् 31 दिसंबर, 2016' तक प्रतिष्ठापित टीपीपी (इकाईयां)	
		विवक्त पदार्थ	50 mg/Nm³
		सल्फर डायोक्साइड (SO_2)	600 mg/Nm³ (500 मेगावाट से कम क्षमता की इकाईयों से लघु इकाईयां) 200 mg/Nm³ (500 मेगावाट और उससे अधिक क्षमता की इकाईयां)
		नाइट्रोजन के आक्साइड (NOx)	300 mg/Nm³
		पारा (Hg)	0.03 mg/Nm³
		1 जनवरी, 2017'' से प्रतिष्ठापित टीपीपी (इकाईयां)	
		विवक्त पदार्थ	30 mg/Nm³
		सल्फर डायोक्साइड (SO_2)	100 mg/Nm³
		नाइट्रोजन के आक्साइड	100 mg/Nm³

		(NOx)	
		पारा (Hg)	0.03 mg/Nm³

* टीपीपी (इकाईयां) इस अधिसूचना के प्रकाशन की तारीख से दो वर्ष के भीतर परिसीमाओं को पूरा करेंगी।

** इसके अंतर्गत सभी टीपीपी (इकाईयां) हैं, जिन्हें पर्यावरणीय निकासी प्रदान की गई है और संनिर्माण के अधीन हैं।

[फा. सं. क्यू-15017/40/2007-सीपीडब्ल्यू]

डा. राशिद हसन, सलाहकार

टिप्पण :- मूल नियम भारत के राजपत्र, असाधारण, भाग II, खंड 3, उपखंड (ii) में सं. का.आ. 844(अ) 19 नवंबर, 1986 द्वारा प्रकाशित किए गए थे और उनका पश्चातवर्ती का.आ. 433(अ) तारीख 18 अप्रैल, 1987 ; सा.का.नि 176(अ) तारीख 2 अप्रैल, 1996; सा.का.नि. 97 (अ), तारीख 18 फ़रवरी, 2009 ; सा.का.नि 149(अ) तारीख 4 मार्च, 2009 ; सा.का.नि. 543(अ) तारीख 22 जुलाई, 2009 ; सा.का.नि. 739(अ) तारीख 9 सितम्बर, 2010 ; सा.का.नि. 809(अ) तारीख 4 अक्टूबर, 2010, सा.का.नि. 215(अ) तारीख 15 मार्च, 2011 ; सा.का.नि. 221(अ) तारीख 18 मार्च, 2011 ; सा.का.नि. 354(अ) तारीख 2 मई, 2011 ; सा.का.नि. 424(अ) तारीख 1 जून, 2011 ; सा.का.नि. 446(अ) तारीख 13 जून, 2011 ; सा.का.नि. 152(अ) तारीख 16 मार्च, 2012 ; सा.का.नि. 266(अ) तारीख 30 मार्च, 2012 ; सा.का.नि. 277(अ) तारीख 31 मार्च, 2012; सा.का.नि. 820(अ) तारीख 9 नवम्बर, 2012 ; सा.का.नि. 176(अ) तारीख 18 मार्च, 2013 ; सा.का.नि. 535(अ) तारीख 7 अगस्त, 2013 ; सा.का.नि. 771(अ) तारीख 11 दिसम्बर, 2013 ; सा.का.नि. 2(अ) तारीख 2 जनवरी, 2014 ; सा.का.नि. 229(अ) तारीख 28 मार्च, 2014 ; सा.का.नि. 232(अ) तारीख 31 मार्च, 2014 ; सा.का.नि. 325(अ) तारीख 7 मई, 2014, सा.का.नि. 612(अ) तारीख 25 अगस्त, 2014 और अन्तिम संशोधन सा.का.नि. 789(अ) तारीख 11 नवम्बर, 2014 किया गया था।

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 7th December, 2015

S.O. 3305(E).— In exercise of the powers conferred by sections 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely:–

1. (1) These rules may be called the Environment (Protection) Amendment Rules, 2015.

(2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986, in Schedule – I, -

(a) after serial number 5 and entries relating thereto, the following serial number and entries shall be inserted, namely:–

Sr. No.	Industry	Parameter	Standards
1	2	3	4
"5A.	**Thermal Power Plant (Water consumption limit)**	**Water consumption**	I. All plants with Once Through Cooling (OTC) shall install Cooling Tower (CT) and achieve specific water consumption upto maximum of 3.5m³/MWh within a period

			of two years from the date of publication of this notification. II. All existing CT-based plants reduce specific water consumption upto maximum of 3.5m^3/MWh within a period of two years from the date of publication of this notification. III. New plants to be installed after 1st January, 2017 shall have to meet specific water consumption upto maximum of 2.5 m^3/MWh and achieve zero waste water discharged";

(b) for serial number 25, and the entries related thereto, the following serial number and entries shall be substituted, namely:-

Sr. No.	Industry	Parameter	Standards
1	2	3	4
"25.	Thermal Power Plant	**TPPs (units) installed before 31st December, 2003***	
		Particulate Matter	100 mg/Nm^3
		Sulphur Dioxide (SO_2)	600 mg/Nm^3 (Units Smaller than 500MW capacity units) 200 mg/Nm^3 (for units having capacity of 500MW and above)
		Oxides of Nitrogen (NOx)	600 mg/Nm^3
		Mercury (Hg)	0.03 mg/Nm^3(for units having capacity of 500MW and above)
		TPPs (units) installed after 1st January,2003, upto 31st December, 2016*	
		Particulate Matter	50 mg/Nm^3
		Sulphur Dioxide (SO_2)	600 mg/Nm^3 (Units Smaller than 500MW capacity units) 200 mg/Nm^3 (for units having capacity of 500MW and above)
		Oxides of Nitrogen (NOx)	300 mg/Nm^3
		Mercury (Hg)	0.03 mg/Nm^3
		TPPs (units) to be installed from 1st January, 2017**	
		Particulate Matter	30 mg/Nm^3
		Sulphur Dioxide (SO_2)	100 mg/Nm^3
		Oxides of Nitrogen (NOx)	100 mg/Nm^3
		Mercury (Hg)	0.03 mg/Nm^3

*TPPs (units) shall meet the limits within two years from date of publication of this notification.

**Includes all the TPPs (units) which have been accorded environmental clearance and are under construction".

[F. No. Q-15017/40/2007-CPW]

Dr. RASHID HASAN, Advisor

Note: - The principal rules were published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-section (i) *vide* number S.O. 844(E), dated the 19th November, 1986 and subsequently amended *vide* the following notifications:—
S.O. 433(E), dated 18th April 1987; G.S.R. 176(E) dated 2nd April, 1996; G.S.R. 97(E), dated the 18th February, 2009; G.S.R. 149(E), dated the 4th March , 2009; G.S.R. 543(E), dated 22nd July, 2009; G.S.R. 739(E), dated the 9th September, 2010; G.S.R. 809(E), dated, the 4th October, 2010, G.S.R. 215(E), dated the 15th March, 2011; G.S.R. 221(E), dated the 18th March, 2011; G.S.R. 354(E), dated the 2nd May, 2011; G.S.R. 424(E), dated the 1st June, 2011; G.S.R. 446(E), dated the 13th June, 2011; G.S.R. 152(E), dated the 16th March, 2012; G.S.R. 266(E), dated the 30th March, 2012; and G.S.R. 277(E), dated the 31st March, 2012; and G.S.R. 820(E), dated the 9th November, 2012; G.S.R. 176(E), dated the 18th March, 2013; G.S.R. 535(E), dated the 7th August, 2013; G.S.R. 771(E), dated the 11th December, 2013; G.S.R. 2(E), dated the 2nd January, 2014; G.S.R. 229(E), dated the 28th March, 2014; G.S.R. 232(E), dated the 31st March, 2014; G.S.R. 325(E), dated the 07th May, 2014, G.S.R. 612,(E), dated the 25th August, 2014 and lastly amended vide notification G.S.R. 789(E), dated 11th November, 2014.

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भारत का राजपत्र
The Gazette of India

असाधारण
EXTRAORDINARY
भाग II—खण्ड 3—उप-खण्ड (ii)
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प्राधिकार से प्रकाशित
PUBLISHED BY AUTHORITY

सं. 590] नई दिल्ली, सोमवार, मार्च 7, 2016/फाल्गुन 17, 1937
No. 590] NEW DELHI, MONDAY, MARCH 7, 2016/ PHALGUNA 17, 1937

पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय

शुद्धिपत्र

नई दिल्ली, 7 मार्च, 2016

का.आ. 682(अ).—भारत के राजपत्र में प्रकाशित पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय की अधिसूचना सा.का.नि. 3305(अ) तारीख 7 दिसंवर, 2015 द्वारा अधिसूचित पर्यावरण (संरक्षण) संशोधन नियम, 2015 के अंतर्गत आने वाली नीचे उल्लिखित प्रविष्टियों को निम्न पढ़ें:

1. पृष्ठ सं. 2, क्रम सं. 25, पंक्ति सं. 2 के नीचे सारणी में स्तम्भ 3 और 4 में "31 **दिसंबर, 2003 से पहले संस्थापित टीपीपी (इकाईयां)**"

2. पृष्ठ सं. 2, क्रम सं. 25, पंक्ति सं. 6 की सारणी के स्तम्भ 4 में "300 mg/Nm^3" के स्थान पर "600 mg/Nm^3" पढ़ें

3. पृष्ठ सं. 2, क्रम सं. 25, पंक्ति सं. 8 की सारणी के स्तम्भ 3 और 4 में "1 जनवरी, 2003" के स्थान पर "1 **जनवरी**, 2004" पढ़ें

[फा.सं. क्यू.15017/40/2007-सीपीडब्ल्यू]

डा. राशिद हसन, सलाहकार

272

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

CORRIGENDUM

New Delhi, the 7th March, 2016

S.O. 682(E).—In the notification of the Government of India in the Ministry of Environment, Forest and Climate Change vide number S.O. 3305(E), dated the 7th December, 2015, published in the Gazette of India, Part II, Section 3, Sub-section (ii), in page 4, in the Table, against serial number 25, for "1st January, 2003" substitute "1st January, 2004".

[F.No. Q-15017/40/2007-CPW]

Dr. RASHID HASAN, Advisor

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रजिस्ट्री सं० डी० एल०-33004/99 REGD. NO. D. L.-33004/99

भारत का राजपत्र
The Gazette of India

असाधारण
EXTRAORDINARY
भाग II—खण्ड 3—उप-खण्ड (i)
PART II—Section 3—Sub-section (i)
प्राधिकार से प्रकाशित
PUBLISHED BY AUTHORITY

सं. 435] नई दिल्ली, शुक्रवार, जून 29, 2018/आषाढ़ 8, 1940
No. 435] NEW DELHI, FRIDAY, JUNE 29, 2018/ASHADHA 8, 1940

पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय

अधिसूचना

नई दिल्ली, 28 जून, 2018

सा.का.नि. 593 (अ).— भारत के राजपत्र, असाधारण में भारत सरकार, पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय की दिनांक 16 अक्तूबर, 2017 की अधिसूचना संख्या सा.का.नि. 3337 (अ) के द्वारा एक प्रारूप अधिसूचना प्रकाशित की गई थी जिसमें उन सभी व्यक्तियों, जिनके उससे प्रभावित होने की संभावना थी, से उस तारीख से जिसकी उक्त अधिसूचना की राजपत्र की प्रतियां जन-साधारण को उपलब्ध कराई गई थीं, साठ दिन की अवधि के भीतर आपत्तियां और सुझाव मांगे गए थे।

और, राजपत्र की प्रतियां दिनांक 16 अक्तूबर, 2017 को जन-साधारण को उपलब्ध कराई गई थीं।

और, केंद्र सरकार द्वारा इस प्रारूप अधिसूचना के प्रत्युत्तर में सभी व्यक्तियों और पक्षों से प्राप्त सभी आपत्तियों और सुझावों पर विधिवत् रूप से विचार किया गया है।

अतः अब, पर्यावरण (संरक्षण) नियम, 1986 के नियम (5) के उप नियम (3) के साथ पठित पर्यावरण (संरक्षण) अधिनियम, 1986 (1986 का 29) की धारा 6 और 25 द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए, केंद्र सरकार, एतद्द्वारा पर्यावरण (संरक्षण) नियम, 1986 में और संशोधन करने के लिए निम्नलिखित संशोधन करती है, अर्थात्:—

1. (1) इन नियमों का संक्षिप्त नाम पर्यावरण (संरक्षण) संशोधन नियम, 2018 है।
   (2) ये राजपत्र में प्रकाशन की तारीख को प्रवृत्त होंगे।
2. पर्यावरण (संरक्षण) नियम, 1986 की अनुसूची 1 में,-
   (क) स्तंभ 4 में क्रम संख्या 5क के सामने, मद 3 के स्थान पर निम्नलिखित मद रखी जाएगी, अर्थात:—

"III. विनिर्दिष्ट जल उपभोग, तारीख 1 जनवरी, 2017 के पश्चात् संस्थापित किए गए नए संयंत्र के लिए 3.0 मी3/एमडब्ल्यूएच से अधिकतम नहीं होगा और ये संयंत्र शून्य अपशिष्ट जल बहाव को हासिल करेंगे।"

(ख) क्रम संख्या 5 क और उससे संबंधित प्रविष्टियों के पश्चात् निम्नलिखित क्रम संख्या और प्रविष्टियों को अंत:स्थापित किया जाएगा, अर्थात्:-

क्रम सं	उद्योग	पैरामीटर	मानक
1	2	3	4
"5ख	तापीय विद्युत संयंत्र (जल उपभोग सीमा समुद्री जल का प्रयोग)	जल उपभोग	उपरोक्त क्रम सं 5क में स्तंभ 4 में मद I से III समुद्री जल का प्रयोग करने वाले तापीय विद्युत संयंत्र पर लागू नहीं होगा";

(ग) क्रम सं 25 में, निम्नलिखित टिप्पण अंत:स्थापित किया जाएगा, अर्थात:—

"टिप्पण : सल्फर डाइआक्साइड, नाइट्रोजन और धूल-कण के लिए सभी मानीटर किए गए मान को शुष्क आधार पर 6% आक्सीजन के लिए संशोधित किया जाएगा।";

(घ) क्रम सं 33 और उससे संबंधित प्रविष्टियों के पश्चात् निम्निलिखित क्रम संख्या और प्रविष्टियों को अंत:स्थापित किया जाएगा:-

क्रम सं	उद्योग	पैरामीटर	मानक
1	2	3	4
"33क	आर्द्र-फ्लू गैस डीसल्फयुराईजेशन (एफजीडी) के साथ तापीय विद्युत संयंत्र	चिमनी की ऊंचाई/मीटर में सीमा	विद्युत उत्पादन क्षमता: 100 मेगावाट और अधिक एच= 6.902 (क्यू x 0.277)$^{0.555}$ अथवा 100 मीटर न्यूनतम 100 मेगावाट से कम एच= 6.902 (क्यू x 0.277)$^{0.555}$ अथवा 30 मीटर जो भी अधिक हो"; क्यू=सल्फर डाइआक्साइड की कि.ग्रा./उत्सर्जन दर" एच= मीटर में भैतिक स्टाक ऊंचाई।" "चिमनी से जुड़ी सभी यूनिटों का योग **टिप्पणी :** ये मानक कोयला/लिग्नाइट आधारित तापीय विद्युत संयंत्रों पर लागू होंगे।

[फा. सं. क्यू-15017/40/2007-सीपीडब्ल्यू)]

डॉ. ए. सेंथिल वेल, वैज्ञानिक 'जी'

टिप्पण : मूल नियम के राजपत्र असाधारण, भाग II, खंड 3, उपखंड (i) का.आ. 844 (अ) तारीख 19 नवम्बर, 1986 द्वारा प्रकाशित किया गया था और पिछली बार अधिसूचना सा.का.नि. 568 (अ) दिनांक 18 जून, 2018 के द्वारा संशोधित किया गया।

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 28th June, 2018

G.S.R. 593 (E).—Whereas, a draft notification, for Thermal Power Plants was published in the Gazette of India, Extraordinary, vide notification of the Government of India in the erstwhile Ministry of Environment, Forest and Climate Change number G.S.R. 3337(E), dated the 16th October, 2017, inviting objections and suggestions from all persons likely to be affected thereby within a period of sixty days from the dated on which copies of the Gazette containing the said notification were made available to the public;

And Whereas, copies of the Gazette were made available to the public on the 16th October, 2017;

And Whereas, all objections and suggestions received from all persons and stakeholders in response to the draft notification have been duly considered by the Central Government;

Now, therefore, in exercise of the powers conferred by sections 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986) read with sub-rule (3) of rule 5 of the Environment (Protection) Rules, 1986, the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely:-

1. (1) These rules may be called the Environment (Protection) Amendment Rules, 2018.

(2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986, in Schedule-I,-

(a) against serial number 5A, in column 4, for item III, the following item shall be substituted, namely:-
"III. Specific water consumption shall not exceed maximum of 3.0 m^3/MWh for new plants installed after the 1st January, 2017 and these plants shall also achieve zero waste water discharge.";

(b) after serial number 5A and the entries relating thereto, the following serial number and entries shall be inserted, namely:-

Sl. No.	Industry	Parameter	Standards
1	2	3	4
"5B.	Thermal Power Plant (water consumption limit) using sea water	Water consumption	Items I to III in column 4 in serial number 5A above shall not be applicable to the Thermal Power Plants using sea water";

(c) in serial number 25, the following Note shall be inserted, namely:—

"Note: All monitored values for SO_2, NOx and Particulate Matter shall be corrected to 6% Oxygen, on dry basis";

(d) after serial number 33 and the entries relating thereto, the following serial number and entries shall be inserted, namely:—

Sl. No.	Industry	Parameter	Standards
1	2	3	4

"33A.	Thermal Power Plants with wet Flue Gas Desulphurization (FGD)	Stack Height/Limit in Meters	Power generation capacity: 100 MW and above $H=6.902(QX0.277)^{0.555}$ or 100 m minimum Less than 100 MW $H=6.902(QX0.277)^{0.555}$ or 30 m whichever is more"; Q = Emission rate of SO_2 in kg/hr* H = Physical stack height in meter *total of the all Unit's connected to stack **Note:** These standards shall apply to coal / lignite based Thermal Power Plants.".

[F. No. Q-15017/40/2007-CPW]
DR. A. SENTHIL VEL, Scientist 'G'

Note: The principal rules were published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-section (i) *vide* number S.O. 844 (E), dated the 19th November, 1986 and last amended *vide* notification number G.S.R. 263(E), dated the 22nd March, 2018.

RAKESH SUKUL

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भारत का राजपत्र
The Gazette of India

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असाधारण
EXTRAORDINARY

भाग II—खण्ड 3—उप-खण्ड (i)
PART II—Section 3—Sub-section (i)

प्राधिकार से प्रकाशित
PUBLISHED BY AUTHORITY

सं. 540] नई दिल्ली, वृहस्पतिवार, अक्तूबर 22, 2020/आश्विन 30, 1942
No. 540] NEW DELHI, THURSDAY, OCTOBER 22, 2020/ASVINA 30, 1942

पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय

अधिसूचना

नई दिल्ली, 19 अक्तूबर, 2020

सा.का.नि. 662(अ).—केंद्रीय सरकार, पर्यावरण (संरक्षण) अधिनियम, 1986 (1986 का 29) की धारा 6 और धारा 25 द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए पर्यावरण (संरक्षण) नियम, 1986 का और संशोधन करने के लिए निम्नलिखित नियम बनाती है, अर्थात् :–

1.(1) इन नियमों का संक्षिप्त नाम पर्यावरण (संरक्षण) संशोधन नियम, 2020 है ।

(2) ये उनके राजपत्र में प्रकाशन की तारीख को प्रवृत्त होंगे ।

2. पर्यावरण (संरक्षण) नियम, 1986 की अनुसूची 1 में,--

क्र. सं. 25 के सामने, "जनवरी, 2003 के पश्चात् 31 दिसंबर, 2016 तक प्रतिष्ठापित टीपीपी (इकाईयां)", शीर्ष के अधीन, नाइट्रोजन के आक्साइड (NOx) के संबंध में, " 300 mg/Nm^3", अंकों और अक्षरों के स्थान पर, स्तंभ 4 में, "450 mg/Nm^3", अंक और अक्षर रखे जाएंगे ।

[फा.सं. क्यू-15017/40/2007-सीपीडब्ल्यू]

जिगमेत टक्पा, संयुक्त सचिव

278 (65)

टिप्पण : —मूल नियम भारत के राजपत्र, असाधारण, भाग II, खंड 3, उपखंड (ii) में सं. का.आ. 844(अ) 19 नवंबर, 1986 द्वारा प्रकाशित किए गए थे और उनका अंतिम संशोधन अधिसूचना सा.का.नि. 48 (अ), तारीख 24 जनवरी, 2020 द्वारा किया गया ।

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 19th October, 2020

G.S.R. 662(E).—In exercise of the powers conferred by sections 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely:—

1. (1) These rules may be called the Environment (Protection) Amendment Rules, 2020.

   (2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986, in Schedule – I, -

against S. No. 25, under the heading "TPPs (units) installed after 1st January, 2003, upto 31st December, 2016", in respect of Oxides of Nitrogen (NOx), for figure and letters "300 mg/Nm^3" in column 4, the figure and letters "450 mg/Nm^3" shall be substituted.

[F. No. Q-15017/40/2007-CPW]

JIGMET TAKPA, Joint Secretary

Note : The principle rules were published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-section (i) *vide* number S.O. 844(E), dated the 19th November, 1986 and lastly amended *vide* notification G.S.R. 48(E), dated the 24th January, 2020.

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सी.जी.-डी.एल.-अ.-01042021-226335
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असाधारण
EXTRAORDINARY

भाग II—खण्ड 3—उप-खण्ड (i)
PART II—Section 3—Sub-section (i)

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PUBLISHED BY AUTHORITY

सं. 192] नई दिल्ली, बृहस्पतिवार, अप्रैल 1, 2021/चैत्र 11, 1943
No. 192] NEW DELHI, THURSDAY, APRIL 1, 2021/CHAITRA 11, 1943

पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय

अधिसूचना

नई दिल्ली, 31 मार्च, 2021

सा.का.नि. 243(अ).—केन्द्रीय सरकार, पर्यावरण (संरक्षण) अधिनियम, 1986 (1986 का 29) की धारा 3, धारा 6 और धारा 25 द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए, पर्यावरण (संरक्षण) नियम, 1986 का और संशोधन करने के लिए निम्नलिखित नियम बनाती है, अर्थात् :-

1. (1) इन नियमों का संक्षिप्त नाम पर्यावरण (संरक्षण) संशोधन नियम, 2021 है।

(2) ये नियम राजपत्र में प्रकाशन की तारीख को प्रवृत्त होंगे।

2. पर्यावरण (संरक्षण) नियम, 1986 की अनुसूची-1, के क्रम संख्यांक 25 में, "*टीपीपी (इकाईयां) इस अधिसूचना के प्रकाशन की तारीख से दो वर्ष के भीतर सीमाओं को पूरा करेंगी", अक्षरों, कोष्ठकों और शब्दों के स्थान पर, निम्नलिखित रखा जाएगा, अर्थात् :-

"*(i) पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय, विद्युत मंत्रालय, केन्द्रीय विद्युत प्राधिकरण (सीईए) और केन्द्रीय प्रदूषण नियंत्रण बोर्ड के प्रतिनिधियों से मिलकर बने कार्य बल का गठन केन्द्रीय प्रदूषण नियंत्रण बोर्ड (सीपीसीबी) द्वारा सारणी-1 में यथाविनिर्दिष्ट तीन प्रवर्गों में सारणी-1 के स्तंभ (4) में यथाविनिर्दिष्ट समय सीमा के भीतर उत्सर्जन मानदंडों के अनुरूप होने के लिए उनकी अवस्थिति के आधार पर तापीय विद्युत संयत्रों के प्रवर्गीकरण हेतु किया जाएगा, अर्थात् :-

सारणी-1

क्र.सं.	प्रवर्ग	अवस्थिति/स्थान	अनुपालन के लिए समय सीमाएं	
			निवृत्त नहीं होने वाली इकाईयां	निवृत्त होने वाली इकाईयां
(1)	(2)	(3)	(4)	(5)
1	प्रवर्ग क	10 लाख से अधिक जनसंख्या वाले राष्ट्रीय राजधानी क्षेत्र या शहरों की 10 किलोमीटर की परिधि के भीतर 1	31 दिसम्बर, 2022 तक	31 दिसम्बर, 2022 तक
2	प्रवर्ग ख	गंभीर रूप से प्रदूषित क्षेत्रों या गैर प्राप्ति शहरों की 10 किलोमीटर की परिधि के भीतर 2	31 दिसम्बर, 2023 तक	31 दिसम्बर, 2025 तक
3	प्रवर्ग ग	प्रवर्ग क और ख में सम्मिलित से भिन्न	31 दिसम्बर, 2024 तक	31 दिसम्बर, 2025 तक

[1] भारत की 2011 की जनगणना के अनुसार ।

[2] सीपीसीबी द्वारा यथापरिभाषित ।

(ii) सारणी-1 के स्तंभ (5) में यथाविनिर्दिष्ट तारीख के पूर्व निवृत्त होने के लिए घोषित तापीय विद्युत संयंत्र से, उस स्थिति में जहां ऐसे संयंत्र उनके निवृत्त होने के आधार पर छूट के लिए सीपीसीबी और सीईए को एक प्रतिज्ञान प्रस्तुत करते हैं, विनिर्दिष्ट मानदंडों को पूर्ण करने की अपेक्षा नहीं की जाएगी:

परन्तु ऐसे संयंत्रों से, उस स्थिति में जहां उनका प्रचालन प्रतिज्ञान में यथाविनिर्दिष्ट तारीख से आगे जारी रहता है, जनित विद्युत के प्रति यूनिट पर 0.20 रुपए की दर से पर्यावरण प्रतिकर उद्ग्रहीत किया जाएगा;

(iii) निवृत्त नहीं होने वाले तापीय विद्युत संयंत्र से, सारणी-1 के स्तंभ (4) में यथाविनिर्दिष्ट तारीख के पश्चात्, सारणी-2 में विनिर्दिष्ट दरों के अनुसार पर्यावरण प्रतिकर उद्ग्रहीत किया जाएगा, अर्थात् :-

सारणी-2

समय-सीमा से आगे गैर अनुपालन प्रचालन	पर्यावरणीय प्रतिकर (रुपए प्रति यूनिट जनित विद्युत)		
	प्रवर्ग क	प्रवर्ग ख	प्रवर्ग ग
0-180 दिवस	0.10	0.07	0.05
181-365 दिवस	0.15	0.10	0.075
366 दिवस और अधिक	0.20	0.15	0.10"

[फा.सं. क्यू-15017/40/2007-सीपीडब्ल्यू]

नरेश पाल गंगवार, संयुक्त सचिव

टिप्पणः मूल नियम, भारत के राजपत्र, असाधारण, भाग II, खंड 3, उपखंड (i) में अधिसूचना संख्या का.आ. 844(अ), तारीख 19 नवम्बर, 1986 द्वारा प्रकाशित किए गए थे और उनका अंतिम संशोधन अधिसूचना संख्या सा.का.नि. 662(अ), तारीख 19 अक्तूबर, 2020 द्वारा किया गया ।

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 31st March, 2021

G.S.R. 243(E).—In exercise of the powers conferred by sections 3, 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely:—

1. (1) These rules may be called the Environment (Protection) Amendment Rules, 2021.

(2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986, in Schedule – I, in serial number 25 for letters, brackets and words "*TPPs (units) shall meet the limits within two years from date of publication of this notification", the following shall be substituted, namely: -

"* (i) A task force shall be constituted by Central Pollution Control Board (CPCB) comprising of representative from Ministry of Environment and Forest and Climate Change, Ministry of Power, Central Electricity Authority (CEA) and CPCB to categorise thermal power plants in three categories as specified in the Table-I on the basis of their location to comply with the emission norms within the time limit as specified in column (4) of the Table-I, namely: -

Table-I

Sl. No.	Category	Location/area	Timelines for compliance	
			Non retiring units	Retiring units
(1)	(2)	(3)	(4)	(5)
1	Category A	Within 10 km radius of National Capital Region or cities having million plus population[1].	Upto 31st December 2022	Upto 31st December 2022
2	Category B	Within 10 km radius of Critically Polluted Areas[2] or Non-attainment cities[2]	Upto 31st December 2023	Upto 31st December 2025
3	Category C	Other than those included in category A and B	Upto 31st December 2024	Upto 31st December 2025

[1] As per 2011 census of India.

[2] As defined by CPCB.

(ii) the thermal power plant declared to retire before the date as specified in column (5) of Table-I shall not be required to meet the specified norms in case such plants submit an undertaking to CPCB and CEA for exemption on ground of retirement of such plant:

Provided that such plants shall be levied environment compensation at the rate of rupees 0.20 per unit electricity generated in case their operation is continued beyond the date as specified in the Undertaking;

(iii) there shall be levied environment compensation on the non-retiring thermal power plant, after the date as specified in column (4) of Table-I, as per the rates specified in the Table-II, namely:-

Table-II

Non-Compliant operation beyond the Timeline	Environmental Compensation (Rs. per unit electricity generated)		
	Category A	Category B	Category C
0-180 days	0.10	0.07	0.05
181-365 days	0.15	0.10	0.075
366 days and beyond	0.20	0.15	0.10. "

[F. No. Q-15017/40/2007-CPW]

NARESH PAL GANGAWAR, Jt. Secy.

Note: The principle rules were published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-section (i) vide number S.O. 844(E), dated the 19th November, 1986 and lastly amended vide notification G.S.R. 662(E), dated the 19th October, 2020.

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भारत का राजपत्र
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असाधारण
EXTRAORDINARY

भाग II—खण्ड 3—उप-खण्ड (i)
PART II—Section 3—Sub-section (i)

प्राधिकार से प्रकाशित
PUBLISHED BY AUTHORITY

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पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय

अधिसूचना

नई दिल्ली, 5 सितम्बर, 2022

सा.का.नि. 682(अ).—केन्द्रीय सरकार, पर्यावरण (संरक्षण) अधिनियम, 1986 (1986 का 29) की धारा 3, धारा 6 और धारा 25 द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए, पर्यावरण (संरक्षण) नियम, 1986 का और संशोधन करने के लिए निम्नलिखित नियम बनाती है, अर्थात् :-

1. (1) इन नियमों का संक्षिप्त नाम पर्यावरण (संरक्षण) दूसरा संशोधन नियम, 2022 है।

(2) ये राजपत्र में उनके प्रकाशन की तारीख को प्रवृत्त होंगे।

2. पर्यावरण (संरक्षण) नियम, 1986 की अनुसूची 1 के क्रम सं. 25 में, "*(i) सारणी 1" के स्थान पर निम्नलिखित रखा जाएगा, अर्थात् :--

सारणी-1

क्रम सं.	प्रवर्ग	अवस्थान/क्षेत्र	अनुपालन के लिए समय-सीमा (निवृत्त न होने वाली इकाईयां)		अनुपालन से छूट के लिए इकाईयों को निवृत्त करने की अंतिम तारीख	
			SO_2 उत्सर्जन से भिन्न पैरामीटर	SO_2 उत्सर्जन	SO_2 उत्सर्जन से भिन्न पैरामीटर	SO_2 उत्सर्जन
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1.	प्रवर्ग क	राष्ट्रीय राजधानी क्षेत्र या 10 लाख से	31 दिसंबर,	31 दिसंबर,	31 दिसंबर,	

		अधिक जनसंख्या वाले शहरों[1] की दस किलोमीटर की परिधि के भीतर।	2022 तक	2024 तक	2022 तक	31 दिसंबर, 2027 तक
2.	प्रवर्ग ख	गंभीर रूप से प्रदूषित क्षेत्रों[1] की या गैर-प्राप्ति शहरों[2] की दस किलोमीटर के अर्धव्यास के भीतर	31 दिसंबर, 2023 तक	31 दिसंबर, 2025 तक	31 दिसंबर, 2025 तक	
3.	प्रवर्ग ग	प्रवर्ग क और ख में सम्मिलित से भिन्न	31 दिसंबर, 2024 तक	31 दिसंबर, 2026 तक	31 दिसंबर, 2025 तक	

1 भारत की 2011 की जनगणना के अनुसार

2 केन्द्रीय प्रदूषण नियंत्रण बोर्ड द्वारा यथा-परिभाषित।

3. "'(ii)" के स्थान पर निम्नलिखित रखा जाएगा, अर्थात् :--

'(ii)(क) सारणी 1 के स्तंभ (6) में यथा-विनिर्दिष्ट तारीख से पूर्व निवृत्त होने के लिए घोषित तापीय विद्युत संयंत्र से, ऐसे संयंत्रों द्वारा केंद्रीय प्रदूषण नियंत्रण बोर्ड और केंद्रीय विद्युत प्राधिकरण को ऐसे संयंत्र द्वारा निवृत्त होने के आधार पर छूट के लिए वचनबंध प्रस्तुत करने की दशा में SO_2 उत्सर्जन से भिन्न पैरामीटर के लिए विनिर्दिष्ट मानकों को पूरा करने की अपेक्षा नहीं होगी:

परंतु ऐसे संयंत्रों पर सारणी 1 के स्तंभ (4) में यथा-विनिर्दिष्ट तारीख से उनके द्वारा वचनबंध में यथा-विनिर्दिष्ट तारीख से आगे जारी रहता है, उनके प्रचालन की दशा में जनित विद्युत की प्रति इकाई पर 0.40 रुपए की दर से पर्यावरण प्रतिकर उदग्रहित किया जाएगा;

(ii)(ख) सारणी 1 के स्तंभ (7) में यथा-विनिर्दिष्ट तारीख से पूर्व निवृत्त होने के लिए घोषित तापीय विद्युत संयंत्र से, ऐसे संयंत्रों द्वारा केंद्रीय प्रदूषण नियंत्रण बोर्ड और केंद्रीय विद्युत प्राधिकरण को ऐसे संयंत्र द्वारा निवृत्त होने के आधार पर छूट के लिए वचनबंध प्रस्तुत करने की दशा में SO_2 उत्सर्जनों से भिन्न विनिर्दिष्ट मानकों को पूरा करने की अपेक्षा नहीं होगी:

परंतु ऐसे संयंत्रों पर सारणी 1 के स्तंभ (5) में यथा-विनिर्दिष्ट तारीख से उनके द्वारा वचनबंध में यथा विनिर्दिष्ट तारीख से आगे जारी रहता है, उनके प्रचालन की दशा में जनित विद्युत की प्रति इकाई पर 0.40 रुपए की दर से पर्यावरण प्रतिकर उदग्रहित किया जाएगा;'

4. "'(iii)" के स्थान पर निम्नलिखित रखा जाएगा, अर्थात्:--

"(iii) सारणी 1 के स्तंभ (4) और स्तंभ (5) में यथा-विनिर्दिष्ट तारीख के पश्चात् निवृत्त न होने वाले तापीय विद्युत संयंत्रों पर सारणी-2 में विनिर्दिष्ट दरों के अनुसार, पर्यावरण प्रतिकर उदग्रहित किया जाएगा, अर्थात्:--

सारणी-2

समय-सीमा से आगे अननुपालन प्रचालन	पर्यावरण प्रतिकर (प्रति इकाई जनित विद्युत)
0-180 दिन	0.20
181-365 दिन	0.30
366 दिन और उससे आगे	0.40"

[फा. सं. क्यू-15017/40/2007-सीपीडब्ल्यू]

नरेश पाल गंगवार, अपर सचिव

टिप्पण : मूल नियम, भारत के राजपत्र, असाधारण, भाग II, खंड 3, उपखंड (i) में संख्यांक का.आ. 844(अ), तारीख 19 नवंबर, 1986 द्वारा प्रकाशित किए गए थे और उनका अंतिम संशोधन अधिसूचना संख्यांक सा.का.नि. 143(अ), तारीख 22 फरवरी, 2022 द्वारा किया गया ।

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 5th September, 2022

G.S.R. 682(E).—In exercise of the powers conferred by sections 3, 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely:—

1. (1) These rules may be called the Environment (Protection) Second Amendment Rules, 2022.

(2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986, in Schedule – I, in serial number 25 for "* (i) Table 1" the following shall be substituted, namely: -

Table-I

Sl. No.	Category	Location/area	Timelines for compliance (Non-retiring units)		Last date for retirement of units for exemption from compliance	
			parameters other than SO_2 emissions	SO_2 emissions	parameters other than SO_2 emissions	SO_2 emissions
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	Category A	With 10 km radius of National Capital Region or cities having million plus population[1].	Up to 31st December 2022	Up to 31st December 2024	Up to 31st December 2022	Up to 31st December 2027
2	Category B	With 10 km radius of Critically Polluted Areas[2] or Non-attainment cities[2]	Up to 31st December 2023	Up to 31st December 2025	Up to 31st December 2025	
3	Category C	Other than those included in category A and B	Up to 31st December 2024	Up to 31st December 2026	Up to 31st December 2025	

[1] As per 2011 census of India.

[2] as defined by CPCB.

3. For "* (ii)" the following shall be substituted, namely: -

'(ii) (a) The thermal power plant declared to retire before the date as specified in column (6) of Table-I shall not be required to meet the specified norms for parameters other than SO_2 emissions in case such plants submit an undertaking to CPCB and CEA for exemption on ground of retirement of such plant:

Provided that such plants shall be levied environment compensation from the dates as specified in column (4) of table –I, at the rate of rupees 0.40 per unit electricity generated in case their operation is continued beyond the date as specified in the undertaking;

(ii) (b) The thermal power plant declared to retire before the date as specified in column (7) of Table-I shall not be required to meet the specified norms for SO_2 emissions in case such plants submit an undertaking to CPCB and CEA for exemption on ground of retirement of such plant:

Provided that such plants shall be levied environment compensation from the dates as specified in column (5) of table –I, at the rate of rupees 0.40 per unit electricity generated in case their operation is continued beyond the date as specified in the undertaking;'

(72)
285

4. For "* (iii)" the following shall be substituted, namely: -

"(iii) there shall be levied environment compensation on the non-retiring thermal power plants, after the date as specified in column (4) and (5) of Table-I, as per the rates specified in the Table-II, namely: -

Table-II

Non-Compliant operation beyond the Timeline	Environmental Compensation (Rs. per unit electricity generated)
0-180 days	0.20
181-365 days	0.30
366 days and beyond	0.40"

[F. No. Q-15017/40/2007-CPW]

NARESH PAL GANGWAR, Addl. Secy.

Note : The principle rules were published in the Gazette of India, Extraordinary, Part II, Section 3, Sub-section (i) vide number S.O. 844(E), dated the 19th November, 1986 and lastly amended vide notification G.S.R. 143(E), dated the 22nd February, 2022.

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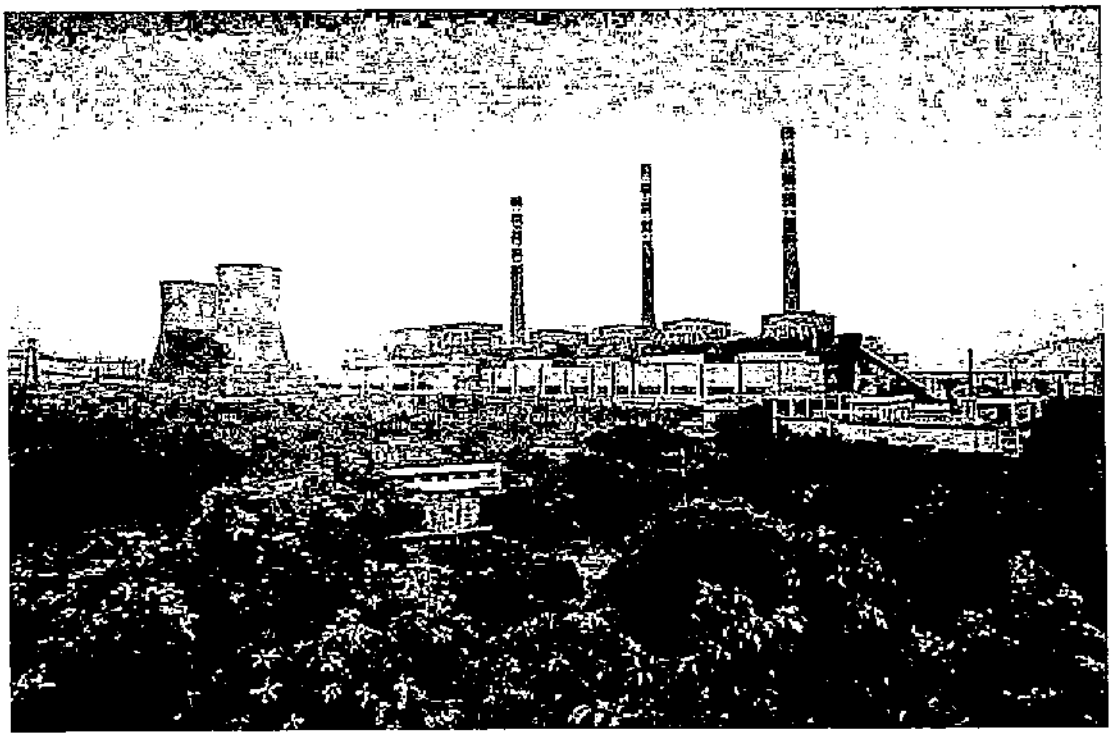
Study to survey ambient atmospheric SO_2 concentrations in different category of cities based on their vicinity to thermal power plants (TPPs)



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31 May 2024

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CONTENTS

Chapter No.	Chapter Title	Page No.
Chapter 1	Executive Summary	4 – 6
Chapter 2	Survey of ambient atmospheric SO_2 concentrations in different category of cities: Phase-I	7 – 40
Chapter 3	Contribution of SO_2 emissions from Coal-based TPPs towards ambient atmospheric SO_2, Sulfate Aerosols, PM2.5, and PM10 mass concentrations in different category cities during Phase I of survey	41 – 75
Chapter 4	Survey of ambient atmospheric SO_2 concentrations in different category of cities: Phase-II	76 – 89
Chapter 5	Contribution of SO_2 emissions from Coal-based TPPs towards ambient atmospheric SO_2, Sulfate Aerosols, PM2.5, and PM10 mass concentrations in different category cities during Phase II of survey	90 – 107
Chapter 6	Survey of ambient atmospheric SO_2 concentrations in different category of cities: Phase-III	108 – 135
Chapter 7	Contribution of SO_2 emissions from Coal-based TPPs towards ambient atmospheric SO_2, Sulfate Aerosols, PM2.5, and PM10 mass concentrations in different category cities during Phase III of survey	136 – 159
Chapter 8	Summary of results from three Phases Survey on ambient atmospheric SO2 concentration in different category cities	160 - 169
Chapter 9	Discussion on the chances of acid rain and need for quantifying the lifecycle cost and benefits of FGD implementation in TPPs across India	170 – 186
Chapter 10	Conclusions of Recommendations	187 - 194
	References	195 – 197

Executive Summary

To address environmental issues, the Ministry of Environment, Forest, and Climate Change (MoEF&CC) in India has mandated that TPPs install Flue Gas Desulfurization (FGD) units to control SO_2 emissions and improve air quality. These regulations, part of the "Environment (Protection) Amendment Rules 2015," aim to reduce PM2.5, SOx, NOx, and mercury emissions from TPPs.

In this context, the Central Electricity Authority (CEA), under the direction of the Ministry of Power (MoP), Government of India (GoI), signed an MOU with IIT Delhi to conduct a comprehensive survey of ambient air SO_2 concentrations across three categories of cities from February 2023 to February 2024: cities without coal-based TPPs (Category-1), cities with coal-based TPPs without FGDs (Category-2), and cities with coal-based TPPs with FGDs (Category-3). The survey, conducted by IIT Delhi in three phases, assessed SO_2 levels and the impact of TPPs on local air quality. Results indicated that all surveyed locations were within the National Ambient Air Quality Standards (NAAQS) of 80 $\mu g/m^3$ based on 24 hours average measurements. Daily mean SO_2 concentrations ranged from 2.48 ± 0.49 $\mu g/m^3$ to 9.26 ± 3.28 $\mu g/m^3$ in Category-1 cities, 3.12 ± 0.81 $\mu g/m^3$ to 6.48 ± 3.08 $\mu g/m^3$ in Category-2 cities, and 4.24 ± 0.31 $\mu g/m^3$ to 12.51 ± 2.82 $\mu g/m^3$ in Category-3 cities. Even the maximum instantaneous ambient air SO_2 concentrations measured across the cities and phases of our survey never exceeded the daily mean permissible limit, confirming compliance with NAAQS.

Our study assessed the contribution of SO_2 emissions from coal-based thermal power plants to ambient SO_2 concentrations across different city categories. In Category-1 cities, the energy sector's contribution was relatively low, ranging from 11.44% to 16.53%, with New Delhi at 16.53% (1.36 $\mu g/m^3$), Hyderabad at 11.57% (0.42 $\mu g/m^3$), and Lucknow at 11.44% (0.66 $\mu g/m^3$). In Category-2 cities, contributions were more significant, ranging from 27.99% (1.82 $\mu g/m^3$) to 38.57% (1.99 $\mu g/m^3$), with notable values in Kolkata, Nagpur, Kota, and Shahdol. Category-3 cities such as Ghaziabad, Khargone, and Gautam Buddha Nagar showed contributions between 17.37% (1.43 $\mu g/m^3$) and 22.54% (2.17 $\mu g/m^3$), exhibiting seasonal variations.

Our study reveals that the contribution of sulfate aerosols (SO_4) from SO_2 emissions of coal-based TPPs to ambient PM2.5 and PM10 concentrations varies significantly across different city categories and seasons. Averaging across all cities and phases, contributions ranged from 0.96% (0.44 $\mu g/m^3$) to 5.21% (3.30 $\mu g/m^3$) for PM2.5 and from 0.57% (0.49 $\mu g/m^3$) to 3.67% (3.60 $\mu g/m^3$) for PM10. The highest contributions were in Category-2 cities, averaging 3.83% (2.19 $\mu g/m^3$) to PM2.5 and 2.87% (2.49 $\mu g/m^3$) to PM10. Category-3 cities showed intermediate contributions, averaging 2.45% (1.61 $\mu g/m^3$) to PM2.5 and 1.97% (2.13 $\mu g/m^3$) to PM10, while Category-1 cities had the lowest, averaging 1.79% (0.93 $\mu g/m^3$) to PM2.5 and 1.04% (1.07 $\mu g/m^3$) to PM10. Installing FGD systems with an 87.5% SO_2 removal efficiency in all coal-based TPPs across India

would reduce PM2.5 concentrations by up to 4.56% (2.89 μg/m³) and PM10 concentrations by up to 3.21% (3.15 μg/m³) across all surveyed cities and seasons. These findings indicate that while TPP SO_2 emissions contribute to ambient PM levels, their impact is relatively minor. Implementing FGD systems in all TPPs would likely have an insignificant impact on lowering PM2.5 and PM10 levels, resulting in only a marginal improvement (5%) in PM air quality. It should be noted that SO_2, a colourless gas, does not directly reduce visibility but contributes to haze formation after being converted into sulfate particles. Therefore, eliminating SO_2 emissions from TPPs is likely to result in a modest improvement in visibility and a reduction in haze formation.

Our study also explored the lifecycle of SO_2 in the atmosphere and the likelihood of acid rain in India. Once emitted, SO_2 undergoes oxidation, forming sulfuric acid or sulfate aerosols through gas-phase reactions with hydroxyl radicals and aqueous-phase reactions in cloud droplets with oxidants like hydrogen peroxide and ozone. However, in India, acid rain is mitigated by alkaline substances like ammonia (NH_3) from agricultural activities and carbonate minerals in dust, which neutralize sulfuric acid. Consequently, acid rain is not a significant issue in most parts of India except in the southern peninsular region where alkaline substances are less prevalent. However, the sea breeze naturally keeps ambient SO_2 levels lower in coastal areas of peninsular India. Additionally, the inherent alkalinity of seawater droplets, due to the presence of bicarbonate ions and carbonate ions, effectively neutralizes sulfuric acid in the atmosphere over coastal areas.

While FGD implementation will significantly reduce SO_2 emissions from TPPs, it is likely to have only a nominal impact on lowering ambient air PM2.5 and PM10 levels, as SO_2 and sulfate aerosol concentrations in the surveyed cities are already low and within NAAQS. Further, there are no credible studies quantifying the overall life-cycle assessment (LCA) of costs and benefits of FGDs in the Indian context. Current FGD technologies will increase CO_2 emissions, water consumption, and secondary pollution due to the mining and transportation of limestone/gypsum. Each SO_2 molecule captured by FGDs releases a CO_2 molecule, and FGD operations also contribute to CO_2 emissions. Additionally, sulfate aerosols block solar radiation, partially offsetting CO_2-induced global warming. The impacts of reduced SO_2 and increased CO_2 emissions on India's regional climate, monsoon system, and extreme weather events are not well-studied. Our study estimates that installing FGD systems with 87.5% SO_2 removal efficiency in all coal-based TPPs across India would reduce annual SO_2 emissions by 4.88 MT per year, but this would result in an immediate increase of 14.4 MT per year in CO_2 emissions from mining, transportation, reagent operations, and increased auxiliary power consumption (APC). Additionally, considering the LCA of FGD implementation suggested by several previous studies, which accounts for both immediate and long-term environmental impacts, the reduction in SO_2 emissions could lead to an increase in annual equivalent CO_2 emissions by a few hundred MT of CO_2 per year and would consume an extra couple of hundred million liters of water annually. It is important to note that the exact additional CO_2 emissions beyond the immediate increases, as well as the additional water

consumption, can only be accurately determined through a comprehensive LCA of FGD implementation across all TPPs in India. It's worth noting that SO_2 and CO_2 have significantly different atmospheric lifetimes, which carries important implications for climate policy. SO_2 has a short atmospheric lifetime ranging from a few hours to about 15 days, while CO_2 persists for over 100 years. While SO_2 is a significant air pollutant and its emissions should be reduced, the trade-off between reducing SO_2 and increasing CO_2 emissions must be carefully considered. If reducing a relatively smaller amount of SO_2 emissions comes at the cost of a larger increase in CO_2 emissions, it raises serious concerns. This scenario necessitates a broader debate among stakeholders to ensure that efforts to improve air quality do not inadvertently strain water resources, exacerbate global warming, and impact the regional weather and climate of India.

India should heed the lessons from China's experience, as the idea that cleaning up air pollution can worsen atmospheric warming may seem counterintuitive but is a real and ongoing issue. Recently published research articles (Wang et al. 2024; Pearse, 2024) highlight how a dramatic reduction in Chinese air pollution, coinciding with the installation of FGD systems in coal-based TPPs, has been attributed to the recent extraordinary heating over the Northeast Pacific region, leading to more heat waves with global climate consequences.

Based on our survey conducted over two years ago, discussions with the CEA, and considering subsequent price escalations due to inflation, it is reasonable to assume that the current cost of FGD systems is approximately Rs. 1.20 Crore per MW. With a total installed capacity of 211,860 MW in coal-based TPPs across India as of May 31, 2023, the total cost of installing FGD systems would be approximately Rs. 254,232 Crore, excluding running and maintenance costs.

Finally, based on our findings that current ambient air SO_2 levels are within NAAQS and that eliminating SO_2 emissions from TPPs would only marginally improve PM air quality, the urgency of FGD installation must be reassessed. Our recommendations are as follows: Consider halting FGD installation in TPPs that have not yet begun and revisit this decision after taking the following steps. Conduct a follow-up study to comprehensively evaluate the LCA of implementing FGD technology in coal-based TPPs across India. This assessment should include various FGD technologies, operating and maintenance costs, and impacts on electricity prices. Initiating a broader stakeholder debate after this evaluation is crucial to weigh the investment in non-sustainable, CO_2-emitting sources against expanding renewable energy like solar and wind. Gradually phase out older and less efficient coal-based TPPs and transition to a sustainable energy future, ensuring the country's energy security. The installation of FGD systems and carbon capture technologies should not justify the continued use of CO_2-intensive sources. Instead, prioritize cleaner energy alternatives that offer long-term benefits and promote energy security, while developing strategies that address both air quality and climate goals.

CHAPTER-2: SURVEY OF AMBIENT ATMOSPHERIC SO_2 CONCENTRATIONS IN DIFFERENT CATEGORY OF CITIES: PHASE-I

2.1 Introduction

One of the basic information that must be considered while formulating any policy on SO_2 reduction for achieving clean air goals for cities is an assessment of current status of ambient air SO_2 concentrations in various cities across the country. It is only through such a survey, one can know the status of the air pollution levels with regards SO_2 in different category cities of the country and confirm if the air quality in these cities is meeting the National Ambient Air Quality Standards (NAAQS) for SO_2 set by the MoEF&CC, Govt. of India.

In this chapter, we discuss the results of a measurement-based baseline survey of ambient atmospheric SO_2 concentrations that has been conducted in different category of cities across India based on their vicinity to coal based thermal power plants (TPPs). Cities across the country are classified into three categories based on their vicinity to coal based thermal power plants (TPPs) and the status of FGD installation in these TPPs. These categories are:

Category-1: Cities with no coal based TPP.
Category-2: Cities with a coal based TPP in which FGD has not been installed and the TPP is located within 10km from the boundary of the city.
Category-3: Cities with a coal based TPP in which FGD has been installed and the TPP is located within a distance of 10km from the boundary of the city.

This measurement-based survey of ambient air SO_2 concentrations in different category cities has been conducted in three phases. First phase of the survey started on 12th February 2023 and continued up to 29th May 2023, while the second phase of the survey started on 15th July 2023 and ended on 14th August 2023. Third phase of the survey started on 8th November 2023 and ended on 21st February 2024.

2.1 Cities and Measurement Sites Selected for Phase-I of the Survey

In the first phase of this survey, measurements have been conducted in six different cities (two cities under each category) across India namely, New Delhi (Category-1), Hyderabad (Category-1), Kolkata (Category-2), Nagpur (Category-2), Ghaziabad (Category-3), and Gautam Buddha Nagar (Category-3). In order to capture the spatial variability in ambient air SO_2 concentrations within each city, survey was conducted at two different locations in all six cities for one month period each. Measurements were conducted at more than one location in each city so that the results of our survey are able capture the variation in ambient air SO_2 concentrations within the city in a better way and hence it can be considered as the representative of that city. Conducting

the survey at two different locations also helped us know if there exists a gradient in SO_2 concentrations with distance from the TPP for Category-2 and Category-3 cities. The present survey also allows us to confirm if the ambient air SO_2 concentrations in these cities are meeting the NAAQS set by the MoEF&CC. Additionally, we wanted to examine the effectiveness of the FGDs in limiting the ambient air SO_2 concentrations in Category-3 cities which are located in the vicinity of TPPs with FGD system installed in them.

It is worth mentioning here that all cities chosen for our baseline survey fall under the category of "non-attainment cities with million plus population" as per the Central Pollution Control Board (CPCB) classification. In all six cities, we carried out our survey by conducting measurements at two different locations for one month period at each measurement site. For cities which have TPPs in their vicinity, we have conducted this survey of ambient air SO_2 concentrations in such a way that one of the measurement site is close to the TPP (at a distance of about 1-10 km from the TPP) while the second measurement site is at a distance of about 40-60 km from the location of the TPP.

During the first phase of the survey, following measurement sites were identified in the selected six cities across India (two cities under each category).

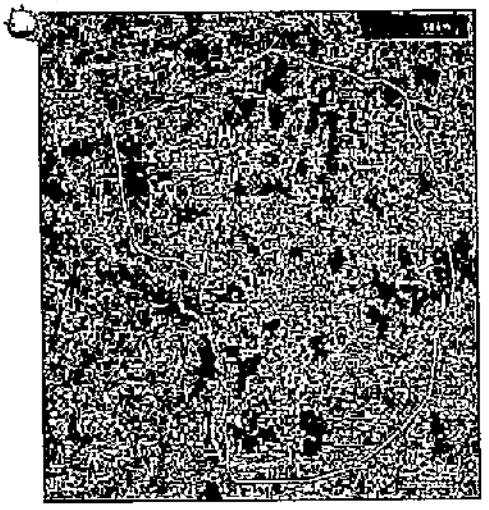
<u>Category-1 Cities</u>

Delhi:

Location 1	**Indian Institute of Technology Delhi Hauz Khas, New Delhi, Delhi – 110016, India.**
Location 2	**CSIR-National Physical Laboratory Dr. K.S. Krishnan Marg, New Delhi – 110012, India.**

Figure 2.1: Satellite image (google earth) showing location of the measurement sites for Category-1 city Delhi considered during Phase-I of the survey

Hyderabad:

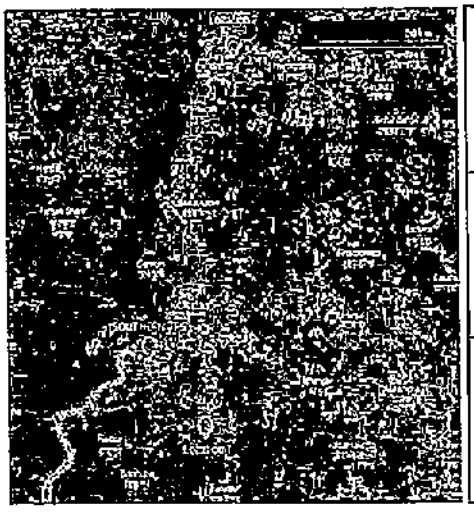


Location 1	University of Hyderabad, India Post Lingampally CR Rao Road, Hyderabad Central University Rd, Gachibowli, Hyderabad, Telangana 500046, India.
Location 2	TKR College of Engineering & Technology, Survey No.8/A, Medbowli, Meerpet, Hyderabad – 500097, India.

Figure 2.2: Satellite image (google earth) showing location of the measurement sites for Category-1 city Hyderabad considered during Phase-I of the survey

Category-2 Cities

Kolkata:



SOUTHERN TPS	Garden Reach, Kolkata – 700024, WB, India. Operated by the CESC Limited.
Location 1	Ramakrishna Mission Vidyalaya, Narendrapur, Kolkata – 700103, WB, India.
Location 2	University of Kalyani, Block C, Nadia, Kalyani, West Bengal-741245, India.

Figure 2.3: Satellite image (google earth) showing location of the measurement sites for Category-2 city Kolkata considered during Phase-I of the survey

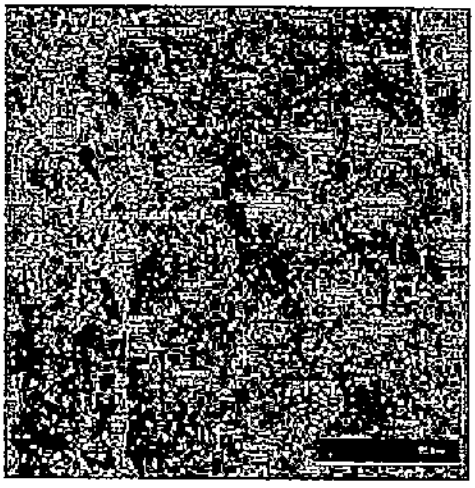
Nagpur:

KHAPARKHEDA TPS	Khaperkheda Town, Nagpur district. Operated by the Maharashtra State Power Generation Company Limited.
Location 1	Rashtrasant Tukadoji Maharaj Nagpur University, Chhatrapati Shivaji Maharaj Administrative Premises, Ravindranath Tagore Marg, Nagpur – 440001, MH, India.
Location 2	Vivekanand Polytechnic, SitaSaongi Post – Sitasaongi, Tal – Tumsar, District – Bhandara, Maharashtra – 441907, India.

Figure 2.4: Satellite image (google earth) showing location of the measurement sites for Category-2 city Nagpur considered during Phase-I of the survey

Category-3 Cities

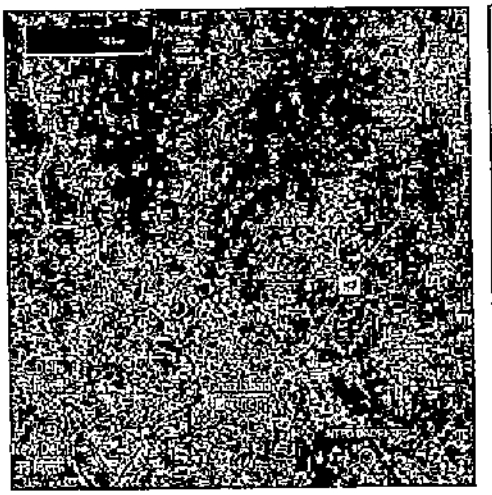
Gautam Buddha Nagar:



NTPC DADRI TPP	Gautam Budh Nagar, Ghaziabad, UP – 201008, India. Operated by the NTPC.
Location 1	Shiv Nadar University, NH - 91, Tehsil Dadri, Gautam Buddha Nagar, UP - 201314, India.
Location 2	Government Polytechnic, Vill. Sutawali, Rehra Road, Amroha UP - 2 44255, India.

Figure 2.5: Satellite image (google earth) showing location of the measurement sites for Category-3 city Gautam Buddha Nagar (GBN) considered during Phase-I of the survey

Ghaziabad:



NTPC DADRI TPP	Gautam Budh Nagar, Ghaziabad, UP – 201008, India. Operated by the NTPC.
Location 1	Ajay Kumar Garg Engineering College (AKGEC), 27th Km Stone, Delhi-Hapur Bypass Road, P.O. Adhyatmik Nagar, Ghaziabad – 201009, India.
Location 2	Swami Vivekanand Subharti University, Subhartipuram, NH-58, Delhi-Haridwar Bypass Road, Meerut-250005, India.

Figure 2.6: Satellite image (google earth) showing location of the measurement sites for Category-3 city Ghaziabad considered during Phase-I of the survey

2.3 Measurement Plan for Phase-I of the Survey

In the first phase of this survey, our aim was to make simultaneous measurements of ambient air SO_2 concentrations in all six cities (at least at one location in each city) so as to avoid any seasonal bias in the results of our survey from different cities that can be caused due to seasonal variations in general meteorological conditions prevailing across the country which influence the large scale transport and removal of SO_2 as well all air pollutants and hence the lifetime of SO_2 in the atmosphere. We made continuous measurements of ambient air SO_2 concentrations averaged after every 10-minute intervals (or more frequently) for at least 30 days during the survey period at each measurement site in all six cities. In every city, first the continuous measurements were made for one month period at the first measurement site and then the measurements were made for another month at the second measurement site in the same city. If we wish to compare the results of the survey from different cities, then it is important to make simultaneous measurements in all cities during the same month or season so that the result from each city qualifies as the representative values of ambient air SO_2 concentrations from that city corresponding to the chosen month or season. This avoids any kind of possible bias in the results of the survey due to seasonal variability in meteorological parameters which are known to influence the transport and removal of SO_2 from the atmosphere and hence its concentrations. That means, the results of our survey on ambient air SO_2 concentrations are based on at least 4320 air samples from each measurement location and a total of at least 8640 air samples for each city. In the first phase, ambient air SO_2 concentrations from six different cities have been surveyed. First phase of the survey started on 12th February 2023 and continued up to 29th May 2023.

2.4 Measurement Technique and Equipment used in the Survey

We used pulsed fluorescence technology based SO_2 gas analyzers having a pulsing source lamp in the ultraviolet (UV) wavelength of 214 nm to make continuous measurement of ambient air SO_2 concentrations in all selected measurement sites. All SO_2 gas analyzers used in this study were calibrated on-site on every 24 hours basis. Daily calibration and regular maintenance of the SO_2 gas analyzer systems is crucial for making reliable measurements using these sophisticated equipment. Two different types of calibration were performed to ensure the reliability of the measurement data (i) Span gas calibration involving measurement of a known standard concentration of gas kept in a cylinder and (ii) Zero air calibration involving measurement of a zero-air gas with no SO_2 kept in another cylinder. The entire measurement system involving a SO_2 gas analyzer, a calibrator analyzer both mounted in a rack, span gas cylinder, zero-air cylinder, a data acquisition system for saving the data and display in a monitor, power backup system was housed in a standalone portable air-conditioned hut in every measurement site. In all our survey sites, measurements of ambient air SO_2 concentrations has been made by keeping our equipment on the rooftop of a three-story building or inside a room on the 3rd floor of a building. Inlet height in all our measurement sites was fixed at about 20 meters above the ground level.

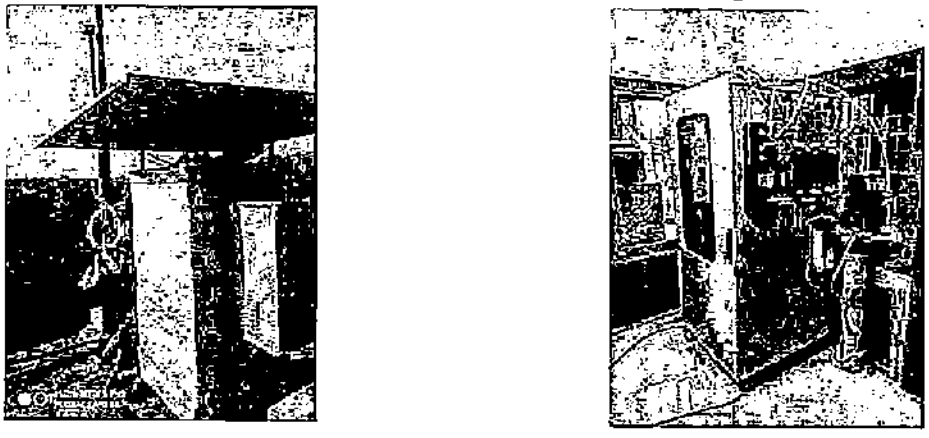


Figure 2.7: Left-side image is showing one of our standalone air-conditioned portable hut with SO_2 gas analyzer kept on the rooftop of a three-story building at one of the measurement site and the right-side image is of the same system kept inside a room in another measurement site.

Figure 2.7 shows the images of the Standalone air-conditioned portable hut with SO_2 gas analyzer and all necessary accessories for ambient air monitoring, data acquisition and storage, on-site calibration of SO_2 gas analyzers, power backup system used in our survey.

2.5 Results from Phase-I of the Survey

This section presents the results of measurements conducted in various category cities across the country during Phase I of our survey. Table 2.1 summarizes the daily mean, maximum instantaneous, and minimum instantaneous values of ambient air SO_2 concentrations measured

at two different locations in six cities, classified into three categories, during the pre-monsoon season. In the Category 1 city of New Delhi, the maximum instantaneous ambient air SO_2 concentration was 29.37 µg/m³, the minimum was 0.83 µg/m³, and the daily mean values ranged from 7.22 ± 2.73 µg/m³ to 9.26 ± 3.28 µg/m³. In Hyderabad, the maximum concentration was 7.86 µg/m³, the minimum was 1.01 µg/m³, and the daily mean values ranged from 2.48 ± 0.49 µg/m³ to 4.65 ± 0.55 µg/m³. In the Category 2 city of Kolkata, the maximum instantaneous concentration was 32.25 µg/m³, the minimum was 1.29 µg/m³, and the daily mean values ranged from 4.32 ± 1.51 µg/m³ to 6.48 ± 3.08 µg/m³. In Nagpur, the maximum ambient air SO_2 concentration was 20.54 µg/m³, the minimum was 1.13 µg/m³, and the daily mean values ranged from 3.55 ± 0.53 µg/m³ to 6.07 ± 2.83 µg/m³. In the Category 3 city of Ghaziabad, the maximum instantaneous concentration was 33.51 µg/m³, the minimum was 2.62 µg/m³, and the daily mean values ranged from 7.87 ± 1.89 µg/m³ to 8.51 ± 2.56 µg/m³. In Gautam Buddha Nagar, the maximum ambient air SO_2 concentration was 33.34 µg/m³, the minimum was 2.71 µg/m³, and the daily mean values ranged from 8.31 ± 2.03 µg/m³ to 9.86 ± 2.12 µg/m³.

Summarizing by city categories, Category 1 cities had maximum instantaneous ambient air SO_2 concentrations of up to 29.37 µg/m³ and minimum concentrations down to 0.83 µg/m³, with daily mean values ranging from 2.48 to 9.26 µg/m³. Category 2 cities had maximum concentrations of up to 32.25 µg/m³ and minimum concentrations down to 1.13 µg/m³, with daily mean values ranging from 3.55 to 6.48 µg/m³. Category 3 cities had maximum concentrations of up to 33.51 µg/m³ and minimum concentrations down to 2.62 µg/m³, with daily mean values ranging from 7.87 to 9.86 µg/m³. These results highlight the variability in ambient air SO_2 concentrations across different locations and city categories, with Category 2 and Category 3 cities both showing higher SO_2 levels. As the National Ambient Air Quality Standards (NAAQS) or the maximum permissible limit of ambient air SO_2 concentrations based on 24 hours average measurements for industrial, residential, rural, and other areas as notified by the MoEF&CC, Govt. of India is 80 µg/m³, results of our survey confirm that the ambient air SO_2 concentrations in all cities are meeting the existing standards during the period of our survey.

As evident from Table 2.1, the daily mean values of ambient air SO_2 concentrations measured at various locations in all six cities during Phase I of our survey are comparable to the SO_2 data from the CPCB/SPCB/PCC measurement sites in those cities (https://cpcb.nic.in/air-pollution/), thereby validating the robustness of our collected data.

Next, we discuss the findings of our survey from Category-1 cities with no coal based TPP with more details. These two cities are Delhi and Hyderabad. For the city of Delhi, our survey of ambient air SO_2 concentrations started in Location-1 on 12th February and continued up to 14th March 2023. While the survey in the second location of Delhi or Location-2 was conducted during the period 23rd March to 22nd April 2023.

Name of City (Measurement Site, distance from TPP)	Data Analysis Duration	This Study SO_2 Concentration ($\mu g/m^3$)			CPCB/SPCB measurements ($\mu g/m^3$)
		Maximum (Instantaneous)	Minimum (Instantaneous)	Daily Mean ± 1σ (NAAQS = 80 $\mu g/m^3$)	
New Delhi Location-1	12-02-2023 to 14-03-2023	29.37	1.9	9.26 ± 3.28	10.65 ± 1.26
New Delhi Location-2	23-03-2023 to 22-04-2023	23.28	0.83	7.22 ± 2.73	
Hyderabad Location-1	23-03-2023 to 22-04-2023	7.86	2.72	4.65 ± 0.55	2.91 ± 0.82
Hyderabad Location-2	29-04-2023 to 29-05-2023	4.61	1.01	2.48 ± 0.49	
Kolkata Location-1 15 Km from SOUTHERN TPS	12-02-2023 to 14-03-2023 (One month)	32.25	1.29	6.48 ± 3.08	6.95 ± 3.19
Kolkata Location-2 51 Km from SOUTHERN TPS	23-03-2023 to 22-04-2023 (One month)	21.51	1.37	4.92 ± 1.51	
Nagpur Location-1 15 Km from KHAPARKHEDA TPS	23-03-2023 to 22-04-2023 (One month)	20.54	1.21	6.07 ± 2.83	6.31 ± 1.08
Nagpur Location-2 57 Km from KHAPARKHEDA TPS	29-04-2023 to 29-05-2023 (One month)	9.46	1.13	3.55 ± 0.53	
Ghaziabad Location-1 13 Km from DADRI TPP	23-03-2023 to 22-04-2023 (One month)	33.51	2.92	8.51 ± 2.56	6.25 ± 2.16
Ghaziabad Location-2 42 Km from DADRI TPP	29-04-2023 to 29-05-2023 (One month)	18.66	2.62	7.87 ± 1.89	
Gautam Buddha Nagar Location-1 10 Km from DADRI TPP	23-03-2023 to 22-04-2023 (One month)	33.34	4.60	9.86 ± 2.12	10.97 ± 1.69
Gautam Buddha Nagar Location-2 53 Km from DADRI TPP	29-04-2023 to 29-05-2023 (One month)	17.54	2.71	8.31 ± 2.03	

Table 2.1: Daily mean, maximum, and minimum values of ambient air SO_2 concentration ($\mu g/m^3$) measured at two different locations of six different cities classified under three different categories from across the country during Phase-I of our survey are listed here. SO_2 concentrations data from CPCB/SPCB measurements sites from each city are also mentioned.

Figure 2.8 shows the time series of daily mean ambient air SO_2 concentration ($\mu g/m^3$) measured on different days of our survey at two different measurement sites in Delhi. Figure 2.9 shows the diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) measured on different days of our survey at two different measurement sites in Delhi. Figures 2.8 and 2.9 illustrate significant diurnal variations as well as notable intra-day fluctuations in ambient air SO2 concentrations at both of these measurement locations in Delhi. Table 2.1 lists the maximum instantaneous, minimum instantaneous, and daily mean values of ambient air SO_2 concentration ($\mu g/m^3$) measured at two different locations of all six cities from across the country that were selected during Phase-I of our survey. Maximum instantaneous values of ambient air SO_2 concentrations measured at location-1 and location-2 of Delhi during phase-I of our survey are 29.37 $\mu g/m^3$ and 23.28 $\mu g/m^3$ respectively. While the minimum instantaneous values of ambient air SO_2 concentrations measured at location-1 and location-2 of Delhi during phase-I of our survey are 1.90 $\mu g/m^3$ and 0.83 $\mu g/m^3$ respectively. Monthly average daily mean values of ambient air SO_2 concentrations measured at location-1 and location-2 of Delhi during phase-I of our survey are 9.26±3.28 $\mu g/m^3$ and 7.22±2.73 $\mu g/m^3$ respectively. As the National Ambient Air Quality Standards (NAAQS) or the maximum permissible limit of ambient air SO_2 concentrations based on 24 hours average measurements for industrial, residential, rural, and other areas as notified by the MoEF&CC, Govt. of India is 80 $\mu g/m^3$, results of our survey confirm that the ambient air SO_2 concentrations in Delhi are meeting the existing standards during the period of our survey.

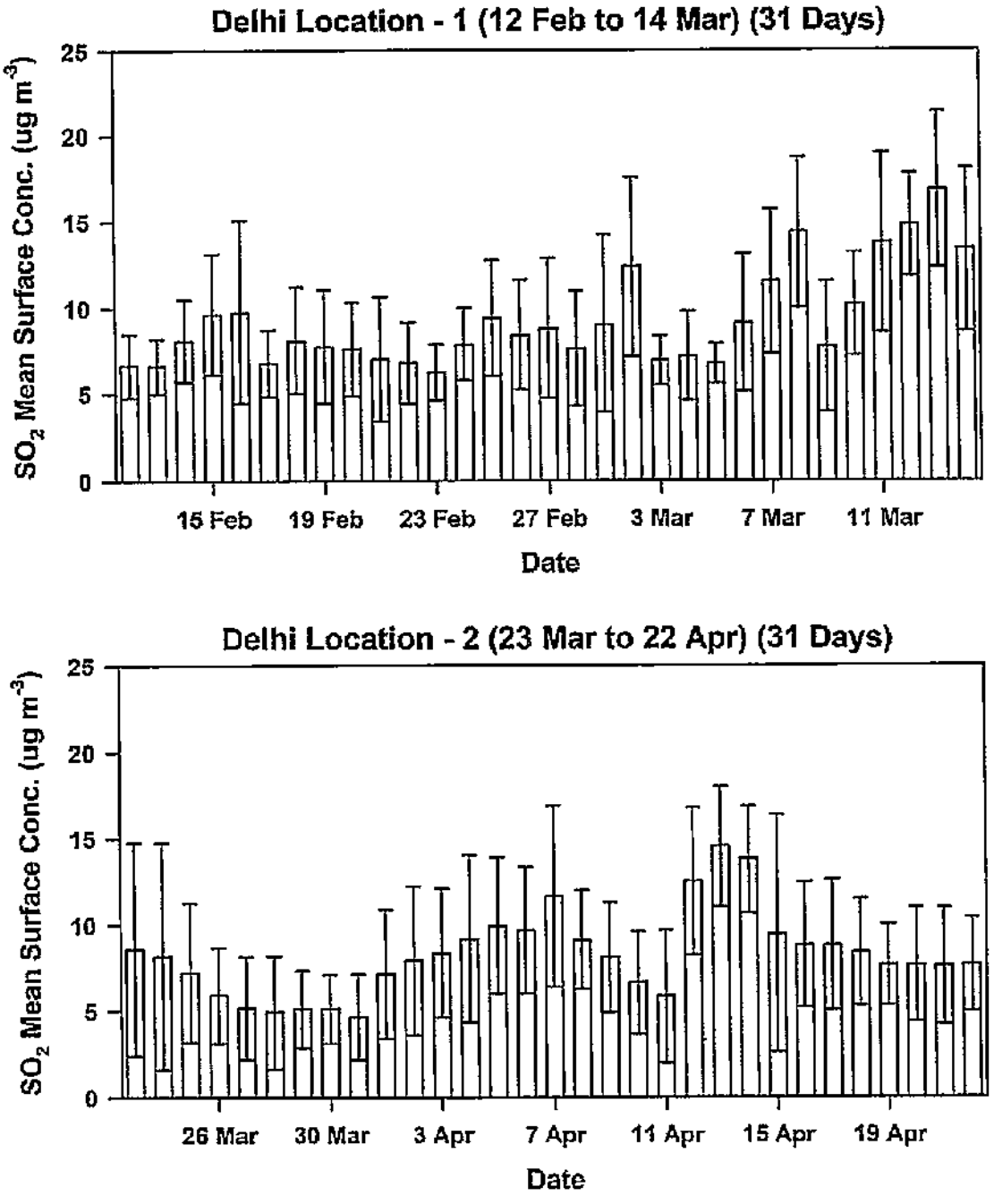


Figure 2.8: Time series of daily mean ambient air SO_2 concentration ($\mu g/m^3$) for all days (12th February – 14th March 2023) as measured in Location-1 of Delhi (upper panel) and for the period 23rd March – 22nd April 2023 in Location-2 of Delhi (lower panel). Vertical lines on each bar represents the $\pm 1\sigma$ standard deviation variation around the daily mean values for each day.

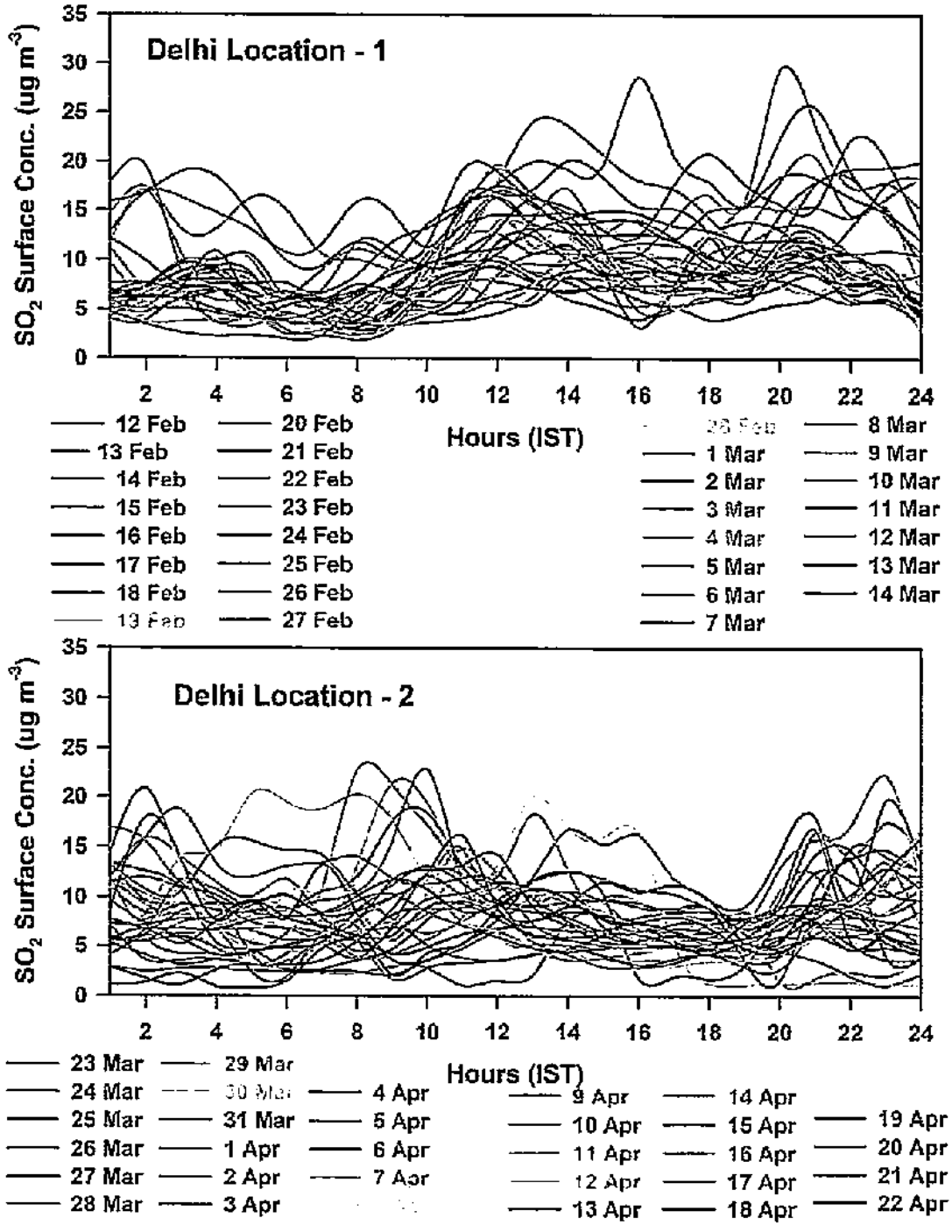


Figure 2.9: Diurnal variation of ambient air SO_2 concentration (µg/m^3) for all days (12th February – 14th March 2023) as measured in Location-1 of Delhi (upper panel) and for the period 23rd March – 22nd April 2023 in Location-2 of Delhi (lower panel).

Diurnal variations in ambient air SO_2 concentrations are influenced by a combination of factors, including fluctuations in SO_2 emissions from different sources, variations in atmospheric boundary (or mixed) layer height throughout the day, changes in wind patterns or air circulation,

and other meteorological conditions. Additionally, elevated levels of SO_2 aloft (above the boundary layer in the free troposphere), resulting from regional-scale air pollution, can also impact ambient air SO_2 concentrations. This occurs through the downward mixing of constituents from the elevated layer with the surface layer during the boundary layer's evolution after sunrise in the morning hours. In general, potential sources of SO_2 over any location include emissions from energy sector, transportation sector (burning of fossil fuel), industries (such as petroleum refineries, cement manufacturing, paper pulp manufacturing, iron and steel, and metal smelting, processing facilities, brick kilns, etc.), residential sector (involving burning of fossil fuel or biomass for various purposes including usage of diesel/petrol generators), agricuitural waste burning, solid waste treatment etc. SO_2 is also used in bleaching materials, as a fumigant, preserving dry fruits to prevent discoloration. In the residential sector SO_2 gas can be emitted from tobacco smoke, improperly or inadequately vented solid/gas fuel appliances (such as biomass or fossil fuel-based cooking stoves, furnaces, heaters), as well as kerosene or wood or coal stoves or burning of these things for any other household purposes. It is also worth mentioning here that in nature, volcanic eruptions also release SO_2 into the air. The presence of multiple peaks in the diurnal patterns of ambient air SO_2 concentrations at various times of the day, including evening and nighttime, on different days throughout our measurement period at both sites in Delhi suggests a strong influence of local sources within approximately 60 km of the measurement site. This inference is supported by numerous previous studies using dispersion models and chemical transport models. These studies have shown that the influence of a single fixed-point SO_2 emission source, such as a thermal power plant with a capacity of up to 2000 MW, under moderate wind speed conditions of up to 5 m/s (or 18 km/h), on ambient air SO_2 concentrations beyond about 120 km from the source is generally minimal (*Fioletov et al.* 2015). Beyond this distance, the emissions from the fixed-point source become part of the regional background concentration, typically decreasing by about two orders of magnitude compared to the highest concentrations observed near the source.

Figure 2.10 shows the monthly mean pattern of diurnal variation of ambient air concentration of SO_2 observed at both measurement sites in Delhi during Phase-I of our survey. One of the unique features noticeable in the monthly mean diurnal pattern from both measurement sites is the gradual increase in ambient air concentrations during daytime after sunrise till 10AM or up to local noon. Thereafter the monthly mean diurnal patterns of SO_2 generally show a decreasing trend up to about 7 PM in the evening (although we noticed random spikes in SO_2 at different times and lasting for couple of hours on different days). We also noted a second peak in ambient air SO_2 concentrations in both measurement locations at around 9-10 PM in the late evening. While SO_2 concentrations in location-1 generally decreased gradually after this late evening peak to reach minimum values just before the sunrise but, in location-2, the monthly values remained high during late night up to 2-3 AM, probably due to some local activities contributing to spikes in SO_2 concentrations during such late-night hours on several days of our survey period.

Nevertheless, higher values of ambient air SO_2 concentrations were generally observed during the daytime and relatively lower values were noted during nighttime during our survey period.

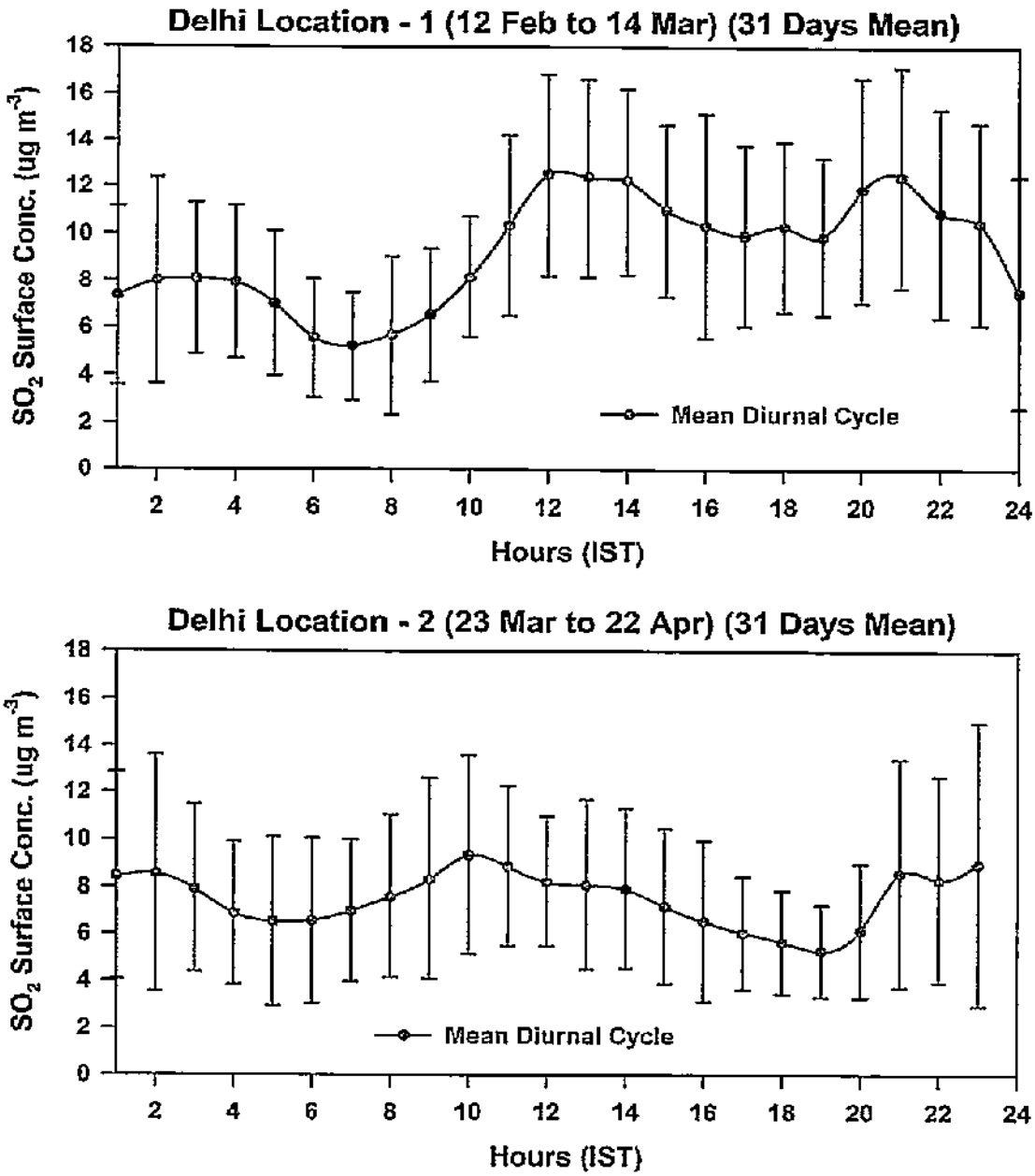


Figure 2.10: Monthly mean pattern of diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) for Location-1 (upper panel) and Location-2 (lower panel) of Delhi. Vertical lines in this figure represents the $\pm 1\sigma$ standard deviation variation around the monthly mean values for each hour.

If the SO_2 concentrations at any location were influenced solely by sources with constant emission rates or those with minimal diurnal variations in emission rates (such as TPPs), then the

diurnal pattern of ambient air SO_2 concentrations would largely be governed by the vertical movement of the atmospheric boundary layer. This would result in higher SO_2 concentrations at night due to the shallow boundary layer and lower concentrations during the day due to the increased boundary layer height, better ventilation, and the presence of higher OH radical levels in the atmosphere, which oxidize SO_2 to form sulfate aerosols.

During our survey period, we observed that the diurnal variations of ambient air SO_2 concentrations in Delhi increased after sunrise, gradually reaching their peak either during or shortly after peak traffic hours. This morning rise in SO_2 concentrations, despite the increasing boundary layer height during the same period, indicates a significant contribution from local sources during the forenoon. Additionally, the higher SO_2 concentrations during the daytime, particularly the increasing trend in the forenoon, could also be attributed to the downward mixing of SO_2-rich air from an elevated layer into the surface layer as the boundary layer height evolves after sunrise. This elevated layer of SO_2-rich air likely results from regional-scale pollution or haze caused by emissions from various sectors such as industrial, energy, transportation, agriculture, and residential activities over densely populated and industrial areas like the Indo-Gangetic belt.

Gradual decrease in SO_2 concentrations after the daytime maxima is likely due to increased boundary layer height, higher ventilation during afternoon hours, and presence of higher OH radical in the atmosphere during this time which efficiently oxidizes SO_2 to sulfate aerosols. It is worth mentioning here that the heterogeneous aqueous-phase oxidation of SO_2 plays a more significant role than its gas-phase oxidation with OH. Although there are several pathways for the aqueous-phase oxidation of SO_2, the two most crucial involve its reactions with dissolved O_3 and H_2O_2. In fact, for SO_2, the reaction with H_2O_2 is its most significant oxidation pathway. This heterogeneous oxidation of SO_2 occurs through its dissolution in water from clouds and fog, followed by reactions with other dissolved species, and can take place both day and night. The oxidation via the dissolved H_2O_2 pathway is greatly enhanced when ammonia (NH_3), the main alkaline gas in the atmosphere, dissolves in the reacting droplets and neutralizes the acidity. As the decreasing trend continues into the afternoon, ambient air SO_2 concentrations in Delhi typically reach a minimum by around 7 PM. Afterward, SO_2 concentrations begin to rise rapidly, peaking again between 9-10 PM. This rapid increase over 1-2 hours is likely due to the quick collapse of the boundary layer after sunset, which traps the prevailing SO_2 in a smaller volume of air close to the surface, combined with continued emissions from transportation, residential, and industrial sectors within the city and nearby areas during the late evening hours.

As mentioned earlier, while SO_2 concentrations at location-1 generally decreased after the late evening peak, reaching their lowest values just before sunrise, at location-2, the ambient air SO_2 concentrations often remained high until 2-3 AM, likely due to local activities emitting SO_2 during

these late-night hours, as observed on several days during our survey period. Nevertheless, the highest ambient air SO_2 concentrations were typically observed during the daytime, with relatively lower values recorded at night throughout our survey period.

Next, we discuss the findings from our survey in Hyderabad, the second Category-1 city selected for Phase-I. Our survey of ambient air SO_2 concentrations in Hyderabad began at Location-1 on March 23 and continued until April 22, 2023. The survey at the second measurement location, Location-2, started on April 29 and continued until May 29, 2023. Figure 2.11 shows the time series of daily mean ambient air SO2 concentrations ($\mu g/m^3$) measured on various days at the two different measurement sites in Hyderabad. It is clear from Figures 2.8 and 2.11 that ambient air SO_2 concentrations in Hyderabad are much lower compared to Delhi. Additionally, Figure 2.11 indicates that day-to-day variations in ambient air SO_2 concentrations in Hyderabad, particularly at Location-1, are also lower than those observed in Delhi.

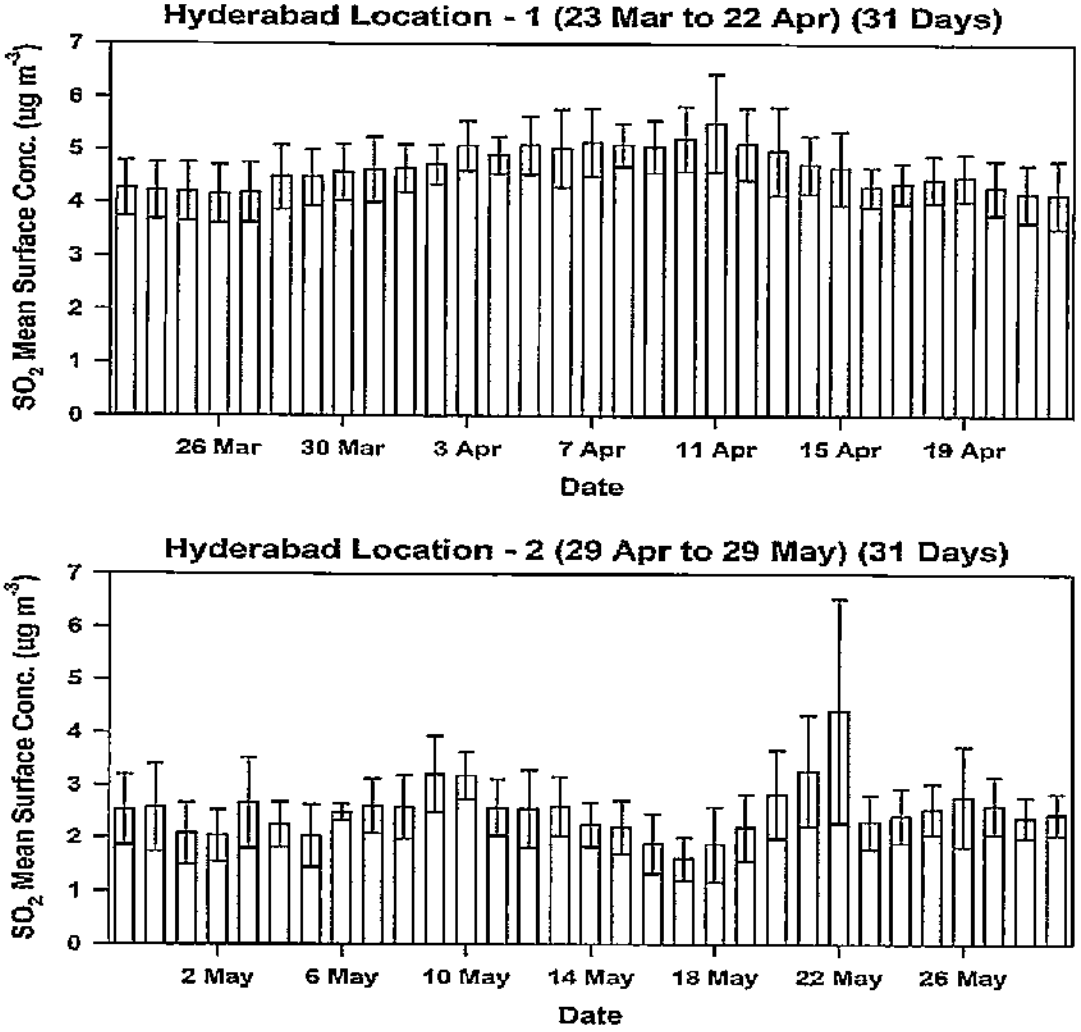
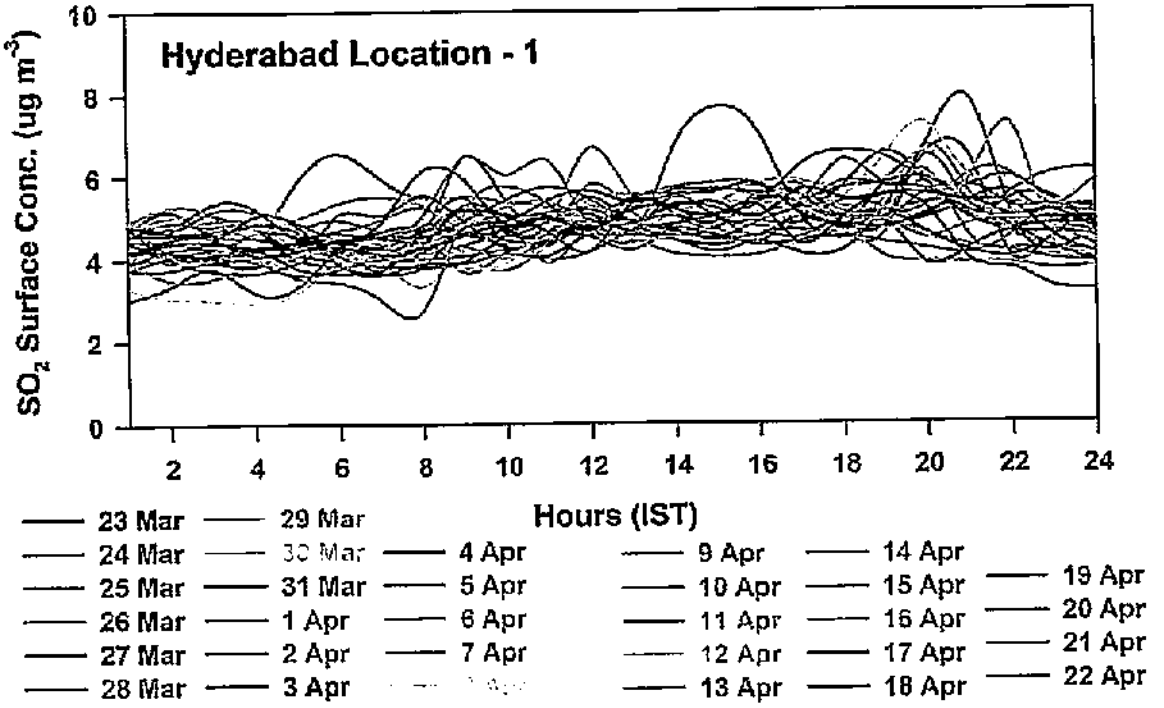


Figure 2.11: Time series of daily mean ambient air SO_2 concentration ($\mu g/m^3$) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Hyderabad (upper panel) and for the period 29th April – 29th May 2023 in Location-2 of Hyderabad (lower panel). Vertical lines

on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.



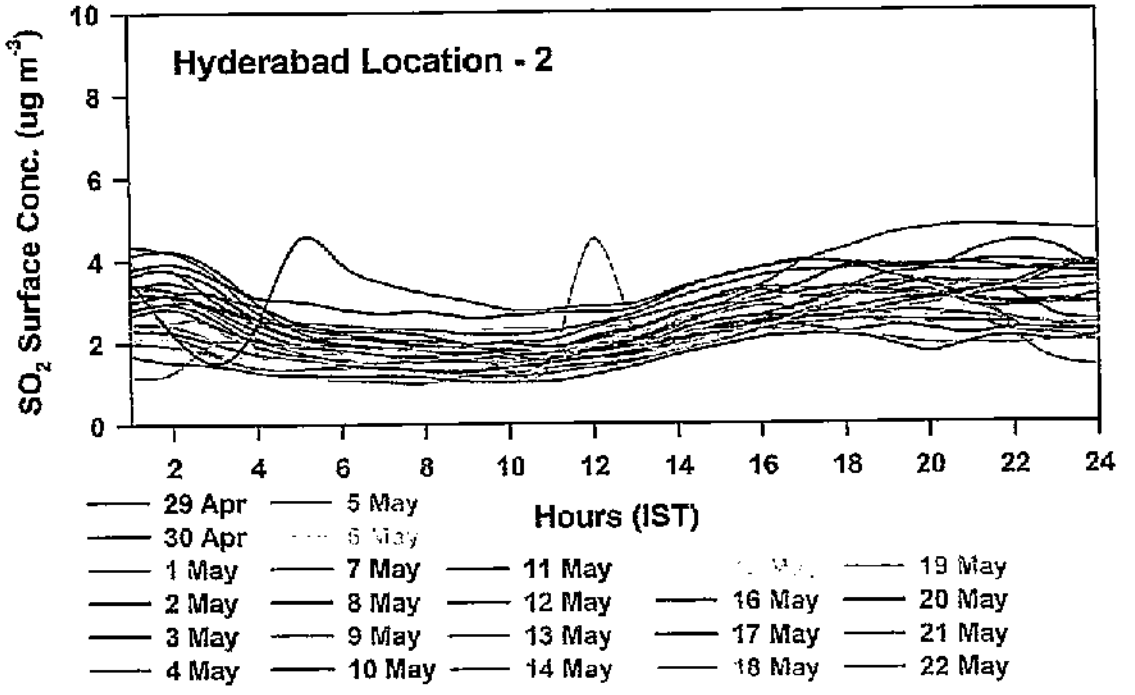


Figure 2.12: Diurnal variation of ambient air SO_2 concentration (µg/m^3) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Hyderabad (upper panel) and for the period 29th April – 29th May 2023 in Location-2 of Hyderabad (lower panel).

Figure 2.12 shows the diurnal variation of ambient air SO_2 concentrations ($\mu g/m^3$) measured on different days at two different sites in Hyderabad. Figures 2.11 and 2.12 indicate that both diurnal variations and intra-day variability in ambient air SO_2 concentrations are minimal at both measurement locations in Hyderabad. As stated in Table-1, the maximum instantaneous SO_2 concentrations recorded at Location-1 and Location-2 during Phase-I of our survey are 7.86 $\mu g/m^3$ and 4.81 $\mu g/m^3$, respectively. The minimum values are 2.72 $\mu g/m^3$ and 1.01 $\mu g/m^3$, respectively. The monthly average daily mean SO_2 concentrations are 4.65 ± 0.55 $\mu g/m^3$ at Location-1 and 2.48 ± 0.49 $\mu g/m^3$ at Location-2. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations over a 24-hour average for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. Our survey results confirm that ambient air SO_2 concentrations in Hyderabad are well within these standards during the survey period.

Diurnal variations in ambient air SO_2 concentrations are influenced by several factors, including fluctuations in SO_2 emissions from various sources, changes in atmospheric boundary (or mixed) layer height, variations in wind patterns or air circulation, and other meteorological conditions. The relatively smooth variations with fewer spikes in the diurnal patterns of ambient air SO_2 concentrations throughout our measurement period at both Hyderabad sites suggest a weaker influence of local sources compared to Delhi. However, the occasional random spikes in SO_2 concentrations at different times and locations within Hyderabad (sometimes observed at one site but not the other) indicate that these spikes are caused by emissions from various nearby local sources.

Figure 2.13 shows the monthly mean pattern of diurnal variation in ambient air SO_2 concentration at both measurement sites in Hyderabad during Phase-I of our survey. It is evident from Figure 2.13 that the diurnal variations in ambient air SO_2 concentration in Hyderabad are minimal and significantly less pronounced compared to those observed in Delhi. At Location-1 in Hyderabad, the monthly mean pattern of diurnal variation in SO_2 concentration remains almost flat throughout the day, with slightly higher values in the evening, peaking around 8 PM. This evening peak is likely due to increased local emissions from the transport and residential sectors around this time, as well as the collapse of the boundary layer after sunset. At Location-2, the monthly mean pattern shows maximum SO_2 concentrations in the evening after sunset, remaining high until about 2 AM, with minimum values noted in the forenoon hours. The slow but steady increase in ambient air SO_2 concentrations during the afternoon, despite the higher boundary layer height, is likely due to the gradual buildup of SO_2 levels within the city from various daytime activities and the transport of regional SO_2 plumes from upwind sources.

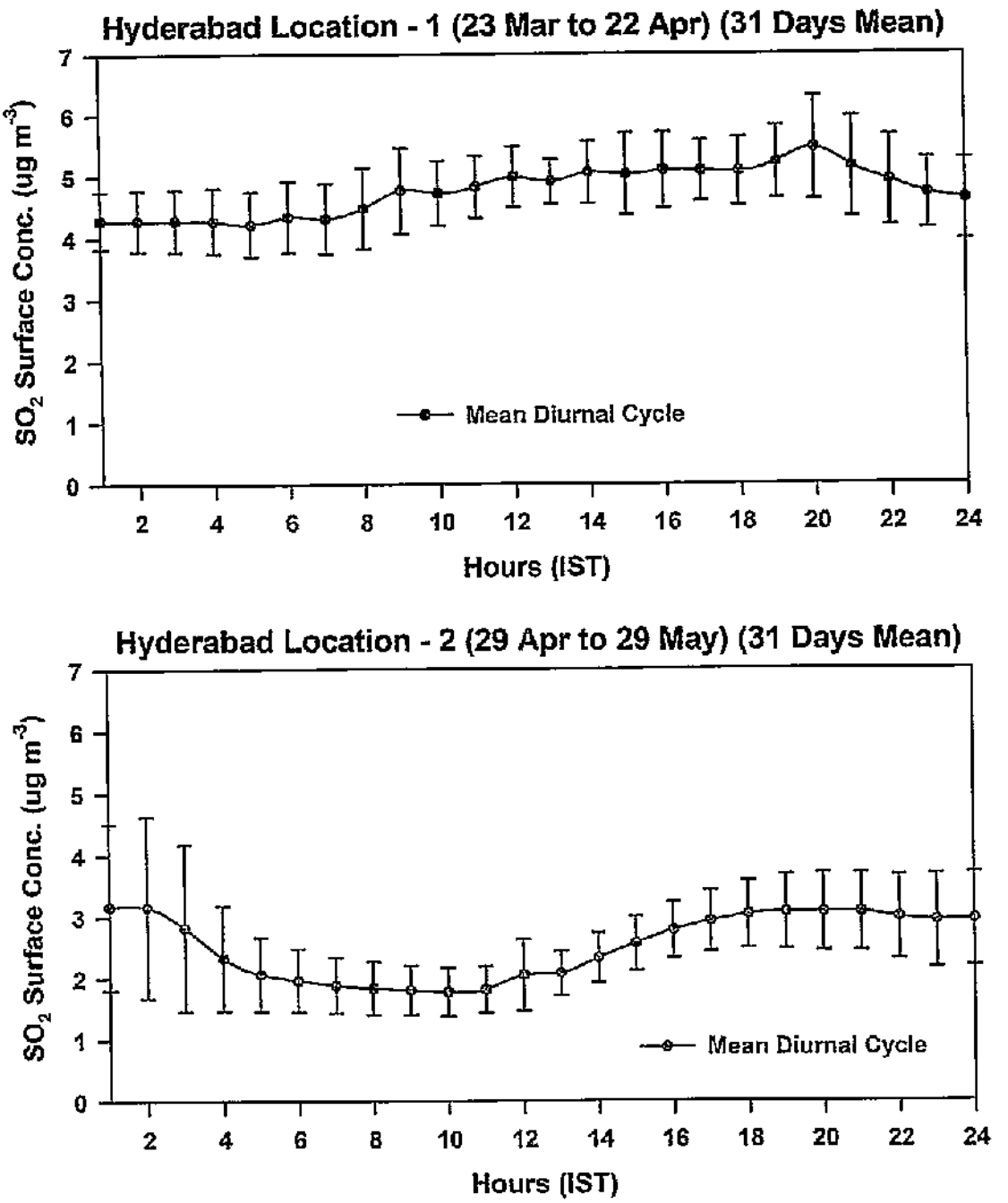


Figure 2.13: Monthly mean pattern of diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) for Location-1 (upper panel) and Location-2 (lower panel) of Hyderabad. Vertical lines in this figure represents the $\pm 1\sigma$ standard deviation variation around the monthly mean values for each hour.

Next, we discuss the findings from our survey in Category-2 cities, which have a coal-based TPP without an installed FGD, located within 10 km of the city boundary. The Category-2 cities selected in Phase-I of our survey are Kolkata and Nagpur.

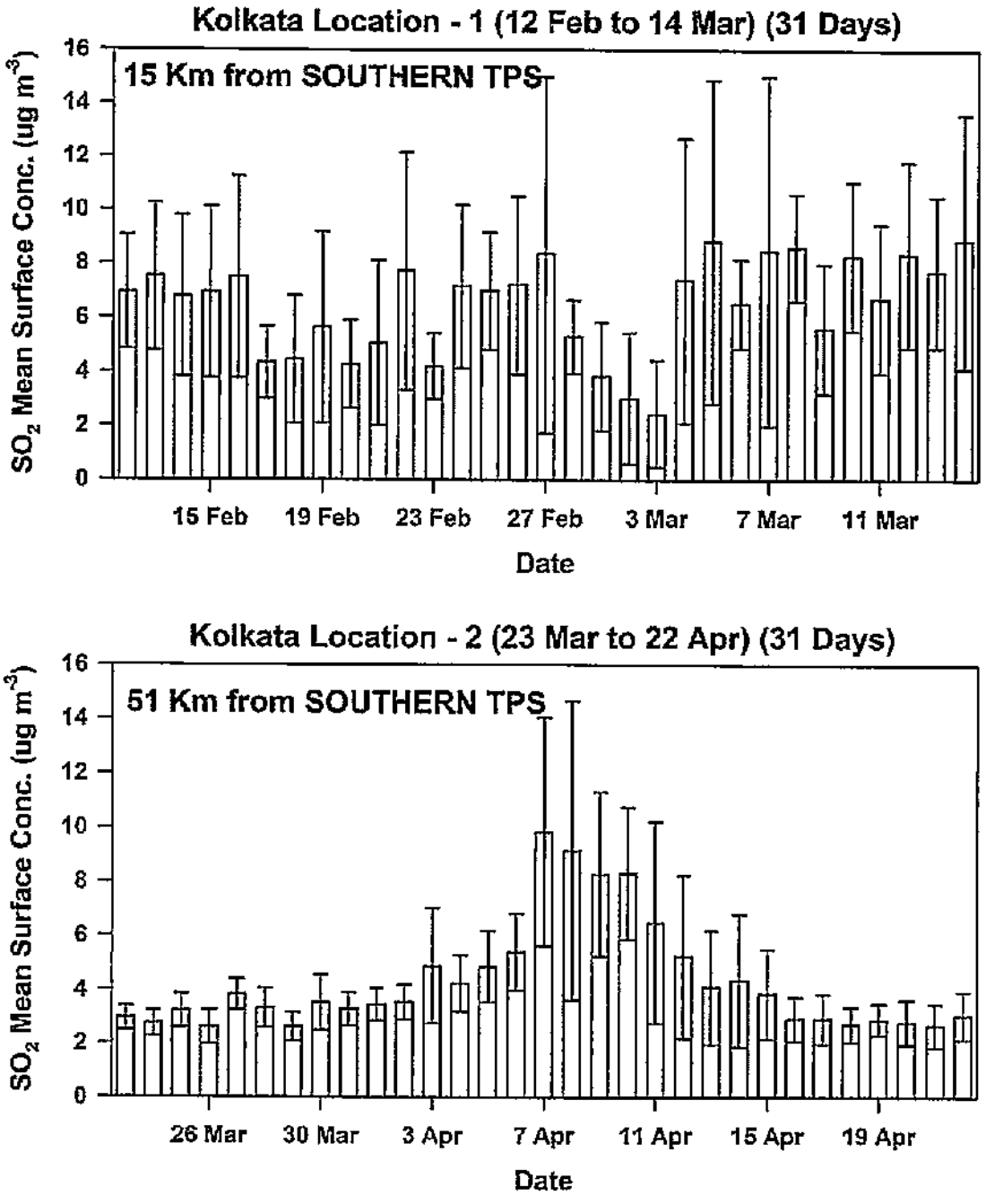


Figure 2.14: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (12th February – 14th March 2023) as measured in Location-1 of Kolkata (upper panel) and for the period 23rd March – 22nd April 2023 in Location-2 of Kolkata (lower panel). Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

For the city of Kolkata, our survey of ambient air SO_2 concentrations began at Location-1 on February 12 and continued until March 14, 2023. The survey at the second measurement site, Location-2, started on March 23 and continued until April 22, 2023.

Figure 2.14 depicts the time series of daily mean ambient air SO_2 concentrations ($\mu g/m^3$) measured on various days of our survey at the two different measurement sites in Kolkata. It is evident from the results presented in Figure 2.14 that there are significant day-to-day variations in ambient air SO_2 concentrations in the city of Kolkata, particularly at Location 1.
Figure 2.15 illustrates the diurnal variation of ambient air SO_2 concentrations ($\mu g/m^3$) measured on different days of our survey at the two different measurement sites in Kolkata. It is apparent from Figures 2.14 and 2.15 that there are substantial diurnal variations as well as significant intra-day variations in ambient air SO_2 concentrations at both of these measurement locations in Kolkata.

Table 2.1 lists the maximum instantaneous, minimum instantaneous, and daily mean values of ambient air SO_2 concentrations ($\mu g/m^3$) measured at the two different locations in all six cities across the country selected during Phase-I of our survey. The maximum instantaneous values of ambient air SO_2 concentrations measured at Location-1 and Location-2 of Kolkata during Phase-I of our survey are 32.25 $\mu g/m^3$ and 21.41 $\mu g/m^3$, respectively. The minimum instantaneous values measured at Location-1 and Location-2 of Kolkata during Phase-I of our survey are 1.29 $\mu g/m^3$ and 1.37 $\mu g/m^3$, respectively. The monthly average daily mean values of ambient air SO_2 concentrations measured at Location-1 and Location-2 of Kolkata during Phase-I of our survey are 6.48 ± 3.08 $\mu g/m^3$ and 4.32 ± 1.51 $\mu g/m^3$, respectively. As per the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. Our survey results confirm that ambient air SO_2 concentrations in Kolkata are within these standards during the survey period.

Diurnal variations in ambient air SO_2 concentrations over both measurement locations of Kolkata are characterized by relatively lower values during the nighttime and higher values during daytime. However, multiple spikes in ambient air SO_2 concentrations are noted at different times of the day (including evening and nighttime) on different days throughout the survey period in location-1 of Kolkata, thereby indicating a strong influence of local sources within a distance of approximately 60 km from the measurement site, such as transportation sector, residential activities, and industrial emissions in creating these spikes. The role of TPPs in creating these short spikes in ambient air SO_2 concentrations can be ruled out because TPP units typically operate continuously and are not switched on and off intermittently. Unlike location-1, spikes in ambient air SO_2 concentrations are noted only during daytime in location-2 of Kolkata, thereby suggesting that the sources responsible for creating these spikes in SO_2 concentrations over location-2 are active only during daytime. Incoherency associated with the occurrences of these random spikes in diurnal pattern of ambient air SO_2 concentration on different days over both the measurement locations of Kolkata (for example often a spike in SO_2 concentration is noted in only one of the measurement locations but no such spike is noted around the same time on the

same day in the other measurement location and vice-versa) indicate that these spikes are mostly caused by emissions from different local sources nearby each measurement site with a much shorter distance of influence (less than 50 km).

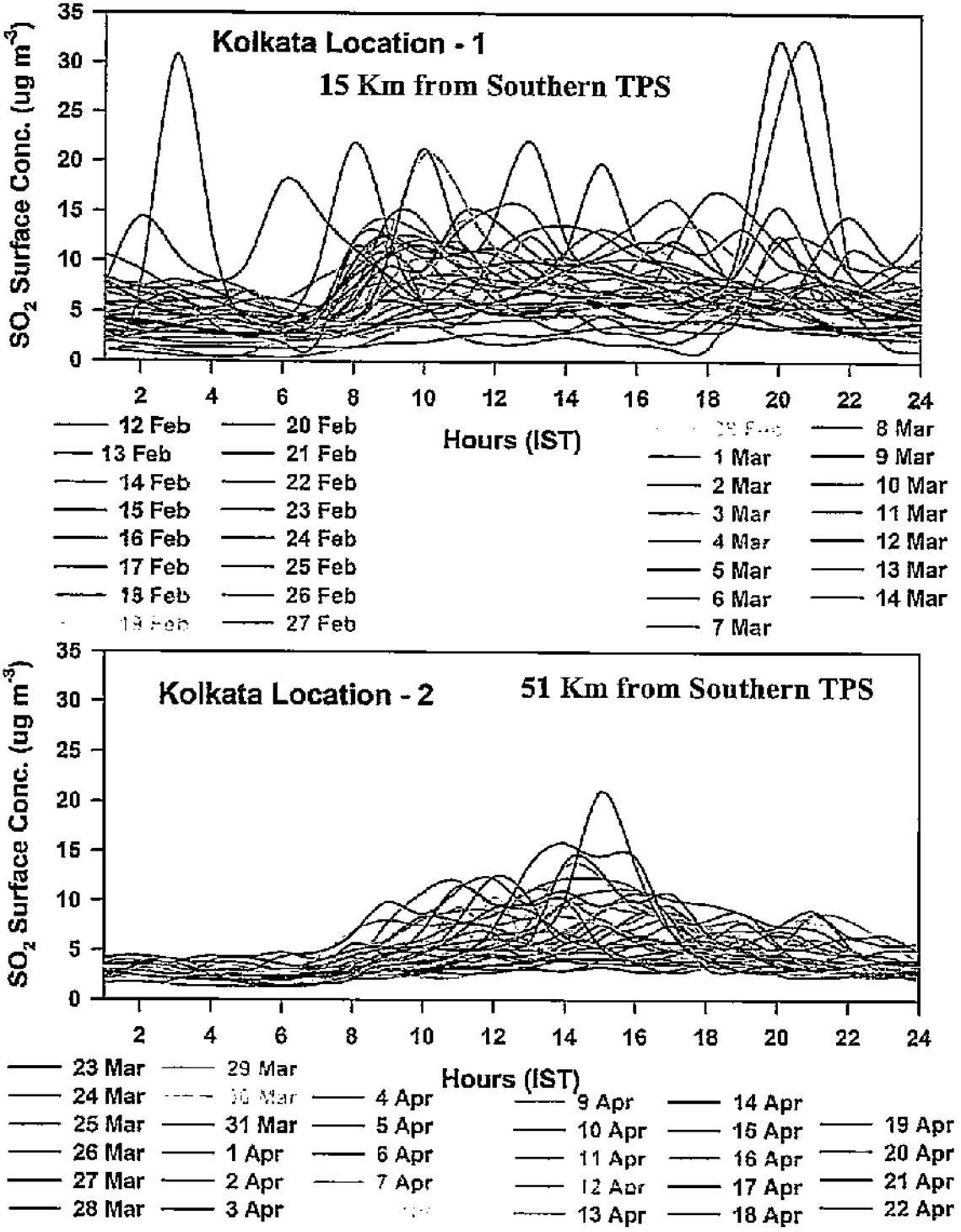


Figure 2.15: Diurnal variation of ambient air SO_2 concentration (µg/m^3) for all days (12th February – 14th March 2023) as measured in Location-1 of Kolkata (upper panel) and for the period 23rd March – 22nd April 2023 in Location-2 of Kolkata (lower panel).

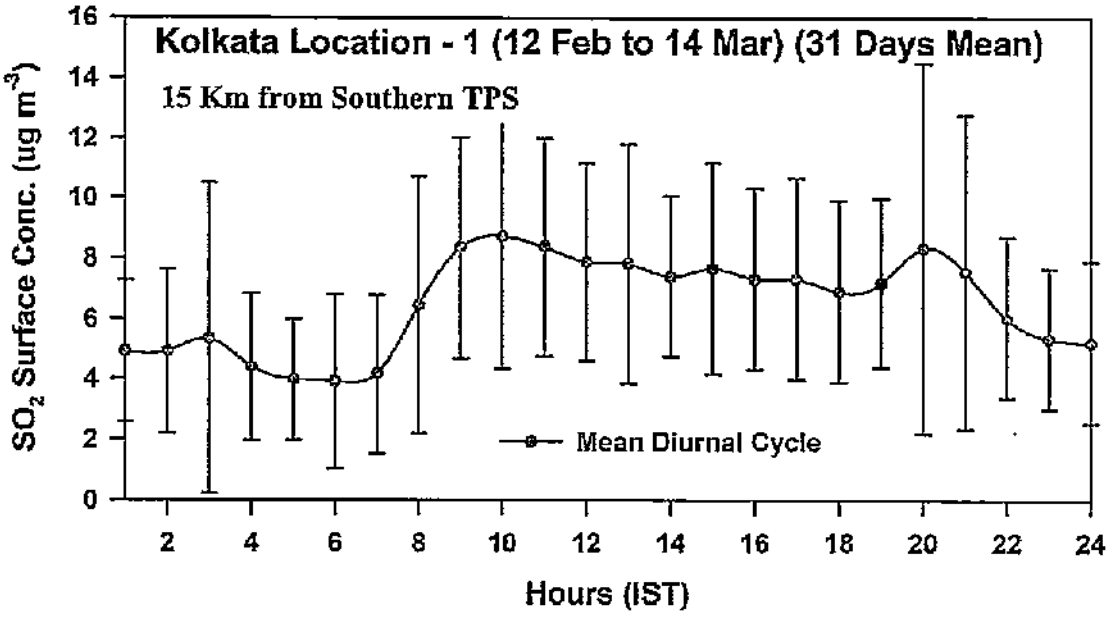
Figure 2.16 shows the monthly mean pattern of diurnal variation of ambient air SO_2 concentration observed at both measurement sites in Kolkata during Phase-I of our survey. As mentioned earlier, diurnal variations in ambient air SO_2 concentrations over both measurement locations of Kolkata are characterized by relatively lower values during the nighttime and higher values during daytime. However, there are also some clearly noticeable differences in the diurnal patterns of ambient air SO_2 concentrations over the two different measurement locations of Kolkata. For example, the ambient air SO_2 concentrations over location-1 of Kolkata increases rather rapidly almost immediately after sunrise to reach a maxima by around 10AM and thereafter either remains steady almost throughout the day or shows a very gentle decreasing trend up to around 6PM in the evening before increasing again to reach another maxima at around 8PM in the evening. On the contrary, ambient air SO_2 concentrations over location-2 of Kolkata increases slowly but steadily after sunrise to reach a maxima in the afternoon hours by around 3PM, in spite of the increases in the boundary layer height during the same period of time. It is likely that the rapid increases in SO_2 concentrations noted over location-1 of Kolkata are caused by emissions from various sectors (especially transportation, industrial, and residential sectors) within the city which becomes more active immediately after sunrise in the morning hours. As the location-2 of Kolkata is in a more suburban locality rather than within the metropolitan city of Kolkata, we notice a slow but steady increase in SO_2 concentrations in this site after sunrise due to slow buildup of SO_2 levels caused by emissions from local sources as well as contributed by transport of regional SO_2 plumes from upwind sources to this measurement site. The evening peak in SO_2 concentrations noted in location-1 of Kolkata is likely due to peak in local emissions from transport and residential sector around this time or slightly before it as well as a collapse of the boundary layer height after sunset. SO_2 concentrations in location-1 generally decreased gradually after this late evening peak to reach minimum values just before the sunrise. Thus, higher values of ambient air SO_2 concentrations were generally observed during the daytime and lower values were noted during nighttime over both measurement sites of Kolkata during our survey period. Lower values of ambient air SO_2 concentrations during nighttime in spite of lower boundary layer height during this time is likely due to decrease in activities contributing to emissions of SO_2 from various local sources such as transportation, industrial, and residential sectors.

Next, we discuss the findings from the second Category-2 city selected for Phase-I, which is Nagpur. Our survey of ambient air SO_2 concentrations began at the first measurement site, Location-1, in Nagpur on March 23 and continued until April 22, 2023. The survey at the second measurement site, Location-2, started on April 29 and continued until May 29, 2023.

Figure 2.17 illustrates the time series of daily mean ambient air SO_2 concentrations ($\mu g/m^3$) measured on various days of our survey at the two different measurement sites in Nagpur. It is apparent from the results presented in Figure 2.17 that the day-to-day variations in ambient air SO_2 concentrations at Location-1 are much larger than those noted at Location-2 in Nagpur. This

suggests that the ambient air SO_2 concentrations at Location-1 in Nagpur are influenced by a greater number of sources with significant day-to-day variations compared to those at Location-2.

Figure 2.18 depicts the diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) measured on different days of our survey at both measurement sites in Nagpur. It is evident from Figures 2.17 and 2.18 that there are substantial diurnal variations as well as significant intra-day variations in ambient air SO_2 concentrations at Location-1 compared to Location-2 in Nagpur.



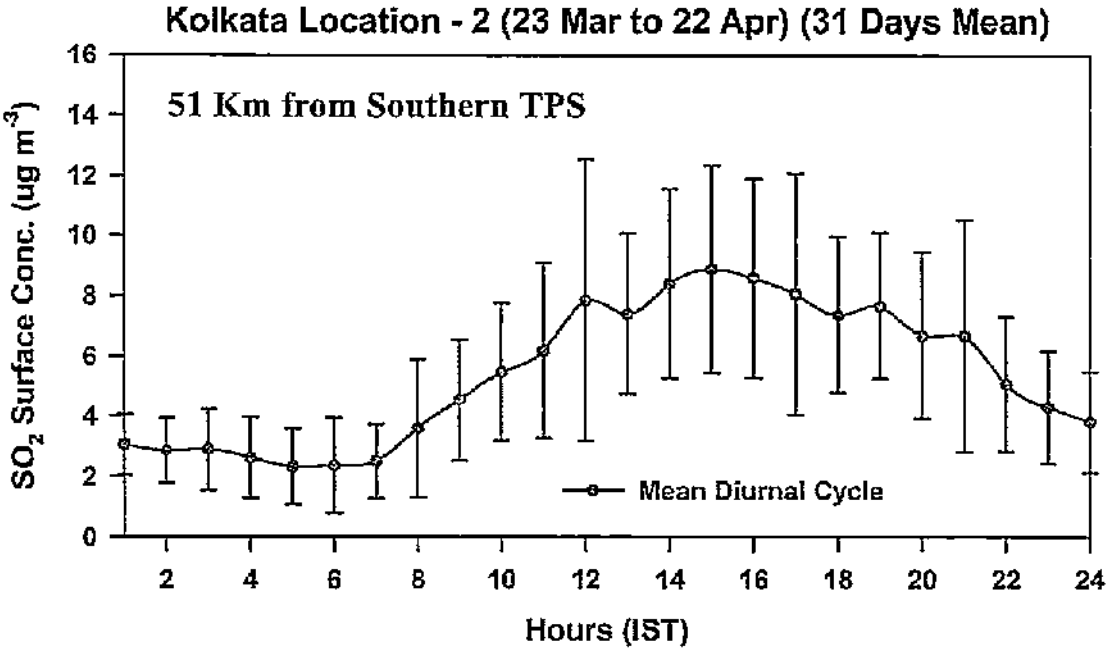


Figure 2.16: Monthly mean pattern of diurnal variation of ambient air SO_2 concentration (µg/m³) for Location-1 (upper panel) and Location-2 (lower panel) of Kolkata. Vertical lines in this figure represents the ±1σ standard deviation variation around the monthly mean values for each hour.

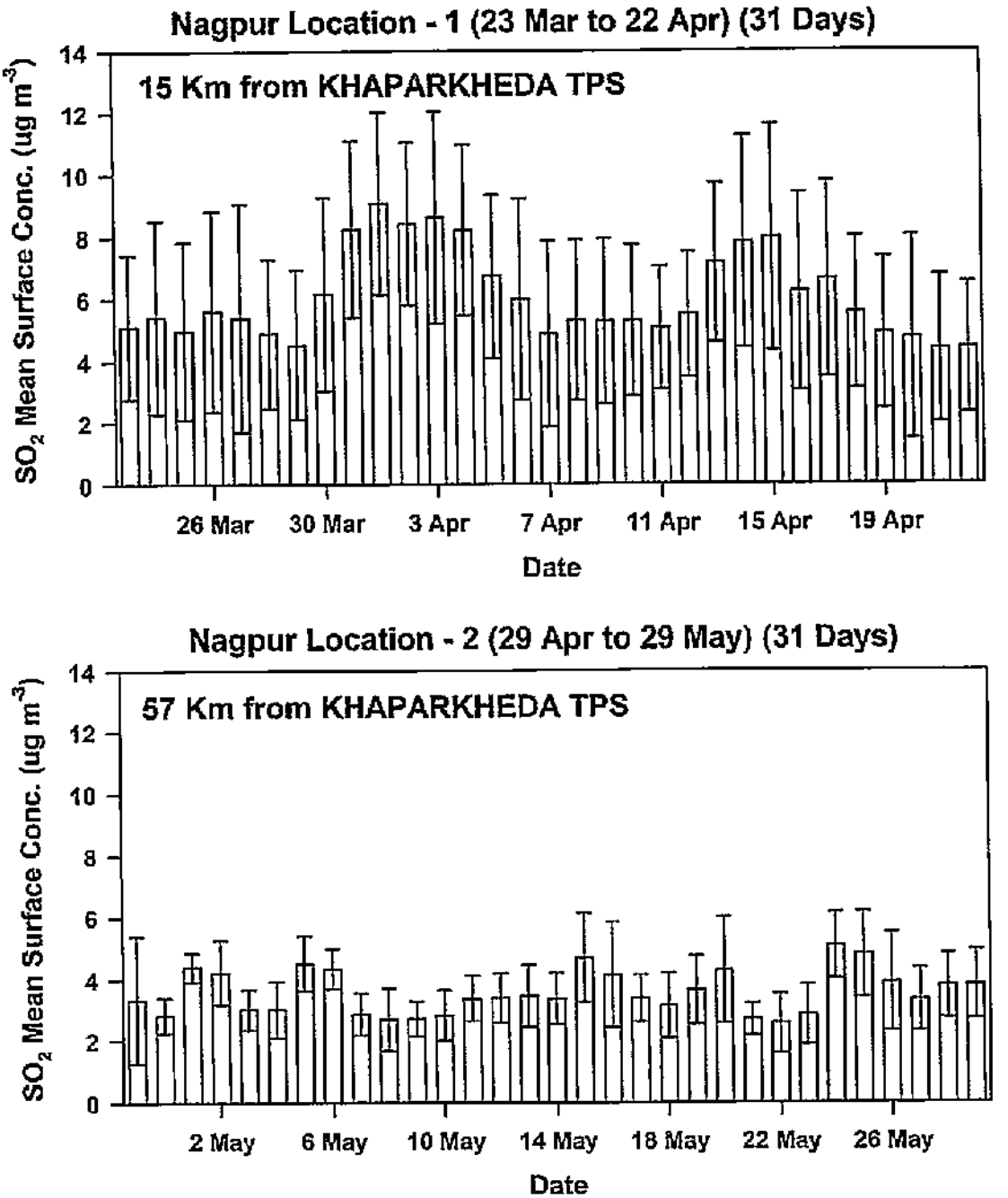


Figure 2.17: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Nagpur (upper panel) and for the period 29th April – 29th May 2023 in Location-2 of Nagpur (lower panel). Vertical lines on

each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Table 2.1 presents the maximum instantaneous, minimum instantaneous, and daily mean values of ambient air SO_2 concentration ($\mu g/m^3$) measured at two different locations in all six cities across the country selected during Phase-I of our survey. The maximum instantaneous values of ambient air SO2 concentrations measured at Location-1 and Location-2 of Nagpur during Phase-I of our survey are 20.54 $\mu g/m^3$ and 9.46 $\mu g/m^3$, respectively. The minimum instantaneous values measured at Location-1 and Location-2 of Nagpur during Phase-I of our survey are 1.21 $\mu g/m^3$ and 1.13 $\mu g/m^3$, respectively. The monthly average daily mean values of ambient air SO_2 concentrations measured at Location-1 and Location-2 of Nagpur during Phase-I of our survey are 6.07 ± 2.83 $\mu g/m^3$ and 3.55 ± 0.53 $\mu g/m^3$, respectively. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. Our survey results confirm that ambient air SO_2 concentrations in Nagpur meet these existing standards during the survey period.

Interestingly, our survey results reveal significant differences in the diurnal variations of ambient air SO_2 concentrations between the two measurement locations in Nagpur. In Location-1, SO_2 concentrations typically peak during the daytime, especially in the forenoon hours, and decrease during the nighttime. However, there are considerable day-to-day variations in this pattern. Multiple spikes in SO_2 concentrations occur at various times of the day, including evening and nighttime, throughout the survey period in Location-1. This suggests a strong influence of local sources within the city contributing to these spikes, which typically last for a maximum of 1-2 hours each time. On the contrary, ambient air SO_2 concentrations in Location-2 of Nagpur show little diurnal variability and minimal day-to-day variations throughout our survey period. While spikes in SO_2 concentrations are also observed in Location-2 on some days, they are much smaller in magnitude compared to those in Location-1. Additionally, the randomness associated with the occurrence of these spikes in the diurnal pattern of ambient air SO_2 concentration at both measurement locations in Nagpur indicates that they are primarily caused by emissions from various nearby local sources, with a shorter distance of influence (less than 60 km).

Figure 2.19 illustrates the monthly mean pattern of diurnal variation in ambient air SO_2 concentration observed at both measurement sites in Nagpur during Phase-I of our survey. As mentioned earlier, the monthly mean pattern of diurnal variations in ambient air SO_2 concentrations over Location-1 of Nagpur is characterized by relatively lower values during the nighttime and higher values during the daytime, especially in the forenoon hours. The ambient air SO_2 concentrations over Location-1 of Nagpur increase rather rapidly almost immediately after sunrise, reaching a maximum around 9 AM. Subsequently, they either remain steady for the

next couple of hours or show a very gentle decreasing trend until around 6 PM in the evening before increasing again to reach another maximum around midnight.

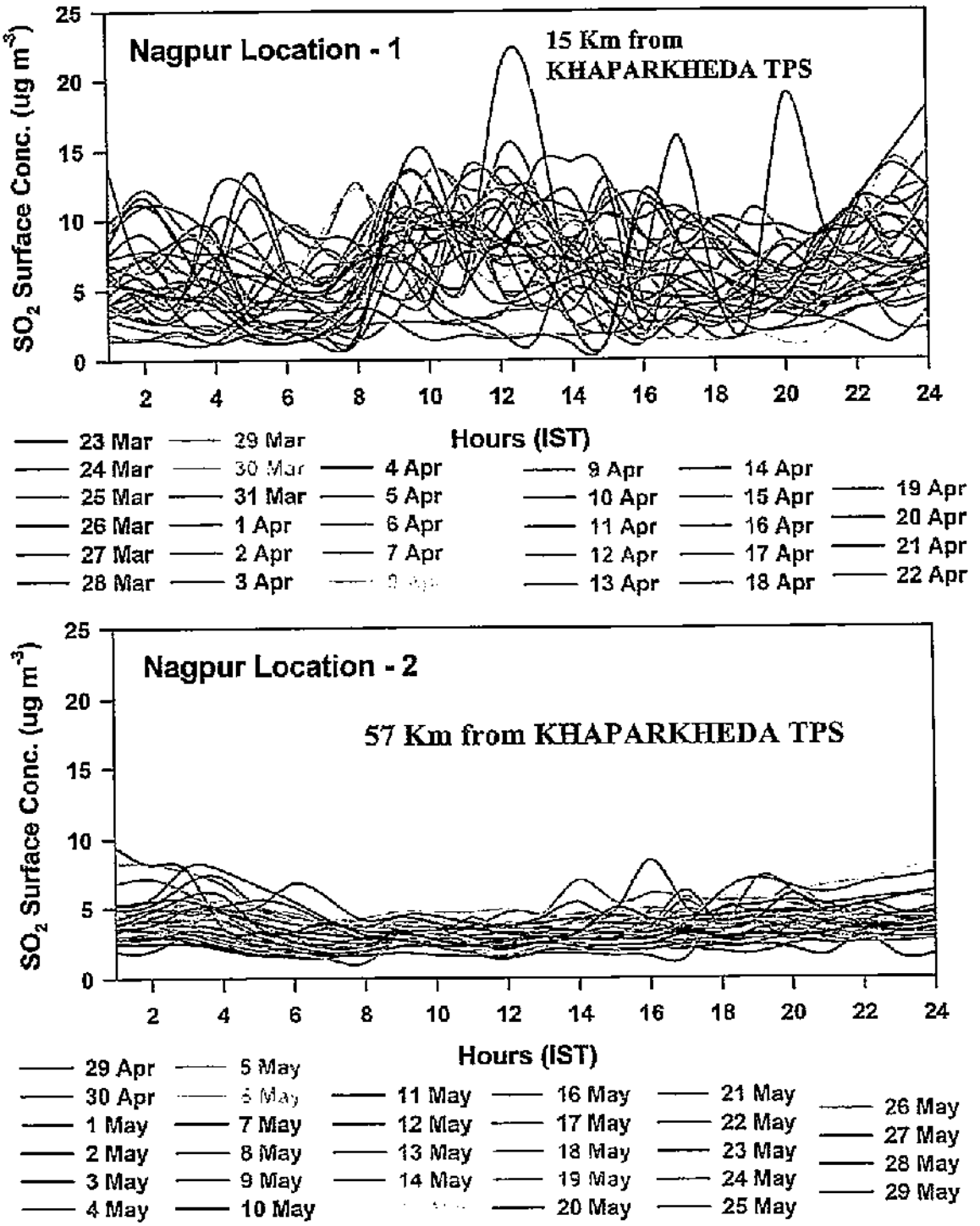


Figure 2.18: Diurnal variation of ambient air SO_2 concentration (µg/m^3) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Nagpur (upper panel) and for the period 29th April – 29th May 2023 in Location-2 of Nagpur (lower panel).

Conversely, ambient air SO_2 concentrations in Location-2 of Nagpur do not show such pronounced diurnal variability. In fact, we observed relatively higher values in ambient air SO_2 concentration during nighttime compared to daytime values in Location-2 of Nagpur.

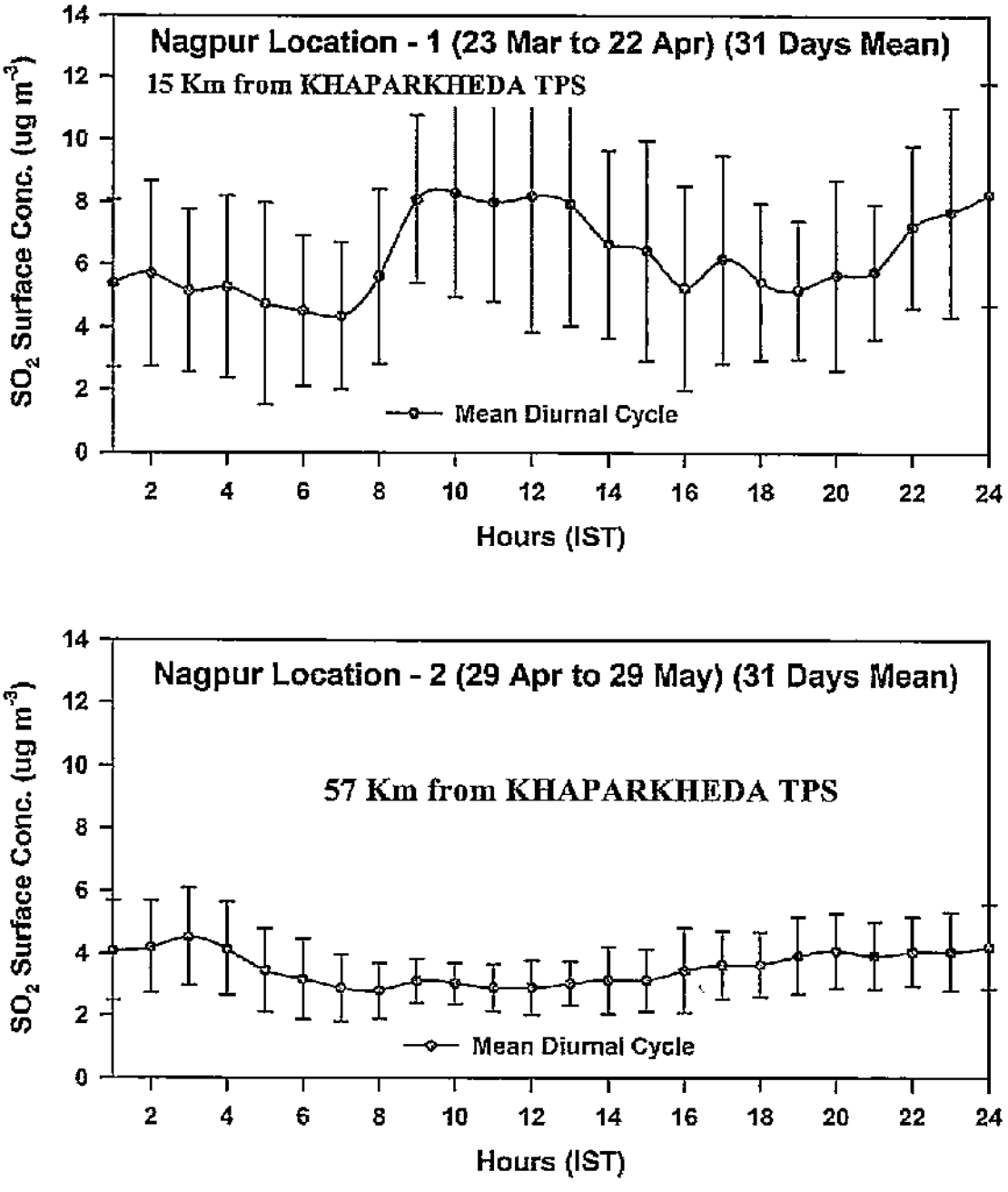
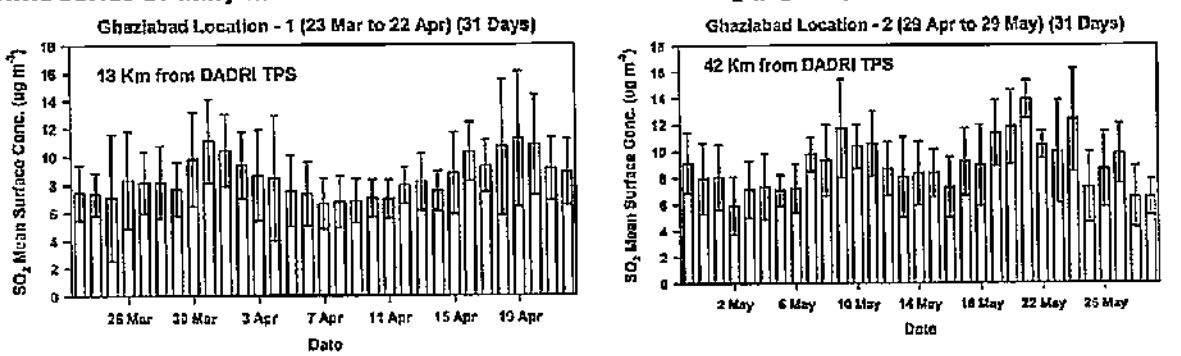


Figure 2.19: Monthly mean pattern of diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) for Location-1 (upper panel) and Location-2 (lower panel) of Nagpur. Vertical lines in this figure represents the $\pm 1\sigma$ standard deviation variation around the monthly mean values for each hour.

The monthly mean pattern of diurnal variation in ambient air concentration of SO_2 at location-2 Nagpur indicates peak values in the evening hours after sunset, which typically remain elevated until about 2 AM, with minimum values observed in the forenoon hours around 10 AM. Despite the higher boundary layer height during the daytime at this second measurement location in Nagpur, there is a gradual but consistent increase in ambient air SO_2 concentrations during the afternoon. This increase is likely attributed to the slow accumulation of SO_2 levels resulting from emissions from various sectors predominantly active during the daytime, as well as the transport of regional SO_2 plumes from upwind sources to this measurement location throughout the day. Thus, the findings of our survey suggest that ambient air SO_2 concentrations in Location-2 of Nagpur are primarily influenced by the transport of regional SO_2 plumes to the measurement site, which is modulated by relatively weaker local sources throughout the day.

Next, we delve into the findings of our survey concerning Category-3 cities featuring a coal-based Thermal Power Plant (TPP) equipped with Flue Gas Desulfurization (FGD), situated within 10 kilometers from the city boundary. Category-3 cities selected during Phase-I of our survey comprise Gautam Buddha Nagar and Ghaziabad, both located in the state of Uttar Pradesh.

Time series of daily mean ambient air concentration of SO_2 (µg/m³) measured in Ghaziabad



National Ambient Air Quality Standards (NAAQS)
[NAAQS Notification dated 18th November, 2009]

S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air: Industrial, Residential, Rural and other Areas	Concentration in Ambient Air: Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
1	Sulphur Dioxide (SO_2), µg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

Figure 2.20: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Ghaziabad (upper left panel) and for the period 29th April – 29th May 2023 in Location-2 of Ghaziabad (upper right panel). Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Our survey of ambient air SO_2 concentrations at the first measurement site, Location-1, in Ghaziabad commenced on March 23 and extended until April 22, 2023. Subsequently, the survey at the second measurement site, Location-2, in Ghaziabad began on April 29 and continued until May 29, 2023. Figure 2.20 displays the time series of daily mean ambient air SO_2 concentration ($\mu g/m^3$) measured on various days of our survey at these two distinct measurement sites in Ghaziabad.

The results depicted in Figure 2.20 illustrate substantial day-to-day variations in ambient air SO_2 concentrations at both Location-1 and Location-2 of Ghaziabad. This suggests that the ambient air SO_2 concentrations at these locations are influenced by numerous sources of SO_2 exhibiting significant day-to-day variations. Table 2.1 presents the maximum instantaneous, minimum instantaneous, and daily mean values of ambient air SO_2 concentration measured at both measurement sites in all six cities across the country selected during Phase-I of our survey. The maximum instantaneous values of ambient air SO2 concentrations measured at Location-1 and Location-2 of Ghaziabad during Phase-I of our survey are 33.51 $\mu g/m^3$ and 18.66 $\mu g/m^3$, respectively. The minimum instantaneous values measured at Location-1 and Location-2 of Ghaziabad during Phase-I of our survey are 2.92 $\mu g/m^3$ and 2.62 $\mu g/m^3$, respectively. The monthly average daily mean values of ambient air SO_2 concentrations measured at Location-1 and Location-2 of Ghaziabad during Phase-I of our survey are 8.51 ± 2.56 $\mu g/m^3$ and 7.87 ± 1.89 $\mu g/m^3$, respectively. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. Our survey results confirm that ambient air SO_2 concentrations in Ghaziabad meet these existing standards during the survey period.

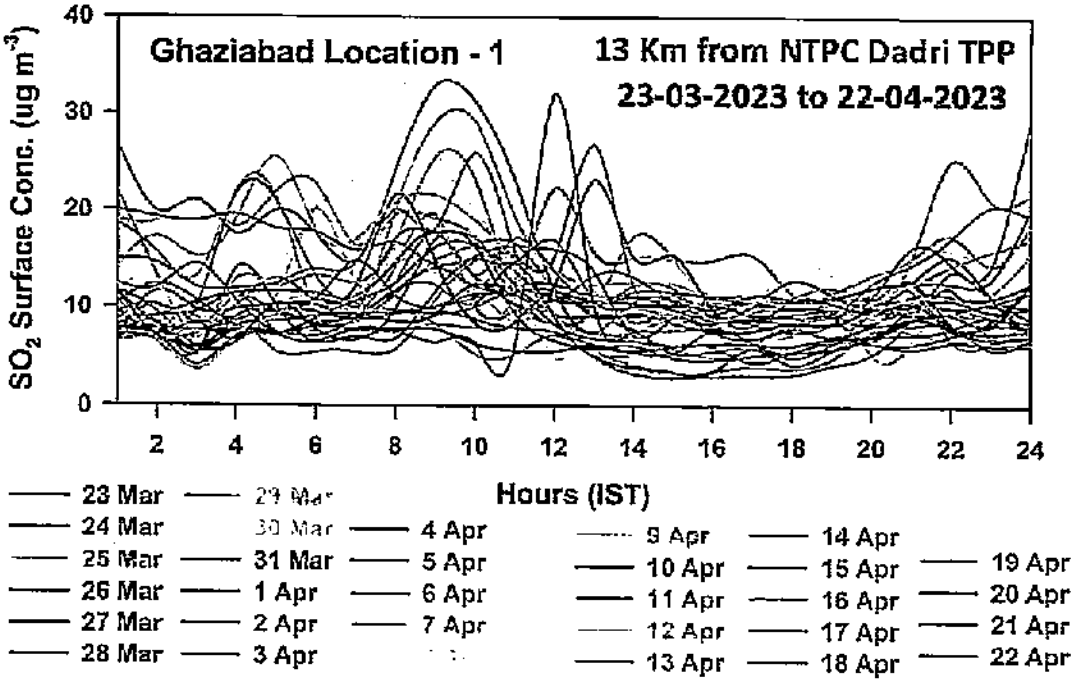
Additionally, Figure 2.21 illustrates the diurnal variation of ambient air SO_2 concentration measured on different days of our survey at both measurement sites in Ghaziabad. It is apparent from Figure 2.21 that substantial diurnal variations, along with significant intra-day variations, exist in ambient air SO_2 concentrations at both Location-1 and Location-2 of Ghaziabad. Interestingly, our survey results reveal both commonalities and significant differences in the diurnal variations of ambient air SO_2 concentrations between the two measurement locations in Ghaziabad. At both sites, SO_2 concentrations generally tend to be higher during nighttime. However, Location 1 exhibits multiple spikes in SO2 concentrations during the forenoon hours throughout the survey period, suggesting a strong influence of local sources within the city contributing to these short-lived spikes, typically lasting 1-2 hours. Conversely, Location 2 shows a more consistent diurnal pattern, with higher SO_2 values at night and lower values during the daytime, particularly in the forenoon hours, indicating less influence from immediate local sources. While occasional spikes are also observed at Location 2, they are smaller in magnitude compared to those at Location 1. The randomness of these spikes suggests they are primarily

caused by emissions from nearby local sources with a shorter range of influence than the approximately 40 km distance between the two sites. This variability highlights the complex interplay of local emission sources in shaping ambient air quality in Ghaziabad, underscoring the need for more detailed investigations to identify and mitigate these sources.

Figure 2.21 illustrates the monthly mean pattern of diurnal variation in ambient air SO_2 concentration observed at both measurement sites in Ghaziabad during Phase-I of our survey. At Location 1, the SO_2 concentrations exhibit a bimodal pattern with peaks around 8 AM and 10 PM and a midday trough, indicating potential influences from local emissions and atmospheric dispersion conditions. Located just 13 km from NTPC Dadri TPP, Location 1 shows relatively stable SO_2 concentrations throughout the day, with slight peaks in the morning and late afternoon, fluctuating between approximately 6 to 12 $\mu g/m^3$. In contrast, Location 2, situated 42 km from NTPC Dadri TPP, displays a pronounced decrease in SO_2 concentrations from midnight to noon, reaching a low in the early afternoon, and then gradually increasing back to initial levels by midnight. This pattern may be influenced by regional transport and diurnal atmospheric boundary layer dynamics, with concentrations varying more significantly, ranging from about 4 to 12 $\mu g/m^3$. Both locations exhibit a noticeable diurnal cycle and higher variability during certain hours of the day, especially at Location 1, possibly due to fluctuating emission rates and meteorological conditions. However, the differences between the two locations are stark: SO_2 levels at Location 1 remain relatively higher and more stable compared to Location 2, which experiences a significant daytime dip. This difference could be attributed to the proximity to various emission sources, including NTPC Dadri TPP, resulting in more stable and elevated SO_2 levels at Location 1. Meanwhile, the greater distance of Location 2 from Ghaziabad city and the TPP allows for dispersion and dilution effects, leading to lower daytime concentrations. Thus, while both locations show variability in SO_2 levels, Location 1 has higher concentrations, likely due to its proximity to NTPC Dadri TPP and other emission sources in Ghaziabad. The diurnal variations at both sites are influenced by various emission sources and atmospheric processes, with the primary difference being the magnitude and timing of the diurnal peaks, reflecting the distance from emission sources and local environmental factors.

Next, we discuss the findings of our survey from the second Category-3 city namely Gautam Buddha Nagar from Uttar Pradesh, having a coal-based Thermal Power Plant (TPP) equipped with Flue Gas Desulfurization (FGD), situated within 10 kilometres from the city boundary.

Our measurements at the first measurement site, Location-1 of Gautam Buddha Nagar, began on March 23 and continued until April 22, 2023. Subsequently, the survey at the second measurement site, Location-2, commenced on April 29 and extended until May 29, 2023.


Ghaziabad Location - 1
13 Km from NTPC Dadri TPP
23-03-2023 to 22-04-2023
SO2 Surface Conc. (ug m-3)
Hours (IST)
23 Mar
24 Mar
25 Mar
26 Mar
27 Mar
28 Mar
29 Mar
30 Mar
31 Mar
1 Apr
2 Apr
3 Apr
4 Apr
5 Apr
6 Apr
7 Apr
8 Apr
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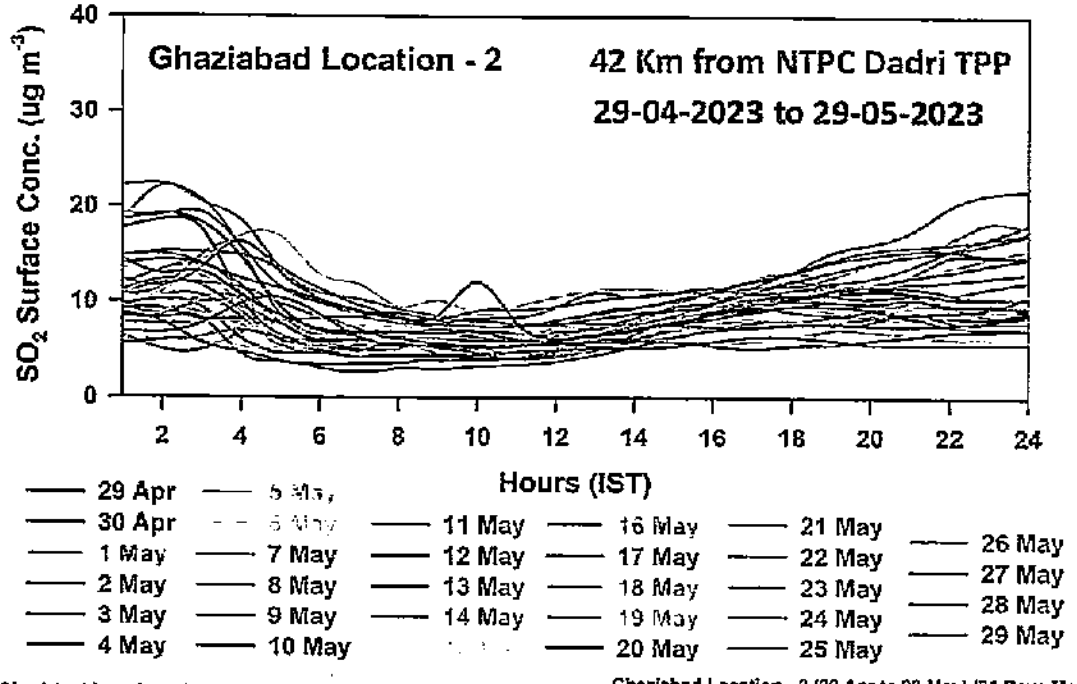
20 Apr
21 Apr
22 Apr


Ghaziabad Location - 2
42 Km from NTPC Dadri TPP
29-04-2023 to 29-05-2023
SO2 Surface Conc. (ug m-3)
Hours (IST)
29 Apr
30 Apr
1 May
2 May
3 May
4 May
5 May
6 May
7 May
8 May
9 May
10 May
11 May
12 May
13 May
14 May
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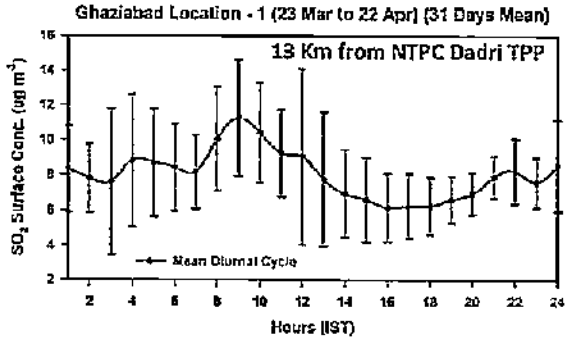
27 May
28 May
29 May


Ghaziabad Location - 1 (23 Mar to 22 Apr) (31 Days Mean)
13 Km from NTPC Dadri TPP
SO2 Surface Conc. (ug m-3)
Mean Diurnal Cycle
Hours (IST)

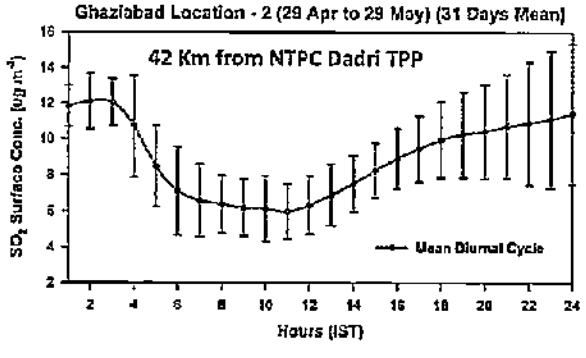

Ghaziabad Location - 2 (29 Apr to 29 May) (31 Days Mean)
42 Km from NTPC Dadri TPP
SO2 Surface Conc. (ug m-3)
Mean Diurnal Cycle
Hours (IST)

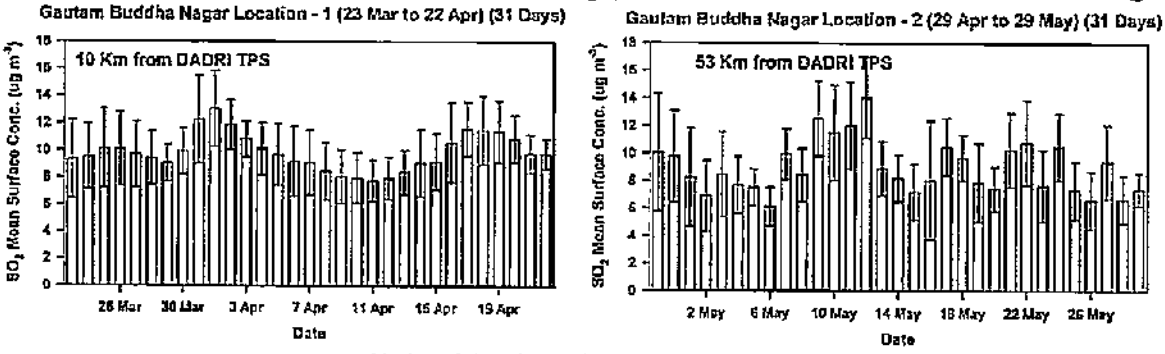
Figure 2.21: Diurnal variation of ambient air SO_2 concentration (µg/m³) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Ghaziabad (top panel) and for the period 29 April – 29 May 2023 in Location-2 of Ghaziabad (middle panel). Monthly mean pattern of diurnal variation of ambient air SO_2 concentration (µg/m³) derived from measurements made at both locations of Ghaziabad are also shown. Vertical lines in lower panels represent the ±1σ standard deviation variation around the monthly mean values for each hour.

Figure 2.22 depicts the time series of daily mean ambient air SO_2 concentration measured on various days of our survey at these two distinct measurement sites in Gautam Buddha Nagar. The results depicted in Figure 2.22 illustrate substantial day-to-day variations in ambient air SO_2 concentrations at both Location-1 and Location-2 of Gautam Buddha Nagar. This suggests that the ambient air SO_2 concentrations at both these locations are influenced by numerous sources of SO_2 exhibiting significant day-to-day variations. Table 2.1 presents the maximum instantaneous, minimum instantaneous, and daily mean values of ambient air SO_2 concentration measured at both measurement sites in all six cities across the country selected during Phase-I of our survey. The maximum instantaneous values of ambient air SO_2 concentrations measured at Location-1 and Location-2 of Gautam Buddha Nagar during Phase-I of our survey are 33.34 µg/m³ and 17.54 µg/m³, respectively. The minimum instantaneous values measured at Location-1 and Location-2 of Ghaziabad during Phase-I of our survey are 4.60 µg/m³ and 2.71 µg/m³, respectively. The monthly average daily mean values of ambient air SO_2 concentrations measured at Location-1 and Location-2 of Gautam Buddha Nagar during Phase-I of our survey are 9.86 ± 2.12 µg/m³ and 8.31 ± 2.03 µg/m³, respectively. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 µg/m³. Our survey results confirm that ambient air SO_2 concentrations in Gautam Buddha Nagar meet these existing standards during the survey period.

Figure 2.23 illustrates the diurnal variation of ambient air SO_2 concentration measured on different days of our survey at both measurement sites in Gautam Buddha Nagar. The figure shows substantial diurnal variations and significant intra-day variations in SO_2 concentrations at both Location 1 and Location 2. Similar to our findings in Ghaziabad, the survey reveals both similarities and significant differences in diurnal variations of SO_2 concentrations between the two locations. At both sites, SO_2 concentrations generally tend to be higher during nighttime. However, Location 1 exhibits multiple spikes in SO_2 concentrations during the forenoon hours throughout the survey period, indicating a strong influence of local sources within the city contributing to these short-lived spikes, typically lasting 1-2 hours. In contrast, Location 2 shows a more consistent diurnal pattern, with higher SO_2 values at night and lower values during the daytime, particularly in the forenoon hours, suggesting less influence from immediate local

sources. While occasional spikes are also observed at Location 2, they are smaller in magnitude compared to those at Location 1. The randomness of these spikes suggests they are primarily caused by emissions from nearby local sources with a shorter range of influence than the approximately 50 km distance between the two sites. This variability highlights the complex interplay of local emission sources in shaping ambient air quality in Gautam Buddha Nagar.

Time series of daily mean concentration of SO_2 (µg/m³) measured in Gautam Buddha Nagar

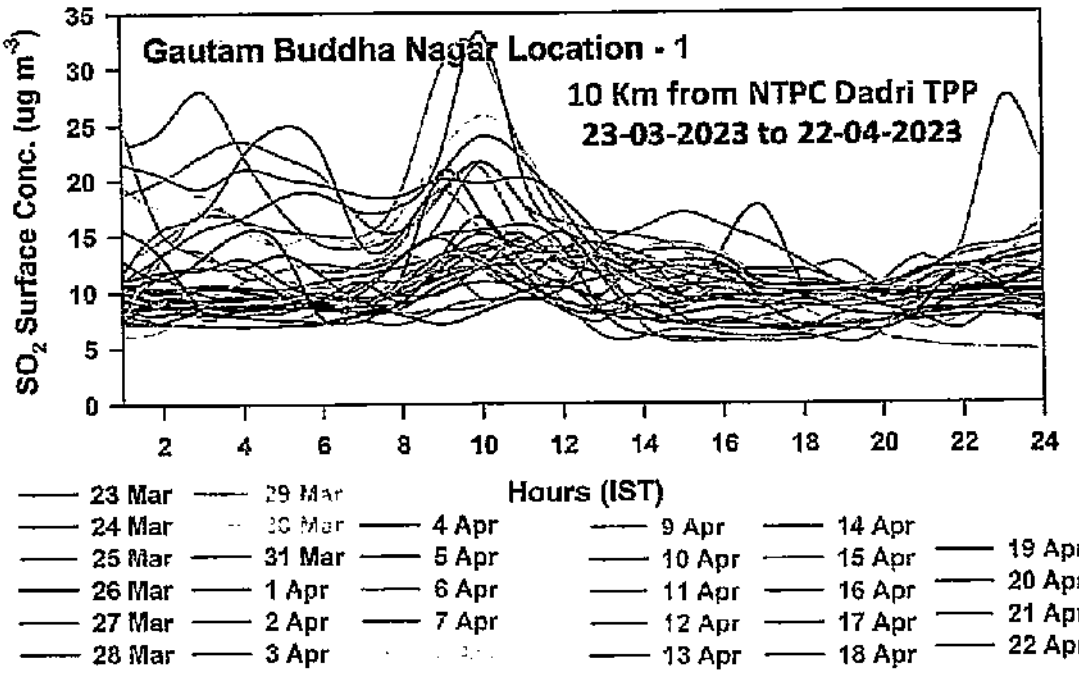


National Ambient Air Quality Standards (NAAQS)
(NAAQS Notification dated 18th November, 2009)

S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (notified by Central Government)	
1	Sulphur Dioxide (SO_2), µg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

Figure 2.22: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Gautam Buddha Nagar (upper left panel) and for the period 29th April – 29th May 2023 in Location-2 of Gautam Buddha Nagar (upper right panel). Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Figure 2.23 also illustrates the monthly mean pattern of diurnal variation in ambient air SO_2 concentration observed at both measurement sites in Gautam Buddha Nagar during Phase-I of our survey. At Location 1, the SO_2 concentrations exhibit a bimodal pattern with peaks around 10 AM and 12 AM, and an evening trough around 7 PM, indicating potential influences from local emissions, boundary layer dynamics, and atmospheric dispersion conditions. Located just 10 km from NTPC Dadri TPP, Location 1 shows relatively stable SO_2 concentrations throughout the day, with slight peaks in the morning and late-night hours, fluctuating between approximately 6 to 12 µg/m³. In contrast, Location 2, situated 53 km from NTPC Dadri TPP, displays a pronounced decrease in SO_2 concentrations from 3 AM to around noon, reaching a low just before noon, and then gradually increasing back to higher levels by midnight. This pattern may be influenced by regional transport and diurnal atmospheric boundary layer dynamics, with mean concentrations varying more significantly, ranging from about 4 to 12 µg/m³.


Gautam Buddha Nagar Location - 1
10 Km from NTPC Dadri TPP
23-03-2023 to 22-04-2023
SO2 Surface Conc. (ug m-3)
Hours (IST)
23 Mar
24 Mar
25 Mar
26 Mar
27 Mar
28 Mar
29 Mar
30 Mar
31 Mar
1 Apr
2 Apr
3 Apr
4 Apr
5 Apr
6 Apr
7 Apr
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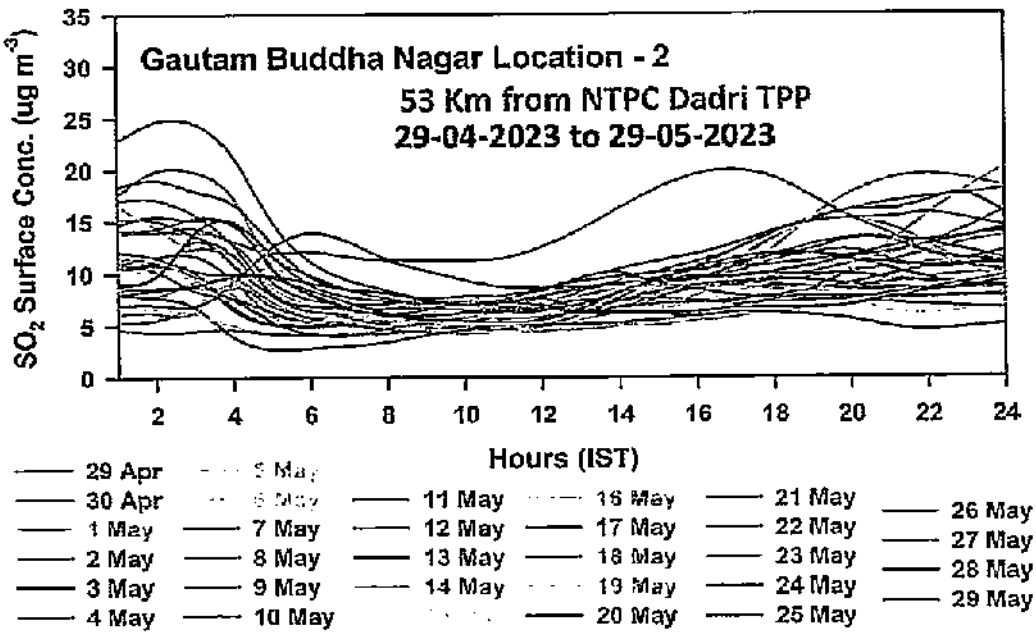
22 Apr


Gautam Buddha Nagar Location - 2
53 Km from NTPC Dadri TPP
29-04-2023 to 29-05-2023
SO2 Surface Conc. (ug m-3)
Hours (IST)
29 Apr
30 Apr
1 May
2 May
3 May
4 May
5 May
6 May
7 May
8 May
9 May
10 May
11 May
12 May
13 May
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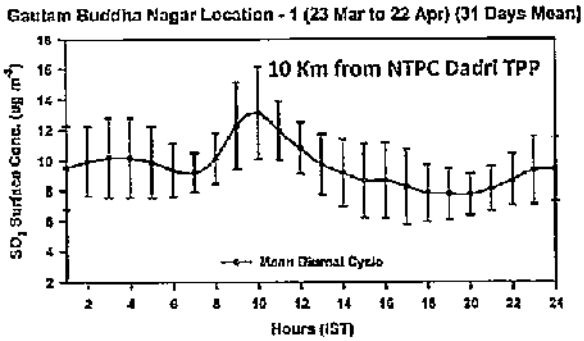

Gautam Buddha Nagar Location - 1 (23 Mar to 22 Apr) (31 Days Mean)
10 Km from NTPC Dadri TPP
SO2 Surface Conc. (ug m-3)
Mean Diurnal Cycle
Hours (IST)

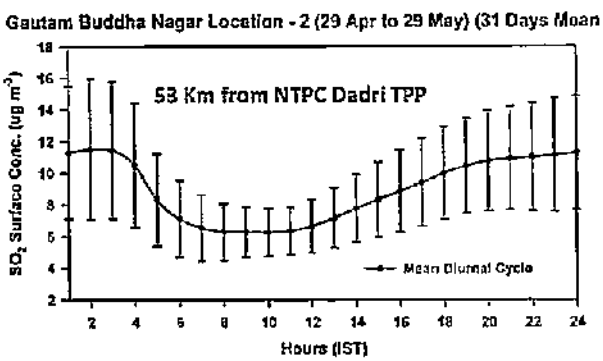

Gautam Buddha Nagar Location - 2 (29 Apr to 29 May) (31 Days Mean
53 Km from NTPC Dadri TPP
SO2 Surface Conc. (ug m-3)
Mean Diurnal Cycle
Hours (IST)

Figure 2.23: Diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) for all days (23rd March – 22nd April 2023) as measured in Location-1 of Gautam Buddha Nagar (upper panel) and for the period 29 April – 29 May 2023 in Location-2 of Gautam Buddha Nagar (middle panel). Monthly mean pattern of diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) derived from measurements made at both locations of Gautam Buddha Nagar are also shown. Vertical lines in lower panels represent the $\pm 1\sigma$ standard deviation variation around the monthly mean values for each hour.

Both locations exhibit a noticeable diurnal cycle and higher variability during certain hours of the day, especially at Location 1, possibly due to varying emission and meteorological conditions. However, the differences between the two locations are stark: SO_2 levels at Location 1 remain relatively higher and more stable compared to Location 2, which experiences a significant daytime dip. This difference could be attributed to the proximity to various emission sources, including NTPC Dadri TPP, resulting in more stable and elevated SO_2 levels at Location 1. Meanwhile, the greater distance of Location 2 from the Gautam Buddha Nagar city and the TPP allows for dispersion and dilution effects, leading to lower daytime concentrations. Thus, while both locations show variability in SO_2 levels, Location 1 has higher concentrations, likely due to its proximity to NTPC Dadri TPP and other emission sources in Gautam Buddha Nagar and the nearby city of Ghaziabad. The diurnal variations at both sites are influenced by various emission sources and atmospheric processes, with the primary difference being the magnitude and timing of the diurnal peaks, reflecting the distance from emission sources and local environmental factors.

CHAPTER-3: CONTRIBUTION OF SO_2 EMISSIONS FROM COAL-BASED TPPS TOWARDS AMBIENT ATMOSPHERIC SO_2, SULFATE AEROSOLS, PM2.5, AND PM10 MASS CONCENTRATIONS IN DIFFERENT CATEGORY CITIES DURING PHASE I OF SURVEY

To understand the contribution of SO_2 emissions from the power sector, specifically coal-based thermal power plants (TPPs), on ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in various cities selected for this survey, we conducted a series of meticulously planned simulations using the WRF-Chem chemical transport model. These simulations aimed to delineate the contributions of various sources, particularly TPP emissions, to ambient air SO_2 and sulfate aerosols as components of PM2.5 and PM10 mass concentrations across the surveyed cities. Additionally, we aimed to determine the contributions of major aerosol types, including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust, to the ambient air concentrations of PM2.5 and PM10 in these cities. Specifically, we sought to quantify the impact of SO_2 emissions from TPPs on the ambient air concentrations of PM2.5 and PM10 in the cities included in this survey.

Model setup and Simulation Details

The Weather Research and Forecasting model coupled with a chemistry module (WRF-Chem) is a regional system designed for both operational weather forecasting and atmospheric chemistry research (Skamarock, 2008; Powers et al., 2017). In this study, WRF-Chem version 4.2.2 was utilized to conduct nine sets of atmospheric chemistry simulations over Delhi spanning from March 23rd to April 22nd, 2023. The model domains were centered at Delhi (77.12° E and 28.38° N), each covering approximately 2,250,000 square kilometres at a horizontal resolution of 10 km, with 150x150 grid cells in the outer domain and a horizontal resolution of 3 km, with 136x136 grid cells in the inner domain, following a nested WRF-Chem modeling setup. The model included 44 vertical levels on a hybrid-sigma coordinate system, extending from the surface to about 10 hPa as the model top pressure.

The NCEP GDAS Final Analysis data, available at 6-hour intervals and with a resolution of 0.25°x0.25°, provided the meteorological initial and lateral boundary conditions for the model simulations covering the period from March 23rd to April 22nd, 2023. Anthropogenic emissions were based on the EDGAR-v6.1 (2023) dataset. ERA5 Temperature, Water Vapor, and Wind data were used for both the WRF-Chem simulations and the Four-Dimensional Data Assimilation (FDDA) approach. Initial and lateral chemical boundary conditions for the WRF-Chem model simulations were obtained from previously available results from the Community Atmospheric Model With Chemistry (CAM-Chem) simulations.

CAM-Chem is the atmospheric component of the NCAR Community Earth System Model (CESM) and is used for global tropospheric and stratospheric atmospheric composition simulations, employing the MOZART chemical mechanism with various complexity choices for tropospheric and stratospheric chemistry. The WRF-Chem simulation setup incorporated the Model of Emissions of Gases and Aerosols from Nature (MEGAN) for online calculation of biogenic emissions and utilized Visible and Infrared Imaging Radiometer Suite (VIIRS) data for fire-related emissions within the simulation domain. The physical and chemical parameterization schemes selected for the WRF-Chem simulations discussed in this chapter are summarized in Table 3.1.

Table 3.1: WRF-Chem Physics and Chemistry schemes used in this study

Category	Schemes
Microphysics Schemes	Lin et al. scheme
Shortwave Radiation Scheme	Rapid Radiative Transfer Model new version (RRTMG) Scheme
Longwave Radiation Scheme	Rapid Radiative Transfer Model new version (RRTMG) Scheme
Surface Layer	Revised MM5 Monin-Obukhov Scheme
Land Surface	Noah Land Surface Model
Planetary Boundary Layer	Yonsei University (YSU) PBL scheme
Cumulus Parameterization	Grell 3D ensemble scheme
Emission	EDGAR-v5 (Primary pollutants and VOCs) (2015) MEGAN Biogenic (Online), FINN Biomass Burning (2019)
Gas-phase chemical mechanism & Aerosol module Scheme	MOZART & MOSAIC (4 Bin) + VBS (Volatility Basis Set) for organic aerosol evolution
Analysis Nudging	UVTQ Nudging in every 6 hours for Temperature, Water Vapor and Winds. Nudging Coeff. 0.001 s^{-1} and no nudging in the PBL
Photolysis Scheme	Fast-J photolysis scheme

In this study, our aim was to understand the contribution of SO_2 emissions from the power sector, specifically coal-based thermal power plants (TPPs), on ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in various cities selected for this survey. Emissions were categorized into several sectors, including Fossil fuel combustion for Energy (thermal power plants), Residential and Commercial (Fossil Fuel and biomass burning for cooking and other domestic use (power backup using diesel/petrol generators, heating in winter) and business (hotels, restaurants, street vendors, crematories, generators) use, other non-energy usage of fuels), Industry (combustion and production processes, losses from solvent use in production and end-use, Oil refineries and Transformation industry, Combustion for manufacturing, Non-metallic minerals production, Chemical processes, Iron and steel production, Non-ferrous metals production, Food and Paper, Non energy use of fuels), Land Transportation (both road and off-road vehicles), Agriculture (involving livestock and crop production, Agricultural manure/fertilizer management, soil management, usage of agricultural machineries, transportation associated with agriculture, agriculture waste burning (other than stubble burning)), Waste management

(covering solid waste, including landfill emissions and open trash burning, as well as residential and industrial wastewater), and Forest Fire and Grass Fire (representing natural burning of forest and grassland).

To assess the sectoral contribution to ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in Delhi, we employed an emission suppression method. This involved conducting a series of systematically designed simulations using the WRF-Chem model, where emissions from a specific sector were disabled in each simulation. Further details of the simulation setup are provided in Table 3.2.

Table 3.2: List of numerical experiments performed using WRF-Chem model for quantifying the sectoral emission contribution to ambient atmospheric SO_2 atmospheric SO_2, sulfate aerosols, PM2.5, and PM10

Experiment Design using WRF-Chem model for Source Apportionment of SO_2 in different category cities

To estimate the **contribution of individual emission sectors** on the air pollution levels (SO_2) for various cities, following experiments were designed

S. No.	Emission Sector	Simulation Name
1	All emission Sectors active	CNTL
2	Industrial Sector emissions switched off (0%)	NoIND
3	Power Sector emissions switched off (0%)	NoENE
4	Transport Sector switched off (0%)	NoTRA
5	Residential Sector switched off (0%)	NoRES
6	Agriculture Sector switched off (0%)	NoAGR
7	Waste Burning Sector switched off (0%)	NoTRB
8	Biogenic Emission Sector switched off (0%)	NoBio
9	Biomass Burning Emission switched off (0%)	NoBB

/03/24

Table 3.3: Emission Details: EDGAR-v6.1 (2023) Emission Sectors and Their Emission Activities

EDGAR-v6.1 (2018): Emission Sectors and Emission Activities

Sectors	Emission Sources	Crippa et al. (2022)
Energy	Power industry (Thermal Power Plants)	
Industry	Oil refineries and Transformation industry, Combustion for manufacturing, Non-metallic minerals production, Construction activities, Chemical processes, Iron and steel production, Non-ferrous metals production, Food and Paper, Non-energy use of fossil fuels	
Transportation	Aviation cruise, Aviation landing & takeoff, Aviation climbing & descent, Road transportation no resuspension, Road transportation resuspension, Railways, pipelines, off-road transport, Shipping	
Residential	Fossil Fuel and biomass burning for cooking and other domestic use (power backup using diesel/petrol generators, heating in winter) and business (hotels, restaurants, street vendors, crematories, generators) use, other non-energy usage of fuels	
Agriculture	Agricultural manure/fertilizer management, soil management, usage of agricultural machineries, transportation associated with agriculture, agriculture waste burning (other than stubble burning)	
Waste	Solid waste incineration, covering solid waste, including landfill emissions and open trash burning, as well as residential and industrial wastewater	

In this study, we utilized MEGAN biogenic emissions, a modeling system designed to calculate emission rates of chemical compounds from terrestrial ecosystems to the atmosphere under varying environmental conditions. While emissions from biomass burning, considered natural sources, are not accounted for in the MEGAN model, it simulates net emission rates, factoring in losses of primary emissions within the canopy. The model employs canopy-scale emission factors, derived from above-canopy flux measurements or extrapolated from leaf and branch level data using a built-in canopy environment model.

MEGAN calculates the net primary emission of 19 compound classes, further decomposed into 147 individual species such as Isoprene, Monoterpene, sesquiterpenes, carbon monoxide, methanol, alkanes, alkenes, aldehydes, acids, ketones, and other oxygenated VOCs. The MEGAN model, in conjunction with the Modern Era Retrospective Analysis for Research and Applications (MERRA) meteorological fields, generated a global emission dataset of biogenic volatile organic compounds (BVOC) available on a monthly basis.

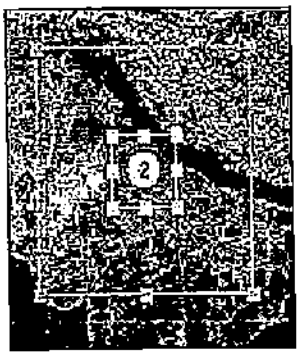
Additionally, the Fire INventory from NCAR (FINN) provides a daily, high-resolution fire emissions product for atmospheric chemistry models. Open biomass burning constitutes a significant portion of total global emissions of greenhouse gases, reactive trace gases, and particulate matter. Although sporadic and highly variable, open biomass burning emissions can impact local, regional, and global air quality, as well as climate forcings. FINN utilizes satellite observations of active fires and land cover, along with emission factors and estimated fuel loadings, to offer daily,

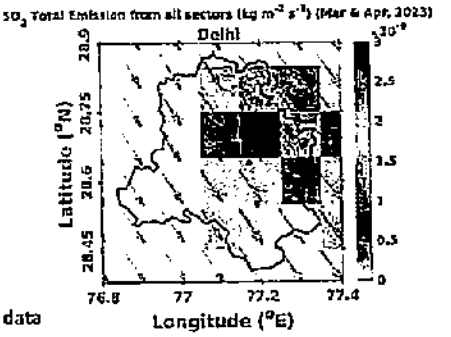
highly resolved (1kmX1km) estimates of open burning emissions for use in regional and global chemical transport models. Since 2012, fire detections from both MODIS and VIIRS satellite instruments have been incorporated into FINN for emission calculations.

Chemical Transport Modeling for Delhi

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category 1 City:
New Delhi





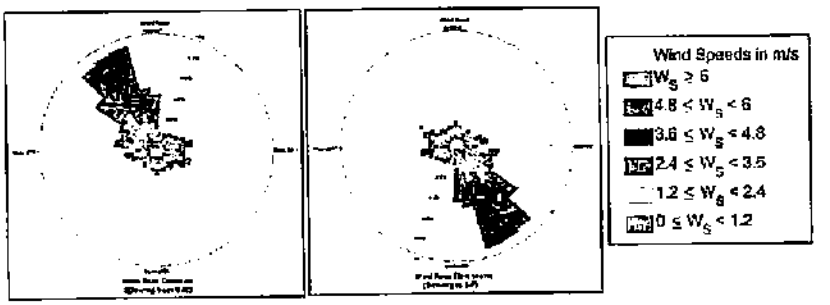


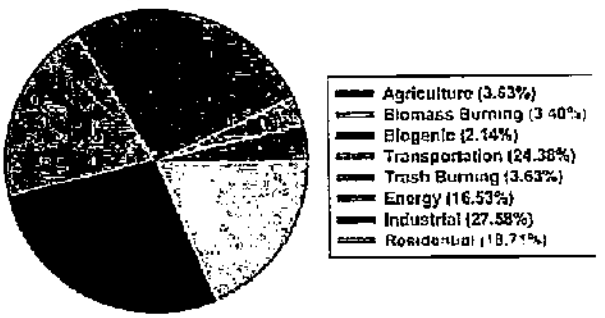
Figure 3.1: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Delhi during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category 1 City:
New Delhi

Phase I
Pre-monsoon Season

Delhi SO_2 (17.26 ± 6.20 ug m^{-3})(23 Mar to 22 Apr, 2023)



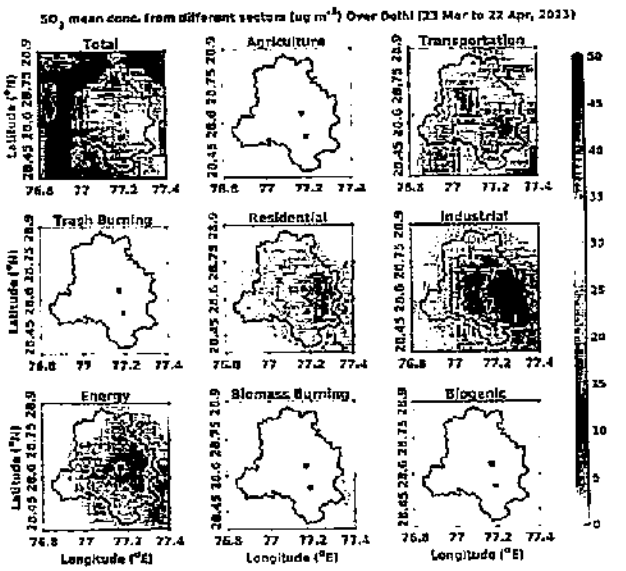


Figure 3.2: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Delhi during the simulation period from 23rd March to 22nd April 2023.

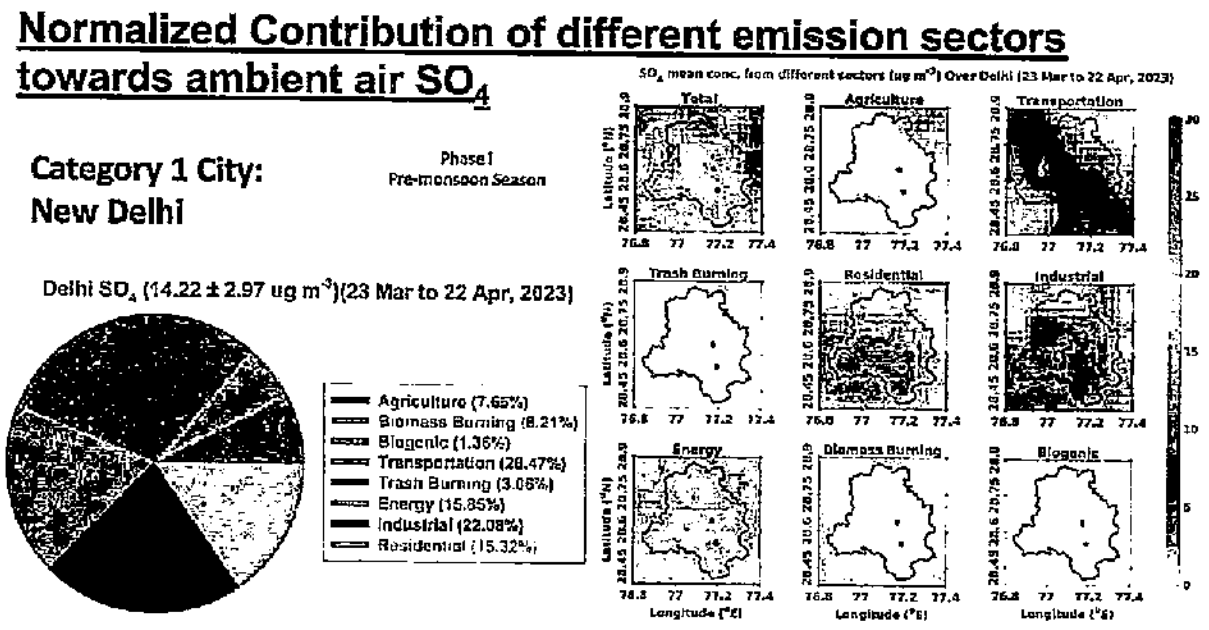


Figure 3.3: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in New Delhi during the simulation period from 23rd March to 22nd April 2023.

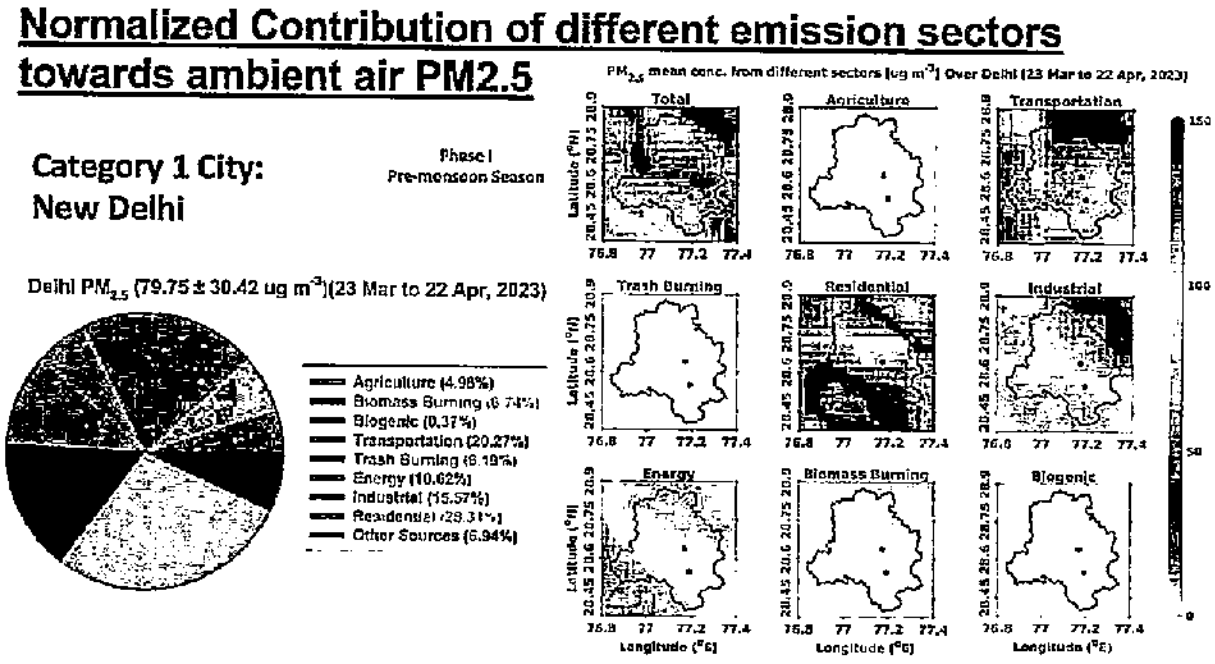


Figure 3.4: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in New Delhi during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

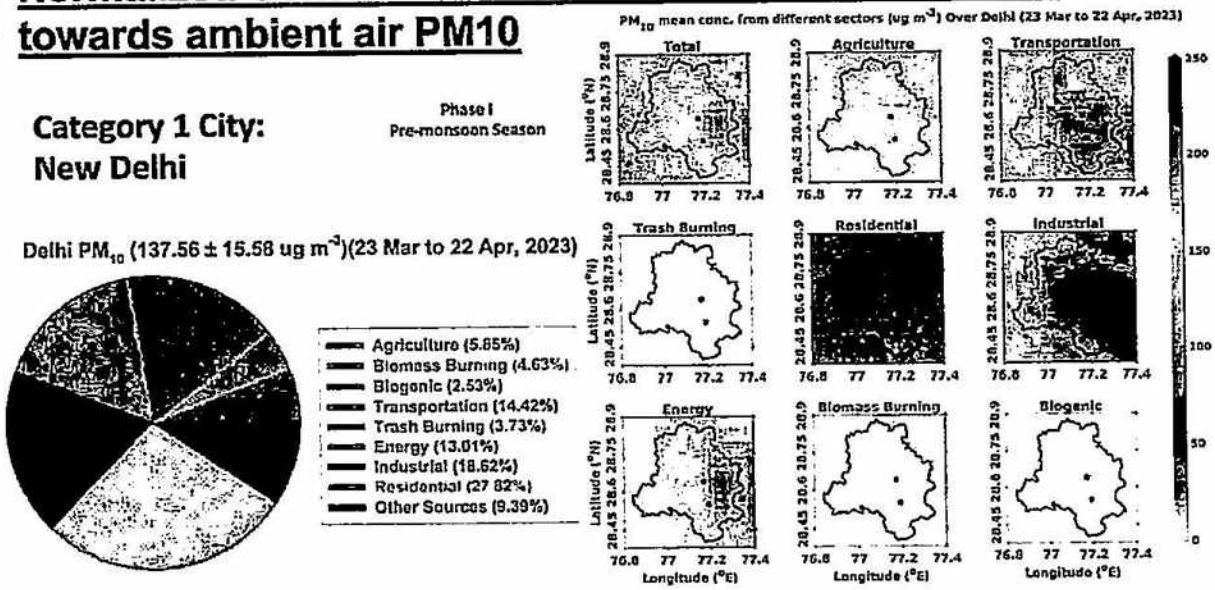


Figure 3.5: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in New Delhi during the simulation period from 23rd March to 22nd April 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Delhi during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

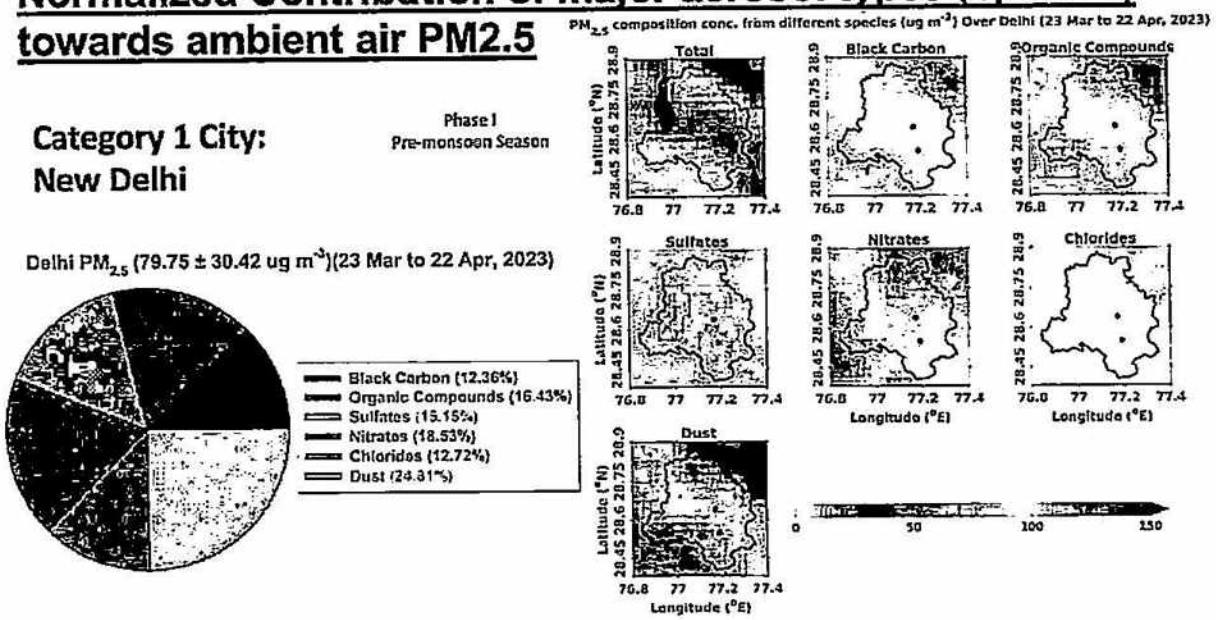


Figure 3.6: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in New Delhi during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of major aerosol types (species) towards ambient air PM10

Category 1 City: New Delhi

Phase I
Pre-monsoon Season

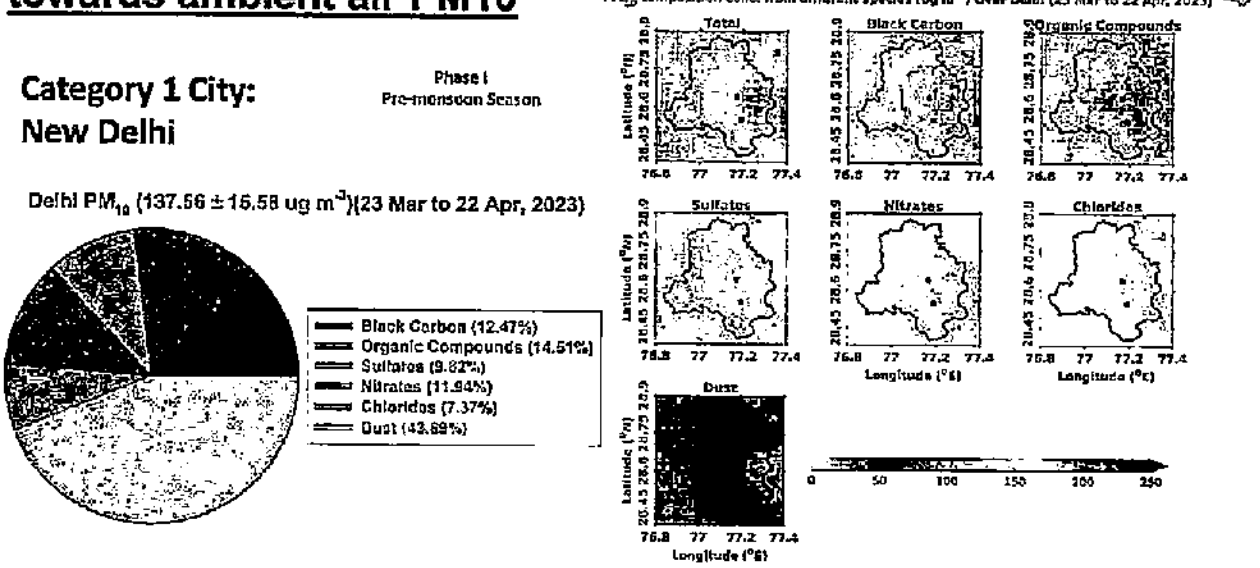
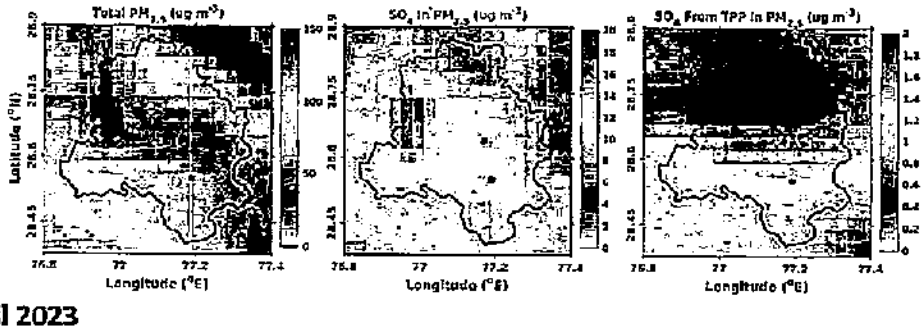


Figure 3.7: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in New Delhi during the simulation period from 23rd March to 22nd April 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category 1 City: New Delhi



23rd March to 22 April 2023

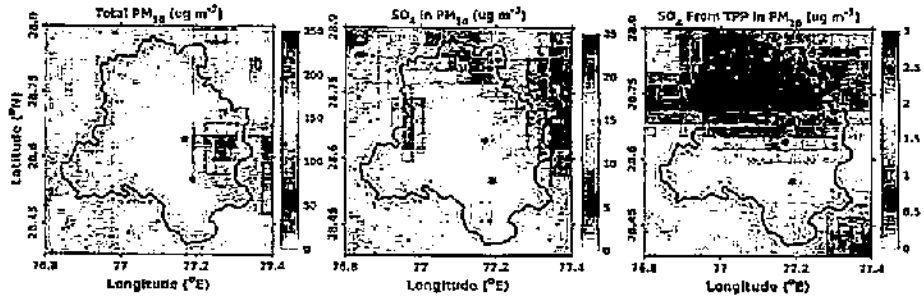


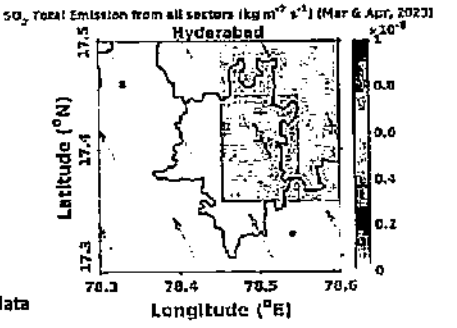
Figure 3.8: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in New Delhi during the simulation period from 23rd March to 22nd April 2023.

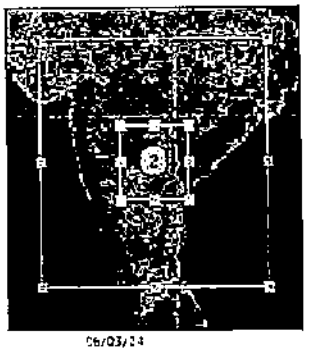
Next, we conducted another series of systematically designed WRF-Chem model simulations to determine the contribution of different sources to SO_2 and sulfate aerosols in Hyderabad, the second Category-1 city considered during Phase I of our survey. Additionally, we aimed to understand the contribution of the power sector to the ambient atmospheric SO_2, PM2.5, and PM10 concentrations in Hyderabad during our survey. We used WRF-Chem version 4.2.2 to perform a set of nine atmospheric chemistry simulations over Hyderabad from March 23 to April 22, 2023. The model domains are centered at Hyderabad (78.28° E and 17.21° N). Each simulation domain covers approximately 2,250,000 square kilometres at a horizontal resolution of 10 km × 10 km, with 150 × 150 grid cells in the outer domain and a resolution of 3 km × 3 km, with 136 × 136 grid cells in the inner domain, following a nested WRF-Chem modeling setup. The model includes 44 vertical levels (on a hybrid-sigma coordinate system) from the surface to about 10 hPa as the top pressure level. We used NCEP GDAS Final Analysis data (available at 6-hour intervals) with a resolution of 0.25° × 0.25° to provide meteorological initial and lateral boundary conditions for the simulation period. To estimate the sectoral emission contributions to ambient atmospheric SO2, sulfate aerosols, PM2.5, and PM10 concentrations in Hyderabad, we used an emission suppression method. This involved a series of systematically designed WRF-Chem simulations where emissions from a particular sector were turned off in each simulation. The details of the simulation setup are described in Table 3.2.

Chemical Transport Modeling for Hyderabad

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category 1 City: Hyderabad





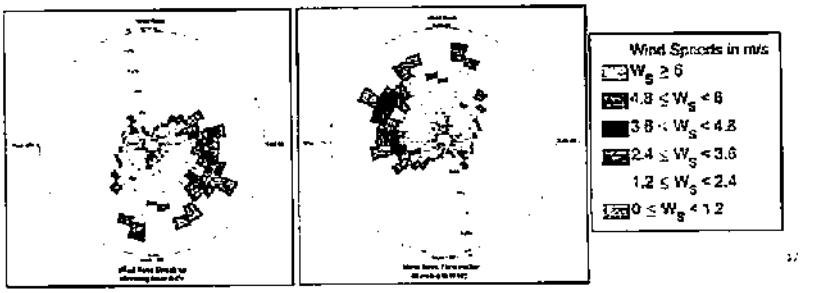


Figure 3.9: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Hyderabad during the simulation period from 23rd March to 22nd April 2023.

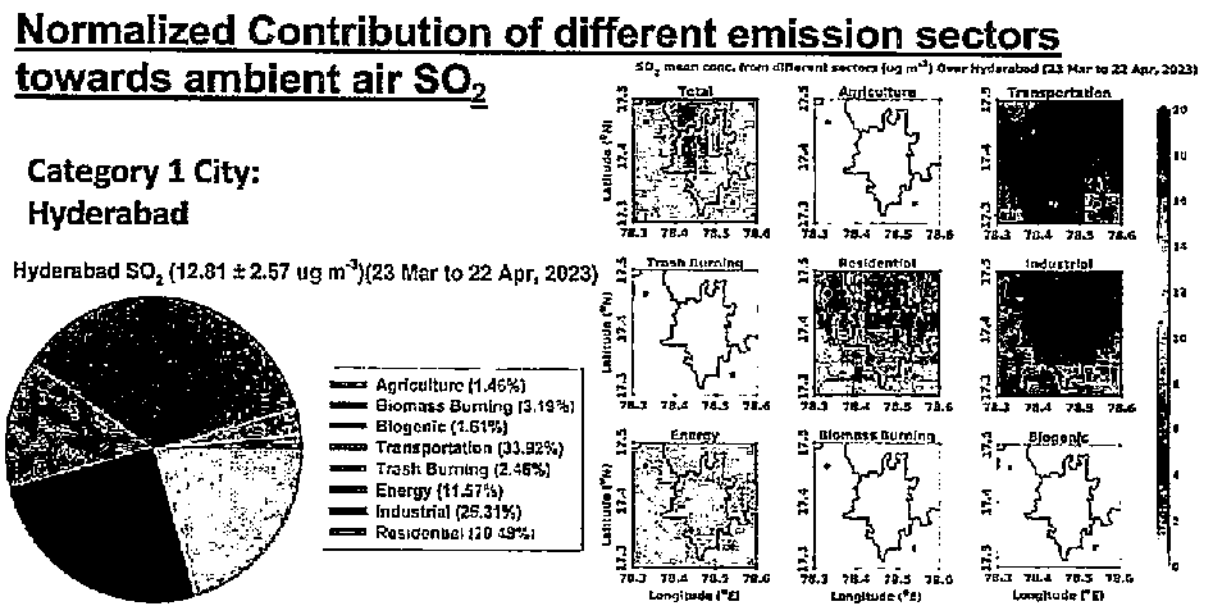


Figure 3.10: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

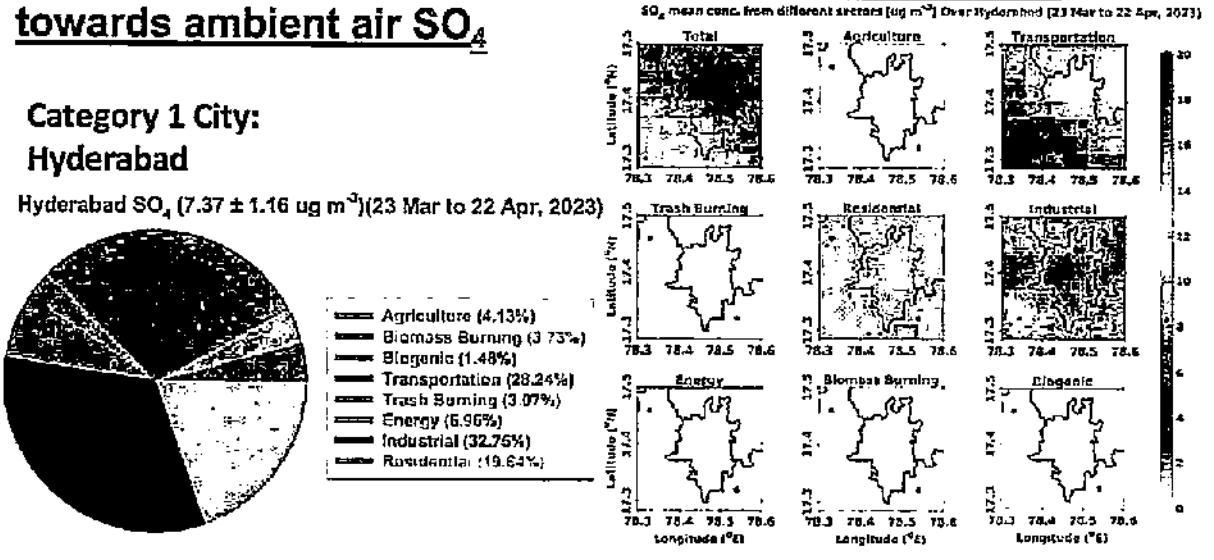
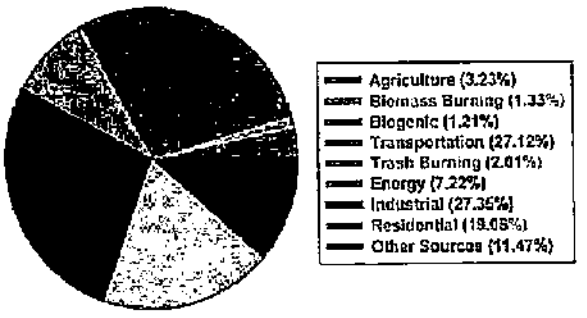


Figure 3.11: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM2.5

Category 1 City: Hyderabad

Hyderabad $PM_{2.5}$ (45.23 ± 4.12 ug m^{-3})(23 Mar to 22 Apr, 2023)



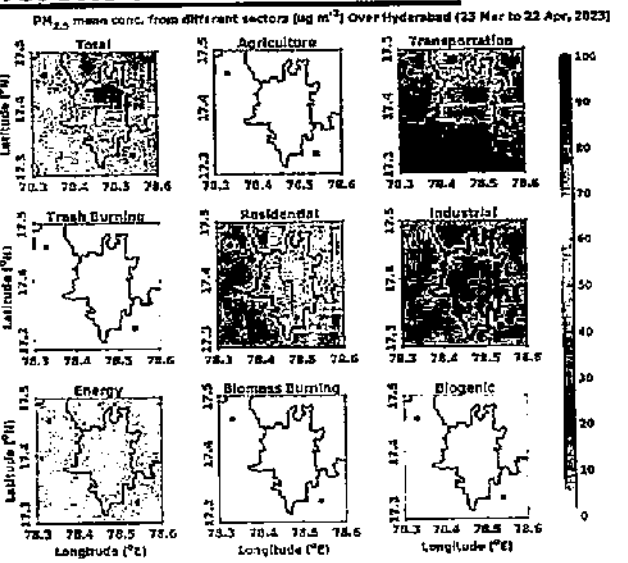
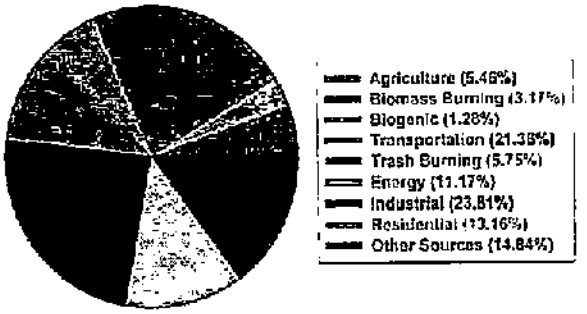


Figure 3.12: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

Category 1 City: Hyderabad

Hyderabad PM_{10} (85.18 ± 6.54 ug m^{-3})(23 Mar to 22 Apr, 2023)



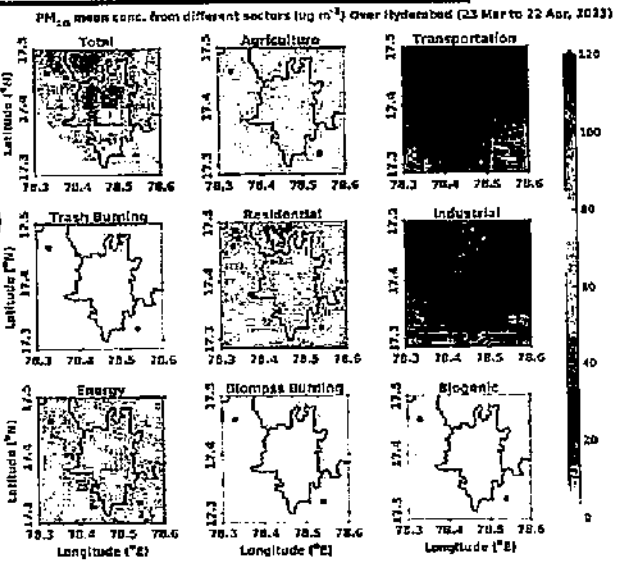


Figure 3.13: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

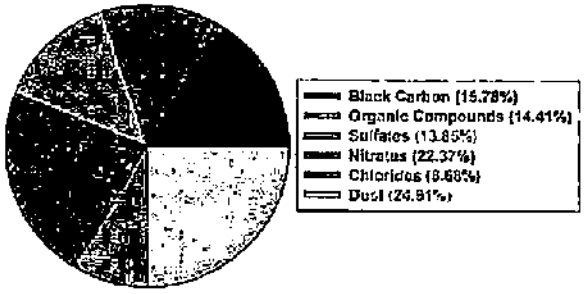
Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Hyderabad during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

Category 1 City: Hyderabad

Phase I
Pre-monsoon Season

Hyderabad $PM_{2.5}$ (45.23 ± 4.12 ug m^{-3})(23 Mar to 22 Apr, 2023)



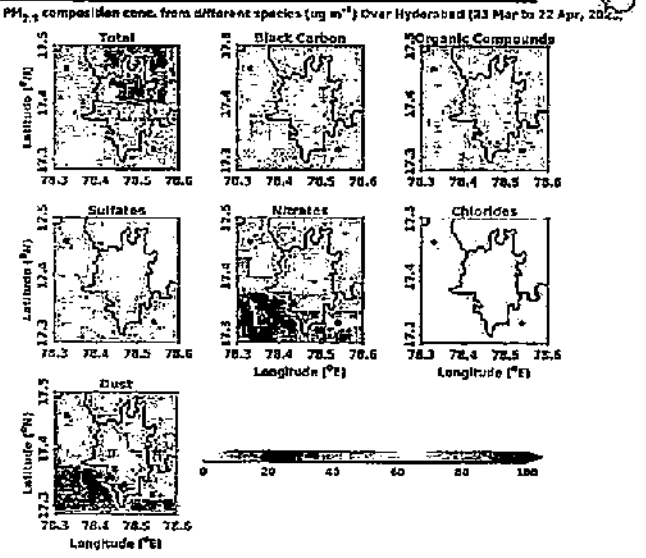


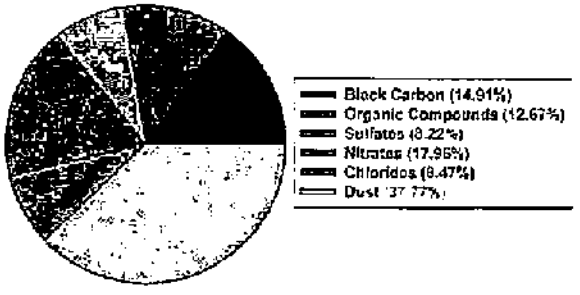
Figure 3.14: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of major aerosol types (species) towards ambient air PM10

Category 1 City: Hyderabad

Phase I
Pre-monsoon Season

Hyderabad PM_{10} (85.18 ± 6.54 ug m^{-3})(23 Mar to 22 Apr, 2023)



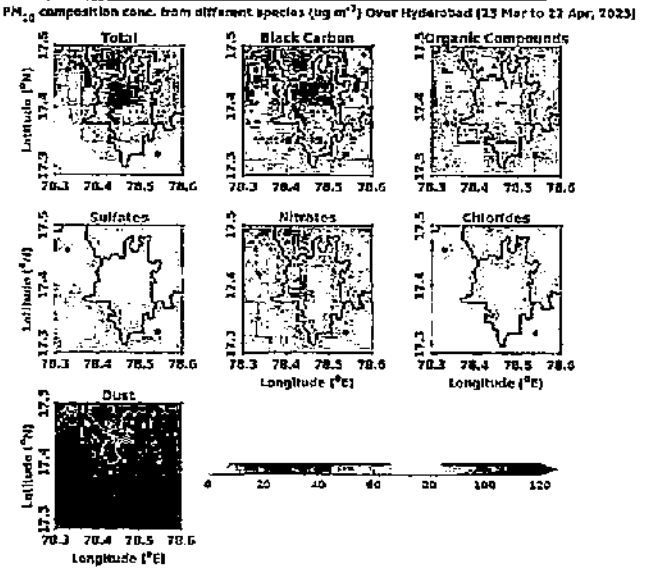


Figure 3.15: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from

thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category 1 City: Hyderabad

23rd March to 22 April 2023

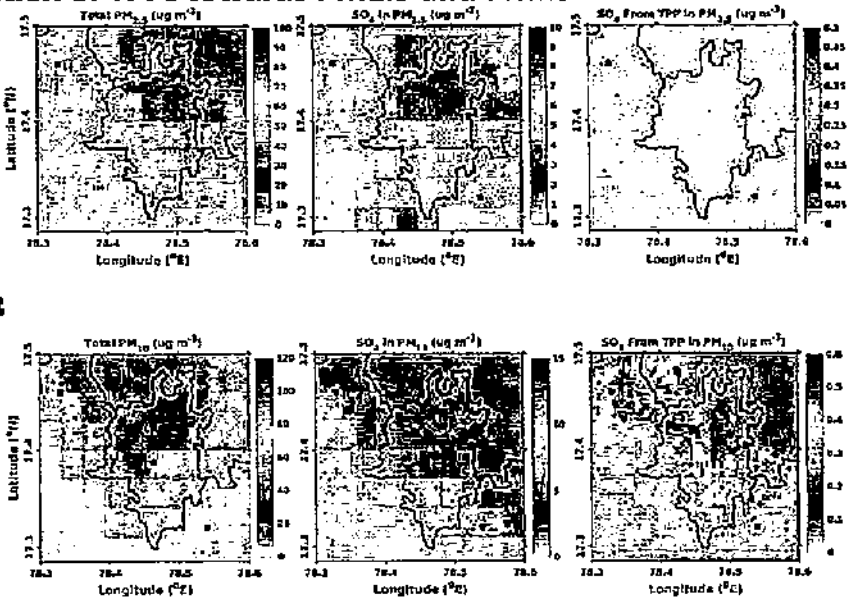


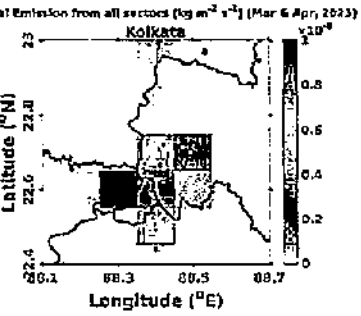
Figure 3.16: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Hyderabad during the simulation period from 23rd March to 22nd April 2023.

Next, we conducted another series of systematically designed WRF-Chem model simulations to determine the contributions of various sources to SO_2 and sulfate aerosols in Kolkata, the first Category-2 city considered during Phase-I of our survey. We also aimed to understand the power sector's impact on the ambient atmospheric SO_2, PM2.5, and PM10 concentrations in Kolkata during our survey. WRF-Chem version 4.2.2 was used to conduct a set of nine atmospheric chemistry simulations over Kolkata from March 23 to April 22, 2023. For this study, the model domains are centered at Kolkata (88.22° E and 22.34° N). Each simulation domain covers approximately 2,250,000 square kilometres with a horizontal resolution of 10 km^2, consisting of 150x150 grid cells in the outer domain. The inner domain has a horizontal resolution of 3 km^2 with 136x136 grid cells, following a nested WRF-Chem modeling setup with 44 vertical levels (using a hybrid-sigma coordinate system) extending from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis data (available at 6-hour intervals) with a resolution of 0.25°x0.25° were used to provide meteorological initial and lateral boundary conditions for the model simulations from March 23 to April 22, 2023. To estimate the sectoral emission contributions to the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Kolkata, we used an emission suppression method. We systematically designed a series of WRF-Chem model simulations where emissions from a particular sector were switched off in each simulation. The details of the simulation setup are described in Table 3.2.

Chemical Transport Modeling for Kolkata

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category 2 City: Kolkata



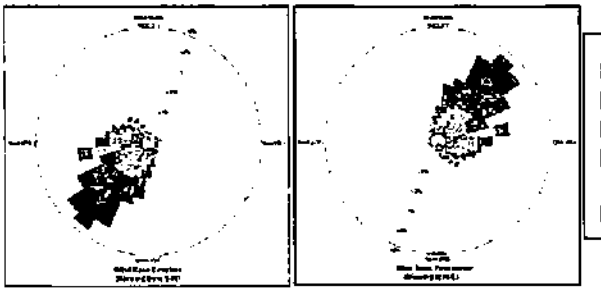
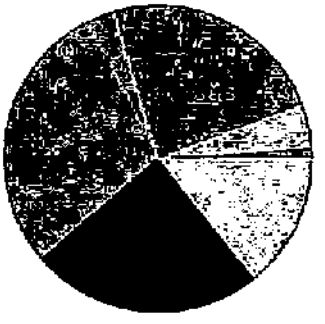


Figure 3.17: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Kolkata during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category 2 City: Kolkata

Kolkata SO_2 (13.16 ± 3.98 ug m^{-3})(23 Mar to 22 Apr, 2023)



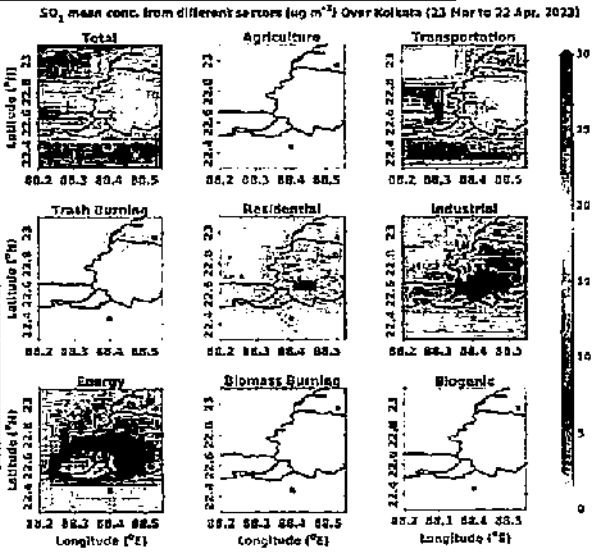
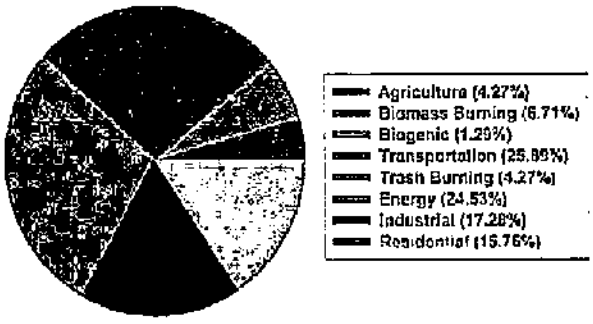


Figure 3.18: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Kolkata during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air SO_4

Category 2 City:
Kolkata

Kolkata SO_4 (8.28 ± 1.97 ug m^{-3})(23 Mar to 22 Apr, 2023)



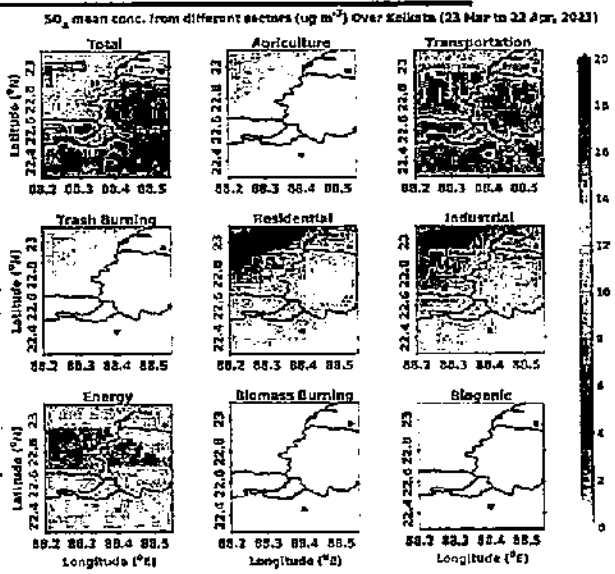
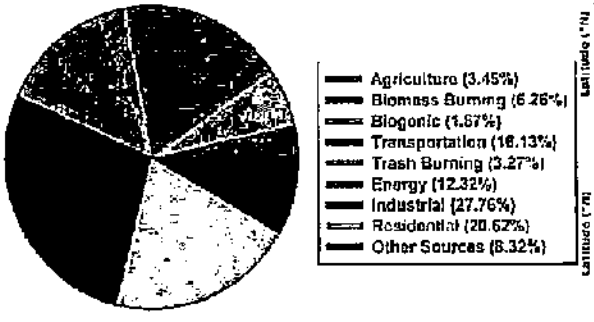


Figure 3.19: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Kolkata during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM2.5

Category 2 City:
Kolkata

Kolkata $PM_{2.5}$ (31.53 ± 7.75 ug m^{-3})(23 Mar to 22 Apr, 2023)



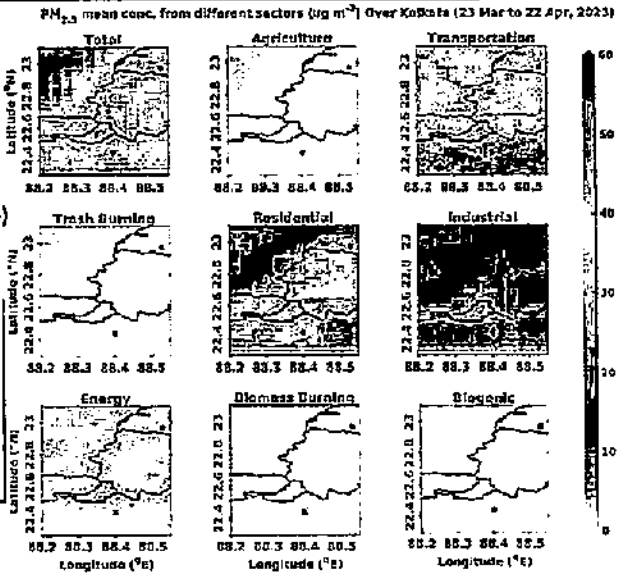
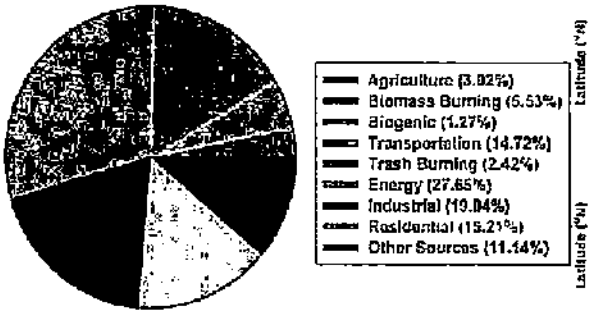


Figure 3.20: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Kolkata during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

Category 2 City:
Kolkata



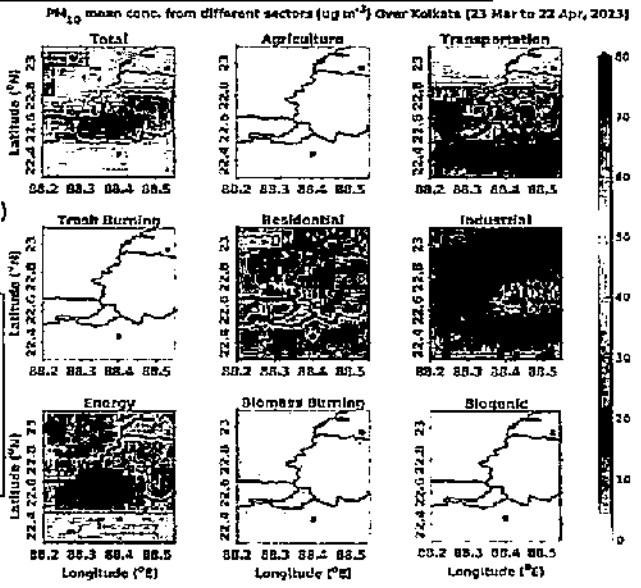


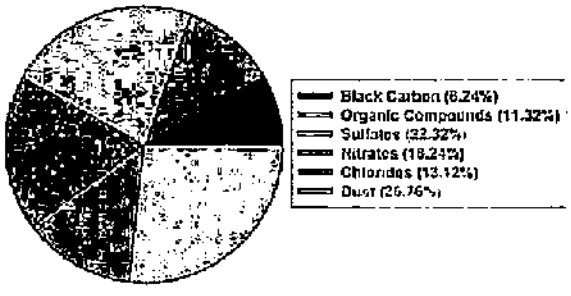
Figure 3.21: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Kolkata during the simulation period from 23rd March to 22nd April 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Kolkata during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

Category 2 City:
Kolkata

Phase I
Pre-monsoon Season



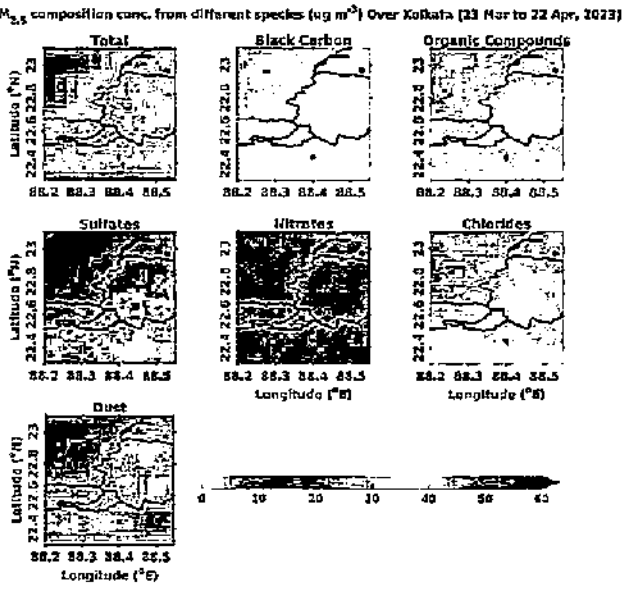


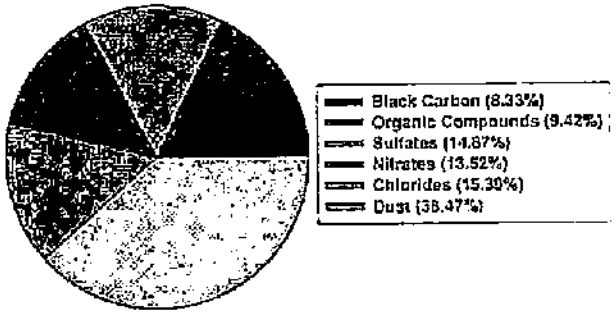
Figure 3.22: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Kolkata during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of major aerosol types (species) towards ambient air PM10

Category 2 City: Kolkata

Phase I
Pre-monsoon Season

Kolkata PM_{10} (52.69 ± 6.98 ug m^{-3})(23 Mar to 22 Apr, 2023)



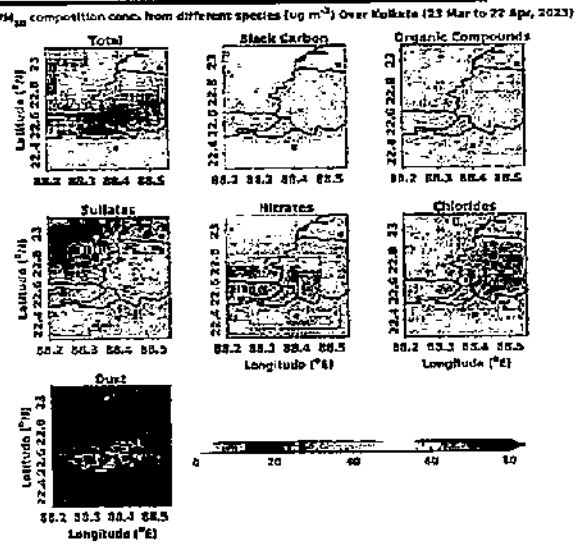


Figure 3.23: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Kolkata during the simulation period from 23 March to 22 April 2023.

By assessing the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of emissions from the energy sector, particularly SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 in the city of Kolkata that originated from SO_2 emissions from TPPs during our survey.

Contribution of TPPs towards PM2.5 and PM10

Category 2 City: Kolkata

23rd March to 22 April 2023

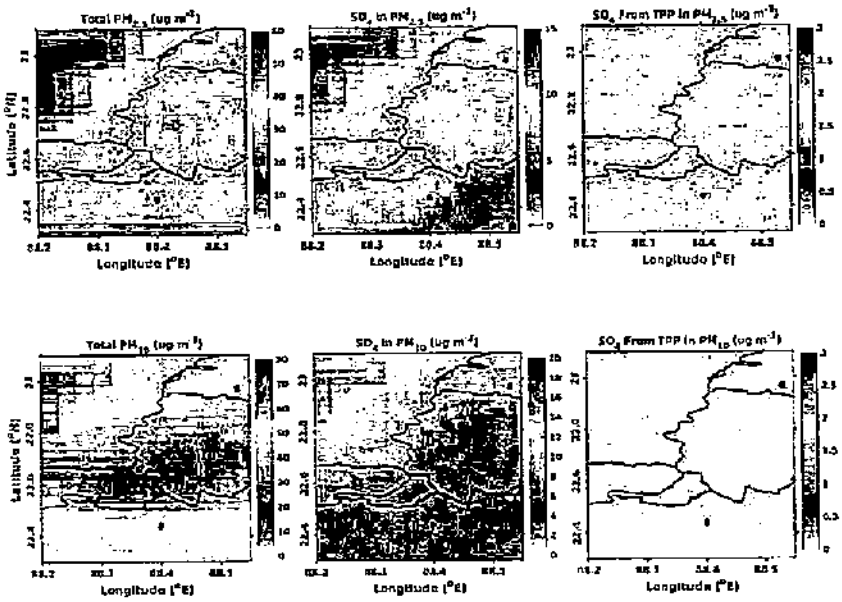


Figure 3.24: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Kolkata during the simulation period from 23rd March to 22nd April 2023.

Next, we conducted another series of systematically designed WRF-Chem model simulations to determine the contributions of different sources to SO_2 and sulfate aerosols in Nagpur, the second Category-2 city considered during Phase-I of our survey. Additionally, we aimed to understand the contribution of the power sector to the ambient atmospheric concentrations of SO_2, PM2.5, and PM10 in Nagpur during our survey. For this study, we used WRF-Chem version 4.2.2 to perform a set of nine atmospheric chemistry simulations over Nagpur from March 23 to April 22, 2023. The model domains are centered at Nagpur (79.04°E, 21.08°N). Each simulation domain covers approximately 2,250,000 square kilometres, with a horizontal resolution of 10x10 km^2 in the outer domain (150x150 grid cells) and 3x3 km^2 in the inner domain (136x136 grid cells), following a nested WRF-Chem modeling setup. The model uses 44 vertical levels (on a hybrid-sigma coordinate system) from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis data (available at six-hourly intervals) with a resolution of 0.25°x0.25° provided the meteorological initial and lateral boundary conditions for the simulation period. To estimate the sectoral emission contributions to the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Nagpur, we used an emission suppression method. This involved a series of systematically designed WRF-Chem model simulations in which emissions from specific sectors were switched off in each simulation. The details of the simulation setup are described in Table 3.2.

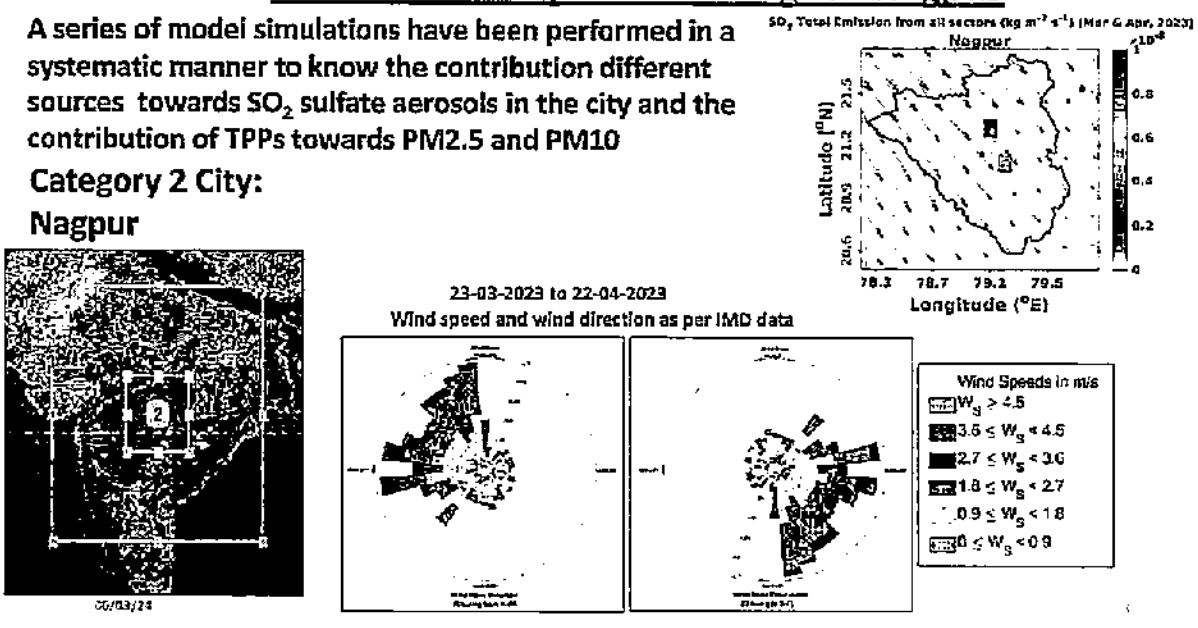


Figure 3.25: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Nagpur during the simulation period from 23rd March to 22nd April 2023.

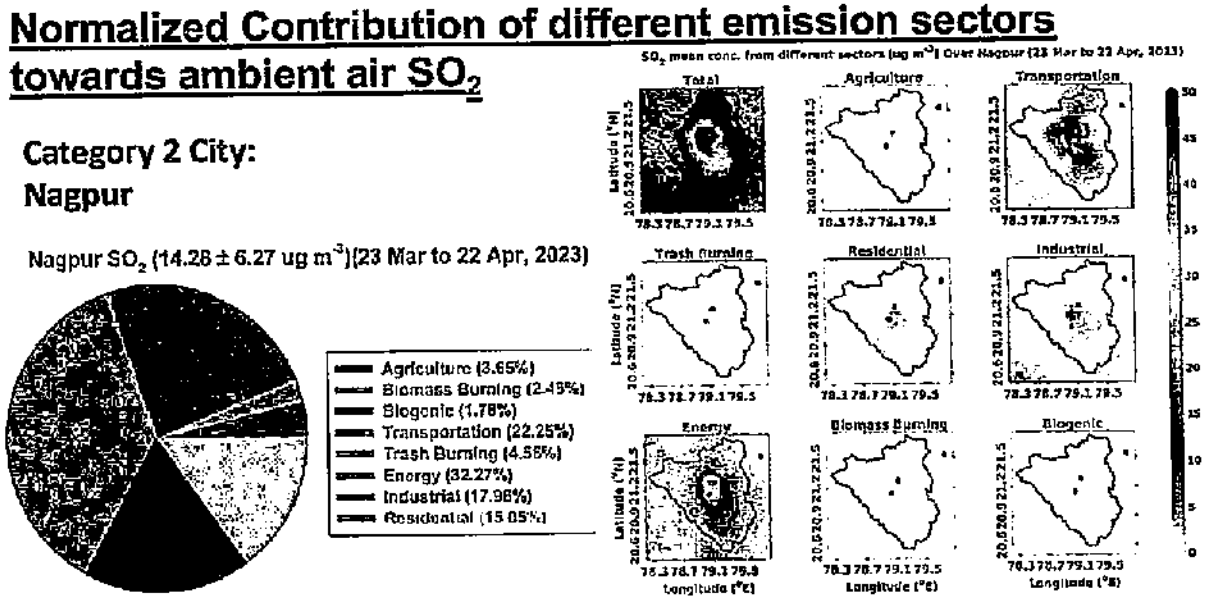


Figure 3.26: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

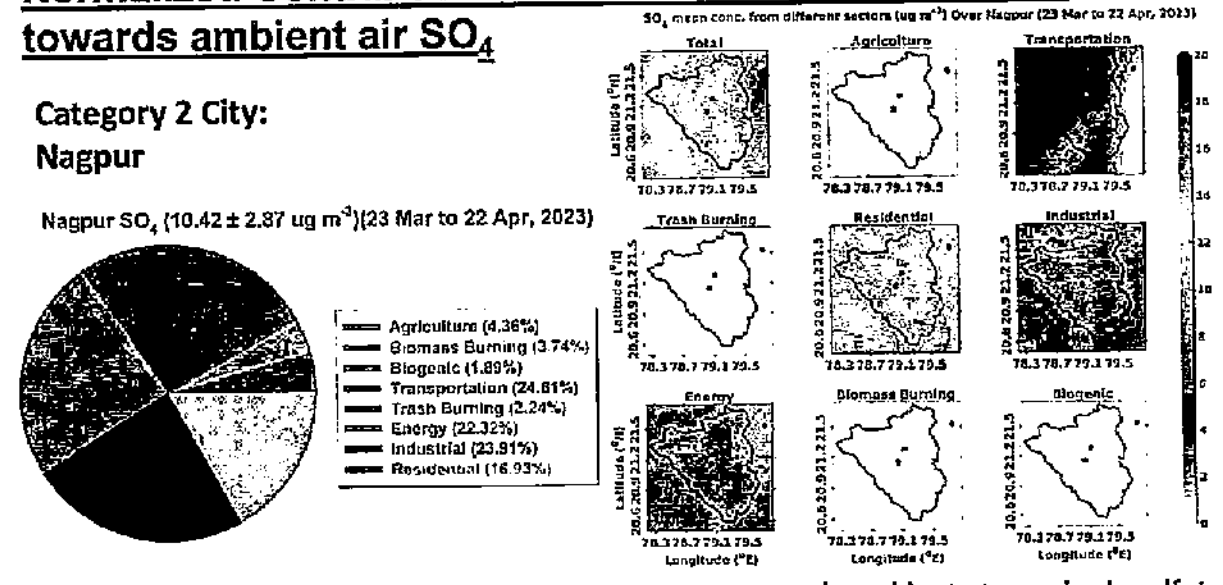
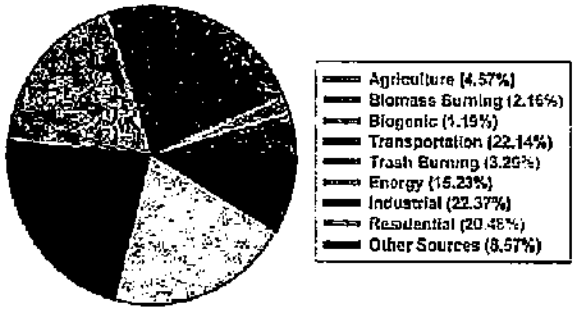


Figure 3.27: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM2.5

Category 2 City:
Nagpur

Nagpur $PM_{2.5}$ (62.63 ± 6.06 ug m^{-3})(23 Mar to 22 Apr, 2023)



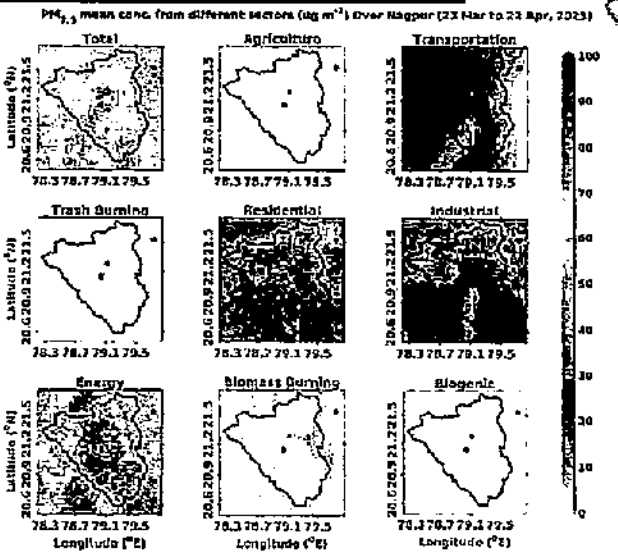
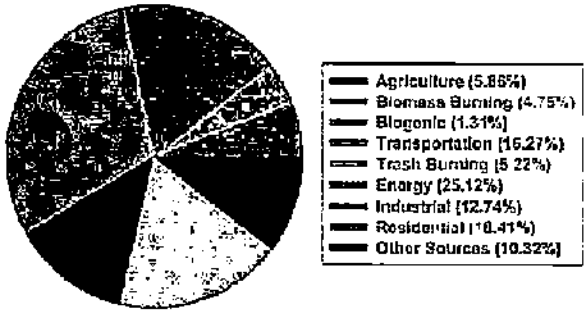


Figure 3.28: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

Category 2 City:
Nagpur

Nagpur PM_{10} (83.71 ± 6.58 ug m^{-3})(23 Mar to 22 Apr, 2023)



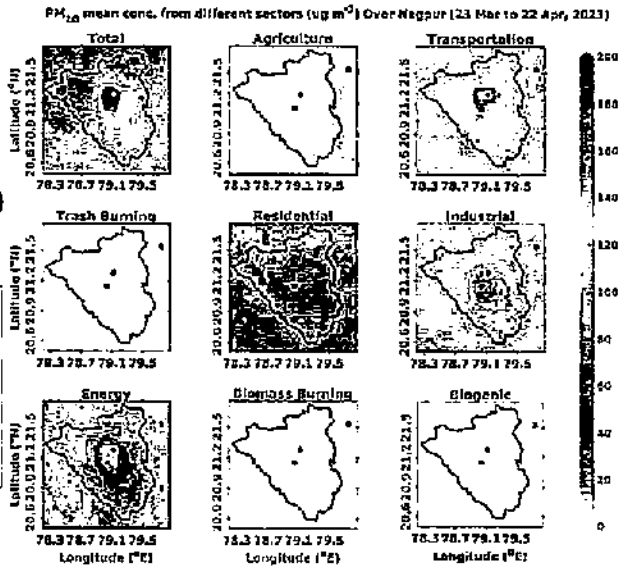


Figure 3.29: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

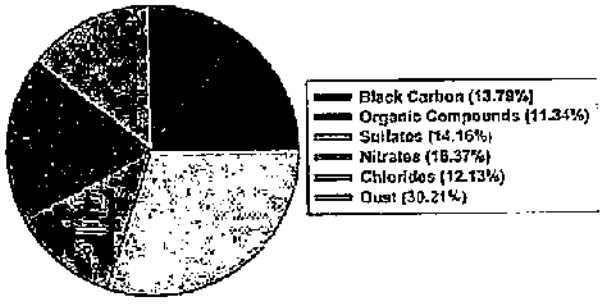
Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Nagpur during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

Category 2 City: Nagpur

Phase I
Pre-monsoon Season

Nagpur $PM_{2.5}$ (62.53 ± 6.06 ug m^{-3})(23 Mar to 22 Apr, 2023)



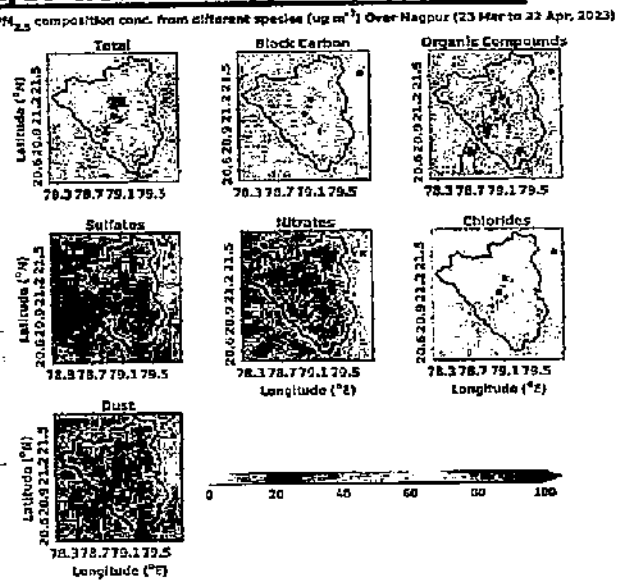


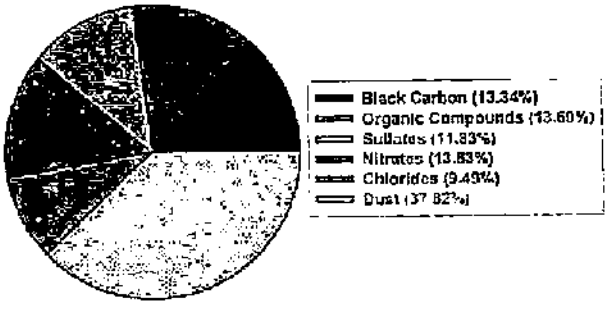
Figure 3.30: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of major aerosol types (species) towards ambient air PM10

Category 2 City: Nagpur

Phase I
Pre-monsoon Season

Nagpur PM_{10} (83.71 ± 6.58 ug m^{-3})(23 Mar to 22 Apr, 2023)



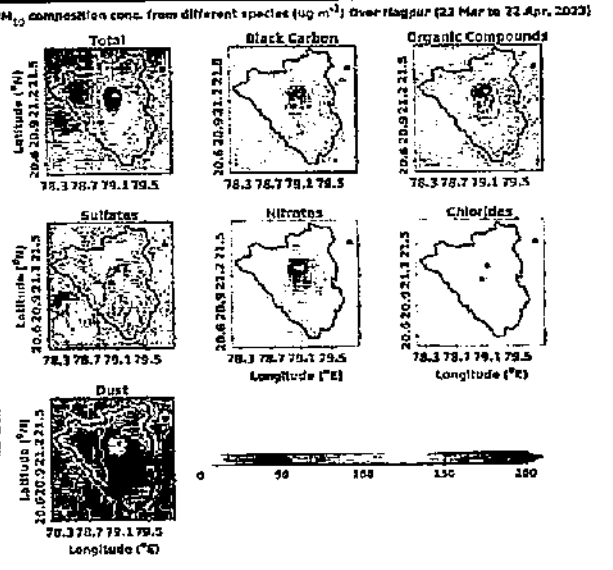


Figure 3.31: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

By assessing the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of emissions from the energy sector, particularly SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5

and PM10 that originated from SO_2 emissions from TPPs in the city of Nagpur during the survey period.

Contribution of TPPs towards PM2.5 and PM10

Category 2 City: Nagpur

23rd March to 22 April 2023

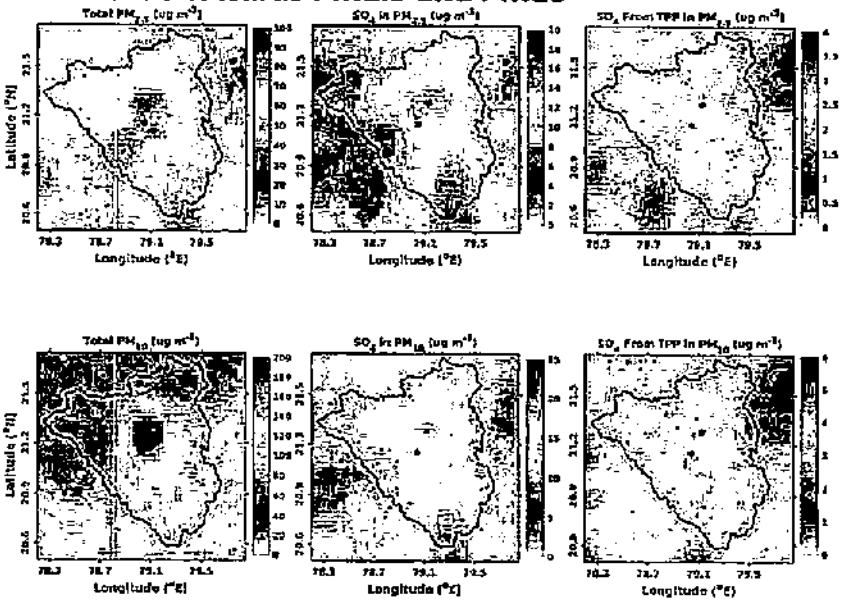


Figure 3.32: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Nagpur during the simulation period from 23rd March to 22nd April 2023.

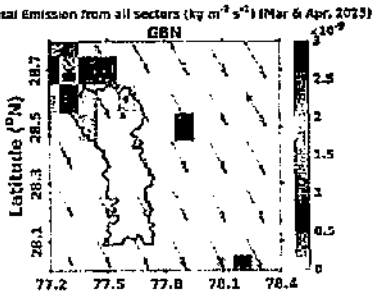
Next, we conducted another series of systematically designed WRF-Chem model simulations to determine the contribution of different sources to SO_2 and sulfate aerosols in Gautam Buddha Nagar, the first Category-3 city considered during Phase-I of our survey. Additionally, we aimed to understand the impact of the power sector on ambient atmospheric SO_2, PM2.5, and PM10 concentrations in Gautam Buddha Nagar during the survey period. We used WRF-Chem version 4.2.2 to perform a set of nine atmospheric chemistry simulations over Gautam Buddha Nagar from March 23 to April 22, 2023. The model domains are centered at Gautam Buddha Nagar (77.61° E and 28.34° N). Each simulation domain covers approximately 2,250,000 square kilometers with a horizontal resolution of 10x10 km^2, consisting of 150x150 grid cells in the outer domain, and a horizontal resolution of 3x3 km^2 with 136x136 grid cells in the inner domain, following a nested WRF-Chem modeling setup. The model features 44 vertical levels on a hybrid-sigma coordinate system, starting from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis data (available at 6-hour intervals) with a resolution of 0.25°x0.25° were used to provide meteorological initial and lateral boundary conditions for the simulations. To estimate the sectoral emission contributions to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Gautam Buddha Nagar, we employed an emission suppression method. We modified the emissions assuming that FGD was operational in only two units of the NTPC Dadri TPP during Phase I of our survey. We systematically designed the WRF-

Chem simulations so that emissions from a particular sector were switched off in each simulation. The details of the simulation setup are described in Table 3.2.

Chemical Transport Modeling for GBN

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh



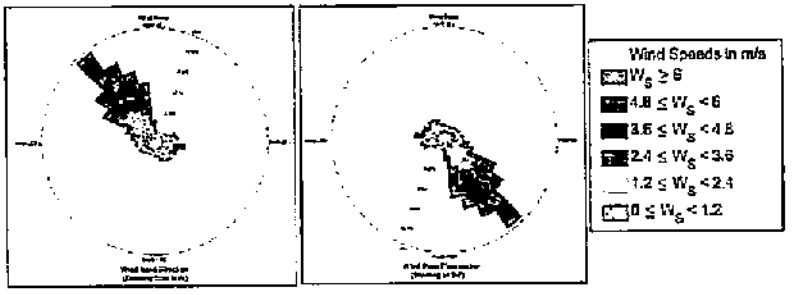


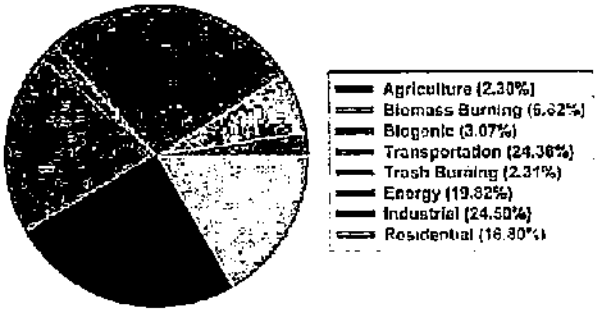
Figure 3.33: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Gautam Buddha Nagar during the simulation period from 23rd March to 22nd April 2023.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh

Phase I
Pre-monsoon Season

GBN SO_2 (15.49 ± 7.15 ug m^{-3})(23 Mar to 22 Apr, 2023)



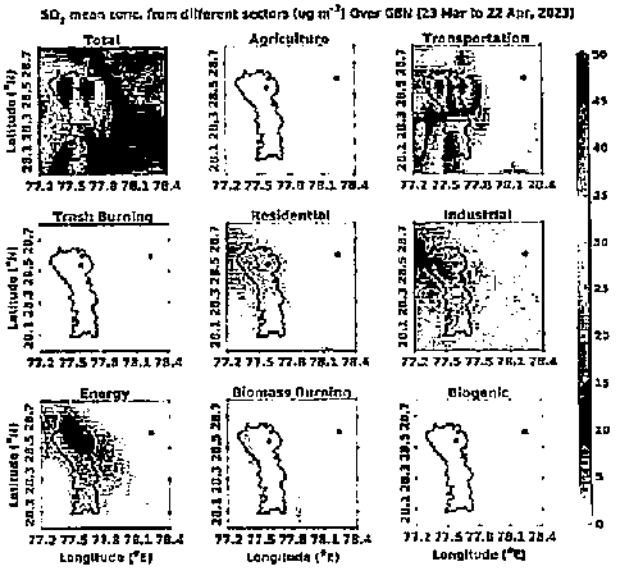


Figure 3.34: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in GBN during the simulation period from 23rd March to 22nd April 2023.

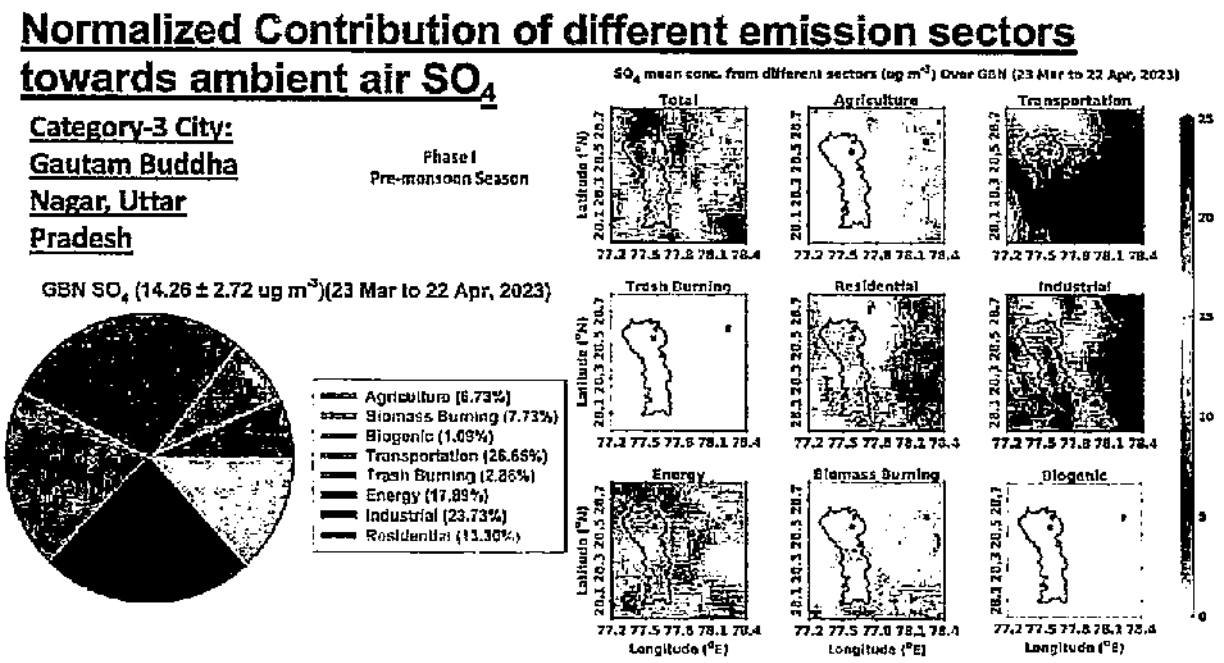


Figure 3.35: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in GBN during the simulation period from 23rd March to 22nd April 2023.

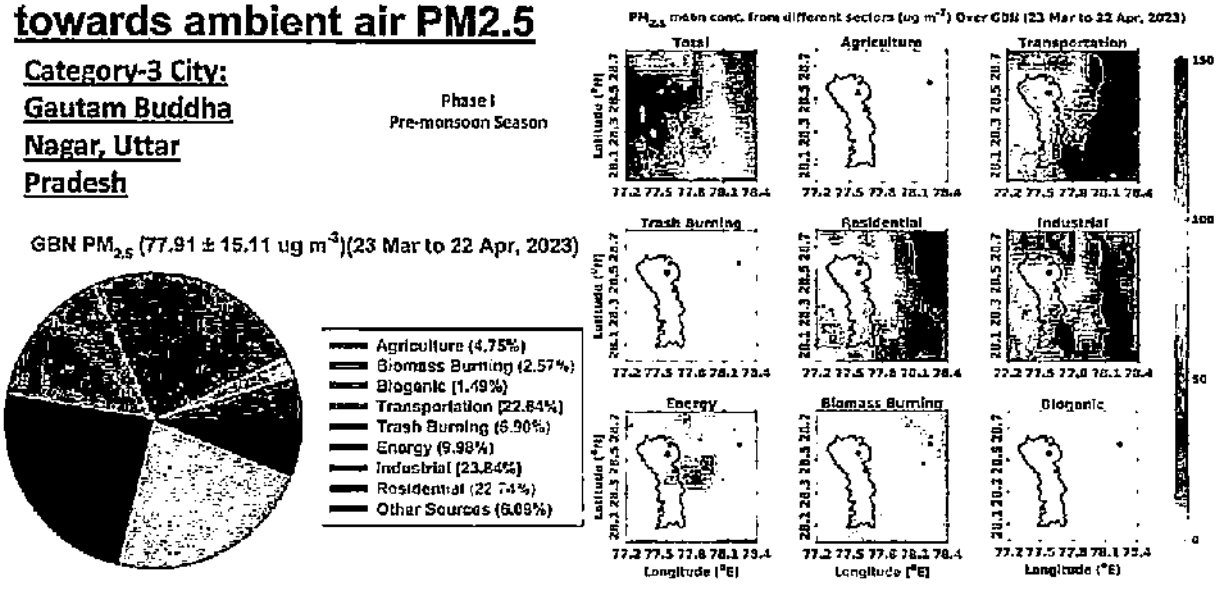


Figure 3.36: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in GBN during the simulation period from 23 March to 22 April 2023.

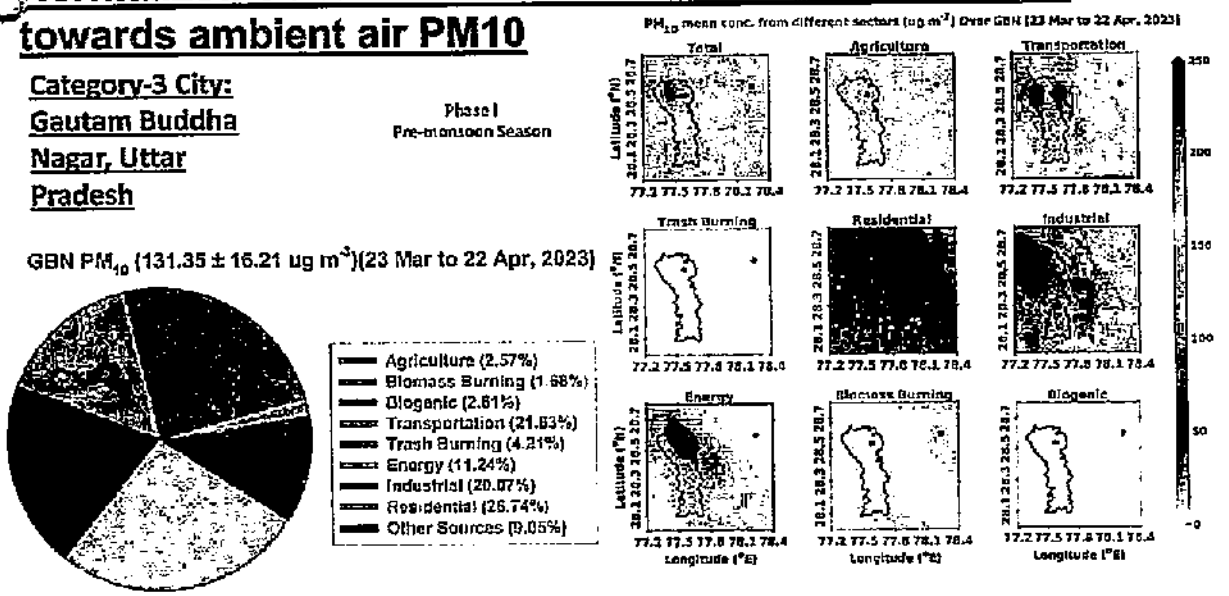


Figure 3.37: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 23rd March to 22nd April 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Gautam Buddha Nagar during the survey period.

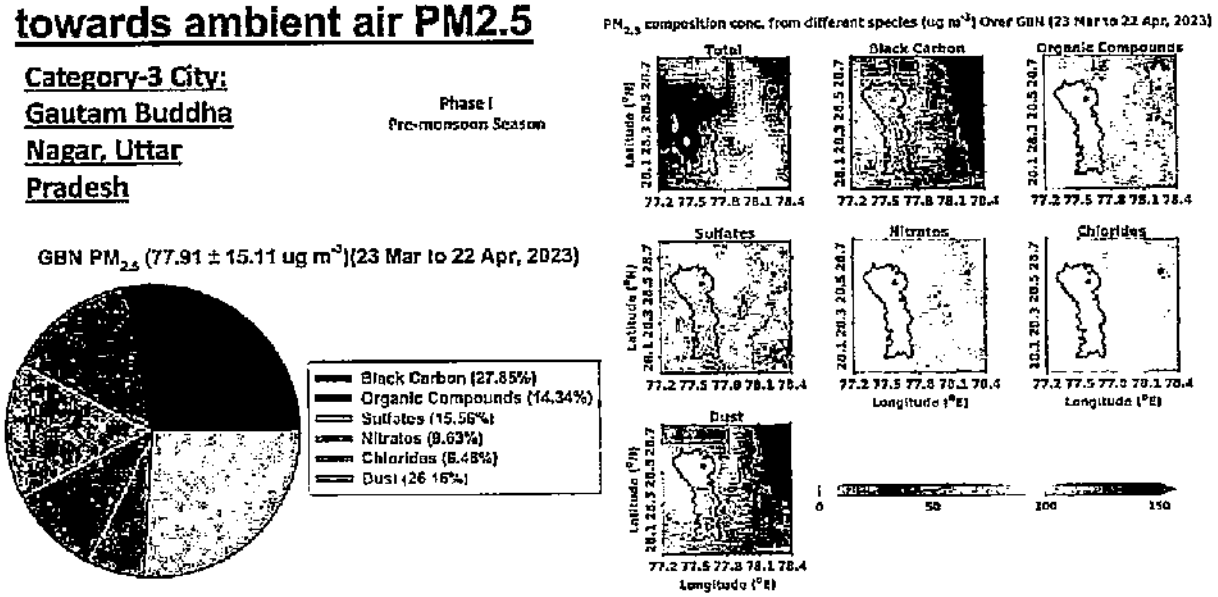


Figure 3.38: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in GBN during the simulation period from 23 March to 22 April 2023.

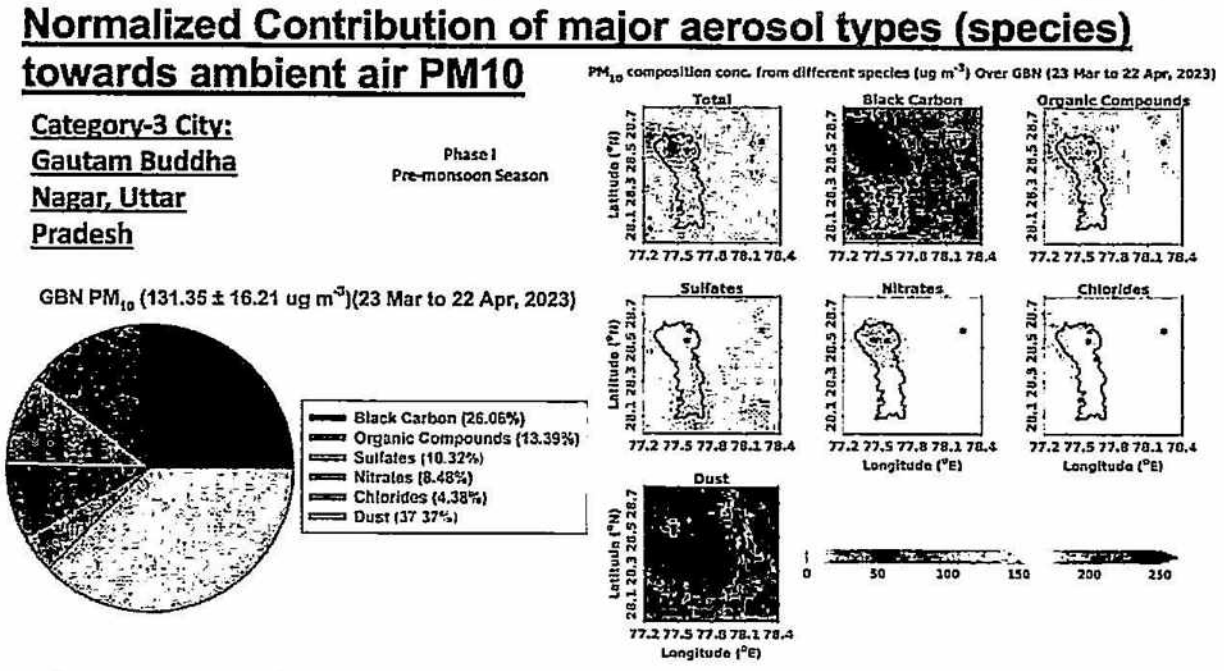


Figure 3.39: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 23rd March to 22nd April 2023.

By assessing the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of emissions from the energy sector, particularly SO_2 emissions from TPPs, we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 in the city of Gautam Buddha Nagar that originated from SO_2 emissions from TPPs during the survey period.

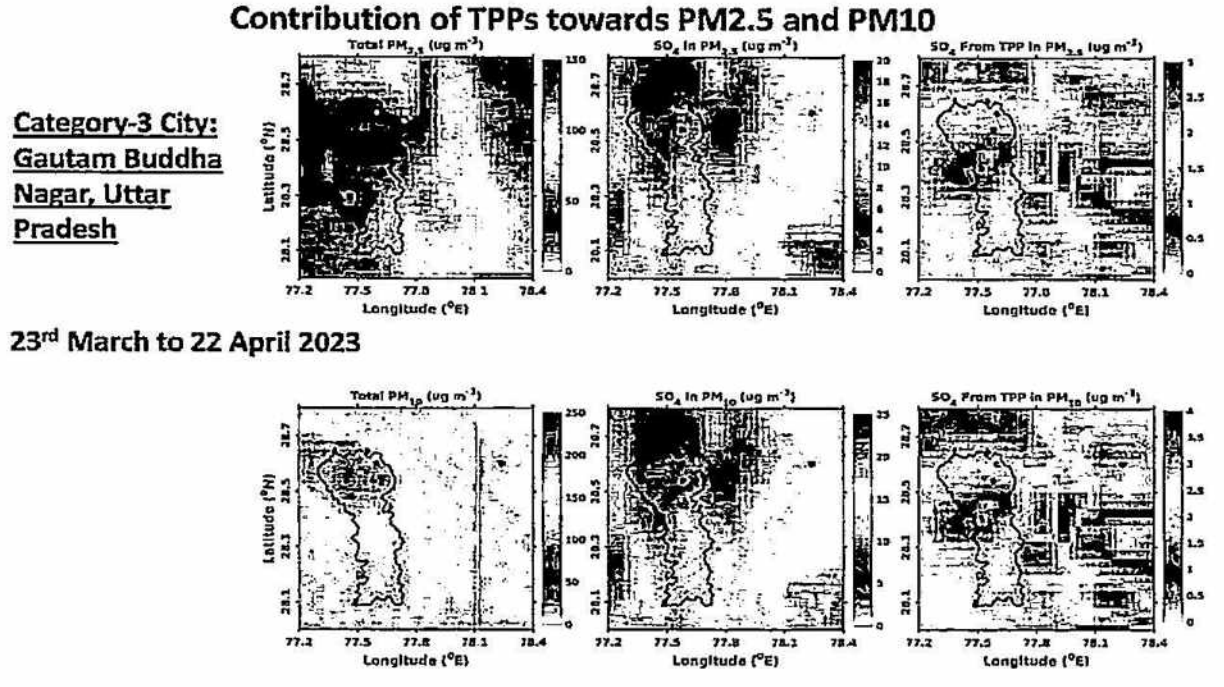


Figure 3.40: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in GBN during the simulation period from 23rd March to 22nd April 2023.

We conducted another series of systematically designed WRF-Chem model simulations to analyse the contribution of various sources to SO_2 and sulfate aerosols in Ghaziabad, the first Category-3 city in Phase-I of our survey. Additionally, we aimed to understand the influence of the power sector on ambient atmospheric SO_2, PM2.5, and PM10 concentrations in Ghaziabad during our survey. We utilized WRF-Chem version 4.2.2 to conduct a series of nine atmospheric chemistry simulations over Ghaziabad from March 23 to April 22, 2023. The model domains are centered at Ghaziabad (77.25° E and 28.40° N). Each simulation domain encompasses approximately 2,250,000 square kilometres with a horizontal resolution of 10x10 km^2, consisting of 150x150 grid cells in the outer domain, and a horizontal resolution of 3x3 km^2 with 136x136 grid cells in the inner domain following a nested WRF-Chem modeling setup. The model features 44 vertical levels on a hybrid-sigma coordinate system, extending from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis data (available at 6-hour intervals) with a resolution of 0.25°x0.25° were utilized to provide meteorological initial and lateral boundary conditions for the simulations. To estimate the sectoral emission contributions to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Ghaziabad, we implemented an emission suppression method. We modified the emissions assuming that FGD was operational in only two units of the NTPC Dadri TPP during Phase I of our survey. We conducted a series of systematically designed WRF-Chem model simulations by disabling emissions from a specific emission sector in each simulation. The simulation setup details are provided in Table 3.2.

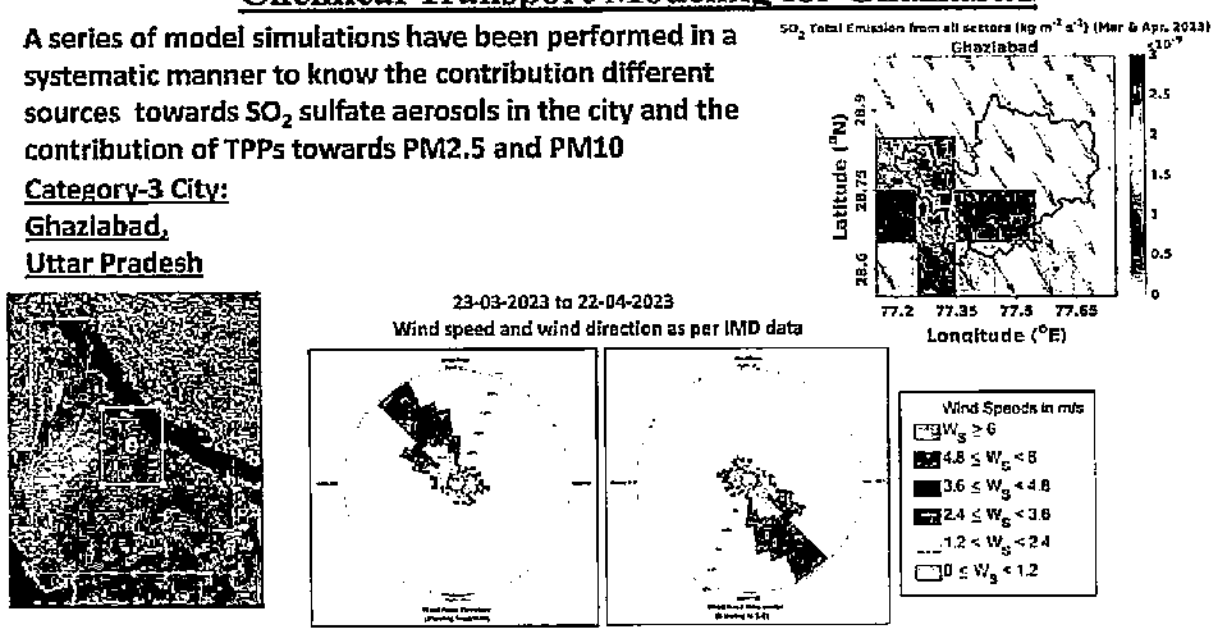


Figure 3.41: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

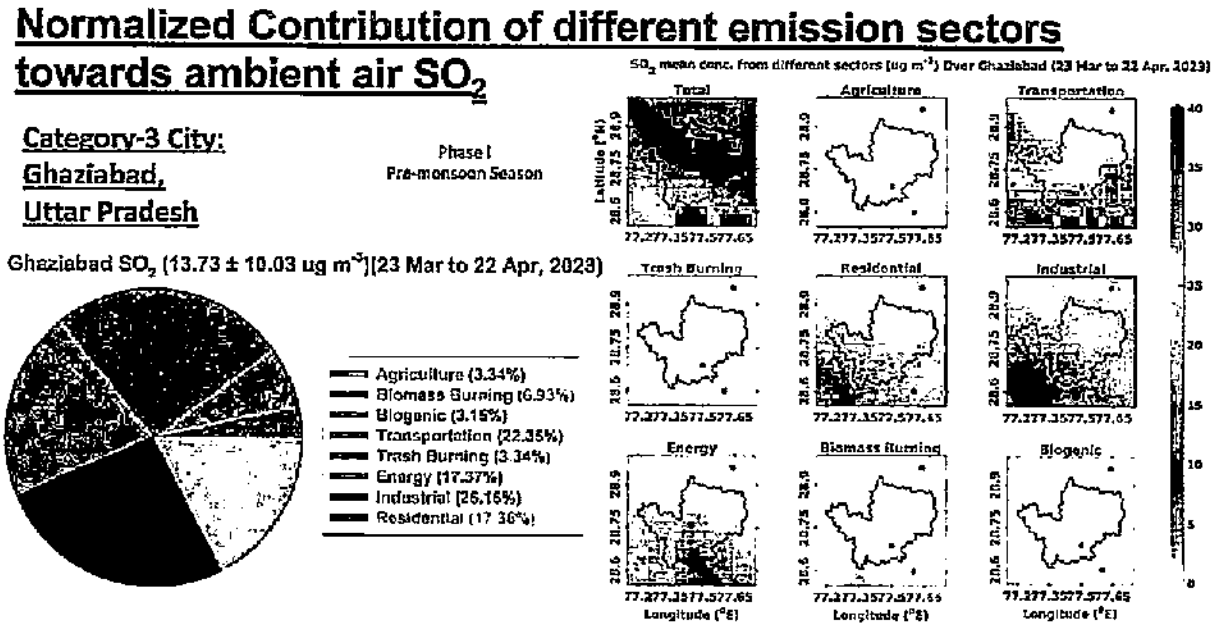


Figure 3.42: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

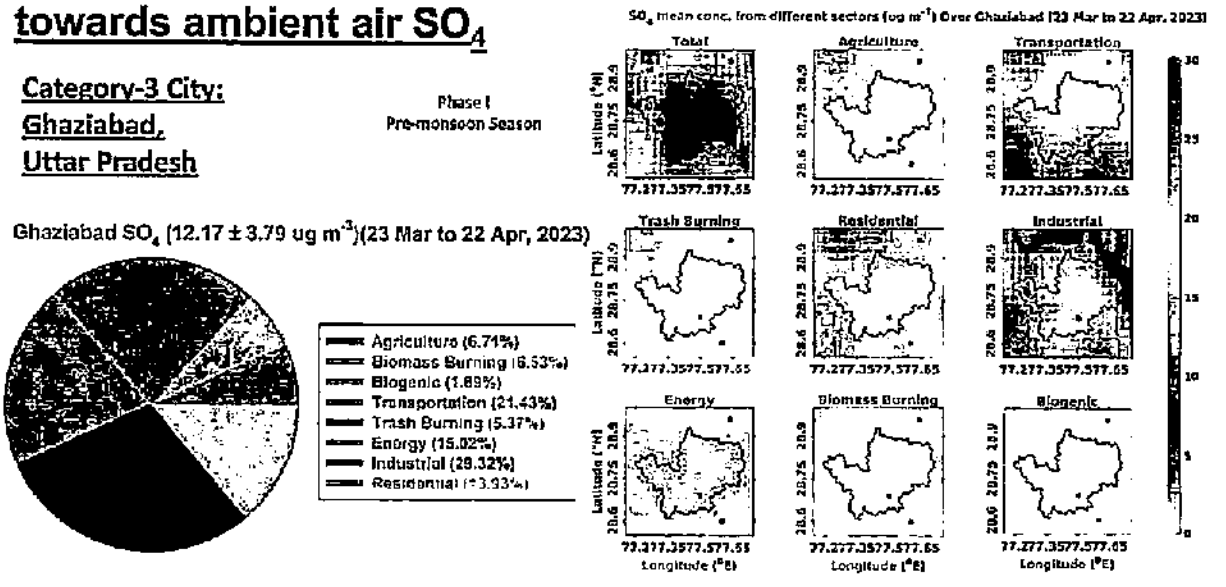


Figure 3.43: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

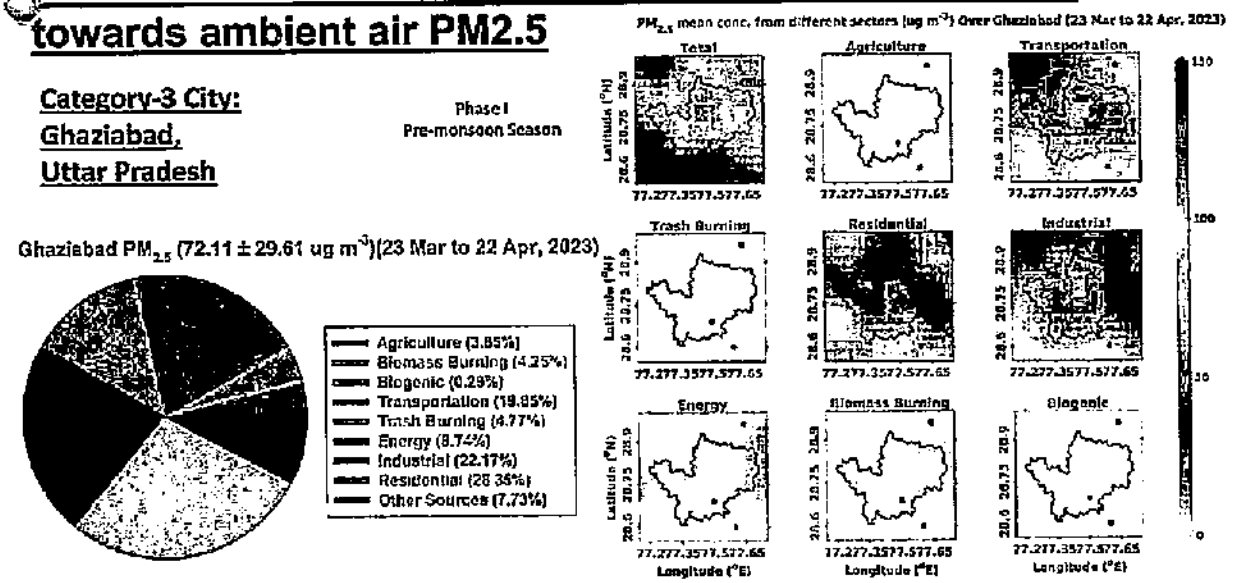


Figure 3.44: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

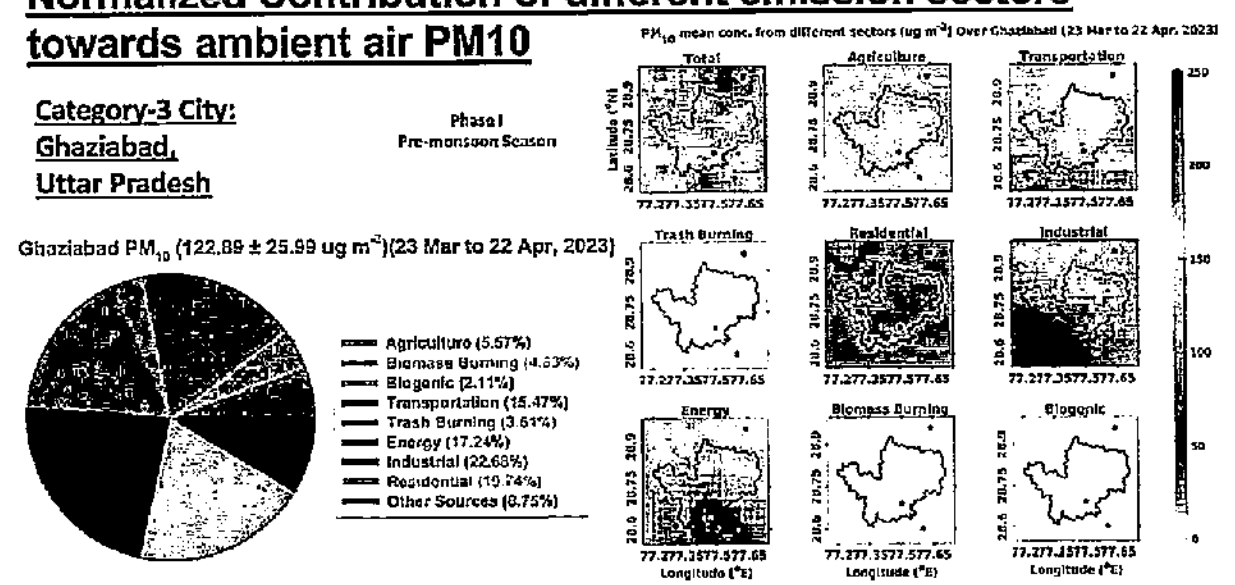


Figure 3.45: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Ghaziabad during the survey period.

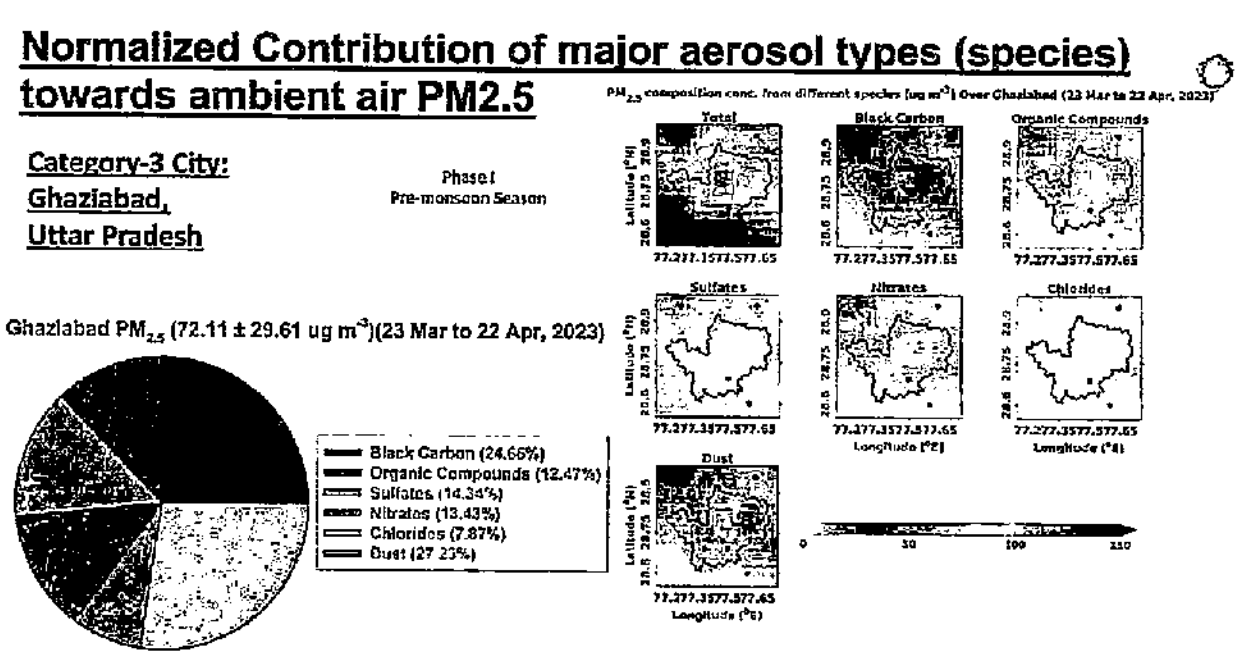


Figure 3.46: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

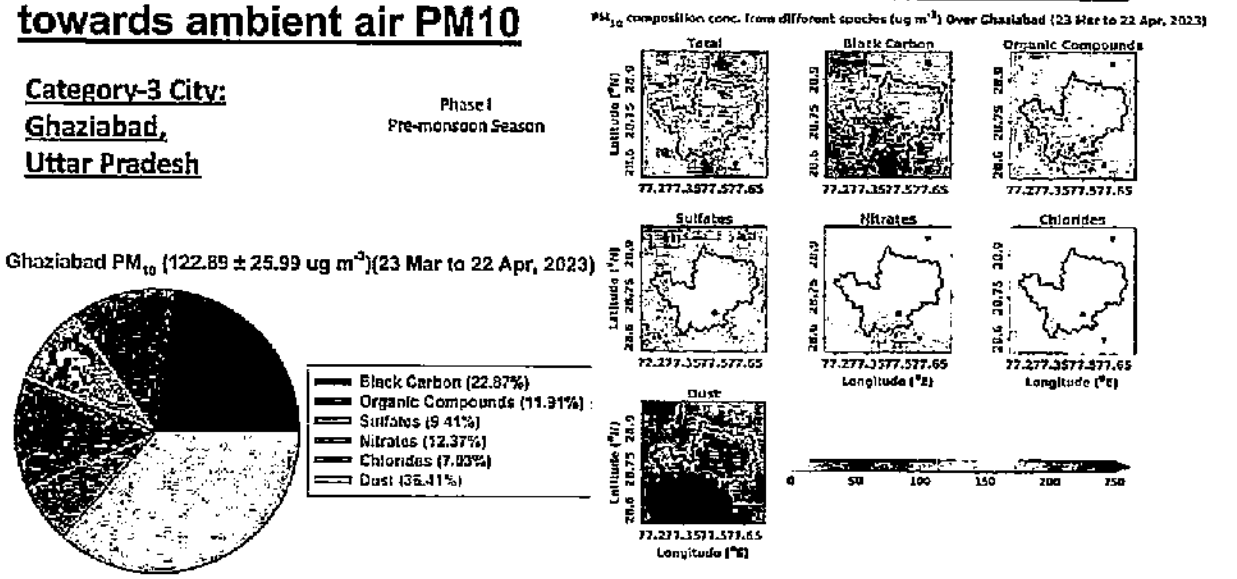


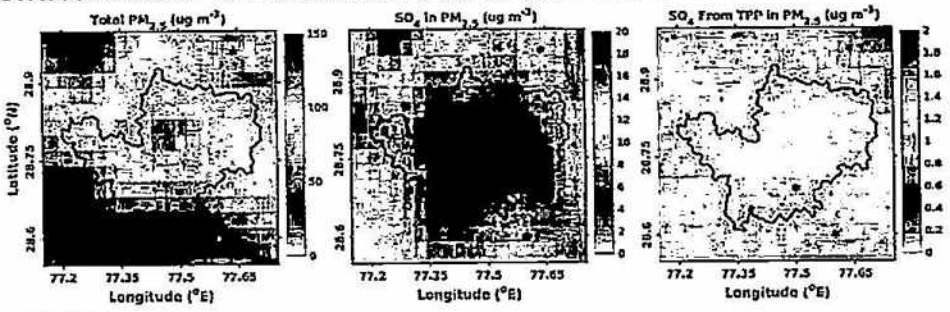
Figure 3.47: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

By assessing the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of emissions from the energy sector, particularly SO_2 emissions from TPPs,

we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the city of Ghaziabad during the survey period.

Contribution of TPPs towards PM2.5 and PM10

Category-3 City: Ghaziabad, Uttar Pradesh



23rd March to 22 April 2023

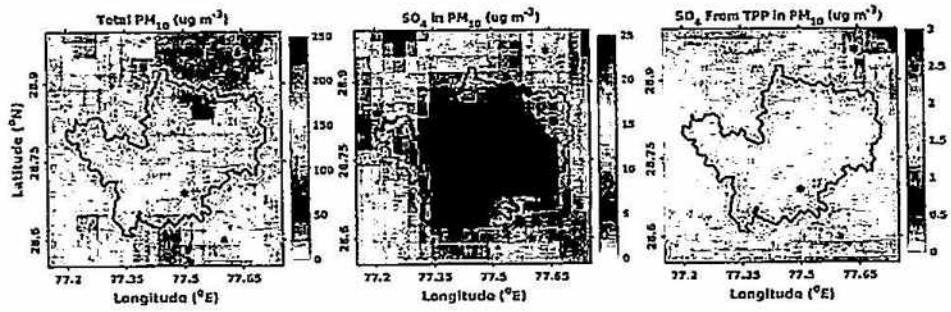


Figure 3.48: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Ghaziabad during the simulation period from 23rd March to 22nd April 2023.

Based on the results from a series of meticulously planned simulations, the contribution of SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric SO_2 concentrations during Phase I of the survey (Pre-monsoon season) exhibits significant spatial variability and distinct trends across all cities. Despite this variability, we analyse the average contribution of TPPs to ambient atmospheric SO_2 concentrations in each city and city category. In Category-1 cities, which have no coal-based TPPs, New Delhi and Hyderabad exhibit different contributions. In New Delhi, the power sector's contribution to ambient SO_2 concentrations is consistent at 16.53% across two survey periods. In Hyderabad, the power sector's contribution is lower, averaging 11.57%. In Category-2 cities, which have coal-based TPPs without installed FGD within 10 km of the city boundary, the average contribution of the power sector to ambient SO_2 concentrations is higher. Kolkata shows an average contribution of 28.66%, while Nagpur displays a slightly higher average contribution of 32.27%. In Category-3 cities, which have coal-based TPPs with installed FGD within 10 km of the city boundary, the contributions are lower than in Category-2 cities. In Ghaziabad, the average contribution from the power sector is 17.37%, while in Gautam Buddha Nagar, it is slightly higher at 19.82%. In summary, Category-2 cities, which have TPPs without FGD systems, exhibit the highest average contribution of TPPs to ambient SO_2 concentrations, followed by Category-3 cities, where TPPs have installed FGDs, and finally,

Category-1 cities, which have no coal-based TPPs. This pattern highlights the significant impact of TPPs, particularly those without FGDs, on the SO_2 levels in nearby cities.

After discussing the average contribution of TPPs to ambient atmospheric SO_2 concentrations in each city and city category, we examine the normalized contribution of the power sector, specifically coal-based thermal power plants (TPPs), to ambient atmospheric SO_2 concentrations at specific measurement locations across different cities during our survey period. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. Our survey results confirm that ambient air SO_2 concentrations at all measurement locations across the six cities met the existing standards during the survey period. Examining the variability in the normalized contribution of the power sector, specifically coal-based thermal power plants (TPPs), to ambient atmospheric SO_2 concentrations reveals significant differences across various cities and city categories during our survey period. In Category-1 cities with no coal-based TPPs, the contribution of the power sector to ambient SO_2 concentrations is relatively low, ranging from 9% to 19%. For instance, New Delhi locations show SO_2 contributions of 18% and 19%, with absolute concentrations of 1.67 ± 0.93 $\mu g/m^3$ and 1.37 ± 0.61 $\mu g/m^3$, respectively. Hyderabad locations report contributions of 9% and 15%, with absolute concentrations of 0.42 ± 0.07 $\mu g/m^3$ and 0.37 ± 0.03 $\mu g/m^3$, respectively. In Category-2 cities, where TPPs without FGD installations are located within 10 km from the city boundary, the contributions are markedly higher. For instance, Kolkata locations show contributions of 23% and 25%, with absolute concentrations of 1.49 ± 0.09 $\mu g/m^3$ and 1.08 ± 0.03 $\mu g/m^3$, respectively, while Nagpur locations report even higher contributions of 39% and 22%, with absolute concentrations of 2.37 ± 0.31 $\mu g/m^3$ and 0.78 ± 0.17 $\mu g/m^3$, respectively. This indicates the significant impact of nearby TPPs without FGD systems on local air quality. Category-3 cities, with TPPs having FGD installations within 10 km, exhibit varied contributions. Ghaziabad locations show contributions of 33% and 13%, with absolute concentrations of 2.81 ± 0.72 $\mu g/m^3$ and 1.03 ± 0.47 $\mu g/m^3$, respectively, while Gautam Buddha Nagar locations have contributions of 26% and 17%, with absolute concentrations of 2.56 ± 0.62 $\mu g/m^3$ and 1.41 ± 0.43 $\mu g/m^3$, respectively. These findings highlight that the presence and proximity of TPPs, along with the implementation of FGD systems, play crucial roles in determining the extent of SO_2 emissions from the power sector, thereby influencing local air quality.

Table 3.5 summarizes the contribution of sulfate aerosols (SO_4) in PM2.5 and PM10, as well as the specific contribution of sulfate aerosols originating from SO_2 emissions from the power sector (coal based TPPs) to ambient atmospheric PM2.5 and PM10 concentrations across various cities during the Phase I survey period from March to April 2023.

	Name of City (Measurement Site, distance from TPP)	Period of Survey	Total SO_2 ($\mu g\ m^{-3}$)	SO_2 from Power Sector ($\mu g\ m^{-3}$)
Category-1	New Delhi Location-1	12-02-2023 to 14-03-2023	9.26 ± 3.28	1.67 ± 0.93
	New Delhi Location-2	23-03-2023 to 22-04-2023	7.22 ± 2.73	1.37 ± 0.61
	Hyderabad Location-1	23-03-2023 to 22-04-2023	4.65 ± 0.55	0.42 ± 0.07
	Hyderabad Location-2	29-04-2023 to 29-05-2023	2.48 ± 0.49	0.37 ± 0.03
Category-2	Kolkata Location-1 15 Km from SOUTHERN TPS	12-02-2023 to 14-03-2023 (One month)	6.48 ± 3.08	1.49 ± 0.09
	Kolkata Location-2 51 Km from SOUTHERN TPS	23-03-2023 to 22-04-2023 (One month)	4.32 ± 1.51	1.08 ± 0.03
	Nagpur Location-1 15 Km from KHAPARKHEDA TPS	23-03-2023 to 22-04-2023 (One month)	6.07 ± 2.83	2.37 ± 0.31
	Nagpur Location-2 57 Km from KHAPARKHEDA TPS	29-04-2023 to 29-05-2023 (One month)	3.55 ± 0.53	0.78 ± 0.17
Category-3	Ghaziabad Location-1 13 Km from DADRI TPP	23-03-2023 to 22-04-2023 (One month)	8.51 ± 2.56	2.81 ± 0.72
	Ghaziabad Location-2 42 Km from DADRI TPP	29-04-2023 to 29-05-2023 (One month)	7.87 ± 1.89	1.03 ± 0.47
	Gautam Buddha Nagar Location-1 10 Km from DADRI TPP	23-03-2023 to 22-04-2023 (One month)	9.36 ± 2.12	2.56 ± 0.62
	Gautam Buddha Nagar Location-2 53 Km from DADRI TPP	29-04-2023 to 29-05-2023 (One month)	8.31 ± 2.03	1.41 ± 0.43

Table 3.4: Normalized contribution of Power sector towards ambient atmospheric SO_2 concentrations at specific measurement locations in various cities during the period of our survey from 23rd March to 22nd April 2023.

Summary of results during Phase-I (March to April 2023)

City	Total PM2.5 ($\mu g\ m^{-3}$)	Total PM10 ($\mu g\ m^{-3}$)	Sulfate aerosol contribution in PM2.5 (%)	Sulfate aerosol in PM2.5 ($\mu g\ m^{-3}$)	Sulfate aerosol in PM10 (%)	Sulfate aerosol in PM10 ($\mu g\ m^{-3}$)	Contribution of SO_2 pollution from TPP towards Sulfate aerosol in PM2.5 (%)	Sulfate aerosol in PM2.5 contributed from SO_2 emissions from TPPs ($\mu g\ m^{-3}$)	Sulfate aerosol in PM10 contributed from SO_2 emissions from TPPs ($\mu g\ m^{-3}$)	Sulfate aerosol in PM2.5 contributed from SO_2 emissions from TPPs ($\mu g\ m^{-3}$)	Sulfate aerosol in PM10 contributed from SO_2 emissions from TPPs ($\mu g\ m^{-3}$)
Delhi	79.75 ± 19.04	137.56 ± 23.77	15.15	12.09 ± 2.73	9.82	13.51 ± 1.71	15.85	1.92 ± 0.51	2.25 ± 0.72	2.41 ± 0.81	1.64 ± 0.39
Hyderabad	45.23 ± 4.12	85.18 ± 6.54	13.85	6.26 ± 0.57	8.22	7.00 ± 0.54	6.96	0.44 ± 0.04	0.49 ± 0.04	0.96 ± 0.09	0.57 ± 0.04
Nagpur	62.53 ± 6.05	93.71 ± 6.58	14.16	8.85 ± 0.86	11.83	9.90 ± 0.78	22.32	1.98 ± 0.19	2.21 ± 0.17	3.16 ± 0.31	2.64 ± 0.21
Kolkata	31.53 ± 7.75	52.89 ± 6.98	22.32	7.04 ± 1.73	14.97	7.86 ± 1.04	24.53	1.73 ± 0.42	1.93 ± 0.25	5.48 ± 1.35	3.65 ± 0.48
Gautam Buddha Nagar	77.91 ± 11.81	131.35 ± 16.21	15.56	12.12 ± 2.12	10.32	13.55 ± 2.31	17.89	2.17 ± 0.55	2.55 ± 0.56	2.78 ± 0.63	1.94 ± 0.26
Ghaziabad	72.11 ± 22.39	122.89 ± 17.69	14.34	10.34 ± 3.11	9.41	11.56 ± 2.37	15.02	1.55 ± 0.43	1.83 ± 0.46	2.15 ± 0.78	1.49 ± 0.35

Table 3.5: Contribution of Power sector towards ambient atmospheric sulfate aerosols, PM2.5 and PM10 concentrations in various cities during Phase I from 23 March to 22 April 2023.

In Category-1 cities like Delhi, sulfate aerosols contributed 15.15% (12.09 $\mu g/m^3$) to PM2.5 and 9.82% (13.51 $\mu g/m^3$) to PM10. In Hyderabad, sulfate aerosols contributed 13.85% (6.26 $\mu g/m^3$)

to PM2.5 and 8.22% (7.00 μg/m³) to PM10. For Category-1 cities, the average contribution of sulfate aerosols in PM2.5 was 14.50% (9.18 μg/m³) and in PM10, it was 9.02% (10.26 μg/m³). In Category-2 cities such as Nagpur, sulfate aerosols contributed 14.16% (8.85 μg/m³) to PM2.5 and 11.83% (9.90 μg/m³) to PM10, whereas in Kolkata, the contributions were higher at 22.32% (7.04 μg/m³) to PM2.5 and 14.87% (7.86 μg/m³) to PM10. For Category-2 cities, the average contribution of sulfate aerosols in PM2.5 was 18.24% (7.95 μg/m³) and in PM10, it was 13.35% (8.88 μg/m³). For Category-3 cities like Gautam Buddha Nagar, sulfate aerosols contributed 15.56% (12.12 μg/m³) to PM2.5 and 10.32% (13.55 μg/m³) to PM10, while in Ghaziabad, the contributions were 14.34% (10.34 μg/m³) to PM2.5 and 9.41% (11.56 μg/m³) to PM10. For Category-3 cities, the average contribution of sulfate aerosols in PM2.5 was 14.95% (11.23 μg/m³) and in PM10, it was 9.87% (12.56 μg/m³). Thus our study indicate a significant presence of sulfate aerosols in particulate matter across all city categories, with Category-2 cities showing the highest average contributions.

During the Phase-I survey, we also estimated the contribution of SO_2 emissions from the energy sector, specifically coal-based thermal power plants (TPPs), to the total ambient air SO_4 (sulfate aerosol) concentration and found that it varied significantly across different cities and city categories. In Category-1 cities (Delhi and Hyderabad), which do not have any coal-based TPPs, the contribution of the energy sector to ambient SO_4 levels was relatively low. Delhi exhibited a higher contribution at 15.85% (2.25 μg/m³), while Hyderabad had a much lower contribution of 6.96% (0.51 μg/m³). On average, Category-1 cities showed an energy sector contribution of 11.41% (1.38 μg/m³) to ambient SO_4 concentrations. In Category-2 cities (Nagpur and Kolkata), which are located near coal-based TPPs without flue-gas desulfurization (FGD) systems, the contributions were notably higher. Nagpur showed a contribution of 22.32% (2.33 μg/m³), and Kolkata had an even higher contribution of 24.53% (2.03 μg/m³). The average contribution of the energy sector in Category-2 cities was 23.43% (2.18 μg/m³). In Category-3 cities (Gautam Buddha Nagar and Ghaziabad), which are near coal-based TPPs with FGD systems, the contributions were significant but varied. Gautam Buddha Nagar had a contribution of 17.89% (2.55 μg/m³), and Ghaziabad showed a contribution of 15.02% (1.83 μg/m³). On average, the energy sector contributed 16.46% (2.19 μg/m³) to ambient SO_4 concentrations in Category-3 cities. Overall, the contribution of SO_2 emissions from coal-based TPPs to ambient SO_4 concentrations was higher in Category-2 cities, with an average contribution of 23.43% (2.18 μg/m³), compared to 16.46% (2.19 μg/m³) in Category-3 cities and 11.41% (1.38 μg/m³) in Category-1 cities. This indicates a significant impact of coal-based TPP emissions on sulfate aerosol levels, particularly in cities near TPPs without FGD systems.

The specific contribution of sulfate aerosols originating from SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric PM2.5 and PM10 concentrations also varied across different cities and city categories. In Delhi, the contribution was 2.41% (1.92

µg/m³) in PM2.5 and 1.64% (2.25 µg/m³) in PM10. In Hyderabad, the contributions were lower at 0.96% (0.44 µg/m³) in PM2.5 and 0.57% (0.49 µg/m³) in PM10. For Category-1 cities, the average contribution to PM2.5 was 1.69% (1.18 µg/m³) and to PM10, it was 1.11% (1.37 µg/m³). Nagpur had contributions of 3.16% (1.98 µg/m³) in PM2.5 and 2.64% (2.21 µg/m³) in PM10, while Kolkata had 5.48% (1.73 µg/m³) in PM2.5 and 3.65% (1.93 µg/m³) in PM10. For Category-2 cities, the average contribution to PM2.5 was 4.32% (1.86 µg/m³) and to PM10, it was 3.15% (2.07 µg/m³). In Gautam Buddha Nagar, the contributions were 2.78% (2.17 µg/m³) in PM2.5 and 1.94% (2.55 µg/m³) in PM10, whereas in Ghaziabad, they were 2.15% (1.55 µg/m³) in PM2.5 and 1.49% (1.83 µg/m³) in PM10. For Category-3 cities, the average contribution to PM2.5 was 2.47% (1.86 µg/m³) and to PM10, it was 1.72% (2.19 µg/m³). These figures indicate that SO_2 emissions from TPPs contribute a measurable but relatively small portion of sulfate aerosols in PM2.5 and PM10, with Category-2 cities experiencing the highest average contributions.

Overall, the contribution of SO_2 emissions from the power sector, which convert to sulfate aerosols, ranged from 0.96% to 5.48% in PM2.5 and from 0.57% to 3.65% in PM10 across the cities during Phase I of the survey. This indicates variability in the impact of power sector emissions on sulfate aerosol concentrations. While SO_2 emissions from TPPs do contribute to sulfate aerosol mass concentrations in PM2.5 and PM10, their overall contribution remains a small fraction (less than 6%) of the total PM2.5 and PM10 mass concentrations across various city categories, especially during the spring and pre-monsoon season, indicating that other sources are more significant contributors to ambient air PM levels.

CHAPTER-4: SURVEY OF AMBIENT ATMOSPHERIC SO_2 CONCENTRATIONS IN DIFFERENT CATEGORY OF CITIES: PHASE-II

In the first phase of this survey, measurements were conducted in six distinct cities: New Delhi, Kolkata, Ghaziabad, Gautam Buddha Nagar, Nagpur, and Hyderabad, with two cities from each category. Measurements were carried out at two separate locations within each city for a duration of one month. This survey yielded valuable data for understanding the baseline levels and variations in ambient atmospheric SO_2 concentrations across these cities. However, to enhance the robustness of our findings with statistically significant data, we decided to conduct simultaneous measurements at two different locations within each city, extend the survey to other seasons, and include additional cities. This expansion involved simultaneous measurements of SO_2 concentrations at two different locations in all three categories of cities during another season. Conducting simultaneous measurements from different locations allow us to compare ambient air SO_2 concentration values at varying distances from coal-based thermal power plants (TPPs) in Category-2 and Category-3 cities. Furthermore, this approach allowed us to assess the concentrations measured during the survey against the National Ambient Air Quality Standards (NAAQS) established by the Central Pollution Control Board (CPCB) to determine whether they complied with these standards. Thus, the second phase of the survey was undertaken with the objective of simultaneously measuring ambient atmospheric SO_2 concentrations at two different locations in all three categories of cities during another season.

Cities across the country were classified into three categories based on their proximity to coal-based thermal power plants (TPPs) and the implementation status of Flue Gas Desulfurization (FGD) systems in these TPPs. As mentioned earlier in Chapter-2, these categories are:

Category-1: Cities with no coal based TPP.
Category-2: Cities with a coal based TPP in which FGD has not been installed and the TPP is located within 10km from the boundary of the city.
Category-3: Cities with a coal based TPP in which FGD has been installed and the TPP is located within a distance of 10km from the boundary of the city.
The second phase of the survey started on 15th July 2023 and ended on 14th August 2023.

Cities and Measurement Sites Selected for Phase-II of the Survey

During Phase-II, we conducted the measurement-based survey in the following three cities corresponding to three different city categories.

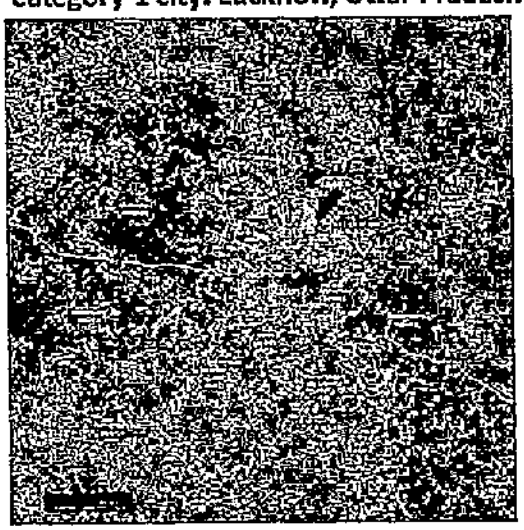
Table 4.1: Cities selected for conducting the survey Phase-II

S. No.	City Name	City Category	Capacity of TPP	No. of Units	Population of the city
1	Lucknow	Category-1	-	-	4589838
2	Kota	Category-2	1240 MW	7	1951014
3	Gautam Buddha Nagar	Category-3	1820 MW	6	1648115

It is important to note that all the cities selected for our survey are classified as "non-attainment cities with million-plus populations" by the Central Pollution Control Board (CPCB). In each city, we conducted the survey by measuring ambient air SO2 concentrations at two different locations for a period of one month at each site. For cities with TPPs in their vicinity, the survey was designed so that one measurement site was close to the TPP (approximately 1-10 km away), while the second site was located about 40-60 km from the TPP.

Identification of Measurement sites in each city

Category-1 city: Lucknow, Uttar Pradesh



Sampling height: 20m above ground

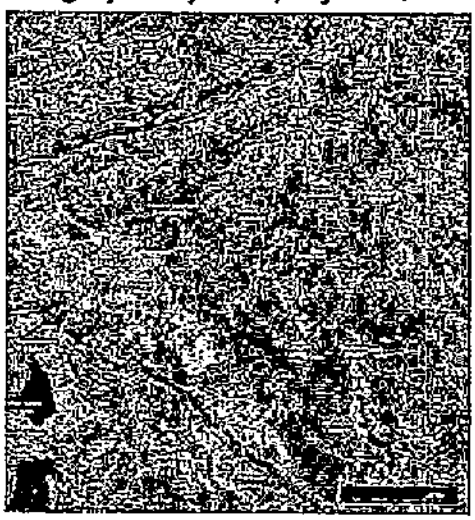
Location 1	Amity University Lucknow Campus, Malhaur (Near Railway Station), Gomti Nagar Extension, Lucknow, Uttar Pradesh 226028, India.
Location 2	Babasaheb Bhimrao Ambedkar University, Vidya Vihar, Raebareli Road, Lucknow, Uttar Pradesh 226025, India.

Distance between Location-1 and Location-2 is 18 Km

Figure 4.1: Satellite image (google earth) showing location of the measurement sites for Category-1 city Lucknow considered during Phase-II of the survey

Identification of Measurement sites in each city

Category-2 City: Kota, Rajasthan



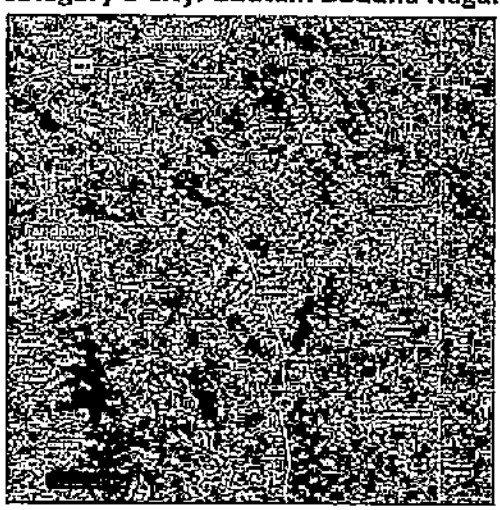
Sampling height: 20m above ground

KOTA Super TPP	TPP Developer: Rajasthan Rajya Vidyut Utpadan Nigam.
Location 1	University of Kota, Kota city, Rajasthan (6 Km from Kota Super TPP)
Location 2	Government ITI college Sultanpur, Kota, Rajasthan (40 Km from Kota Super TPP)

Figure 4.2: Satellite image (google earth) showing location of the measurement sites for Category-2 city Kota considered during Phase-II of the survey

Identification of Measurement sites in each city

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh



Sampling height: 20m above ground

NTPC DADRI TPP	Developer: NTPC
Location 1	Shiv Nadar University 9 Km from NTPC DADRI TPP
Location 2	Maharaja Agrasen Polytechnic College 46 Km from NTPC DADRI TPP

Figure 4.3: Satellite image (google earth) showing location of the measurement sites for Category-3 city Gautam Buddha Nagar considered during Phase-II of the survey

Measurement Plan for Phase-II of the Survey

We conducted simultaneous measurements at two pre-identified locations in each of the three cities to avoid biases in our SO2 concentration data due to seasonal variations in temperature,

wind, relative humidity, and other meteorological factors that influence the transport, removal, and lifetime of SO2 in the atmosphere. Measurements in all three cities were conducted during the same period.

Continuous measurements were taken every 10 minutes at two different locations in each city for at least 30 days during the survey period. It was crucial to perform simultaneous measurements across the six different locations in the three cities within the same month or season to ensure that our data accurately represented SO2 concentrations for that specific season. This approach eliminated any potential bias due to seasonal variability in meteorological conditions.

In total, we collected at least 4320 air samples at each location, resulting in a minimum of 8640 samples per city. Therefore, ambient SO2 concentrations in three different cities were surveyed during Phase II of our study.

Measurement technique and equipment involved:
We used the same equipment and followed the same measurement techniques as described in Chapter 2; therefore, those details are not repeated here.

Measurement data from Phase-II of the Survey

This section presents the results of the measurements conducted in various category cities across the country during Phase II of our survey. In this phase, measurements commenced simultaneously at all locations across three cities on July 15, 2023, and concluded on August 14, 2023. Table 4.2 summarizes the maximum instantaneous, minimum instantaneous, and daily mean values of ambient air SO2 concentrations measured at two different locations in each of the three category cities selected for Phase II of our survey during the summer monsoon season. In the Category 1 city of Lucknow, the maximum instantaneous ambient air SO_2 concentration was 11.92 $\mu g/m^3$, the minimum was 2.83 $\mu g/m^3$, and the daily mean values ranged from 5.62 ± 1.14 $\mu g/m^3$ to 5.95 ± 1.56 $\mu g/m^3$. In the Category 2 city of Kota, the maximum ambient air SO_2 concentration was 18.65 $\mu g/m^3$, the minimum was 0.75 $\mu g/m^3$, and the daily mean values ranged from 3.12 ± 0.81 $\mu g/m^3$ to 5.15 ± 1.75 $\mu g/m^3$. In the Category 3 city of Gautam Buddha Nagar, the maximum instantaneous ambient air SO_2 concentration was 16.61 $\mu g/m^3$, the minimum was 1.45 $\mu g/m^3$, and the daily mean values ranged from 5.89 ± 1.65 $\mu g/m^3$ to 6.15 ± 2.56 $\mu g/m^3$. Summarizing by city categories, Category 1 cities had maximum instantaneous ambient air SO_2 concentrations of up to 11.92 $\mu g/m^3$ and minimum concentrations down to 2.83 $\mu g/m^3$, with daily mean values ranging from 5.62 to 5.95 $\mu g/m^3$. Category 2 cities had maximum concentrations of up to 18.65 $\mu g/m^3$ and minimum concentrations down to 0.75 $\mu g/m^3$, with daily mean values ranging from 3.12 to 5.15 $\mu g/m^3$. Category 3 cities had maximum concentrations of up to 16.61 $\mu g/m^3$ and minimum concentrations down to 1.45 $\mu g/m^3$, with

daily mean values ranging from 5.89 to 6.15 μg/m³. Thus our survey results highlight the variability in ambient air SO_2 concentrations across different locations and city categories, with Category 2 and Category 3 cities generally showing higher SO_2 levels. As the National Ambient Air Quality Standards (NAAQS) or the maximum permissible limit of ambient air SO_2 concentrations based on 24 hours average measurements for industrial, residential, rural, and other areas as notified by the MoEF&CC, Govt. of India is 80 μg/m³, results of our survey confirm that the ambient air SO_2 concentrations in all cities are meeting the existing standards during the period of our survey.

As evident from Table 4.2, the daily mean values of ambient air SO_2 concentrations measured at various locations in all three cities during Phase II of our survey are comparable to the SO_2 data from the CPCB/SPCB/PCC measurement sites in those cities (https://cpcb.nic.in/air-pollution/), thereby validating the robustness of our collected data.

Summary of survey results from Phase-II

Name of City (Nearest Coal-based Thermal Power Plant)	Data Analysis Duration	This Study SO₂ Concentration (μg/m³)			CPCB/SPCB/PCC Measurements (μg/m³)
		Maximum (Instantaneous)	Minimum (Instantaneous)	Daily Mean ± 1σ (NAAQS = 80 μg/m³)	
Lucknow Location-1	15-07-2023 to 14-08-2023	10.86	3.79	5.62 ± 1.14	3.21 ± 1.03
Lucknow Location-2		11.92	2.83	5.95 ± 1.56	
Kota Location-1 7 Km from Kota Super TPP		18.65	0.95	5.15 ± 1.75	4.48 ± 1.17
Kota Location-2 40 Km from Kota Super TPP		9.74	0.75	3.12 ± 0.81	
Gautam Buddha Nagar Location-1 9 Km from DADRI TPP		16.61	1.45	6.15 ± 2.56	5.74 ± 0.91
Gautam Buddha Nagar Location-2 46 Km from DADRI TPP		12.51	2.65	5.89 ± 1.65	

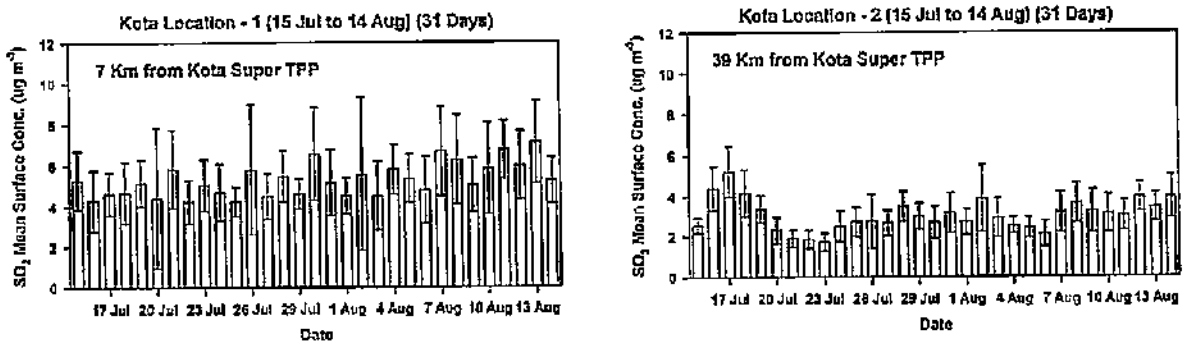
Table 4.2: Daily mean, maximum, and minimum values of ambient air SO_2 concentration (μg/m³) measured at two different locations of three different cities classified under three different categories from across the country during Phase-II of our survey are listed here. SO_2 concentrations data from CPCB/SPCB measurements sites from each city are also mentioned.

Next, we discuss the findings from our survey in the Category-2 city of Kota, which has a coal-based TPP without an installed FGD in more detail. Figure 4.4 presents the time series of daily mean ambient air SO_2 concentrations (μg/m³) measured on various days at two different sites in Kota. Figure 4.5 shows the diurnal variation of ambient air SO_2 concentrations (μg/m³) recorded at these sites on different days. Both figures illustrate significant diurnal variations and notable intra-day fluctuations in ambient air SO_2 concentrations at both measurement locations in Kota. The maximum instantaneous values of ambient air SO_2 concentrations recorded at Location 1 and Location 2 in Kota during Phase II were 18.65 μg/m³ and 9.74 μg/m³, respectively. The

minimum instantaneous values of ambient air SO_2 concentrations recorded at Location 1 and Location 2 in Kota during Phase I were 0.95 µg/m³ and 0.75 µg/m³, respectively. The monthly average daily mean values of ambient air SO_2 concentrations at Location 1 and Location 2 in Kota during Phase II were 5.15 ± 1.75 µg/m³ and 3.12 ± 0.81 µg/m³, respectively.

According to the National Ambient Air Quality Standards (NAAQS), the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas, as notified by the MoEF&CC, Government of India, is 80 µg/m³. The results of our survey confirm that the ambient air SO_2 concentrations in Kota were within the permissible limits during the period of our survey.

Time series of daily mean ambient air concentration of SO_2 (µg/m³) measured in Kota



National Ambient Air Quality Standards (NAAQS)
[NAAQS Notification dated 18th November, 2009]

S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (notified by Central Government)	
1	Sulphur Dioxide (SO_2), µg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

Figure 4.4: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (15th July to 14th August 2023) as measured in Location-1 of Kota (upper left panel) and in Location-2 of Kota (upper right panel). Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

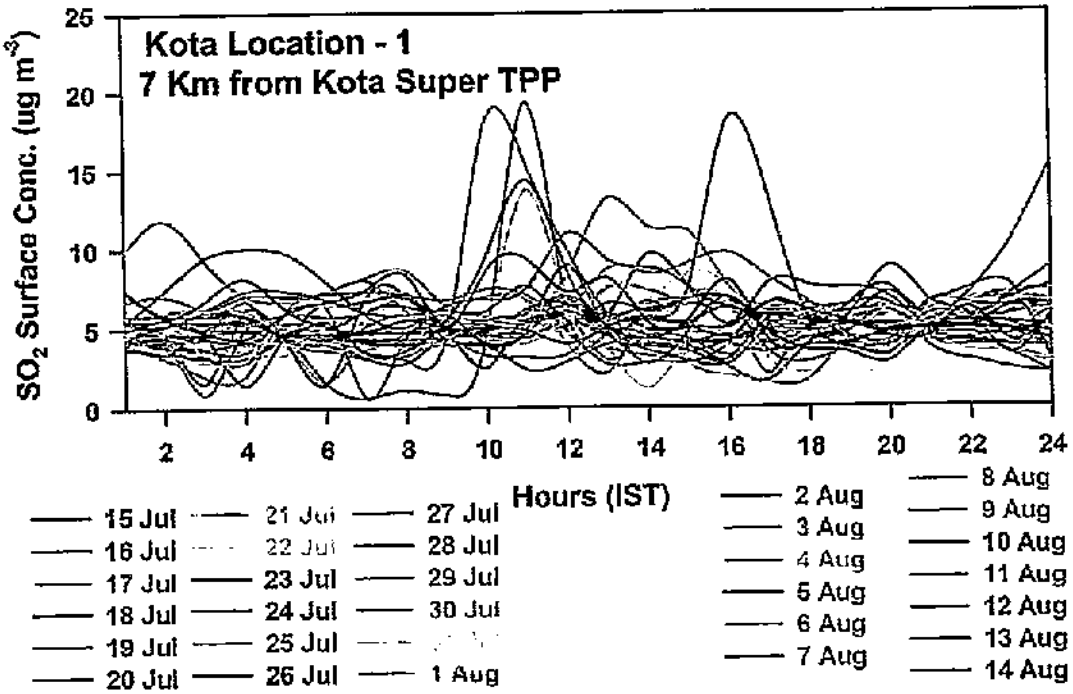
As mentioned earlier in Chapter-2 that the diurnal variations in ambient air SO_2 concentrations are influenced by a combination of several factors such as variability in SO_2 emission flux from different sources, variations in atmospheric boundary (or mixed) layer height throughout the day, changes in wind patterns or air circulation, and other meteorological conditions. In general, potential sources of SO_2 over any location include emissions from energy sector, transportation sector (burning of fossil fuel), industries (such as petroleum refineries, cement manufacturing, paper pulp manufacturing, iron and steel, and metal smelting, processing facilities, brick kilns,

etc.), residential sector (involving burning of fossil fuel or biomass for various purposes including usage of diesel/petrol generators), agricultural waste burning, solid waste treatment etc. SO_2 is also used in bleaching materials, as a fumigant, preserving dry fruits to prevent discoloration. In the residential sector SO_2 gas can be emitted from tobacco smoke, improperly or inadequately vented solid/gas fuel appliances (such as biomass or fossil fuel-based cooking stoves, furnaces, heaters), as well as kerosene or wood or cooking coal stoves or burning of these things for any other household purposes.

In general, we observed that the ambient air SO_2 concentrations at both measurement locations in Kota exhibit weaker diurnal variability compared to the variations noted in different cities during Phase-I of the survey. However, we did observe occasional spikes in SO_2 concentrations, primarily during the daytime at Location-1. These spikes, typically lasting 1-2 hours, suggest the influence of local sources within the city affecting the ambient air SO_2 levels at Location-1. Interestingly, there are significant differences in diurnal variations of ambient air SO_2 concentrations between the two locations. Unlike Location-1, Location-2 did not experience major spikes in SO_2 concentrations, indicating that it is less influenced by local sources. Consequently, location-2 exhibited very minimal diurnal variability throughout the survey period. While some weak spikes were also observed at location-2 on certain days, they were much smaller in magnitude compared to those at location-1. The randomness in the occurrence of these spikes at both locations suggests they are primarily caused by emissions from nearby local sources, other than the TPP, with a shorter distance of influence, less than the approximate 50 km distance between the two measurement locations.

The monthly mean pattern of diurnal variation in ambient air SO_2 concentration at both measurement locations in Kota showed minimal diurnal variability. At Location-1, the monthly mean pattern indicated slightly higher values during the forenoon hours, likely due to spikes caused by local sources other than TPP emissions. Generally, ambient air SO_2 concentrations were marginally higher during the nighttime, likely due to a shallower boundary layer at night, resulting in a smaller volume for air pollutants to disperse vertically.

Next, we discuss the findings from our survey in Lucknow, a Category-1 city selected for Phase II, which does not have any coal-based TPP within 10 km of its boundary. Figure 4.6 presents the time series of daily mean ambient air SO_2 concentrations ($\mu g/m^3$) measured on various days at two different sites in Lucknow. Figure 4.7 shows the diurnal variation of ambient air SO_2 concentrations ($\mu g/m^3$) recorded at these sites on different days. The maximum instantaneous values of ambient air SO2 concentrations recorded at Location 1 and Location 2 in Lucknow during Phase II were 10.86 $\mu g/m^3$ and 11.92 $\mu g/m^3$, respectively. The minimum instantaneous values of ambient air SO2 concentrations recorded at Location 1 and Location 2 in Delhi during Phase I were 3.79 $\mu g/m^3$ and 2.83 $\mu g/m^3$, respectively.


Kota Location - 1
7 Km from Kota Super TPP
SO2 Surface Conc. (ug m-3)
Hours (IST)
15 Jul
16 Jul
17 Jul
18 Jul
19 Jul
20 Jul
21 Jul
22 Jul
23 Jul
24 Jul
25 Jul
26 Jul
27 Jul
28 Jul
29 Jul
30 Jul
1 Aug
2 Aug
3 Aug
4 Aug
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7 Aug
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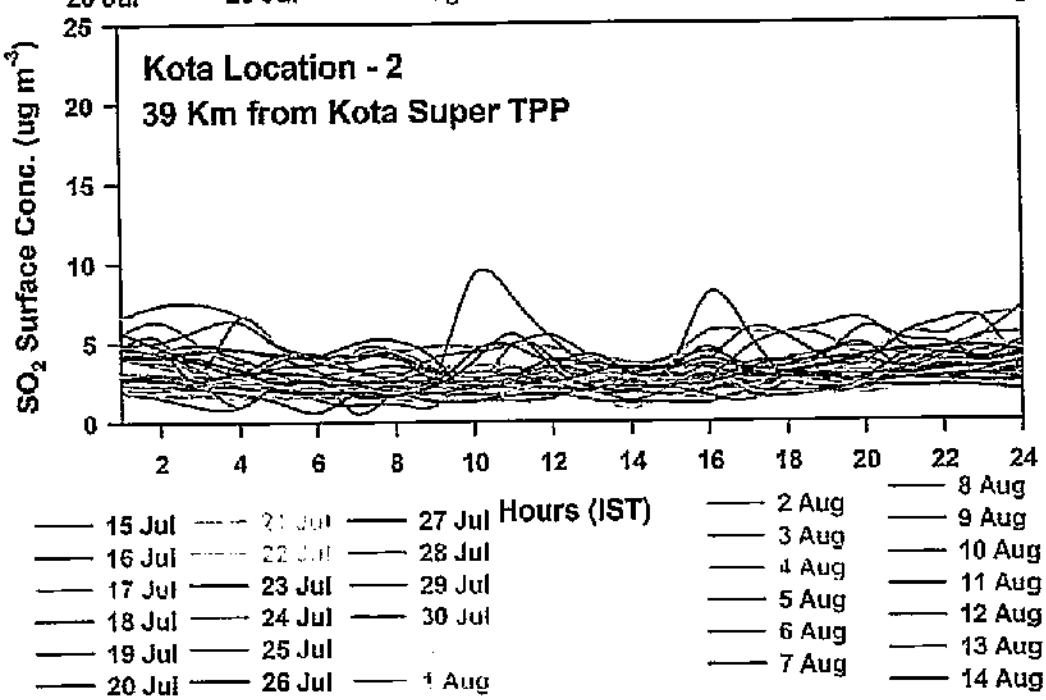
12 Aug
13 Aug
14 Aug


Kota Location - 2
39 Km from Kota Super TPP
SO2 Surface Conc. (ug m-3)
Hours (IST)
15 Jul
16 Jul
17 Jul
18 Jul
19 Jul
20 Jul
21 Jul
22 Jul
23 Jul
24 Jul
25 Jul
26 Jul
27 Jul
28 Jul
29 Jul
30 Jul
1 Aug
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3 Aug
4 Aug
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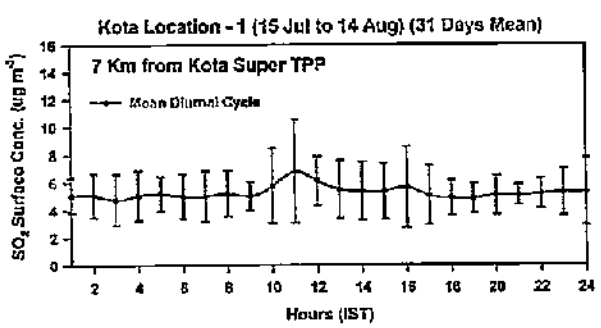
12 Aug
13 Aug
14 Aug


Kota Location - 1 (15 Jul to 14 Aug) (31 Days Mean)
7 Km from Kota Super TPP
Mean Diurnal Cycle
SO2 Surface Conc. (ug m-3)
Hours (IST)

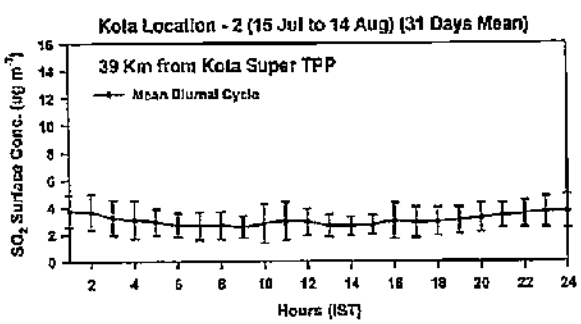
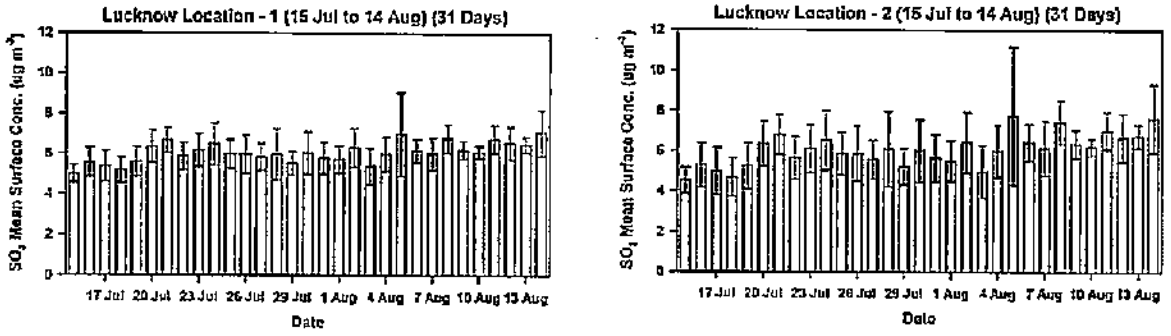

Kota Location - 2 (15 Jul to 14 Aug) (31 Days Mean)
39 Km from Kota Super TPP
Mean Diurnal Cycle
SO2 Surface Conc. (ug m-3)
Hours (IST)

Figure 4.5: Diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) for all days (15 July to 14 August 2023) as measured in Location-1 of Kota (upper panel) and Location-2 of Kota (middle panel). Monthly mean pattern of diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) derived from measurements made at both locations of Kota are also shown. Vertical lines in lower panels represent the $\pm 1\sigma$ standard deviation variation around the monthly mean values for each hour.

The monthly average daily mean values of ambient air SO2 concentrations at Location 1 and Location 2 in Lucknow during Phase II were 5.62 ± 1.14 $\mu g/m^3$ and 5.95 ± 1.56 $\mu g/m^3$, respectively.

According to the National Ambient Air Quality Standards (NAAQS), the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas, as notified by the MoEF&CC, Government of India, is 80 $\mu g/m^3$. The results of our survey confirm that the ambient air SO_2 concentrations in Lucknow were within the permissible limits during the period of our survey.

Time series of daily mean ambient air concentration of SO_2 ($\mu g/m^3$) measured in Lucknow



National Ambient Air Quality Standards (NAAQS)
[NAAQS Notification dated 18th November, 2009]

S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (notified by Central Government)	
1	Sulphur Dioxide (SO_2), $\mu g/m^3$	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

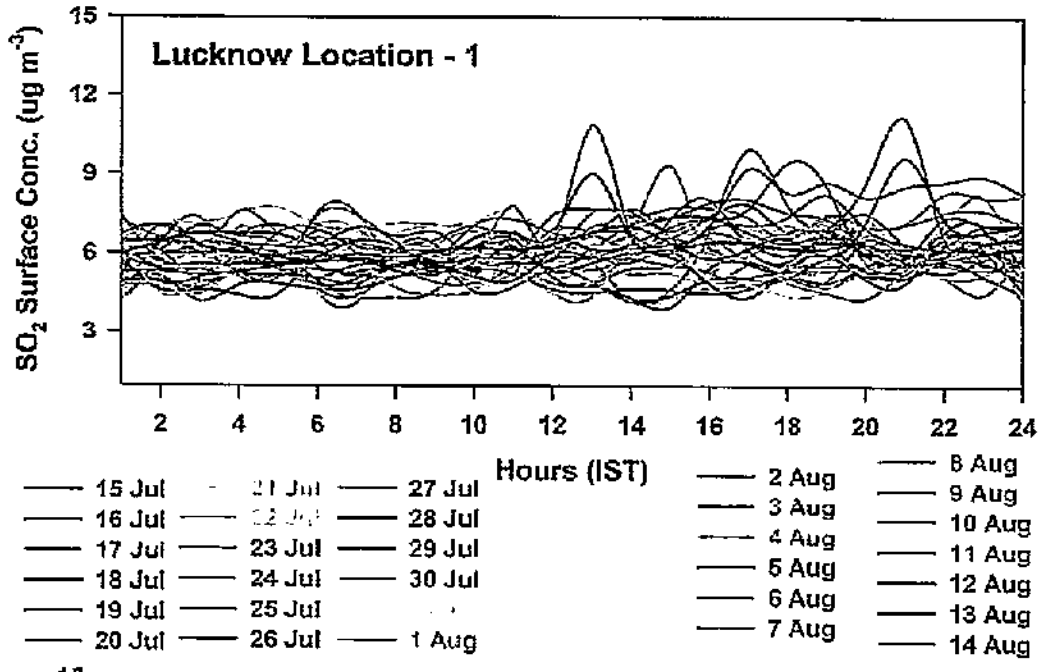
Figure 4.6: Time series of daily mean ambient air SO_2 concentration ($\mu g/m^3$) for all days (15 July to 14 August 2023) as measured in Location-1 of Lucknow (upper left panel) and for the period 15th July to 14th August 2023 in Location-2 of Lucknow (upper right panel). Vertical lines on each bar represents the $\pm 1\sigma$ standard deviation variation around the daily mean values for each day.

During Phase II of our survey in Lucknow, we observed occasional spikes in ambient air SO_2 concentrations at both measurement locations of Lucknow. However, no clear pattern in the diurnal variability of SO_2 was noted at either of the measurement locations. These spikes,

typically lasting for 1-2 hours and occurring at different times throughout the day, suggest that local sources within the city are independently influencing the ambient air SO_2 levels at both sites. Notably, there were no systematic differences in the diurnal variations of SO_2 concentrations between the two locations. The randomness in the occurrence of these spikes at both locations indicates that they are primarily caused by emissions from nearby local sources, which have a shorter range of influence than the approximate 50 km distance between the two measurement sites. This variability underscores the complex interplay of local emission sources in shaping the ambient air quality in Lucknow, highlighting the need for more detailed investigations to identify and mitigate these sources.

The monthly mean pattern of diurnal variation in ambient air SO_2 concentration at both measurement locations in Lucknow shows minimal diurnal variability, as depicted in figure 4.7. Although occasional spikes in SO_2 concentrations were observed, no distinct diurnal pattern was evident at either site. These spikes, typically lasting 1-2 hours and occurring at various times throughout the day, indicate that local sources within the city independently influence SO_2 levels at both locations, in addition to contributing to the background SO_2 level as part of regional air pollution. Notably, there were no systematic differences in the diurnal variations of SO_2 concentrations between the two sites. The randomness of these spikes indicates that they are primarily caused by emissions from nearby local sources, rather than a consistent, time-of-day dependent pattern. Despite the lack of a clear diurnal pattern, these spikes illustrate the influence of local activities and sources on ambient air SO_2 levels. For instance, traffic emissions, industrial activities, or other urban processes could be contributing to these sporadic increases in SO_2 concentrations. The absence of a significant difference between the two locations further suggests that these local sources are dispersed across the city, affecting both measurement sites similarly. This randomness underscores the complex nature of urban air quality, where multiple, variable factors can influence pollutant levels at any given time.

Next, we discuss the findings of our survey from Gautam Buddha Nagar in Uttar Pradesh, the Category-3 city selected for Phase II, having a coal-based Thermal Power Plant (TPP) equipped with FGD, situated within 10 kilometres of the city boundary. Figure 4.8 presents the time series of daily mean ambient air SO_2 concentrations measured on various days at two different sites in Gautam Buddha Nagar. Figure 4.9 shows the diurnal variation of ambient air SO_2 concentrations recorded at these sites on different days. The maximum instantaneous values of ambient air SO_2 concentrations recorded at Location 1 and Location 2 in Gautam Buddha Nagar during Phase II were 16.61 $\mu g/m^3$ and 12.51 $\mu g/m^3$, respectively. The minimum instantaneous values of ambient air SO_2 concentrations recorded at Location 1 and Location 2 in Gautam Buddha Nagar during Phase II were 1.45 $\mu g/m^3$ and 2.65 $\mu g/m^3$, respectively. The monthly average daily mean values of ambient air SO_2 concentrations at Location 1 and Location 2 during Phase II were 6.15 ± 2.56 $\mu g/m^3$ and 5.89 ± 1.65 $\mu g/m^3$, respectively.


Lucknow Location - 1
SO_2 Surface Conc. (ug m^{-3})
Hours (IST)
15 Jul
16 Jul
17 Jul
18 Jul
19 Jul
20 Jul
21 Jul
22 Jul
23 Jul
24 Jul
25 Jul
26 Jul
27 Jul
28 Jul
29 Jul
30 Jul
1 Aug
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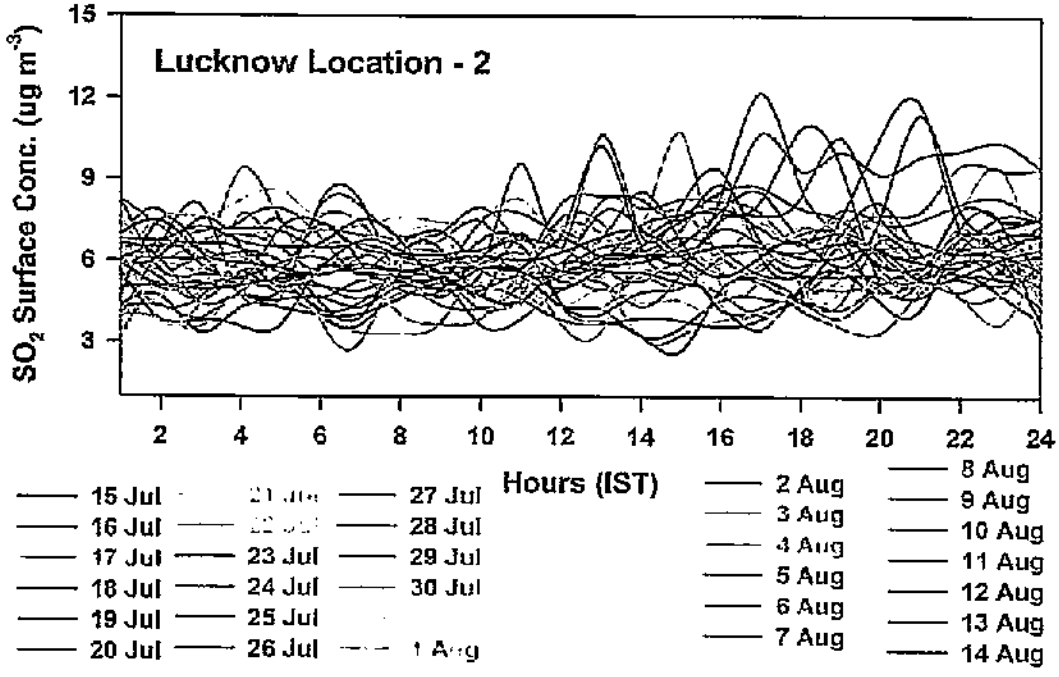
9 Aug
10 Aug
11 Aug
12 Aug
13 Aug
14 Aug


Lucknow Location - 2
SO_2 Surface Conc. (ug m^{-3})
Hours (IST)
15 Jul
16 Jul
17 Jul
18 Jul
19 Jul
20 Jul
21 Jul
22 Jul
23 Jul
24 Jul
25 Jul
26 Jul
27 Jul
28 Jul
29 Jul
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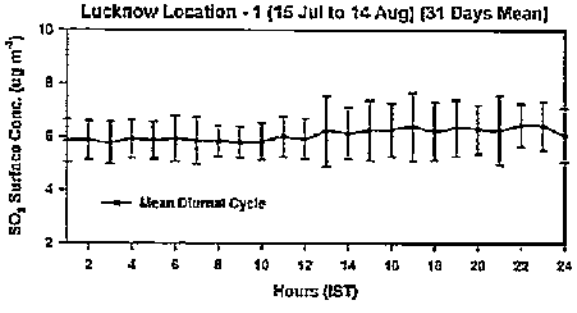
14 Aug


Lucknow Location - 1 (15 Jul to 14 Aug) (31 Days Mean)
SO_2 Surface Conc. (ug m^{-3})
Mean Diurnal Cycle
Hours (IST)

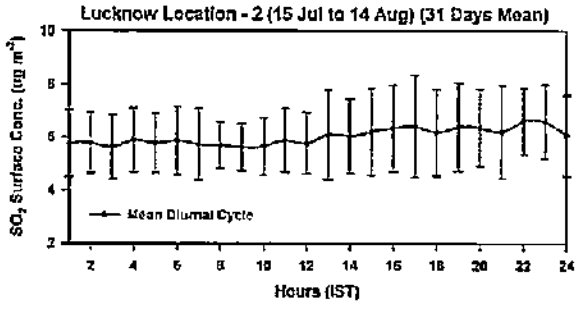
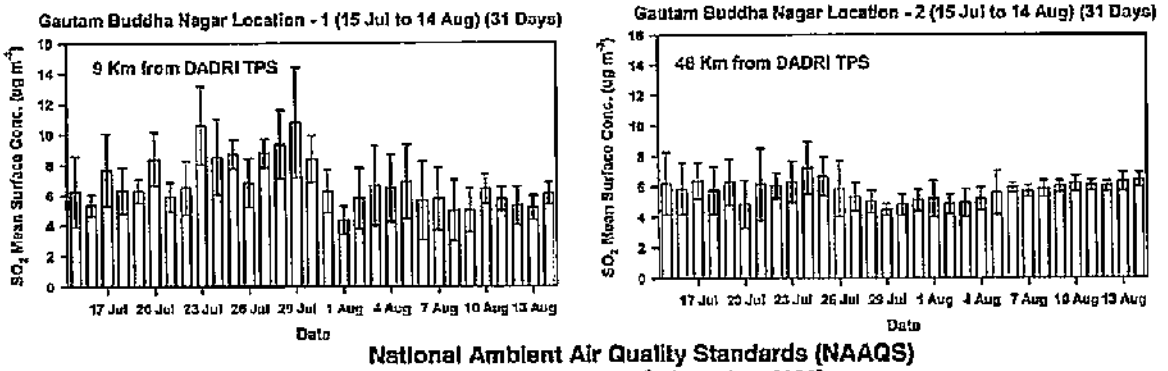

Lucknow Location - 2 (15 Jul to 14 Aug) (31 Days Mean)
SO_2 Surface Conc. (ug m^{-3})
Mean Diurnal Cycle
Hours (IST)

Figure 4.7: Diurnal variation of ambient air SO_2 concentration for all days (15 July to 14 August 2023) as measured in Location-1 (upper panel) and Location-2 (middle panel) of Lucknow. Monthly mean pattern of diurnal variation of ambient air SO_2 concentration derived from measurements made at both locations are also shown. Vertical lines in lower panels represent the ±1σ standard deviation variation around the monthly mean values for each hour.

Time series of daily mean ambient air concentration of SO_2 (µg/m³) measured in GBN



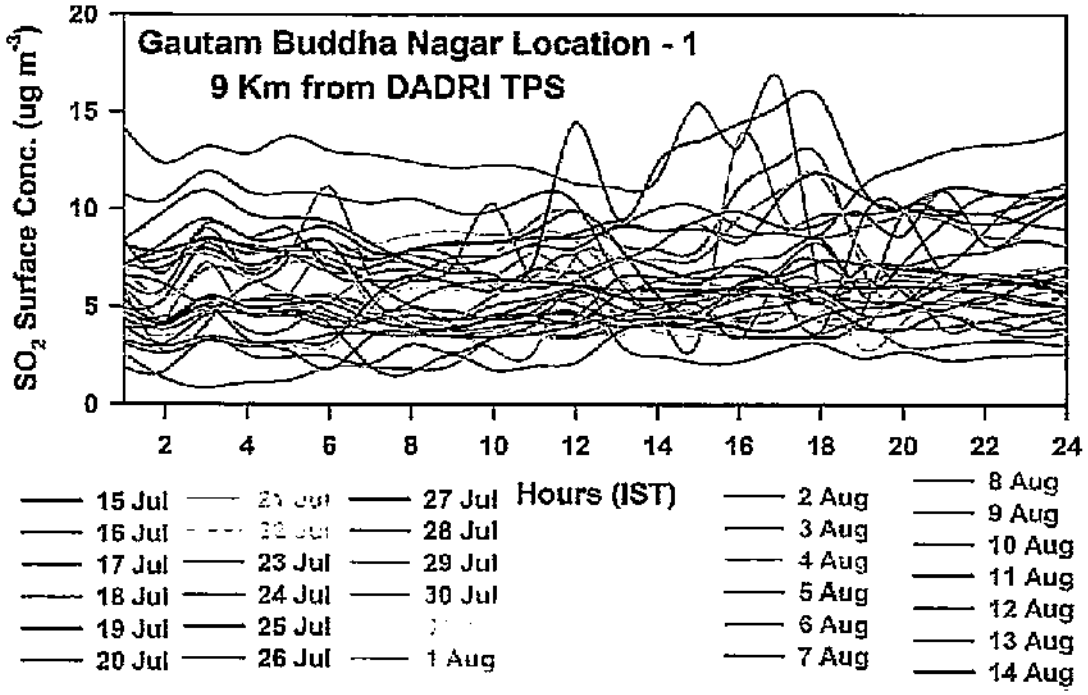
National Ambient Air Quality Standards (NAAQS)
[NAAQS Notification dated 18th November, 2009]

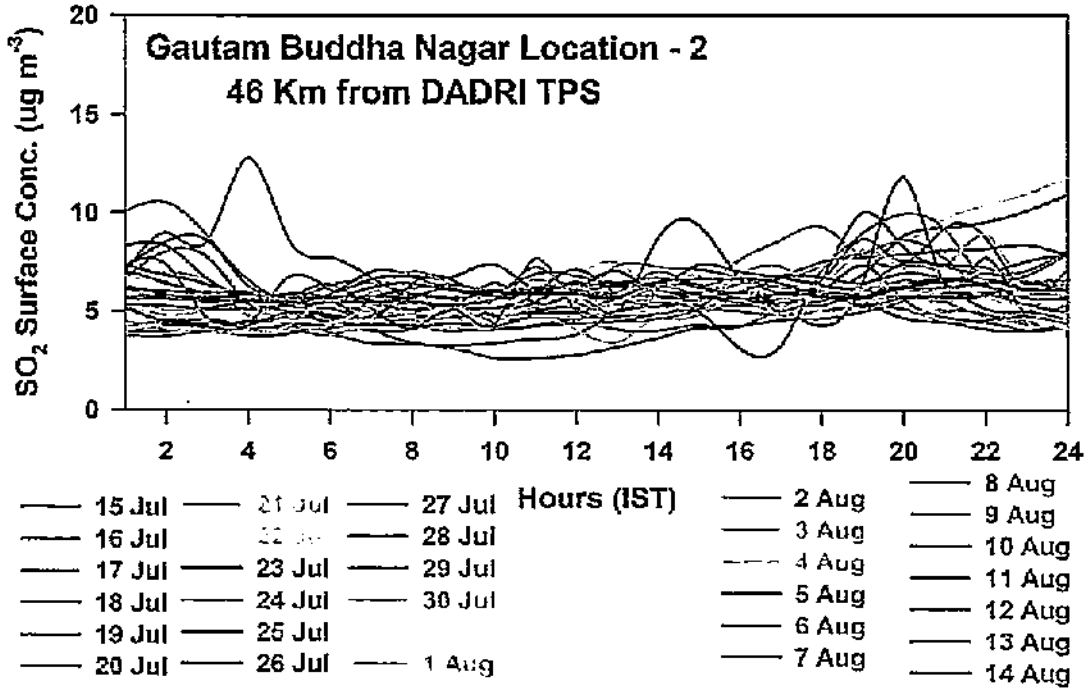
S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air		Methods of Measurement
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (notified by Central Government)	
1	Sulphur Dioxide (SO_2), µg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

Figure 4.8: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (15th July to 14th August 2023) as measured in Location-1 of Gautam Buddha Nagar (upper left panel) and for the period 15th July to 14th August 2023 in Location-2 of Gautam Buddha Nagar (upper right panel). Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

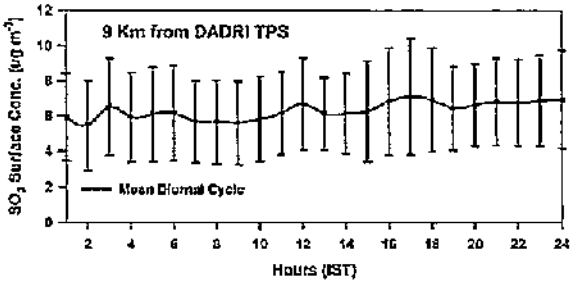
As per the National Ambient Air Quality Standards (NAAQS), the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas, as notified by the MoEF&CC, Government of India, is 80 µg/m³. The results of our survey confirm that the ambient air SO_2 concentrations in Gautam Buddha Nagar were within the permissible limits during the period of our survey.

Figure 4.9 illustrates the diurnal variation of ambient air SO_2 concentrations (in µg/m³) on different days of the month, based on measurements at two locations in Gautam Buddha Nagar. At Location 1, SO_2 concentrations exhibit greater variability throughout the day, with some peaks reaching up to 15 µg/m³.





Gautam Buddha Nagar Location - 1 (15 Jul to 14 Aug) (31 Days Mean)



Gautam Buddha Nagar Location - 2 (15 Jul to 14 Aug) (31 Days Mean)

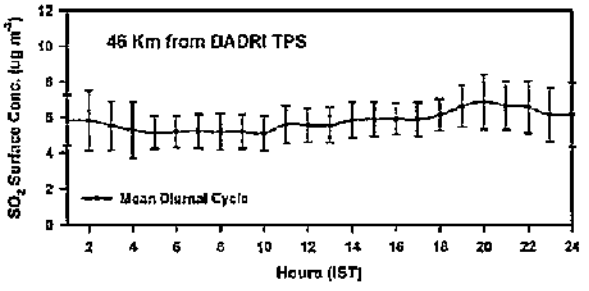


Figure 4.9: Diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) for all days (15th July to 14th August 2023) as measured in Location-1 (upper panel) and Location-2 (middle panel) of Gautam Buddha Nagar. Monthly mean pattern of diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) derived from measurements made at both locations are also shown. Vertical lines in lower panels represent the $\pm 1\sigma$ standard deviation variation around the monthly mean values for each hour.

The diurnal patterns at Location 1 show multiple fluctuations, with concentrations generally oscillating between 0 and 10 $\mu g/m^3$ and occasionally rising above this range. This suggests significant day-to-day variations and potentially stronger influences from dominant SO_2 sources, such as the NTPC Dadri TPP, as well as various other local sources within the city. These sources independently influence SO_2 levels at both locations and contribute to the background SO_2 levels as part of regional air pollution, affected by varying meteorological conditions on different days. In contrast, Location 2 shows more consistent and lower SO_2 concentrations, predominantly staying between 0 and 10 $\mu g/m^3$, with fewer peaks above this range. The patterns here appear smoother and less volatile, indicating a more stable ambient air quality regarding SO_2 levels, possibly due to the greater distance from major emission sources like NTPC Dadri TPP. Both locations share a general range of SO_2 concentrations, typically between 0 and 10 $\mu g/m^3$. However, Location 1 exhibits higher peak values and more pronounced fluctuations, while Location 2 demonstrates steadier and lower concentrations. These differences highlight the impact of proximity to pollution sources and potentially differing local activities on ambient air quality, including SO_2 concentrations.

Figure 4.9 also presents the mean diurnal patterns of ambient air SO_2 concentrations obtained from measurements at two different locations in Gautam Buddha Nagar during Phase II of our survey. Location 1, situated approximately 9 km from the NTPC Dadri TPS, shows ambient air SO_2 concentrations generally ranging between 5 and 7 $\mu g/m^3$ throughout the day, with some fluctuations and intra-day variability indicated by the vertical bars. Concentrations peak slightly in the early morning and late evening. In contrast, Location 2, 46 km from the NTPC Dadri TPS, displays more stable ambient air SO_2 concentrations, primarily varying between 4 and 6 $\mu g/m^3$, with minimal fluctuations and overall lower levels compared to Location 1. Both locations exhibit similar overall diurnal trends, with concentrations remaining relatively stable throughout the day and minor increases during specific periods. However, Location 1 experiences higher mean concentrations and greater variability, likely due to its proximity to the NTPC Dadri TPS and other local sources of SO_2 in Gautam Buddha Nagar and Ghaziabad. These differences highlight the impact of distance from major emission sources on ambient air quality and SO_2 concentrations, with closer proximity leading to higher and more variable SO_2 levels.

CHAPTER-5: CONTRIBUTION OF SO_2 EMISSIONS FROM COAL-BASED TPPS TOWARDS AMBIENT ATMOSPHERIC SO_2, SULFATE AEROSOLS, PM2.5, AND PM10 MASS CONCENTRATIONS IN DIFFERENT CATEGORY CITIES DURING PHASE II OF SURVEY

To understand the contribution of SO_2 emissions from the power sector, specifically coal-based thermal power plants (TPPs), on ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in various cities selected for Phase II of the survey, we conducted a series of meticulously planned simulations using the WRF-Chem chemical transport model. These simulations aimed to delineate the contributions of various sources, particularly TPP emissions, to ambient air SO_2 and sulfate aerosols as components of PM2.5 and PM10 mass concentrations across the surveyed cities. Additionally, we aimed to determine the contributions of major aerosol types, including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust, to the ambient air concentrations of PM2.5 and PM10 in these cities. Specifically, we sought to quantify the impact of SO_2 emissions from TPPs on the ambient air concentrations of sulfate aerosols, PM2.5 and PM10 mass concentrations in the cities included in the Phase II of this survey.

Model setup and Simulation Details

The Weather Research and Forecasting model coupled with a chemistry module (WRF-Chem) is a regional system designed for both operational weather forecasting and atmospheric chemistry research (Skamarock, 2008; Powers et al., 2017). In this study, WRF-Chem version 4.2.2 was utilized to conduct nine sets of atmospheric chemistry simulations over the city of interest (Lucknow, Kota, and Gautam Buddha Nagar during Phase II of the survey) spanning from 15th July to 14th August 2023. For the first set of simulations, the model domains were centered at Kota (75.84° E and 25.18° N), each covering approximately 2,250,000 square kilometres at a horizontal resolution of 10 km, with 150x150 grid cells in the outer domain and a horizontal resolution of 3 km, with 136x136 grid cells in the inner domain, following a nested WRF-Chem modeling setup. The model included 44 vertical levels on a hybrid-sigma coordinate system, extending from the surface to about 10 hPa as the model top pressure.

The NCEP GDAS Final Analysis data, available at 6-hour intervals and with a resolution of 0.25°x0.25°, provided the meteorological initial and lateral boundary conditions for the model simulations covering the period from 15th July to 14th August 2023. Anthropogenic emissions were based on the EDGAR-v6.1 (2023) dataset. ERA5 Temperature, Water Vapor, and Wind data were used for both the WRF-Chem simulations and the Four-Dimensional Data Assimilation (FDDA) approach. Initial and lateral chemical boundary conditions for the WRF-Chem model

simulations were obtained from previously available results from the Community Atmospheric Model With Chemistry (CAM-Chem) simulations.

To evaluate the sectoral contributions to ambient atmospheric concentrations of SO2, sulfate aerosols, PM2.5, and PM10 in the selected cities of Lucknow, Kota, and Gautam Buddha Nagar during Phase II of the survey, we utilized an emission suppression method. This approach involved conducting a series of systematically designed simulations using the WRF-Chem model, where emissions from specific sectors were disabled in each simulation. The details of the model configuration, the various anthropogenic, biomass burning, and biogenic emissions considered, as well as the numerical experiment design, are provided in Chapter 3 and are therefore not repeated here.

Chemical Transport Modeling for Kota, Rajasthan

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category-2 City:
Kota, Rajasthan

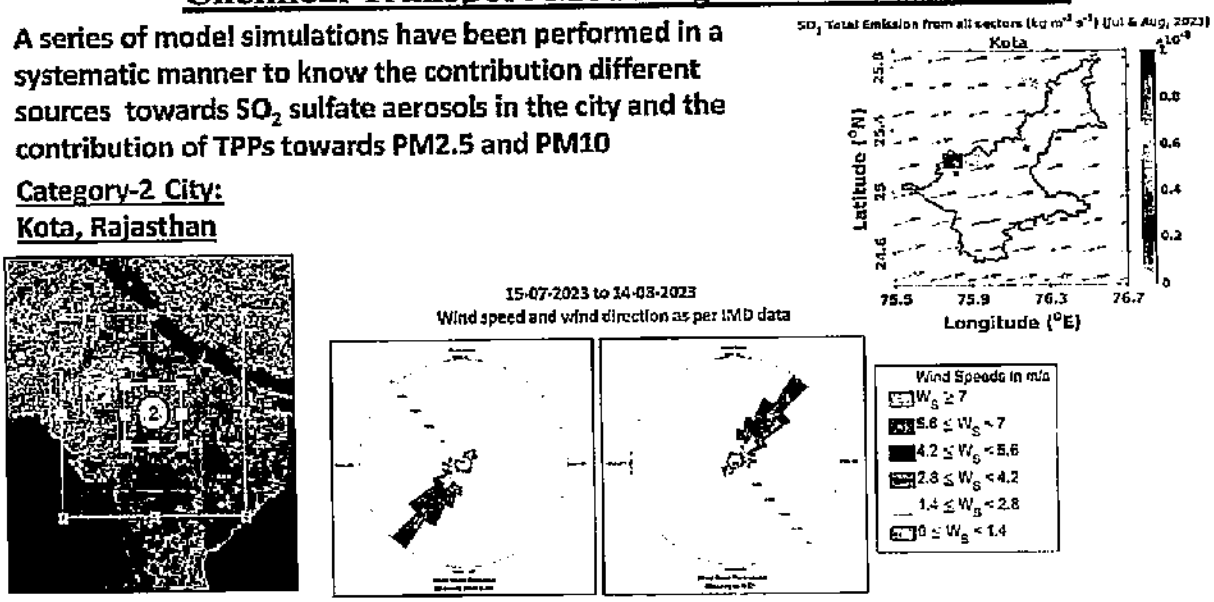


Figure 5.1: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Kota during the simulation period from 15th July to 14th August 2023.

First, we present the results of our simulations, detailing the contributions of major emission sectors to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 mass concentrations in the city of Kota during Phase II of our survey.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-2 City: Kota, Rajasthan

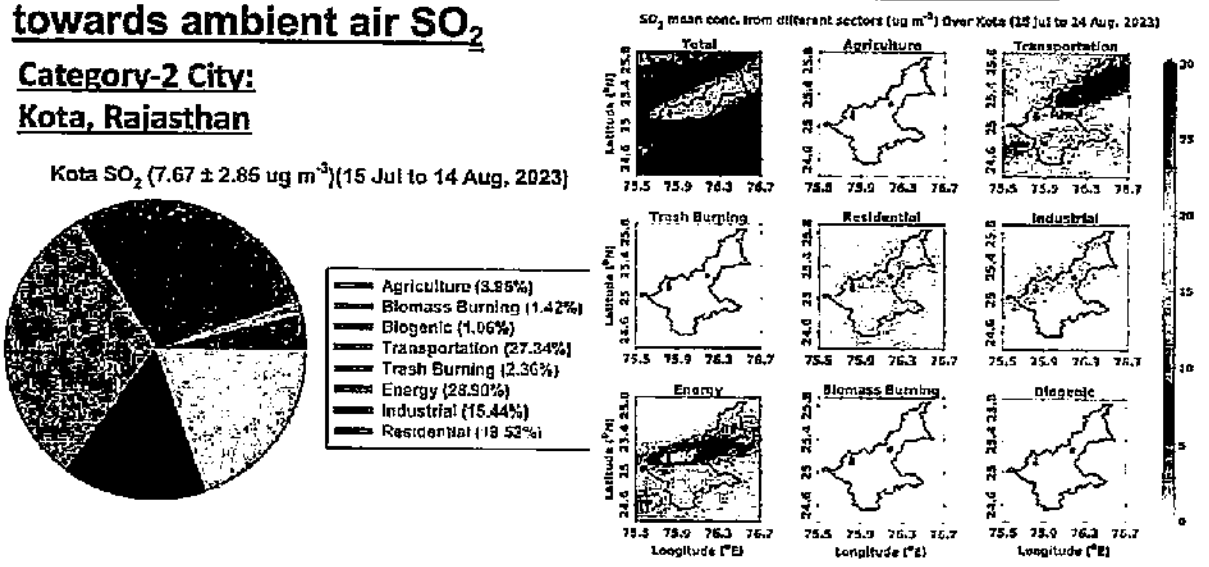


Figure 5.2: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Kota during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of different emission sectors towards ambient air SO_4

Category-2 City: Kota, Rajasthan

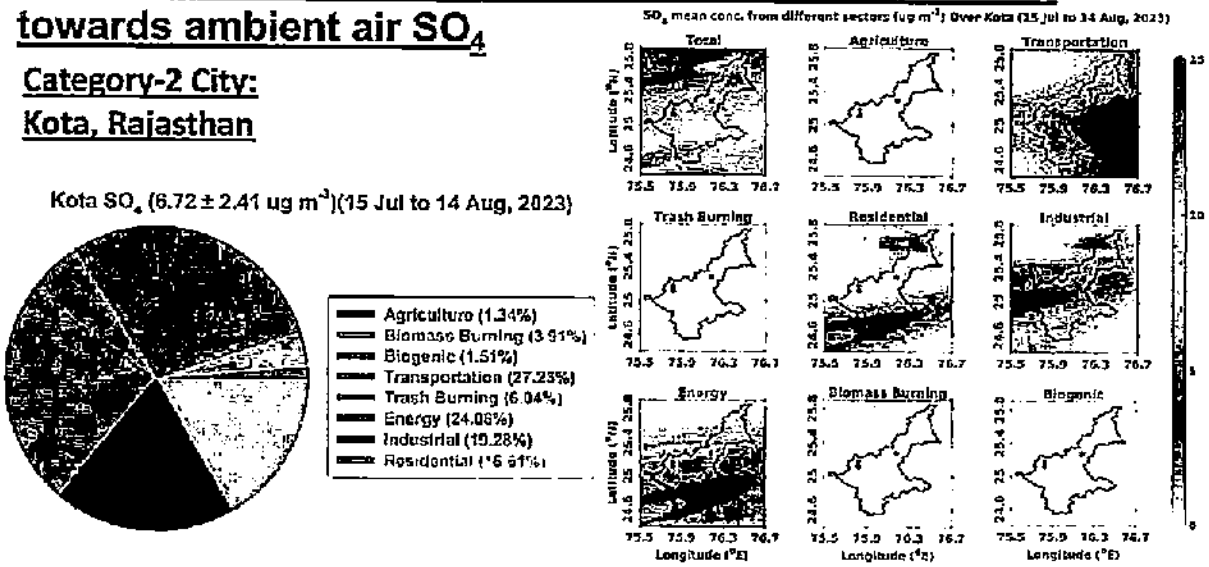


Figure 5.3: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Kota during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of different emission sectors towards ambient air PM2.5

Category-2 City: Kota, Rajasthan

Kota $PM_{2.5}$ (48.69 ± 6.14 ug m^{-3})(15 Jul to 14 Aug, 2023)

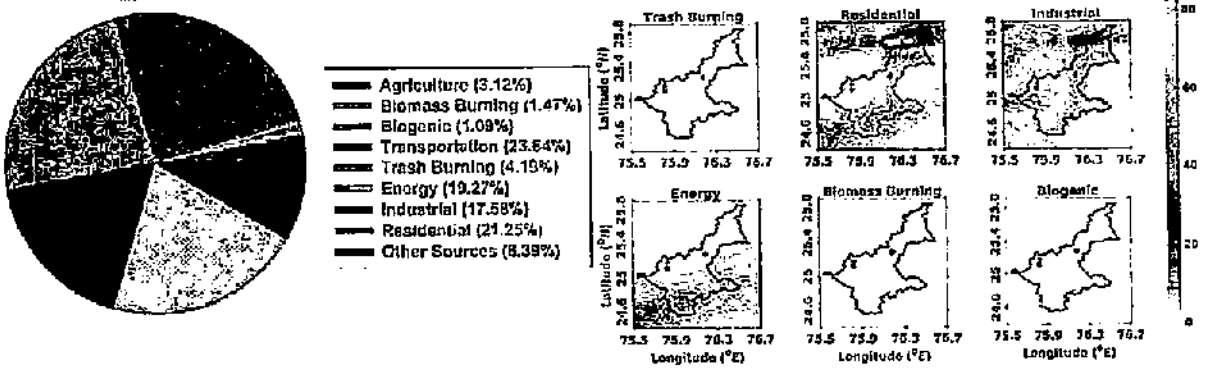


Figure 5.4: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Kota during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

Category-2 City: Kota, Rajasthan

Kota PM_{10} (65.74 ± 6.47 ug m^{-3})(15 Jul to 14 Aug, 2023)

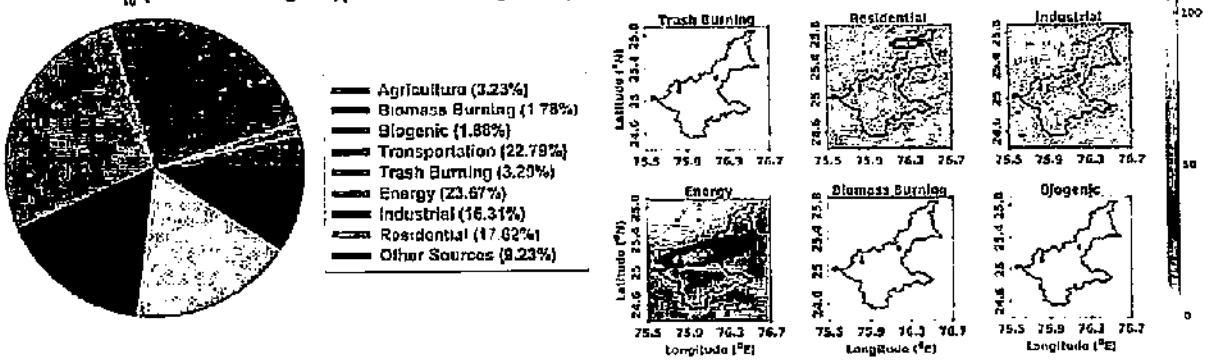


Figure 5.5: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Kota during the simulation period from 15th July to 14th August 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Kota during the survey period.

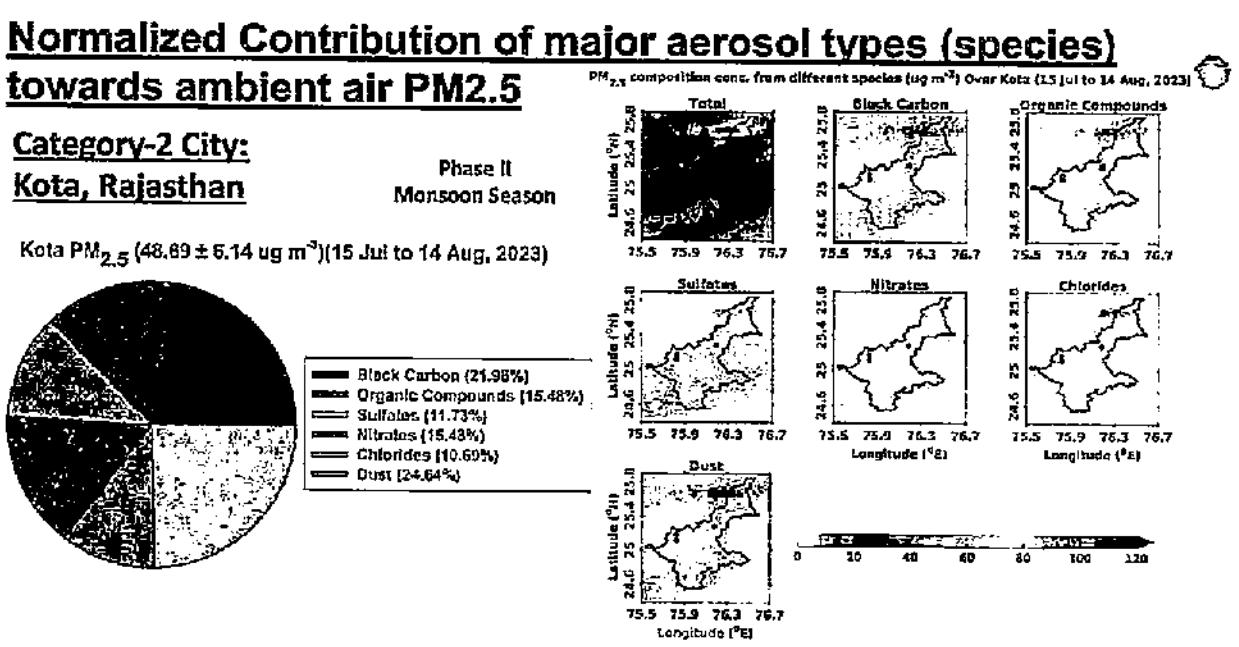


Figure 5.6: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Kota during the simulation period from 15th July to 14th August 2023.

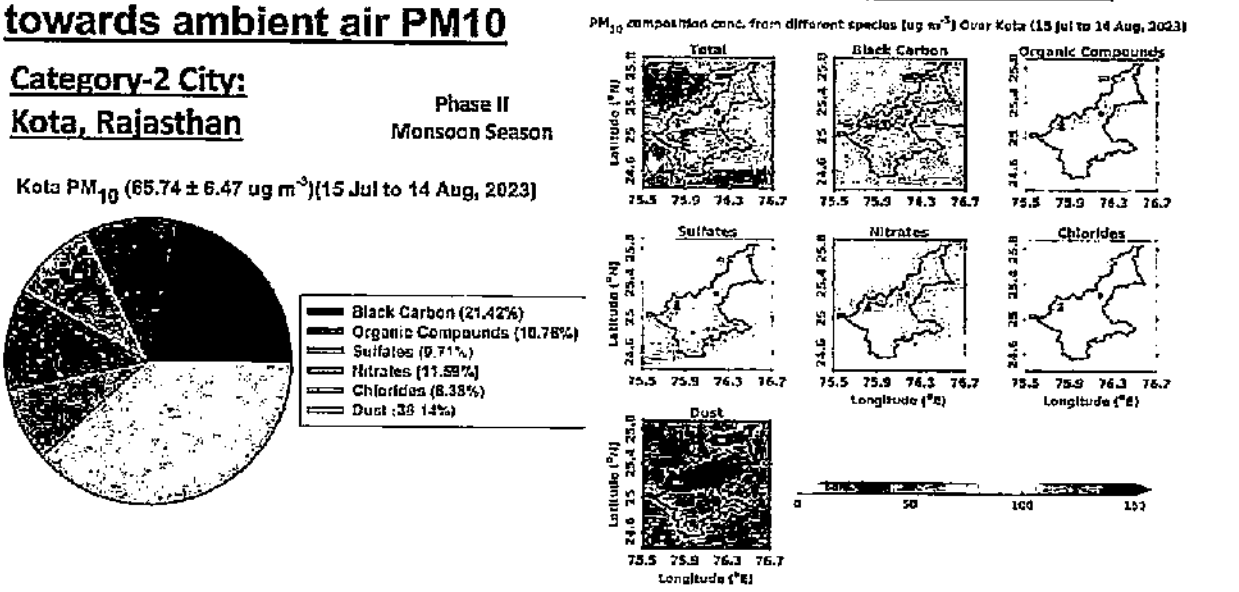


Figure 5.7: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Kota during the simulation period from 15th July to 14th August 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category-2 City: Kota, Rajasthan

15th July to 14th Aug 2023

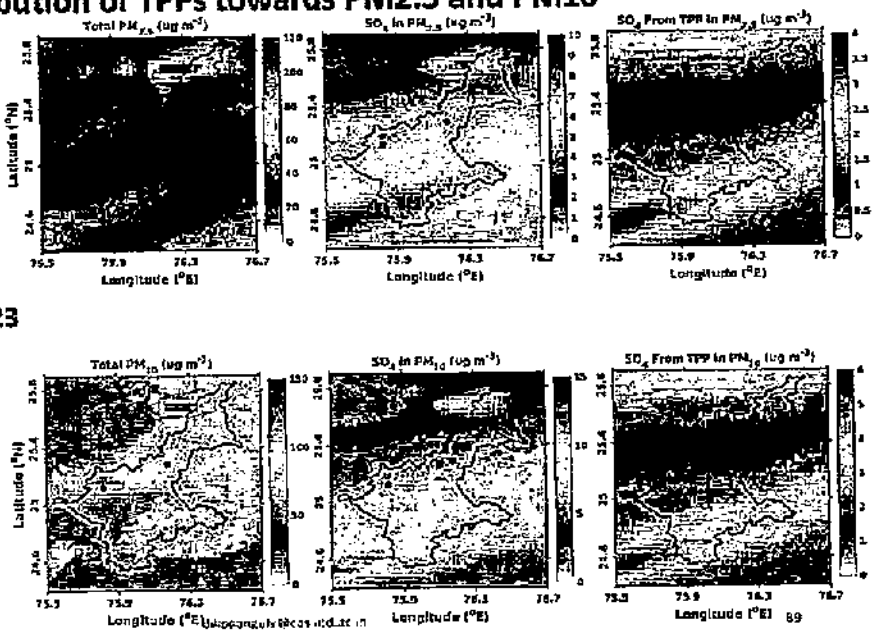
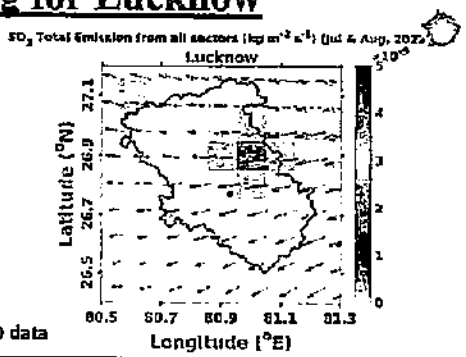


Figure 5.8: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Kota during the simulation period from 15th July to 14th August 2023.

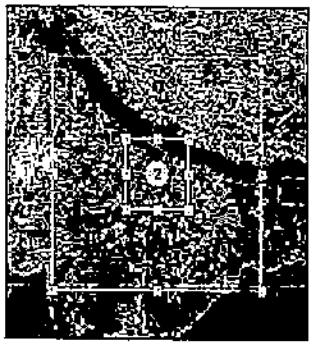
Next we performed another series of systematically designed WRF-Chem model simulations to know the contribution different sources towards SO_2 and sulfate aerosols in Lucknow, which is a Category-1 city considered during the Phase-II of our survey. We also wanted to understand the contribution of Power sector towards the ambient atmospheric SO_2, PM2.5, and PM10 concentrations in the city of Lucknow during our survey. WRF-Chem version 4.2.2 has been used to perform a set of nine atmospheric chemistry simulations over Lucknow for 15th July to 14th August 2023. For this study, the model domains are centered at Lucknow (80.57° E and 26.51° N). Each of the simulation domain covers approximately 2250000 square Km area at a horizontal resolution of 10x10 Km^2, with 150x150 grid cells in the outer domain and horizontal resolution of 3x3 Km^2, with 136x136 grid cells in the inner domain following nested WRF-Chem modeling setup and 44 vertical levels (on a hybrid-sigma coordinate system) starting from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis (available at 6 hourly intervals) with a resolution of 0.25°x0.25° have been used to provide meteorological initial and lateral boundary conditions to the model simulation of 15th July to 14th August 2023. To estimate the sectoral emission contribution towards the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Lucknow, we followed an emission suppression method. The details of the model configuration, the various anthropogenic, biomass burning, and biogenic emissions considered, as well as the numerical experiment design, are provided in Chapter 3 and are therefore not repeated here.

Chemical Transport Modeling for Lucknow

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10



Category-1 city:
Lucknow, Uttar Pradesh



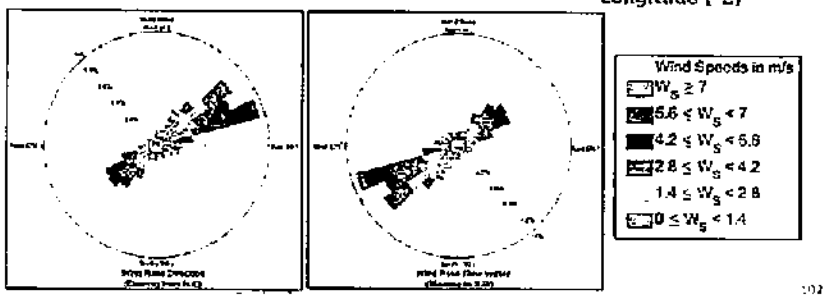
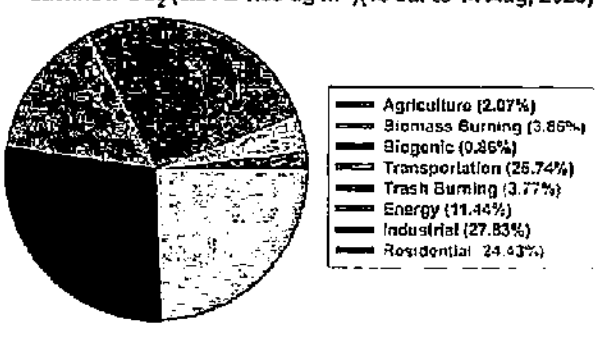


Figure 5.9: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Lucknow during the simulation period from 15th July to 14th August 2023.

First, we present the results of our simulations, detailing the contributions of major emission sectors to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 mass concentrations in the city of Lucknow during Phase II of our survey.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-1 city:
Lucknow, Uttar Pradesh



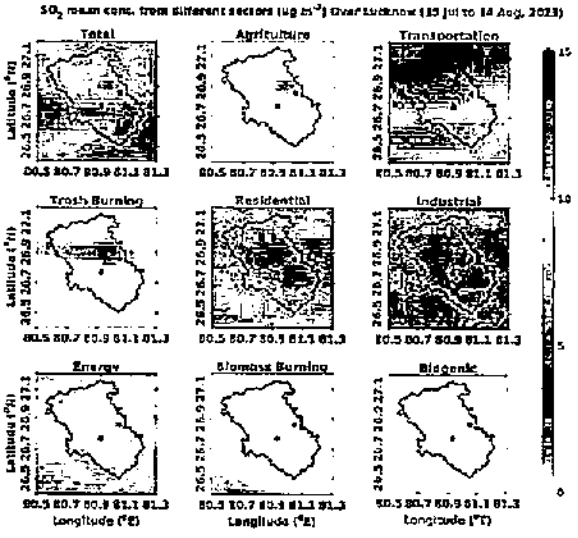


Figure 5.10: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of different emission sectors towards ambient air SO_4

Category-1 city:
Lucknow, Uttar Pradesh

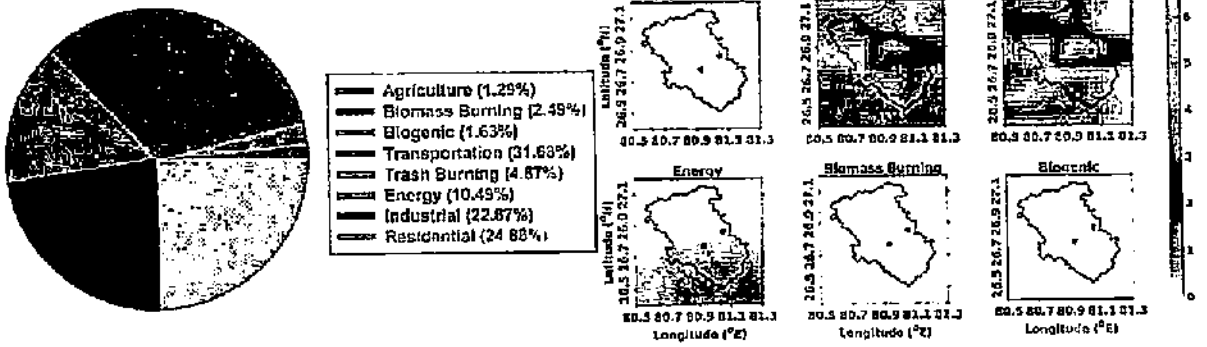


Figure 5.11: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of different emission sectors towards ambient air PM2.5

Category-1 city:
Lucknow, Uttar Pradesh

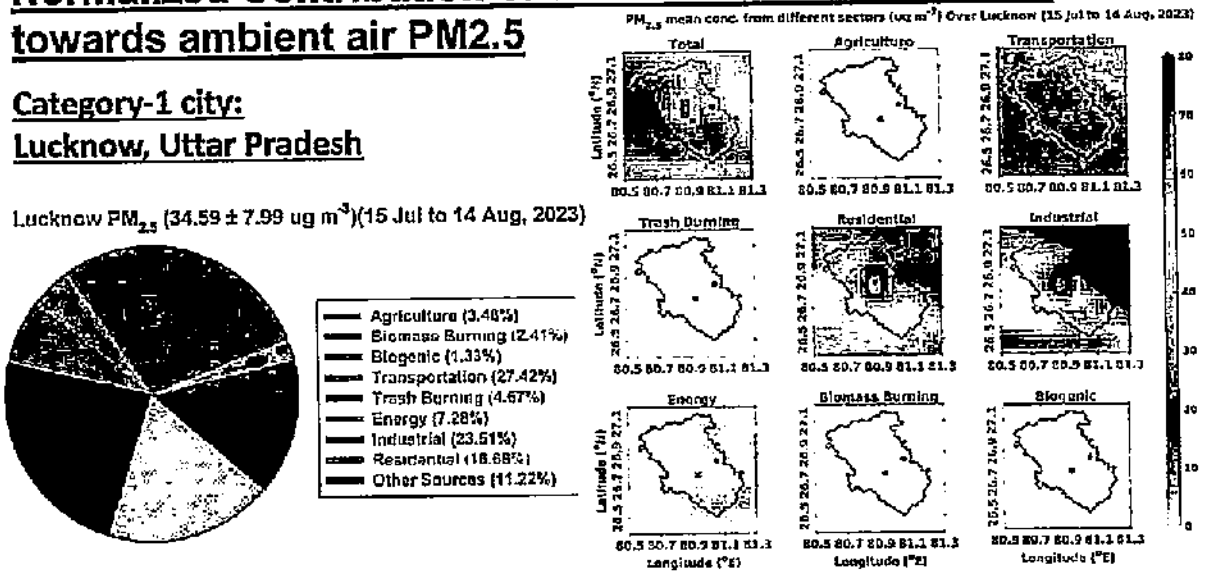
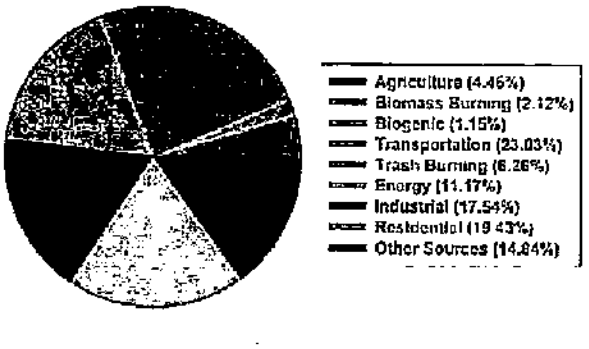


Figure 5.12: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

Category-1 city:
Lucknow, Uttar Pradesh



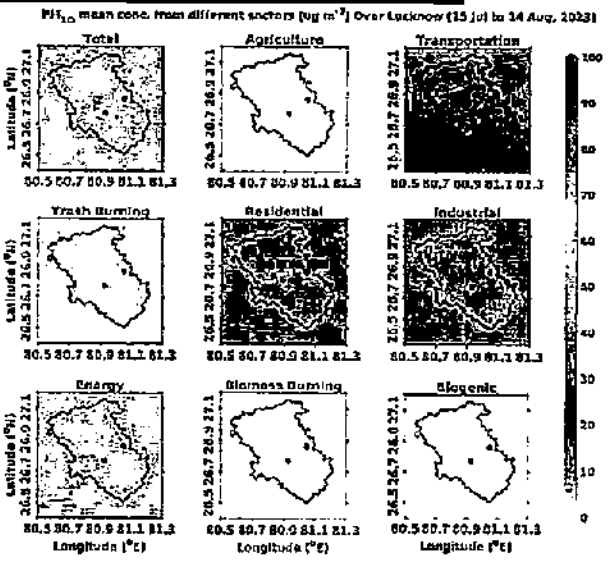


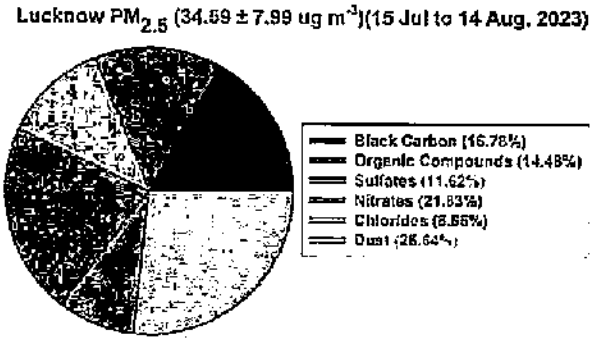
Figure 5.13: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Lucknow during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

Category-1 city:
Lucknow, Uttar Pradesh

Phase II
Monsoon Season



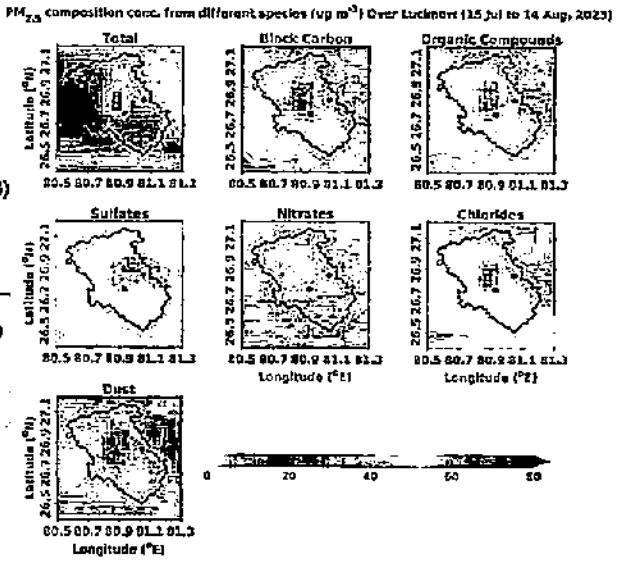


Figure 5.14: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

Normalized Contribution of major aerosol types (species) towards ambient air PM10

Category-1 city:
Lucknow, Uttar Pradesh

Phase II
Monsoon Season

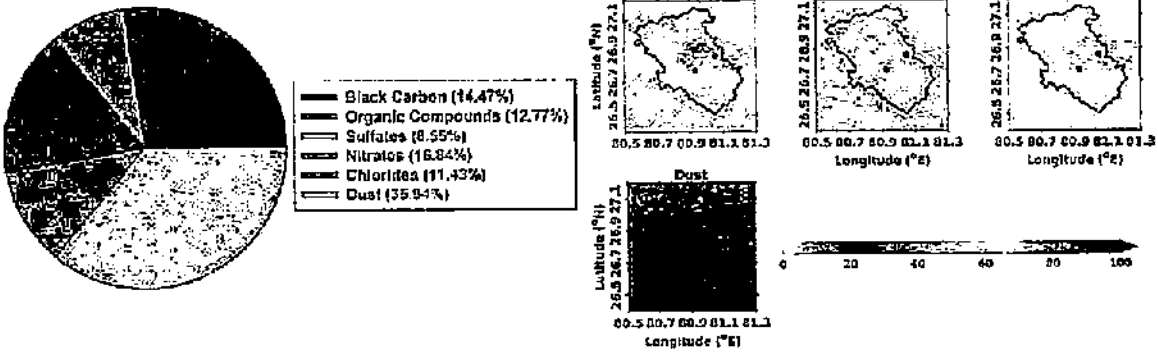
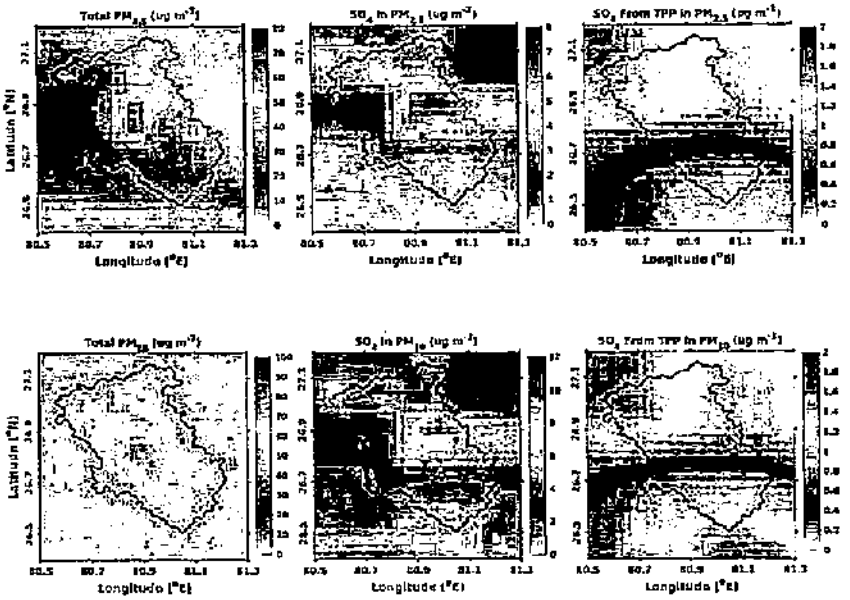


Figure 5.15: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category-1 city:
Lucknow, Uttar Pradesh



15th July to 14th Aug 2023

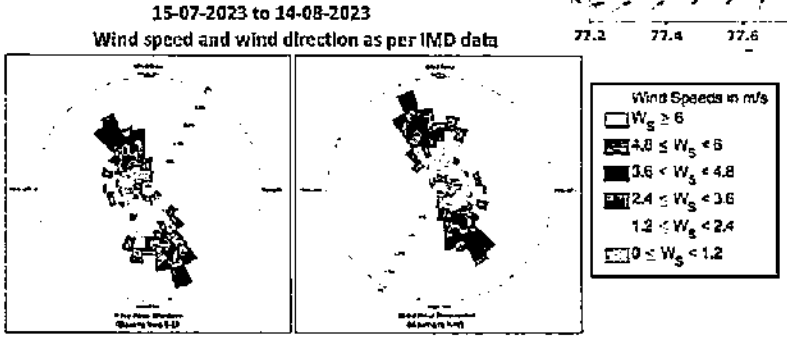
Figure 5.16: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Lucknow during the simulation period from 15th July to 14th August 2023.

Next, we performed another series of systematically designed WRF-Chem model simulations to know the contribution different sources towards SO_2 and sulfate aerosols in Gautam Buddha Nagar, which is a Category-3 city considered during the Phase-II of our survey. We also wanted to understand the contribution of SO_2 emissions from the power sector, specifically coal-based thermal power plants (TPPs), on ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in the city of Gautam Buddha Nagar during our survey. WRF-Chem version 4.2.2 has been used to perform a set of nine atmospheric chemistry simulations over Gautam Buddha Nagar for 15th July to 14th August 2023. For this study, the model domains are centered at Gautam Buddha Nagar (77.61° E and 28.34° N). Each of the simulation domain covers approximately 2250000 square Km area at a horizontal resolution of 10x10 Km^2, with 150x150 grid cells in the outer domain and horizontal resolution of 3x3 Km^2, with 136x136 grid cells in the inner domain following nested WRF-Chem modeling setup and 44 vertical levels (on a hybrid-sigma coordinate system) starting from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis (available at 6 hourly intervals) with a resolution of 0.25°x0.25° have been used to provide meteorological initial and lateral boundary conditions to the model simulation of 15th July to 14th August 2023. To estimate the sectoral emission contribution towards the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Gautam Buddha Nagar, we followed an emission suppression method. We modified the emissions assuming that FGD was operational in two units of the NTPC Dadri TPP during Phase II of our survey. The details of the model configuration, the various anthropogenic, biomass burning, and biogenic emissions considered, as well as the numerical experiment design, are provided in Chapter 3 and are therefore not repeated here.

Chemical Transport Modeling for GBN, Uttar Pradesh

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh



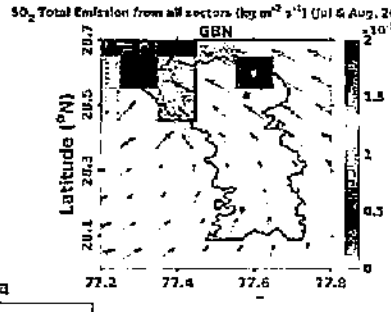


Figure 5.17: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over GBN during the simulation period from 15th July to 14th August 2023.

First, we present the results of our simulations, detailing the contributions of major emission sectors to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 mass concentrations in the city of Gautam Buddha Nagar during Phase II of our survey.

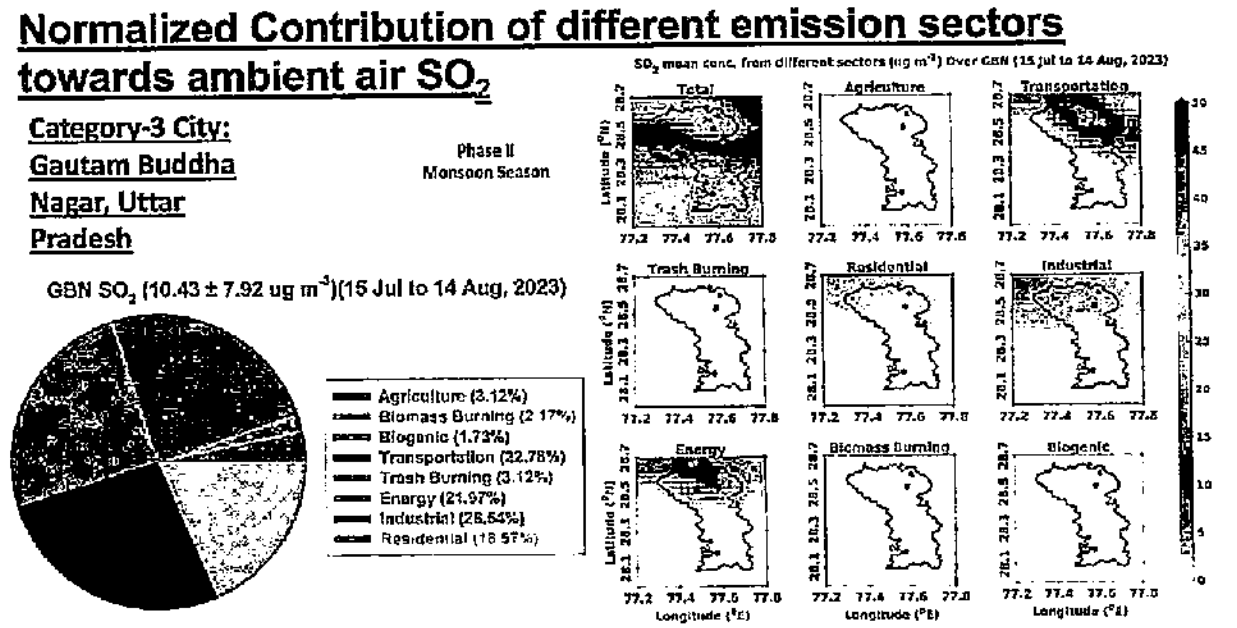


Figure 5.18: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in GBN during the simulation period from 15th July to 14th August 2023.

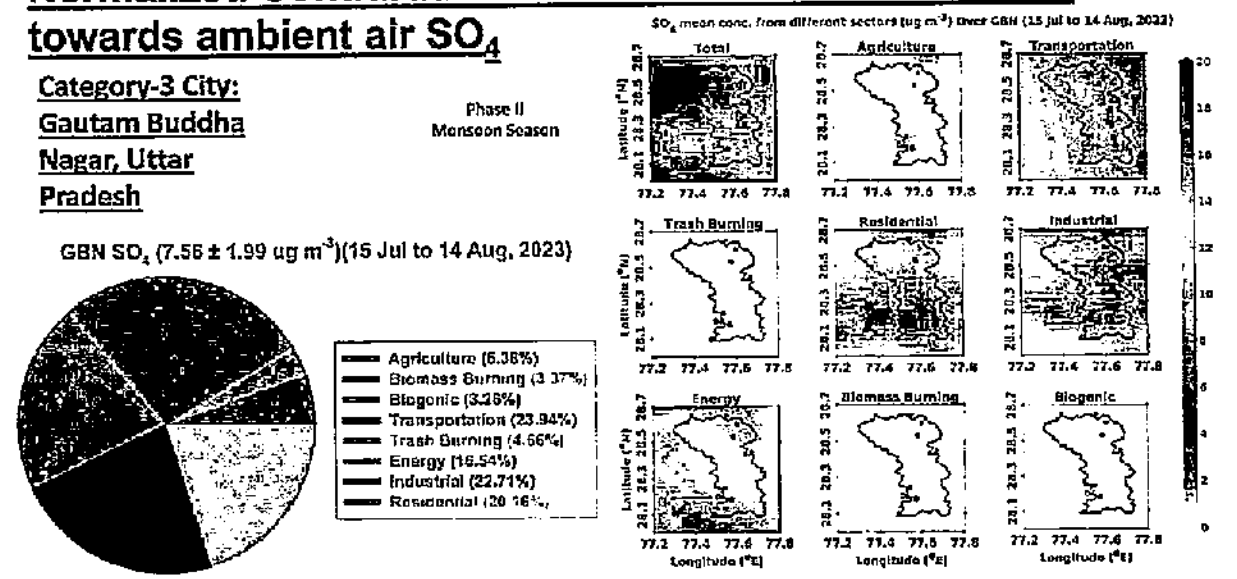


Figure 5.18: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in GBN during the simulation period from 15th July to 14th August 2023.

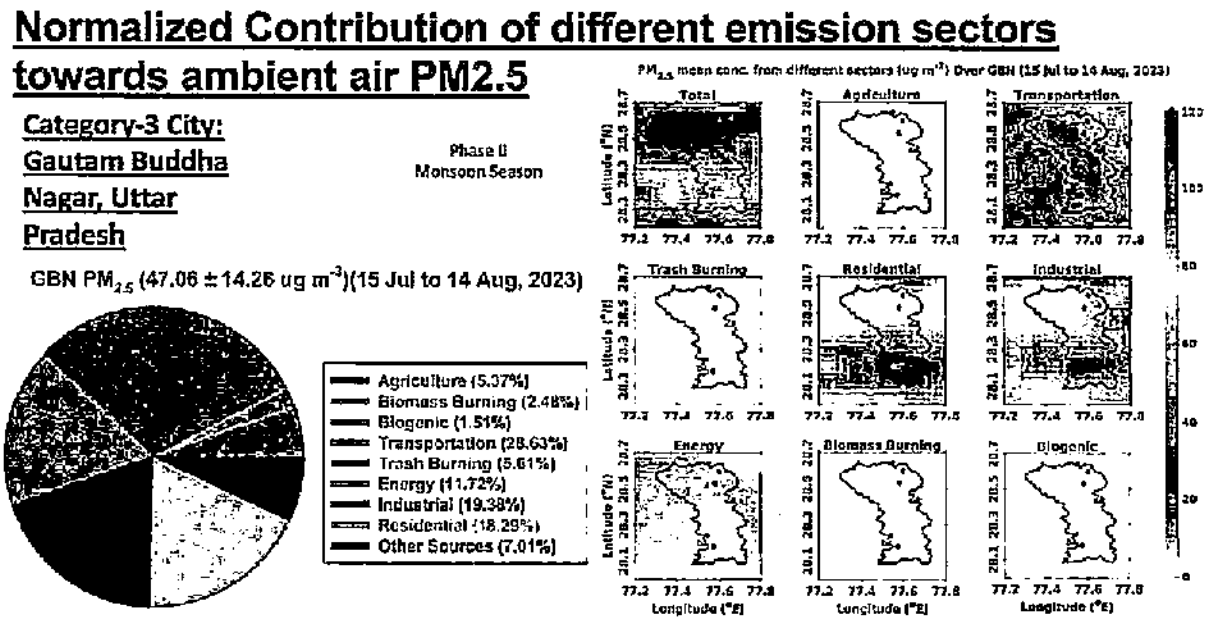


Figure 5.19: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in GBN during the simulation period from 15th July to 14th August 2023.

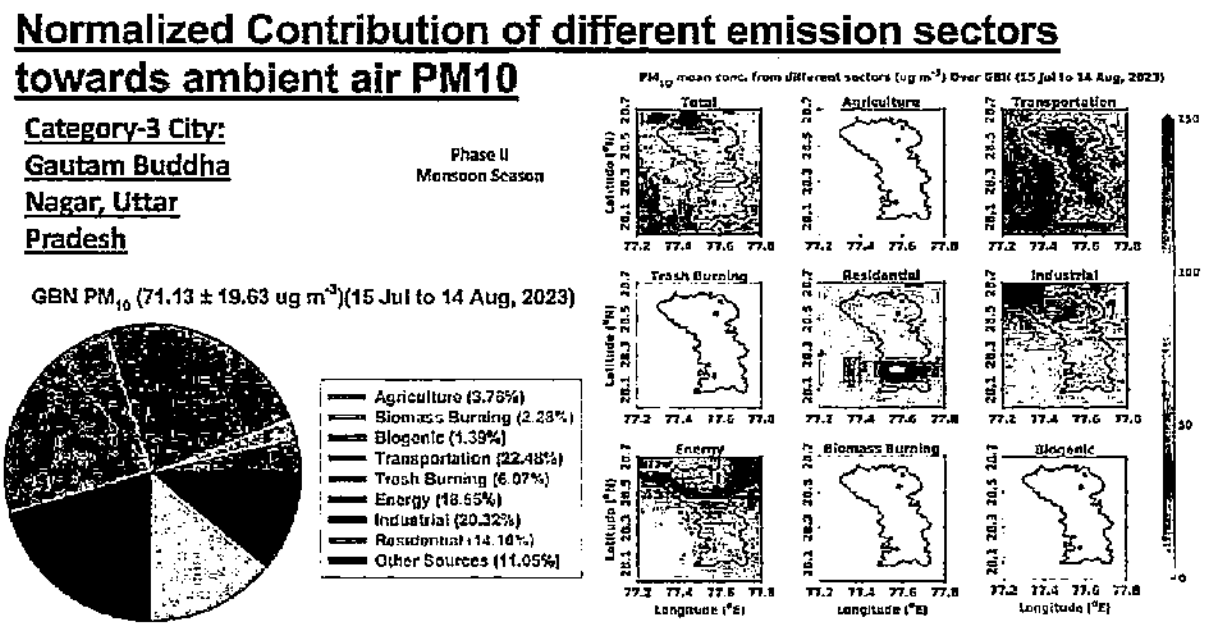


Figure 5.20: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 15th July to 14th August 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates,

chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Gautam Buddha Nagar during the survey period.

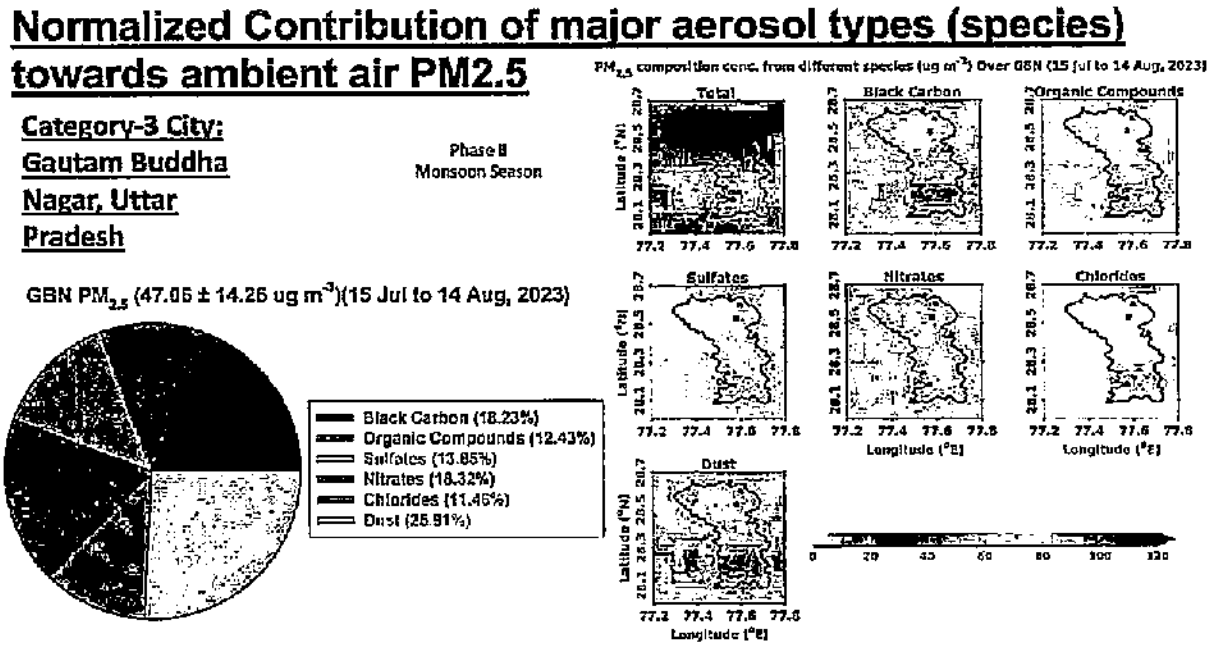


Figure 5.21: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in GBN during the simulation period from 15th July to 14th August 2023.

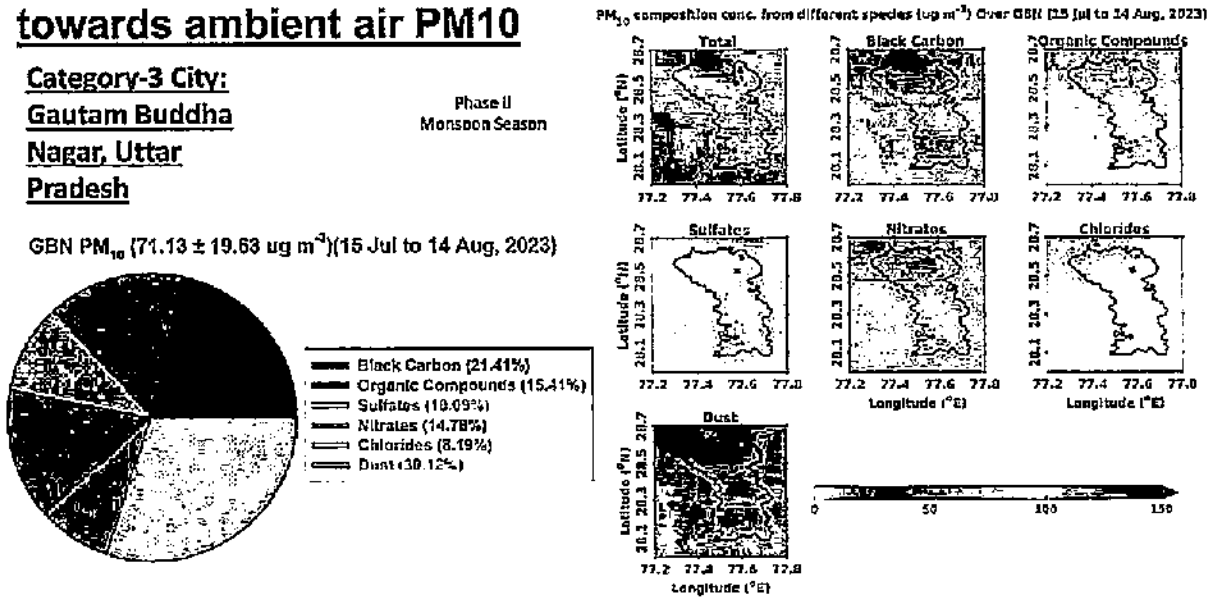


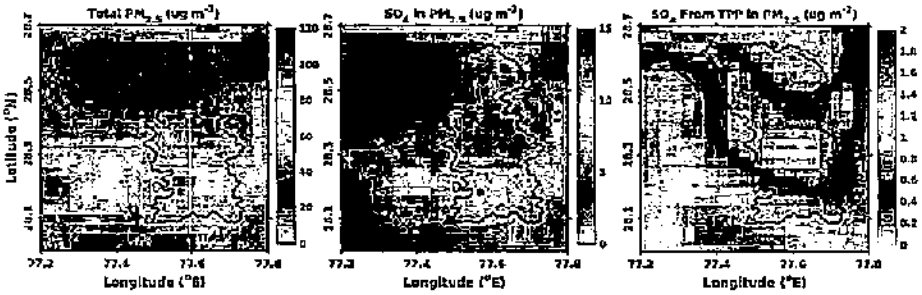
Figure 5.22: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 15th July to 14th August 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from

thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh



15th July to 14th Aug 2023

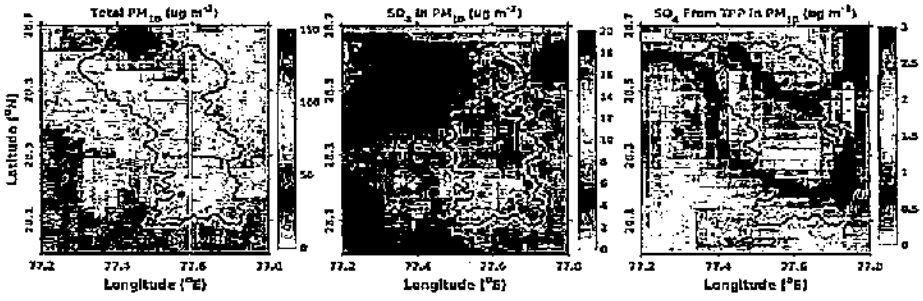


Figure 5.23: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in GBN during the simulation period from 15th July to 14th August 2023.

Based on the results from a series of meticulously planned simulations, the contribution of SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric SO_2 concentrations during Phase II of the survey (summer monsoon season) exhibits significant spatial variability across all cities. Despite this variability, we analyse the average contribution of TPPs to ambient atmospheric SO_2 concentrations in each city and city category. In Category-1 cities, which include cities with no coal-based TPP, the average contribution of TPPs to ambient SO_2 concentrations was 11.44% in Lucknow. For Category-2 cities, which have a coal-based TPP without FGD installed and located within 10km from the city boundary, Kota exhibited an average contribution of 28.9% from TPPs to ambient SO_2 levels. In Category-3 cities, which include a coal-based TPP with FGD installed and located within 10km from the city boundary, Gautam Buddha Nagar showed an average TPP contribution of 21.97%. These findings illustrate that the presence and operational status of FGDs in TPPs significantly influence the contribution of power sector emissions to ambient SO_2 levels. Category-2 cities, which lack FGD installations, displayed higher contributions compared to Category-1 and Category-3 cities, emphasizing the efficacy of FGDs in mitigating SO_2 emissions. Thus, our analysis highlights the varying impact of coal-based thermal power plants on ambient SO_2 levels during the summer monsoon season, with significant differences noted among city categories.

Summary of results from Phase-II of survey (Jul to Aug 2023)

Name of City (Measurement Site, distance from TPP)	Period of Survey	Total SO_2 ($\mu g\ m^{-3}$) ($\mu g/m^3$)	SO_2 from Power Sector ($\mu g\ m^{-3}$)
Lucknow Location-1	15-07-2023 to 14-08-2023	5.62 ± 1.14	0.45±0.03
Lucknow Location-2		5.95 ± 1.56	0.55±0.07
Kota Location-1 7 Km from Kota Super TPP		5.15 ± 1.75	3.35±1.21
Kota Location-2 40 Km from Kota Super TPP		3.12 ± 0.81	1.28±0.21
Gautam Buddha Nagar Location-1 9 Km from DADRI TPP		6.15 ± 2.56	1.41±0.43
Gautam Buddha Nagar Location-2 46 Km from DADRI TPP		5.89 ± 1.65	1.24±0.31

Table 5.4: Normalized contribution of Power sector towards ambient atmospheric SO_2 concentrations at specific measurement locations in various cities during the period of our survey from 15th July to 14th August 2023.

After discussing the average contribution of TPPs to ambient atmospheric SO_2 concentrations in each city and city category, we examine the normalized contribution of the power sector, specifically coal-based thermal power plants (TPPs), to ambient atmospheric SO_2 concentrations at specific measurement locations across different cities during the Phase II of our survey. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. As evident from the data presented in Table 5.3, our survey results confirm that ambient air SO_2 concentrations at all measurement locations across the six cities met the existing standards during the survey period. In Category-1 city Lucknow, the contribution of TPPs to SO_2 levels was relatively low, ranging from 8% to 9%, with absolute concentrations of 0.45 ± 0.03 $\mu g/m^3$ and 0.55 ± 0.07 $\mu g/m^3$. Conversely, in Category-2 city Kota, TPPs had a significantly higher impact, contributing 65% and 41% to SO_2 levels, with absolute concentrations of 3.35 ± 1.21 $\mu g/m^3$ and 1.28 ± 0.21 $\mu g/m^3$. In Category-3 city Gautam Buddha Nagar, the contribution was moderate, at 23% and 21%, with absolute concentrations of 1.41 ± 0.43 $\mu g/m^3$ and 1.24 ± 0.31 $\mu g/m^3$. This variability highlights the substantial influence of TPPs on local SO_2 concentrations, especially in cities with TPPs near their boundaries. The data suggests that while other sources of SO_2 emissions might be more prevalent in Category-1 cities, TPPs are a primary contributor in Category-2 cities. Overall, the findings indicate that the proximity to thermal power plants and the status of FGD implementation significantly affect SO_2 concentrations, with locations closer to TPPs showing higher contributions from the power sector.

Summary of results from Phase-II of survey (Jul to Aug 2023)

City	TOR PM2.5 (µg/m³)	TOR PM10 (µg/m³)	Sulfate aerosols in PM2.5 (%)	Sulfate aerosols in PM2.5 (µg/m³)	Sulfate aerosols in PM10 (%)	Sulfate aerosols in PM10 (µg/m³)	Contribution of SO2 emissions from TPPs towards Sulfate aerosols (%)	Sulfate aerosols contributing from SO2 emissions from TPPs in PM2.5 (µg/m³)	Sulfate aerosols contributing from SO2 emissions from TPPs in PM2.5 (%)	Sulfate aerosols contributing from SO2 emissions from TPPs in PM10 (µg/m³)	Sulfate aerosols contributing from SO2 emissions from TPPs in PM10 (%)
Gautam Buddha Nagar	47.05±11.49	71.13±15.68	13.65	6.42±1.31	10.09	7.18±1.69	16.54	1.06±0.43	1.25±0.43	2.26±0.80	1.75±0.52
Kota	48.69±6.14	65.74±6.47	11.73	5.71±0.72	9.71	6.38±0.53	24.08	1.38±0.17	1.54±0.15	2.82±0.36	2.34±0.23
Lucknow	34.59±7.89	52.57±3.14	11.62	4.02±0.93	8.55	4.49±0.27	10.49	0.42±0.10	0.47±0.05	1.22±0.28	0.90±0.05

Table 5.4: Contribution of Power sector towards ambient atmospheric sulfate aerosols, PM2.5 and PM10 concentrations in various category cities during the period of our survey from 15th July to 14th August 2023.

Table 5.4 summarizes the contribution of sulfate aerosols (SO_4) in PM2.5 and PM10, as well as the specific contribution of sulfate aerosols originating from SO_2 emissions from the power sector (coal based TPPs) to ambient atmospheric PM2.5 and PM10 concentrations across various cities during the survey period from 15th July to 14th August 2023. In Category-1 cities, such as Lucknow, sulfate aerosols contributed 11.62% (4.02 µg/m³) to $PM_{2.5}$ and 8.55% (4.49 µg/m³) to PM_{10}. In Category-2 cities, such as Kota, sulfate aerosols contributed 11.73% (5.71 µg/m³) to $PM_{2.5}$ and 9.71% (6.38 µg/m³) to PM_{10}. In Category-3 cities, such as Gautam Buddha Nagar, sulfate aerosols contributed 13.65% (6.42 µg/m³) to $PM_{2.5}$ and 10.09% (7.18 µg/m³) to PM_{10}. On average, the contributions of sulfate aerosols to $PM_{2.5}$ were 13.65% (6.42 µg/m³) in Category-3 cities, 11.73% (5.71 µg/m³) in Category-2 cities, and 11.62% (4.02 µg/m³) in Category-1 cities. For PM_{10}, the average contributions were 10.09% (7.18 µg/m³) in Category-3 cities, 9.71% (6.38 µg/m³) in Category-2 cities, and 8.55% (4.49 µg/m³) in Category-1 cities. These figures indicate a significant presence of sulfate aerosols in particulate matter across all city categories, with Category-3 cities showing the highest contributions.

During the Phase-II survey, we also estimated the contribution of SO_2 emissions from the energy sector, specifically coal-based thermal power plants (TPPs), to the total ambient air SO_4 (sulfate aerosol) concentration and found that it varied significantly across different cities and city categories. In the Category-1 city of Lucknow, the contribution of SO_2 emissions from TPPs towards the total ambient air SO_4 concentration was 10.49%, corresponding to an absolute concentration of 0.50 µg/m³. For the Category-2 city of Kota, the contribution of SO_2 emissions from TPPs towards the total ambient air SO_4 concentration was 24.08%, equating to an absolute concentration of 1.62 µg/m³. In the Category-3 city of Gautam Buddha Nagar, the contribution of SO_2 emissions from TPPs towards the total ambient air SO_4 concentration was 16.54%, translating to an absolute concentration of 1.25 µg/m³. Thus, Category-2 cities, with coal-based

TPPs without FGD systems, exhibit the highest contributions of SO_2 emissions from TPPs towards the total ambient air SO_4 concentration. In contrast, Category-1 cities, which have no coal-based TPPs, show the lowest contributions, while Category-3 cities, which have TPPs with FGD systems, have intermediate contributions.

The specific contribution of sulfate aerosols originating from SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric $PM_{2.5}$ and PM_{10} concentrations also varied across different cities and city categories. In Lucknow, the contribution was 1.22% (0.42 $\mu g/m^3$) in $PM_{2.5}$ and 0.90% (0.47 $\mu g/m^3$) in PM_{10}. In Kota, the contributions were 2.82% (1.38 $\mu g/m^3$) in $PM_{2.5}$ and 2.34% (1.54 $\mu g/m^3$) in PM_{10}. In Gautam Buddha Nagar, the contributions were 2.26% (1.06 $\mu g/m^3$) in $PM_{2.5}$ and 1.76% (1.25 $\mu g/m^3$) in PM_{10}. On average, the contributions of sulfate aerosols originating from SO_2 emissions from TPPs to $PM_{2.5}$ were 2.26% (1.06 $\mu g/m^3$) in Category-3 cities, 2.82% (1.38 $\mu g/m^3$) in Category-2 cities, and 1.22% (0.42 $\mu g/m^3$) in Category-1 cities. For PM_{10}, the average contributions were 1.76% (1.25 $\mu g/m^3$) in Category-3 cities, 2.34% (1.54 $\mu g/m^3$) in Category-2 cities, and 0.90% (0.47 $\mu g/m^3$) in Category-1 cities. These figures indicate that SO_2 emissions from TPPs contribute a measurable, but relatively small portion of sulfate aerosols in $PM_{2.5}$ and PM_{10}.

Overall, the contribution of SO_2 emissions from the power sector, which convert to sulfate aerosols, ranged from 1.22% to 2.82% in $PM_{2.5}$ and from 0.90% to 2.34% in PM_{10} across the cities during Phase II of the survey. This indicates variability in the impact of power sector emissions on sulfate aerosol concentrations. While SO_2 emissions from TPPs do contribute to sulfate aerosol mass concentrations in $PM_{2.5}$ and PM_{10}, their overall contribution remains a small fraction (less than 3%) of the total $PM_{2.5}$ and PM_{10} mass concentrations, especially during the summer monsoon season, indicating that other sources are more significant contributors to ambient air PM levels.

CHAPTER-6: SURVEY OF AMBIENT ATMOSPHERIC SO_2 CONCENTRATIONS IN DIFFERENT CATEGORY OF CITIES: PHASE-III

In the first phase of this survey, measurements were conducted in six distinct cities: New Delhi, Kolkata, Ghaziabad, Gautam Buddha Nagar, Nagpur, and Hyderabad, with two cities from each category. These measurements were carried out at two different locations within each city for a one-month period during the spring and pre-monsoon season (February to May). This phase provided valuable data for understanding the baseline levels and variations in ambient atmospheric SO_2 concentrations across these cities during the spring and pre-monsoon seasons. To enhance the robustness of our findings with statistically significant data, we decided to conduct simultaneous measurements at two different locations within each city, extend the survey to other seasons, and include additional cities. Therefore, Phase II of this survey involved simultaneous measurements of SO_2 concentrations at two different locations in three cities: Lucknow, Kota, and Gautam Buddha Nagar, during the monsoon season. Conducting simultaneous measurements from different locations allowed us to compare ambient air SO_2 concentration values at varying distances from coal-based thermal power plants (TPPs) in Category-2 and Category-3 cities. Additionally, it enabled us to assess whether the measured concentrations complied with the National Ambient Air Quality Standards (NAAQS) established by the Central Pollution Control Board (CPCB).

To further enhance the robustness and statistical significance of our findings, we extended the survey to additional cities and conducted simultaneous SO_2 concentration measurements at different locations within these cities during the other seasons. Therefore, the second phase of the survey aimed to measure ambient atmospheric SO_2 concentrations simultaneously at two different locations in cities from all three categories during the monsoon season. In the third phase, we extended these measurements to more cities during the winter season.

Thus, Phase III of the survey was designed with the objective of measuring SO_2 concentrations during the winter season in (a) cities/towns with FGD installed in TPPs, and (b) cities/towns with TPPs without FGD installed. Additionally, the survey aimed to assess the contribution of SO_2 emissions from TPPs to sulfate aerosols present in PM10 and PM2.5 in both types of cities. We also sought to determine, based on our measurement-based survey, whether FGD installations were making a difference in ambient air SO_2 concentrations with FGD-equipped TPPs.
Cities across the country were classified into three categories based on their proximity to coal-based thermal power plants (TPPs) and the implementation status of Flue Gas Desulfurization (FGD) systems in these TPPs. As mentioned earlier in Chapter-2, these categories are:

Category-1: Cities with no coal based TPP.

Category-2: Cities with a coal based TPP in which FGD has not been installed and the TPP is located within 10km from the boundary of the city.

Category-3: Cities with a coal based TPP in which FGD has been installed and the TPP is located within a distance of 10km from the boundary of the city.

The third phase of the survey started on 8th November 2023 and ended on 21st February 2024.

Cities and Measurement Sites Selected for Phase-III of the Survey

Survey of ambient atmospheric SO_2 concentrations in different category of cities have been conducted in three phases to cover different cities in different geographical locations of the country and different seasons.

In the first phase of this survey, measurements have been conducted in six different cities namely, New Delhi, Kolkata, Ghaziabad, Gautam Buddha Nagar, Nagpur, and Hyderabad (two cities from each category). Measurements during the first phase of the survey were conducted at two different locations for one month period each in all six cities during spring and pre-monsoon season (February to May). In the second phase of this survey, simultaneous measurements have been conducted in three different cities namely, Lucknow, Kota, and Gautam Buddha Nagar (one city from each category). During the second phase of our survey, simultaneous measurements were conducted at two different locations in all three cities during monsoon season (July- August).

To make the findings of our survey more robust with statistically significant data, it was decided to extend this survey to a few more cities by conducting simultaneous measurements of SO_2 concentrations at different locations in these cities during the winter season as well. We conducted measurement-based survey in the following four cities corresponding to category-2 and category-3 during winter season.

Table 6.1: Cities selected for conducting the survey Phase-III

S. No.	City/District Name	City Category	Capacity of TPP	No. of Units	Population of the city
1	Kota (Rajasthan)	Category-2	1240 MW	7	1951014
2	Gautam Buddha Nagar (U.P.)	Category-3	1820 MW	6	1648115
3	Shahdol (M. P.)	Category-2	1340 MW	5	86681
4	Khargone (M. P.)	Category-3	1320 MW	2	116150

It is worth mentioning here that two (Kota and Gautam Buddha Nagar) out of the four cities chosen for our survey fall under the category of "non-attainment cities with a million-plus population" according to the Central Pollution Control Board (CPCB) classification. In all four

cities, we conducted the survey by performing simultaneous measurements at three different locations for a one-and-a-half-month period at each site.

For cities with TPPs in their vicinity, we designed the survey to measure ambient air SO_2 concentrations at two sites close to the TPP (approximately 1-10 km away), one in the upwind direction and the other in the downwind direction. Additionally, we conducted measurements at a third site located in the downwind direction of the TPP, at a distance of about 40-60 km from the TPP. We first conducted simultaneous measurements at three sites each in Kota and Gautam Buddha Nagar from November 8th to December 24th 2023. Subsequently, we performed simultaneous measurements at three sites each in Shahdol and Khargone from January 8th to February 21st 2024.

Dispersion Modeling (using AERMOD) of SO_2 from Thermal Power Plants (TPPs) to understand the distance of influence of TPPs towards ambient SO_2 concentration and identification of measurement sites for the survey

The AERMOD Dispersion Model Version 9 was employed to understand and quantify the dispersion characteristics of SO_2 from various TPPs based on their operational capacity during the survey period. Dispersion models like AERMOD, which are typically Lagrangian models, use mathematical formulations to characterize the atmospheric processes dispersing pollutants emitted by a source. With emissions and meteorological inputs, a dispersion model can predict concentrations at selected downwind receptor locations. Our goal was to use the results of our dispersion modelling to understand the extent of TPP SO_2 emission influence on ambient air concentrations of SO_2 and to identify suitable measurement sites for Phase III of our survey. In this study, the horizontal resolution of the dispersion modelling simulations was set to 500m x 500m, and the simulations were performed over a model domain area of 300km x 300km, with the thermal power plant location as the centre of the model domain in each simulation.

Figure 6.1 displays the spatial pattern of the highest hourly, 24-hourly, and monthly dispersion of SO_2 from the Dadri TPP during the simulation period from November 8th to December 24th, 2023. Figure 6.2 presents the results of our AERMOD simulation, showing SO_2 concentrations as a function of distance from the Dadri TPP in the direction of maximum dispersion during the simulation period. The graphs illustrate how SO_2 concentrations decrease with increasing distance from the TPP. With a horizontal resolution of 500m, all concentrations plotted in Figures 6.1 and 6.2 represent an area of 500m x 500m around each receptor point. This means that the SO_2 concentrations corresponding to the 0 km label on the X-axis in various panels of Figure 6.2 refer to the average surface concentration of SO_2 over an area of 500m x 500m around the TPP. Similarly, concentrations at any distance from the TPP, as marked on the X-axis in Figure 6.2, refer to the average surface concentration over an area of 500m x 500m around the receptor point at that distance from the TPP. The top panel in Figure 6.2 shows the highest hourly SO_2

concentrations, revealing a sharp decline as the distance increases, particularly noticeable within the first 25 km from the TPP. Beyond this range, the concentrations level off but continue to decrease gradually up to 120 km. The middle and bottom panels in Figure 6.2 focus on the highest 24-hour and monthly average concentrations, respectively. Both metrics show a similar pattern of decrease, with concentrations remaining significantly below the National Ambient Air Quality Standards (NAAQS) for SO_2. Specifically, the 24-hour concentration limit is set at 80 $\mu g/m^3$, and the annual (there is no standard for monthly) average at 50 $\mu g/m^3$, both of which are well adhered to at all distances from the TPP.

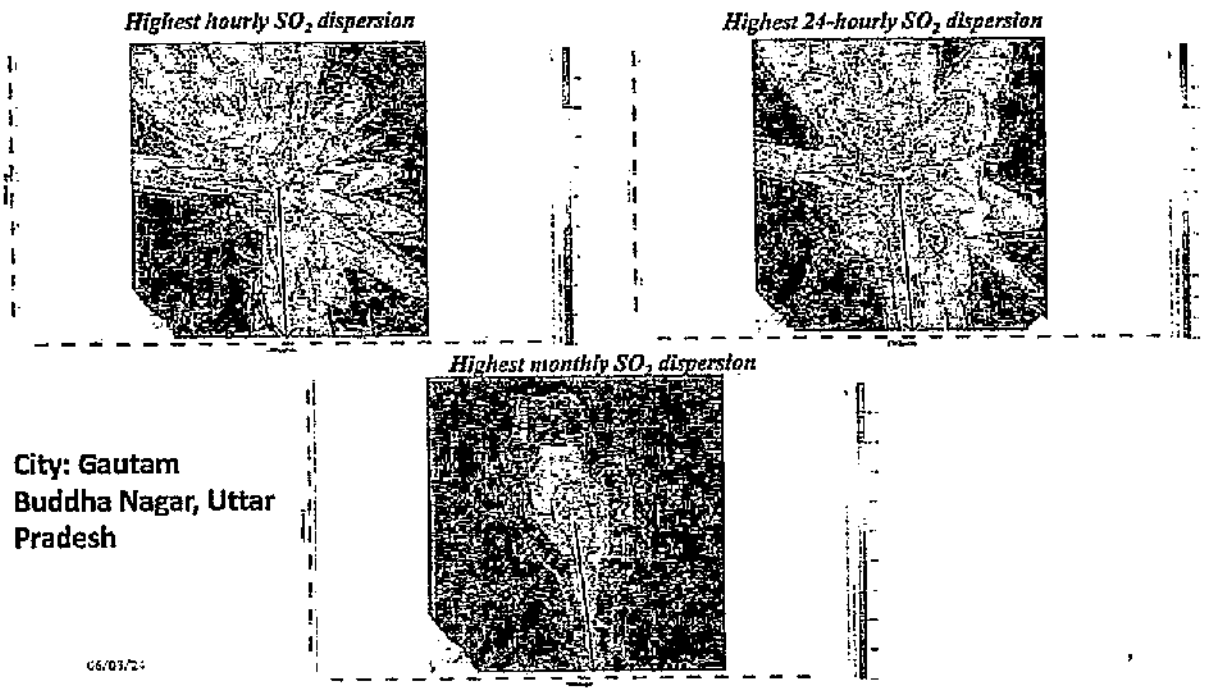


Figure 6.1: Highest hourly, 24-hourly, and monthly dispersion of SO_2 from the Dadri TPP during the simulation period from 8th November to 24th December 2023. The black arrows show the direction of maximum dispersion of SO2 as simulated by the model.

City: Gautam Buddha Nagar, Uttar Pradesh

SO_2 Concentration versus Distance plot for Nov-Dec 2024

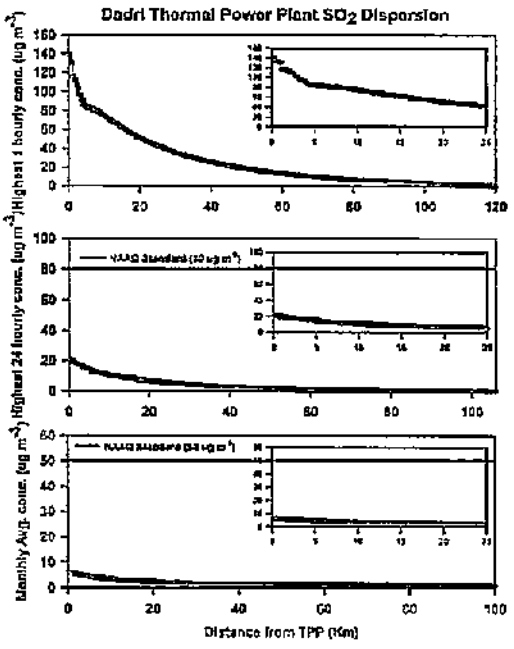


Figure 6.2: Highest hourly, 24-hourly, and monthly concentration of SO_2 plotted as a function of distance from the Dadri TPP in the direction of maximum dispersion during the simulation period from 8th November to 24th December 2023.

These results underscore the effective dispersion of SO_2 emissions with distance from the source, highlighting the localized nature of the impact near the TPP and demonstrating compliance with environmental standards at greater distances. This dispersion modeling helps in assessing the environmental impact of SO_2 emissions and in planning mitigation strategies effectively.

It is important to note that air pollution dispersion models like AERMOD are designed to understand the dispersion of primary air pollutants by considering only their dry and wet deposition processes, without accounting for any chemical reactions that might occur during their atmospheric dispersion. For example, as the SO_2 plume travels downwind, it is likely to undergo oxidation through gas-phase reactions with hydroxyl radicals (OH) during the daytime or aqueous-phase heterogeneous oxidation with H_2O_2 and O_3 through its dissolution in cloud and fog water. Because dispersion models do not account for these chemical processes, the actual decrease in SO_2 concentrations with increasing distance from the TPP is likely faster than what is simulated. Chemical transport models like WRF-Chem do consider the transformation of primary air pollutants into secondary pollutants but are typically run at a coarser resolution than dispersion models. Therefore, using both dispersion models and chemical transport models together provides a better understanding of the dispersion of air pollutants like SO_2 that serve as precursors for secondary pollutants.

The results of our dispersion modelling of SO_2 emissions from the NTPC Dadri TPP in Gautam Buddha Nagar using AERMOD model helped us determine the extent of SO_2 emission influence on ambient air concentrations of SO_2 and identify suitable measurement sites for Phase III of our survey. As previously mentioned, we designed Phase III survey to measure ambient air SO_2 concentrations at two sites close to the TPP (approximately 1-10 km away), one in the upwind direction and the other in the downwind direction. Additionally, we conducted measurements at a third site located in the downwind direction, approximately 40-60 km from the TPP.

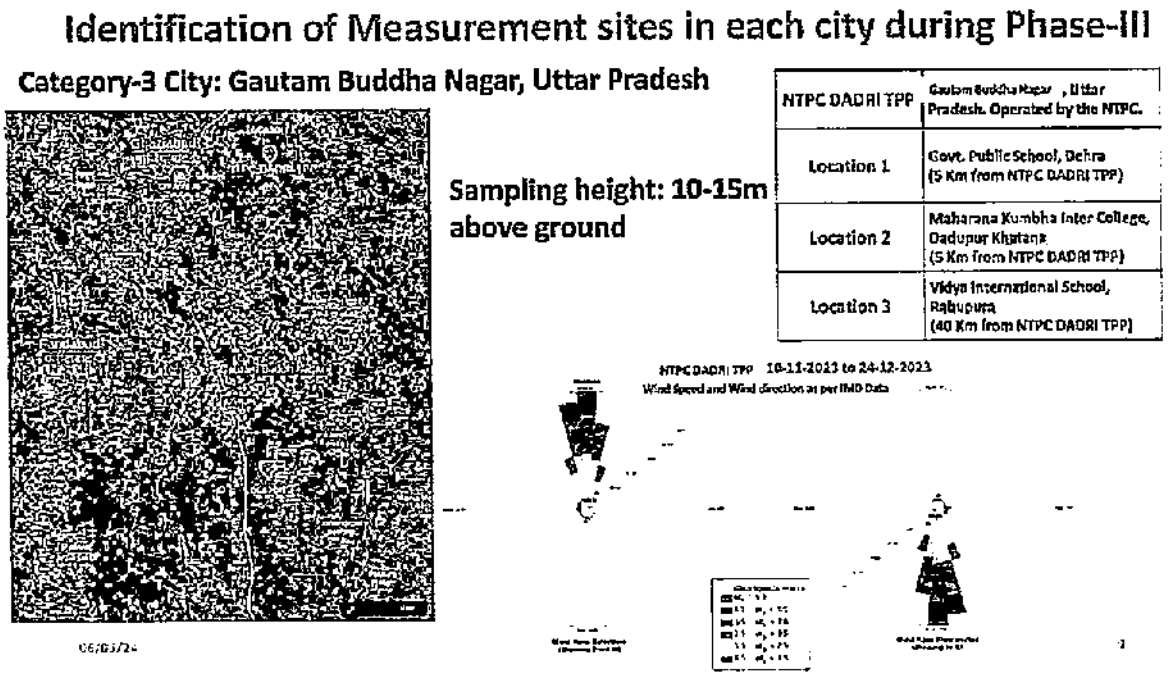


Figure 6.3: Satellite image (google earth) showing location of the measurement sites for Category-3 city GBN considered during Phase-III of the survey

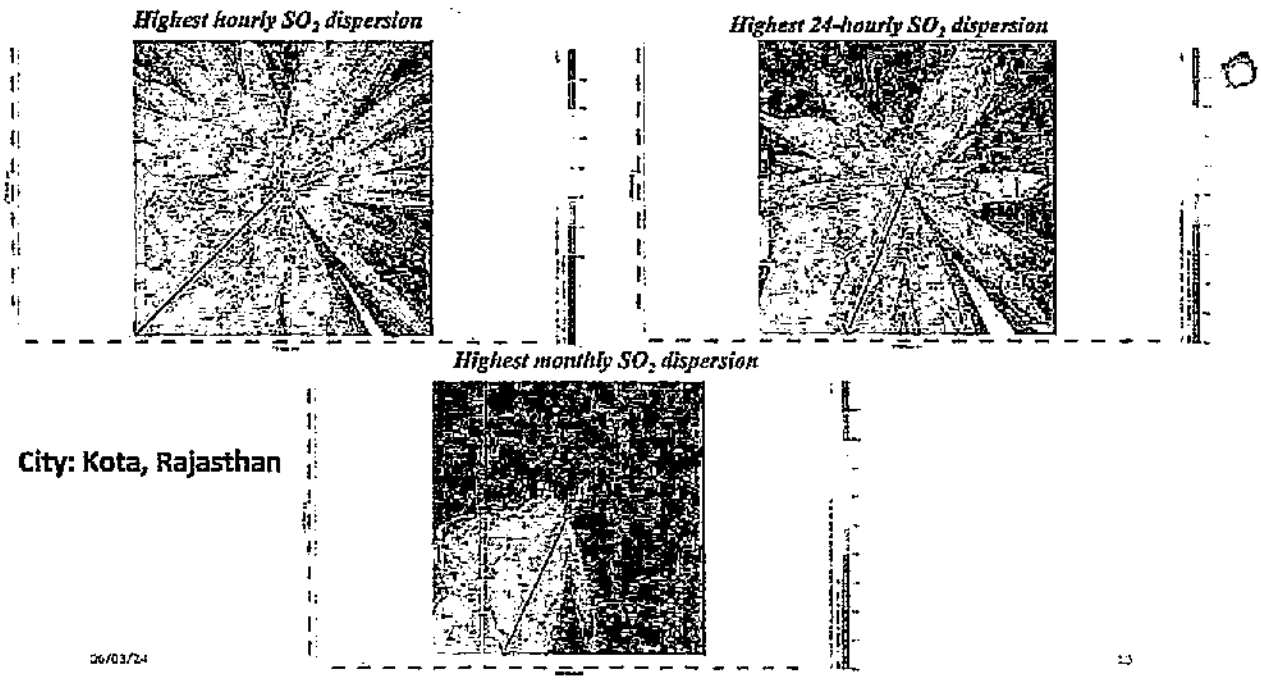


Figure 6.4: Highest hourly, 24-hourly, and monthly dispersion of SO_2 from the Kota Super TPP during the simulation period from 8th November to 24th December 2023. The black arrows show the direction of maximum dispersion of SO2 as simulated by the model.

City: Kota, Rajasthan

SO_2 Concentration versus Distance plot for Nov-Dec 2024

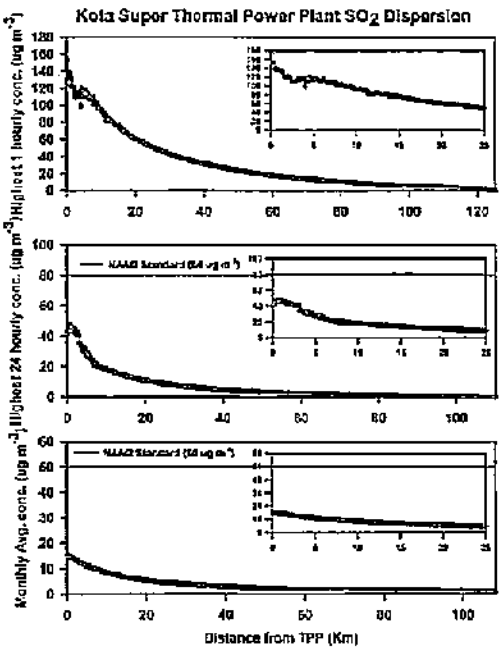


Figure 6.5: Highest hourly, 24-hourly, and monthly concentration of SO_2 plotted as a function of distance from the Kota TPP in the direction of maximum dispersion during the simulation period from 8th November to 24th December 2023.

Figure 6.5 displays the results of our dispersion modeling using AERMOD for SO_2 emissions from the Kota Super Thermal Power Plant (TPP) in Rajasthan, illustrating the relationship between SO_2 concentration and distance from the TPP for November-December 2024. The top panel in Figure 6.5 shows the highest hourly SO_2 concentrations, which decrease significantly as the distance from the TPP increases, particularly within the first 20 km. Beyond this range, the concentrations continue to decline but at a slower rate, extending up to 120 km. The middle panel illustrates the highest 24-hour SO_2 concentrations, with a sharp initial drop-off that levels out as the distance increases, staying well below the National Ambient Air Quality Standards (NAAQS) limit of 80 $\mu g/m^3$ at all distances from the TPP. The bottom panel shows the monthly average SO_2 concentrations, also demonstrating a rapid decrease within the first 20 km, remaining under the NAAQS limit of 50 $\mu g/m^3$ at all distances from the TPP. These results highlight the localized impact of SO_2 emissions from the TPP, with significant concentration reductions as the distance from the emission source (or the TPP) increases, ensuring compliance with environmental standards. This analysis underscores the importance of spatial considerations in air quality management around thermal power plants.

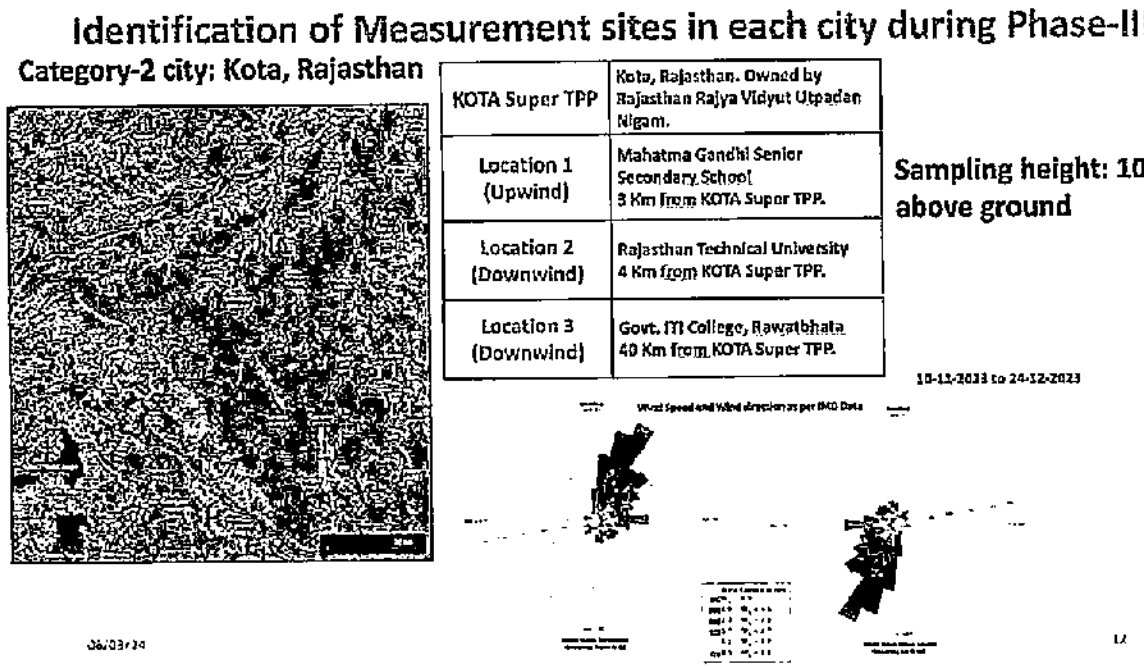


Figure 6.6: Satellite image (google earth) showing location of the measurement sites for Category-2 city Kota considered during Phase-III of the survey

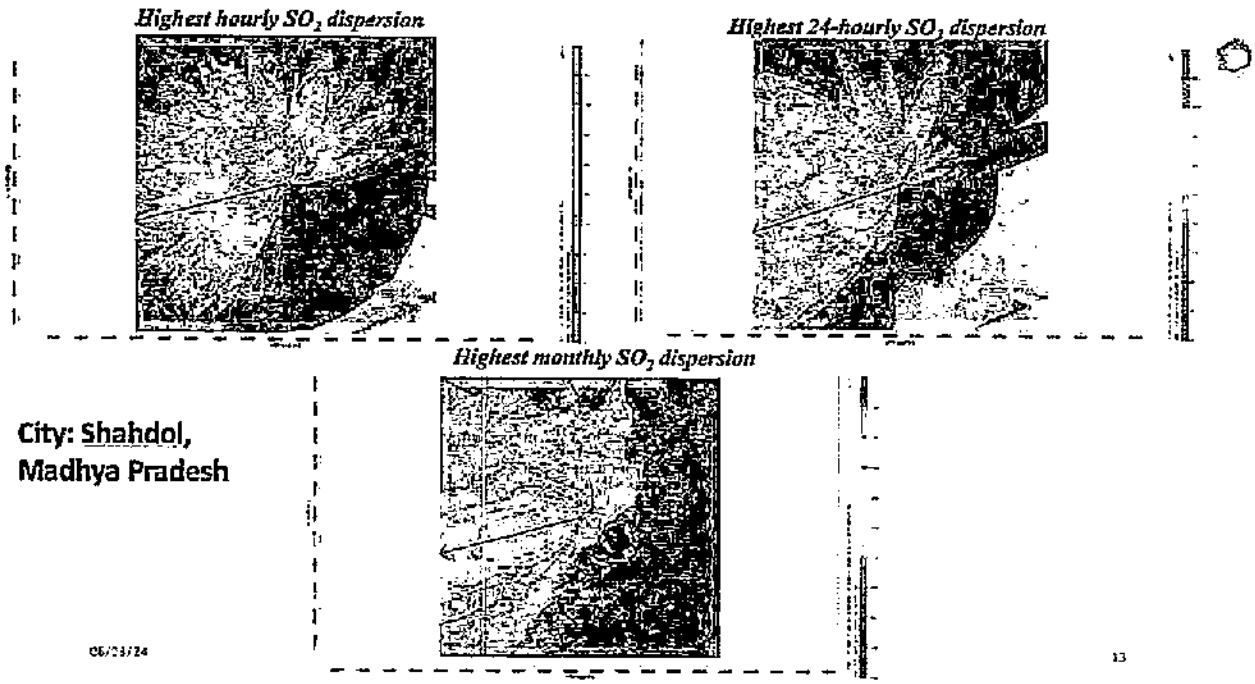


Figure 6.7: Highest hourly, 24-hourly, and monthly dispersion of SO_2 from the Shahdol TPP during the simulation period from 8th January to 21st February 2024. The black arrows show the direction of maximum dispersion of SO_2 as simulated by the model.

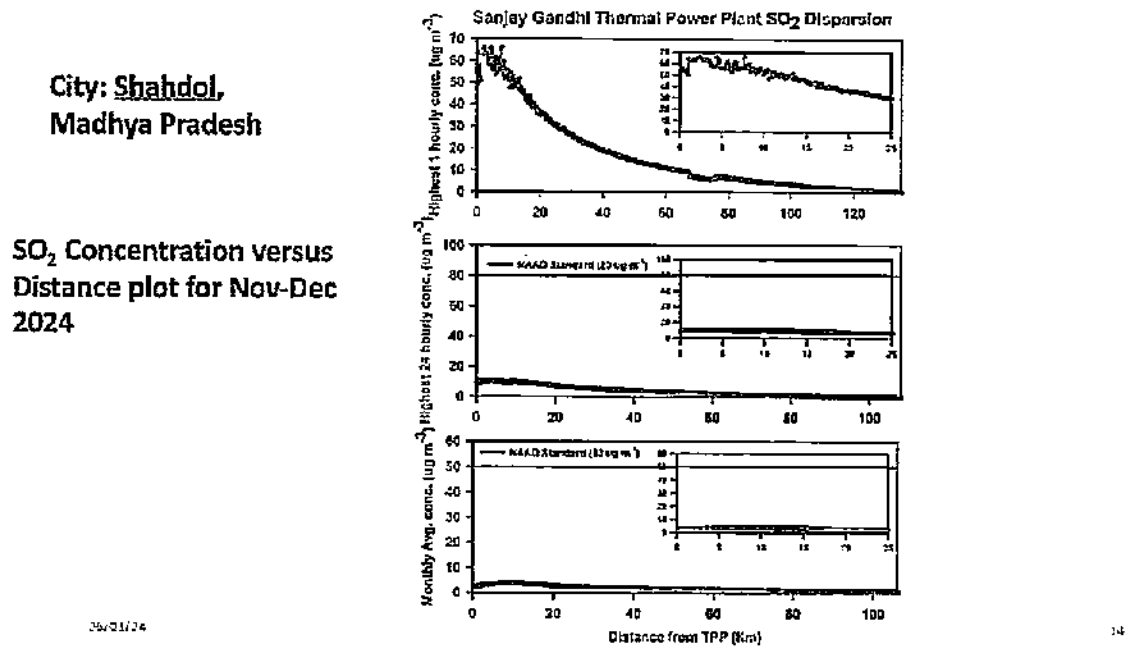


Figure 6.8: Highest hourly, 24-hourly, and monthly concentration of SO_2 plotted as a function of distance from the Shahdol TPP in the direction of maximum dispersion during the simulation period from 8th January to 21st February 2024.

Figure 6.8 presents the results of our dispersion modeling using AERMOD for SO_2 emissions from the Sanjay Gandhi Thermal Power Plant (TPP) in Shahdol, Madhya Pradesh, showing the

relationship between SO_2 concentration and distance from the TPP for November-December 2024. The top panel depicts the highest hourly SO_2 concentrations, which demonstrate a steep decline within the first 20 km from the TPP, followed by a more gradual decrease up to 120 km. The middle panel shows the highest 24-hour SO_2 concentrations, which similarly drop sharply within the initial 20 km and then level out, maintaining values well below the National Ambient Air Quality Standards (NAAQS) limit of 80 µg/m³ at all distances from the TPP. The bottom graph illustrates the monthly average SO_2 concentrations, exhibiting a rapid reduction within the first 20 km and remaining under the NAAQS limit of 50 µg/m³ at all distances from the TPP. These results highlight the localized impact of SO_2 emissions from the TPP, with significant concentration reductions as the distance from the emission source increases, ensuring compliance with environmental standards beyond a certain range.

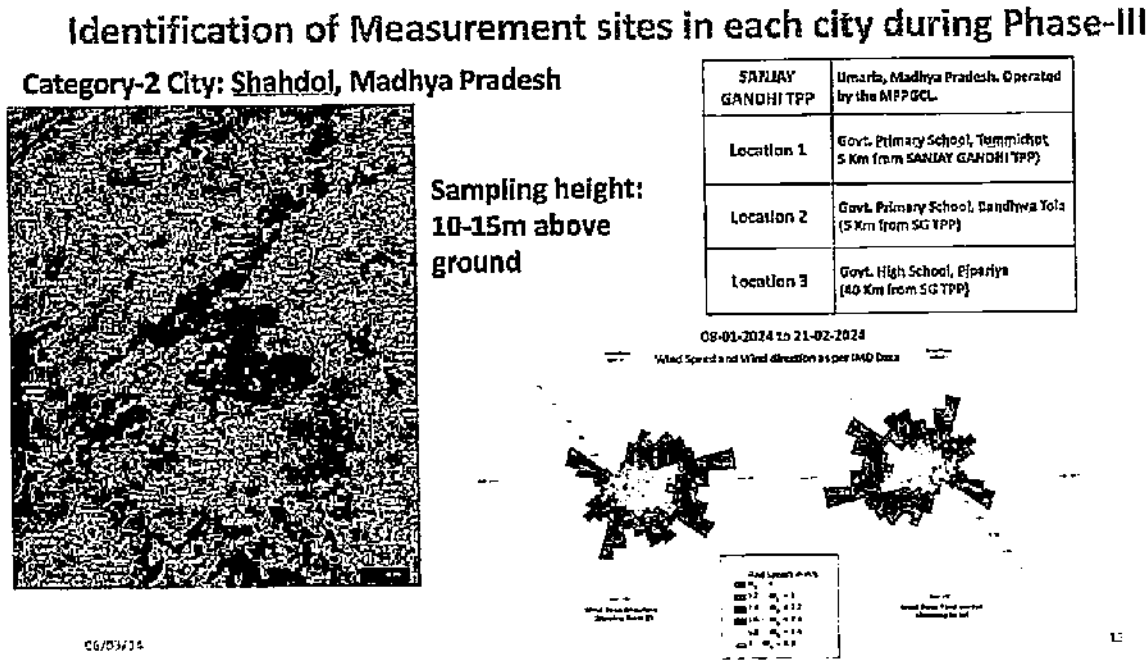


Figure 6.9: Satellite image (google earth) showing location of the measurement sites for Category-2 city Shahdol considered during Phase-III of the survey

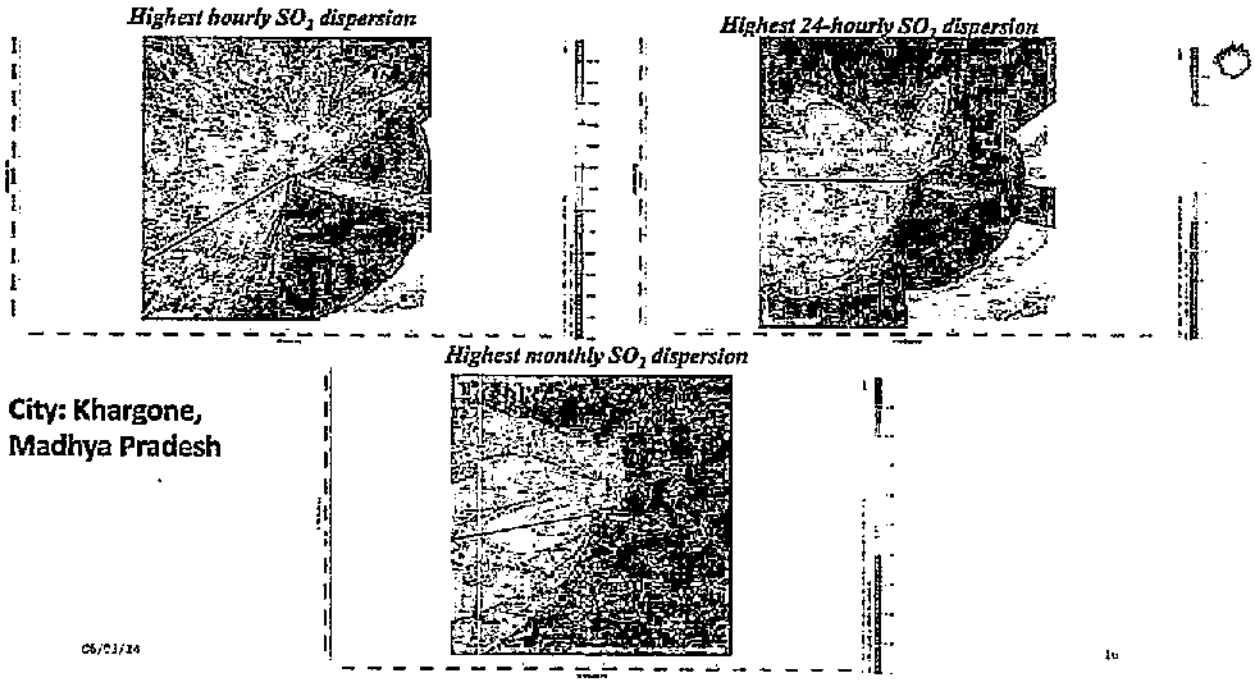


Figure 6.10: Highest hourly, 24-hourly, and monthly dispersion of SO_2 from the Khargone TPP during the simulation period from 8th January to 21st February 2024. The black arrows show the direction of maximum dispersion of SO_2 as simulated by the model.

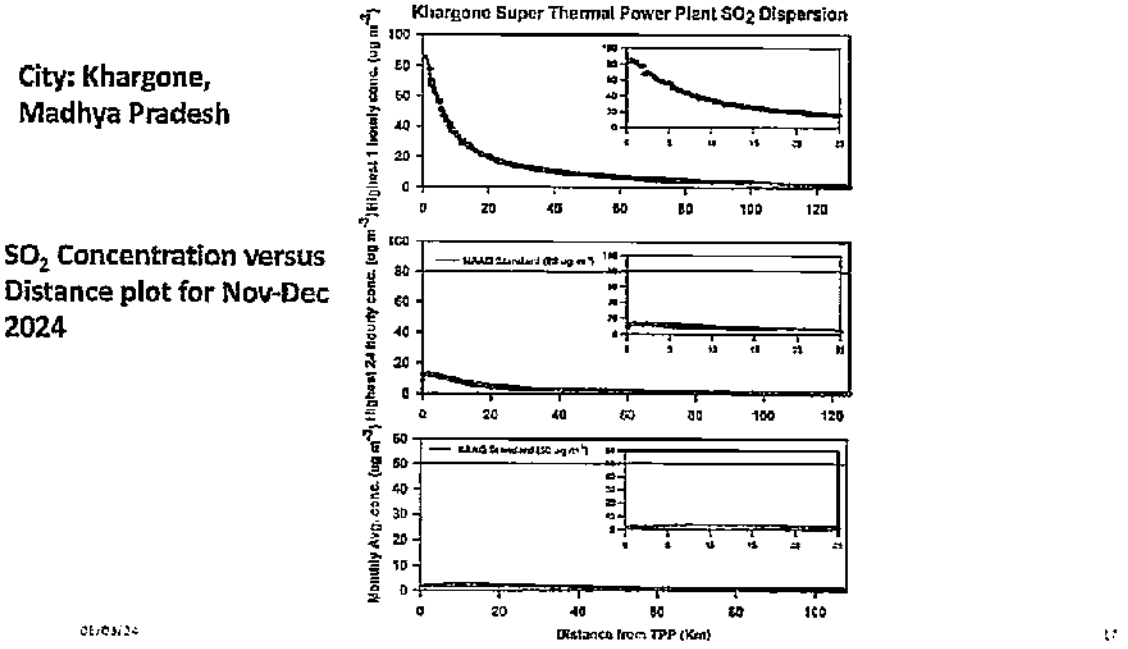


Figure 6.11: Highest hourly, 24-hourly, and monthly concentration of SO_2 plotted as a function of distance from the Khargone TPP in the direction of maximum dispersion during the simulation period from 8th January to 21st February 2024.

Figure 6.11 displays the results of our dispersion modeling using AERMOD for SO_2 emissions from the Khargone Super Thermal Power Plant (TPP) in Khargone, Madhya Pradesh, illustrating the relationship between SO_2 concentration and distance from the TPP for November-December 2024. The top panel shows the highest hourly SO_2 concentrations, which significantly decrease within the first 20 km from the TPP and continue to decline gradually up to 120 km. The middle panel depicts the highest 24-hour SO_2 concentrations, which similarly drop sharply within the initial 20 km and then level off, maintaining values well below the National Ambient Air Quality Standards (NAAQS) limit of 80 $\mu g/m^3$ at all distances from the TPP. The bottom panel presents the monthly average SO_2 concentrations, exhibiting a rapid reduction within the first 20 km and remaining under the NAAQS limit of 50 $\mu g/m^3$ at all distances from the TPP. These results highlight the localized impact of SO_2 emissions from the TPP, with significant concentration reductions as the distance from the emission source increases, ensuring compliance with environmental standards. This analysis underscores the importance of considering spatial dispersion when assessing the environmental impact of thermal power plant emissions.

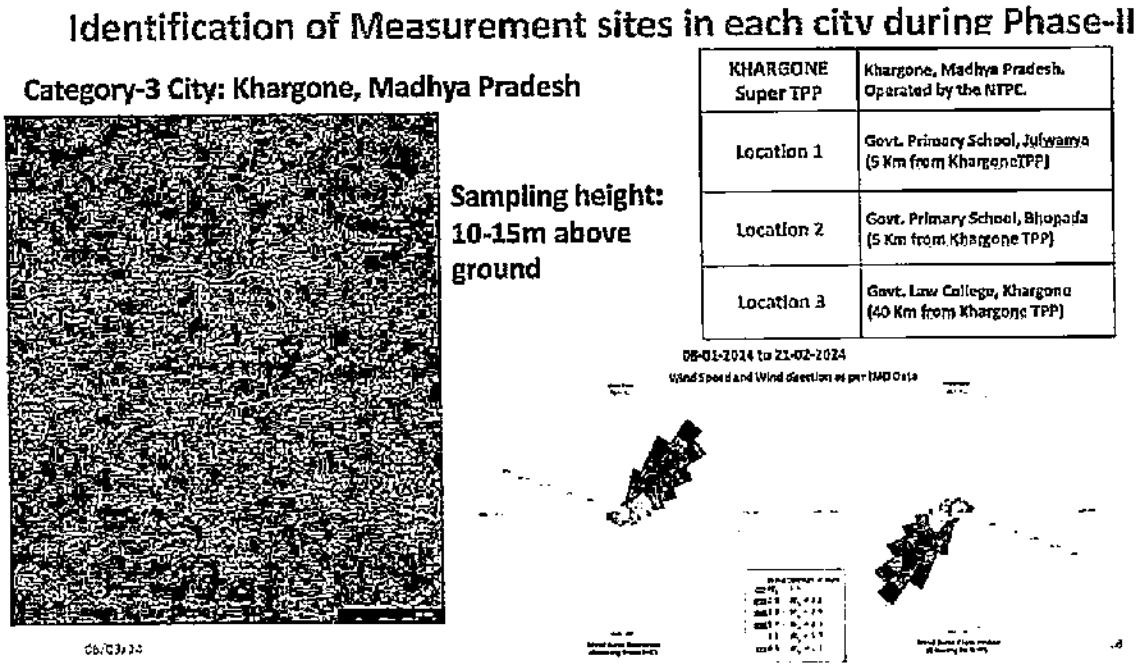


Figure 6.12: Satellite image (google earth) showing location of the measurement sites for Category-2 city Khargone considered during Phase-III of the survey

Measurement Plan for Phase-III of the Survey

We made simultaneous measurements at three pre-identified locations in each of the four cities so as to avoid any biases in our measured SO_2 concentration data due to seasonal variations in SO_2 concentrations caused by seasonal variations in temperature, wind, relative humidity, and other meteorological variables which influence the transport and removal of SO_2 and hence the lifetime of SO_2 in the atmosphere. As all cities considered in Phase III had TPPs in their vicinity,

we designed the survey to measure ambient air SO_2 concentrations at two sites close to the TPP (approximately 1-10 km away), one in the upwind direction and the other in the downwind direction. Additionally, we conducted measurements at a third site located in the downwind direction of the TPP, at a distance of about 40-60 km from the TPP. We first conducted simultaneous measurements at three sites each in Kota and Gautam Buddha Nagar from November 8th to December 24th 2023. Subsequently, we performed simultaneous measurements at three sites each in Shahdol and Khargone from January 8th to February 21st 2024. We made continuous measurements at every 10-minute intervals from three different locations in each of these cities for 45 days during the survey period. It was important to make simultaneous measurements in each of the six different measurement locations spread across the three cities in the same month or season so that our measurement data can be considered as truly representative SO_2 concentrations from each of the cities in the same season. This avoids any kind of bias in our measured SO_2 concentrations due to seasonal variability of temperature, wind, relative humidity, and other meteorological variables which influence the transport and removal of SO_2 from the atmosphere. That means, we measured at least 6,480 air samples at each location and a total of at least 19,440 samples were collected in each city. Thus, ambient SO_2 concentrations from a total of three different cities were surveyed during Phase-III of our study.

Measurement technique and equipment involved:
We used the same equipment and followed the same measurement techniques as described in Chapter 2; therefore, those details are not repeated here.

Measurement data from Phase-III of the Survey

This section presents the results of the measurements conducted in various category cities across the country during Phase III of our survey. In this phase, we first conducted simultaneous measurements at three sites each in Kota and Gautam Buddha Nagar from November 8th to December 24th, 2023. Subsequently, we performed simultaneous measurements at three sites each in Shahdol and Khargone from January 8th to February 21st, 2024. Table 6.2 summarizes the daily mean, maximum instantaneous, and minimum instantaneous values of ambient air SO_2 concentrations measured at three different locations in each of the four cities selected for Phase III of our survey during the winter season.

In the Category 2 city of Kota, the maximum instantaneous ambient air SO_2 concentration was measured to be 68.09 $\mu g/m^3$, the minimum was 0.77 $\mu g/m^3$, and the daily mean values ranged from 3.23 ± 0.71 $\mu g/m^3$ to 11.23 ± 4.94 $\mu g/m^3$. In Shahdol, another Category 2 city, the maximum ambient air SO_2 concentration was 22.91 $\mu g/m^3$, the minimum was 1.06 $\mu g/m^3$, and the daily mean values ranged from 4.42 ± 0.78 $\mu g/m^3$ to 5.78 ± 1.13 $\mu g/m^3$. In the Category 3 city of

Gautam Buddha Nagar, the maximum instantaneous SO_2 concentration was 70.14 µg/m³, the minimum was 0.54 µg/m³, and the daily mean values ranged from 6.51 ± 0.93 µg/m³ to 12.51 ± 2.82 µg/m³. It is noteworthy that the highest values in both Kota and Gautam Buddha Nagar were measured on November 13th, the day after the Diwali festival, which is characterized by the bursting of firecrackers that significantly contributed to these peak values. Excluding this anomalous high SO_2 concentration during the Diwali festival, the maximum instantaneous SO_2 concentration measured in Gautam Buddha Nagar and Kota during our survey was 36.41 µg/m³ and 48.56 µg/m³ respectively. In Khargone, another Category 3 city, the maximum ambient air SO_2 concentration was 11.73 µg/m³, the minimum was 1.14 µg/m³, and the daily mean values ranged from 4.24 ± 0.31 µg/m³ to 4.39 ± 0.43 µg/m³.

Summarizing by city categories, Category 2 cities had maximum instantaneous SO_2 concentrations of up to 68.09 µg/m³ and minimum concentrations down to 0.77 µg/m³, with daily mean values ranging from 3.23 to 11.23 µg/m³. Category 3 cities had maximum concentrations of up to 70.14 µg/m³ and minimum concentrations down to 0.54 µg/m³, with daily mean values ranging from 4.24 to 12.51 µg/m³. These results highlight the variability in ambient air SO_2 concentrations across different locations and city categories, with Category 3 cities generally showing higher SO_2 levels. Additionally, the measured SO_2 concentrations were generally higher at downwind sites compared to upwind sites, and SO_2 levels tended to decrease with increasing distance from the TPP across all cities.

As the National Ambient Air Quality Standards (NAAQS) or the maximum permissible limit of ambient air SO_2 concentrations based on 24 hours average measurements for industrial, residential, rural, and other areas as notified by the MoEF&CC, Govt. of India is 80 µg/m³, results of our survey confirm that the ambient air SO_2 concentrations in all cities are meeting the existing standards during the period of our survey.

As evident from Table 6.2, the daily mean values of ambient air SO_2 concentrations measured at various locations in all four cities during Phase III of our survey are comparable to the SO_2 data from the CPCB/SPCB/PCC measurement sites in those cities (https://cpcb.nic.in/air-pollution/), thereby validating the robustness of our collected data.

Next, we discuss the findings of our survey from all four cities one by one with more details. Figure 6.13 show the time series of daily mean ambient SO_2 concentrations measured from November 8 to December 24, 2023, at three sites in Gautam Buddha Nagar (GBN). One site is upwind (Location-1) and two are downwind (Location-2 and Location-3) relative to the Dadri Thermal Power Plant (TPP). At Location-1, which is 5 km upwind from the TPP, SO_2 concentrations remained relatively low, fluctuating between approximately 5 and 20 µg/m³, with standard deviation bars indicating moderate daily variability. In contrast, at the downwind sites, Location-

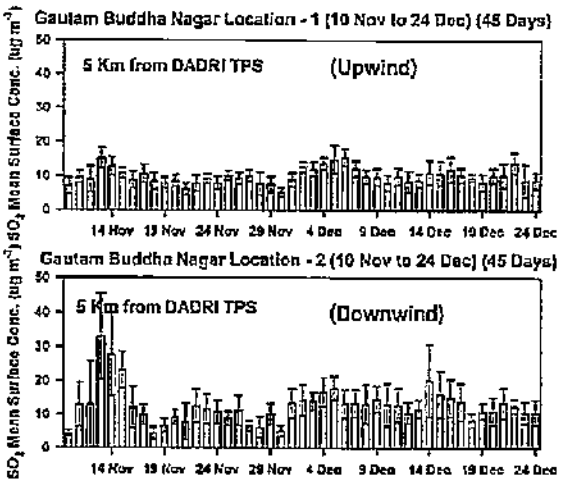
2 (5 km from the TPP) and Location-3 (40 km from the TPP), SO_2 concentrations were higher and more variable. Location-2 recorded highest daily mean values ranging from about 10 to 35 μg/m³, showing noticeable peaks around mid-November and early December.

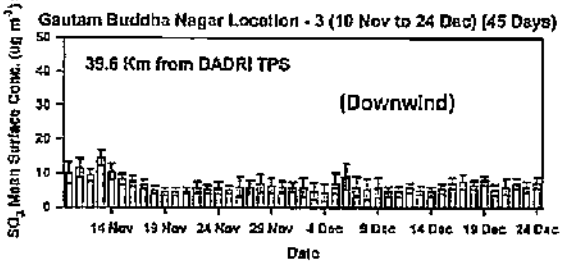
Summary of survey results from Phase-III (Nov 2023 to Feb 2024)

Name of City (Measurement Site/Distance from TPP)	Period of Survey	The Study SO_2 Concentration (μg m⁻³)			CPCB/SPCB measurements SO_2 (μg/m³)
		Maximum (Instantaneous)	Minimum (Instantaneous)	Daily Mean ± 1σ (NAAQS = 80 μg m⁻³)	
3 Km from Kota Super TPS (upwind)	10-11-2023 to 24-12-2023 (1.5 months)	29.21	0.89	5.13 ± 1.96	8.97 ± 2.34
4 Km from Kota Super TPS (downwind)		68.09	1.54	11.23 ± 4.94	
40 Km from Kota Super TPS (downwind)		27.74	0.77	3.23 ± 0.71	
5 Km from DADRI TPP (upwind)	10-11-2023 to 24-12-2023 (1.5 months)	25.14	2.46	9.82 ± 1.59	12.48 ± 1.74
5 Km from DADRI TPP (downwind)		70.14	1.19	12.51 ± 2.82	
40 Km from DADRI TPP (downwind)		18.61	0.54	6.51 ± 0.93	
5 Km from SG TPS (upwind)	08-01-2024 to 21-02-2024 (1.5 months)	13.58	1.64	5.21 ± 1.58	6.11 ± 1.85
5 Km from SG TPS (downwind)		22.91	1.19	5.78 ± 1.13	
40 Km from SG TPS (downwind)		12.73	1.06	4.42 ± 0.78	
5 Km from Khargone TPP (upwind)	08-01-2024 to 21-02-2024 (1.5 months)	9.52	2.37	4.38 ± 0.38	3.37 ± 0.85
5 Km from Khargone TPP (downwind)		11.73	1.14	4.24 ± 0.31	
40 Km from Khargone TPP (downwind)		8.37	1.45	4.39 ± 0.43	

Table 6.2: Daily mean, maximum, and minimum values of ambient air SO_2 concentration (μg/m³) measured at two different locations of four different cities classified under three different categories from across the country during Phase-III of our survey are listed here. SO_2 concentrations data from CPCB/SPCB measurements sites from each city are also mentioned.

Time series of daily mean ambient air concentration of SO_2 (μg/m³) measured in GBN





National Ambient Air Quality Standards (NAAQS)
(NAAQS Notification dated 18th November 2009)

Sl. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air: Industrial, Residential, Rural and other Areas	Concentration in Ambient Air: Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
1	Sulphur Dioxide (SO_2), μg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

There has been no occurrences of ambient SO_2 concentrations exceeding the NAAQS at any of the measurement locations in GBN throughout the period of our survey (Even the instantaneous values have never exceeded the standard)

Figure 6.13: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (8th November to 24th December 2023) as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of GBN. Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Location-3 exhibited daily mean SO_2 concentrations between roughly 5 and 20 µg/m³, with less pronounced peaks and lower overall variability compared to Location-2. It is worth mentioning here that despite the higher SO_2 levels at the downwind sites, none of the measured daily mean concentrations at any of the locations exceeded the National Ambient Air Quality Standards (NAAQS) limit of 80 µg/m³. This indicates that the ambient air quality in terms of SO_2 concentrations remained well within permissible levels throughout the survey period, even considering the instantaneous values reflected by the vertical standard deviation bars. This further confirms the effective management of SO_2 emissions in the vicinity of the Dadri TPP.

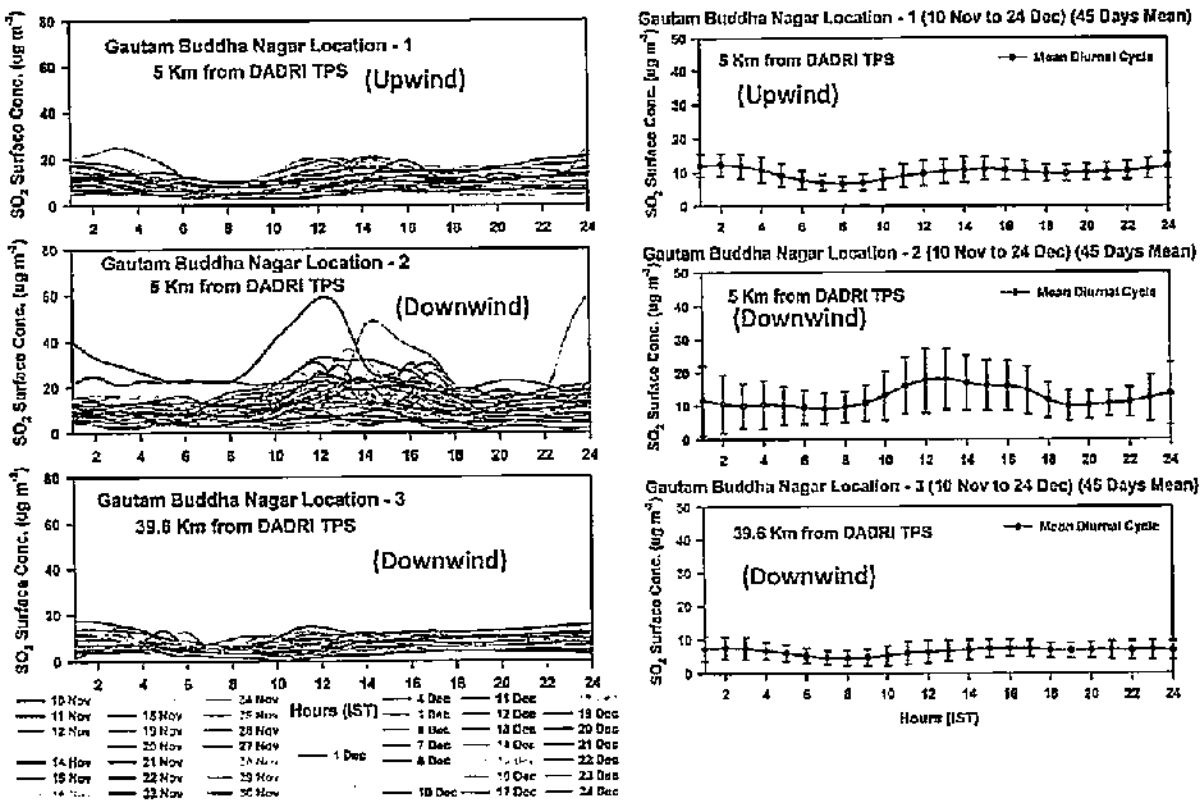


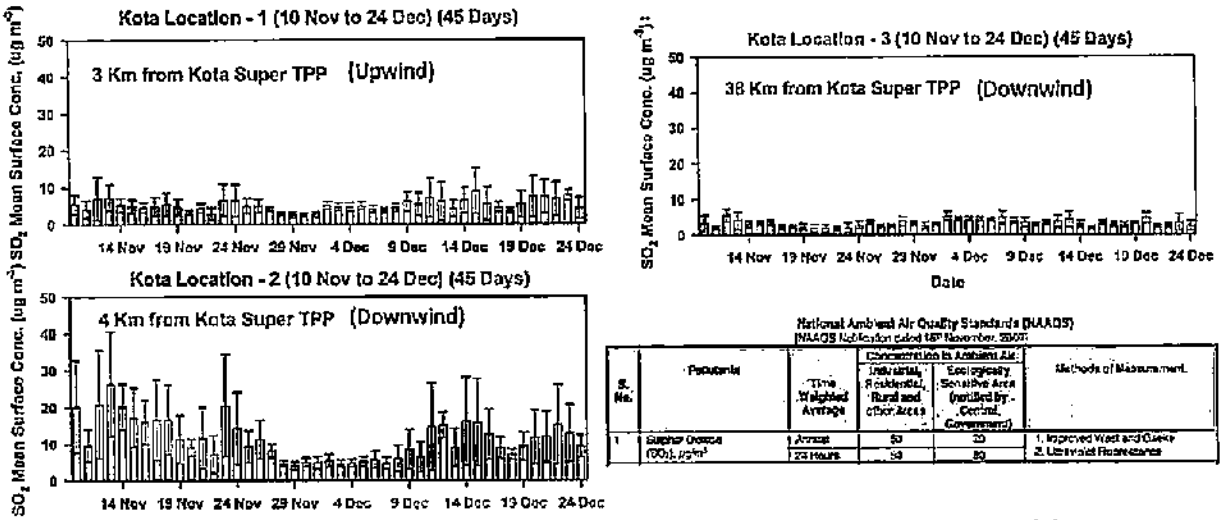
Figure 6.14: Diurnal variation of ambient air SO_2 concentration (µg/m³) for all days (8th November to 24th December 2023) as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of GBN. 45-days mean pattern of diurnal variation of ambient air SO_2 concentration (µg/m³) derived from measurements made at all three sites of GBN are also shown. Vertical lines in all panels on the right represent the ±1σ standard deviation variation around the monthly mean values for each hour.

Figure 6.14 shows the diurnal variation of ambient air SO_2 concentration ($\mu g/m^3$) measured from November 8 to December 24, 2023, at one upwind (Location-1) and two downwind (Location-2 and Location-3) sites in Gautam Buddha Nagar (GBN). At Location 1, situated 5 km upwind from the Dadri TPP, SO_2 concentrations are relatively stable with minor fluctuations throughout the day. The levels generally remain low, with small increases observed in the early morning, midday, and late evening. These fluctuations can be attributed to local residential activities such as cooking, vehicular emissions, and industrial contributions. Additionally, emissions from diesel generators used as power backups in office complexes, educational institutes, construction activities, and housing societies may contribute to these variations. Meteorological factors and the diurnal variation of the atmospheric boundary layer, which is typically shallower during nighttime, early morning, and late evening, also trap pollutants closer to the ground. The overall low and stable SO_2 concentrations at Location 1, compared to Location 2, indicate that TPP emissions have a relatively smaller influence at this upwind site during the winter season, largely due to the prevailing wind direction. Location 2, located 5 km downwind from the Dadri TPP, exhibits a more pronounced diurnal variation in SO_2 concentrations. The levels are higher compared to the upwind site, with noticeable peaks during midday and late evening. The midday peak likely corresponds to the TPP's operational hours and increased industrial and vehicular activities, while the late evening peak may be influenced by residential activities such as cooking and emissions from diesel generators. Meteorological conditions, such as wind direction and speed, play a significant role in transporting TPP emissions and other sources to this site. The atmospheric boundary layer's variation, which is generally deeper during the daytime, allows for better dispersion of pollutants, whereas a shallower boundary layer in the evening leads to higher concentrations of air pollutants near the surface during nighttime. Observed spikes in SO_2 concentrations lasting for 2-4 hours during daytime on different days of our survey indicates that the stronger emissions from multiple local sources are overwhelming the expected dilution of the concentrations during the midday. At Location 3, about 40 km downwind from the Dadri TPP, the diurnal variation in SO_2 concentrations is less pronounced than at Location 2 and similar to Location 1. SO_2 levels at Location 3 are only slightly lower than at the upwind site Location 1 but show a smoother diurnal cycle compared to Location 2. There are minor increases throughout the day, with less distinct peaks. This pattern suggests a diluted impact of TPP emissions and other SO_2 sources due to the greater distance, coupled with contributions from local sources such as transportation, minor industrial activities, and diesel generators. Meteorological factors, including wind patterns and boundary layer dynamics, influence the dispersion and concentration of SO_2 at this site, leading to a more moderated variation.

Figure 6.14 also shows the mean diurnal variability of ambient air SO_2 concentrations at three measurement locations in Gautam Buddha Nagar during Phase III of our survey, situated at different distances and directions (upwind and downwind) relative to the Dadri TPP. At Location

1 (5 km upwind from the TPP), SO_2 concentrations remain relatively low and stable throughout the day, with slight increases in the early morning and late evening, which can be attributed to local residential activities, vehicular emissions, and the use of diesel generators. At Location 2 (5 km downwind from the TPP), we noted a more pronounced diurnal variation, with higher SO_2 levels and noticeable peaks during midday and late evening. These midday peaks are likely due to a combination of emissions from the TPP as well as various local sources such as diesel generators, industrial activities, and vehicular traffic. Despite the expectation of pollutant dilution due to a deeper atmospheric boundary layer during midday, the spikes in SO_2 concentrations suggest that emissions from these multiple local sources are overwhelming the dilution effect. Location 3 (40 km downwind from the TPP) shows a smoother diurnal cycle with less pronounced peaks, indicating a more diluted impact of the TPP emissions due to the greater distance. However, the minor increases in SO_2 levels throughout the day still reflect contributions from local sources like residential, transportation and industrial activities. Overall, the higher midday SO_2 concentrations, especially at Location 2, underscore the significant role of local emissions from the residential sector, diesel generators, industries, and vehicular traffic, in addition to TPP emissions, in influencing ambient SO_2 levels. These local sources contribute to elevated SO_2 concentrations, particularly during midday when emissions are high, indicating their strong impact on air pollution in the region despite the natural dilution processes expected at this time of day.

Time series of daily mean ambient air concentration of SO_2 (µg/m³) measured in Kota



National Ambient Air Quality Standards (NAAQS)
[NAAQS Notification dated 16th November, 2009]

S. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air: Industrial, Residential, Rural and other Areas	Concentration in Ambient Air: Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
1	Sulphur Dioxide (SO_2), µg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

There has been no occurrences of ambient SO_2 concentrations exceeding the NAAQS at any of the measurement locations in Kota throughout the period of our survey (Even the instantaneous values have never exceeded the standard)

Figure 6.15: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (8th November to 24th December 2023) as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of Kota. Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Figure 6.15 presents the time series of daily mean ambient air SO_2 concentrations (µg/m³) from November 8 to December 24, 2023, at three locations in Kota: one upwind (Location-1) and two downwind (Location-2 and Location-3) relative to the Kota Super TPP. The vertical lines on each bar represent the ±1σ standard deviation around the daily mean values. At Location 1, situated 3 km upwind from the TPP, SO_2 concentrations remain consistently low throughout the measurement period, with values generally below 10 µg/m³. The low and stable concentrations at this site indicate minimal influence from the TPP emissions due to the upwind positioning. In contrast, Location 2, located 4 km downwind from the TPP, shows higher SO_2 concentrations with significant daily variability. The levels at this site often peak between 10 and 40 µg/m³, indicating a stronger influence from the TPP emissions and potentially other local sources. The higher variability and elevated concentrations suggest that the emissions from the TPP are more concentrated downwind, particularly impacting this location.

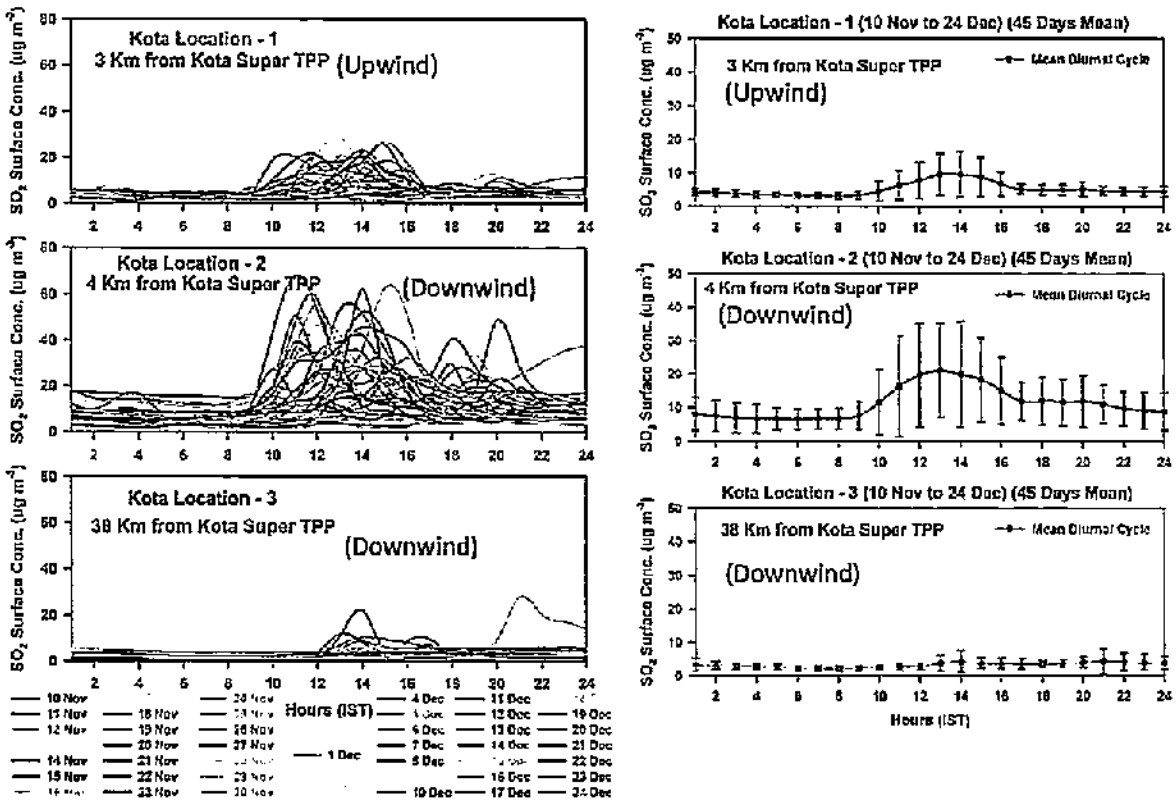


Figure 6.16: Diurnal variation of ambient air SO_2 concentration (µg/m³) for all days (8th November to 24th December 2023) as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of Kota. 45-days mean pattern of diurnal variation of ambient air SO_2 concentration (µg/m³) derived from measurements made at all three sites of Kota are also shown. Vertical lines in all panels on the right represent the ±1σ standard deviation variation around the monthly mean values for each hour.

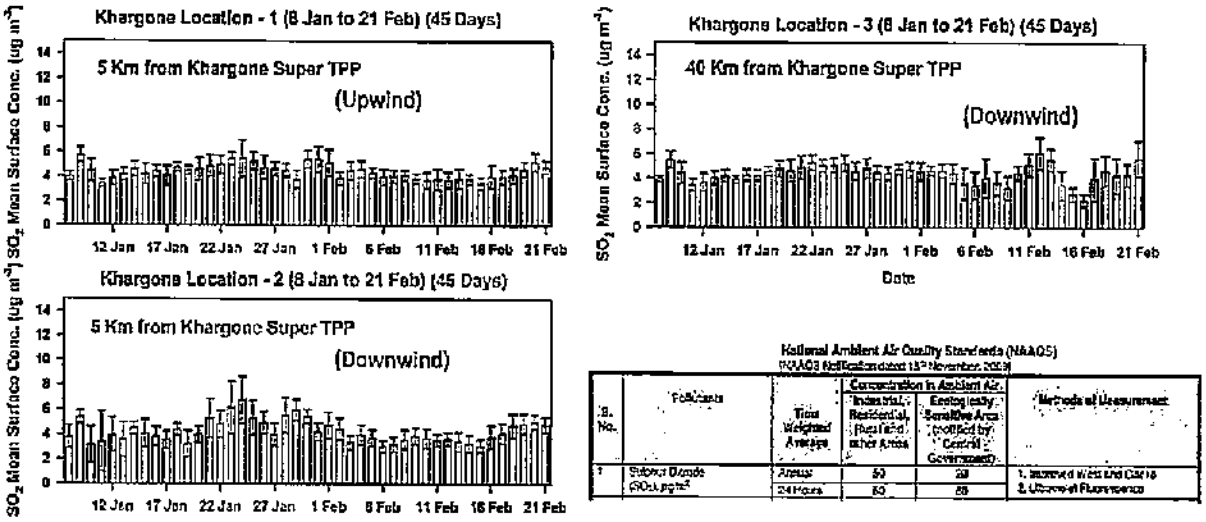
Location 3, situated about 38 km downwind from the TPP, exhibits SO_2 concentrations similar to Location 1, with generally low values and minor fluctuations throughout the period. The SO_2 levels at this site remain well below 10 $\mu g/m^3$, indicating that the emissions from the TPP are sufficiently dispersed by the time they reach this distance, resulting in lower concentrations. Across all three sites, the measured SO_2 concentrations are significantly below the National Ambient Air Quality Standards (NAAQS) limit of 80 $\mu g/m^3$ for 24-hour average measurements. This compliance with the NAAQS suggests that the ambient air quality in terms of SO_2 remains within permissible levels in Kota during the survey period, despite the proximity to the TPP.

Figure 6.16 displays the diurnal variation of ambient air SO_2 concentrations ($\mu g/m^3$) from November 8 to December 24, 2023, at one upwind (Location-1) and two downwind (Location-2 and Location-3) sites in Kota measured during Phase III of our survey. At Location-1, situated 3 km upwind from the Kota Super TPP, SO_2 concentrations remain consistently low throughout the day, with minor fluctuations. These levels are influenced by local emissions from residential activities, vehicular traffic, and possibly some industrial contributions including brick kilns. The spikes observed lasting 2-3 hours at different times, mostly during the daytime, could be attributed to bursts of activity from these local sources. In contrast, Location-2, 4 km downwind from the Kota Super TPP, exhibits much higher and more variable SO_2 concentrations. Notable spikes in SO_2 levels are observed, particularly during midday, likely due to a combination of emissions from the TPP, local industries, diesel generators, brick kilns, and the transportation sector. These spikes contribute significantly to the overall midday peak in SO_2 concentrations, underscoring the strong impact of local emissions. The frequent spikes lasting a few hours on individual days indicate episodic activities such as industrial operations or increased traffic, which overwhelm the expected natural dilution during midday due to a deeper atmospheric boundary layer. Location-3, 38 km downwind from the Kota Super TPP, shows lower concentrations similar to Location-1, with a more stable diurnal pattern. The lower and more stable SO_2 levels in Location 3 suggest that the emissions from the TPP are significantly dispersed by the time they reach this distance, and local sources have a lesser impact here as compared to Location-2.

The right three panels in Figure 6.16 illustrate the 45-day mean diurnal variation in SO_2 concentrations at the three locations, with vertical lines representing the $\pm 1\sigma$ standard deviation around the mean values for each hour. Location-1 shows a stable mean diurnal pattern with low SO_2 levels throughout the day. Location-2, however, displays a distinct midday peak, indicating higher emissions during this period, which may be due to increased activity from local industries, residential sector emissions including diesel generators, brick kilns, and transportation activities, along with emissions from the TPP. These midday spikes on individual days contribute significantly to the mean pattern observed, especially in Location 2 and Location 1. Whereas Location-3 shows a relatively flat diurnal cycle with minor variations, indicating effective dispersion and dilution of TPP emissions at this greater distance.

Comparing the three sites in Kota, we find that Location-2 exhibits the highest variability and concentrations, highlighting the significant impact of the TPP and other nearby local emission sources. Locations 1 and 3 have lower and more stable concentrations, with Location-1 being slightly more variable due to closer proximity to local sources as well as the TPP. Despite these variations, all measured SO_2 concentrations across the sites remain well below the NAAQS limit of 80 µg/m³, indicating that the ambient air quality in terms of SO_2 is within permissible levels throughout the survey period.

Time series of daily mean ambient air concentration of SO_2 (µg/m³) measured in Khargone



National Ambient Air Quality Standards (NAAQS)

Sl. No.	Pollutants	Time Weighted Average	Concentration in Ambient Air: Industrial, Residential, Rural and other Areas	Concentration in Ambient Air: Ecologically Sensitive Area (notified by Central Government)	Methods of Measurement
1	Sulphur Dioxide (SO_2), µg/m³	Annual	50	20	1. Improved West and Gaeke 2. Ultraviolet Fluorescence
		24 Hours	80	80	

There has been no occurrences of ambient SO_2 concentrations exceeding the NAAQS at any of the measurement locations in Khargone throughout the period of our survey (Even the instantaneous values have never exceeded the standard)

Figure 6.17: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (8th January to 21st February 2024) as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of Khargone. Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Figure 6.17 presents the time series of daily mean ambient air SO_2 concentrations (µg/m³) from January 8 to February 21, 2024, at three locations in Khargone, Madhya Pradesh: one upwind (Location-1) and two downwind (Location-2 and Location-3) relative to the Khargone Super TPP. The vertical lines on each bar represent the ±1σ standard deviation around the daily mean values. At Location 1, situated 5 km upwind from the TPP, daily mean SO_2 concentrations remain consistently low, generally ranging between 2 and 6 µg/m³. The stable and low levels indicate steady but minimal influence from the TPP emissions, as this site is upwind. The day to day fluctuations are minor and likely attributable to local sources other than the TPP such as residential activities and vehicular traffic. In contrast, Location 2, located 5 km downwind from the TPP, shows higher daily mean SO_2 concentrations with more noticeable daily variability. The levels often range between 4 and 10 µg/m³, with some days maximum values reaching almost

up to 12 μg/m³. These elevated concentrations are likely due to the combined influence of emissions from the TPP and other local sources, such as other industries, diesel generators, and vehicular traffic. The greater variability in SO_2 levels at this site underscores the impact of emission sources other than the TPP. Location 3, positioned 40 km downwind from the TPP, exhibits daily mean SO_2 concentrations similar to Location 1, with values generally between 2 and 6 μg/m³. The reduced day-to-day variability in SO_2 concentrations at all measurement locations, along with the smaller differences in SO_2 levels among the three sites, suggests that SO_2 pollution in the region is more regional than local in nature. This could imply that emissions from other sources, or the dispersal pattern of emissions from the TPP, compensate for the lower concentrations expected at the upwind Location 1 and the more distant downwind Location 3 compared to the downwind Location 2, which is closer to the TPP. Consequently, we find a more uniform distribution of SO_2 concentrations across the region. Nevertheless, across all three sites, the measured SO_2 concentrations are significantly below the National Ambient Air Quality Standards (NAAQS) limit of 80 μg/m³ for 24-hour average measurements. That means the ambient air quality in terms of SO_2 remains within permissible levels in Khargone during the survey period.

Figure 6.18 shows the diurnal variation of ambient air SO_2 concentrations from January 8 to February 21, 2024, at one upwind (Location-1) and two downwind (Location-2 and Location-3) sites in Khargone. At Location-1, situated 5 km upwind from the Khargone Super TPP, SO_2 concentrations exhibit relatively low variability throughout the day, generally remaining between 4 and 8 μg/m³. These levels highlight the impact of emissions from the TPP as well as local sources such as residential activities and vehicular traffic. At Location-2, 5 km downwind from the TPP, SO_2 concentrations show higher variability and increased levels, often ranging from 5 to 10 μg/m³, with occasional peaks. This increased variability indicates a significant influence from the TPP emissions, combined with local industrial activities, residential activities, diesel generators, and vehicular traffic. Location-3, 40 km downwind from the TPP, presents SO_2 concentrations similar to Location-2, generally ranging from 5 to 7 μg/m³, reflecting a dispersed yet consistent impact of the TPP emissions and suggesting regional pollution influences.

The right three panels in Figure 6.18 illustrate the 45-day mean diurnal variation in SO_2 concentrations at the three locations, with vertical lines representing the ±1σ standard deviation around the mean values for each hour. Location-1 shows a stable mean diurnal pattern with relatively low SO_2 levels throughout the day, typically between 5 and 6 μg/m³. Location-2 displays a slight dip in SO_2 concentrations in the morning hours after sunrise, likely caused by the dilution of air pollutants due to the increase in boundary layer height during this time. Similarly, Location-3, despite being 40 km from the TPP, shows SO_2 levels comparable to Location-1, suggesting that regional pollution transport mechanisms and boundary layer dynamics contribute to similar concentration levels at this distance.

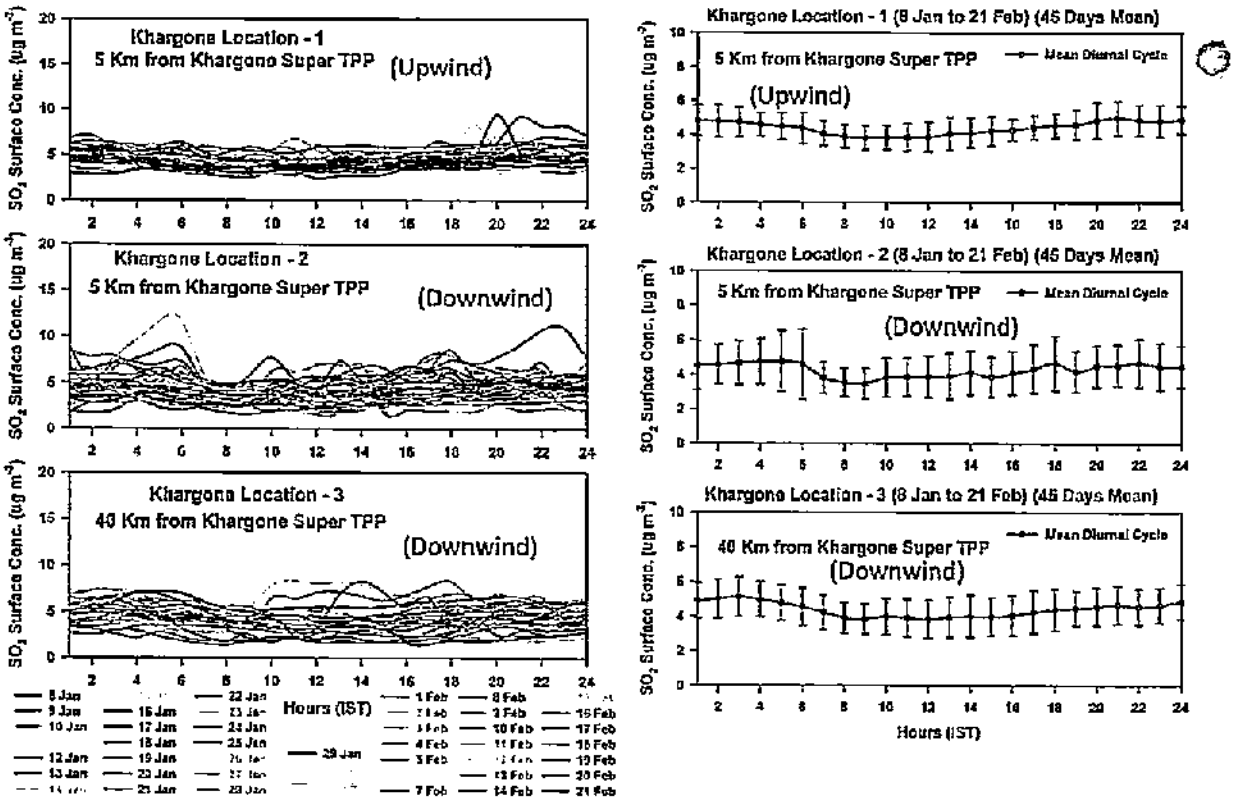


Figure 6.18: Diurnal variation of ambient air SO_2 concentration (µg/m³) for all days (8th January to 21st February 2024) as measured in Location-1 of Khargone (upper left panel) and Location-2 (upper right panel). 45-days mean pattern of diurnal variation of ambient air SO_2 concentration (µg/m³) derived from measurements made at all three sites of Khargone are also shown. Vertical lines in all panels on the right represent the ±1σ standard deviation variation around the monthly mean values for each hour.

The variations in boundary layer height play a crucial role in modulating ambient SO_2 concentrations at all three sites. During the day, a higher boundary layer allows for better dispersion of pollutants, leading to lower concentrations. Conversely, a lower boundary layer at night traps pollutants closer to the ground, resulting in higher concentrations. This pattern is evident in the relatively higher concentrations of ambient SO_2 during nighttime for all three locations. The lack of significant differences in SO_2 concentrations between the upwind and downwind sites suggests that regional sources and the overall dispersion of TPP emissions contribute to a more uniform distribution of SO_2 across the region, rather than localized variations. All measured SO_2 concentrations at the three sites are significantly below the National Ambient Air Quality Standards (NAAQS) limit of 80 µg/m³ for 24-hour average measurements. This compliance indicates that the ambient air quality in terms of SO_2 is well within permissible levels in Khargone during the survey period.

Time series of daily mean ambient air concentration of SO_2 (µg/m³) measured in Shahdol

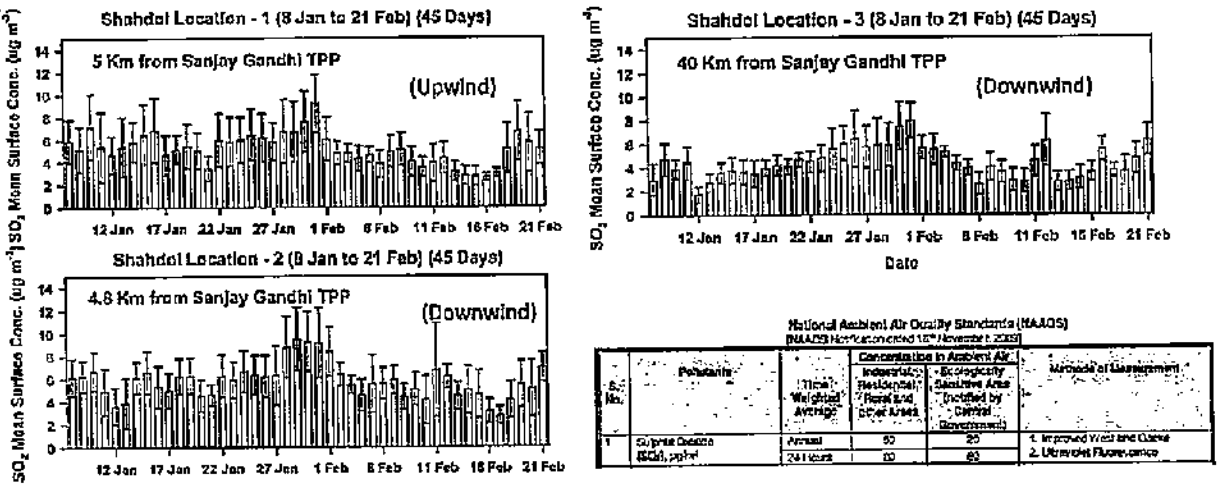


Figure 6.19: Time series of daily mean ambient air SO_2 concentration (µg/m³) for all days (8th January to 21st February 2024) as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of Shahdol. Vertical lines on each bar represents the ±1σ standard deviation variation around the daily mean values for each day.

Figure 6.19 presents the time series of daily mean ambient air SO_2 concentrations (µg/m³) from January 8 to February 21, 2024, at three locations in Shahdol, Madhya Pradesh: one upwind (Location-1) and two downwind (Location-2 and Location-3) relative to the Sanjay Gandhi TPP. The vertical lines on each bar represent the ±1σ standard deviation around the daily mean values. At Location-1, situated 5 km upwind from the TPP, daily mean SO_2 concentrations show moderate variability, generally ranging between 2 and 10 µg/m³. Day-to-day variations exhibit some peaks, with higher values around late January and mid-February. These fluctuations likely result from local residential activities, vehicular traffic, and occasional industrial emissions. Location-2, located 4.8 km downwind from the TPP, experiences higher variability and increased daily mean SO_2 levels, often ranging from 4 to 12 µg/m³, with several peaks reaching up to 14 µg/m³. The pronounced day-to-day variations at this site reflect the significant influence of TPP emissions, along with contributions from local industries, diesel generators, and traffic. This location records the highest SO_2 concentrations among the three sites, highlighting the strong impact of the nearby TPP emissions. Location-3, 40 km downwind from the TPP, shows significantly lower SO_2 concentrations compared to Location-2 and Location-1. The daily mean SO_2 levels generally range from 2 to 8 µg/m³, with fewer and smaller peaks. The day-to-day variations at this site are more stable, indicating a drop in SO_2 levels due to the dispersion of pollutants with increasing distance from the major source.

The measured daily mean SO_2 concentrations at all three sites are well below the National Ambient Air Quality Standards (NAAQS) limit of 80 µg/m³ for 24-hour average measurements. This compliance with the NAAQS indicates that the ambient air quality in terms of SO_2 remains

within permissible levels in Shahdol during the survey period. Effective emission control at the TPP and relatively low contributions from other local SO_2 sources ensure that, despite some variability, the overall air quality remains safe and well-managed across the region. The lower concentrations at the far downwind Location-3 further demonstrate the dispersal effect, which reduces ambient air SO_2 levels as the distance from the TPP increases.

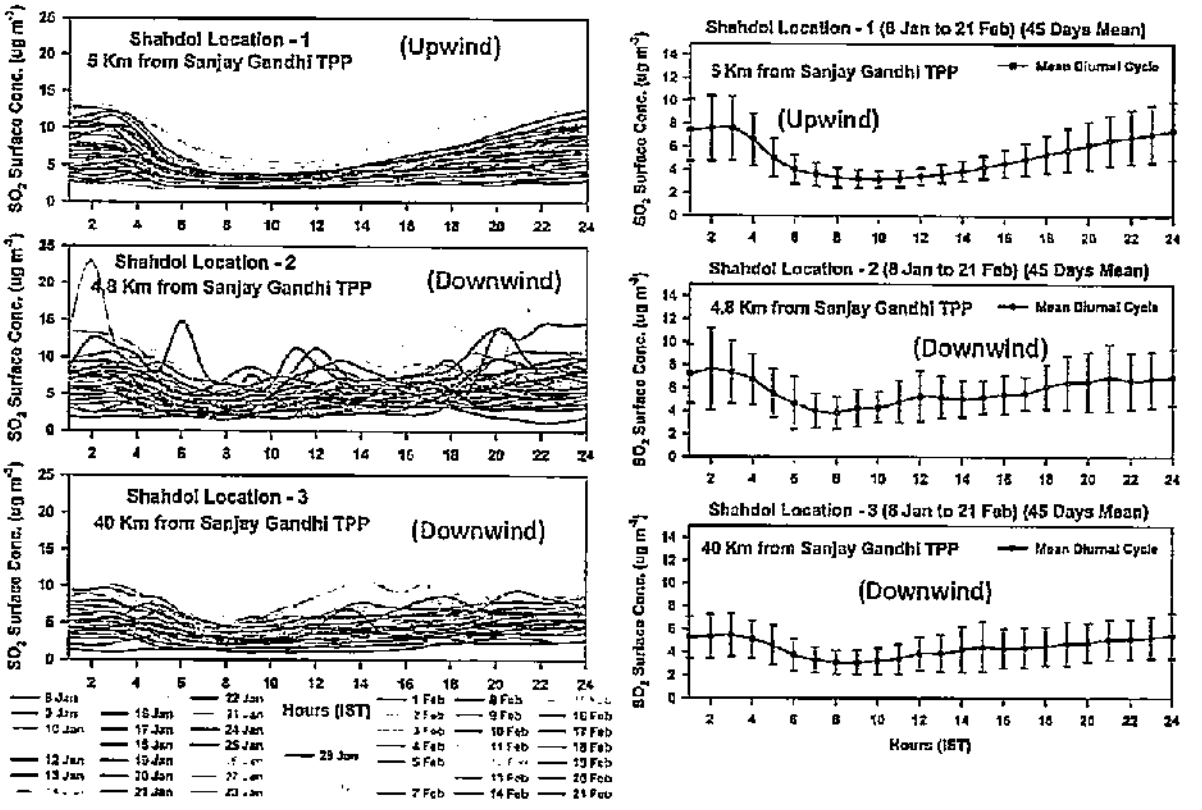


Figure 6.20: Diurnal variation of ambient air SO_2 concentration (µg/m³) for all days (8th January to 21st February 2024) as measured as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of Shahdol. 45-days mean pattern of diurnal variation of ambient air SO_2 concentration (µg/m³) derived from measurements made at all three sites of Shahdol are also shown. Vertical lines in all panels on the right represent the ±1σ standard deviation variation around the monthly mean values for each hour.

Figure 6.20 displays the diurnal variation of ambient air SO_2 concentrations (µg/m³) from January 8 to February 21, 2024, at three locations in Shahdol: one upwind (Location-1) and two downwind (Location-2 and Location-3) relative to the Sanjay Gandhi TPP. At Location-1, situated 5 km upwind from the TPP, SO_2 concentrations show a notable increase during the late evening and night, peaking around 10-15 µg/m³. Throughout the day, concentrations generally stay between 4 and 10 µg/m³, indicating the influence of local sources such as residential activities and vehicular traffic. The day-to-day variations and minor fluctuations reflect routine activities and

changes in meteorological conditions, such as wind speed and direction, which can affect pollutant dispersion. Location-2, located 4.8 km downwind from the TPP, exhibits higher variability and increased SO_2 levels, with frequent peaks reaching up to 20 $\mu g/m^3$. Significant diurnal fluctuations occur, particularly during the late evening and night. Random spikes in SO_2 concentrations lasting 2-3 hours on different days and at different times suggest episodic emissions. These spikes are likely caused by short-term increases in emissions from sources other than the TPP such as local industries, diesel generators, and vehicular traffic, exacerbated by meteorological conditions that trap pollutants near the ground. The vertical movement of the atmospheric boundary layer also plays a crucial role, as a lower boundary layer at night traps pollutants including SO_2 closer to the surface, resulting in higher concentrations. Location-3, 40 km downwind from the TPP, shows lower concentrations compared to Location-2, generally ranging from 2 to 15 $\mu g/m^3$. Day-to-day variations at this site are more stable and exhibit lower overall concentrations, indicating the dispersal effect of pollutants with increasing distance from the major source. SO_2 levels generally peak during the late evening and night, similar to the other locations, but with lower intensity due to the distance from the TPP. The influence of the atmospheric boundary layer is also evident here, as nighttime trapping of pollutants leads to higher concentrations of SO_2.

The right three panels of Figure 6.20 illustrate the 45-day mean diurnal variation in SO_2 concentrations at the three locations, with vertical lines representing the $\pm 1\sigma$ standard deviation around the mean values for each hour. Location-1 shows a stable mean diurnal pattern, with SO_2 levels typically decreasing after sunrise and gradually increasing in the evening, ranging from 4 to 8 $\mu g/m^3$. Location-2 exhibits a similar pattern but with higher concentrations, ranging from 5 to 12 $\mu g/m^3$. A slight dip in the morning hours is likely due to the increased boundary layer height, which dilutes pollutants. At night, the boundary layer height decreases, trapping air pollutants and leading to higher concentrations of SO_2. Location-3, despite being 40 km from the TPP, presents a similar diurnal pattern to Location-1 but with even lower concentrations, typically ranging from 3 to 7 $\mu g/m^3$. This demonstrates the dispersal of pollutants over distance and a decrease in SO_2 levels far from the TPP. All measured SO_2 concentrations at the three sites are significantly below the National Ambient Air Quality Standards (NAAQS) limit of 80 $\mu g/m^3$ for 24-hour average measurements. This compliance with NAAQS indicates that ambient air quality in terms of SO_2 remains well within permissible levels in Shahdol during the survey period. The effective emission control at the TPP and relatively low contributions from other local SO_2 sources ensure that, despite some variability, overall air quality remains safe and well-managed across the region. The impact of meteorological variations and the vertical movement of the atmospheric boundary layer further emphasizes the role of pollutant dispersion in maintaining air quality standards.

Impact of FGD operation on daily mean ambient air concentration of SO_2 in category-3 cities during Phase-III of the Survey

During Phase III of the survey, we conducted measurements in two Category-3 cities, Gautam Buddha Nagar and Khargone. During this period, the flue gas desulfurization (FGD) units in some of the stacks of the TPPs in these cities were operational.

Daily mean ambient air concentration of SO_2 ($\mu g/m^3$) during FGD operation in TPPs

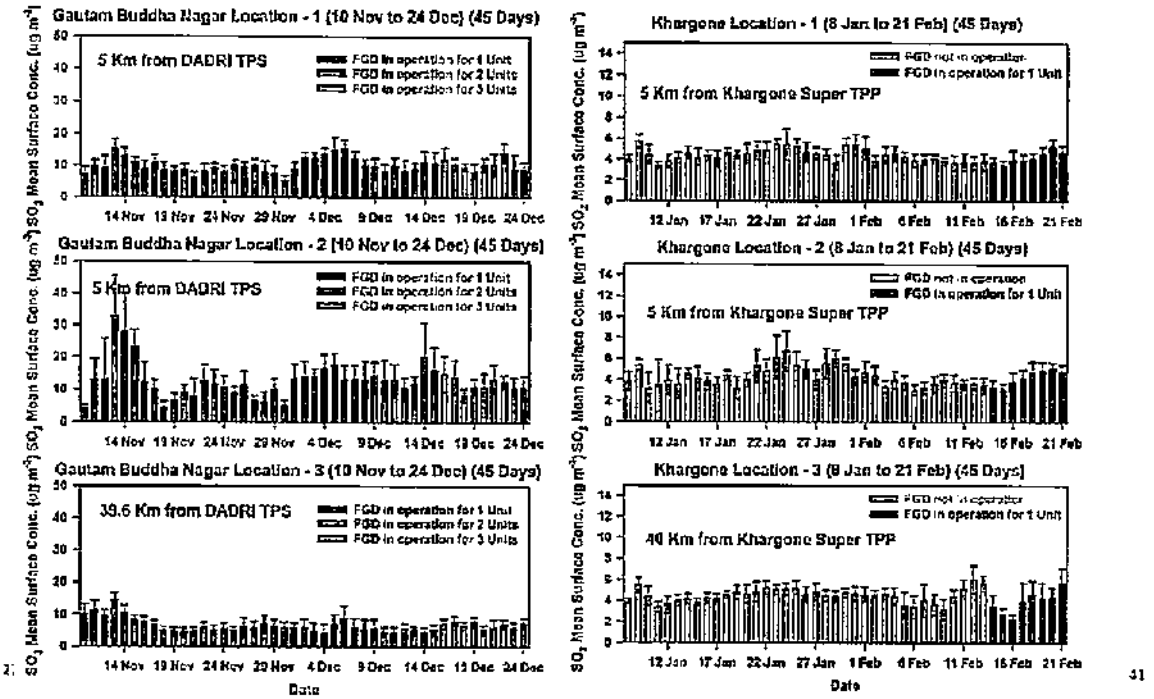


Figure 6.21: Left three panels show the time series of daily mean ambient air SO_2 concentration ($\mu g/m^3$) during 8th November to 24th December 2023 as measured in one upwind (Location-1) and two downwind (Location-2 and Location-3) sites of GBN. Right three panels show the time series of daily mean ambient air SO_2 concentration measured at three sites in Khargone during 8th January to 21st February 2024.

The left three panels of Figure 6.21 show the time series of daily mean ambient air SO_2 concentrations ($\mu g/m^3$) from November 8 to December 24, 2023, measured at one upwind (Location-1) and two downwind (Location-2 and Location-3) sites in Gautam Buddha Nagar (GBN). The right three panels display the time series of daily mean ambient air SO_2 concentrations at three sites in Khargone from January 8 to February 21, 2024. In GBN, the FGD was operational in at least one unit of the TPP for the entire 45 days of our survey, whereas in Khargone, the FGD was operational for only eight out of the 45 days.

As evident from the data in Figure 6.21, no notable systematic differences in ambient air SO_2 concentrations were observed with the operation of FGD units during the survey period at any of the measurement locations in both GBN and Khargone. Although there was large day-to-day variability in ambient air SO_2 concentrations at all measurement sites in both cities, this variability did not correlate with the operation of FGD units or the number of FGD units in operation at either of these TPPs, raising doubts about the effectiveness of the installed FGD systems in lowering SO_2 concentrations in the ambient air around these two TPPs.

CHAPTER-7: CONTRIBUTION OF SO_2 EMISSIONS FROM COAL-BASED TPPS TOWARDS AMBIENT ATMOSPHERIC SO_2, SULFATE AEROSOLS, PM2.5, AND PM10 MASS CONCENTRATIONS IN DIFFERENT CATEGORY CITIES DURING PHASE III OF SURVEY

In order to understand the contribution of SO_2 emissions from the power sector, specifically coal-based thermal power plants (TPPs), on ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in various cities selected for Phase III of the survey, we conducted a series of meticulously planned simulations using the WRF-Chem chemical transport model. These simulations aimed to delineate the contributions of various sources, particularly TPP emissions, to ambient air SO_2 and sulfate aerosols as components of PM2.5 and PM10 mass concentrations across the surveyed cities. Additionally, we aimed to determine the contributions of major aerosol types, including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust, to the ambient air concentrations of PM2.5 and PM10 in these cities through a comprehensive modeling approach. Specifically, we sought to quantify the impact of SO_2 emissions from TPPs on the ambient air concentrations of sulfate aerosols, PM2.5 and PM10 mass concentrations in the cities included in the Phase III of this survey. The insights gained from this study also contribute to a better understanding of the regional and local impacts of SO_2 emissions from TPPs on air quality. This understanding can further help us assess the expected benefits of stringent emission regulations, specifically advanced SO_2 control technologies like Flue-gas desulfurization (FGD), on ambient air SO_2 and sulfate aerosols as components of PM2.5 and PM10 mass concentrations across the surveyed cities.

Model setup and Simulation Details

The Weather Research and Forecasting model coupled with a chemistry module (WRF-Chem) is a regional system designed for both operational weather forecasting and atmospheric chemistry research (Skamarock, 2008; Powers et al., 2017). In this study, WRF-Chem version 4.2.2 was used to conduct nine sets of atmospheric chemistry simulations for each city of interest: Kota and Gautam Buddha Nagar, covering the period from November 8th to December 24th, 2023, and Shahdol and Khargone, covering the period from January 8th to February 21st, 2024. For the first set of simulations, model domains were centered at Gautam Buddha Nagar (77.61° E and 28.34° N), each covering approximately 2,250,000 square kilometres at a horizontal resolution of 10 km, with 150x150 grid cells in the outer domain and a horizontal resolution of 3 km, with 136x136 grid cells in the inner domain, following a nested WRF-Chem modeling setup. The model included 44 vertical levels on a hybrid-sigma coordinate system, extending from the surface to about 10 hPa as the model top pressure. The NCEP GDAS Final Analysis data, available at 6-hour intervals and with a resolution of 0.25°x0.25°, provided the meteorological initial and lateral boundary conditions for the model simulations covering two periods from November 8th to December

24th, 2023, and from January 8th to February 21st, 2024. Anthropogenic emissions were based on the EDGAR-v6.1 (2023) dataset. ERA5 Temperature, Water Vapor, and Wind data were used for both the WRF-Chem simulations and the Four-Dimensional Data Assimilation (FDDA) approach. Initial and lateral chemical boundary conditions for the WRF-Chem model simulations were obtained from previously available results from the Community Atmospheric Model With Chemistry (CAM-Chem) simulations.

To evaluate the sectoral contributions to ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in the selected cities of Kota, Gautam Buddha Nagar, Shahdol and Khargone during Phase II of the survey, we utilized an emission suppression method. This approach involved conducting a series of systematically designed simulations using the WRF-Chem model, where emissions from specific sectors were disabled in each simulation. We modified the emissions assuming that FGD was operational in two units of the NTPC Dadri TPP during Phase III of our survey. The details of the model configuration, the various anthropogenic, biomass burning, and biogenic emissions considered, as well as the numerical experiment design, are provided in Chapter 3 and are therefore not repeated here.

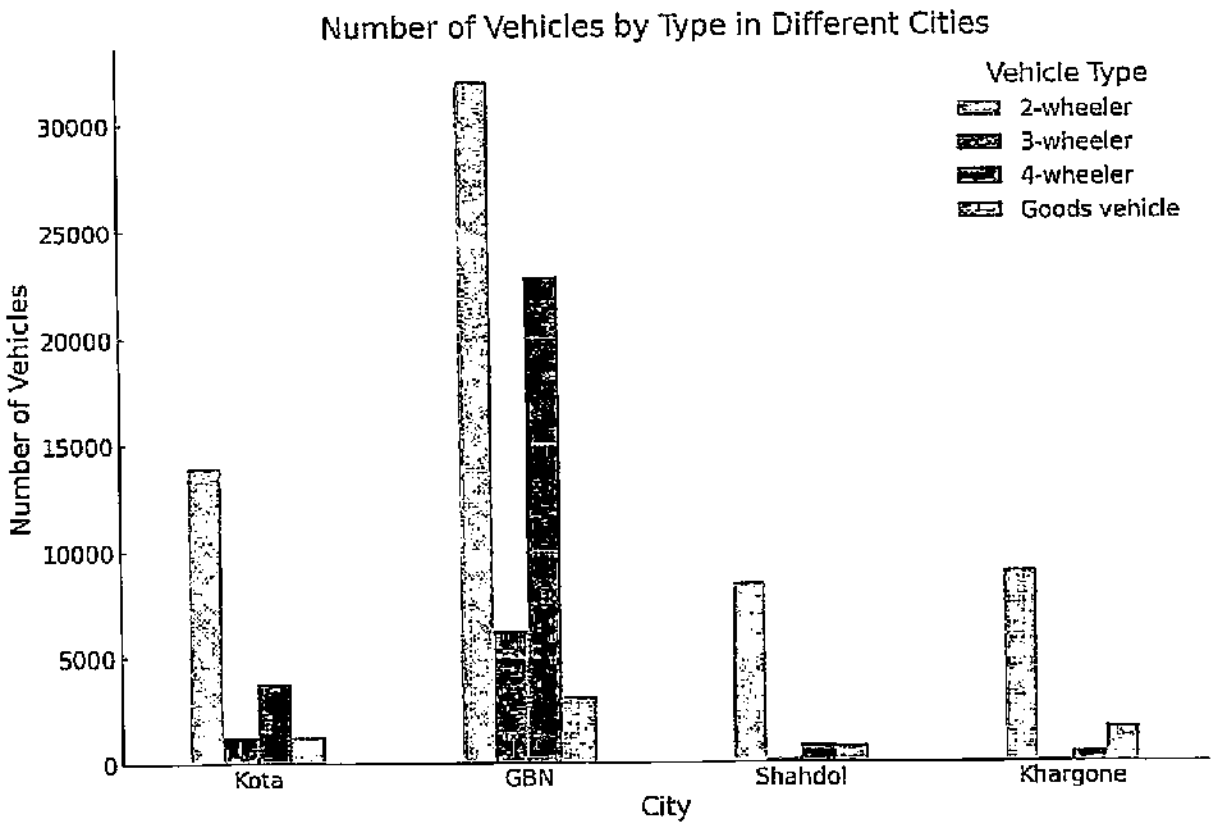


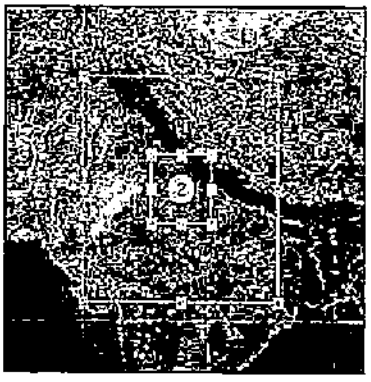
Figure 7.1: Total number of registered vehicles of different categories in the four cities selected during Phase-III of our survey as per the Road Transport Year Book 2019-20.

Figure 7.1 illustrates the number of different types of vehicles across four cities selected for Phase III of the survey: Kota, GBN (Gautam Buddha Nagar), Shahdol, and Khargone, as per the Road Transport Year Book 2019-20 (https://morth.nic.in/road-transport-year-books). Among these cities, GBN shows the highest numbers in all vehicle categories, with 32,034 two-wheelers, 6,212 three-wheelers, 22,826 four-wheelers, and 3,162 goods vehicles. Kota follows with significant numbers, particularly in two-wheelers (13,950) and four-wheelers (3,823). Shahdol and Khargone have considerably lower vehicle counts, with Shahdol having 8,460 two-wheelers and Khargone having 9,027 two-wheelers. Goods vehicles are relatively fewer across all cities, with GBN having the highest at 3,162. The data highlights the varying distribution and density of vehicle types in these cities, with GBN having the highest vehicle presence overall. This data has been used in preparing the emission inventory for transportation sector, which has been further utilized in this study to understand the sectoral contributions to ambient atmospheric concentrations of SO_2, sulfate aerosols, PM2.5, and PM10 in the selected cities.

Chemical Transport Modeling using WRF-Chem model

A series of Separate Model simulations have been performed in a systematic way to conduct source apportionment studies for each city

Category-3 city: GBN, Uttar Pradesh



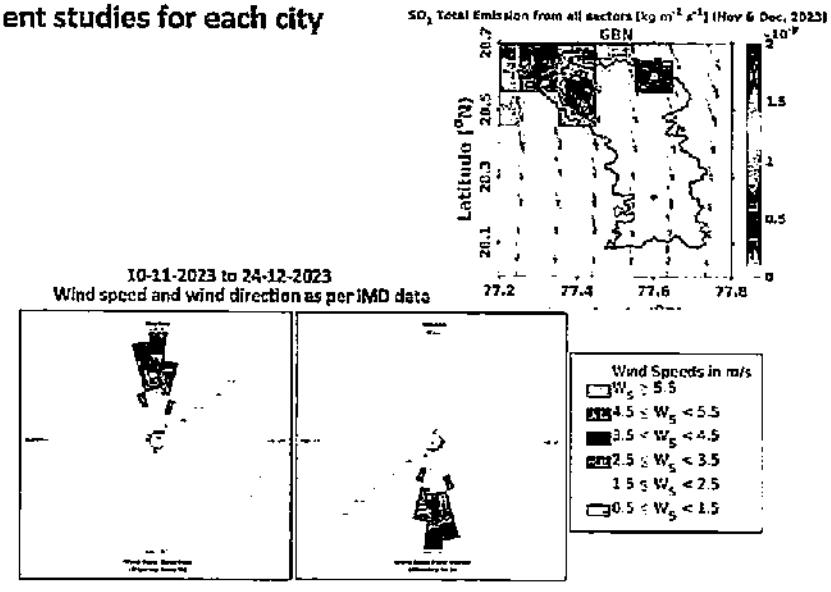


Figure 7.2: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over GBN during the simulation period from 8th November to 24th December 2023.

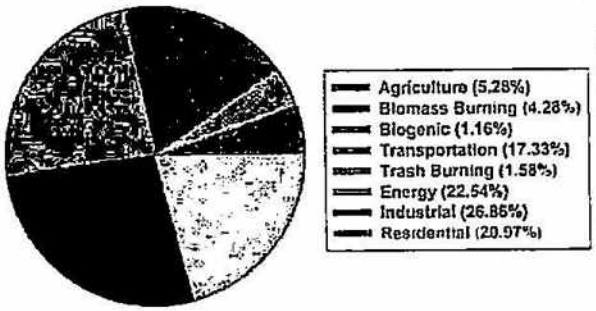
First, we present the results of our simulations, detailing the contributions of major emission sectors to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 mass concentrations in the city of Gautam Buddha Nagar during Phase III of our survey.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh

Phase III
Winter Season

GBN SO_2 (26.08 ± 10.38 ug m^{-3})(10 Nov to 24 Dec, 2023)



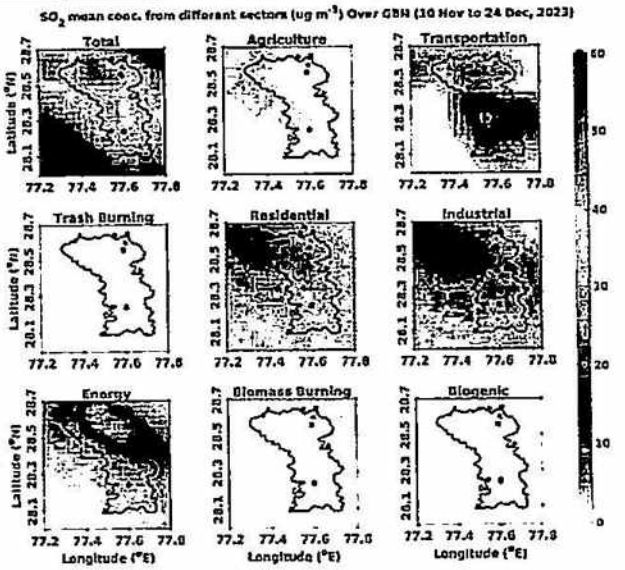


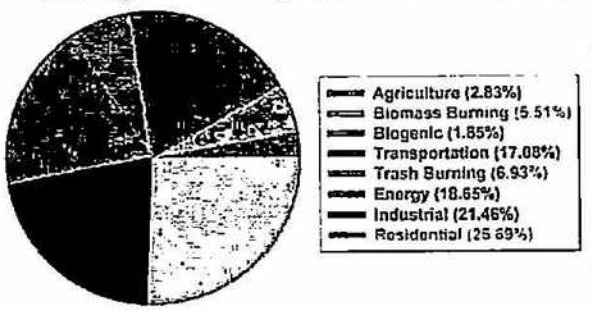
Figure 7.3: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

Normalized Contribution of different emission sectors towards ambient air SO_4

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh

Phase III
Winter Season

GBN SO_4 (20.37 ± 6.35 ug m^{-3})(10 Nov to 24 Dec, 2023)



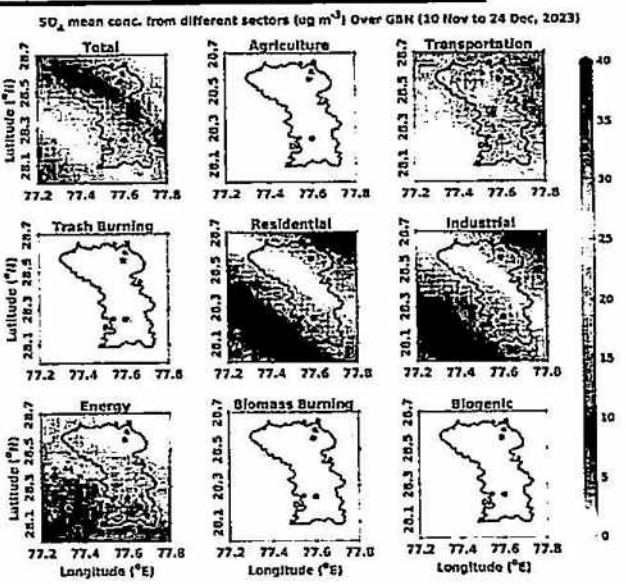


Figure 7.4: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in GBN during the simulation period from 8th November to 24th December 2023.

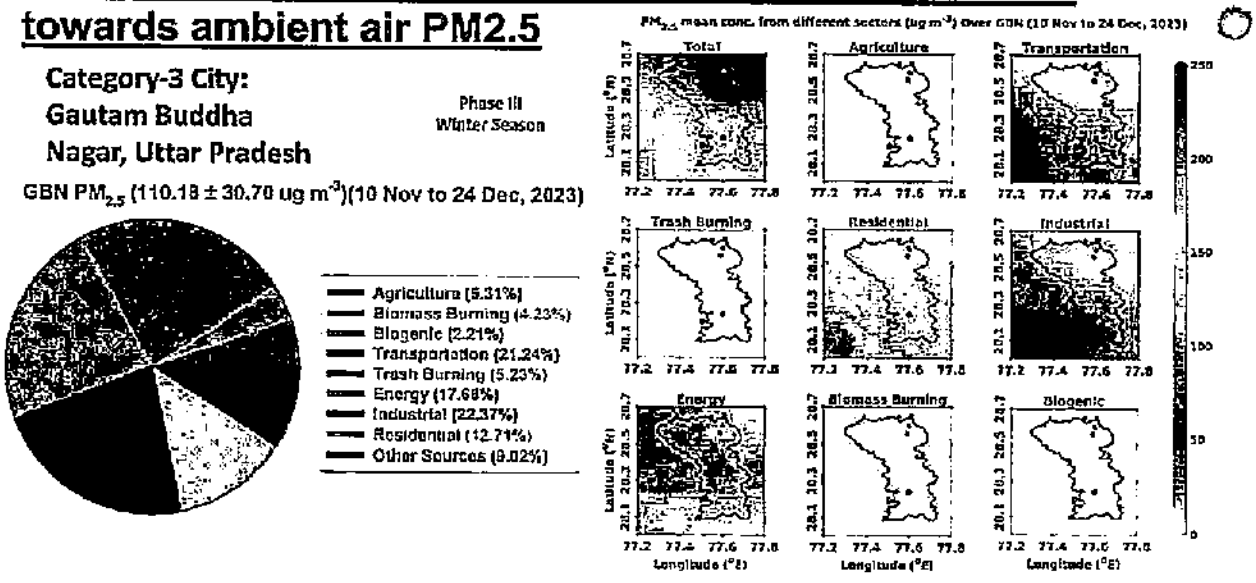


Figure 7.5: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

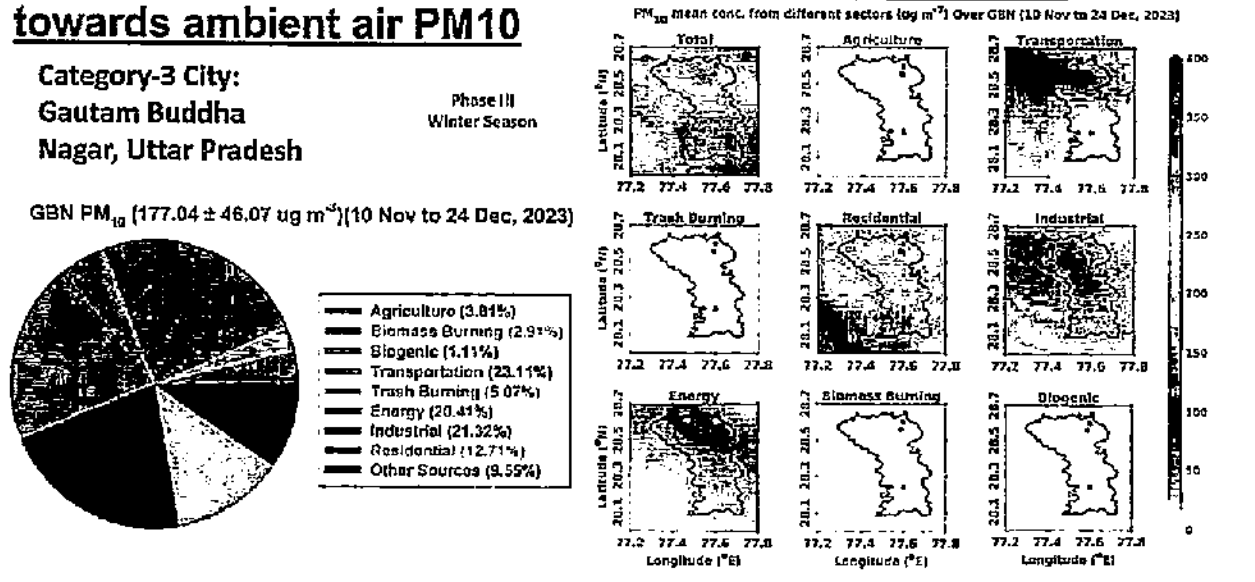


Figure 7.6: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Gautam Buddha Nagar during the survey period.

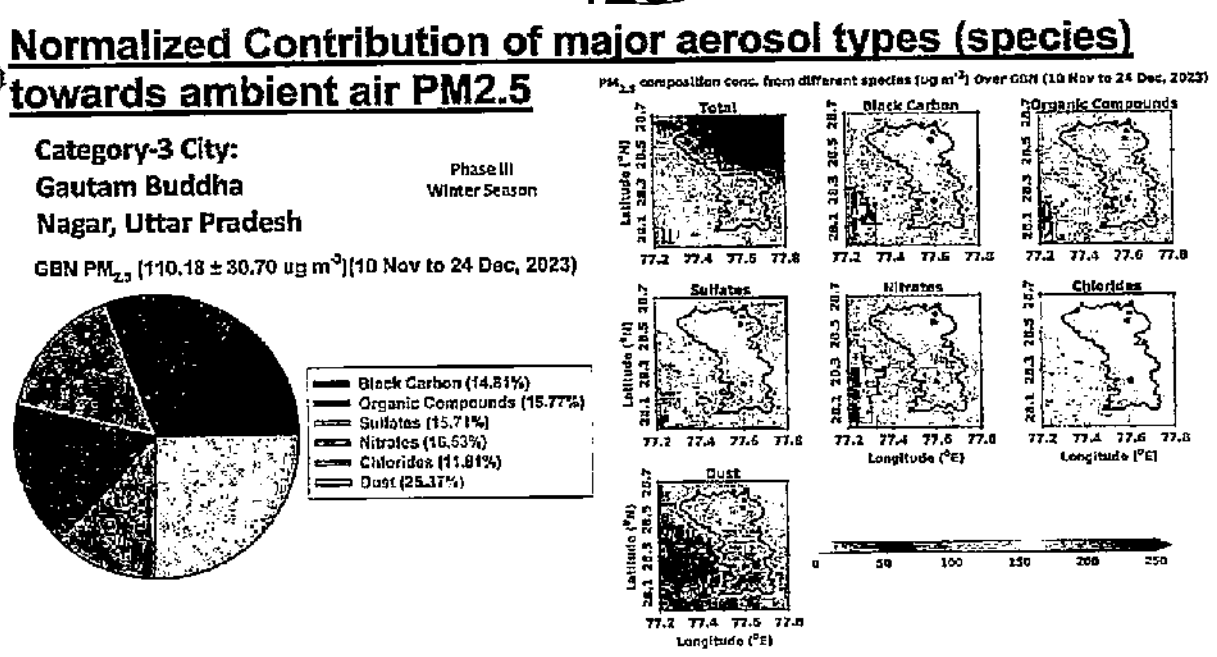


Figure 7.7: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

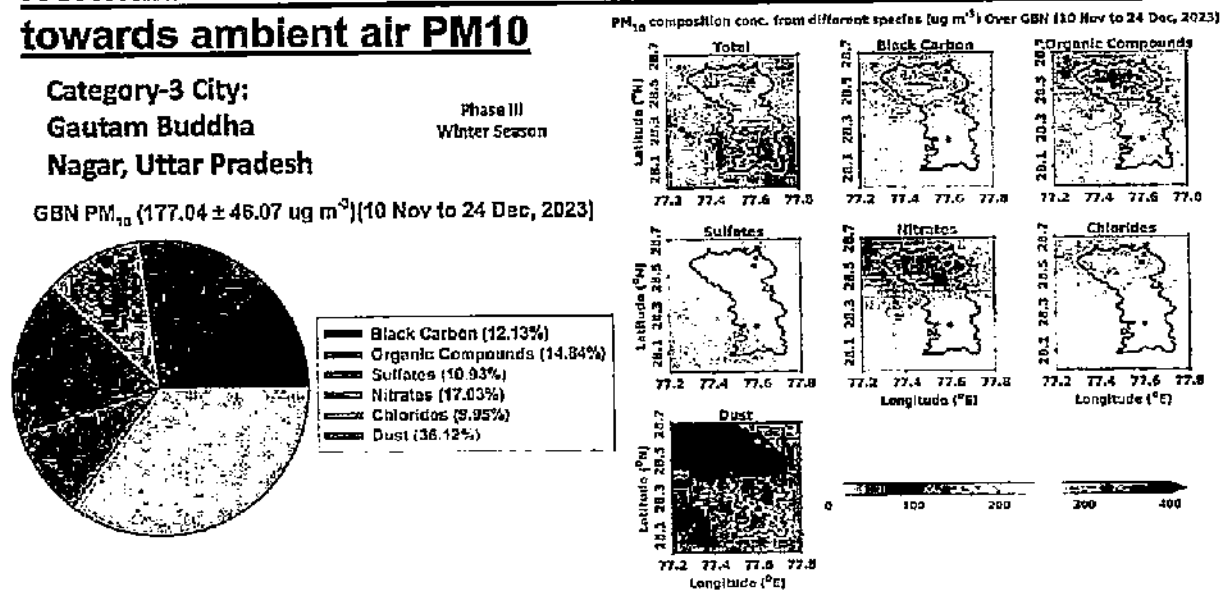


Figure 7.8: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category-3 City: Gautam Buddha Nagar, Uttar Pradesh

10th Nov to 24th Dec 2023

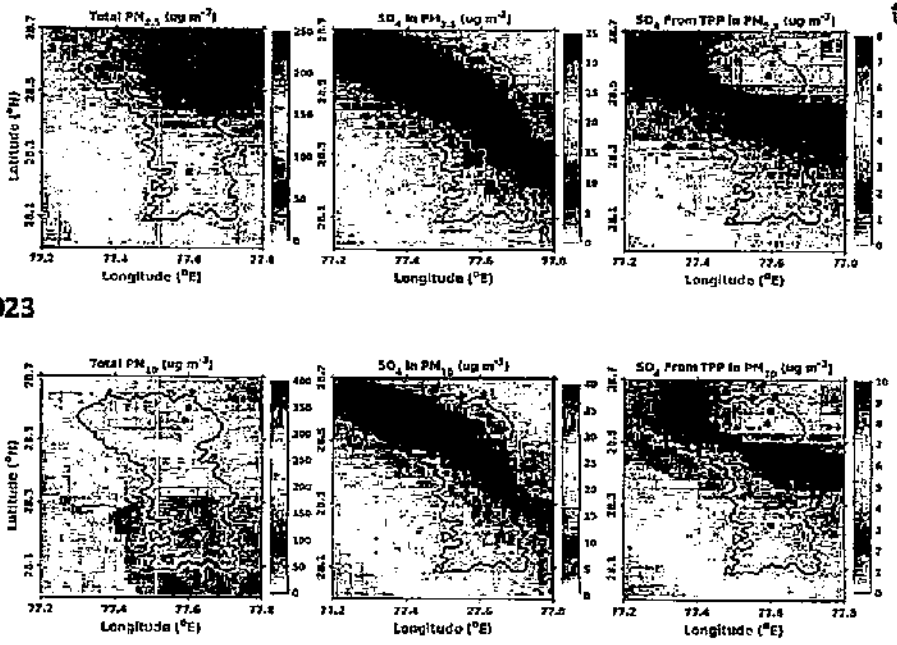


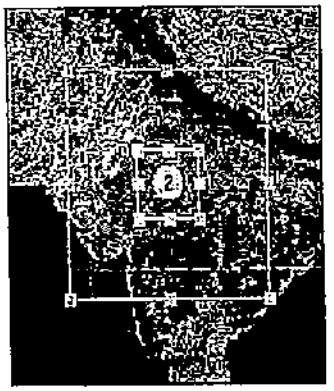
Figure 7.9: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

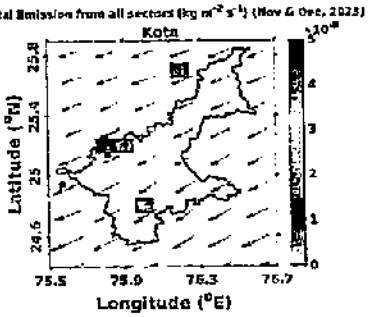
Next we performed another series of systematically designed WRF-Chem model simulations to know the contribution different sources towards SO_2 and sulfate aerosols in Kota, which is a Category-2 city considered during the Phase-III of our survey. We also wanted to understand the contribution of Power sector towards the ambient atmospheric SO_2, PM2.5, and PM10 concentrations in the city of Kota during our survey. WRF-Chem version 4.2.2 has been used to perform a set of nine atmospheric chemistry simulations over Kota for November 8th to December 24th, 2023. For this study, the model domains are centered at Kota (75.84° E and 25.18° N). Each of the simulation domain covers approximately 2250000 square Km area at a horizontal resolution of 10x10 Km^2, with 150x150 grid cells in the outer domain and horizontal resolution of 3x3 Km^2, with 136x136 grid cells in the inner domain following nested WRF-Chem modeling setup and 44 vertical levels (on a hybrid-sigma coordinate system) starting from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis (available at 6 hourly intervals) with a resolution of 0.25°x0.25° have been used to provide meteorological initial and lateral boundary conditions to the model simulation of November 8th to December 24th, 2023. To estimate the sectoral emission contribution towards the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Kota, we followed an emission suppression method. The details of the model configuration, the various anthropogenic, biomass burning, and biogenic emissions considered, as well as the numerical experiment design, are provided in Chapter 3 and are therefore not repeated here.

Chemical Transport Modeling for Kota, Rajasthan

- A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category-2 city: Kota, Rajasthan





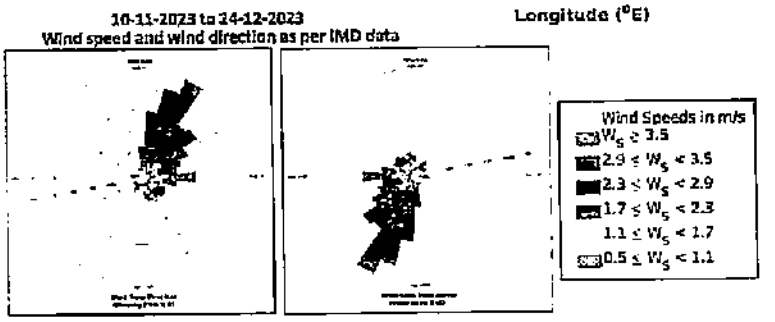
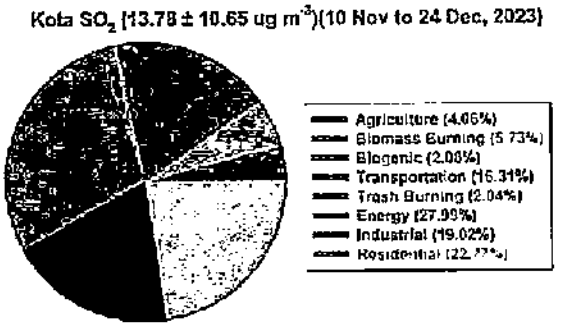


Figure 7.10: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Kota during the simulation period from 8th November to 24th December 2023.

First, we present the results of our simulations, detailing the contributions of major emission sectors to ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 mass concentrations in the city of Kota during Phase II of our survey.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-2 city: Kota, Rajasthan



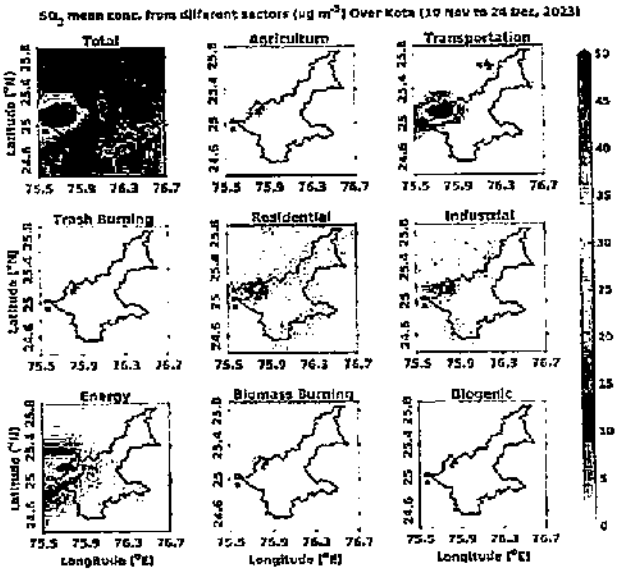
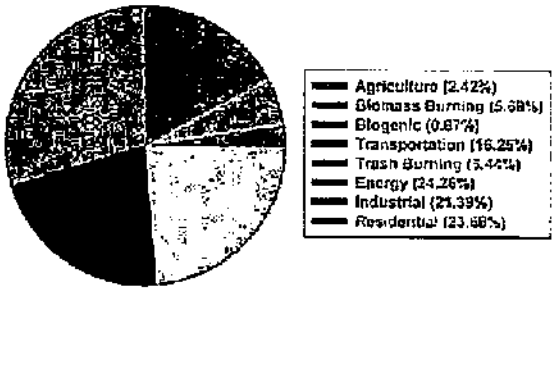


Figure 7.11: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Kota during the simulation period from 8th November to 24th December 2023.

Normalized Contribution of different emission sectors towards ambient air SO_4

Category-2 city: Kota, Rajasthan



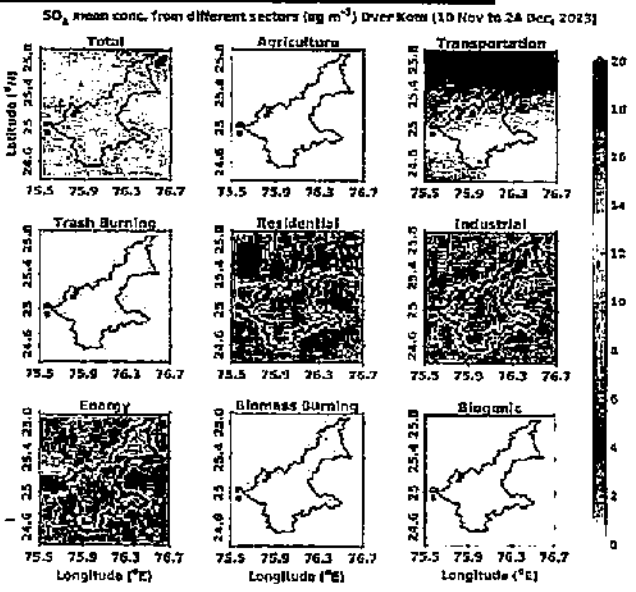
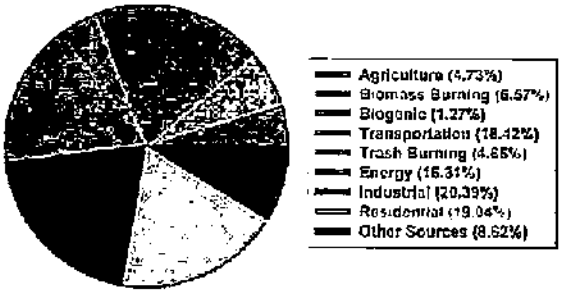


Figure 7.12: Contribution of different emission sectors towards ambient atmospheric sulfate aerosols concentrations in Kota during the simulation period from 8th November to 24th December 2023.

Normalized Contribution of different emission sectors towards ambient air PM2.5

Category-2 city: Kota, Rajasthan



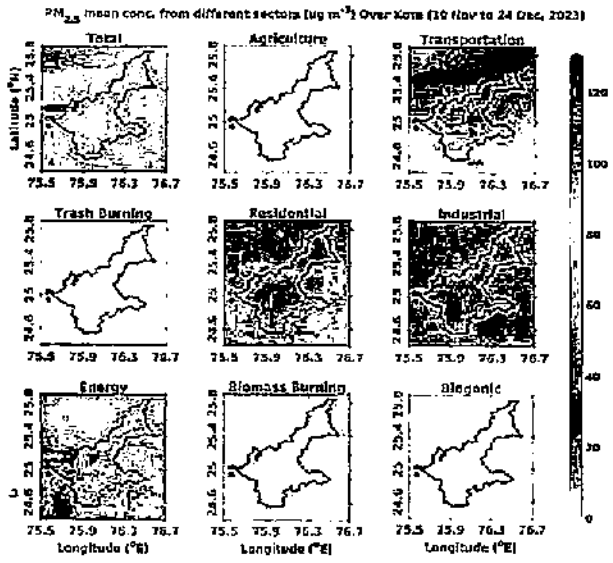
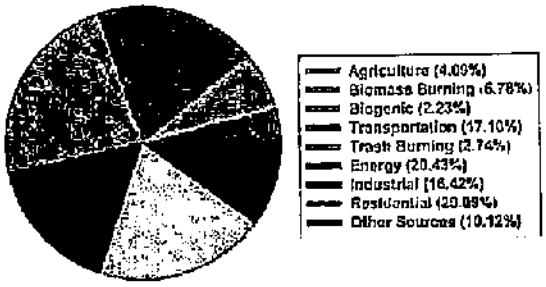


Figure 7.13: Contribution of different emission sectors towards ambient atmospheric PM2.5 aerosols concentrations in Kota during the simulation period from 8th November to 24th December 2023.

Normalized Contribution of different emission sectors towards ambient air PM10

Category-2 city: Kota, Rajasthan

Kota PM_{10} (114.71 ± 9.74 ug m^{-3})(10 Nov to 24 Dec, 2023)



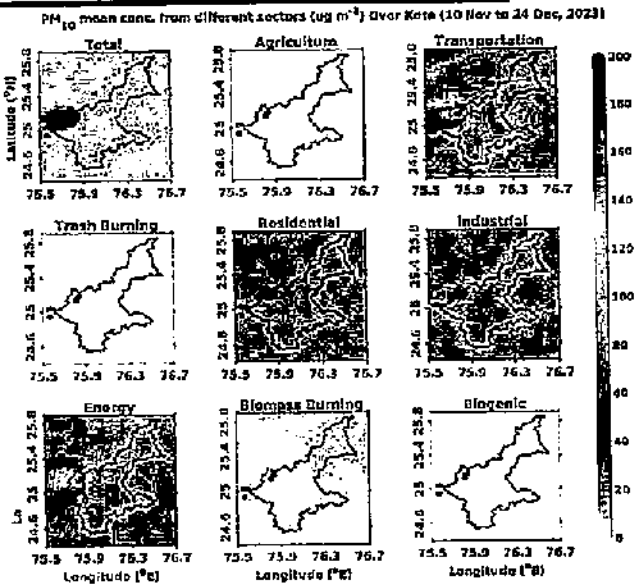


Figure 7.14: Contribution of different emission sectors towards ambient atmospheric PM10 aerosols concentrations in Kota during the simulation period from 8th November to 24th December 2023.

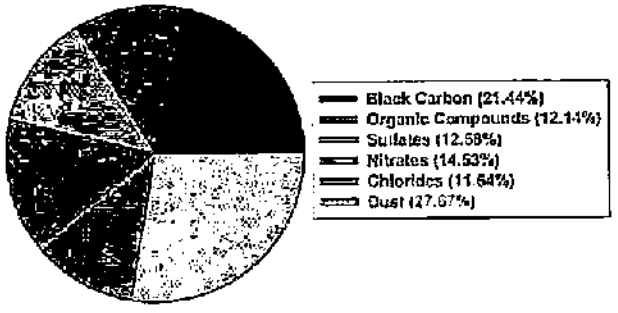
Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Kota during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

Category-2 city: Kota, Rajasthan

Phase III
Winter Season

Kota $PM_{2.5}$ (72.69 ± 14.75 ug m^{-3})(10 Nov to 24 Dec, 2023)



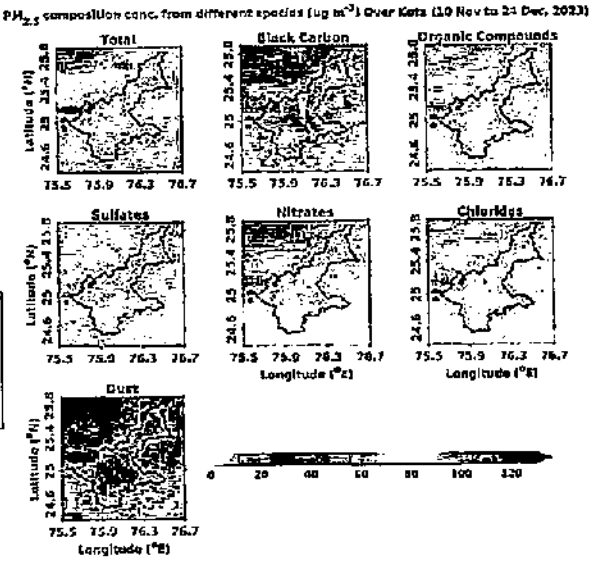


Figure 7.15: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Kota during the simulation period from 8th November to 24th December 2023.

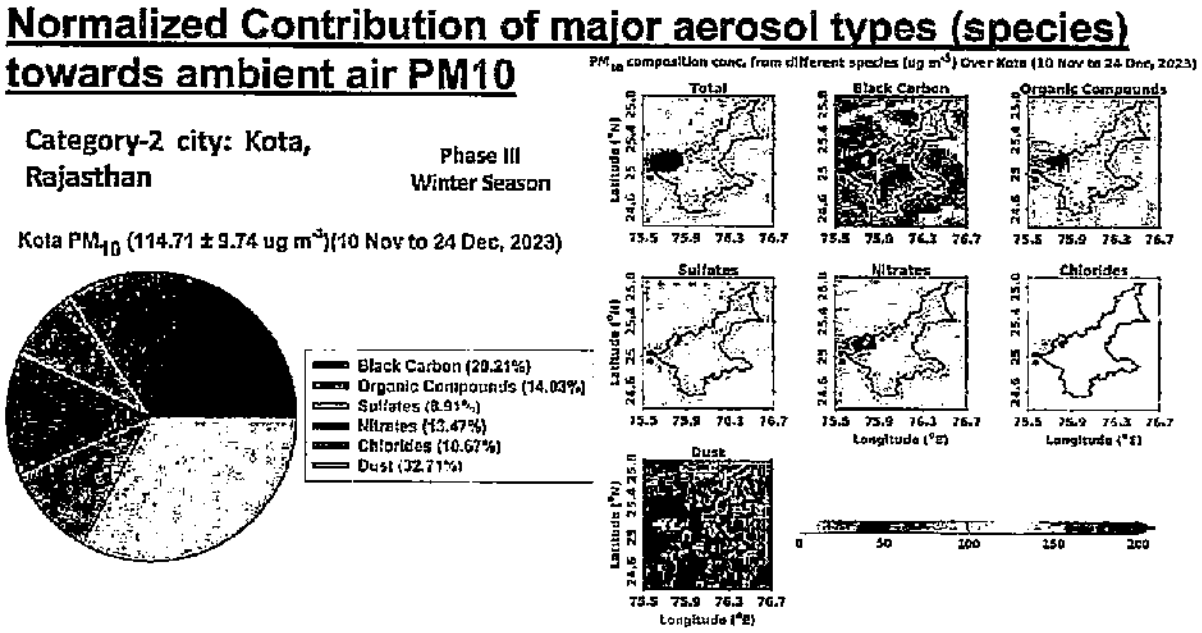


Figure 7.16: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in GBN during the simulation period from 8th November to 24th December 2023.

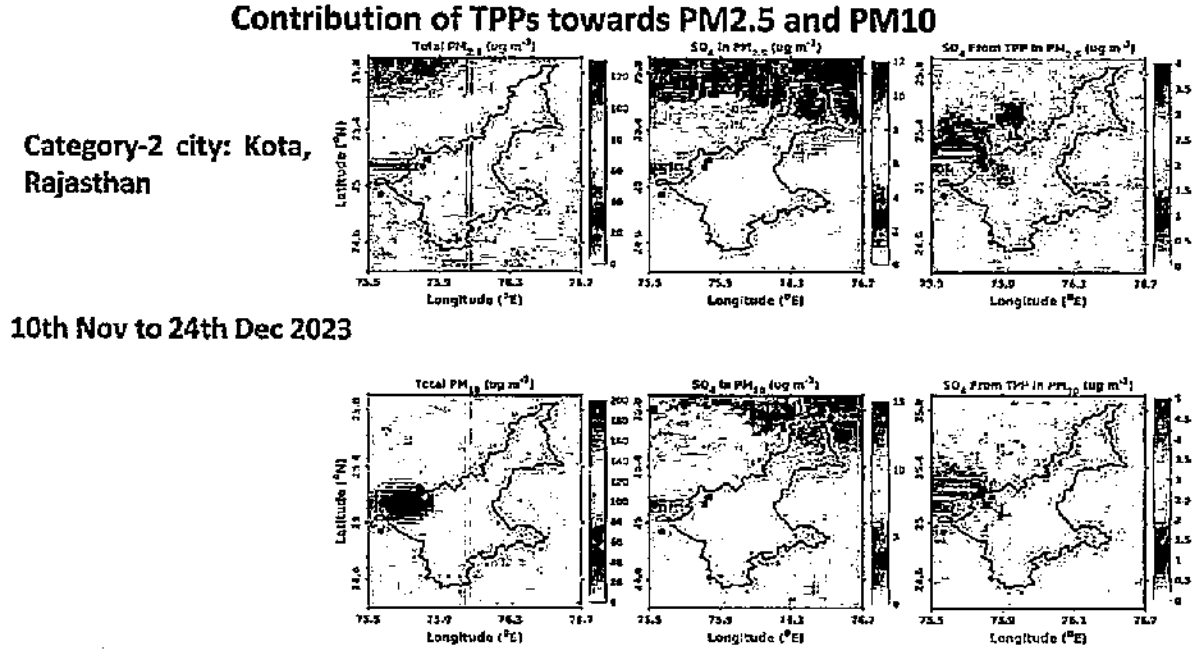


Figure 7.17: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Kota during the simulation period from 8th November to 24th December 2023.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Next we performed another series of systematically designed WRF-Chem model simulations to know the contribution different sources towards SO_2 and sulfate aerosols in Shahdol, which is a Category-2 city considered during the Phase-III of our survey. We also wanted to understand the contribution of Power sector towards the ambient atmospheric SO_2, PM2.5, and PM10 concentrations in the city of Shahdol during our survey. WRF-Chem version 4.2.2 has been used to perform a set of nine atmospheric chemistry simulations over Shahdol for January 8th to February 21st, 2024. For this study, the model domains have centre at Shahdol (81.07° E and 23.31° N).

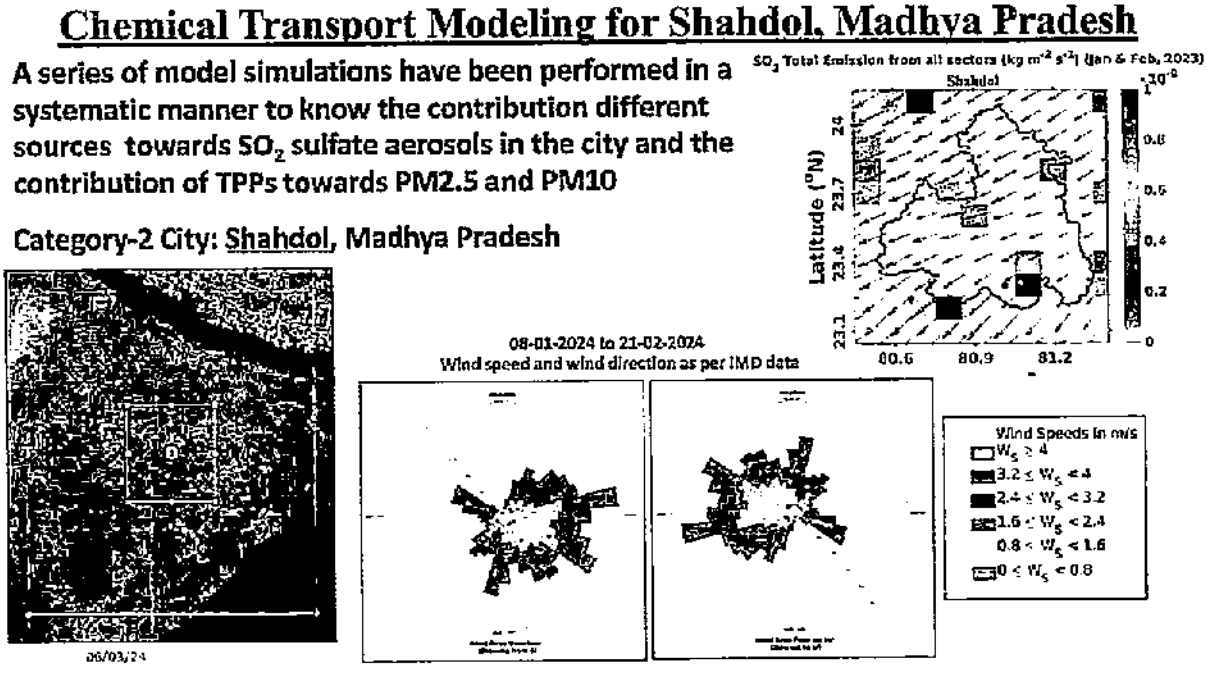


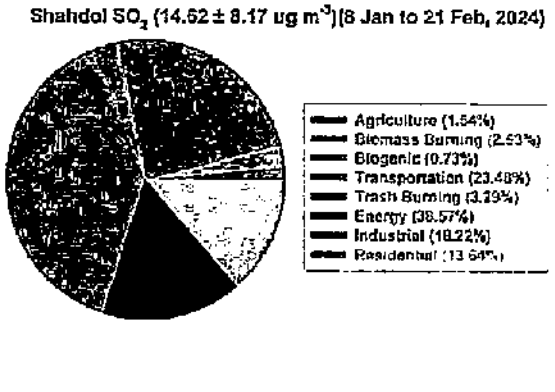
Figure 7.18: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Shahdol during the simulation period from 8th January to 21st February 2024.

Each of the simulation domain covers approximately 2250000 square Km area at a horizontal resolution of 10x10 Km^2, with 150x150 grid cells in the outer domain and horizontal resolution of 3x3 Km^2, with 136x136 grid cells in the inner domain following nested WRF-Chem modeling setup and 44 vertical levels (on a hybrid-sigma coordinate system) starting from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis (available at 6 hourly intervals) with a resolution of 0.25°x0.25° have been used to provide meteorological initial and lateral

boundary conditions to the model simulation of January 8th to February 21st, 2024. To estimate the sectoral emission contribution towards the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Shahdol, we followed an emission suppression method. The details of the model configuration, the various anthropogenic, biomass burning, and biogenic emissions considered, as well as the numerical experiment design, are provided in Chapter 3 and are therefore not repeated here.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-2 City: Shahdol, Madhya Pradesh



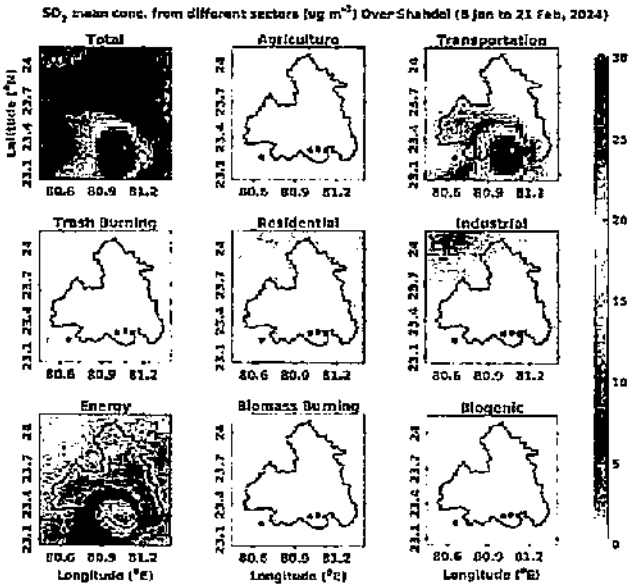
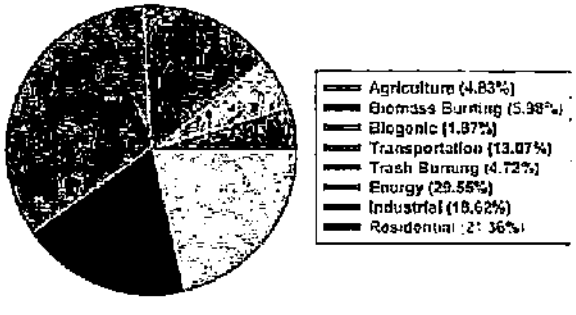


Figure 7.19: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

Normalized Contribution of different emission sectors towards ambient air SO_4

Category-2 City: Shahdol, Madhya Pradesh



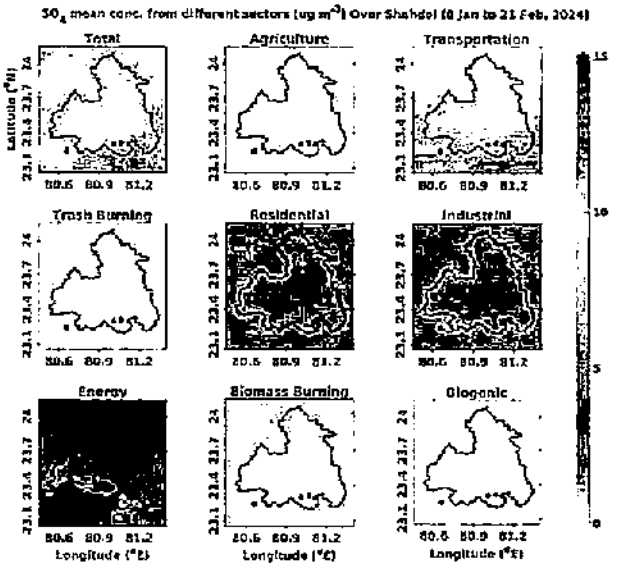


Figure 7.20: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

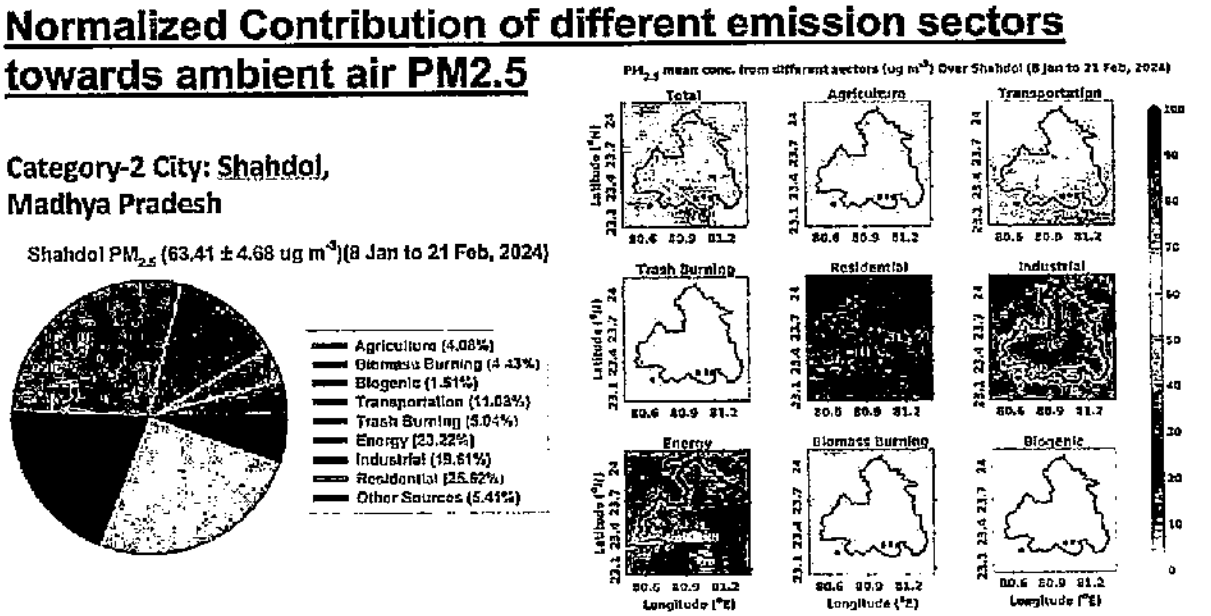


Figure 7.21: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

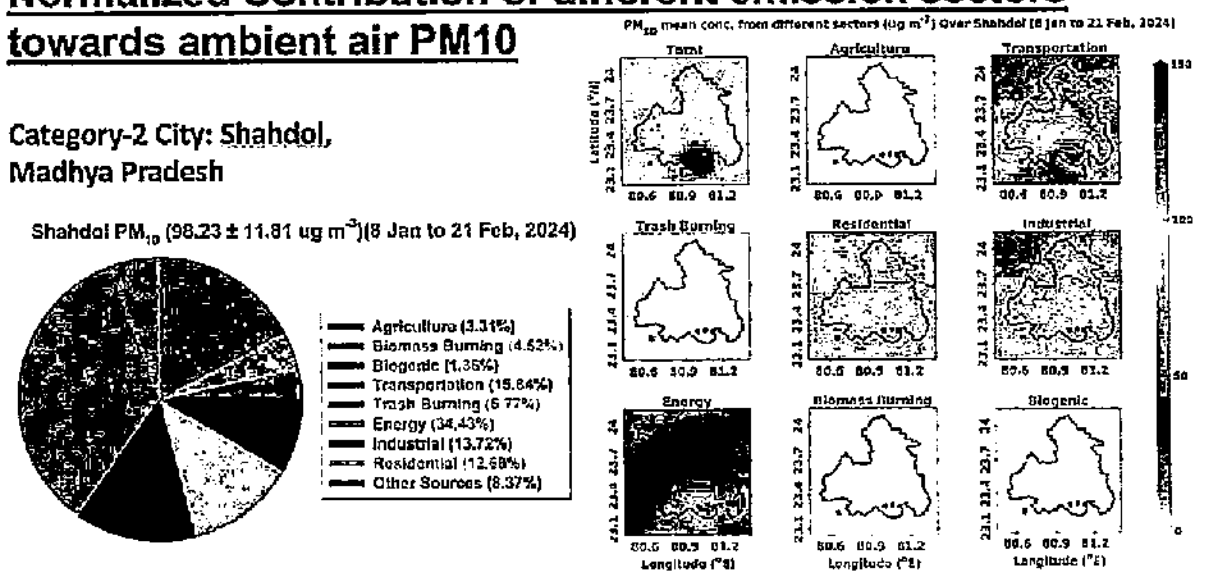


Figure 7.22: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

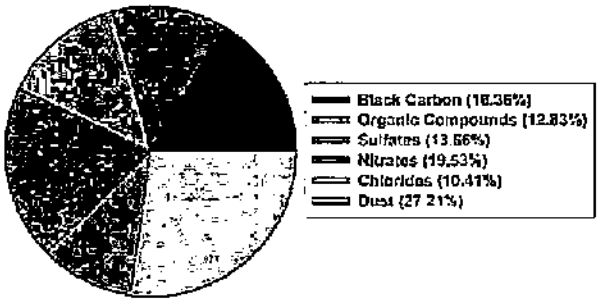
Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Shahdol during the survey period.

Normalized Contribution of major aerosol types (species) towards ambient air PM2.5

Category-2 City: Shahdol, Madhya Pradesh

Phase III Winter Season

Shahdol $PM_{2.5}$ (63.41 ± 4.68 ug m^{-3})(8 Jan to 21 Feb, 2024)



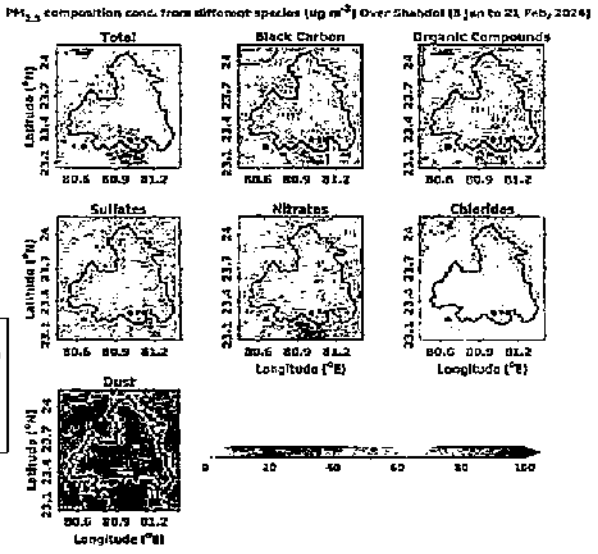


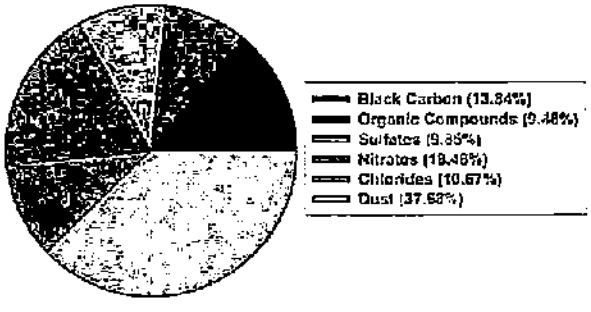
Figure 7.23: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

Normalized Contribution of major aerosol types (species) towards ambient air PM10

Category-2 City: Shahdol, Madhya Pradesh

Phase III Winter Season

Shahdol PM_{10} (98.23 ± 11.81 ug m^{-3})(8 Jan to 21 Feb, 2024)



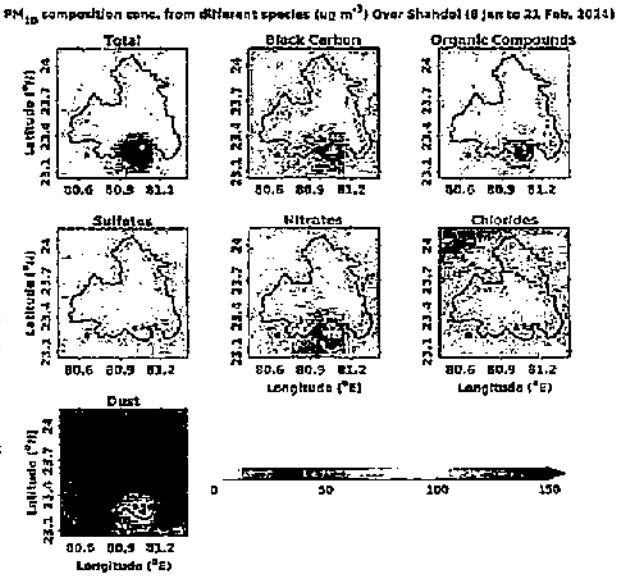


Figure 7.24: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Contribution of TPPs towards PM2.5 and PM10

Category-2 City: Shahdol, Madhya Pradesh

8th Jan to 21st Feb 2024

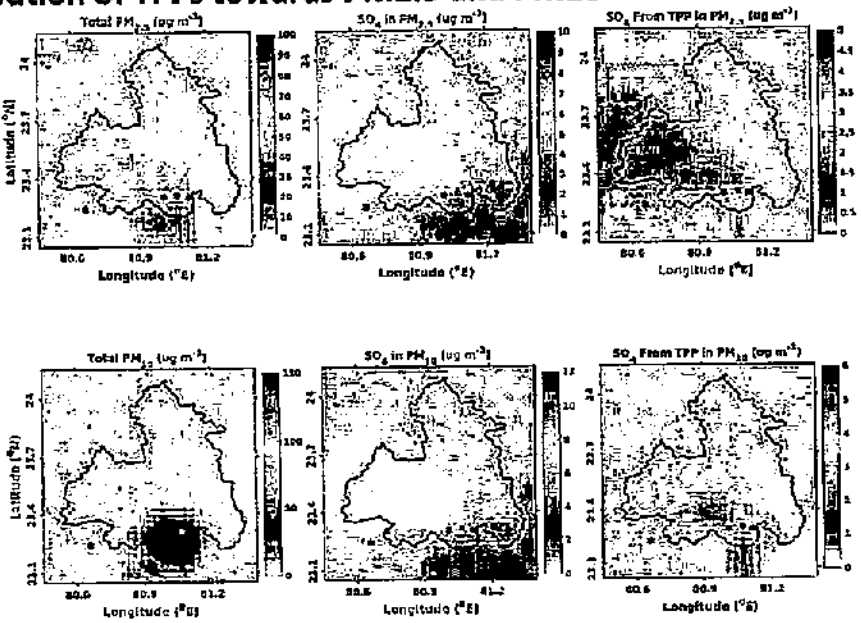


Figure 7.25: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Shahdol during the simulation period from 8th January to 21st February 2024.

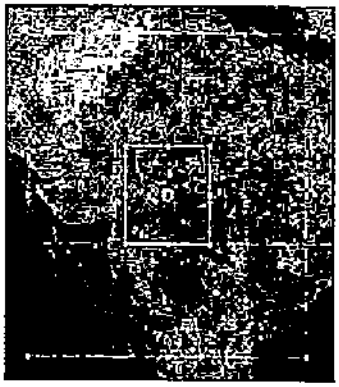
Next we performed another series of systematically designed WRF-Chem model simulations to know the contribution different sources towards SO_2 and sulfate aerosols in Khargone, which is a Category-3 city considered during the Phase-III of our survey. We also wanted to understand the contribution of Power sector towards the ambient atmospheric SO_2, PM2.5, and PM10 concentrations in the city of Khargone during our survey. WRF-Chem version 4.2.2 has been used to perform a set of nine atmospheric chemistry simulations over Khargone for January 8th to February 21st, 2024. For this study, the model domains are centered at Khargone (75.84° E and 22.06° N). Each of the simulation domain covers approximately 2250000 square Km area at a horizontal resolution of 10x10 Km^2, with 150x150 grid cells in the outer domain and horizontal resolution of 3x3 Km^2, with 136x136 grid cells in the inner domain following nested WRF-Chem modeling setup and 44 vertical levels (on a hybrid-sigma coordinate system) starting from the surface to about 10 hPa as the model top pressure. NCEP GDAS Final Analysis (available at 6 hourly intervals) with a resolution of 0.25°x0.25° have been used to provide meteorological initial

and lateral boundary conditions to the model simulation of January 8th to February 21st, 2024. To estimate the sectoral emission contribution towards the ambient atmospheric SO_2, sulfate aerosols, PM2.5, and PM10 concentrations in Khargone, we followed an emission suppression method. We modified the emissions assuming that FGD was operational in one of the two units of the Khargone TPP during Phase III of our survey.

Chemical Transport Modeling for Khargone, Madhya Pradesh

A series of model simulations have been performed in a systematic manner to know the contribution different sources towards SO_2 sulfate aerosols in the city and the contribution of TPPs towards PM2.5 and PM10

Category-3 City: Khargone, Madhya Pradesh



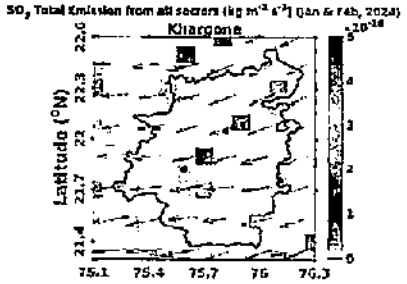


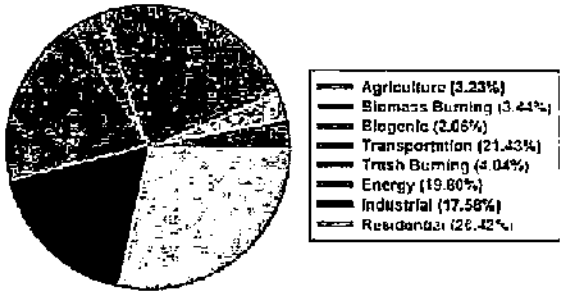
Figure 7.26: Simulation domain, gridded SO_2 emissions used as input in the model simulation and the monthly mean near surface wind speed and wind directions over Khargone during the simulation period from 8th January to 21st February 2024.

Normalized Contribution of different emission sectors towards ambient air SO_2

Category-3 City: Khargone, Madhya Pradesh

Phase III
Winter Season

Khargone SO_2 (9.63 ± 3.00 ug m^{-3})(8 Jan to 21 Feb, 2024)



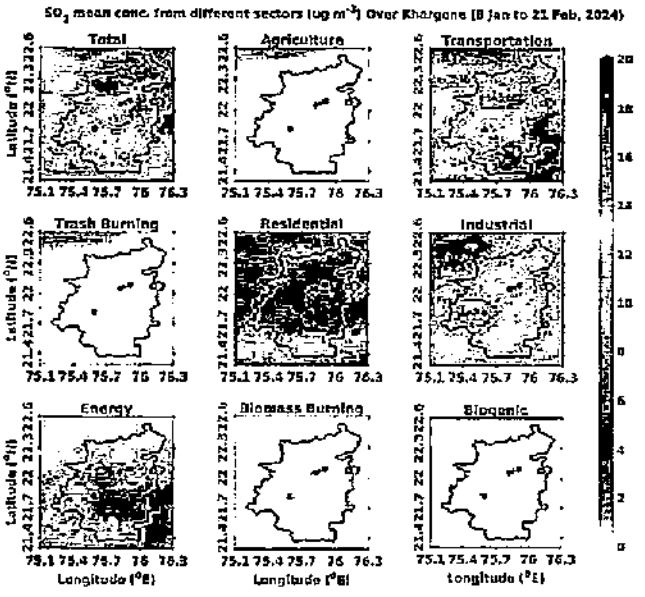


Figure 7.27: Contribution of different emission sectors towards ambient atmospheric SO_2 concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

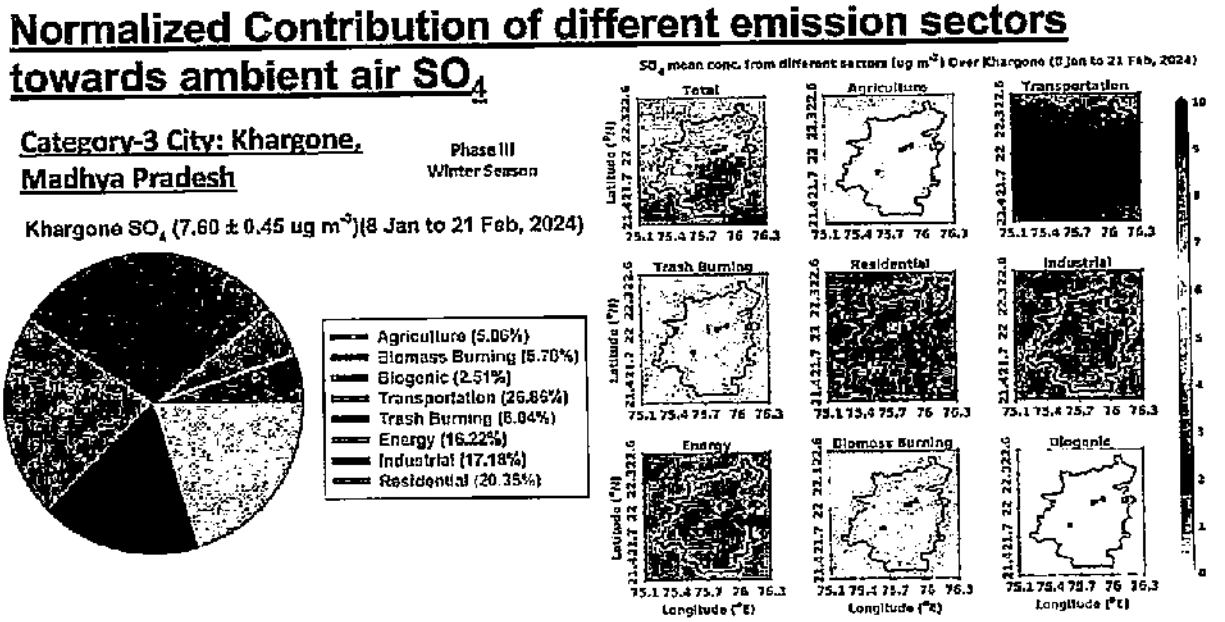


Figure 7.28: Contribution of different emission sectors towards ambient atmospheric sulfate aerosol concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

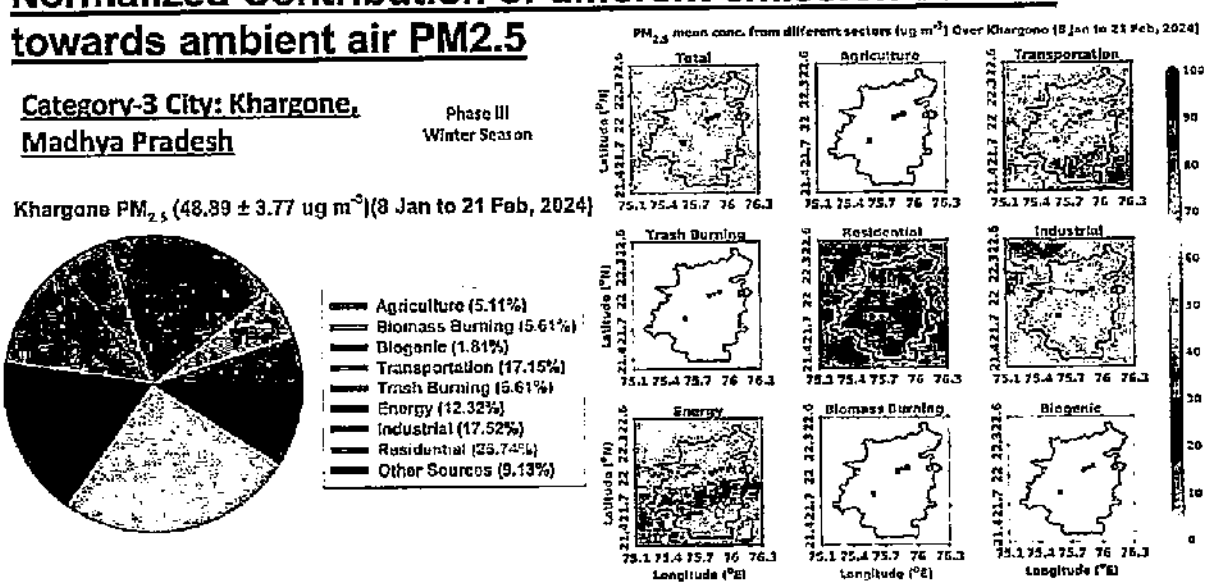


Figure 7.29: Contribution of different emission sectors towards ambient atmospheric PM2.5 concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

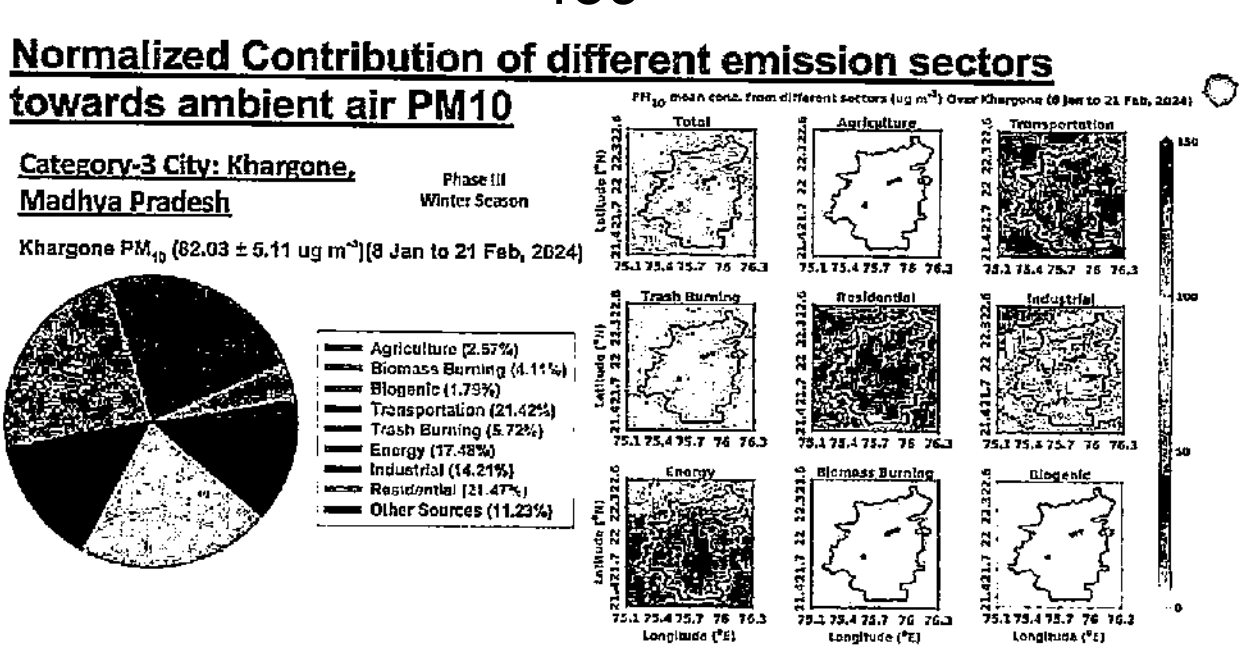


Figure 7.30: Contribution of different emission sectors towards ambient atmospheric PM10 concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

Next, we present the results of our simulations, which provide information on the contributions of major aerosol types—including black carbon (BC), organic compounds, sulfates, nitrates, chlorides, and dust—to the ambient air concentrations of PM2.5 and PM10 in the city of Khargone during the survey period.

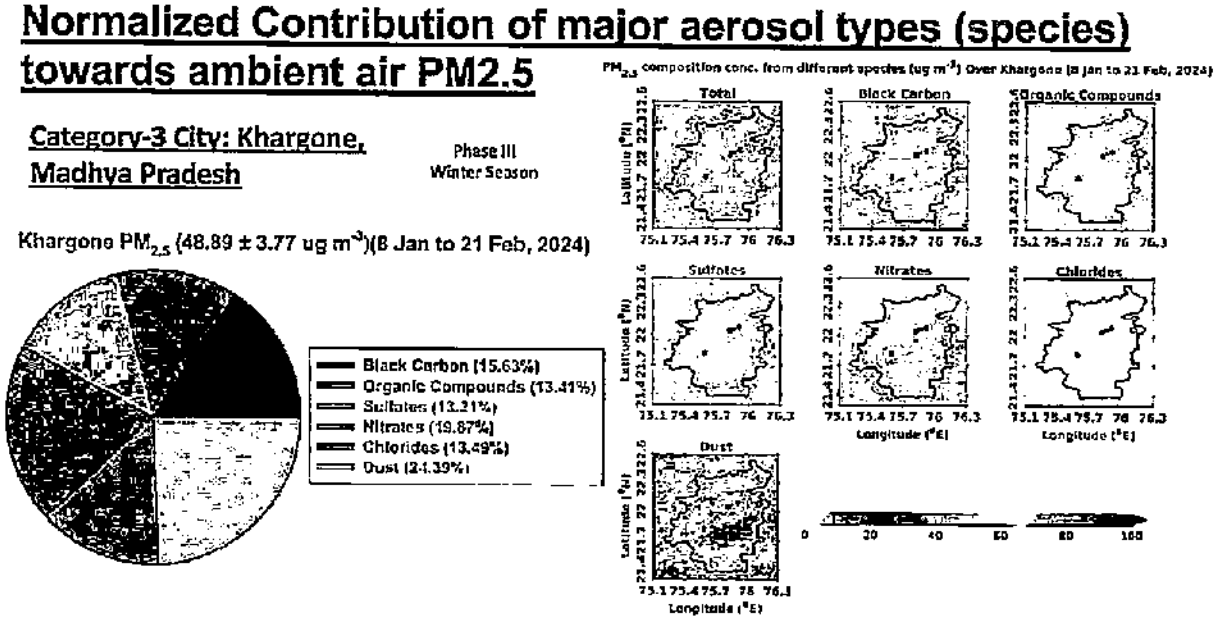


Figure 7.31: Contribution of major aerosol types (species) towards ambient atmospheric PM2.5 concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

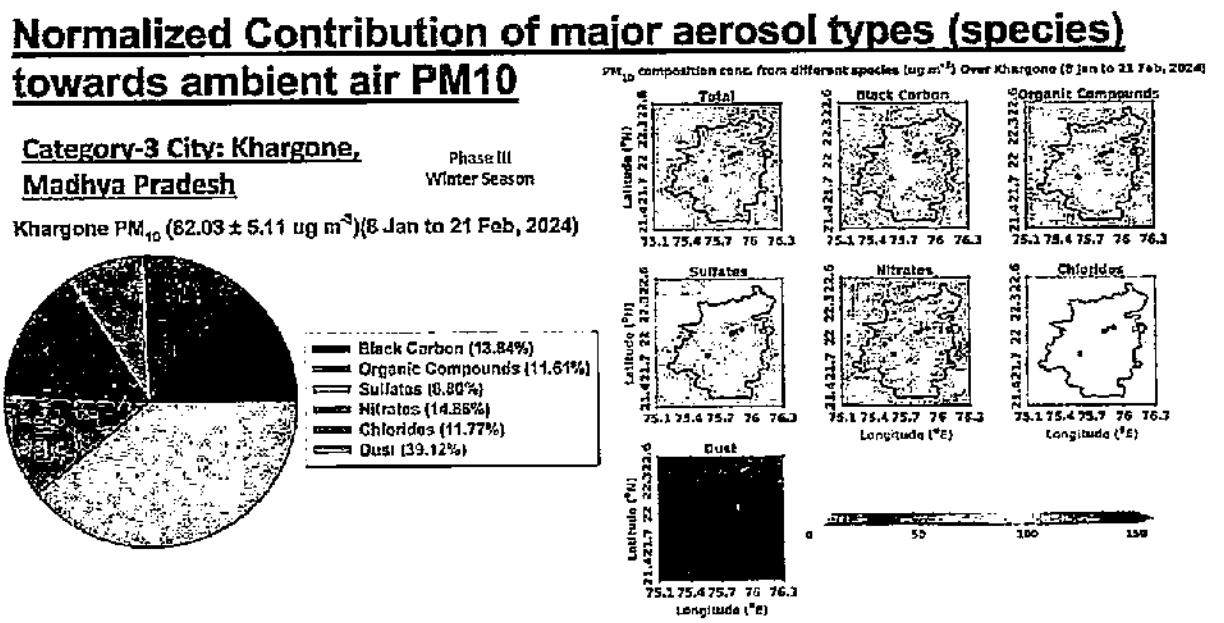


Figure 7.32: Contribution of major aerosol types (species) towards ambient atmospheric PM10 concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

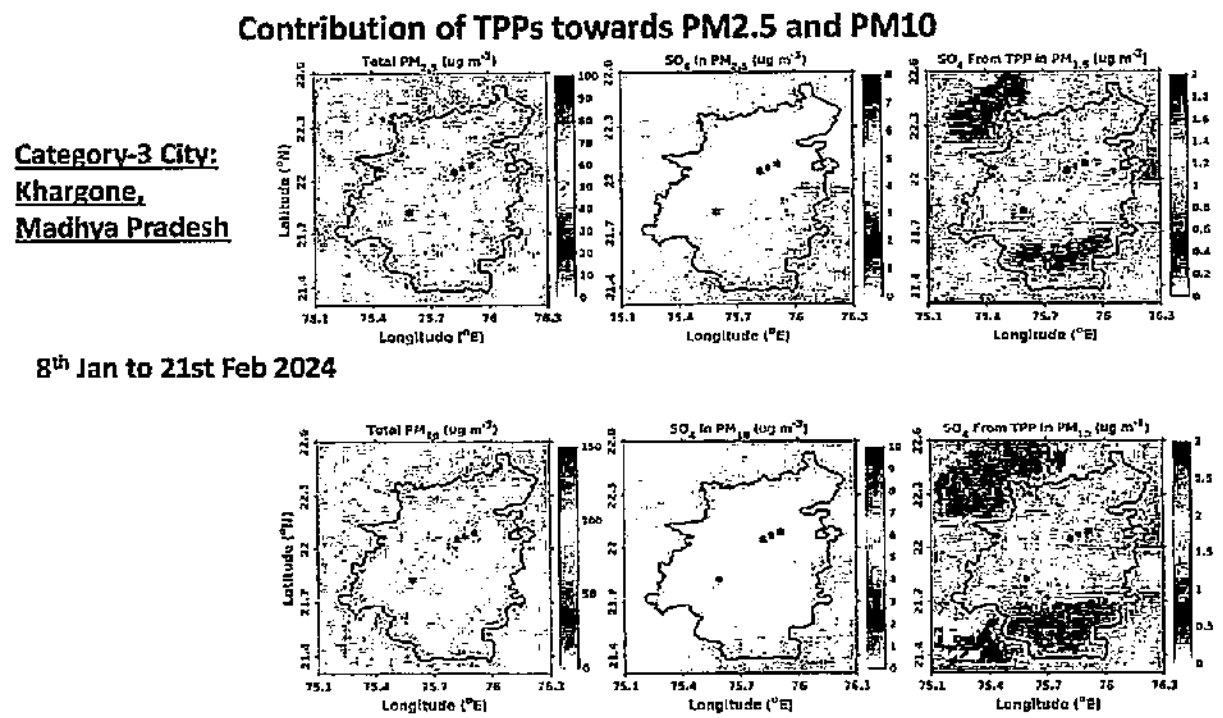


Figure 7.33: Contribution of SO_2 emissions from power sector towards sulfate aerosols as part of ambient atmospheric PM2.5 and PM10 concentrations in Khargone during the simulation period from 8th January to 21st February 2024.

By determining the total amount of sulfate aerosols in ambient air PM2.5 and PM10 concentrations and the contribution of energy sector emissions, specifically SO_2 emissions from thermal power plants (TPPs), we estimated the portion of sulfate aerosols in ambient air PM2.5 and PM10 that originated from SO_2 emissions from TPPs in the cities included in this survey.

Summary of results from Phase-III (Nov 2023 to Feb 2024)

Name of City (Measurement Site, distance from TPP)	Period of Survey	Total SO_2 (µg m^{-3})	SO_2 from Power Sector (µg m^{-3})
3 Km from Kota Super TPS (upwind)	10-11-2023 to 24-12-2023 (1.5 months)	5.13 ± 1.96	1.73 ± 0.43
4 Km from Kota Super TPS (downwind)		11.23 ± 4.94	2.44 ± 0.31
40 Km from Kota Super TPS (downwind)		3.23 ± 0.71	1.39 ± 0.27
5 Km from DADRI TPP (upwind)	10-11-2023 to 24-12-2023 (1.5 months)	9.82 ± 1.59	3.34 ± 1.17
5 Km from DADRI TPP (downwind)		12.51 ± 2.82	5.63 ± 0.73
40 Km from DADRI TPP (downwind)		6.51 ± 0.93	1.24 ± 0.83
5 Km from SG TPS (upwind)	08-01-2024 to 21-02-2024 (1.5 months)	5.21 ± 1.58	1.06 ± 0.09
5 Km from SG TPS (downwind)		5.78 ± 1.13	1.04 ± 0.11
40 Km from SG TPS (downwind)		4.42 ± 0.78	1.89 ± 0.28
5 Km from Khargone TPP (upwind)	08-01-2024 to 21-02-2024 (1.5 months)	4.38 ± 0.38	0.92 ± 0.17
5 Km from Khargone TPP (downwind)		4.24 ± 0.31	1.19 ± 0.28
40 Km from Khargone TPP (downwind)		4.39 ± 0.43	1.05 ± 0.19

Table 7.1: Normalized contribution of Power sector towards ambient atmospheric SO_2 concentrations at specific measurement locations in various cities during the period of our survey from 8th November 2023 to 21st February 2024.

Based on the results from a series of meticulously planned simulations using the WRF-Chem chemical transport model, the contribution of SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric SO_2 concentrations during Phase III of our survey (the winter season) exhibits significant variability across different cities. In Category-2 cities like Kota, the average contribution of TPPs to SO_2 levels was 27.99%. In Shahdol, another Category-2 city, the average contribution of TPPs to SO_2 concentrations was notably higher at 38.57%. Meanwhile, Category-3 cities such as Gautam Buddha Nagar showed a lower average contribution from TPPs, at 22.54%, and in Khargone, the TPPs contributed an average of 19.80% to SO_2 levels. Summarizing by city category, Category-2 cities experienced a higher average contribution of TPPs to SO_2 levels, with averages of 27.99% in Kota and 38.57% in Shahdol. In

contrast, Category-3 cities showed lower average contributions from TPPs, with 22.54% in Gautam Buddha Nagar and 19.80% in Khargone. This data highlights the variability in the influence of TPPs on local air quality, with contributions generally higher in Category-2 cities compared to Category-3 cities. This data underscores the varying impact of coal-based thermal power plants on ambient SO_2 levels during the winter season, with significant differences observed between city categories.

After discussing the average contribution of TPPs to ambient atmospheric SO_2 concentrations in each city and city category, we examine the normalized contribution of the power sector, specifically coal-based thermal power plants (TPPs), to ambient atmospheric SO_2 concentrations at specific measurement locations across different cities during the Phase II of our survey. According to the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. As evident from the data presented in Table 5.3, our survey results confirm that ambient air SO_2 concentrations at all measurement locations across the six cities met the existing standards during the survey period. The data presented in Table 7.1 summarizes the approximate contribution of the power sector, specifically coal based thermal power plants (TPP), to ambient atmospheric SO_2 concentrations at various measurement locations across different cities during Phase III our survey period. For each city, measurements were taken at three locations: one upwind and two downwind from the respective thermal power plants (TPPs). In Kota (Category-2), the upwind and downwind locations showed different levels of TPP contributions. At 3 km upwind, the TPPs contributed 34% (1.73 ± 0.43 $\mu g/m^3$), while at 4 km and 40 km downwind, the contributions were 22% (2.44 ± 0.31 $\mu g/m^3$) and 42% (1.39 ± 0.27 $\mu g/m^3$), respectively. In Gautam Buddha Nagar (Category-3), the upwind location (5 km) had a TPP contribution of 34% (3.34 ± 1.17 $\mu g/m^3$), while the downwind locations (5 km and 40 km) had contributions of 45% (5.63 ± 0.73 $\mu g/m^3$) and 19% (1.24 ± 0.83 $\mu g/m^3$), respectively. In Shahdol (Category-2), the upwind and downwind locations at 5 km showed contributions of 20% (1.06 ± 0.09 $\mu g/m^3$) and 18% (1.04 ± 0.11 $\mu g/m^3$), while at 40 km downwind, the contribution was 42% (1.89 ± 0.28 $\mu g/m^3$). In Khargone (Category-3), the upwind location (5 km) had a contribution of 21% (0.92 ± 0.17 $\mu g/m^3$), while the downwind locations (5 km and 40 km) had contributions of 28% (1.19 ± 0.28 $\mu g/m^3$) and 24% (1.05 ± 0.19 $\mu g/m^3$), respectively. These findings, derived from a combination of actual measurements and modeling studies, highlight the varying impact of TPP emissions on ambient air SO_2 concentrations in different locations and underscore the significant contribution of the power sector to ambient SO_2 levels across the surveyed cities. As per the National Ambient Air Quality Standards (NAAQS) set by the MoEF&CC, Government of India, the maximum permissible limit for ambient air SO_2 concentrations based on 24-hour average measurements for industrial, residential, rural, and other areas is 80 $\mu g/m^3$. Our survey results confirm that the ambient air SO_2 concentrations at all measurement locations across four cities met the existing standards

during the survey period. Overall, our measurement data and analysis of modeling results indicate that the proximity to thermal power plants significantly affects SO_2 concentrations, with closer locations showing higher contributions from the power sector.

Summary of results from Phase-III (Nov 2023 to Feb 2024)

Gautam Buddha Nagar	110.18 ± 23.47	177.04 ± 42.82	15.71	17.31 ± 3.31	10.93	19.35 ± 2.31	18.65	3.23 ± 0.91	3.80 ± 1.67	2.93 ± 0.93	2.15 ± 0.52
Kota	72.69 ± 14.75	114.71 ± 9.74	14.43	10.49 ± 2.13	11.39	13.07 ± 1.11	24.26	2.54 ± 0.52	3.17 ± 0.03	3.50 ± 0.71	2.76 ± 0.02
Khargone	48.89 ± 4.27	82.03 ± 5.43	13.21	6.46 ± 0.75	8.80	7.22 ± 0.63	16.22	1.05 ± 0.15	1.23 ± 0.37	2.14 ± 0.38	1.51 ± 0.27
Shahdol	63.41 ± 4.68	98.23 ± 11.81	17.62	11.17 ± 0.82	12.41	12.19 ± 1.47	29.55	3.30 ± 0.24	3.60 ± 0.05	5.21 ± 0.38	3.67 ± 0.05

Table 7.2: Contribution of Power sector towards ambient atmospheric sulfate aerosols, PM2.5 and PM10 concentrations in various category cities during the period of our survey from 8th November 2023 to 21st February 2024.

Table 7.2 summarizes the contribution of sulfate aerosols (SO_4) in PM2.5 and PM10, as well as the specific contribution of sulfate aerosols originating from SO_2 emissions from the power sector (coal based TPPs) to ambient atmospheric PM2.5 and PM10 concentrations across various cities during the Phase III of our survey period from 8th November 2023 to 21st February 2024. In Category-3 cities, such as Gautam Buddha Nagar, sulfate aerosols contributed 15.71% (17.31 $\mu g/m^3$) to PM2.5 and 10.93% (19.35 $\mu g/m^3$) to PM10. Similarly, in Khargone, sulfate aerosols contributed 13.21% (6.46 $\mu g/m^3$) to PM2.5 and 8.80% (7.22 $\mu g/m^3$) to PM10. For Category-2 cities, the contributions in Kota were 14.43% (10.49 $\mu g/m^3$) to PM2.5 and 11.39% (13.07 $\mu g/m^3$) to PM10, while in Shahdol, they were 17.62% (11.17 $\mu g/m^3$) to PM2.5 and 12.41% (12.19 $\mu g/m^3$) to PM10. On average, Category-3 cities exhibited sulfate aerosol contributions of 14.46% (11.89 $\mu g/m^3$) to PM2.5 and 9.87% (13.29 $\mu g/m^3$) to PM10, whereas Category-2 cities showed higher contributions at 16.03% (10.83 $\mu g/m^3$) to PM2.5 and 11.90% (12.63 $\mu g/m^3$) to PM10. These results highlight that while sulfate aerosol concentrations are significant in both categories, Category-2 cities tend to have higher percentages and absolute concentrations compared to Category-3 cities.

During the Phase III, the contribution of SO_2 emissions from the energy sector, specifically coal-based thermal power plants (TPPs), to the total ambient air SO_4 (sulfate aerosol) concentration varied significantly across different cities and city categories. In Category-2 cities, such as Kota and Shahdol, the contributions were substantial. In Kota, SO_2 emissions from TPPs contributed 24.26% (2.61 $\mu g/m^3$) to the total ambient air SO_4 concentration. Similarly, in Shahdol, the

contribution was even higher at 29.55% (3.01 μg/m³). Category-3 cities also exhibited significant contributions from TPPs. In Gautam Buddha Nagar, the SO_2 emissions from TPPs contributed 18.65% (3.80 μg/m³) to the total ambient air SO_4 concentration. In Khargone, the contribution was 16.22% (1.23 μg/m³). When averaging the contributions across the cities within each category, we observe the following: For Category-2 cities, the average contribution of SO_2 emissions from TPPs towards the total ambient air SO_4 concentration was 26.91% (2.81 μg/m³). For Category-3 cities, the average contribution was 17.44% (2.52 μg/m³). These findings indicate that cities with coal-based thermal power plants, both with and without FGD systems, experience considerable contributions of SO_2 emissions from the energy sector to the total ambient air SO_4 concentrations. Notably, the highest sulfate aerosol contributions in absolute terms were observed in the Category-3 city of Gautam Buddha Nagar, with concentrations reaching 3.80 μg/m³. This is likely due to the overall higher concentrations of total sulfate aerosol, PM2.5, and PM10 in Gautam Buddha Nagar compared to other cities in Phase III of our survey, as well as the assumption that the FGD was operational in only two units of the NTPC Dadri TPP during this period.

The specific contribution of sulfate aerosols originating from SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric PM2.5 and PM10 concentrations also varied across different cities and city categories. In Gautam Buddha Nagar, the contribution was 2.93% (3.23 μg/m³) in PM2.5 and 2.15% (3.80 μg/m³) in PM10. In Khargone, the contributions were 2.14% (1.05 μg/m³) in PM2.5 and 1.51% (1.23 μg/m³) in PM10. For Category-2 cities, Kota saw contributions of 3.50% (2.54 μg/m³) in PM2.5 and 2.76% (3.17 μg/m³) in PM10, while Shahdol had higher contributions of 5.21% (3.30 μg/m³) in PM2.5 and 3.67% (3.60 μg/m³) in PM10. On average, the contribution of SO_2 emissions from TPPs to sulfate aerosols in Category-3 cities was 2.54% (2.14 μg/m³) in PM2.5 and 1.83% (2.52 μg/m³) in PM10. In comparison, Category-2 cities had higher contributions, with averages of 4.36% (2.92 μg/m³) in PM2.5 and 3.22% (3.39 μg/m³) in PM10. These figures indicate that SO_2 emissions from TPPs contribute a measurable, albeit relatively small, portion of sulfate aerosols in PM2.5 and PM10.

Overall, the contribution of SO_2 emissions from the power sector, which convert to sulfate aerosols, ranged from 2.14% to 5.21% in PM2.5 and from 1.51% to 3.67% in PM10 across the cities during Phase-III of the survey. This indicates variability in the impact of power sector emissions on sulfate aerosol concentrations. While SO_2 emissions from TPPs do contribute to sulfate aerosol mass concentrations in PM2.5 and PM10, their overall contribution remains a small fraction (less than 6%) of the total PM2.5 and PM10 mass concentrations across various city categories, especially during the winter season, indicating that other sources are more significant contributors to ambient air PM levels.

CHAPTER-8: SUMMARY OF RESULTS FROM THREE PHASES SURVEY ON AMBIENT ATMOSPHERIC SO_2 CONCENTRATIONS IN DIFFERENT CATEGORY OF CITIES

This chapter summarizes the results of our measurement-based survey on ambient air SO_2 concentrations across different city categories during three distinct survey periods: Phase I (pre-monsoon season, February to May 2023), Phase II (summer monsoon season, July to August 2023), and Phase III (winter season, November 2023 to February 2024). The survey was conducted in 10 cities, categorized as follows: Category 1 - Cities with no coal-based TPP; Category 2 - Cities with a coal-based TPP without FGD installed, located within 10 km from the city boundary; and Category 3 - Cities with a coal-based TPP with FGD installed, also located within 10 km from the city boundary. In Category 1, the survey was conducted in three cities: New Delhi and Hyderabad during Phase I (pre-monsoon season), and Lucknow during Phase II (summer monsoon season). For Category 2, the survey included four cities: Kolkata and Nagpur during Phase I (pre-monsoon season), Kota during both Phase II (summer monsoon season) and Phase III (winter season), and Shahdol during Phase III (winter season). In Category 3, the survey was conducted in three cities: Ghaziabad and Gautam Buddha Nagar during Phase I (pre-monsoon season), Gautam Buddha Nagar again during Phase II (summer monsoon season) and Phase III (winter season), and Khargone during Phase III (winter season). Thus the surveys spanned three distinct periods, including pre-monsoon, summer monsoon, and winter seasons, providing a comprehensive assessment of ambient air SO_2 concentrations across different environmental conditions and city categories.

8.1 Ambient Air SO_2 Concentration In Different Category Cities

In this section we summarize the results of our measurement-based survey on ambient air SO_2 concentrations across different category cities during all three phases. In Category 1 cities, New Delhi recorded the highest maximum instantaneous SO_2 concentration of 29.37 $\mu g/m^3$ during Phase I (pre-monsoon season), while the lowest minimum instantaneous value was 0.83 $\mu g/m^3$, also in New Delhi during the same phase. The daily mean SO_2 concentrations in Category 1 cities ranged from 2.48 to 9.26 $\mu g/m^3$. For Category 2 cities, Kota exhibited the highest maximum instantaneous SO_2 concentration of 68.09 $\mu g/m^3$ during Phase III (winter season), and the lowest minimum value was 0.75 $\mu g/m^3$, recorded in Kota during Phase II (summer monsoon season). The daily mean values for SO_2 in Category 2 cities varied from 3.12 to 11.23 $\mu g/m^3$. In Category 3 cities, Gautam Buddha Nagar had the highest maximum instantaneous SO_2 concentration of 70.14 $\mu g/m^3$ during Phase III (winter season), while the lowest minimum value was 0.54 $\mu g/m^3$, also observed in Gautam Buddha Nagar during Phase III. It is noteworthy that the highest values in Gautam Buddha Nagar were measured on November 13th, the day after the Diwali festival, which is characterized by the bursting of firecrackers that could have contributed to these peak

values. The daily mean SO_2 concentrations in Category 3 cities ranged from 4.24 to 12.51 µg/m³. Importantly, ambient SO_2 levels across all city categories and phases remained well within the National Ambient Air Quality Standards (NAAQS) of 80 µg/m³, which is the maximum permissible limit for 24-hour average measurements as notified by the MoEF&CC, Government of India. Even the instantaneous maximum values never exceeded this daily mean standard limit.

Generally, downwind sites exhibited higher SO_2 concentrations compared to upwind sites, and SO_2 levels tended to decrease with increasing distance from the TPP across all cities. These results highlight the variability in ambient air SO_2 concentrations across different locations and city categories, with Category 2 and Category 3 cities generally showing higher SO_2 levels. The findings of our survey clearly indicate that proximity to thermal power plants significantly affects ambient air SO_2 concentrations, with locations closer to TPPs showing higher values.

Our survey also revealed some important common features in the diurnal patterns of ambient air SO_2 concentrations across cities. We observed significant diurnal variations and intra-day fluctuations, with multiple peaks at various times of the day, including evening and nighttime, in all city categories and throughout the survey phases. These spikes, lasting 2-4 hours, are likely caused by local sources within approximately 60 km of the measurement sites, such as transportation, residential activities, and industrial emissions. The role of TPPs in these spikes can be ruled out because (i) TPP units typically operate continuously and are not switched on and off intermittently, and (ii) such intermittent spikes were observed even in Category-1 cities with no TPPs within 10 km of their boundaries. A significant influence of boundary layer dynamics on ambient air SO_2 concentrations was noted in all cities throughout the survey phases.

Overall, our survey underscored the significant impact of proximity to thermal power plants, various other local sources, wind speed, predominant wind direction, and boundary layer dynamics on ambient air SO_2 concentrations across different city categories.

Importantly, our survey data showed no notable systematic differences in ambient air SO_2 concentrations between the Category 2 and Category 3 cities. Additionally, we did not observe any significant changes in SO_2 levels with the operation of FGD units at the measurement locations in the Category 3 cities, namely GBN and Khargone, despite large day-to-day variability. However, this variability did not correlate with either the operation or the number of FGD units in operation at these TPPs.

The analysis of ambient air SO_2 concentrations across multiple cities, supported by dispersion modelling results from the AERMOD model, demonstrates a clear pattern of decreasing SO_2 levels with increasing distance from thermal power plants (TPPs). Our findings indicate that the highest hourly, 24-hourly, and monthly SO_2 concentrations drop significantly within the first 20 to 25 km

from the TPPs. Beyond this range, concentrations level off but continue to decrease gradually up to 120 km. This trend is consistent across Category-2 and Category-3 cities, including GBN, Kota, Shahdol, and Khargone. These observations align with numerous previous studies using dispersion and chemical transport models, which show that SO_2 emissions beyond 120 km from a fixed-point source like a TPP generally become part of the regional background concentration and decrease by over two orders of magnitude compared to the highest levels near the source, under moderate wind speed conditions of up to 5 m/s (or 18 km/h) (Fioletov et al. 2015).

8.2 Contribution of Energy Sector (Coal based Thermal Power Plants) Emissions Towards Ambient Air SO_2 Concentration In Different Category Cities

Results from a series of meticulously planned simulations using the WRF-Chem chemical transport model reveal that the contribution of SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric SO_2 concentrations during all phases of our survey exhibited significant spatial and seasonal variability across different cities. Our analysis shows that the energy sector's contribution to total ambient air SO_2 concentrations varies markedly across different city categories during the various phases of the study.

In Category-1 cities, which have no coal-based TPPs, the energy sector's contribution to ambient SO_2 concentrations was relatively low. New Delhi showed a contribution of 16.53% (1.36 $\mu g/m^3$) during Phase-I (pre-monsoon season). In Hyderabad, the contribution was 11.57% (0.41 $\mu g/m^3$) in the same phase. During Phase-II (monsoon season), Lucknow recorded contributions of 11.44% (0.66 $\mu g/m^3$). These results indicate that in Category-1 cities, other sources contributing to the regional pollution play a more significant role in ambient SO_2 levels compared to emissions from the energy sector.

For Category-2 cities, which have coal-based TPPs without Flue Gas Desulfurization (FGD) installed and located within 10 km from the city boundary, the energy sector's contribution to ambient SO_2 concentrations were generally significant. Kolkata showed contributions of 28.66% (1.55 $\mu g/m^3$), and Nagpur showed 32.27% (1.56 $\mu g/m^3$) during Phase-I (pre-monsoon season). In Phase-II (monsoon season), energy sector's contribution to ambient SO_2 concentrations in Kota was 28.9% (1.11 $\mu g/m^3$). During Phase III (winter season), Kota had a 27.99% contribution (1.82 $\mu g/m^3$) from the energy sector to ambient SO_2 concentrations, while Shahdol showed a 38.57% contribution (1.99 $\mu g/m^3$). These results underscore the significant impact of coal-based TPP emissions in Category-2 cities.

In Category-3 cities, which have coal-based TPPs with FGD installed and located within 10 km from the city boundary, the energy sector's contributions were also notable. Ghaziabad showed contributions of 17.37% (1.43 $\mu g/m^3$) during Phase-I (pre-monsoon season). GBN had

contributions of 19.82% (1.80 μg/m³) from the energy sector to ambient SO_2 concentrations in Phase-I (pre-monsoon season), 21.97% (1.33 μg/m³) in Phase-II (monsoon season), and 22.54% (2.17 μg/m³) in Phase-III (winter season). Khargone had contributions of 19.8% (0.86 μg/m³) from the energy sector to ambient SO_2 concentrations during Phase-III (winter season). These results indicate some seasonal variation, with the highest contributions generally observed in the winter season and the lowest during the pre-monsoon season.

Overall, our study shows that the energy sector's contribution to ambient air SO_2 concentrations ranged from 11.44% (0.66 μg/m³) to 38.57% (1.99 μg/m³) across all cities and phases of the survey. The highest contributions were observed in Category-2 and Category-3 cities, underscoring the significant impact of coal-based TPP emissions on ambient air SO_2 in these cities. While SO_2 emissions from TPPs are among the major contributors to ambient air SO_2 concentrations in several cities, especially in Category-2 and Category-3, other sources such as industrial, residential, and transportation sectors also significantly contribute to ambient air SO_2 levels in all cities. Therefore, stringent emission control measures must be implemented across all sectors contributing to SO_2 emissions to effectively reduce the total ambient air SO_2 concentrations and improve regional air quality.

8.3 Contribution of total Sulfate aerosols (SO_4) originating from all SO_2 sources Towards PM2.5 and PM10 Mass Concentrations In Different Category Cities

Our study demonstrates that the contribution of total sulfate aerosols originating from all SO_2 sources towards PM2.5 and PM10 mass concentrations varies significantly across different categories of cities and seasons. By averaging the data from different cities and seasons within each category, we gain a clearer understanding of these contributions.

In Category-1 cities, which have no coal-based thermal power plants (TPPs), sulfate aerosol contributions were relatively low. In Delhi, sulfate aerosols contributed 15.15% (12.09 μg/m³) to PM2.5 and 9.82% (13.51 μg/m³) to PM10 during Phase-I (pre-monsoon season). In Hyderabad, the contributions were 13.85% (6.26 μg/m³) to PM2.5 and 8.22% (7.00 μg/m³) to PM10 during the same phase. In Lucknow, the sulfate contributions were 11.62% (4.02 μg/m³) to PM2.5 and 8.55% (4.49 μg/m³) to PM10 during Phase-II (monsoon season). Averaging these values, Category-1 cities had an average sulfate contribution of approximately 13.54% (7.46 μg/m³) to PM2.5 and 8.86% (8.33 μg/m³) to PM10.

In Category-2 cities, which are near coal-based TPPs without flue-gas desulfurization (FGD) systems, sulfate aerosol contributions were higher. In Kolkata, the contributions were 22.32% (7.04 μg/m³) to PM2.5 and 14.87% (7.86 μg/m³) to PM10 during Phase-I (pre-monsoon season). For Nagpur, the contributions were 14.16% (8.85 μg/m³) to PM2.5 and 11.83% (9.90 μg/m³) to

PM10 during the same period. In Kota, sulfate contributions were 11.73% (5.71 μg/m³) to PM2.5 and 9.71% (6.38 μg/m³) to PM10 during Phase-II (monsoon season), which increased to 14.43% (10.49 μg/m³) to PM2.5 and 11.39% (13.07 μg/m³) to PM10 during Phase-III (winter season). In Shahdol, the contributions were 17.62% (11.17 μg/m³) to PM2.5 and 12.41% (12.19 μg/m³) to PM10 during Phase-III. Averaging these values, Category-2 cities had average sulfate contributions of approximately 16.45% (8.05 μg/m³) to PM2.5 and 12.04% (9.88 μg/m³) to PM10.

In Category-3 cities, which are near coal-based TPPs with FGD systems, sulfate aerosol contributions were the highest. In Gautam Buddha Nagar, the contributions were 15.56% (12.12 μg/m³) to PM2.5 and 10.32% (13.55 μg/m³) to PM10 during Phase-I (pre-monsoon season). During Phase-II (monsoon season), the contributions in Gautam Buddha Nagar were 13.65% (6.42 μg/m³) to PM2.5 and 10.09% (7.18 μg/m³) to PM10. In Phase-III (winter season), the contributions in Gautam Buddha Nagar were 15.71% (17.31 μg/m³) to PM2.5 and 10.93% (19.35 μg/m³) to PM10. In Khargone, the contributions were 13.21% (6.46 μg/m³) to PM2.5 and 8.80% (7.22 μg/m³) to PM10 during Phase-III. Averaging these values, Category-3 cities had average sulfate contributions of approximately 14.53% (10.58 μg/m³) to PM2.5 and 10.04% (11.83 μg/m³) to PM10.

Overall, Category-2 and Category-3 cities experienced significantly higher contributions of sulfate aerosols to PM2.5 and PM10 compared to Category-1 cities. Category-1 cities, which have no coal-based thermal power plants (TPPs), showed the lowest average sulfate aerosol contributions, at approximately 13.54% (7.46 μg/m³) to PM2.5 and 8.86% (8.33 μg/m³) to PM10. In contrast, Category-2 cities, located near TPPs without flue-gas desulfurization (FGD) systems, exhibited higher average sulfate aerosol contributions of 16.45% (8.05 μg/m³) to PM2.5 and 12.04% (9.88 μg/m³) to PM10. Category-3 cities, which are near TPPs with FGD systems, had intermediate average contributions in relative percentage terms, with 14.53% to PM2.5 and 10.04% to PM10. However, in absolute concentration terms, Category-3 cities showed the highest concentrations of sulfate aerosols, with 10.58 μg/m³ in PM2.5 and 11.83 μg/m³ in PM10, likely due to their higher absolute PM2.5 and PM10 concentrations compared to Category-2 and Category-1 cities.

This comparison clearly highlights that cities closer to coal-based TPPs, regardless of the presence of FGD systems, experience significantly higher sulfate aerosol contributions. Specifically, Category-2 cities had an average of 16.45% (8.05 μg/m³) sulfate contribution to PM2.5 and 12.04% (9.88 μg/m³) to PM10, while Category-3 cities had slightly lower averages of 14.53% (10.58 μg/m³) to PM2.5 and 10.04% (11.83 μg/m³) to PM10. In stark contrast, Category-1 cities had much lower averages of 13.54% (7.46 μg/m³) to PM2.5 and 8.86% (8.33 μg/m³) to PM10.

Our study also reveals notable seasonal variations in sulfate aerosol contributions to both PM2.5 and PM10 during Phase-I (pre-monsoon season), Phase-II (monsoon season), and Phase-III (winter season). For instance, in Kota, the sulfate aerosol contributions to PM2.5 rose from 11.73% (5.71 μg/m³) in the monsoon season to 14.43% (10.49 μg/m³) in the winter season, and for PM10, from 9.71% (6.38 μg/m³) to 11.39% (13.07 μg/m³) in the same periods. Similarly, in Gautam Buddha Nagar, contributions to PM2.5 varied from 15.56% (12.12 μg/m³) during the pre-monsoon season to 13.65% (6.42 μg/m³) during the monsoon season, and further to 15.71% (17.31 μg/m³) during the winter season. For PM10 in Gautam Buddha Nagar, the contributions were 10.32% (13.55 μg/m³) during the pre-monsoon season, 10.09% (7.18 μg/m³) during the monsoon season, and 10.93% (19.35 μg/m³) during the winter season. These variations indicate a higher impact of sulfate aerosols during colder months, likely due to increased emissions and atmospheric stability changes. The higher levels of sulfate aerosols in winter months can be attributed to several factors including higher emissions from heating sources and reduced dispersion due to atmospheric stability, which allows pollutants to accumulate. These findings underscore the need for targeted air quality management strategies that consider both the proximity to TPPs and seasonal variations to effectively control sulfate aerosol pollution.

8.4 Contribution of Energy Sector (Coal based Thermal Power Plants) Emissions Towards Ambient Air SO_4 (Sulfate aerosol) Concentration In Different Category Cities

Results from a series of meticulously planned simulations using the WRF-Chem chemical transport model were analysed to understand the contribution of SO_2 emissions from the power sector, specifically from coal-based thermal power plants (TPPs), to ambient atmospheric sulfate aerosol (SO_4) concentrations in different category cities considered in this survey. Our analysis shows that the energy sector's contribution to the total ambient air sulfate aerosol concentrations varies significantly across different city categories during various study phases.

In Category-1 cities, which have no coal-based TPPs, the contributions of SO_2 emissions from TPPs to ambient sulfate aerosols were consistently lower. In Delhi, during Phase I (pre-monsoon season), the contribution from TPP SO_2 emissions was 15.85% (2.25 μg/m³). Hyderabad, also in Phase I, showed a much lower contribution of 6.96% (0.51 μg/m³). In Phase II (monsoon season), Lucknow exhibited a contribution of 10.49% (0.50 μg/m³). Averaging these contributions across the phases, Category-1 cities had an average contribution of 11.77% (1.09 μg/m³) from SO_2 emissions from TPPs to ambient sulfate aerosols.

Category-2 cities, which are near TPPs without flue-gas desulfurization (FGD) systems, exhibited the highest contributions of SO_2 emissions from TPPs to ambient sulfate aerosols. In Phase I (pre-monsoon season), Nagpur showed a contribution of 22.32% (2.33 μg/m³), and Kolkata exhibited a contribution of 24.53% (2.03 μg/m³). In Phase II (monsoon season), Kota showed a contribution

of 24.08% (1.62 μg/m³). During Phase III (winter season), Kota's contribution was 24.26% (2.61 μg/m³), while Shahdol had the highest contribution among all cities at 29.55% (3.01 μg/m³). On average, Category-2 cities had an energy sector contribution of 24.55% (2.32 μg/m³) to ambient sulfate aerosols.

Category-3 cities, which are near TPPs with FGD systems, also showed significant contributions of SO_2 emissions from TPPs to ambient sulfate aerosols. During Phase I (pre-monsoon season), Gautam Buddha Nagar had a contribution of 17.89% (2.55 μg/m³), while Ghaziabad showed a contribution of 15.02% (1.83 μg/m³). In Phase II (monsoon season), Gautam Buddha Nagar had a contribution of 16.54% (1.25 μg/m³). During Phase III (winter season), Gautam Buddha Nagar's contribution was 18.65% (3.80 μg/m³), and Khargone exhibited a contribution of 16.22% (1.23 μg/m³). Averaging these contributions, Category-3 cities had an energy sector contribution of 16.86% (2.33 μg/m³) to ambient sulfate aerosols.

Overall, the contribution of SO_2 emissions from coal-based TPPs to ambient sulfate aerosols was highest in Category-2 cities, with an average contribution of 24.55% (2.32 μg/m³), followed by Category-3 cities with 16.86% (2.33 μg/m³), and lowest in Category-1 cities at 11.77% (1.09 μg/m³). These results indicate that coal-based TPP emissions significantly impact sulfate aerosol levels, particularly in cities near TPPs without FGD systems. Notably, the highest contribution of SO_2 emissions from TPPs to ambient sulfate aerosols in absolute terms were observed in the Category-3 city of Gautam Buddha Nagar, with concentrations reaching 3.80 μg/m³. This is likely due to the overall higher concentrations of total sulfate aerosol, PM2.5, and PM10 in Gautam Buddha Nagar compared to other cities in Phase III of our survey, as well as the assumption that the FGD was operational in only two units of the NTPC Dadri TPP during this period.

Across all cities and phases, the contribution of TPP SO_2 emissions to ambient sulfate aerosols ranged from approximately 6.96% (0.51 μg/m³) to 29.55% (3.01 μg/m³). Thus, our study shows that even if we completely eliminated SO_2 emissions from TPPs using FGDs, it would reduce ambient air sulfate aerosol concentrations across all surveyed cities and seasons by 6.96% (0.51 μg/m³) to 29.55% (3.01 μg/m³). Additionally, installing FGD systems with an 80% SO_2 removal efficiency in all coal-based TPPs across India would result in a reduction in sulfate aerosol concentrations across all surveyed cities and seasons by 5.67% (0.41 μg/m³) to 23.64% (2.41 μg/m³).

This indicates that while SO_2 emissions from TPPs are significant contributors to ambient sulfate aerosols, especially in Category-2 and Category-3 cities, other sources such as industrial activities, residential emissions, and the transportation sector also play crucial roles. Therefore, stringent emission control measures must be implemented across all sectors contributing to SO_2 emissions to effectively reduce total ambient air sulfate aerosol concentrations and improve overall air

quality. By addressing SO_2 emissions comprehensively, not just from TPPs but also from other significant sources, we can achieve more substantial reductions in sulfate aerosol levels and enhance air quality across all surveyed cities.

8.5 Contribution of Sulfate Aerosols (SO_4) Formed Due to SO_2 Emissions From TPPs Towards PM2.5 and PM10 Mass Concentrations In Different Category Cities

Our study demonstrates that the contribution of sulfate aerosols (SO_4) formed due to SO_2 emissions from coal-based thermal power plants (TPPs) to ambient air PM2.5 and PM10 mass concentrations varies significantly across different categories of cities and seasons.

Category-1 cities, which have no coal-based TPPs, showed the lowest contributions of sulfate aerosols (SO_4) formed due to SO_2 emissions from coal-based TPPs to ambient air PM2.5 and PM10 mass concentrations. In Hyderabad during Phase I (pre-monsoon season), the contribution was 0.96% to PM2.5 (0.44 $\mu g/m^3$) and 0.57% to PM10 (0.49 $\mu g/m^3$). In Lucknow during Phase II (monsoon season), the contributions were 1.22% to PM2.5 (0.42 $\mu g/m^3$) and 0.90% to PM10 (0.47 $\mu g/m^3$). In Delhi, despite being a Category-1 city, the contributions were significantly higher due to regional transport of SO_2 or sulfate aerosols from nearby TPPs, with Phase I contributions of 2.41% to PM2.5 (1.92 $\mu g/m^3$) and 1.64% to PM10 (2.25 $\mu g/m^3$). On average, Category-1 cities had contributions of approximately 1.79% to PM2.5 (0.93 $\mu g/m^3$) and 1.04% to PM10 (1.07 $\mu g/m^3$) from sulfate aerosols (SO_4) formed due to SO_2 emissions from TPPs.

Category-2 cities, which are near TPPs without flue-gas desulfurization (FGD) systems, showed more substantial contributions of sulfate aerosols (SO_4) formed due to SO_2 emissions from coal-based TPPs to ambient air PM2.5 and PM10 mass concentrations. In Kolkata during Phase I (pre-monsoon season), the contributions were 5.48% to PM2.5 (1.73 $\mu g/m^3$) and 3.65% to PM10 (1.93 $\mu g/m^3$). In Nagpur, the contributions were 3.16% to PM2.5 (1.98 $\mu g/m^3$) and 2.64% to PM10 (2.21 $\mu g/m^3$) during the same phase. In Kota during Phase II (monsoon season), the contributions were 2.82% to PM2.5 (1.38 $\mu g/m^3$) and 2.34% to PM10 (1.54 $\mu g/m^3$), increasing to 3.50% to PM2.5 (2.54 $\mu g/m^3$) and 2.76% to PM10 (3.17 $\mu g/m^3$) in Phase III (winter season). Shahdol in Phase III showed the highest contribution with 5.21% to PM2.5 (3.30 $\mu g/m^3$) and 3.67% to PM10 (3.60 $\mu g/m^3$). On average, Category-2 cities had contributions of approximately 3.83% to PM2.5 (2.19 $\mu g/m^3$) and 2.87% to PM10 (2.49 $\mu g/m^3$) from sulfate aerosols (SO_4) formed due to SO_2 emissions from TPPs.

Category-3 cities, which are near TPPs with FGD systems, had significant contributions as well of sulfate aerosols (SO_4) formed due to SO_2 emissions from coal-based TPPs to ambient air PM2.5 and PM10 mass concentrations. In Gautam Buddha Nagar during Phase I (pre-monsoon season), the contributions were 2.78% to PM2.5 (2.17 $\mu g/m^3$) and 1.94% to PM10 (2.55 $\mu g/m^3$). In Phase II (monsoon season), the contributions were 2.26% to PM2.5 (1.06 $\mu g/m^3$) and 1.76% to PM10

(1.25 μg/m³). During Phase III (winter season), the contributions were 2.93% to PM2.5 (3.23 μg/m³) and 2.15% to PM10 (3.80 μg/m³). In Ghaziabad during Phase I, the contributions were 2.15% to PM2.5 (1.55 μg/m³) and 1.49% to PM10 (1.83 μg/m³). In Khargone during Phase III, the contributions were 2.14% to PM2.5 (1.05 μg/m³) and 1.51% to PM10 (1.23 μg/m³). On average, Category-3 cities had contributions of approximately 2.45% to PM2.5 (1.61 μg/m³) and 1.97% to PM10 (2.13 μg/m³) from sulfate aerosols (SO_4) formed due to SO_2 emissions from TPPs.

Overall, the contribution of SO_2 emissions from coal-based TPPs to ambient sulfate aerosols in PM2.5 and PM10 mass concentrations was highest in Category-2 cities, with an average contribution of 3.83% to PM2.5 (2.19 μg/m³) and 2.87% to PM10 (2.49 μg/m³). Category-3 cities showed intermediate contributions, averaging 2.45% to PM2.5 (1.61 μg/m³) and 1.97% to PM10 (2.13 μg/m³), while Category-1 cities had the lowest contributions, averaging 1.79% to PM2.5 (0.93 μg/m³) and 1.04% to PM10 (1.07 μg/m³).

The range of contribution of sulfate aerosols (SO_4) formed due to SO_2 emissions from coal-based TPPs to ambient air PM2.5 and PM10 mass concentrations across all cities and phases varied from 0.96% (0.44 μg/m³) to 5.21% (3.30 μg/m³) for PM2.5 and from 0.57% (0.49 μg/m³) to 3.67% (3.60 μg/m³) for PM10. Thus, our study indicates that completely eliminating SO_2 emissions from TPPs would result in a maximum reduction in PM2.5 concentrations of up to 5.21% (3.30 μg/m³) and PM10 concentrations of up to 3.67% (3.60 μg/m³) across all surveyed cities and seasons. Furthermore, installing FGD systems with an 87.5% SO_2 removal efficiency in all coal-based TPPs across India would lead to a maximum reduction in PM2.5 concentrations of up to 4.56% (2.89 μg/m³) and PM10 concentrations of up to 3.21% (3.15 μg/m³) across all surveyed cities and seasons. This reveals that SO_2 emissions from TPPs contribute relatively little to ambient air PM2.5 and PM10 mass concentrations in the cities and seasons surveyed in this study. Consequently, there would be only a marginal improvement (maximum of 5%) in particulate matter air quality even after eliminating all SO_2 emissions from TPPs. It should be noted that SO_2, a colourless gas, does not directly reduce visibility but contributes to haze formation after being converted into sulfate particles. Therefore, eliminating SO_2 emissions from TPPs is likely to result in a modest improvement in visibility and a reduction in haze formation.

The combustion of coal in coal-fired thermal power plants, in addition to being a major source of carbon dioxide (CO_2) emissions, also results in the direct emission of primary particulate matter (PM) such as fly ash, black carbon (BC), and various heavy metals. Additionally, it emits several particulate matter precursors, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs), from the stacks (chimneys) of the TPPs into the atmosphere. Together, these emissions contribute significantly to ambient air PM2.5 and PM10 mass concentrations. However, eliminating only SO_2 emissions from TPPs using flue-gas desulfurization (FGD) technology, which can reduce SO_2 emissions by anywhere between 50% to 99%, is unlikely to result in a significant overall improvement in PM2.5 and PM10 mass concentrations in the different category cities surveyed in this study. Our study shows that SO_2

emissions from TPPs, which convert to sulfate aerosols, are a minor contributor (maximum up to 5%) to particulate matter levels in the various category cities considered in this survey. Thus, comprehensive emission control measures targeting all major pollutants and particulate matter precursors emitted from various sources, including TPPs, are necessary to achieve meaningful improvements in air quality.

CHAPTER-9: DISCUSSION ON THE CHANCES OF ACID RAIN AND NEED FOR QUANTIFYING THE LIFECYCLE COST AND BENEFITS OF FGD IMPLEMENTATION IN TPPS ACROSS INDIA

This chapter discusses the lifecycle of SO_2 in the atmosphere and the potential for acid rain in India. It argues for the urgent need to conduct a comprehensive life-cycle assessments of FGD technologies, including carbon capture systems, in the Indian context. The discussion emphasizes the crucial need for studying the lifecycle costs and benefits of FGD implementation in coal-based TPPs in India to truly understand their environmental impact and to ensure that our clean air goals do not conflict with our climate change mitigation targets. Additionally, the chapter also addresses the financial costs of FGD implementation in TPPs across India.

9.1 Lifecycle of SO_2 In The Atmosphere And Chances of Acid Rain In India

Once emitted into the atmosphere, SO_2 undergoes oxidation processes that converts it into sulfuric acid (H_2SO_4) or sulfate aerosols (SO_4^{2-}). The oxidation of SO_2 occurs through both homogeneous (gas phase) and heterogeneous (aqueous phase) pathways. In the gas phase, SO_2 is oxidized primarily through reactions with hydroxyl radicals (OH) and other oxidants.

Homogeneous (Gas Phase) Oxidation: The key steps in the homogeneous oxidation pathway are as follows:

1. Reaction with Hydroxyl Radicals (OH):

$$SO_2 + OH \rightarrow HSO_3$$

Here, sulfur dioxide (SO_2) reacts with the hydroxyl radical (OH) to form the HSO_3 radical.

2. Further Oxidation:

$$HSO_3 + O_2 \rightarrow SO_3 + HO_2$$

The HSO_3 radical further reacts with molecular oxygen (O_2) to form sulfur trioxide (SO_3) and the hydroperoxyl radical (HO_2).

3. Formation of Sulfuric Acid:

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Next, Sulfur trioxide (SO_3) reacts rapidly with water vapor (H_2O) to form sulfuric acid (H_2SO_4).

These reactions primarily occur in the presence of sunlight, which is necessary for the formation of OH radicals through photolytic reactions. As H_2SO_4 is highly water soluble, gaseous H_2SO_4 rapidly dissolves into the aqueous phase of aerosol particles and cloud droplets.

Heterogeneous (Aqueous Phase) Oxidation: In the aqueous phase, SO_2 dissolves in cloud droplets, rain, fog, or other water-containing particles and undergoes oxidation through several pathways. The key steps in the heterogeneous oxidation pathway are as follows:

1. Dissolution in Water:

$$SO_2(gas) \leftrightarrow SO_2(aq)$$

$$SO_2(aq) + H_2O \leftrightarrow H_2SO_3$$

Sulfur dioxide (SO_2) gas dissolves in water to form sulfurous acid (H_2SO_3).

2. Oxidation by Dissolved Oxygen:

$$H_2SO_3 + 1/2(O_2) \rightarrow H_2SO_4$$

Sulfurous acid (H_2SO_3) is oxidized by dissolved molecular oxygen (O_2) to form sulfuric acid (H_2SO_4).

3. Oxidation by Hydrogen Peroxide (H_2O_2):

$$H_2SO_3 + H_2O_2 \rightarrow H_2SO_4 + H_2O$$

Hydrogen peroxide (H_2O_2) is a very efficient oxidizing agent that can oxidize sulfurous acid (H_2SO_3) to sulfuric acid (H_2SO_4).

4. Oxidation by Ozone (O_3):

$$H_2SO_3 + O_3 \rightarrow H_2SO_4 + O_2$$

Ozone (O_3) can also oxidize sulfurous acid (H_2SO_3) to sulfuric acid (H_2SO_4).

The efficiency of these oxidation processes is influenced by various factors, including pH, temperature, and the presence of catalysts such as transition metal ions (TMIs) like Fe(III) and Mn(II). It is noteworthy that the heterogeneous aqueous-phase oxidation of SO_2 is more significant than its gas-phase oxidation with OH. In fact, the reaction of SO_2 with H_2O_2 is its most important oxidation pathway. This heterogeneous oxidation occurs through the dissolution of SO_2 in water from clouds and fog, followed by reactions with other dissolved species, and can take place both day and night. The oxidation via the dissolved H_2O_2 pathway is significantly enhanced when ammonia (NH3), the main alkaline gas in the atmosphere, dissolves in the reacting droplets and neutralizes the acidity. In environments with abundant ambient ammonia, such as across India, SO_2 is rapidly removed by cloud and fog droplets, ultimately forming ammonium sulfate [$(NH_4)_2SO_4$] aerosols. SO_2 is a colourless gas that does not directly reduce visibility but contributes to haze formation after being converted into sulfate particles.

SO_2 is also known to adhere to and then react on dust particles. For some mineral compositions, SO_2 uptake on dust particles is sensitive to relative humidity, the mineral composition of the particle, and the availability of H_2O_2, the relevant oxidant.

Atmospheric dust containing carbonate minerals, such as calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), and sodium carbonate (Na_2CO_3), plays a crucial role in neutralizing sulfuric acid (H_2SO_4) dissolved in fog, clouds, and raindrops. These minerals act as bases when they dissolve in water, forming inorganic salts like calcium sulfate ($CaSO_4$), magnesium sulfate ($MgSO_4$), and sodium sulfate (Na_2SO_4). Initially, these salts remain in the atmosphere as particulate matter (aerosols) and are eventually deposited on surfaces through dry deposition or washed out by precipitation. These neutralization reactions occur both in the gas phase and within cloud or raindrop water, reducing the concentration of free H_2SO_4 in the atmosphere and decreasing the acidity of rainwater.

Once SO_2 is oxidized to H_2SO_4 on particle surfaces, glyoxal, one of the most prevalent organic compounds in the atmosphere, adheres to these surfaces and reacts to form oligomers and organosulfate compounds. These processes are enhanced under high humidity conditions.

SO_2, being heavier than dry air, is also removed from the atmosphere through dry deposition, especially on wet surfaces. Precipitation scavenging (wet deposition) offers another method for removing atmospheric SO_2. Modeling studies indicate that slightly more than half of global atmospheric SO_2 is removed through gas- and aqueous-phase oxidation, while the remainder is scavenged through wet and dry deposition processes.

The lifetime of SO_2 in the atmosphere varies depending on several factors, including weather conditions, geographic location, and the presence of other chemicals. Typically, SO_2 has a lifetime ranging from a few hours to about two weeks in the troposphere before converting into sulfate aerosol particles (*von Glasow et al.* 2009). The atmospheric lifetime of SO_2 is typically a couple of days, but under certain conditions, such as low humidity or high wind speed, it can travel long distances (a few hundred km) and persist for longer periods. SO_2 is typically removed from the atmosphere through oxidation, forming sulfate aerosols (SO_4). This process can occur within a few hours to a few days, depending on the availability of oxidizing agents such as hydroxyl radicals (OH) and hydrogen peroxide (H_2O_2). As rainfall efficiently removes SO_2 from the atmosphere through wet deposition, regions with frequent rain can see the atmospheric lifetime of SO_2 reduced to less than a day due to this washout effect. In urban and industrial areas with higher concentrations of air pollutants, the presence of other chemicals and particulates also influence the rate at which SO_2 is removed from the atmosphere. In a recent study, Chen et al. (2024) estimated the mean chemical lifetime of SO_2 over the Indian region, finding it to range from 16 to 34 hours, with shorter values during the summer and longer values during the winter months. Overall, the atmospheric lifetime of SO_2 is typically short, ranging from a few hours to a few days, due to its rapid conversion to sulfate aerosols and removal through dry and wet deposition.

Chances of Acid Rain in India:

The natural pH of rainwater is slightly acidic, typically around 5.6, due to the presence of carbon dioxide (CO_2) in the atmosphere. When CO_2 dissolves in rainwater, it forms carbonic acid (H_2CO_3), a weak acid that slightly lowers the pH. This natural acidity is a normal part of the Earth's water cycle and is not harmful to the environment. However, this pH can be modified by the presence of acids (such as H_2SO_4, HNO_3, and RCOOH) and bases (such as NH_3 and $CaCO_3$) in the atmosphere. When all these influences are considered, the pH of natural rain typically ranges from 5 to 7. The term "acid rain" refers to precipitation with a pH below 5. Such low pH values generally occur only when the atmosphere contains large amounts of acidic substances from anthropogenic emissions and air pollution.

Overall, the acidity of precipitation is regulated by neutralization reactions with alkaline species, such as soil dust rich in carbonates, and dissolved gases like ammonia (NH_3) emitted from agricultural activities, including fertilizer use and livestock.

The neutralization of precipitation acidity by ammonia (NH_3) is a critical process in maintaining the pH balance of rainwater, especially in regions with significant agricultural activities. Ammonia is predominantly released into the atmosphere from sources such as fertilizer application, animal waste from livestock, and natural soil emissions. When NH_3 is present in the atmosphere, it can readily dissolve in cloud water and react with acidic compounds like sulfuric acid (H_2SO_4) and nitric acid (HNO_3). These acids are commonly produced from the oxidation of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emitted from industrial processes, vehicle exhaust, and other anthropogenic sources.

The reaction between NH_3 and these acids results in the formation of neutral salts, such as ammonium sulfate ($(NH_4)_2SO_4$) and ammonium nitrate (NH_4NO_3). These salts effectively neutralize the acidic content of precipitation. For instance, when ammonia reacts with sulfuric acid, the following reaction occurs:

$$2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$$

This process substantially lowers the acidity of raindrops, bringing their pH closer to neutral. The neutralization by NH_3 is especially effective in agricultural areas where ammonia emissions are high due to extensive fertilizer use and livestock operations. This neutralization mechanism naturally helps to mitigate the environmental impacts of acid rain. By neutralizing acidic components in precipitation, ammonia plays a crucial role in protecting various ecosystems and infrastructure from acidification.

Van Damme et al. (2018) analysed ten years of daily IASI satellite observations to create a high-resolution map of atmospheric ammonia across the globe. Their goal was to identify, categorize, and quantify the world's ammonia emission hotspots. They reported that the Indo-Gangetic Plain

(IGP) is a major source of NH_3, with the highest concentration of NH_3 column burden in the world found in this region.

Besides NH_3, dust containing carbonate minerals such as calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), and sodium carbonate (Na_2CO_3) can significantly reduce the likelihood of acid rain. These carbonate minerals can neutralize sulfuric acid (H_2SO_4) dissolved in rainwater through various chemical processes. Here, we discuss the neutralization of sulfuric acid by calcium carbonate. Calcium carbonate ($CaCO_3$) is a basic (alkaline) compound that can neutralize acids through the following chemical reaction:

$$CaCO_3 + H_2SO_4 \rightarrow CaSO_4 + CO_2 + H_2O$$

In this reaction, calcium carbonate ($CaCO_3$) reacts with sulfuric acid (H_2SO_4) to form calcium sulfate ($CaSO_4$), carbon dioxide (CO_2), and water (H_2O). This neutralization process reduces the acidity of rainwater. The resulting calcium sulfate ($CaSO_4$) can either remain as particulate matter or get washed out by precipitation. This reaction can occur both in the gas phase and in cloud or raindrop water, reducing the concentration of free H_2SO_4 in the atmosphere and thereby decreasing the acidity of rain. Dust particles containing $CaCO_3$ can also settle on surfaces and directly neutralize acidic compounds present on those surfaces, preventing them from being washed into waterways. During rainfall, $CaCO_3$ particles can be incorporated into raindrops. As rainwater containing H_2SO_4 comes into contact with these particles, the neutralization reaction occurs within the raindrop, leading to neutral pH precipitation. Thus the presence of $CaCO_3$-rich dust inhibits the formation of acid rain by neutralizing acidic species in the atmosphere before they can dissolve in rainwater. This process effectively reduces the potential for acid rain formation. Even if H_2SO_4 has already dissolved in rainwater, the presence of $CaCO_3$ can buffer the pH of the water, preventing it from becoming acidic. This buffering capacity is crucial in regions with high levels of atmospheric dust containing $CaCO_3$. Thus, the abundance of dust containing calcium carbonate ($CaCO_3$) plays a crucial role in mitigating the formation and impact of acid rain. By neutralizing sulfuric acid (H_2SO_4) in the atmosphere and rainwater, $CaCO_3$ reduces the acidity of precipitation and protects ecosystems. This natural buffering process is very effective in regions with high dust levels, contributing to a more balanced and neutral environment.

Due to the high soil dust content rich in carbonate minerals like calcium carbonate ($CaCO_3$) and the abundance of ammonia (NH_3) in the ambient air across India, both of which are alkaline, acid rain is not a serious issue in most parts of the country, except for southern peninsular India where the concentrations of alkaline substances like ammonia and carbonate-rich dust in the air are relatively low. However, frequent dilution caused by the sea breeze naturally keeps ambient SO_2 levels lower in coastal areas of peninsular India. Additionally, the inherent alkalinity of seawater droplets, due to the presence of bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^{2-}), effectively neutralizes sulfuric acid (H_2SO_4) in the atmosphere over coastal areas (Hedin and Likens, 1996; Kulshrestha et al., 2005; Shukla et al., 2010; Lee and Chen, 2011; Sharma et al., 2023).

9.2 Need For Quantifying The Lifecycle Cost And Benefits of FGD Implementation in TPPs in India

While there is no doubt that FGD implementation will significantly reduce SO_2 emissions from TPPs, there are, to the best of our knowledge, no credible studies that have quantified the overall life-cycle cost and benefits of FGD implementation in coal-based TPPs, especially in the Indian context. Based on the most prevalent FGD technologies available today, it is certain that CO_2 emissions will increase and there will be additional water consumption with FGD implementation in these TPPs. Primary reason for this increase in CO_2 emissions with the implementation of FGD in a coal based TPPs is that for every molecule of SO_2 captured by the FGD, a molecule of CO_2 will be released into the atmosphere for all kinds of FGD technologies. Other reasons for extra emission of CO_2 with the implementation of FGD are due to activities linked with the functioning of these FGD units. Additionally, it is well known that sulfate aerosols are highly efficient at blocking solar radiation from reaching the Earth's surface, partially offsetting the global warming caused by greenhouse gases like CO_2. However, there are no credible studies on the impacts of a sudden reduction in SO_2 emissions combined with simultaneous increases in CO_2 emissions on India's regional climate, including the Indian monsoon system, extreme weather events such as floods and droughts, and surface ozone levels. Therefore, it is crucial to quantify the long-term environmental and climate change impacts of FGD implementation in India to ensure that our clean air goals do not conflict with our climate change mitigation targets. Additionally, the increased warming due to reduced SO_2 emissions and increased CO_2 emissions is likely to exacerbate the adverse impacts of heat stress on human health, which also needs to be quantified.

Quantifying the overall life-cycle costs and benefits of FGD implementation in coal-based TPPs across India comprehensively is beyond the scope of our present study. Nevertheless, we present a discussion based on simple calculations that quantify the immediate reduction in SO_2 emissions and the likely increase in CO_2 emissions with the implementation of FGD in coal-based TPPs across India (excluding long-term impacts).

Figure 9.1 presents a comparison of total annual SO_2 emissions from India according to three different emission inventories: SMOG-India-v2 (2019) (Venkatraman et al., 2020), EDGAR-v5 (2015), and EDGAR-v6.1 (2018) (Crippa et al., 2022). The top panel shows that the total annual SO_2 emissions from India are 7.85 MT/year for SMOG-India-v2, 9.96 MT/year for EDGAR-v5, and 10.60 MT/year for EDGAR-v6.1. The bottom three panels detail the contributions of various emission sectors to the total annual SO_2 emissions for each inventory. In terms of the energy sector (primarily coal-based TPPs), SMOG-India-v2 reports 4.31 MT/year, which is 54.9% of the total emissions. EDGAR-v5 lists 5.85 MT/year from the energy sector, contributing 58.7% of the

total, while EDGAR-v6.1 indicates 6.51 MT/year from the energy sector, accounting for 61.4% of the total emissions. For the industrial sector, SMOG-v2 records 3.24 MT/year, which is 41.3% of the total SO_2 emissions. EDGAR-v5 reports 3.13 MT/year from the industrial sector, contributing 31.4% of the total, and EDGAR-v6.1 shows 3.18 MT/year from the industrial sector, making up 30% of the total emissions. In summary, the energy sector's contribution to total SO_2 emissions ranges from 54.9% to 61.4%, with absolute emissions between 4.31 MT/year and 6.51 MT/year across the inventories. The industrial sector contributes between 30% and 41.3%, with absolute emissions ranging from 3.13 MT/year to 3.24 MT/year.

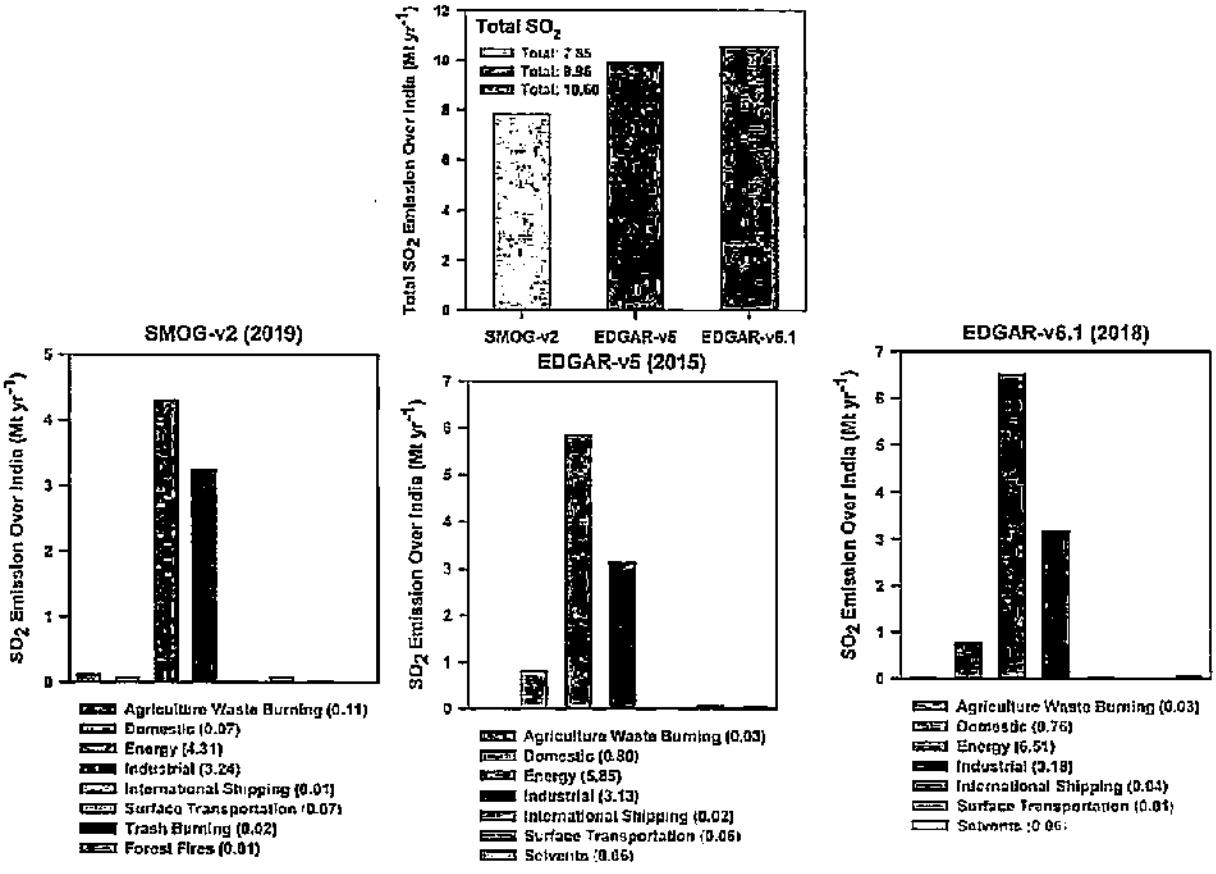


Figure 9.1: Comparison of total annual emission (MT per year) of SO_2 from India as per three different emission inventories namely, SMOG-India-v2 (2019), EDGAR-v5 (2015) & EDGAR-v6.1 (2018). Contribution of SO_2 emissions from various sectors are also shown.

The SO_2 removal efficiency of FGD systems generally ranges from 60% to 95%, depending on various factors such as mandatory compliance requirements based on the age of the TPP and FGD technology. Installing FGD systems with 87.5% SO_2 removal efficiency in all coal-based TPPs across India is expected to reduce total annual SO_2 emissions by 48.0% to 53.8%. In absolute

terms, this would mean a decrease in total annual SO_2 emissions between 3.77 MT/year and 5.70 MT/year.

Calculation of increase in CO_2 emissions with the implementation of FGD in coal-based TPPs across India (excluding long-term impacts):

We start our estimation by first calculating the total CO_2 emissions from a 600 MW Coal-Based TPP Unit with and without FGD installed in it. We do this calculation with following assumptions:

- Plant Load Factor (PLF): 60%
- Gross Calorific Value (GCV) of coal: 3800 Kcal/kg
- Fuel Emission Factor: 92.5 kg CO_2/GJ (as per Eggleston et al. 2006)
- Oxidation Factor: 0.98 (as per Eggleston et al. 2006)
- Carbon Content in Coal: 40%
- Transportation Distances:
  - Coal: 1000 km (by Rail)
  - Limestone: 500 km (by Road)
  - Gypsum: 200 km (by Road)
- Vehicle Load Capacity: 30 tons per trip
- Fuel Efficiency: 3.29 km per litre of diesel
- CO_2 Emission Factor for Diesel: 2.68 kg CO_2 per litre of diesel (as per Eggleston et al. 2006)
- CO_2 emissions in mining: 45.95 Kg CO_2 per Ton (as per CMPDI, Coal India Limited)
- FGD Efficiency: 87.5%

CO_2 emissions from the TPP will result from (i) the combustion of coal, (ii) chemical reactions during desulfurization using limestone, (iii) mining of coal and limestone, (iv) transportation of coal, limestone, and gypsum, and (v) auxiliary power consumption (APC) for operating the FGD system. Let's calculate the CO_2 emissions from each of these factors one by one.

First we calculate the total CO_2 emissions per day from this TPP operating without FGD

CO_2 emission due to combustion of coal:

Total energy generated by the TPP in one day = 600 MW x 24 hours x 0.60 x 1000 = 8640000 kWh
Assuming the specific coal consumption in TPPs across India to be 0.626315789 kg/KWh (source: CEA Coal Report) and all other assumptions mention earlier, it is possible to calculate the total coal consumption in the given TPP as approximately 5411.37 Tons/day.

Assuming carbon content in coal as 40%, total carbon in 5411.37 Ton of coal = 0.40 × 5411.37 Tons = 2164.55 tons of carbon

As the molecular weight of CO_2 is 44 g/mole, 1 Ton of carbon will produce 3.67 tons of CO_2.

Hence, CO_2 emitted from coal combustion =2164.55 Tons of carbon × 3.67 = 7943.9 Tons of CO_2 per day.

Assuming oxidation factor of carbon as 0.98 (that means 98% of carbon coal is oxidized to CO_2) during TPP operation, actual CO_2 emitted from coal combustion = 7943.9 x 0.98 = 7785 Tons of CO_2 per day.

Alternatively, as per the method suggested by Eggleston et al. (2006), CO_2 Emissions = (5411.37 Tons/day × 3800 Kcal/kg × 4.184 J/cal × 92.5 kg CO_2/GJ x 0.98) / (1000 kg/Ton × 1000 kJ/GJ) = 7799.2 Tons CO_2 per day

We consider 7799 tons of CO_2 emissions per day from coal combustion for further analysis.

CO_2 emissions due to Coal Mining

CO_2 emissions due to Coal Mining = 5411.37 tons/day x 45.95 Kg CO_2/Ton = 248.65 Tons of CO_2/day

CO_2 emissions due to Coal Transportation

We assume that coal is transported from the mines to the TPP through railway.

CO_2 emission due to Coal Transportation = 5411.37 Ton/day x 1000 km x 0.00996 = 53.9 Tons/day

(We used the emission factor for freight transport mentioned on Indian railway website as 0.00996 kg CO_2/Ton-km.)

Thus total CO_2 Emissions due to operation of the TPP without FGD
= 7799 + 248.65 + 53.9 Tons per day
= 8101.55 Tons CO_2 per day

Now we calculate the extra CO_2 emissions per day from this TPP when Flue Gas Desulfurization (FGD) is implemented in the power plant.

CO_2 emissions due to chemical reactions during desulfurization using limestone:

Chemical reactions of desulfurization using limestone FGD is as follows:

$CaCO_3 (s) + SO_2 (g) + 1/2\ O_2(g) + 2H_2O(l) \rightarrow CaSO_4.2H_2O(s) + CO_2 (g)$ Overall reaction

$CaCO_3(s) + \text{Heat} \longrightarrow CaO\ (s) + CO_2(g)$ Calcination of Limestone

$CaO(s) + H_2O \longrightarrow Ca(OH)_2(s) + \text{Heat}$ Exothermic reaction

$Ca(OH)_2(s) + SO_2(g) \rightarrow CaSO_3(s) + H_2O(l)$ Neutralization reaction

$CaSO_3(aq) + 2H_2O(l) + 1/2O_2(g) \rightarrow CaSO_4 \cdot 2H_2O(s)$ (Gypsum) Gypsum production

While the overall chemical reaction remains consistent across all limestone-based FGD systems, the intermediate reactions and their sequence may vary depending on the specific FGD technology employed. This, in turn, influences the auxiliary power consumption and the by-products generated by the system. Nonetheless, regardless of the FGD technology used, each SO_2 molecule captured by FGD systems results in the release of a CO_2 molecule, and the operation of these systems also contributes to CO_2 emissions.

64 grams of SO_2 generates 44 grams of CO_2.

First determine the amount of sulfur in the coal assuming sulfur content in coal as 0.4%.

Amount of sulfur in coal = 5411.37 Ton × 0.004 = 21.65 Ton

As molecular weight of sulfur (S) is 32 g/mol, and the molecular weight of SO_2 is 64 g/mol. Therefore, 1 Ton of sulfur produces 2 Tons of SO_2.
Hence, 21.65 Ton of sulfur will produce 43.3 Tons of SO_2 per day

Amount of SO_2 that will be removed by the FGD = 43.3 Tons x 0.875 = 37.89 Tons per day

1 mole SO_2 produces 1 mole of CO_2
Therefore, 37.89 Ton SO_2 produces = 37.89 x 44/64 = 26.05 Tons of CO_2 per day

Limestone required and Gypsum Production due to FGD operation:
Limestone ($CaCO_3$) consumption for FGD operation = 37.89 x 100/64 = 59.2 Tons per day
Gypsum produced = 37.89 x 172/64 = 101.83 Tons per day

Thus, CO_2 emitted during desulfurization using limestone = 26.05 Tons per day

CO_2 emissions due to mining activities:

Limestone Mining Emissions: CO_2 from Limestone Mining = 59.2 Tons/day × 0.05 Tons CO_2/Ton = 2.96 Tons of CO_2 per day

CO_2 emissions due to transportation of limestone, and gypsum:

Limestone Transportation: Number of Trips (Limestone)= 59.2 tons/30 tons/trip=2 trips/day
Gypsum Transportation: Number of Trips (Gypsum)= 101.83 tons/30 tons/trip=4 trips/day

Calculate the Total Distance Travelled
Total Distance (Limestone)=2 trips/day×500 km/trip=1000 km/day
Total Distance (Gypsum)=4 trips/day×200 km/trip=800 km/day

Calculate the Total Diesel Consumption
Diesel Consumption (Limestone)=1000 km/day/3.29 km/liter=304 liters/day
Diesel Consumption (Gypsum)=800 km/day/3.29 km/liter=243 liters/day

Calculate CO_2 Emissions from Diesel Consumption
CO_2 Emission Factor for Diesel used for GHG calculations in India =2.68 kg CO_2/liter
CO_2 from Diesel (Limestone)=304 ltrs/day×2.68 kg CO_2/liter=814.72 kg CO_2/day=0.815 tons CO_2/day
CO_2 from Diesel (Gypsum)=243 liters/day×2.68 kg CO_2/liter=651.24 kg CO_2/day=0.65 tons CO_2 per day

Thus total CO2 Emissions from Transportation of limestone and gypsum:
CO_2 from Transportation of limestone and gypsum =0.815 +0.65 = 1.465 CO2 Tons per day

CO_2 emissions due to auxiliary power consumption (APC):

When Flue Gas Desulfurization (FGD) is implemented, it typically increases the auxiliary power consumption (APC) of the plant. We assume a 1% increase in APC due to FGD and calculate the additional CO2 emissions.

Extra CO_2 emitted due to increase in APC (1%) = 1 % of 8101.55 = 81.02 Tons CO_2 per day

Addition of CO_2 Emissions Due to 1% extra lime stone consumption due to Increased Auxiliary Power Consumption (APC) = 1% of 26.05 Tons per day = 0.26 Tons per day

Thus Total CO_2 Emissions in the TPP with FGD = 8101.55 + 26.05 + 2.96 + 1.465 + 81.02 +0.26 Tons per day

= 8213.3 Tons CO_2/day

Hence, the total CO_2 emissions from a 600 MW coal-based TPP unit operating at 60% PLF and having an operational FGD working (with 87.5% efficiency), considering all sources including combustion, limestone use, mining activities, transportation, and an increased APC due to FGD, is approximately 8213 Tons of CO_2 per day.

This means that with the implementation of an FGD system, CO_2 emissions from this 600 MW coal-based TPP will increase by approximately 1.38%. In absolute terms, this translates to an additional emission of 111.8 Tons of CO_2 per day from the 600 MW coal-based TPP.

According to the Central Electricity Authority (CEA), the total power generated from coal-based TPPs across India, based on the total installed capacity as of May 31, 2023, is approximately 211.86 GW. Assuming all coal-based TPPs across India operate under the same conditions as the above 600 MW TPP unit, the total CO_2 emissions from all TPPs in India without FGD installation would be approximately 2.86 million tons (MT) of CO_2 per day. This equates to 1044.14 MT of CO_2 per year.

Thus, installing FGD systems with 87.5% SO_2 removal efficiency in all coal-based TPPs across India is expected to reduce total annual SO_2 emissions by 4.88 MT per year but this will also result in an additional 14.4 MT of CO_2 emissions per year immediately.

However, it is important to emphasize here that the above calculation only accounts for the immediate and direct additional CO_2 emissions (~1.38%) expected in coal-based thermal power plants (TPPs) due to the implementation of flue gas desulfurization (FGD) systems. Several previous studies have demonstrated that the total environmental impact, including the overall increase in CO_2 emissions resulting from FGD implementation, is likely to be significantly higher when considering the life cycle assessment (LCA) of such air pollution control technologies in coal-based TPPs (Xu et al., 2010; Feng et al., 2014; Shi et al., 2017; Fort and Cerny, 2018; Xiong et al., 2020; Phungrassami and Usubharatana, 2021; Kim et al., 2021; Zhang et al., 2024). LCA is an internationally standardized methodology used to systematically and scientifically assess the environmental impacts associated with all stages of a product's life cycle, from inception to disposal. A comprehensive LCA of FGD systems should consider not only the immediate and direct increases in CO_2 emissions from TPPs but also the long-term environmental impacts, including secondary pollutant generation, wastewater production, freshwater depletion, land-use and land-cover changes, deforestation, changes in ecotoxicity, impacts on surface ozone, and

alterations in weather and climate. These impacts should be quantified in terms of additional equivalent CO_2 emissions resulting from FGD implementation (Xu et al., 2010).

We argue that the LCA and Life Cycle Costing (LCC) of FGD implementation in coal-based TPPs across India, along with the estimation of additional equivalent CO_2 emissions—considering various long-term environmental impacts—must be region-specific and dependent on the particular FGD technology adopted in each TPP (Feng et al., 2014; Fort and Cerny, 2018; Kim et al., 2021; Zhang et al., 2024). Given that conducting a comprehensive LCA and LCC analysis of FGD implementation across all coal-based TPPs in India is beyond the scope of our current study, we focus on summarizing key findings from previous research and identifying critical areas that warrant further investigation in subsequent studies.

Kim et al. (2021) estimated that the removal of 1 kg of SO_2 using conventional wet limestone scrubbing FGD and carbonate melt FGD (CMFGD) techniques results in approximately 177.3 kg and 32.14 kg of additional equivalent CO_2 emissions, respectively. Furthermore, Kim et al. (2021) estimated that removing 1 kg of SO_2 using conventional wet limestone scrubbing FGD requires an additional 67.79 litres of freshwater. These estimates are based on a life cycle assessment (LCA) that considers both the immediate CO_2 increase and the long-term environmental impacts of 18 different factors, including freshwater depletion, land-use changes, deforestation, ecotoxicity, impacts on ozone, weather, and climate change.

Phungrassami and Usubharatana (2021) conducted an environmental problem-shifting analysis of various air pollution control technologies used in coal-fired TPPs based on LCA methodology. Their findings indicate that while FGD implementation may effectively reduce SO_2 emissions, it ultimately results in greater adverse environmental impacts due to the increased energy demands associated with the construction, operation, and maintenance of FGD systems. This is true even when carbon capture and storage (CCS) technology is employed alongside FGD, as it leads to higher overall CO_2 emissions, human toxicity, and terrestrial acidification effects. Phungrassami and Usubharatana (2021) estimated that for every kilogram of SO_2 emission reduction achieved by wet limestone-gypsum-based FGD systems, an additional 4.64 kg of CO_2 is emitted, and a significant 60–80 tons per hour of water is consumed for a 600 MW TPP, which also reduces the overall boiler efficiency of the TPP. Their study underscores the necessity of conducting a thorough LCA and LCC study to minimize environmental trade-offs associated with the implementation of air pollution control technologies such as FGD systems.

Shi et al. (2017) demonstrated that wet limestone-based FGD systems, which dominate the market share in China, significantly increase fly ash emissions that contribute to haze and generate secondary gypsum particles, which are primarily less than 2.5 μm in size. Additionally, Shi et al. (2017) found that these systems emit substantial amounts of extra CO_2 and consume

considerable energy, raw materials, and water resources. Their study further estimated that for every ton of SO_2 emission reduction achieved by wet limestone-gypsum-based FGD systems, an additional 4.13 tons of CO_2 is emitted, and approximately 16.79 tons of freshwater is consumed.

In another study, Cordoba (2015) showed that in conventional wet limestone based FGD systems, limestone is usually used after being pulverized to an average size of 5–20 μm, which consumes significant amount of extra energy. Furthermore, in circulating fluidized bed flue gas desulfurization (CFB-FGD) systems, quicklime is typically made by the thermal decomposition of limestone in a lime kiln. This process requires heating the material above 825°C, called calcination or lime-burning, to release CO_2 and produce quicklime.

Feng et al. (2014) highlighted that the production of FGD system manufacturing materials (such as various categories of steel, aluminium, cement, etc.), transport of raw materials required for FGD system manufacturing, manufacturing of the FGD system itself, transport of the FGD system to the TPP site, production of desulfurizer, quarrying of limestone, and FGD system operation and maintenance must all be considered as part of the LCA and LCC analysis when quantifying the total environmental impact, including the overall increase in CO_2 emissions resulting from FGD implementation in coal-based TPPs. For example, Feng et al. (2014) estimated that manufacturing a wet limestone FGD system for a 2x300 MW coal-fired TPP in China requires approximately 1761 tons of steel as well as various other resources. Feng et al. (2014) further compared the estimates of atmospheric emissions and resource consumption based on the LCA of two different FGD technologies for a 2x300 MW coal-fired TPP in China. According to their estimates, the LCA of a CFB-FGD and a conventional wet limestone-based FGD system for a 2x300 MW coal-fired TPP in China results in an extra 111,815 and 82,402 Tons of equivalent CO_2 emissions per year, respectively (considering 7,000 hours of annual operating time of the FGD systems), in addition to the immediate and direct additional CO_2 emissions due to SO_2 emission scrubbing by limestone. Furthermore, Feng et al. (2014) estimated that the operation of a CFB-FGD and a conventional wet limestone-based FGD system for a 2x300 MW coal-fired TPP in China requires 453 and 630 million litres of freshwater per year.

While there is considerable variability and significant uncertainty in the estimates of additional CO_2 emissions due to FGD implementation, previous studies consistently indicate that the overall increase in CO_2 emissions, beyond the immediate impact, and the associated freshwater consumption are likely to be significantly higher when considering the life cycle assessment (LCA) of FGD implementation in coal-based thermal power plants. These studies highlight the critical need to comprehensively assess both the immediate and long-term environmental impacts, including the estimation of additional equivalent CO_2 emissions, associated with FGD implementation. This underscores the importance of conducting thorough LCA and LCC analyses

to fully understand and mitigate potential adverse outcomes, while minimizing the environmental trade-offs involved in deploying FGD systems across all coal-based TPPs in India.

The implementation of carbon capture technologies in thermal power plants (TPPs) is essential to mitigate the CO_2 emissions generated by these facilities. As coal-based TPPs are significant contributors to global greenhouse gas emissions, incorporating carbon capture can help reduce their environmental impact. These technologies can capture a substantial portion of the CO_2 produced during combustion, preventing it from entering the atmosphere. By integrating carbon capture systems, we can lower the carbon footprint of TPPs, contributing to climate change mitigation efforts and supporting cleaner energy production. This approach is crucial for balancing the need for reliable energy with the urgent need to reduce greenhouse gas emissions.

It's worth noting in this discussion that sulfur dioxide (SO_2) and carbon dioxide (CO_2) have significantly different atmospheric lifetimes, which carries important implications for climate policy. SO_2 has a short atmospheric lifetime, ranging from several hours to a maximum of about 15 days. This means that any SO_2 molecule emitted is likely to be removed from the atmosphere within roughly two weeks. In contrast, CO_2 has a much longer atmospheric lifetime, persisting for over 100 years. This means that any CO_2 molecule emitted can remain in the atmosphere for about a century.

A recent article (Pearse, 2024) published by the Yale School of the Environment highlights how cleaning up air pollution, while beneficial for public health, can significantly contribute to global warming. Another study by Wang et al. (2024) attributes the recent extraordinary heating over the Northeast Pacific region to a dramatic reduction in Chinese air pollution, which coincided with the installation of FGD systems in coal-based TPPs. Both studies explain that reducing sulfate aerosols, which reflect sunlight and cool the atmosphere, has led to more heat waves, such as the "Blob" in the Pacific Ocean. This phenomenon underscores the complex relationship between air quality improvements and climate change, suggesting that decreased aerosol emissions may exacerbate warming and demands more research in this direction. These findings highlight the need for balanced strategies to address both air quality and climate goals. India should heed the lessons from China's experience, as the idea that cleaning up air pollution can worsen atmospheric warming may seem counterintuitive, but it is a real and ongoing issue.

In another recent study, Gao et al. (2022) propose that reducing sources of atmospheric oxidants could be a promising approach for sustainably mitigating secondary sulfate aerosols. They advocate for an oxidant control strategy, adjusted seasonally or during pollution episodes, targeting dominant oxidants specific to those periods. However, further research is needed to confirm the feasibility of this oxidant control approach in reducing secondary pollutants like sulfate aerosols in the Indian atmosphere.

While SO_2 is a significant air pollutant and its emissions should be reduced, the trade-off between reducing SO_2 and increasing CO_2 emissions must be carefully considered. If reducing a relatively smaller amount of SO_2 emissions comes at the cost of a larger increase in CO_2 emissions, it raises serious concerns. This scenario necessitates a broader debate among stakeholders to ensure that efforts to improve air quality do not inadvertently strain valuable water resources, exacerbate global warming, and impact the Earth's climate system, particularly the regional weather and climate of India.

When deciding on the installation of FGD systems in coal-based TPPs across India, it is crucial to consider both health and climate impacts. While reducing sulfate aerosols from sulfur dioxide (SO_2) emissions can lower respiratory and chronic diseases, providing clear health benefits, these aerosols also have a cooling effect by reflecting sunlight. Their reduction could lead to unintended climate consequences, such as accelerated warming, which could increase heat stress and potentially cause more severe health impacts than those from chronic exposure to sulfate aerosols. For instance, in 2022, Europe experienced significant mortality from extreme heat, with 60,000 deaths (Ballester et al., 2023; Choudhary et al., 2023). Schumacher et al. (2024) demonstrated that many climate models failed to capture the exacerbated summer warming in Europe, primarily due to their neglect of long-term aerosol changes, particularly the regional brightening and associated warming caused by global sulfate aerosol reductions. Additionally, removing reflecting aerosols could negatively impact agricultural productivity and food security due to higher temperatures and altered precipitation patterns (Mbow et al., 2019). Therefore, comprehensive studies are necessary to fully understand these impacts and guide policymakers in preparing for potential extreme weather conditions that could increase heat stress on humans, plants, and animals, affect food production, and increase electricity demand due to the installation of FGD systems in all coal-based TPPs in India. This underscores the need for balanced strategies that address both air quality improvements and climate change mitigation to avoid unintended consequences such as increased heat stress and its associated health impacts.

9.3 Cost of FGD Implementation In TPPs Across India

To assess the indigenous FGD manufacturing capacity within India, we reached out to various private and public sector companies, including international firms operating in India. This survey was conducted almost two years ago, during March-April 2022. We requested information regarding FGD technologies, sources of raw materials used in FGD manufacturing, costs of FGD systems, and the timeframe for manufacturing FGD units. Ganguly and Dey (2022) provides complete details of this survey.

Based on our survey conducted more than two years ago and discussions with the CEA, considering subsequent price escalations due to inflation, it is reasonable to assume that the current cost of FGD systems is approximately Rs. 1.20 Crore per MW. The total installed capacity of coal-based TPPs across India as of May 31, 2023, is approximately 211.86 GW or 211,860 MW. Therefore, the total cost of installing FGD systems in all coal-based TPPs across India would be approximately Rs. 2,54,232 Crore. This cost estimate is only for the initial installation and does not include running and maintenance costs, which will directly impact the current electricity unit price in India. Furthermore, the actual installation costs are likely to increase if carbon capture technologies are mandated along with FGD systems. Hence, we strongly recommend conducting a follow-up study to comprehensively assess the overall life-cycle costs (LCC) and benefits of implementing FGD in coal-based TPPs across India for various available FGD technologies, including an assessment of the cost impact on the current electricity unit price in India, as well as the operating and maintenance expenses of these systems.

Once a comprehensive LCA and LCC assessment and evaluation of the benefits of installing FGD systems in all coal-based TPPs across the country are completed, it is essential to initiate a broader debate among stakeholders. This discussion should address whether it is prudent to invest heavily in these non-sustainable, CO_2-emitting energy sources or whether it would be more beneficial to redirect these funds toward the rapid expansion of renewable energy sources such as solar and wind power. Furthermore, there is an urgent need to aggressively phase out coal-based thermal power plants, particularly the older and less efficient ones, to ensure a more sustainable and environmentally friendly energy future. Installing FGD systems to reduce air pollution should not serve as a smokescreen to justify continuing power generation from these environmentally harmful, CO_2-intensive sources. Instead, the focus should be on transitioning to cleaner energy alternatives that offer long-term benefits for the environment and public health. This strategy would mitigate the adverse effects of air pollution and climate change and promote energy security and sustainability for future generations.

CHAPTER-10: CONCLUSIONS AND RECOMENDATIONS

A comprehensive measurement-based survey of ambient air SO_2 concentrations was conducted across three different city categories during three distinct survey periods: Phase I (pre-monsoon season, February to May 2023), Phase II (summer monsoon season, July to August 2023), and Phase III (winter season, November 2023 to February 2024). The survey was conducted in 10 cities, categorized as follows: Category 1 - Cities with no coal-based TPP; Category 2 - Cities with a coal-based TPP without FGD installed, located within 10 km from the city boundary; and Category 3 - Cities with a coal-based TPP with FGD installed, also located within 10 km from the city boundary. In Category 1, the survey was conducted in three cities: New Delhi and Hyderabad during Phase I (pre-monsoon season), and Lucknow during Phase II (summer monsoon season). For Category 2, the survey included four cities: Kolkata and Nagpur during Phase I (pre-monsoon season), Kota during both Phase II (summer monsoon season) and Phase III (winter season), and Shahdol during Phase III (winter season). In Category 3, the survey was conducted in three cities: Ghaziabad and Gautam Buddha Nagar during Phase I (pre-monsoon season), Gautam Buddha Nagar again during Phase II (summer monsoon season) and Phase III (winter season), and Khargone during Phase III (winter season).

Major findings of this survey are listed below:

- The daily mean ambient air SO_2 concentrations in Category 1 cities ranged from 2.48 to 9.26 $\mu g/m^3$. In Category 1 cities, New Delhi recorded the highest maximum instantaneous SO_2 concentration of 29.37 $\mu g/m^3$ during Phase I (pre-monsoon season). The lowest minimum instantaneous SO_2 concentration in Category 1 cities was 0.83 $\mu g/m^3$, also in New Delhi during Phase I.
- The daily mean ambient air SO_2 values in Category 2 cities ranged from 3.12 to 11.23 $\mu g/m^3$. Among these cities, Kota exhibited the highest maximum instantaneous SO_2 concentration of 48.56 $\mu g/m^3$ under normal conditions, with values peaking at 68.09 $\mu g/m^3$ during festival days in Phase III (winter season). The lowest minimum instantaneous SO_2 concentration in Category 2 cities was 0.75 $\mu g/m^3$, recorded in Kota during Phase II (summer monsoon season).
- The daily mean SO_2 concentrations in Category 3 cities ranged from 4.24 to 12.51 $\mu g/m^3$. In Category 3 cities, Gautam Buddha Nagar had the highest maximum instantaneous SO_2 concentration of 36.41 $\mu g/m^3$ under normal conditions, with values peaking at 70.14 $\mu g/m^3$ during festival days in Phase III (winter season). The lowest minimum instantaneous SO_2 concentration in Category 3 cities was 0.54 $\mu g/m^3$, also observed in Gautam Buddha Nagar during Phase III.
- **Compliance with NAAQS:** Ambient air SO_2 levels across all city categories and phases remained well within the National Ambient Air Quality Standards (NAAQS) of 80 $\mu g/m^3$, which is the maximum permissible limit for 24-hour average measurements as notified by the

MoEF&CC, Government of India. Even the instantaneous maximum values never exceeded this daily mean standard limit.

- **Spatial Variability and Impact of Proximity to TPPs:** Measurement sites downwind of TPPs exhibited higher ambient air SO_2 concentrations than upwind sites, and SO_2 levels decreased with increasing distance from TPPs in Category-2 and Category-3 cities. Proximity to thermal power plants significantly affected ambient air SO_2 concentrations, with locations closer to TPPs showing higher values.
- **Variability in ambient air SO_2 concentrations:** Significant diurnal variations and intra-day fluctuations were observed in ambient air SO_2 concentrations, with multiple peaks likely caused by local sources within 60 km, such as transportation, residential activities, and industrial emissions. Although TPPs contributed significantly to the baseline SO_2 concentrations, especially in Category-2 and Category-3 cities, they were ruled out as causes for these short (lasting 2-4 hours) spikes due to their continuous operation. Boundary layer dynamics and wind characteristics significantly influenced ambient air SO_2 concentrations across all cities and phases.
- **Effectiveness of FGD:** No notable systematic differences in ambient air SO_2 concentrations were observed between Category 2 and Category 3 cities. The operation of FGD units in the two Category 3 cities selected for our survey, namely GBN and Khargone, did not significantly affect SO_2 levels, despite large day-to-day variability. Additionally, this variability did not correlate with the operation or the number of FGD units in operation at either of these TPPs, raising doubts about the effectiveness of the installed FGD systems in lowering SO_2 concentrations in the ambient air around these two TPPs.

Major findings of our investigation on the contribution of energy sector (coal-based TPPs) emissions towards ambient air SO_2 concentration in different category cities are listed below:

Our study reveals that the contribution of SO_2 emissions from coal-based thermal power plants (TPPs) to ambient atmospheric SO_2 concentrations exhibited significant spatial and seasonal variability across different cities.

Category-1 Cities: The energy sector's contribution to ambient air SO_2 concentrations was relatively low in these cities. The average contribution of TPPs to ambient SO_2 concentrations was 13.18%, ranging from 11.44% to 16.53%. New Delhi showed a contribution of 16.53% (1.36 $\mu g/m^3$) during Phase-I (pre-monsoon season), Hyderabad 11.57% (0.41 $\mu g/m^3$) in the same phase, and Lucknow 11.44% (0.66 $\mu g/m^3$) during Phase-II (monsoon season).

Category-2 Cities: The energy sector's contribution to ambient air SO_2 concentrations was generally significant, averaging 31.68%. The energy sector's contribution ranged from 27.99% to 38.57%. Kolkata showed a contribution of 28.66% (1.55 $\mu g/m^3$) and Nagpur 32.27% (1.56 $\mu g/m^3$) during Phase-I (pre-monsoon season). Kota showed 28.9% (1.11 $\mu g/m^3$) in Phase-II (monsoon

season) and 27.99% (1.82 µg/m³) in Phase-III (winter season). Shahdol had the highest contribution of 38.57% (1.99 µg/m³) in Phase-III.

Category-3 Cities: Significant contributions of coal-based thermal power plants (TPPs) to ambient atmospheric SO_2 concentrations were observed in these cities, averaging 20.38%, with contributions ranging from 17.37% to 22.54%. Ghaziabad showed contributions of 17.37% (1.43 µg/m³) during Phase-I (pre-monsoon season). Gautam Buddha Nagar (GBN) had contributions of 19.82% (1.80 µg/m³) in Phase-I, 21.97% (1.33 µg/m³) in Phase-II, and 22.54% (2.17 µg/m³) in Phase-III. Khargone showed 19.8% (0.86 µg/m³) in Phase-III.

Overall Findings: The energy sector's contribution to ambient air SO_2 concentrations ranged from 11.44% (0.66 µg/m³) to 38.57% (1.99 µg/m³) across all cities and phases. Category-2 cities exhibited the highest contributions, followed by Category-3 and Category-1 cities, underscoring the significant impact of coal-based TPP emissions. However, other sources such as industrial, residential, and transportation sectors also significantly contribute to ambient air SO_2 levels in all cities.

Major findings on the contribution of sulfate aerosols (SO_4) originating from SO_2 emissions by TPPs towards ambient air PM2.5 and PM10 mass concentrations in different category cities are listed below:

Category-1 cities: These cities, which have no coal-based TPPs, showed the lowest contributions of sulfate aerosols originating from SO2 emissions by TPPs towards ambient air PM2.5 and PM10 mass concentrations. For example, Hyderabad had contributions of 0.96% to PM2.5 (0.44 µg/m³) and 0.57% to PM10 (0.49 µg/m³) during Phase I, while Lucknow had contributions of 1.22% to PM2.5 (0.42 µg/m³) and 0.90% to PM10 (0.47 µg/m³) during Phase II. Despite being a Category-1 city, Delhi showed significantly higher contributions due to regional transport of SO_2 or sulfate aerosols from nearby TPPs, with contributions of 3.94% to PM2.5 (3.64 µg/m³) and 2.58% to PM10 (4.07 µg/m³) during Phase I. On average, Category-1 cities had contributions of approximately 1.79% to PM2.5 (0.93 µg/m³) and 1.04% to PM10 (1.07 µg/m³), with a range of 0.44 to 3.64 µg/m³ for PM2.5 and 0.47 to 4.07 µg/m³ for PM10.

Category-2 cities: These cities, which are near TPPs with FGD systems, had the highest contributions. In Gautam Buddha Nagar during Phase I, the contributions were 2.78% to PM2.5 (2.17 µg/m³) and 1.94% to PM10 (2.55 µg/m³). In Phase II, the contributions were 2.26% to PM2.5 (1.06 µg/m³) and 1.76% to PM10 (1.25 µg/m³), increasing to 2.93% to PM2.5 (3.23 µg/m³) and 2.15% to PM10 (3.80 µg/m³) in Phase III. Ghaziabad showed contributions of 2.15% to PM2.5 (1.55 µg/m³) and 1.49% to PM10 (1.83 µg/m³) during Phase I. Khargone, in Phase III, showed contributions of 2.14% to PM2.5 (1.05 µg/m³) and 1.51% to PM10 (1.23 µg/m³). On average,

Category-3 cities had contributions of approximately 2.45% to PM2.5 (1.61 µg/m³) and 1.97% to PM10 (2.13 µg/m³), with a range of 1.99 to 5.72 µg/m³ for PM2.5 and 2.23 to 5.75 µg/m³ for PM10.

Category-3 cities: These cities, which are near TPPs with FGD systems, had the highest contributions. In Gautam Buddha Nagar during Phase I, the contributions were 2.78% to PM2.5 (2.17 µg/m³) and 1.94% to PM10 (2.55 µg/m³). In Phase II, the contributions were 2.26% to PM2.5 (1.06 µg/m³) and 1.76% to PM10 (1.25 µg/m³), increasing to 2.93% to PM2.5 (3.23 µg/m³) and 2.15% to PM10 (3.80 µg/m³) in Phase III. Ghaziabad showed contributions of 2.15% to PM2.5 (1.55 µg/m³) and 1.49% to PM10 (1.83 µg/m³) during Phase I. Khargone, in Phase III, showed contributions of 2.14% to PM2.5 (1.05 µg/m³) and 1.51% to PM10 (1.23 µg/m³). On average, Category-3 cities had contributions of approximately 2.45% to PM2.5 (1.61 µg/m³) and 1.97% to PM10 (2.13 µg/m³), with a range of 1.99 to 5.72 µg/m³ for PM2.5 and 2.23 to 5.75 µg/m³ for PM10.

Overall findings: The contribution of SO_2 emissions from coal-based TPPs to ambient sulfate aerosols in PM2.5 and PM10 mass concentrations was highest in Category-2 cities, with an average contribution of 3.83% to PM2.5 (2.19 µg/m³) and 2.87% to PM10 (2.49 µg/m³). Category-3 cities showed intermediate contributions, averaging 2.45% to PM2.5 (1.61 µg/m³) and 1.97% to PM10 (2.13 µg/m³), while Category-1 cities had the lowest contributions, averaging 1.79% to PM2.5 (0.93 µg/m³) and 1.04% to PM10 (1.07 µg/m³). The range of contribution of sulfate aerosols (SO_4) formed due to SO_2 emissions from coal-based TPPs to ambient air PM2.5 and PM10 mass concentrations across all cities and phases varied from 0.96% (0.44 µg/m³) to 5.21% (3.30 µg/m³) for PM2.5 and from 0.57% (0.49 µg/m³) to 3.67% (3.60 µg/m³) for PM10.

Implications of our findings: Our study indicates that installing FGD systems with an 87.5% SO_2 removal efficiency in all coal-based TPPs across India would lead to a maximum reduction in PM2.5 concentrations of up to 4.56% (2.89 µg/m³) and PM10 concentrations of up to 3.21% (3.15 µg/m³). This reveals that SO_2 emissions from TPPs contribute relatively little to ambient air PM2.5 and PM10 mass concentrations in the surveyed cities and seasons. Consequently, there would be only a marginal improvement (5%) in particulate matter air quality even after eliminating all SO_2 emissions from TPPs. It should be noted that SO_2, a colourless gas, does not directly reduce visibility but contributes to haze formation after being converted into sulfate particles. Therefore, eliminating SO_2 emissions from TPPs is likely to result in a modest improvement in visibility and a reduction in haze formation. Comprehensive emission control measures targeting all major pollutants and particulate matter precursors emitted from various sources, including TPPs, are necessary to achieve meaningful improvements in air quality.

Major points based on our discussion on the lifecycle of SO_2 in the atmosphere and the potential for acid rain in India, and lifecycle costs and benefits of FGD implementation in TPPs across India are listed below:

- SO_2 has an atmospheric lifetime ranging from a few hours to about 15 days due to its rapid conversion to sulfate aerosols and removal via dry and wet deposition. In contrast, CO_2 has a much longer atmospheric lifetime, persisting for over 100 years. This means that while an SO_2 molecule is likely to be removed from the atmosphere within roughly two weeks, a CO_2 molecule can remain in the atmosphere for about a century.
- Due to the high soil dust content rich in carbonate minerals like calcium carbonate ($CaCO_3$) and the abundance of ammonia (NH_3) in the ambient air across India, both of which are alkaline, acid rain is not a serious issue in most parts of the country, except for southern peninsular India where the concentrations of alkaline substances like ammonia and carbonate-rich dust in the air are relatively low. However, frequent dilution caused by the sea breeze naturally keeps ambient SO_2 levels lower in coastal areas of peninsular India. Additionally, the inherent alkalinity of seawater droplets, due to the presence of bicarbonate ions (HCO_3^-) and carbonate ions (CO_3^{2-}), effectively neutralizes sulfuric acid (H_2SO_4) in the atmosphere over coastal areas.
- The combustion of coal in coal-fired thermal power plants, in addition to being a major source of carbon dioxide (CO_2) emissions, also results in the direct emission of primary particulate matter (PM) such as fly ash, black carbon (BC), and various heavy metals. Additionally, it emits several particulate matter precursors, including sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs), from the stacks (chimneys) of the TPPs into the atmosphere. Together, these emissions contribute significantly to ambient air PM2.5 and PM10 mass concentrations. However, eliminating only SO_2 emissions from TPPs using FGD technology, which can reduce SO_2 emissions by anywhere between 50% to 99%, is unlikely to result in a significant overall improvement in PM2.5 and PM10 mass concentrations in the different category cities surveyed in this study.
- While FGD implementation will significantly reduce SO_2 emissions from TPPs, there are no credible studies quantifying the overall life-cycle costs and benefits of FGDs in the Indian context. Current FGD technologies will increase CO_2 emissions, water consumption, and secondary pollution due to the mining and transportation of limestone/gypsum, FGD system manufacturing, operation and maintenance.
- Our study estimates that installing FGD systems with 87.5% SO_2 removal efficiency in all coal-based TPPs across India would reduce annual SO_2 emissions by 4.88 MT per year, but this would result in an immediate increase of approximately 14.4 MT per year in CO_2 emissions from mining, transportation, reagent operations, and increased auxiliary power consumption.

- While the above estimate only accounts for the immediate and direct additional CO_2 emissions, several previous studies have demonstrated that the total environmental impact, including the overall increase in CO_2 emissions beyond the immediate impact and freshwater consumption is likely to be significantly higher when considering the life cycle assessment (LCA) of FGD implementation in coal-based TPPs. These studies highlight the critical need to comprehensively assess both the immediate and long-term environmental impacts, including the estimation of additional equivalent CO_2 emissions, associated with FGD implementation. This underscores the importance of conducting thorough LCA and LCC analyses to fully understand and mitigate potential adverse outcomes, while minimizing the environmental trade-offs involved in deploying FGD systems across all coal-based TPPs in India.
- Although it is well known that sulfate aerosols are highly efficient at blocking solar radiation from reaching the Earth's surface, partially offsetting the global warming caused by greenhouse gases like CO_2, there are no credible studies on the impacts of a sudden reduction in SO_2 emissions combined with simultaneous increases in CO_2 emissions on India's regional weather and climate, including the Indian monsoon system, extreme weather events such as floods and droughts, surface ozone levels, human health, agriculture, etc. Therefore, it is crucial to quantify the long-term environmental and climate change impacts of FGD implementation in India to ensure that our clean air goals do not conflict with our climate change mitigation targets. Additionally, the increased warming due to reduced SO_2 emissions and increased CO_2 emissions is likely to exacerbate the adverse impacts of heat stress on human health and agriculture, which also needs to be quantified.
- India should heed the lessons from China's experience, as the idea that cleaning up air pollution can worsen atmospheric warming may seem counterintuitive but is a real and ongoing issue. Recently published research articles (Wang et al. 2024; Pearse, 2024) highlight how a dramatic reduction in Chinese air pollution, coinciding with the installation of FGD systems in coal-based TPPs, has been attributed to the recent extraordinary heating over the Northeast Pacific region, leading to more heat waves with global climate consequences. These findings underscore the complex relationship between air quality improvements and climate change, suggesting that decreased aerosol emissions, accompanied by increased greenhouse gas emissions, are likely to exacerbate warming. This demands more research in this direction and highlights the need for balanced strategies to address both air quality and climate goals.
- While SO_2 is a significant air pollutant and its emissions should be reduced, the trade-off between reducing SO_2 and increasing CO_2 emissions must be carefully considered. If reducing a relatively smaller amount of SO_2 emissions comes at the cost of a larger increase in CO_2 emissions, it raises serious concerns. This scenario necessitates a broader debate among stakeholders to ensure that efforts to improve air quality do not inadvertently strain valuable water resources, exacerbate global warming, and impact the Earth's climate system, particularly the regional weather and climate of India.

- Policy decisions regarding the installation of FGD systems in coal-based TPPs in India should balance the health benefits and climate impacts. While reducing sulfate aerosols can mitigate respiratory diseases, the concurrent increase in CO_2 emissions may exacerbate global warming, leading to heightened heat stress and potentially more severe health consequences (Ballester et al., 2023; Choudhary et al., 2023; Schumacher et al., 2024). Comprehensive studies are required to fully understand these impacts and to develop strategies to cope with extreme weather conditions that could affect food production and electricity generation and demand in India (Mbow et al., 2019).
- Based on our survey conducted over two years ago, discussions with the CEA, and considering subsequent price escalations due to inflation, it is reasonable to assume that the current cost of FGD systems is approximately Rs. 1.20 Crore per MW. As of May 31, 2023, the total installed capacity of coal-based TPPs across India is about 211.86 GW or 211,860 MW. Therefore, the total cost of installing FGD systems in all coal-based TPPs across India would be approximately Rs. 2,54,232 Crore. This estimate does not include the running and maintenance costs of the FGD systems.

Recommendations and Way Forward

- Considering that present ambient air SO_2 levels across all cities in our survey are well within the National Ambient Air Quality Standards (NAAQS), and recognizing that eliminating all SO_2 emissions from TPPs would result in only a marginal improvement in particulate matter air quality in these cities, along with the fact that current FGD technologies will increase CO_2 emissions, water consumption, and cause secondary pollution due to the mining and transportation of limestone/gypsum, the urgency of FGD installation across India must be reassessed. It may be prudent to halt the installation of FGD systems in thermal power plants that have not yet started this process and revisit this decision after considering these factors and taking the following suggested steps.
- FGD projects currently being implemented may be allowed to complete/operate for a year. After this period, a review of the impact of FGD operation on ambient air quality and regional meteorological changes may be conducted to determine any further necessary actions.
- Conduct a follow-up study to comprehensively evaluate the life-cycle assessment (LCA) and life-cycle costs (LCC) and benefits of implementing FGD technology in coal-based TPPs across India. This LCA and LCC estimate should encompass various available FGD technologies, operating and maintenance expenses, and the impact of FGD implementation on the current electricity unit price in India.
- Conduct another detailed study to evaluate the health benefits of reducing sulfate aerosols, specifically in mitigating respiratory diseases, vis-à-vis the potential health consequences of heat stress that are likely to be caused by the sudden disappearance of regional cooling effects from sulfate aerosols and the concurrent increase in CO_2 emissions. This study should

also consider the broader climate impacts, such as intensified warming and heightened heat stress, to prepare for extreme weather conditions affecting human health, food production, and electricity generation and demand resulting from FGD implementation across India.

- Initiate a broader debate among stakeholders after completing the life-cycle cost assessment to discuss the prudence of investing heavily in non-sustainable, CO_2-emitting energy sources versus redirecting funds towards rapidly expanding renewable energy sources like solar and wind power.
- Gradually phase out older and less efficient coal-based thermal power plants to transition to a sustainable and environmentally responsible energy future, while ensuring the country's energy security remains intact. The installation of FGD systems and carbon capture technologies should not be used as a smokescreen to justify the continued power generation from these unsustainable, CO_2-intensive sources. Prioritize transitioning to cleaner energy alternatives, which offer long-term environmental and public health benefits, and promote energy security and sustainability for future generations.
- It is recommended to develop balanced strategies that effectively address both air quality and climate goals.

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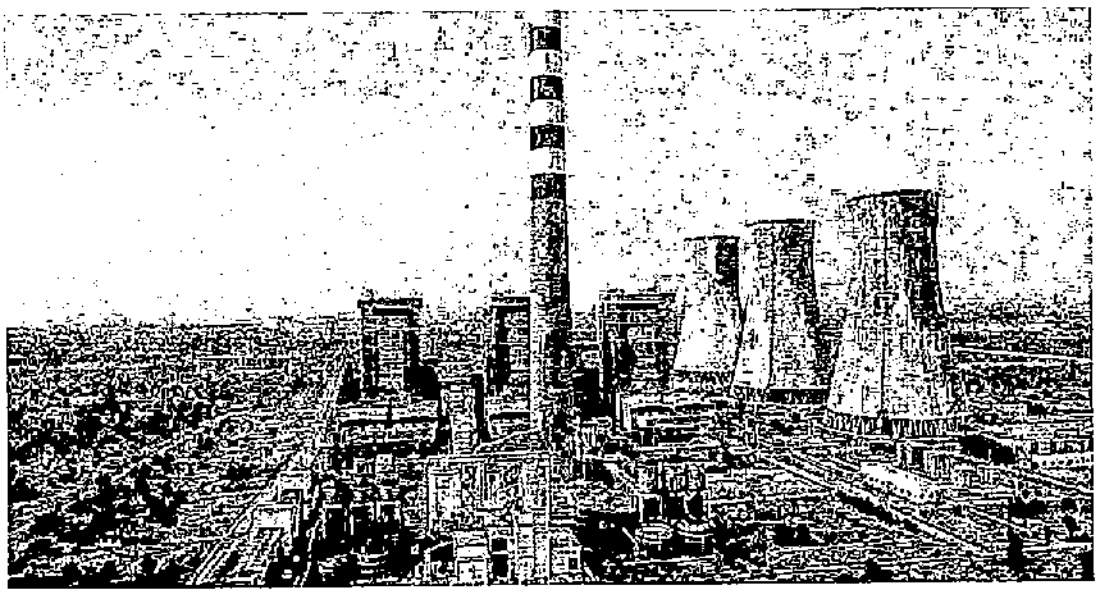
4831

Analysis of Historical Ambient Air Quality Data along with Emission from coal-based Thermal Power Plants for Developing a Decision Support System



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FOREWORD

NITI Aayog (National Institution for Transforming India) is the apex public policy think tank of Government of India having multiple verticals for addressing different needs of new India. Energy vertical, one among them deals with power, coal, petroleum, renewable energy and atomic power and examines projects for investment decisions. In its endeavour, NITI Aayog intended to review the latest notification (Dec. 7, 2025) of Ministry of Environment, Forest and Climate Change (MoEF & CC) that reframed the emission guideline for coal-based TPP. This notification introduced new flue gas emission norms for SO_2, NOx, and Mercury (Hg) based on generation capacity (MW) and commissioning year of TPP, compelling installation of flue gas desulphurization (FGD) technology to comply with SO_2 norms. In this context, NITI Aayog entrusted a study on the emission from coal based TPP and ambient air quality in the perspective of the new emission norms to CSIR-National Environmental Engineering Research Institute (NEERI) considering the expertise available.

The study included a detailed analysis of online continuous monitoring station (OCEMS) from TPP stacks and ambient air quality data from continuous ambient air quality monitoring station (CAAQMS) spread across India. Data from more than 343 OCEMS and 464 CAAQMS data were analysed. Emission data of particulate matter, NOx and SO_2 from TPP stacks provided by Central Pollution Control Board (CPCB), New Delhi, as well as National Thermal Power Corporation (NTPC) were analysed. CAAQMS data were gathered from CPCB web site.

It was observed that with the existing SO_2 emission load, the ground level concentration (GLC) of SO_2 rarely exceed the prescribed regulatory limit.

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Table of Contents

1. Introduction

1.1	Preamble	1.1
1.2	Background of the Study	1.2
1.3	Objective and Scope of Work	1.3
1.4	Structure of the Report	1.3

2. Power Generation in India

2.1	Introduction	2.1
2.2	Resource-wise power generation	2.1
2.3	Region-wise power generation	2.1
2.4	Sector-wise power generation	2.1
2.5	State-wise power generation	2.3
2.6	Classification of Thermal Power Station	2.6
2.6.1	Based on Location	2.6
2.6.2	Based on Power generation and Commissioning Year	2.11
2.6.3	Based on Combustion Technology	2.11
2.7	Status of FGD	2.12

3. Online Continuous Emission Monitoring System

3.1	Introduction	3.1
3.2	Data Analysis of OCEMS Data	3.1
3.2.1	Data Pre-processing	3.1
3.2.2	Data Visualization	3.2

4. Continuous Ambient Air Quality Monitoring Station

4.1	Introduction	4.1
4.2	Data Analysis of CAAQMS Data	4.2
4.2.1	Data Collection	4.2
4.2.2	Data Summary	4.4
4.3	Data Evaluation	4.5
4.4	Compliance Status of CAAQMS	4.7
4.5	Ambient air quality near TPP having FGD installed	4.16

5. Discussion

5.1	Introduction	5.1
5.2	Manual monitoring of SO_2 in India	5.2
5.2.1	SO_2 monitoring at Delhi under SA study (2007 – 08).	5.2
5.2.2	Ambient air SO_2 levels at remotely located TPP	5.3
5.3	Conversion of SO_2 to Sulphate by Eatough et. al. (1994)	5.5

5.3.1	Gas-Phase Homogeneous Reaction	5.5
5.3.2	Aqueous-Phase reaction	5.5
5.3.3	Heterogenous reactions on solid surfaces	5.6
5.4	Chemical speciation of PM in different studies	5.6
5.4.1	PM study at remote area TPP	5.6
5.4.2	Source apportionment study at Pit Head Thermal Power Plant area	5.7
5.4.3	Sulphur in ambient air particulate matter – Data at National level	5.9
5.4.4	Sulphate content of PM in Indian studies	5.10
5.5	Review of Reports on FGD	5.11
5.5.1	Air quality around Chandrapur Super Thermal Power Station	5.11
5.5.2	Report on air quality of Tamil Nadu	5.14
5.6	Lime consumption and Gypsum disposal in FGD	5.15
5.7	Rationale behind reduced stack height for TPS having FGD?	5.16
5.8	CO_2 Emission due to FGD operation	5.17
5.8.1	CO_2 Emission due to mining and transportation	5.19
5.8.2	CO_2 Emission due to coal combustion in TPP	5.20
5.8.3	Overall CO_2 Emission due to FGD and TPP	5.21

6. Conclusions and Recommendations

6.1	Conclusion from data analysis	6.1
6.1.1	PM Emission and concentration	6.1
6.1.2	SO_2 Emission and concentration	6.1
6.1.3	FGD System in TPP	6.3
6.2	Recommendations	6.4

Annexure

A1	List of TPS having OCEMS data.
A2	Data visualization of the OCEMS data.
A3	Comparison of emission standards.
B1	List of CAAQMS
B2	Data visualization of the CAAQMS data.

List of Tables

2. Power Generation in India

2.1	Categorization of the TPS based on their location.	2.6
2.2	Boiler classification based on pressure and temperature.	2.11

3. Online Continuous Emission Monitoring System

3.1	Summary of OCEMS data analysed.	3.3

4. Continuous Ambient Air Quality Monitoring Station

4.1	Number of CAAQMS in different States.	4.4
4.2(a)	Compliance status of PM_{10} Monitoring.	4.7
4.2(b)	Compliance status of $PM_{2.5}$ Monitoring.	4.8
4.2(c)	Compliance status of SO_2 Monitoring.	4.9
4.2(d)	Compliance status of NO_2 Monitoring	4.10
4.3(a)	Compliance status of PM_{10} Monitoring	4.11
4.3(b)	Compliance status of $PM_{2.5}$ Monitoring.	4.12
4.3(c)	Compliance status of SO_2 Monitoring.	4.13
4.3(d)	Compliance status of NO_2 Monitoring	4.14

5. Discussion

5.1	CO_2 emission if Limestone is transported by Road.	5.19
5.2	CO_2 emission if Limestone is transported by Rail.	5.19
5.3	CO_2 emission due to FGD and Power plant operation.	5.21

List of Figures

1. Introduction

1.1 Schematic diagram of thermal power plant (TPP). 1.1

2. Power Generation in India

2.1 Resource-wise total installed power generation capacity (MW) in India. 2.1

2.2 Region-wise total installed power generation capacity (MW) in India. 2.2

2.3 Sector-wise total installed power generation capacity (MW) in India 2.2

2.4 State-wise overall power generation capacity. 2.3

2.5 State-wise installed coal based thermal power generation capacity (%) in India. 2.4

2.6 State-wise distribution of coal based TPS. 2.5

2.7 Share of category wise TPS with different sectors. 2.6

2.8 Millennium cities of India. 2.7

2.9 TPS of Category 'A' (9%) 2.8

2.10 TPS of Category 'B' (13%) 2.9

2.11 TPS of Category 'C' (78%) 2.10

2.12 TPS share based on its capacity, year of commissioning and boiler technology. 2.11

2.13 Status of FGD in different TPS. 2.12

3. Online Continuous Emission Monitoring System

3.1 Authority-wise distribution of collected OCEMS data for each state. 3.4

3.2 Commissioning year wise distribution of collected OCEMS data for each state. 3.4

3.3 Capacity wise distribution of collected OCEMS data for each state. 3.5

3.4 Category wise distribution of collected OCEMS data for each state. 3.5

3.5 Emission rate of different pollutants from TPS commissioned in three different times (2003, 2016, after 2017). 3.6

4. Continuous Ambient Air Quality Monitoring Station

4.1 Air quality parameters of Manual and automatic method of monitoring. 4.1

4.2 Location of 447 CAAQMS in India. 4.2

4.3 Location of 132 non-attainment cities in India. 4.3

4.4 Two independent and separate $PM_{2.5}$ and PM_{10} sampler. 4.5

4.5(a) Compliance status (%) of ambient air PM_{10} as measured by CAQMS. 4.11

4.5(b) Compliance status (%) of ambient air $PM_{2.5}$ as measured by CAQMS 4.12

4.5(c) Compliance status (%) of ambient air SO_2 as measured by CAQMS 4.13

4.5(d) Compliance status (%) of ambient air NO_2 as measured by CAQMS 4.14

4.6 Graphical presentation of compliance status of air pollutants 4.15

5. Discussion

5.1	Box plot of manual monitoring of SO_2 at Delhi (2007- 08).	5.3
5.2	SO_2 at Lalitpur, U.P. during year-long monitoring (2022 - 23).	5.4
5.3	Sulphate and Elemental Sulphur in PM at Lalitpur during year-long monitoring (2022 - 23).	5.7
5.4	Ten open cast coal mines in Singrauli area.	5.8
5.5	Large number of coal-based TPS in Singrauli area.	5.8
5.6	Street map of coal mine and TPS in Singrauli area.	5.9
5.7	Schematic diagram of TPS emission over coal mine top in Singrauli area.	5.9
5.8	Elemental sulphur in PM collected over PTFE filter during 2021-23.	5.10
5.9	Sulphate content in PM collected over PTFE filters under different studies.	5.10
5.10	Monthly variation of daily maximum mixing height & ventilation at Chandrapur.	5.12
5.11	Box plot of monthly variation of daily average PM_{10} and $PM_{2.5}$ at Chandrapur (2019 – 2022).	5.13
5.12	Box plot of monthly variation of daily average SO_2 and NO_2 at Chandrapur (2019 – 2022).	5.13
5.13	Box plot of Mercury content in particulate matter collected over PTFE.	5.14
5.14	Isopleth of GLC of SO_2 for stack height of 275 m and 150 m.	5.17
5.15	CO_2 emission due to FGD and Power plant operation.	5.21

Abbreviations

AI/ML	Artificial Intelligence/ Machine Learning
APC	Auxiliary Power Consumption
CAAQMS	Continuous Ambient Air Quality Monitoring System /Station
CEA	Central Electricity Authority
CO_2	Carbon Dioxide
CPCB	Central Pollution Control Board
CSIR-NEERI	Council of Scientific and Industrial Research - National Environmental Engineering Research Institute
CSTPS	Chandrapur Super Thermal Power Station
ED-XRF	Energy Dispersive X-Ray Fluorescence
EIA	Environmental Impact Assessment
ESP	Electrostatic Precipitator
FGD	Fuel Gas De-Sulphurisation
GCV	Gross Calorific Value
GHG	Greenhouse Gas
GIS	Geographic Information System
GLC	Ground Level Concentration
IC	Ion Chromatography
LPGCL	Lalitpur Power Generation Company Limited
MIDC	Maharashtra Industrial Development Corporation
MoEF&CC	Ministry of Environment, Forest and Climate Change
MT	Metric Tonnes
MW	Megawatts
NAAQM	National Ambient Air Quality Monitoring

NAAQS	National Ambient Air Quality Standards
NAMP	National Air Quality Monitoring Programme
NCL	Northern Coalfield Limited
NTPC	National Thermal Power Corporation
OCEMS	Online Continuous Emission Monitoring System
PCB	Pollution Control Board
PM	Particulate Matter
PTFE	Poly-Tetra-Fluoro-Ethylene
R&D	Research and Development
RTI	Right to Information
SA	Source Apportionment
SCR	Selective Catalytic Reduction
SO_2	Sulphur Dioxide
SOP	Standard Operating Procedure
SPCB	State Pollution Control Board
SSI	Small-Scale Industries
STPS	Super Thermal Power Station
TPD	Tons Per Day
TPPs	Thermal Power Plants
TPS	Thermal Power Station
ULB	Urban Local Body
UNEP	United Nations Environment Program
VEO	Visual Emission Observation
WRF	Weather Research and Forecasting (Model)

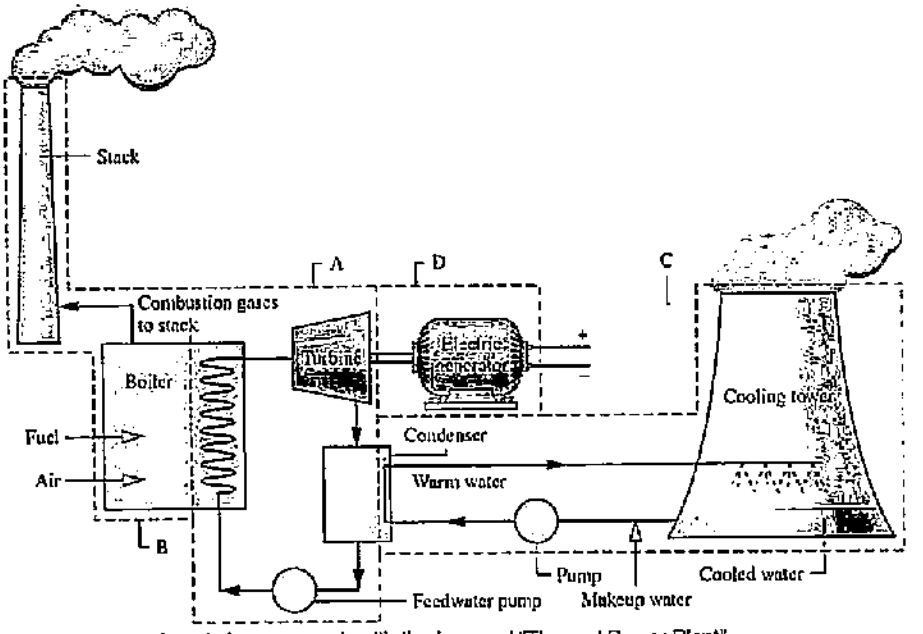
Chapter 1

Introduction

1.1 Preamble

Coal is the primary source of power generation in India. However Indian coal is characterized by low calorific value, high ash, and low sulfur content. The increase in thermal power generation led to concerns about emissions of pollutants in the atmosphere. The high ash content led to a change in the design of the electrostatic precipitator (ESP) and bag house filter. Due to the large amount of ash, several electric fields must be added in series in the ESP for effective reduction of fly ash emission. As per an estimate, a 210 MW unit requires 6.5 times more collecting plate area for unit power generation for Indian coal-based TPS than European coal. The addition of a large size power plant at one station (660 MW x 3) led to the release of a relatively larger amount of SO_2 from a point (tri-flue stack). It was believed that a large amount of SO_2 from three units may lead to adverse impacts on the environment through acid formation, deposition and damage to property and human health. The fear of the likely adverse impact on the environment by SO_2 led to regulatory intervention by way of notification for reducing the emission load of SO_2 from 600 mg/Nm^3 to 100 mg/Nm^3 in the new power plants installed after Jan 1, 2017. Accordingly, the Ministry of Environment, Forest & Climate Change (MoEF&CC), vide its Notification dated December 7, 2015, has amended the Environment (Protection) Rules.

To comply with the amended Rules, the coal-based thermal power stations are required to install a Flue Gas Desulphurization (FGD) system at the end of the flue gas treatment system after ESP and before its release through tall stacks in the atmosphere.



Source: Google image search with the keyword "Thermal Power Plant".

Fig. 1.1: Schematic diagram of thermal power plant (TPP)

1.2 Background of the Study

Niti Aayog received representation from stakeholders, both Govt. and Private players regarding the need for the installation of an FGD system in coal-based TPPs to reduce SO_2 concentration in the ambient air. It was contended that due to the low sulphur content of domestic Indian coal, the ambient air SO_2 levels are also relatively very low, and therefore, FGD installations may not necessarily be required.

It was brought forward that FGD installations would lead to increased auxiliary power consumption, a corresponding rise in coal consumption, and thus the proportionate increase of CO_2 emission, an increase in water consumption, pressure on mining and transportation of limestone, and disposal of Gypsum. In addition, FGD installation would certainly invite foreign players to supply and install, leading to FOREX outflows. We do not seem to have any studies in India that correlate the measured levels of SO_2 from power stations and ground-level concentrations of SO_2. Only in environmental impact assessment (EIA) studies is the impact of SO_2 assessed using source dispersion models, and the stack height is adjusted to comply with the ground level concentration (GLC) of ambient air SO_2.

With this background, NITI Aayog was awarded a study for being conducted by CSIR-NEERI, Nagpur, titled "Analysis of historical ambient air quality data across India for developing a decision support system." using available emission and ambient air quality data of SO_2 from CAAQMS and other pollutants from coal-based TPPs. The broad TOR of the study is presented in section 1.3.

1.3 Objective and Scope of Work

- Analysis of Online Continuous Emission Monitoring System (OCEMS) Data generated by coal-based thermal power plants (TPP). Emission data is to be collected from CPCB / MoEF&CC.

- Analysis of ambient air quality monitoring station (CAAQMS) and online continuous emission monitoring system (OCEMS) data across India available with CPCB and possibly all industrial operators, which can be made available through CPCB.

- A literature review will be carried out for studies related to SO_2 emissions, FGD implementation, etc.

- Examining the stipulations of the Ministry of Environment, Forest & Climate Change (MoEF&CC) Notification dated December 7, 2015, that has amended the Environment (Protection) Rules and related succeeding orders.

1.4 Structure of the Report

The report begins with the history of air pollution, the need for coal, its large-scale mining, and power generation. The increasing population and power demand lead to large amounts of coal combustion, causing higher levels of air pollutant emission, particularly SO_2, forcing regulatory authorities to consider its control using FGD, which is covered in Chapter 1.

Chapter 2 provides statistics on electrical power generation by different agencies, coal consumption, TPS categories (A, B, C), boiler types, and the FGD status of TPS in India. The emission of SO_2 is monitored using an online continuous emission monitoring station (OCEMS) installed in each stack as per the instruction of CPCB, Delhi. The data generated in OCEMS is transmitted and stored in the CPCB server. The OCEMS data for 343 power station stacks is analyzed and presented in Chapter 3. The data analysis shows the emission rates of PM, SO_2, and NO_2 from TPP in terms of different capacities and installation dates.

The ambient air quality is measured in different cities and industrial areas using a continuous ambient air quality monitoring station (CAAQMS), and the data is conveyed to the CPCB central server. The data from 464 CAAQMS is downloaded, analysed and discussed. Besides this, NTPC also gathered ambient air quality data at 486 stations near TPS and analysed it. Chapter 4 summarizes CAAQMS data for particulate matter (PM_{10}, $PM_{2.5}$) and gaseous pollutants (SO_2 and NO_2) in these stations.

Chapter 5 presents a discussion on data obtained in other studies, source apportionment studies, and studies in isolated TPP coal mining areas. Review of reports by international agencies, wherein the need for FGD in Indian TPP is emphasized without any field data analysis. Lime requirement, its transportation, gypsum transportation and corresponding CO_2 emission are also presented.

Chapter 6 provides observations and recommendations based on the entire study. Whether the decision to reduce SO_2 emission is based on achieving emission targets or meeting ambient air quality standards is discussed. The need for Indian TPP is to control particulate matter and not SO_2 emission due to typical coal characteristics, which is discussed. Finally, the recommendations on the need for FGD for new plants and already installed FGD.

Chapter 2

Power Generation in India

2.1 Introduction

This chapter presents the power generation capacity of different agencies, such as state, central, and Private Operators (Independent Power Producers). Regional or sector-wise distribution of power generation capacity, category of TPS (A, B, C) based on its location in the National Capital Region (NCR), millennium cities having population above 10 Lakhs, etc. is presented.

2.2 Resource-wise power generation

India's total installed electrical power generation capacity is 434195.20 MW as of March 21, 2024, comprising coal, renewal energy, hydroelectric, nuclear, diesel and gas. **Fig. 2.1** shows the share of each resource.

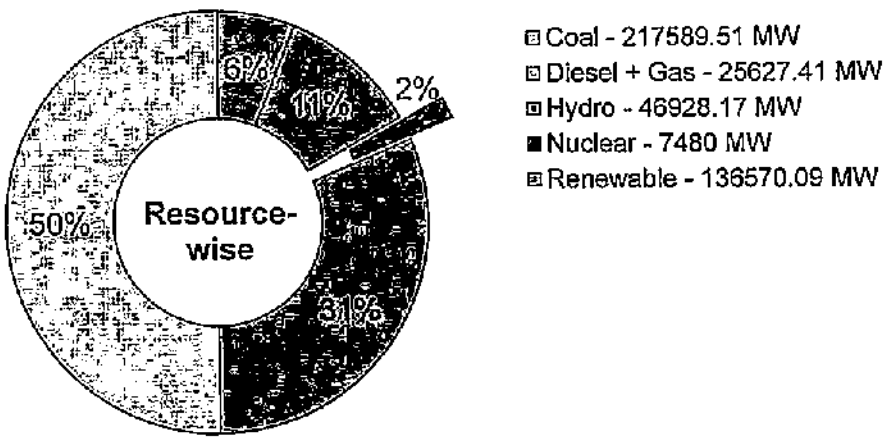


Fig.2.1: Resource-wise total installed power generation capacity (MW) in India.

2.3 Region-wise power generation

Due to the large geographical spread, power generation is divided into five regions: the north-eastern, eastern, northern, southern and western regions. **Fig. 2.2** shows the region-wise distribution of power generation in India.

2.4 Sector-wise power generation

Central, State Government and Private sector agencies own the power generation company. The share of each sector for power generation from different resources is given in Fig. 2.3. The Private sector generates more power compared to the Government

sector. This power generation capacity includes all types of resources like solar, coal, wind, etc.

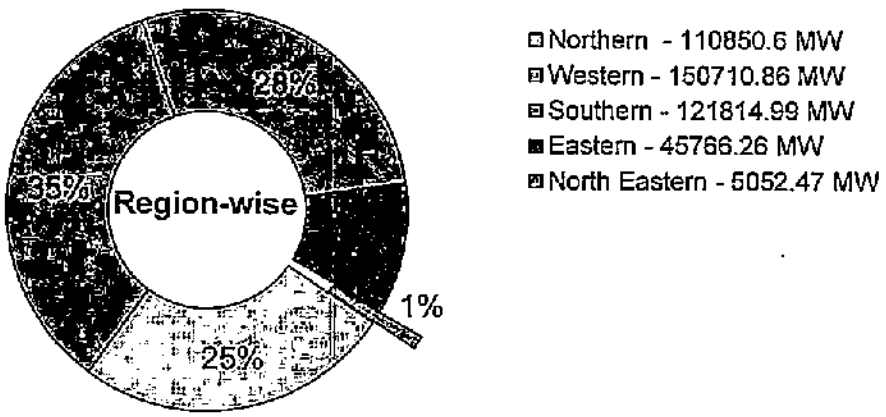


Fig.2.2: Region-wise total installed power generation capacity (MW) in India.

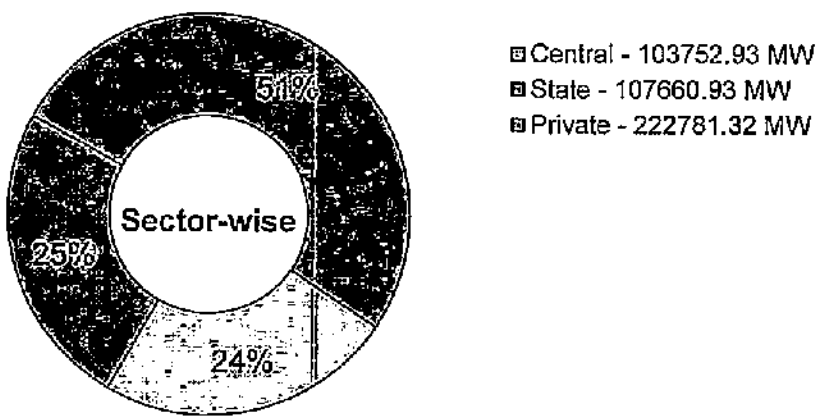


Fig.2.3: Sector-wise total installed power generation capacity (MW) in India.

2.5 State-wise power generation

State-wise overall power generation capacity is shown in **Fig. 2.4.**

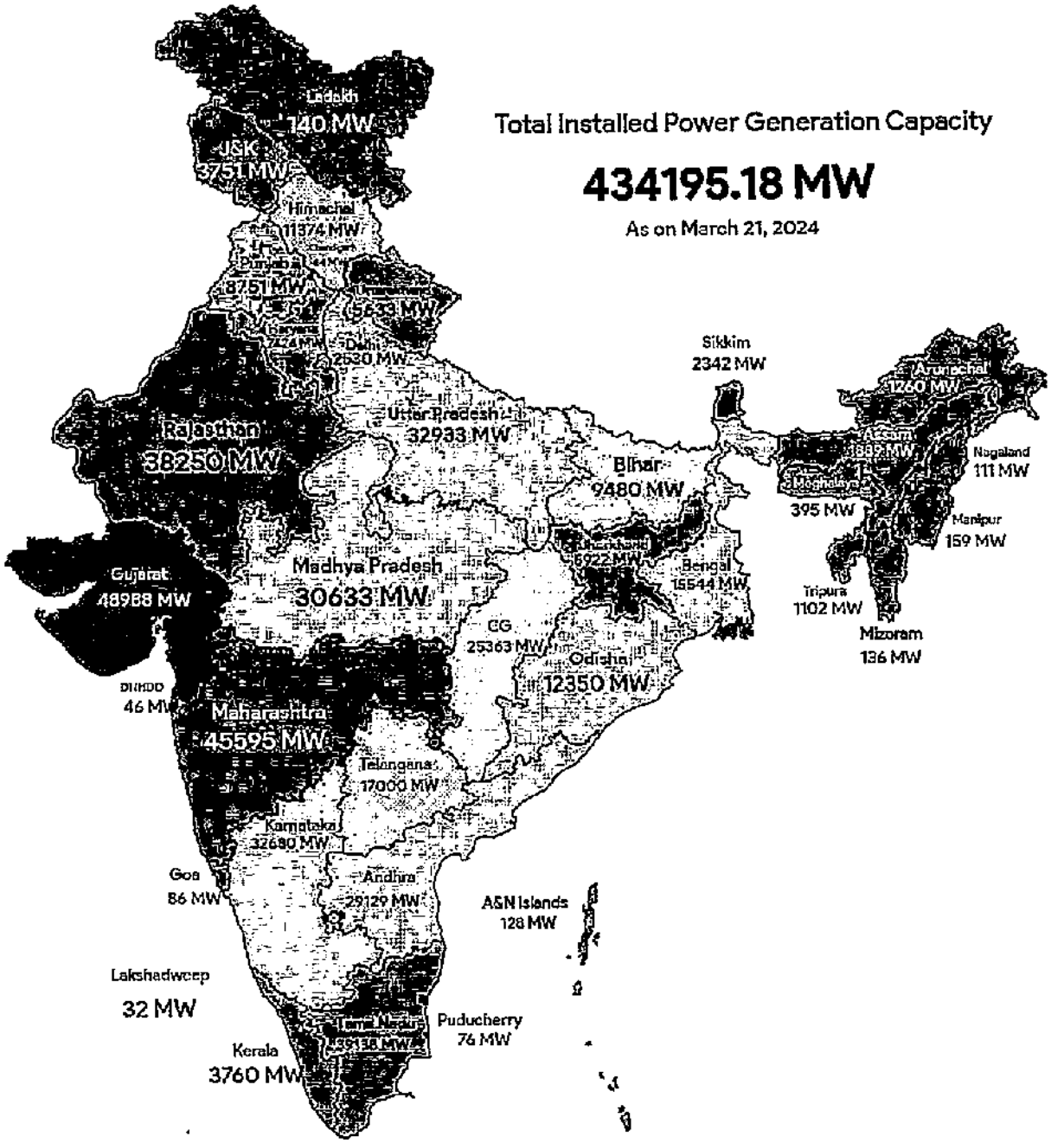


Fig 2.4: State-wise overall power generation capacity.

The percentage share of thermal power generation capacity of each state is shown in **Fig. 2.5** along with generation capacity in MW is depicted in **Fig. 2.6**. More than 50% of power capacity obtained by coal-based TPP is installed in Uttar Pradesh, Maharashtra, Chhattisgarh, Madhya Pradesh, and Gujarat.

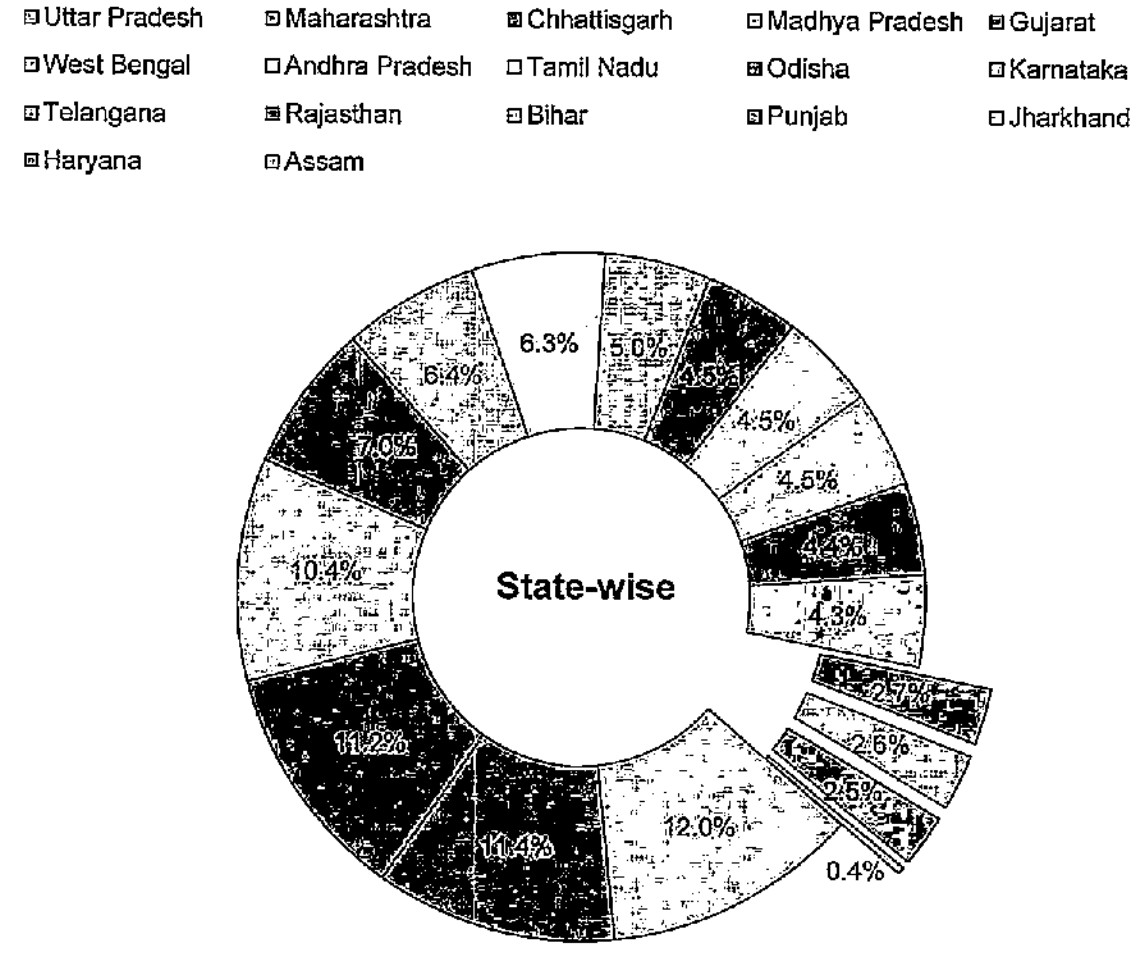


Fig.2.5: State-wise installed coal-based thermal power generation capacity (%) in India.

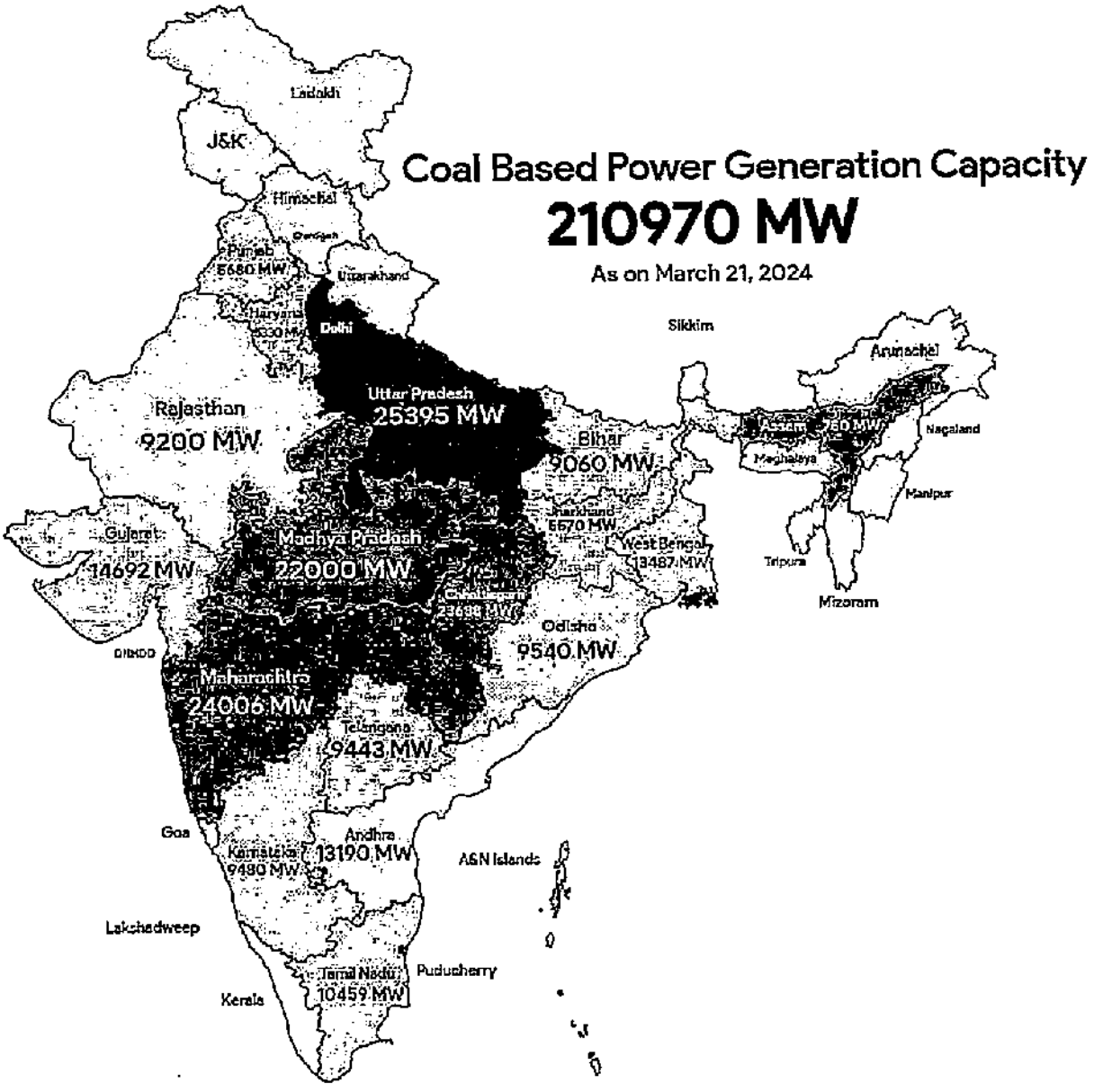


Fig 2.6: State-wise distribution of coal-based TPS.

2.5

2.6 Classification of Thermal Power Station

2.6.1 Based on Location

The Government of India (GoI) categorized coal-based TPS into three categories, 'A', 'B', and 'C', depending on its proximity to the National Capital Region and critically polluted area (MoEF&CC, 2022). The criteria for categorization are given in **Table 2.1**.

Table 2.1: Categorization of the TPS based on their location

S.No.	Category	Location /Area
1.	Category - A	Within a 10 km radius of the National Capital Region or cities having a million plus population.
2.	Category - B	Within a 10 km radius of Critically Polluted Areas or Non-attainment Cities.
3.	Category - C	Other than those included in category A and B.

The share of TPS in different categories is presented in **Fig. 2.7**. If stringent rules are to be imposed, it can be started from category 'A'. However, due reasoning by way of identifying the impact on SO_2 concentration observed in nearby monitoring stations (CAAQMS) and emission load from nearby TPS needs to be established.

The largest number of coal-based TPPs are in Category C (78.2%), followed by Category B (12.8%) and Category A (9.04%). Further, there is sector-wise distribution of a number of coal-based TPPs under each category (Pl see Fig. 1.5 (B)). The State authorities have the majority stack holding in Category 'A' TPPs, whereas Private authorities hold the highest share in Category 'C' and Category 'B'. However, Central authorities handle a minimum number of TPPs of each category.

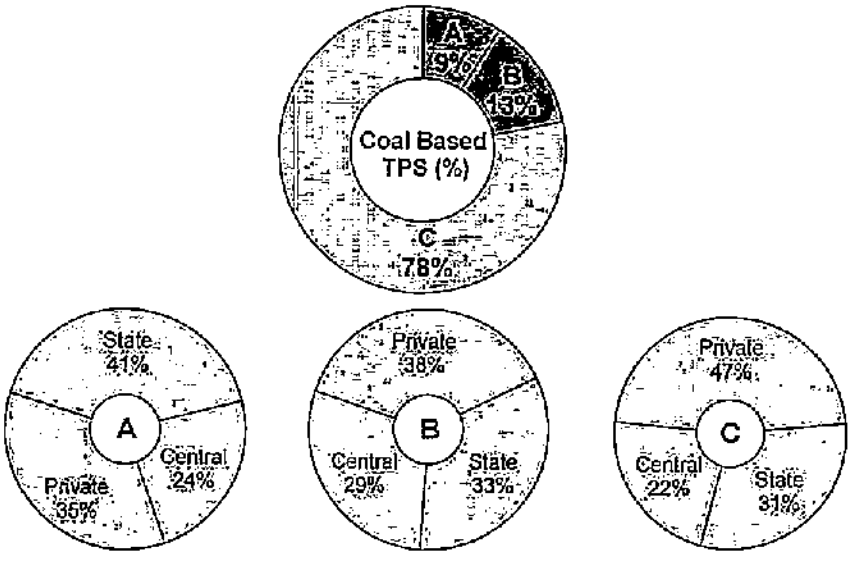


Fig 2.7: Share of category wise TPS with different sectors.

One of the concerns while deciding the category of TPS is the nearby city population that can be affected due to exposure to air pollutants. In view of this, the millennium cities are identified and located on a map to realize their relative position with respect to TPS (Fig. 2.8). A Digital copy of such a map is prepared, wherein the location of TPS and millennium cities can be identified for any decision making.

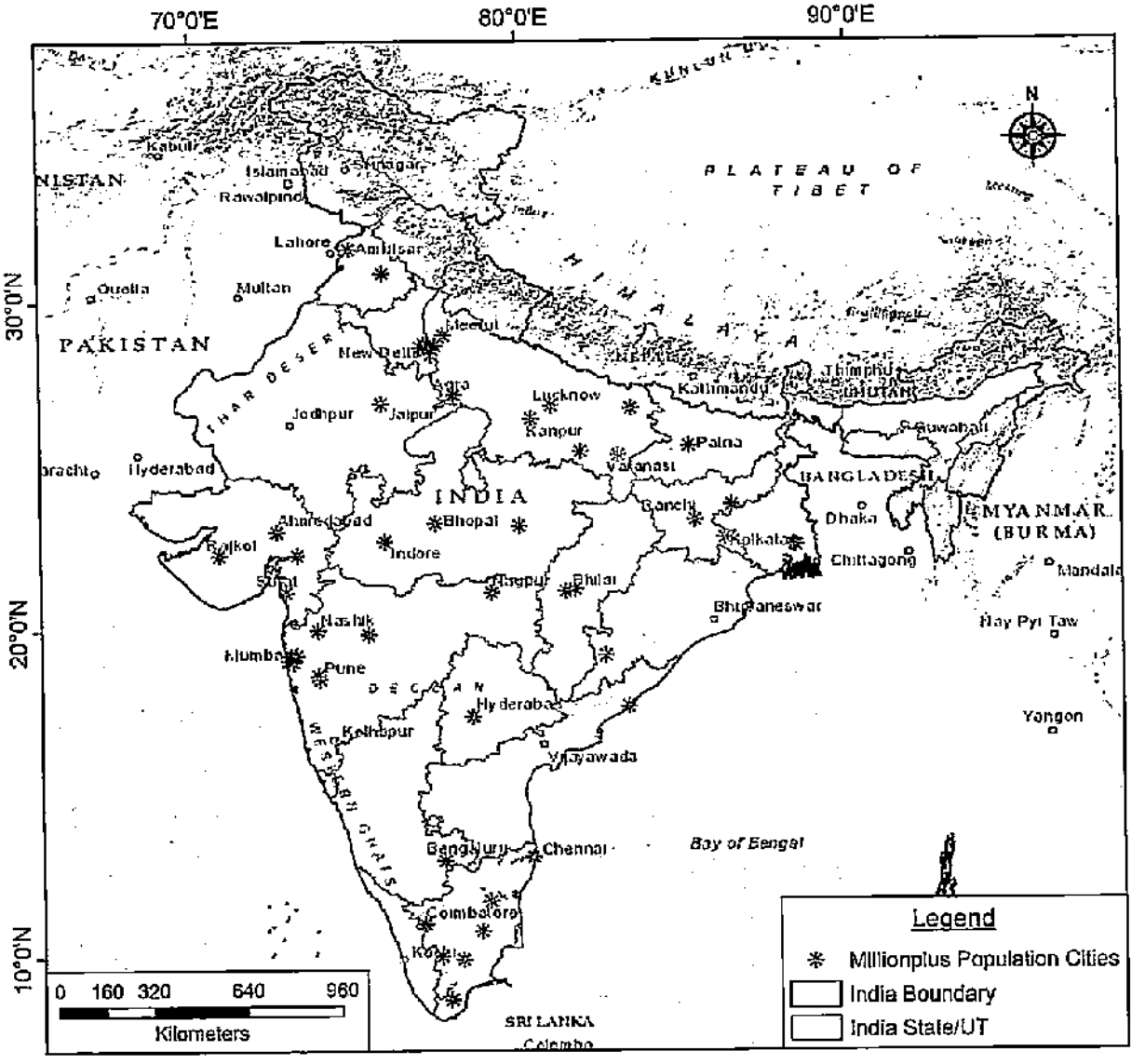


Fig. 2.8: Millennium cities of India.

TPS of the 'A', 'B' and 'C' categories is shown in **Fig. 2.9, 2.10,** and **2.11**. The list of TPS of the different categories is given in Annexure – A1.

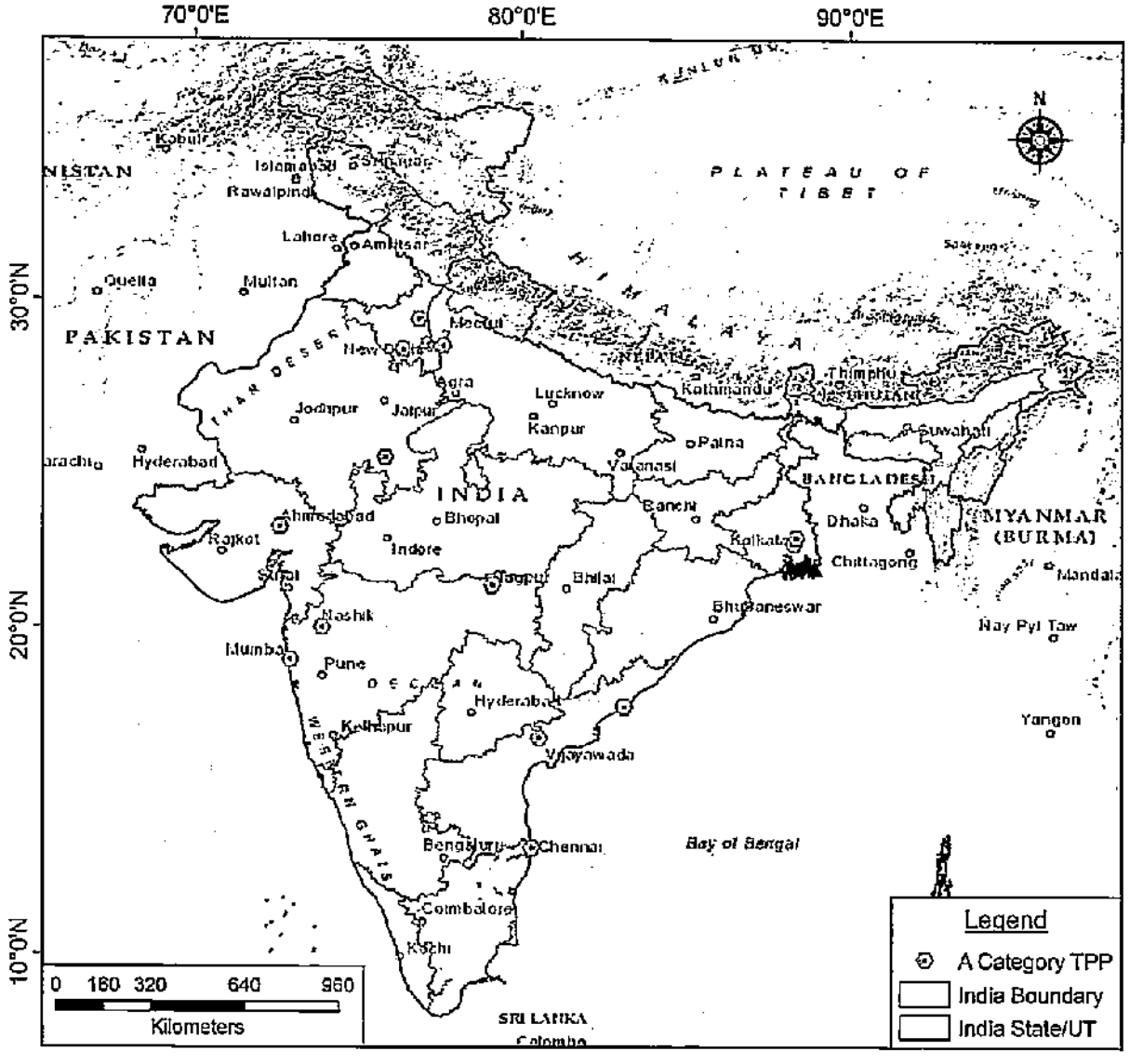


Fig. 2.9: TPS of Category 'A' (9%).

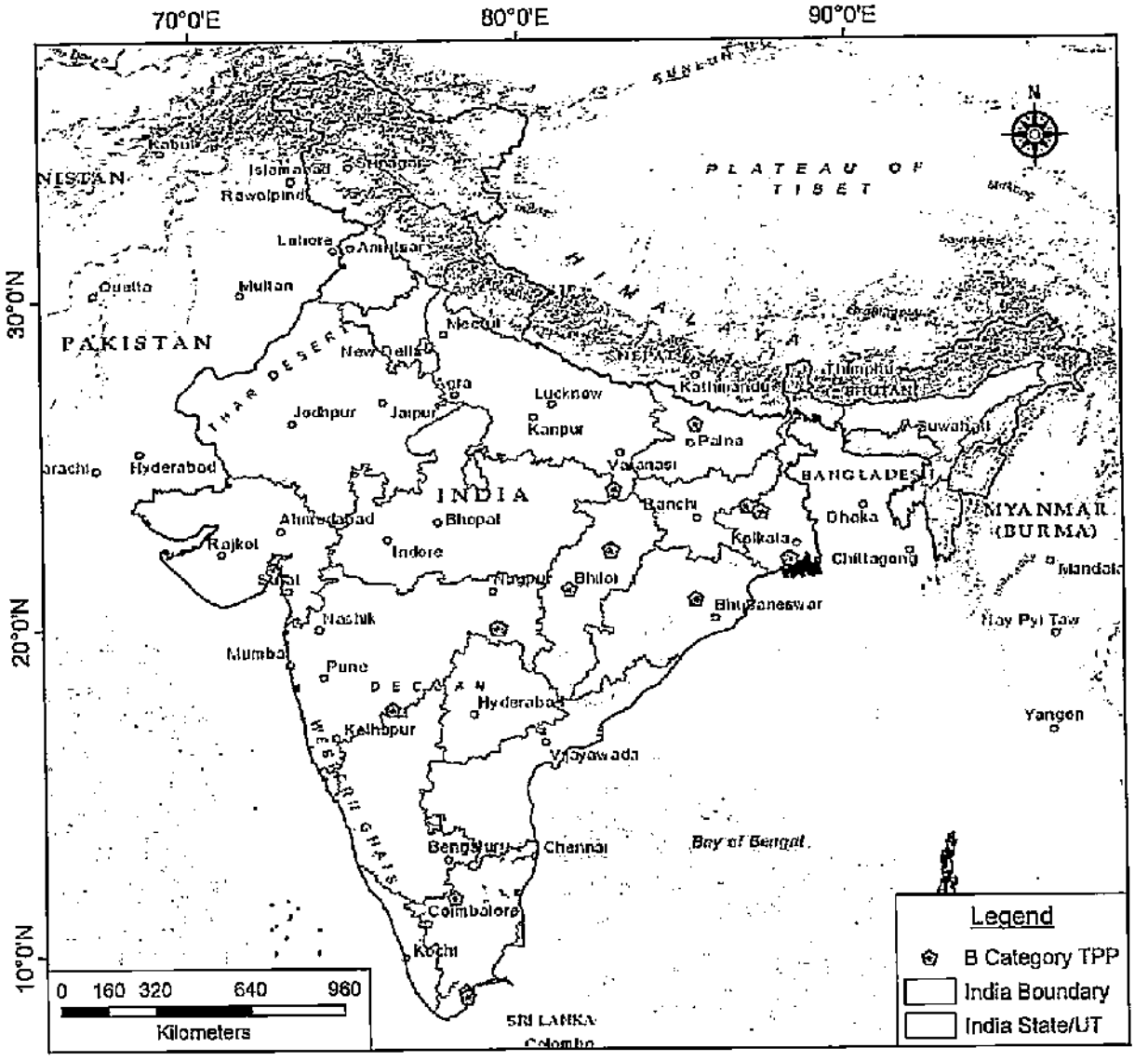


Fig. 2.10: TPS of Category 'B' (13%).

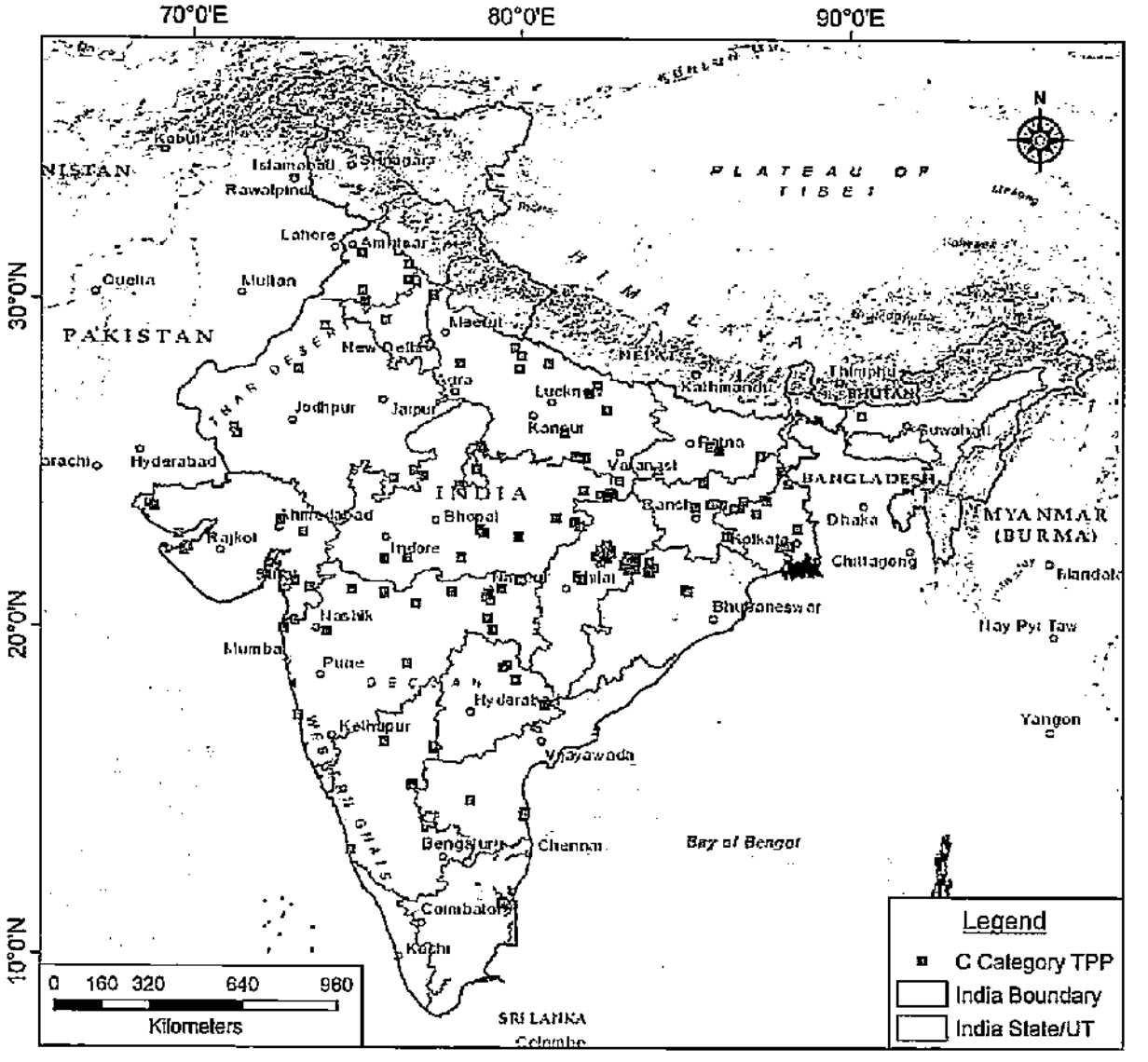


Fig. 2.11: TPS of Category 'C' (78%).

2.10

2.6.2 Based on Power Generation and Commissioning Year

Coal-based TPS are also classified based on their power generation capacity and year of commissioning, which is given in **Fig. 2.12.** Guidelines are for TPS before 2003, between 2003 and 2016, and beyond 2016. Besides this, TPS below 500 MW and those equal to or above 500 MW also have to follow different regulatory requirements.

2.6.3 Based on Combustion Technology

TPS are also grouped based on boiler technology, such as sub-critical, super-critical, and ultra-super-critical. The difference of these boilers is due to steam temperature and pressure. **Table 2.2** gives the details of boiler classification.

Table 2.2: Boiler classification based on pressure and temperature

Boiler Type	Main steam pressure (MPa)	Main steam temperature (°C)
Sub-Critical	<22.1	Up to 565
Super-Critical	22.1–25	540–580
Ultra-Super-Critical	>25	>580

Source: Nalbandian, 2008: pp. 8

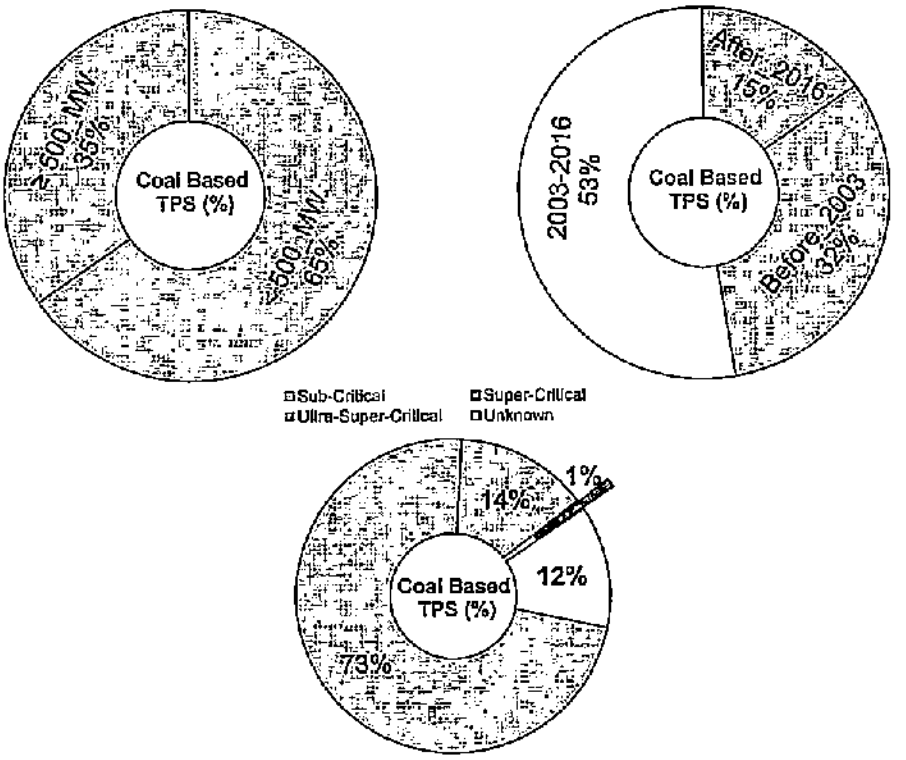


Fig. 2.12: TPS share based on its capacity, year of commissioning and boiler technology.

2.7 Status of FGD installation in TPP

As per the notification of 2015, the current status of FGD implementation is shown in Fig. 2.13.

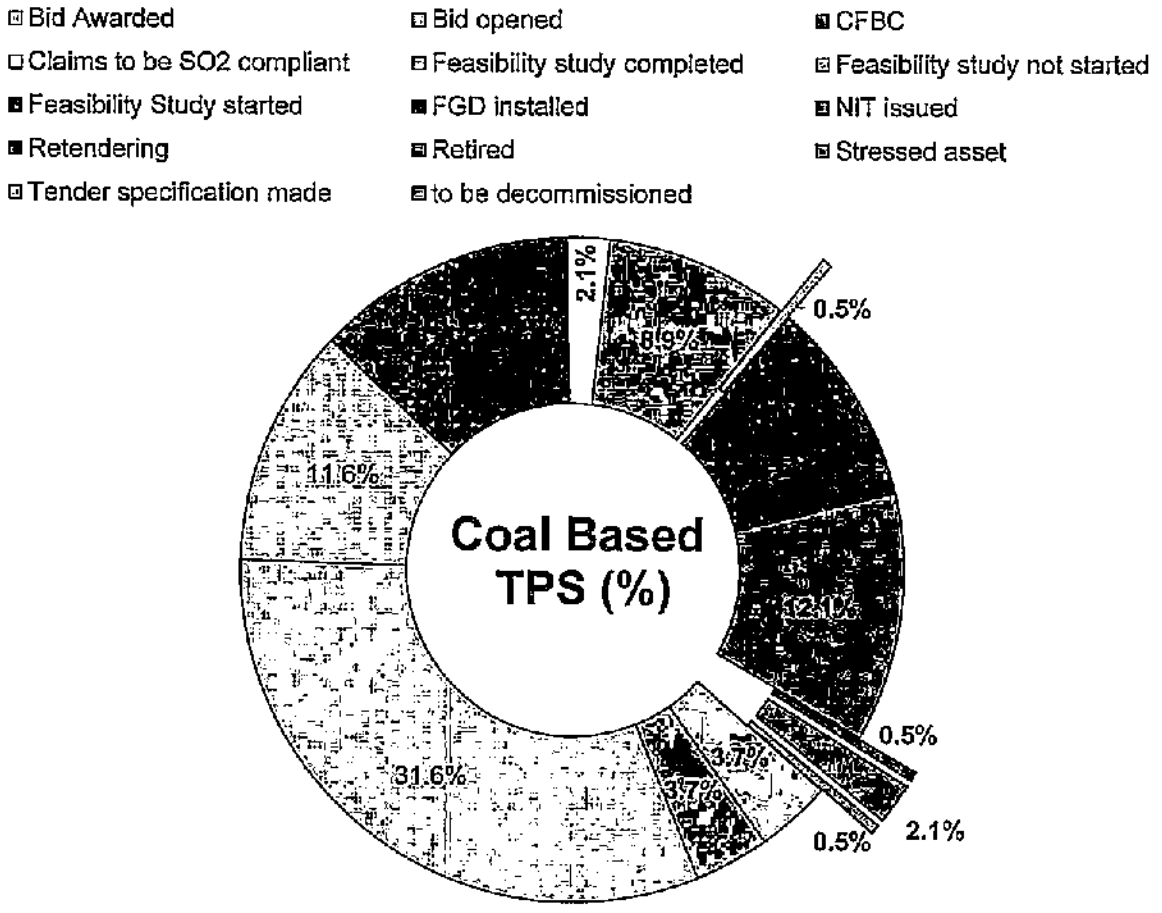


Fig. 2.13: Status of FGD in different TPS.

References:

1. MoEF&CC New Delhi (2022): Notification Dt. 5th September, 2022, No. G.S.R. 682(E). Categorization of TPS in A, B, C.
2. CPCB: B-33014/7/2021/IPC-II/TPP Dt. (23/6/2022): Amended category of TPS in A, B, and C.

Chapter 3

Online Continuous Emission Monitoring System

3.1 Introduction

To monitor the amount of air pollutants released and effluent discharge from industries (with high pollution potential), CPCB (vide its letter No. B-29016/04/06PCI-1/5401 dated 05.02.2014 issued directions under section 18(1)b of the Water and Air Acts to the SPCB and Pollution Control Committees for directing the 17 categories of highly polluting industries for installation of online effluent quality and emission monitoring systems. The directions envisage the installation of an online continuous emission monitoring system (OCEMS) in 17 categories of highly polluting industries and Common Hazardous waste and Biomedical waste incinerators. This intends to measure Particulate Matter, NH_3 (Ammonia), SO_2 (Sulphur Dioxide), NOx (Oxides of Nitrogen) and other sector-specific parameters, not later than by March 31, 2015, and transmission of online data so generated simultaneously to SPCB/ PCC and CPCB as well. The deadline was later extended to June 31, 2015. PM, SO_2 and NOx need to be monitored using OCEMS.

3.2 Data Analysis of OCEMS Data

In order to comply with the above order, all TPS were required to install OCEMS. Data from 343 stacks of TPS using Indian coal were gathered from CPCB, Delhi. The summary of data is presented in **Table 3.1**. For each state:

- The number of TPS,
- Total number of stacks,
- Plant belonging to State, Central or Private sector,
- Commissioned before 2003, between 2003 to 2016 or beyond 2016,
- Capacity of the unit
- The category of TPS (A, B, C) is presented due to its location.

3.2.1 Data Pre-processing and Analysis

Annexure A1 provides a list of TPS, which is analysed for visualization of PM, SO_2, and NOx emission The list of TPS can be accessed through CPCB. The information provided in the annexure can be understood by following nomenclature as follows:

State	:	Andhra Pradesh
City	:	Simhadri
Organization	:	NTPC
TPS ID	:	3672
TPS Name	:	C_A_500_Simhadri_2002
Combustion Technology	:	Sub-Critical, Critical, Supercritical
Commissioning Year	:	2002
FGD Status	:	Bid awarded or opened, Feasibility study, NIT issued

- TPS ID is the identification number derived from CPCB's list of TPS.
- TPS Name contains several information. The following example explains the meaning of each term in the TPS Name:

C_A_500_Simhadri_2002	:	C: Central Govt.; A: Category; 500: Capacity (MW); Simhadri: Name; 2002: Year of commissioning.
S_A_210_Tata Rao_1989	:	S: State Govt.; A: Category; 210: Capacity (MW); Tata Rao: Name; 1989: Year of commissioning.
P_B_685_Raikheda_2016	:	P: Private; B: Category; 685: Capacity (MW); Raikheda: Name; 2016: Year of commissioning.

OCEMS data gathered is analysed in terms of its share in each state; central, state and private operator (Fig. 3.1); year of commissioning (Fig. 3.2); capacity (Fig. 3.3); and category 'A', 'B', 'C' (Fig. 3.4).

3.2.2 Data Visualization

Annexure A2 provides a graphical visualization of OCEMS data. **Fig. 3.5** shows a box plot of the emission rate for (a) PM, (b) SO_2, and **(c)** NO_2 for all the 343 stacks together. It can be seen that the stringent PM emission limit from 2003, 2016 to 2017 is reflected in reducing emission load as the box plot is gradually moving down towards a lower emission rate. To meet the regulatory requirement of reduced emissions, the number of electric fields and collecting plate areas were increased.

Contrary to this, the emission limit of SO_2 is reduced from 600 mg/Nm^3 to 100 mg/Nm^3. However, the emission load continues to increase with the increase in power generation capacity. On the same line of SO_2, the regulatory limit value of NO_2 is also reduced over years (2003 - 2016 - 2017), however, the emission load continues to exceed the limit. The rationale behind reducing the regulatory limit value of gaseous pollutants is not known.

Table No. 3.1: Summary of OCEMS data analysed.

No.	State	Number of TPS	Total No. of Stack	Number of Stacks										
				Authority			Year of Commissioning			Capacity (MW)		Category		
				Central	State	Private	Before 2003	2003-2016	After Jan 2017	≥ 500	< 500	A	B	C
1	Andhra Pradesh	5	14	3	7	4	5	6	3	8	6	9		5
2	Assam	1	2	2				1	1		2			2
3	Bihar	4	8	8			3	3	2	3	5		3	5
4	Chhattisgarh	16	41	16	4	21	9	23	9	18	23		15	26
5	Gujarat	11	33		20	13	18	14	1	7	26	3		30
6	Haryana	5	11	3	7	1	2	9		6	5	8		3
7	Jharkhand	6	12	4	2	6	6	5	1	2	10			12
8	Karnataka	4	9	3	4	2	4	2	3	4	5			9
9	Madhya Pradesh	11	28	11	5	12	9	16	3	17	11			28
10	Maharashtra	14	33	6	16	11	10	17	6	17	16	4	9	20
11	Odisha	5	13	5	1	7	3	10		10	3		2	11
12	Punjab	5	15		10	5	8	5	2	4	11			15
13	Rajasthan	7	24	2	18	4	8	14	2	5	19	6		18
14	Tamil Nadu	9	27	14	8	5	14	9	4	9	18	3	5	19
15	Telangana	5	11	6	5		7	3	1	6	5			11
16	Uttar Pradesh	15	41	16	11	14	14	21	6	13	28			41
17	West Bengal	8	21	6	12	3	14	7		3	18		2	19
Total		**131**	**343**	**105**	**130**	**108**	**134**	**165**	**44**	**132**	**211**	**33**	**36**	**274**

Annexure A3 provides emission standard thermal power station of India and other countries.

Ref: CPCB (August 2018): Guidelines for Continuous Emission Monitoring Systems.

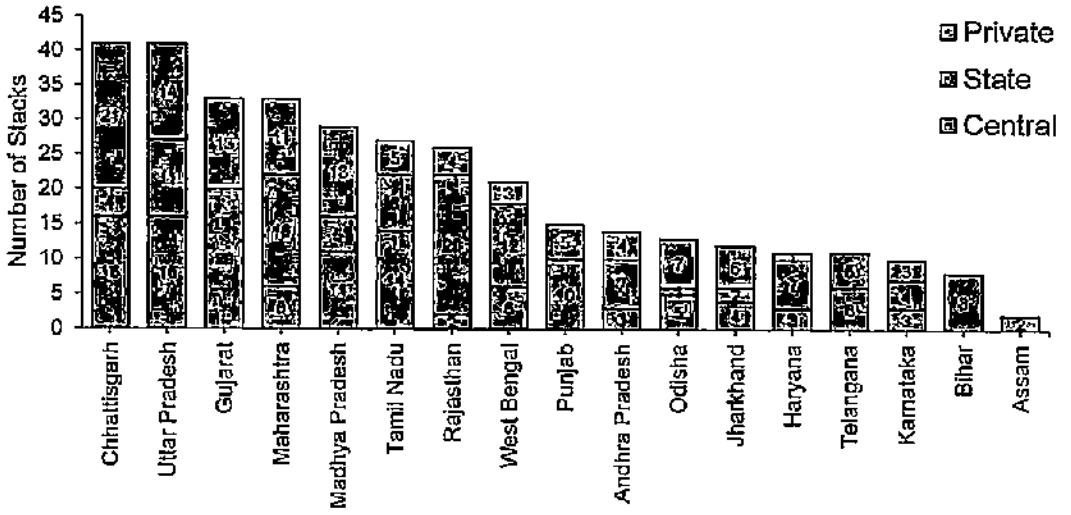


Fig. 3.1: Authority-wise distribution of collected OCEMS data for each state

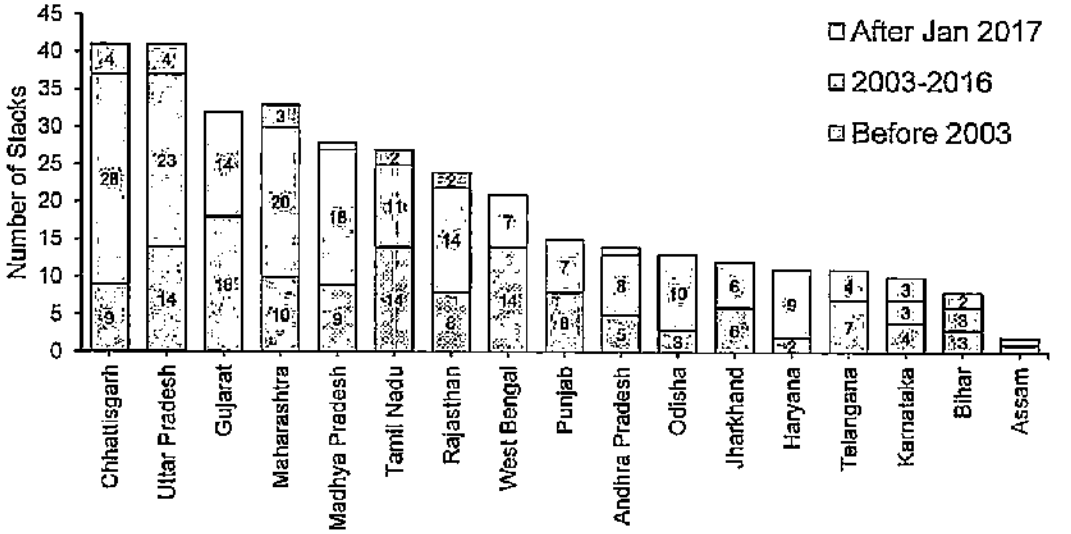


Fig. 3.2: Commissioning year wise distribution of collected OCEMS data for each state

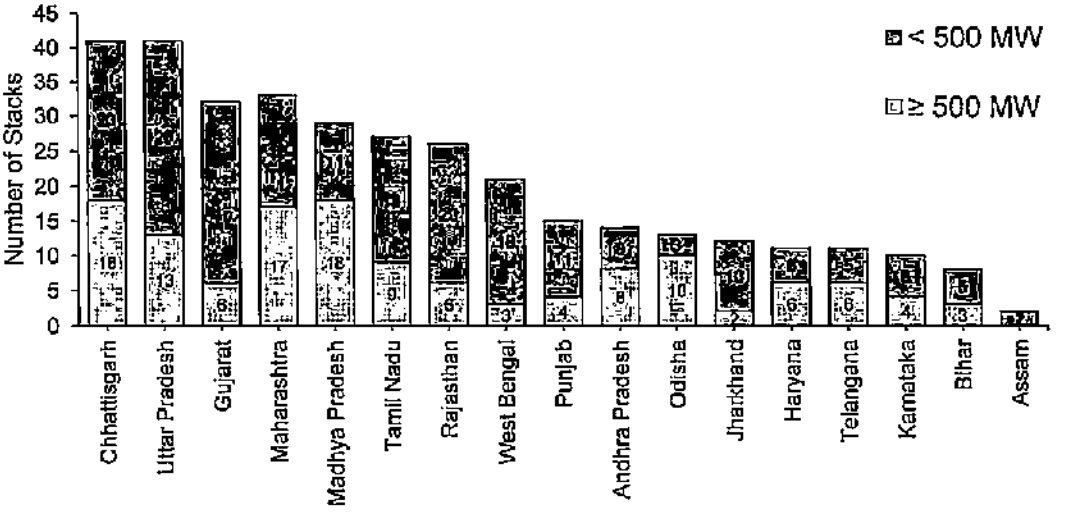


Fig. 3.3: Capacity wise distribution of collected OCEMS data for each state

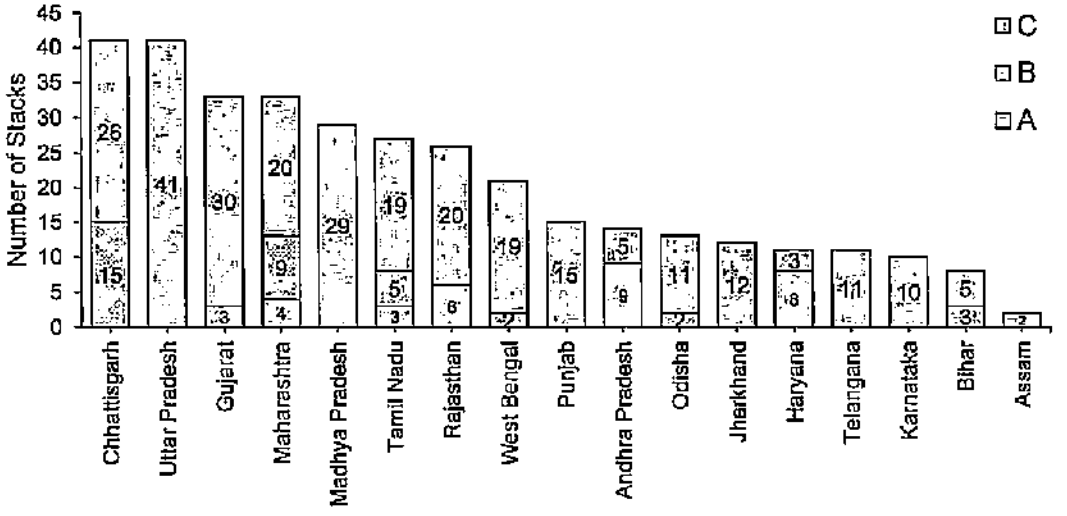


Fig. 3.4: Category wise distribution of collected OCEMS data for each state

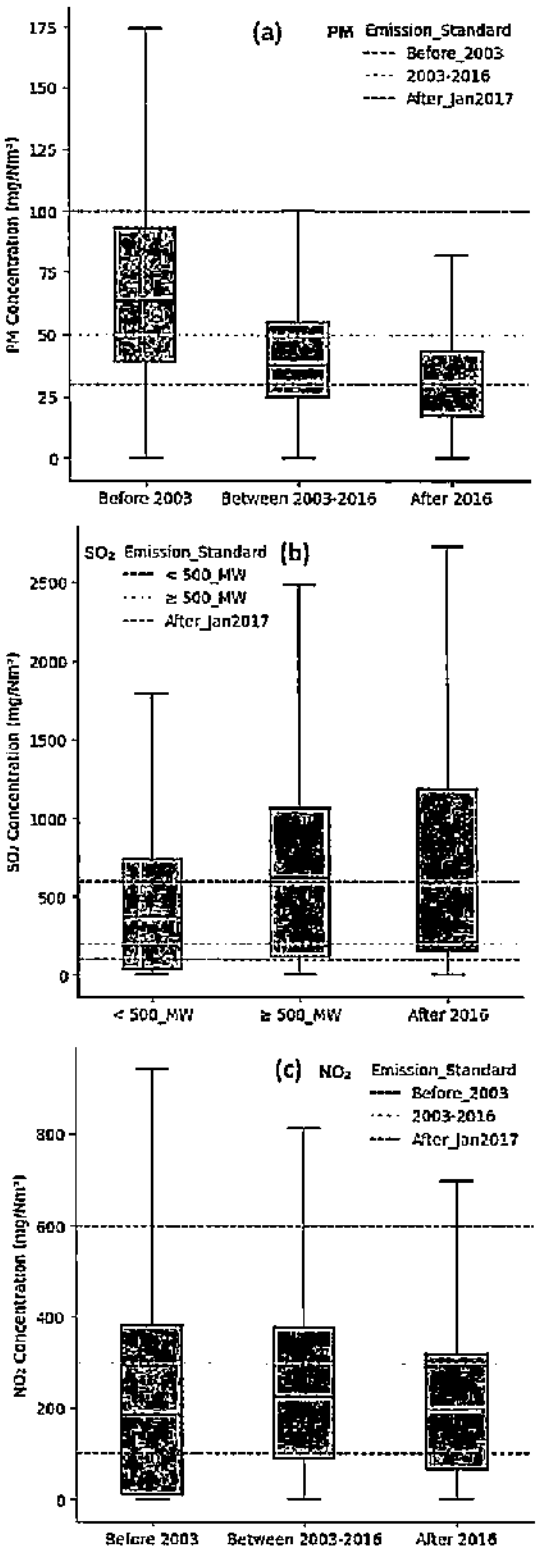


Fig. 3.5: Emission rate of different pollutants from TPS commissioned in three different times (2003, 2016, after 2017).

3.6

CHAPTER 4

Continuous Ambient Air Quality Monitoring

4.1 Introduction

Under the Air (Prevention & Control of Pollution) Act of 1981, the CPCB notified the fourth version of the National Ambient Air Quality Standards (NAAQS) in 2009. There are 12 identified health-based parameters, which are to be measured at the national level and with a view to having data comparison. The methods prescribed in the notification for respective parameters are a combination of both manual methods and continuous online methods. The manual method has some parameters measured by physical properties, while the remaining is by the wet chemical method. The manual methods have the disadvantage of random error due to manual intervention, whereas real-time monitoring may have systematic errors. **Fig. 4.1** shows the air quality parameters monitored under different methods.

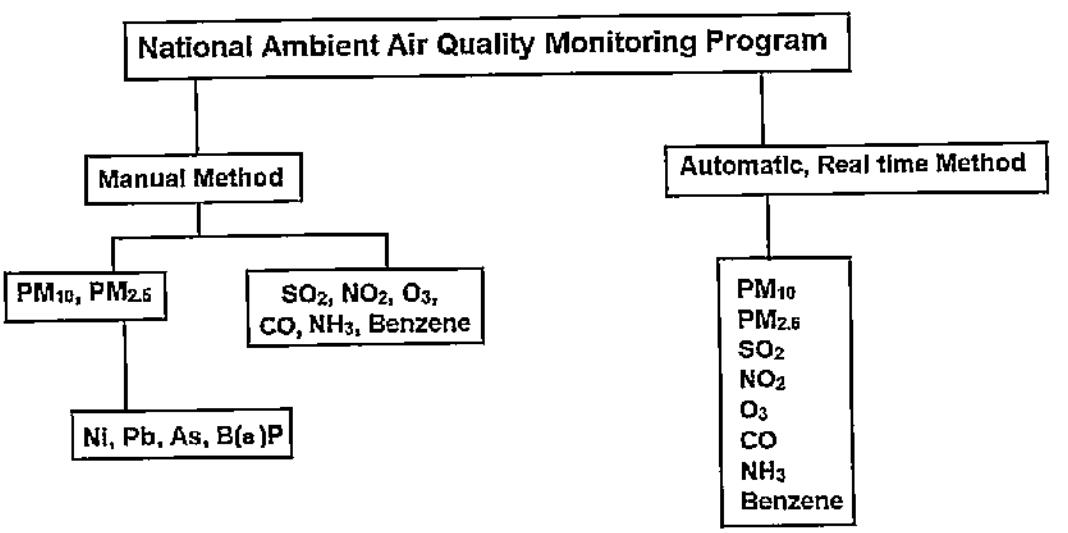


Fig. 4.1: Air quality parameters of Manual and automatic method of monitoring.

Due to the relatively lesser uncertainty of the real-time monitoring system and data availability in a structured format, CAAQMS data is analyzed and presented.

4.2 Data Analysis of CAAQMS Data

4.2.1 Data Collection

Data from the CPCB server were downloaded for varying periods. For major metropolitan cities, data is available from 2016 onwards, whereas for small cities, data from 2018 is available. For north-east states, data from 2021 is available. All available PM10, PM2.5, SO_2 and NO_2 data were downloaded and analyzed. CAAQMS data of 464 stations are shown in **Fig. 4.2.**

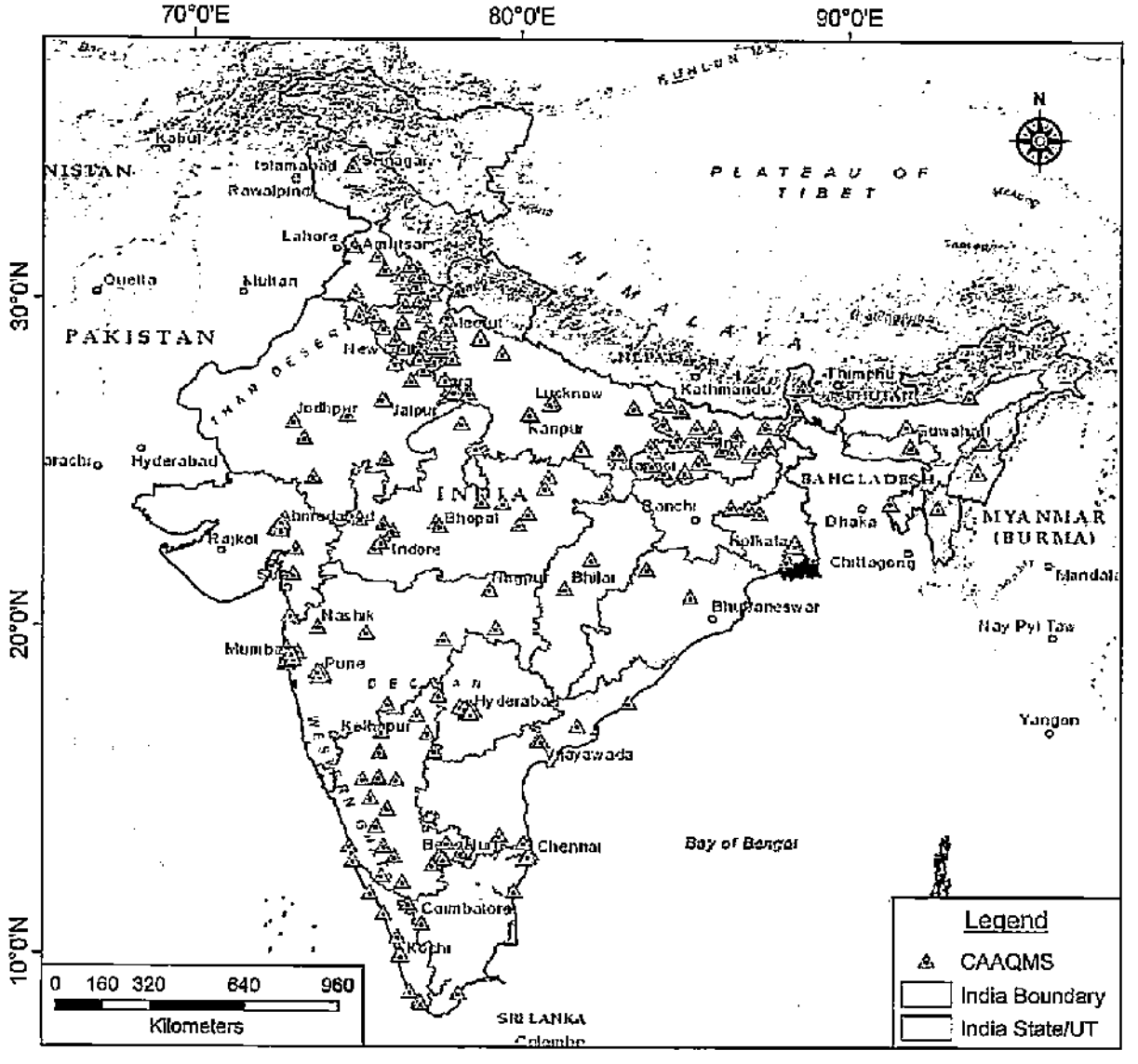


Fig. 4.2: Location of 464 CAAQMS in India.

Based on the data gathered under the NAAQM program, both by manual and automatic real-time methods, the cities that are non-compliant with respect to air quality parameters are identified. These cities are named non-attainment cities and are 132 as of today. **Fig. 4.3** shows the location of all such non-attainment cities.

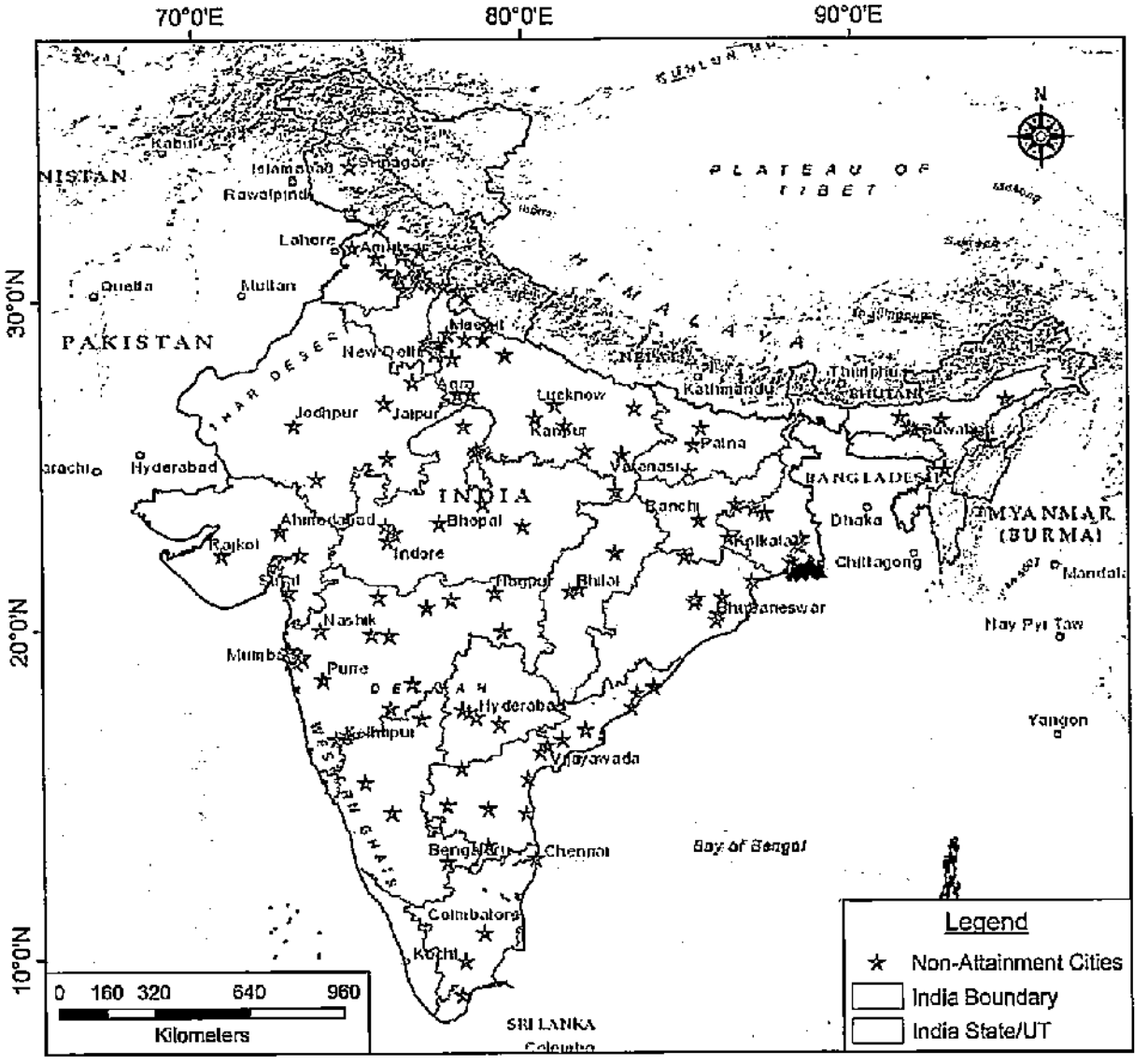


Fig. 4.3: Location of 132 non-attainment cities in India.

4.2.2 Data Summary

Table 4.1 presents the number of cities with CAAQMS and the number of CAAQMS in each state. In 238 cities in India, a total of 464 CAAQMS are installed. The list of CAAQMS is given in **Annexure B1**, and the pictorial presentation is in **Annexure B2**.

Table 4.1: Number of CAAQMS in different States.

No.	State / UT	Number of Cities having CAAQMS	Number of CAAQMS in the State / UT
	States		
1	Andhra Pradesh	8	10
2	Arunachal Pradesh	1	1
3	Assam	6	9
4	Bihar	25	35
5	Chhattisgarh	8	13
6	Gujarat	7	17
7	Haryana	23	30
8	Himachal Pradesh	1	1
9	Jharkhand	1	1
10	Karnataka	26	39
11	Kerala	8	9
12	Madhya Pradesh	14	42
13	Maharashtra	10	41
14	Manipur	1	2
15	Meghalaya	1	2
16	Mizoram	1	1
17	Nagaland	1	1
18	Odisha	9	12
19	Punjab	8	8
20	Rajasthan	27	31
21	Sikkim	1	1
22	Tamil Nadu	16	26
23	Telangana	1	14
24	Tripura	1	2
25	Uttar Pradesh	19	56
26	Uttarakhand	3	3
27	West Bengal	6	13
	Total	**233**	**420**
	Union Territories		
1	Chandigarh (UT)	1	3
2	Delhi (UT)	1	39
3	Jammu and Kashmir (UT)	1	1
4	Puducherry (UT)	1	1
	Total	**4**	**44**
	Overall Total	**238**	**464**

4.3 Data Evaluation

Annexure B2 (68 pages) visually represents large-size data gathered by CAAQMS. Air quality data is visualized by box-whisker plots for each parameter namely PM_{10}, $PM_{2.5}$, SO_2 and NO_2 in the ambient air.

Each box plot has an X-axis of the concentration of pollutant and a Y-axis as the name of the CAAQMS site. The box-whisker shows the minimum, first, second, third quartile and maximum values of air quality parameters. Outliers are excluded from the plot. A red vertical hard line shows the regulatory limit value for each parameter. A notable point in the box plot is that PM values exceed the regulatory limit value at each site. However, SO_2 remain within the regulatory limit value of 80 $\mu g/m^3$ at most of the sites.

Gaseous samples are collected through a tube and analyzed in respective SO_2 and NO_2 analyzers. Measurement of PM_{10} and $PM_{2.5}$ is carried out independently by two separate sampling inlets, as shown in **Fig. 4.4.**

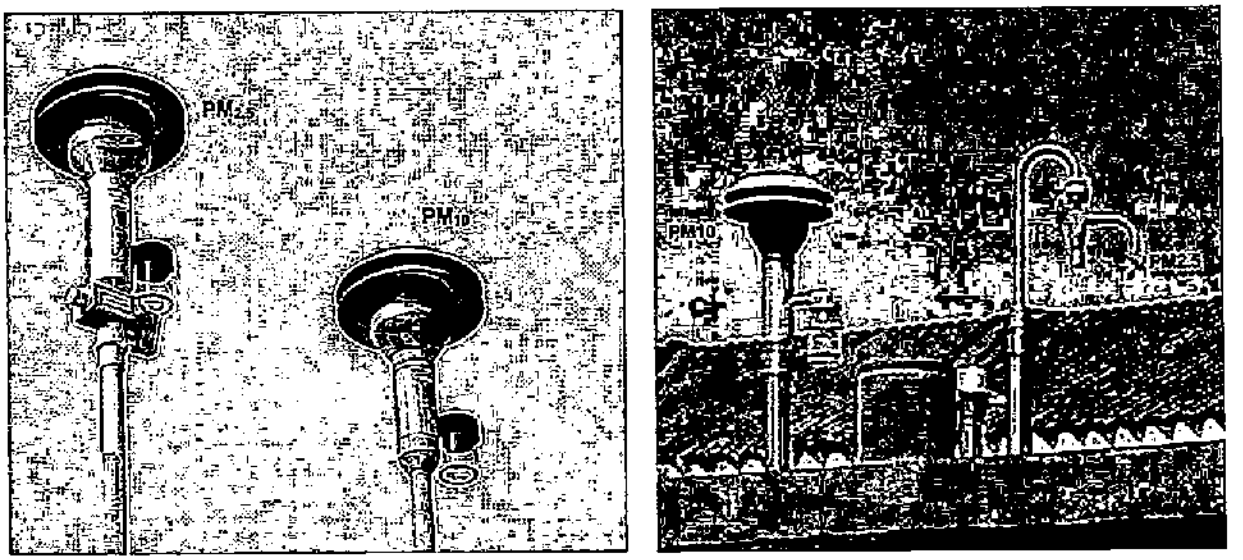


Fig. 4.4: Two independent and separate $PM_{2.5}$ and PM_{10} samplers.

A total of 464 CAAQMS data were analyzed, and the summary of state-wise data in respect of violation of regulatory norms for PM_{10}, $PM_{2.5}$, SO_2 and NO_2 is presented in Table 4.2(a), 4.2(b) 4.2(c), and 4.2(d) respectively. With reference to ambient air SO_2, please refer to **Table 4.2(c)**. It can be seen that three CAAQMS each in Bihar, Gujarat, M.P. and one station each in Maharashtra, Rajasthan, and Tamil Nadu each exceed the regulatory limit of 80 $\mu g/m^3$ of SO_2 that too only one-quarter of the four years data. One station in Maharashtra exceeds SO_2 levels for less than 50% data.

The same state-wise data in tabular format is presented at the National level by combining each state and Union Territories data in Table 4.3(a), 4.3(b), 4.3(c) and 4.3(d) along with its pictorial representation in Fig. 4.5(a), 4.5(b), 4.5(c), and 4.5(d) for PM_{10}, $PM_{2.5}$, SO_2 and NO_2 respectively. It can be seen in **Table 4.3(c)** that for ambient air SO_2, out of 464 stations only 12 CAAQMS station exceed the regulatory limit of 80 $\mu g/m^3$ that too only one quarter of the four years data. SO_2 values at one station exceed for more than 25% and less than 50% data. Number of stations that exceeds regulatory limit value is 3% of the total number of stations.

For the sake of clarity of terms like a "quarter of several years' data", the regulatory guideline violation is graphically explained in **Fig. 4.6**. It can be seen that PM_{10} level does not exceed at 9% CAAQMS stations (top row), whereas at 2% stations (bottom row) exceed the regulatory limit entirely. Similarly for SO_2, 97% of CAAQMS does not violate the regulatory limit value. Only 3% of the CAAQMS exceed the regulatory limit for less than 25% of its data. Stations that violates SO_2 level is given below:

State	CAAQMS Station Name	Violation	Page
Bihar	Collectorate_Gaya, IGSC_Complex_Patna, Muzaffarpur_Collectorate	< 25% Data	B2-8
Gujarat	GIDC_Ankaleshwar, IIPHG_Gandhinagar, Maninagar_Ahmedabad	< 25% Data	B2-20
M.P.	Betul_Collectorate, Mandideep Sector New Industrial Area, Singrauli_Surya Kiran Bhawan Dudhichua	< 25% Data	B2-36
Maharashtra	Karve_Road_Pune_MPCB	< 25% Data	B2-40
Rajasthan	RIICO_Bhiwadi	< 25% Data	B2-49
Tamil Nadu	Sona_College_Salem	< 25% Data	B2-53
Maharashtra	RC_Shivajinagar_Pune_IITM	< 50% Data	B2-40

Since the current ambient air SO_2 level is very low, installation of FGD will not yield any additional advantage of air quality improvement, instead PM reduction should be the target for ambient air quality improvement.

4.4 Compliance Status of CAAQMS

Table 4.2 (a): Compliance status of PM_{10} Monitoring.

State	Number of CAAQMS	No Data	No Violation	Violation of < 25% Data	Violation of >25% & < 50% Data	Violation of >50% & < 75% Data	Violation >75% Data	100% Data Violation
Andhra Pradesh	10	2	1	6	0	1	0	0
Arunachal Pradesh	1	0	0	1	0	0	0	0
Assam	9	2	1	0	3	0	1	2
Bihar	35	0	3	2	2	18	10	0
Chandigarh	3	0	0	0	1	2	0	0
Chhattisgarh	13	4	2	1	0	1	2	3
Delhi	39	1	0	0	0	17	21	0
Gujarat	17	0	0	2	7	7	1	0
Haryana	30	4	0	0	1	20	5	0
Himachal Pradesh	1	0	0	0	0	0	1	0
J & K	1	0	0	0	1	0	0	0
Jharkhand	1	0	0	0	1	0	0	0
Karnataka	39	1	9	18	8	2	1	0
Kerala	9	0	1	8	0	0	0	0
Madhya Pradesh	42	0	3	13	9	15	2	0
Maharashtra	41	1	0	6	20	14	0	0
Manipur	2	0	1	1	0	0	0	0
Meghalaya	2	0	2	0	0	0	0	0
Mizoram	1	0	0	1	0	0	0	0
Nagaland	1	0	0	1	0	0	0	0
Odisha	12	2	0	0	2	1	4	3
Puducherry	1	0	1	0	0	0	0	0
Punjab	8	0	0	0	5	3	0	0
Rajasthan	31	21	0	0	4	4	2	0
Sikkim	1	0	1	0	0	0	0	0
Tamil Nadu	26	3	6	15	1	1	0	0
Telangana	14	1	6	2	4	1	0	0
Tripura	2	0	0	1	1	0	0	0
Uttar Pradesh	56	2	0	1	18	23	12	0
Uttarakhand	3	2	0	0	1	0	0	0
West Bengal	13	0	0	0	10	3	0	0
Total	**464**	**46**	**37**	**79**	**99**	**133**	**62**	**8**

334
522
319

Table 4.2 (b): Compliance status of $PM_{2.5}$ Monitoring.

State	Number of CAAQMS	No Data	No Violation	Violation of < 25% Data	Violation of >25% & < 50% Data	Violation of >50% & < 75% Data	Violation >75% Data	100% Data Violation
Andhra Pradesh	10	2	3	5	0	0	0	0
Arunachal Pradesh	1	0	1	0	0	0	0	0
Assam	9	2	1	0	3	0	1	2
Bihar	35	0	0	3	12	19	1	0
Chandigarh	3	0	0	1	1	1	0	0
Chhattisgarh	13	5	4	0	0	2	2	0
Delhi	39	1	0	0	2	35	1	0
Gujarat	17	0	0	5	10	1	1	0
Haryana	30	0	0	0	13	17	0	0
Himachal Pradesh	1	0	0	0	1	0	0	0
J & K	1	0	0	1	0	0	0	0
Jharkhand	1	0	0	0	0	1	0	0
Karnataka	39	4	9	23	1	2	0	0
Kerala	9	0	4	5	0	0	0	0
Madhya Pradesh	42	1	9	14	16	2	0	0
Maharashtra	41	2	0	14	22	3	0	0
Manipur	2	0	1	1	0	0	0	0
Meghalaya	2	0	2	0	0	0	0	0
Mizoram	1	0	1	0	0	0	0	0
Nagaland	1	0	0	1	0	0	0	0
Odisha	12	2	0	1	1	2	4	2
Puducherry	1	0	1	0	0	0	0	0
Punjab	8	0	2	6	0	0	0	0
Rajasthan	31	21	0	3	5	2	0	0
Sikkim	1	0	1	0	0	0	0	0
Tamil Nadu	26	4	7	15	0	0	0	0
Telangana	14	0	6	5	3	0	0	0
Tripura	2	0	0	0	2	0	0	0
Uttar Pradesh	56	0	0	6	27	23	0	0
Uttarakhand	3	2	0	1	0	0	0	0
West Bengal	13	0	0	1	11	1	0	0
Total	**464**	46	52	111	130	111	10	4

Table 4.2 (c): Compliance status of SO_2 Monitoring.

State	Number of CAAQMS	No Data	No Violation	Violation of < 25% Data	Violation of >25% & < 50% Data	Violation of >50% & < 75% Data	Violation >75% Data	100% Data Violation
Andhra Pradesh	10	2	8	0	0	0	0	0
Arunachal Pradesh	1	0	1	0	0	0	0	0
Assam	9	2	7	0	0	0	0	0
Bihar	35	0	32	3	0	0	0	0
Chandigarh	3	0	3	0	0	0	0	0
Chhattisgarh	13	4	9	0	0	0	0	0
Delhi	39	8	31	0	0	0	0	0
Gujarat	17	0	14	3	0	0	0	0
Haryana	30	1	29	0	0	0	0	0
Himachal Pradesh	1	0	1	0	0	0	0	0
J & K	1	0	1	0	0	0	0	0
Jharkhand	1	0	1	0	0	0	0	0
Karnataka	39	1	38	0	0	0	0	0
Kerala	9	0	9	0	0	0	0	0
M.P.	42	0	39	3	0	0	0	0
Maharashtra	41	9	30	1	1	0	0	0
Manipur	2	0	2	0	0	0	0	0
Meghalaya	2	0	2	0	0	0	0	0
Mizoram	1	0	1	0	0	0	0	0
Nagaland	1	0	1	0	0	0	0	0
Odisha	12	2	10	0	0	0	0	0
Puducherry	1	0	1	0	0	0	0	0
Punjab	8	0	8	0	0	0	0	0
Rajasthan	31	21	9	1	0	0	0	0
Sikkim	1	0	1	0	0	0	0	0
Tamil Nadu	26	3	22	1	0	0	0	0
Telangana	14	0	14	0	0	0	0	0
Tripura	2	0	2	0	0	0	0	0
Uttar Pradesh	56	2	54	0	0	0	0	0
Uttarakhand	3	2	1	0	0	0	0	0
West Bengal	13	0	13	0	0	0	0	0
Total	**464**	**57**	**394**	**12**	**1**	**0**	**0**	**0**

Table 4.2 (d): Compliance status of NO_2 Monitoring.

State	Number of CAAQMS	No Data	No Violation	Violation of < 25% Data	Violation of >25% & < 50% Data	Violation of >50% & < 75% Data	Violation >75% Data	100% Data Violation
Andhra Pradesh	10	2	8	0	0	0	0	0
Arunachal Pradesh	1	0	1	0	0	0	0	0
Assam	9	2	7	0	0	0	0	0
Bihar	35	0	17	14	4	0	0	0
Chandigarh	3	0	1	2	0	0	0	0
Chhattisgarh	13	4	8	0	0	0	0	1
Delhi	39	0	12	26	1	0	0	0
Gujarat	17	0	14	2	1	0	0	0
Haryana	30	0	22	7	1	0	0	0
Himachal Pradesh	1	0	1	0	0	0	0	0
J & K	1	0	1	0	0	0	0	0
Jharkhand	1	0	1	0	0	0	0	0
Karnataka	39	1	37	1	0	0	0	0
Kerala	9	0	9	0	0	0	0	0
Madhya Pradesh	42	3	34	5	0	0	0	0
Maharashtra	41	2	27	12	0	0	0	0
Manipur	2	0	2	0	0	0	0	0
Meghalaya	2	0	2	0	0	0	0	0
Mizoram	1	0	1	0	0	0	0	0
Nagaland	1	0	1	0	0	0	0	0
Odisha	12	2	9	1	0	0	0	0
Puducherry	1	0	1	0	0	0	0	0
Punjab	8	0	8	0	0	0	0	0
Rajasthan	31	21	7	3	0	0	0	0
Sikkim	1	0	1	0	0	0	0	0
Tamil Nadu	26	3	23	0	0	0	0	0
Telangana	14	0	12	2	0	0	0	0
Tripura	2	0	2	0	0	0	0	0
Uttar Pradesh	56	1	32	21	2	0	0	0
Uttarakhand	3	2	1	0	0	0	0	0
West Bengal	13	0	9	4	0	0	0	0
Total	464	43	311	100	9	0	0	1

Table 4.3 (a): Compliance status of PM_{10} Monitoring.

Compliance Status of PM_{10}	No. of CAAQMS
No Data	46
No Violation	37
Violation of < 25% Data	79
Violation of >25% & < 50% Data	99
Violation of >50% & < 75% Data	133
Violation >75% Data	62
100% Data Violation	8
Total CAAQMS Data	**464**

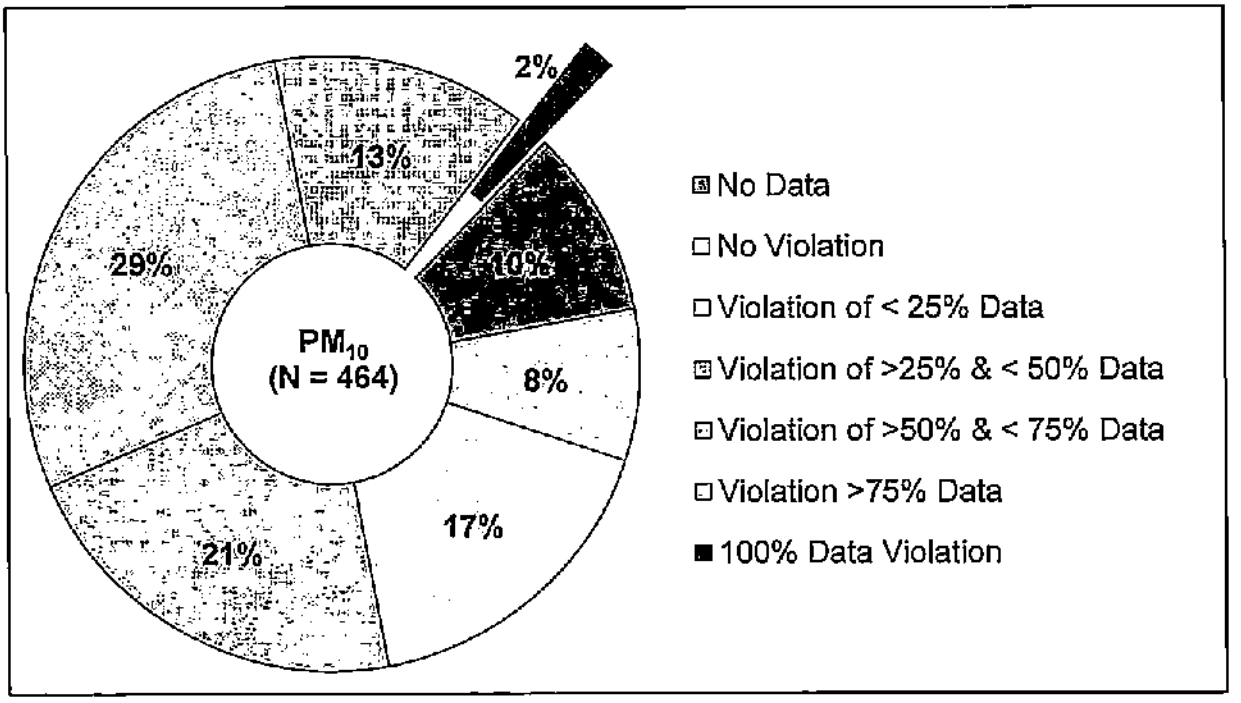


Fig. 4.5(a): Compliance status (%) of ambient air PM_{10} measured by CAQMS.

Table 4.3 (b): Compliance status of $PM_{2.5}$ Monitoring.

Compliance Status of $PM_{2.5}$	No. of CAAQMS
No Data	46
No Violation	52
Violation of < 25% Data	111
Violation of >25% & < 50% Data	130
Violation of >50% & < 75% Data	111
Violation >75% Data	10
100% Data Violation	4
Total CAAQMS Data	**464**

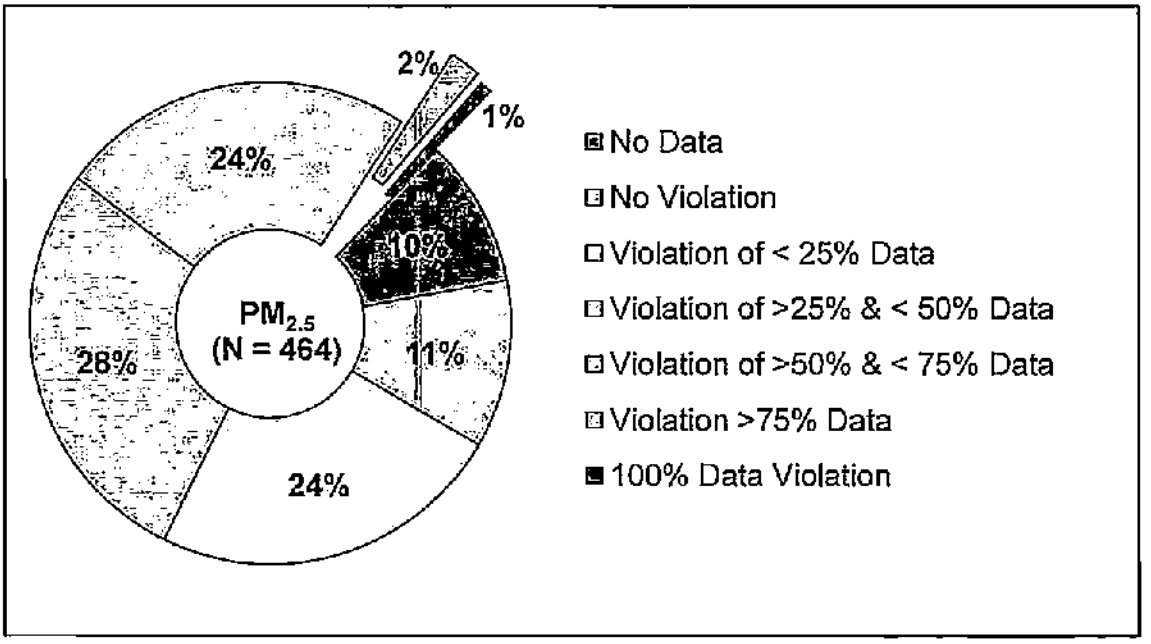


Fig. 4.5(b): Compliance status (%) of ambient air $PM_{2.5}$ measured by CAQMS.

Table 4.3 (c): Compliance status of SO_2 Monitoring.

Compliance Status of SO_2	No. of CAAQMS
No Data	57
No Violation	394
Violation of < 25% Data	**12**
Violation of >25% & < 50% Data	1
Violation of >50% & < 75% Data	0
Violation >75% Data	0
100% Data Violation	0
Total CAAQMS Data	**464**

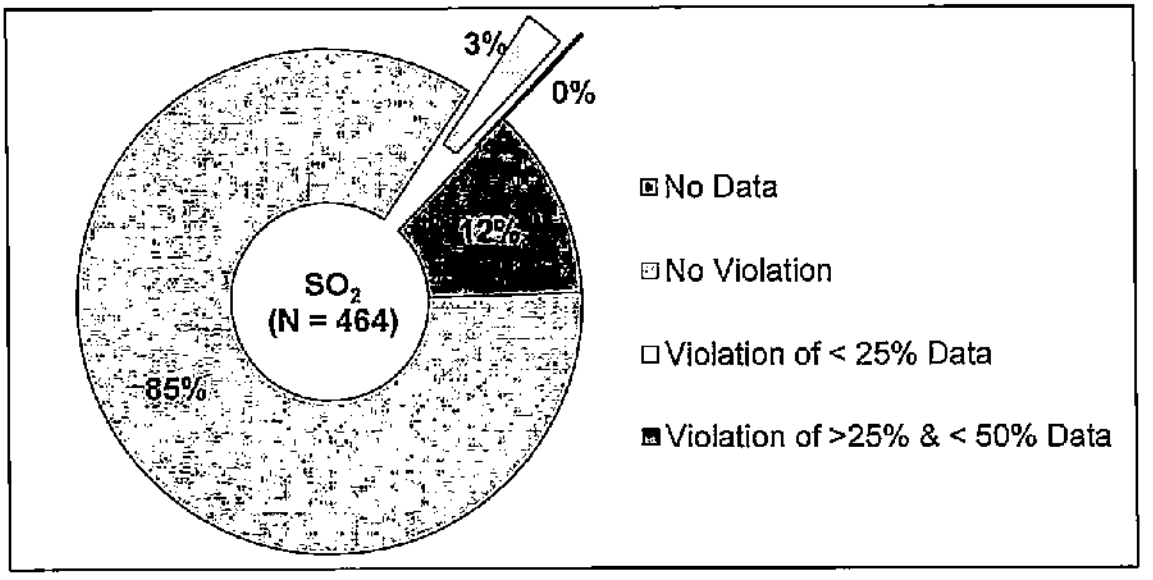


Fig. 4.5(c): Compliance status (%) of ambient air SO_2 as measured by CAQMS.

Table 4.3 (d): Compliance status of NO_2 Monitoring.

Compliance Status of NO_2	No. of CAAQMS
No Data	43
No Violation	311
Violation of < 25% Data	100
Violation of >25% & < 50% Data	9
Violation of >50% & < 75% Data	0
Violation >75% Data	0
100% Data Violation	1
Total CAAQMS Data	**464**

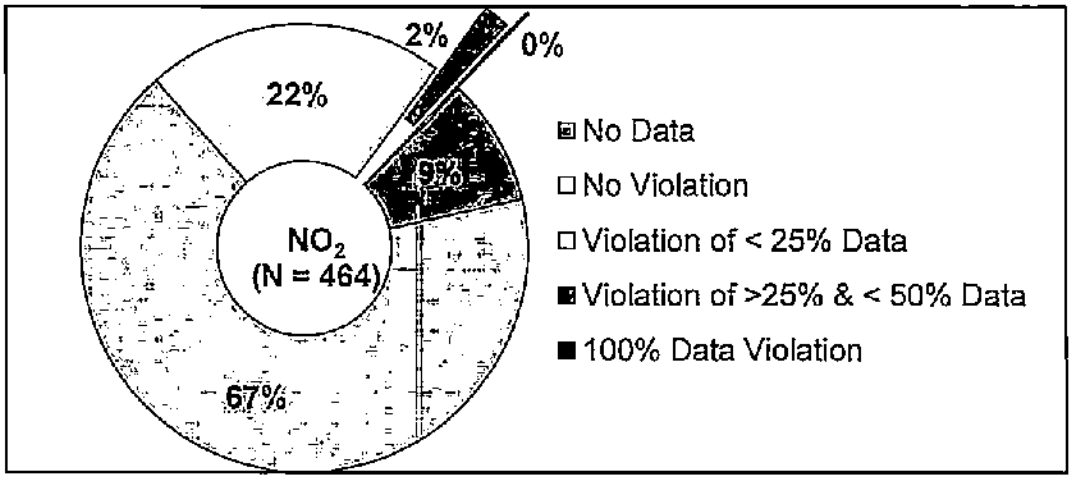
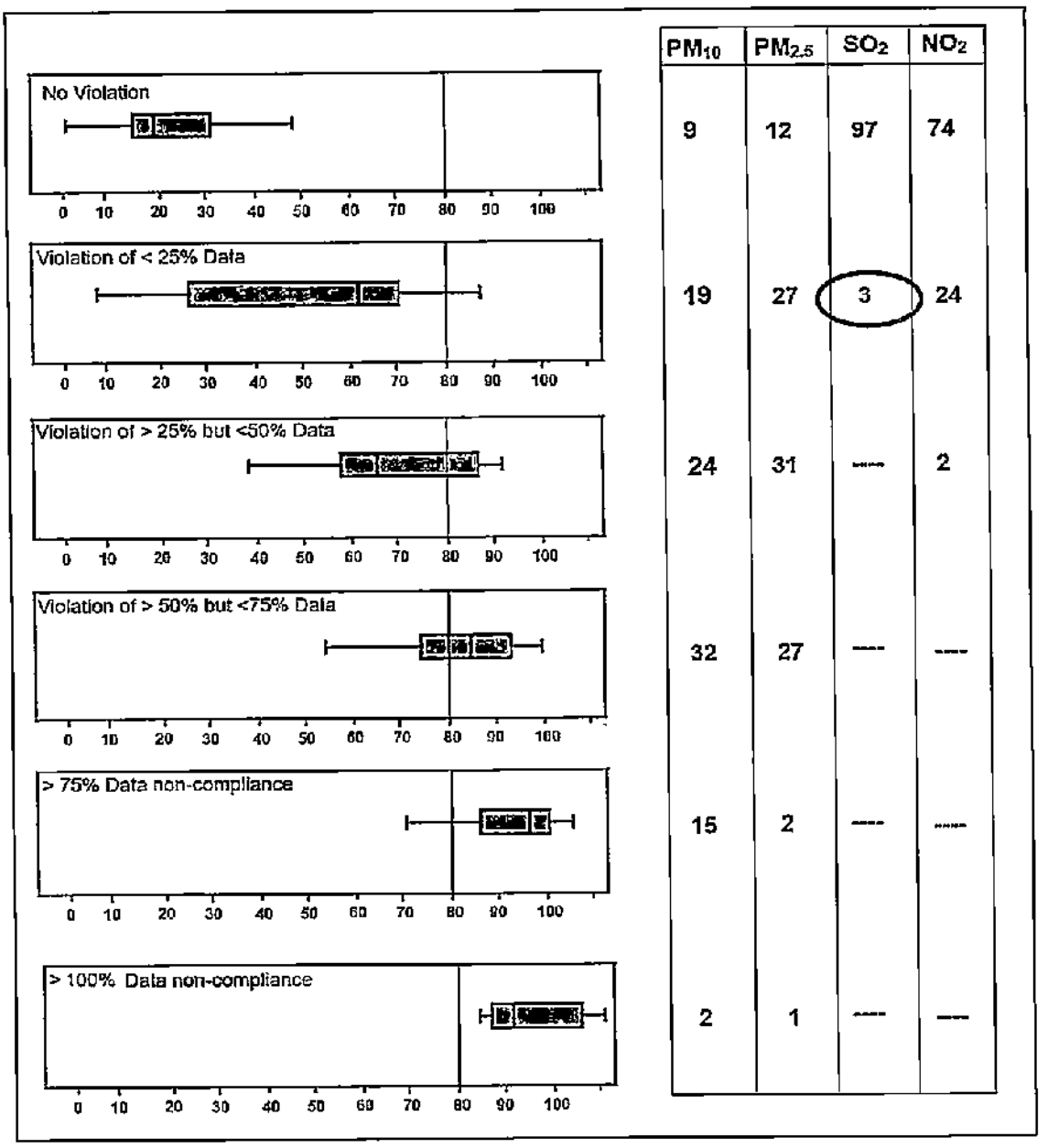


Fig. 4.5(d): Compliance status (%) of ambient air NO_2 measured by CAQMS.



Note: Regulatory compliance limit of 80 μg/m³ for SO_2 is shown for the pictorial explanation of data. For other parameters, the respective regulatory limits should apply. All values given on the right side column are in % of the total CAAQMS station. Since the values are rounded off to the nearest whole number, some station violations may not be shown.

Fig. 4.6: Graphical presentation of compliance (%) status of air pollutants (CAAQMS data).

4.5 Ambient air quality near TPP having FGD installed

Till the time of CAAQMS data collection, FGD was installed in 24 units of TPP having a total generation capacity of 10600 MW. The ambient air quality gathered by CAAQMS surrounding these TPP was also analysed, and it was found that the ambient air average SO_2 level was 19.39 $\mu g/m^3$. CAAQMS operated by NTPC near TPP without FGD were also analysed, and it was found that the average SO_2 level is 14.82 $\mu g/m^3$. This clearly indicates that SO_2 at ground level is not affected by the release from nearby TPP. At the same time, the CAAQMS data of nearby urban areas operated by CPCB / SPCB also does not reach the regulatory limit values (80 μg/m3); instead, it is very low. In effect, it can be concluded that installation of FGD does not lead to improved air quality in terms of SO_2 due to very low emission load.

References

- CPCB: Guidelines for measuring Ambient Air Pollutants, Volume-I; National Ambient Air Quality Series: NAAQMS/36/2012-13.
- CPCB: Guidelines for Real-Time Sampling & Analyses; Volume II.

Chapter 5

Discussion

5.1 Introduction

The emission standards of the new coal-based TPP are regulated via Notification No. S.O. 3305(E) dated 7th December 2015 of MoEF&CC, according to which the emission standard for SO_2 is 100 to 600 mg/Nm^3 based on its year of installation and capacity. The literature search /review does not confirm the availability of any scientific study to arrive at the newly proposed emission standard. Without any background study, the very low emission limit of 100 mg/Nm^3 for Indian coal-based TPP appears to be arbitrary and an attempt to come close to or better than the emission standard of other developed countries (Pl. refer Annexure A3, page A3 - 4). The sulphur content of coals of other countries is much higher compared to Indian coal (<0.5%); therefore, prima facie, there does not seem to be a justified reason for reducing the SO_2 emission limit in Indian coal-based TPP, too, with a short implementation time.

It is worth noting that countries having high sulphur coal are necessarily required to install FGD for sulphur emission reduction. Once FGD is installed, the emission limit can be reduced to 100 mg/Nm^3 as FGD would serve the purpose. However, for low sulphur Indian coal, since the existing SO_2 emission limit does not affect the ground level, as evident from CAAQMS data analysis, lowering the SO_2 emission limit to 100 mg/Nm^3 is like competing with other countries' regulations. For meeting such a lower limit of SO_2 emission, the necessity of FGD arises, which is an extra investment and appears to be only towards competing with other countries.

If the emitted SO_2 after atmospheric dilution gets deposited on water bodies, plants, or land surfaces, it can impact them due to its inherent acidity. It was observed in the past (1960s) that the TPP of the United Kingdom using high sulphur coal led to acid deposition on the water bodies, loss of fish life and forest cover in Scandinavian countries. This led to a historic International meeting on June 5, 1972, at Rio-de-Janeiro, resulting in the birth of the United Nations Environment Program (UNEP) and the declaration of Environment Day (June 5). Reducing the SO_2 emission load of low sulphur coal to such a low level, as proposed in India, in an arbitrary manner, may be due to the fear born out of this incident in the past. This needs to be evaluated in the Indian context, where coal has very low sulphur content.

In the Indian environment eco-system, TPS uses low sulphur coal, leading to lower emissions of SO_2, but any negative environmental impact due to its deposition on plants, soil, and water bodies has not been noticed. All ground-level measurements show a very low level of SO_2. A question that arises is, do these environmental components (land plant, water body) have sufficient buffering capacity to neutralize the deposited acidic Sulphur to the extent that any scientific study or visible environmental impairment does not notice the impact of SO_2 release?

Comparing the coal characteristics of different countries, it can be seen that coal with GCV (≥5000 Kcal/kg), low ash (6 - 10 %) and high sulphur content (≥1.0 %), the priority goes towards limiting the emission of SO_2. In the same context, Indian coal has lower GCV (3400 Kcal/kg), high ash (>42%) and low sulphur (<0.5%), so the

priority should be to primarily reduce PM emission instead of SO_2. The existing ESP having a large collecting plate area (9 field ESP) controls PM, which can be further polished by using a wet scrubber. Wet scrubbers would also reduce SO_2 to some extent, beyond what is emitted today, besides reducing PM emissions. An argument put forth is wet scrubber would increase the acidity of wastewater, which may corrode the leading metallic components. At this point neutralizing potential of fly ash should also be considered.

TPPs have fly ash ponds where bottom ash slurry is disposed. The wastewater generated in the wet scrubber is also likely to be disposed of in the same ash pond. The increase in acidity of ash pond water to the extent that it damages the environment needs to be studied. If such a need arises, offline treatment for neutralizing wet scrubber wastewater is also an option. Without these field-level studies, directly employing FGD to reduce SO2 is a costlier option. The option of using a wet scrubber as a polishing unit for PM emission control should be with caution of the availability of water and its sustainable operation. There were instances in the past when TPPs (CSTPS, Chandrapur) were shut down during summer due to a shortage of water.

In the earlier Chapters (3 & 4), an analysis of measurements done by OCEMS and CAAQMS is presented. This includes visualization of large-size data, and comparison of regulatory limit values with second and third-quartile values for assessment of compliance. In this chapter, results and outcomes of past studies, including data gathered under other projects by CSIR-NEERI, reports of International agencies, other reputed Indian institutes, etc., are discussed.

5.2 Monitoring of SO_2 in India

Chapter 4 provides a detailed analysis of SO_2 measured by CAAQMS for 464 sites. The measurement is carried out by auto-samplers and analysers without much manual intervention like sample handling, sample processing and analysis. Therefore, it can be believed that the SO_2 data generated by CAAQMS is relatively less biased. Most of the data shows the SO_2 values below the regulatory limit value of 80 $\mu g/m^3$. The obvious question is, "Is there any study site apart from the CAAQMS location where the SO_2 level was observed to be relatively high"? CSIR-NEERI is engaged in SO_2 measurement under different industrial and urban area projects. Major among them is air quality monitoring under source apportionment city at Delhi (2007-08); air quality monitoring around Lalitpur Power Generation Company Limited, (LPGCL) Lalitpur, U.P.; air quality monitoring near pit head thermal power station of Singrauli Coal mine are of Northern coalfields limited, Singrauli (M.P.). National Ambient Air Quality Monitoring (NAAQM) Program is in six cities, namely Delhi, Mumbai, Kolkata, Chennai, Hyderabad, and Nagpur. Some short-term studies were also carried out using sulphur-bearing copper ore processing and imported coal. The outcome of some of the studies is as follows.

5.2.1 SO_2 monitoring at Delhi under source apportionment study (2007 – 08).

CPCB sponsored a source apportionment study for Delhi (SA Delhi by NEERI, Nagpur) consisting of manual monitoring of SO_2 at ten sites within the Delhi metropolitan city. Different air quality parameters were measured manually at ten sites in three different seasons. **Fig. 5.1** shows the box plot of SO_2 levels at ten sites in

Delhi in three seasons. One of the location's small-scale industries (SSI) showed relatively high levels of SO_2 during two seasons. During summer, the SO_2 levels were very low, which may be attributed to either wind direction reversal or relatively higher summer mixing height and wind velocity, leading to higher ventilation and thus dilution. However, during post-monsoon and winter, the SO_2 levels in the SSI area were very high. The emission inventory study revealed that small-scale industries in the region use unspecified fuels, high calorific value coal of high sulphur content and the emissions was released at a very low elevation of 30 m. Subsequent to the SA-Delhi study, the industries were shifted out of the SSI area in view of the pollution problem. In the present scenario, analysis of CAAQMS observed SO_2 levels at 39 stations at Delhi are below 30 $\mu g/m^3$ (pl. refer to Annexure B2, page B2-17).

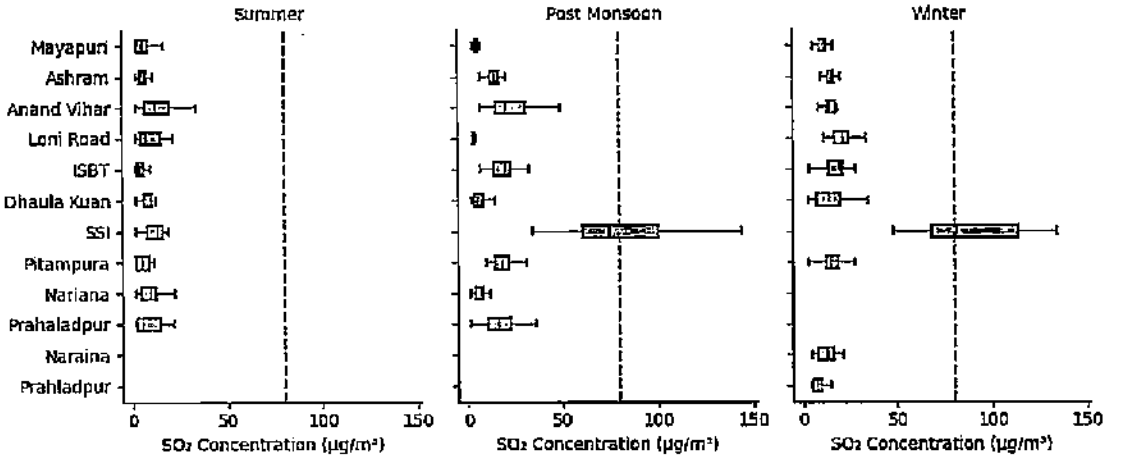


Fig. 5.1: Box plot of manual monitoring of SO_2 at Delhi (2007- 08).

5.2.2 Ambient air SO_2 levels at remotely located TPP

In order to understand the ambient air quality at a site not affected by any other source except a coal-based thermal power plant, the data of a coal-based thermal power plant at Lalitpur, U.P., was chosen. The TPP at Lalitpur Power Generation Company Limited (LPGCL), Tehsil Mahroni, Lalitpur, Uttar Pradesh, is surrounded by green cover within 25 km. This study site has a peculiarity that within a radius of 25 km, there is no activity other than coal-based TPP of 1800 MW (3 x 600 MW). Therefore, SO_2 observed at this site can be attributed only to TPP emission and not to any other activity. The plant has three boilers installed with super-critical technology. The total indigenous coal consumption is 8.51 MMTPA. An electrostatic precipitator of more than 99.9% efficiency is provided to control particulate matter to below 50 mg/Nm^3. The emission is vented through a single tri-flue stack of 275 m in height. Ambient air particulate matter (PM_{10} and $PM_{2.5}$) and SO_2 were measured throughout the year at four sites: Chiglaua, Mirchwara, R & D Yard and Vishnu Mandir.

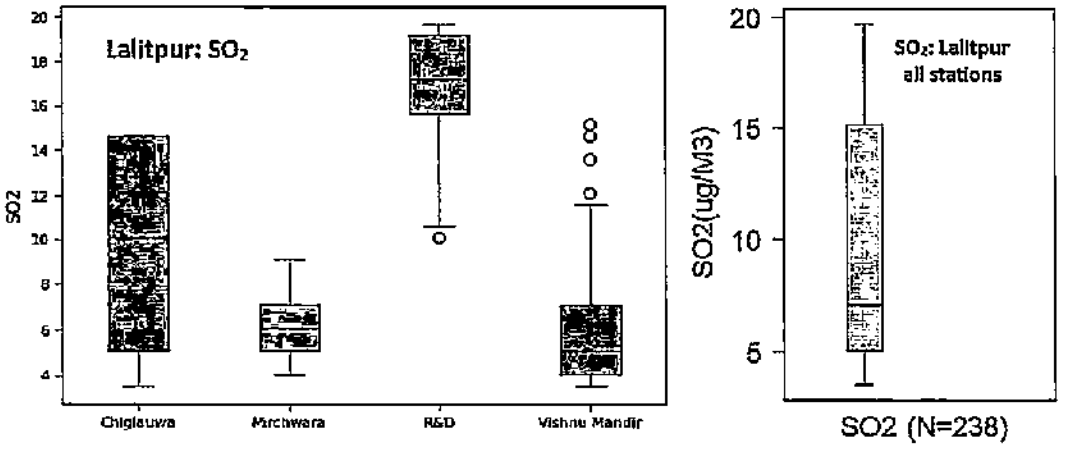


Fig. 5.2: SO_2 at Lalitpur, U.P. during year-long monitoring (2022 - 23).

Fig. 5.2 shows the measured SO_2 at four stations. There are 238 sample data to exhibit the ambient air SO_2 levels. It can be seen that most of the time the measured SO_2 levels are very low and is below 20 $\mu g/m^3$ as seen in the box plot shown on the right side. This gives two points to ponder:

i) The released SO_2 undergoes a chemical transformation in the atmosphere and is, therefore, not found at ground level. This goes against the assumption of the conservative nature of SO_2, which is assumed in the source dispersion modelling. Gaussian-based model assumes that particulate matter, SO_2 and NOx are conservative in nature. These are expected to be found as per the conservative dispersion model following Pasquill-Gifford-Turner-derived dispersion coefficient-based models.

The Prairie Grass experiment is a classic example of an experiment conducted during July-August 1956. For that experiment, a known amount of tracer SO_2 was released from a height of 46 cm above ground level and the concentration of SO_2 was measured on arcs at distances of 50 m, 100 m, 200 m, 400 m and 800 m. This experiment formed the basis of the subsequently developed source dispersion model with a very important assumption that the chemical species are conservative and do not undergo a chemical transformation in the atmosphere in a short distance and time.

In the case of the release of pollutants from a height of 275 m in TPP, even if particulate matter is assumed to be conservative, the gaseous species can undergo chemical transformation under the influence of strong solar insolation at elevated levels, by reacting with other chemical species of flue gas or of atmosphere, moisture etc. These reaction products are not included in the mathematical models that we are using for regulatory compliance, such as environmental impact assessment (EIA) studies.

ii) If the released SO_2 undergoes a chemical transformation in the atmosphere, it can be found as a secondary sulphate ion in the particulate matter. As on today, we do not have air monitoring network at National level to measure particulate matter bound sulphate ion. The National Ambient Air Quality Monitoring (NAQM) program does not include sulphate as a parameter for analysis.

5.3 Conversion of SO_2 to Sulphate (Eatough et al., 1994)

Gaseous emissions initially get diluted, followed by their deposition in water bodies, plants, land or chemical transformation in the atmosphere. One of the chemical transformations is to form salt, for example, ammonium sulphate, which may appear in particulate form. The formation of particulate sulphate is suggested to occur by three types of reactions:

- gas-phase homogeneous reactions,
- aqueous-phase reactions, and
- heterogeneous reactions on the surface of solids.

5.3.1 Gas-phase Homogeneous Reaction

The gas phase reaction requires hydroxyl radical, which is formed in the atmosphere from several sources like NO_2, HONO and H_2O_2. Photolysis reaction as follows:

$$NO_2 + h\nu \rightarrow NO + O$$
$$O + O_2 \rightarrow O_3$$
$$O_3 + h\nu \rightarrow O_2 + O$$
$$O + H_2O \rightarrow 2OH$$

$$HONO + h\nu \rightarrow OH + NO$$

$$H_2O_2 + h\nu \rightarrow 2OH$$

Under high solar insolation, formation of hydroxyl ion is also increased, leading to the above reaction.

$$OH + SO_2 \rightarrow HOSO_2$$
$$HOSO_2 + O_2 \rightarrow SO_3 + HO_2$$
$$SO_3 + H_2O \rightarrow H_2SO_4$$

Since the above reaction is a function of solar radiation, the transformation rate from SO_2 to Sulphate will be higher as we move from a higher latitude to the equator. Besides this, studies also report that during daytime, the reaction rate is high compared to nighttime due to relatively higher solar radiation. On the same line, the conversion rate in arid western United States and humid eastern United States is modelled, which shows the impact of solar radiation and humidity. India being closer to the equator, with relatively high solar radiation, the conversion of SO_2 to sulphate is expected at a higher rate.

5.3.2 Aqueous-Phase reaction

If water droplets are present in the atmosphere, particulate sulphate formation is faster than that of the gas phase reaction. Gaseous SO_2 can be adsorbed into water droplets as per:

$SO_2(g) <=> SO_2(aq)$,
$SO_2(aq) <=> HSO_3^- + H^+$
$HSO_3^- <=> SO_3^{=} + H^+$

Ozone and SO_2 are both moderately soluble in water, while hydrogen peroxide is very soluble. The high conversion rate of SO_2 to sulphate sometimes encountered in fog and clouds can be attributed to the high solubility of H_2O_2 in water.

5.3.3 Heterogenous reactions on solid surfaces

Gaseous SO_2 conversion also occurs by adsorption on the surfaces of solid graphite, soot particles, fly ash, dust, MgO, Fe_2O_3 and MnO_2 and subsequent reaction with oxidants in the particle. The presence of co-pollutants and relative humidity also affects the rate of reaction. When an aqueous film covers the particles, oxidation is enhanced.

The relative contribution of heterogeneous reactions on surfaces is generally considered to be minor compared to hydroxyl radical and aqueous H_2O_2 oxidation. However, under certain circumstances, i.e., plumes with high particle density (>100 $\mu g/m^3$), heterogeneous reactions could be important. In Indian TPS, the emission of SO_2 is accompanied by a large amount of PM, and therefore, most of the sulphate ion should be found in PM.

5.4 Chemical sulphur of PM in different studies

Analysis of ambient air SO_2 data all over Indian cities and area close to TPP does not suggest that emitted SO_2 is impacting at ground level. An alternate hypothesis is that the gaseous SO_2 is converted to particulate sulphate ($SO_4^{=}$). If gaseous SO_2 undergoes atmospheric transformation to secondary particulate matter, it should be found as sulphur and sulphate ion. In order to have an assessment of chemical sulphur in PM, the data generated under other studies is presented here. These studies are for remote area TPP, which is not affected by any other source (Lalitpur TPP) and source apportionment study at pit-head TPP (Northern Coalfields Limited, Singrauli).

Elemental sulphur is measured using the energy-dispersive X-ray fluorescence (ED-XRF) technique. CSIR-NEERI, Nagpur is using this technique to measure sulphur in particulate matter collected on poly tetra fluoro ethylene (PTFE) filters under different studies in Indian urban centres. After the measurement of sulphur by non-destructive technique, the same PM collected on the PTFE filter is extracted in demineralized water using a sonicator, followed by its analysis using an Ion Chromatograph (IC).

5.4.1 PM study at remote area TPP

CSIR-NEERI collected samples at Lalitpur Power Generation Company Limited (LPGCL), Lalitpur, U.P., in which ambient air particulate matter and its sulphur and sulphate content were measured to understand the presence due to atmospheric chemical transformation.

Fig. 5.3 shows the elemental sulphur and sulphate content of ambient air $PM_{2.5}$ and PM_{10} sampled on a PTFE filter over a year. The molecular weight relation of sulphur and sulphate ions is shown below. If PM contains 32 mass units of elemental sulphur, the sulphate content should be 96 mass units. In other words, one unit of elemental sulphur would show three units of sulphate ion.

$$\begin{array}{ccc} S & \rightarrow & SO_4^{=} \\ 32 & & 96 \end{array}$$

A somewhat similar relationship is found between the two in the box plot (Fig. 5.3). However, there is a gap in correlating gaseous SO_2 with elemental sulphur and sulphate of PM. This is further explained in another study carried out in the pit head thermal power station area.

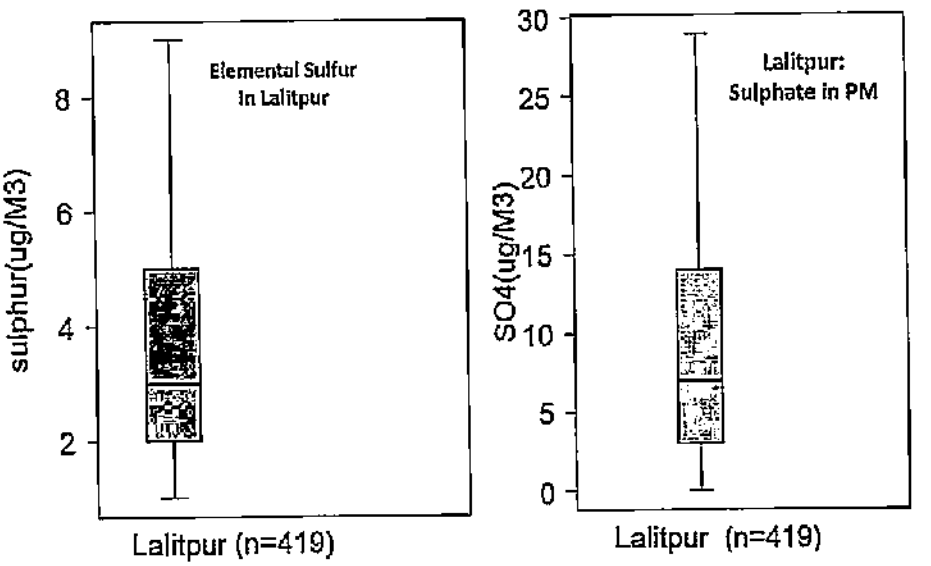


Fig. 5.3: Sulphate and Elemental Sulphur in PM at Lalitpur during year-long monitoring (2022 - 23).

5.4.2 Source apportionment study at Pit Head Thermal Power Plant area

A source apportionment study was carried in the pit head thermal power station area of the Singrauli coal mine area (**Fig. 5.4**). There are ten coal mines of Northern Coalfield Limited in operation. A large number of thermal power stations are in operation due to their shorter transport distance from coal mines.

All the TPS together have some 42 stacks bellowing out smoke. **Fig. 5.5** shows the stacks in the pit head. It can be seen from the opacity of emission smoke that most of them emit air pollutants at a higher rate than the permissible regulatory limit. **Fig. 5.6** shows the location of the TPS stack close to the coal mine in the street map.

The study involves the sampling of particulate matter (PM10, PM2.5) in the ambient air at the top of the mine and also from the ground level. It may be noted that

the top surface of the coal mine overburden is at the level of the stack top. Schematically, this is shown in **Fig. 5.7**. The objective of sampling at the mine top and ground level is to differentiate the impact of emission at different elevations. Collected PM_{10} and $PM_{2.5}$ were analysed for Elements using ED-XRF, Ions using an Ion chromatograph, and Carbon using a DRI Carbon analyser.

Fig. 5.4: Ten open cast coal mines in Singrauli area.

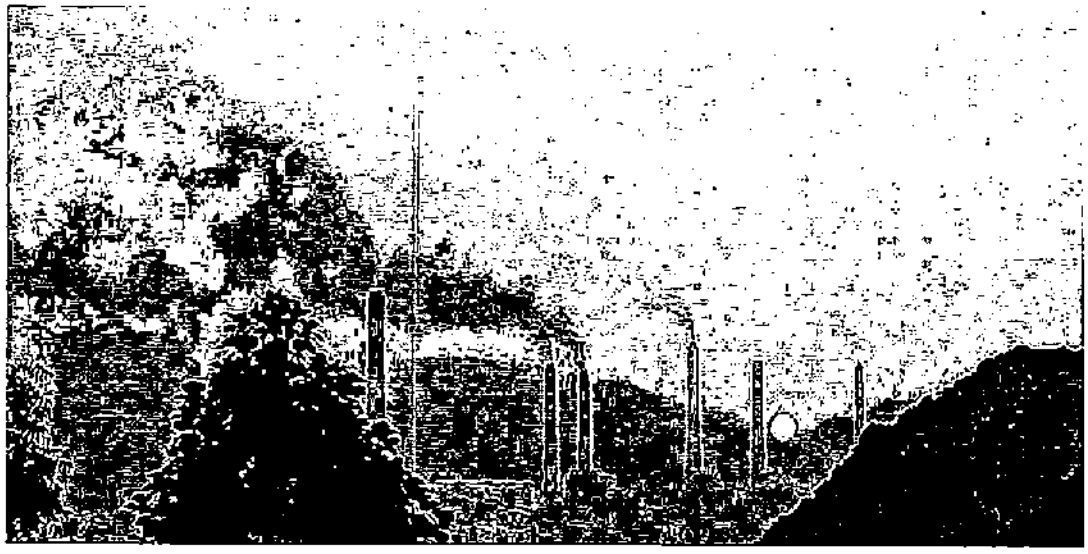


Fig. 5.5: A large number of coal-based TPS in the Singrauli area

Chemical speciation data analysis shows that PM sampled at coal mine tops contains a relatively larger fraction of elements and soluble ions. Elemental content shows the source of PM as over-burden dust and ions, which convert gaseous pollutants (SO_2) to PM in the atmosphere. The carbon fraction in the PM at the top of the coal mine is relatively low, indicating that vehicular emission and coal dust particles are not lifted to higher elevations in the atmosphere.

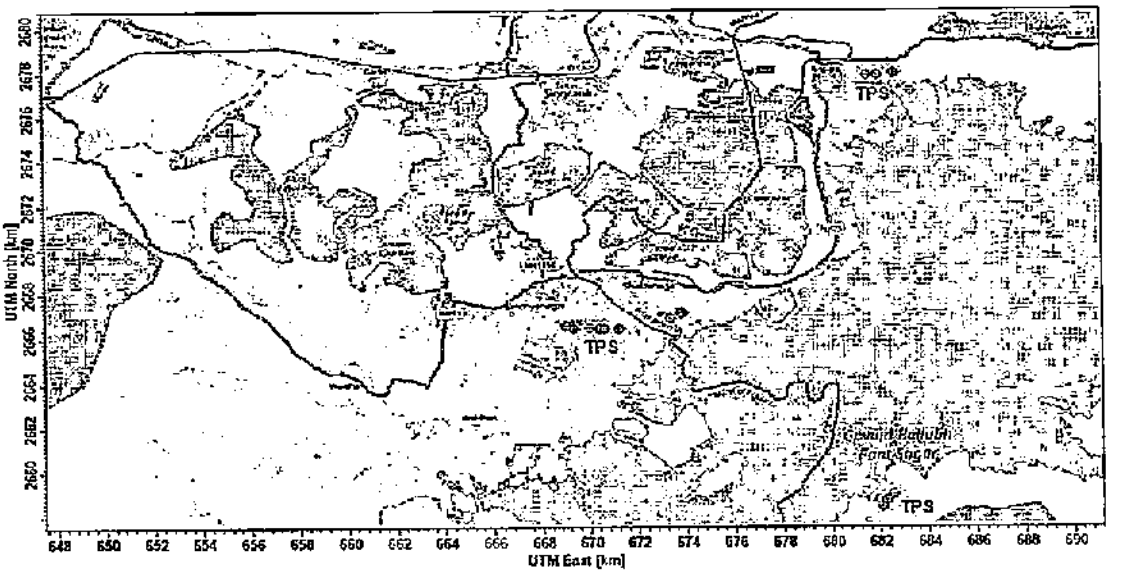


Fig. 5.6: Street map of coal mine and TPS in Singrauli area.

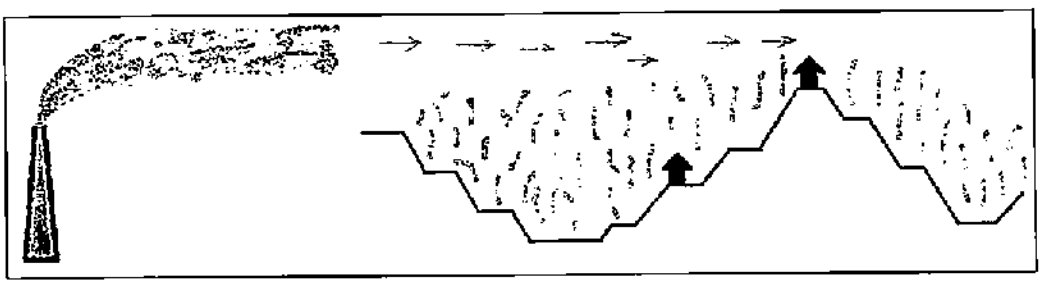


Fig. 5.7: Schematic diagram of TPS emission over coal mine top in Singrauli area.

PM sampled at ground level were also analysed for its chemical species, and it was found that ions were relatively low at ground level PM compared to that at the top of mine. Signatures of coal particles and diesel vehicle emissions were found at ground-level PM samples. The comparison of ground level and mine top PM chemical speciation indicates that a part of SO_2 is converted to particulate sulphate in the atmosphere at higher elevations along the plume path and gets dispersed. The impact can be observed at ground level but in very low concentrations due to dilution.

5.4.3 Sulphur in ambient air particulate matter – Data at National level

Ambient air particulate matter collected over PTFE under different projects in the last three years analysed in ED-XRF is discussed in this section. **Fig. 5.8** shows the box plot of elemental sulphur in the PTFE filter for a three-year study period. The data includes PM collected in Indian cities (5792 PTFE samples) and the Middle East (611 PTFE samples) to provide an unbiased view. For Indian samples, the outlier value of elemental sulphur was below 20 $\mu g/m^3$. After removing the outliers, the highest level is 8 $\mu g/m^3$. The sulphur content of about 611 PM samples collected in the Middle-east

countries shows the highest (excluding outlier) value of 16 µg/m³. The study site in the Middle-Eastern country has a large number of gas-based refineries fitted with flue gas desulphurization (FGD).

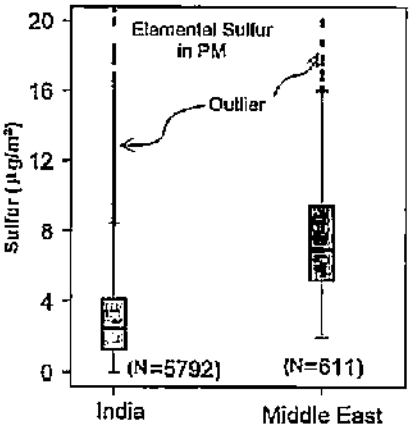
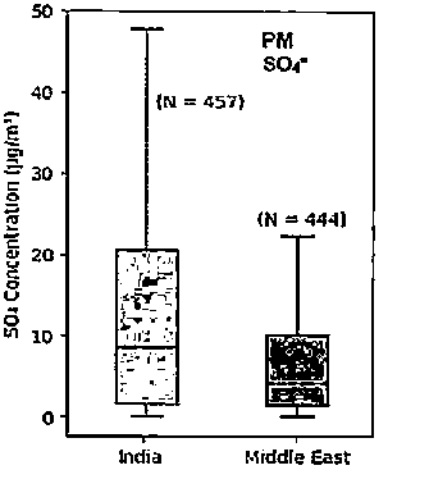


Fig. 5.8: Elemental sulphur in PM collected over PTFE filter during 2021-23.

5.4.4 Sulphate content of PM in Indian studies

In order to extend the scientific discussion on forms of atmospheric sulphur, the obvious question is, "Is there any study which has documented the presence of sulphate ion in particulate matter surrounding coal-based thermal power stations"? If so, "what is the extent of sulphate content in ambient air PM"? Analysis of sulphate in PM collected from different field samples in India and Middle East countries is shown in **Fig. 5.9.**



$S \longrightarrow SO_4^{=}$
32 96

Fig. 5.9: Sulphate content in PM collected over PTFE filters under different studies.

This data consists of ambient air PM collected on PTFE over different cities, urban centres, mining areas, thermal power plants, etc., in the last three years. It can be seen that up to third quartile sulphate ($SO_4^{=}$) in ambient air PM samples is below 20 µg/m³. Based on this information, if a flue gas desulfurization technique is installed to reduce sulphur emission from the thermal power stations, it will reduce a part of it, and the overall reduction in ambient air PM will be at the most 20 µg/m³.

Referring to **Fig. 5.8**, the maximum sulphur content in Indian atmospheric PM is 8 $\mu g/m^3$ for a sample size of 5792. Considering the mass balance, the sulphate content should be three times the sulphur content, i.e. about 24 $\mu g/m^3$.

5.5 Review of Reports on FGD

There are several published reports on the air quality of Indian cities and industrial areas having large size TPS. These reports provide opinions on the need for FGD in those power plants but lacks scientific justification or data analysis on ambient air SO_2 levels. A few of those available reports are discussed in this section.

5.5.1 Air quality around Chandrapur Super Thermal Power Station

An independent research organisation, the Centre for Research on Energy and Clean Air (CREA), established in December 2019 in Helsinki, published a report on the health impacts of Chandrapur Super Thermal Power Station (CSTPS), Maharashtra. One of the key suggestion / opinion / finding of the report is that installation of Flue Gas Desulphurisation (FGD) will reduce SO_2 by 63-92%. Installation of FGD will also be able to reduce Mercury (Hg) emissions by 33%. A similar report is prepared for the states of West Bengal and Tamil Nadu and recommends the same suggestion of installation of FGD for SO_2 emission control.

These recommendations in the report do not appear to be driven by any factual field data analysis. Ambient air SO_2 levels of Chandrapur city is not discussed in such report to warrant installation of FGD. Such reports presents simulation of SO_2 emission with and without FGD using CalPuff Model. The simulation result shows that without FGD, the ground-level concentration of SO_2 will be relatively low. It needs to be worth mentioning that any mathematical simulation of ambient air quality with varying emission rates under similar meteorological condition would always show higher GLC for higher emission rate and vice-versa. Considering the non-conservative nature of gaseous SO_2 that too at very low emission rate, the impact can better be assessed by actual field measurement of ambient SO_2.

For the sake of probing into the Chandrapur city air quality, CAAQMS data for the Chandrapur Khutala area, MIDC is analysed and is presented in Annexure 'B2 - 40'. It can be seen that even the daily maximum value of SO_2 in four years' time (2019 - 22) did not exceed 40 $\mu g/m^3$. The mean of four years daily average value remains below 15 $\mu g/m^3$, which is much below the stipulated regulatory limit for SO_2 (80 $\mu g/m^3$). This clearly indicates that SO_2 emission from the stack top of Chandrapur STPS does not impact ground-level SO_2.

Such report on Chandrapur STPS gives monthly moving average $PM_{2.5}$ and PM_{10} from 2017 to 2021. The variation of ambient air quality is attributed to seasonal variation of micro-meteorology. Variation in meteorology can be better explained by variation of atmospheric mixing height and atmospheric ventilation of the region. For Chandrapur city, hourly mixing height and wind speed for one year is determined using weather research forecast (WRF) model. Atmospheric ventilation is determined by multiplying mixing height (m) with corresponding wind speed (m/s) of that hour. The

monthly variation of ventilation is sufficient to correlate with air quality. **Fig. 5.10** shows the monthly variation of mixing height and ventilation of Chandrapur city.

The variation of ventilation and mixing height should corresponds to the variation of air quality parameters if meteorological conditions are the influencing factor. **Fig. 5.11** and **5.12** shows the monthly variation of PM_{10}, $PM_{2.5}$, SO_2 and NO_2. It can be seen for all the pollutants, monthly variation corresponds to the mixing height and ventilation. During May to September (summer and rain), the air pollution levels lowers due to higher dilution and washout by rain.

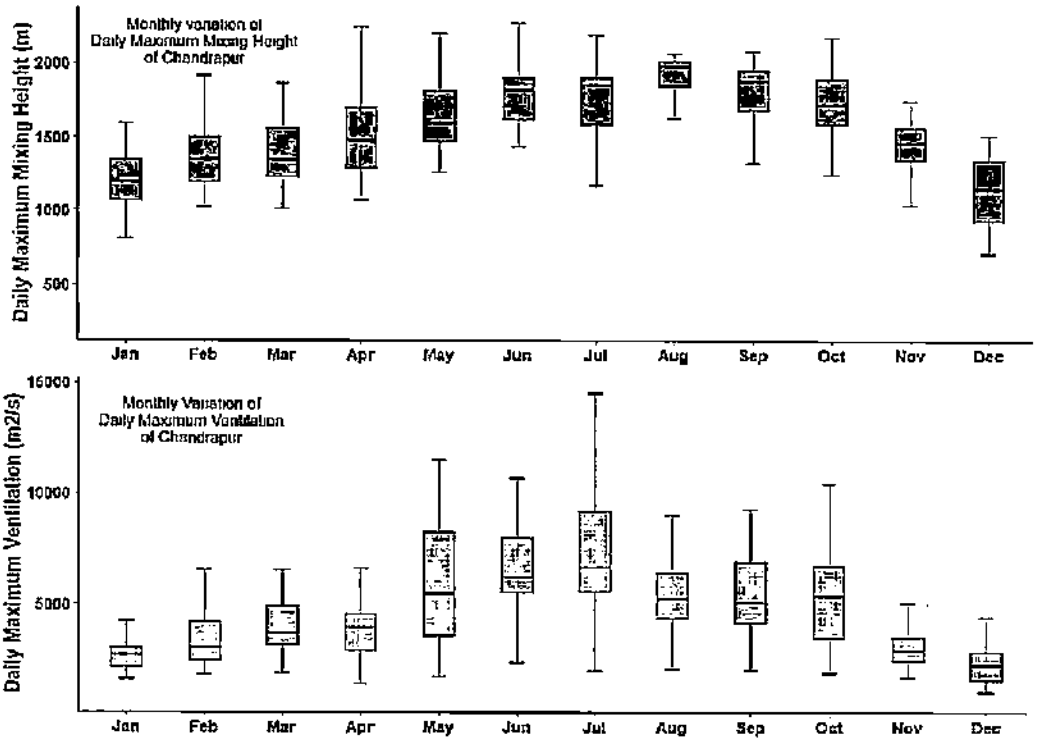


Fig. 5.10: Monthly variation of daily maximum mixing height & ventilation at Chandrapur.

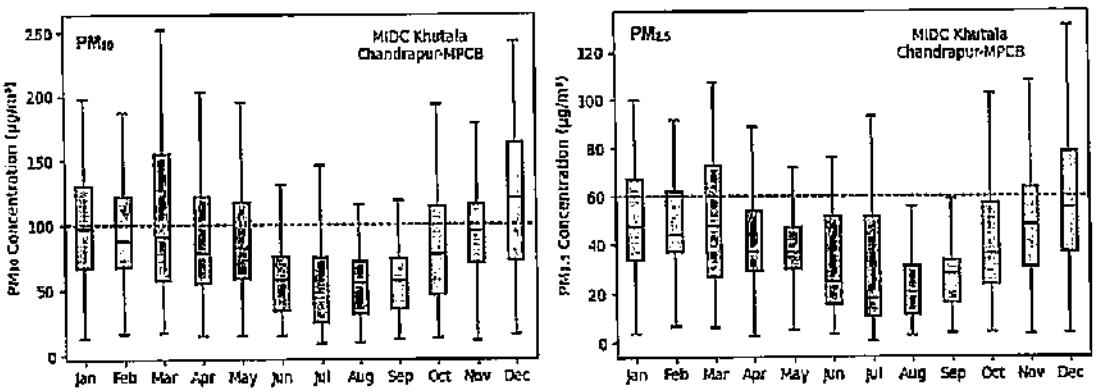


Fig. 5.11: Box plot of monthly variation of daily average PM_{10} and $PM_{2.5}$ at Chandrapur (2019 – 2022).

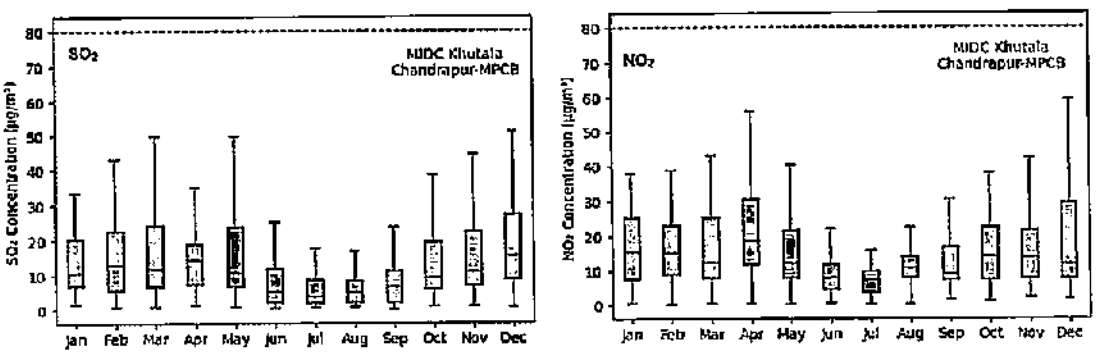


Fig. 5.12: Box plot of monthly variation of daily average SO_2 and NO_2 at Chandrapur (2019 – 2022).

Such report "on Chandrapur STPS" also suggests the need for mercury control in thermal power stations. Analysis of 5794 PTFE filters of ambient air particulate matter and 612 of the Middle East shows that in India, only a few samples show the presence of mercury, which are outliers for the given number of data. The box plot of mercury in the particulate form is presented in **Fig. 5.13**. It can be seen that, barring some outliers, mercury is absent in the atmosphere. Presently, TPS have installed analysers in the chimney of TPS for mercury monitoring. The relevant question is whether the recommendation for the installation of a mercury monitor came after some scientific study showing the presence of Mercury in the atmosphere or is it an arbitrary decision similar to the reduction of SO_2 emission.

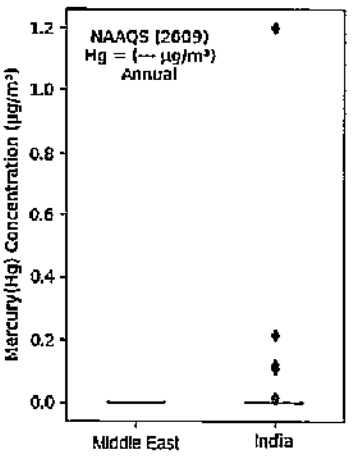


Fig. 5.13: Box plot of Mercury content in particulate matter collected over PTFE.

5.5.2 Report on air quality of Tamil Nadu

According to the **Emission Watch - Tamil Nadu 2021** report on the air quality of Tamil Nadu concludes that due to the high emission rate of SO_2 leading to poor air quality, it is necessary to install FGD and mercury monitoring and control systems. Following are some excerpts of the report:

a) A report describes the power stations of Neyveli, Chennai, Tuticorin and Mettur. Among these four major coal-burning clusters in Tamil Nadu, Neyveli and Chennai rank among the top 50 SO_2 hotspots globally in 2019.
b) There are discrepancies in the power plant emissions data (OCEMS) collected through RTI and the data provided on the PCB website (the RTI information was obtained for three months - April, May and June 2021). The data procured through RTI shows unusually low values for SO_2 emissions in absence of any control methods for few units.
c) The reactive gases such as SO_2 and NOx react with other gases and materials, and turn into secondary particles to form a major portion of particulate matter ($PM_{2.5}$), which is a globally known health hazard.

Analysis of CAAQMS data of Tamil Nadu- It is observed that Sona College Salem (Pl. refer Annexure B2 - 53), is the only station in Tamil Nadu, where ambient air SO_2 levels exceeds the regulatory limit value of 80 $\mu g/m^3$ for a very short duration. Remaining all stations show very low values of SO_2, thereby contradicting the conclusions given in such report.

Annexure A2 - 36 of this report provides the OCEMS data of SO_2 from different power stations in Tamil Nadu. It can be seen that TPS of less than 500 MW have relatively lower SO_2 emission rates. However, only two TPS of 500 MW commissioned in 2019 and 2021 show very high levels of SO_2 emission, around 2000 mg/Nm^3. There is no correlation between the SO_2 level of Sona College, Salem, and emission from New Neyveli Lignite TPS, which thereby contradicts the findings (b) of such reports.

5.6 Lime consumption and Gypsum disposal in FGD

Operation of FGD requires limestone as raw material, water for making slurry preparation, auxiliary power for pump operation etc. After the completion of the chemical reaction of lime water with SO_2, the product is gypsum, which needs to be disposed of by its supply to the cement plant. Most of the reports are restricted to the need of FGD to reduce SO_2 emission and do not discuss the cost involved in the disposal of gypsum generated in FGD. The overall FGD cost should also include the quantification of solid gypsum generated and its disposal mechanism. The carbon footprint left by the mining of limestone, its transportation, and associated water consumption should also be considered in decision-making.

As per the notification of MoEF&CC, fly ash needs to be procured by the cement plant and used as admixture up to 35%. If there is no cement plant in the vicinity of TPS, the cost of transportation of fly ash to distant cement is to be borne by the TPS and sometimes, the cost to accept the fly ash in the cement plant.

Cement manufacturing uses 2.5% gypsum, 61.5% clinker and 35% fly ash for producing finished cement. Gypsum generated in TPS can be used in cement plants. While FGD installation is promoted for the reduction of SO_2 emission and reduction of ambient air SO_2 levels, the commercial benefit of selling gypsum generated from FGD to cement plants is also promoted. A point that needs to be noted is that cement plants are private entities which aim for profit maximization. In this process, cement plants may buy fly ash and gypsum from TPS at the lowest rate. If the cement plant is far away, the TPS may have to pay for the transportation and assimilation of gypsum in the cement plant.

Most of the major cement plants use gypsum from two major sources. Mineral gypsum is obtained from mining activity, and industrial gypsum is obtained from different industries. Gypsum generated in FGD falls under industrial gypsum, which has a purity above 50%. The gypsum generated from TPS needs to be analysed for its purity and needs to be documented for record and future reference. In India, Bikaner mines are the source of Gypsum and have a purity of 50%. Mineral gypsum is imported from Oman and Iran and has a purity of 90%. Gypsum of any purity can be used by adjusting it with imported gypsum to meet the requirements of the cement industry.

Currently, imported gypsum from Oman costs Rs. 2500/- per ton at Mumbai port. After the addition of transportation charges, the cost at the cement plant gate reaches Rs. 3600/- per metric ton. Cost-benefit analysis of overall FGD should include the comparison of imported gypsum and industrial gypsum, including its transportation. The final electricity tariff should be determined by considering all such costs for a remote TPP, for which the source of Lime and disposal at the Cement plant is far away.

pH of Limewater

During the file study of TPP having FGD in operation, the data on the pH of limewater was discussed. It was learnt that the pH of limewater is around 8.5 when fresh, and it reaches 5.4 after one cycle of SO_2 removal. Is there any record of the pH of fresh and

exhausted limewater for FGD operation? This data needs to be generated and analysed for each batch of limewater so that the effectiveness of the reaction and a standard operating procedure (SOP) can be developed and applied for all TPP in India. Currently, we are relying on the SOP developed by technologists of other countries. An ardent need is to apply the same in a few TPPs and maintain a record or future reference.

5.7 Rationale behind reduced stack height for TPS with FGD?

While going through different TPS having FGD, it is observed that new stacks of relatively shorter height are constructed with acid resistant cladding. A few issues are raised in this:

(i) How the new stack height was determined? Was there any source dispersion modelling exercise with the use of WRF generated gridded meteorology data carried out to arrive at a new stack height with revised emission load due to the implementation of FGD? The newly proposed stack is of lower height (150 m) than the previously designed 275 m stack for 500 MW and above. The temperature of flue gas emission with FGD will be relatively lower, thereby reducing the effective stack height ($H = h + \Delta h$) owing to lesser thermal buoyancy. There do not seem to be any margin of safety in case the ESP and / or FGD fails.

In case of failure of FGD / ESP, the entire dust load will be emitted at a relatively much lower elevation and may cause havoc in the vicinity of TPS. The time required for a thermal power plant to shut down is relatively longer compared to hydro-electrical power plants.

To understand the impact of SO_2 on ambient air if the FGD fails for some time, a simulation exercise is carried out. State-of-the-art CalPuff model is used in a meteorological domain of 48 km x 48 km, with sub-grid resolution of 4 km x 4 km. Two scenario is considered, one with stack height of 275 m and other with 150 m for a 600 MW TPP. GLC of SO_2 due to two scenarios is shown in **Fig. 5.14.** It can be seen that if the stack height is small (150 m), a large area will be under a non-compliance zone with a higher GLC of SO_2. Thus, the decision to reduce the stack height due to the installation of FGD needs reconsideration.

(ii) A new shorter stack (150 m) is constructed with acid-resistant cladding in the flue gas line along with FGD. In the absence of FGD, about 1250 mg/Nm3 of SO_2 passes through the stack, and there is no apprehension of corrosion of the metallic flue line. After the installation of FGD, the emission of SO_2 reduces to 200 mg/Nm^3, which is apparently wet due to FGD. Does such a relatively small amount of SO_2 (200 mg/Nm^3), cause corrosion of metallic flue-gas line? If so, what is the time (years) for the flue line to get corroded?

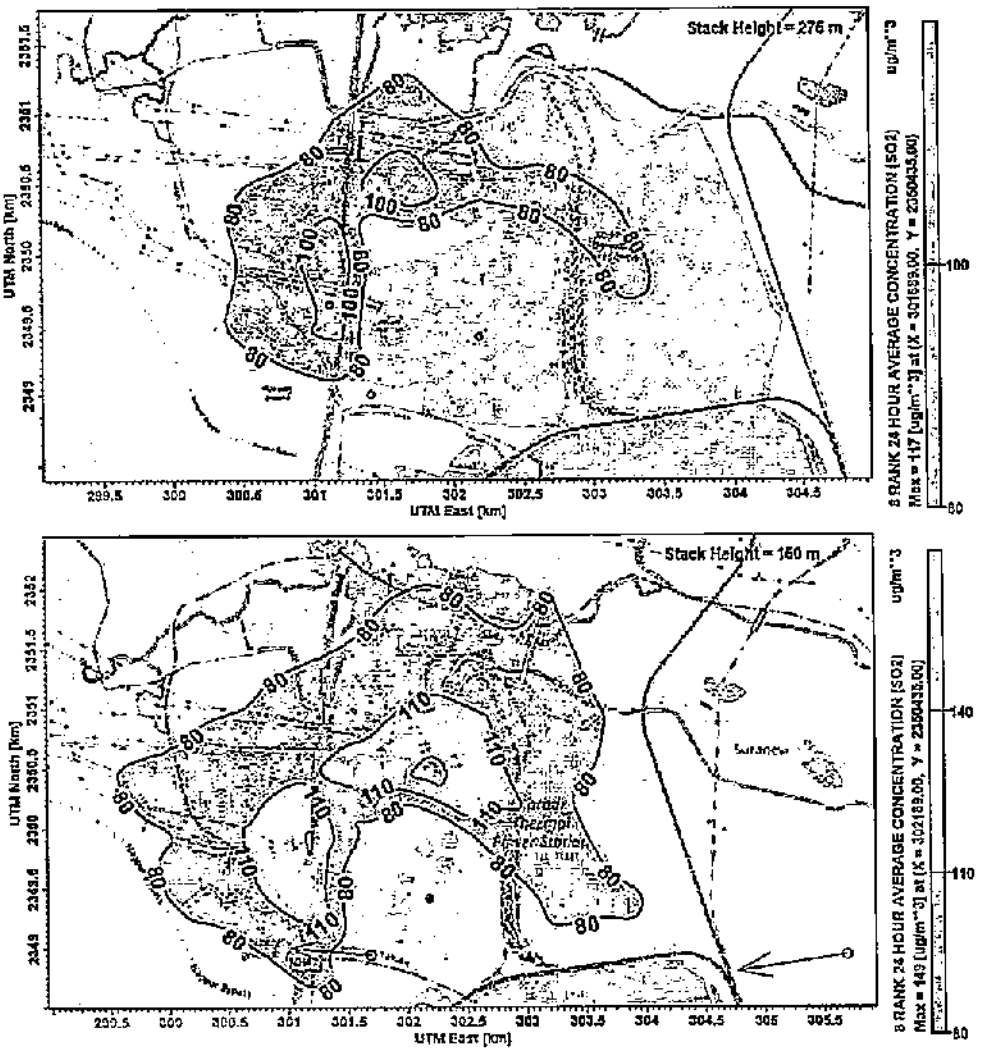


Fig. 5.14: Isopleth of GLC of SO_2 for stack height of 275 m and 150 m.

5.8 CO_2 Emission due to FGD operation

Since the chemical reaction between SO_2 and lime water leads to the emission of CO_2, a study is required to understand the extent of CO_2 emission. The CO_2 emission needs to be estimated under scope 1, 2 and 3. This includes the distance between the source of Limestone, TPS, & cement plant and the mode of transport of limestone and gypsum, i.e. by road or rail. Since these distances are variable for different TPS locations in India, a case study of one plant at Jharsuguda is considered for analysis.

The feasibility of FGD in thermal power stations can be analysed using the assessment of CO_2 emission during the life cycle of the raw material of FGD. CO_2 is emitted during limestone mining, its transportation by road, operation of FGD, chemical reaction of lime with SO_2 and gypsum formation, followed by transportation

of wet gypsum to cement plant. All these CO_2 emissions are covered under Scope 1, 2 and 3 emissions for estimating GHG release.

1.	**Limestone requirement in Vedanta Ltd., Jharsuguda.**	
1.1	Limestone requirement/hour for unit MW of 135 MW capacity (MT)	2
1.2	Limestone requirement/hour for unit MW of 600 MW capacity (MT)	5
1.3	Limestone requirement for CPP of 135 MW x 9 per day (MT)	432
1.4	Limestone requirement for TPP of 600 MW x 4 per day (MT)	480
Total Limestone requirement per day at Vedanta Ltd. Jharsuguda. (MT)		**912**

2.	**CO_2 Emission due to limestone mining**	
2.1	CO_2 emission per ton of limestone mining (kg CO_2 / T $CaCO_3$)	3.0
Total CO_2 Emission per day for Vedanta Ltd. in limestone mining (MT)		**3**

3.	**Estimate of CO_2 emission in limestone transportation by Road**	
3.1	Average Distance for Limestone transportation (km)	1200
3.2	Average load carried by vehicle (MT)	30
3.3	Number of truck trips per day	30
3.4	Total distance covered by all trucks per day (km)	36480
3.5	Distance covered per Liter of Diesel (km)	3.29
3.6	Total Diesel Consumption per day (L)	11088.15
3.7	Emission factor (kg CO_2 / Litre)	2.64
Total CO_2 Emission in transporting Limestone by Road per day (MT)		**29**
4.	**Estimate of CO_2 emission in limestone transportation by Rail.**	
4.1	CO_2 emission if transported by Rail (kg CO_2/t-km)	0.00996
Total CO_2 emission per day for transporting lime by rail (MT)		**11**

Theoretically, SO_2 emission can be reduced by installing the FGD as per the following chemical reaction:

$$Limestone: CaCO_3\,(s) + SO_2\,(g) \rightarrow CaSO_3\,(s) + CO_2\,(g)$$
$$Lime: \quad Ca(OH)_2\,(s) + SO_2\,(g) \rightarrow CaSO_3\,(s) + H_2O(l)$$
$$CaSO_3\,(s) + \tfrac{1}{2}O_2\,(g) + 2H_2O(l) \rightarrow CaSO_4 \cdot 2H_2O(s)$$

- One mole CO_2 is being generated by absorption of one mole of SO_2 in all desulphurization process.

An additional 0.5% CO_2 will be produced to neutralize SO_2. The coal consumption is also expected to increase up to 1 % (due to APC) depending on the FGD.

- technology and Green House Gas (CO_2) will be released additionally due to increased coal consumption.
- 64 grams of SO_2 will generate 44 grams of CO_2.
- 1 MT $CaCO_3$ will generate 0.44 MT of CO_2.
- 1 MT $CaCO_3$ will generate 1.36 MT of Gypsum.
- Wet Gypsum at TPP with surface moisture would be approximately 1.5 T per Ton of Limestone.

CO_2 generated in converting **346320 MT** of limestone to Limewater per day at Vedanta Ltd. Jharsuguda (MT)	401

Estimate of CO_2 emission in Gypsum transportation by Road to Cement Plant	
Gypsum Generated per day at Vedanta Ltd. Jharsuguda (MT)	1240
Average Distance for Gypsum transportation (km)	200
Average load carried by vehicle (MT)	30
Number of truck trips per day	41
Total distance covered by all trucks per day (km)	8268.8
Distance covered per Litre of Diesel (km)	3.29
Total Diesel Consumption per day (L)	2513
Emission factor (kg CO_2 /litre)	2.64
CO_2 Emission in transporting Limestone by Road per day (MT) for Vedanta Ltd. Jharsuguda.	7

Overall CO_2 emitted per day (in MT) at Vedanta Ltd. Jharsuguda per day due to addition of FGD would be sum of:	
Mining of limestone	3
Transportation of limestone by Rail	11
Chemical reaction in gypsum formation	401
Transportation of Gypsum to Cement Plant	7
Total CO_2 emission due to addition of FGD (MT) per day.	**422**

5.8.1 CO_2 emission due to mining and transportation

In the CO_2 emission estimate, limestone is considered to be available in mines near central Madhya Pradesh, Katni, which is the closest mine.

Scenario 1: Limestone transport by Road.

Table 5.1: CO_2 emission if Limestone is transported by Road.

No.	CO_2 Emission (TPD)	TPD	%
1	Mining of limestone	3	0.004
2	Transportation of limestone 100% by Road	29	0.048
3	CO_2 emission due to Limewater making from Limestone	401	0.656
4	Transportation of Gypsum to Cement Plant	7	0.011
6	CO_2 emission due to Coal combustion (T/d)	60740	99.28
7	**Overall CO_2 emission due to Coal combustion and FGD (TPD)**	**61180**	**100**

Scenario 2: Limestone transport by Rail.

Table 5.2: CO_2 emission if Limestone is transported by Rail.

No.	CO_2 Emission (TPD)	TPD	%
1	Mining of limestone	3	0.004
2	Transportation of limestone 100% by Rail	11	0.018
3	CO_2 emission due to Limewater making from Limestone	401	0.648
4	Transportation of Gypsum to Cement Plant	13	0.022
5	CO_2 emission due to auxiliary power consumption for FGD operation (MT/day)	797	1.286
6	CO_2 emission due to Coal combustion (TPD)	60740	98.02
7	**Overall CO_2 emission due to Coal combustion and FGD (TPD)**	**61965**	**100**

5.8.2 CO_2 Emission due to coal combustion in power plant operation

		Unit	Apr-23	May-23	Jun-23	Jul-23	Aug-23	Sep-23	Oct-23	Nov-23	Dec-23
CPP	Coal Consumption	MT	549556	579921	598731	745018	737142	661292	694110	610803	653938
	Coal GCV	kcal/kg	3024	2947	2880	2727	2790	2862	2865	3004	3043
135 x 9 MW	Coal Consumption	GJ	6953101	7151056	7214628	8501247	8604426	7919249	8319884	7676469	8324591
	CO_2 Emission - from Coal Consumption	MT	634783	652856	658659	776121	785541	722988	759564	700823	759994
	LDO Consumption	MT	143	135	115	42	102	24	125	30	48
	LDO GCV	kcal/kg	10773	10865	10865	10832	10815	10796	10863	10698	10784
	LDO Consumption	GJ	6449	6128	5232	1912	4613	1082	5670	1349	2157
	CO_2 Emission from LDO Consumption	MT	454	431	368	135	325	76	399	95	152
	Total CO_2 from CPP	**MT**	635237	653287	659028	776256	785866	723064	759963	700918	760145
TPP	Coal Consumption	MT	930776	1011937	988347	1025605	952207	1008397	1020165	988285	903475
	Coal GCV	kcal/kg	3143	3047	3086	2816	2882	2890	3020	3171	3312
600 x 4 MW	Coal Consumption	GJ	12238346	12899913	12763117	12083487	11480354	12191215	12891971	13113113	12519156
	CO_2 Emission - from Coal Consumption	MT	1117300	1177698	1165209	1103162	1048099	1112997	1176973	1197162	1142936
	LDO Consumption	MT	311	202	243	240	320	220	238	164	373
	LDO GCV	kcal/kg	10780	10732	10656	10776	10738	10782	10831	10831	10829
	LDO Consumption	GJ	14036	9056	10845	10821	14398	9944	10766	7454	16917
	CO_2 Emission from LDO Consumption	MT	988	638	763	762	1014	700	758	525	1191
	Total CO_2 from TPP	**MT**	1118288	1178335	1165972	1103924	1049113	1113697	1177730	1197686	1144127
	Overall CO_2 Emission per Month	MT	1753525	1831622	1825000	1880180	1834978	1836761	1937693	1898605	1904273
	Overall CO_2 Emission per day	**MT**	58451	59085	60833	60651	59193	61225	62506	63287	61426

The average CO_2 emission from Vedanata Ltd., Jharsuguda, is **60740 MT per day.**

363
551
348

5.8.3 Overall CO_2 Emission due to FGD and TPP

Considering rail transport as an economic transport system, the overall CO_2 emission for FGD operation and coal combustion in power plant will be as follows:

Table 5.3: CO_2 emission due to FGD and Power plant operation.

	CO_2 Emission (TPD)	TPD	%
1	CO_2 emission due to overall FGD operation (T/d)	1225	2
2	CO_2 emission due to Coal combustion (T/d)	60740	98
3	Overall CO_2 emission due to Coal combustion and FGD (TPD)	61965	100

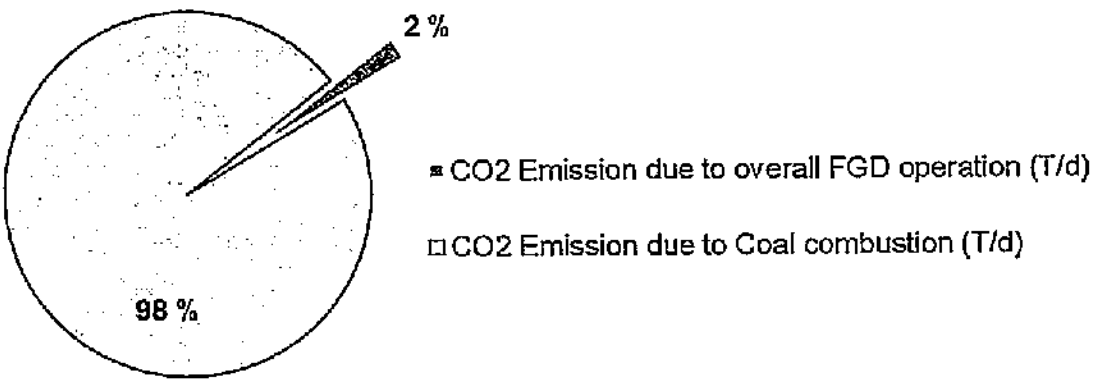


Fig. 5.15: CO_2 emission due to FGD and Power plant operation.

As shown in **Fig. 5.15**, the CO_2 emission data shows that the operation of FGD increases the CO_2 emission by an additional 1225 tons per day or 2% of the overall CO_2 emission. The relative merit of releasing SO_2 and CO_2 having different atmospheric life spans needs to be considered while considering the option of reducing SO_2 emissions arbitrarily, leading to the need for FGD. SO_2 is expected to have life span of 14 days, where-as CO_2 have life span in years leading to global warming. This can affect the net zero carbon objective by the year 2050.

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Chapter 6

Conclusion and Recommendations

6.1 Conclusion from data analysis

Under the study, online continuous emission monitoring systems and continuous ambient air quality monitoring station data were analysed. Besides this, some TPPs were also visited where FGDs are in operation. Literature related to SO_2 and FGD were also studied to arrive at any conclusion with a scientific background. The subsequent sections present the observations on particulate matter, SO_2 emission, ambient air quality, and FGD system in TPS.

6.1.1 PM Emission and concentration

The data on ambient air quality measured by continuous ambient air quality monitoring station (CAAQMS) was downloaded from the CPCB / SPCB website for 464 sites across India. Increasing ambient air PM levels are certainly a matter of concern with the increasing capacity of TPS. Therefore, there is an immediate need to control PM emissions from all sources, including TPS.

Emission data from 131 coal-based thermal power stations with 343 stacks have been analysed. As per the latest emission norms of 2015, MoEF&CC, the norms for PM is limited to 30 mg/Nm^3. For achieving this PM emission level, the ESP size needs to be increased up to 9 electric field in series. Visual observation of stack tops in different power plants over a long time shows instances when the opacity due to flue gas emission is very high, indicating that the emission norms are not always met. These instances of very high PM emission appear during the rapping of the collecting plate, though for a short duration. This appears to be a violation of PM emission load norms and how it is accommodated in the regulatory framework is not clear. While deciding the regulatory limit value of emission, the unscheduled emission during the rapping of the collecting plate and the use of furnace oil need to be given due consideration. This would require a review of emission load viz. a. viz. ESP performance.

The discussion on PM emission control is very important with reference to SO_2 emission reduction. Since the impact of SO_2 at ground level is not found to be significant enough to warrant the need for FGD, another argument proposed is the conversion of gaseous SO_2 to particulate sulphate. If the PM equivalent to transformed particulate sulphate is captured at the source itself by improved control technology, the demand for FGD will not arise.

6.1.2 SO_2 Emission

SO_2 measured from 464 CAAQMS spread across India were analysed, and it was found that out of 464 sites, only 13 sites have the highest SO_2 levels beyond the prescribed limit of 80 µg/m^3, which is 3% of the CAAQMS data. The data of these 3% stations exceed the regulatory limit of 80 µg/m^3 only in the 4th quartile. Thus, the CAAQMS data analysis

does not suggest that SO_2 emission from Indian coal-based TPS is impacting the ambient air quality.

Analysis of SO_2 emission from the TPP stack (OCEMS data) indicates that most of the time, SO_2 emission exceeds the currently prevailing arbitrary emission norm of 200 - 600 mg/Nm^3. The installation of FGD will certainly reduce the load of SO_2 into the atmosphere. However, the existing ambient air data analysis does not indicate the impact of SO_2 on the surrounding air environment. However, the motivation behind setting new emission norms can be due to two reasons:

1) **Meeting the emission target:** In order to achieve the National or regional target of any pollutant emission, control at the source is required. For example, greenhouse gas emission reduction is aimed at attaining net zero by 2070. This can be achieved by reducing the emission of CO_2 from major sources like thermal power stations. However, in the case of SO_2, no such National or regional target is to be met; therefore, reducing the emission at source needs scientific reasoning.

2) **Meeting the ambient air quality norms:** Regulatory guidelines on ambient air quality require pollution levels to be below the prescribed health-based standards. In this endeavour, emission control at source is exercised to the extent that released pollutants after dispersion in the atmosphere attains ambient concentration values which are below the regulatory norm, and it does not adversely impact the environment. In the case of SO_2, the emission rate should be permitted to the level so as to restrict ambient air SO_2 below 80 μg/m^3.

Since gaseous SO_2 is not found as expected in the atmosphere, its chemical transformation to sulphate particle is another likely possibility. Therefore, the presence of elemental sulphur in ambient air PM is analysed. For this, the sulphur content of ambient air PM over the last three years is analysed. The sulphur of PM collected on the PTFE filter was analysed using ED-XRF. A total of 5792 PM samples in India spread in urban centres, coal mining areas and Thermal Power Stations (TPS) were analysed. It was found that the maximum sulphur content was 20 μg/m^3 in all these PM samples, which includes outliers. A statistical analysis consisting of the removal of outliers reveals the highest elemental sulphur content of 8 μg/m^3 in particulate matter. Even if all sulphur is considered as particulate sulphate, the increase in PM load would be 24 μg/m^3 (32 S : 96 $SO_4^=$).

Since no study focused on measuring ambient air PM's sulphate content, the sulphate (SO4=) data measured from different sites were also compiled and found that third quartile of sulphate represents about 20 μg/m^3 for sample size of 457. Fourth quartile data ranges from 20 to 47 μg/m^3.

Since there is no air quality monitoring network in India aimed to measure the impact of the emission of TPP, there is a need to set up an additional network or add some additional parameters to the existing National Air Quality Monitoring Programme (NAMP). The additional parameters that should be included are elemental sulphur, particulate sulphate, and nitrate, which are indicators of coal burning. The PM sampler used under this new air monitoring network should collect PM on PTFE (Poly-tetra-fluoro-ethylene) Membrane Filters to measure ions and elements with higher precision.

- Appropriate institutional mechanisms and infrastructural development for capacity building in regulatory agencies, TPS and ULB is the need of the hour.

6.1.4 FGD System in TPP

In TPP, where FGDs are already installed, some experiments can be carried out to understand the extent of PM and SO_2 control if only water is used for wet scrubbing. Data on the use of additional water and limestone, the varying pH of limewater, power consumption, and related CO_2 emissions are required. OCEMS data from such operations need to be stored and analysed to create the emission inventory of TPS with FGD that can be used in subsequent dispersion modelling exercises under EIA protocols. The generated data can also be used to design industrial pollution control systems in other sectors.

In TPS, having FGD installed, ideally, PM control using nine electric fields should not be required. Less number of electric field with hybrid bag filter and / or wet scrubber may be sufficient. This also requires a study of the complete pressure profile of Induced Draft and Forced Draft fan capacity so that furnace operation heat exchange can be better performed. Further, the stack height needed to meet the regulatory requirement of ground-level concentrations (GLCs) of pollutants is also to be studied using gridded meteorological data. If TPP has an older 275 m stack, it should be maintained for emergency use.

The duration of flue gas flow or the volume of gas that can evaporate a unit volume of water needs to be studied. The present FGD system uses a very thick slurry of limewater to create an umbrella of limewater above the flue gas path. Pumps are used, which consume energy if the slurry is viscous. The power consumption using water and lime slurry needs to be studied for the same or necessary amount of emission control.

From the gathered data of FGD installation, itis not yet fully established except the reduced SO_2 emission rate. In future, we may be forced to come up with proposals to reduce other pollutants like mercury (Hg) and NOx emissions, the impact of which is not yet established. Even the presence of mercury in coal is not established by any large-size coal sample analysis.

- **Impact of FGD**

Globally, carbon markets aim to incentivise those generators that are reducing their carbon footprint and penalize those who are emitting carbon. With the installation of FGD, the country may be increasing its carbon footprint with a reduction in SO_2 emission, which is not advisable as per the present ambient air quality levels. Further, it is also important to note that Sulphur dioxide (SO_2) and carbon dioxide (CO_2) have different atmospheric lifetimes. SO_2 has a short atmospheric lifetime of several hours to about 15 days, while CO_2 persists for over 100 years.

- **Increase of tariff due to FGD installation**

The current cost of FGD systems is approximately Rs. 1.40 Crore per MW. As per recent CEA data estimate, around Rs. 1,47,000 Crores capital investment will be required for the installation of the remaining 105 GW coal-based power plants. Now, it becomes

imperative that the country make timely decisions so that consumers can be prevented from additional financial burdens.

- **Impact due to reduced stack height**

A study on the new shorter stack height (150 m), constructed with acid-resistant cladding in the flue gas line along with FGD. In the absence of FGD, about 1250 mg/Nm^3 of SO_2 passes through the stack, and there is no apprehension of corrosion of the metallic flue line. After the installation of FGD, the emission of SO_2 reduces to 200 mg/Nm^3, which is apparently wet due to FGD. Does such a relatively small amount of SO_2 (200 mg/Nm^3), cause corrosion of metallic flue-gas line? If so, what is the time (years) for the flue line to get corroded?

6.2 Recommendations

The analysis suggests that the ambient SO_2 concentration in all the monitoring stations (CAAQMS) is well below the prescribed norms of 80 µg/m^3. This is despite the fact that most of the TPPs have not installed FGDs. Installation of FGDs in TPPs leads to higher capital investment, increased power consumption, increased consumer tariff, and higher water and carbon footprint without environmental benefits. Thus, the above suggests the following

1. An appropriate decision may be taken by the concerned authority regarding the installation of FGDs in TPPs considering that the ambient SO_2 concentration is well below the prescribed limit.

2. A study on the use of bag filters after ESP (with maintenance management) to ensure continuous PM control needs to be explored. The PM emission should be limited up to the level that covers the PM generated by conversion from gaseous SO_2 in ambient air to secondary particulate matter. If this is achieved, there will be no need for SO_2 control at the source.

3. The observation of the opacity of flue gas at the stack top does not suggest controlled emission of PM, and therefore, there is a need for the development of artificial intelligence / machine learning (AI/ML) tools on the visual image (observation) of the opacity of flue gas at the stack top and its correlation with OCEMS data. This will help develop the emission measurement system based on the opacity of flue gas. Visual Emission Observation (VEO) was already practised in developed countries (USA), where opacity inspectors regularly record and report the emission at a particular time of the day. With current progress in AI/ML technology, India can use it for emission regulation.

4. There is a need to revisit the stack emission norms for SO_2 as per the circular of MoEF&CC, 2015, with consideration of India's latitudinal position, close to the equator compared to European countries, the USA, the UK, developed countries who have given guidelines for SO_2 emission control. India has higher and stronger solar insolation, leading to high ground-level heating, vertical convection, high mixing height, high ventilation, etc.

ANNEXURE(S)

Annexure - A1

State	City	Organization	TPS ID	TPS Name	Combustion Technology	Commissioning Year	FGD Status
Andhra Pradesh	Simhadri	NTPC	3672	C_A_500_Simhadri_2002	Sub-Critical	2002	Bid Awarded
Andhra Pradesh	Simhadri	NTPC	3672	C_A_500_Simhadri_2011	Sub-Critical	2011	Bid Awarded
Andhra Pradesh	Simhadri	NTPC	3672	C_A_500_Simhadri_2012	Sub-Critical	2012	Bid Awarded
Andhra Pradesh	Vijayawada	APGENCO	4317	S_A_210_Tata Rao_1994	Sub-Critical	1994	Feasibility Study Started
Andhra Pradesh	Vijayawada	APGENCO	4317	S_A_210_Tata Rao_1989	Sub-Critical	1989	Feasibility Study Started
Andhra Pradesh	Vijayawada	APGENCO	4317	S_A_210_Tata Rao_1979	Sub-Critical	1979	Feasibility Study Started
Andhra Pradesh	Vijayawada	APGENCO	4317	S_A_500_Tata Rao_2009	Sub-Critical	2009	Feasibility Study Started
Andhra Pradesh	Visakhapatnam	HNPC	5874	P_A_520_Vizag_2015	Sub-Critical	2015	Feasibility Study Completed
Andhra Pradesh	Visakhapatnam	HNPC	5874	P_A_520_Vizag_2016	Sub-Critical	2016	Feasibility Study Completed
Andhra Pradesh	Kadapa	APGENCO	4084	S_C_210_Rayalaseema_1994	Sub-Critical	1994	Feasibility Study Completed
Andhra Pradesh	Kadapa	APGENCO	4084	S_C_210_Rayalaseema_2010	Sub-Critical	2010	Feasibility Study Completed
Andhra Pradesh	Kadapa	APGENCO	4084	S_C_210_Rayalaseema_2007	Sub-Critical	2007	Feasibility Study Completed
Andhra Pradesh	Nellore	SEIL	5509	P_C_660_SGPL_2016	Super-Critical	2016	Bid Opened
Andhra Pradesh	Nellore	SEIL	5509	P_C_660_SGPL_2017	Super-Critical	2017	Bid Opened
Assam	Kumguri	NTPC	5875	C_C_250_Bongaigaon_2015	Sub-Critical	2015	Bid Awarded
Assam	Kumguri	NTPC	5875	C_C_250_Bongaigaon_2017	Sub-Critical	2017	Bid Awarded
Bihar	Barh	NTPC	3194	C_C_660_Barh_2014	Super-Critical	2014	Bid Awarded
Bihar	Barh	NTPC	3194	C_C_660_Barh_2015	Super-Critical	2015	Bid Awarded
Bihar	Nabi Nagar	NTPC	7825	C_C_660_Nabi Nagar_2019	Super-Critical	2019	Bid Awarded
Bihar	Barauni	NTPC	5980	C_C_110_Barauni_1983	Sub-Critical	1983	To Be Decommissioned
Bihar	Barauni	NTPC	5980	C_C_110_Barauni_1985	Sub-Critical	1985	To Be Decommissioned
Bihar	Kanti	NTPC	5903	C_B_110_Muzaffarpur Kanti_1985	Sub-Critical	1985	NIT Issued
Bihar	Kanti	NTPC	5903	C_B_195_Muzaffarpur Kanti_2015	Sub-Critical	2015	NIT Issued
Bihar	Kanti	NTPC	5903	C_B_195_Muzaffarpur Kanti_2017	Sub-Critical	2017	NIT Issued
Chhattisgarh	Korba	NTPC	3269	C_B_500_Korba_1987	Sub-Critical	1987	NIT Issued
Chhattisgarh	Korba	NTPC	3269	C_B_500_Korba_1988	Sub-Critical	1988	NIT Issued
Chhattisgarh	Korba	NTPC	3269	C_B_200_Korba_1983	Sub-Critical	1983	Bid Awarded
Chhattisgarh	Korba	NTPC	3269	C_B_200_Korba_1984	Sub-Critical	1984	Bid Awarded
Chhattisgarh	Korba	NTPC	3269	C_B_500_Korba_1989	Sub-Critical	1989	NIT Issued
Chhattisgarh	Korba	NTPC	3269	C_B_500_Korba_2010	Sub-Critical	2010	NIT Issued
Chhattisgarh	Bhilai	NSPCL	3951	C_B_14_Bhilai_1982	Sub-Critical	1982	Bid Awarded
Chhattisgarh	Bhilai	NSPCL	3951	C_B_250_Bhilai_2009	Sub-Critical	2009	Bid Awarded
Chhattisgarh	Bhilai	NSPCL	3951	C_B_30_Bhilai_1982	Sub-Critical	1982	Bid Awarded
Chhattisgarh	Bhilai	NSPCL	3951	C_B_30_Bhilai_1983	Sub-Critical	1983	Bid Awarded
Chhattisgarh	Bhilai	NSPCL	3951	C_B_250_Bhilai_1992	Sub-Critical	1982	Bid Awarded
Chhattisgarh	Raikheda	APL	4691	P_B_685_Raikheda_2016	Super-Critical	2016	Feasibility Study Not Started
Chhattisgarh	Raikheda	APL	4691	P_B_685_Raikheda_2015	Super-Critical	2015	Feasibility Study Not Started
Chhattisgarh	Korba	CSPGCL	5589	S_B_250_Dr Shyama_2008	Sub-Critical	2008	NIT Issued
Chhattisgarh	Korba	CSPGCL	5589	S_B_250_Dr Shyama_2007	Sub-Critical	2007	NIT Issued
Chhattisgarh	Pathadi	LANCO	441	P_C_300_Pathadi_2010	Sub-Critical	2010	Tender Specification Made
Chhattisgarh	Pathadi	LANCO	441	P_C_300_Pathadi_2009	Sub-Critical	2009	Tender Specification Made
Chhattisgarh	Akaltara	WPCL	1706	P_C_600_Akaltara_2013	Super-Critical	2013	Feasibility Study Not Started

370

558

Chhattisgarh	Tamnar	JPL	1734	P_C_250_Tamnar_2007	Sub-Critical	2007	Bid Opened
Chhattisgarh	Tamnar	JPL	1734	P_C_600_Tamnar_2014	Sub-Critical	2014	Bid Opened
Chhattisgarh	Tamnar	JPL	1734	P_C_600_Tamnar_2015	Sub-Critical	2015	Bid Opened
Chhattisgarh	Baradarha	DBPCL	2088	P_C_600_Baradarha_2014	Sub-Critical	2014	Bid Awarded
Chhattisgarh	Baradarha	DBPCL	2088	P_C_600_Baradarha_2015	Sub-Critical	2015	Bid Awarded
Chhattisgarh	Sipat	NTPC	3673	C_C_500_Sipat_2007	Sub-Critical	2007	Bid Awarded
Chhattisgarh	Sipat	NTPC	3673	C_C_500_Sipat_2008	Sub-Critical	2008	Bid Awarded
Chhattisgarh	Sipat	NTPC	3673	C_C_660_Sipat_2011	Super-Critical	2011	Bid Awarded
Chhattisgarh	Sipat	NTPC	3673	C_C_660_Sipat_2012	Super-Critical	2012	Bid Awarded
Chhattisgarh	BANDAKHAR	MCCPL	4307	P_C_300_Bhandhakhar_2015	Sub-Critical	2015	Claims to be SO2 compliant
Chhattisgarh	Ratija	SCPL	4313	P_C_50_Ratija_2013	Sub-Critical	2013	CFBC
Chhattisgarh	Ratija	SCPL	4313	P_C_50_Ratija_2016	Sub-Critical	2016	CFBC
Chhattisgarh	Chakabura	ACB	4664	P_C_30_Chakabura_2007	Sub-Critical	2007	CFBC
Chhattisgarh	Chakabura	ACB	4664	P_C_30_Chakabura_2014	Sub-Critical	2014	CFBC
Chhattisgarh	Marwa	CSPGCL	4716	S_C_500_Marwa_2016	Sub-Critical	2016	NIT Issued
Chhattisgarh	Marwa	CSPGCL	4716	S_C_500_Marwa_2014	Sub-Critical	2014	NIT Issued
Chhattisgarh	Nawapara	TRNE	5342	P_C_300_Nawapara_2016	Sub-Critical	2016	Claims to be SO2 compliant
Chhattisgarh	Nawapara	TRNE	5342	P_C_300_Nawapara_2017	Sub-Critical	2017	Claims to be SO2 compliant
Chhattisgarh	Uchpinda	RKMPPL	6317	P_C_360_Uchpinda_2017	Sub-Critical	2017	Feasibility Study Not Started
Chhattisgarh	Uchpinda	RKMPPL	6317	P_C_360_Uchpinda_2019	Sub-Critical	2019	Feasibility Study Not Started
Chhattisgarh	Uchpinda	RKMPPL	6317	P_C_360_Uchpinda_2016	Sub-Critical	2016	Feasibility Study Not Started
Chhattisgarh	Uchpinda	RKMPPL	6317	P_C_360_Uchpinda_2015	Sub-Critical	2015	Feasibility Study Not Started
Chhattisgarh	Lara	NTPC	7790	C_C_800_Lara_2018	Super-Critical	2018	Bid Awarded
Gujarat	Sabarmati	TOR. POW.	5526	P_A_110_Sabarmati_1985	Sub-Critical	1985	Bid Opened
Gujarat	Sabarmati	TOR. POW.	5526	P_A_110_Sabarmati_1988	Sub-Critical	1988	Bid Opened
Gujarat	Sabarmati	TOR. POW.	5526	P_A_125_Sabarmati_2003	Sub-Critical	2003	Bid Opened
Gujarat	Wanakbori	GSECL	241	S_C_210_Wankabori_1983	Sub-Critical	1983	NIT Issued
Gujarat	Wanakbori	GSECL	241	S_C_210_Wankabori_1986	Sub-Critical	1986	NIT Issued
Gujarat	Wanakbori	GSECL	241	S_C_210_Wankabori_1982	Sub-Critical	1982	NIT Issued
Gujarat	Wanakbori	GSECL	241	S_C_210_Wankabori_1998	Sub-Critical	1998	NIT Issued
Gujarat	Wanakbori	GSECL	241	S_C_210_Wankabori_1984	Sub-Critical	1984	NIT Issued
Gujarat	Wanakbori	GSECL	241	S_C_210_Wankabori_1987	Sub-Critical	1987	NIT Issued
Gujarat	Nani Chher	GMDCL	859	S_C_125_Akrimota_2007	Sub-Critical	2007	CFBC
Gujarat	Nani Chher	GMDCL	859	S_C_125_Akrimota_2006	Sub-Critical	2006	CFBC
Gujarat	Dahej SEZ Area		2145	S_C_ Gandhi Nagar (I)	Sub-Critical		Cancelled
Gujarat	Khanot	GSECL	4205	S_C_75_Kutch LIG_2009	Sub-Critical	2009	
Gujarat	Khanot	GSECL	4205	S_C_75_Kutch LIG_1997	Sub-Critical	1997	
Gujarat	Khanot	GSECL	4205	S_C_70_Kutch LIG_1991	Sub-Critical	1991	Retired
Gujarat	Khanot	GSECL	4205	S_C_70_Kutch LIG_1990	Sub-Critical	1990	Retired
Gujarat	Ukai	GSECL	4206	S_C_500_Ukai_2013	Sub-Critical	2013	NIT issued
Gujarat	Ukai	GSECL	4206	S_C_210_Ukai_1985	Sub-Critical	1985	NIT Issued
Gujarat	Ukai	GSECL	4206	S_C_120_Ukai_1976	Sub-Critical	1976	NIT Issued
Gujarat	Sikka	GSECL	4209	S_C_250_Sikka_2015	Sub-Critical	2015	Bid opened
Gujarat	Sector 30	GSECL	4213	S_C_210_Gandhi Nagar (II)_1998	Sub-Critical	1998	NIT issued
Gujarat	Sector 30	GSECL	4213	S_C_200_Gandhi Nagar (II)_1991	Sub-Critical	1991	NIT issued
Gujarat	Sector 30	GSECL	4213	S_C_200_Gandhi Nagar (II)_1990	Sub-Critical	1990	NIT Issued
Gujarat	Tunda	CGPL	5616	P_C_660_Mundra_2012	Super-Critical	2012	Bid Awarded

371
559
366

Gujarat	Tunda	CGPL	5616	P_C_330_Mundra_2009	Sub-Critical	2009	Bid Awarded
Gujarat	Tunda	CGPL	5616	P_C_660_Mundra_2011	Super-Critical	2011	Bid Awarded
Gujarat	Tunda	CGPL	5616	P_C_330_Mundra_2010	Sub-Critical	2010	Bid Awarded
Gujarat	Tunda	CGPL	5616	P_C_660_Mundra_2010	Super-Critical	2010	Bid Awarded
Gujarat	Salaya	EPGL	5790	P_C_600_Salaya_2012	Sub-Critical	2012	Tender Specification Made
Gujarat	Salaya	EPGL	5790	P_C_600_Salaya_2013	Sub-Critical	2013	Tender Specification Made
Gujarat	Nani Naroli	GIPCL	5901	P_C_125_Surat LIG_1999	Sub-Critical	1999	CFBC
Gujarat	Nani Naroli	GIPCL	5901	P_C_125_Surat LIG_2010	Sub-Critical	2010	CFBC
Gujarat	Nani Naroli	GIPCL	5901	P_C_125_Surat LIG_2000	Sub-Critical	2000	CFBC
Haryana	Jhajjar	JhPL(HR)	141	P_A_660_Mahatma Gandhi_2012	Super-Critical	2012	FGD Installed
Haryana	Jhajjar	NTPC	545	C_A_500_Indira Gandhi_2012	Sub-Critical	2012	Bid Awarded
Haryana	Jhajjar	NTPC	545	C_A_500_Indira Gandhi_2010	Sub-Critical	2010	Bid Awarded
Haryana	Jhajjar	NTPC	545	C_A_500_Indira Gandhi_2011	Sub-Critical	2011	Bid Awarded
Haryana	Assan	HPGCL	3456	S_A_250_Panipat_2004	Sub-Critical	2004	Bid Awarded
Haryana	Assan	HPGCL	3456	S_A_250_Panipat_2005	Sub-Critical	2005	Bid Awarded
Haryana	Assan	HPGCL	3456	S_A_210_Panipat_2001	Sub-Critical	2001	Bid Awarded
Haryana	Assan	HPGCL	3456	S_A_210_Panipat_1989	Sub-Critical	1989	Retired
Haryana	Hisar	HPGCL	399	S_C_600_Rajiv Gandhi_2011	Sub-Critical	2011	NIT Issued
Haryana	Hisar	HPGCL	399	S_C_600_Rajiv Gandhi_2010	Sub-Critical	2010	NIT Issued
Haryana	YamunaNagar		562	S_C_300_Yamuna Nagar_2008	Sub-Critical	2008	NIT Issued
Jharkhand	Chandrapura	DVC	420	C_C_250_Chandrapura_2011	Sub-Critical	2011	Bid Opened
Jharkhand	Chandrapura	DVC	420	C_C_130_Chandrapura_1968	Sub-Critical	1968	Retired
Jharkhand	Adityapur	ADHUNIK	1236	P_C_270_Mahadev Prasad_2012	Sub-Critical	2012	Feasibility Study Completed
Jharkhand	Dombhui	MPL	1817	P_C_525_Malthon RB_2011	Sub-Critical	2011	Bid Awarded
Jharkhand	Mauza-Govindpur	DVC	5273	C_C_200_Bokaro_1993	Sub-Critical	1993	Retired
Jharkhand	Mauza-Govindpur	DVC	5273	C_C_500_Bokaro_2016	Sub-Critical	2016	Bid opened
Jharkhand	Jamshedpur	TATA PCL	5533	P_C_120_Jojobera_2000	Sub-Critical	2000	Bid Awarded
Jharkhand	Jamshedpur	TATA PCL	5533	P_C_120_Jojobera_2001	Sub-Critical	2001	Bid Awarded
Jharkhand	Jamshedpur	TATA PCL	5533	P_C_120_Jojobera_2005	Sub-Critical	2005	Bid Awarded
Jharkhand	Jamshedpur	TATA PCL	5533	P_C_120_Jojobera_2011	Sub-Critical	2011	Bid Awarded
Jharkhand	Lalpania Bokaro	TVNL	5741	S_C_210_Tenughat_1996	Sub-Critical	1996	Feasibility Study Completed
Jharkhand	Lalpania Bokaro	TVNL	5741	S_C_210_Tenughat_1997	Sub-Critical	1997	Feasibility Study Completed
Karnataka	Torangallu	JSWEL	2258	P_C_300_Torangallu_2009	Sub-Critical	2009	
Karnataka	Torangallu	JSWEL	2258	P_C_130_Torangallu_2000	Sub-Critical	2000	
Karnataka	Torangallu	JSWEL	2258	P_C_300_Torangallu_2009	Sub-Critical	2009	
Karnataka	Bellary	KPCL	4333	S_C_500_Bellary_2007	Sub-Critical	2007	Bid opened
Karnataka	Kudgi	NTPC	5714	C_C_800_Kudgi_2016	Super-Critical	2016	Bid Awarded
Karnataka	Kudgi	NTPC	5714	C_C_800_Kudgi_2017	Super-Critical	2017	Bid Awarded
Karnataka	Kudgi	NTPC	5714	C_C_800_Kudgi_2018	Super-Critical	2018	Bid Awarded
Karnataka	Raichur	KPCL	5870	S_C_210_Raichur_1999	Sub-Critical	1999	Bid Awarded
Karnataka	Raichur	KPCL	5870	S_C_210_Raichur_1985	Sub-Critical	1985	Bid Awarded
Karnataka	Raichur	KPCL	5870	S_C_210_Raichur_1994	Sub-Critical	1994	Bid Awarded
Madhya Pradesh	Siddhikhurd	SPL	1571	P_C_660_Sasan_2014	Super-Critical	2014	Bid Awarded
Madhya Pradesh	Siddhikhurd	SPL	1571	P_C_660_Sasan_2013	Super-Critical	2013	Bid Awarded
Madhya Pradesh	Siddhikhurd	SPL	1571	P_C_660_Sasan_2015	Super-Critical	2015	Bid Awarded
Madhya Pradesh	Chachai		2050	P_C_210_Anuppur (I)_2009	Sub-Critical	2009	Bid Awarded
Madhya Pradesh	Gangal	NTPC	7482	C_C_800_Gadarwara_2018	Super-Critical	2018	Bid Awarded

372
560

Madhya Pradesh	Nigari	JPPVL	2238	P_C_660_Nigri_2015	Super-Critical	2015	NIT Issued
Madhya Pradesh	Nigari	JPPVL	2238	P_C_660_Nigri_2014	Super-Critical	2014	NIT Issued
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_500_Vindhyachal_2006	Sub-Critical	2006	Bid awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_210_Vindhyachal_1990	Sub-Critical	1990	Bid Awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_210_Vindhyachal_1991	Sub-Critical	1991	Bid Awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_500_Vindhyachal_1999	Sub-Critical	1999	Bid awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_500_Vindhyachal_2000	Sub-Critical	2000	Bid awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_210_Vindhyachal_1987	Sub-Critical	1987	Bid Awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_210_Vindhyachal_1988	Sub-Critical	1988	Bid Awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_500_Vindhyachal_2013	Sub-Critical	2013	Bid awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_500_Vindhyachal_2007	Sub-Critical	2007	Bid awarded
Madhya Pradesh	Vindhyanagar	NTPC	3666	C_C_500_Vindhyachal_2012	Sub-Critical	2012	Bid awarded
Madhya Pradesh	Bandhaura	APL	4924	P_C_600_Mahan_2012	Sub-Critical	2012	Feasibility Study Started
Madhya Pradesh	Sarni	MPPGCL	5204	S_C_250_Satpura_2013	Sub-Critical	2013	Feasibility Study Started
Madhya Pradesh	Sarni	MPPGCL	5204	S_C_210_Satpura_1983	Sub-Critical	1983	Feasibility Study Started
Madhya Pradesh	Sarni	MPPGCL	5204	S_C_210_Satpura_1984	Sub-Critical	1984	Feasibility Study Started
Madhya Pradesh	Sarni	MPPGCL	5204	S_C_200_Satpura_1979	Sub-Critical	1979	Feasibility Study Started
Madhya Pradesh	Sirchopi	JPPVL	5477	P_C_250_Bina_2013	Sub-Critical	2013	Feasibility Study Started
Madhya Pradesh	Sirchopi	JPPVL	5477	P_C_250_Bina_2012	Sub-Critical	2012	Feasibility Study Started
Madhya Pradesh	Mundi	MPPGCL	5899	S_C_600_Shri Singhaji_2014	Sub-Critical	2014	NIT Issued
Madhya Pradesh	Barela	JHAPL	5983	P_C_600_Seloni_2016	Super-Critical	2016	Feasibility Study Completed
Madhya Pradesh	Laharpur	MBPMPL	6136	P_C_600_Anuppur (II)_2016	Sub-Critical	2016	Bid awarded
Madhya Pradesh	Laharpur	MBPMPL	6136	P_C_600_Anuppur (II)_2015	Sub-Critical	2015	Bid awarded
Madhya Pradesh	Laharpur	MBPMPL	6136	P_C_600_Anuppur (II)	Sub-Critical		Bid awarded
Maharashtra	Nagpur	MAHAGENCO	5465	S_A_210_Khaperkheda_1989	Sub-Critical	1989	Feasibility Study Completed
Maharashtra	Mumbai	TROMBAY TPS	5961	P_A_500_Trombay_1984	Sub-Critical	1984	FGD Installed
Maharashtra	Mumbai	TROMBAY TPS	5961	P_A_250_Trombay_2009	Sub-Critical	2009	FGD Installed
Maharashtra	Mumbai	TROMBAY TPS	5961	P_A_180_Trombay_1984	Sub-Critical	1984	FGD Installed
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_500_Chandrapur_2016	Sub-Critical	2016	Feasibility Study Completed
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_500_Chandrapur_2015	Sub-Critical	2015	Feasibility Study Completed
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_210_Chandrapur_1985	Sub-Critical	1985	Feasibility Study Completed
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_500_Chandrapur_1992	Sub-Critical	1992	
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_500_Chandrapur_1991	Sub-Critical	1991	
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_210_Chandrapur_1986	Sub-Critical	1986	Feasibility study completed
Maharashtra	Chandrapur	MAHAGENCO	2806	S_B_500_Chandrapur_1997	Sub-Critical	1997	
Maharashtra	Fatatewadi	NTPC	5716	C_B_660_Solapur_2017	Super-Critical	2017	Bid Awarded
Maharashtra	Fatatewadi	NTPC	5716	C_B_660_Solapur_2019	Super-Critical	2019	Bid Awarded
Maharashtra	Tirora	APL	943	P_C_660_Tirora Gondia_2013	Super-Critical	2013	Bid Awarded
Maharashtra	Tirora	APL	943	P_C_660_Tirora Gondia_2014	Super-Critical	2014	Bid Awarded
Maharashtra	Tirora	APL	943	P_C_660_Tirora Gondia_2012	Super-Critical	2012	Bid Awarded
Maharashtra	Agwan	APL	1387	P_C_250_Dahanu_1995	Sub-Critical	1995	FGD Installed
Maharashtra	Mohabala	GMR ENERG	2124	P_C_300_GMR Warora_2013	Sub-Critical	2013	Bid Opened
Maharashtra	Jalgoan		3449	S_C_210_Bhusawal (I)_1982	Sub-Critical	1982	To Be Decommissioned
Maharashtra	Jalgaon	MAHAGENCO	3450	S_C_500_Bhusawal (II)_2012	Sub-Critical	2012	Bid Opened
Maharashtra	Jalgaon	MAHAGENCO	3450	S_C_500_Bhusawal (II)_2013	Sub-Critical	2013	Bid Opened
Maharashtra	Mouda	NTPC	3671	C_C_500_Mauda_2012	Sub-Critical	2012	Bid Awarded
Maharashtra	Mouda	NTPC	3671	C_C_500_Mauda_2013	Sub-Critical	2013	Bid Awarded

373
561
358

Maharashtra	Mouda	NTPC	3671	C_C_660_Mauda_2016	Super-Critical	2016	Bid Awarded
Maharashtra	Mouda	NTPC	3671	C_C_660_Mauda_2017	Super-Critical	2017	Bid Awarded
Maharashtra	Amravati	RATTANINDIA	5428	P_C_270_Amaravati_2015	Sub-Critical	2015	Tender Specification Made
Maharashtra	Amravati	RATTANINDIA	5428	P_C_270_Amaravati_2014	Sub-Critical	2014	Tender Specification Made
Maharashtra	Amravati	RATTANINDIA	5428	P_C_270_Amaravati_2013	Sub-Critical	2013	Tender Specification Made
Maharashtra	Paras	MAHAGENCO	5489	S_C_250_Paras_2010	Sub-Critical	2010	Bid Awarded
Maharashtra	Paras	MAHAGENCO	5489	S_C_250_Paras_2007	Sub-Critical	2007	Bid Awarded
Maharashtra	Parli	MAHAGENCO	5737	S_C_250_Parli (I)_2007	Sub-Critical	2007	Bid Opened
Maharashtra	Parli	MAHAGENCO	5737	S_C_250_Parli (I)_2010	Sub-Critical	2010	Bid Opened
Maharashtra	Parli		5743	S_C_250_Parli (II)_2016	Sub-Critical	2016	Bid Opened
Odisha	Kamlanga	GMR ENERG	3945	P_B_350_Kamalanga_2013	Sub-Critical	2013	Bid Opened
Odisha	Kamlanga	GMR ENERG	3945	P_B_350_Kamalanga_2014	Sub-Critical	2014	Bid Opened
Odisha	Banharpalli	IBPIL	889	S_C_210_Ind Barath_1995	Sub-Critical	1995	Feasibility Study Started
Odisha	Talcher	NTPC	3670	C_C_500_Talcher_2006	Sub-Critical	2006	Bid Awarded
Odisha	Talcher	NTPC	3670	C_C_500_Talcher_2005	Sub-Critical	2005	Bid Awarded
Odisha	Talcher	NTPC	3670	C_C_500_Talcher_1996	Sub-Critical	1996	Bid Awarded
Odisha	Talcher	NTPC	3670	C_C_500_Talcher_1995	Sub-Critical	1995	Bid Awarded
Odisha	Talcher	NTPC	3670	C_C_500_Talcher_2003	Sub-Critical	2003	Bid Awarded
Odisha	Derang	JITPL	5018	P_C_600_Derang_2015	Sub-Critical	2015	Bid Opened
Odisha	Derang	JITPL	5018	P_C_600_Derang_2014	Sub-Critical	2014	Bid Opened
Odisha	Banjari	SEL	5500	P_C_600_Sterlite_2010	Sub-Critical	2010	Feasibility Study Started
Odisha	Banjari	SEL	5500	P_C_600_Sterlite_2012	Sub-Critical	2012	Feasibility Study Started
Odisha	Banjari	SEL	5500	P_C_600_Sterlite_2011	Sub-Critical	2011	Feasibility Study Started
Punjab	Rajpura	NPL	124	P_C_700_Nabha_2014	Super-Critical	2014	Bid Awarded
Punjab	Talwandi	TSPL	1719	P_C_660_Talwandi Sabo_2016	Super-Critical	2016	Tender Specification Made
Punjab	Talwandi	TSPL	1719	P_C_660_Talwandi Sabo_2015	Super-Critical	2015	Tender Specification Made
Punjab	Talwandi	TSPL	1719	P_C_660_Talwandi Sabo_2014	Super-Critical	2014	Tender Specification Made
Punjab	Lehra Mohabbat	PSPCL	2127	S_C_210_Guru Hargobind_1997	Sub-Critical	1997	Feasibility Study Completed
Punjab	Lehra Mohabbat	PSPCL	2127	S_C_210_Guru Hargobind_1998	Sub-Critical	1998	Feasibility Study Completed
Punjab	Lehra Mohabbat	PSPCL	2127	S_C_250_Guru Hargobind_2008	Sub-Critical	2008	Feasibility Study Completed
Punjab	Lehra Mohabbat	PSPCL	2127	S_C_250_Guru Hargobind_2010	Sub-Critical	2010	Feasibility Study Completed
Punjab	Ropar	PSPCL	4362	S_C_210_Ropar_1992	Sub-Critical	1992	NIT Issued
Punjab	Ropar	PSPCL	4362	S_C_210_Ropar_1988	Sub-Critical	1988	NIT Issued
Punjab	Ropar	PSPCL	4362	S_C_210_Ropar_1989	Sub-Critical	1989	NIT Issued
Punjab	Ropar	PSPCL	4362	S_C_210_Ropar_1993	Sub-Critical	1993	NIT Issued
Punjab	Ropar	PSPCL	4362	S_C_210_Ropar_1985	Sub-Critical	1985	Retired
Punjab	Ropar	PSPCL	4362	S_C_210_Ropar_1984	Sub-Critical	1984	Retired
Punjab	Goindwal Sahib	GPGSL (GVK)	5317	P_C_270_Goindwal Sahib_2016	Sub-Critical	2016	Bid Opened
Rajasthan	KOTA	RRVUNL	4548	S_A_210_Kota_1988	Sub-Critical	1988	To Be Decommissioned
Rajasthan	KOTA	RRVUNL	4548	S_A_210_Kota_1989	Sub-Critical	1989	To Be Decommissioned
Rajasthan	KOTA	RRVUNL	4548	S_A_210_Kota_1997	Sub-Critical	1997	To Be Decommissioned
Rajasthan	KOTA	RRVUNL	4548	S_A_110_Kota_1983	Sub-Critical	1983	To Be Decommissioned
Rajasthan	KOTA	RRVUNL	4548	S_A_195_Kota_2004	Sub-Critical	2004	To Be Decommissioned
Rajasthan	KOTA	RRVUNL	4548	S_A_195_Kota_2009	Sub-Critical	2009	To Be Decommissioned
Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh_1998	Sub-Critical	1998	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh_2001	Sub-Critical	2001	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh_2002	Sub-Critical	2002	

Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh_2003	Sub-Critical	2003	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh_2009	Sub-Critical	2009	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh_2000	Sub-Critical	2000	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_250_Suratgarh	Sub-Critical		
Rajasthan	Suratgarh	RRVUNL	1567	S_C_660_Suratgarh_2021	Super-Critical	2021	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_660_Suratgarh_2019	Super-Critical	2019	
Rajasthan	Suratgarh	RRVUNL	1567	S_C_660_Suratgarh	Sub-Critical		
Rajasthan	Bhadresh	RWPL (JSW)	1693	P_C_135_Jallpa Kapurdi_2013	Sub-Critical	2013	CFBC
Rajasthan	Bhadresh	RWPL (JSW)	1693	P_C_135_Jallpa Kapurdi_2011	Sub-Critical	2011	CFBC
Rajasthan	Bhadresh	RWPL (JSW)	1693	P_C_135_Jallpa Kapurdi_2010	Sub-Critical	2010	CFBC
Rajasthan	Chowki Motipura	RRVUNL	2086	S_C_125_Giral_2008	Sub-Critical	2008	CFBC
Rajasthan	Chowki Motipura	RRVUNL	2086	S_C_125_Giral_2007	Sub-Critical	2007	CFBC
Rajasthan	Jhalawar	RRVUNL	2678	S_C_600_Kalisindh_2015	Super-Critical	2015	Bid Awarded
Rajasthan	Jhalawar	RRVUNL	2678	S_C_600_Kalisindh_2014	Super-Critical	2014	Bid Awarded
Rajasthan	Kawai	APL	4596	P_C_660_Kawai_2014	Super-Critical	2014	Bid Awarded
Rajasthan	Bikaner	NLC	5676	C_C_125_Barsingsar_2011	Sub-Critical	2011	CFBC
Rajasthan	Bikaner	NLC	5676	C_C_125_Barsingsar_2010	Sub-Critical	2010	CFBC
Tamil Nadu	TIRUVALLUR	NTECL	4784	C_A_500_Vallur_2014	Sub-Critical	2014	Bid Awarded
Tamil Nadu	TIRUVALLUR	NTECL	4784	C_A_500_Vallur_2013	Sub-Critical	2013	Bid Awarded
Tamil Nadu	TIRUVALLUR	NTECL	4784	C_A_500_Vallur_2012	Sub-Critical	2012	Bid Awarded
Tamil Nadu	METTUR	TANGEDCO	1684	S_B_210_Mettur_1987	Sub-Critical	1987	NIT Issued
Tamil Nadu	METTUR	TANGEDCO	1684	S_B_210_Mettur_1989	Sub-Critical	1989	NIT Issued
Tamil Nadu	METTUR	TANGEDCO	1684	S_B_210_Mettur_1990	Sub-Critical	1990	NIT Issued
Tamil Nadu	MELAMARUTHURA	CEPL	3942	P_B_600_Muthiara_2014	Sub-Critical	2014	Feasibility Study Completed
Tamil Nadu	MELAMARUTHURA	CEPL	3942	P_B_600_Muthiara_2016	Sub-Critical	2016	Feasibility Study Completed
Tamil Nadu	Neyveli	Neyveli Lignite	1382	C_C_210_Neyveli (II)_1986	Sub-Critical	1986	Bid Opened
Tamil Nadu	Neyveli	Neyveli Lignite	1382	C_C_210_Neyveli (II)_1991	Sub-Critical	1991	Bid Opened
Tamil Nadu	Neyveli	Neyveli Lignite	1382	C_C_210_Neyveli (II)_1992	Sub-Critical	1992	Bid Opened
Tamil Nadu	Neyveli	Neyveli Lignite	1382	C_C_210_Neyveli (II)_1987	Sub-Critical	1987	Bid Opened
Tamil Nadu	Neyveli	Neyveli Lignite	1382	C_C_210_Neyveli (II)_1993	Sub-Critical	1993	Bid Opened
Tamil Nadu	Tuticorin	TANGEDCO	1724	S_C_210_Tuticorin_1982	Sub-Critical	1982	NIT Issued
Tamil Nadu	Tuticorin	TANGEDCO	1724	S_C_210_Tuticorin_1992	Sub-Critical	1992	NIT Issued
Tamil Nadu	Tuticorin	TANGEDCO	1724	S_C_210_Tuticorin_1990	Sub-Critical	1990	NIT Issued
Tamil Nadu	Tuticorin	TANGEDCO	1724	S_C_210_Tuticorin_1979	Sub-Critical	1979	NIT Issued
Tamil Nadu	Tuticorin	TANGEDCO	1724	S_C_210_Tuticorin_1980	Sub-Critical	1980	NIT Issued
Tamil Nadu	Neyveli	TAQA	2540	P_C_250_Neyveli Zero_2015	Sub-Critical	2015	Bid Awarded
Tamil Nadu	Cuddalore	IL&FS	4607	P_C_600_Cuddalore IL&FS_2016	Super-Critical	2016	FGD Installed
Tamil Nadu	Cuddalore	IL&FS	4607	P_C_600_Cuddalore IL&FS_2015	Super-Critical	2015	FGD Installed
Tamil Nadu	Neyveli	Neyveli Lignite	3839	C_C_500_New Neyveli_2021	Sub-Critical	2021	Bid Opened
Tamil Nadu	Neyveli	Neyveli Lignite	3839	C_C_500_New Neyveli_2019	Sub-Critical	2019	Bid Opened
Tamil Nadu	Neyveli	Neyveli Lignite	5725	C_C_210_Neyveli (I)_2002	Sub-Critical	2002	
Tamil Nadu	Neyveli	Neyveli Lignite	5725	C_C_250_Neyveli (I)_2015	Sub-Critical	2015	
Tamil Nadu	Neyveli	Neyveli Lignite	5725	C_C_210_Neyveli (I)_2003	Sub-Critical	2003	
Tamil Nadu	Neyveli	Neyveli Lignite	5725	C_C_250_Neyveli (I)_2011	Sub-Critical	2011	
Telangana	New Paloncha	TSGENCO	2352	S_C_250_Kothagudem_1998	Sub-Critical	1998	Feasibility Study Completed
Telangana	New Paloncha	TSGENCO	2352	S_C_250_Kothagudem_1997	Sub-Critical	1997	Feasibility Study Completed
Telangana	Chelpur	TSGENCO	2609	S_C_600_Kakatiya_2015	Sub-Critical	2015	Feasibility Study Completed

Telangana	Chelpur	TSGENCO	2609	S_C_500_Kakatiya_2010	Sub-Critical	2010	Feasibility Study Completed
Telangana	Singareni	SCCL	6159	S_C_600_Pegadapalli_2016	Sub-Critical	2016	Bid Awarded
Telangana	Ramagundem	NTPC	3665	C_C_500_Ramagundem (I)_1989	Sub-Critical	1989	Bid Awarded
Telangana	Ramagundem	NTPC	3665	C_C_500_Ramagundem (I)_2005	Sub-Critical	2005	Bid Awarded
Telangana	Ramagundem	NTPC	3665	C_C_200_Ramagundem (I)_1984	Sub-Critical	1984	Bid Awarded
Telangana	Ramagundem	NTPC	3665	C_C_200_Ramagundem (I)_1983	Sub-Critical	1983	Bid Awarded
Telangana	Ramagundem	NTPC	3665	C_C_500_Ramagundem (I)_1988	Sub-Critical	1988	Bid Awarded
Telangana	Ramagundem	TSGENCO	4062	C_C_62.5_Ramagundem (II)_1971	Sub-Critical	1971	To Be Decommissioned
Uttar Pradesh	Barkhera	BEPL	1662	P_C_45_Barkhera_2011	Sub-Critical	2011	CFBC
Uttar Pradesh	Kastuwa-Kunderki	BEPL	1663	P_C_45_Kundarki_2012	Sub-Critical	2012	CFBC
Uttar Pradesh	Khambarkhera	BEPL	1664	P_C_45_Khambarkhera_2011	Sub-Critical	2011	CFBC
Uttar Pradesh	Utraula	BEPL	1666	P_C_45_Utraula_2012	Sub-Critical	2012	CFBC
Uttar Pradesh	Maqsoodpur	BEPL	1667	P_C_45_Maqsoodpur_2011	Sub-Critical	2011	CFBC
Uttar Pradesh	Rausar Kothi	RPSCL	1705	P_C_300_Rosa_2009	Sub-Critical	2009	Bid Awarded
Uttar Pradesh	Rausar Kothi	RPSCL	1705	P_C_300_Rosa_2011	Sub-Critical	2011	Bid Awarded
Uttar Pradesh	Rausar Kothi	RPSCL	1705	P_C_300_Rosa_2010	Sub-Critical	2010	Bid Awarded
Uttar Pradesh	Rausar Kothi	RPSCL	1705	P_C_300_Rosa_2012	Sub-Critical	2012	Bid Awarded
Uttar Pradesh	Vidyut Nagar	UPRVUNL	2148	S_C_110_Harduaganj_1978	Sub-Critical	1978	Feasibility Study Started
Uttar Pradesh	Vidyut Nagar	UPRVUNL	2148	S_C_250_Harduaganj_2011	Sub-Critical	2011	Feasibility Study Started
Uttar Pradesh	Vidyut Nagar	UPRVUNL	2148	S_C_250_Harduaganj_2012	Sub-Critical	2012	Feasibility Study Started
Uttar Pradesh	Ambedkar Nagar	NTPC	3196	C_C_110_Tanda_1988	Sub-Critical	1988	Bid Awarded
Uttar Pradesh	Ambedkar Nagar	NTPC	3196	C_C_110_Tanda_1998	Sub-Critical	1998	Bid Awarded
Uttar Pradesh	Ambedkar Nagar	NTPC	3196	C_C_110_Tanda_1990	Sub-Critical	1990	Bid Awarded
Uttar Pradesh	Ambedkar Nagar	NTPC	3196	C_C_660_Tanda_2021	Super-Critical	2021	Bid Awarded
Uttar Pradesh	Ambedkar Nagar	NTPC	3196	C_C_660_Tanda_2019	Super-Critical	2019	Bid Awarded
Uttar Pradesh	Ambedkar Nagar	NTPC	3196	C_C_110_Tanda_1989	Sub-Critical	1989	Bid Awarded
Uttar Pradesh	Rihand Nagar	NTPC	3197	C_C_500_Rihand_1988	Sub-Critical	1988	Bid Awarded
Uttar Pradesh	Rihand Nagar	NTPC	3197	C_C_500_Rihand_2005	Sub-Critical	2005	Bid Awarded
Uttar Pradesh	Rihand Nagar	NTPC	3197	C_C_500_Rihand_2013	Sub-Critical	2013	Bid Awarded
Uttar Pradesh	Rihand Nagar	NTPC	3197	C_C_500_Rihand_2012	Sub-Critical	2012	Bid Awarded
Uttar Pradesh	Rihand Nagar	NTPC	3197	C_C_500_Rihand_1989	Sub-Critical	1989	Bid Awarded
Uttar Pradesh	Unchahar	NTPC	3677	C_C_210_Firoz Gandhi_2006	Sub-Critical	2006	
Uttar Pradesh	Unchahar	NTPC	3677	C_C_210_Firoz Gandhi_1989	Sub-Critical	1989	Bid Awarded
Uttar Pradesh	Unchahar	NTPC	3677	C_C_210_Firoz Gandhi_1999	Sub-Critical	1999	Bid Awarded
Uttar Pradesh	Unchahar	NTPC	3677	C_C_210_Firoz Gandhi_1988	Sub-Critical	1988	Bid Awarded
Uttar Pradesh	Parichha	UPRVUNL	5041	S_C_250_Parichha_2012	Sub-Critical	2012	Feasibility Study started
Uttar Pradesh	Parichha	UPRVUNL	5041	S_C_110_Parichha_1984	Sub-Critical	1984	Feasibility Study started
Uttar Pradesh	Parichha	UPRVUNL	5041	S_C_250_Parichha_2013	Sub-Critical	2013	Feasibility Study started
Uttar Pradesh	Parichha	UPRVUNL	5041	S_C_210_Parichha_2006	Sub-Critical	2006	Feasibility Study started
Uttar Pradesh	Parichha	UPRVUNL	5041	S_C_210_Parichha_2007	Sub-Critical	2007	Feasibility Study started
Uttar Pradesh	Burogaon	LPGCL	5402	P_C_660_Lalitpur_2015	Super-Critical	2015	Retendering
Uttar Pradesh	Burogaon	LPGCL	5402	P_C_660_Lalitpur_2016	Super-Critical	2016	Retendering
Uttar Pradesh	Obra	UPRVUNL	5695	S_C_200_OBRA_1979	Sub-Critical	1979	Retired
Uttar Pradesh	Obra	UPRVUNL	5695	S_C_200_OBRA_1982	Sub-Critical	1982	Retired
Uttar Pradesh	Obra	UPRVUNL	5695	S_C_200_OBRA_1977	Sub-Critical	1977	Retired
Uttar Pradesh	Prayagraj	PPGCL (Tata)	5955	P_C_660_Bara_2015	Super-Critical	2015	Bid awarded
Uttar Pradesh	Prayagraj	PPGCL (Tata)	5955	P_C_660_Bara_2016	Super-Critical	2016	Bid awarded

Uttar Pradesh	Prayagraj	PPGCL (Tata)	5955	P_C_660_Bara_2017	Super-Critical	2017	Bid awarded
Uttar Pradesh	Meja	NTPC	6671	C_C_660_Meja_2018	Super-Critical	2018	Bid awarded
West Bengal	Durgapur	DPL	3372	S_B_300_D.P.L_2008	Sub-Critical	2008	Bid Opened
West Bengal	Durgapur	DPL	3372	S_B_250_D.P.L_2014	Sub-Critical	2014	Bid Opened
West Bengal	Pujali	CESC	1468	P_C_250_Budge_1997	Sub-Critical	1997	Bid Opened
West Bengal	Pujali	CESC	1468	P_C_250_Budge_1999	Sub-Critical	1999	Bid Opened
West Bengal	Pujali	CESC	1468	P_C_250_Budge_2010	Sub-Critical	2010	Bid Opened
West Bengal	Durgapur	DVC	2695	C_C_210_Durgapur_1982	Sub-Critical	1982	Retired
West Bengal	Farakka	NTPC	3206	C_C_500_Farakka_2011	Sub-Critical	2011	Bid Awarded
West Bengal	Farakka	NTPC	3206	C_C_500_Farakka_1994	Sub-Critical	1994	Bid Awarded
West Bengal	Farakka	NTPC	3206	C_C_200_Farakka_1986	Sub-Critical	1986	Bid Awarded
West Bengal	Farakka	NTPC	3206	C_C_200_Farakka_1987	Sub-Critical	1987	Bid Awarded
West Bengal	Bandel	WBPDC	4316	S_C_60_Bandel_1965	Sub-Critical	1965	Retired
West Bengal	Bandel	WBPDC	4316	S_C_210_Bandel_1982	Sub-Critical	1982	Retired
West Bengal	East Midnapore	WBPDC	5486	S_C_210_Kolaghat_1994	Sub-Critical	1994	
West Bengal	East Midnapore	WBPDC	5486	S_C_210_Kolaghat_1986	Sub-Critical	1986	Retired
West Bengal	East Midnapore	WBPDC	5486	S_C_210_Kolaghat_1995	Sub-Critical	1995	
West Bengal	East Midnapore	WBPDC	5486	S_C_210_Kolaghat_1991	Sub-Critical	1991	
West Bengal	East Midnapore	WBPDC	5486	S_C_210_Kolaghat_1990	Sub-Critical	1990	Retired
West Bengal	East Midnapore	WBPDC	5486	S_C_210_Kolaghat_1984	Sub-Critical	1984	
West Bengal	Santaldihi	WBPDC	5752	S_C_250_Santaldih_2007	Sub-Critical	2007	Bid Opened
West Bengal	Santaldihi	WBPDC	5752	S_C_250_Santaldih_2011	Sub-Critical	2011	Bid Opened
West Bengal	Raghunathpur	DVC	5915	C_C_600_Raghunathpur_2014	Super-Critical	2014	Bid Awarded

TPS Name: Authority_Category_Capacity(MW)_TPSName_Commissioning_Year
Authority: C-Central, S-State, P-Private, Category: A, B, C
For Example: P_C_660_Bara _2017 (Authority: Private, Category: C, Capacity (MW): 660, TPS Name: Bara, Commissioning Year: 2017

Abbreviation: NTPC: National Thermal Power Corporation, APGENCO: Andhra Pradesh Power Generation Corporation Limited, HNPC: Hinduja National Power Corporation Ltd., SEIL: Sembcorp Energy India Limited, NSPCL: National Thermal Power Corporation and Steel Authority of India Limited., APL: Adani Power Limited, CSPGCL: Chhattisgarh State Power Generation Company Limited, LANCO: Lanco Amarkantak Power Limited, WPCL: Wardha Power Company Ltd, JPL: Jindal Power Ltd., DBPCL: Dainik Bhaskar Power Ltd, MCCPL: Maruti Clean Coal and Power Limited, SCPL: Spectrum Coal and Power Limited, ACB: ACB (INDIA) LTD., TRNE: TRN Energy Pvt. Ltd., RKMPPL: RKM Powergen Pvt. Limited, TOR. POW.: Torrent Power Ltd, GSECL: Gujarat State Electricity Corporation Limited, GMDCL: Gujarat Mineral Development Corparation Limited, CGPL: Coastal Gujarat Power Ltd., EPGL: Essar Power Limited, GIPCL: Gujarat Industries Power Company Limited, JhPL(HR): Jhajjar Power Ltd., HPGCL: Haryana Power Generation Corporation Limited, DVC: Damodar Valley Corporation, ADHUNIK: Adhunik Power And Natural Resources Limited, MPL: Malthon Power Limited, TATA PCL: Tata Power Company Ltd., TVNL: Tenughat Vidyut Nigam Limited, JSWEL: JSW Energy Ltd., KPCL: Karnataka Power Corporation Limited, SPL: Sasan Power Limited, JPPVL: Jal Prakash Power Ventures Limited, MPPGCL: M. P. Power Generating Corporation Limited, JHAPL: Jal Prakash Power Ventures Limited, MBPMPL: MB Power Madhya Pradesh Ltd, MAHAGENCO: Maharashtra State Power Generation Company Limited, TROMBAY TPS: Tata Power Company Ltd., GMR ENERG: Gmr Energy Limited, RATTANINDIA: Rattan India Power Limited, IBPIL: Ind Bharath Power Infra Limited, JITPL: Jindal India Thermal Power Ltd., SEL: Sterlite Energy Ltd., NPL: Nabha Power Ltd., TSPL: Talwandi Sabo Power Limited, PSPCL: Punjab State Power Corp. Ltd., GPGSL (GVK):, GVK Power (Goindwal Sahib) Limited, RRVUNL: Rajasthan Rajya Vidyut Utpadan Nigam Limited, RWPL (JSW): Raj West Power Limited, NLC: Neyveli Lignite Corporation, NTECL: NTPC Tamilnadu Energy Company Limited, TANGEDCO: Tamil Nadu Generation & Distribution Corp. Ltd., CEPL: Coastal Energen Pvt. Ltd., NEYVELI LIGNITE: Neyveli Lignite Corporation Limited, TAQA: TAQA Neyveli Power Company Pvt. Ltd, IL&FS: IL & FS Tamil Nadu Power Company Limited, TSGENCO: Telangana State Genco, SCCL: Singareni Collieries Co Ltd, BEPL: Bajaj Energy Pvt. Ltd., RPSCL: Rosa Power Supply Co. Ltd., UPRVUNL: Uttar Pradesh Rajya Vidyut Utpadan Nigam Limited, LPGCL: Lalitpur Power Generation Co Ltd, PPGCL (Tata): Prayagraj Power Generation Company Ltd., DPL: Durgapur Projects Limited, CESC: Calcutta Electric Supply Co. Ltd., WBPDC: West Bengal Power Development Corp. Limited

377

565

Annexure - A2

Graphical visualization of OCEMS data generated by TPP.

Explanation of plot is as follows:

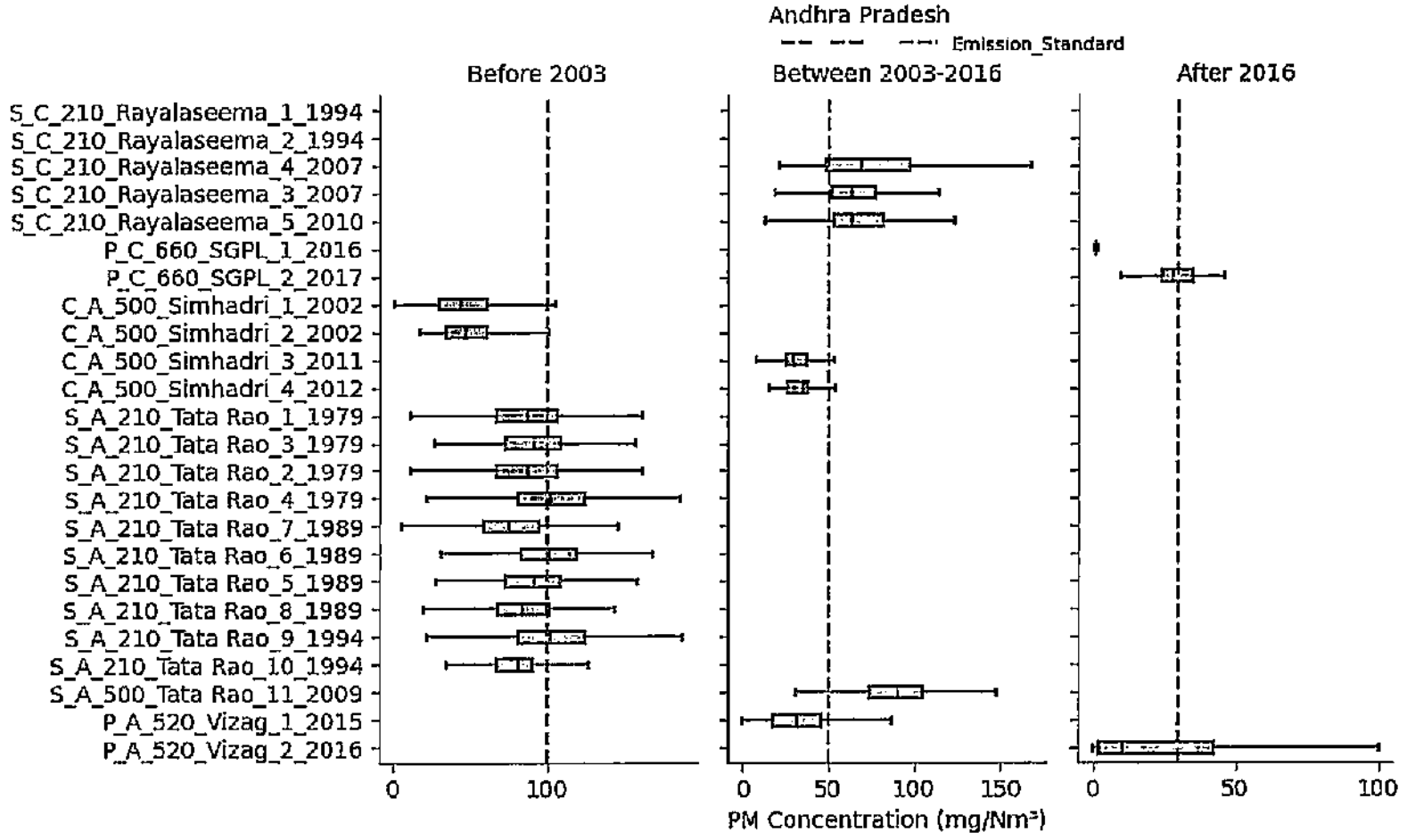
There are three box plots each for TPS:
- installed before 2003,
- between 2003 to 2016 and those
- beyond 2016.

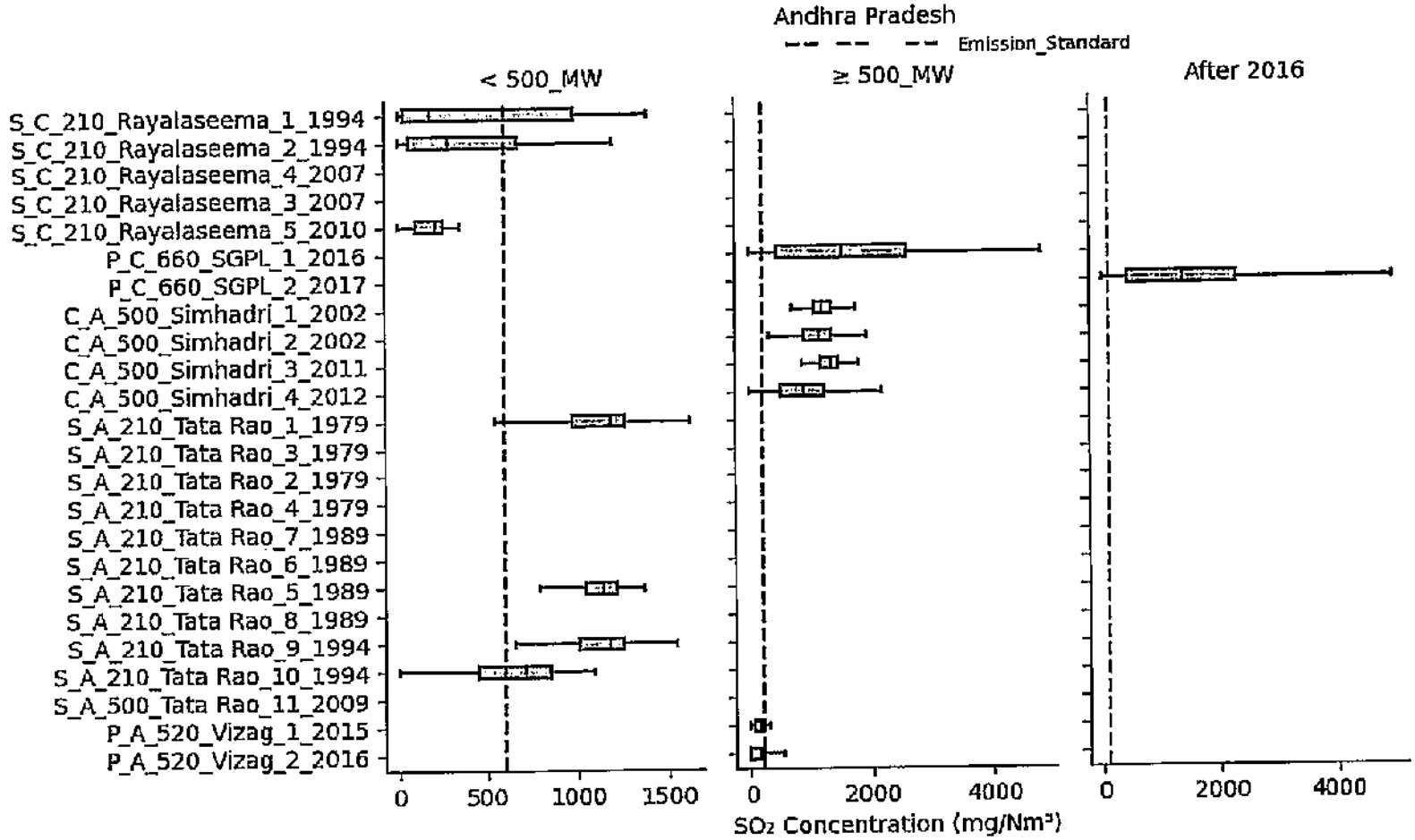
On Y-axis, the name of power plant stack is given. It can be seen that in each plot, a vertical dashed coloured line is given, which is the regulatory limit of emission in mg/Nm^3. For the case of Particulate Matter (PM) the limit of emission rate is:

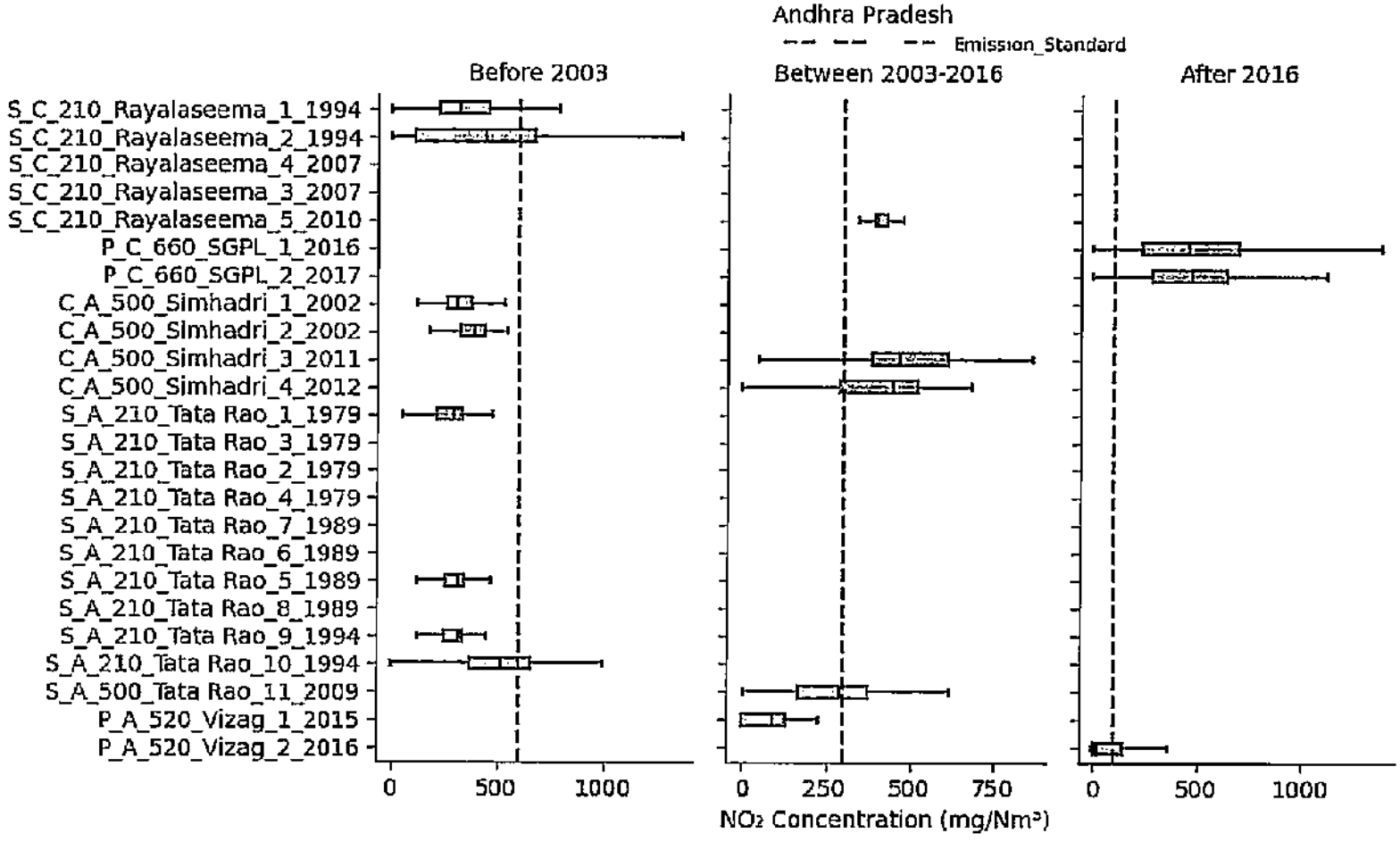
- 100 mg/Nm^3, for TPP commissioned before 2003;
- 50 mg/Nm^3, for TPP commissioned between 2003 and 2016;
- 30 mg/Nm^3, for new TPS after 2016 have a regulatory limit of 30 mg/Nm^3.

The plots are made for PM, SO_2 and NO_2 emission rates in three different pages / plots.

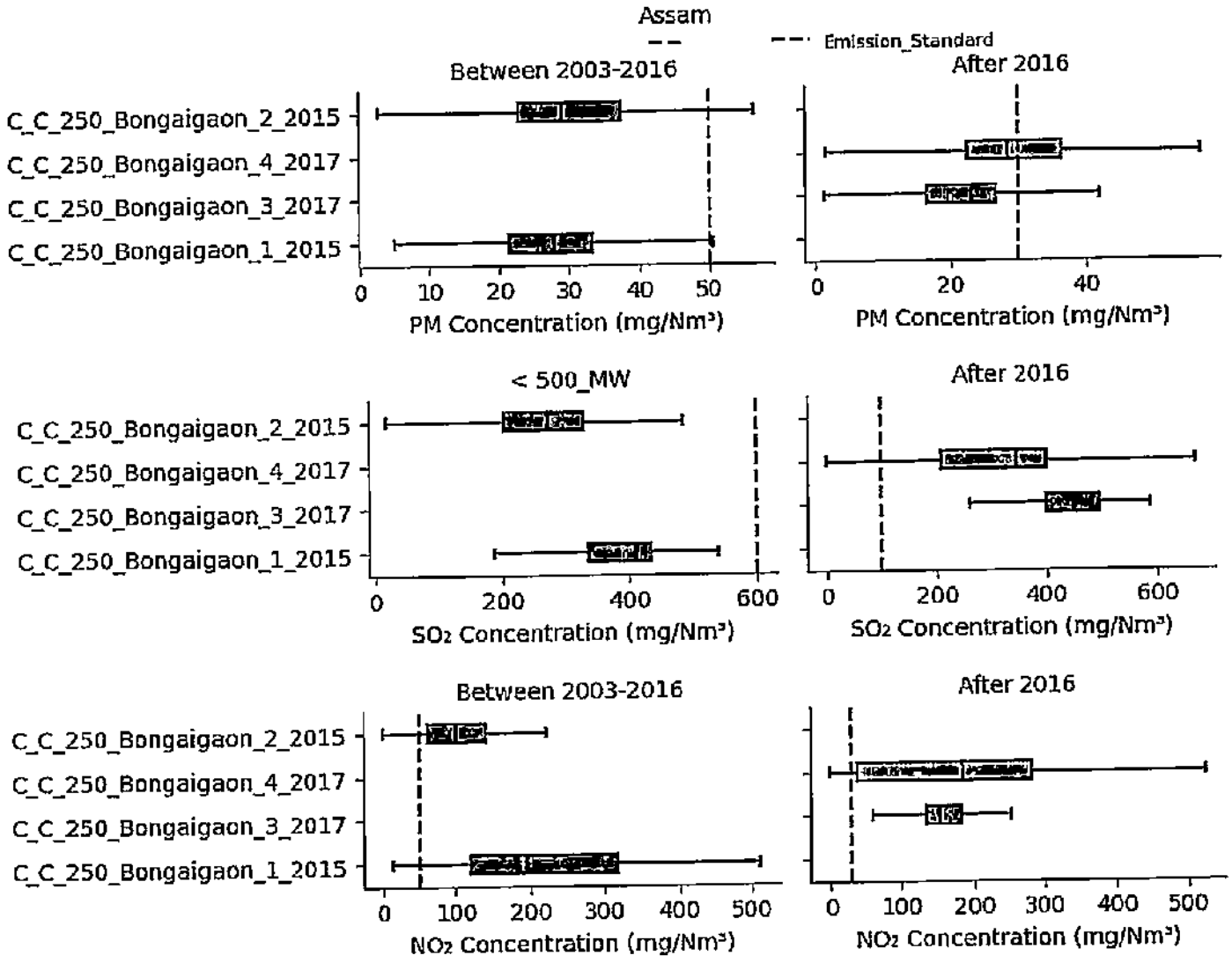
Andhra Pradesh



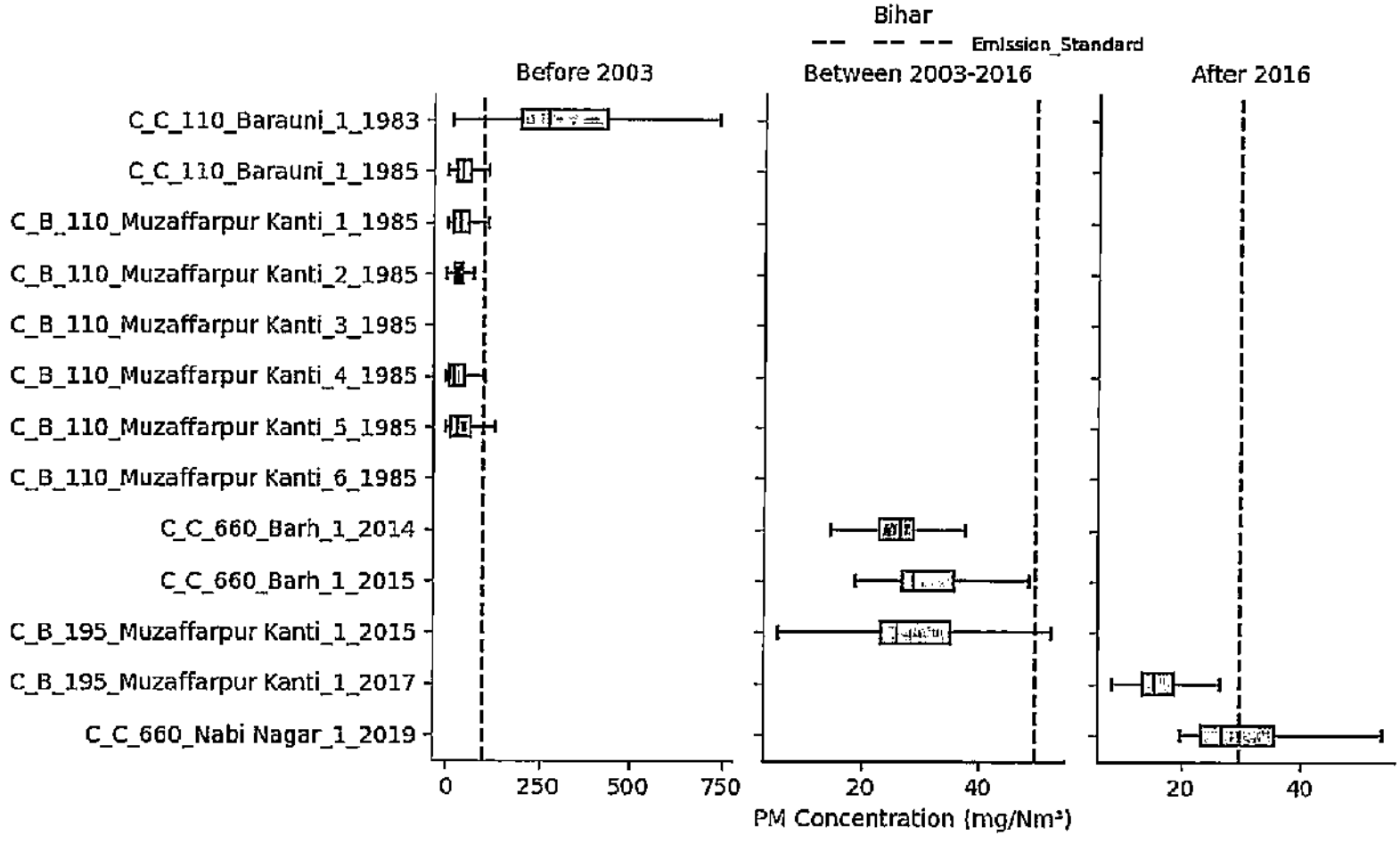

Andhra Pradesh
Emission_Standard
< 500_MW
≥ 500_MW
After 2016
S_C_210_Rayalaseema_1_1994
S_C_210_Rayalaseema_2_1994
S_C_210_Rayalaseema_4_2007
S_C_210_Rayalaseema_3_2007
S_C_210_Rayalaseema_5_2010
P_C_660_SGPL_1_2016
P_C_660_SGPL_2_2017
C_A_500_Simhadri_1_2002
C_A_500_Simhadri_2_2002
C_A_500_Simhadri_3_2011
C_A_500_Simhadri_4_2012
S_A_210_Tata Rao_1_1979
S_A_210_Tata Rao_3_1979
S_A_210_Tata Rao_2_1979
S_A_210_Tata Rao_4_1979
S_A_210_Tata Rao_7_1989
S_A_210_Tata Rao_6_1989
S_A_210_Tata Rao_5_1989
S_A_210_Tata Rao_8_1989
S_A_210_Tata Rao_9_1994
S_A_210_Tata Rao_10_1994
S_A_500_Tata Rao_11_2009
P_A_520_Vizag_1_2015
P_A_520_Vizag_2_2016
0
500
1000
1500
0
2000
4000
0
2000
4000
SO2 Concentration (mg/Nm3)

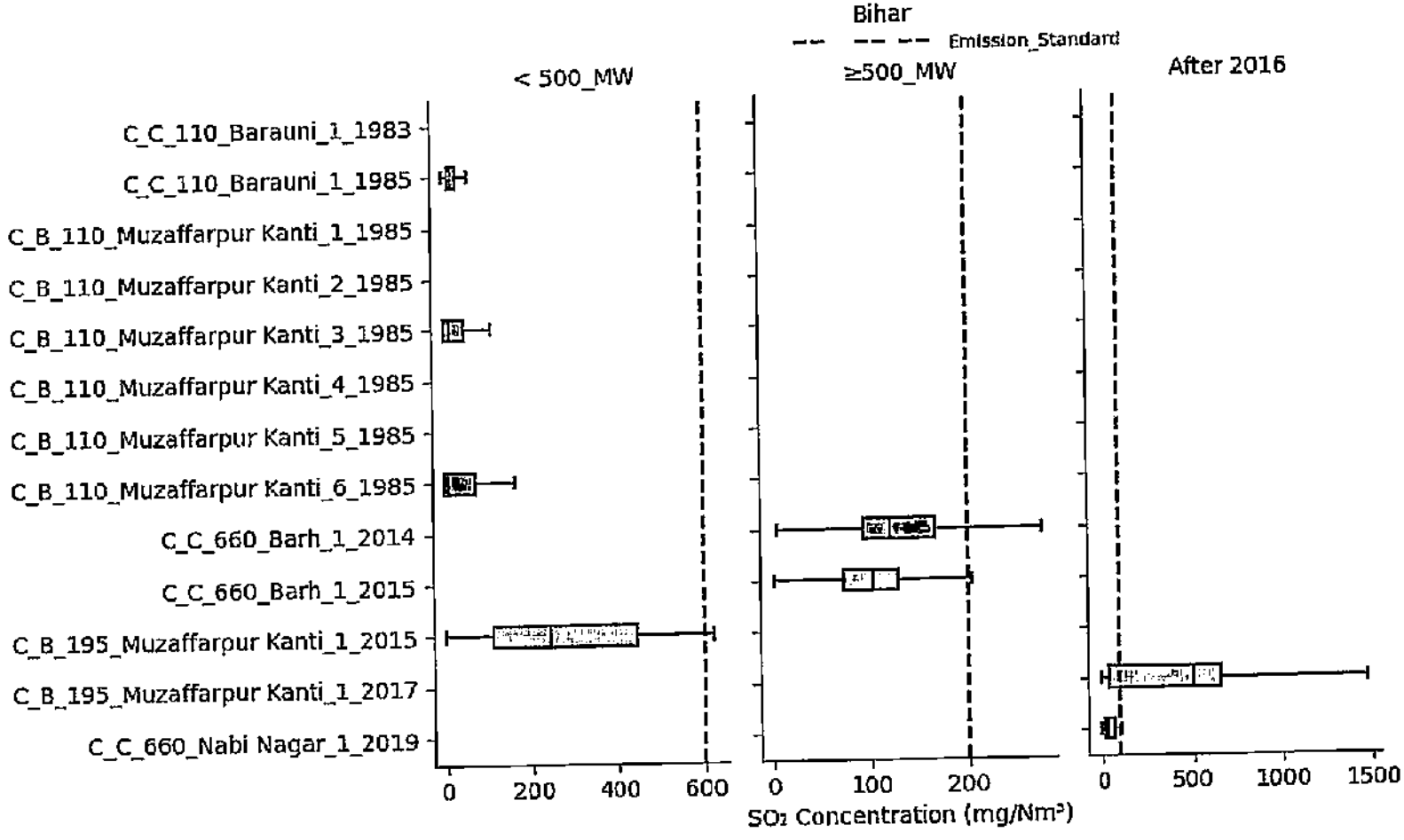

Andhra Pradesh
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Rayalaseema_1_1994
S_C_210_Rayalaseema_2_1994
S_C_210_Rayalaseema_4_2007
S_C_210_Rayalaseema_3_2007
S_C_210_Rayalaseema_5_2010
P_C_660_SGPL_1_2016
P_C_660_SGPL_2_2017
C_A_500_Simhadri_1_2002
C_A_500_Simhadri_2_2002
C_A_500_Simhadri_3_2011
C_A_500_Simhadri_4_2012
S_A_210_Tata Rao_1_1979
S_A_210_Tata Rao_3_1979
S_A_210_Tata Rao_2_1979
S_A_210_Tata Rao_4_1979
S_A_210_Tata Rao_7_1989
S_A_210_Tata Rao_6_1989
S_A_210_Tata Rao_5_1989
S_A_210_Tata Rao_8_1989
S_A_210_Tata Rao_9_1994
S_A_210_Tata Rao_10_1994
S_A_500_Tata Rao_11_2009
P_A_520_Vizag_1_2015
P_A_520_Vizag_2_2016
0
500
1000
0
250
500
750
0
500
1000
NO₂ Concentration (mg/Nm³)

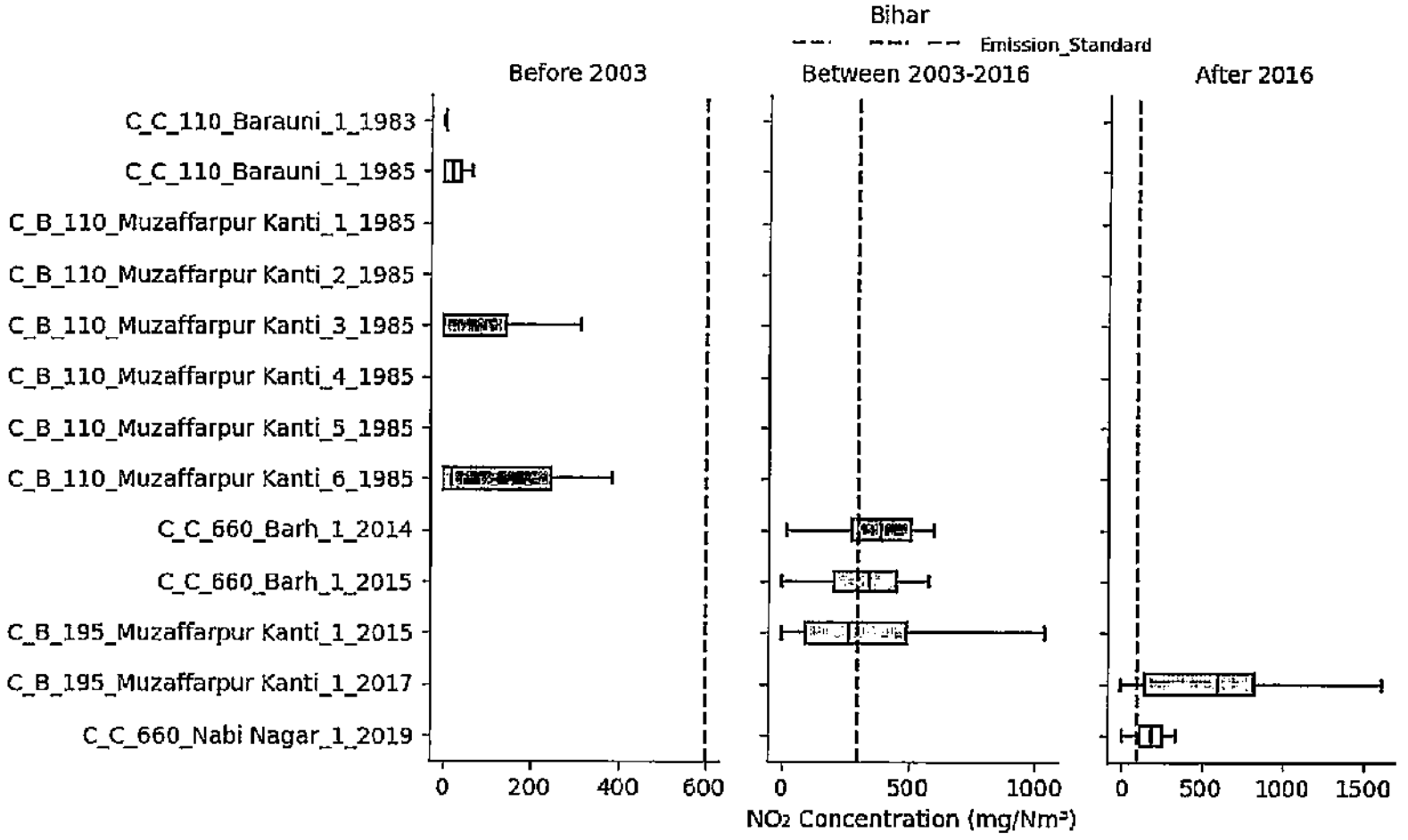
Assam


Assam
Emission_Standard
Between 2003-2016
After 2016
C_C_250_Bongaigaon_2_2015
C_C_250_Bongaigaon_4_2017
C_C_250_Bongaigaon_3_2017
C_C_250_Bongaigaon_1_2015
0 10 20 30 40 50
PM Concentration (mg/Nm³)
0 20 40
PM Concentration (mg/Nm³)
< 500_MW
After 2016
0 200 400 600
SO₂ Concentration (mg/Nm³)
0 200 400 600
SO₂ Concentration (mg/Nm³)
Between 2003-2016
After 2016
0 100 200 300 400 500
NO₂ Concentration (mg/Nm³)
0 100 200 300 400 500
NO₂ Concentration (mg/Nm³)

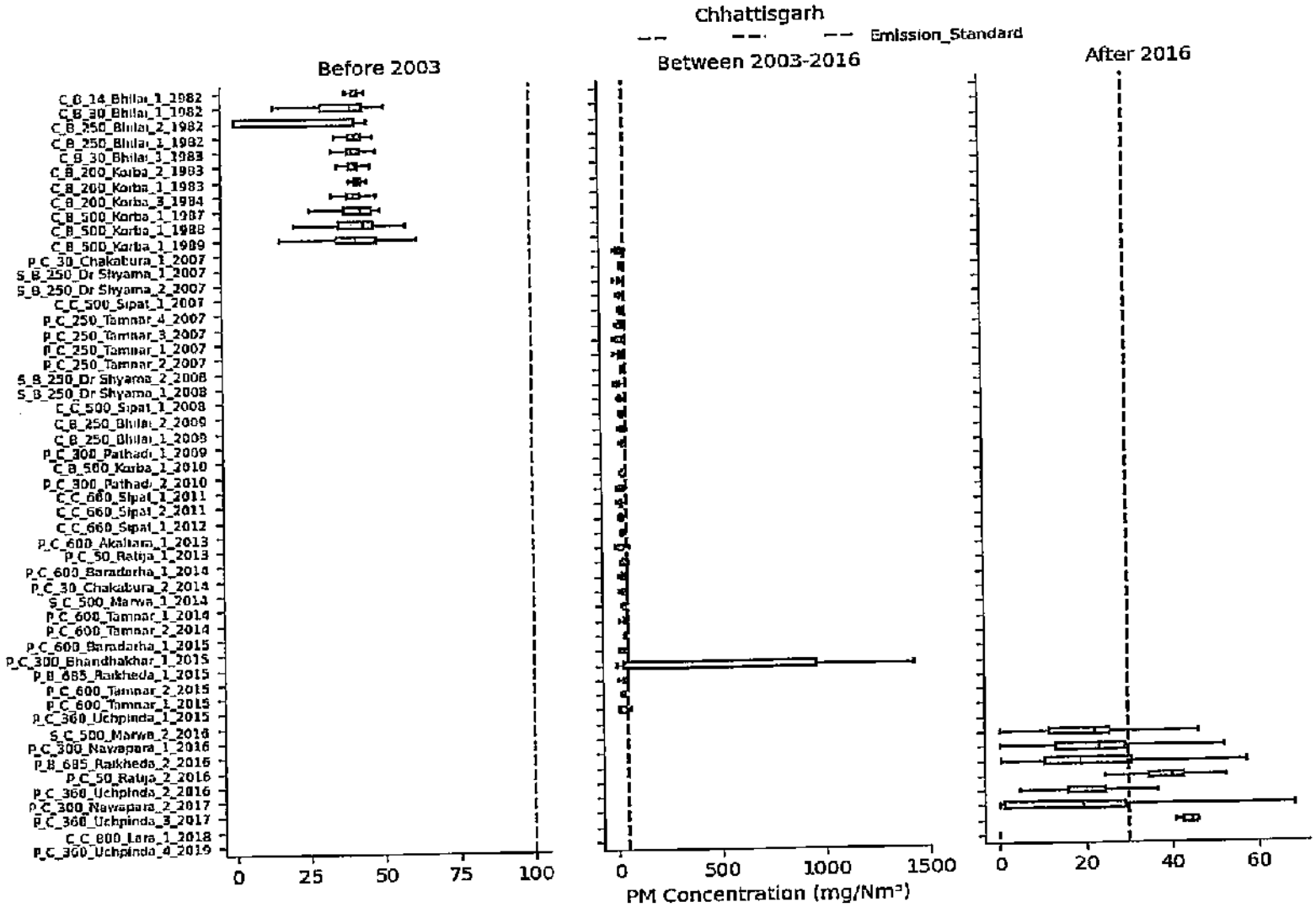
Bihar

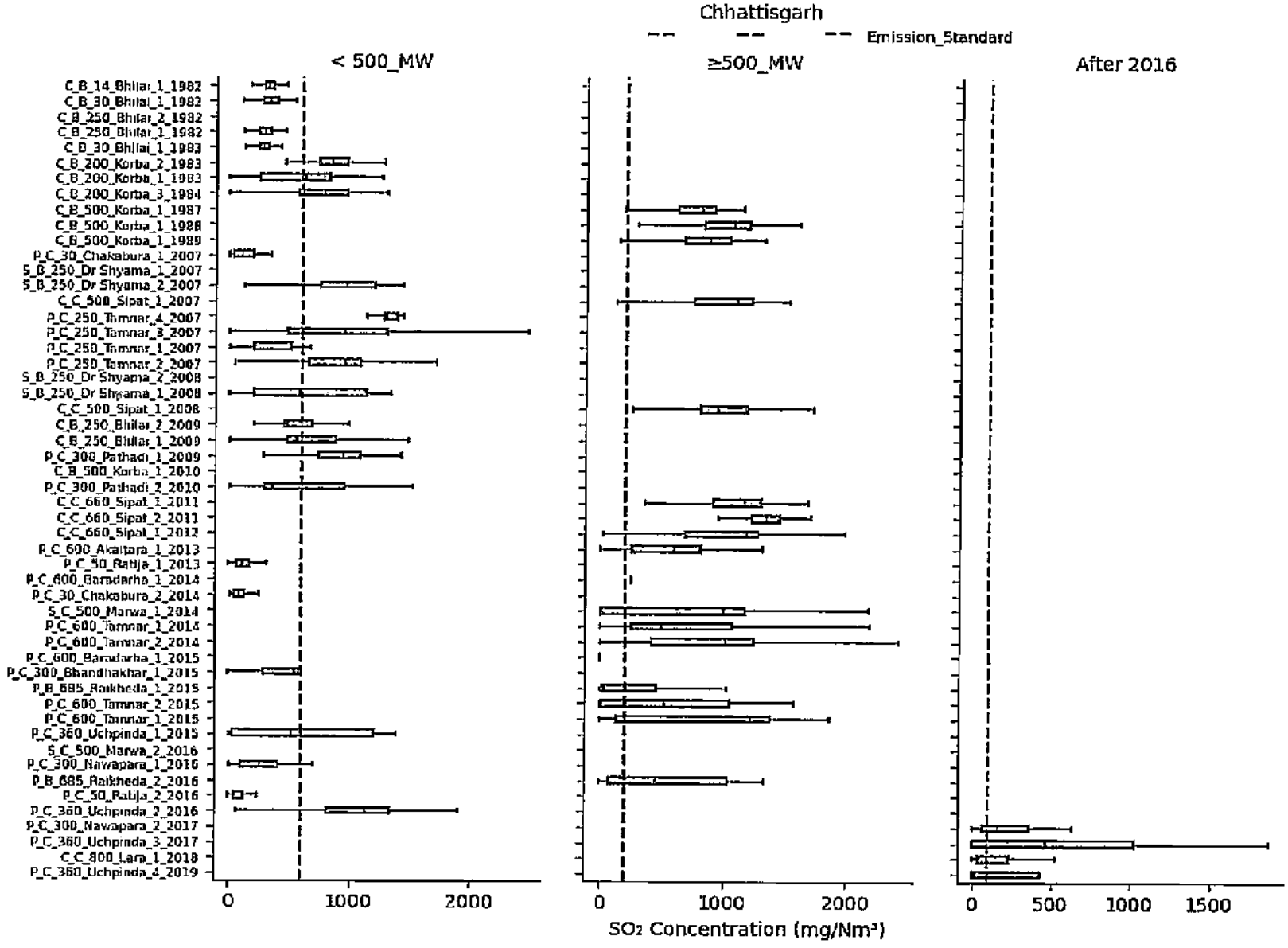

Bihar
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_C_110_Barauni_1_1983
C_C_110_Barauni_1_1985
C_B_110_Muzaffarpur Kanti_1_1985
C_B_110_Muzaffarpur Kanti_2_1985
C_B_110_Muzaffarpur Kanti_3_1985
C_B_110_Muzaffarpur Kanti_4_1985
C_B_110_Muzaffarpur Kanti_5_1985
C_B_110_Muzaffarpur Kanti_6_1985
C_C_660_Barh_1_2014
C_C_660_Barh_1_2015
C_B_195_Muzaffarpur Kanti_1_2015
C_B_195_Muzaffarpur Kanti_1_2017
C_C_660_Nabi Nagar_1_2019
0
250
500
750
20
40
20
40
PM Concentration (mg/Nm³)

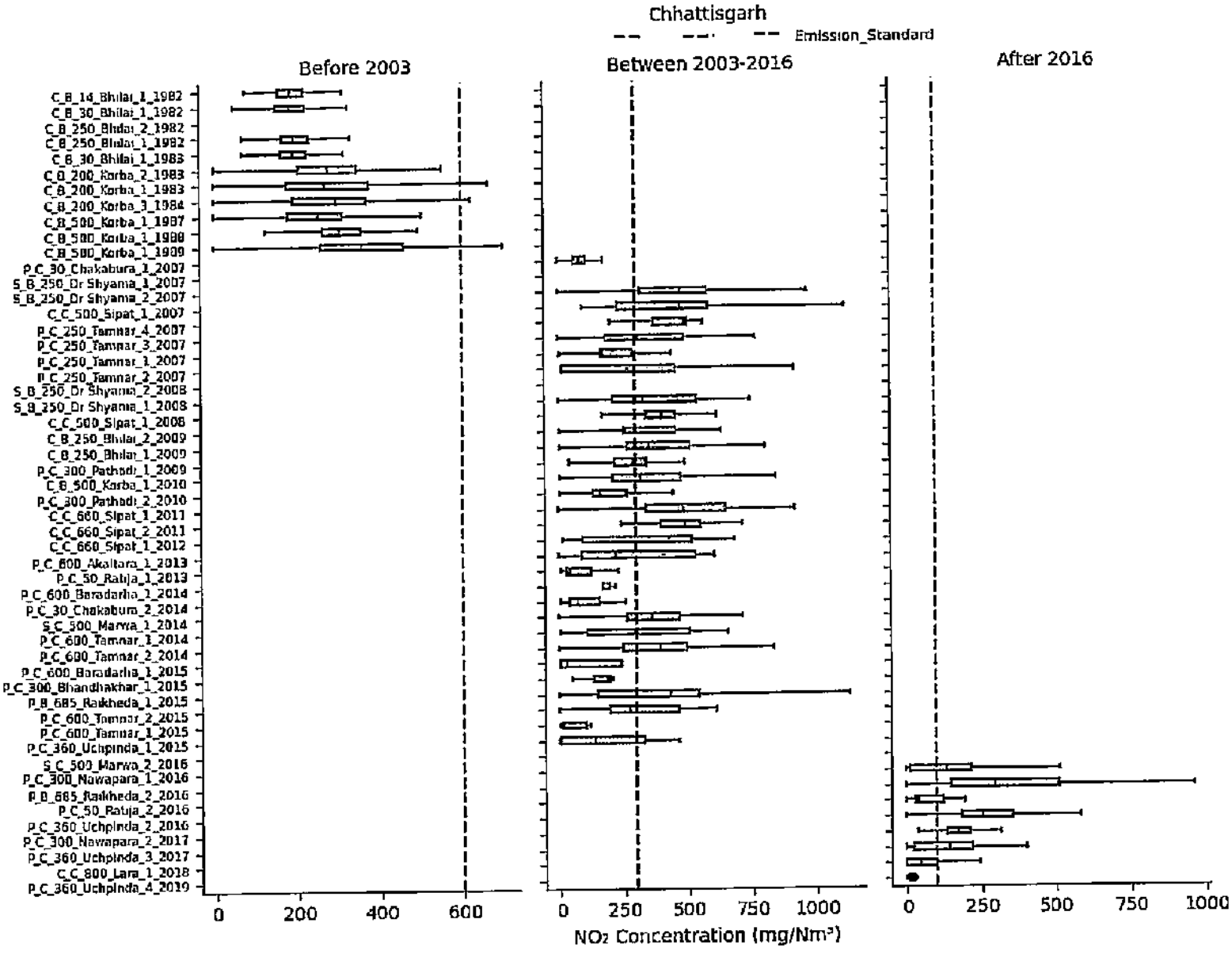

Bihar
Emission_Standard
< 500_MW
≥500_MW
After 2016
C_C_110_Barauni_1_1983
C_C_110_Barauni_1_1985
C_B_110_Muzaffarpur Kanti_1_1985
C_B_110_Muzaffarpur Kanti_2_1985
C_B_110_Muzaffarpur Kanti_3_1985
C_B_110_Muzaffarpur Kanti_4_1985
C_B_110_Muzaffarpur Kanti_5_1985
C_B_110_Muzaffarpur Kanti_6_1985
C_C_660_Barh_1_2014
C_C_660_Barh_1_2015
C_B_195_Muzaffarpur Kanti_1_2015
C_B_195_Muzaffarpur Kanti_1_2017
C_C_660_Nabi Nagar_1_2019
0
200
400
600
0
100
200
0
500
1000
1500
SO₂ Concentration (mg/Nm³)


Bihar
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_C_110_Barauni_1_1983
C_C_110_Barauni_1_1985
C_B_110_Muzaffarpur Kanti_1_1985
C_B_110_Muzaffarpur Kanti_2_1985
C_B_110_Muzaffarpur Kanti_3_1985
C_B_110_Muzaffarpur Kanti_4_1985
C_B_110_Muzaffarpur Kanti_5_1985
C_B_110_Muzaffarpur Kanti_6_1985
C_C_660_Barh_1_2014
C_C_660_Barh_1_2015
C_B_195_Muzaffarpur Kanti_1_2015
C_B_195_Muzaffarpur Kanti_1_2017
C_C_660_Nabi Nagar_1_2019
0
200
400
600
0
500
1000
0
500
1000
1500
NO2 Concentration (mg/Nm3)

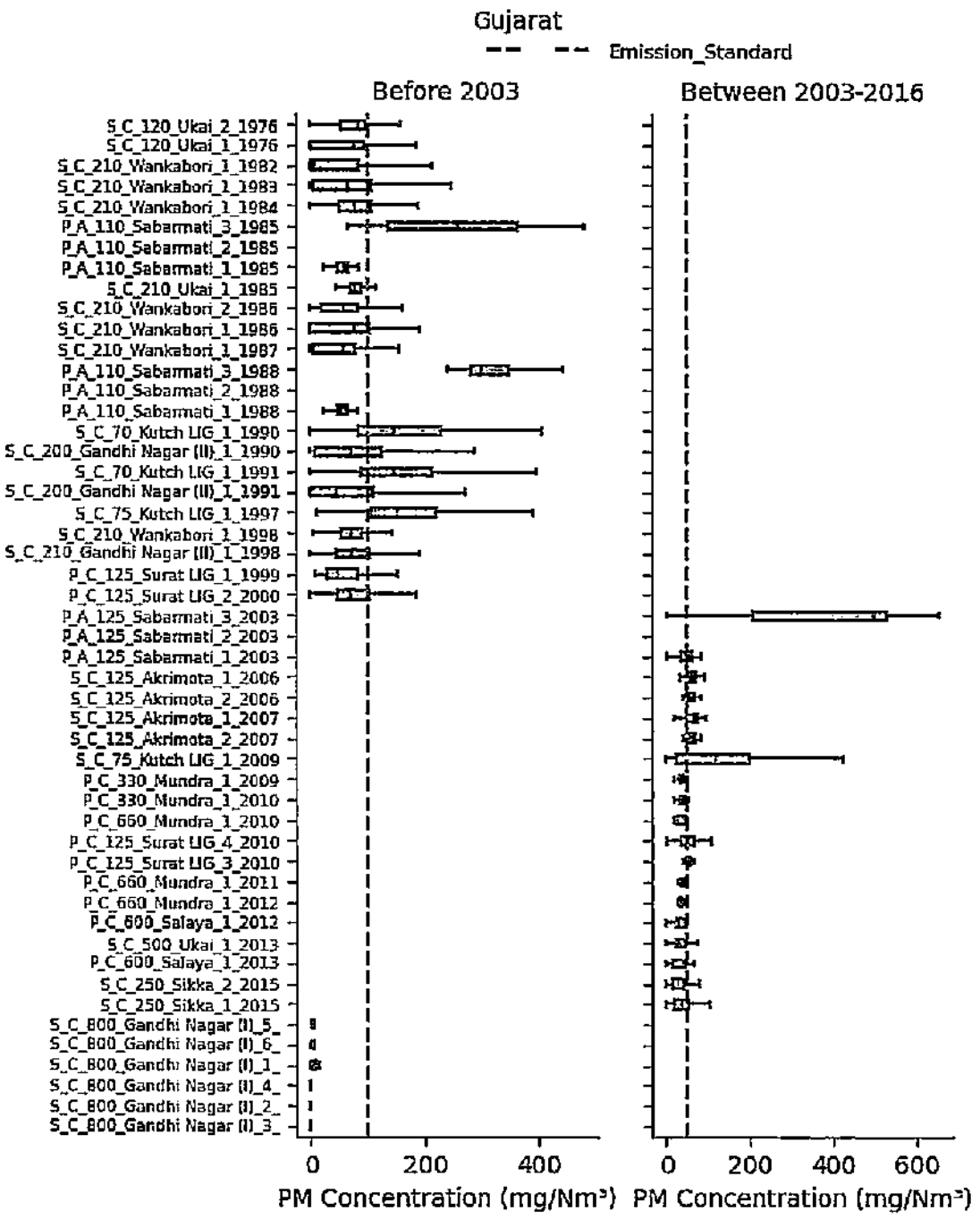
Chhattisgarh

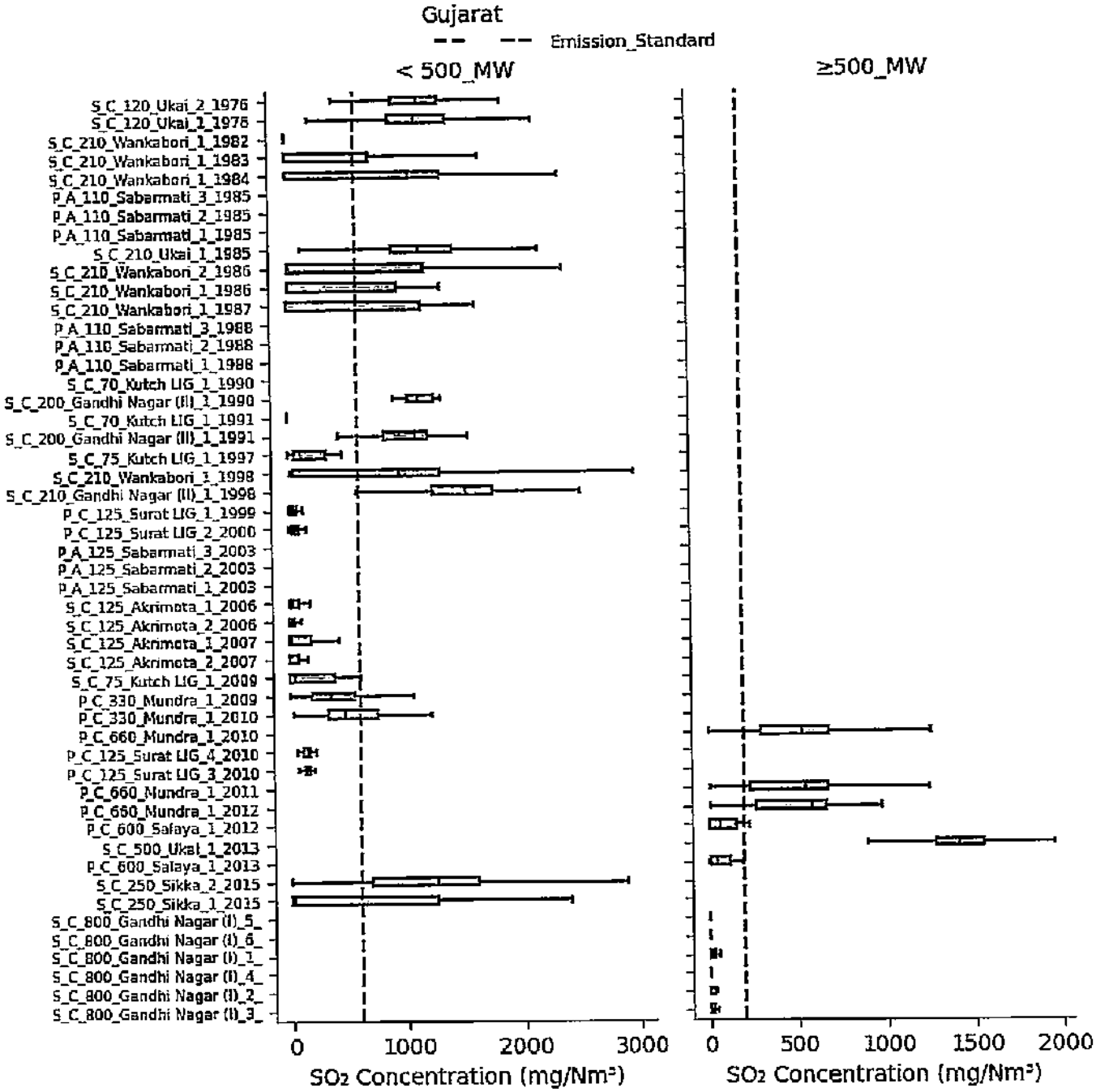


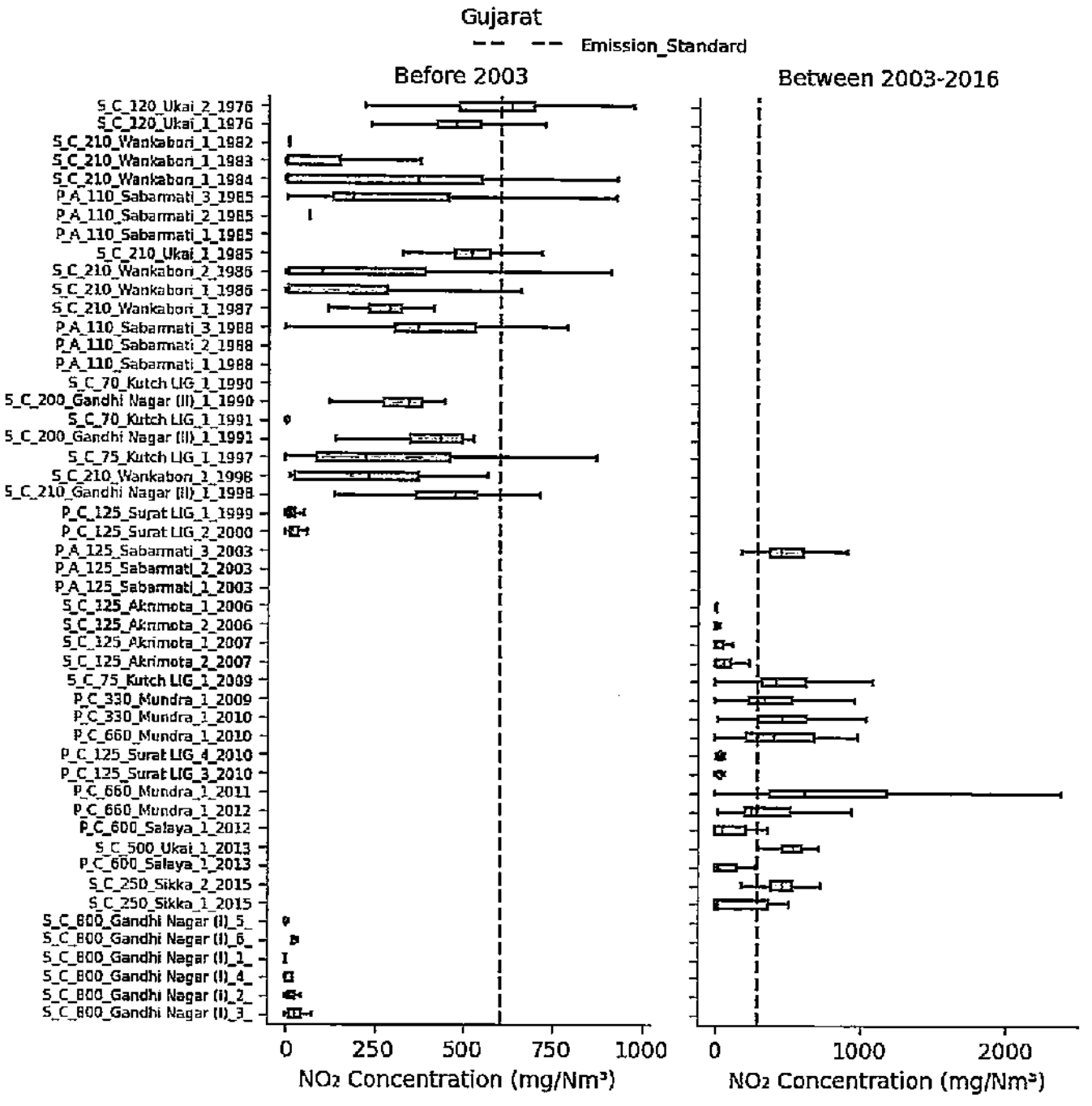

Chhattisgarh
Emission_Standard
< 500_MW
≥500_MW
After 2016
C_B_14_Bhilai_1_1982
C_B_30_Bhilai_1_1982
C_B_250_Bhilai_2_1982
C_B_250_Bhilai_1_1982
C_B_30_Bhilai_1_1983
C_B_200_Korba_2_1983
C_B_200_Korba_1_1983
C_B_200_Korba_3_1984
C_B_500_Korba_1_1987
C_B_500_Korba_1_1988
C_B_500_Korba_1_1989
P_C_30_Chakabura_1_2007
S_B_250_Dr Shyama_1_2007
S_B_250_Dr Shyama_2_2007
C_C_500_Sipat_1_2007
P_C_250_Tamnar_4_2007
P_C_250_Tamnar_3_2007
P_C_250_Tamnar_1_2007
P_C_250_Tamnar_2_2007
S_B_250_Dr Shyama_2_2008
S_B_250_Dr Shyama_1_2008
C_C_500_Sipat_1_2008
C_B_250_Bhilai_2_2009
C_B_250_Bhilai_1_2009
P_C_300_Pathadi_1_2009
C_B_500_Korba_1_2010
P_C_300_Pathadi_2_2010
C_C_660_Sipat_1_2011
C_C_660_Sipat_2_2011
C_C_660_Sipat_1_2012
P_C_600_Akaltara_1_2013
P_C_50_Ratija_1_2013
P_C_600_Baradarha_1_2014
P_C_30_Chakabura_2_2014
S_C_500_Marwa_1_2014
P_C_600_Tamnar_1_2014
P_C_600_Tamnar_2_2014
P_C_600_Baradarha_1_2015
P_C_300_Bhandhakhar_1_2015
P_B_685_Raikheda_1_2015
P_C_600_Tamnar_2_2015
P_C_600_Tamnar_1_2015
P_C_360_Uchpinda_1_2015
S_C_500_Marwa_2_2016
P_C_300_Nawapara_1_2016
P_B_685_Raikheda_2_2016
P_C_50_Ratija_2_2016
P_C_360_Uchpinda_2_2016
P_C_300_Nawapara_2_2017
P_C_360_Uchpinda_3_2017
C_C_800_Lara_1_2018
P_C_360_Uchpinda_4_2019
0
1000
2000
0
1000
2000
0
500
1000
1500
SO2 Concentration (mg/Nm3)


Chhattisgarh
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_B_14_Bhilai_1_1982
C_B_30_Bhilai_1_1982
C_B_250_Bhilai_2_1982
C_B_250_Bhilai_1_1982
C_B_30_Bhilai_1_1983
C_B_200_Korba_2_1983
C_B_200_Korba_1_1983
C_B_200_Korba_3_1984
C_B_500_Korba_1_1987
C_B_500_Korba_1_1988
C_B_500_Korba_1_1989
P_C_30_Chakabura_1_2007
S_B_250_Dr Shyama_1_2007
S_B_250_Dr Shyama_2_2007
C_C_500_Sipat_1_2007
P_C_250_Tamnar_4_2007
P_C_250_Tamnar_3_2007
P_C_250_Tamnar_1_2007
P_C_250_Tamnar_2_2007
S_B_250_Dr Shyama_2_2008
S_B_250_Dr Shyama_1_2008
C_C_500_Sipat_1_2008
C_B_250_Bhilai_2_2009
C_B_250_Bhilai_1_2009
P_C_300_Pathadi_1_2009
C_B_500_Korba_1_2010
P_C_300_Pathadi_2_2010
C_C_660_Sipat_1_2011
C_C_660_Sipat_2_2011
C_C_660_Sipat_1_2012
P_C_600_Akaltara_1_2013
P_C_50_Ratija_1_2013
P_C_600_Baradarha_1_2014
P_C_30_Chakabura_2_2014
S_C_500_Marwa_1_2014
P_C_600_Tamnar_1_2014
P_C_600_Tamnar_2_2014
P_C_600_Baradarha_1_2015
P_C_300_Bhandhakhar_1_2015
P_B_685_Raikheda_1_2015
P_C_600_Tamnar_2_2015
P_C_600_Tamnar_1_2015
P_C_360_Uchpinda_1_2015
S_C_500_Marwa_2_2016
P_C_300_Nawapara_1_2016
P_B_685_Raikheda_2_2016
P_C_50_Ratija_2_2016
P_C_360_Uchpinda_2_2016
P_C_300_Nawapara_2_2017
P_C_360_Uchpinda_3_2017
C_C_800_Lara_1_2018
P_C_360_Uchpinda_4_2019
0
200
400
600
0
250
500
750
1000
0
250
500
750
1000
NO2 Concentration (mg/Nm3)

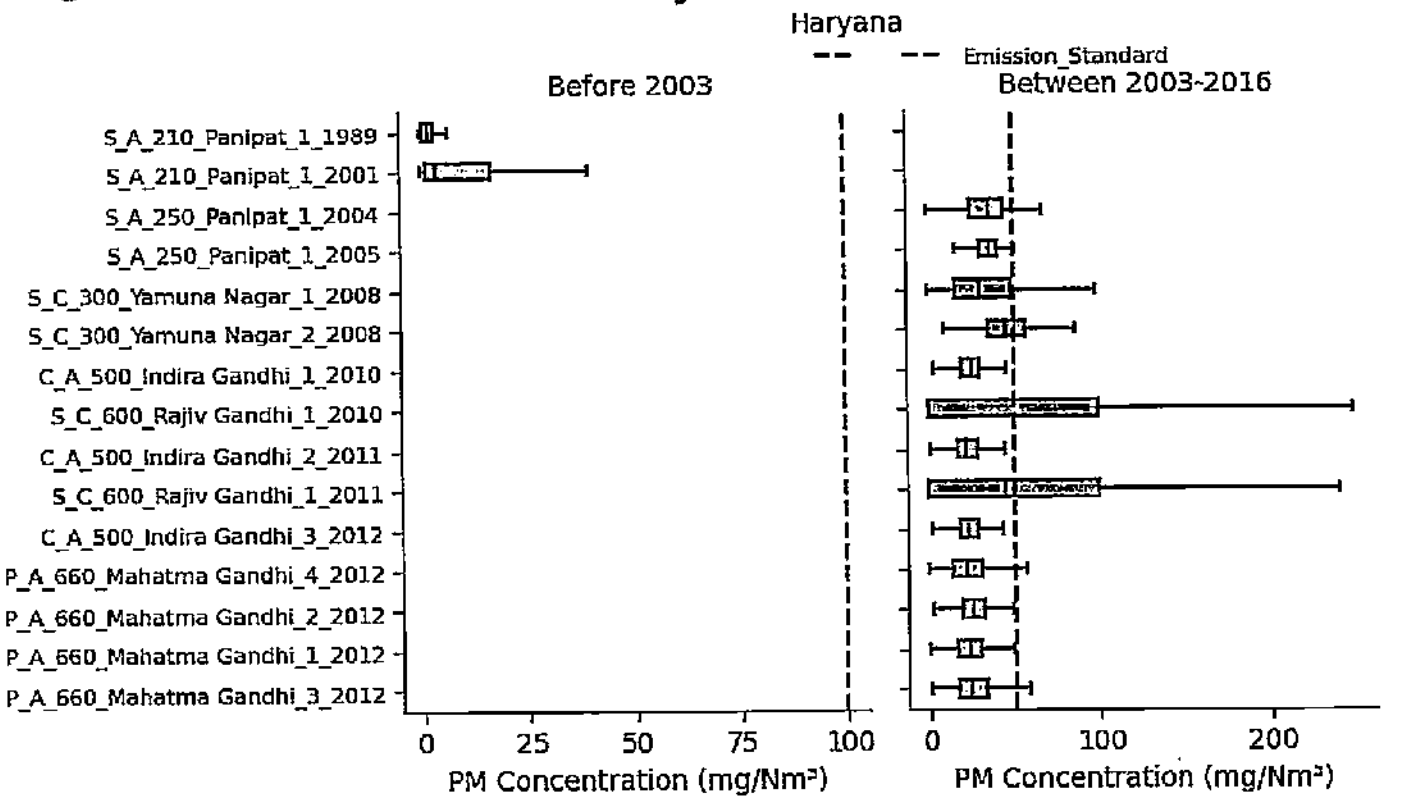
Gujarat

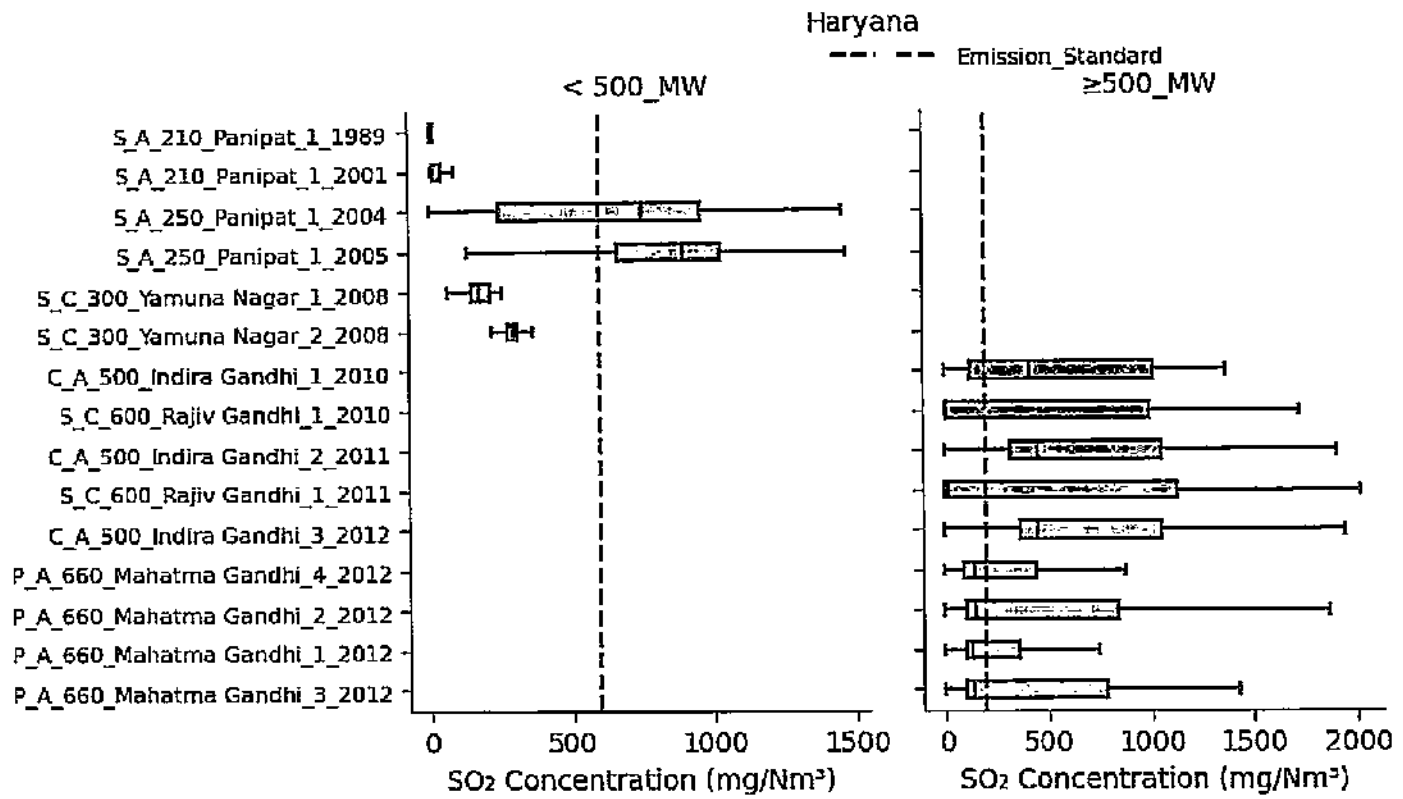

Gujarat
Emission_Standard
Before 2003
Between 2003-2016
S_C_120_Ukai_2_1976
S_C_120_Ukai_1_1976
S_C_210_Wankabori_1_1982
S_C_210_Wankabori_1_1983
S_C_210_Wankabori_1_1984
P_A_110_Sabarmati_3_1985
P_A_110_Sabarmati_2_1985
P_A_110_Sabarmati_1_1985
S_C_210_Ukai_1_1985
S_C_210_Wankabori_2_1986
S_C_210_Wankabori_1_1986
S_C_210_Wankabori_1_1987
P_A_110_Sabarmati_3_1988
P_A_110_Sabarmati_2_1988
P_A_110_Sabarmati_1_1988
S_C_70_Kutch LIG_1_1990
S_C_200_Gandhi Nagar (II)_1_1990
S_C_70_Kutch LIG_1_1991
S_C_200_Gandhi Nagar (II)_1_1991
S_C_75_Kutch LIG_1_1997
S_C_210_Wankabori_1_1998
S_C_210_Gandhi Nagar (II)_1_1998
P_C_125_Surat LIG_1_1999
P_C_125_Surat LIG_2_2000
P_A_125_Sabarmati_3_2003
P_A_125_Sabarmati_2_2003
P_A_125_Sabarmati_1_2003
S_C_125_Akrimota_1_2006
S_C_125_Akrimota_2_2006
S_C_125_Akrimota_1_2007
S_C_125_Akrimota_2_2007
S_C_75_Kutch LIG_1_2009
P_C_330_Mundra_1_2009
P_C_330_Mundra_1_2010
P_C_660_Mundra_1_2010
P_C_125_Surat LIG_4_2010
P_C_125_Surat LIG_3_2010
P_C_660_Mundra_1_2011
P_C_660_Mundra_1_2012
P_C_600_Salaya_1_2012
S_C_500_Ukai_1_2013
P_C_600_Salaya_1_2013
S_C_250_Sikka_2_2015
S_C_250_Sikka_1_2015
S_C_800_Gandhi Nagar (I)_5_
S_C_800_Gandhi Nagar (I)_6_
S_C_800_Gandhi Nagar (I)_1_
S_C_800_Gandhi Nagar (I)_4_
S_C_800_Gandhi Nagar (I)_2_
S_C_800_Gandhi Nagar (I)_3_
0
200
400
0
200
400
600
PM Concentration (mg/Nm³)
PM Concentration (mg/Nm³)

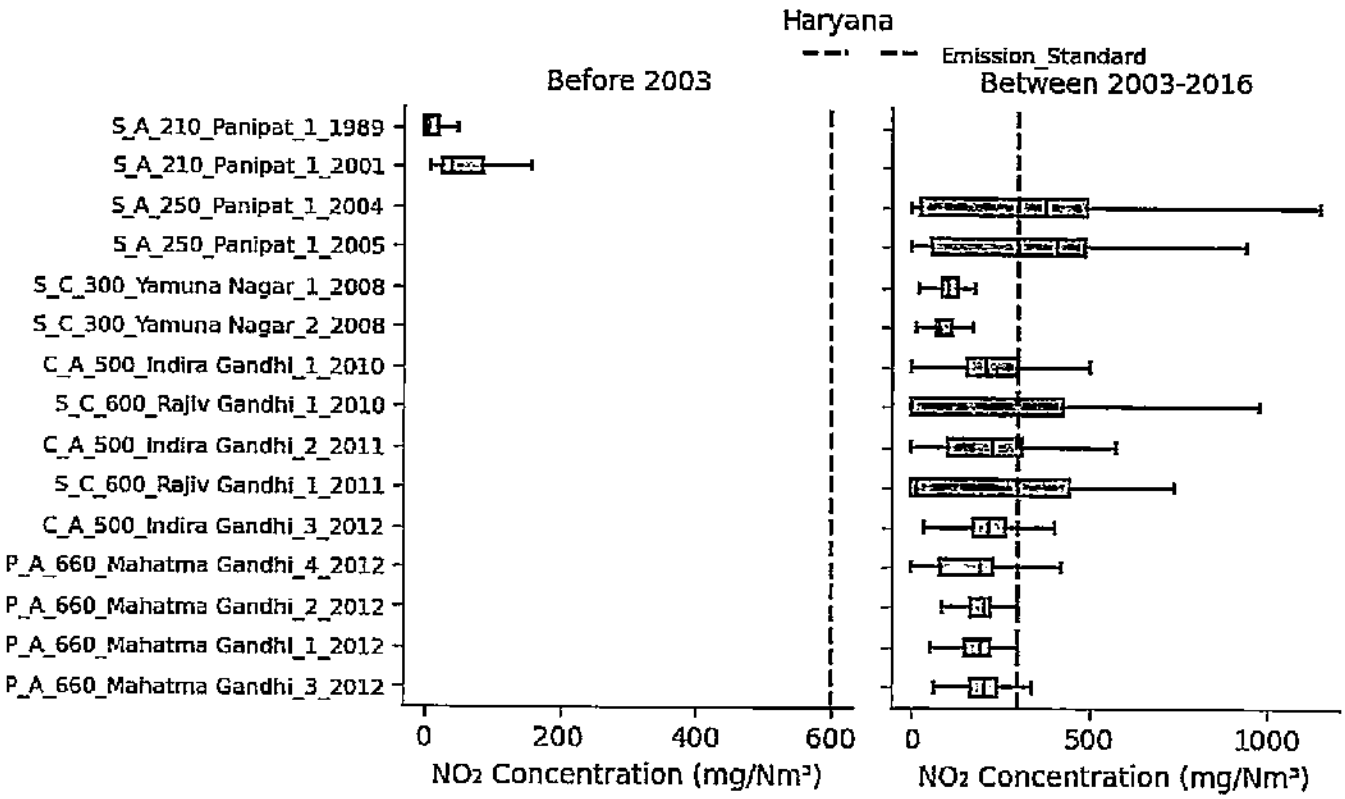

Gujarat
Emission_Standard
< 500_MW
≥500_MW
S_C_120_Ukai_2_1976
S_C_120_Ukai_1_1976
S_C_210_Wankabori_1_1982
S_C_210_Wankabori_1_1983
S_C_210_Wankabori_1_1984
P_A_110_Sabarmati_3_1985
P_A_110_Sabarmati_2_1985
P_A_110_Sabarmati_1_1985
S_C_210_Ukai_1_1985
S_C_210_Wankabori_2_1986
S_C_210_Wankabori_1_1986
S_C_210_Wankabori_1_1987
P_A_110_Sabarmati_3_1988
P_A_110_Sabarmati_2_1988
P_A_110_Sabarmati_1_1988
S_C_70_Kutch LIG_1_1990
S_C_200_Gandhi Nagar (II)_1_1990
S_C_70_Kutch LIG_1_1991
S_C_200_Gandhi Nagar (II)_1_1991
S_C_75_Kutch LIG_1_1997
S_C_210_Wankabori_1_1998
S_C_210_Gandhi Nagar (II)_1_1998
P_C_125_Surat LIG_1_1999
P_C_125_Surat LIG_2_2000
P_A_125_Sabarmati_3_2003
P_A_125_Sabarmati_2_2003
P_A_125_Sabarmati_1_2003
S_C_125_Akrimota_1_2006
S_C_125_Akrimota_2_2006
S_C_125_Akrimota_1_2007
S_C_125_Akrimota_2_2007
S_C_75_Kutch LIG_1_2009
P_C_330_Mundra_1_2009
P_C_330_Mundra_1_2010
P_C_660_Mundra_1_2010
P_C_125_Surat LIG_4_2010
P_C_125_Surat LIG_3_2010
P_C_660_Mundra_1_2011
P_C_660_Mundra_1_2012
P_C_600_Salaya_1_2012
S_C_500_Ukai_1_2013
P_C_600_Salaya_1_2013
S_C_250_Sikka_2_2015
S_C_250_Sikka_1_2015
S_C_800_Gandhi Nagar (I)_5_
S_C_800_Gandhi Nagar (I)_6_
S_C_800_Gandhi Nagar (I)_1_
S_C_800_Gandhi Nagar (I)_4_
S_C_800_Gandhi Nagar (I)_2_
S_C_800_Gandhi Nagar (I)_3_
0
1000
2000
3000
SO2 Concentration (mg/Nm3)
0
500
1000
1500
2000
SO2 Concentration (mg/Nm3)


Gujarat
Emission_Standard
Before 2003
Between 2003-2016
S_C_120_Ukai_2_1976
S_C_120_Ukai_1_1976
S_C_210_Wankabori_1_1982
S_C_210_Wankabori_1_1983
S_C_210_Wankabori_1_1984
P_A_110_Sabarmati_3_1985
P_A_110_Sabarmati_2_1985
P_A_110_Sabarmati_1_1985
S_C_210_Ukai_1_1985
S_C_210_Wankabori_2_1986
S_C_210_Wankabori_1_1986
S_C_210_Wankabori_1_1987
P_A_110_Sabarmati_3_1988
P_A_110_Sabarmati_2_1988
P_A_110_Sabarmati_1_1988
S_C_70_Kutch LIG_1_1990
S_C_200_Gandhi Nagar (II)_1_1990
S_C_70_Kutch LIG_1_1991
S_C_200_Gandhi Nagar (II)_1_1991
S_C_75_Kutch LIG_1_1997
S_C_210_Wankabori_1_1998
S_C_210_Gandhi Nagar (II)_1_1998
P_C_125_Surat LIG_1_1999
P_C_125_Surat LIG_2_2000
P_A_125_Sabarmati_3_2003
P_A_125_Sabarmati_2_2003
P_A_125_Sabarmati_1_2003
S_C_125_Akrimota_1_2006
S_C_125_Akrimota_2_2006
S_C_125_Akrimota_1_2007
S_C_125_Akrimota_2_2007
S_C_75_Kutch LIG_1_2009
P_C_330_Mundra_1_2009
P_C_330_Mundra_1_2010
P_C_660_Mundra_1_2010
P_C_125_Surat LIG_4_2010
P_C_125_Surat LIG_3_2010
P_C_660_Mundra_1_2011
P_C_660_Mundra_1_2012
P_C_600_Salaya_1_2012
S_C_500_Ukai_1_2013
P_C_600_Salaya_1_2013
S_C_250_Sikka_2_2015
S_C_250_Sikka_1_2015
S_C_800_Gandhi Nagar (I)_5_
S_C_800_Gandhi Nagar (I)_6_
S_C_800_Gandhi Nagar (I)_1_
S_C_800_Gandhi Nagar (I)_4_
S_C_800_Gandhi Nagar (I)_2_
S_C_800_Gandhi Nagar (I)_3_
0
250
500
750
1000
NO2 Concentration (mg/Nm3)
0
1000
2000
NO2 Concentration (mg/Nm3)

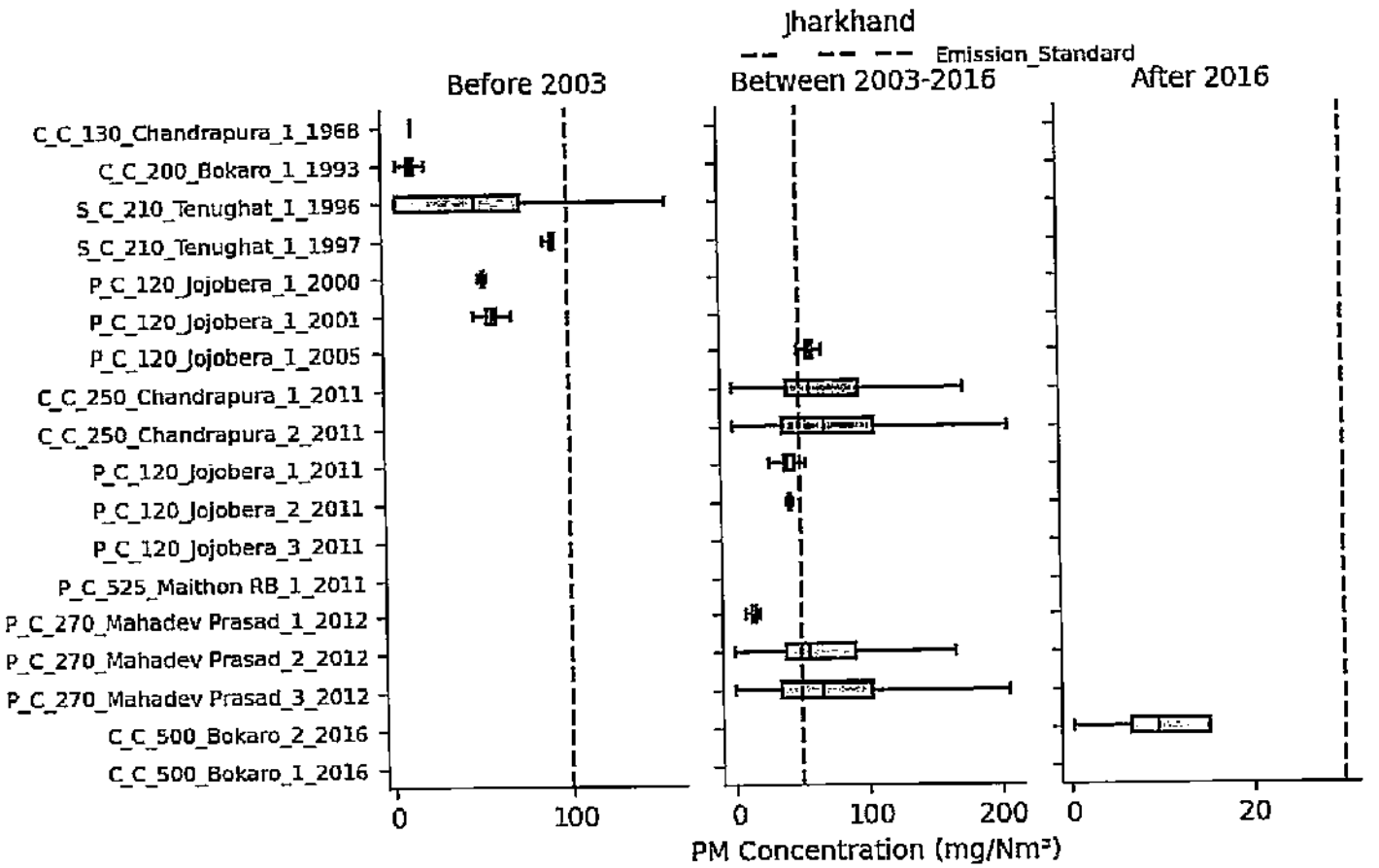
Haryana

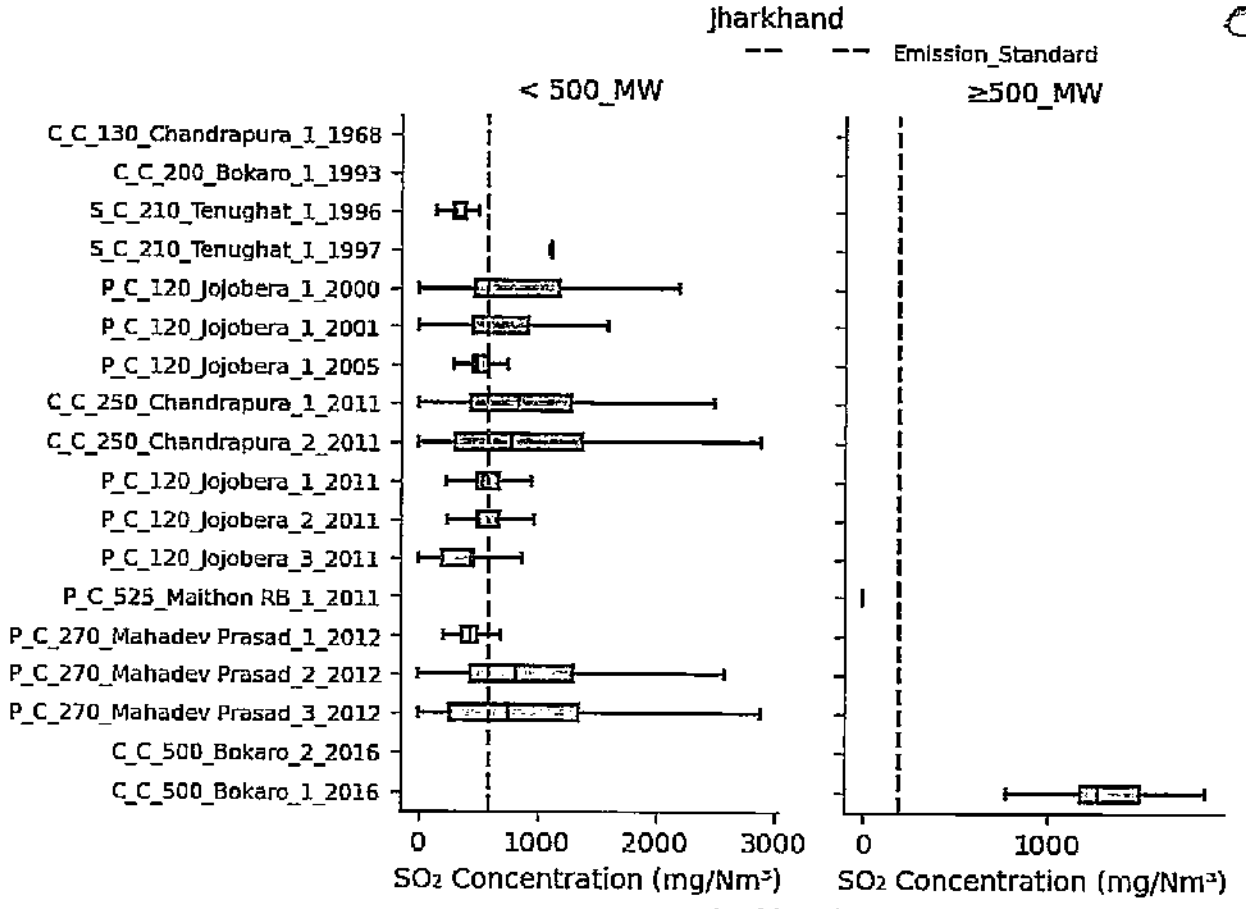

Haryana
Emission_Standard
Before 2003
Between 2003-2016
S_A_210_Panipat_1_1989
S_A_210_Panipat_1_2001
S_A_250_Panipat_1_2004
S_A_250_Panipat_1_2005
S_C_300_Yamuna Nagar_1_2008
S_C_300_Yamuna Nagar_2_2008
C_A_500_Indira Gandhi_1_2010
S_C_600_Rajiv Gandhi_1_2010
C_A_500_Indira Gandhi_2_2011
S_C_600_Rajiv Gandhi_1_2011
C_A_500_Indira Gandhi_3_2012
P_A_660_Mahatma Gandhi_4_2012
P_A_660_Mahatma Gandhi_2_2012
P_A_660_Mahatma Gandhi_1_2012
P_A_660_Mahatma Gandhi_3_2012
0
25
50
75
100
0
100
200
PM Concentration (mg/Nm³)
PM Concentration (mg/Nm³)

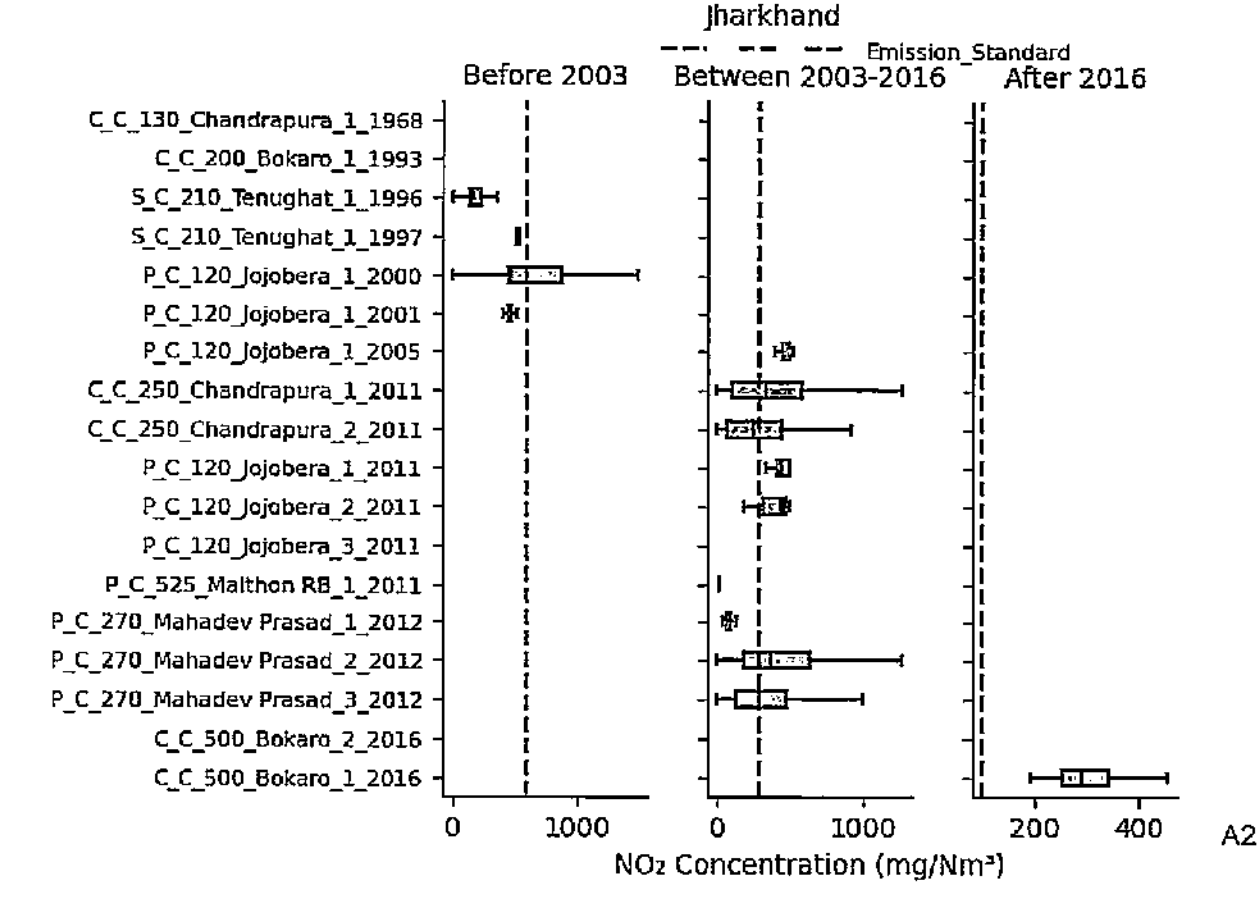

Haryana
Emission_Standard
< 500_MW
≥500_MW
S_A_210_Panipat_1_1989
S_A_210_Panipat_1_2001
S_A_250_Panipat_1_2004
S_A_250_Panipat_1_2005
S_C_300_Yamuna Nagar_1_2008
S_C_300_Yamuna Nagar_2_2008
C_A_500_Indira Gandhi_1_2010
S_C_600_Rajiv Gandhi_1_2010
C_A_500_Indira Gandhi_2_2011
S_C_600_Rajiv Gandhi_1_2011
C_A_500_Indira Gandhi_3_2012
P_A_660_Mahatma Gandhi_4_2012
P_A_660_Mahatma Gandhi_2_2012
P_A_660_Mahatma Gandhi_1_2012
P_A_660_Mahatma Gandhi_3_2012
0
500
1000
1500
0
500
1000
1500
2000
SO₂ Concentration (mg/Nm³)
SO₂ Concentration (mg/Nm³)


Haryana
Emission_Standard
Before 2003
Between 2003-2016
S_A_210_Panipat_1_1989
S_A_210_Panipat_1_2001
S_A_250_Panipat_1_2004
S_A_250_Panipat_1_2005
S_C_300_Yamuna Nagar_1_2008
S_C_300_Yamuna Nagar_2_2008
C_A_500_Indira Gandhi_1_2010
S_C_600_Rajiv Gandhi_1_2010
C_A_500_Indira Gandhi_2_2011
S_C_600_Rajiv Gandhi_1_2011
C_A_500_Indira Gandhi_3_2012
P_A_660_Mahatma Gandhi_4_2012
P_A_660_Mahatma Gandhi_2_2012
P_A_660_Mahatma Gandhi_1_2012
P_A_660_Mahatma Gandhi_3_2012
0
200
400
600
0
500
1000
NO2 Concentration (mg/Nm3)
NO2 Concentration (mg/Nm3)

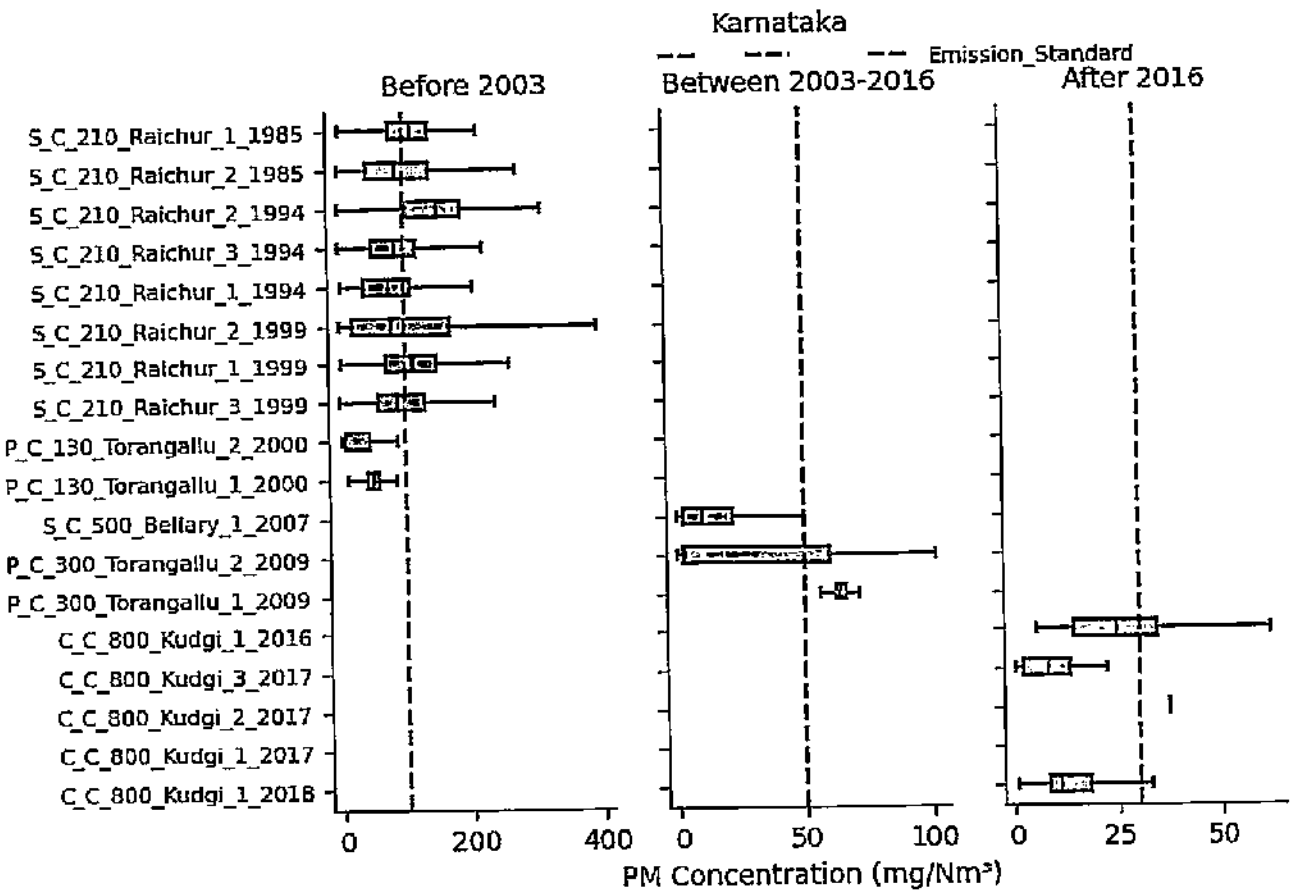
Jharkhand

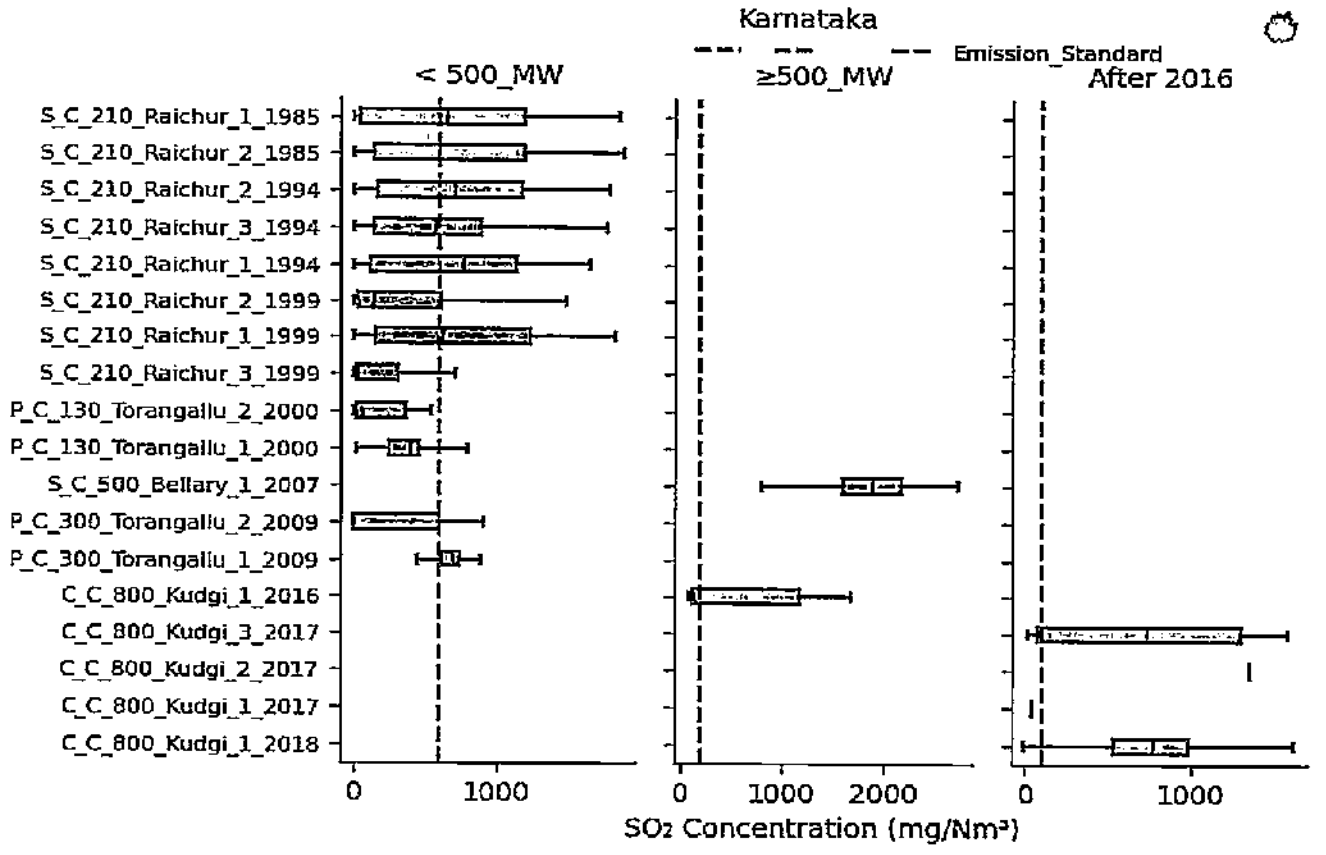

Jharkhand
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_C_130_Chandrapura_1_1968
C_C_200_Bokaro_1_1993
S_C_210_Tenughat_1_1996
S_C_210_Tenughat_1_1997
P_C_120_Jojobera_1_2000
P_C_120_Jojobera_1_2001
P_C_120_Jojobera_1_2005
C_C_250_Chandrapura_1_2011
C_C_250_Chandrapura_2_2011
P_C_120_Jojobera_1_2011
P_C_120_Jojobera_2_2011
P_C_120_Jojobera_3_2011
P_C_525_Maithon RB_1_2011
P_C_270_Mahadev Prasad_1_2012
P_C_270_Mahadev Prasad_2_2012
P_C_270_Mahadev Prasad_3_2012
C_C_500_Bokaro_2_2016
C_C_500_Bokaro_1_2016
0
100
0
100
200
0
20
PM Concentration (mg/Nm³)

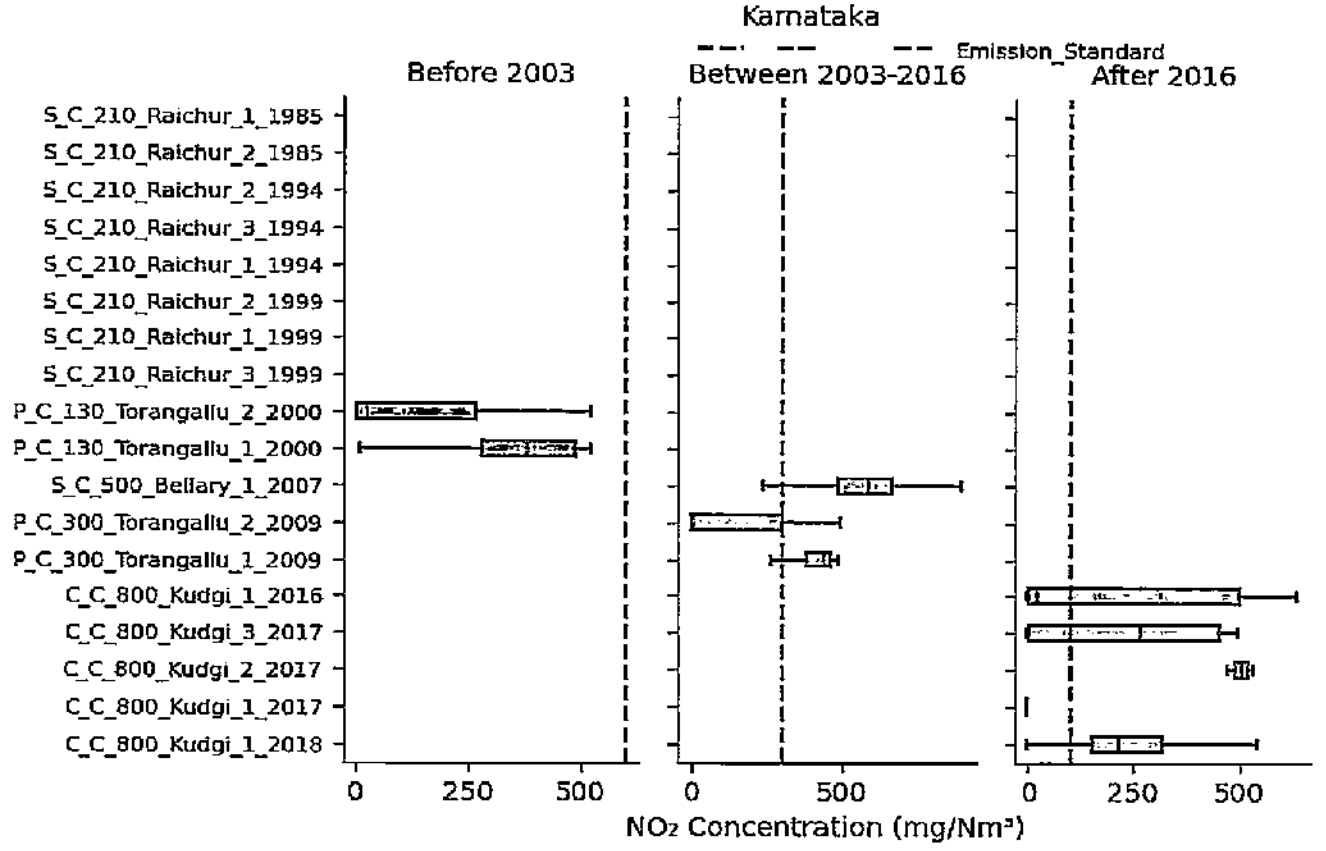

Jharkhand
Emission_Standard
< 500_MW
≥500_MW
C_C_130_Chandrapura_1_1968
C_C_200_Bokaro_1_1993
S_C_210_Tenughat_1_1996
S_C_210_Tenughat_1_1997
P_C_120_Jojobera_1_2000
P_C_120_Jojobera_1_2001
P_C_120_Jojobera_1_2005
C_C_250_Chandrapura_1_2011
C_C_250_Chandrapura_2_2011
P_C_120_Jojobera_1_2011
P_C_120_Jojobera_2_2011
P_C_120_Jojobera_3_2011
P_C_525_Maithon RB_1_2011
P_C_270_Mahadev Prasad_1_2012
P_C_270_Mahadev Prasad_2_2012
P_C_270_Mahadev Prasad_3_2012
C_C_500_Bokaro_2_2016
C_C_500_Bokaro_1_2016
0
1000
2000
3000
SO2 Concentration (mg/Nm3)
0
1000
SO2 Concentration (mg/Nm3)


Jharkhand
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_C_130_Chandrapura_1_1968
C_C_200_Bokaro_1_1993
S_C_210_Tenughat_1_1996
S_C_210_Tenughat_1_1997
P_C_120_Jojobera_1_2000
P_C_120_Jojobera_1_2001
P_C_120_Jojobera_1_2005
C_C_250_Chandrapura_1_2011
C_C_250_Chandrapura_2_2011
P_C_120_Jojobera_1_2011
P_C_120_Jojobera_2_2011
P_C_120_Jojobera_3_2011
P_C_525_Maithon RB_1_2011
P_C_270_Mahadev Prasad_1_2012
P_C_270_Mahadev Prasad_2_2012
P_C_270_Mahadev Prasad_3_2012
C_C_500_Bokaro_2_2016
C_C_500_Bokaro_1_2016
0
1000
0
1000
200
400
NO2 Concentration (mg/Nm3)

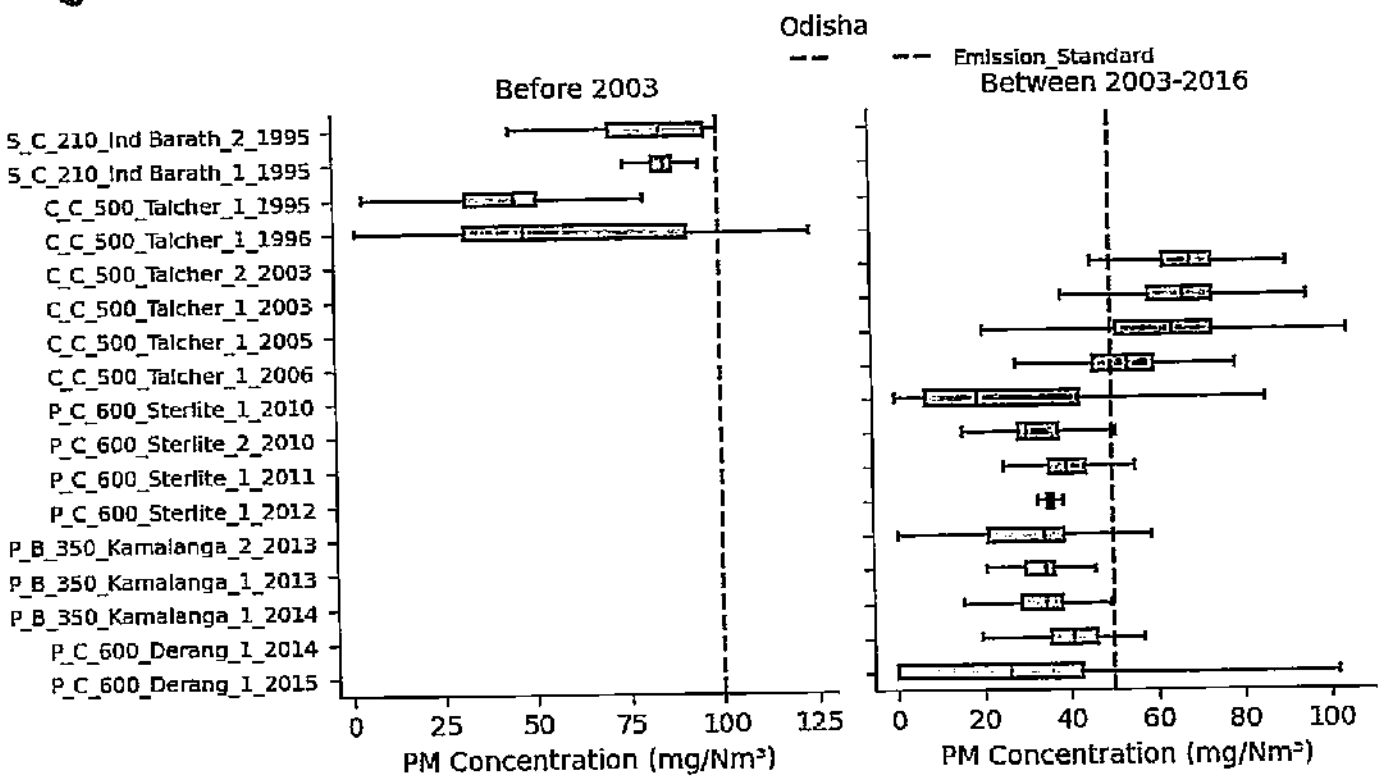
Karnataka

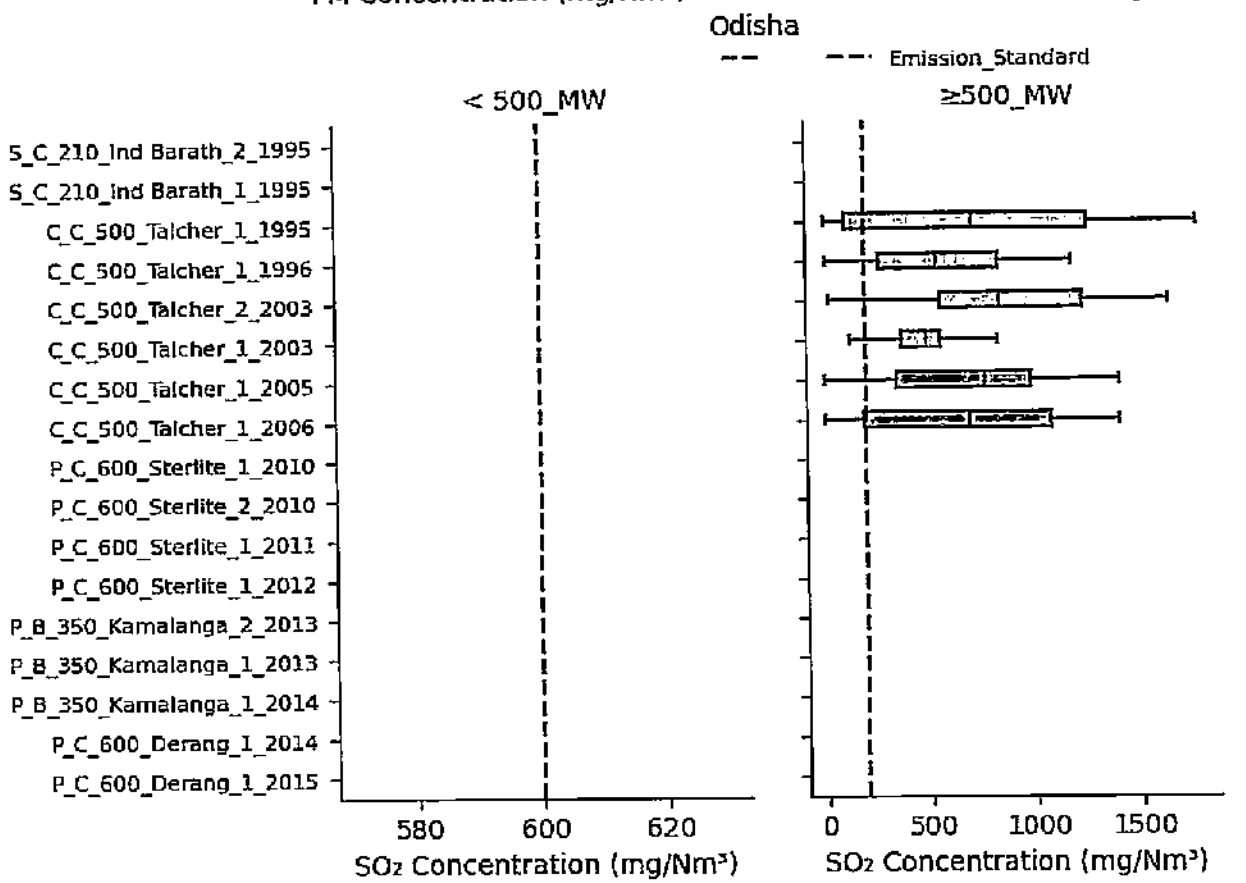

Karnataka
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Raichur_1_1985
S_C_210_Raichur_2_1985
S_C_210_Raichur_2_1994
S_C_210_Raichur_3_1994
S_C_210_Raichur_1_1994
S_C_210_Raichur_2_1999
S_C_210_Raichur_1_1999
S_C_210_Raichur_3_1999
P_C_130_Torangallu_2_2000
P_C_130_Torangallu_1_2000
S_C_500_Bellary_1_2007
P_C_300_Torangallu_2_2009
P_C_300_Torangallu_1_2009
C_C_800_Kudgi_1_2016
C_C_800_Kudgi_3_2017
C_C_800_Kudgi_2_2017
C_C_800_Kudgi_1_2017
C_C_800_Kudgi_1_2018
0
200
400
0
50
100
0
25
50
PM Concentration (mg/Nm³)

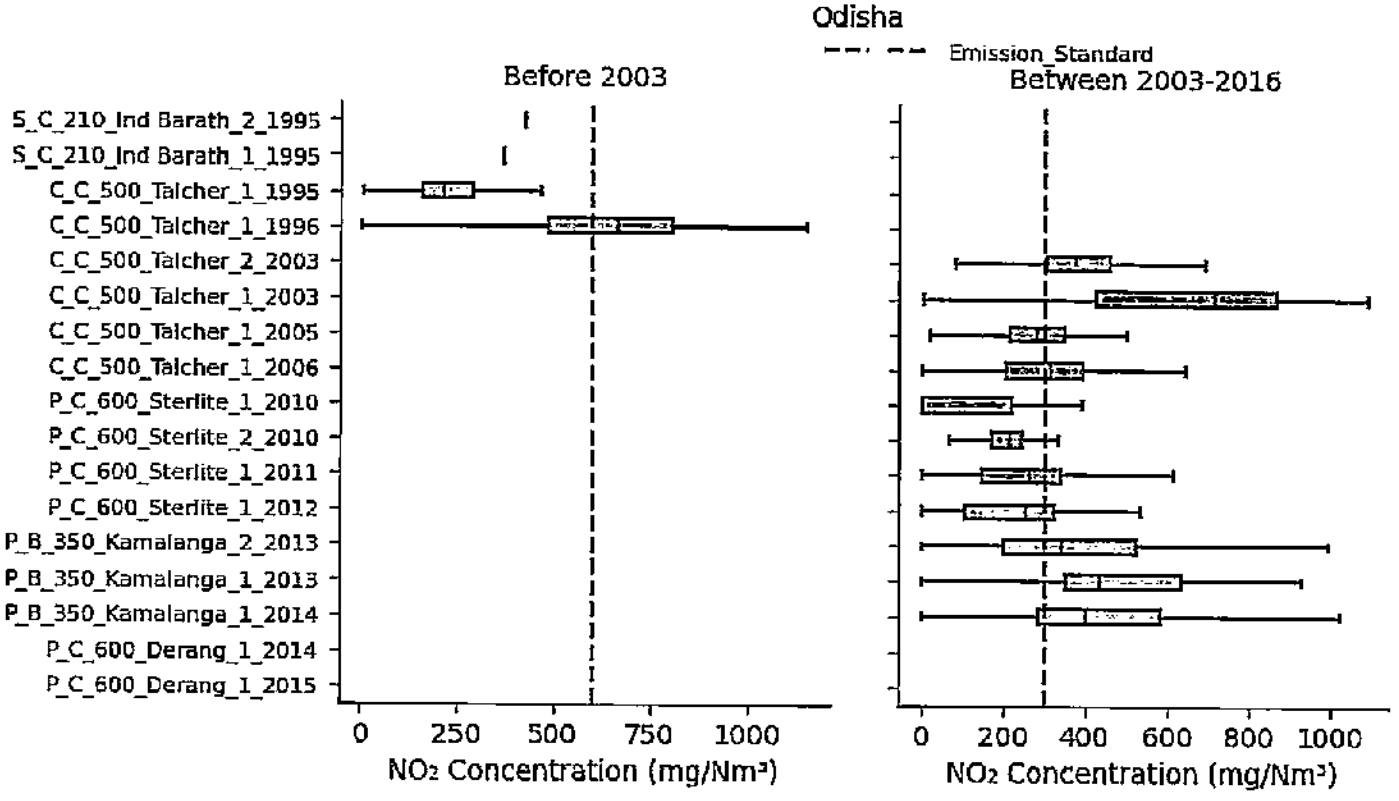

Karnataka
Emission_Standard
< 500_MW
≥500_MW
After 2016
S_C_210_Raichur_1_1985
S_C_210_Raichur_2_1985
S_C_210_Raichur_2_1994
S_C_210_Raichur_3_1994
S_C_210_Raichur_1_1994
S_C_210_Raichur_2_1999
S_C_210_Raichur_1_1999
S_C_210_Raichur_3_1999
P_C_130_Torangallu_2_2000
P_C_130_Torangallu_1_2000
S_C_500_Bellary_1_2007
P_C_300_Torangallu_2_2009
P_C_300_Torangallu_1_2009
C_C_800_Kudgi_1_2016
C_C_800_Kudgi_3_2017
C_C_800_Kudgi_2_2017
C_C_800_Kudgi_1_2017
C_C_800_Kudgi_1_2018
0
1000
0
1000
2000
0
1000
SO2 Concentration (mg/Nm3)


Karnataka
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Raichur_1_1985
S_C_210_Raichur_2_1985
S_C_210_Raichur_2_1994
S_C_210_Raichur_3_1994
S_C_210_Raichur_1_1994
S_C_210_Raichur_2_1999
S_C_210_Raichur_1_1999
S_C_210_Raichur_3_1999
P_C_130_Torangallu_2_2000
P_C_130_Torangallu_1_2000
S_C_500_Bellary_1_2007
P_C_300_Torangallu_2_2009
P_C_300_Torangallu_1_2009
C_C_800_Kudgi_1_2016
C_C_800_Kudgi_3_2017
C_C_800_Kudgi_2_2017
C_C_800_Kudgi_1_2017
C_C_800_Kudgi_1_2018
0
250
500
0
500
0
250
500
NO2 Concentration (mg/Nm3)

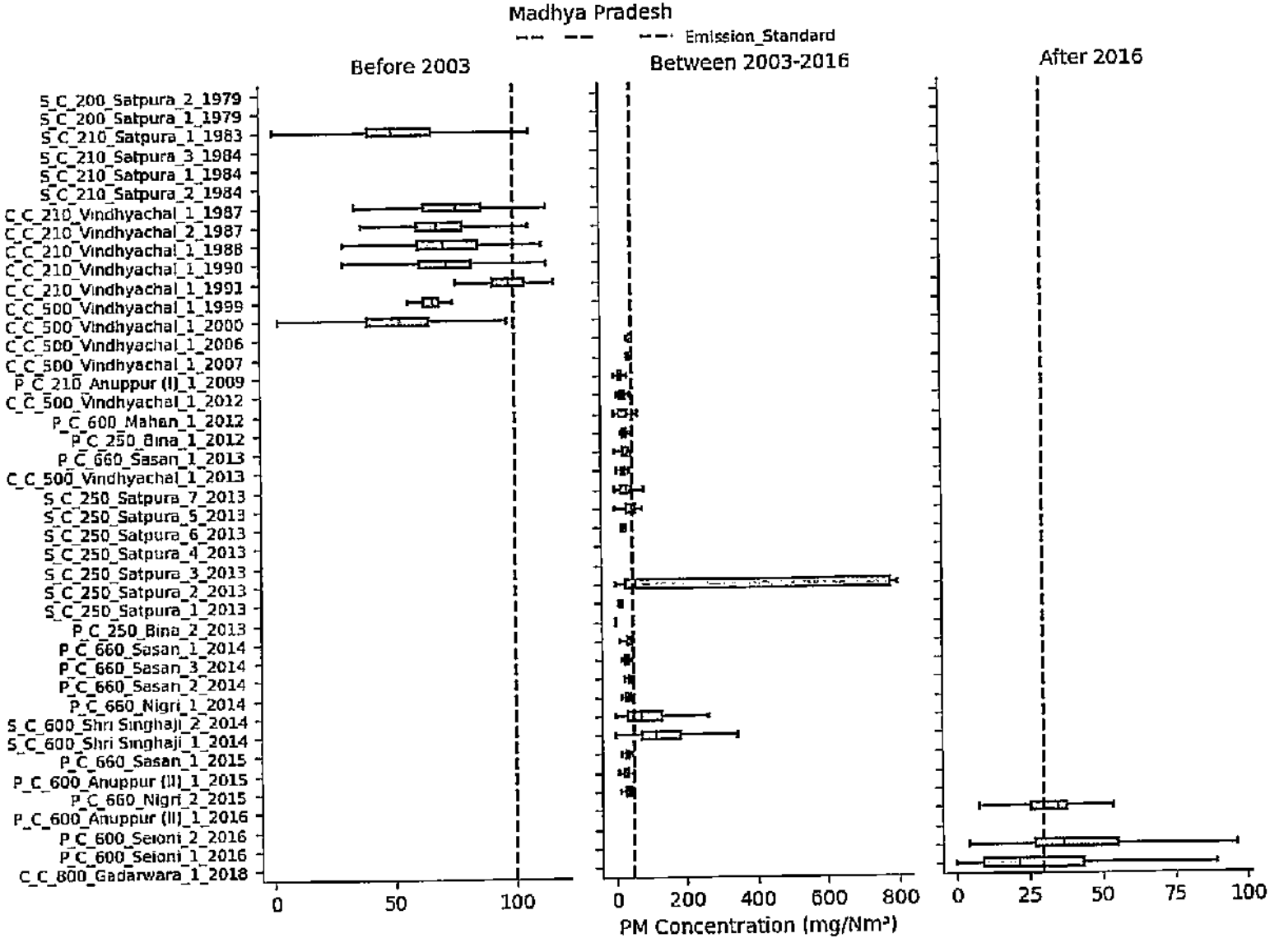
Odisha

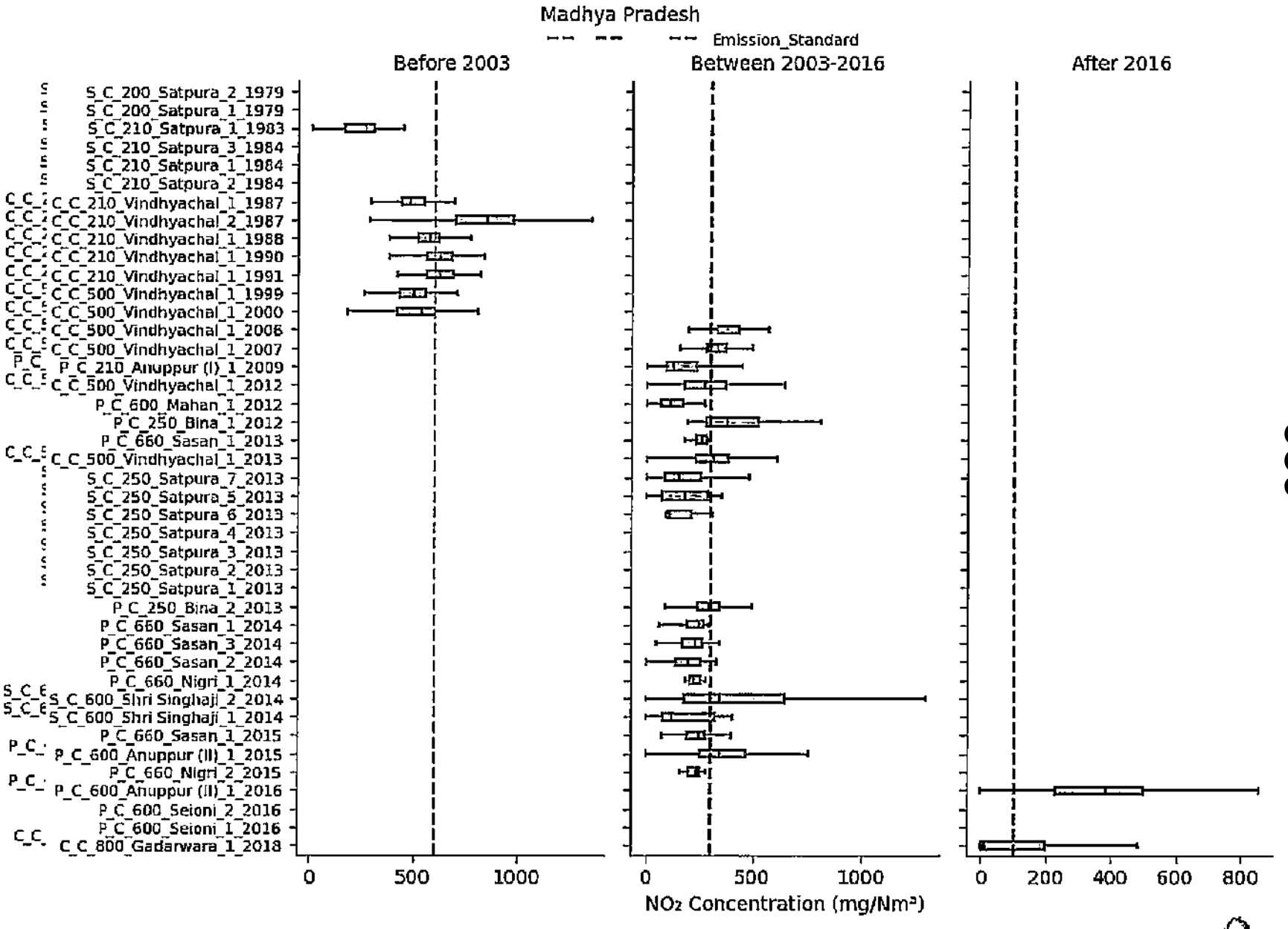

Odisha
Emission_Standard
Before 2003
Between 2003-2016
S_C_210_Ind Barath_2_1995
S_C_210_Ind Barath_1_1995
C_C_500_Talcher_1_1995
C_C_500_Talcher_1_1996
C_C_500_Talcher_2_2003
C_C_500_Talcher_1_2003
C_C_500_Talcher_1_2005
C_C_500_Talcher_1_2006
P_C_600_Sterlite_1_2010
P_C_600_Sterlite_2_2010
P_C_600_Sterlite_1_2011
P_C_600_Sterlite_1_2012
P_B_350_Kamalanga_2_2013
P_B_350_Kamalanga_1_2013
P_B_350_Kamalanga_1_2014
P_C_600_Derang_1_2014
P_C_600_Derang_1_2015
0 25 50 75 100 125
PM Concentration (mg/Nm³)
0 20 40 60 80 100
PM Concentration (mg/Nm³)


Odisha
Emission_Standard
< 500_MW
≥500_MW
S_C_210_Ind Barath_2_1995
S_C_210_Ind Barath_1_1995
C_C_500_Talcher_1_1995
C_C_500_Talcher_1_1996
C_C_500_Talcher_2_2003
C_C_500_Talcher_1_2003
C_C_500_Talcher_1_2005
C_C_500_Talcher_1_2006
P_C_600_Sterlite_1_2010
P_C_600_Sterlite_2_2010
P_C_600_Sterlite_1_2011
P_C_600_Sterlite_1_2012
P_B_350_Kamalanga_2_2013
P_B_350_Kamalanga_1_2013
P_B_350_Kamalanga_1_2014
P_C_600_Derang_1_2014
P_C_600_Derang_1_2015
580 600 620
SO₂ Concentration (mg/Nm³)
0 500 1000 1500
SO₂ Concentration (mg/Nm³)

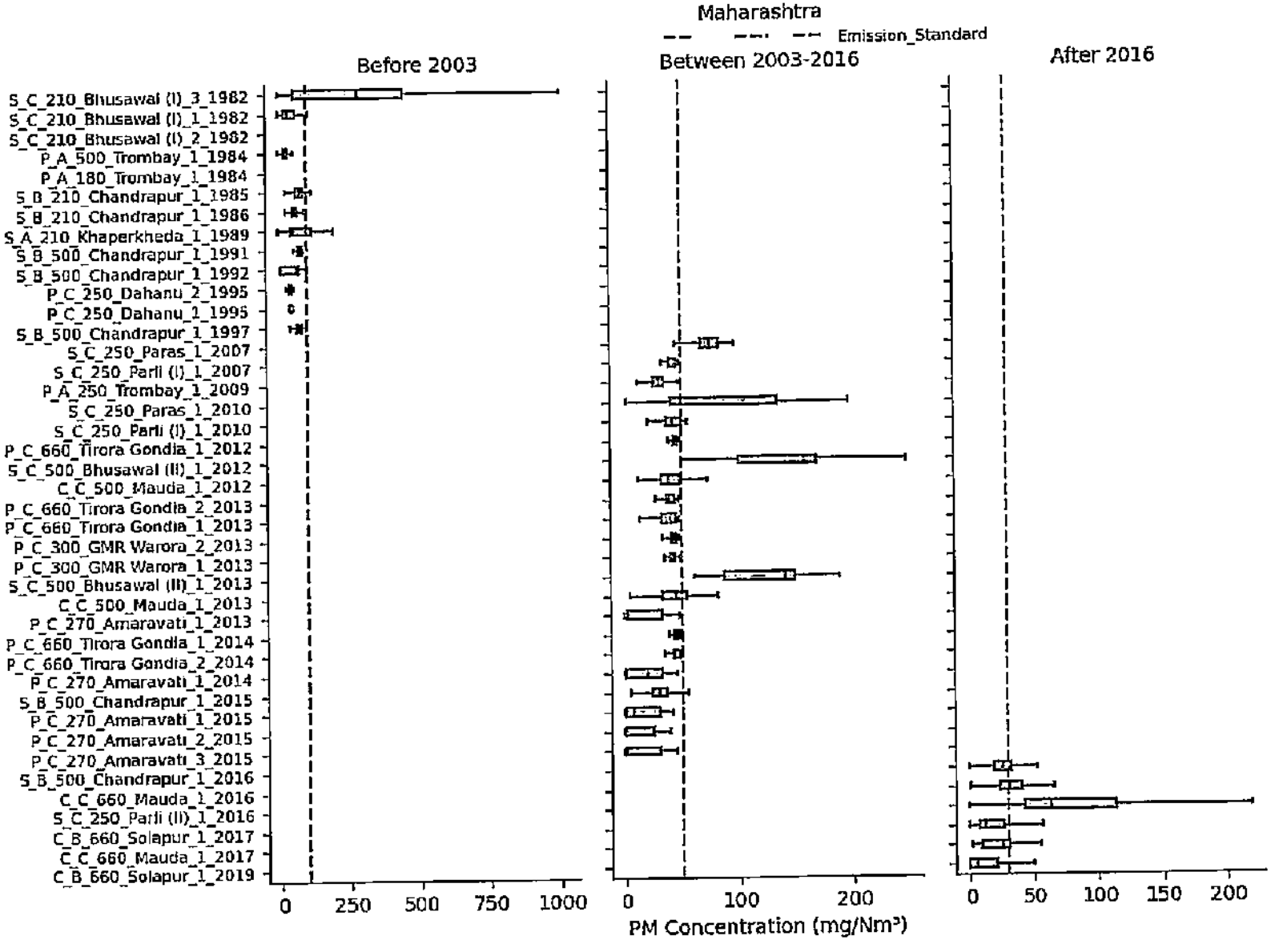

Odisha
Emission_Standard
Before 2003
Between 2003-2016
S_C_210_Ind Barath_2_1995
S_C_210_Ind Barath_1_1995
C_C_500_Talcher_1_1995
C_C_500_Talcher_1_1996
C_C_500_Talcher_2_2003
C_C_500_Talcher_1_2003
C_C_500_Talcher_1_2005
C_C_500_Talcher_1_2006
P_C_600_Sterlite_1_2010
P_C_600_Sterlite_2_2010
P_C_600_Sterlite_1_2011
P_C_600_Sterlite_1_2012
P_B_350_Kamalanga_2_2013
P_B_350_Kamalanga_1_2013
P_B_350_Kamalanga_1_2014
P_C_600_Derang_1_2014
P_C_600_Derang_1_2015
0 250 500 750 1000
NO2 Concentration (mg/Nm3)
0 200 400 600 800 1000
NO2 Concentration (mg/Nm3)

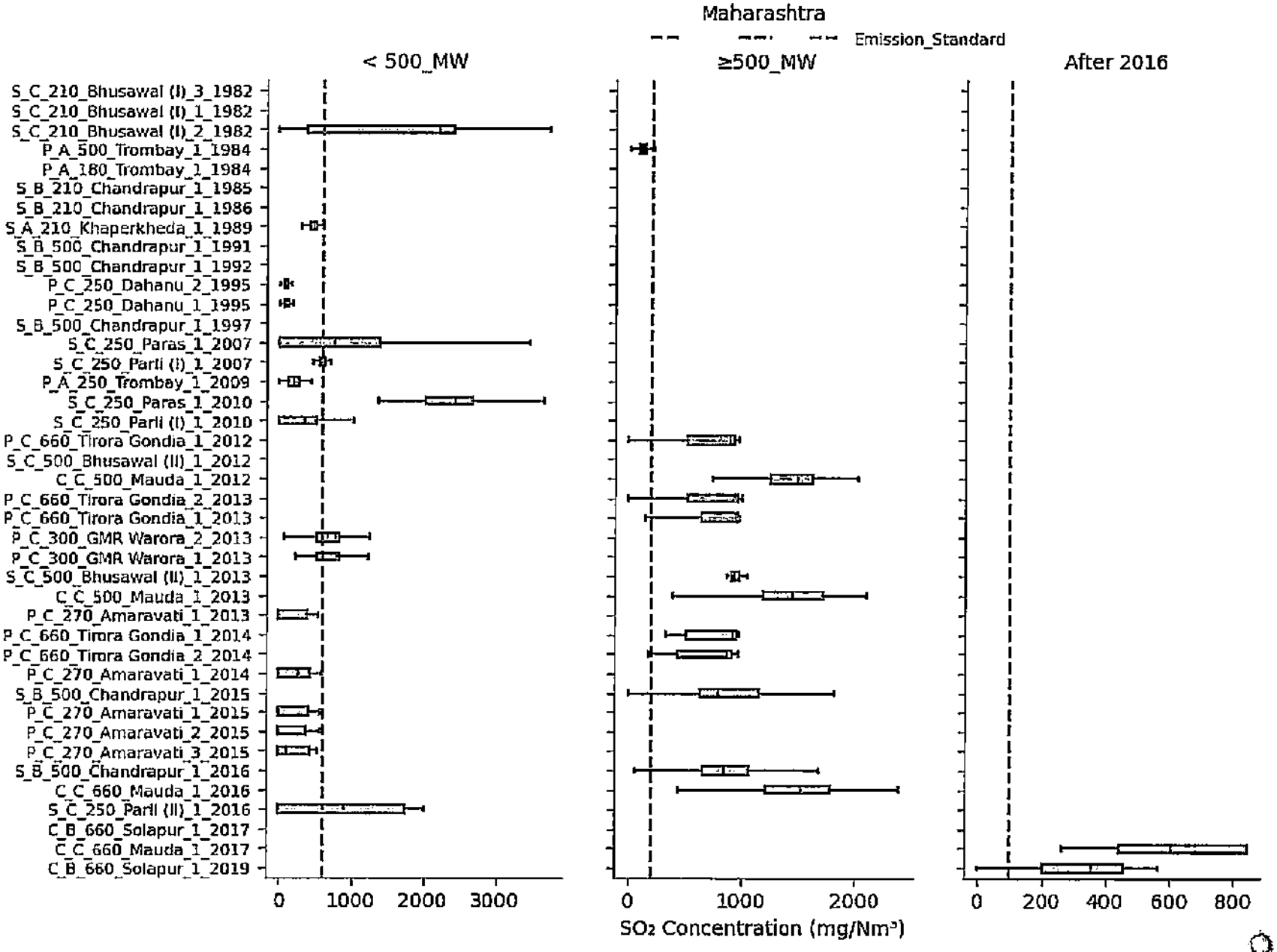
Madhya Pradesh

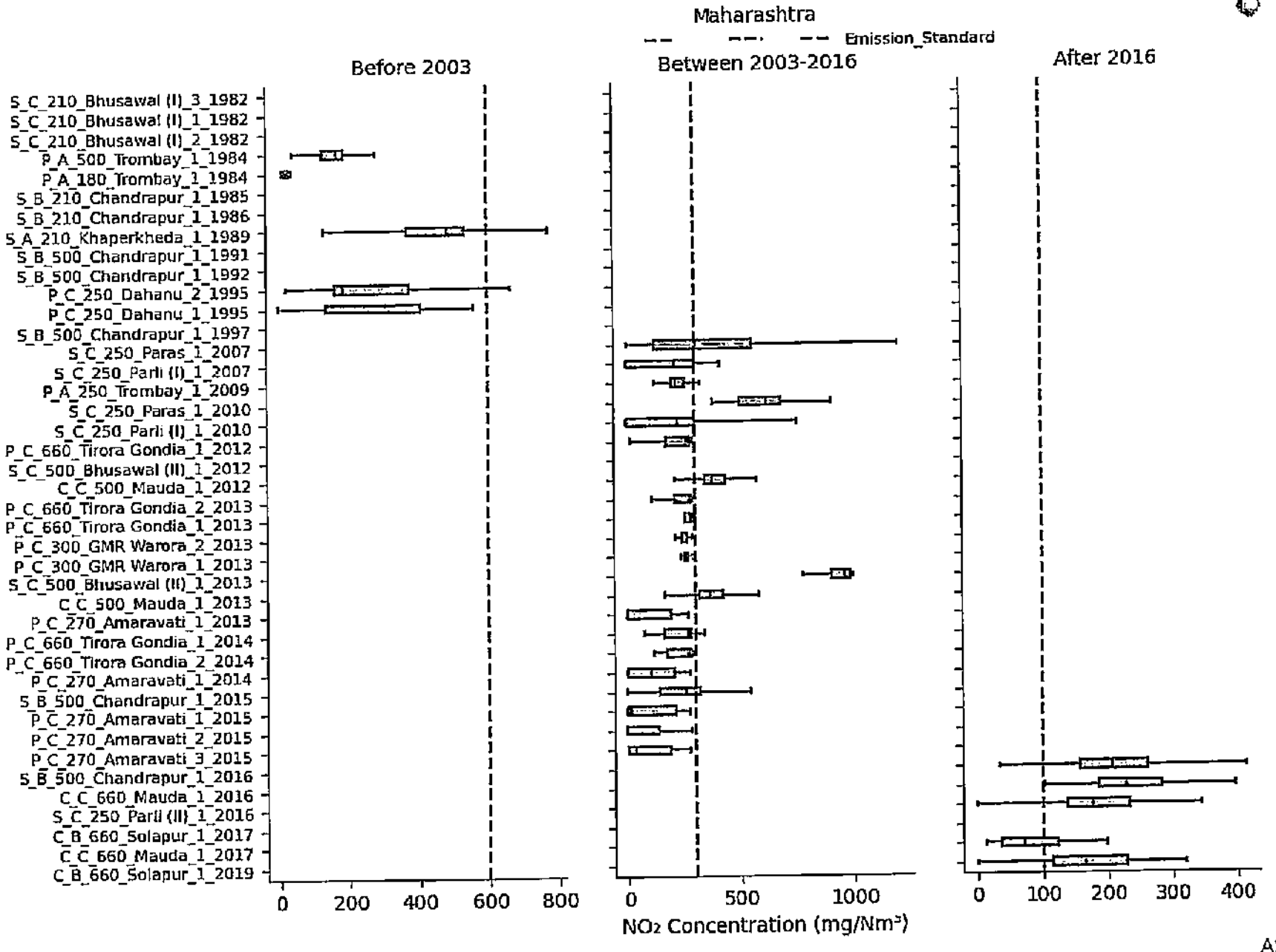


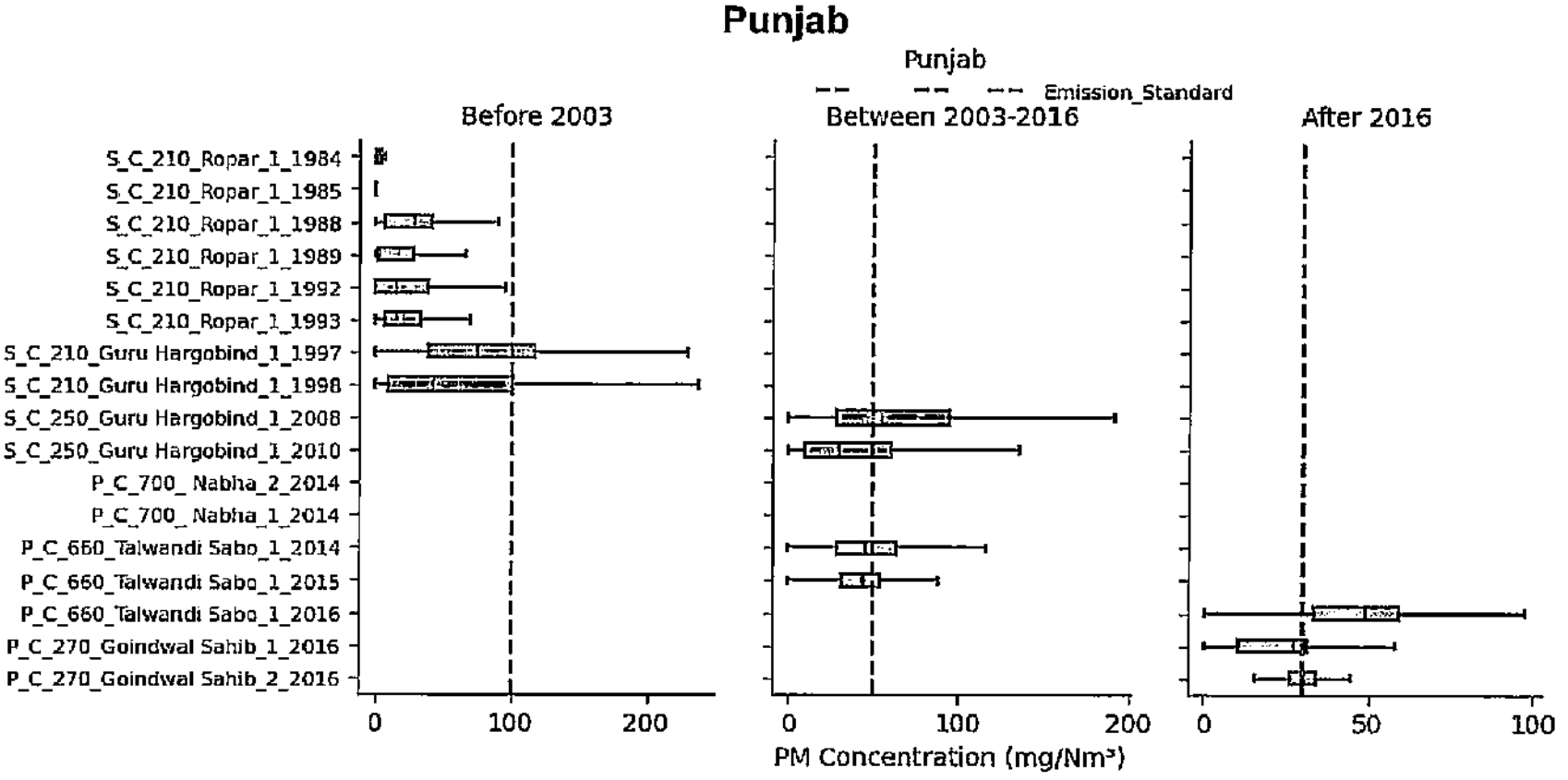

Madhya Pradesh
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_200_Satpura_2_1979
S_C_200_Satpura_1_1979
S_C_210_Satpura_1_1983
S_C_210_Satpura_3_1984
S_C_210_Satpura_1_1984
S_C_210_Satpura_2_1984
C_C_210_Vindhyachal_1_1987
C_C_210_Vindhyachal_2_1987
C_C_210_Vindhyachal_1_1988
C_C_210_Vindhyachal_1_1990
C_C_210_Vindhyachal_1_1991
C_C_500_Vindhyachal_1_1999
C_C_500_Vindhyachal_1_2000
C_C_500_Vindhyachal_1_2006
C_C_500_Vindhyachal_1_2007
P_C_210_Anuppur (I)_1_2009
C_C_500_Vindhyachal_1_2012
P_C_600_Mahan_1_2012
P_C_250_Bina_1_2012
P_C_660_Sasan_1_2013
C_C_500_Vindhyachal_1_2013
S_C_250_Satpura_7_2013
S_C_250_Satpura_5_2013
S_C_250_Satpura_6_2013
S_C_250_Satpura_4_2013
S_C_250_Satpura_3_2013
S_C_250_Satpura_2_2013
S_C_250_Satpura_1_2013
P_C_250_Bina_2_2013
P_C_660_Sasan_1_2014
P_C_660_Sasan_3_2014
P_C_660_Sasan_2_2014
P_C_660_Nigri_1_2014
S_C_600_Shri Singhaji_2_2014
S_C_600_Shri Singhaji_1_2014
P_C_660_Sasan_1_2015
P_C_600_Anuppur (II)_1_2015
P_C_660_Nigri_2_2015
P_C_600_Anuppur (II)_1_2016
P_C_600_Seioni_2_2016
P_C_600_Seioni_1_2016
C_C_800_Gadarwara_1_2018
0
500
1000
0
500
1000
0
200
400
600
800
NO2 Concentration (mg/Nm3)

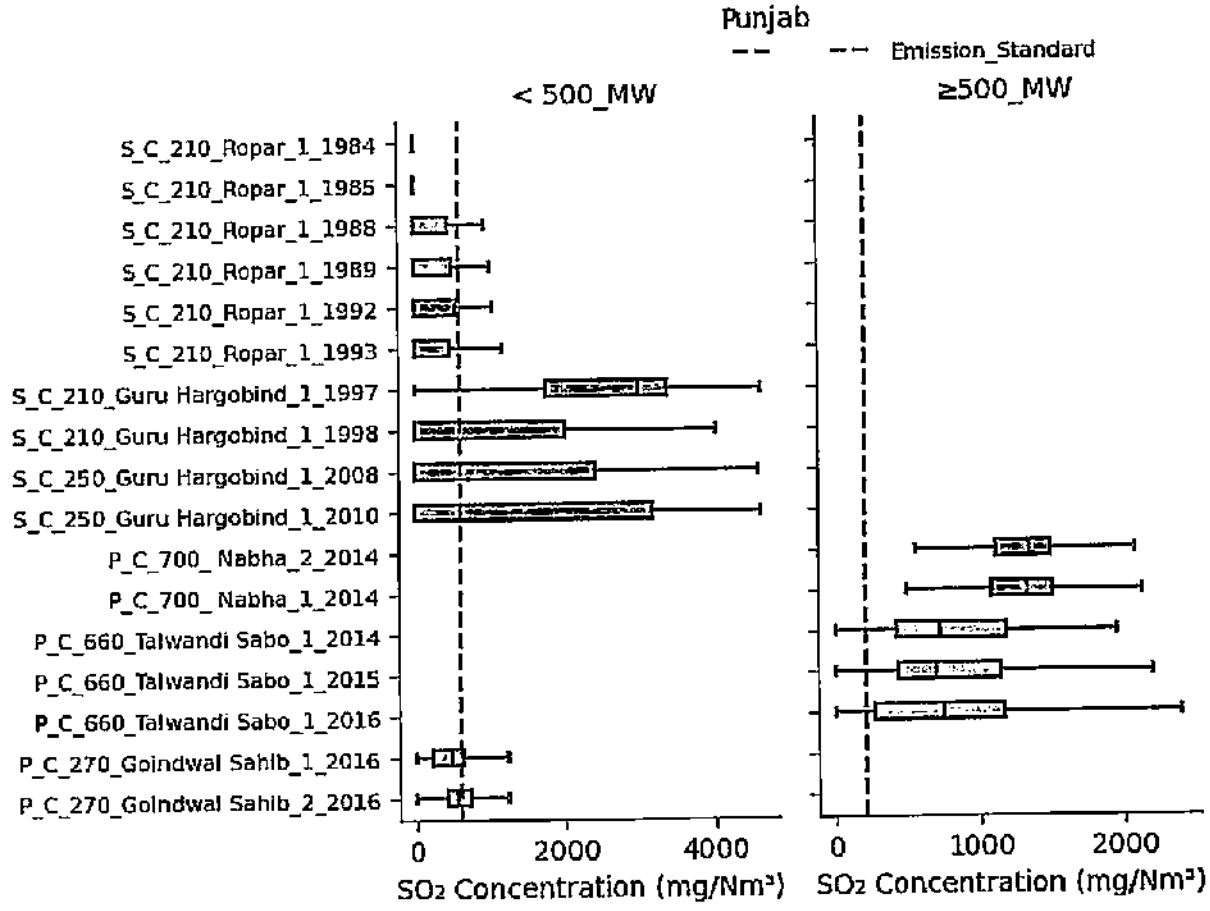
Maharashtra

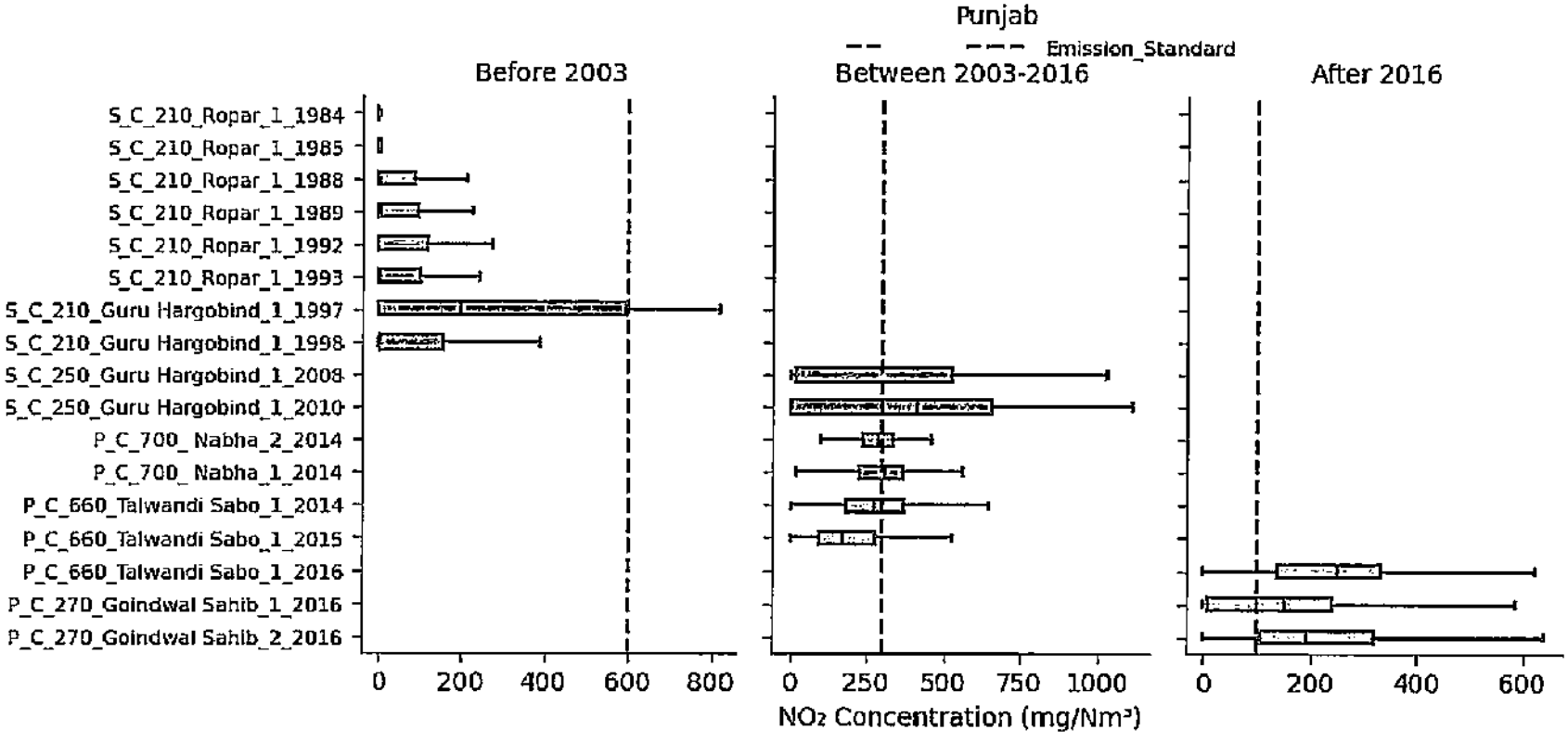



Maharashtra
Emission_Standard
< 500_MW
≥500_MW
After 2016
S_C_210_Bhusawal (I)_3_1982
S_C_210_Bhusawal (I)_1_1982
S_C_210_Bhusawal (I)_2_1982
P_A_500_Trombay_1_1984
P_A_180_Trombay_1_1984
S_B_210_Chandrapur_1_1985
S_B_210_Chandrapur_1_1986
S_A_210_Khaperkheda_1_1989
S_B_500_Chandrapur_1_1991
S_B_500_Chandrapur_1_1992
P_C_250_Dahanu_2_1995
P_C_250_Dahanu_1_1995
S_B_500_Chandrapur_1_1997
S_C_250_Paras_1_2007
S_C_250_Parli (I)_1_2007
P_A_250_Trombay_1_2009
S_C_250_Paras_1_2010
S_C_250_Parli (I)_1_2010
P_C_660_Tirora Gondia_1_2012
S_C_500_Bhusawal (II)_1_2012
C_C_500_Mauda_1_2012
P_C_660_Tirora Gondia_2_2013
P_C_660_Tirora Gondia_1_2013
P_C_300_GMR Warora_2_2013
P_C_300_GMR Warora_1_2013
S_C_500_Bhusawal (II)_1_2013
C_C_500_Mauda_1_2013
P_C_270_Amaravati_1_2013
P_C_660_Tirora Gondia_1_2014
P_C_660_Tirora Gondia_2_2014
P_C_270_Amaravati_1_2014
S_B_500_Chandrapur_1_2015
P_C_270_Amaravati_1_2015
P_C_270_Amaravati_2_2015
P_C_270_Amaravati_3_2015
S_B_500_Chandrapur_1_2016
C_C_660_Mauda_1_2016
S_C_250_Parli (II)_1_2016
C_B_660_Solapur_1_2017
C_C_660_Mauda_1_2017
C_B_660_Solapur_1_2019
0
1000
2000
3000
0
1000
2000
0
200
400
600
800
SO2 Concentration (mg/Nm3)

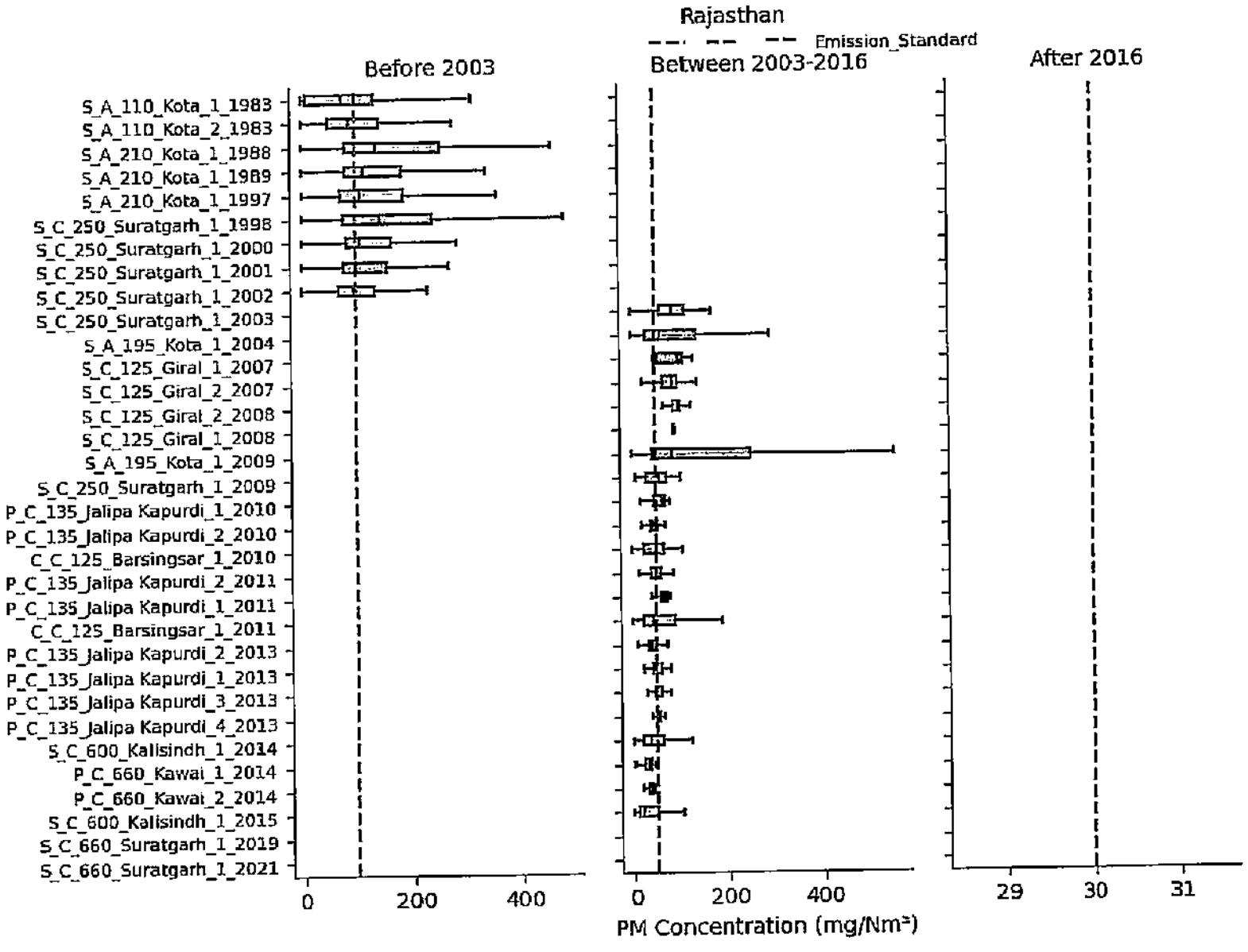

Maharashtra
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Bhusawal (I)_3_1982
S_C_210_Bhusawal (I)_1_1982
S_C_210_Bhusawal (I)_2_1982
P_A_500_Trombay_1_1984
P_A_180_Trombay_1_1984
S_B_210_Chandrapur_1_1985
S_B_210_Chandrapur_1_1986
S_A_210_Khaperkheda_1_1989
S_B_500_Chandrapur_1_1991
S_B_500_Chandrapur_1_1992
P_C_250_Dahanu_2_1995
P_C_250_Dahanu_1_1995
S_B_500_Chandrapur_1_1997
S_C_250_Paras_1_2007
S_C_250_Parli (I)_1_2007
P_A_250_Trombay_1_2009
S_C_250_Paras_1_2010
S_C_250_Parli (I)_1_2010
P_C_660_Tirora Gondia_1_2012
S_C_500_Bhusawal (II)_1_2012
C_C_500_Mauda_1_2012
P_C_660_Tirora Gondia_2_2013
P_C_660_Tirora Gondia_1_2013
P_C_300_GMR Warora_2_2013
P_C_300_GMR Warora_1_2013
S_C_500_Bhusawal (II)_1_2013
C_C_500_Mauda_1_2013
P_C_270_Amaravati_1_2013
P_C_660_Tirora Gondia_1_2014
P_C_660_Tirora Gondia_2_2014
P_C_270_Amaravati_1_2014
S_B_500_Chandrapur_1_2015
P_C_270_Amaravati_1_2015
P_C_270_Amaravati_2_2015
P_C_270_Amaravati_3_2015
S_B_500_Chandrapur_1_2016
C_C_660_Mauda_1_2016
S_C_250_Parli (II)_1_2016
C_B_660_Solapur_1_2017
C_C_660_Mauda_1_2017
C_B_660_Solapur_1_2019
0
200
400
600
800
0
500
1000
0
100
200
300
400
NO2 Concentration (mg/Nm3)

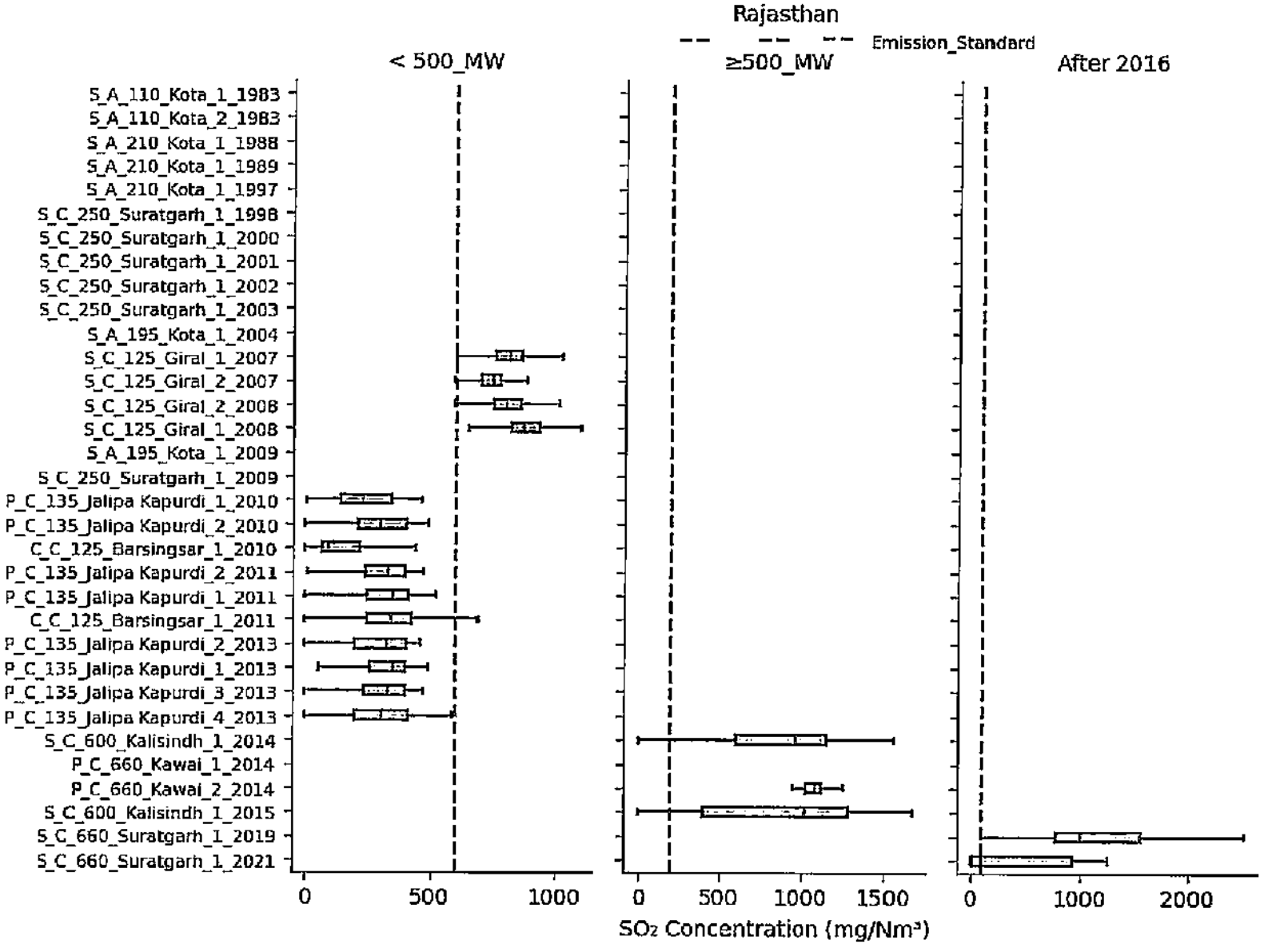

Punjab
Punjab
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Ropar_1_1984
S_C_210_Ropar_1_1985
S_C_210_Ropar_1_1988
S_C_210_Ropar_1_1989
S_C_210_Ropar_1_1992
S_C_210_Ropar_1_1993
S_C_210_Guru Hargobind_1_1997
S_C_210_Guru Hargobind_1_1998
S_C_250_Guru Hargobind_1_2008
S_C_250_Guru Hargobind_1_2010
P_C_700_ Nabha_2_2014
P_C_700_ Nabha_1_2014
P_C_660_Talwandi Sabo_1_2014
P_C_660_Talwandi Sabo_1_2015
P_C_660_Talwandi Sabo_1_2016
P_C_270_Goindwal Sahib_1_2016
P_C_270_Goindwal Sahib_2_2016
0
100
200
0
100
200
0
50
100
PM Concentration (mg/Nm³)

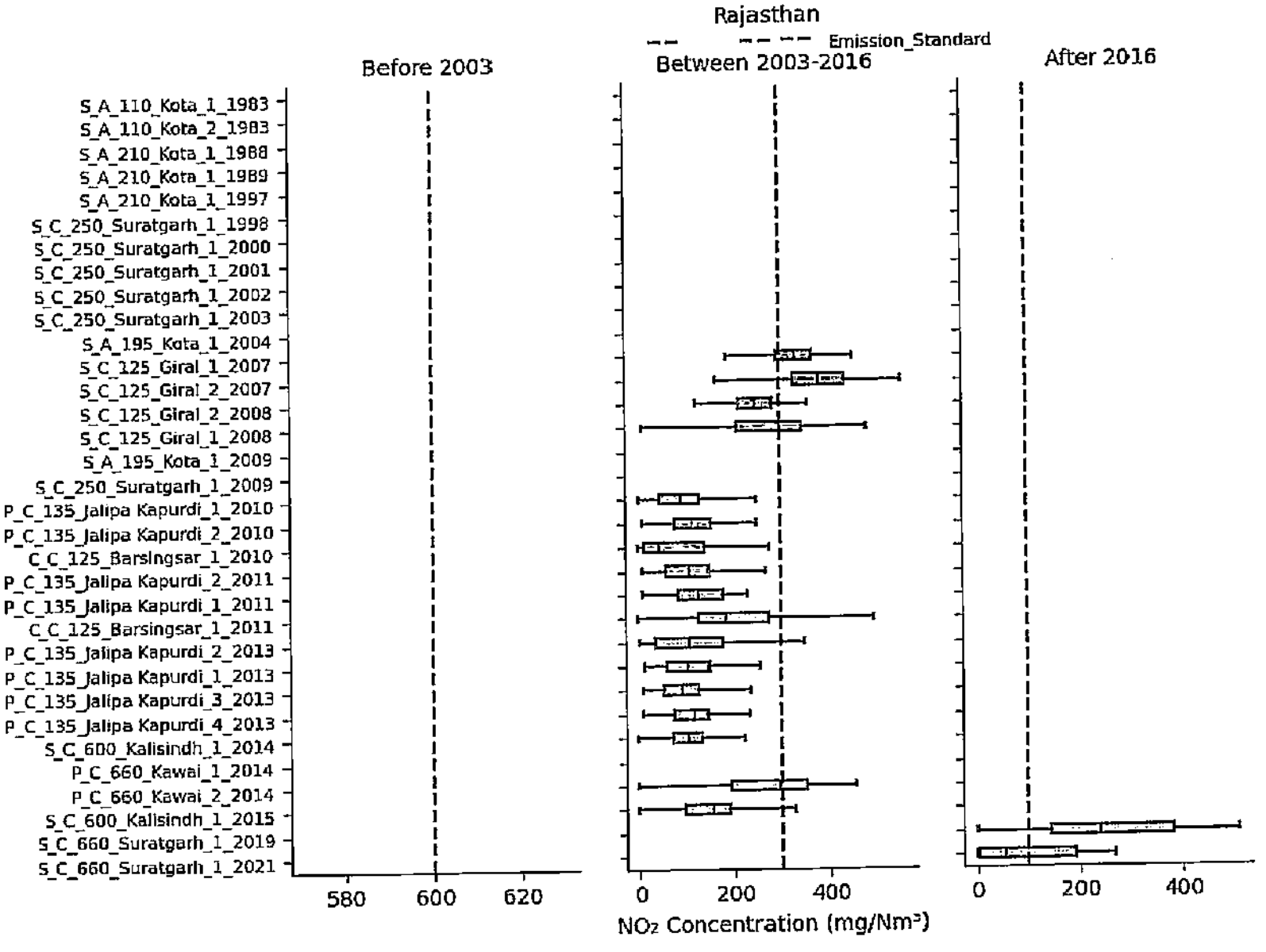

Punjab
Emission_Standard
< 500_MW
≥500_MW
S_C_210_Ropar_1_1984
S_C_210_Ropar_1_1985
S_C_210_Ropar_1_1988
S_C_210_Ropar_1_1989
S_C_210_Ropar_1_1992
S_C_210_Ropar_1_1993
S_C_210_Guru Hargobind_1_1997
S_C_210_Guru Hargobind_1_1998
S_C_250_Guru Hargobind_1_2008
S_C_250_Guru Hargobind_1_2010
P_C_700_ Nabha_2_2014
P_C_700_ Nabha_1_2014
P_C_660_Talwandi Sabo_1_2014
P_C_660_Talwandi Sabo_1_2015
P_C_660_Talwandi Sabo_1_2016
P_C_270_Goindwal Sahib_1_2016
P_C_270_Goindwal Sahib_2_2016
0
2000
4000
SO2 Concentration (mg/Nm3)
0
1000
2000
SO2 Concentration (mg/Nm3)


Punjab
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Ropar_1_1984
S_C_210_Ropar_1_1985
S_C_210_Ropar_1_1988
S_C_210_Ropar_1_1989
S_C_210_Ropar_1_1992
S_C_210_Ropar_1_1993
S_C_210_Guru Hargobind_1_1997
S_C_210_Guru Hargobind_1_1998
S_C_250_Guru Hargobind_1_2008
S_C_250_Guru Hargobind_1_2010
P_C_700_ Nabha_2_2014
P_C_700_ Nabha_1_2014
P_C_660_Talwandi Sabo_1_2014
P_C_660_Talwandi Sabo_1_2015
P_C_660_Talwandi Sabo_1_2016
P_C_270_Goindwal Sahib_1_2016
P_C_270_Goindwal Sahib_2_2016
0 200 400 600 800
0 250 500 750 1000
0 200 400 600
NO2 Concentration (mg/Nm3)

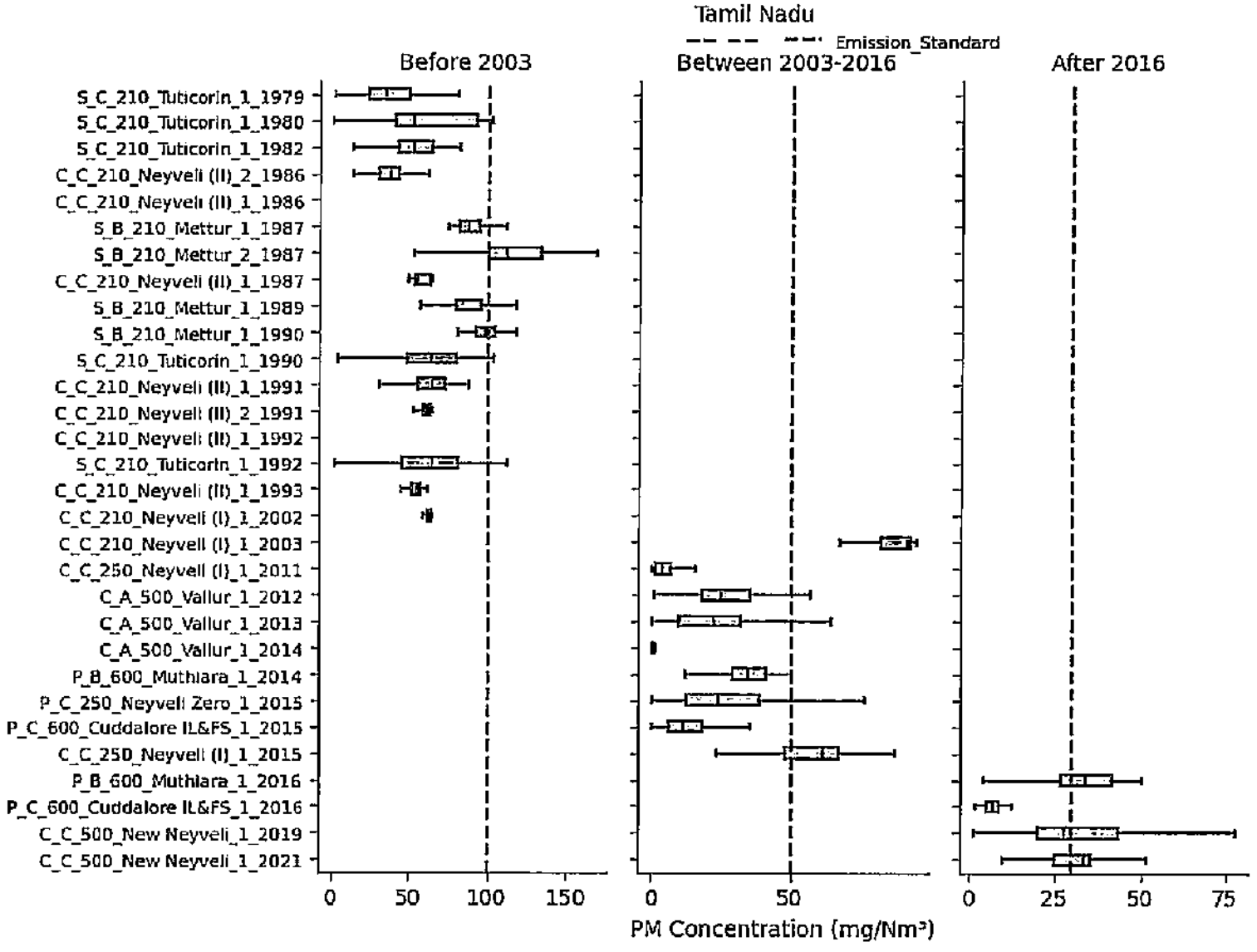
Rajasthan

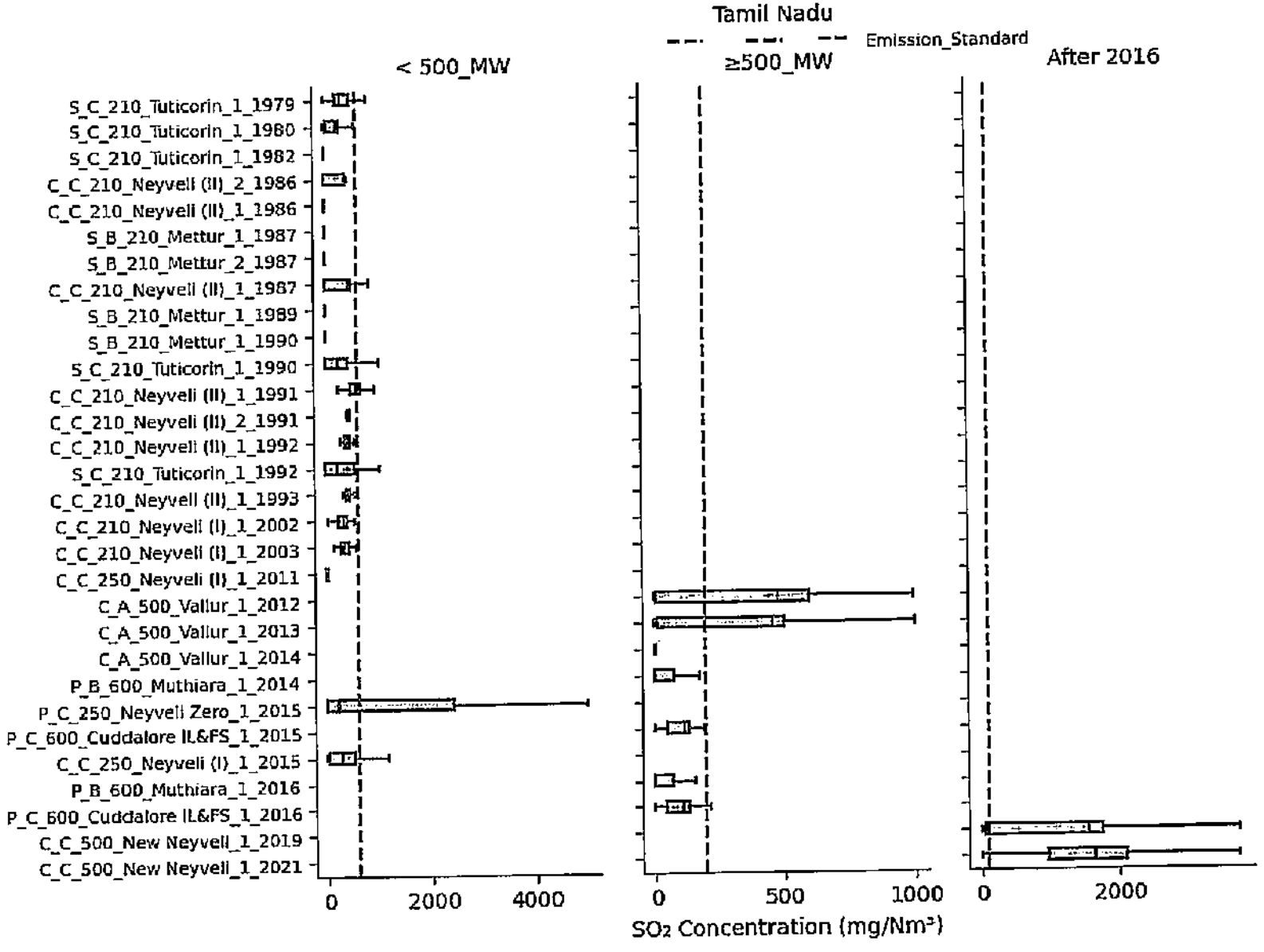

Rajasthan
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_A_110_Kota_1_1983
S_A_110_Kota_2_1983
S_A_210_Kota_1_1988
S_A_210_Kota_1_1989
S_A_210_Kota_1_1997
S_C_250_Suratgarh_1_1998
S_C_250_Suratgarh_1_2000
S_C_250_Suratgarh_1_2001
S_C_250_Suratgarh_1_2002
S_C_250_Suratgarh_1_2003
S_A_195_Kota_1_2004
S_C_125_Giral_1_2007
S_C_125_Giral_2_2007
S_C_125_Giral_2_2008
S_C_125_Giral_1_2008
S_A_195_Kota_1_2009
S_C_250_Suratgarh_1_2009
P_C_135_Jalipa Kapurdi_1_2010
P_C_135_Jalipa Kapurdi_2_2010
C_C_125_Barsingsar_1_2010
P_C_135_Jalipa Kapurdi_2_2011
P_C_135_Jalipa Kapurdi_1_2011
C_C_125_Barsingsar_1_2011
P_C_135_Jalipa Kapurdi_2_2013
P_C_135_Jalipa Kapurdi_1_2013
P_C_135_Jalipa Kapurdi_3_2013
P_C_135_Jalipa Kapurdi_4_2013
S_C_600_Kalisindh_1_2014
P_C_660_Kawai_1_2014
P_C_660_Kawai_2_2014
S_C_600_Kalisindh_1_2015
S_C_660_Suratgarh_1_2019
S_C_660_Suratgarh_1_2021
0
200
400
0
200
400
29
30
31
PM Concentration (mg/Nm³)

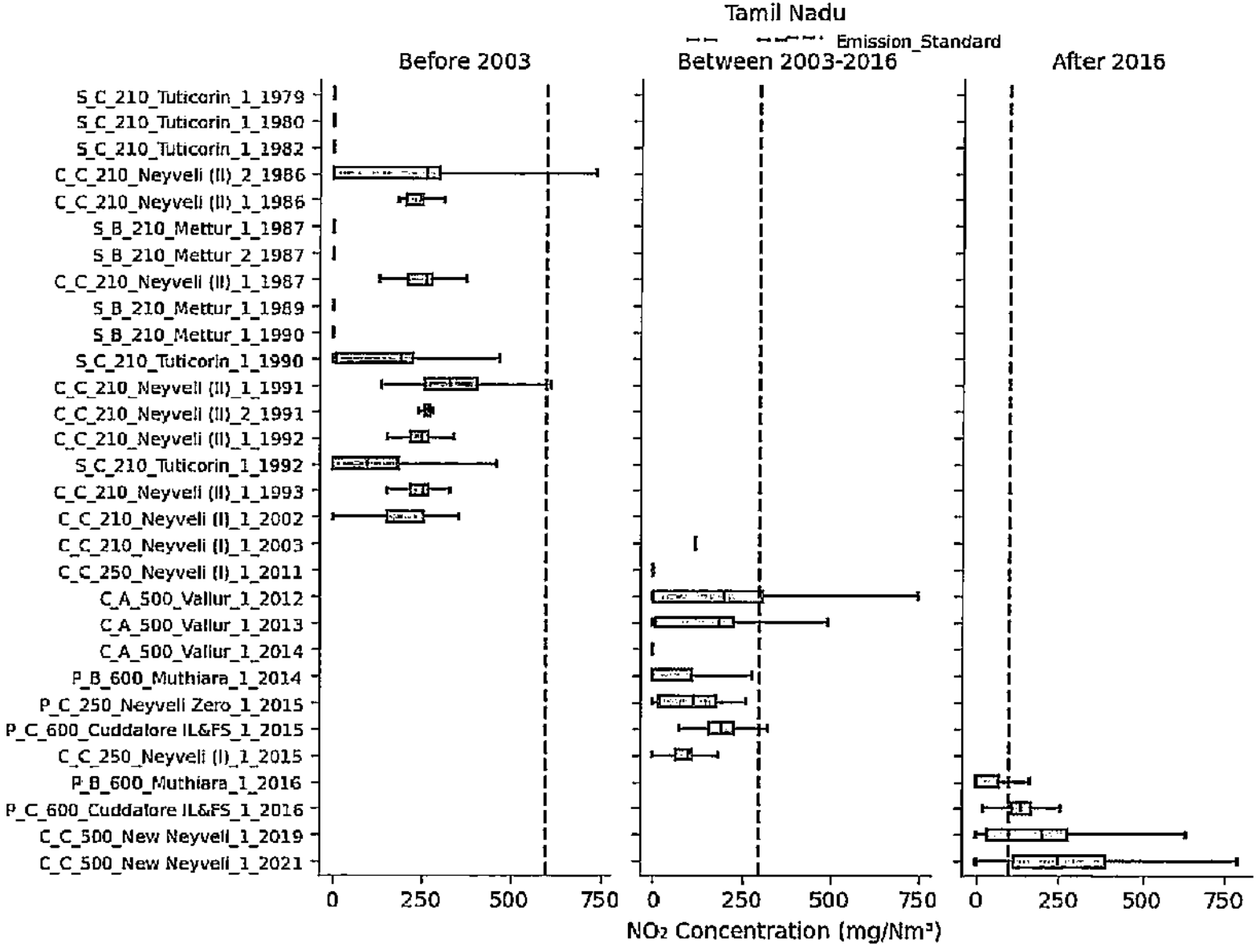

Rajasthan
Emission_Standard
< 500_MW
≥500_MW
After 2016
S_A_110_Kota_1_1983
S_A_110_Kota_2_1983
S_A_210_Kota_1_1988
S_A_210_Kota_1_1989
S_A_210_Kota_1_1997
S_C_250_Suratgarh_1_1998
S_C_250_Suratgarh_1_2000
S_C_250_Suratgarh_1_2001
S_C_250_Suratgarh_1_2002
S_C_250_Suratgarh_1_2003
S_A_195_Kota_1_2004
S_C_125_Giral_1_2007
S_C_125_Giral_2_2007
S_C_125_Giral_2_2008
S_C_125_Giral_1_2008
S_A_195_Kota_1_2009
S_C_250_Suratgarh_1_2009
P_C_135_Jalipa Kapurdi_1_2010
P_C_135_Jalipa Kapurdi_2_2010
C_C_125_Barsingsar_1_2010
P_C_135_Jalipa Kapurdi_2_2011
P_C_135_Jalipa Kapurdi_1_2011
C_C_125_Barsingsar_1_2011
P_C_135_Jalipa Kapurdi_2_2013
P_C_135_Jalipa Kapurdi_1_2013
P_C_135_Jalipa Kapurdi_3_2013
P_C_135_Jalipa Kapurdi_4_2013
S_C_600_Kalisindh_1_2014
P_C_660_Kawai_1_2014
P_C_660_Kawai_2_2014
S_C_600_Kalisindh_1_2015
S_C_660_Suratgarh_1_2019
S_C_660_Suratgarh_1_2021
0
500
1000
0
500
1000
1500
0
1000
2000
SO2 Concentration (mg/Nm3)


Rajasthan
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_A_110_Kota_1_1983
S_A_110_Kota_2_1983
S_A_210_Kota_1_1988
S_A_210_Kota_1_1989
S_A_210_Kota_1_1997
S_C_250_Suratgarh_1_1998
S_C_250_Suratgarh_1_2000
S_C_250_Suratgarh_1_2001
S_C_250_Suratgarh_1_2002
S_C_250_Suratgarh_1_2003
S_A_195_Kota_1_2004
S_C_125_Giral_1_2007
S_C_125_Giral_2_2007
S_C_125_Giral_2_2008
S_C_125_Giral_1_2008
S_A_195_Kota_1_2009
S_C_250_Suratgarh_1_2009
P_C_135_Jalipa Kapurdi_1_2010
P_C_135_Jalipa Kapurdi_2_2010
C_C_125_Barsingsar_1_2010
P_C_135_Jalipa Kapurdi_2_2011
P_C_135_Jalipa Kapurdi_1_2011
C_C_125_Barsingsar_1_2011
P_C_135_Jalipa Kapurdi_2_2013
P_C_135_Jalipa Kapurdi_1_2013
P_C_135_Jalipa Kapurdi_3_2013
P_C_135_Jalipa Kapurdi_4_2013
S_C_600_Kalisindh_1_2014
P_C_660_Kawai_1_2014
P_C_660_Kawai_2_2014
S_C_600_Kalisindh_1_2015
S_C_660_Suratgarh_1_2019
S_C_660_Suratgarh_1_2021
580
600
620
0
200
400
0
200
400
NO2 Concentration (mg/Nm3)

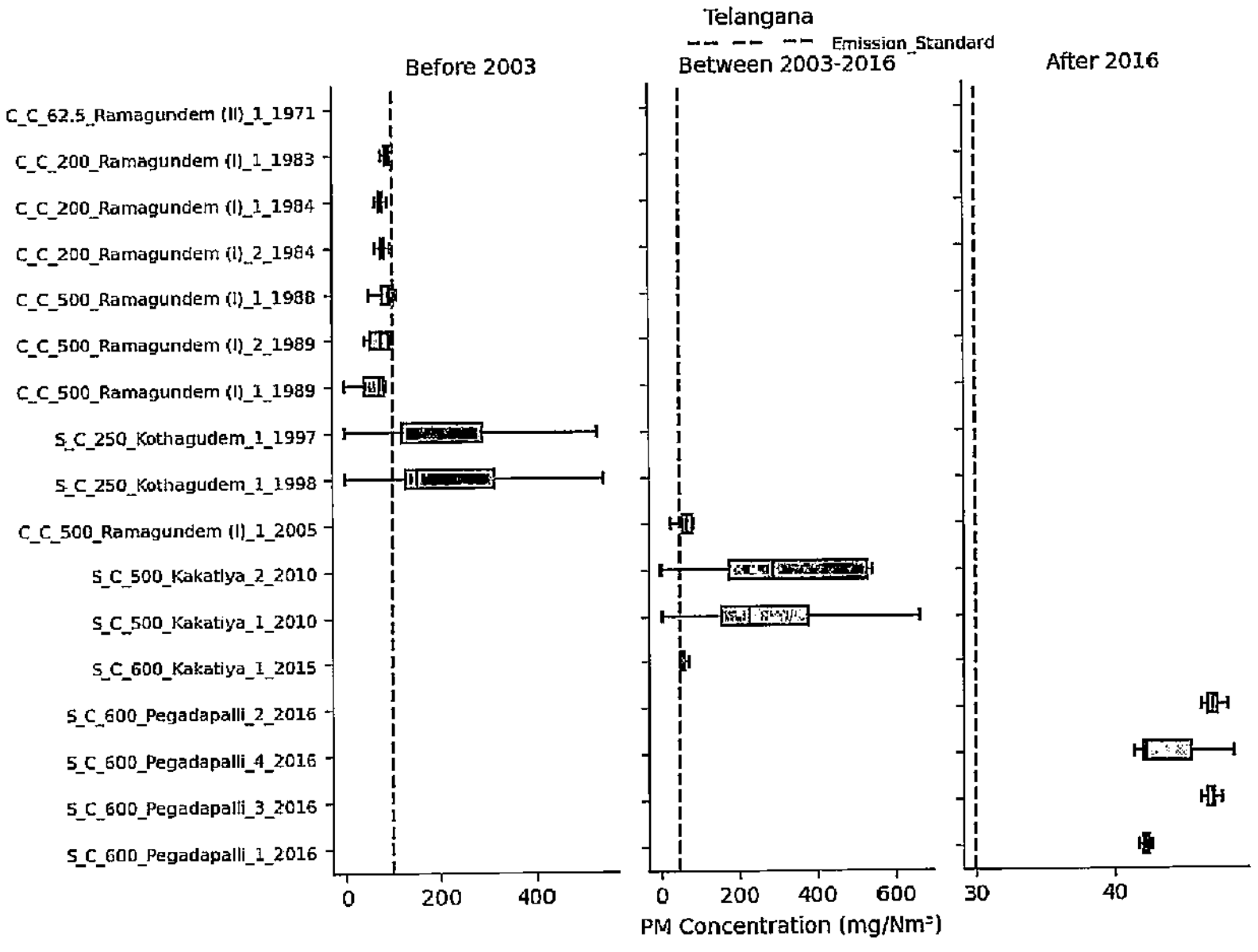
Tamil Nadu

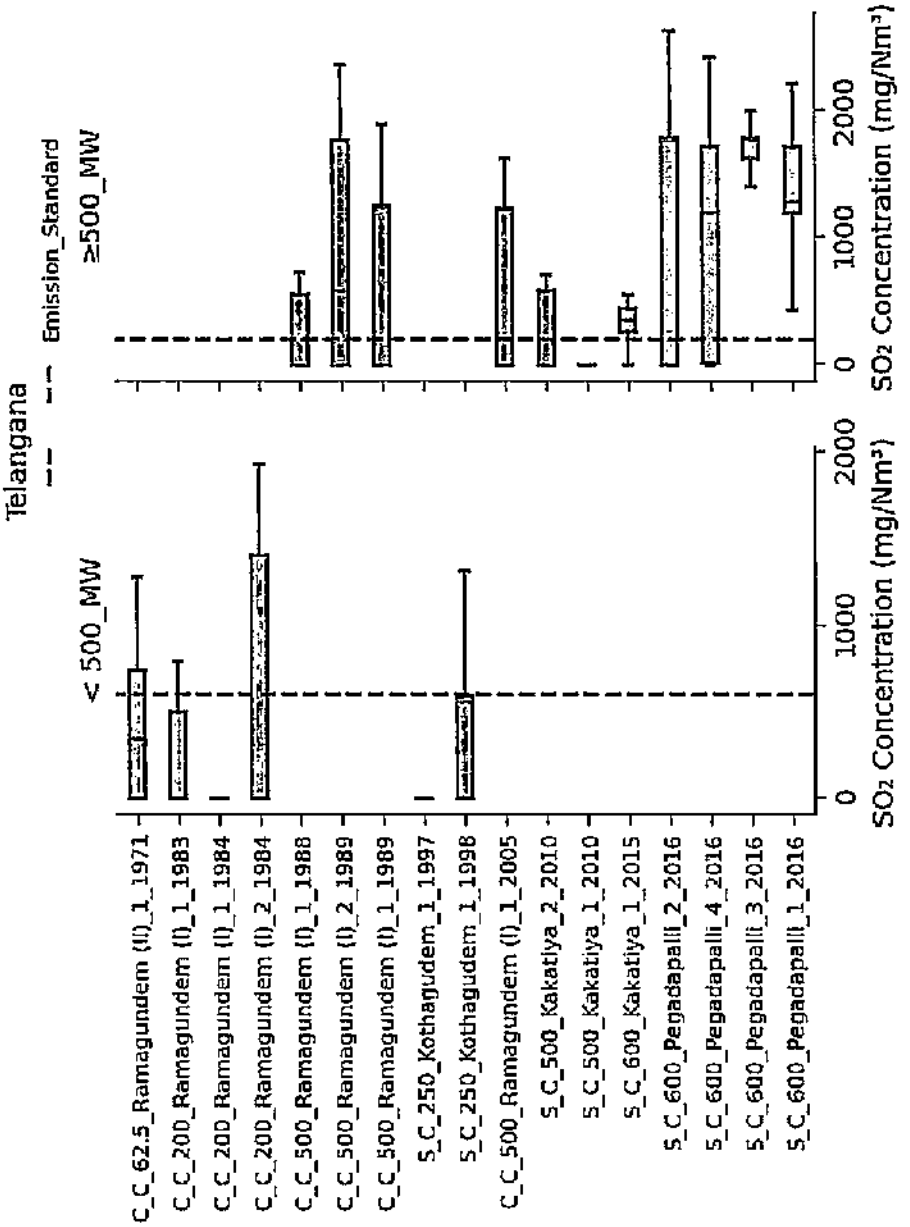

Tamil Nadu
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Tuticorin_1_1979
S_C_210_Tuticorin_1_1980
S_C_210_Tuticorin_1_1982
C_C_210_Neyveli (II)_2_1986
C_C_210_Neyveli (II)_1_1986
S_B_210_Mettur_1_1987
S_B_210_Mettur_2_1987
C_C_210_Neyveli (II)_1_1987
S_B_210_Mettur_1_1989
S_B_210_Mettur_1_1990
S_C_210_Tuticorin_1_1990
C_C_210_Neyveli (II)_1_1991
C_C_210_Neyveli (II)_2_1991
C_C_210_Neyveli (II)_1_1992
S_C_210_Tuticorin_1_1992
C_C_210_Neyveli (II)_1_1993
C_C_210_Neyveli (I)_1_2002
C_C_210_Neyveli (I)_1_2003
C_C_250_Neyveli (I)_1_2011
C_A_500_Vallur_1_2012
C_A_500_Vallur_1_2013
C_A_500_Vallur_1_2014
P_B_600_Muthiara_1_2014
P_C_250_Neyveli Zero_1_2015
P_C_600_Cuddalore IL&FS_1_2015
C_C_250_Neyveli (I)_1_2015
P_B_600_Muthiara_1_2016
P_C_600_Cuddalore IL&FS_1_2016
C_C_500_New Neyveli_1_2019
C_C_500_New Neyveli_1_2021
0
50
100
150
0
50
0
25
50
75
PM Concentration (mg/Nm³)

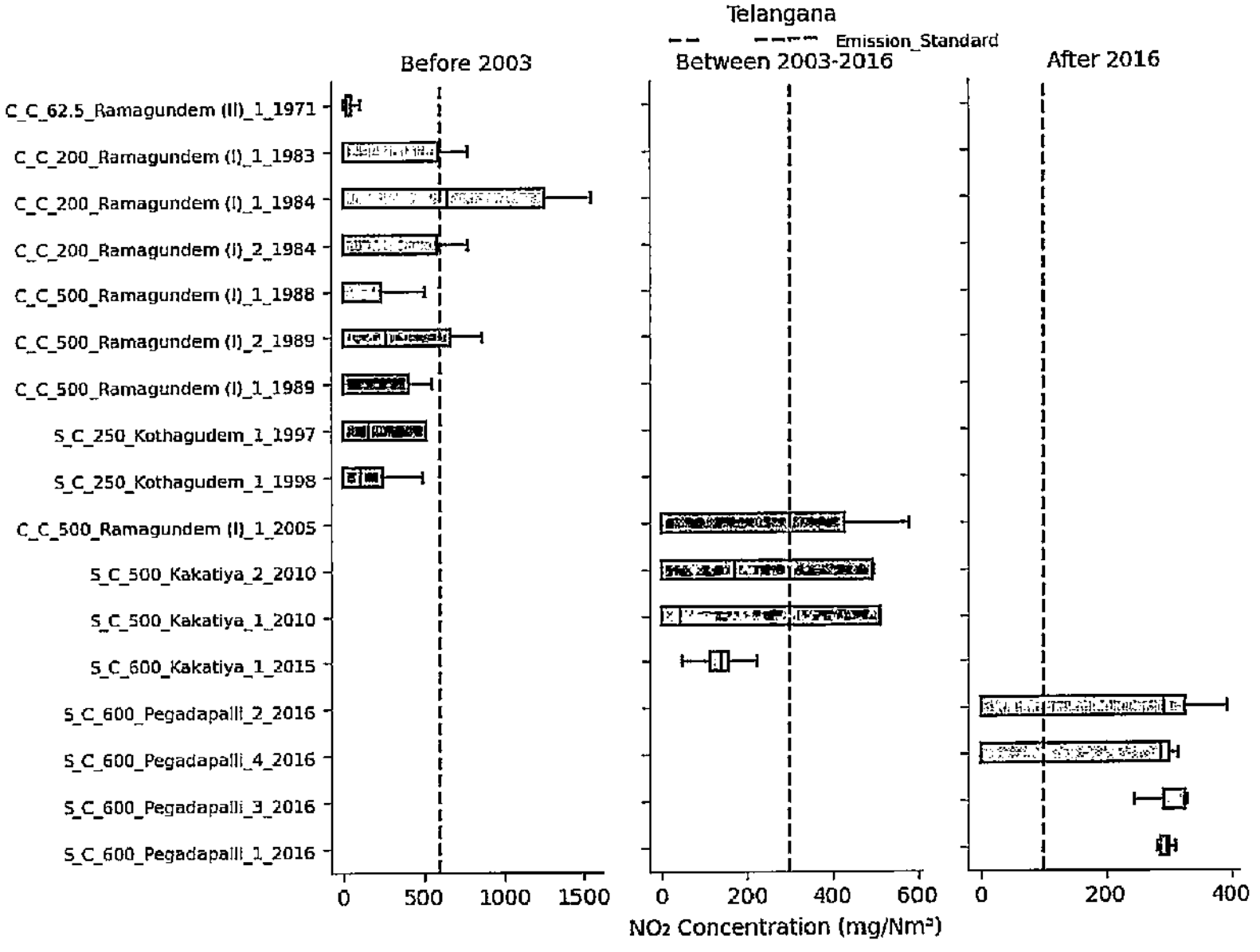

Tamil Nadu
Emission_Standard
< 500_MW
≥500_MW
After 2016
S_C_210_Tuticorin_1_1979
S_C_210_Tuticorin_1_1980
S_C_210_Tuticorin_1_1982
C_C_210_Neyveli (II)_2_1986
C_C_210_Neyveli (II)_1_1986
S_B_210_Mettur_1_1987
S_B_210_Mettur_2_1987
C_C_210_Neyveli (II)_1_1987
S_B_210_Mettur_1_1989
S_B_210_Mettur_1_1990
S_C_210_Tuticorin_1_1990
C_C_210_Neyveli (II)_1_1991
C_C_210_Neyveli (II)_2_1991
C_C_210_Neyveli (II)_1_1992
S_C_210_Tuticorin_1_1992
C_C_210_Neyveli (II)_1_1993
C_C_210_Neyveli (I)_1_2002
C_C_210_Neyveli (I)_1_2003
C_C_250_Neyveli (I)_1_2011
C_A_500_Vallur_1_2012
C_A_500_Vallur_1_2013
C_A_500_Vallur_1_2014
P_B_600_Muthiara_1_2014
P_C_250_Neyveli Zero_1_2015
P_C_600_Cuddalore IL&FS_1_2015
C_C_250_Neyveli (I)_1_2015
P_B_600_Muthiara_1_2016
P_C_600_Cuddalore IL&FS_1_2016
C_C_500_New Neyveli_1_2019
C_C_500_New Neyveli_1_2021
0
2000
4000
0
500
1000
0
2000
SO2 Concentration (mg/Nm3)


Tamil Nadu
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_210_Tuticorin_1_1979
S_C_210_Tuticorin_1_1980
S_C_210_Tuticorin_1_1982
C_C_210_Neyveli (II)_2_1986
C_C_210_Neyveli (II)_1_1986
S_B_210_Mettur_1_1987
S_B_210_Mettur_2_1987
C_C_210_Neyveli (II)_1_1987
S_B_210_Mettur_1_1989
S_B_210_Mettur_1_1990
S_C_210_Tuticorin_1_1990
C_C_210_Neyveli (II)_1_1991
C_C_210_Neyveli (II)_2_1991
C_C_210_Neyveli (II)_1_1992
S_C_210_Tuticorin_1_1992
C_C_210_Neyveli (II)_1_1993
C_C_210_Neyveli (I)_1_2002
C_C_210_Neyveli (I)_1_2003
C_C_250_Neyveli (I)_1_2011
C_A_500_Vallur_1_2012
C_A_500_Vallur_1_2013
C_A_500_Vallur_1_2014
P_B_600_Muthiara_1_2014
P_C_250_Neyveli Zero_1_2015
P_C_600_Cuddalore IL&FS_1_2015
C_C_250_Neyveli (I)_1_2015
P_B_600_Muthiara_1_2016
P_C_600_Cuddalore IL&FS_1_2016
C_C_500_New Neyveli_1_2019
C_C_500_New Neyveli_1_2021
0
250
500
750
NO2 Concentration (mg/Nm3)

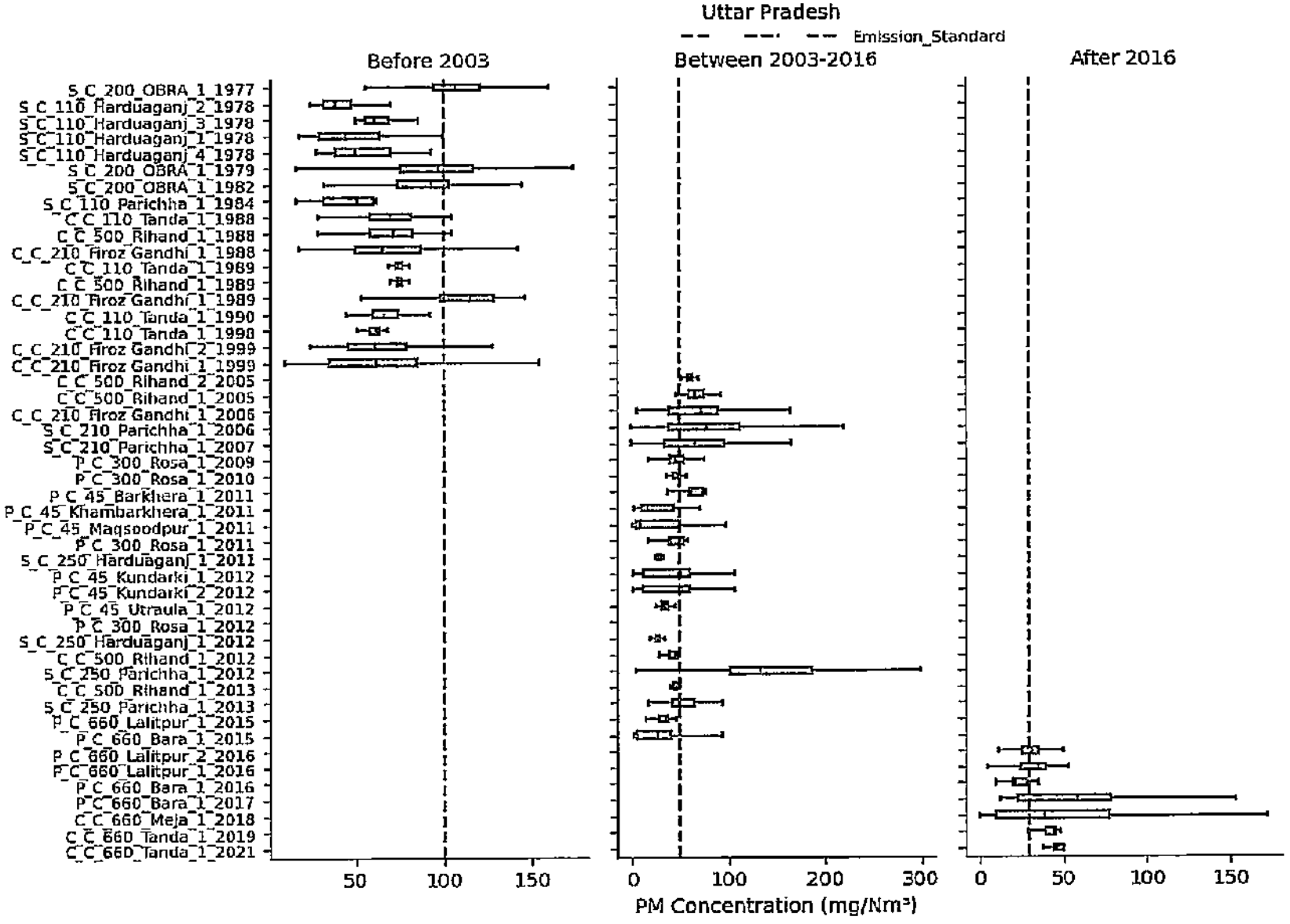
Telangana

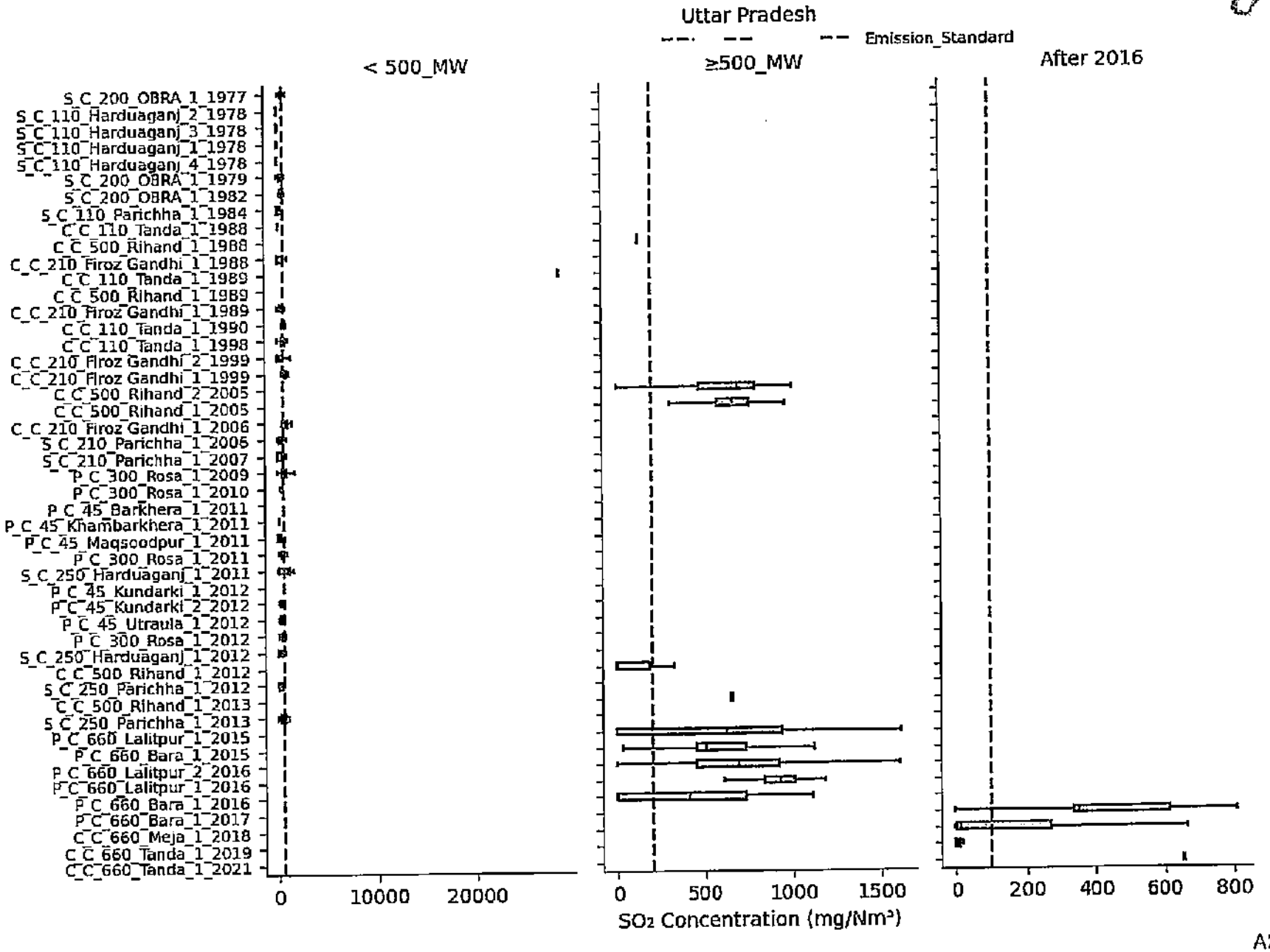

Telangana
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_C_62.5_Ramagundem (II)_1_1971
C_C_200_Ramagundem (I)_1_1983
C_C_200_Ramagundem (I)_1_1984
C_C_200_Ramagundem (I)_2_1984
C_C_500_Ramagundem (I)_1_1988
C_C_500_Ramagundem (I)_2_1989
C_C_500_Ramagundem (I)_1_1989
S_C_250_Kothagudem_1_1997
S_C_250_Kothagudem_1_1998
C_C_500_Ramagundem (I)_1_2005
S_C_500_Kakatiya_2_2010
S_C_500_Kakatiya_1_2010
S_C_600_Kakatiya_1_2015
S_C_600_Pegadapalli_2_2016
S_C_600_Pegadapalli_4_2016
S_C_600_Pegadapalli_3_2016
S_C_600_Pegadapalli_1_2016
0
200
400
0
200
400
600
30
40
PM Concentration (mg/Nm³)


Telangana
Emission_Standard
< 500_MW
≥500_MW
C_C_62.5_Ramagundem (II)_1_1971
C_C_200_Ramagundem (I)_1_1983
C_C_200_Ramagundem (I)_1_1984
C_C_200_Ramagundem (I)_2_1984
C_C_500_Ramagundem (I)_1_1988
C_C_500_Ramagundem (I)_2_1989
C_C_500_Ramagundem (I)_1_1989
S_C_250_Kothagudem_1_1997
S_C_250_Kothagudem_1_1998
C_C_500_Ramagundem (I)_1_2005
S_C_500_Kakatiya_2_2010
S_C_500_Kakatiya_1_2010
S_C_600_Kakatiya_1_2015
S_C_600_Pegadapalli_2_2016
S_C_600_Pegadapalli_4_2016
S_C_600_Pegadapalli_3_2016
S_C_600_Pegadapalli_1_2016
0
1000
2000
SO2 Concentration (mg/Nm³)

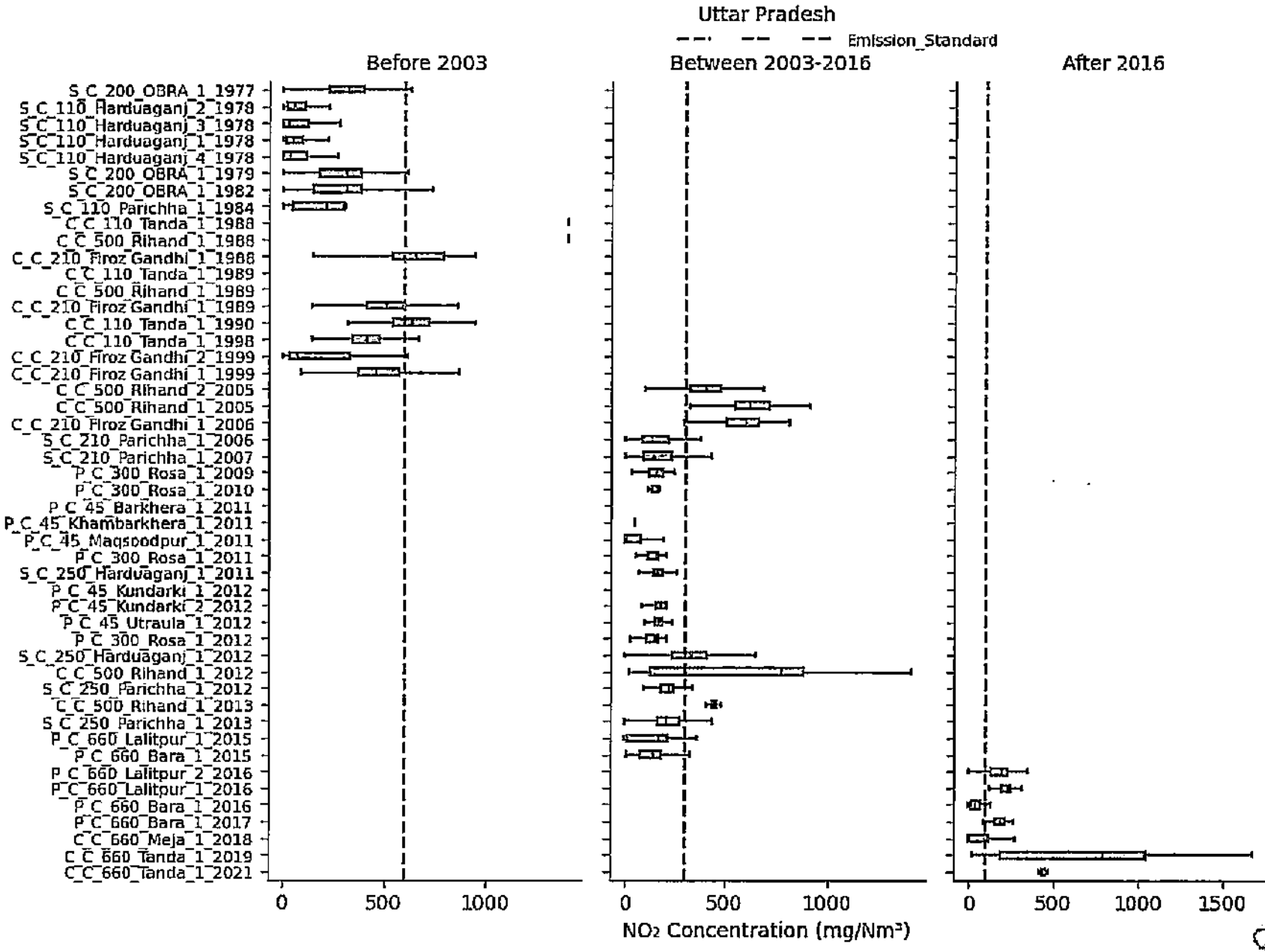

Telangana
Emission_Standard
Before 2003
Between 2003-2016
After 2016
C_C_62.5_Ramagundem (II)_1_1971
C_C_200_Ramagundem (I)_1_1983
C_C_200_Ramagundem (I)_1_1984
C_C_200_Ramagundem (I)_2_1984
C_C_500_Ramagundem (I)_1_1988
C_C_500_Ramagundem (I)_2_1989
C_C_500_Ramagundem (I)_1_1989
S_C_250_Kothagudem_1_1997
S_C_250_Kothagudem_1_1998
C_C_500_Ramagundem (I)_1_2005
S_C_500_Kakatiya_2_2010
S_C_500_Kakatiya_1_2010
S_C_600_Kakatiya_1_2015
S_C_600_Pegadapalli_2_2016
S_C_600_Pegadapalli_4_2016
S_C_600_Pegadapalli_3_2016
S_C_600_Pegadapalli_1_2016
0
500
1000
1500
0
200
400
600
0
200
400
NO2 Concentration (mg/Nm3)

Uttar Pradesh

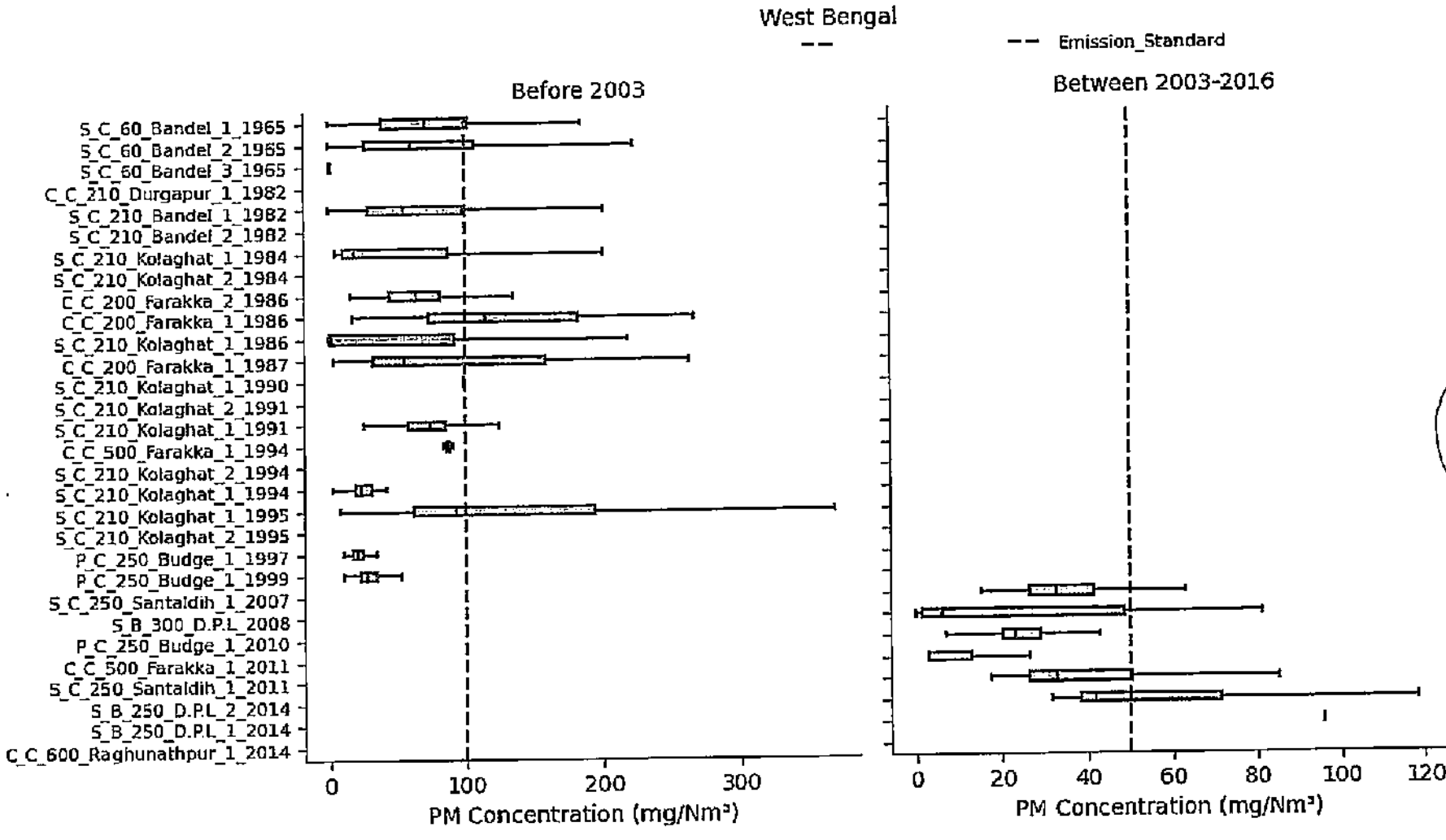


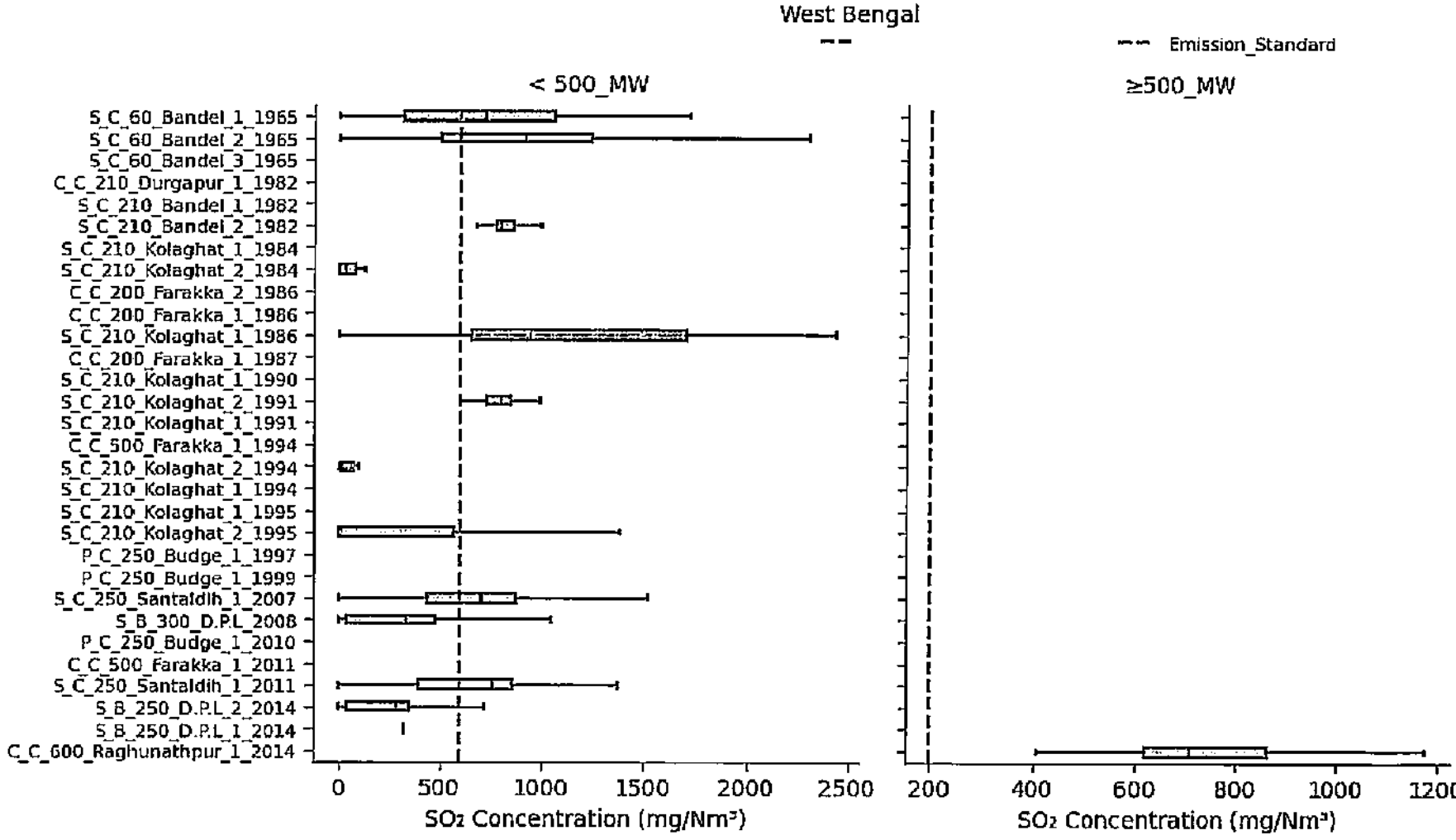

Uttar Pradesh
Emission_Standard
< 500_MW
≥500_MW
After 2016
S_C_200_OBRA_1_1977
S_C_110_Harduaganj_2_1978
S_C_110_Harduaganj_3_1978
S_C_110_Harduaganj_1_1978
S_C_110_Harduaganj_4_1978
S_C_200_OBRA_1_1979
S_C_200_OBRA_1_1982
S_C_110_Parichha_1_1984
C_C_110_Tanda_1_1988
C_C_500_Rihand_1_1988
C_C_210_Firoz Gandhi_1_1988
C_C_110_Tanda_1_1989
C_C_500_Rihand_1_1989
C_C_210_Firoz Gandhi_1_1989
C_C_110_Tanda_1_1990
C_C_110_Tanda_1_1998
C_C_210_Firoz Gandhi_2_1999
C_C_210_Firoz Gandhi_1_1999
C_C_500_Rihand_2_2005
C_C_500_Rihand_1_2005
C_C_210_Firoz Gandhi_1_2006
S_C_210_Parichha_1_2006
S_C_210_Parichha_1_2007
P_C_300_Rosa_1_2009
P_C_300_Rosa_1_2010
P_C_45_Barkhera_1_2011
P_C_45_Khambarkhera_1_2011
P_C_45_Maqsoodpur_1_2011
P_C_300_Rosa_1_2011
S_C_250_Harduaganj_1_2011
P_C_45_Kundarki_1_2012
P_C_45_Kundarki_2_2012
P_C_45_Utraula_1_2012
P_C_300_Rosa_1_2012
S_C_250_Harduaganj_1_2012
C_C_500_Rihand_1_2012
S_C_250_Parichha_1_2012
C_C_500_Rihand_1_2013
S_C_250_Parichha_1_2013
P_C_660_Lalitpur_1_2015
P_C_660_Bara_1_2015
P_C_660_Lalitpur_2_2016
P_C_660_Lalitpur_1_2016
P_C_660_Bara_1_2016
P_C_660_Bara_1_2017
C_C_660_Meja_1_2018
C_C_660_Tanda_1_2019
C_C_660_Tanda_1_2021
0
10000
20000
0
500
1000
1500
0
200
400
600
800
SO₂ Concentration (mg/Nm³)

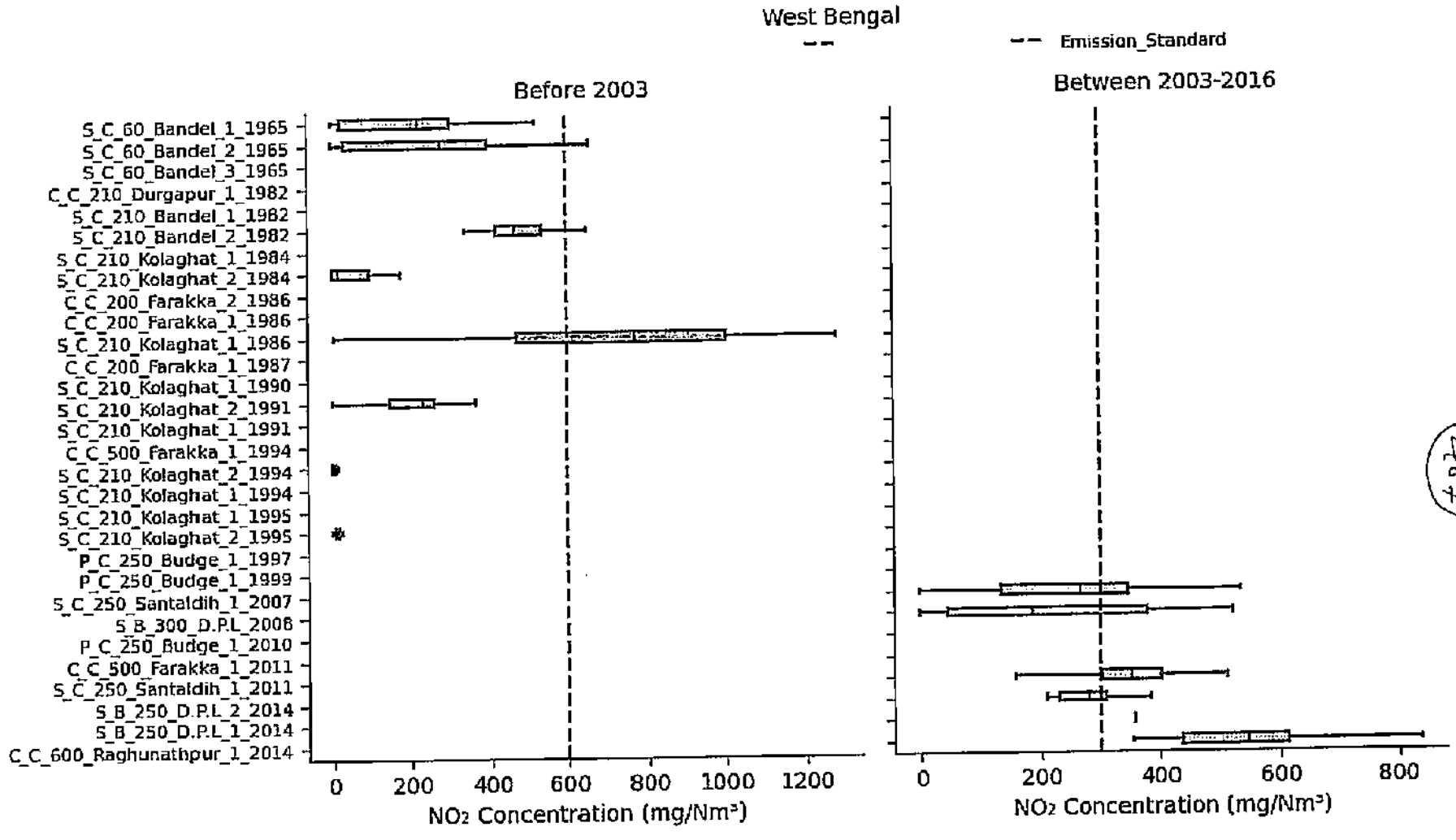
606 03


Uttar Pradesh
Emission_Standard
Before 2003
Between 2003-2016
After 2016
S_C_200_OBRA_1_1977
S_C_110_Harduaganj_2_1978
S_C_110_Harduaganj_3_1978
S_C_110_Harduaganj_1_1978
S_C_110_Harduaganj_4_1978
S_C_200_OBRA_1_1979
S_C_200_OBRA_1_1982
S_C_110_Parichha_1_1984
C_C_110_Tanda_1_1988
C_C_500_Rihand_1_1988
C_C_210_Firoz Gandhi_1_1988
C_C_110_Tanda_1_1989
C_C_500_Rihand_1_1989
C_C_210_Firoz Gandhi_1_1989
C_C_110_Tanda_1_1990
C_C_110_Tanda_1_1998
C_C_210_Firoz Gandhi_2_1999
C_C_210_Firoz Gandhi_1_1999
C_C_500_Rihand_2_2005
C_C_500_Rihand_1_2005
C_C_210_Firoz Gandhi_1_2006
S_C_210_Parichha_1_2006
S_C_210_Parichha_1_2007
P_C_300_Rosa_1_2009
P_C_300_Rosa_1_2010
P_C_45_Barkhera_1_2011
P_C_45_Khambarkhera_1_2011
P_C_45_Maqsoodpur_1_2011
P_C_300_Rosa_1_2011
S_C_250_Harduaganj_1_2011
P_C_45_Kundarki_1_2012
P_C_45_Kundarki_2_2012
P_C_45_Utraula_1_2012
P_C_300_Rosa_1_2012
S_C_250_Harduaganj_1_2012
C_C_500_Rihand_1_2012
S_C_250_Parichha_1_2012
C_C_500_Rihand_1_2013
S_C_250_Parichha_1_2013
P_C_660_Lalitpur_1_2015
P_C_660_Bara_1_2015
P_C_660_Lalitpur_2_2016
P_C_660_Lalitpur_1_2016
P_C_660_Bara_1_2016
P_C_660_Bara_1_2017
C_C_660_Meja_1_2018
C_C_660_Tanda_1_2019
C_C_660_Tanda_1_2021
0
500
1000
0
500
1000
0
500
1000
1500
NO2 Concentration (mg/Nm3)

West Bengal


West Bengal
Emission_Standard
Before 2003
Between 2003-2016
S_C_60_Bandel_1_1965
S_C_60_Bandel_2_1965
S_C_60_Bandel_3_1965
C_C_210_Durgapur_1_1982
S_C_210_Bandel_1_1982
S_C_210_Bandel_2_1982
S_C_210_Kolaghat_1_1984
S_C_210_Kolaghat_2_1984
C_C_200_Farakka_2_1986
C_C_200_Farakka_1_1986
S_C_210_Kolaghat_1_1986
C_C_200_Farakka_1_1987
S_C_210_Kolaghat_1_1990
S_C_210_Kolaghat_2_1991
S_C_210_Kolaghat_1_1991
C_C_500_Farakka_1_1994
S_C_210_Kolaghat_2_1994
S_C_210_Kolaghat_1_1994
S_C_210_Kolaghat_1_1995
S_C_210_Kolaghat_2_1995
P_C_250_Budge_1_1997
P_C_250_Budge_1_1999
S_C_250_Santaldih_1_2007
S_B_300_D.P.L_2008
P_C_250_Budge_1_2010
C_C_500_Farakka_1_2011
S_C_250_Santaldih_1_2011
S_B_250_D.P.L_2_2014
S_B_250_D.P.L_1_2014
C_C_600_Raghunathpur_1_2014
0
100
200
300
PM Concentration (mg/Nm³)
0
20
40
60
80
100
120
PM Concentration (mg/Nm³)


West Bengal
Emission_Standard
< 500_MW
≥500_MW
S_C_60_Bandel_1_1965
S_C_60_Bandel_2_1965
S_C_60_Bandel_3_1965
C_C_210_Durgapur_1_1982
S_C_210_Bandel_1_1982
S_C_210_Bandel_2_1982
S_C_210_Kolaghat_1_1984
S_C_210_Kolaghat_2_1984
C_C_200_Farakka_2_1986
C_C_200_Farakka_1_1986
S_C_210_Kolaghat_1_1986
C_C_200_Farakka_1_1987
S_C_210_Kolaghat_1_1990
S_C_210_Kolaghat_2_1991
S_C_210_Kolaghat_1_1991
C_C_500_Farakka_1_1994
S_C_210_Kolaghat_2_1994
S_C_210_Kolaghat_1_1994
S_C_210_Kolaghat_1_1995
S_C_210_Kolaghat_2_1995
P_C_250_Budge_1_1997
P_C_250_Budge_1_1999
S_C_250_Santaldih_1_2007
S_B_300_D.P.L_2008
P_C_250_Budge_1_2010
C_C_500_Farakka_1_2011
S_C_250_Santaldih_1_2011
S_B_250_D.P.L_2_2014
S_B_250_D.P.L_1_2014
C_C_600_Raghunathpur_1_2014
0
500
1000
1500
2000
2500
200
400
600
800
1000
1200
SO2 Concentration (mg/Nm3)
SO2 Concentration (mg/Nm3)


West Bengal
Emission_Standard
Before 2003
Between 2003-2016
S_C_60_Bandel_1_1965
S_C_60_Bandel_2_1965
S_C_60_Bandel_3_1965
C_C_210_Durgapur_1_1982
S_C_210_Bandel_1_1982
S_C_210_Bandel_2_1982
S_C_210_Kolaghat_1_1984
S_C_210_Kolaghat_2_1984
C_C_200_Farakka_2_1986
C_C_200_Farakka_1_1986
S_C_210_Kolaghat_1_1986
C_C_200_Farakka_1_1987
S_C_210_Kolaghat_1_1990
S_C_210_Kolaghat_2_1991
S_C_210_Kolaghat_1_1991
C_C_500_Farakka_1_1994
S_C_210_Kolaghat_2_1994
S_C_210_Kolaghat_1_1994
S_C_210_Kolaghat_1_1995
S_C_210_Kolaghat_2_1995
P_C_250_Budge_1_1997
P_C_250_Budge_1_1999
S_C_250_Santaldih_1_2007
S_B_300_D.P.L_2008
P_C_250_Budge_1_2010
C_C_500_Farakka_1_2011
S_C_250_Santaldih_1_2011
S_B_250_D.P.L_2_2014
S_B_250_D.P.L_1_2014
C_C_600_Raghunathpur_1_2014
0
200
400
600
800
1000
1200
NO2 Concentration (mg/Nm3)
0
200
400
600
800
NO2 Concentration (mg/Nm3)

Annexure – A3

Emission standards of Thermal Power Station

Power generation facilities all around the world are obliged to comply with emission standards[1] in order to reap environmental and social benefit along with maximum power generation. These emission standards are played a vital role for the country's sustainable development. However, the requirements for emission standards vary per country that is determined by the country's level of knowledge and environmental acceptability. The World Bank has recommended siting guideline for different capacity of thermal power plant based on good, moderate and poor airshed (See Table).

Table: World Bank guidelines for siting of power plants:

Power Plant Capacity	Airshed category	Environmental assessment and emission requirements
Less than 500 MW	Good air quality	Subject to the maximum emission levels specified in the guidelines including SO_2 emission of 0.2 tpd per MW of capacity (maximum of 100 tpd for 500 MW) and maximum concentration of 2000 mg/m^3.
Greater than equal to 500 MW	Good air quality	Subject to the maximum emission levels specified in the guidelines including SO_2 emission of 0.2 tpd per MW upto 500 MW and 0.1 tpd for each additional capacity over 500 MW.
Less than 500 MW	Moderate air quality	Subject to the maximum emission levels specified in the guidelines provided that the environmental assessment shows that the plant will not lead to either the airshed dropping into category having poor air quality or an increase of more than 5 µg/m^3 in the annual mean level for the entire airshed of the pollutant. If either of these conditions is not satisfied, then lower site-specific emission levels should be established. The limit of 5 µg/m^3 increase will apply to the cumulative total impact of all power plants built in the airshed within any 10 years, beginning and after the date of the guidelines comes into effect.
Greater than or equal to 500 MW	Moderate air quality and all plants in airshed with poor air quality	Subject to site specific requirements that includes offset provisions to ensure that no net increase in the total emissions within the airshed of the pollutants which are the reason for the airshed being classified as having moderate or poor air quality. The measures agreed under the offset provisions must be implemented before the power plant comes fully on stream.

Source: The World Bank and *"Review of environmental guidelines: India vs other countries"* TERI Report obtained from CEA archive.

[1] The emission standards are regulatory or legal requirements that quantify permissiable limits of air pollutant emitted from any specific source in to the atmosphere.

This study focuses on emission standard of coal based thermal power station and ambient air of different country with specific attention towards India. For each country, emission standards are formulated to reduce the level of a particular pollutant's concentration and to set a control over emissions up to a desired level.

Emission standards of TPS in India

India began enacting environmental regulations at the end of 1970 to combat with modern environmental issues. The major environmental legislation of India is *Wildlife Protection Act* in 1972, *Water Pollution Prevention Act* in 1974, *Forest Protection Act* in 1980, and *Air Pollution Prevention and Control Act* in 1981. The first comprehensive environmental law ("*Environmental Protection Act*") in India was passed by the Federal Parliament in May 1986. The Environmental Protection Act of India (EPA, India) went into effect on November 19, 1986. In this way, modern environmental legal system has been developed in India. The Environment (Protection) Act (No. 29 of 1986, 23 May 1986, last amended in 1991) state that the implementation of power plant projects requires clearance from the MoEF & CC via an environmental impact assessment. The old emission standards (1989) consider only particulate matter based on their power generation capacity (MW).

Emission standard guideline for thermal power station in India

Old Emission Standards (1989)				
Power generation capacity (MW)	PM	SO_2	NO_X	Hg
< 210 MW	350 mg/Nm^3	None	None	None
≥ 210 MW	150 mg/Nm^3	None	None	None

New Emission Standards (2015)	
Parameter	Standards (in mg/Nm^3)
TPPs(units) installed before 31st December 2003*	
Particulate Matter (PM)	100
Sulphur Dioxide (SO_2)	600 (For units having < 500 MW capacity) 200 (For units having ≥ 500 MW capacity)
Oxides of Nitrogen (NOx)	600
Mercury (Hg)	0.03 (For units having ≥ 500 MW capacity)
TPPs(units) installed after 1st January, 2003, up to 31st December 2016*	
Particulate Matter (PM)	50
Sulphur Dioxide (SO_2)	600 (For units having < 500 MW capacity) 200 (For units having ≥ 500 MW capacity)
Oxides of Nitrogen (NOx)	300
Mercury (Hg)	0.03
TPPs (units) to be installed from 1st January, 2017**	
Particulate Matter (PM)	30
Sulphur Dioxide (SO_2)	100
Oxides of Nitrogen (NOx)	100
Mercury (Hg)	0.03

* Units shall meet the limits within two years from date of publication of this notification.
** Includes all the units, which have been accorded environmental clearance and under construction.

Source: MOEF & CC Notification No: S.O.3305 (E) titled 'Environmental (Protection) Amendment rules, 2015 dated 7.12.2015.

The MoEF&CC has notified with Notification No: S.O.3305 (E) titled 'Environmental (Protection) Amendment rules, 2015 dated 7.12.2015 to revise the emission standards for coal-based Thermal Power Plants in the country, with the primary aim of minimizing pollution. For this purpose, Thermal power stations are categorized into 3 categories,

- namely those:- (i) Installed before 31st December, 2003 (ii) Installed after 2003 upto 31st December, 2016 and (iii) Installed after 31st December, 2016 (See Table:). These emission standards are stringent for recent plants compared to older plants and it is highly stringent for upcoming plants in future. As compared with other countries, India adopted highly stringent emission norms, especially for newly constructed TPP (See Table). The SO_2 permissible limit is 100 for new TPP that is more than the emission standard adopted by China and more than the other countries. Furthermore, NO_x permissible limits are equivalent to China and less than other countries. The particulate matter permissible limits are much lesser but it more than China, European Union, United States, and Korea.

The emission standards (2015) have not specified about the time period of monitoring of pollutant. However, the pollutant emissions are regularly monitored through online continuous monitoring system (OCEMS) in TPP, as mandated by MoEF&CC. The OCEMS data provide 24h averaged data for each day. Therefore, it become important to know about the time period of monitoring of permissible limits of pollutant to fulfill the compliances of the emission standards.

Emission limits for existing and new power plants in selected countries /regions (mg/Nm^3)

Region	Policy	SO_2		NO_x		PM	
		Existing	New	Existing	New	Existing	New
China[a]	Emission standard of air pollutants for thermal power plant, 2011	100-400	50	100-200	100	30	20
European Union	Industrial Emissions Directive, 2010	200-400	150-400	200-450	150-400	20-30	10-20
United States[b]	New Source Performance Standards, 2015	160-640	160	117-640	117	23	23
India	Environment (Protection) Amendment Rules, 2015	200-600	100	300-600	100	50-100	30
Indonesia	MOE decree no. 21 2008	750	750	850	750	150	100
Japan[c]	Air Pollution Control Law 1993	-	-	123-513	123-513	30-100	30-100
Mexico[d]	Mexican Official Standard NOM-085-ECOL-1994 (in PPMV for SO_2 and NO_x)	550-2200	30-2200	110-375	25-375	60-450	60-450
Philippines	National Emission Standards for Particulate Matter for Stationary Sources	1000-1500	200-700	1000-1500	500-1000	150-200	150-200
South Africa	The Minimum Emissions Standards are published by the government	3500	500	1100	750	100	50
Korea	Special Measures for Metropolitan Air Qality Improvement, 2002	286	229	308	164	40	20-30
Thailand	Royal Thai Government Gazette	700-1300	180-360	400	200	80-320	80
Vietnam	Industrial emission standards for dust and inorganic substances,2005	1500	500	1000	650-1000	400	200

[a]"New" Special emission limits for air pollutants applicable to key areas adopted in China.
[b]US emission limits were converted from lb/MBtu to mg/m^3 assuming an F-factor of 1800 standard cu. Ft. of CO_2 and a CO_2 content of 12% in the flue gas.
[c]Japan Air Pollution Control Law (APCL) specifies emission limits for SO_x, NO_x, and PM that differ depending on the scale of facilities, technologies, and regions. Prior to the construction of new plants in Japan, local authorities and power generation companies usually arrive at bilateral pollution prevention agreements more stringent than those mandated in the APCL, 1993.
[d]For Mexico, SO2 and NOX are expressed in parts per million by volume (PPMV).

Notes: "Existing" refers to the emission limit for currently operating power plants. "New" refers to the limit for planned or proposed plants.

Source: "*Advances in ultra-low emission control technologies for coal-fired power plants*" by Tao Wang and published by Elsevier.

Emission limits for existing coal-fired power plants*				
Jurisdiction	**SO_2**	**NOx**	**PM**	**Hg**
EU: from 2023, hard coal	130	150	8	4
EU: from 2023, lignite	130	175	8	7
China: from 2020	35	50	10	30
EU: from 2015	200	200	20	–
U.S.	640	640	23	1.6
China: All plants	200	100	30	30
South Korea	286	308	36	–
Japan	200	376	46	–
India: units installed after 2003*	**200**	**600**	**50**	**30**
Turkey	400	200	50	–
Chile	400	500	50	–
South Africa*	680	1020	68	–
India: units installed before 2003*	200	300	100	30
Indonesia	589	589	107	–
Australia	–	856	109	–
Philippines	1607	1607	214	–
Vietnam	500	1000	400	–
***Unit: mg/Nm³, except Hg as µg/Nm³, dry STP 6% oxygen.**				

Emission limits for new coal-fired power plants*				
Jurisdiction	**SO_2**	**NOx**	**PM**	**Hg**
China	35	50	10	30
United States – MATS	60	99	13	0.5
EU, hard coal	75	85	5	2
EU, lignite	75	85	5	4
India	**100**	**100**	**30**	**30**
Turkey	150	150	10	30
South Korea	229	164	18	30
Vietnam	350	455	140	30
Philippines	594	1071	161	30
South Africa	680	1020	68	30
Indonesia	804	804	107	30
Australia	–	856	109	30
***Unit: mg/Nm³, except Hg as µg/Nm³, dry STP 6% oxygen.**				

Source: https://energyandcleanair.org/

Annexure - B1

List of continuous ambient air quality monitoring station (CAAQMS)

State / UT	City	No. of CAAQMS station
Andhra Pradesh	Rajamahendravaram	Anand Kala Kshetram, Rajamahendravaram - APPCB
Andhra Pradesh	Chittoor	Gangineni Cheruvu, Chittoor - APPCB
Andhra Pradesh	Anantapur	Gulzarpet, Anantapur - APPCB
Andhra Pradesh	Visakhapatnam	GVM Corporation, Visakhapatnam - APPCB
Andhra Pradesh	Vijayawada	Kanuru, Vijayawada - APPCB
Andhra Pradesh	Vijayawada	PWD Grounds, Vijayawada - APPCB
Andhra Pradesh	Amaravati	Secretariat, Amaravati - APPCB
Andhra Pradesh	Tirupati	Tirumala, Tirupati - APPCB
Andhra Pradesh	Tirupati	Vaikuntapuram, Tirupati - APPCB
Andhra Pradesh	Kadapa	Yerramukkapalli, Kadapa - APPCB
Arunachal Pradesh	Naharlagun	Naharlagun, Naharlagun - APSPCB
Assam	Nalbari	Bata Chowk, Nalbari - PCBA
Assam	Byrnihat	Central Academy for SFS, Byrnihat - PCBA
Assam	Nagaon	Christianpatty, Nagaon - PCBA
Assam	Sivasagar	Girls College, Sivasagar - PCBA
Assam	Guwahati	IITG, Guwahati - PCBA
Assam	Guwahati	LGBI Airport, Guwahati - PCBA
Assam	Guwahati	Pan Bazaar, Guwahati - PCBA
Assam	Guwahati	Railway Colony, Guwahati - PCBA
Assam	Silchar	Tarapur, Silchar - PCBA
Bihar	Muzaffarpur	Buddha Colony, Muzaffarpur - BSPCB
Bihar	Buxar	Central Jail, Buxar - BSPCB
Bihar	Siwan	Chitragupta Nagar, Siwan - BSPCB
Bihar	Gaya	Collectorate, Gaya - BSPCB
Bihar	Bihar Sharif	D M Colony, Bihar Sharif - BSPCB
Bihar	Sasaram	Dada Peer, Sasaram - BSPCB
Bihar	Rajgir	Dangi Tola, Rajgir - BSPCB
Bihar	Chhapra	Darshan Nagar, Chhapra - BSPCB
Bihar	Bhagalpur	DM Office_Kachari Chowk, Bhagalpur - BSPCB
Bihar	Samastipur	DM Office_Kasipur, Samastipur - BSPCB
Bihar	Begusarai	DRCC Anandpur, Begusarai - BSPCB
Bihar	Patna	DRM Office Danapur, Patna - BSPCB
Bihar	Manguraha	Forest Rest House, Manguraha - BSPCB
Bihar	Motihari	Gandak Colony, Motihari - BSPCB
Bihar	Patna	Govt. High School Shikarpur, Patna - BSPCB
Bihar	Aurangabad	Gurdeo Nagar, Aurangabad - BSPCB
Bihar	Patna	IGSC Planetarium Complex, Patna - BSPCB
Bihar	Hajipur	Industrial Area, Hajipur - BSPCB
Bihar	Bettiah	Kamalnath Nagar, Bettiah - BSPCB
Bihar	Gaya	Kareemganj, Gaya - BSPCB
Bihar	Araria	Kharahiya Basti, Araria - BSPCB
Bihar	Purnia	Mariam Nagar, Purnia - BSPCB
Bihar	Bhagalpur	Mayaganj, Bhagalpur - BSPCB
Bihar	Katihar	Mirchaibari, Katihar - BSPCB
Bihar	Muzafferpur	MIT-Daudpur Kothi, Muzaffarpur - BSPCB
Bihar	Patna	Muradpur, Patna - BSPCB
Bihar	Muzaffarpur	Muzaffarpur Collectorate, Muzaffarpur - BSPCB
Bihar	Arrah	New DM Office, Arrah - BSPCB
Bihar	Saharsa	Police Line, Saharsa - BSPCB

Bihar	Patna	Rajbansi Nagar, Patna - BSPCB
Bihar	Patna	Samanpura, Patna - BSPCB
Bihar	Kishanganj	SDM Office_Khagra, Kishanganj - BSPCB
Bihar	Gaya	SFTI Kusdihra, Gaya - BSPCB
Bihar	Darbhanga	Town Hall - Lal Bagh, Darbhanga - BSPCB
Bihar	Munger	Town Hall, Munger - BSPCB
Chhattisgarh	Bhilai	32Bungalows, Bhilai - CECB
Chhattisgarh	Raipur	AIIMS, Raipur - CECB
Chhattisgarh	Raipur	Bhatagaon New ISBT, Raipur - CECB
Chhattisgarh	Bhilai	Civic Center, Bhilai - Bhilai Steel Plant
Chhattisgarh	Milupara	Govt. Higher Secondary School, Milupara - CECB
Chhattisgarh	Bhilai	Hathkhoj, Bhilai - CECB
Chhattisgarh	Raipur	Krishak Nagar, Raipur - CECB
Chhattisgarh	Bilaspur	Mangala, Bilaspur - NTPC
Chhattisgarh	Chhal	Nawapara SECL Colony, Chhal - CECB
Chhattisgarh	Tumidih	OP Jindal Industrial Park, Tumidih - CECB
Chhattisgarh	Kunjemura	OP Jindal School, Kunjemura - CECB
Chhattisgarh	Korba	Rampur, Korba - CECB
Chhattisgarh	Raipur	Siltara Phase-II, Raipur - CECB
Chhattisgarh	Korba	Urja Nagar, Korba - CECB
Gujarat	Ahmedabad	Chandkheda, Ahmedabad - IITM
Gujarat	Ankleshwar	GIDC, Ankleshwar - GPCB
Gujarat	Nandesari	GIDC, Nandesari - Nandesari Ind. Association
Gujarat	Gandhinagar	GIFT City, Gandhinagar - IITM
Gujarat	Ahmedabad	Gyaspur, Ahmedabad - IITM
Gujarat	Gandhinagar	IIPHG Lekawada, Gandhinagar - IITM
Gujarat	Ahmedabad	Maninagar, Ahmedabad - GPCB
Gujarat	Vapi	Phase-1 GIDC, Vapi - GPCB
Gujarat	Vatva	Phase-4 GIDC, Vatva - GPCB
Gujarat	Ahmedabad	Raikhad, Ahmedabad - IITM
Gujarat	Ahmedabad	Rakhial, Ahmedabad - IITM
Gujarat	Ahmedabad	SAC ISRO Bopal, Ahmedabad - IITM
Gujarat	Ahmedabad	SAC ISRO Satellite, Ahmedabad - IITM
Gujarat	Ahmedabad	Sardar Vallabhbhai Patel Stadium, Ahmedabad - IITM
Gujarat	Surat	Science Center, Surat - SMC
Gujarat	Gandhinagar	Sector-10, Gandhinagar - GPCB
Gujarat	Ahmedabad	SVPI Airport Hansol, Ahmedabad - IITM
Haryana	Bahadurgarh	Arya Nagar, Bahadurgarh - HSPCB
Haryana	Sirsa	F-Block, Sirsa - HSPCB
Haryana	Mandikhera	General Hospital, Mandikhera - HSPCB
Haryana	Yamuna Nagar	Gobind Pura, Yamuna Nagar - HSPCB
Haryana	Bhiwani	H.B. Colony, Bhiwani - HSPCB
Haryana	Fatehabad	Huda Sector, Fatehabad - HSPCB
Haryana	Rohtak	MD University, Rohtak - HSPCB
Haryana	Charkhi Dadri	Mini Secretariat, Charkhi Dadri - HSPCB
Haryana	Dharuhera	Municipal Corporation Office, Dharuhera - HSPCB
Haryana	Sonipat	Murthal, Sonipat - HSPCB
Haryana	Ballabgarh	Nathu Colony, Ballabgarh - HSPCB
Haryana	Faridabad	New Industrial Town, Faridabad - HSPCB
Haryana	Gurugram	NISE Gwal Pahari, Gurugram - IMD
Haryana	Ambala	Patti Mehar, Ambala - HSPCB
Haryana	Jind	Police Lines, Jind - HSPCB
Haryana	Kaithal	Rishi Nagar, Kaithal - HSPCB
Haryana	Faridabad	Sector 11, Faridabad - HSPCB
Haryana	Faridabad	Sector 30, Faridabad - HSPCB
Haryana	Faridabad	Sector- 16A, Faridabad - HSPCB

Haryana	Karnal	Sector-12, Karnal - HSPCB
Haryana	Panipat	Sector-18, Panipat - HSPCB
Haryana	Manesar	Sector-2 IMT, Manesar - HSPCB
Haryana	Gurugram	Sector-51, Gurugram - HSPCB
Haryana	Panchkula	Sector-6, Panchkula - HSPCB
Haryana	Kurukshetra	Sector-7, Kurukshetra - HSPCB
Haryana	Narnaul	Shastri Nagar, Narnaul - HSPCB
Haryana	Palwal	Shyam Nagar, Palwal - HSPCB
Haryana	Gurugram	Teri Gram, Gurugram - HSPCB
Haryana	Hisar	Urban Estate-II, Hisar - HSPCB
Haryana	Gurugram	Vikas Sadan, Gurugram - HSPCB
Himachal Pradesh	Baddi	HIMUDA Complex Phase-1, Baddi - HPPCB
Jharkhand	Dhanbad	Sardar Patel Nagar, Dhanbad - JSPCB
Jharkhand	Jorapokhar	Tata Stadium, Jorapokhar - JSPCB
Karnataka	Haveri	Ashwini Nagar, Haveri - KSPCB
Karnataka	Hassan	B.Katihalli, Hassan - KSPCB
Karnataka	Bengaluru	Bapuji Nagar, Bengaluru - KSPCB
Karnataka	Udupi	Brahmagiri, Udupi - KSPCB
Karnataka	Bengaluru	BTM Layout, Bengaluru - CPCB
Karnataka	Bengaluru	BWSSB Kadabesanahalli, Bengaluru - CPCB
Karnataka	Chikkaballapur	Chikkaballapur Rural, Chikkaballapur - KSPCB
Karnataka	Bengaluru	City Railway Station, Bengaluru - KSPCB
Karnataka	Yadgir	Collector Office, Yadgir - KSPCB
Karnataka	Hubballi	Deshpande Nagar, Hubballi - KSPCB
Karnataka	Davanagere	Devaraj Urs Badavane, Davanagere - KSPCB
Karnataka	Koppal	Diwator Nagar, Koppal - KSPCB
Karnataka	Raichur	Haji Colony, Raichur - KSPCB
Karnataka	Mysuru	Hebbal 1st Stage, Mysuru - KSPCB
Karnataka	Bengaluru	Hebbal, Bengaluru - KSPCB
Karnataka	Bengaluru	Hombegowda Nagar, Bengaluru - KSPCB
Karnataka	Vijayapura	Ibrahimpur, Vijayapura - KSPCB
Karnataka	Bengaluru	Jayanagar 5th Block, Bengaluru - KSPCB
Karnataka	Mangalore	Kadri, Mangalore - KSPCB
Karnataka	Dharwad	Kalabhavan, Dharwad - KSPCB
Karnataka	Chikkamagaluru	Kalyana Nagara, Chikkamagaluru - KSPCB
Karnataka	Kalaburagi	Lal Bahadur Shastri Nagar, Kalaburagi - KSPCB
Karnataka	Hubballi	Lingaraj Nagar, Hubballi - KSPCB
Karnataka	Kalaburagi	Mahatma Basaveswar Colony, Kalaburgi - KSPCB
Karnataka	Bidar	Naubad, Bidar - KSPCB
Karnataka	Gadag	Panchal Nagar, Gadag - KSPCB
Karnataka	Bengaluru	Peenya, Bengaluru - CPCB
Karnataka	Belgaum	Ramteerth Nagar, Belgaum - KSPCB
Karnataka	Bengaluru	RVCE-Mailasandra, Bengaluru - KSPCB
Karnataka	Bengaluru	Sanegurava Halli, Bengaluru - KSPCB
Karnataka	Bengaluru	Shivapura_Peenya, Bengaluru - KSPCB
Karnataka	Bengaluru	Silk Board, Bengaluru - KSPCB
Karnataka	Madikeri	Stuart Hill, Madikeri - KSPCB
Karnataka	Kolar	Tamaka Ind. Area, Kolar - KSPCB
Karnataka	Tumakuru	Thimmalapura, Tumakuru - KSPCB
Karnataka	Chamarajanagar	Urban, Chamarajanagar - KSPCB
Karnataka	Bagalkot	Vidayagiri, Bagalkot - KSPCB
Karnataka	Ramanagara	Vijay Nagar, Ramanagara - KSPCB
Karnataka	Shivamogga	Vinoba Nagara, Shivamogga - KSPCB
Kerala	Thrissur	Corporation Ground, Thrissur - Kerala PCB
Kerala	Ernakulam	Kacheripady, Ernakulam - Kerala PCB
Kerala	Thiruvananthapuram	Kariavattom, Thiruvananthapuram - Kerala PCB

Kerala	Kozhikode	Palayam, Kozhikode - Kerala PCB
Kerala	Thiruvananthapuram	Plammoodu, Thiruvananthapuram - Kerala PCB
Kerala	Kollam	Polayathode, Kollam - Kerala PCB
Kerala	Kannur	Thavakkara, Kannur - Kerala PCB
Kerala	Eloor	Udyogamandal, Eloor - Kerala PCB
Kerala	Kochi	Vyttila, Kochi - Kerala PCB
Madhya Pradesh	Anuppur	Collectorate
Madhya Pradesh	Betul	Collector
Madhya Pradesh	Bhopal	Collector
Madhya Pradesh	Bhopal	Paryavaran
Madhya Pradesh	Bhopal	TT Nagar
Madhya Pradesh	Damoh	Shrivastav Colony
Madhya Pradesh	Dewas	Bhopal Chauraha
Madhya Pradesh	Dewas	Govt MG Hospital
Madhya Pradesh	Gwalior	Maharaja Bada
Madhya Pradesh	Gwalior	PhoolBagh
Madhya Pradesh	Gwalior	City Center
Madhya Pradesh	Gwalior	DD Nagar
Madhya Pradesh	Indore	Airport Area
Madhya Pradesh	Indore	Chhoti Gwaltoli
Madhya Pradesh	Indore	Maguda Nagar
Madhya Pradesh	Indore	Playground
Madhya Pradesh	Indore	Redional Park
Madhya Pradesh	Indore	Regional Park
Madhya Pradesh	Indore	Residence Area
Madhya Pradesh	Indore	Vijay Nagar
Madhya Pradesh	Jabalpur	Govindh Bhavan Colony
Madhya Pradesh	Jabalpur	Gupteshwar
Madhya Pradesh	Jabalpur	Marhatal
Madhya Pradesh	Jabalpur	Suhagi
Madhya Pradesh	Katni	Gole Bazar
Madhya Pradesh	Katni	Regional Office
Madhya Pradesh	Khandwa	Lok Seva Kendra
Madhya Pradesh	Khargone	Nagar Palika
Madhya Pradesh	Maihar	Sharda Temple
Madhya Pradesh	Mandideep	Sector New Industrial Area
Madhya Pradesh	Narsinghpur	District Education Office
Madhya Pradesh	Panna	Collectorate
Madhya Pradesh	Pithampur	Sector-2 Industrial Area
Madhya Pradesh	Ratlam	Shathri Nagar
Madhya Pradesh	Rewa	Collector Office
Madhya Pradesh	Rewa	Regional Office
Madhya Pradesh	Sagar	Collectorate Office
Madhya Pradesh	Sagar	Deen Dayal Nagar
Madhya Pradesh	Satna	Bandhavgar Colony
Madhya Pradesh	Singrauli	Surya Kiran Bhawan Dudhichua
Madhya Pradesh	Singrauli	Trauma Centre Waidhan
Madhya Pradesh	Ujjain	Mahakaleshwar Temple
Maharashtra	Navi Mumbai	Airoli, Navi Mumbai - MPCB
Maharashtra	Pune	Alandi, Pune - IITM
Maharashtra	Mumbai	Bandra Kurla Complex, Mumbai - IITM
Maharashtra	Mumbai	Bandra, Mumbai - MPCB
Maharashtra	Pune	Bhosari, Pune - IITM
Maharashtra	Mumbai	Borivali East, Mumbai - IITM
Maharashtra	Mumbai	Borivali East, Mumbai - MPCB
Maharashtra	Mumbai	Chakala-Andheri East, Mumbai - IITM

Maharashtra	Chandrapur	Chauhan Colony, Chandrapur - MPCB
Maharashtra	Mumbai	Chhatrapati Shivaji Intl. Airport (T2), Mumbai - MPCB
Maharashtra	Mumbai	Colaba, Mumbai - MPCB
Maharashtra	Mumbai	Deonar, Mumbai - IITM
Maharashtra	Nashik	Gangapur Road, Nashik - MPCB
Maharashtra	Pune	Hadapsar, Pune - IITM
Maharashtra	Mumbai	Kandivali East, Mumbai - MPCB
Maharashtra	Pune	Karve Road, Pune - MPCB
Maharashtra	Kalyan	Khadakpada, Kalyan - MPCB
Maharashtra	Mumbai	Khindipada-Bhandup West, Mumbai - IITM
Maharashtra	Mumbai	Kurla, Mumbai - MPCB
Maharashtra	Navi Mumbai	Mahape, Navi Mumbai - MPCB
Maharashtra	Mumbai	Malad West, Mumbai - IITM
Maharashtra	Mumbai	Mazgaon, Mumbai - IITM
Maharashtra	Pune	Mhada Colony, Pune - IITM
Maharashtra	Chandrapur	MIDC Khutala, Chandrapur - MPCB
Maharashtra	Pune	MIT-Kothrud, Pune - IITM
Maharashtra	Aurangabad	More Chowk Waluj, Aurangabad - MPCB
Maharashtra	Mumbai	Mulund West, Mumbai - MPCB
Maharashtra	Mumbai	Navy Nagar-Colaba, Mumbai - IITM
Maharashtra	Navi Mumbai	Nerul, Navi Mumbai - MPCB
Maharashtra	Nagpur	Opp GPO Civil Lines, Nagpur - MPCB
Maharashtra	Thane	Pimpleshwar Mandir, Thane - MPCB
Maharashtra	Mumbai	Powai, Mumbai - MPCB
Maharashtra	Pune	Revenue Colony-Shivajinagar, Pune - IITM
Maharashtra	Navi Mumbai	Sector-19A Nerul, Navi Mumbai - IITM
Maharashtra	Mumbai	Siddharth Nagar-Worli, Mumbai - IITM
Maharashtra	Mumbai	Sion, Mumbai - MPCB
Maharashtra	Solapur	Solapur, Solapur - MPCB
Maharashtra	Pune	Transport Nagar-Nigdi, Pune - IITM
Maharashtra	Mumbai	Vasai West, Mumbai - MPCB
Maharashtra	Mumbai	Vile Parle West, Mumbai - MPCB
Maharashtra	Mumbai	Worli, Mumbai - MPCB
Manipur	Imphal	DM College of Science, Imphal - Manipur PCB
Manipur	Imphal	Manipur University, Imphal - Manipur PCB
Meghalaya	Shillong	JN Stadium, Shillong - Meghalaya PCB
Meghalaya	Shillong	Lumpyngngad, Shillong - Meghalaya PCB
Mizoram	Aizawl	Sikulpuikawn, Aizawl - Mizoram PCB
Nagaland	Kohima	PWD Juction, Kohima - NPCB
Odisha	Tensa	Barsua Iron Ore Mines, Tensa - OSPCB
Odisha	Nayagarh	Dabuna, Nayagarh - OSPCB
Odisha	Rairangpur	Divisional Forest Office, Rairangpur - OSPCB
Odisha	Rourkela	Fertilizer Township, Rourkela - OSPCB
Odisha	Brajrajnagar	GM Office, Brajrajnagar - OSPCB
Odisha	Keonjhar	Jagamohanpur, Keonjhar - OSPCB
Odisha	Baripada	Meher Colony, Baripada - OSPCB
Odisha	Suakati	OMC Colony, Suakati - OSPCB
Odisha	Rourkela	Raghunathpali, Rourkela - OSPCB
Odisha	Rourkela	Sector-2, Rourkela - OSPCB
Odisha	Talcher	Talcher Coalfields,Talcher - OSPCB
Odisha	Bileipada	Tata Township, Bileipada - OSPCB
Punjab	Jalandhar	Civil Line, Jalandhar - PPCB
Punjab	Amritsar	Golden Temple, Amritsar - PPCB
Punjab	Bathinda	Hardev Nagar, Bathinda - PPCB
Punjab	Khanna	Kalal Majra, Khanna - PPCB
Punjab	Patiala	Model Town, Patiala - PPCB

Punjab	Ludhiana	Punjab Agricultural University, Ludhiana - PPCB
Punjab	Rupnagar	Ratanpura, Rupnagar - Ambuja Cements
Punjab	Mandi Gobindgarh	RIMT University, Mandi Gobindgarh - PPCB
Rajasthan	Jaipur	Adarsh Nagar, Jaipur - RSPCB
Rajasthan	Udaipur	Ashok Nagar, Udaipur - RSPCB
Rajasthan	Ajmer	Civil Lines, Ajmer - RSPCB
Rajasthan	Jodhpur	Collectorate, Jodhpur - RSPCB
Rajasthan	Kota	Dhanmandi, Kota - RSPCB
Rajasthan	Rajsamand	Dhoinda, Rajsamand - RSPCB
Rajasthan	Hanumangarh	Housing Board, Hanumangarh - RSPCB
Rajasthan	Pali	Indira Colony Vistar, Pali - RSPCB
Rajasthan	Jhunjhunu	Indra Nagar, Jhunjhunu - RSPCB
Rajasthan	Jodhpur	Jhalamand, Jodhpur - RSPCB
Rajasthan	Dausa	Khatikan Mohalla, Dausa - RSPCB
Rajasthan	Bharatpur	Krishna Nagar, Bharatpur - RSPCB
Rajasthan	Jaipur	Mansarovar Sector-12, Jaipur - RSPCB
Rajasthan	Bikaner	MM Ground, Bikaner - RSPCB
Rajasthan	Alwar	Moti Doongri, Alwar - RSPCB
Rajasthan	Kota	Nayapura, Kota - RSPCB
Rajasthan	Sri Ganganagar	Old City, Sri Ganganagar - RSPCB
Rajasthan	Jaipur	Police Commissionerate, Jaipur - RSPCB
Rajasthan	Pratapgarh	Pragati Nagar, Pratapgarh - RSPCB
Rajasthan	Sikar	Radhakishan Pura, Sikar - RSPCB
Rajasthan	Barmer	Railway Colony, Barmer - RSPCB
Rajasthan	Dholpur	Raja Ganj, Dholpur - RSPCB
Rajasthan	Jhalawar	Rajlaxmi Nagar, Jhalawar - RSPCB
Rajasthan	Banswara	Rati Talai, Banswara - RSPCB
Rajasthan	Bhiwadi	RIICO Ind. Area III, Bhiwadi - RSPCB
Rajasthan	Sawai Madhopur	Sahu Nagar, Sawai Madhopur - RSPCB
Rajasthan	Jodhpur	Samrat Ashok Udhyan, Jodhpur - RSPCB
Rajasthan	Karauli	Satyawati Vihar, Karauli - RSPCB
Rajasthan	Jaipur	Sector-2 Murlipura, Jaipur - RSPCB
Rajasthan	Chittorgarh	Shastri Nagar, Chittorgarh - RSPCB
Rajasthan	Jaipur	Shastri Nagar, Jaipur - RSPCB
Rajasthan	Tonk	Shastri Nagar, Tonk - RSPCB
Rajasthan	Kota	Shrinath Puram, Kota - RSPCB
Rajasthan	Churu	Subash Chowk, Churu - RSPCB
Rajasthan	Sirohi	Vedhaynath Colony, Sirohi - RSPCB
Sikkim	Gangtok	Zero Point GICI, Gangtok - SSPCB
Tamil Nadu	Chennai	Alandur Bus Depot, Chennai - CPCB
Tamil Nadu	Gummidipoondi	Anthoni Pillai Nagar, Gummidipoondi - TNPCB
Tamil Nadu	Chennai	Arumbakkam, Chennai - TNPCB
Tamil Nadu	Palkalaiperur	Bharathidasan University, Palkalaiperur - TNPCB
Tamil Nadu	Ooty	Bombay Castel, Ooty - TNPCB
Tamil Nadu	Ramanathapuram	Chalai Bazaar, Ramanathapuram - TNPCB
Tamil Nadu	Chengalpattu	Crescent University, Chengalpattu - TNPCB
Tamil Nadu	Chennai	Gandhi Nagar_Ennore, Chennai - TNPCB
Tamil Nadu	Ariyalur	Keelapalur, Ariyalur - TNPCB
Tamil Nadu	Kanchipuram	Kilambi, Kanchipuram - TNPCB
Tamil Nadu	Chennai	Kodungaiyur, Chennai - TNPCB
Tamil Nadu	Cuddalore	Kudikadu, Cuddalore - TNPCB
Tamil Nadu	Tirupur	Kumaran College, Tirupur - TNPCB
Tamil Nadu	Chennai	Manali Village, Chennai - TNPCB
Tamil Nadu	Chennai	Manali, Chennai - CPCB
Tamil Nadu	Thoothukudi	Meelavittan, Thoothukudi - TNPCB
Tamil Nadu	Dindigul	Mendonsa Colony, Dindigul - TNPCB

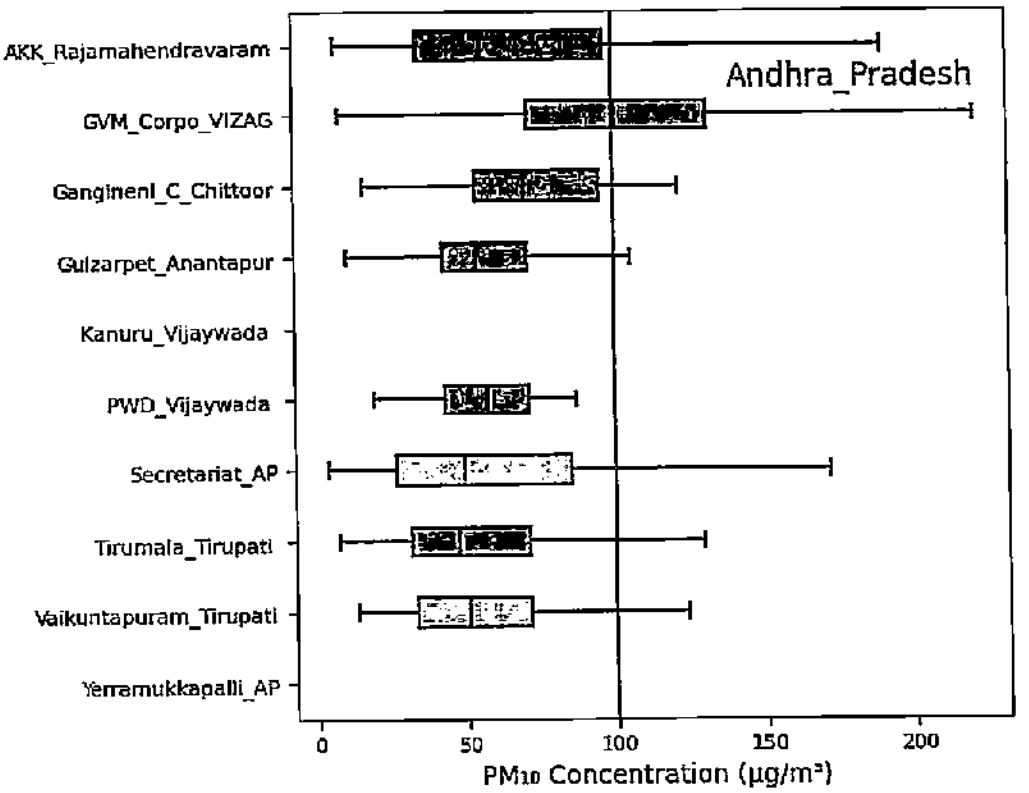
Tamil Nadu	Chennai	Perungudi, Chennai - TNPCB
Tamil Nadu	Coimbatore	PSG College of Arts and Science, Coimbatore
Tamil Nadu	Chennai	Royapuram, Chennai - TNPCB
Tamil Nadu	Cuddalore	Semmandalam, Cuddalore - TNPCB
Tamil Nadu	Coimbatore	SIDCO Kurichi, Coimbatore - TNPCB
Tamil Nadu	Hosur	SIPCOT Phase-1, Hosur - TNPCB
Tamil Nadu	Salem	Sona College of Technology, Salem - TNPCB
Tamil Nadu	Vellore	Vasanthapuram, Vellore - TNPCB
Tamil Nadu	Chennai	Velachery Res. Area, Chennai - CPCB
Telangana	Hyderabad	Bollaram Industrial Area, Hyderabad - TSPCB
Telangana	Hyderabad	Central University, Hyderabad - TSPCB
Telangana	Hyderabad	ECIL Kapra, Hyderabad - TSPCB
Telangana	Hyderabad	ICRISAT Patancheru, Hyderabad - TSPCB
Telangana	Hyderabad	IDA Pashamylaram, Hyderabad - TSPCB
Telangana	Hyderabad	IITH Kandi, Hyderabad - TSPCB
Telangana	Hyderabad	Kokapet, Hyderabad - TSPCB
Telangana	Hyderabad	Kompally Municipal Office, Hyderabad - TSPCB
Telangana	Hyderabad	Nacharam_TSIIC IALA, Hyderabad - TSPCB
Telangana	Hyderabad	New Malakpet, Hyderabad - TSPCB
Telangana	Hyderabad	Ramachandrapuram, Hyderabad - TSPCB
Telangana	Hyderabad	Sanathnagar, Hyderabad - TSPCB
Telangana	Hyderabad	Somajiguda, Hyderabad - TSPCB
Telangana	Hyderabad	Zoo Park, Hyderabad - TSPCB
Tripura	Agartala	Bardowali, Agartala - Tripura SPCB
Tripura	Agartala	Kunjaban, Agartala - Tripura SPCB
Uttar Pradesh	Hapur	Anand Vihar, Hapur - UPPCB
Uttar Pradesh	Varanasi	Ardhali Bazar, Varanasi - UPPCB
Uttar Pradesh	Lucknow	B R Ambedkar University, Lucknow - UPPCB
Uttar Pradesh	Varanasi	Bhelupur, Varanasi - UPPCB
Uttar Pradesh	Moradabad	Buddhi Vihar, Moradabad - UPPCB
Uttar Pradesh	Bareilly	Civil Lines, Bareilly - UPPCB
Uttar Pradesh	Moradabad	Eco Herbal Park, Moradabad - UPPCB
Uttar Pradesh	Moradabad	Employment Office, Moradabad - UPPCB
Uttar Pradesh	Kanpur	FTI Kidwai Nagar, Kanpur - UPPCB
Uttar Pradesh	Meerut	Ganga Nagar, Meerut - UPPCB
Uttar Pradesh	Lucknow	Gomti Nagar, Lucknow - UPPCB
Uttar Pradesh	Varanasi	IESD Banaras Hindu University, Varanasi - UPPCB
Uttar Pradesh	Kanpur	IITK, Kanpur - IITK
Uttar Pradesh	Ghaziabad	Indirapuram, Ghaziabad - UPPCB
Uttar Pradesh	Meerut	Jai Bhim Nagar, Meerut - UPPCB
Uttar Pradesh	Prayagraj	Jhunsi, Prayagraj - UPPCB
Uttar Pradesh	Moradabad	Jigar Colony, Moradabad - UPPCB
Uttar Pradesh	Khurja	Kalindi Kunj, Khurja - UPPCB
Uttar Pradesh	Moradabad	Kashiram Nagar, Moradabad - UPPCB
Uttar Pradesh	Lucknow	Kendriya Vidyalaya, Lucknow - CPCB
Uttar Pradesh	Greater Noida	Knowledge Park - III, Greater Noida - UPPCB
Uttar Pradesh	Greater Noida	Knowledge Park - V, Greater Noida - UPPCB
Uttar Pradesh	Lucknow	Kukrail Picnic Spot-1, Lucknow - UPPCB
Uttar Pradesh	Moradabad	Lajpat Nagar, Moradabad - UPPCB
Uttar Pradesh	Lucknow	Lalbagh, Lucknow - CPCB
Uttar Pradesh	Ghaziabad	Loni, Ghaziabad - UPPCB
Uttar Pradesh	Gorakhpur	Madan Mohan University of Technology, Gorakhpur
Uttar Pradesh	Varanasi	Maldahiya, Varanasi - UPPCB
Uttar Pradesh	Agra	Manoharpur, Agra - UPPCB
Uttar Pradesh	Prayagraj	Motilal Nehru NIT, Prayagraj - UPPCB
Uttar Pradesh	Prayagraj	Nagar Nigam, Prayagraj - UPPCB

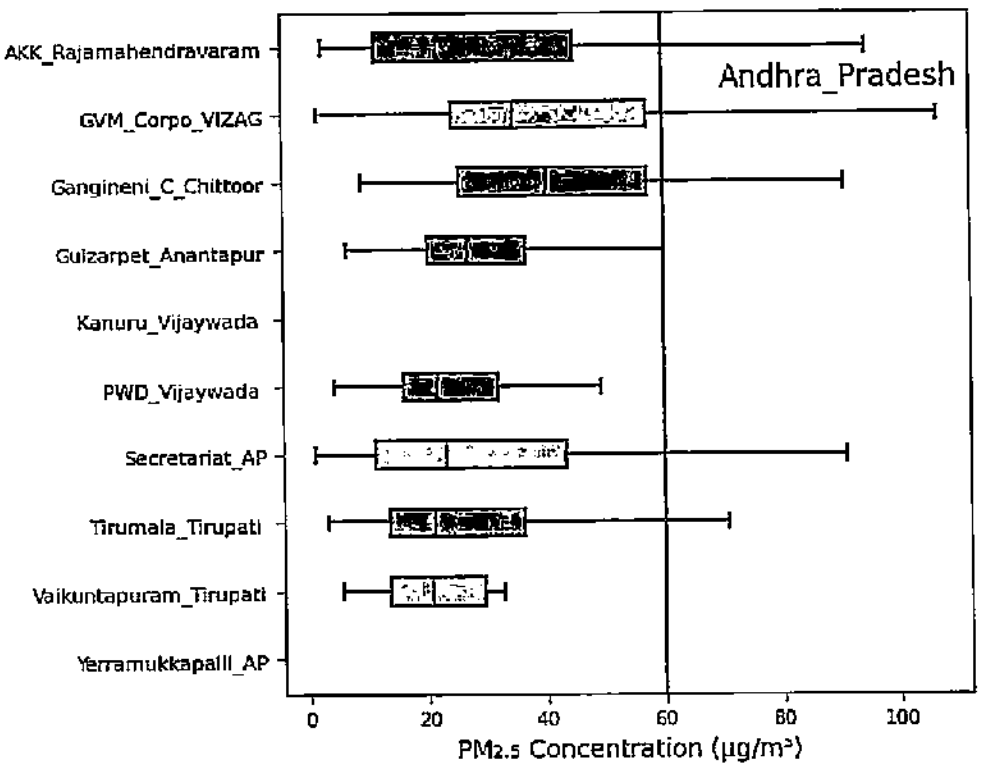
Uttar Pradesh	Firozabad	Nagla Bhau, Firozabad - UPPCB
Uttar Pradesh	Kanpur	Nehru Nagar, Kanpur - UPPCB
Uttar Pradesh	Baghpat	New Collectorate, Baghpat - UPPCB
Uttar Pradesh	Muzaffarnagar	New Mandi, Muzaffarnagar - UPPCB
Uttar Pradesh	Lucknow	Nishant Ganj, Lucknow - UPPCB
Uttar Pradesh	Kanpur	NSI Kalyanpur, Kanpur - UPPCB
Uttar Pradesh	Vrindavan	Omex Eternity, Vrindavan - UPPCB
Uttar Pradesh	Meerut	Pallavpuram Phase 2, Meerut - UPPCB
Uttar Pradesh	Bareilly	Rajendra Nagar, Bareilly - UPPCB
Uttar Pradesh	Agra	Rohta, Agra - UPPCB
Uttar Pradesh	Ghaziabad	Sanjay Nagar, Ghaziabad - UPPCB
Uttar Pradesh	Agra	Sanjay Palace, Agra - UPPCB
Uttar Pradesh	Baghpat	Sardar Patel Inter College, Baghpat - UPPCB
Uttar Pradesh	Noida	Sector - 125, Noida - UPPCB
Uttar Pradesh	Noida	Sector - 62, Noida - IMD
Uttar Pradesh	Noida	Sector-1, Noida - UPPCB
Uttar Pradesh	Noida	Sector-116, Noida - UPPCB
Uttar Pradesh	Agra	Sector-3B Avas Vikas Colony, Agra - UPPCB
Uttar Pradesh	Agra	Shahjahan Garden, Agra - UPPCB
Uttar Pradesh	Agra	Shastripuram, Agra - UPPCB
Uttar Pradesh	Jhansi	Shivaji Nagar, Jhansi - UPPCB
Uttar Pradesh	Lucknow	Talkatora District Industries Center, Lucknow - CPCB
Uttar Pradesh	Moradabad	Transport Nagar, Moradabad - UPPCB
Uttar Pradesh	Ghaziabad	Vasundhara, Ghaziabad - UPPCB
Uttar Pradesh	Firozabad	Vibhab Nagar, Firozabad - UPPCB
Uttar Pradesh	Bulandshahr	Yamunapuram, Bulandshahr - UPPCB
Uttarakhand	Dehradun	Doon University, Dehradun - UKPCB
Uttarakhand	Kashipur	Govt. Girls Inter College, Kashipur - UKPCB
Uttarakhand	Rishikesh	Shivaji Nagar, Rishikesh - UKPCB
West Bengal	Asansol	Asansol Court Area, Asansol - WBPCB
West Bengal	Kolkata	Ballygunge, Kolkata - WBPCB
West Bengal	Howrah	Belur Math, Howrah - WBPCB
West Bengal	Kolkata	Bidhannagar, Kolkata - WBPCB
West Bengal	Kolkata	Fort William, Kolkata - WBPCB
West Bengal	Howrah	Ghusuri, Howrah - WBPCB
West Bengal	Kolkata	Jadavpur, Kolkata - WBPCB
West Bengal	Howrah	Padmapukur, Howrah - WBPCB
West Bengal	Haldia	Priyambada Housing Estate, Haldia - WBPCB
West Bengal	Kolkata	Rabindra Bharati University, Kolkata - WBPCB
West Bengal	Kolkata	Rabindra Sarobar, Kolkata - WBPCB
West Bengal	Durgapur	Sidhu Kanhu Indoor Stadium, Durgapur - WBPCB
West Bengal	Kolkata	Victoria, Kolkata - WBPCB
West Bengal	Siliguri	Ward-32 Bapupara, Siliguri - WBPCB

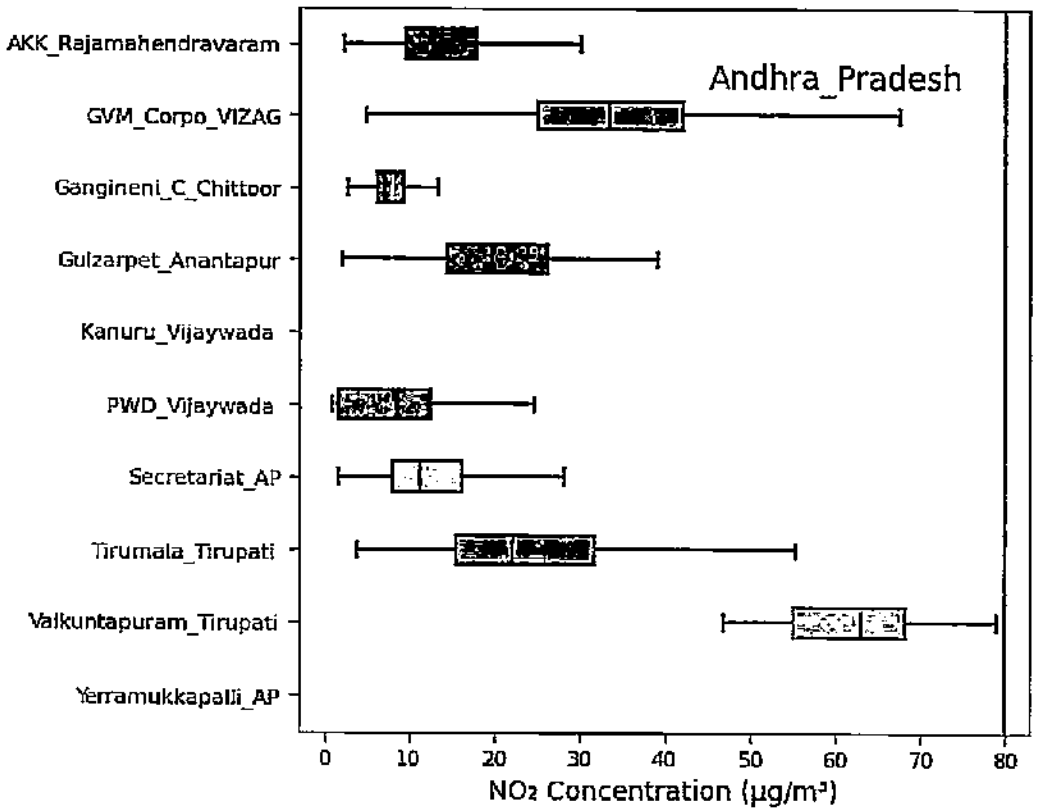
Union Territories		
Chandigarh	Chandigarh	Sector 22, Chandigarh - CPCC
Chandigarh	Chandigarh	Sector-25, Chandigarh - CPCC
Chandigarh	Chandigarh	Sector-53, Chandigarh - CPCC
Delhi	Delhi	Alipur, Delhi - DPCC
Delhi	Delhi	Anand Vihar, Delhi - DPCC
Delhi	Delhi	Ashok Vihar, Delhi - DPCC
Delhi	Delhi	Aya Nagar, Delhi - IMD
Delhi	Delhi	Bawana, Delhi - DPCC
Delhi	Delhi	Burari Crossing, Delhi - IMD
Delhi	Delhi	Chandni Chowk, Delhi - IITM
Delhi	Delhi	CRRI Mathura Road, Delhi - IMD
Delhi	Delhi	Dr. Karni Singh Shooting Range, Delhi - DPCC
Delhi	Delhi	DTU, Delhi - CPCB
Delhi	Delhi	Dwarka-Sector 8, Delhi - DPCC
Delhi	Delhi	East Arjun Nagar, Delhi - CPCB
Delhi	Delhi	IGI Airport (T3), Delhi - IMD
Delhi	Delhi	IHBAS, Dilshad Garden, Delhi - CPCB
Delhi	Delhi	ITO, Delhi - CPCB
Delhi	Delhi	Jahangirpuri, Delhi - DPCC
Delhi	Delhi	Jawaharlal Nehru Stadium, Delhi - DPCC
Delhi	Delhi	Lodhi Road, Delhi - IITM
Delhi	Delhi	Lodhi Road, Delhi - IMD
Delhi	Delhi	Major Dhyan Chand National Stadium, Delhi - DPCC
Delhi	Delhi	Mandir Marg, Delhi - DPCC
Delhi	Delhi	Mundka, Delhi - DPCC
Delhi	Delhi	Najafgarh, Delhi - DPCC
Delhi	Delhi	Narela, Delhi - DPCC
Delhi	Delhi	Nehru Nagar, Delhi - DPCC
Delhi	Delhi	North Campus, DU, Delhi - IMD
Delhi	Delhi	NSIT Dwarka, Delhi - CPCB
Delhi	Delhi	Okhla Phase-2, Delhi - DPCC
Delhi	Delhi	Patparganj, Delhi - DPCC
Delhi	Delhi	Punjabi Bagh, Delhi - DPCC
Delhi	Delhi	Pusa, Delhi - DPCC
Delhi	Delhi	Pusa, Delhi - IMD
Delhi	Delhi	R K Puram, Delhi - DPCC
Delhi	Delhi	Rohini, Delhi - DPCC
Delhi	Delhi	Shadipur, Delhi - CPCB
Delhi	Delhi	Sirifort, Delhi - CPCB
Delhi	Delhi	Sonia Vihar, Delhi - DPCC
Delhi	Delhi	Sri Aurobindo Marg, Delhi - DPCC
Delhi	Delhi	Vivek Vihar, Delhi - DPCC
Delhi	Delhi	Wazirpur, Delhi - DPCC
Jammu and Kashmir	Srinagar	Rajbagh, Srinagar - JKSPCB
Puducherry	Puducherry	Jawahar Nagar, Puducherry - PPCC

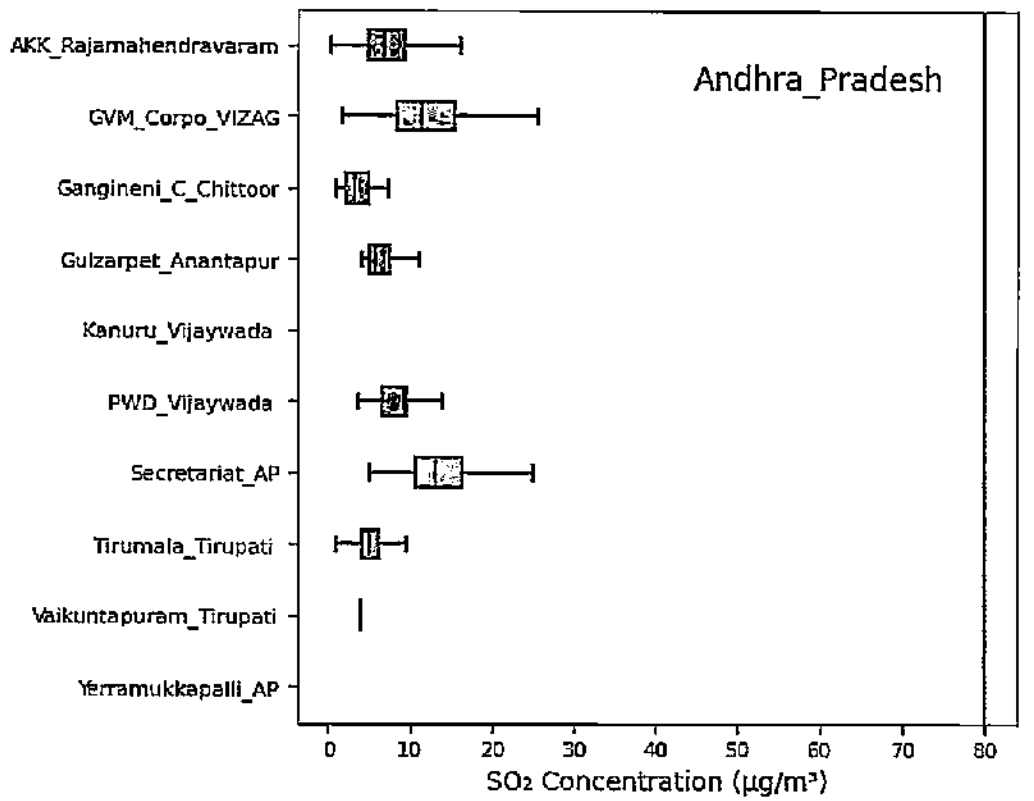
Annexure - B2

Andhra Pradesh



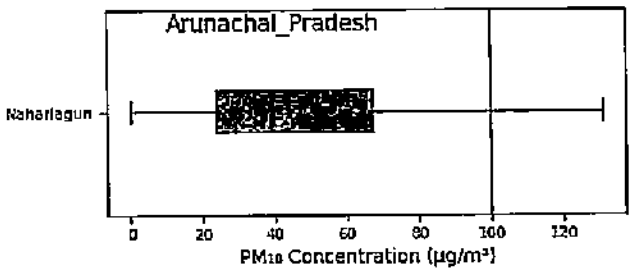


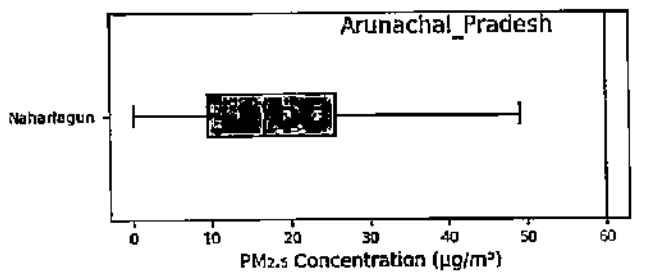

Andhra_Pradesh
AKK_Rajamahendravaram
GVM_Corpo_VIZAG
Gangineni_C_Chittoor
Gulzarpet_Anantapur
Kanuru_Vijaywada
PWD_Vijaywada
Secretariat_AP
Tirumala_Tirupati
Vaikuntapuram_Tirupati
Yerramukkapalli_AP
0
10
20
30
40
50
60
70
80
NO2 Concentration (µg/m3)

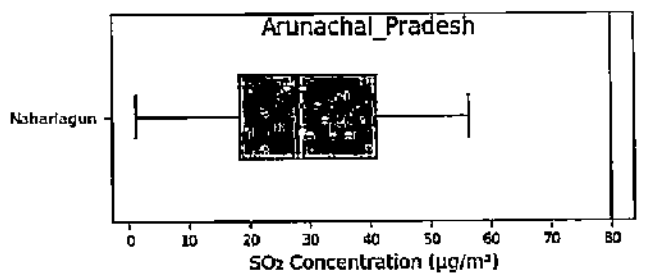

Andhra_Pradesh
AKK_Rajamahendravaram
GVM_Corpo_VIZAG
Gangineni_C_Chittoor
Gulzarpet_Anantapur
Kanuru_Vijaywada
PWD_Vijaywada
Secretariat_AP
Tirumala_Tirupati
Vaikuntapuram_Tirupati
Yerramukkapalli_AP
0
10
20
30
40
50
60
70
80
SO2 Concentration (µg/m3)

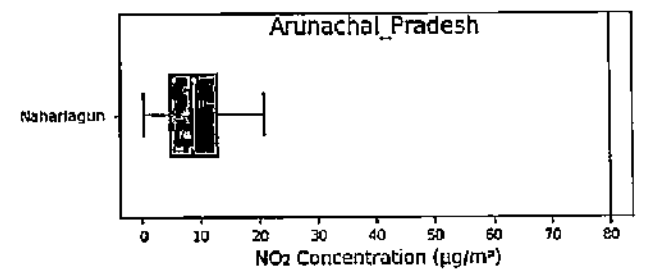
B2 -2

Arunachal Pradesh

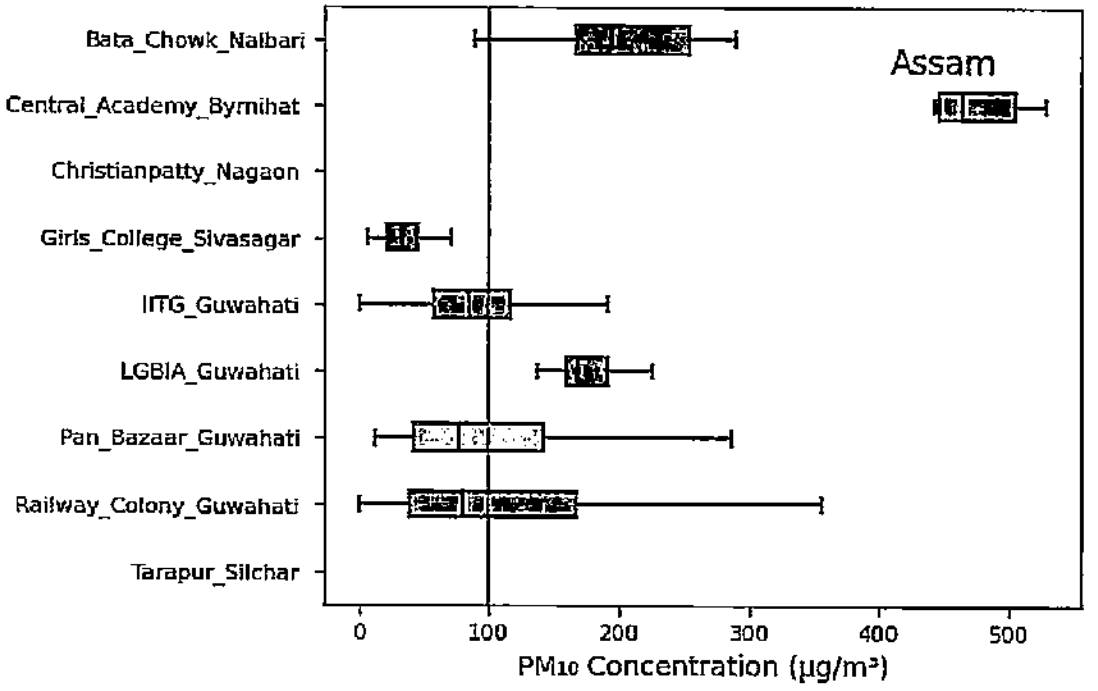


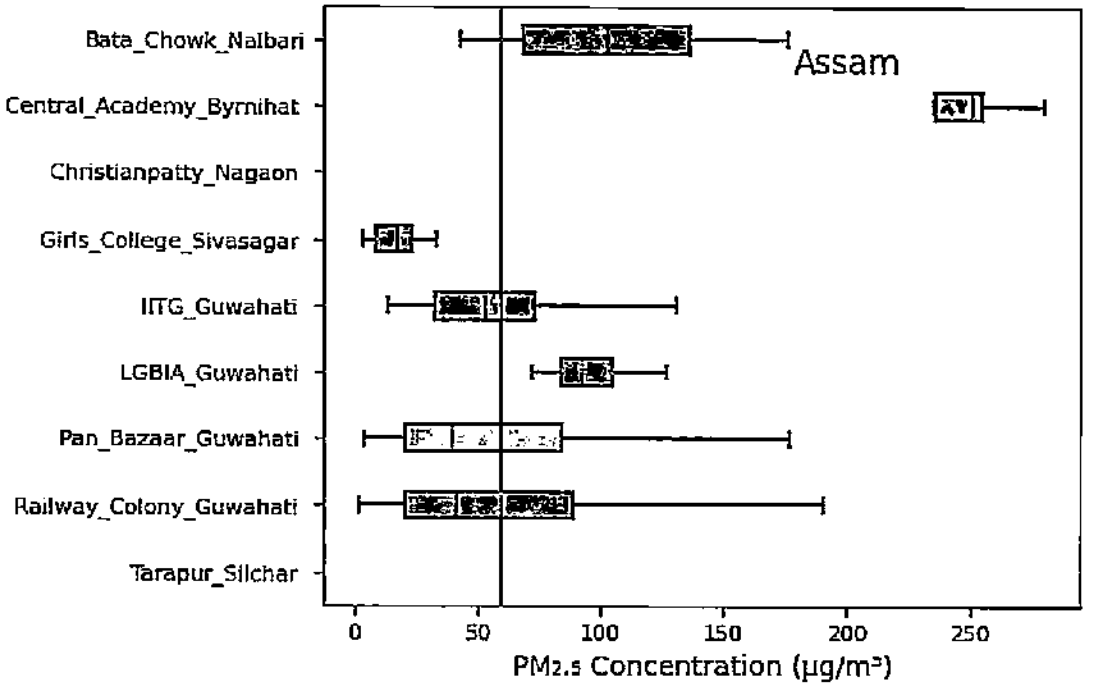


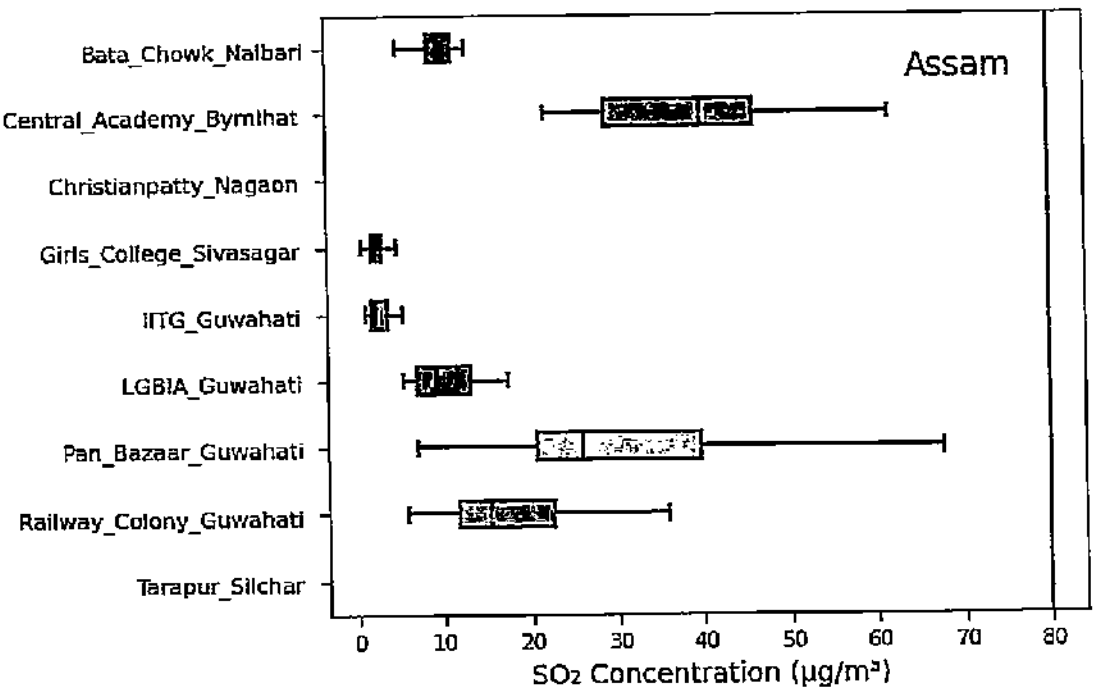


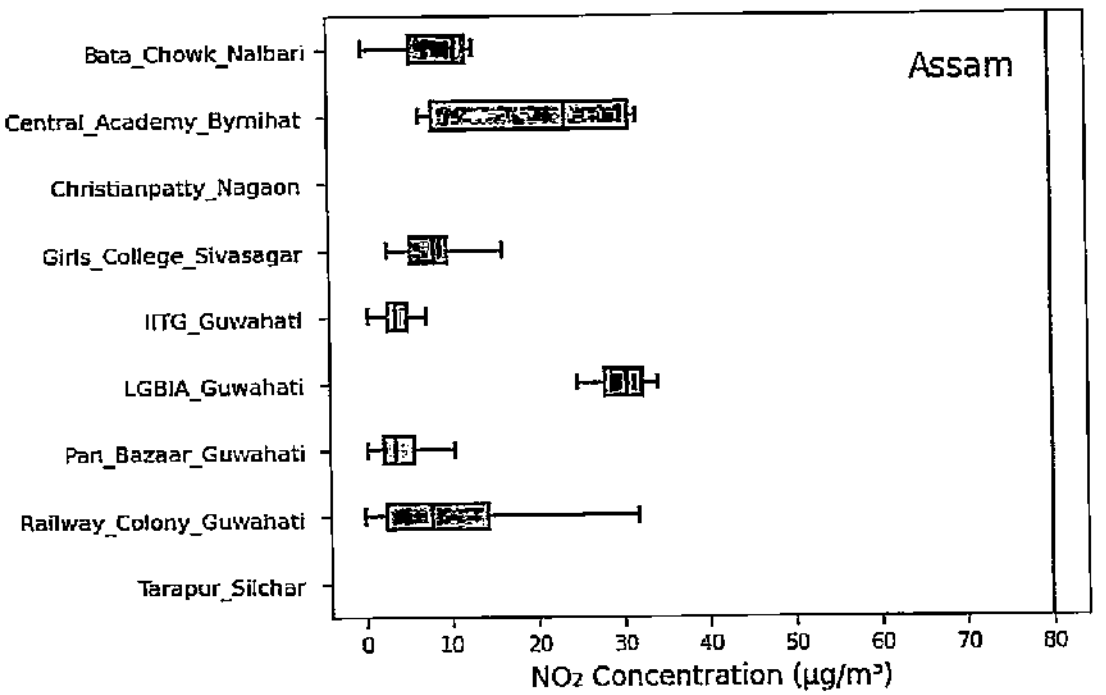


Assam

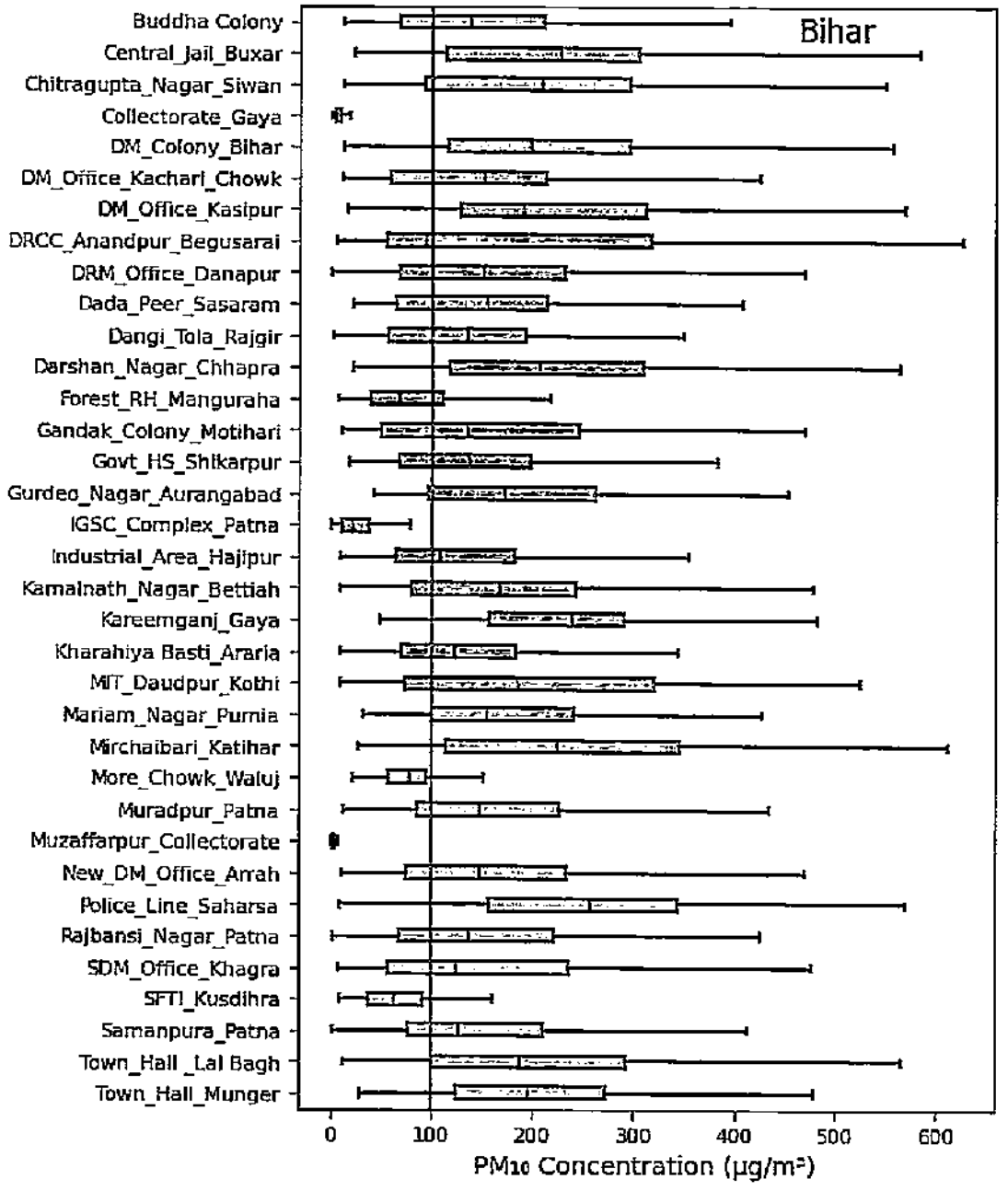

Assam
Bata_Chowk_Nalbari
Central_Academy_Byrnihat
Christianpatty_Nagaon
Girls_College_Sivasagar
IITG_Guwahati
LGBIA_Guwahati
Pan_Bazaar_Guwahati
Railway_Colony_Guwahati
Tarapur_Silchar
0
100
200
300
400
500
PM10 Concentration (µg/m³)

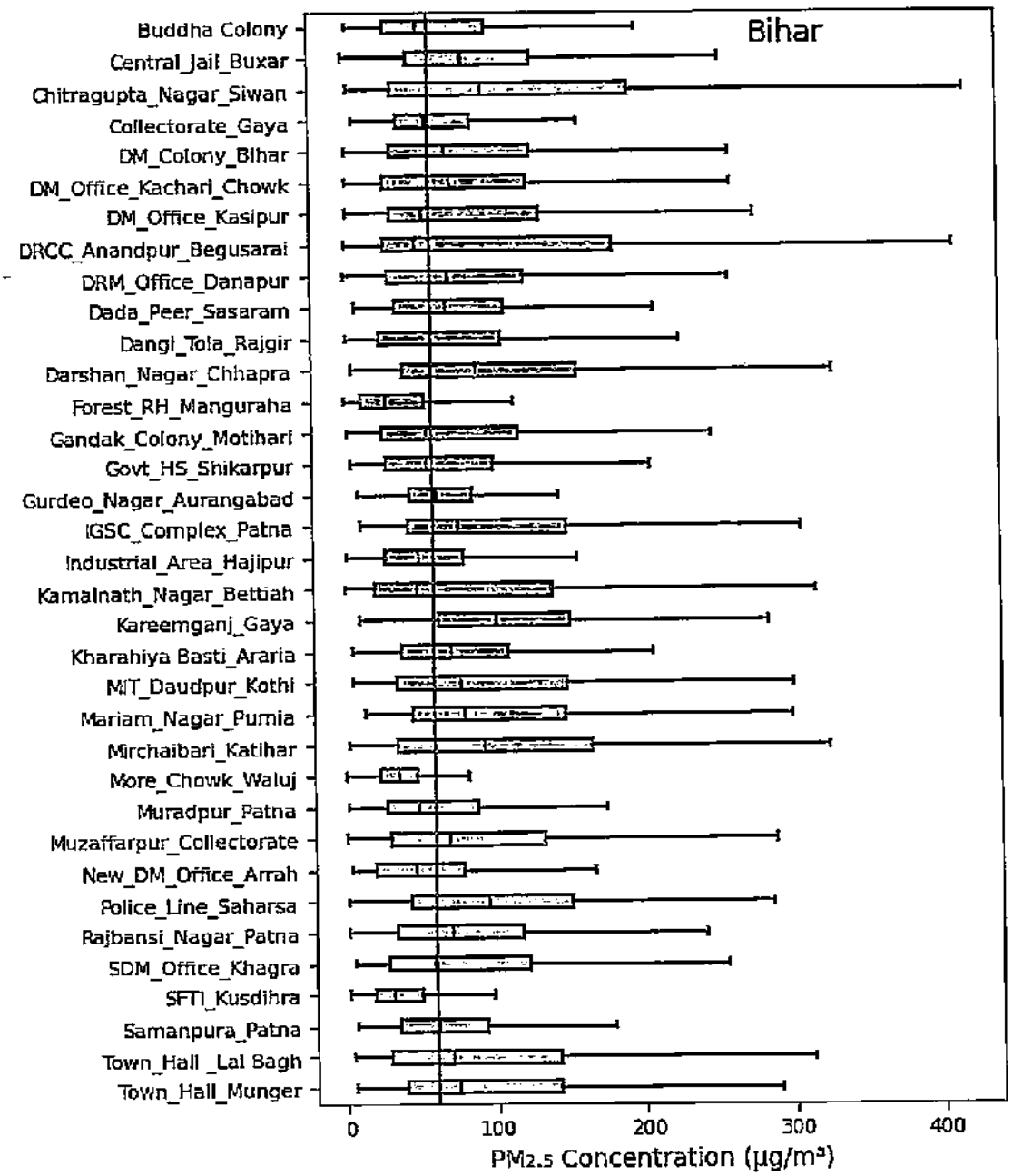

Assam
Bata_Chowk_Nalbari
Central_Academy_Byrnihat
Christianpatty_Nagaon
Girls_College_Sivasagar
IITG_Guwahati
LGBIA_Guwahati
Pan_Bazaar_Guwahati
Railway_Colony_Guwahati
Tarapur_Silchar
0
50
100
150
200
250
PM2.5 Concentration (µg/m³)

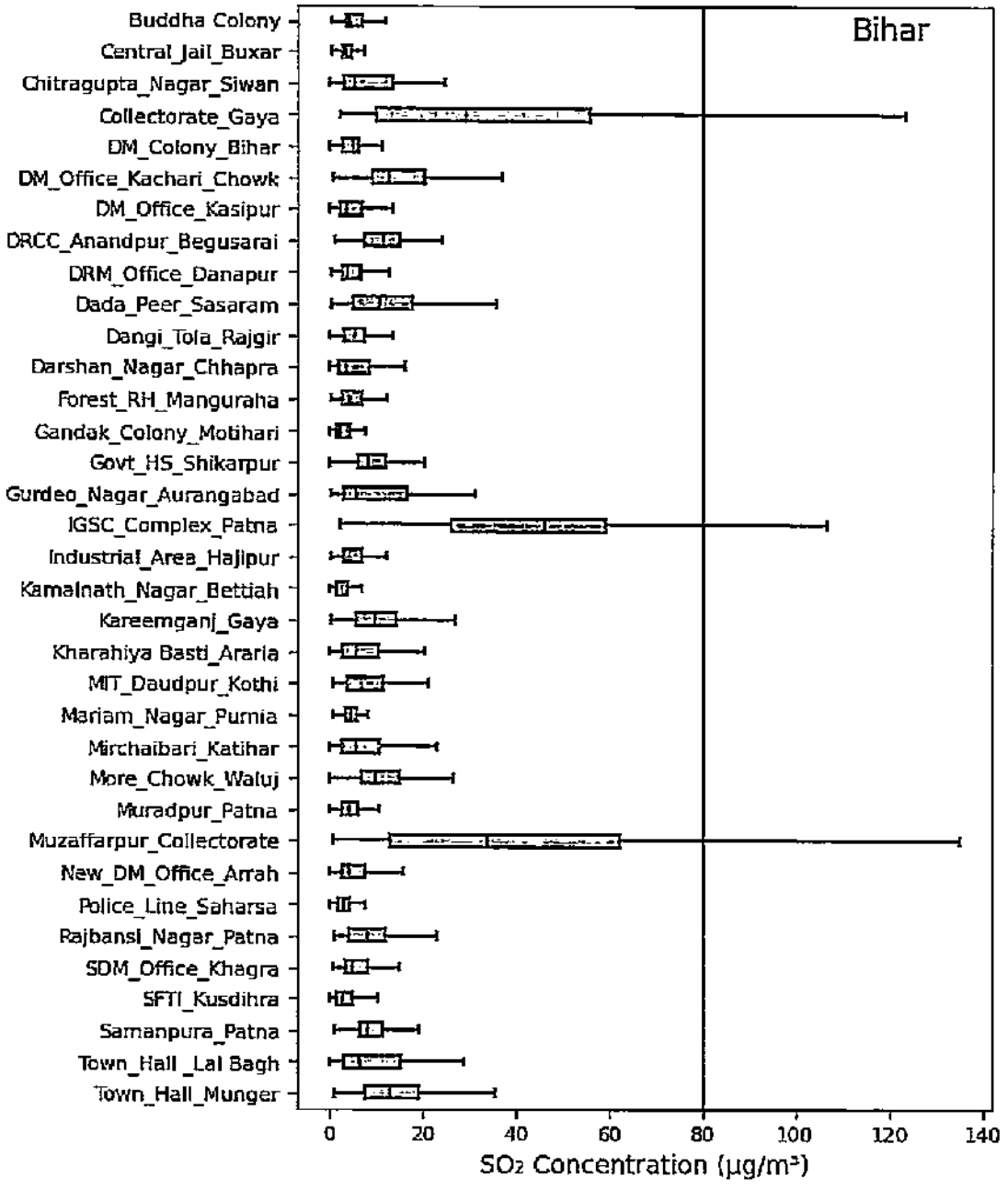

Assam
Bata_Chowk_Nalbari
Central_Academy_Bymihat
Christianpatty_Nagaon
Girls_College_Sivasagar
IITG_Guwahati
LGBIA_Guwahati
Pan_Bazaar_Guwahati
Railway_Colony_Guwahati
Tarapur_Silchar
0
10
20
30
40
50
60
70
80
SO2 Concentration (µg/m3)

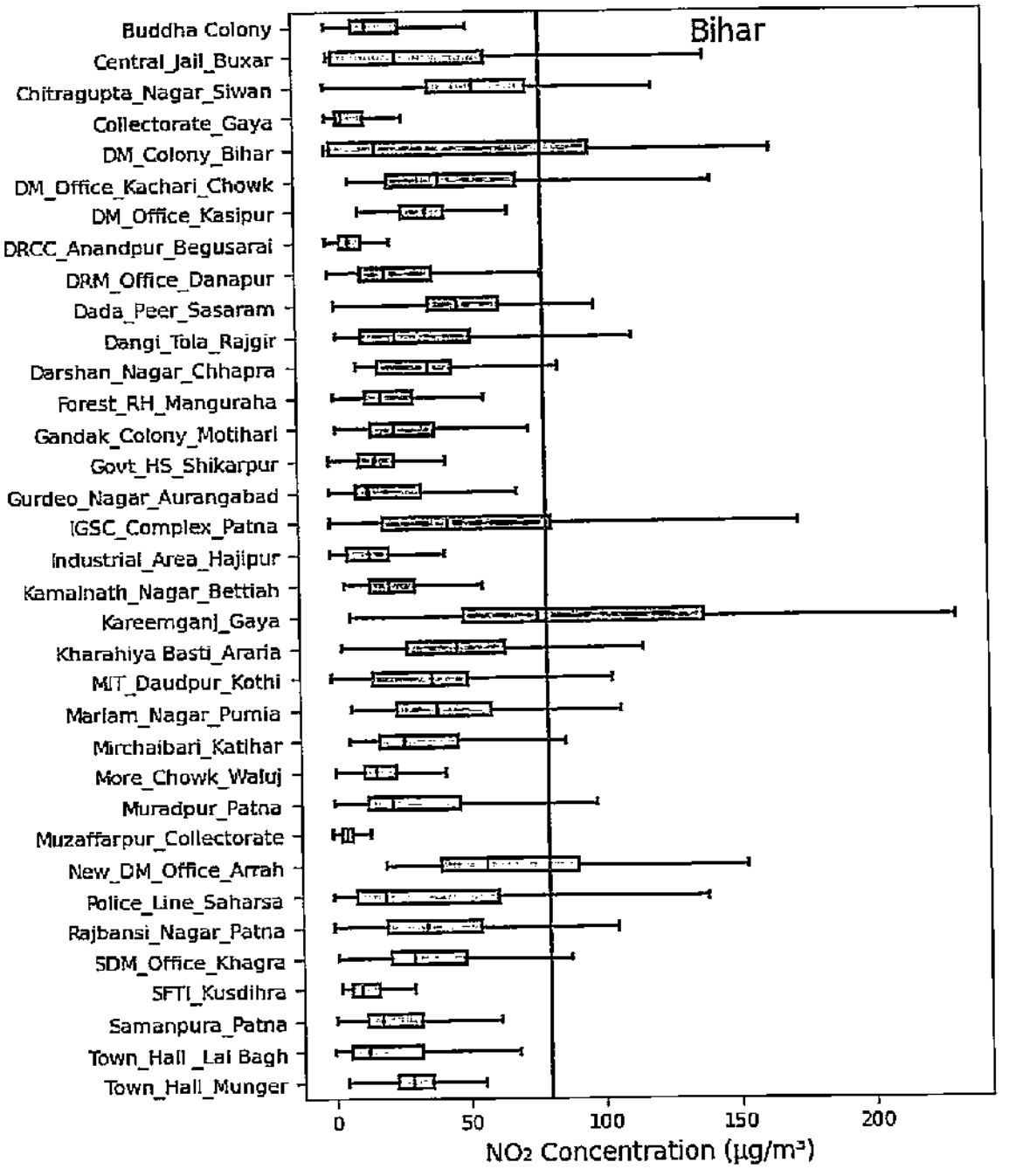

Assam
Bata_Chowk_Nalbari
Central_Academy_Bymihat
Christianpatty_Nagaon
Girls_College_Sivasagar
IITG_Guwahati
LGBIA_Guwahati
Pan_Bazaar_Guwahati
Railway_Colony_Guwahati
Tarapur_Silchar
0
10
20
30
40
50
60
70
80
NO2 Concentration (µg/m3)

Bihar

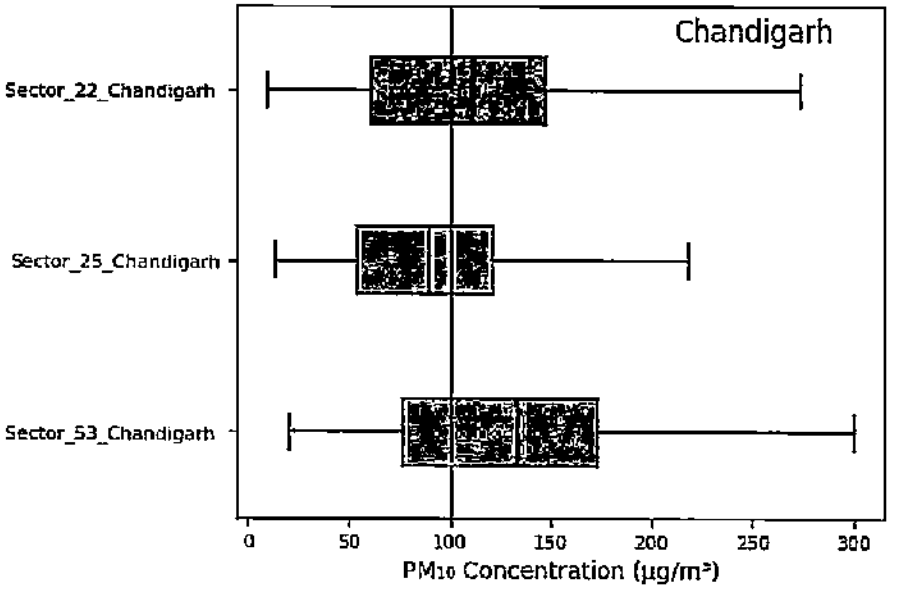

Bihar
Buddha Colony
Central_Jail_Buxar
Chitragupta_Nagar_Siwan
Collectorate_Gaya
DM_Colony_Bihar
DM_Office_Kachari_Chowk
DM_Office_Kasipur
DRCC_Anandpur_Begusarai
DRM_Office_Danapur
Dada_Peer_Sasaram
Dangi_Tola_Rajgir
Darshan_Nagar_Chhapra
Forest_RH_Manguraha
Gandak_Colony_Motihari
Govt_HS_Shikarpur
Gurdeo_Nagar_Aurangabad
IGSC_Complex_Patna
Industrial_Area_Hajipur
Kamalnath_Nagar_Bettiah
Kareemganj_Gaya
Kharahiya Basti_Araria
MIT_Daudpur_Kothi
Mariam_Nagar_Purnia
Mirchaibari_Katihar
More_Chowk_Waluj
Muradpur_Patna
Muzaffarpur_Collectorate
New_DM_Office_Arrah
Police_Line_Saharsa
Rajbansi_Nagar_Patna
SDM_Office_Khagra
SFTI_Kusdihra
Samanpura_Patna
Town_Hall _Lal Bagh
Town_Hall_Munger
0
100
200
300
400
500
600
PM10 Concentration (µg/m³)

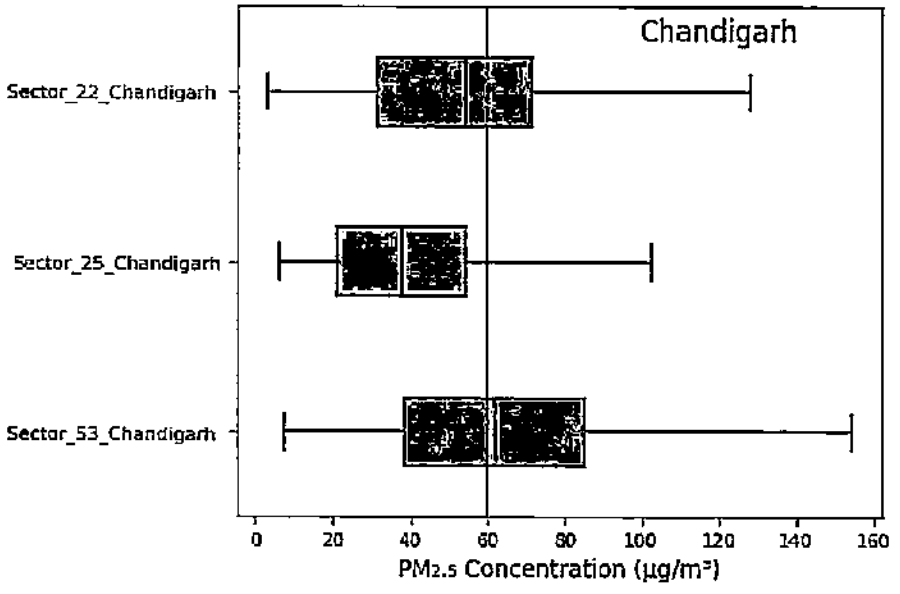

Bihar
Buddha Colony
Central_Jail_Buxar
Chitragupta_Nagar_Siwan
Collectorate_Gaya
DM_Colony_Bihar
DM_Office_Kachari_Chowk
DM_Office_Kasipur
DRCC_Anandpur_Begusarai
DRM_Office_Danapur
Dada_Peer_Sasaram
Dangi_Tola_Rajgir
Darshan_Nagar_Chhapra
Forest_RH_Manguraha
Gandak_Colony_Motihari
Govt_HS_Shikarpur
Gurdeo_Nagar_Aurangabad
IGSC_Complex_Patna
Industrial_Area_Hajipur
Kamalnath_Nagar_Bettiah
Kareemganj_Gaya
Kharahiya Basti_Araria
MIT_Daudpur_Kothi
Mariam_Nagar_Purnia
Mirchaibari_Katihar
More_Chowk_Waluj
Muradpur_Patna
Muzaffarpur_Collectorate
New_DM_Office_Arrah
Police_Line_Saharsa
Rajbansi_Nagar_Patna
SDM_Office_Khagra
SFTI_Kusdihra
Samanpura_Patna
Town_Hall _Lal Bagh
Town_Hall_Munger
0
100
200
300
400
PM2.5 Concentration (µg/m³)

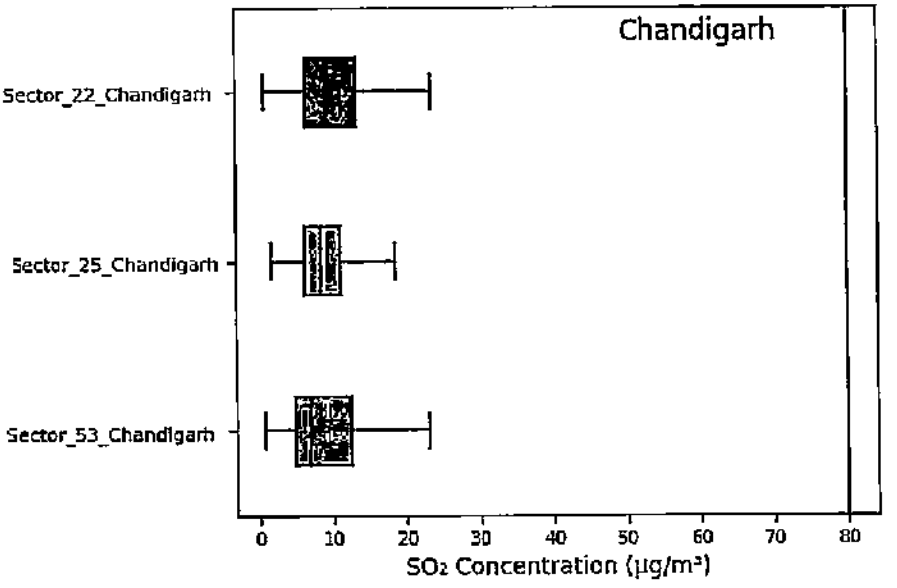

Bihar
Buddha Colony
Central_Jail_Buxar
Chitragupta_Nagar_Siwan
Collectorate_Gaya
DM_Colony_Bihar
DM_Office_Kachari_Chowk
DM_Office_Kasipur
DRCC_Anandpur_Begusarai
DRM_Office_Danapur
Dada_Peer_Sasaram
Dangi_Tola_Rajgir
Darshan_Nagar_Chhapra
Forest_RH_Manguraha
Gandak_Colony_Motihari
Govt_HS_Shikarpur
Gurdeo_Nagar_Aurangabad
IGSC_Complex_Patna
Industrial_Area_Hajipur
Kamalnath_Nagar_Bettiah
Kareemganj_Gaya
Kharahiya Basti_Araria
MIT_Daudpur_Kothi
Mariam_Nagar_Purnia
Mirchaibari_Katihar
More_Chowk_Waluj
Muradpur_Patna
Muzaffarpur_Collectorate
New_DM_Office_Arrah
Police_Line_Saharsa
Rajbansi_Nagar_Patna
SDM_Office_Khagra
SFTI_Kusdihra
Samanpura_Patna
Town_Hall _Lal Bagh
Town_Hall_Munger
0
20
40
60
80
100
120
140
SO2 Concentration (µg/m3)

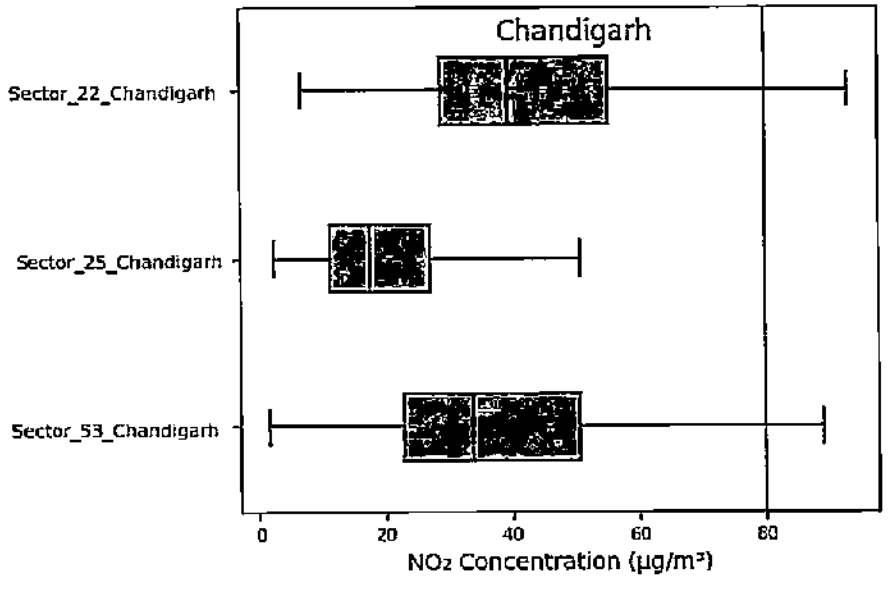

Bihar
Buddha Colony
Central_Jail_Buxar
Chitragupta_Nagar_Siwan
Collectorate_Gaya
DM_Colony_Bihar
DM_Office_Kachari_Chowk
DM_Office_Kasipur
DRCC_Anandpur_Begusarai
DRM_Office_Danapur
Dada_Peer_Sasaram
Dangi_Tola_Rajgir
Darshan_Nagar_Chhapra
Forest_RH_Manguraha
Gandak_Colony_Motihari
Govt_HS_Shikarpur
Gurdeo_Nagar_Aurangabad
IGSC_Complex_Patna
Industrial_Area_Hajipur
Kamalnath_Nagar_Bettiah
Kareemganj_Gaya
Kharahiya Basti_Araria
MIT_Daudpur_Kothi
Mariam_Nagar_Purnia
Mirchaibari_Katihar
More_Chowk_Waluj
Muradpur_Patna
Muzaffarpur_Collectorate
New_DM_Office_Arrah
Police_Line_Saharsa
Rajbansi_Nagar_Patna
SDM_Office_Khagra
SFTI_Kusdihra
Samanpura_Patna
Town_Hall _Lal Bagh
Town_Hall_Munger
0
50
100
150
200
NO2 Concentration (µg/m³)

Chandigarh

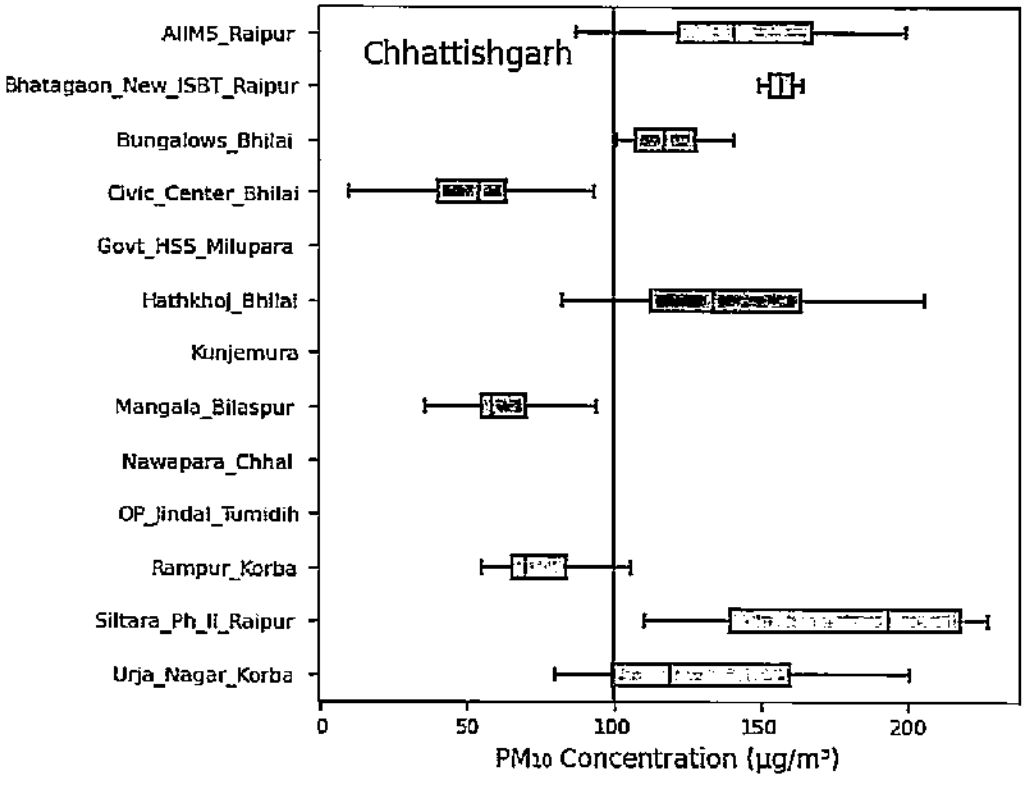

Chandigarh
Sector_22_Chandigarh
Sector_25_Chandigarh
Sector_53_Chandigarh
0
50
100
150
200
250
300
PM10 Concentration (µg/m³)

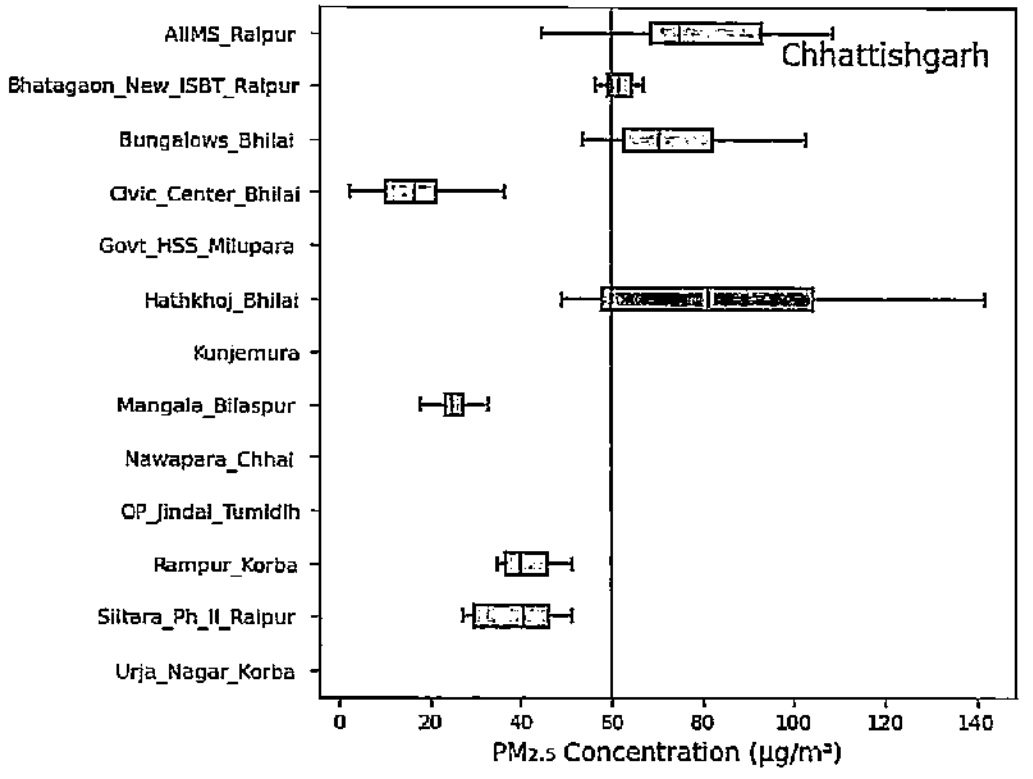

Chandigarh
Sector_22_Chandigarh
Sector_25_Chandigarh
Sector_53_Chandigarh
0
20
40
60
80
100
120
140
160
PM2.5 Concentration (µg/m³)

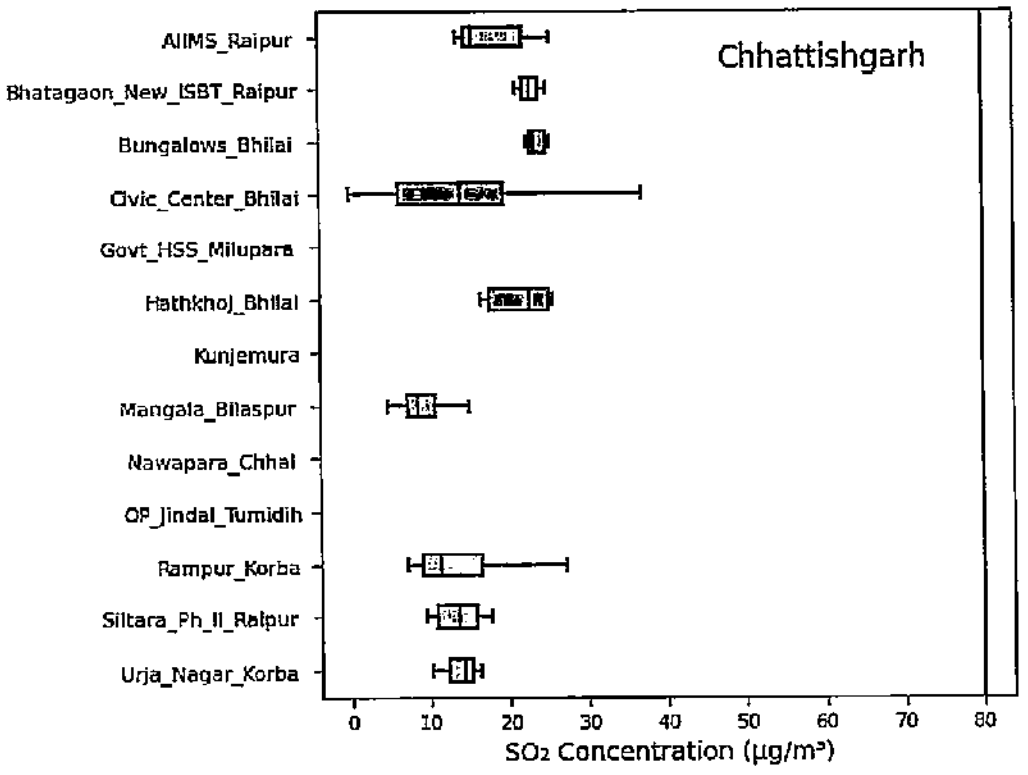

Chandigarh
Sector_22_Chandigarh
Sector_25_Chandigarh
Sector_53_Chandigarh
0
10
20
30
40
50
60
70
80
SO2 Concentration (µg/m³)

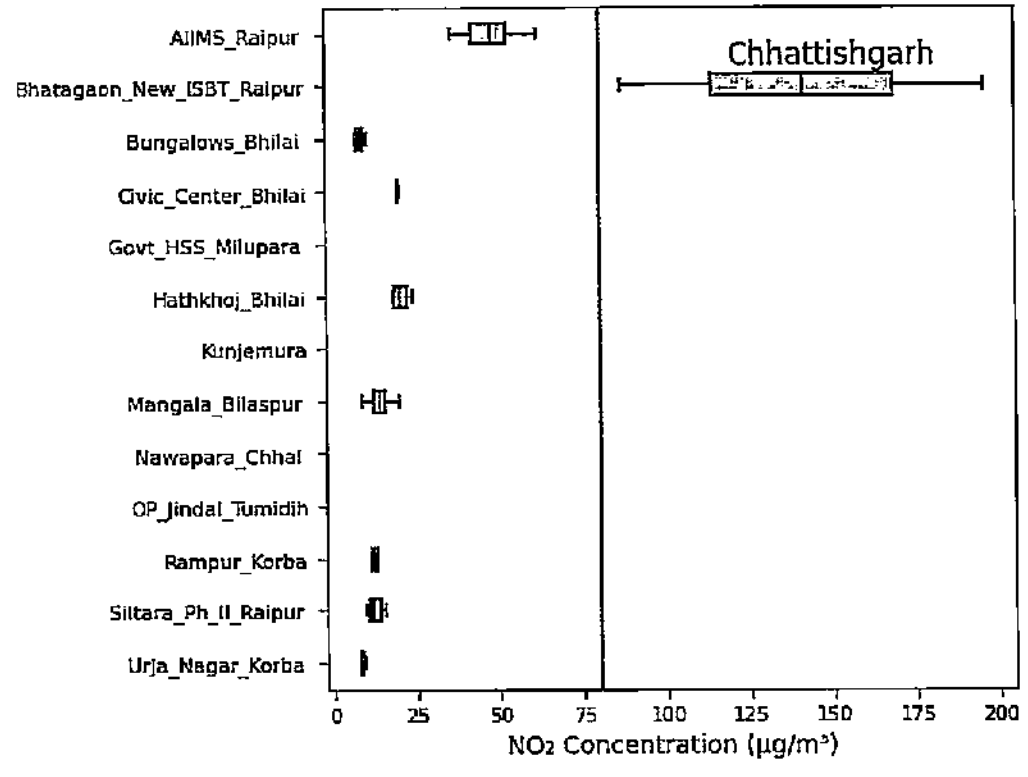

Chandigarh
Sector_22_Chandigarh
Sector_25_Chandigarh
Sector_53_Chandigarh
0
20
40
60
80
NO2 Concentration (µg/m³)

Chhattisgarh

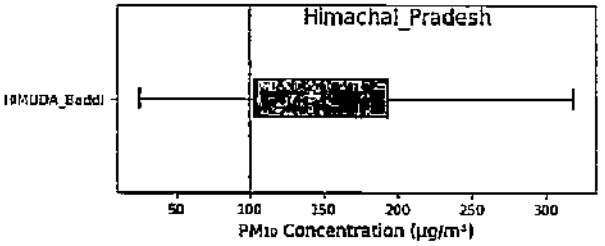


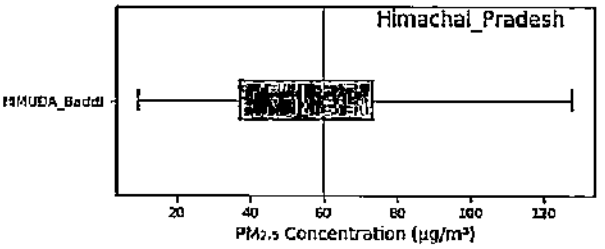


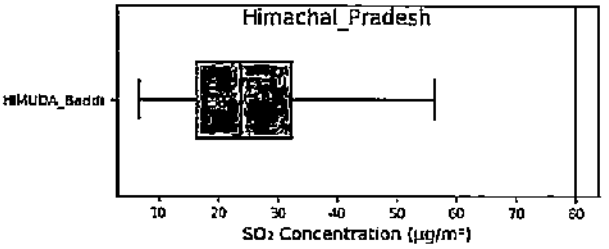

Chhattishgarh
AIIMS_Raipur
Bhatagaon_New_ISBT_Raipur
Bungalows_Bhilai
Civic_Center_Bhilai
Govt_HSS_Milupara
Hathkhoj_Bhilai
Kunjemura
Mangala_Bilaspur
Nawapara_Chhal
OP_Jindal_Tumidih
Rampur_Korba
Siltara_Ph_II_Raipur
Urja_Nagar_Korba
0 10 20 30 40 50 60 70 80
SO2 Concentration (µg/m³)

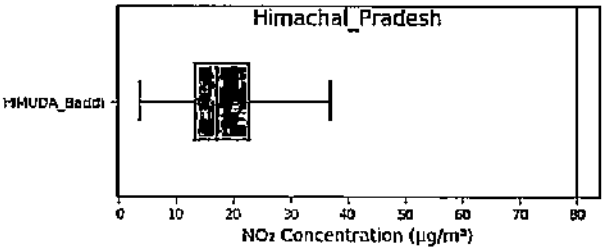

Chhattishgarh
AIIMS_Raipur
Bhatagaon_New_ISBT_Raipur
Bungalows_Bhilai
Civic_Center_Bhilai
Govt_HSS_Milupara
Hathkhoj_Bhilai
Kunjemura
Mangala_Bilaspur
Nawapara_Chhal
OP_Jindal_Tumidih
Rampur_Korba
Siltara_Ph_II_Raipur
Urja_Nagar_Korba
0 25 50 75 100 125 150 175 200
NO2 Concentration (µg/m³)

Himachal Pradesh

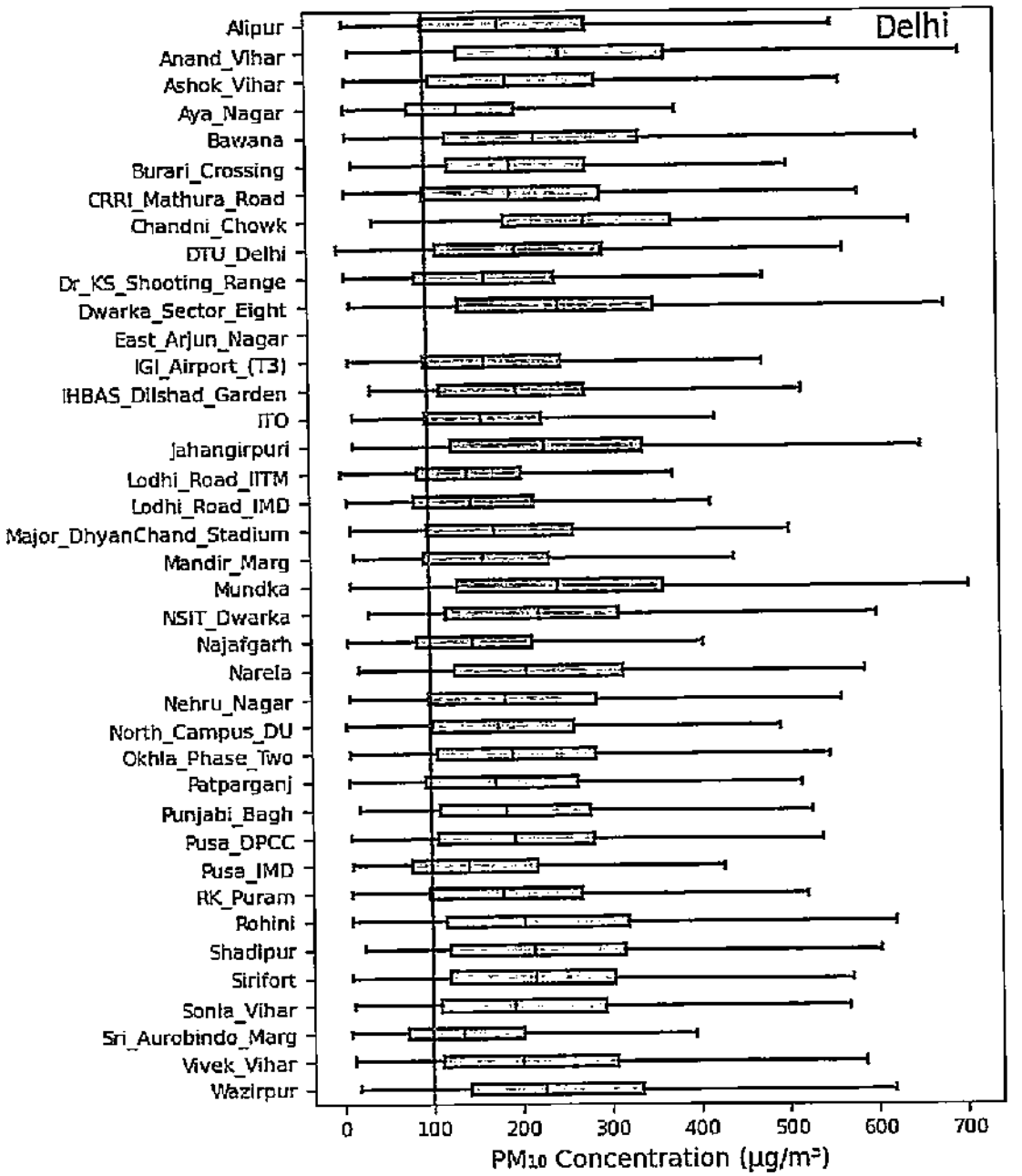


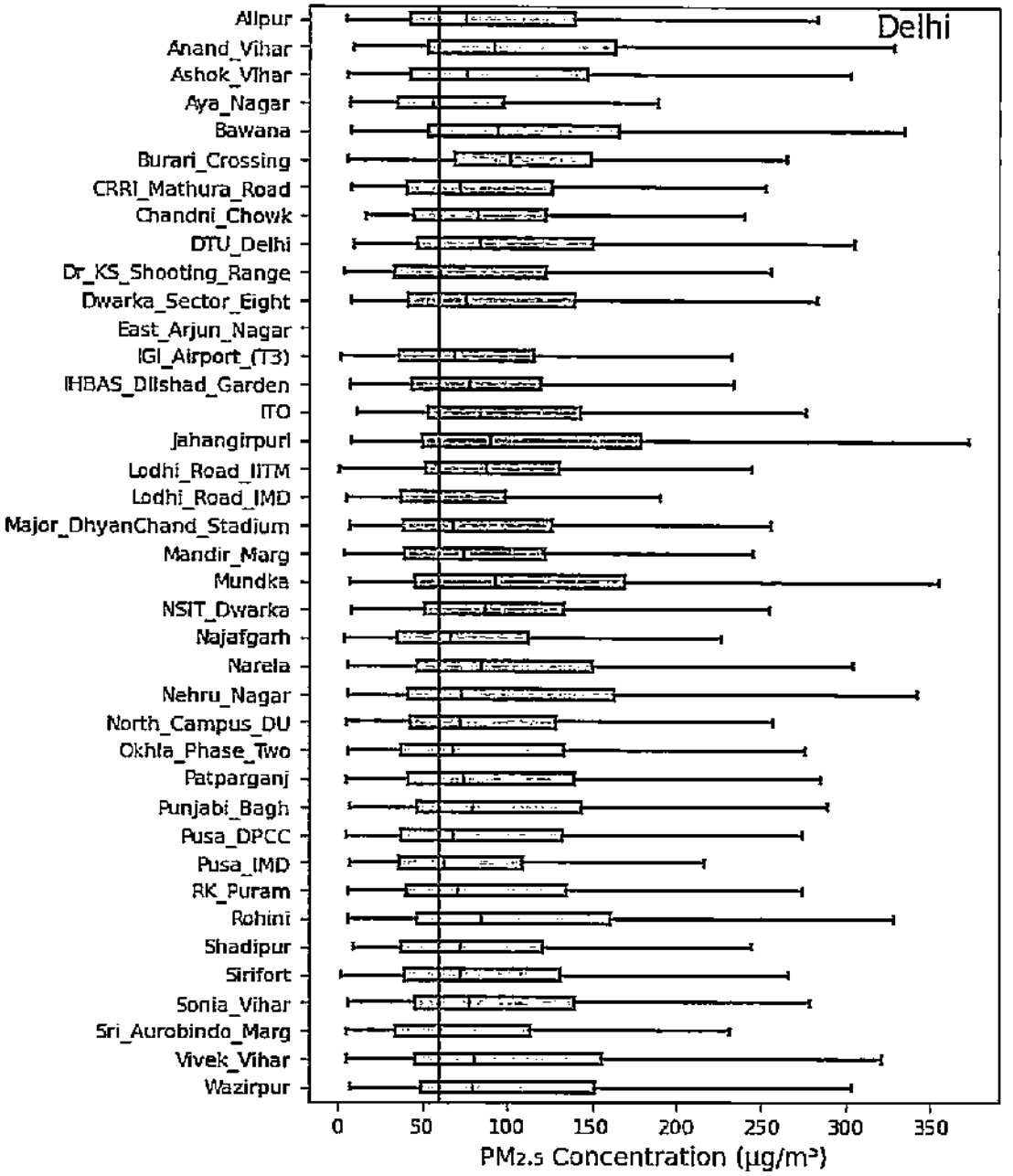


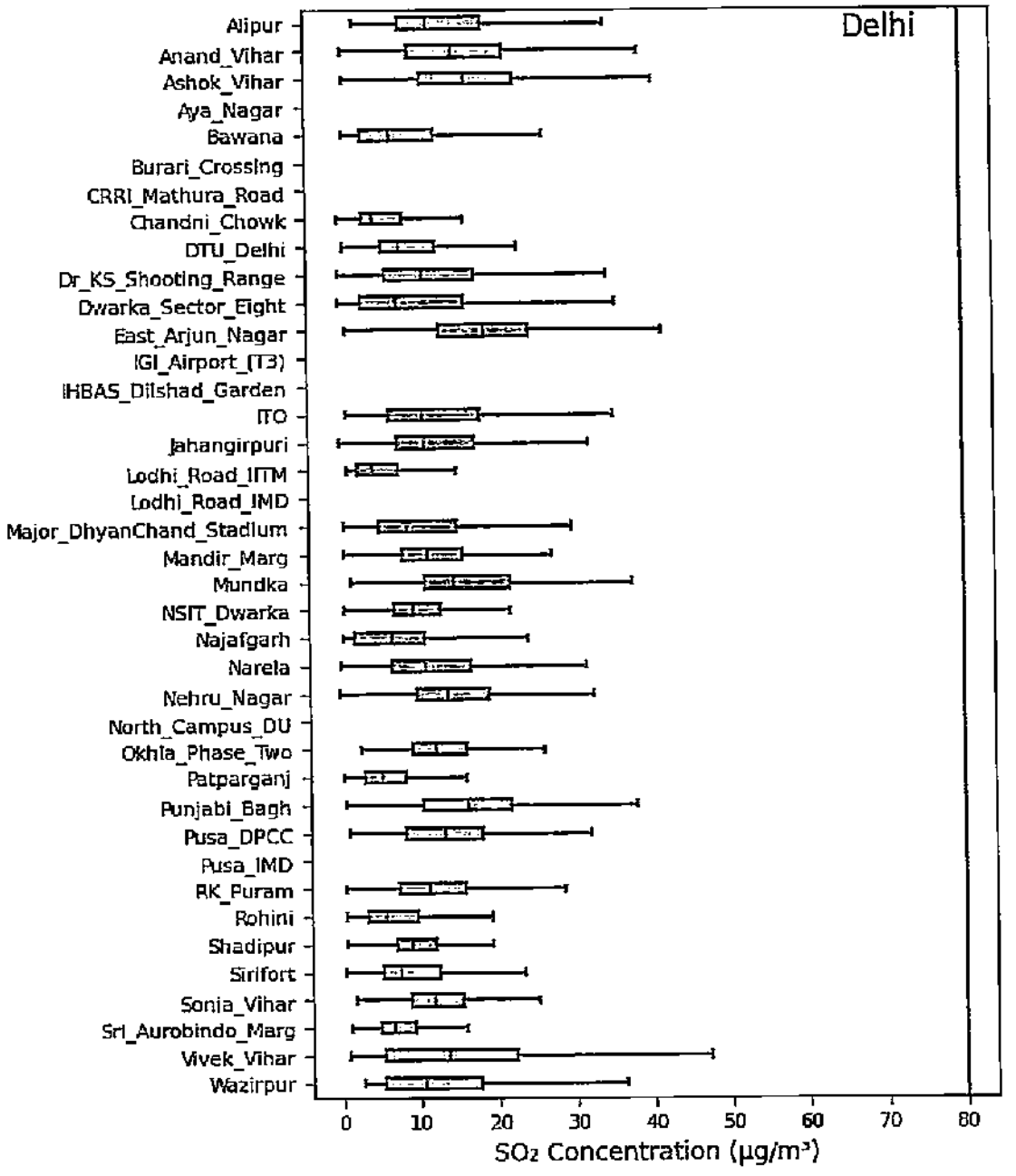


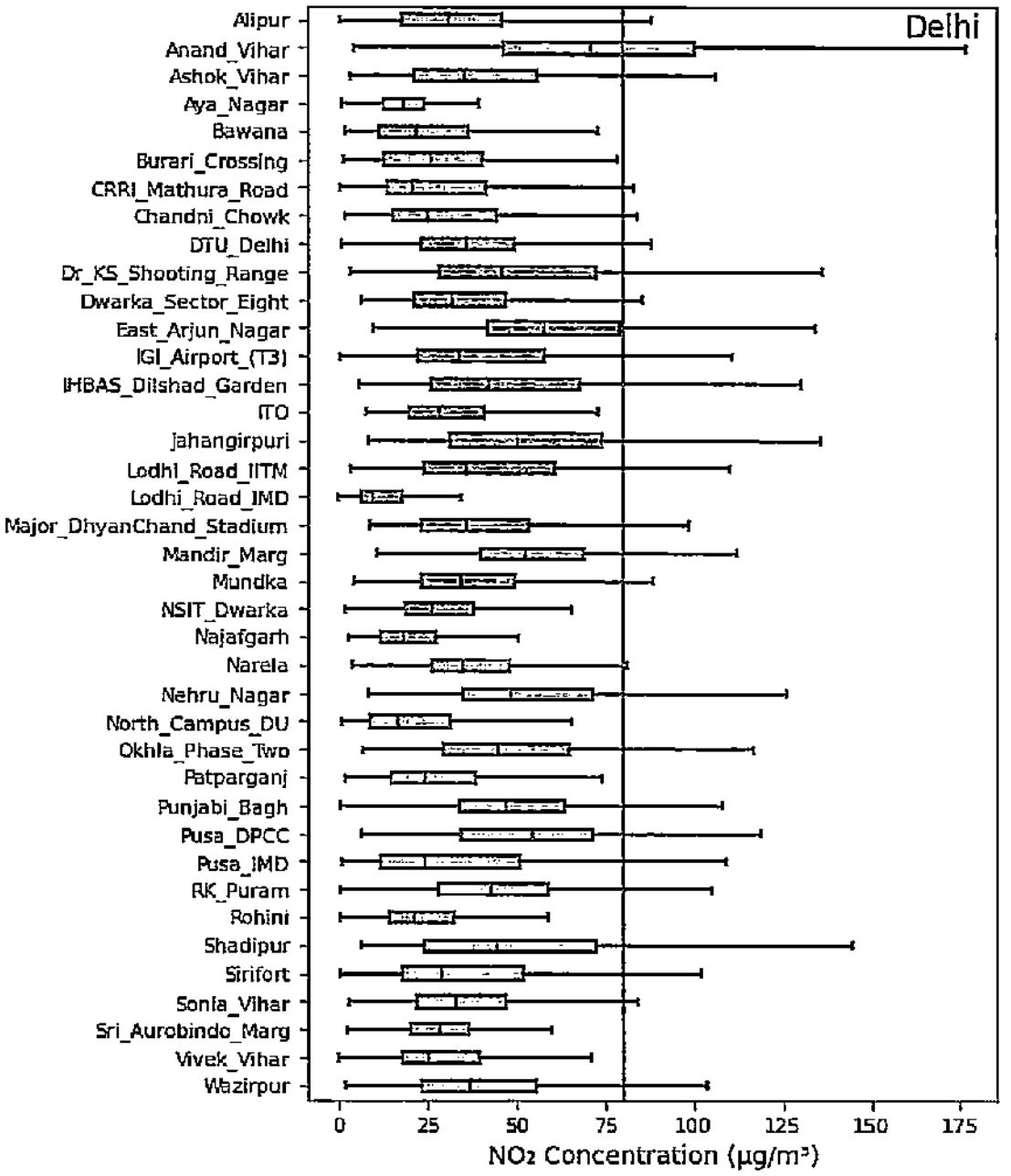


Delhi

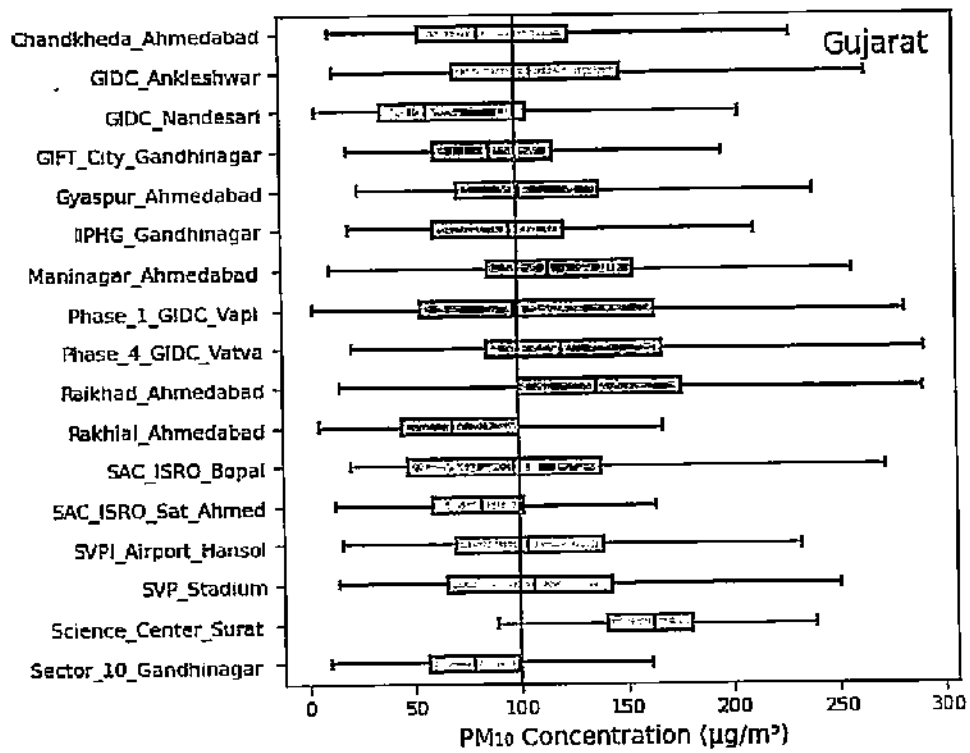

Delhi
Alipur
Anand_Vihar
Ashok_Vihar
Aya_Nagar
Bawana
Burari_Crossing
CRRI_Mathura_Road
Chandni_Chowk
DTU_Delhi
Dr_KS_Shooting_Range
Dwarka_Sector_Eight
East_Arjun_Nagar
IGI_Airport_(T3)
IHBAS_Dilshad_Garden
ITO
Jahangirpuri
Lodhi_Road_IITM
Lodhi_Road_IMD
Major_DhyanChand_Stadium
Mandir_Marg
Mundka
NSIT_Dwarka
Najafgarh
Narela
Nehru_Nagar
North_Campus_DU
Okhla_Phase_Two
Patparganj
Punjabi_Bagh
Pusa_DPCC
Pusa_IMD
RK_Puram
Rohini
Shadipur
Sirifort
Sonia_Vihar
Sri_Aurobindo_Marg
Vivek_Vihar
Wazirpur
0
100
200
300
400
500
600
700
PM10 Concentration (µg/m³)

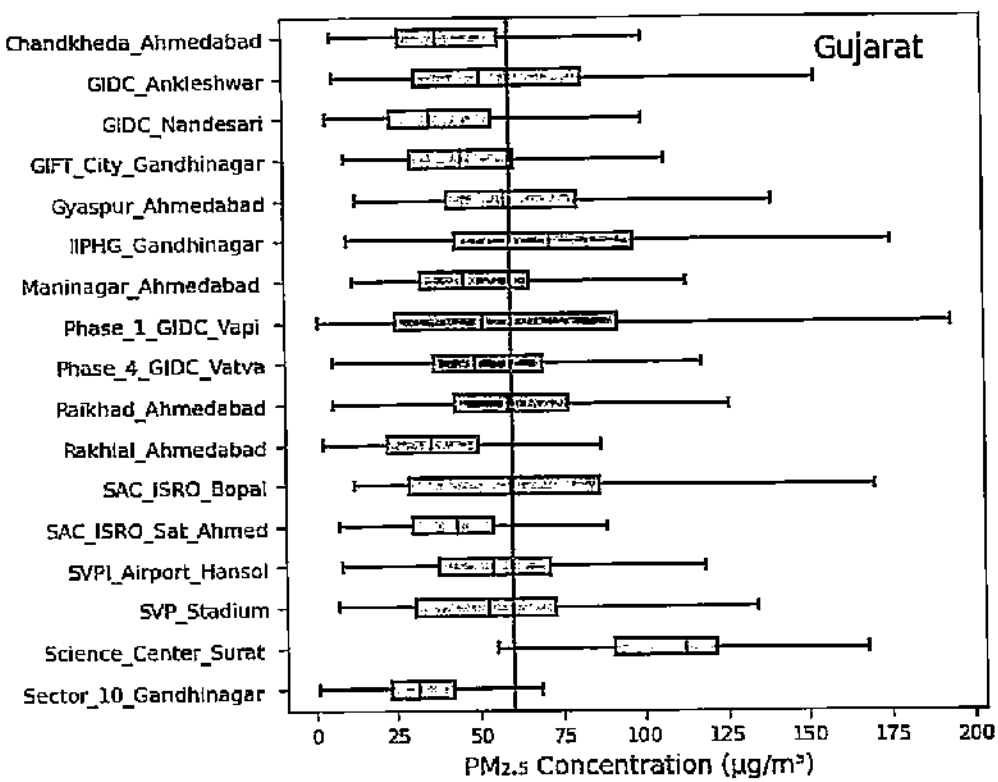

Delhi
Alipur
Anand_Vihar
Ashok_Vihar
Aya_Nagar
Bawana
Burari_Crossing
CRRI_Mathura_Road
Chandni_Chowk
DTU_Delhi
Dr_KS_Shooting_Range
Dwarka_Sector_Eight
East_Arjun_Nagar
IGI_Airport_(T3)
IHBAS_Dilshad_Garden
ITO
Jahangirpuri
Lodhi_Road_IITM
Lodhi_Road_IMD
Major_DhyanChand_Stadium
Mandir_Marg
Mundka
NSIT_Dwarka
Najafgarh
Narela
Nehru_Nagar
North_Campus_DU
Okhla_Phase_Two
Patparganj
Punjabi_Bagh
Pusa_DPCC
Pusa_IMD
RK_Puram
Rohini
Shadipur
Sirifort
Sonia_Vihar
Sri_Aurobindo_Marg
Vivek_Vihar
Wazirpur
0
50
100
150
200
250
300
350
PM2.5 Concentration (µg/m³)

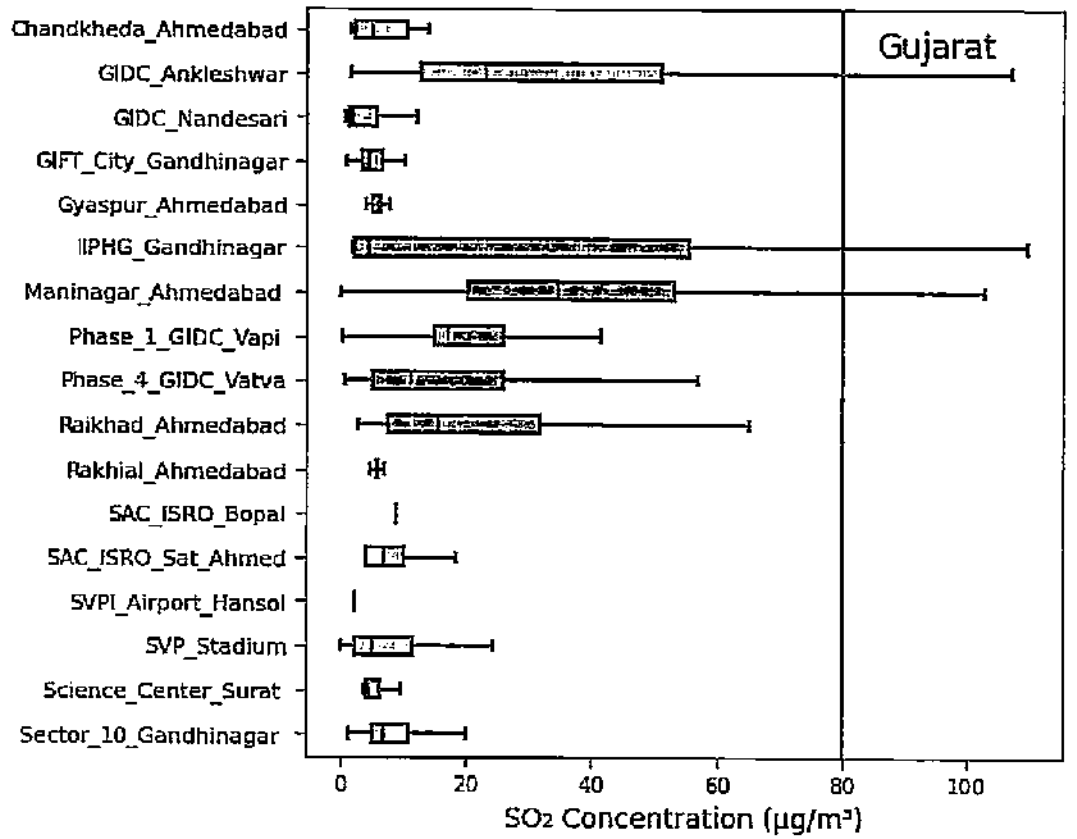

Delhi
Alipur
Anand_Vihar
Ashok_Vihar
Aya_Nagar
Bawana
Burari_Crossing
CRRI_Mathura_Road
Chandni_Chowk
DTU_Delhi
Dr_KS_Shooting_Range
Dwarka_Sector_Eight
East_Arjun_Nagar
IGI_Airport_(T3)
IHBAS_Dilshad_Garden
ITO
Jahangirpuri
Lodhi_Road_IITM
Lodhi_Road_IMD
Major_DhyanChand_Stadium
Mandir_Marg
Mundka
NSIT_Dwarka
Najafgarh
Narela
Nehru_Nagar
North_Campus_DU
Okhla_Phase_Two
Patparganj
Punjabi_Bagh
Pusa_DPCC
Pusa_IMD
RK_Puram
Rohini
Shadipur
Sirifort
Sonia_Vihar
Sri_Aurobindo_Marg
Vivek_Vihar
Wazirpur
0
10
20
30
40
50
60
70
80
SO2 Concentration (µg/m3)

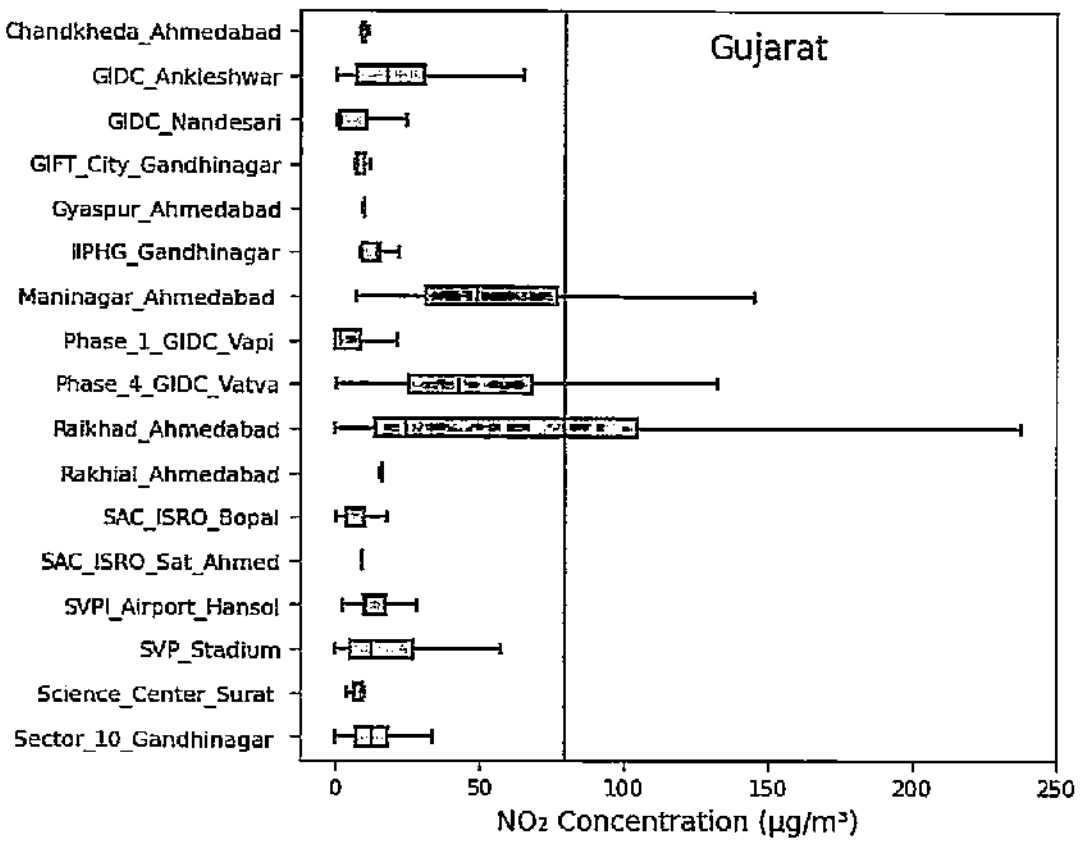

Delhi
Alipur
Anand_Vihar
Ashok_Vihar
Aya_Nagar
Bawana
Burari_Crossing
CRRI_Mathura_Road
Chandni_Chowk
DTU_Delhi
Dr_KS_Shooting_Range
Dwarka_Sector_Eight
East_Arjun_Nagar
IGI_Airport_(T3)
IHBAS_Dilshad_Garden
ITO
Jahangirpuri
Lodhi_Road_IITM
Lodhi_Road_IMD
Major_DhyanChand_Stadium
Mandir_Marg
Mundka
NSIT_Dwarka
Najafgarh
Narela
Nehru_Nagar
North_Campus_DU
Okhla_Phase_Two
Patparganj
Punjabi_Bagh
Pusa_DPCC
Pusa_IMD
RK_Puram
Rohini
Shadipur
Sirifort
Sonia_Vihar
Sri_Aurobindo_Marg
Vivek_Vihar
Wazirpur
0
25
50
75
100
125
150
175
NO₂ Concentration (µg/m³)

Gujarat

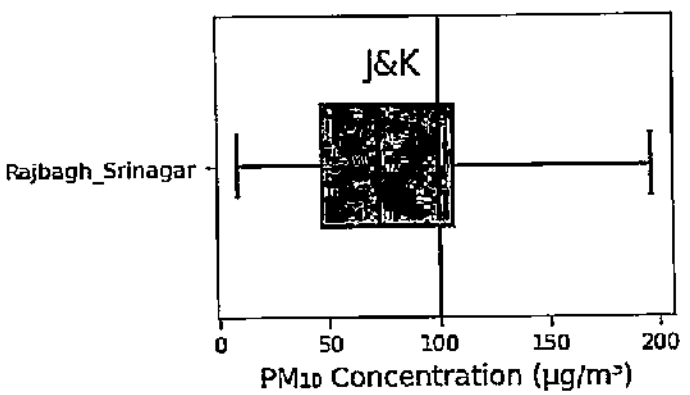

Gujarat
Chandkheda_Ahmedabad
GIDC_Ankleshwar
GIDC_Nandesari
GIFT_City_Gandhinagar
Gyaspur_Ahmedabad
IIPHG_Gandhinagar
Maninagar_Ahmedabad
Phase_1_GIDC_Vapi
Phase_4_GIDC_Vatva
Raikhad_Ahmedabad
Rakhial_Ahmedabad
SAC_ISRO_Bopal
SAC_ISRO_Sat_Ahmed
SVPI_Airport_Hansol
SVP_Stadium
Science_Center_Surat
Sector_10_Gandhinagar
0
50
100
150
200
250
300
PM10 Concentration (µg/m³)

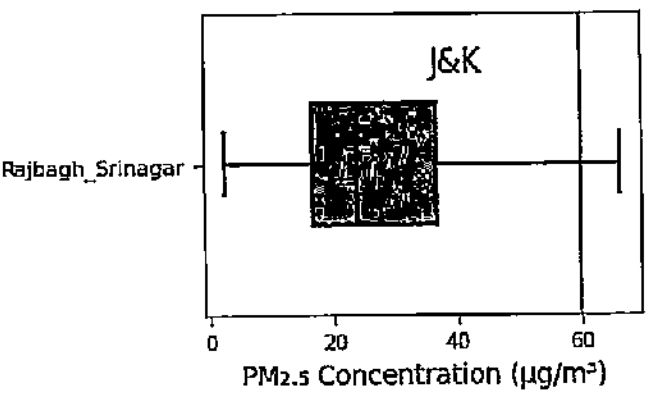

Gujarat
Chandkheda_Ahmedabad
GIDC_Ankleshwar
GIDC_Nandesari
GIFT_City_Gandhinagar
Gyaspur_Ahmedabad
IIPHG_Gandhinagar
Maninagar_Ahmedabad
Phase_1_GIDC_Vapi
Phase_4_GIDC_Vatva
Raikhad_Ahmedabad
Rakhial_Ahmedabad
SAC_ISRO_Bopal
SAC_ISRO_Sat_Ahmed
SVPI_Airport_Hansol
SVP_Stadium
Science_Center_Surat
Sector_10_Gandhinagar
0
25
50
75
100
125
150
175
200
PM2.5 Concentration (µg/m³)

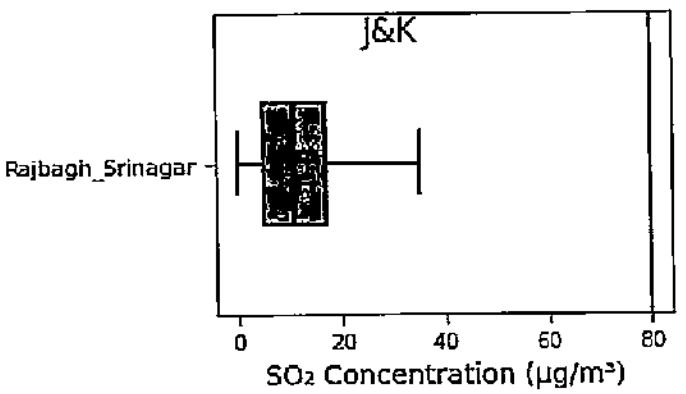

Gujarat
Chandkheda_Ahmedabad
GIDC_Ankleshwar
GIDC_Nandesari
GIFT_City_Gandhinagar
Gyaspur_Ahmedabad
IIPHG_Gandhinagar
Maninagar_Ahmedabad
Phase_1_GIDC_Vapi
Phase_4_GIDC_Vatva
Raikhad_Ahmedabad
Rakhial_Ahmedabad
SAC_ISRO_Bopal
SAC_ISRO_Sat_Ahmed
SVPI_Airport_Hansol
SVP_Stadium
Science_Center_Surat
Sector_10_Gandhinagar
0
20
40
60
80
100
SO2 Concentration (µg/m3)

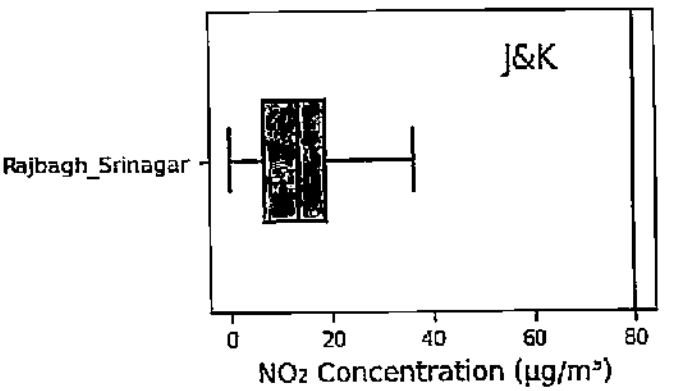

Gujarat
Chandkheda_Ahmedabad
GIDC_Ankleshwar
GIDC_Nandesari
GIFT_City_Gandhinagar
Gyaspur_Ahmedabad
IIPHG_Gandhinagar
Maninagar_Ahmedabad
Phase_1_GIDC_Vapi
Phase_4_GIDC_Vatva
Raikhad_Ahmedabad
Rakhial_Ahmedabad
SAC_ISRO_Bopal
SAC_ISRO_Sat_Ahmed
SVPI_Airport_Hansol
SVP_Stadium
Science_Center_Surat
Sector_10_Gandhinagar
0
50
100
150
200
250
NO2 Concentration (µg/m3)

Jammu & Kashmir

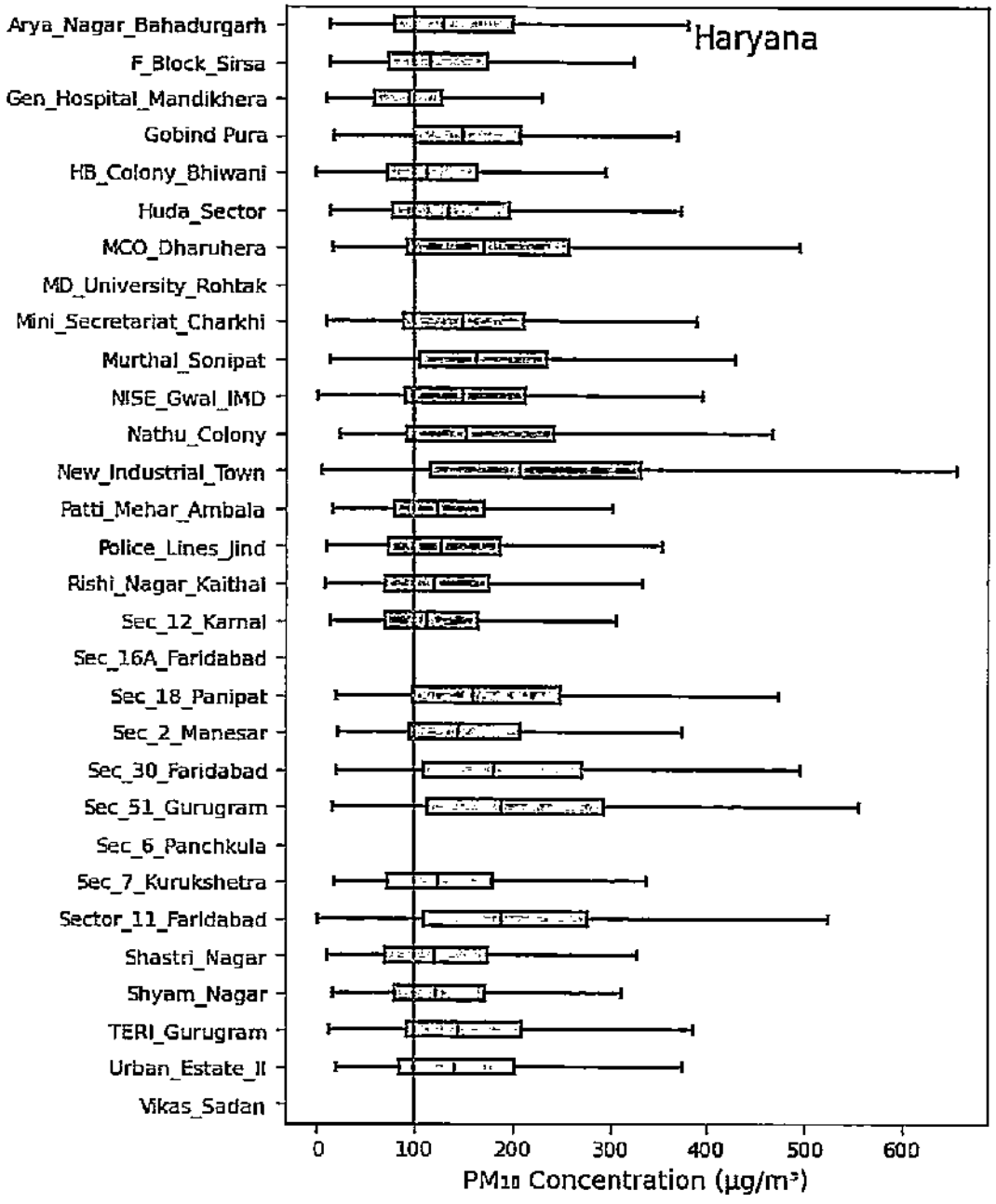


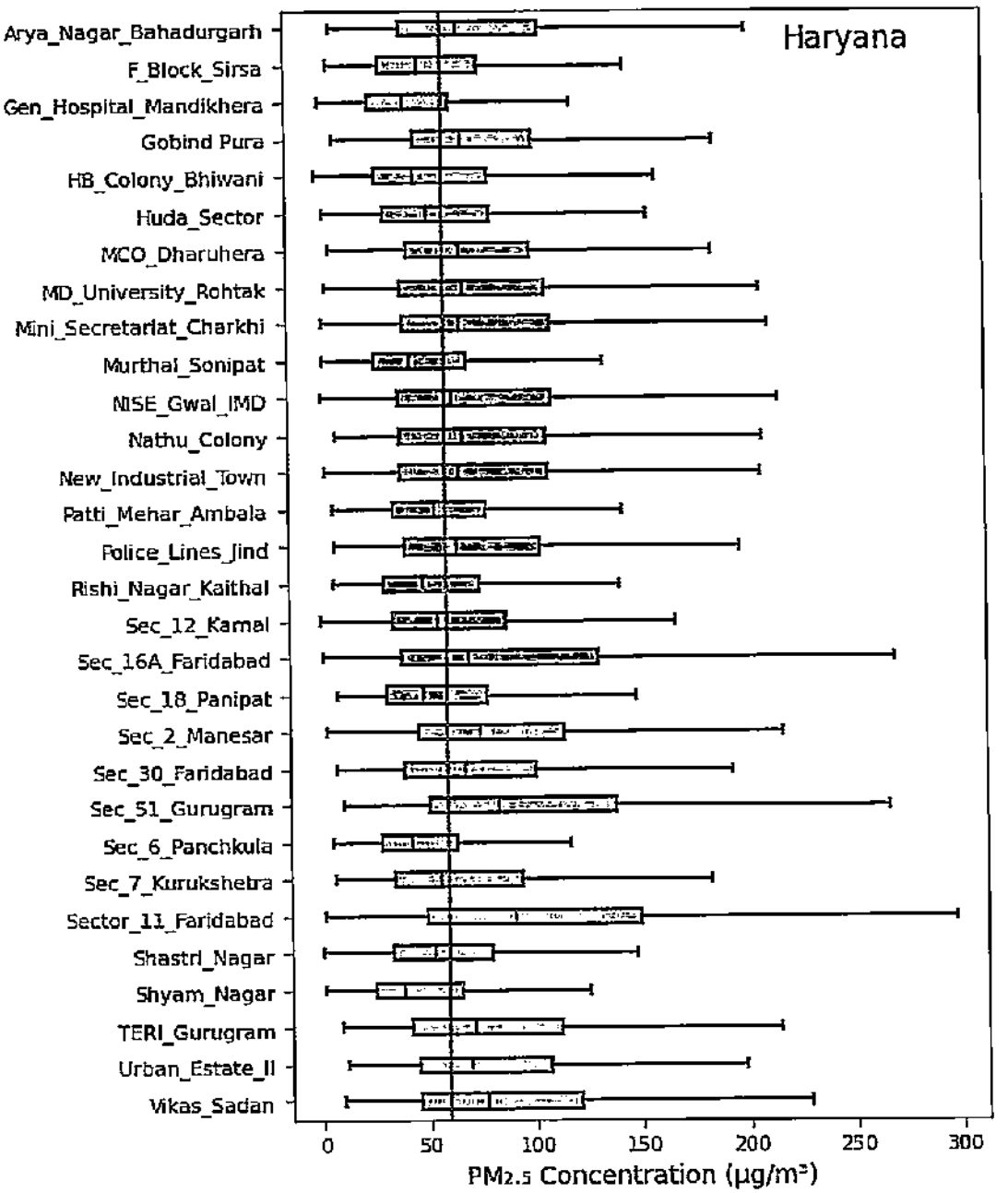


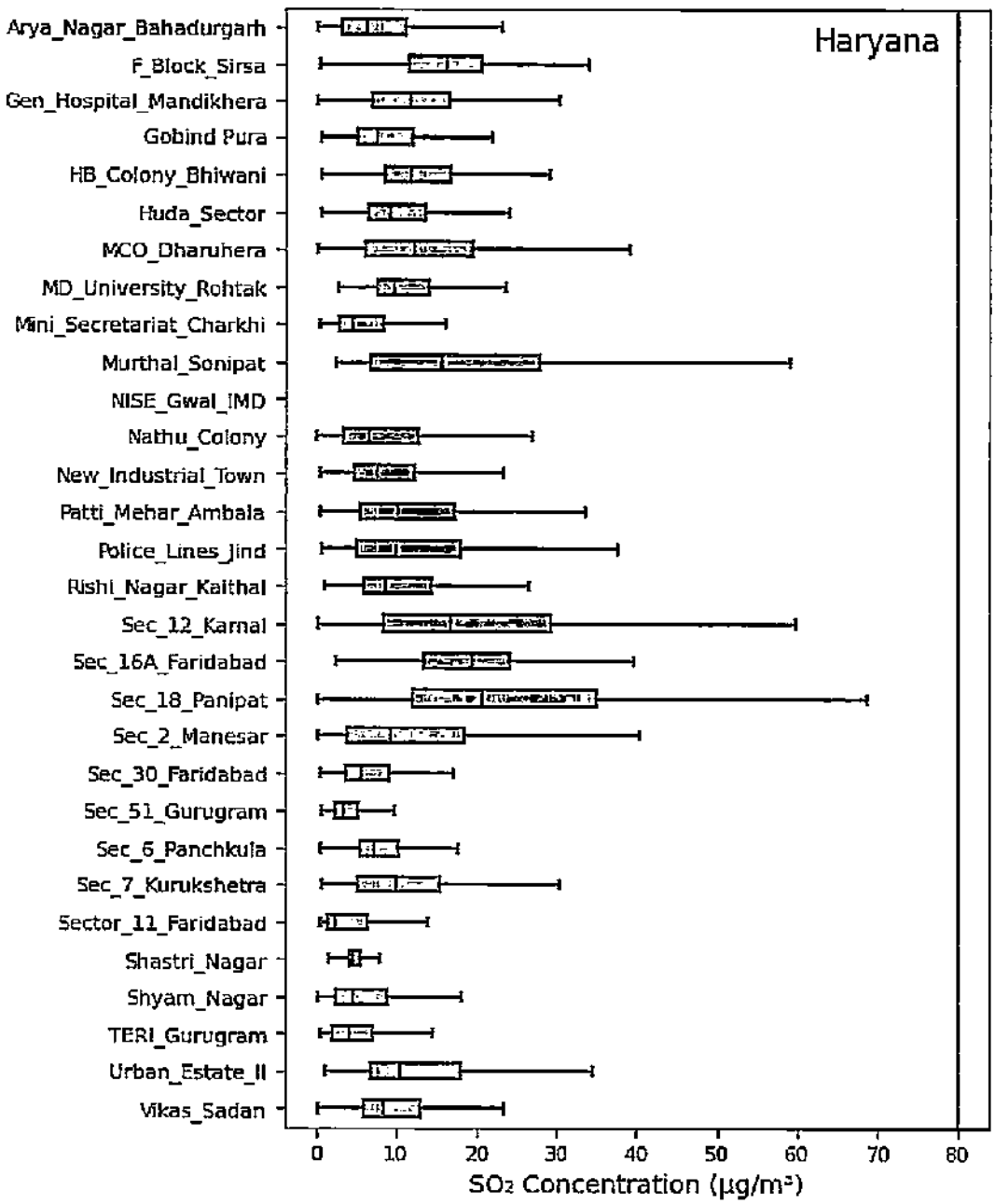


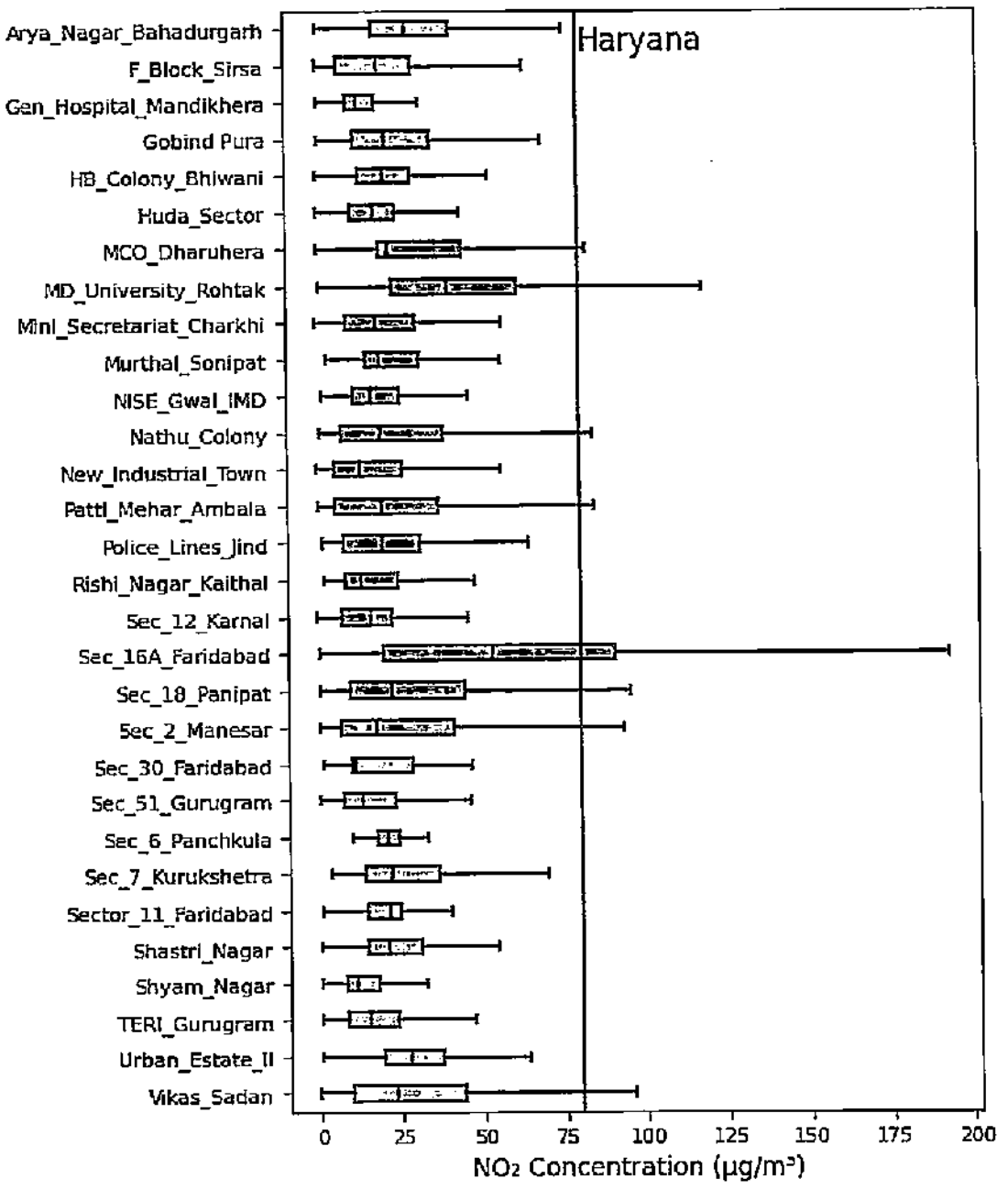


Haryana

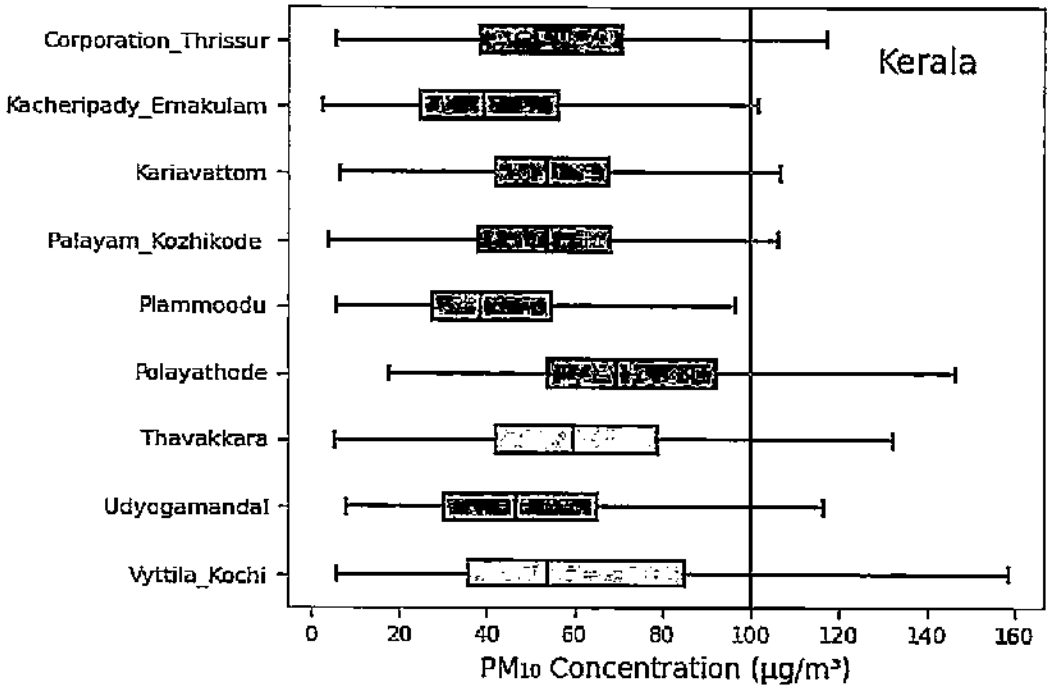

Haryana
Arya_Nagar_Bahadurgarh
F_Block_Sirsa
Gen_Hospital_Mandikhera
Gobind Pura
HB_Colony_Bhiwani
Huda_Sector
MCO_Dharuhera
MD_University_Rohtak
Mini_Secretariat_Charkhi
Murthal_Sonipat
NISE_Gwal_IMD
Nathu_Colony
New_Industrial_Town
Patti_Mehar_Ambala
Police_Lines_Jind
Rishi_Nagar_Kaithal
Sec_12_Karnal
Sec_16A_Faridabad
Sec_18_Panipat
Sec_2_Manesar
Sec_30_Faridabad
Sec_51_Gurugram
Sec_6_Panchkula
Sec_7_Kurukshetra
Sector_11_Faridabad
Shastri_Nagar
Shyam_Nagar
TERI_Gurugram
Urban_Estate_II
Vikas_Sadan
0
100
200
300
400
500
600
PM10 Concentration (µg/m³)

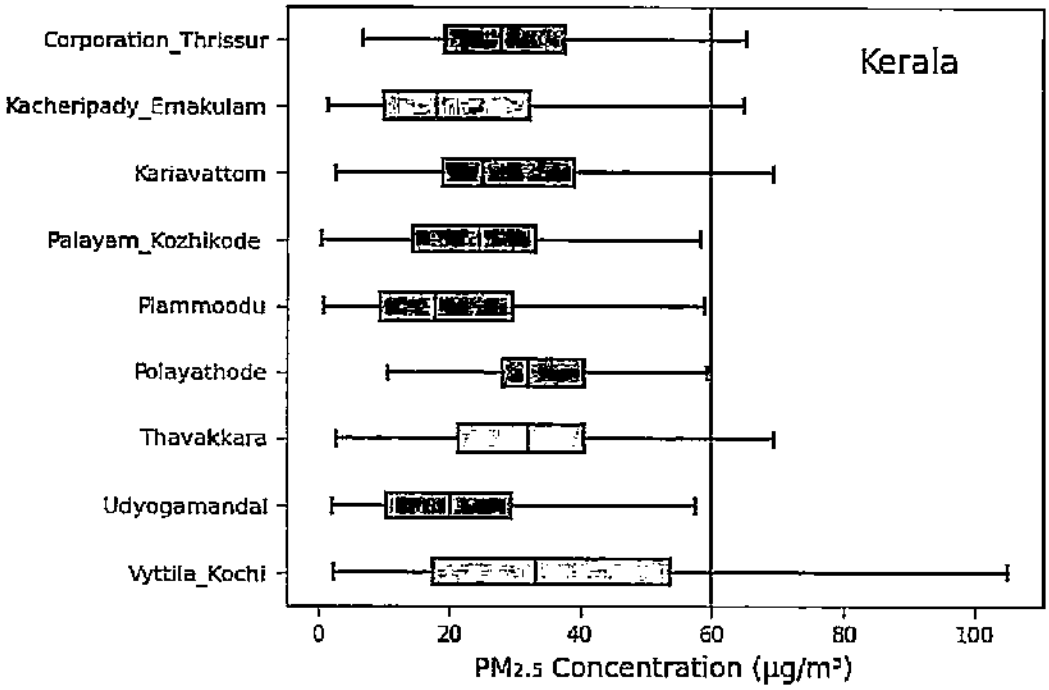

Haryana
Arya_Nagar_Bahadurgarh
F_Block_Sirsa
Gen_Hospital_Mandikhera
Gobind Pura
HB_Colony_Bhiwani
Huda_Sector
MCO_Dharuhera
MD_University_Rohtak
Mini_Secretariat_Charkhi
Murthal_Sonipat
NISE_Gwal_IMD
Nathu_Colony
New_Industrial_Town
Patti_Mehar_Ambala
Police_Lines_Jind
Rishi_Nagar_Kaithal
Sec_12_Kamal
Sec_16A_Faridabad
Sec_18_Panipat
Sec_2_Manesar
Sec_30_Faridabad
Sec_51_Gurugram
Sec_6_Panchkula
Sec_7_Kurukshetra
Sector_11_Faridabad
Shastri_Nagar
Shyam_Nagar
TERI_Gurugram
Urban_Estate_II
Vikas_Sadan
0
50
100
150
200
250
300
PM2.5 Concentration (µg/m³)

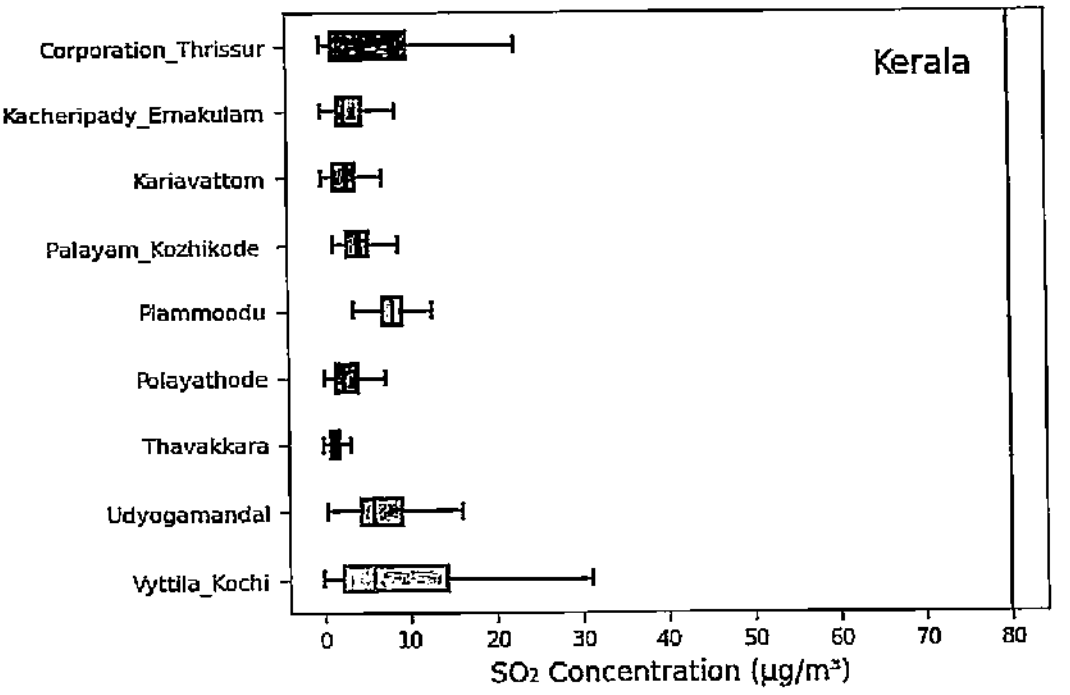

Haryana
Arya_Nagar_Bahadurgarh
F_Block_Sirsa
Gen_Hospital_Mandikhera
Gobind Pura
HB_Colony_Bhiwani
Huda_Sector
MCO_Dharuhera
MD_University_Rohtak
Mini_Secretariat_Charkhi
Murthal_Sonipat
NISE_Gwal_IMD
Nathu_Colony
New_Industrial_Town
Patti_Mehar_Ambala
Police_Lines_Jind
Rishi_Nagar_Kaithal
Sec_12_Karnal
Sec_16A_Faridabad
Sec_18_Panipat
Sec_2_Manesar
Sec_30_Faridabad
Sec_51_Gurugram
Sec_6_Panchkula
Sec_7_Kurukshetra
Sector_11_Faridabad
Shastri_Nagar
Shyam_Nagar
TERI_Gurugram
Urban_Estate_II
Vikas_Sadan
0
10
20
30
40
50
60
70
80
SO₂ Concentration (µg/m³)

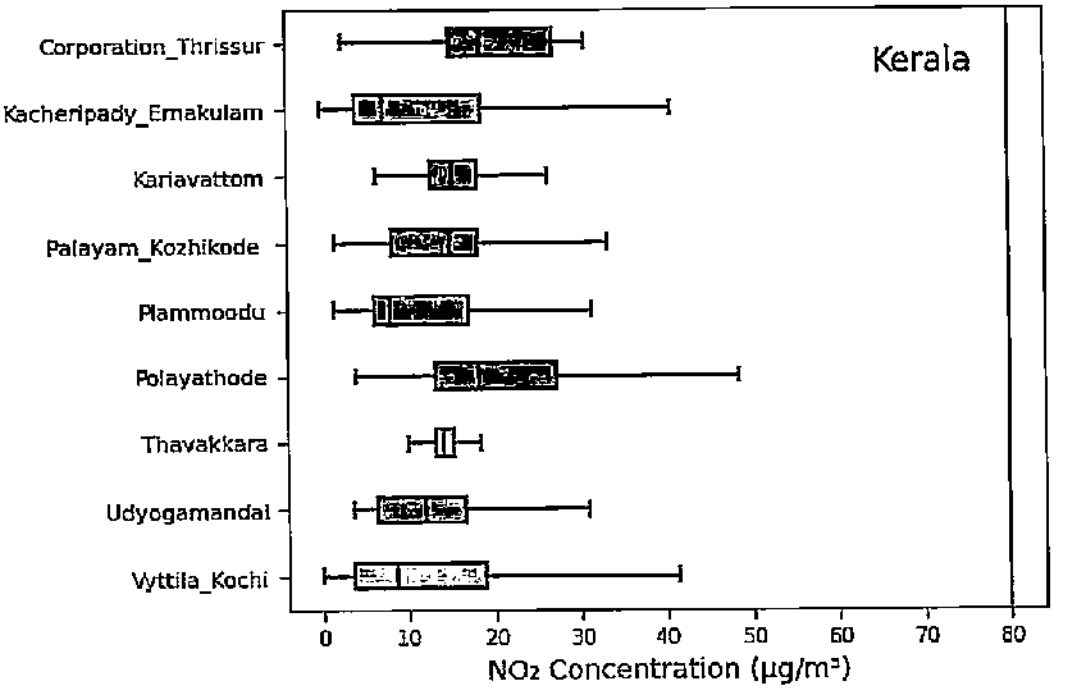

Haryana
Arya_Nagar_Bahadurgarh
F_Block_Sirsa
Gen_Hospital_Mandikhera
Gobind Pura
HB_Colony_Bhiwani
Huda_Sector
MCO_Dharuhera
MD_University_Rohtak
Mini_Secretariat_Charkhi
Murthal_Sonipat
NISE_Gwal_IMD
Nathu_Colony
New_Industrial_Town
Patti_Mehar_Ambala
Police_Lines_Jind
Rishi_Nagar_Kaithal
Sec_12_Karnal
Sec_16A_Faridabad
Sec_18_Panipat
Sec_2_Manesar
Sec_30_Faridabad
Sec_51_Gurugram
Sec_6_Panchkula
Sec_7_Kurukshetra
Sector_11_Faridabad
Shastri_Nagar
Shyam_Nagar
TERI_Gurugram
Urban_Estate_II
Vikas_Sadan
0
25
50
75
100
125
150
175
200
NO₂ Concentration (µg/m³)

Kerala

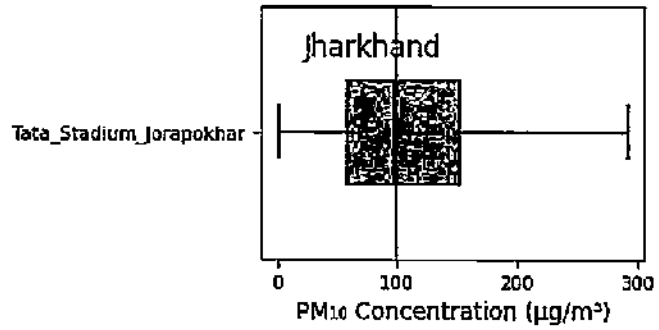

Kerala
Corporation_Thrissur
Kacheripady_Ernakulam
Kariavattom
Palayam_Kozhikode
Plammoodu
Polayathode
Thavakkara
Udyogamandal
Vyttila_Kochi
0
20
40
60
80
100
120
140
160
PM10 Concentration (µg/m³)

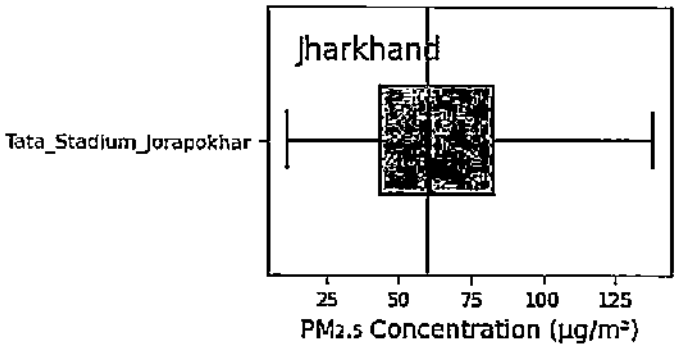

Kerala
Corporation_Thrissur
Kacheripady_Ernakulam
Kariavattom
Palayam_Kozhikode
Plammoodu
Polayathode
Thavakkara
Udyogamandal
Vyttila_Kochi
0
20
40
60
80
100
PM2.5 Concentration (µg/m³)

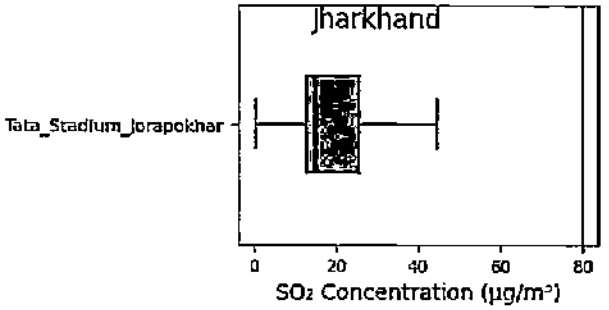

Kerala
Corporation_Thrissur
Kacheripady_Ernakulam
Kariavattom
Palayam_Kozhikode
Plammoodu
Polayathode
Thavakkara
Udyogamandal
Vyttila_Kochi
0
10
20
30
40
50
60
70
80
SO2 Concentration (µg/m³)

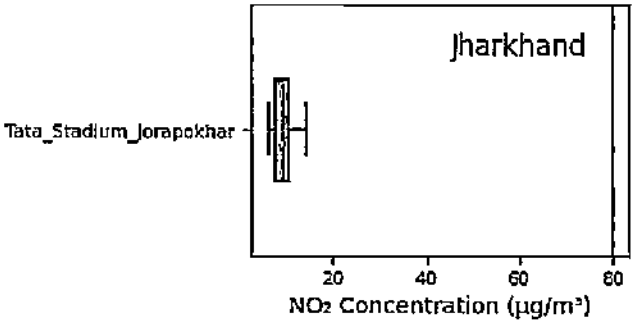

Kerala
Corporation_Thrissur
Kacheripady_Ernakulam
Kariavattom
Palayam_Kozhikode
Plammoodu
Polayathode
Thavakkara
Udyogamandal
Vyttila_Kochi
0
10
20
30
40
50
60
70
80
NO2 Concentration (µg/m³)

Jharkhand

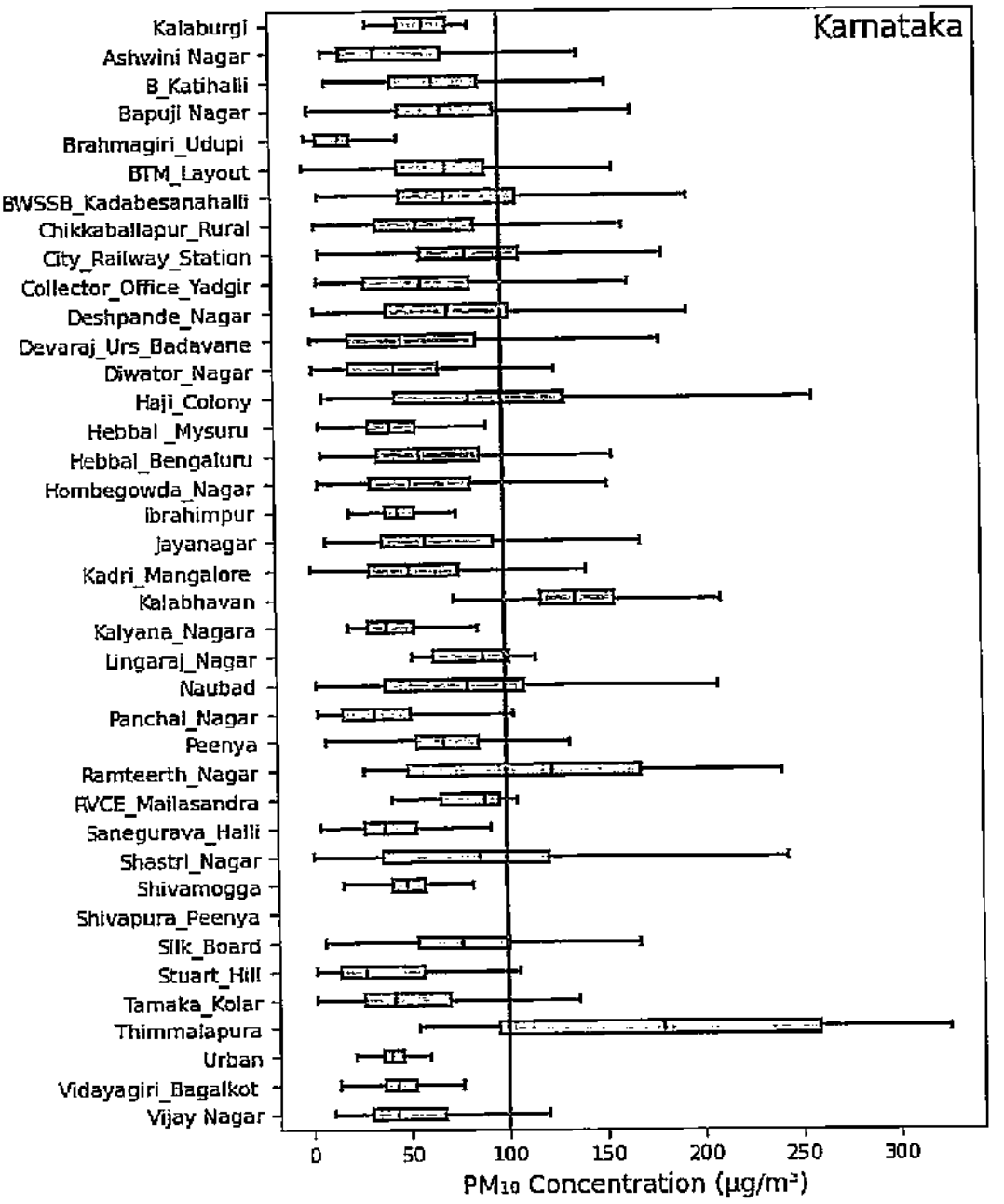

Jharkhand
Tata_Stadium_Jorapokhar
0
100
200
300
PM10 Concentration (µg/m³)

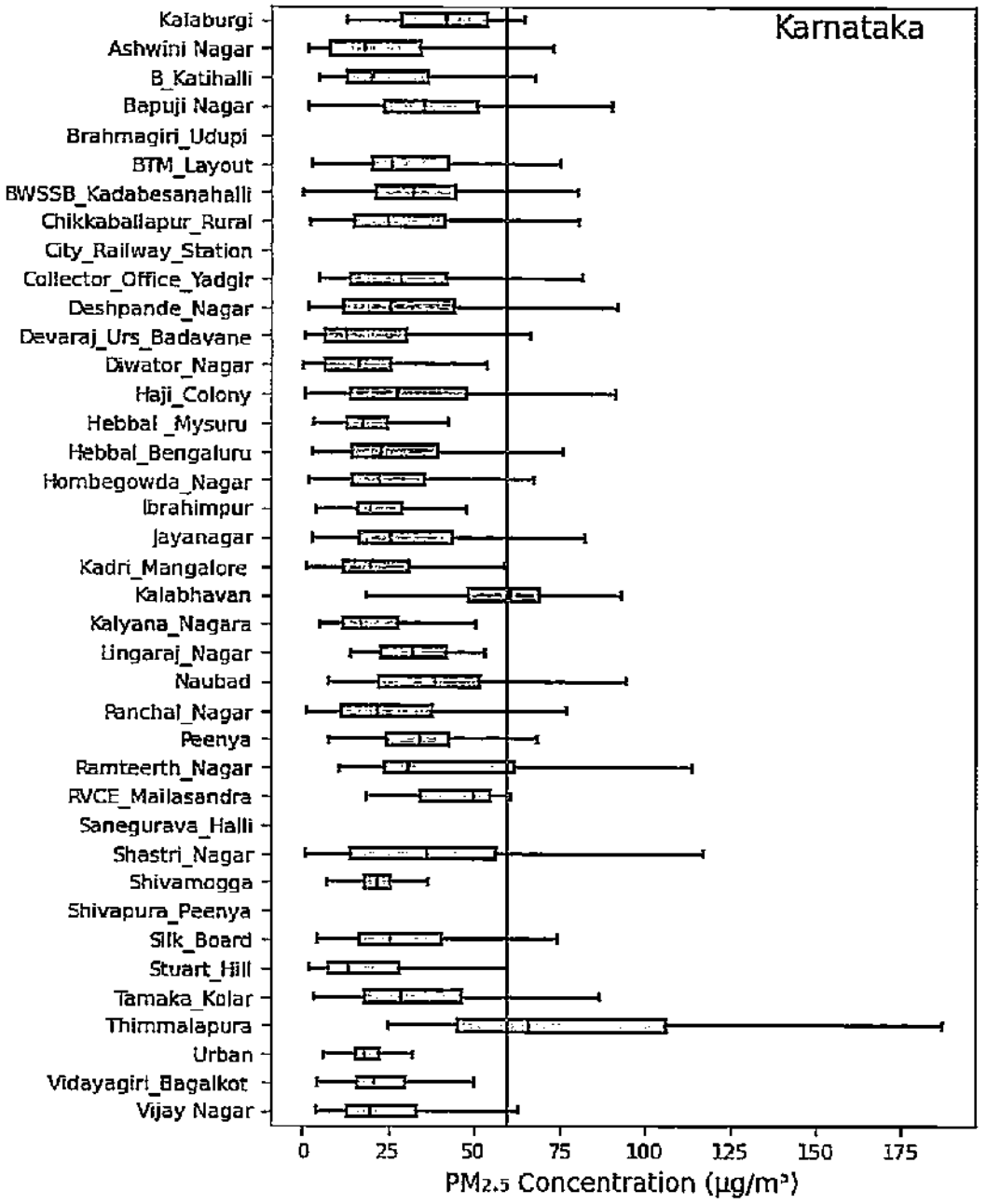

Jharkhand
Tata_Stadium_Jorapokhar
25
50
75
100
125
PM2.5 Concentration (µg/m³)

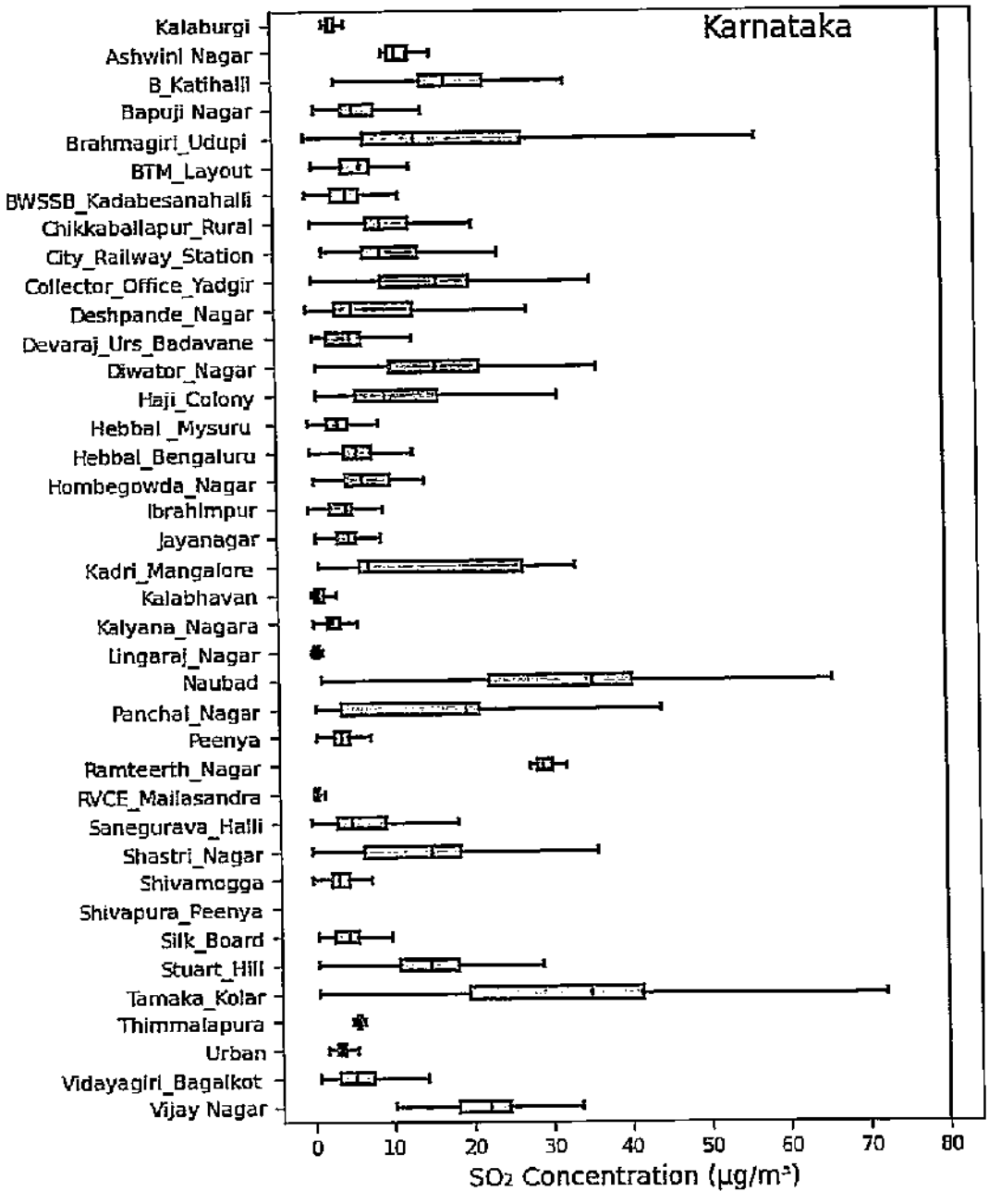

Jharkhand
Tata_Stadium_Jorapokhar
0
20
40
60
80
SO2 Concentration (µg/m³)

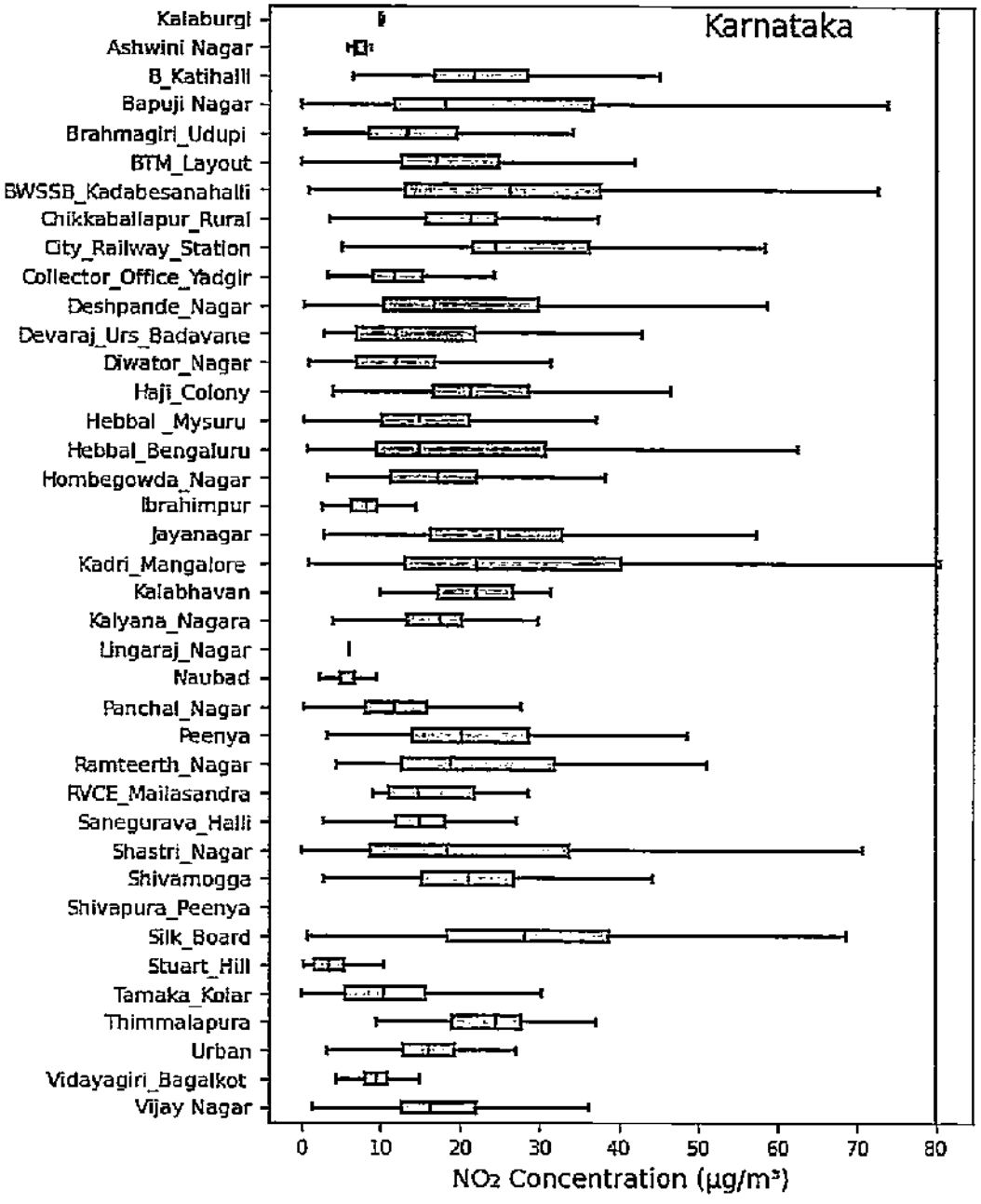

Jharkhand
Tata_Stadium_Jorapokhar
20
40
60
80
NO2 Concentration (µg/m³)

Karnataka

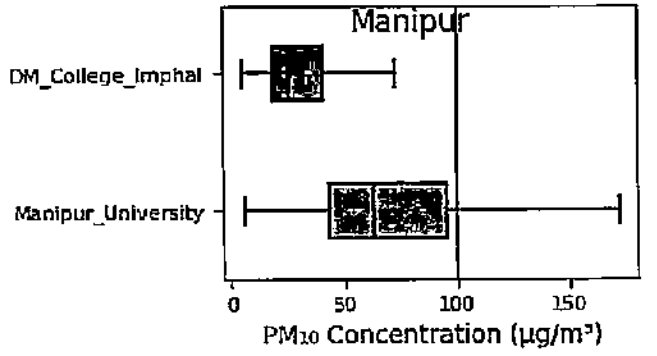

Karnataka
Kalaburgi
Ashwini Nagar
B_Katihalli
Bapuji Nagar
Brahmagiri_Udupi
BTM_Layout
BWSSB_Kadabesanahalli
Chikkaballapur_Rural
City_Railway_Station
Collector_Office_Yadgir
Deshpande_Nagar
Devaraj_Urs_Badavane
Diwator_Nagar
Haji_Colony
Hebbal _Mysuru
Hebbal_Bengaluru
Hombegowda_Nagar
Ibrahimpur
Jayanagar
Kadri_Mangalore
Kalabhavan
Kalyana_Nagara
Lingaraj_Nagar
Naubad
Panchal_Nagar
Peenya
Ramteerth_Nagar
RVCE_Mailasandra
Sanegurava_Halli
Shastri_Nagar
Shivamogga
Shivapura_Peenya
Silk_Board
Stuart_Hill
Tamaka_Kolar
Thimmalapura
Urban
Vidayagiri_Bagalkot
Vijay Nagar
0
50
100
150
200
250
300
PM10 Concentration (µg/m³)

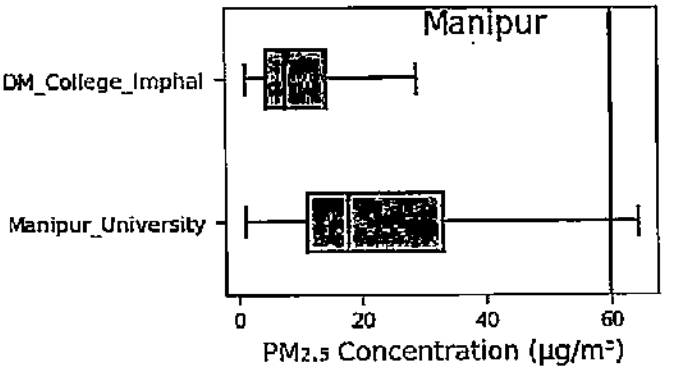

Karnataka
Kalaburgi
Ashwini Nagar
B_Katihalli
Bapuji Nagar
Brahmagiri_Udupi
BTM_Layout
BWSSB_Kadabesanahalli
Chikkaballapur_Rural
City_Railway_Station
Collector_Office_Yadgir
Deshpande_Nagar
Devaraj_Urs_Badavane
Diwator_Nagar
Haji_Colony
Hebbal _Mysuru
Hebbal_Bengaluru
Hombegowda_Nagar
Ibrahimpur
Jayanagar
Kadri_Mangalore
Kalabhavan
Kalyana_Nagara
Lingaraj_Nagar
Naubad
Panchal_Nagar
Peenya
Ramteerth_Nagar
RVCE_Mailasandra
Sanegurava_Halli
Shastri_Nagar
Shivamogga
Shivapura_Peenya
Silk_Board
Stuart_Hill
Tamaka_Kolar
Thimmalapura
Urban
Vidayagiri_Bagalkot
Vijay Nagar
0
25
50
75
100
125
150
175
PM2.5 Concentration (µg/m³)

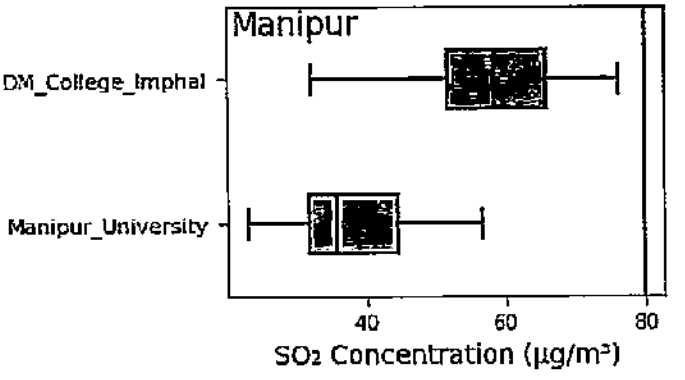

Karnataka
Kalaburgi
Ashwini Nagar
B_Katihalli
Bapuji Nagar
Brahmagiri_Udupi
BTM_Layout
BWSSB_Kadabesanahalli
Chikkaballapur_Rural
City_Railway_Station
Collector_Office_Yadgir
Deshpande_Nagar
Devaraj_Urs_Badavane
Diwator_Nagar
Haji_Colony
Hebbal _Mysuru
Hebbal_Bengaluru
Hombegowda_Nagar
Ibrahimpur
Jayanagar
Kadri_Mangalore
Kalabhavan
Kalyana_Nagara
Lingaraj_Nagar
Naubad
Panchal_Nagar
Peenya
Ramteerth_Nagar
RVCE_Mailasandra
Sanegurava_Halli
Shastri_Nagar
Shivamogga
Shivapura_Peenya
Silk_Board
Stuart_Hill
Tamaka_Kolar
Thimmalapura
Urban
Vidayagiri_Bagalkot
Vijay Nagar
0
10
20
30
40
50
60
70
80
SO2 Concentration (µg/m3)

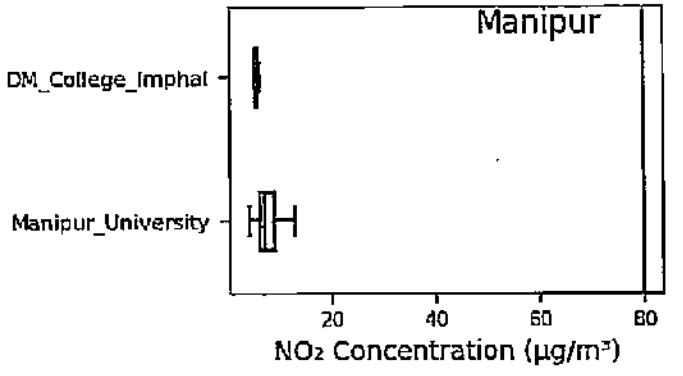

Karnataka
Kalaburgi
Ashwini Nagar
B_Katihalli
Bapuji Nagar
Brahmagiri_Udupi
BTM_Layout
BWSSB_Kadabesanahalli
Chikkaballapur_Rural
City_Railway_Station
Collector_Office_Yadgir
Deshpande_Nagar
Devaraj_Urs_Badavane
Diwator_Nagar
Haji_Colony
Hebbal _Mysuru
Hebbal_Bengaluru
Hombegowda_Nagar
Ibrahimpur
Jayanagar
Kadri_Mangalore
Kalabhavan
Kalyana_Nagara
Ungaraj_Nagar
Naubad
Panchal_Nagar
Peenya
Ramteerth_Nagar
RVCE_Mailasandra
Sanegurava_Halli
Shastri_Nagar
Shivamogga
Shivapura_Peenya
Silk_Board
Stuart_Hill
Tamaka_Kolar
Thimmalapura
Urban
Vidayagiri_Bagalkot
Vijay Nagar
0
10
20
30
40
50
60
70
80
NO2 Concentration (µg/m³)

Manipur

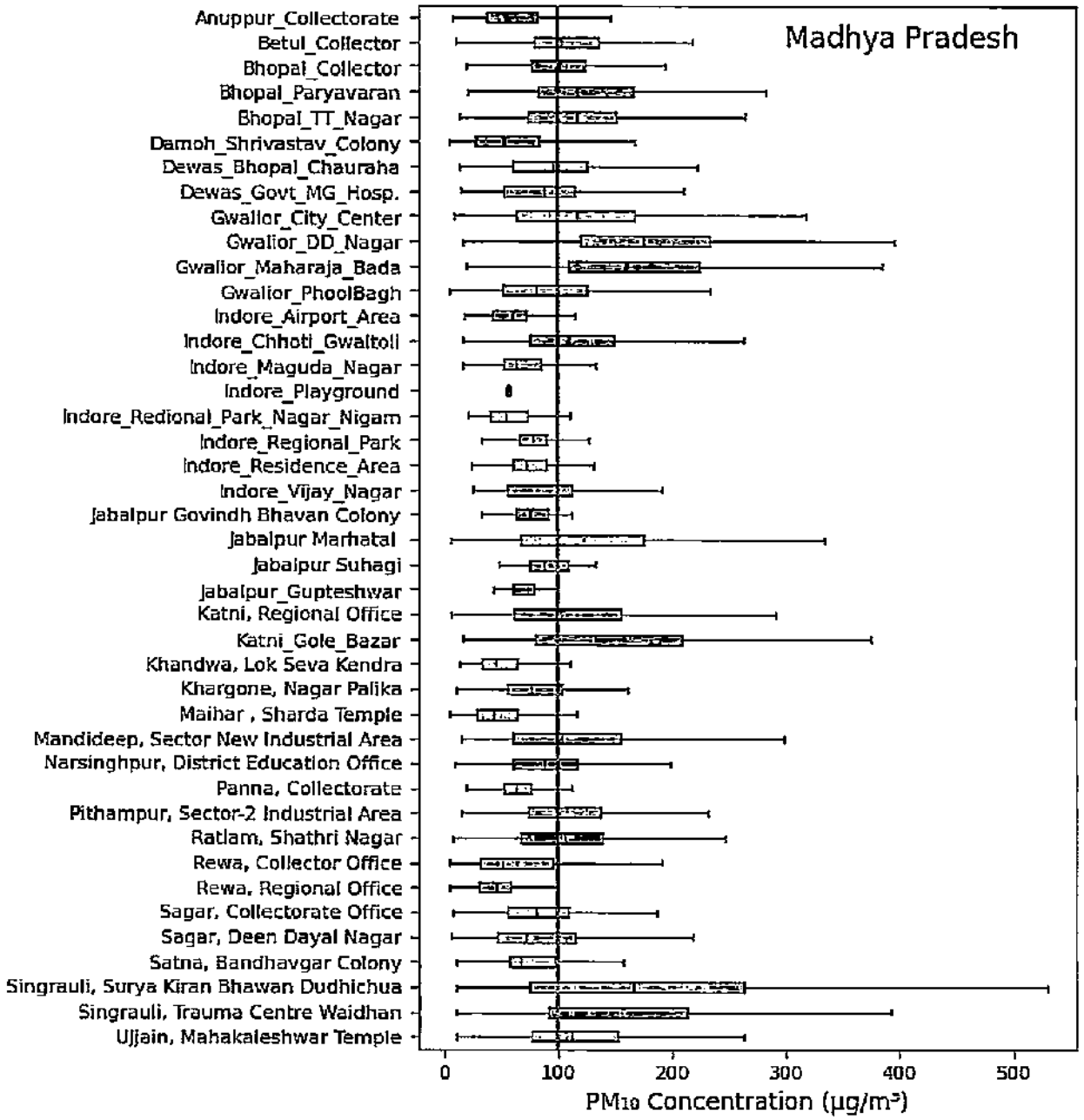

Manipur
DM_College_Imphal
Manipur_University
0
50
100
150
PM10 Concentration (µg/m³)

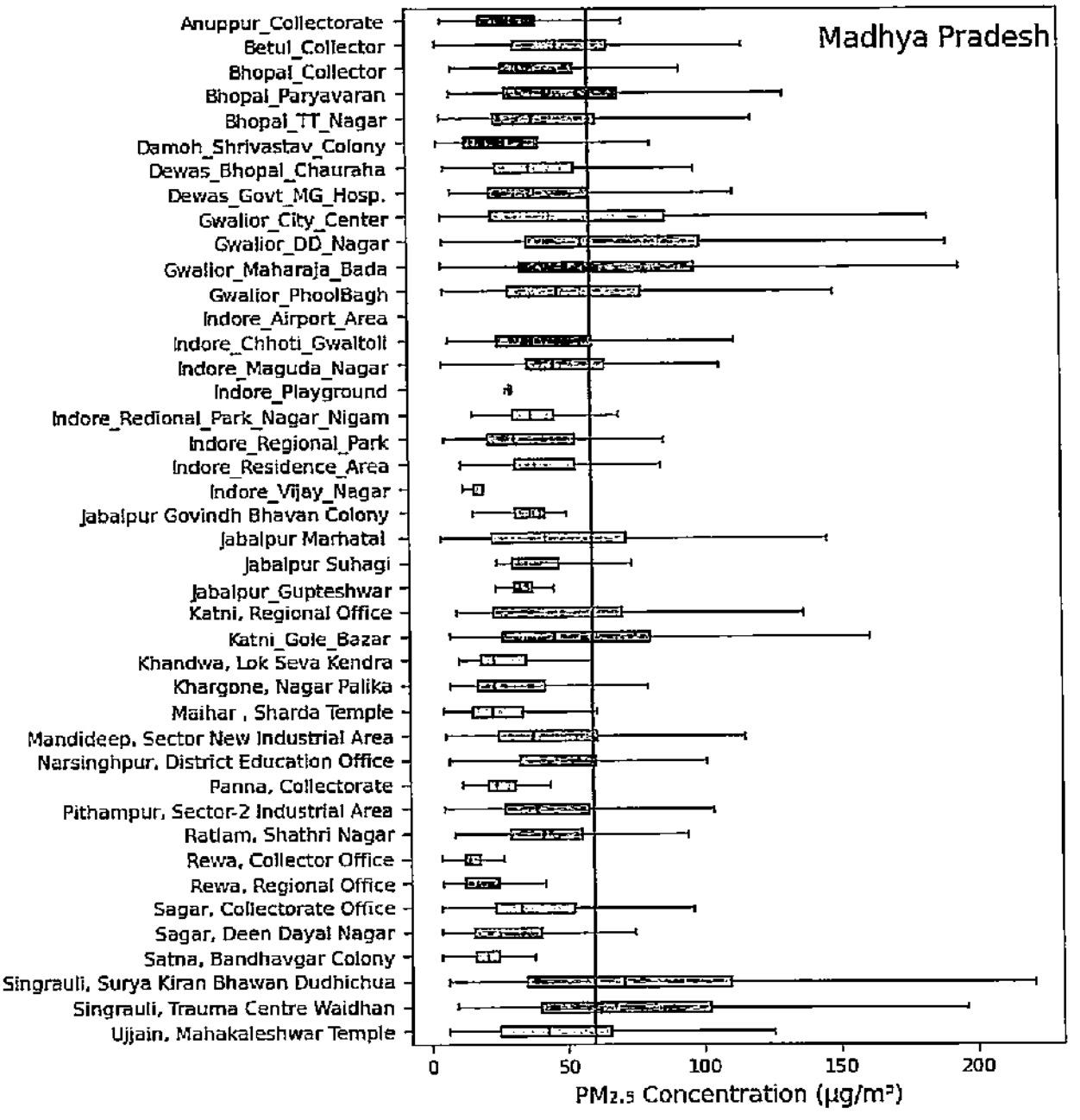

Manipur
DM_College_Imphal
Manipur_University
0
20
40
60
PM2.5 Concentration (µg/m³)

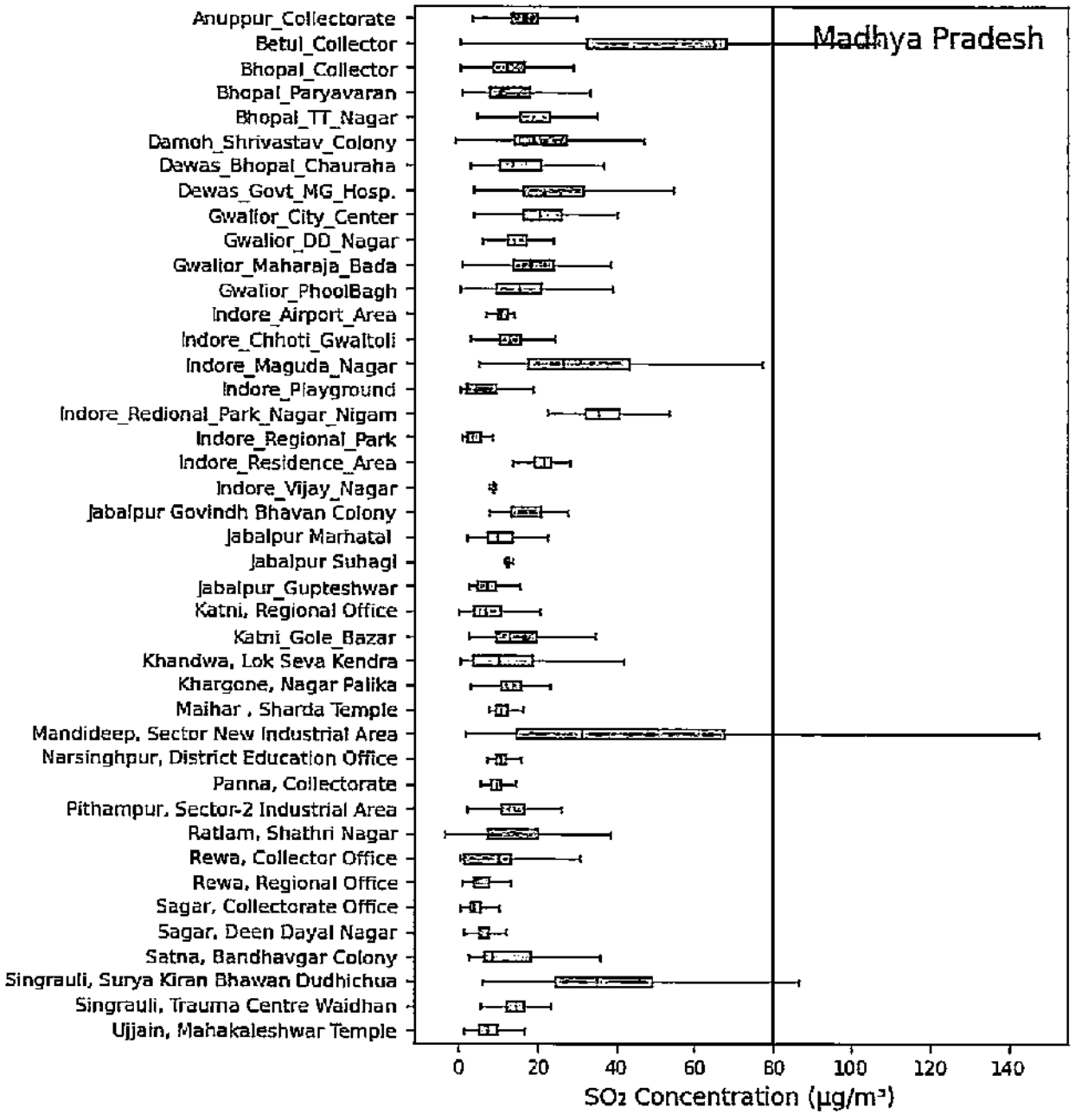

Manipur
DM_College_Imphal
Manipur_University
40
60
80
SO2 Concentration (µg/m³)

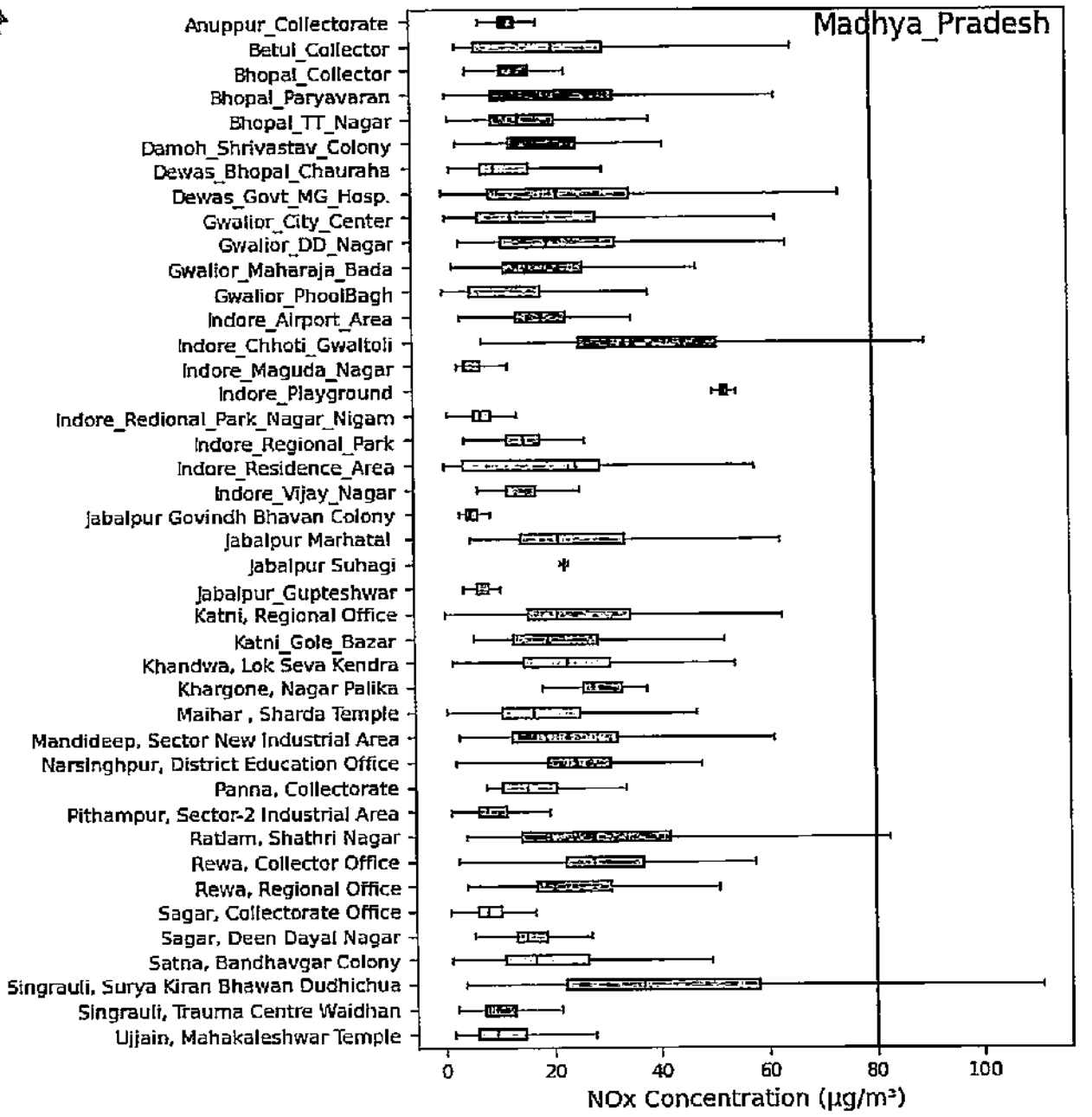

Manipur
DM_College_Imphal
Manipur_University
20
40
60
80
NO2 Concentration (µg/m³)

Madhya Pradesh

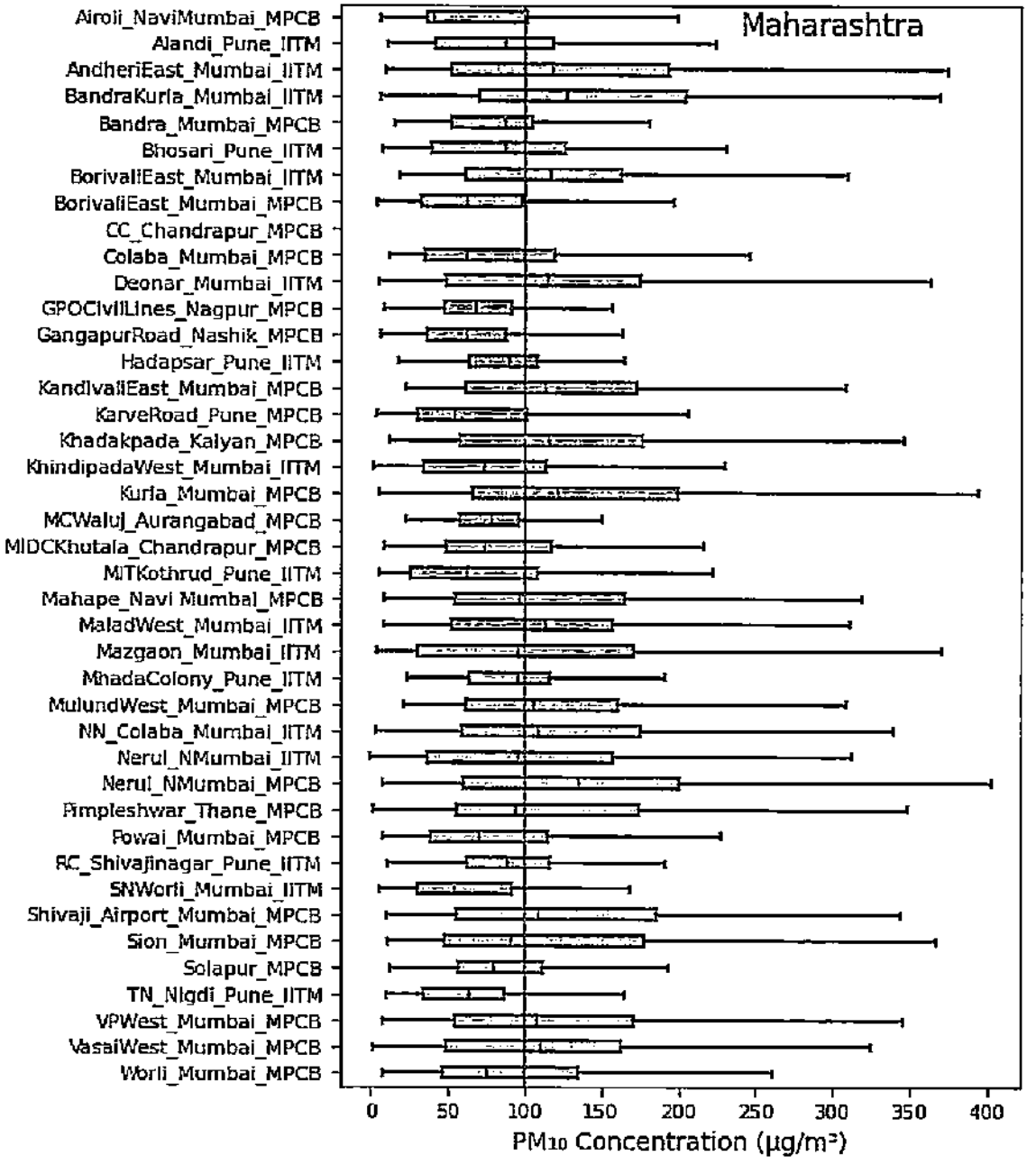


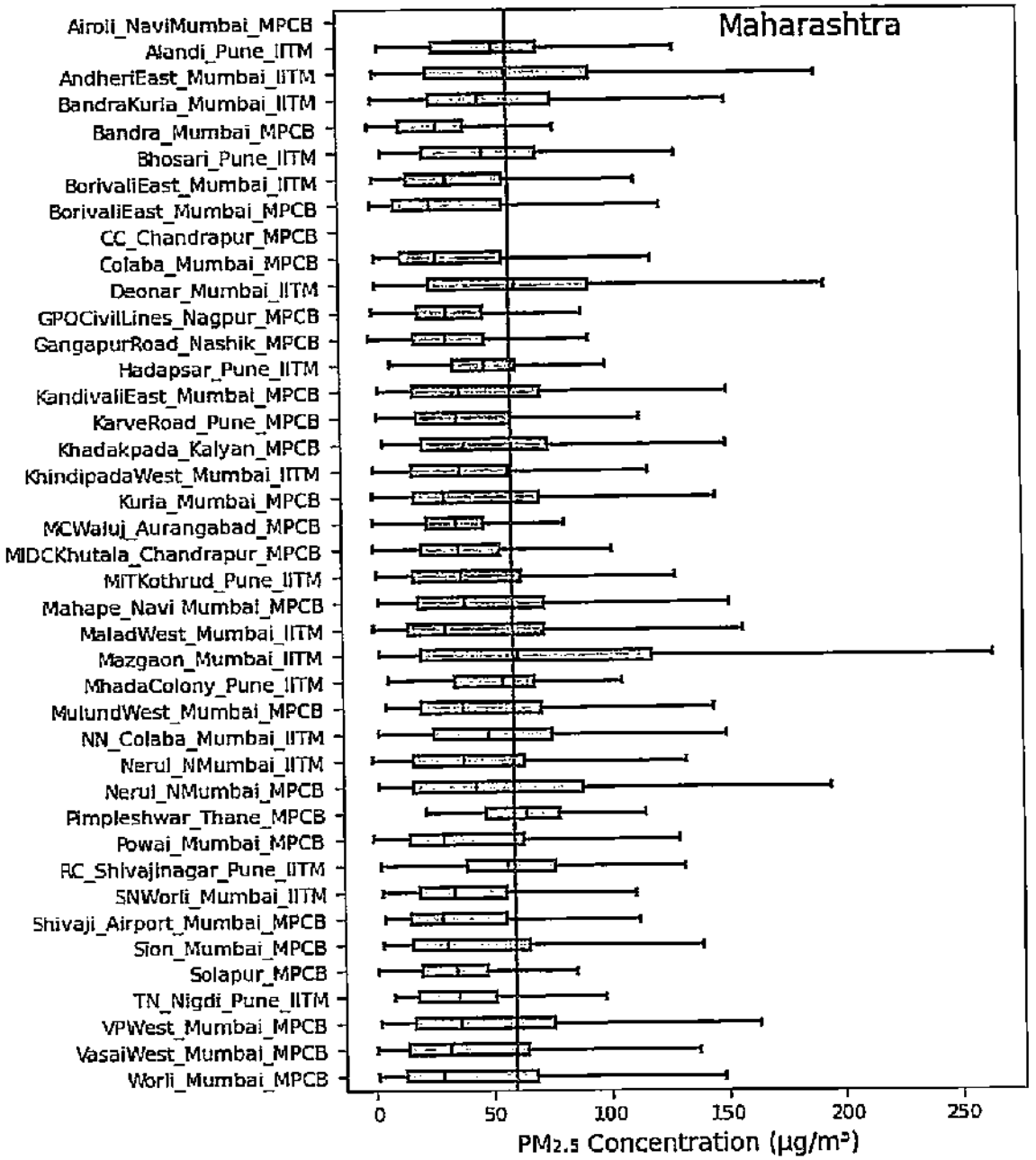

Madhya Pradesh
Anuppur_Collectorate
Betul_Collector
Bhopal_Collector
Bhopal_Paryavaran
Bhopal_TT_Nagar
Damoh_Shrivastav_Colony
Dewas_Bhopal_Chauraha
Dewas_Govt_MG_Hosp.
Gwalior_City_Center
Gwalior_DD_Nagar
Gwalior_Maharaja_Bada
Gwalior_PhoolBagh
Indore_Airport_Area
Indore_Chhoti_Gwaltoli
Indore_Maguda_Nagar
Indore_Playground
Indore_Redional_Park_Nagar_Nigam
Indore_Regional_Park
Indore_Residence_Area
Indore_Vijay_Nagar
Jabalpur Govindh Bhavan Colony
Jabalpur Marhatal
Jabalpur Suhagi
Jabalpur_Gupteshwar
Katni, Regional Office
Katni_Gole_Bazar
Khandwa, Lok Seva Kendra
Khargone, Nagar Palika
Maihar , Sharda Temple
Mandideep, Sector New Industrial Area
Narsinghpur, District Education Office
Panna, Collectorate
Pithampur, Sector-2 Industrial Area
Ratlam, Shathri Nagar
Rewa, Collector Office
Rewa, Regional Office
Sagar, Collectorate Office
Sagar, Deen Dayal Nagar
Satna, Bandhavgar Colony
Singrauli, Surya Kiran Bhawan Dudhichua
Singrauli, Trauma Centre Waidhan
Ujjain, Mahakaleshwar Temple
0
50
100
150
200
PM2.5 Concentration (µg/m³)

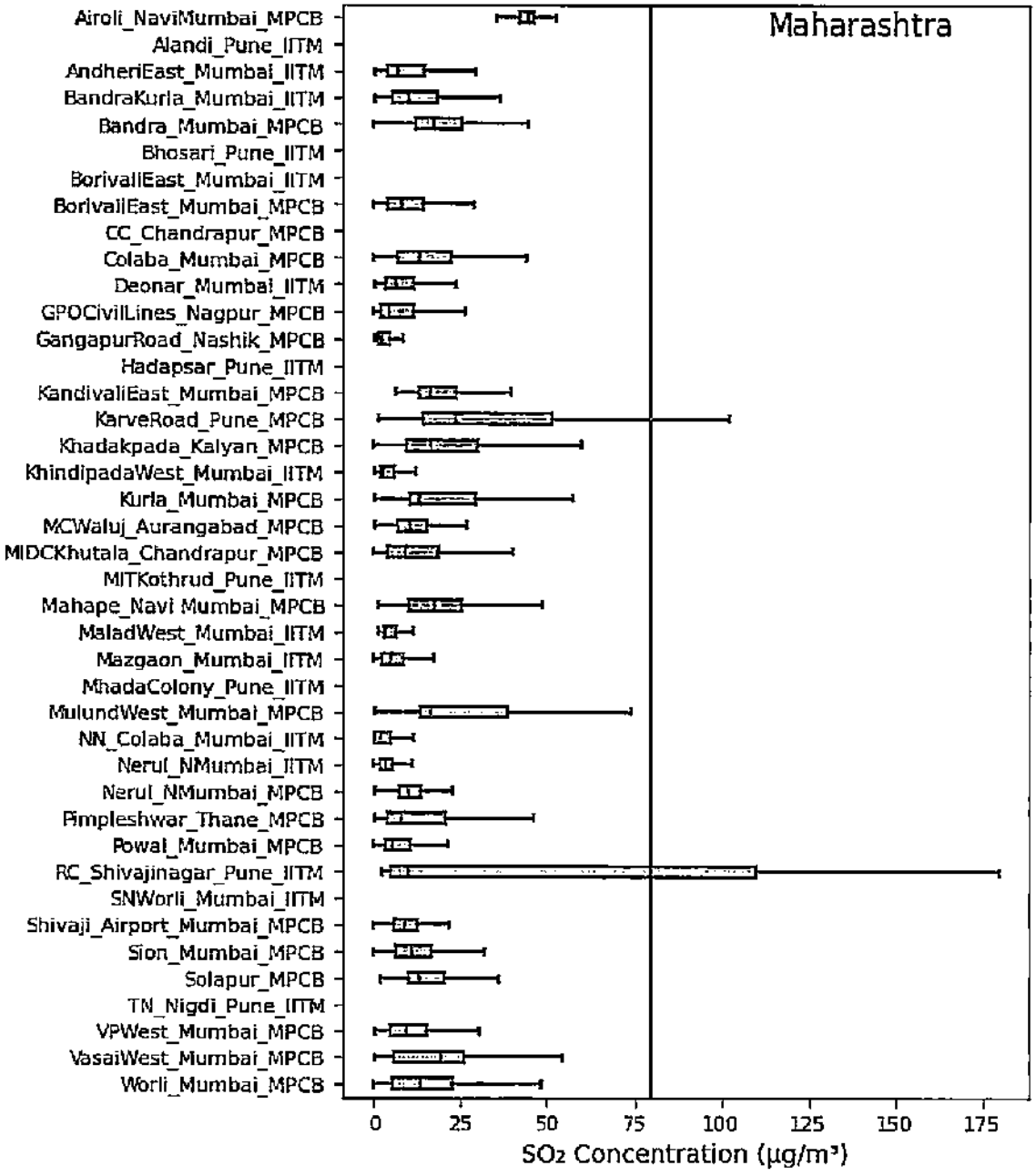

Madhya Pradesh
Anuppur_Collectorate
Betul_Collector
Bhopal_Collector
Bhopal_Paryavaran
Bhopal_TT_Nagar
Damoh_Shrivastav_Colony
Dewas_Bhopal_Chauraha
Dewas_Govt_MG_Hosp.
Gwalior_City_Center
Gwalior_DD_Nagar
Gwalior_Maharaja_Bada
Gwalior_PhoolBagh
Indore_Airport_Area
Indore_Chhoti_Gwaltoli
Indore_Maguda_Nagar
Indore_Playground
Indore_Redional_Park_Nagar_Nigam
Indore_Regional_Park
Indore_Residence_Area
Indore_Vijay_Nagar
Jabalpur Govindh Bhavan Colony
Jabalpur Marhatal
Jabalpur Suhagi
Jabalpur_Gupteshwar
Katni, Regional Office
Katni_Gole_Bazar
Khandwa, Lok Seva Kendra
Khargone, Nagar Palika
Maihar , Sharda Temple
Mandideep, Sector New Industrial Area
Narsinghpur, District Education Office
Panna, Collectorate
Pithampur, Sector-2 Industrial Area
Ratlam, Shathri Nagar
Rewa, Collector Office
Rewa, Regional Office
Sagar, Collectorate Office
Sagar, Deen Dayal Nagar
Satna, Bandhavgar Colony
Singrauli, Surya Kiran Bhawan Dudhichua
Singrauli, Trauma Centre Waidhan
Ujjain, Mahakaleshwar Temple
0
20
40
60
80
100
120
140
SO2 Concentration (µg/m³)

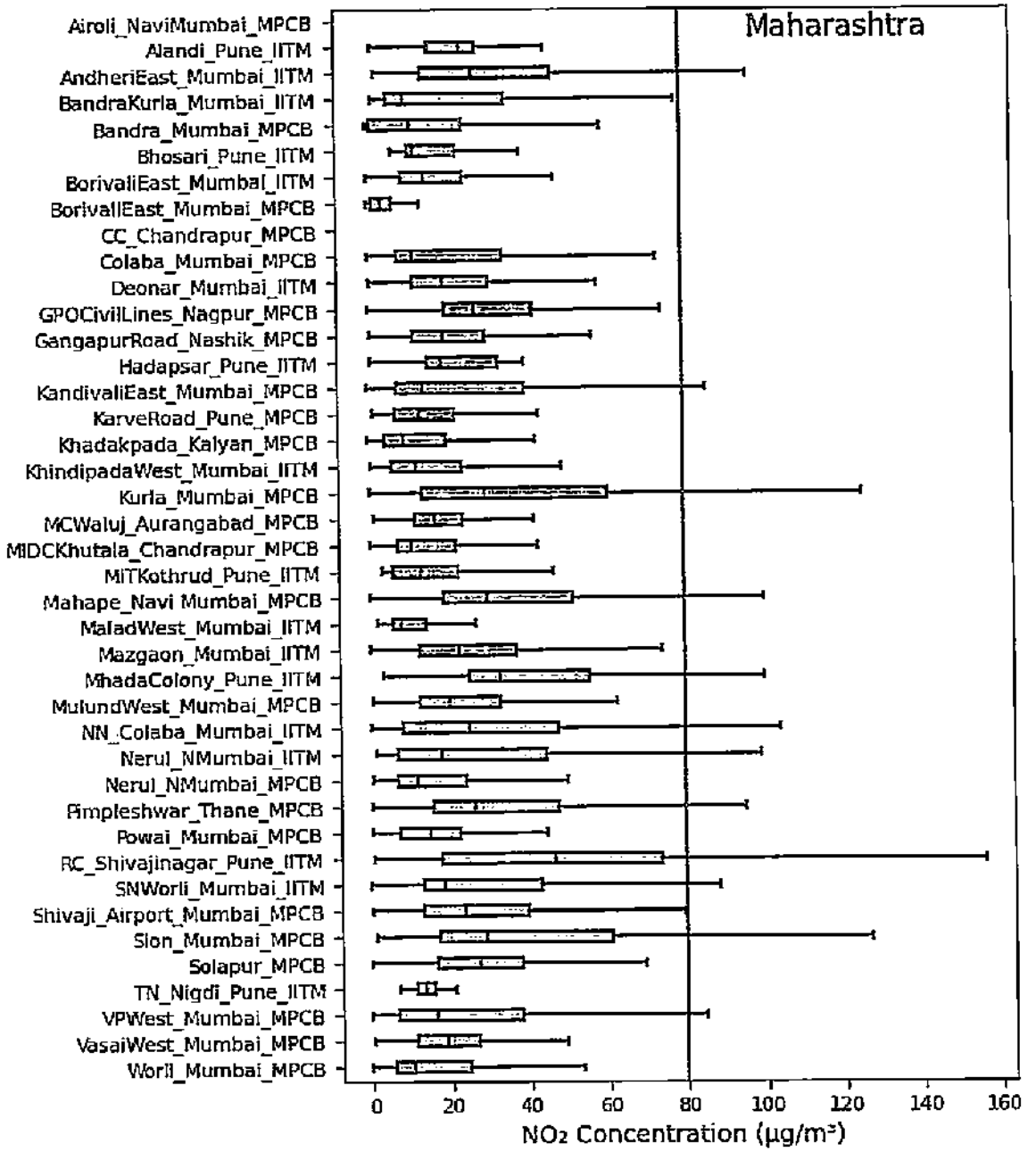

Madhya_Pradesh
Anuppur_Collectorate
Betul_Collector
Bhopal_Collector
Bhopal_Paryavaran
Bhopal_TT_Nagar
Damoh_Shrivastav_Colony
Dewas_Bhopal_Chauraha
Dewas_Govt_MG_Hosp.
Gwalior_City_Center
Gwalior_DD_Nagar
Gwalior_Maharaja_Bada
Gwalior_PhoolBagh
Indore_Airport_Area
Indore_Chhoti_Gwaltoli
Indore_Maguda_Nagar
Indore_Playground
Indore_Redional_Park_Nagar_Nigam
Indore_Regional_Park
Indore_Residence_Area
Indore_Vijay_Nagar
Jabalpur Govindh Bhavan Colony
Jabalpur Marhatal
Jabalpur Suhagi
Jabalpur_Gupteshwar
Katni, Regional Office
Katni_Gole_Bazar
Khandwa, Lok Seva Kendra
Khargone, Nagar Palika
Maihar , Sharda Temple
Mandideep, Sector New Industrial Area
Narsinghpur, District Education Office
Panna, Collectorate
Pithampur, Sector-2 Industrial Area
Ratlam, Shathri Nagar
Rewa, Collector Office
Rewa, Regional Office
Sagar, Collectorate Office
Sagar, Deen Dayal Nagar
Satna, Bandhavgar Colony
Singrauli, Surya Kiran Bhawan Dudhichua
Singrauli, Trauma Centre Waidhan
Ujjain, Mahakaleshwar Temple
0
20
40
60
80
100
NOx Concentration (µg/m³)

Maharashtra

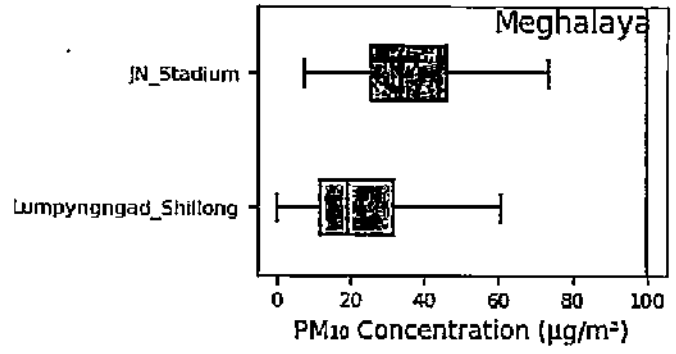


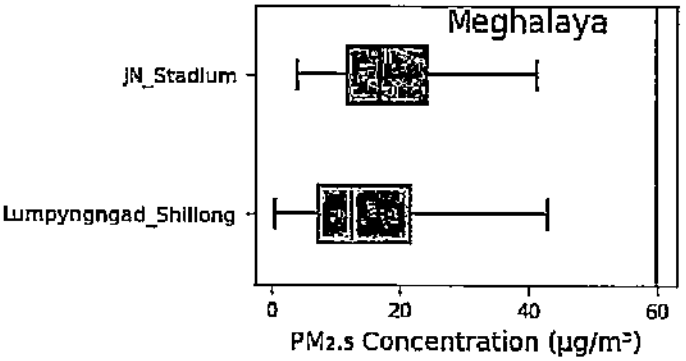

Maharashtra
Airoli_NaviMumbai_MPCB
Alandi_Pune_IITM
AndheriEast_Mumbai_IITM
BandraKurla_Mumbai_IITM
Bandra_Mumbai_MPCB
Bhosari_Pune_IITM
BorivaliEast_Mumbai_IITM
BorivaliEast_Mumbai_MPCB
CC_Chandrapur_MPCB
Colaba_Mumbai_MPCB
Deonar_Mumbai_IITM
GPOCivilLines_Nagpur_MPCB
GangapurRoad_Nashik_MPCB
Hadapsar_Pune_IITM
KandivaliEast_Mumbai_MPCB
KarveRoad_Pune_MPCB
Khadakpada_Kalyan_MPCB
KhindipadaWest_Mumbai_IITM
Kurla_Mumbai_MPCB
MCWaluj_Aurangabad_MPCB
MIDCKhutala_Chandrapur_MPCB
MITKothrud_Pune_IITM
Mahape_Navi Mumbai_MPCB
MaladWest_Mumbai_IITM
Mazgaon_Mumbai_IITM
MhadaColony_Pune_IITM
MulundWest_Mumbai_MPCB
NN_Colaba_Mumbai_IITM
Nerul_NMumbai_IITM
Nerul_NMumbai_MPCB
Pimpleshwar_Thane_MPCB
Powai_Mumbai_MPCB
RC_Shivajinagar_Pune_IITM
SNWorli_Mumbai_IITM
Shivaji_Airport_Mumbai_MPCB
Sion_Mumbai_MPCB
Solapur_MPCB
TN_Nigdi_Pune_IITM
VPWest_Mumbai_MPCB
VasaiWest_Mumbai_MPCB
Worli_Mumbai_MPCB
0
50
100
150
200
250
PM2.5 Concentration (µg/m³)

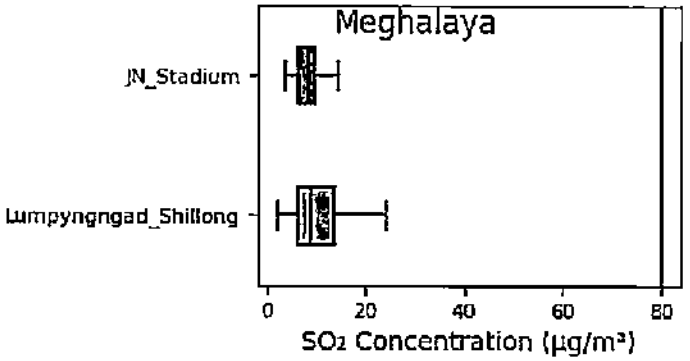

Maharashtra
Airoli_NaviMumbai_MPCB
Alandi_Pune_IITM
AndheriEast_Mumbai_IITM
BandraKurla_Mumbai_IITM
Bandra_Mumbai_MPCB
Bhosari_Pune_IITM
BorivaliEast_Mumbai_IITM
BorivaliEast_Mumbai_MPCB
CC_Chandrapur_MPCB
Colaba_Mumbai_MPCB
Deonar_Mumbai_IITM
GPOCivilLines_Nagpur_MPCB
GangapurRoad_Nashik_MPCB
Hadapsar_Pune_IITM
KandivaliEast_Mumbai_MPCB
KarveRoad_Pune_MPCB
Khadakpada_Kalyan_MPCB
KhindipadaWest_Mumbai_IITM
Kurla_Mumbai_MPCB
MCWaluj_Aurangabad_MPCB
MIDCKhutala_Chandrapur_MPCB
MITKothrud_Pune_IITM
Mahape_Navi Mumbai_MPCB
MaladWest_Mumbai_IITM
Mazgaon_Mumbai_IITM
MhadaColony_Pune_IITM
MulundWest_Mumbai_MPCB
NN_Colaba_Mumbai_IITM
Nerul_NMumbai_IITM
Nerul_NMumbai_MPCB
Pimpleshwar_Thane_MPCB
Powai_Mumbai_MPCB
RC_Shivajinagar_Pune_IITM
SNWorli_Mumbai_IITM
Shivaji_Airport_Mumbai_MPCB
Sion_Mumbai_MPCB
Solapur_MPCB
TN_Nigdi_Pune_IITM
VPWest_Mumbai_MPCB
VasaiWest_Mumbai_MPCB
Worli_Mumbai_MPCB
0
25
50
75
100
125
150
175
SO2 Concentration (µg/m³)

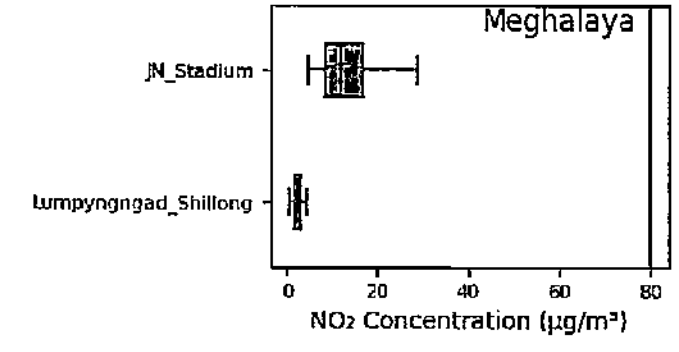

Maharashtra
Airoli_NaviMumbai_MPCB
Alandi_Pune_IITM
AndheriEast_Mumbai_IITM
BandraKurla_Mumbai_IITM
Bandra_Mumbai_MPCB
Bhosari_Pune_IITM
BorivaliEast_Mumbai_IITM
BorivaliEast_Mumbai_MPCB
CC_Chandrapur_MPCB
Colaba_Mumbai_MPCB
Deonar_Mumbai_IITM
GPOCivilLines_Nagpur_MPCB
GangapurRoad_Nashik_MPCB
Hadapsar_Pune_IITM
KandivaliEast_Mumbai_MPCB
KarveRoad_Pune_MPCB
Khadakpada_Kalyan_MPCB
KhindipadaWest_Mumbai_IITM
Kurla_Mumbai_MPCB
MCWaluj_Aurangabad_MPCB
MIDCKhutala_Chandrapur_MPCB
MITKothrud_Pune_IITM
Mahape_Navi Mumbai_MPCB
MaladWest_Mumbai_IITM
Mazgaon_Mumbai_IITM
MhadaColony_Pune_IITM
MulundWest_Mumbai_MPCB
NN_Colaba_Mumbai_IITM
Nerul_NMumbai_IITM
Nerul_NMumbai_MPCB
Pimpleshwar_Thane_MPCB
Powai_Mumbai_MPCB
RC_Shivajinagar_Pune_IITM
SNWorli_Mumbai_IITM
Shivaji_Airport_Mumbai_MPCB
Sion_Mumbai_MPCB
Solapur_MPCB
TN_Nigdi_Pune_IITM
VPWest_Mumbai_MPCB
VasaiWest_Mumbai_MPCB
Worli_Mumbai_MPCB
0
20
40
60
80
100
120
140
160
NO2 Concentration (µg/m³)

Meghalaya

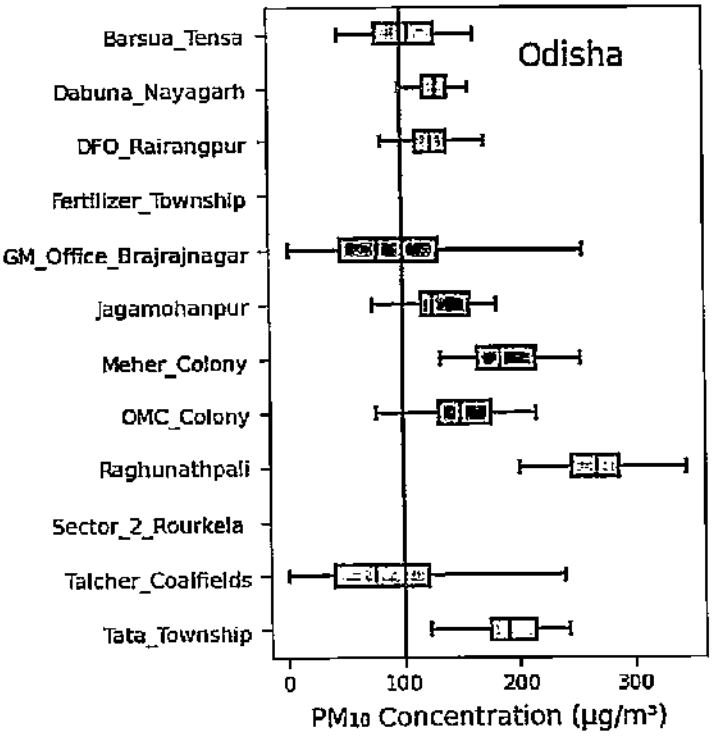

Meghalaya
JN_Stadium
Lumpyngngad_Shillong
0
20
40
60
80
100
PM10 Concentration (µg/m³)

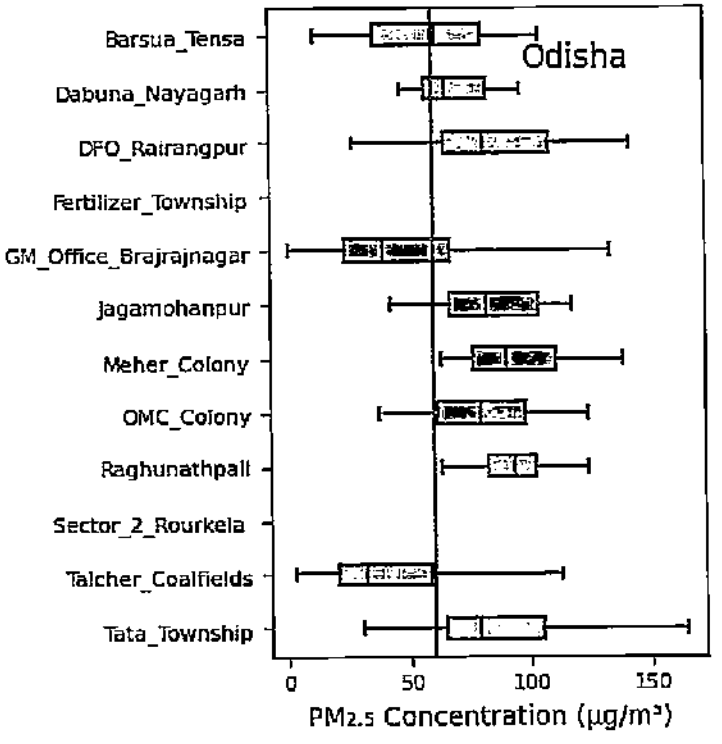

Meghalaya
JN_Stadium
Lumpyngngad_Shillong
0
20
40
60
PM2.5 Concentration (µg/m³)

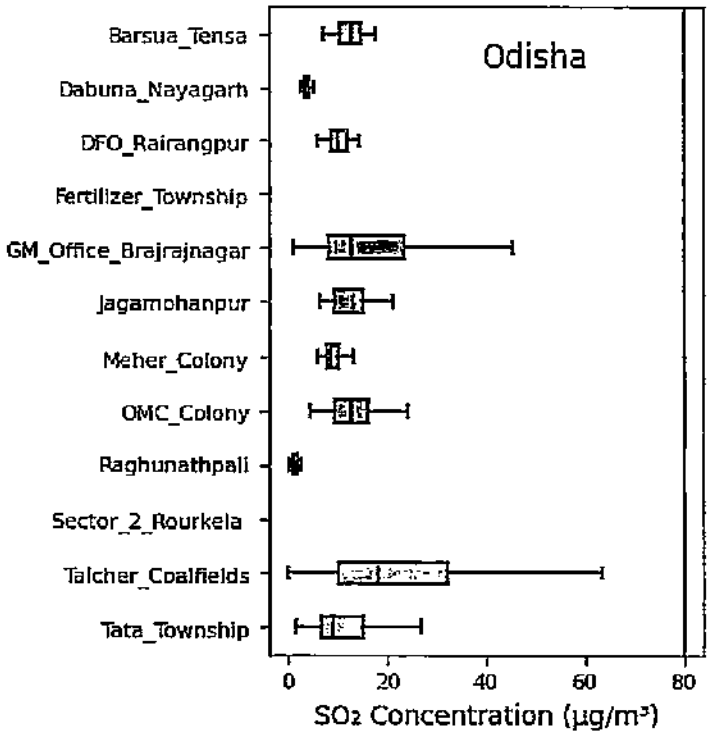

Meghalaya
JN_Stadium
Lumpyngngad_Shillong
0
20
40
60
80
SO2 Concentration (µg/m³)

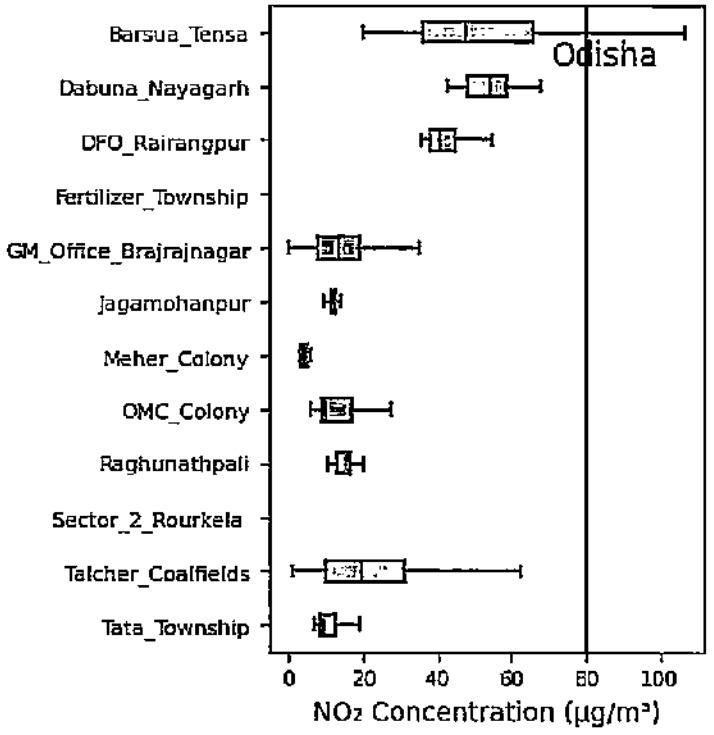

Meghalaya
JN_Stadium
Lumpyngngad_Shillong
0
20
40
60
80
NO2 Concentration (µg/m³)

Odisha

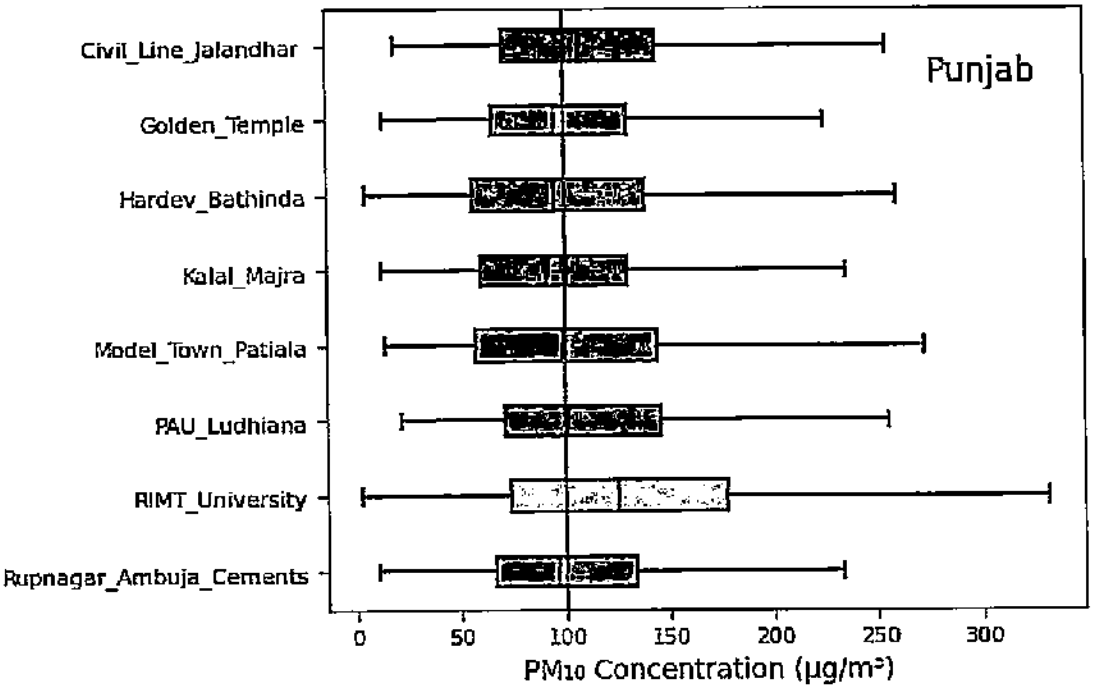

Odisha
Barsua_Tensa
Dabuna_Nayagarh
DFO_Rairangpur
Fertilizer_Township
GM_Office_Brajrajnagar
Jagamohanpur
Meher_Colony
OMC_Colony
Raghunathpali
Sector_2_Rourkela
Talcher_Coalfields
Tata_Township
0
100
200
300
PM10 Concentration (µg/m³)

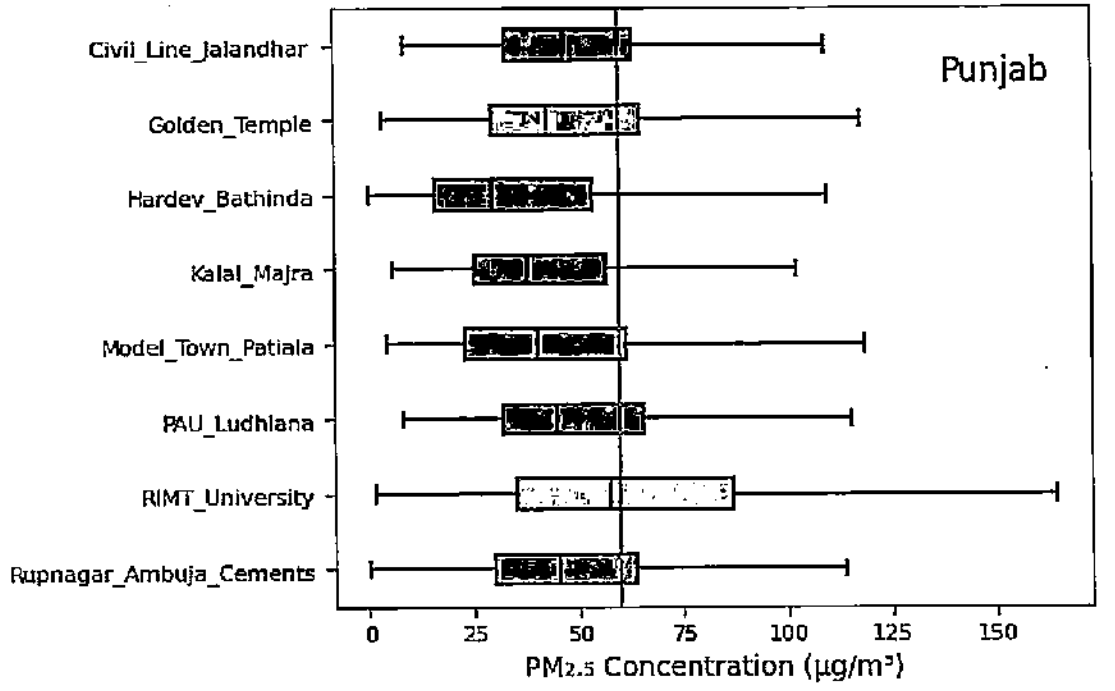

Odisha
Barsua_Tensa
Dabuna_Nayagarh
DFO_Rairangpur
Fertilizer_Township
GM_Office_Brajrajnagar
Jagamohanpur
Meher_Colony
OMC_Colony
Raghunathpali
Sector_2_Rourkela
Talcher_Coalfields
Tata_Township
0
50
100
150
PM2.5 Concentration (µg/m³)

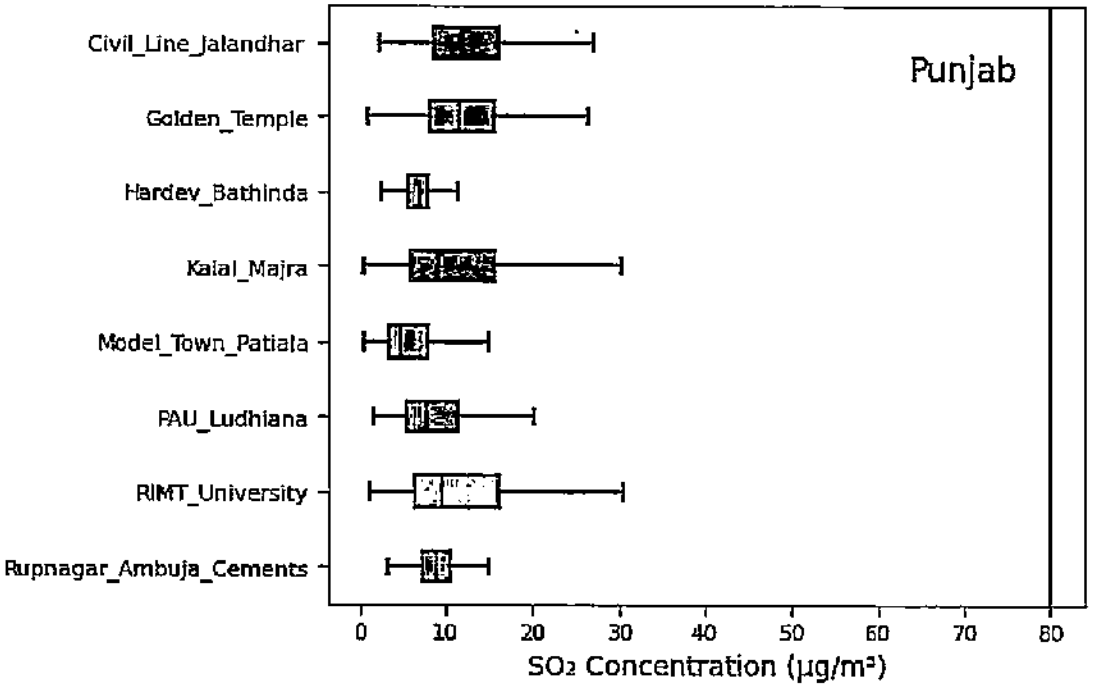

Odisha
Barsua_Tensa
Dabuna_Nayagarh
DFO_Rairangpur
Fertilizer_Township
GM_Office_Brajrajnagar
Jagamohanpur
Meher_Colony
OMC_Colony
Raghunathpali
Sector_2_Rourkela
Talcher_Coalfields
Tata_Township
0
20
40
60
80
SO₂ Concentration (µg/m³)

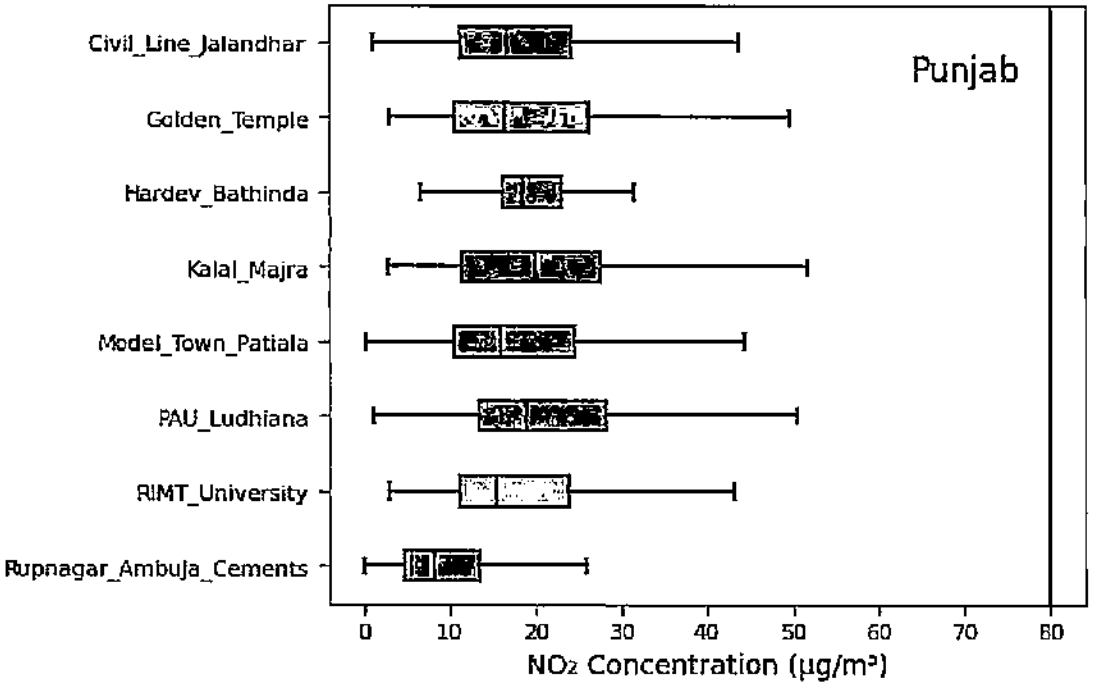

Odisha
Barsua_Tensa
Dabuna_Nayagarh
DFO_Rairangpur
Fertilizer_Township
GM_Office_Brajrajnagar
Jagamohanpur
Meher_Colony
OMC_Colony
Raghunathpali
Sector_2_Rourkela
Talcher_Coalfields
Tata_Township
0
20
40
60
80
100
NO₂ Concentration (µg/m³)

Punjab

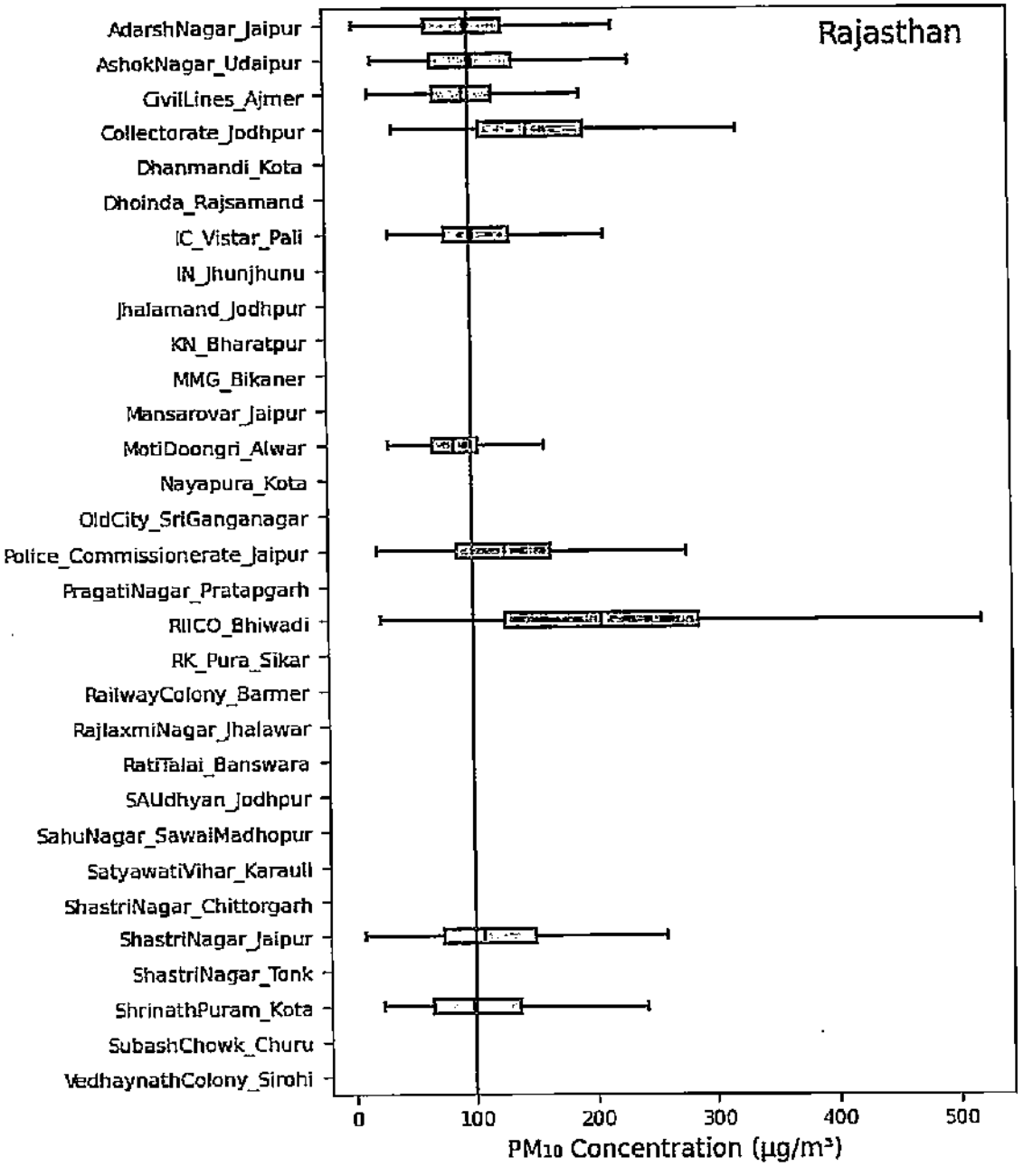

Civil_Line_Jalandhar
Golden_Temple
Hardev_Bathinda
Kalal_Majra
Model_Town_Patiala
PAU_Ludhiana
RIMT_University
Rupnagar_Ambuja_Cements
Punjab
0
50
100
150
200
250
300
PM10 Concentration (µg/m³)

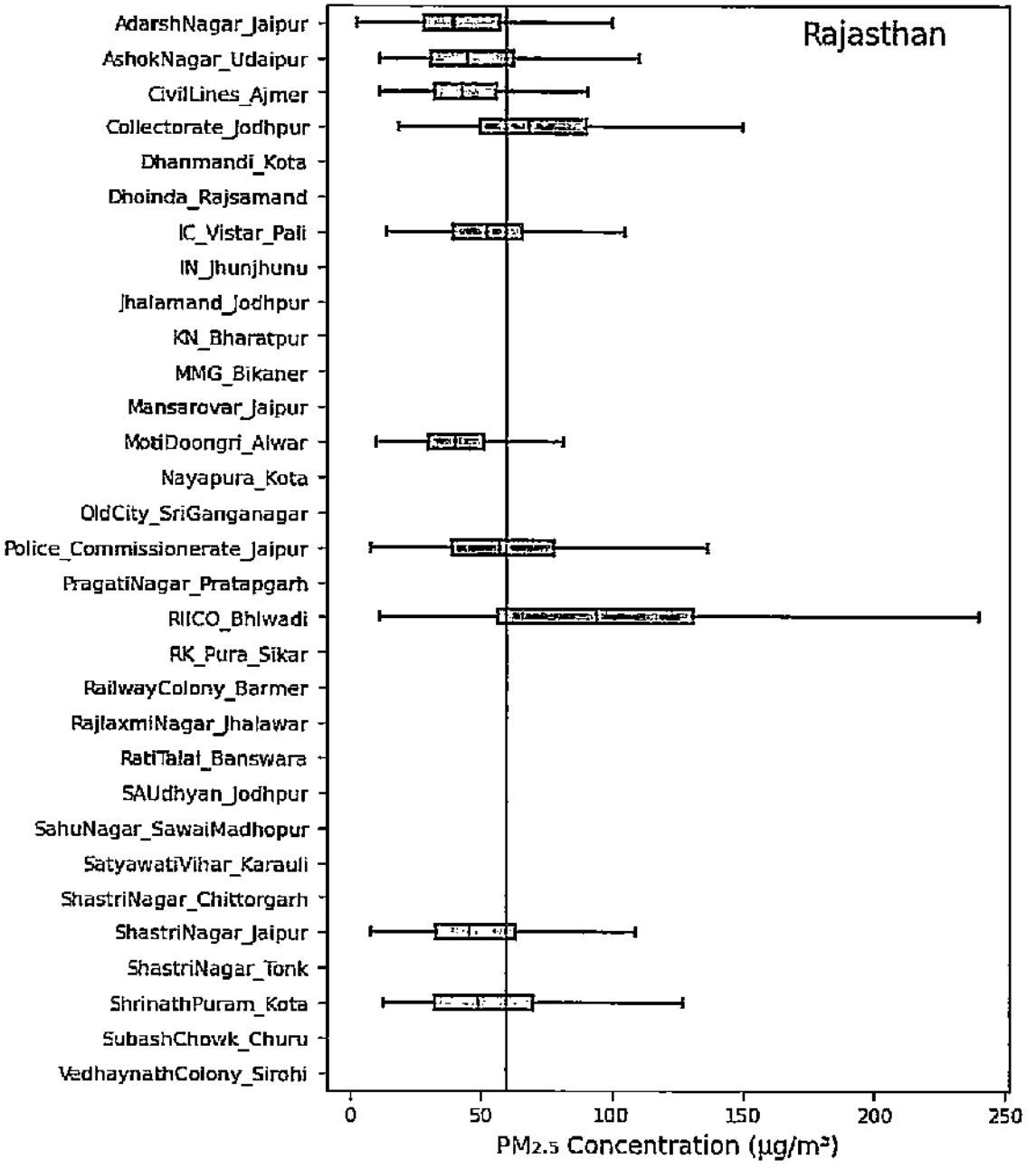

Civil_Line_Jalandhar
Golden_Temple
Hardev_Bathinda
Kalal_Majra
Model_Town_Patiala
PAU_Ludhiana
RIMT_University
Rupnagar_Ambuja_Cements
Punjab
0
25
50
75
100
125
150
PM2.5 Concentration (µg/m³)

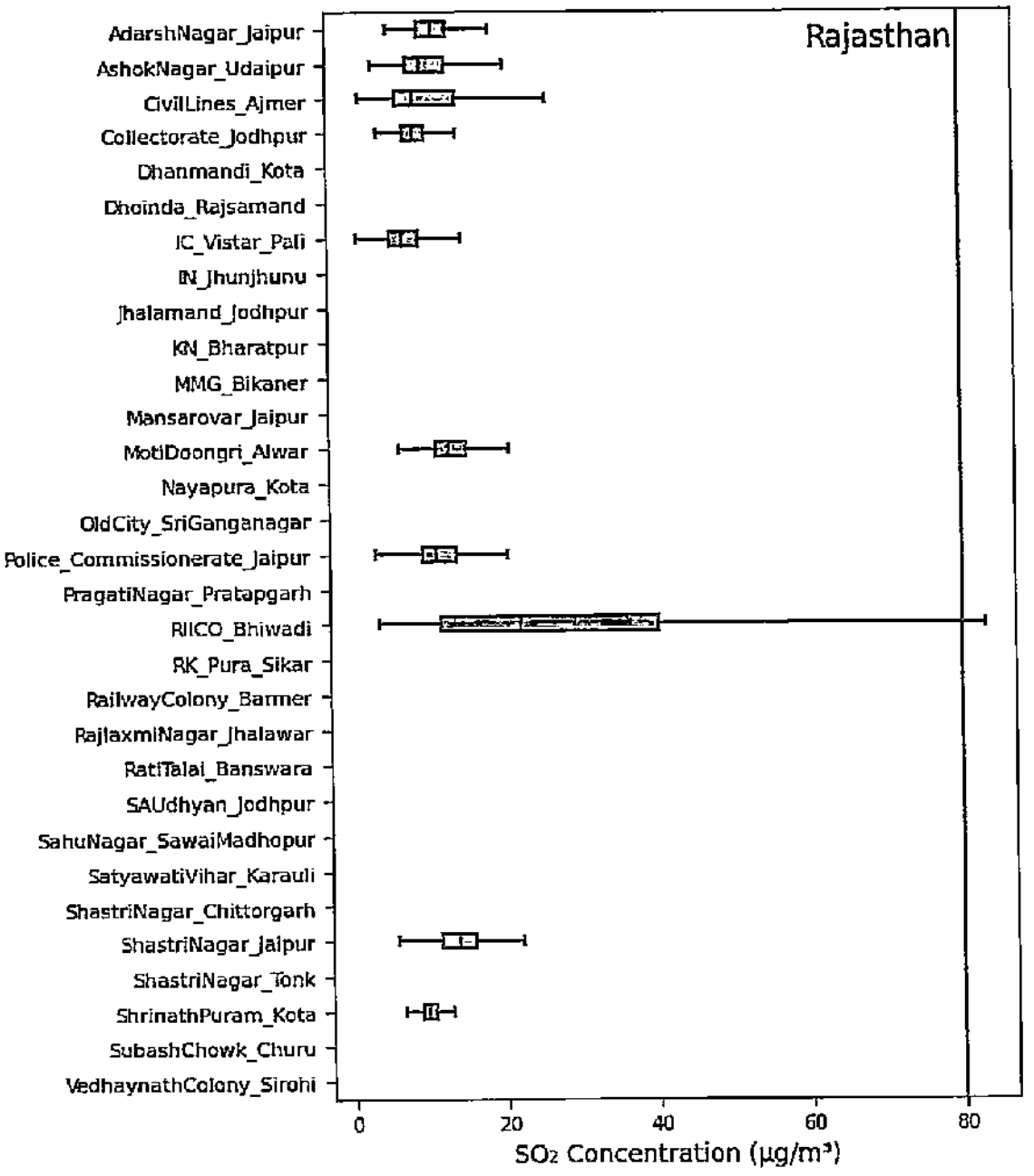

Punjab
Civil_Line_Jalandhar
Golden_Temple
Hardev_Bathinda
Kalal_Majra
Model_Town_Patiala
PAU_Ludhiana
RIMT_University
Rupnagar_Ambuja_Cements
0
10
20
30
40
50
60
70
80
SO₂ Concentration (µg/m³)

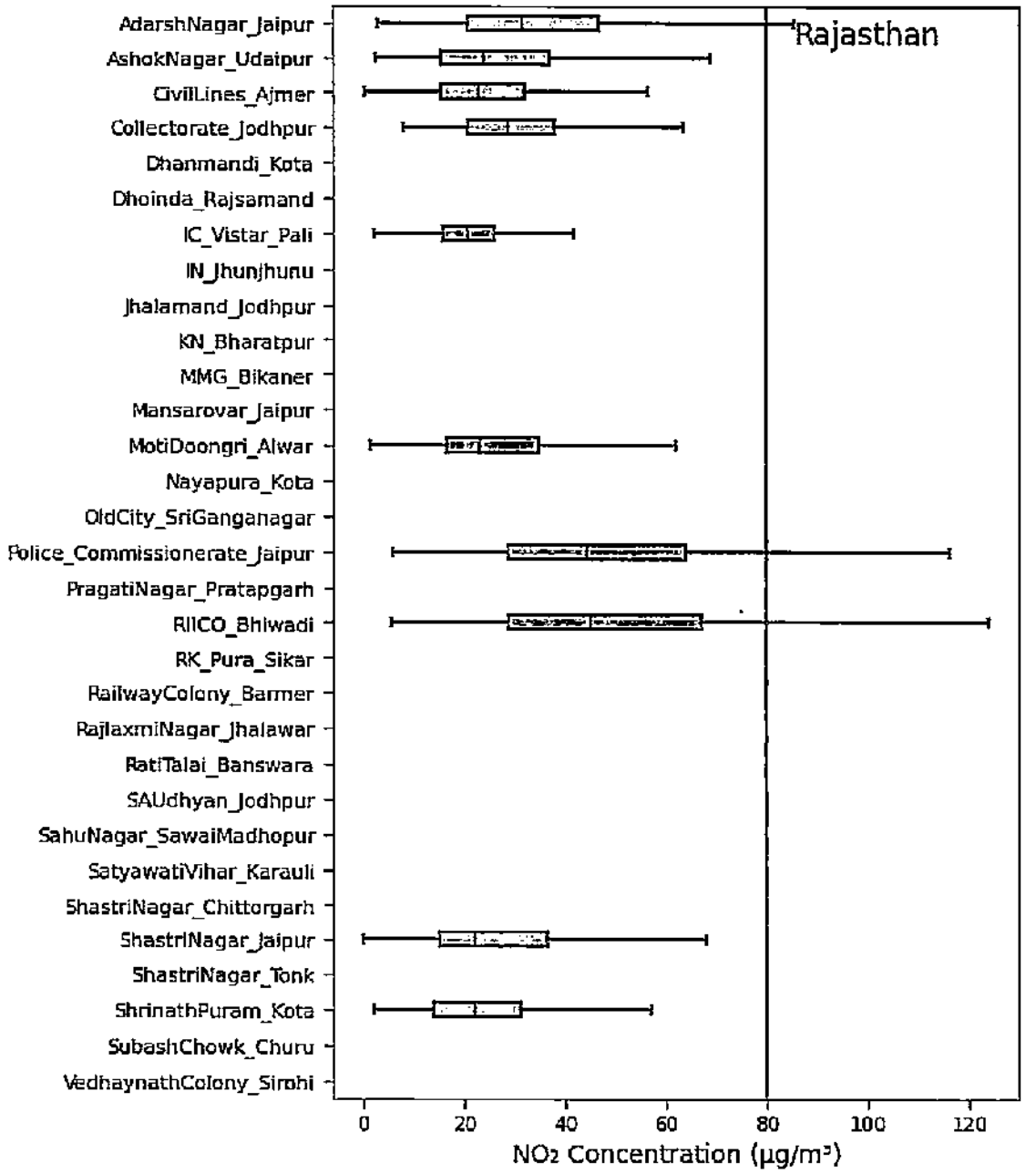

Punjab
Civil_Line_Jalandhar
Golden_Temple
Hardev_Bathinda
Kalal_Majra
Model_Town_Patiala
PAU_Ludhiana
RIMT_University
Rupnagar_Ambuja_Cements
0
10
20
30
40
50
60
70
80
NO₂ Concentration (µg/m³)

Rajasthan

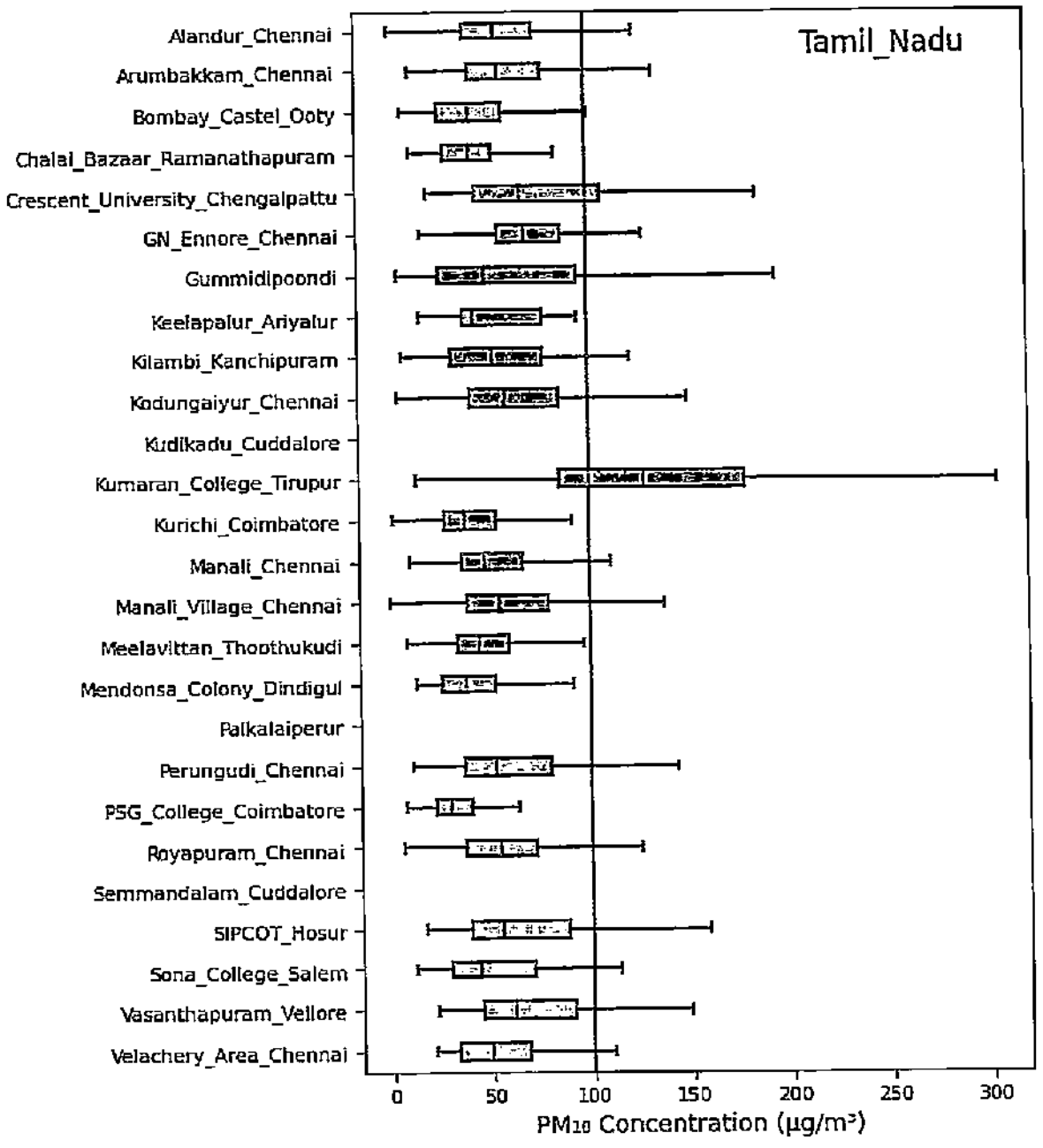

Rajasthan
AdarshNagar_Jaipur
AshokNagar_Udaipur
CivilLines_Ajmer
Collectorate_Jodhpur
Dhanmandi_Kota
Dhoinda_Rajsamand
IC_Vistar_Pali
IN_Jhunjhunu
Jhalamand_Jodhpur
KN_Bharatpur
MMG_Bikaner
Mansarovar_Jaipur
MotiDoongri_Alwar
Nayapura_Kota
OldCity_SriGanganagar
Police_Commissionerate_Jaipur
PragatiNagar_Pratapgarh
RIICO_Bhiwadi
RK_Pura_Sikar
RailwayColony_Barmer
RajlaxmiNagar_Jhalawar
RatiTalai_Banswara
SAUdhyan_Jodhpur
SahuNagar_SawaiMadhopur
SatyawatiVihar_Karauli
ShastriNagar_Chittorgarh
ShastriNagar_Jaipur
ShastriNagar_Tonk
ShrinathPuram_Kota
SubashChowk_Churu
VedhaynathColony_Sirohi
0
100
200
300
400
500
PM10 Concentration (µg/m³)

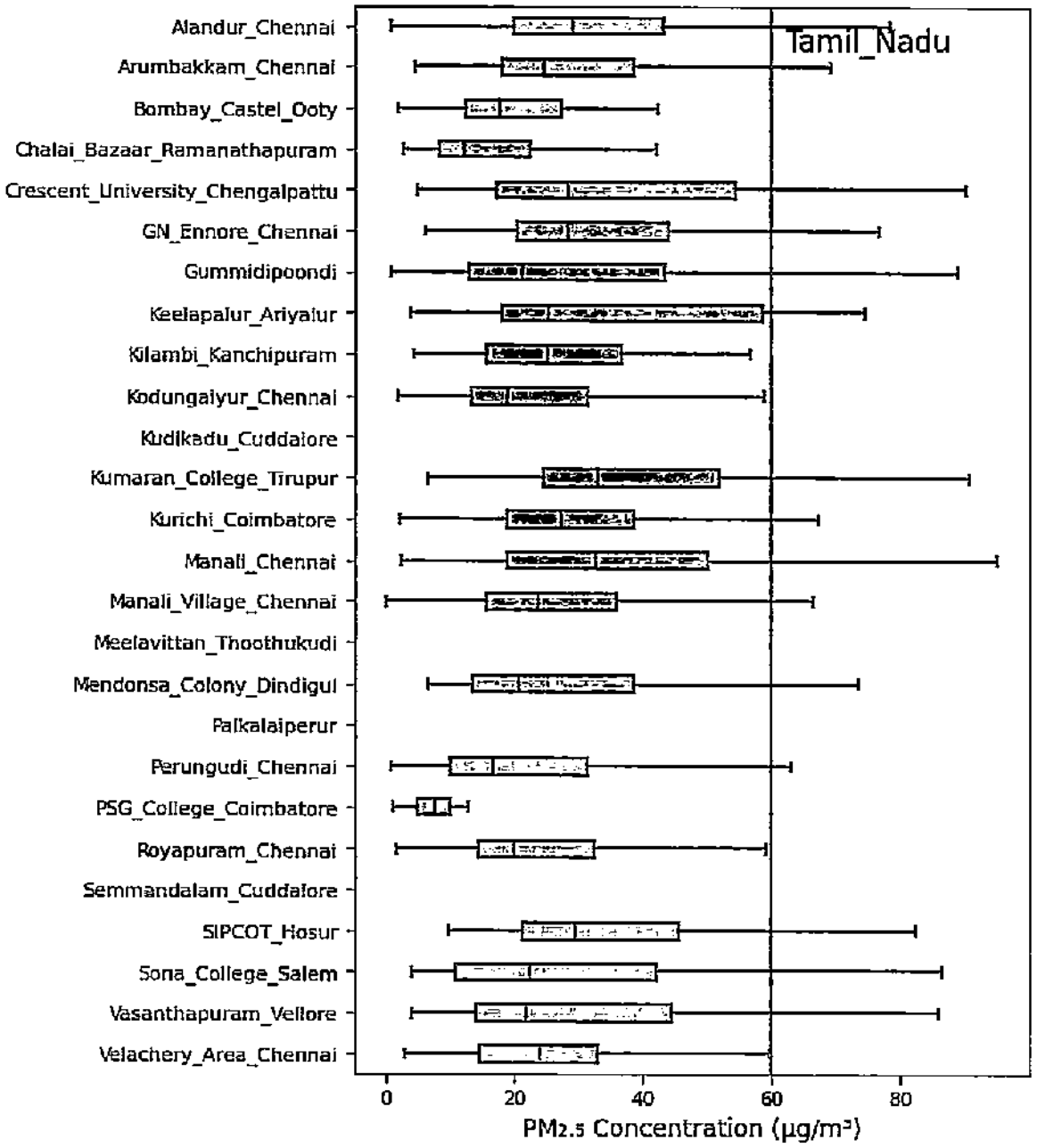

Rajasthan
AdarshNagar_Jaipur
AshokNagar_Udaipur
CivilLines_Ajmer
Collectorate_Jodhpur
Dhanmandi_Kota
Dhoinda_Rajsamand
IC_Vistar_Pali
IN_Jhunjhunu
Jhalamand_Jodhpur
KN_Bharatpur
MMG_Bikaner
Mansarovar_Jaipur
MotiDoongri_Alwar
Nayapura_Kota
OldCity_SriGanganagar
Police_Commissionerate_Jaipur
PragatiNagar_Pratapgarh
RIICO_Bhiwadi
RK_Pura_Sikar
RailwayColony_Barmer
RajlaxmiNagar_Jhalawar
RatiTalai_Banswara
SAUdhyan_Jodhpur
SahuNagar_SawaiMadhopur
SatyawatiVihar_Karauli
ShastriNagar_Chittorgarh
ShastriNagar_Jaipur
ShastriNagar_Tonk
ShrinathPuram_Kota
SubashChowk_Churu
VedhaynathColony_Sirohi
0
50
100
150
200
250
PM2.5 Concentration (µg/m³)

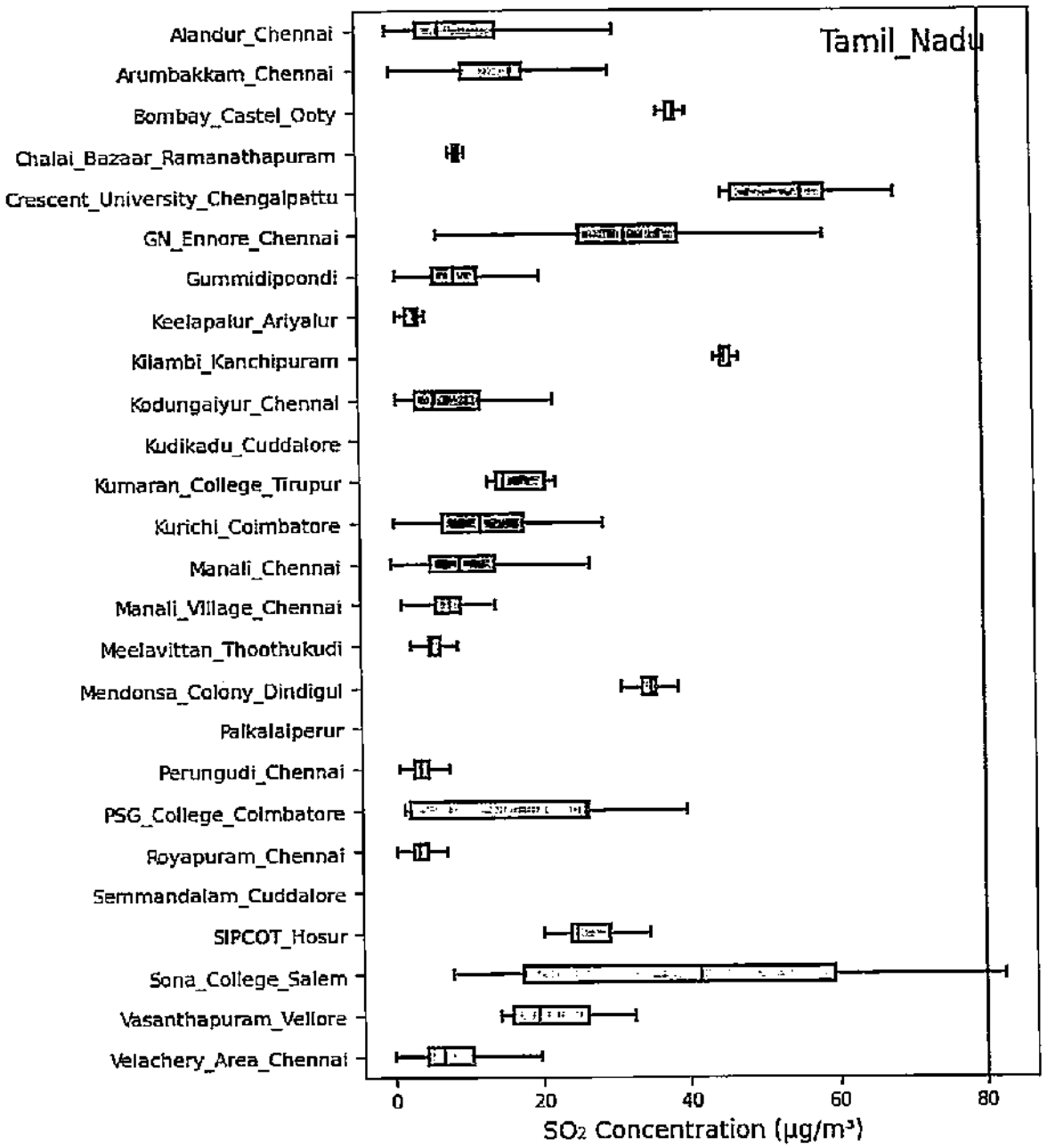

Rajasthan
AdarshNagar_Jaipur
AshokNagar_Udaipur
CivilLines_Ajmer
Collectorate_Jodhpur
Dhanmandi_Kota
Dholnda_Rajsamand
IC_Vistar_Pali
IN_Jhunjhunu
Jhalamand_Jodhpur
KN_Bharatpur
MMG_Bikaner
Mansarovar_Jaipur
MotiDoongri_Alwar
Nayapura_Kota
OldCity_SriGanganagar
Police_Commissionerate_Jaipur
PragatiNagar_Pratapgarh
RIICO_Bhiwadi
RK_Pura_Sikar
RailwayColony_Barmer
RajlaxmiNagar_Jhalawar
RatiTalai_Banswara
SAUdhyan_Jodhpur
SahuNagar_SawaiMadhopur
SatyawatiVihar_Karauli
ShastriNagar_Chittorgarh
ShastriNagar_Jaipur
ShastriNagar_Tonk
ShrinathPuram_Kota
SubashChowk_Churu
VedhaynathColony_Sirohi
0
20
40
60
80
SO2 Concentration (µg/m3)

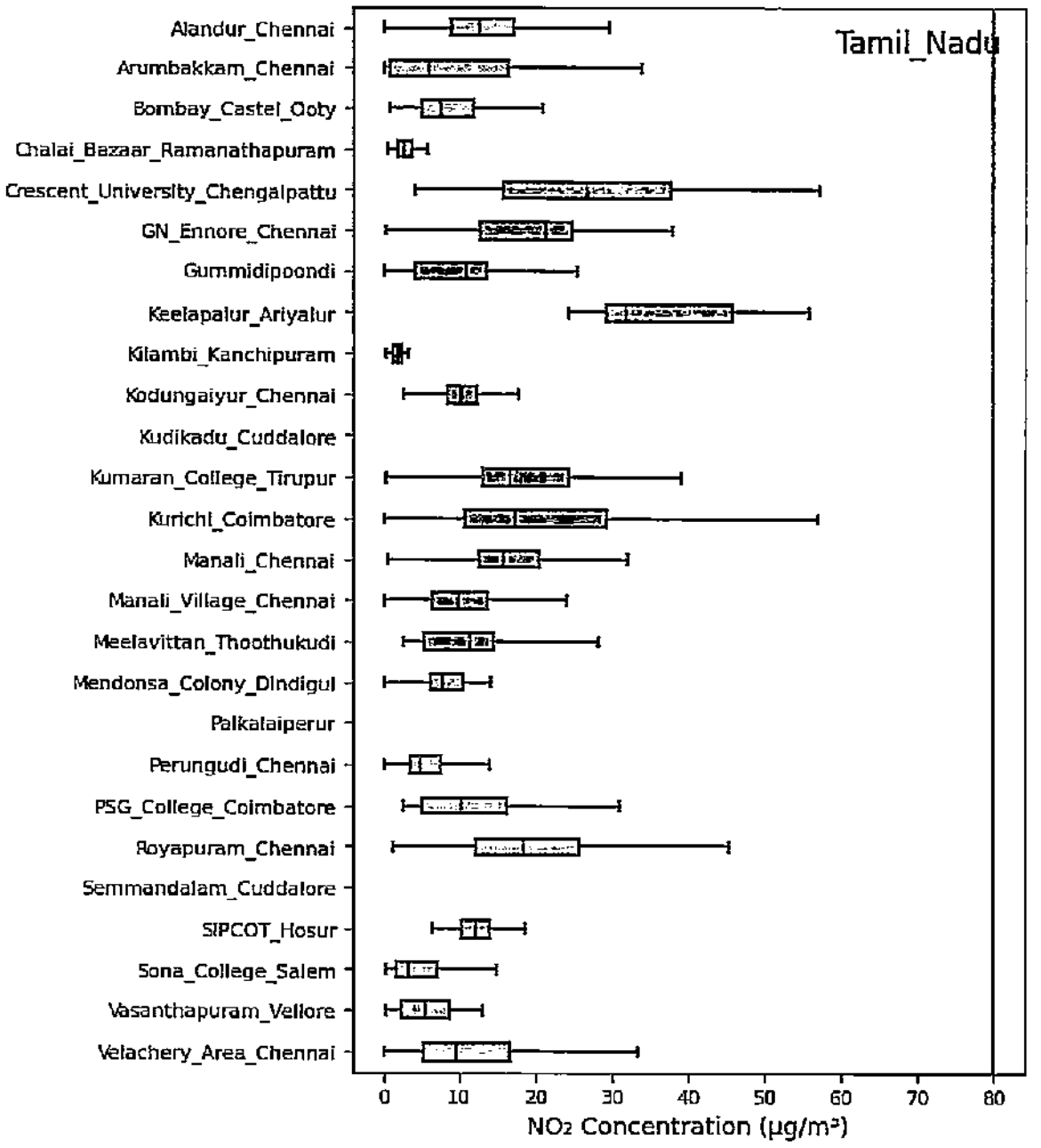

AdarshNagar_Jaipur
AshokNagar_Udaipur
CivilLines_Ajmer
Collectorate_Jodhpur
Dhanmandi_Kota
Dholnda_Rajsamand
IC_Vistar_Pali
IN_Jhunjhunu
Jhalamand_Jodhpur
KN_Bharatpur
MMG_Bikaner
Mansarovar_Jaipur
MotiDoongri_Alwar
Nayapura_Kota
OldCity_SriGanganagar
Police_Commissionerate_Jaipur
PragatiNagar_Pratapgarh
RIICO_Bhiwadi
RK_Pura_Sikar
RailwayColony_Barmer
RajlaxmiNagar_Jhalawar
RatiTalai_Banswara
SAUdhyan_Jodhpur
SahuNagar_SawaiMadhopur
SatyawatiVihar_Karauli
ShastriNagar_Chittorgarh
ShastriNagar_Jaipur
ShastriNagar_Tonk
ShrinathPuram_Kota
SubashChowk_Churu
VedhaynathColony_Sirohi
Rajasthan
0
20
40
60
80
100
120
NO2 Concentration (µg/m³)

Tamil Nadu

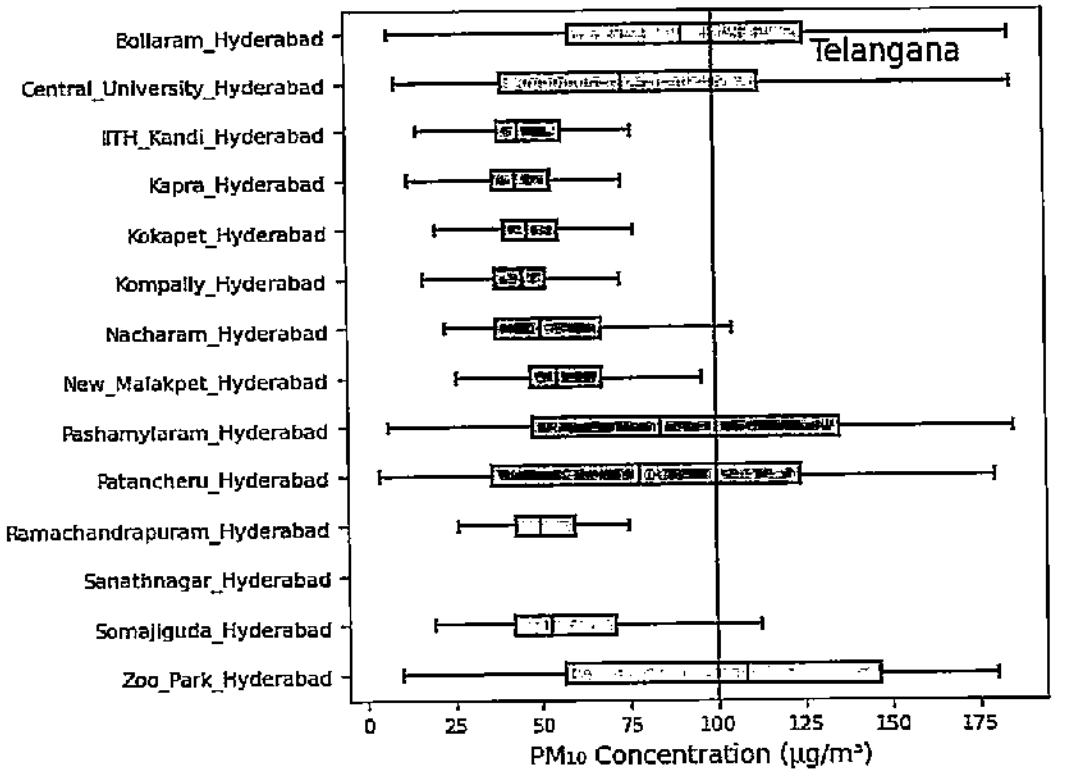

Tamil_Nadu
Alandur_Chennai
Arumbakkam_Chennai
Bombay_Castel_Ooty
Chalai_Bazaar_Ramanathapuram
Crescent_University_Chengalpattu
GN_Ennore_Chennai
Gummidipoondi
Keelapalur_Ariyalur
Kilambi_Kanchipuram
Kodungaiyur_Chennai
Kudikadu_Cuddalore
Kumaran_College_Tirupur
Kurichi_Coimbatore
Manali_Chennai
Manali_Village_Chennai
Meelavittan_Thoothukudi
Mendonsa_Colony_Dindigul
Palkalaiperur
Perungudi_Chennai
PSG_College_Coimbatore
Royapuram_Chennai
Semmandalam_Cuddalore
SIPCOT_Hosur
Sona_College_Salem
Vasanthapuram_Vellore
Velachery_Area_Chennai
0
50
100
150
200
250
300
PM10 Concentration (µg/m³)

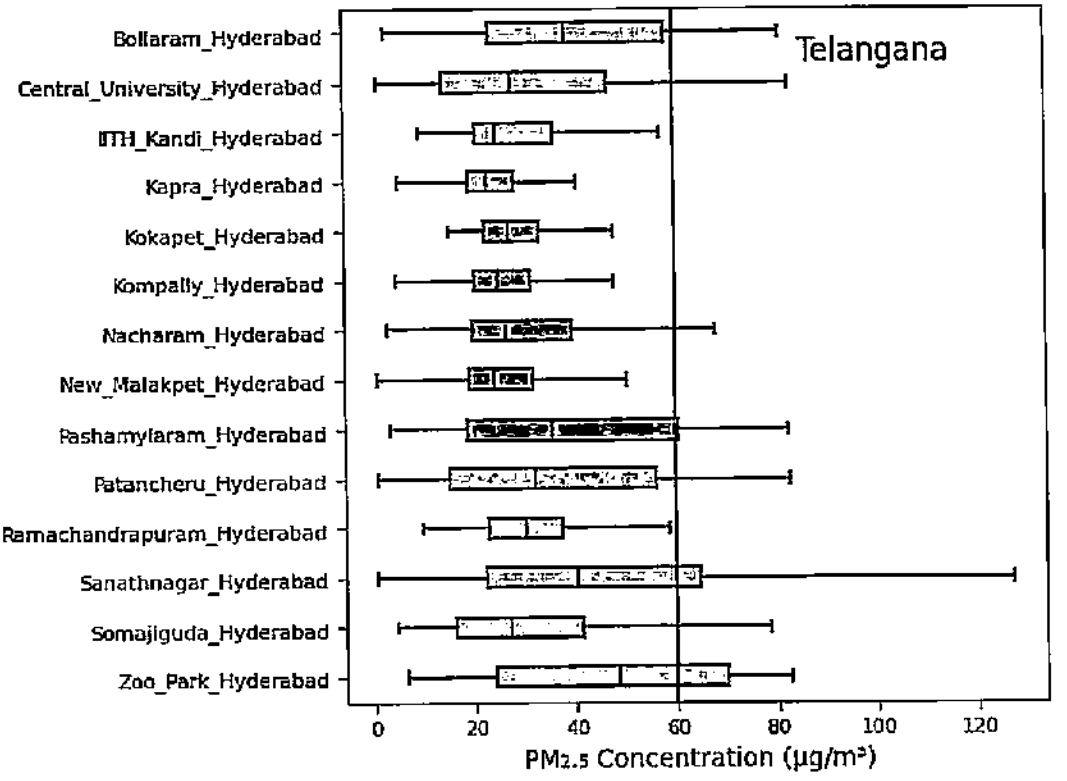

Tamil_Nadu
Alandur_Chennai
Arumbakkam_Chennai
Bombay_Castel_Ooty
Chalai_Bazaar_Ramanathapuram
Crescent_University_Chengalpattu
GN_Ennore_Chennai
Gummidipoondi
Keelapalur_Ariyalur
Kilambi_Kanchipuram
Kodungaiyur_Chennai
Kudikadu_Cuddalore
Kumaran_College_Tirupur
Kurichi_Coimbatore
Manali_Chennai
Manali_Village_Chennai
Meelavittan_Thoothukudi
Mendonsa_Colony_Dindigul
Palkalaiperur
Perungudi_Chennai
PSG_College_Coimbatore
Royapuram_Chennai
Semmandalam_Cuddalore
SIPCOT_Hosur
Sona_College_Salem
Vasanthapuram_Vellore
Velachery_Area_Chennai
0
20
40
60
80
PM2.5 Concentration (µg/m³)

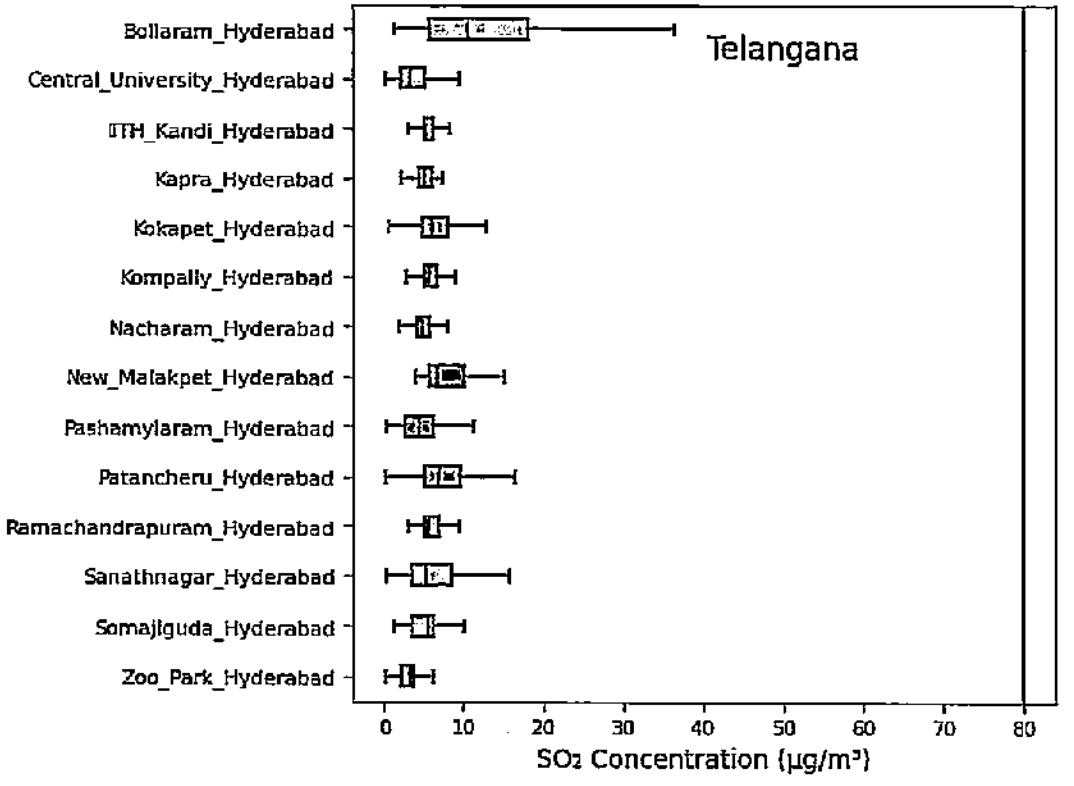

Tamil_Nadu
Alandur_Chennai
Arumbakkam_Chennai
Bombay_Castel_Ooty
Chalai_Bazaar_Ramanathapuram
Crescent_University_Chengalpattu
GN_Ennore_Chennai
Gummidipoondi
Keelapalur_Ariyalur
Kilambi_Kanchipuram
Kodungaiyur_Chennai
Kudikadu_Cuddalore
Kumaran_College_Tirupur
Kurichi_Coimbatore
Manali_Chennai
Manali_Village_Chennai
Meelavittan_Thoothukudi
Mendonsa_Colony_Dindigul
Palkalaiperur
Perungudi_Chennai
PSG_College_Coimbatore
Royapuram_Chennai
Semmandalam_Cuddalore
SIPCOT_Hosur
Sona_College_Salem
Vasanthapuram_Vellore
Velachery_Area_Chennai
0
20
40
60
80
SO2 Concentration (µg/m3)

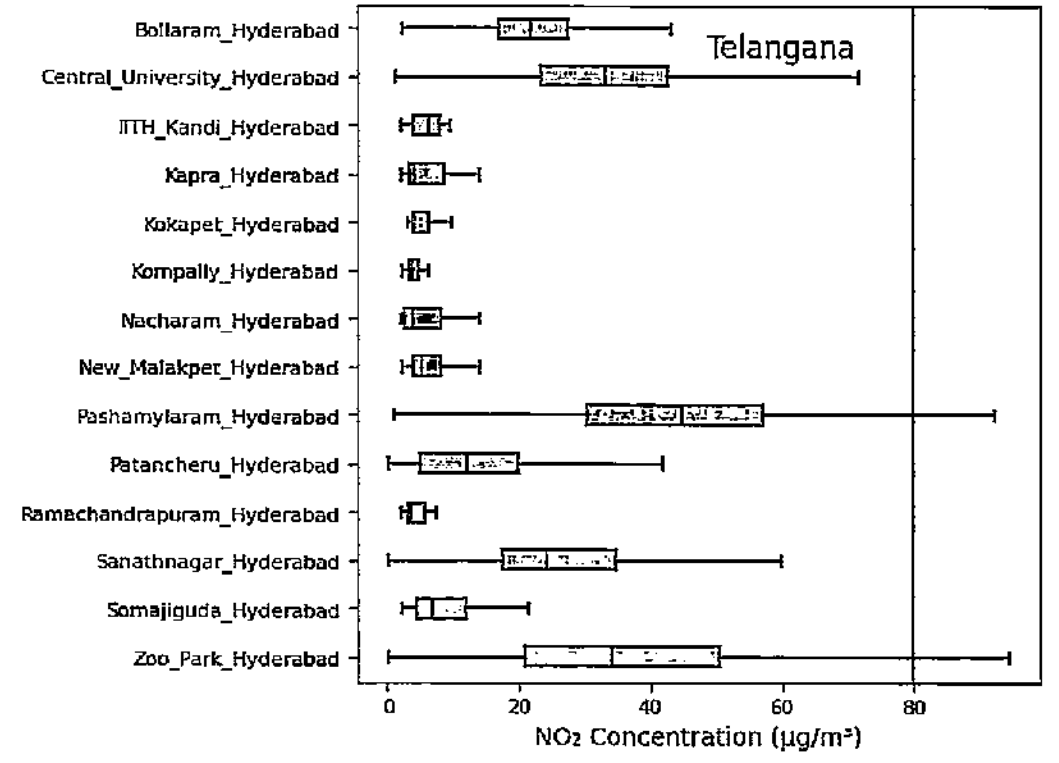

Tamil_Nadu
Alandur_Chennai
Arumbakkam_Chennai
Bombay_Castel_Ooty
Chalai_Bazaar_Ramanathapuram
Crescent_University_Chengalpattu
GN_Ennore_Chennai
Gummidipoondi
Keelapalur_Ariyalur
Kilambi_Kanchipuram
Kodungaiyur_Chennai
Kudikadu_Cuddalore
Kumaran_College_Tirupur
Kurichi_Coimbatore
Manali_Chennai
Manali_Village_Chennai
Meelavittan_Thoothukudi
Mendonsa_Colony_Dindigul
Palkalaiperur
Perungudi_Chennai
PSG_College_Coimbatore
Royapuram_Chennai
Semmandalam_Cuddalore
SIPCOT_Hosur
Sona_College_Salem
Vasanthapuram_Vellore
Velachery_Area_Chennai
0
10
20
30
40
50
60
70
80
NO2 Concentration (µg/m³)

Telangana

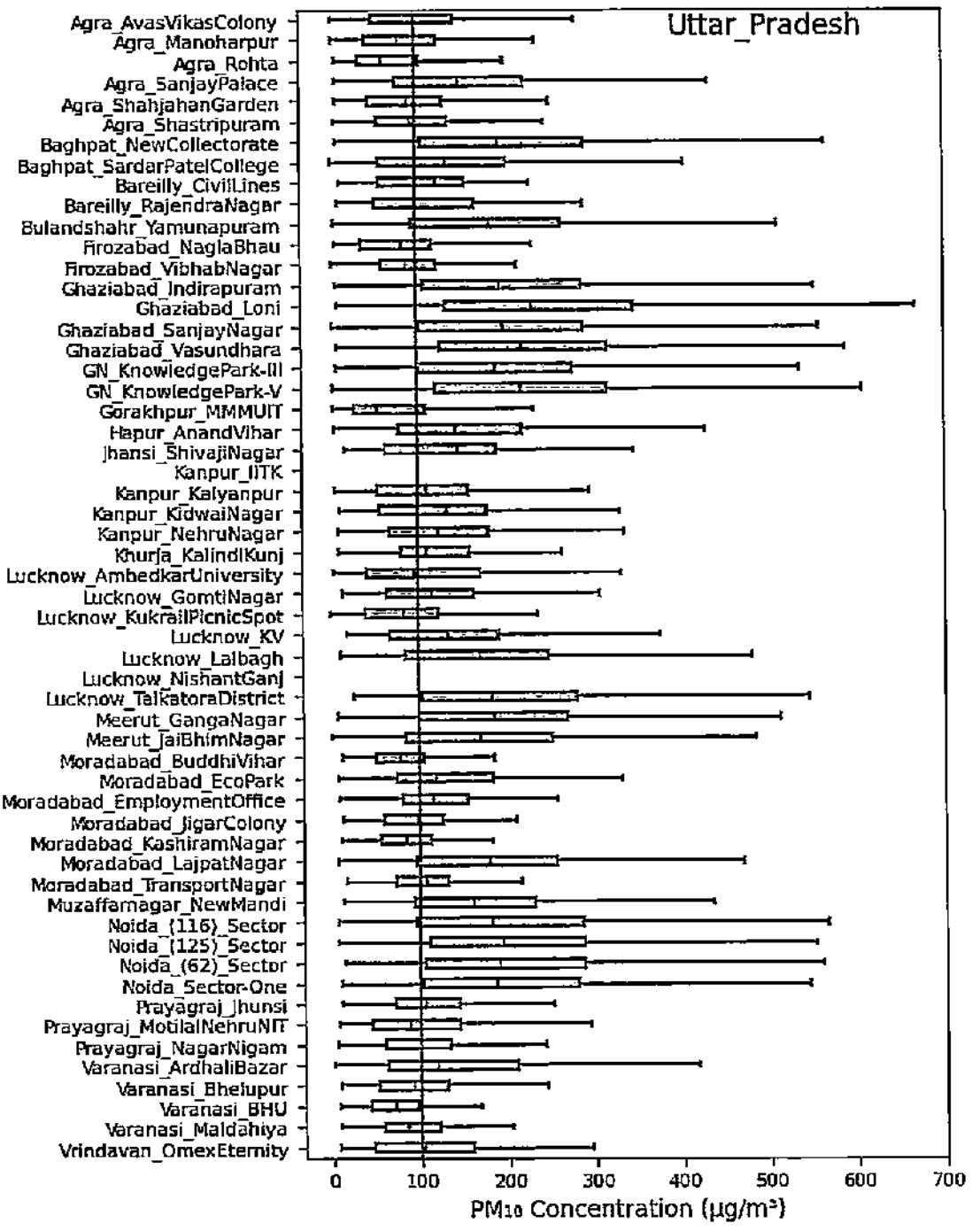

Telangana
Bollaram_Hyderabad
Central_University_Hyderabad
IITH_Kandi_Hyderabad
Kapra_Hyderabad
Kokapet_Hyderabad
Kompally_Hyderabad
Nacharam_Hyderabad
New_Malakpet_Hyderabad
Pashamylaram_Hyderabad
Patancheru_Hyderabad
Ramachandrapuram_Hyderabad
Sanathnagar_Hyderabad
Somajiguda_Hyderabad
Zoo_Park_Hyderabad
0
25
50
75
100
125
150
175
PM10 Concentration (µg/m³)

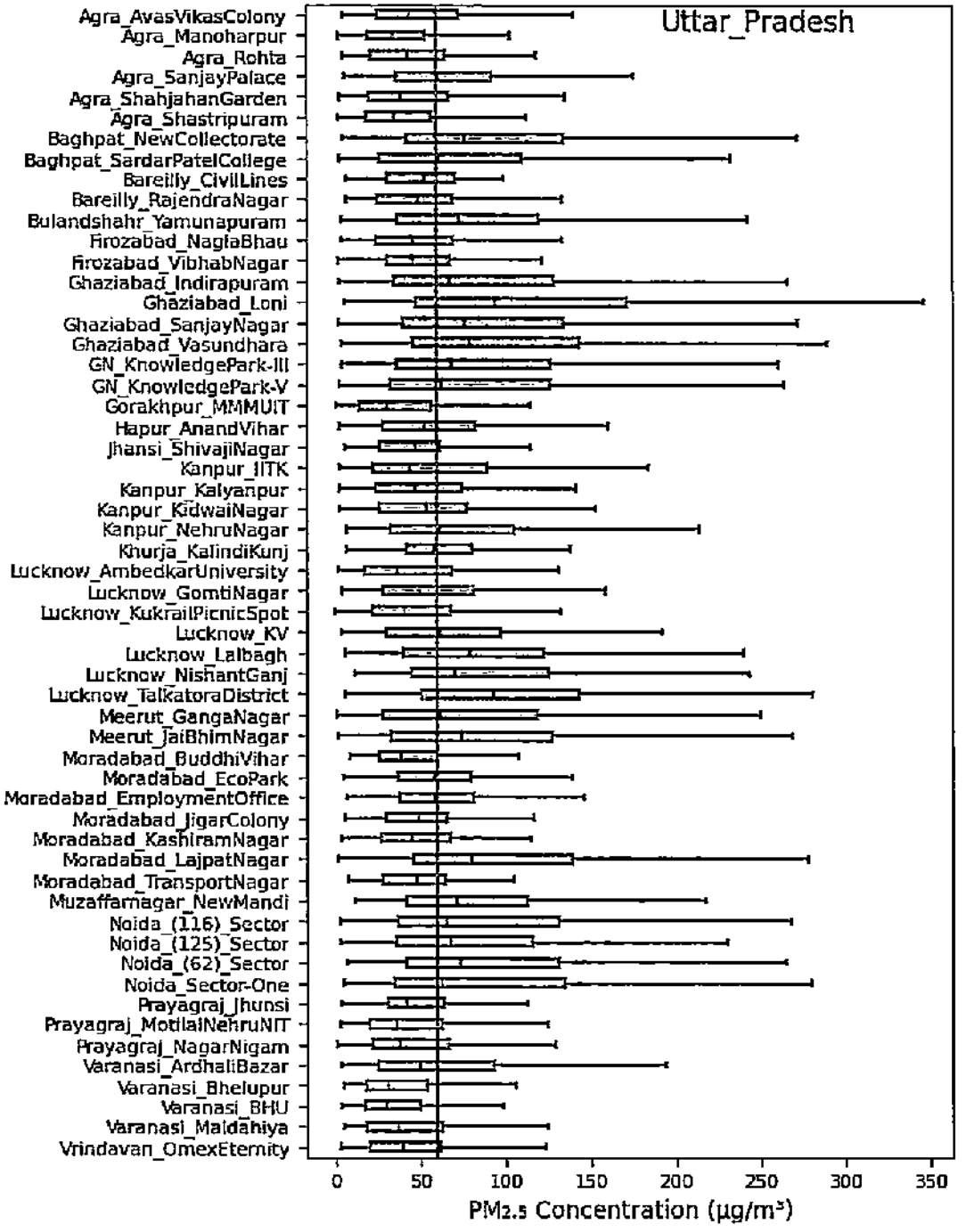

Telangana
Bollaram_Hyderabad
Central_University_Hyderabad
IITH_Kandi_Hyderabad
Kapra_Hyderabad
Kokapet_Hyderabad
Kompally_Hyderabad
Nacharam_Hyderabad
New_Malakpet_Hyderabad
Pashamylaram_Hyderabad
Patancheru_Hyderabad
Ramachandrapuram_Hyderabad
Sanathnagar_Hyderabad
Somajiguda_Hyderabad
Zoo_Park_Hyderabad
0
20
40
60
80
100
120
PM2.5 Concentration (µg/m³)

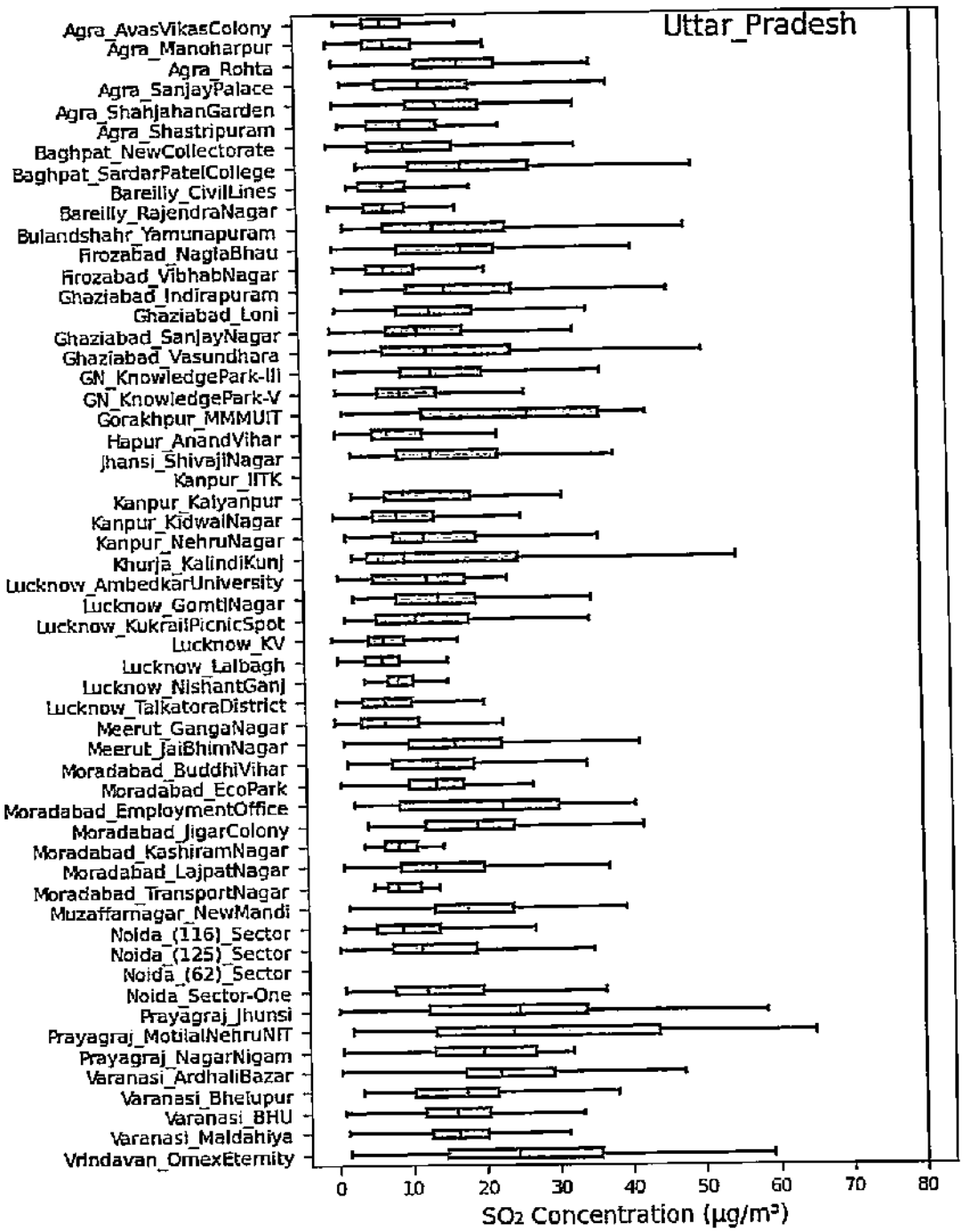

Telangana
Bollaram_Hyderabad
Central_University_Hyderabad
IITH_Kandi_Hyderabad
Kapra_Hyderabad
Kokapet_Hyderabad
Kompally_Hyderabad
Nacharam_Hyderabad
New_Malakpet_Hyderabad
Pashamylaram_Hyderabad
Patancheru_Hyderabad
Ramachandrapuram_Hyderabad
Sanathnagar_Hyderabad
Somajiguda_Hyderabad
Zoo_Park_Hyderabad
0
10
20
30
40
50
60
70
80
SO₂ Concentration (µg/m³)


Telangana
Bollaram_Hyderabad
Central_University_Hyderabad
IITH_Kandi_Hyderabad
Kapra_Hyderabad
Kokapet_Hyderabad
Kompally_Hyderabad
Nacharam_Hyderabad
New_Malakpet_Hyderabad
Pashamylaram_Hyderabad
Patancheru_Hyderabad
Ramachandrapuram_Hyderabad
Sanathnagar_Hyderabad
Somajiguda_Hyderabad
Zoo_Park_Hyderabad
0
20
40
60
80
NO₂ Concentration (µg/m³)

Uttar Pradesh




Uttar_Pradesh
Agra_AvasVikasColony
Agra_Manoharpur
Agra_Rohta
Agra_SanjayPalace
Agra_ShahjahanGarden
Agra_Shastripuram
Baghpat_NewCollectorate
Baghpat_SardarPatelCollege
Bareilly_CivilLines
Bareilly_RajendraNagar
Bulandshahr_Yamunapuram
Firozabad_NaglaBhau
Firozabad_VibhabNagar
Ghaziabad_Indirapuram
Ghaziabad_Loni
Ghaziabad_SanjayNagar
Ghaziabad_Vasundhara
GN_KnowledgePark-III
GN_KnowledgePark-V
Gorakhpur_MMMUIT
Hapur_AnandVihar
Jhansi_ShivajiNagar
Kanpur_IITK
Kanpur_Kalyanpur
Kanpur_KidwaiNagar
Kanpur_NehruNagar
Khurja_KalindiKunj
Lucknow_AmbedkarUniversity
Lucknow_GomtiNagar
Lucknow_KukrailPicnicSpot
Lucknow_KV
Lucknow_Lalbagh
Lucknow_NishantGanj
Lucknow_TalkatoraDistrict
Meerut_GangaNagar
Meerut_JaiBhimNagar
Moradabad_BuddhiVihar
Moradabad_EcoPark
Moradabad_EmploymentOffice
Moradabad_JigarColony
Moradabad_KashiramNagar
Moradabad_LajpatNagar
Moradabad_TransportNagar
Muzaffarnagar_NewMandi
Noida_(116)_Sector
Noida_(125)_Sector
Noida_(62)_Sector
Noida_Sector-One
Prayagraj_Jhunsi
Prayagraj_MotilalNehruNIT
Prayagraj_NagarNigam
Varanasi_ArdhaliBazar
Varanasi_Bhelupur
Varanasi_BHU
Varanasi_Maldahiya
Vrindavan_OmexEternity
0
50
100
150
200
250
300
350
PM2.5 Concentration (µg/m³)


Uttar_Pradesh
Agra_AvasVikasColony
Agra_Manoharpur
Agra_Rohta
Agra_SanjayPalace
Agra_ShahjahanGarden
Agra_Shastripuram
Baghpat_NewCollectorate
Baghpat_SardarPatelCollege
Bareilly_CivilLines
Bareilly_RajendraNagar
Bulandshahr_Yamunapuram
Firozabad_NaglaBhau
Firozabad_VibhabNagar
Ghaziabad_Indirapuram
Ghaziabad_Loni
Ghaziabad_SanjayNagar
Ghaziabad_Vasundhara
GN_KnowledgePark-III
GN_KnowledgePark-V
Gorakhpur_MMMUIT
Hapur_AnandVihar
Jhansi_ShivajiNagar
Kanpur_IITK
Kanpur_Kalyanpur
Kanpur_KidwaiNagar
Kanpur_NehruNagar
Khurja_KalindiKunj
Lucknow_AmbedkarUniversity
Lucknow_GomtiNagar
Lucknow_KukrailPicnicSpot
Lucknow_KV
Lucknow_Lalbagh
Lucknow_NishantGanj
Lucknow_TalkatoraDistrict
Meerut_GangaNagar
Meerut_JaiBhimNagar
Moradabad_BuddhiVihar
Moradabad_EcoPark
Moradabad_EmploymentOffice
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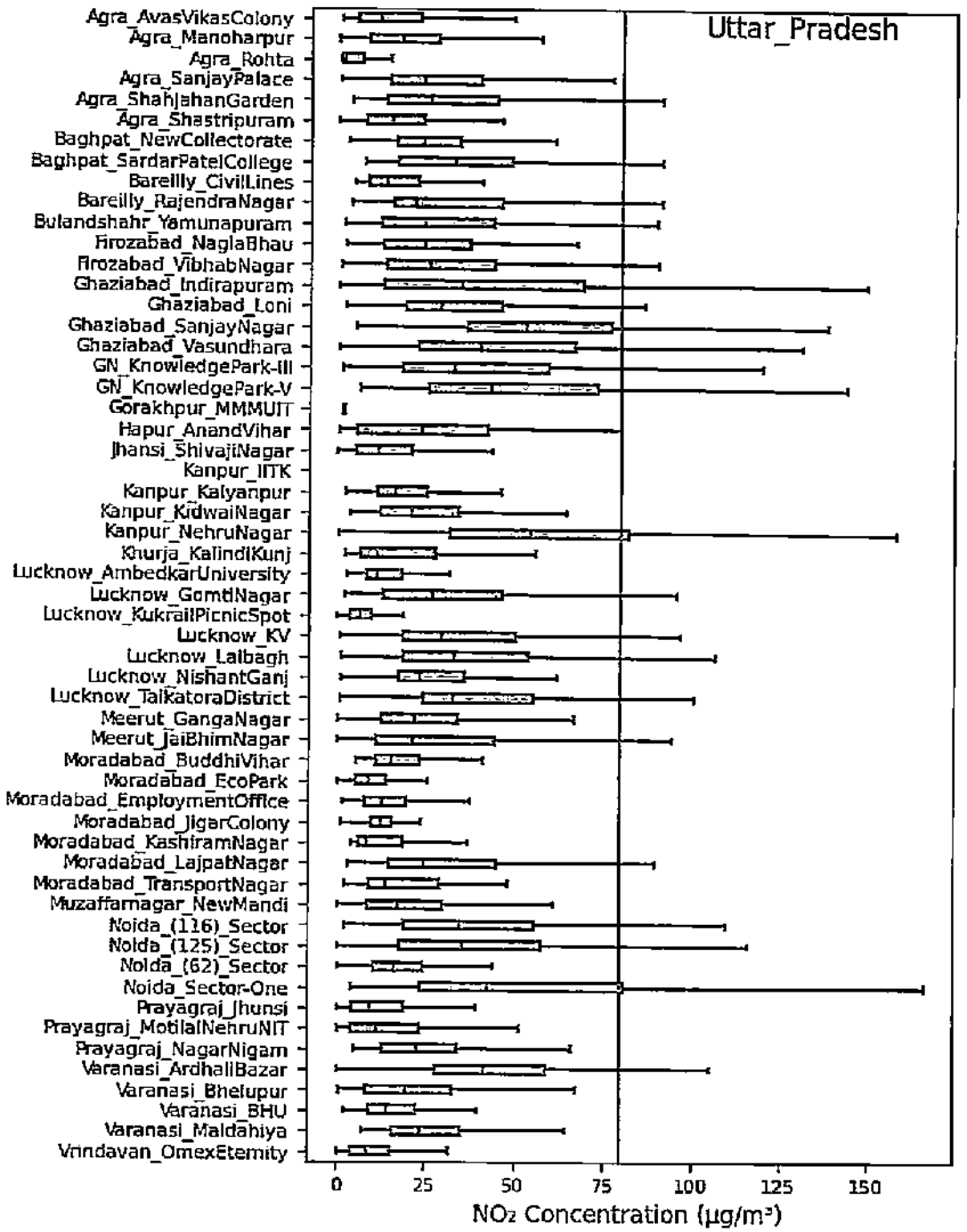
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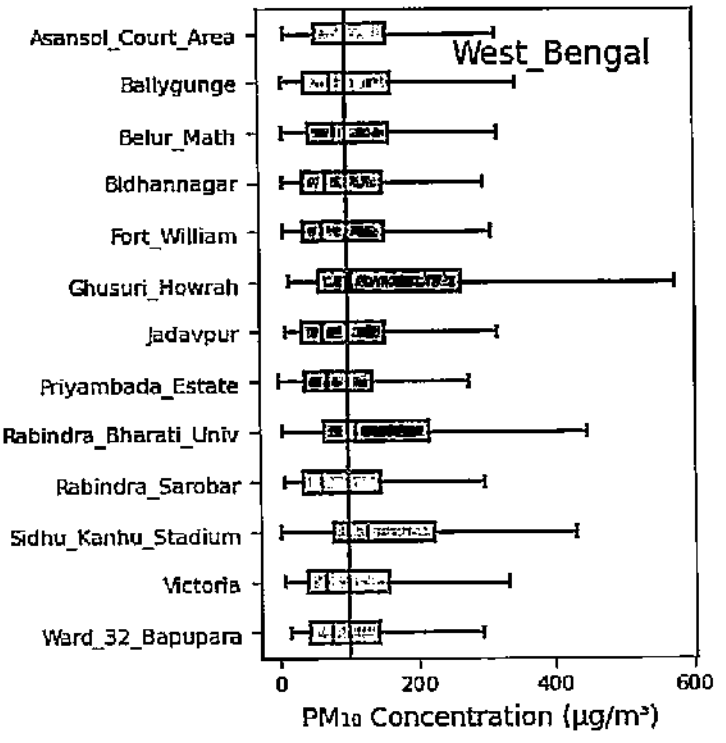
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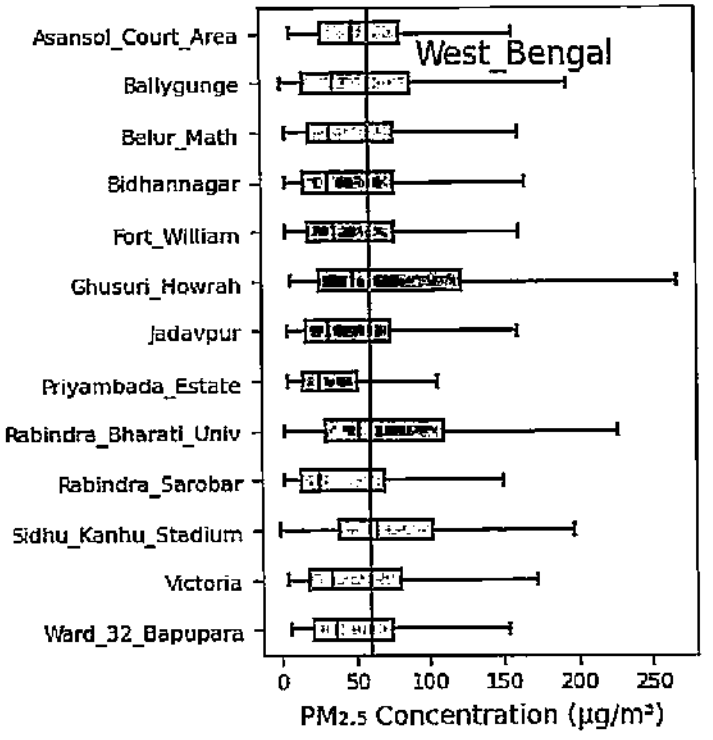
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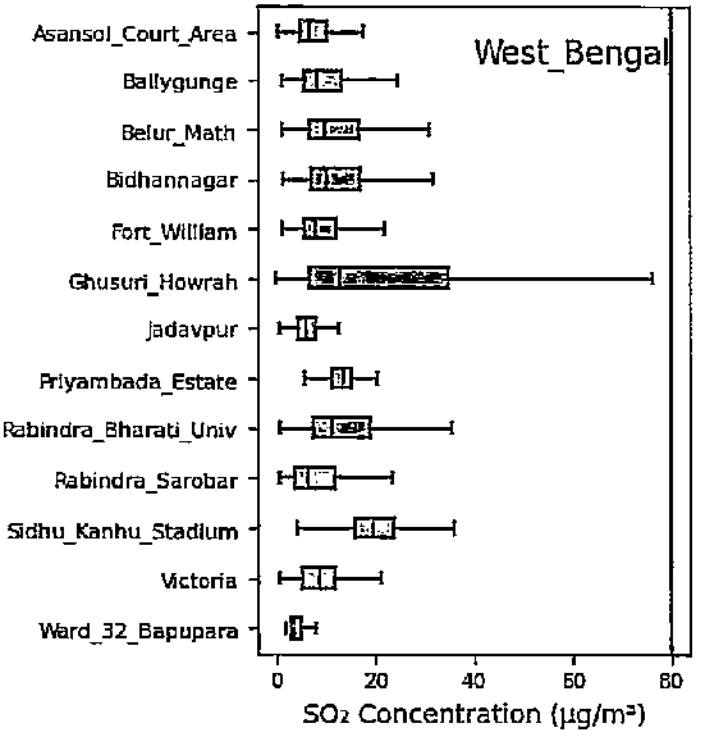
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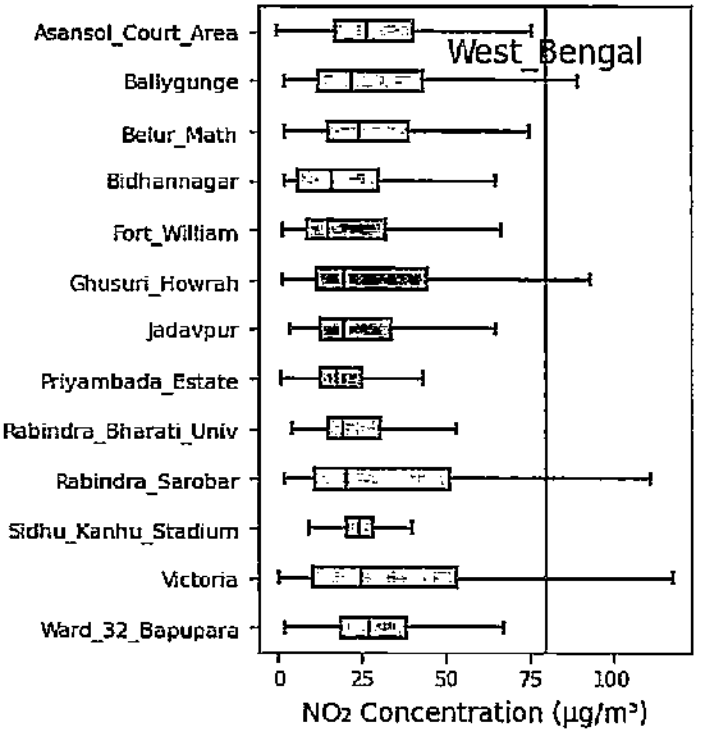
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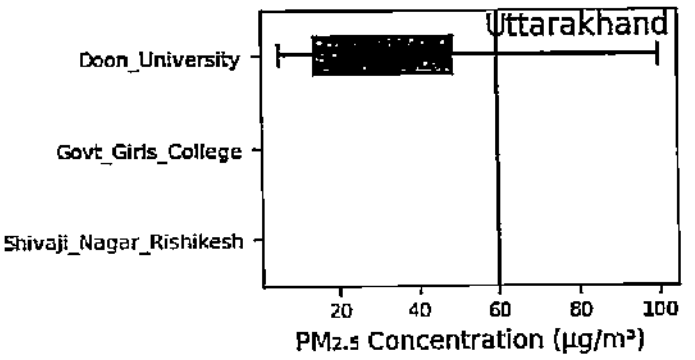
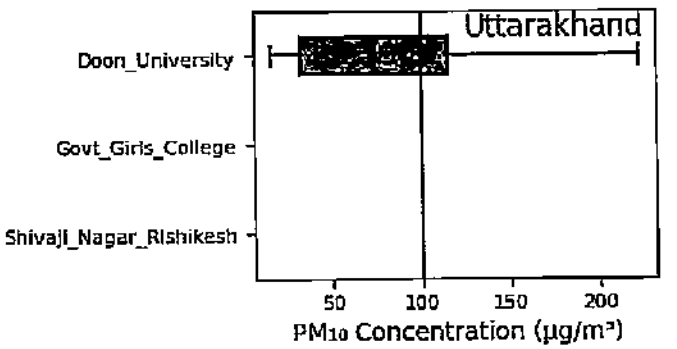
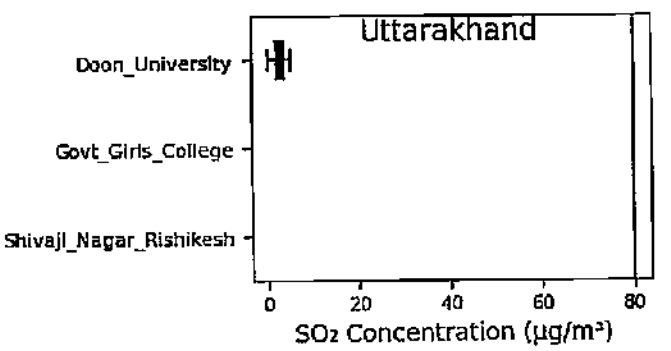
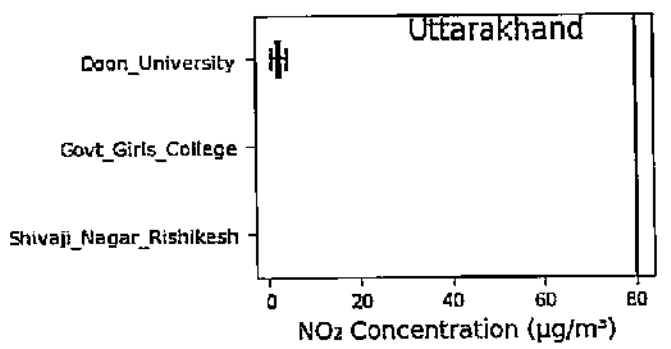
NO2 Concentration (µg/m3)

Uttarakhand









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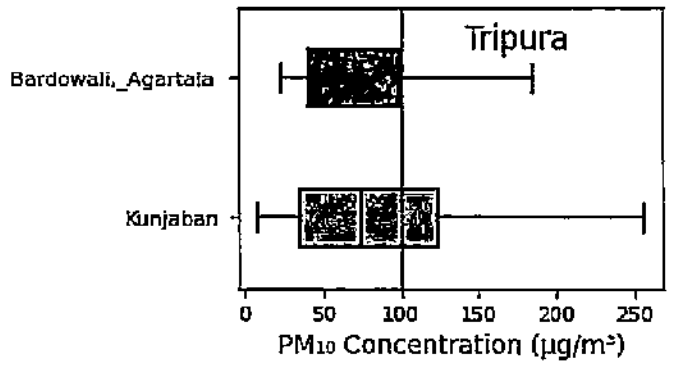
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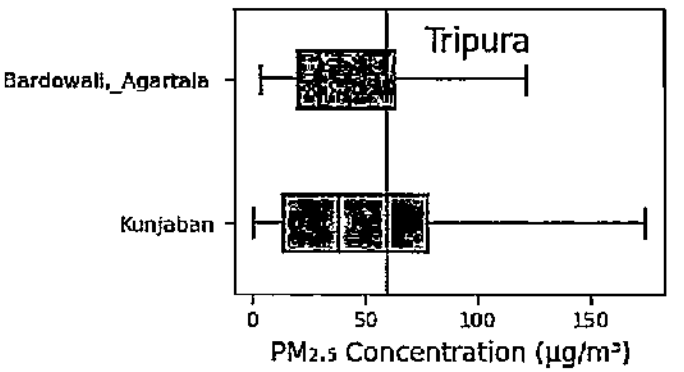
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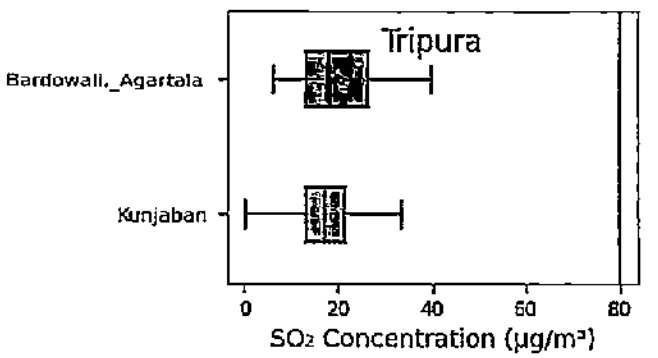
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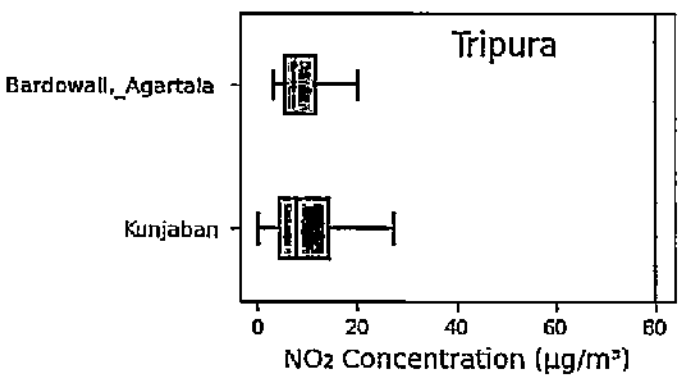
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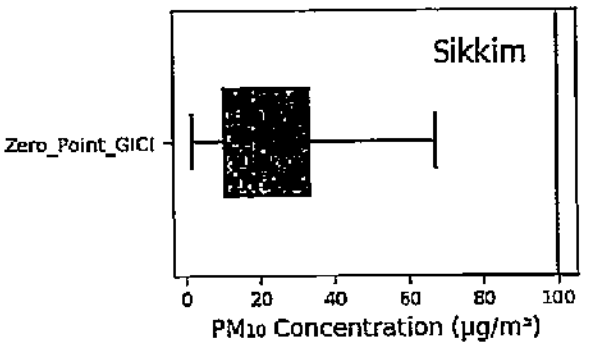
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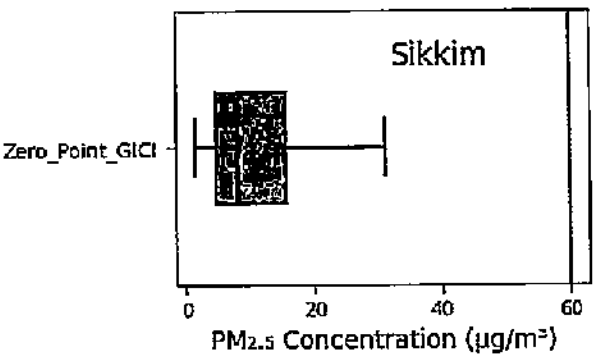
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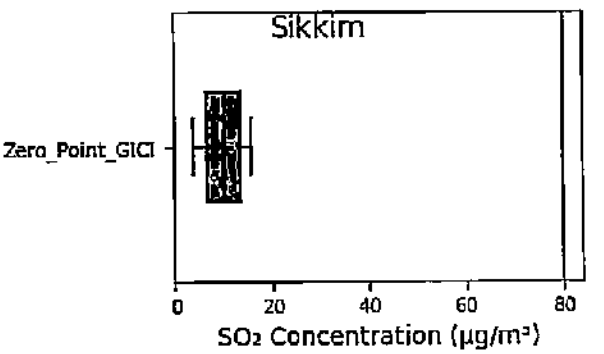
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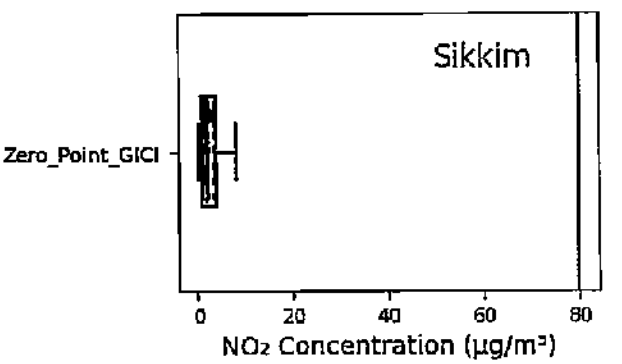
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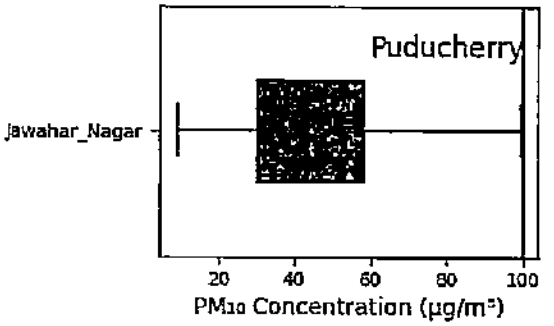
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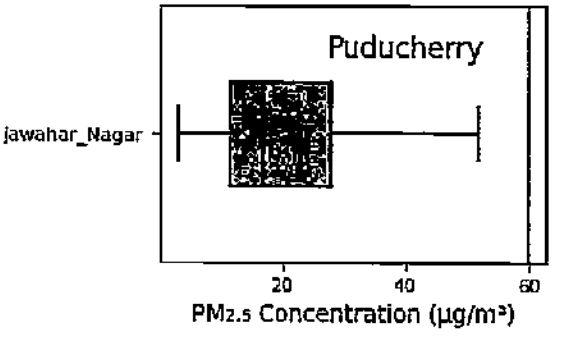
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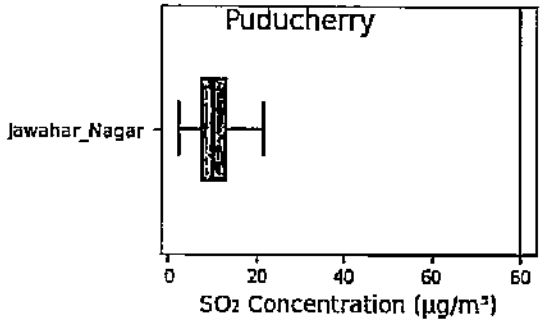
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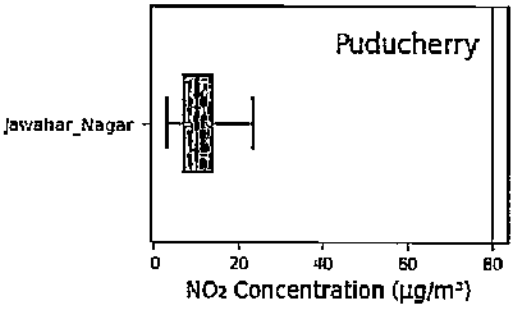
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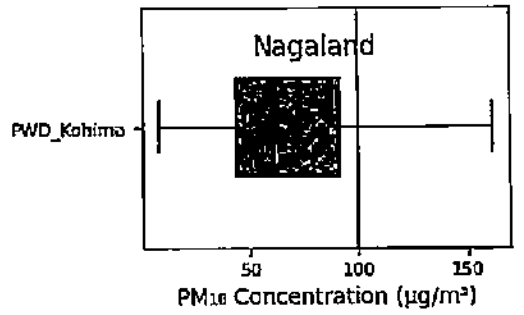
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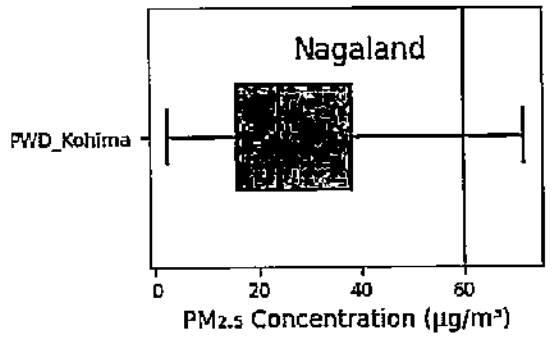
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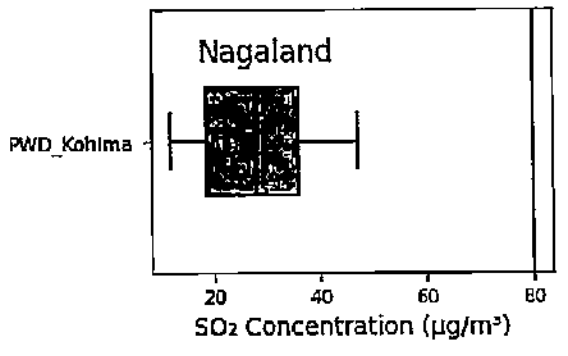
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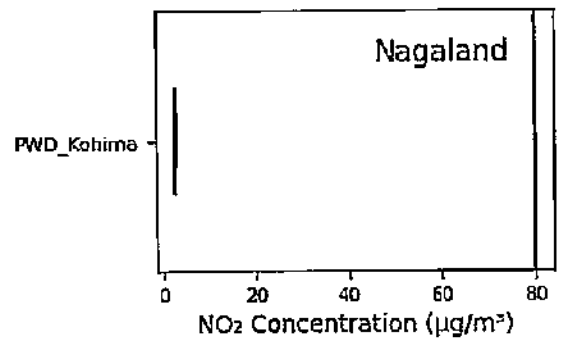
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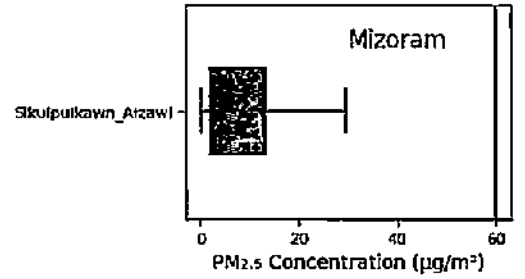
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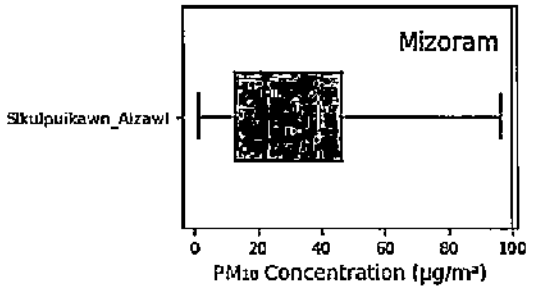
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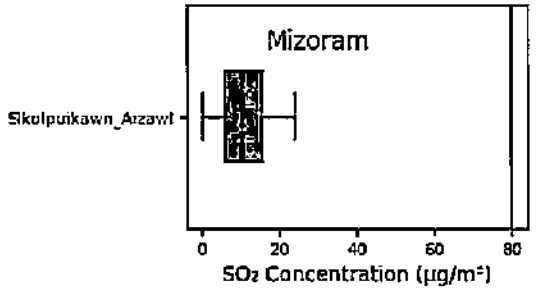
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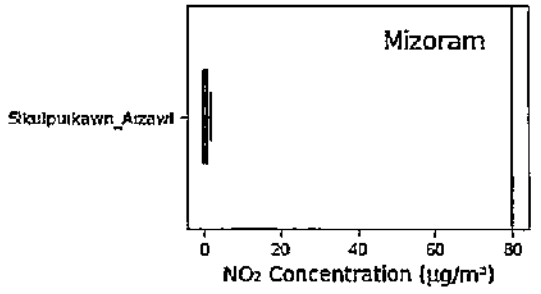
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NO2 Concentration (µg/m³)

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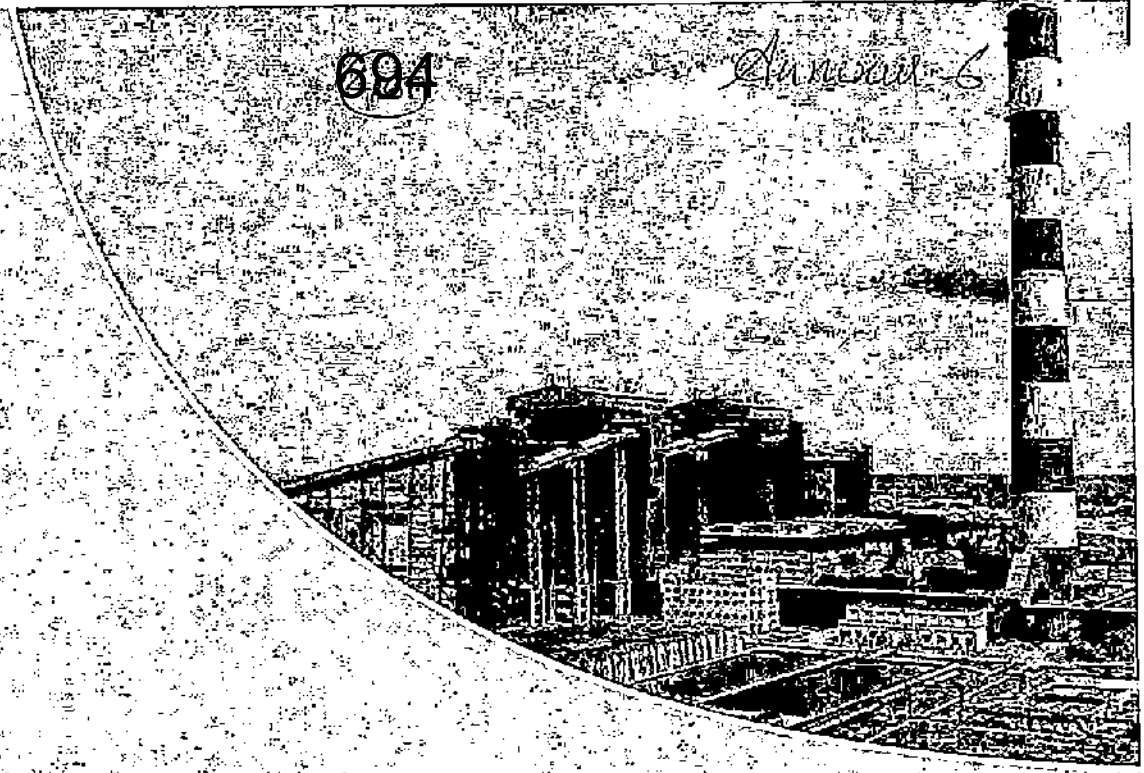
R. Srikanth
A.V. Krishnan
Dizna James



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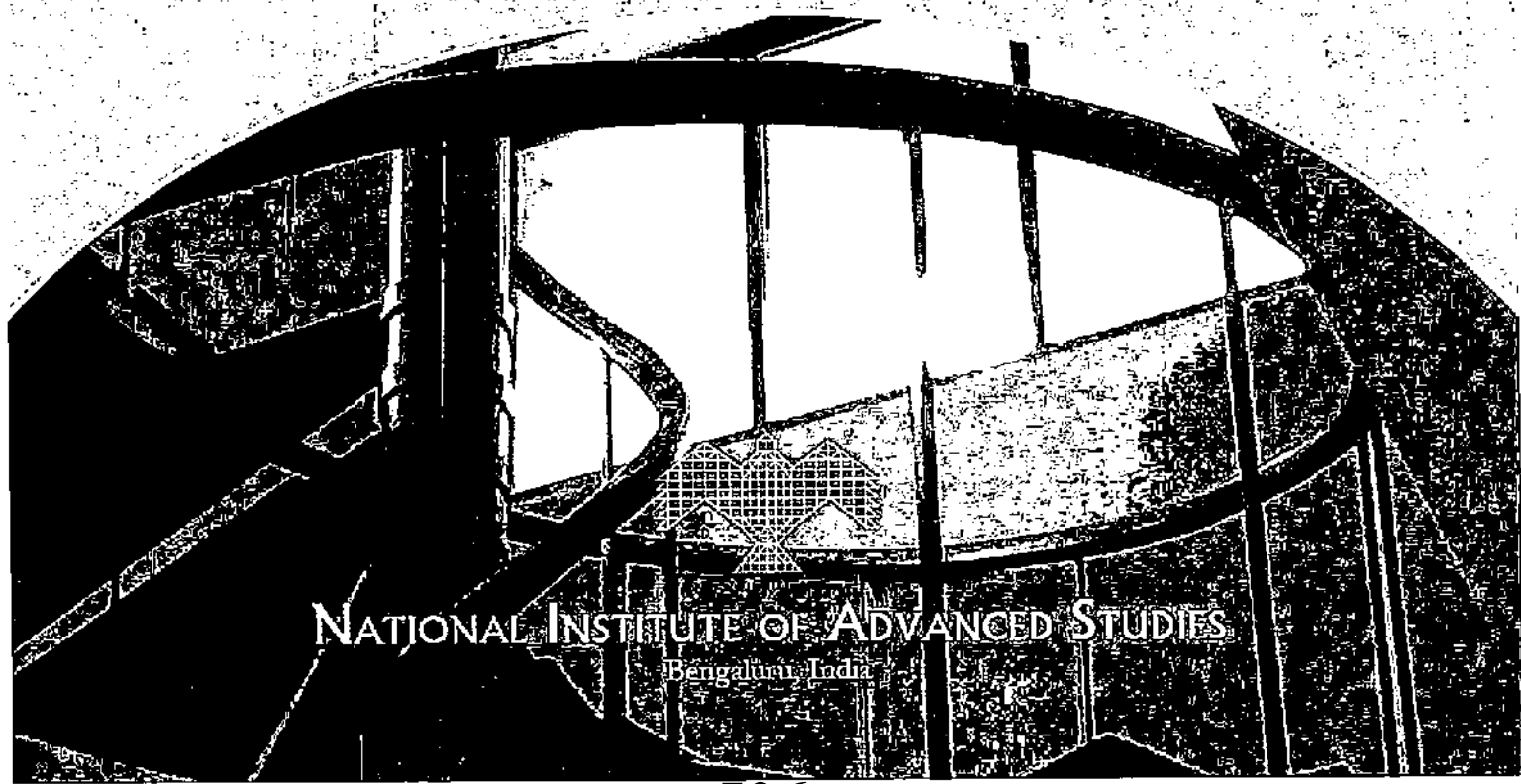

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Bengaluru, India

Research Report NIAS/NSE/EECP/U/RR/15/2024

Economic, Environmental, and Climate Impacts of FGDs in Thermal Power Plants in India

Interim Study Report

Submitted

by

R. Srikanth
A.V. Krishnan
Dizna James

To

Office of the Principal Scientific Adviser
Government of India
New Delhi, India

Energy, Environment, and Climate Change Program
NATIONAL INSTITUTE OF ADVANCED STUDIES
Bengaluru, India

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Cover photo: (Front cover) Raichur Power Corporation's 2 X 800 MW Yeramarus Thermal Power Station, Raichur district, Karnataka
(Back cover) Sri Damodaram Sanjeevaiah 2 X 800 MW Thermal Power Station, Krishnapatnam, Nellore district, Andhra Pradesh

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Table of Contents

Abbreviations iv
List of Tables vi
List of Figures vii
Table of Equations viii
Executive Summary 1
1. Introduction 11
1.1 BackgroundTop of Form 11
1.1.1 Power Scenario of India 11
1.1.2 The Role of Coal in India's Energy Transition 13
1.2 Thermal power plant emissions 13
1.2.1 Characteristics of Indian Coal 14
1.2.2 CO_2 emissions from thermal power plants (TPPs) 14
1.2.3 SO_2 emissions from TPPs 15
1.2.4 Flue Gas Desulfurizer (FGD) 17
1.2.5 Phased implementation Plan for FGD installation 18
2. Objectives 21
3. Study Area 23
4. Data 25
5. Methodology 29
5.1 Emission Modelling for FY 2021-22 29
5.1.1 Preparation of 2021-22 database 29
5.1.2 Validation of the absolute CO_2 emissions estimation method 30
5.1.3 Estimation of SO_2 emissions by TPPs in 2021-22 30
5.1.4 Estimation of total freshwater consumption by TPPs in 2021-22 30
5.2 Emission Modelling for FY 2023-24 31
5.3 Emission Modelling for FY 2030-31 31
5.3.1 Preparation of the 2030-31 database 32
6. Scenario Development for FY 2030-31 and FY 2040-41 35
7. Findings and Conclusions 39
7.1 Impact of FGDs on CO2 emissions: 39
7.2 Impact of FGDs on SO2 emissions 41
7.3 Impact of FGDs on freshwater consumption 42
8. Policy Recommendations 45
9. Acknowledgments 49
10. References 51

Abbreviations

APC	Auxiliary Power Consumption
Bcm	Billion Cubic Meters
BESS	Battery Energy Storage System
Bt	Billion Tonnes
CEA	Central Electricity Authority
CERC	Central Electricity Regulatory Commission
CFBC	Circulating Fluidized Bed Combustion
CPCB	Central Pollution Control Board
DST	Department of Science & Technology
EDGAR	Emission Database for Global Atmospheric Research
FGD	Flue Gas Desulfurizers
FY	Fiscal Year
GCV	Gross Calorific Value
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GoI	Government of India
GW	Gigawatt
GWP	Global warming potential
HFC	Hydrofluorocarbon
Hg	Mercury
Kt	Kilo tonnes
Mcm	Million Cubic Meters
MOEFCC	Ministry of Environment, Forest, and Climate Change
Mt	Million Tonnes
NDC	Nationally Determined Contributions
NEP	National Electricity Plan
NO_2	Nitrogen dioxide

NPP	National Power Portal
PFC	Perfluorocarbon
PLF	Plant Load Factor
PM	Particulate Matter
RES	Renewable Energy Source
R&M	Repair and Maintenance
SO_2	Sulfur Dioxide
SDG	Sustainable Development Goal
T	Tonnes
TPP	Thermal Power Plant
TPS	Thermal Power Station
TWh	Terawatt hours
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
Y-o-Y	Year-On-Year

List of Tables

Table No.	Description	Page No.
Table 1 :	New environmental norms for thermal power plants (MOEFCC, 2015)	19
Table 2 :	Categorization of TPPs for phase-wise installation of FGDs as per CPCB (2022)	19
Table 3 :	CO_2 emission factors for different TPP capacities based on FY 2021-22 CO_2 data	27
Table 4 :	Comparison between actual coal consumption and our estimates for 2021-2022	27
Table 5 :	Specific water consumption data versus CEA norms (Source: Various CEA Reports)	27
Table 6 :	Normative coal requirement of the TPPs in the period 2019-24 (CEA, 2019)	33
Table 7 :	Specific water consumption values used to estimate overall water consumption by TPPs	33
Table 8 :	Status of FGD installations in Thermal Power Plants in India as of September 2024	36
Table 9 :	Technology-wise projections of TPPs and Coal-fired generation by utilities	38
Table 10 :	Impact of FGDs on key parameters for different scenarios	40

List of Figures

Figure No.	Description	Page No.
Figure E1.	Stack emissions from a pre-2003, 2600 MW sub-critical TPS using low-sulfur Indian coal without High-efficiency ESPs and FGDs	3
Figure E2.	Particulate Matter (PM) concentration in the stack emission from a 1200 MW TPS equipped with sub-critical technology and a High-efficiency ESPs but no FGD	4
Figure E3.	Sulfur dioxide (SO_2) concentrations recorded by the Telangana State Pollution Control Board AAQM station in Ramagundam comply with the NAAQ Standard.	4
Figure E4.	PM_{10} concentrations recorded by the Telangana State Pollution Control Board AAQM station in Ramagundam do not comply with the NAAQ Standard	5
Figure E5.	High-efficiency Electrostatic Precipitator (ESP) installed by BHEL in a TPP in India	7
Figure E6.	Retrofit of a new, taller ESP field in parallel with the existing ESP by BHEL in a 210 MW TPP to reduce PM concentrations in the flue gases by 99.97%	8
Figure 1 :	Fuel-wise electricity generation by Utilities in India during FY 2023-24	12
Figure 2 :	Global trends in SO2 emissions (Aas, 2019)	16
Figure 3 :	Thermal power plant exhaust system and wet FGD schematic diagram	17
Figure 4 :	Geographical locations of operational Thermal Power Stations in 2021-22	23
Figure 5 :	Sector-wise TPP installed capacity in 2021-22	26
Figure 6 :	CO_2 emissions from TPPs projected in the three scenarios	41
Figure 7 :	SO_2 emissions from TPPs projected in the three scenarios	42
Figure 8 :	Freshwater consumption by the TPPs in the base year and future scenarios.	43

Table of Equations

No.	Equation Details	Page No.
1	Estimation of the gross generation using the installed capacity and normative PLF	29
2	Estimation of absolute CO2 emission from the TPPs	30
3	Estimation of absolute SO2 emission from the TPPs	30
4	Estimation of the total water consumption using a specific water consumption	31
5	Estimation of the coal consumption by the TPPs using specific coal consumption rate	33
6	Estimation of the total water consumption by FGD-equipped TPPs	34

Executive Summary

Electricity security can be achieved only by '*having a reliable and stable supply of electricity that can meet the demand at all times at an affordable price.*' The reliance on coal for affordable and reliable electricity is indicated by the fact that global coal-fired electricity generation recorded a new peak of 10,648 TWh in 2023, amounting to 35.66% of the World's total electricity generation[1].

Spurred by the sharp increase in peak demand in FY 2023-24, the Central Electricity Authority (CEA) has also raised its forecast for peak electricity demand in FY 2031-32 to 388 GW, which is a 5% increase over the peak demand estimated by the CEA in Volume 1 of the National Electricity Plan (CEA, 2023a; 2024b). Recently, the Ministry of Power (MOP) has increased its estimate of peak demand to 400 GW by FY 2031-32.[2] Therefore, MOP has asserted that the total coal-fired power generation capacity of the country must be progressively enhanced to 283 GW by 2032 from the current (October 2024) level of 217 GW to meet the growing demand for electricity to overcome India's development deficit[3].

On the other hand, the Working Group 1 (WG1) of the Intergovernmental Panel on Climate Change (IPCC) published its Sixth Assessment Report (AR6) quantifying the contribution of different gases to global warming. As per this report, the cumulative emissions of greenhouse gases like carbon dioxide (CO2) and methane have increased global warming by about 1.5°C, while Sulfur dioxide (SO_2) emissions have masked global warming by approximately 0.5°C in the 2010-2019 period relative to 1850-1900[4]. Studies conducted on the success of China in reducing SO_2 aerosol emissions by fitting FGDs indicate that the 'unmasked' warming caused by reducing the aerosol emissions would in turn compound the challenge and urgency of global climate mitigation efforts (Qian et al., 2020; Zheng et al., 2020).[5,6]

Therefore, energy production and consumption are intrinsically linked to climate change and air pollution. Unlike the developed countries which face zero or negligible growth in electricity demand, India has the twin challenge of enhancing electricity consumption to meet its human development needs while ramping up non-fossil fuel sources of energy to reach Net Zero by 2070. Ninety-two percent of the coal used by TPPs in India is supplied from domestic mines and this is the key driver for the affordability

1 IEA (International Energy Agency) (2024). World Energy Outlook 2024.

2 India's power demand forecast to surpass 400 GW by 2031-32: Power Secretary. The Economic Times on July 2, 2024. <https://energy.economictimes.indiatimes.com/news/power/indias-power-demand-forecast-to-surpass-400-gw-by-2031-32-power-secretary/111425728>

3 Press information Bureau, press release: "Total installed thermal power capacity is expected to be 283 GW and non-fossil-fuel-based capacity to be 500 GW by 2031-32: Union Power and New & Renewable Energy Minister." <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=2003922>

4 IPCC (Intergovernmental Panel for Climate Change) (2021). Sixth Assessment Report: Working Group 1: The Physical Science Basis. Summary for Policymakers. <https://doi:10.1017/9781009157896.001>

5 Qian, Y., Scherer, L., Tukker, A., & Behrens, P. (2020). China's potential SO2 emissions from coal by 2050. *Energy Policy, 147*, 111856. <https://doi.org/10.1016/j.enpol.2020.111856>

6 Zheng Yixuan, Qiang Zhang, Dan Tong, Steven Davies, and Ken Caldiera (2020). Climate effects of China's efforts to improve its air quality. *Environ. Res. Lett.* 15 104052. <https://doi.org/10.1088/1748-9326/ab9e21>

of 24x7 electricity in India. Generally, Indian coals (barring Assam and Meghalaya coals) have very low Sulfur content (0.3% - 0.5%) and high-ash content unlike coals burnt by TPPs in countries like China.

The Central Pollution Control Board (CPCB) conducted studies on stack emissions in various climatic conditions in India before mandating the minimum stack heights of TPPs to be 220 m for TPPs having generation capacities between 200 MW and 499 MW and 275 m for TPPs capable of generating 500 MW or more.[7] This mandate has worked effectively over the past 40 years because the ambient air concentrations of SO_2 around the vast majority of TPPs in India is well below the National Ambient Air Quality Standards. However, TPPs located in eco-sensitive areas or those located less than 10 km from the boundaries of metropolitan cities and those using high-Sulfur coal (largely imported) have been granted Environment Clearance (EC) on the condition that they instal & operate Flue Gas Desulfurizers (FGDs) to reduce the SO_2 emissions from the stack and Electrostatic precipitators (ESPs) to reduce Particulate Matter (PM) emissions.

In December 2015, the MOEFCC amended the Environmental (Protection) Rules (EP Rules) to mandate ~600 TPPs in India to reduce SO2 concentrations in the TPP stacks by installing FGDs. However, only 44 of the 537 operating TPPs mandated to retrofit FGDs in India have installed FGDs till September 2024, although 233 FGDs were procured by TPPs till 2023.

In March 2023, the Office of the PSA sanctioned a research project to NIAS to estimate incremental CO_2 emissions from FGDs and quantify Sulphur dioxide emission factors for TPPs. This study aimed to address the unique requirements and implications of deploying FGDs in India and detail alternative technologies for air pollution control from TPPs. This interim report submitted by NIAS summarises the work done till date which was presented in the Stakeholder meeting organised by the office of PSA on November 13, 2024. The key findings of the NIAS study are summarised as follows:

Key Findings

- The average sulfur content of Indian coals used to generate 92% of the electricity produced by TPPs is less than 0.5%, which is very low by international standards.
- The stacks of TPPs in India are 220 m tall (< 500 MW TPPs) or 275 m tall (TPPs with capacity >= 500 MW) as per the Central Pollution Control Board (CPCB) (1984) standards. These stack heights were designed to ensure the effective dispersion of SO_2 over a large area under the climatic conditions in India so that the ground-level (ambient) concentrations of SO_2 comply with the National Ambient Air Quality (NAAQ) Standards. This design basis has proved to be effective all over India since all available data indicates that the ambient SO_2 levels around TPPs are compliant with the current NAAQ standard for SO_2 (80 $\mu g/m^3$ on a 24-hour basis and 50 $\mu g/m^3$ on an annual basis).
- NIAS conducted a study of the air quality around two large TPPs operated by Public Sector Undertakings (PSUs) which utilize the low-sulfur coal mined in the Ramagundam coalfield in

7 CPCB (Central Pollution Control Board) (1984). Comprehensive Industry Document Series. Emissions Regulations Part-1.

Telangana during the 2017-2020 period. In this study, the stack emission data provided by these TPPs was also analyzed (Chauhan et al., 2021).

- As shown in Figure E1 and Figure E2, the stack emissions of Particulate Matter (PM) in both TPPs were compliant with the applicable norms - 100 mg/Nm^3 for TPPs commissioned prior to 2003 and 50 mg/Nm^3 for TPPs commissioned between 2004 and 1st January 2017.
- The concentrations of SO_2 in the stack emissions of both TPPs were in 1500 – 1600 mg/Nm^3 range due to their exclusive use of low-Sulfur Indian coal. Since both TPPs are complying with the stack height norms (CPCB, 1984) and ensuring an adequate exit velocity for the flue gases, the annual average ambient SO_2 concentrations measured in all Ambient Air Quality Measurement Stations (AAQMS) maintained by the two TPPs and the coal mines in and around the Ramagundam town were found to be in the range of 10-15 μg/m^3 – which is less than one-third of the NAAQ standard (Chauhan et al., 2021).
- This was confirmed by analyzing the air quality data collected by the Telangana State Pollution Control Board (TSPCB) in the Godavarikhani AAQMS located in the Ramagundam town where the annual average SO_2 concentration has not exceeded 10 μg/m^3 between 2016 and 2023 even after a new TPP (2 x 600 MW) capacity was commissioned in FY 2016-17 in the vicinity (Figure E3). This proves that FGDs are not required in TPPs using low-sulfur (<0.5%) Indian coal to comply with the NAAQ Standard for SO_2.

Figure E1. Stack emissions from a pre-2003, 2600 MW sub-critical TPS using low-sulfur Indian coal without High-efficiency ESPs and FGDs

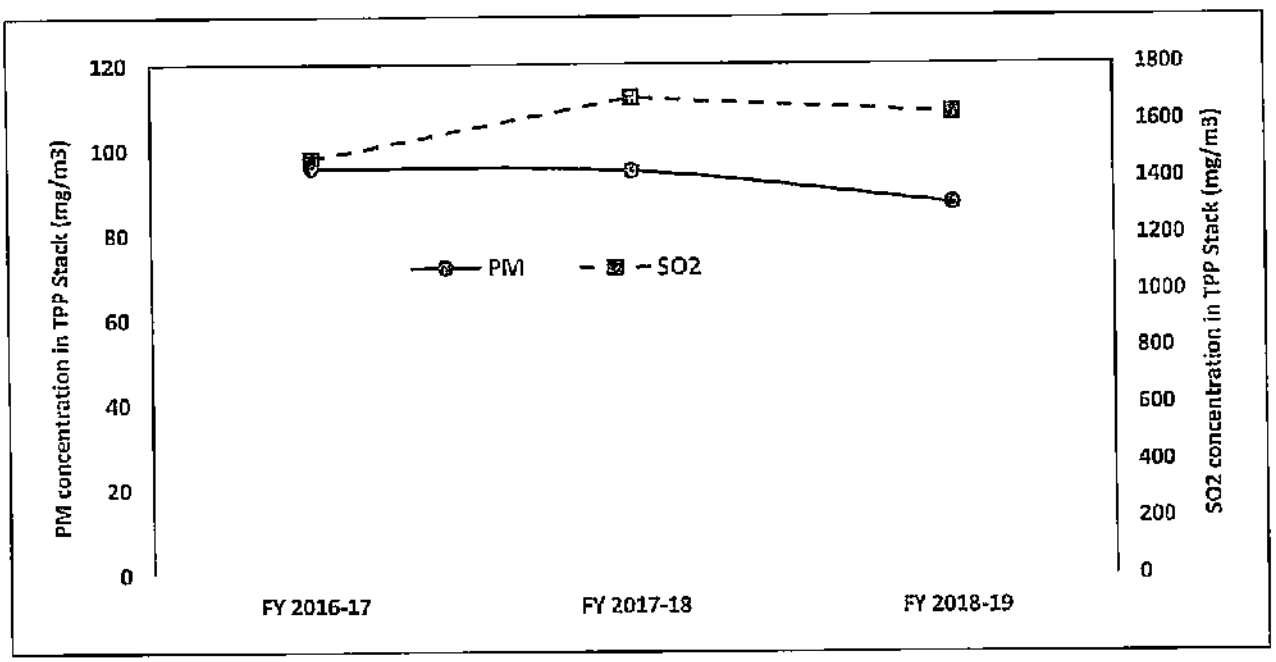


Figure E2. Particulate Matter (PM) concentration in the stack emission from a 1200 MW TPS equipped with sub-critical technology and a High-efficiency ESPs but no FGD

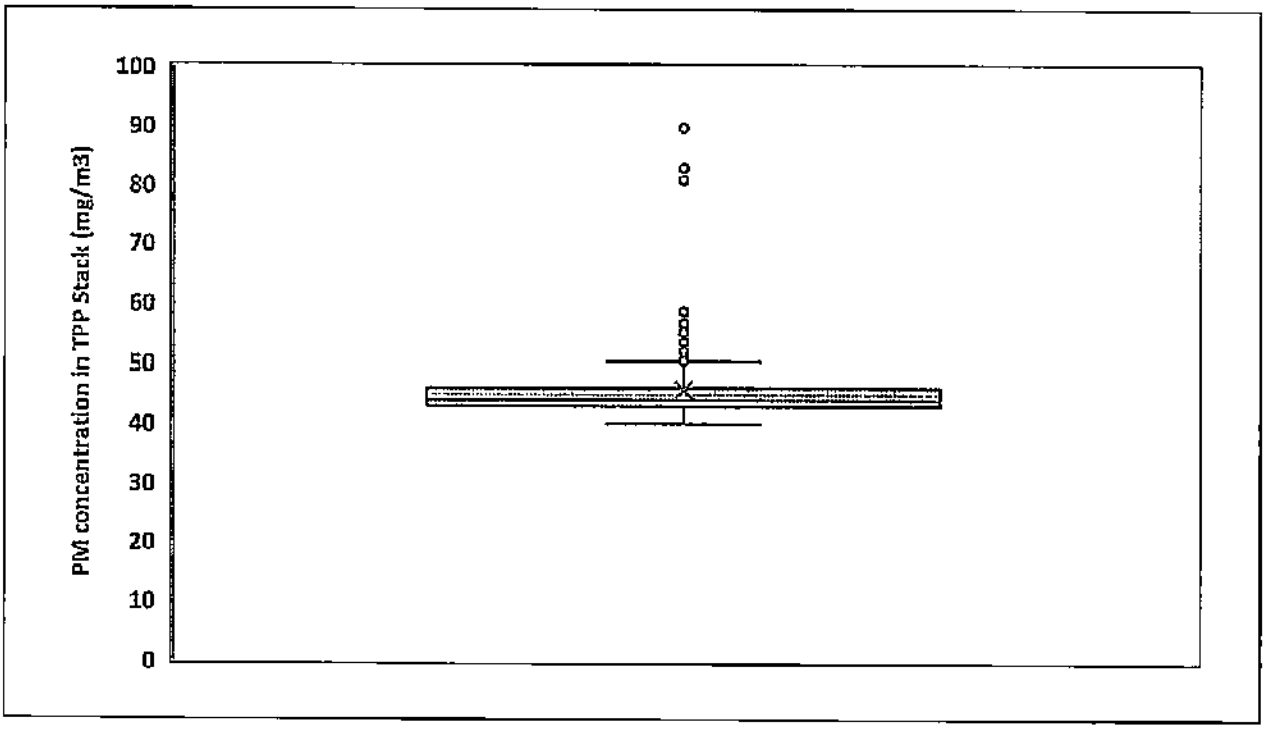


Figure E3. Sulfur dioxide (SO_2) concentrations recorded by the Telangana State Pollution Control Board AAQM station in Ramagundam comply with the NAAQ Standard.

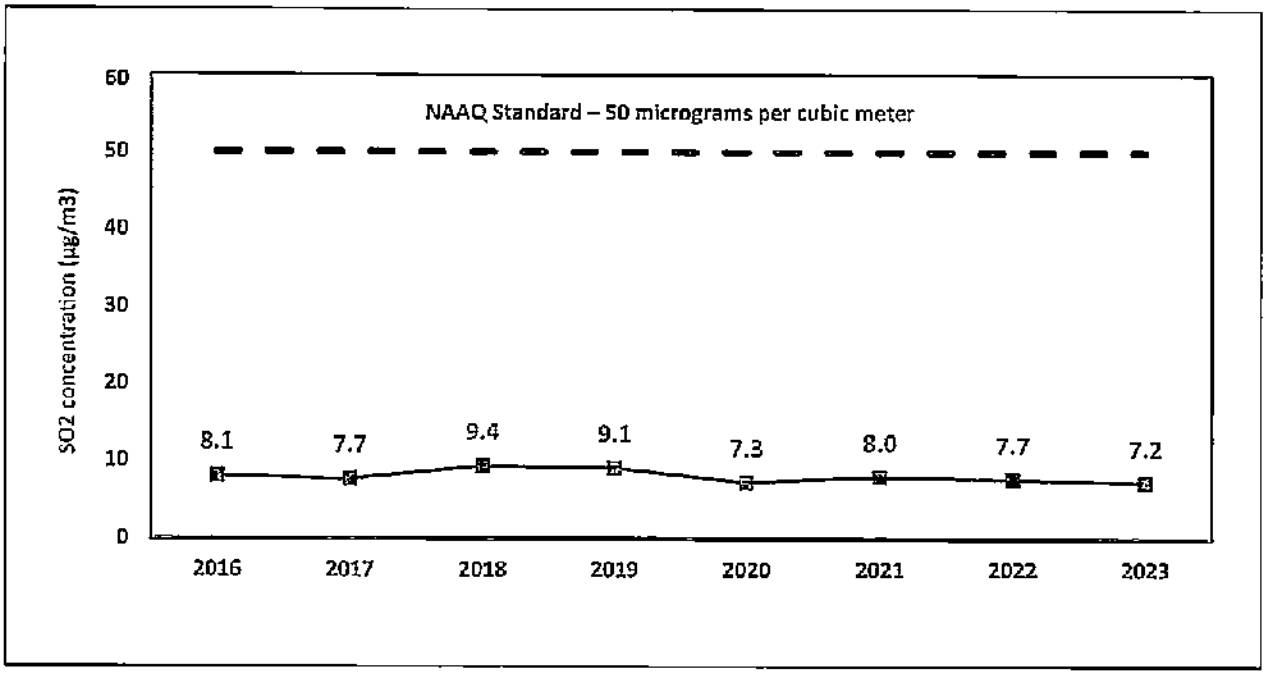
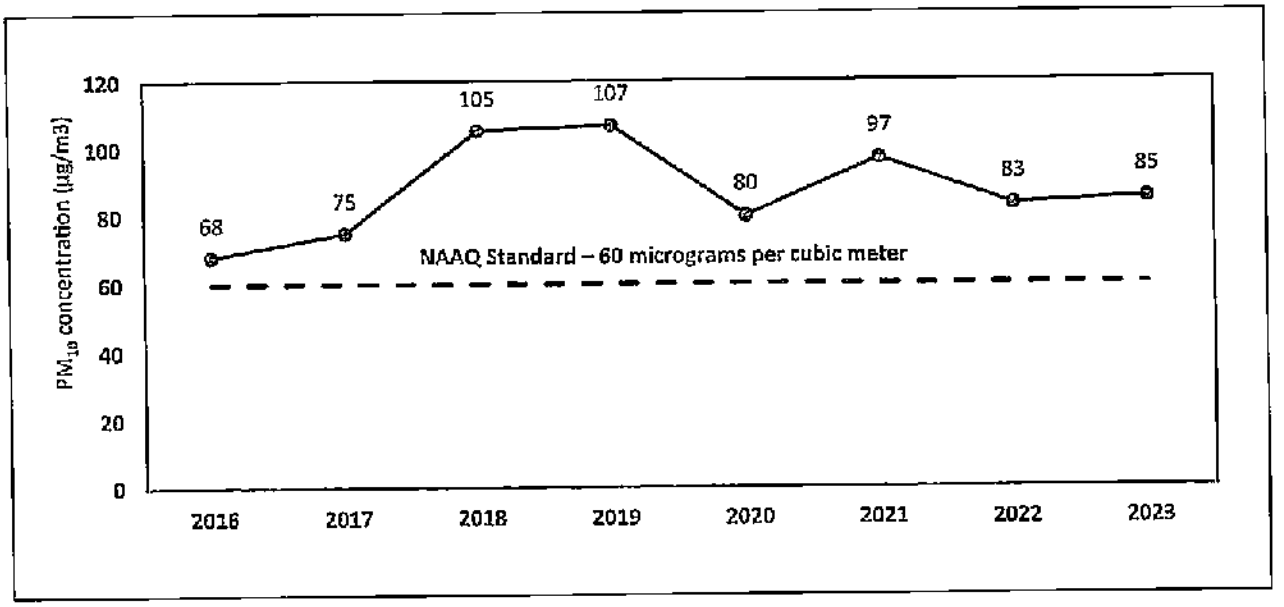


Figure E4. PM_{10} concentrations recorded by the Telangana State Pollution Control Board AAQM station in Ramagundam do not comply with the NAAQ Standard



- However, the PM_{10} concentrations recorded by TSPCB at the Ramagundam AAQM station continuously exceed the annual standard as shown in Figure E4. These measurements indicate that FGDs are redundant in controlling ambient air SO_2 concentrations in TPPs that use low-Sulfur Indian coal and comply with the stack heights specified in CPCB (1984) as well as the exit velocity of flue gases mandated in their original environment clearance.
- Studies by CSIR-NEERI (2024) and IIT-Delhi (2022; 2024) have also proved that FGDs have only a negligible impact on ambient air $PM_{2.5}$ concentrations in nearby towns. This is due to the predominance of other pollution sources (e.g., airborne dust, vehicular exhaust, various industries, use of coal/firewood for cooking) in urban areas and the very low (< 0.5%) Sulfur content of Indian coal coupled with the effective dispersion of SO_2 generated from TPPs due to the tall stacks and the climatic conditions in India.
- According to the CSIR-NEERI (2024) study, the ambient SO_2 concentrations around all TPPs in India (with and without FGDs) generally comply with the NAAQ standard.
- According to the IIT-Delhi (2024) report on FGDs, acid rain is not a significant issue in India due to the presence of alkaline substances in the dust. Even in coastal regions, the sea breeze, together with the alkaline nature of seawater droplets, effectively neutralizes any sulfuric acid formation in the atmosphere.
- On the other hand, installing FGDs in all TPPs by 2030 will increase the Auxiliary Power Consumption (APC) of the TPPs thereby adding approximately 69 million tons of CO_2 emissions to the atmosphere (2025-30) while reducing SO_2 emissions by ~17 million tons. While CO_2 accumulations in the atmosphere contribute to global warming, the IPCC AR 6 report states that anthropogenic SO_2 emissions have masked global warming by ~0.5°C in the 2010-2019 period relative to the 1850-1900 period. Therefore, adding more long-lived CO_2 emissions while removing

short-lived SO_2 emissions by installing FGDs indiscriminately in all TPPs in India despite the low Sulfur content of Indian coal will enhance global warming.

- Further, 80 GW of new thermal capacity (based on domestic, low-sulfur coal) will be added to the Power Grid to meet the baseload demand for electricity in India even after all obsolete and inefficient TPPs in operation today are progressively retired by the year 2032. Extending the study period to 2040 after accounting for the projected retirements and additions of TPPs, the cumulative CO_2 emissions from TPPs between 2024 and 2040 are estimated to be approximately 272 MT due to FGD installations.
- Installing wet FGDs in TPPs reduces their energy efficiency and increases freshwater consumption. Inland TPPs consume approximately 3.79 billion cubic meters of freshwater per year. NIAS estimates that freshwater consumption by TPPs will increase by about 9.6% in 2030 if FGDs are installed in all inland TPPs. Rather, MOP and the State Government can provide the policy support to enable TPPs to comply with the mandate to treat & use sewage water from municipalities within 50 km of the TPP. This is explained in Section 8.
- As per the Central Electricity Authority (CEA), 44 TPPs are equipped with FGDs while another 233 FGDs have been awarded out of 537 TPPs identified for installing FGDs in India. Retrofitting of FGDs in operating TPPs requires long shutdown times (+45 days), which is delaying the commissioning of FGDs even in TPPs that have awarded FGDs. Considering the low-Sulfur Indian coals, 220-275 m tall TPP stacks, and tropical climate around the TPPs in India, NIAS recommends no further need for FGD installations till further studies are undertaken to assess the impact of FGDs in controlling secondary PM pollution from 32 TPPs located within 10 km of cities with +1 million population which have either installed FGDs are at various stages of installing FGDs to comply with the MOEFCC (2015) SO_2 norms. In any case, there is no justifiable need to enforce the MOEFCC (2015) stack emission norms for SO_2 in TPPs in other areas of the country that use coal with less than 0.5% Sulfur content.
- The NIAS study also indicates that Particulate Matter (PM) pollution is the major problem attributed to TPPs using high-ash Indian coal. PM pollution from TPP stacks can be addressed quickly and cost-effectively by retrofitting indigenous High-efficiency ESPs in all TPPs irrespective of their size or location (Figure E5). Installation of High-efficiency ESPs will reduce the stack emissions of PM by 99.97% and enable TPPs to comply with the MOEFCC (2015) stack emission norms for PM (50 mg/m^3 for TPPs installed up to December 2016). Controlling PM emissions from TPP stacks at this level will make the maximum impact on air pollution from TPPs even without FGDs. Without such High-efficiency ESPs, the ambient air concentrations in the communities around TPPs will not comply with the NAAQ standard in the summer and post-monsoon seasons.
- Bharat Heavy Electricals Ltd. (BHEL) has retrofitted High-efficiency ESPs even in older TPPs with space constraints (Figure E6). Installation of such ESPs will cost only Rs. 25 Lakhs per MW compared to Rs. 120 Lakhs per MW for wet FGDs based on imported technology. Further, retrofitting High-efficiency ESPs in operating TPPs requires only 2 days of boiler shutdown for hookup, unlike FGDs which require ~45-day boiler shutdowns during FGD commissioning.

Key Recommendations

- Particulate Matter (PM) pollution is the key concern related to air pollution from TPPs. BHEL has demonstrated the retrofit of High-efficiency ESPs in TPPs with space constraints. Therefore, PM pollution control in TPPs to be prioritized by retrofitting High-efficiency ESPs in all existing TPPs to reduce PM pollution by 99.97% within the next two years.
- Since 32 of the 65 TPPs within 10 km of cities with ÷1 million population have either installed or awarded FGDs, the impacts of FGDs in terms of PM pollution reduction in these cities must be assessed before any future FGDs are awarded.

Figure E5. High-efficiency Electrostatic Precipitator (ESP) installed by BHEL in a TPP in India

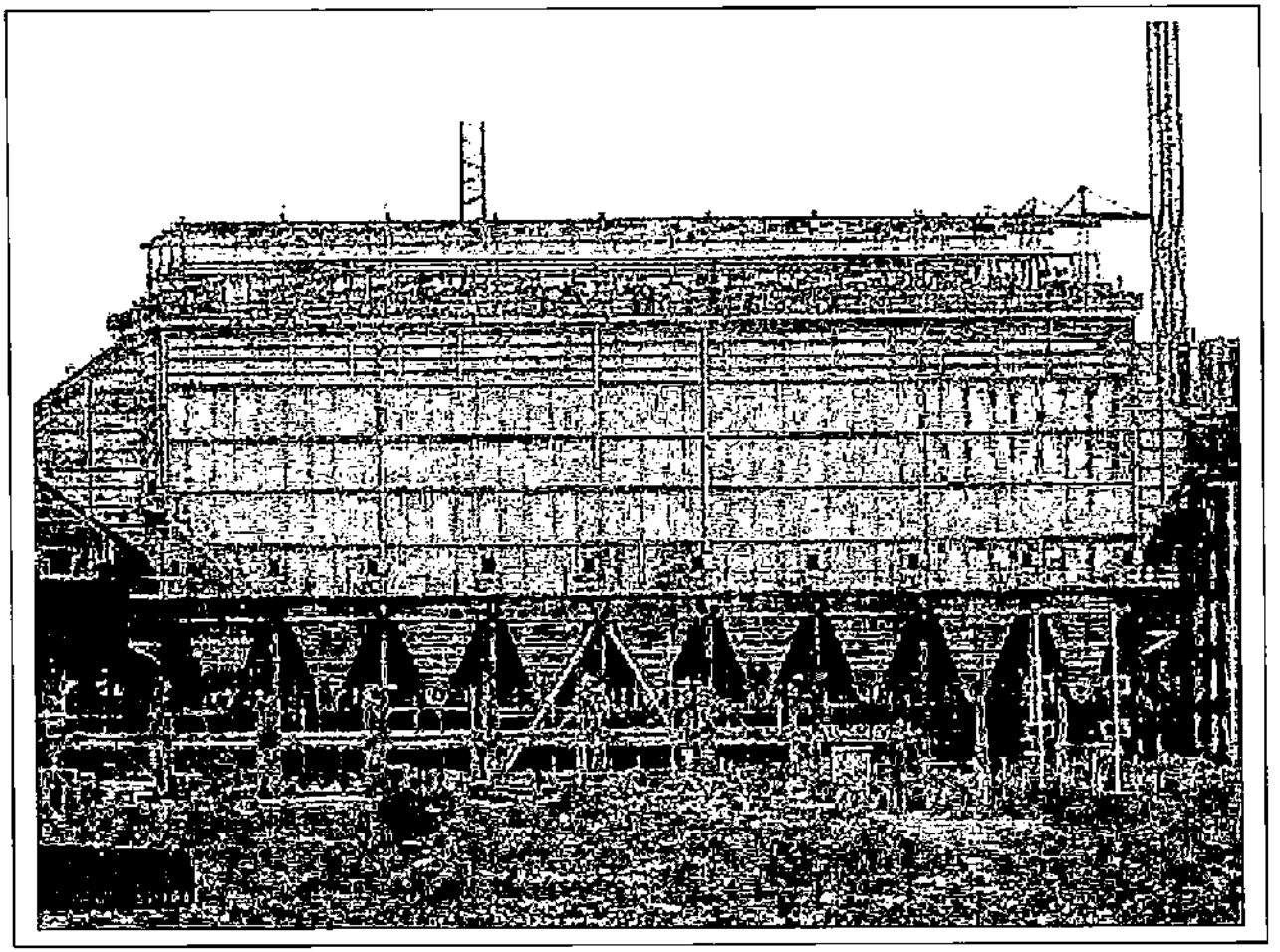
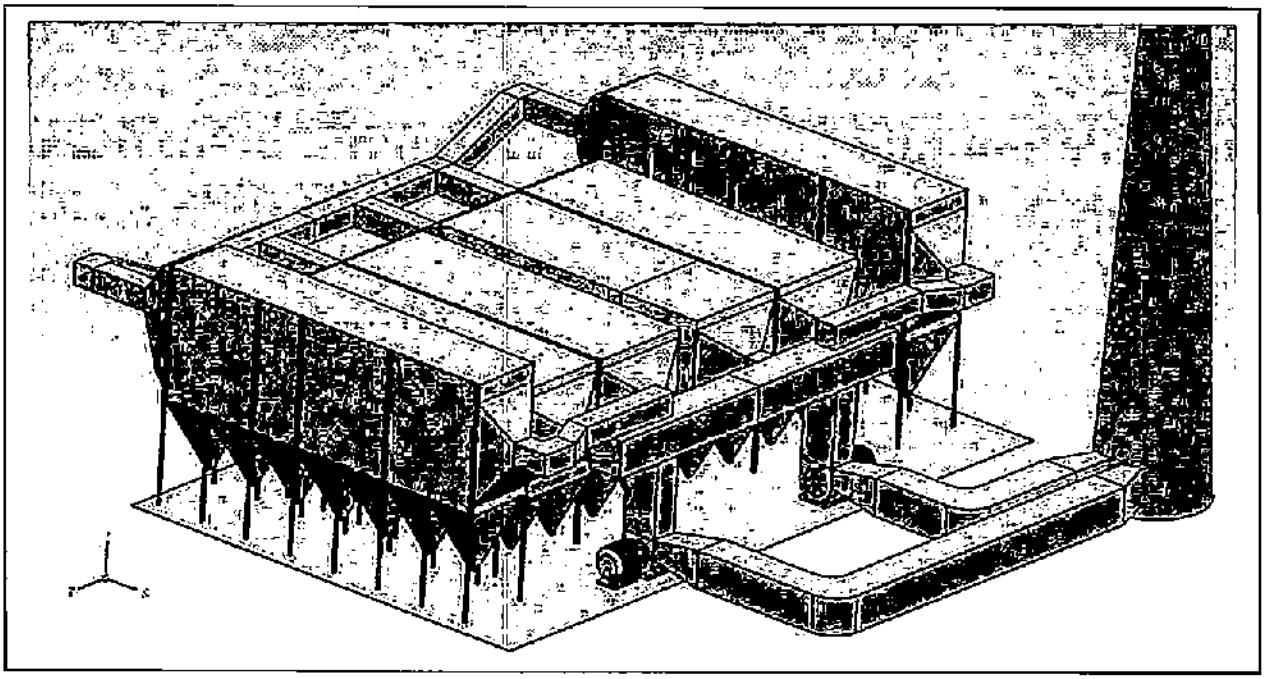


Figure E6. Retrofit of a new, taller ESP field in parallel with the existing ESP by BHEL in a 210 MW TPP to reduce PM concentrations in the flue gases by 99.97%



- TPPs retiring by 2030 to be exempted from SO_2 stack emission norms since these will normally be the obsolete stations with a proportionately lesser contribution to the total electricity generation in the country. This will avoid saddling electricity consumers with large tariff hikes to recover the cost of the FGDs within a short period.
- There is no tangible benefit of fitting FGDs in TPPs not located within 10 km of cities with +1 million population if they are using low-Sulfur coal. Rather, they must be equipped with High-efficiency ESPs for the reasons explained earlier.
- The Environmental (Protection) Rules, 2015 to be amended to limit the SO_2 stack emission norms only to TPPs using Imported coal and/or High (> 0.5%) Sulfur coal.
- Since all new TPPs are (i) based on domestic low-Sulfur coal, (ii) designed with High-efficiency ESPs, and (iii) located more than 10 km away from any city with +1 million population, FGDs to be avoided in TPPs awarded from January 2024 onwards.
- Implementation of these decisions will reduce PM pollution without the adverse impacts of FGDs (higher levels of water consumption & CO_2 emissions), while limiting the financial burden on the power sector thereby minimizing electricity tariff hikes on account of FGD installations.
- India is the 2nd largest coal user after China. Hence, the impact on global warming by installing FGDs in all TPPs must be assessed as has been done in China (Section 1.2.3).
- The effect on India's NDCs if FGDs are installed in all TPPs must be quantified.

- Since coal supplied from domestic coal mines accounts for 92% of the power generated in India, and this reliance is going to increase in future, there should be a greater thrust on the enablers required to use high-ash, low-Sulfur Indian coal more efficiently.
- Using coal washed at the pithead will not only reduce air pollution from TPPs & coal transportation but will also enhance ESP performance as well as boiler efficiency thereby reducing CO_2 emissions. Using washed coal will also reduce water consumption in TPPs. The washeries must be designed & operated to ensure that the ash content of rejects is +62% so that they are unfit for any end-use other than backfilling the coal mine void.
- An integrated cost-benefit analysis of using washed coal in TPPs must be conducted since the dependence on high-ash domestic coal for power generation will continue in India.
- CO_2 emissions from TPPs can be minimized by burning coal more efficiently compared to the current levels of efficiency achieved in the super-critical power plants of India. Integrated Gasification Combined Cycle (IGCC) power plants use coal and water more efficiently and enable CO_2 capture in an efficient manner. While MOC is pursuing Coal gasification projects, MOP must incentivize deployment of IGCC-based power plants.

1. Introduction

1.1 BackgroundTop of Form

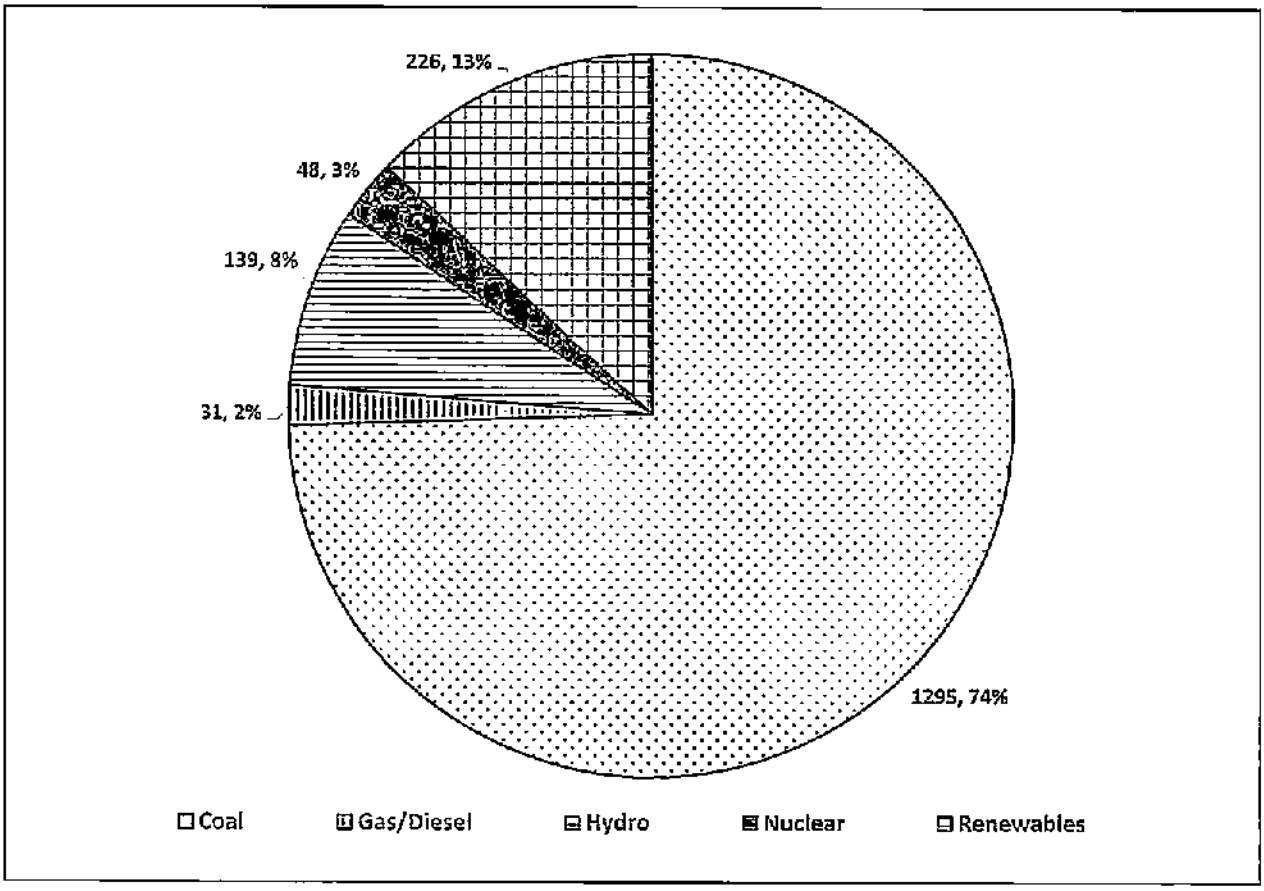
1.1.1 Power Scenario of India

India was ranked as the third-largest electricity producer in the world in 2023, generating 1814 TWh annually, following the China (9566 TWh) and USA (4412 TWh), respectively (IEA, 2024). The fuel-wise break-up of the 1735 TWh of electricity generated by utilities (power generators that supply electricity to the grid) during 2023-24 is shown in Figure 1. The total installed electricity generation capacity of utilities (power generators that supply electricity to the power grid) as of 31 March 2024 was 442 GW. Of this, non-fossil fuel based capacity (solar, wind, hydro, and nuclear) constitutes 45% (199 GW) and the balance consists of fossil-fuel based generation capacity including 218 GW of coal (CEA, 2024a). India's utility-based annual electricity generation reached 1735 TWh in FY 2023-24, marking a Y-o-Y growth rate of 7%. Out of this, coal-based thermal power plants (excluding the captive power plants) generated approximately 1295 TWh, accounting for 74.7% of the total electricity generation. Concurrently, the electricity generation from Variable Renewable Energy (VRE) sources (mainly, Solar and Wind) reached a record-high of 226 TWh, equivalent to 13% of the total electricity generated by utilities. Since VRE sources are intermittent in nature, balancing these sources will be crucial to ensure the stability of the electricity grid till the time storage facilities are developed to a sufficient degree.

The National Electricity Plan (NEP) projections indicate that the installed capacity of coal-based TPPs will reach 259.6 GW by 2031-32 even after assuming a higher contribution from RES and battery energy storage systems (CEA, 2023a). However, the power demand in India is increasing more rapidly than the projections in the NEP due to sharp economic growth prompting the CEA to increase its peak demand projection to 388 GW by FY 2031-32 from the 366 GW projected in the 20th Electric Power Survey and increase the targeted coal-based TPP capacity to 283 GW (CEA, 2022a; CEA, 2024b).

According to the International Energy Agency (IEA, 2024), in 2023, India's coal demand (721 Mt of coal-equivalent or Mtce) was the second highest in the World, only behind China (3469 Mtce) and just ahead of USA (294 Mtce). This indicates the continued reliance of the power sector on coal-based generation. Coal, being an abundant and consistent source of energy is capable of meeting the rapidly growing demand for electricity in India, thus playing a crucial role in ensuring energy security and affordability. Moreover, coal-based power generation significantly contributes to industrial growth directly impacting the economic growth of developing countries like India. The Plant-Load-Factor (PLF) of coal-based TPPs has been increasing continuously for the last 4 years after declining a steady decline between FY 2009-10 and FY 2020-21 (CEA, 2024a).

Figure 1 : Fuel-wise electricity generation by Utilities in India during FY 2023-24



In 2023-24, the total coal received by TPPs in India was amounted to 864.3 Mt, comprising 798.6 Mt (92%) of domestic coal, and 66 Mt (8%) of imported coal. Further, since coal production is showing an increasing trend due to the operationalisation of commercial coal mines as well as the improved performance of the PSUs engaged in coal mining, new TPPs envisaged in the next 8 years to meet the increasing baseload demand are based on domestic coal only. Therefore, the projected increase in coal-fired power generation capacity based on low-sulfur, high-ash domestic coal to meet the anticipated surge in energy demand underscores the need for TPPs to:

- reduce PM pollution by retrofitting indigenous High-efficiency ESPs in all TPPs on mission-mode;
- avoid increasing the CO_2 emissions factor and specific water consumption by indiscriminate use of FGDs in TPPs located outside 10-km from million+ cities and using domestic low-sulfur coal, and
- increase efficiency by increasing the use of washed coal and commencing the deployment of Integrated Gasification and Combined Cycle (IGCC) technologies.

These steps will facilitate our country's energy security while ensuring the sustainable development for power generation ensure energy security and environmental sustainability while meeting India's Nationally Determined Contributions or NDCs (Srikanth and Bhatt, 2023).

India is implementing a robust climate action plan through its updated NDCs, which include an ambitious clean energy transition. India has also submitted its Long-Term Low Carbon Development Strategy (LT-LEDS) to the UNFCCC in November 2022. India committed to achieving 500 GW of non-fossil energy capacity by 2030, thereby reducing the net carbon emissions by 1 billion tons by 2030. This is in line with the country's pledge to reduce carbon intensity by less than 45% by 2030 and achieve net zero carbon emissions by 2070 (MOEFCC, 2022).

1.1.2 The Role of Coal in India's Energy Transition

The reliance on coal-based power generation cannot be eliminated in India's energy mix in the foreseeable future. Intermittent RES cannot be considered to provide energy security, since they are not firm power sources and can cause large fluctuations in the power distribution network because of the diurnal and seasonal variabilities. The energy sector requires reliable baseload power sources to integrate variable RES and balance the grid, necessitating continued dependence on coal-based generation.

Given the rapid growth in electricity demand and slow-paced RES capacity addition during 2022-24, generation planning studies by CEA indicate that the coal-based installed capacity must reach 283 GW by FY 2031-32 from the present (October 2024) level of 217 GW (PIB, 2024). Aligning with these new projections, another 80 GW of coal-lignite-based additions are planned in the next 10 years as per a recent press release from the Ministry of Power (PIB, 2024). Against this, 29 GW of coal-based capacity is already construction while an additional 51 GW of thermal capacity is at various stages of planning & development to meet the power demand during & after FY 2031-32.

1.2 Thermal power plant emissions

Clean air is a crucial and non-negotiable element for environmental well-being as well as toward ensuring better health and quality of life. However, there have been serious concerns over the continuously deteriorating air quality in the dense urban centres across India, posing significant risks to the health of living beings and the environment. Air pollution can have short-term effects due to exposure within a few hours or days, as well as long-term effects such as reduced life expectancy and premature death due to prolonged exposure over several years.

Another critical area that needs holistic intervention is the socio-environmental impacts induced by climate change. Although greenhouse gases (GHGs) do not exhibit immediate health effects akin to toxic air pollutants, they are capable of trapping heat (long-wave radiation) reflected from the earth's surface, thereby increasing the temperature of the lower atmosphere.

While transitioning completely to renewable sources can tackle air pollution and climate change issues, the unreliability of variable RESs would affect the access to reliable power at the consumer end. Therefore, until clean, firm, and affordable power generation alternatives are identified, coal will continue to remain the backbone of the Indian power sector. This necessitates continuous exploration of avenues to ensure sustainable and responsible use of coal in power production. This was envisaged way back in 2012 when the 12th Five Year Plan was finalised and it was declared that all TPPs to be

installed from the 13th Five Year Plan onwards will be based on supercritical technology. As a result of this far-sighted decision the average thermal efficiency of coal-based TPPs in India improved drastically over the years. As of 30 September 2024, supercritical and/or ultra-supercritical technologies are used in 100 TPPs with a total generation capacity of 69.53 GW which is nearly one-third of the total TPP capacity of 217.6 GW on the same date. Further, all 39 of the under-construction TPPs with a total capacity of 28.4 GW as of September 2024 are based on supercritical or ultra-supercritical technology (CEA, 2024c).

The Advanced Ultra-supercritical (AUSC) technology proven at a pilot plant scale in India has demonstrated an efficiency of 46 percent which will reduce CO_2 emission by 20% compared to a sub-critical TPPs and by 11% as compared to supercritical TPPs (MHI, 2023). This is yet another step in the journey of technology upgradation of India's thermal power sector to increase its efficiency and reduce its emissions intensity (PSA, 2019).

1.2.1 Characteristics of Indian Coal

The type of coal used in TPPs of India differs significantly from the coal used in other countries. These unique characteristics need to be understood in detail before introducing emission reduction technologies in TPPs. Generally, Indian coals (barring the tertiary coals found in Assam and Meghalaya) used in thermal power plants can be characterized by high ash content (35 – 45% by weight), high moisture content (4-20% by weight), low Sulfur content (0.2 – 0.7% by weight), and low calorific values (3500 – 4000 kcal/kg on an average). The Sulfur content in Indian coal is significantly lower than that found in the US (1-1.8%) and Chinese coals (+1%) and is therefore classified as "very-low sulfur coal" (Chen-Lin Chou, 2012; Shiyan Chang et al., 2016; Wang Qingyi, 2001).

1.2.2 CO_2 emissions from thermal power plants (TPPs)

Carbon dioxide is the most significant greenhouse gas (GHG) with the highest impact on global warming (IPCC, 2021). This is primarily due to its substantial abundance in the atmosphere although its global warming potential (GWP) is low compared to some other GHGs such as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). An immense volume of CO_2 is emitted into the atmosphere continuously through fossil fuel combustion (coal, gasoline, and natural gas) and industrial processes. CO_2 requires a few centuries to equilibrate among the various carbon reservoirs of the atmosphere, the ocean, and the terrestrial biosphere. After equilibration with the ocean, a significant fraction (~ 20-40%) of CO_2 will be removed from the atmosphere via the slow weathering processes and deposition of $CaCO_3$ (which takes about 3000 to 7000 years). The residual quantum of CO_2 is abundant enough to have a substantial climate impact for thousands of years owing to its large half-life and long-wave radiation capture potential (IPCC, 2021). The climate change caused by the increase in CO_2 concentration will persist for a millennium due to the long atmospheric lifetime of CO_2, even after emissions cease. Some of the irreversible effects of global warming include a reduction in the off-peak rainfall in several regions and a substantial rise in sea levels due to the accelerated melting of glaciers & ice sheets, as well as the thermal expansion of the warming ocean. Therefore, the reduction of CO_2

emissions is of paramount importance to prevent long-term changes and irreversible damage to the overall climate (IPCC, 2021).

Since India's CO2 emissions have surged in recent years as the country tries to enhance energy access and overcome its development deficit, several commitments have been made under India's Nationally Determined Contributions (NDCs) to the United Nations Framework Convention on Climate Change (UNFCCC). These include a pledge to reduce the emissions intensity of its Gross Domestic Product (GDP) by 45% by 2030 (MOEFCC, 2022). These commitments reflect India's recognition of the urgent need to reduce CO_2 emissions and contribute to global efforts to combat climate change. Given India's current reliance on coal for more than 60% of its energy production, achieving these targets will require significant efforts (Srikanth and Bhatt, 2023).

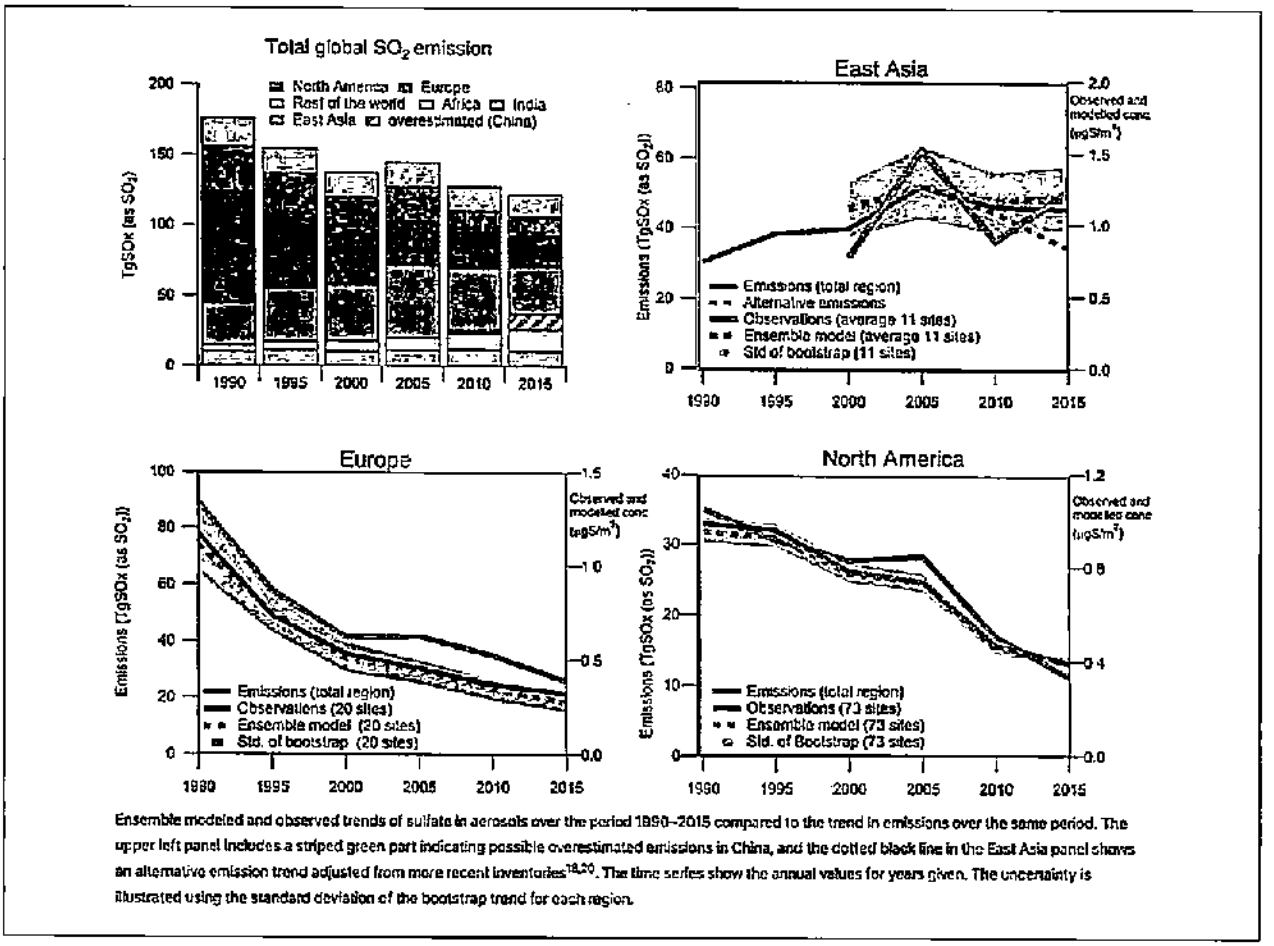
1.2.3 SO_2 emissions from TPPs

TPPs are major emitters of SO_2. The SO_2 emissions from TPPs depend on the sulfur content of coal that undergoes combustion inside the TPP boilers. Sulfur dioxide (SO_2) is a heavy, colourless, and poisonous short-lived gas with a pungent odour. High concentrations of SO_2 in the atmosphere form sulfurous smog and smog formation is further reinforced by the presence of particulate matter. Moreover, SO_2 can combine with nitrogen oxides and ammonia to form particulate matter. Burning of fossil fuels and natural volcanic eruptions emit SO_2 in larger quantities into the atmosphere.

Sulphate aerosols are formed by the oxidation of the SO_2 gas emitted from the stack. These aerosols impact the climate by modifying the radiative forcing, thereby affecting cloud reflectivity and precipitation. The sulphate aerosols scatter the solar radiation and cool the earth's surface resulting in a positive radiative forcing (IPCC, 2021). In 2021, the Working Group 1 (WG1) of the Intergovernmental Panel on Climate Change (IPCC) published its Sixth Assessment Report (AR6) quantifying the contribution of different gases to global warming. As per IPCC (2021), the cumulative emissions of CO_2 & methane have increased global warming by about 1.5°C, while SO_2 emissions have masked global warming by ~0.5°C in the 2010-2019 period relative to the 1850-1900 period.

Global SO_2 emissions declined by approximately 55 TgSO2 (31%) from 1990 to 2015 though the changes varied between regions (Aas, 2019). The largest reduction in worldwide SO_2 emissions from 1990 to 2000 was mainly due to a large reduction in Europe (~42 $TgSO_2$/~54%) coupled with a smaller decrease in North America (~7 $TgSO_2$/~21%) and an increase in East Asia (+10 $TgSO_2$/32%). In the 2000–2015, period, SO_2 emissions in Europe and the US decreased by ~14 and ~13 $TgSO_2$, respectively. While SO_2 emissions in Eastern Asia increased by more than 20 TgSO2 (70%) up to 2005, there was a reduction of ~6 TgSO2 (~13%) between 2005 and 2015. India's SO_2 emissions increased from 4.5 to 15 TgSO2 during the entire 25-year period from 1990 to 2015, which must be due to the steady growth in coal-fired power generation. These trends are shown in Figure 2 (Aas, 2019; 2020).

Figure 2 : Global trends in SO2 emissions (Aas, 2019)



Ensemble modeled and observed trends of sulfate in aerosols over the period 1990–2015 compared to the trend in emissions over the same period. The upper left panel includes a striped green part indicating possible overestimated emissions in China, and the dotted black line in the East Asia panel shows an alternative emission trend adjusted from more recent inventories[18,20]. The time series show the annual values for years given. The uncertainty is illustrated using the standard deviation of the bootstrap trend for each region.

Zheng et al. (2018) explain the various policy measures and technological improvements implemented in China to reduce the emissions of all air pollutants. Specifically, while the consumption of coal in China increased from 3,445 Mt in 2010 to 3,708 Mt in 2017, the emissions of SO_2, PM_{10}, and $PM_{2.5}$ from TPPs decreased by 62%, 38%, and 35%, respectively, mainly due to FGD installations. However, CO_2 emissions from the power sector increased by 16% during the same period (Zheng et al., 2018).

However, Qian et al. (2020) explain that the reduction in SO_2 emissions in China due to the operation of FGDs "*will result in an increase in global average temperature between 2016 and 2050, estimated at ~0.6°C.*" Climate simulations conducted by Zheng et al. (2020) based on a fully coupled ocean and atmosphere climate model indicate that China's reductions in SO_2 emission rates by approximately 70 percent (23.5 million tons) by fitting FGDs in all TPPs between 2006 and 2017 "*may exert a net increase in global radiative forcing of 0.09 ± 0.03 W m^{-2} and a mean warming of 0.12 ± 0.01 °C in the Northern Hemisphere; and may also affect the precipitation rates in East Asia and in more distant regions.*" The success of Chinese policies to reduce aerosol emissions (mainly by fitting FGDs to reduce SO_2 emissions) may bring additional net warming, and this 'unmasked' warming would in turn compound the challenge and urgency of global climate mitigation efforts (Zheng et al., 2020).

When the SOx gases mix with moisture clouds, the suspended water molecules become more acidic, forming sulfuric acid that can cause acid rain in extreme cases. However, acid rain is not a significant issue in India due to the presence of alkaline substances in the dust. Even in coastal regions, the sea breeze, together with the alkaline nature of seawater droplets, effectively neutralizes any sulfuric acid formation in the atmosphere (IIT Delhi, 2024).

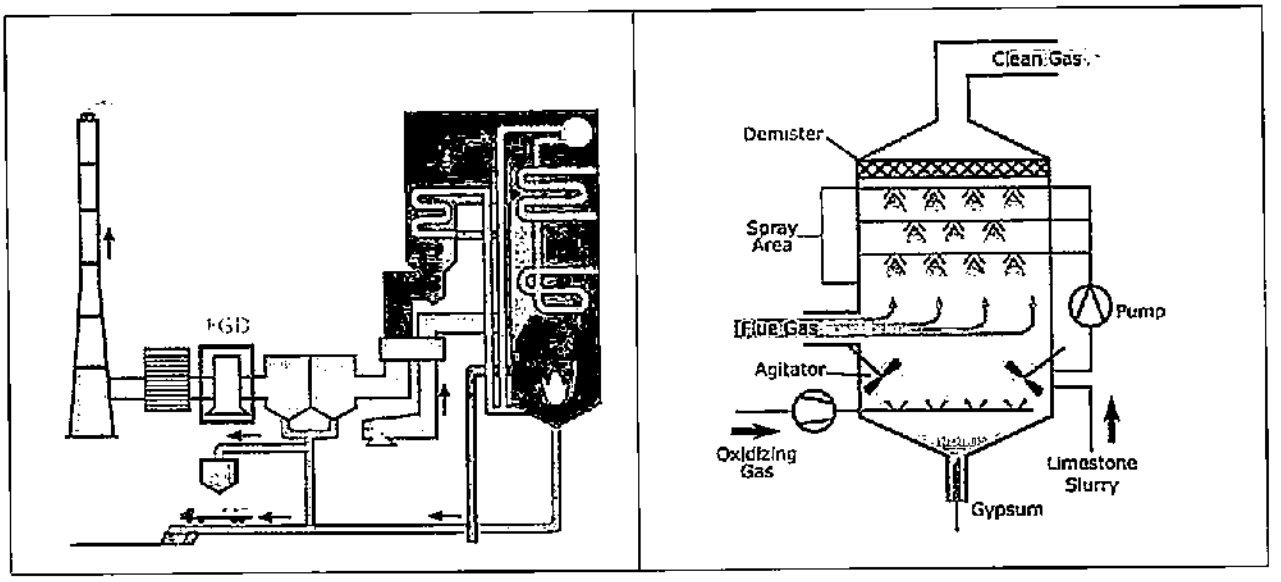
1.2.4 Flue Gas Desulfurizer (FGD)

During the combustion process, 95% of the sulfur present in the coal gets converted and released as SO_2 gas through the TPP stack. The production of SO_2 is directly proportional to the amount of coal consumed and the sulfur content in the coal. To achieve the new emission norms declared by the government, power plants are required to install scrubbers which are also called FGDs.

FGDs work on the principle that SO_2 gas can be neutralized using sodium or calcium-based alkaline reagents such as limestone or seawater. TPPs located along the sea coast (which are largely designed to use imported high-sulfur coal with or without blending domestic low-sulfur coal) use sea water to absorb the SO_2 from flue gas in power plants. Seawater FGDs are a low cost, environment-friendly option for coastal TPPs since they do not create any by-products or waste that need to be treated or disposed of, though they tend to raise the temperature of the outlet water by 1-2°C which has to be mitigated by the TPP if the final temperature of the outlet water exceeds the norms (CEA, 2019a).

Wet FGDs used in inland TPPs use freshwater which is not useful to neutralise the SO_2 emissions on its own. In India, wet FGDs generally use limestone, which must be mined and transported to the TPP. The limestone is crushed to such a fine size that 90% of the crushed limestone passes through a 325-mesh screen and is therefore finer than 44 microns (CEA, 2017).

Figure 3 : Thermal power plant exhaust system and wet FGD schematic diagram



Wet FGDs are the dominant technology in fossil-fuelled large power plants. Most of the FGDs installed in India are wet FGDs. Figure 3 shows the exhaust system of a TPP along with the position of the FGD unit. Initially, the hot flue gas (150°C) discharged from the boiler is passed through an electrostatic precipitator (ESP) and the fly ash is removed. Then the flue gas is fed to the SO_2 absorber. The absorber is steam-saturated with an absorbent (reagent) and water. The limestone absorbs the SO_2 present in the flue gas and converts it into gypsum The reactions happening in the FGD are described below.

1. Limestone Dissolution: Limestone is pulverized and made into a slurry.
   a. $CaCO_3 + H_2O \rightarrow Ca^{2+} + HCO_3^- + OH^-$
2. SO_2 Absorption: SO_2 is absorbed by water in the slurry converting it into sulfur-based acid.
   a. $SO_2 + H_2O \rightarrow H_2SO_3$
   b. $H_2SO_3 \rightarrow H^- + HSO_3^-$
3. Oxidation: Sulphite (SO_3) is converted into sulphate (SO_4)
   a. $HSO_3 + O_2 \rightarrow H^+ + SO_4^{2-}$
4. Precipitation: The absorbed sulphate ion reacts with calcium and forms gypsum
   a. $Ca^{2+} + SO_4^{2-} + 2H_2O \rightarrow CaSO_4.2H_2O$ (gypsum)

1.2.5 Phased implementation Plan for FGD installation

To control the emissions by coal-based TPPs, MOEFCC amended the Environment Protection Rules, 1986 and notified the new emission standards for PM/SO_2/NO_x on the 7 December 2015. The emission norms are based on the date of commissioning and the capacity of the plants. Initially, the TPPs were advised to strictly adhere to the norms by 2017, which was subsequently revised three times to prioritise the TPPs where FGDs have to be progressively fitted since the spare power generation capacity in the country is inadequate to permit the shutdowns (+45 days) required to hook up a large number of FGDs to the operating TPP while ensuring the required availability of power in the National electricity grid.

Since the process of FGD retrofits in existing TPPs takes at least three years from technical feasibility study to commissioning, a Task Force comprising representatives from MOEFCC, MOP, CEA, and CPCB categorized the TPPs into three categories A, B, and C with different timelines for emission norm compliance (CPCB, 2022). This Task Force also came up with estimates for the environmental compensation for the different TPP categories (A, B, and C) in case of non-compliance. Categories A and B were considered as critical categories since these TPPs are within 10 km of a city with a population of at least one million and a severely polluted area, respectively. Category C encompasses all other TPPs.

Table 1 shows the categorization with the latest timelines for compliance by non-retiring TPPs. Since Particulate Matter (specifically PM_{10}) pollution is the criteria pollutant to declare a city as a Non-Attainment city in India, there should have been a similar focus on compliance with PM emission norms forming part of the same MOEFCC (2015) notification. However, the focus on PM pollution from TPPs is missing.

Table 1 : New environmental norms for thermal power plants (MOEFCC, 2015)

Year of Installation	Standards in mg/Nm3			
	PM	SO2	NOx	Hg
Before 31st Dec 2003	100	< 500 MW – 600 ≥ 500 MW - 200	600	≥ 500 MW - 0.03
Between 1st Jan 2004 and 31st Dec 2016	50	< 500 MW – 600 ≥ 500 MW - 200	300	0.03
On or After 1st Jan 2017	30	100	100	0.03

The timelines for implementation of FGD for Categories A, B, and C were initially December 2022, December 2023, and December 2024, respectively. However, extensions were granted to these timelines twice considering the operational challenges faced by the TPPs. The TPPs would require undergoing a shutdown period of 5-6 months to retrofit FGDs into existing plants. In contrast, newly constructed TPPs require only 3-4 months to install these units. Since the prolonged shutdown of operational TPPs significantly impacts the revenues for Generating Companies (GENCOs), the retrofitting process has been delayed or temporarily halted even for those TPPs that have already placed orders for the FGDs. Besides the operational challenges, several financial and technical difficulties contribute to the delays in installing FGDs. The high cost of FGDs and the availability of limited funding pose significant financial constraints. The complexity of integrating FGDs into the existing infrastructure of older TPPs and the need for specialized equipment and skilled labour further complicate and prolong the installation process. As per the latest information obtained from CEA (Private Communication), the number of TPPs in which FGDs are installed till October 2024 is, 44 (22.6 GW), of which 12 TPPs are in Category A, three TPPs (1340 MW) are in Category B (1.8 GW), and the balance 29 TPPs (15.9 GW) are in Category C. Besides these 44 TPPs, 233 TPPs (102 GW) have awarded FGDs for which approximately Rs. 122,000 Crores are committed. Thirty-three (33) TPPs in Category A (7.3 GW capacity), 39 TPPs in Category B (11.9 GW), 188 TPPs in Category C (60.3 GW) have not ordered FGDs till now. These 260 TPPs (79.6 GW) must mobilise a capex of approx. Rs. 96,000 Crores for FGD retrofits alone.

Table 2 : Categorization of TPPs for phase-wise installation of FGDs as per CPCB (2022)

Category	Location/Area	No. of Units (Capacity)	Timelines for compliance
A	Within a 10 km radius of the National Capital Region (NCR) or cities having a million plus population (as per the 2011 census of India)	65 (20.4 GW)	31st Dec 2024
B	Within a 10 km radius of Critically Polluted Areas or Non-attainment cities (as defined by CPCB)	66 (23.3 GW)	31st Dec 2025
C	Other than those included in categories A & B	406 (160.5 GW)	31st Dec 2026
Total	All non-retiring TPPs excluding CFBC-based TPPs	537 (204.2)	

2. Objectives

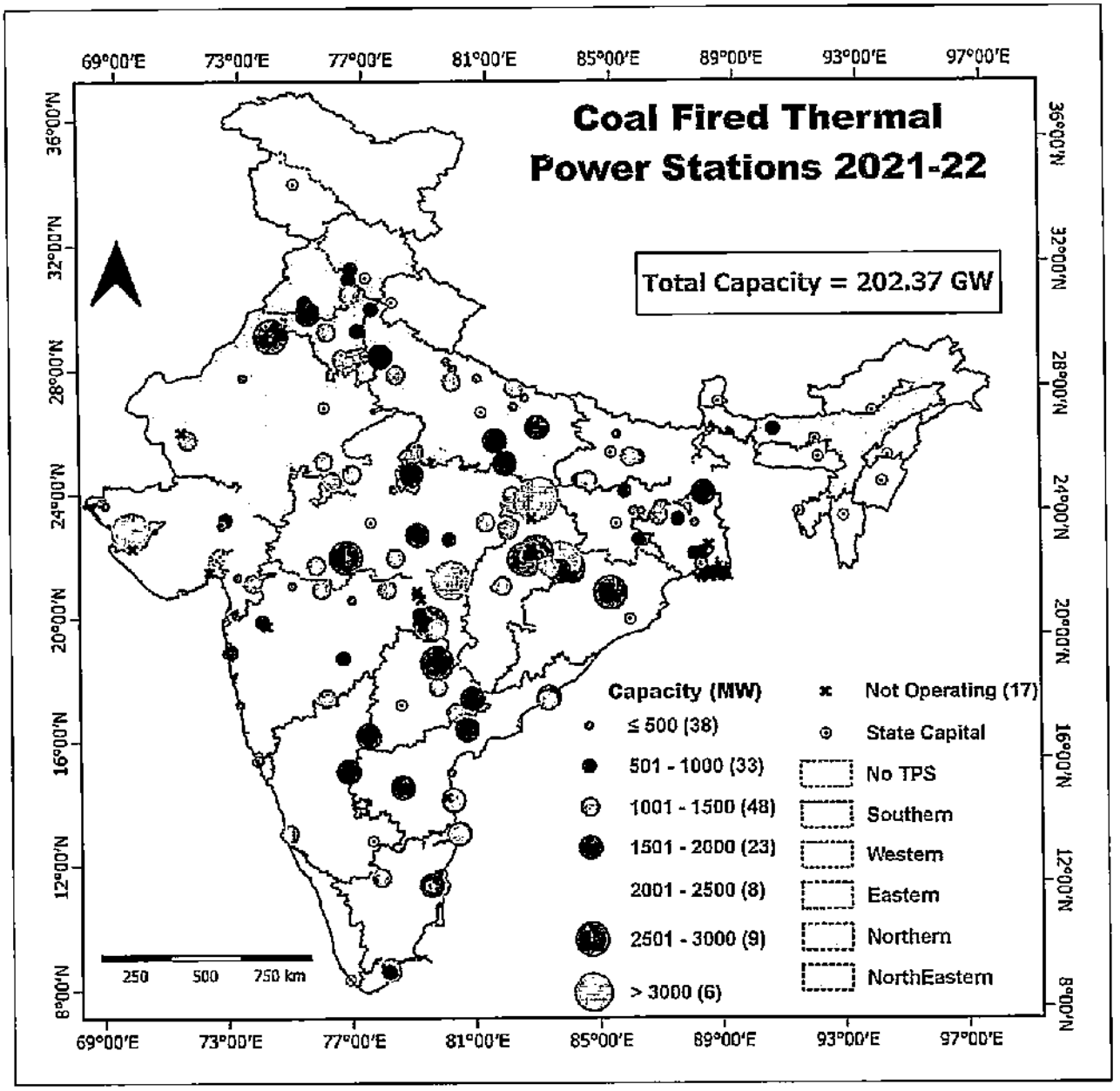
The overarching goal of this research project is to study the interactions between energy security, the environment, and climate change and advance our scientific understanding, which are directly related to the Sustainable Development Goals (SDGs). The objectives are:

- To quantify the CO_2 emissions from the existing and future coal-fired TPPs In India for the years 2030 and 2040, accounting for the projected electricity demand and newer technologies and their likely year of commissioning.
- To quantify the emissions attributed to coal-based TPPs considering the sulfur content of coal and the boiler technologies deployed in the TPPs.
- To estimate the increase in global average temperature between 2020 and 2040 based on the reductions in emissions from TPPs post installation of FGDs.
- To propose alternative strategies for air pollution control in TPPs based on their location, technology, efficiency, local meteorological conditions & affordability.

3. Study Area

Thermal Power Stations (TPSs) contribute the largest share of electricity in India. Initially, all the coal/ lignite-based utility TPPs, operational in FY 2021-22 (base year) were considered for quantifying their CO_2 & SO_2 emissions. The locations of the operational TPS in India in FY 2021-22 are shown in Figure 4, with circular markers of different colours indicating their installed capacities.

Figure 4 : Geographical locations of operational Thermal Power Stations in 2021-22



Thermal Power Stations in India are typically divided into five regions: Eastern, North-Eastern, Northern, Southern and Western. These regions are also shown in different shades in the figure. The Western region has the highest installed capacity of coal-fired TPS (76.06 GW) followed by the Northern Region (58.53 GW) and the Southern Region (53.5 GW) with the Eastern Region coming last with 28.5 GW. with similar capacities, 45.6 GW (140 units) and 40.9 GW (105 units), respectively. The total installed generation capacity of utility-owned TPS as of March 2024 is 217.59 GW which is distributed among 17 states, with the highest installed capacity in Uttar Pradesh, followed by Chhattisgarh. Assam is the only state in the North-Eastern region with 949 GW of coal-fired TPP capacity as of March 2024. The total lignite-fired TPP capacity is only 3% (6.62 GW) of the total TPP capacity of 217.59 GW of coal-fired TPP capacity operated by utilities in India. There is hardly any growth in lignite-fired TPPs since lignite is mined in limited quantities only in three States (Tamil Nadu, Rajasthan, and Gujarat) though lignite-fired TPPs play a key role in providing electricity in these three States. The total lignite-fired electricity generation 34 (TWh) in India is only 2.6% of the total coal-based electricity generated by utilities (1295 TWh) in India (CEA, 2024a).

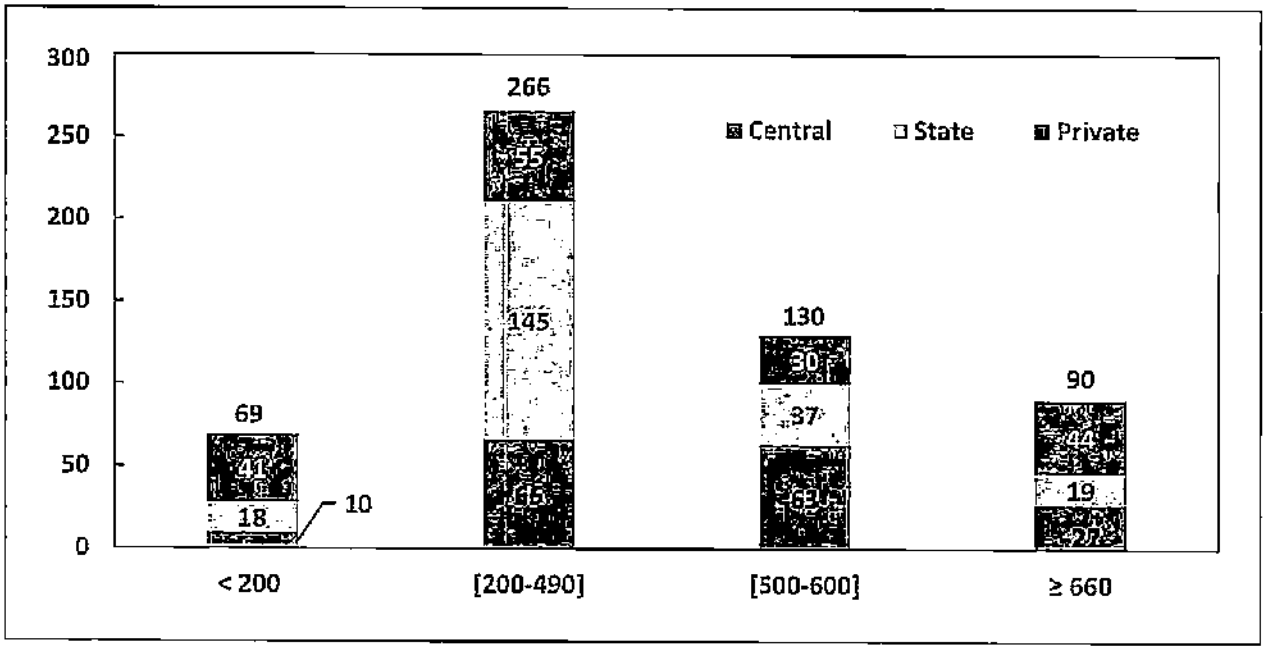
4. Data

The first step in this project was to create a database of operational TPPs along with their geographical coordinates and other parameters. FY 2021-22 is considered as the base year for building the database from the data collected from various government reports since this study commenced in April 2023. The list of operational TPPs along with their operational status and installed capacity is obtained from the CEA report for 2021-22 (CEA, 2023b). This report provides granular data on electricity generation, transmission, distribution, and consumption across various sectors/categories for the FY 2021-22. Among the TPPs, only utility TPPs are considered in the database. The list of operational TPPs is compared with the master list prepared by NIAS considering 2018-19 as the base year for first-level validation to prepare a consolidated database of TPPs in India. This consolidated database comprises key information such as location details (including geographical coordinates), year of commissioning and retirement, FGD unit installation status, installed capacity, generation profile, coal consumption (both domestic and imported), CO_2 emissions, and unit-wise specific water consumption levels.

The base year (FY 2021-22) included 591 TPPs in 182 thermal power stations in India. Among them, 509 units were found to be operating and actual data regarding their generation, fuel consumption, and CO_2 emissions were extracted from the relevant CEA reports. In addition, 46 TPPs with a total capacity of 23.44 GW which are commissioned but not operating since they are considered as '*stressed*' assets are also considered in the database. In addition to the inclusion of their locations, the precise coordinates of TPPs are collected from various reports and websites such as the Global Coal Plant Tracker to capture the geospatial distribution of the emissions from these thermal power plants. The units are clustered based on their geographical locations, and coordinates for the stations are marked in the database. The locations where planned TPSs are likely to be installed in the future, the TPSs that are not operational, and the TPSs with no information available in the open-source domain are marked using different symbols for distinct identification.

The total operating capacity of the 555 coal-based utility TPPs considered in the database is 202 GW which recorded a gross generation of about 1079 TWh. The TPPs use a considerable portion of their generated power to meet the in-house auxiliary power requirements. The average auxiliary power consumption in TPPs of India is around 8-9%. The open-source information suggests that the average auxiliary power consumed by the subcritical and supercritical TPPs is approximately 9.2% and 7.3 % of the gross generation, respectively. The net electricity generation from TPPs after considering the auxiliary power consumption is approximately 993 TWh in FY 2021-22. TPPs are categorized into three sectors, central, state, and private based on their ownership and operation. Sector-wise distribution of TPPs in 2021-22 is shown in Figure 5, along with the number of units in each nameplate capacity range. However, CEA (2024c) indicates that 39 TPPs with a total capacity of 28.4 GW are under construction as of September 2024 since there are expectations of a shortfall in the electricity generation by variable renewable energy (VRE) sources compared to the projections in the National Electricity Plan which is now under revision.

Figure 5 : Sector-wise TPP installed capacity in 2021-22



TPPs installed with Circulating Fluidised Bed Combustion (CFBC) technology and are not required to install FGDs since they capture the SO_2 gas from the flue gas and convert it to gypsum. Besides, there are a few smaller (pre-2003) TPPs with SO_2 emissions lesser than the applicable norms due to various reasons including the use of low-sulfur coal. The TPPs with FGDs/CFBC technology/other technologies are ignored for the purpose of this study. Similarly, lignite-based generation is assumed to be constant @34 TWh between now and 2040 since there is no plan for any major change in the installed capacity of lignite-fired TPPs in India.

The Baseline Carbon Dioxide Emission Database (Version 18.0) documented in CEA (2022b) was used as the source for the data regarding gross electricity generation (GWh), actual auxiliary consumption (%), net electricity generation (GWh), absolute CO_2 emission (tonnes), and specific CO_2 emission rate (t_{CO2}/MWh). Gross electricity generation is the annual total generated electricity in the plant considering their PLF. Net generation is the electricity available for distribution after auxiliary power consumption. The specific CO_2 emission rate is the average CO_2 emitted per unit of electricity generated in the grid. For the base year, the rate is calculated by dividing the absolute CO_2 emissions of all power stations by the total net generation. The station-wise specific CO_2 emissions for the base year are included in the database. As shown in Table 3, the specific CO_2 emissions are averaged over certain ranges of installed capacity for estimating the future CO_2 emissions of TPPs in this study.

The same formula is utilized to estimate the CO_2 emissions in the futuristic scenarios of 2030 and 2040. The annual coal consumption data of the stations are estimated from the station-wise coal receipt and consumption data for 2021-22 based on CEA reports. These reports provide the total amount of domestic and imported coal received by each TPS and the total quantum of coal consumed (Table 4). Data on unit-wise actual consumption of imported coal is not available in the public domain.

The TPS-wise coal consumption is distributed among the units (TPPs) within the TPS based on their installed capacities.

The total water consumption of the TPS can be estimated in a particular year based on the specific water consumption (amount of water consumed per unit of electricity generation) and the amount of electricity generated in that year. The actual specific water consumption of each TPS during FY 2021-22 is obtained from the CEA report of annual environmental emissions by TPPs. The specific water consumption levels available from various sources are compared with the relevant CEA norms and shown in Table 5.

Table 3 : CO_2 emission factors for different TPP capacities based on FY 2021-22 CO_2 data

Unit Capacity Range (MW)	Specific CO2 emission (t/MWh)
≤ 75	1.19
100-150	1.05
180-270	1.05
300-400	0.99
500 – 550 (Type 1- units before 1996)	1.00
500 – 550 (Type 2 – units after 1996)	0.97
600	0.97
660	0.87
800	0.85

Table 4 : Comparison between actual coal consumption and our estimates for 2021-2022

	Actual Data (MT)	Estimates from Database (MT)
Total Coal receipt	694.6	-
Domestic coal receipt	667.6	-
Imported Coal receipt	27	-
Total Coal consumption	697.3	695.14

Table 5 : Specific water consumption data versus CEA norms (Source: Various CEA Reports)

Category	Data available units	Norms (m3/MWh)	Average Specific water consumption (m3/MWh)
TPPs installed before 2017	2	3.5	3.77
TPPs installed after 1st January 2017	37	3	2.90

5. Methodology

5.1 Emission Modelling for FY 2021-22

For generating the database, a master sheet with TPPs actual data for 2021-22 is generated initially. For the distribution of station-wise data among units, validation of the methods, and estimation of emissions, python programming is mainly used. Using NumPy and Pandas libraries, the database is converted into a data frame and calculations are done. The master list consists of the details of the TPPs, metadata that describes the headers, descriptions of the parameters, their units, and other relevant details. The specific CO_2 emissions, specific coal consumption, and specific water consumption are also fed to the master list in the form of a table to be used during the generation of the database.

5.1.1 Preparation of 2021-22 database

For 2021-22, the actual data collected from various CEA reports are included in the database. The coal consumption and CO_2 emissions are available at the station level, which are distributed among their units based on this installed capacity. There are 21 TPPs (units) with no generation and CO_2 emission data available. Since their coal consumption data is available, we consider them as operational in the base year and the gross generation is estimated from the installed capacity and annual PLF of 2021-22.

PLF is commonly considered as a metric to quantify the efficiency of the power plant. The coal-based thermal plants in India are incentivized to operate with an average PLF of 85% which is also known as normative PLF. Analysis shows that a 10% reduction in PLF would result in decreasing the efficiency by 1.3% implying strong dependence of efficiency on PLF. Hence, considering the maximum efficiency, the normative PLF is usually considered for the estimation of specific coal consumption rate and CO_2 emission rate. When the PLF goes below than this normative value, efficiency reduces and in turn coal consumption and CO_2 emissions increase proportionally. In 2021-22, the average PLF achieved by TPPs (including captive power plants) was 58.87%, and 99 TPPs achieved a PLF higher than the All-India average in that year. However, the PLFs of TPPs have increased steadily with the growth in electricity demand. Specifically, the All-India average PLF of TPPs was 64.15% in FY 2022-23 which has increased to 69.09% in FY 2023-24 (CEA, 2024a).

The gross generation is estimated based on the PLF & installed capacity using Equation 1

$$Gross\ generation(GWh) = \frac{capacity\ (GW) \times PLF\ (\%) \times 24 \times 365}{100} \quad (1)$$

The CO_2 emissions of each TPS are estimated using Equation (2), based on an average auxiliary power consumption of 8%, the gross electricity generation from the TPS and the CO_2 emission factor based on the average values given in Table 3.

$$Abs.CO_2\ Emission(Mt) = Gross\ generation(GWh) \times Specific\ CO_2\ rate\left(\frac{t}{MWh}\right) \times 10^{-3} \quad (2)$$

5.1.2 Validation of the absolute CO_2 emissions estimation method

Since an average CO_2 emission factor is used for each TPP capacity range (Table 3), an error may be introduced in the estimation of CO_2 emissions in futuristic scenarios. Hence, to validate the method utilized for the estimation of absolute CO_2 emissions, the CO_2 emissions for the base year are estimated using the actual gross generation and CO_2 emission factor (Table 3) and are compared with the actual data provided by the CEA-CDM database (CEA, 2022b). The average error introduced due to the use of an average CO_2 emission factor was found be only ~2%. Therefore, this methodology is adopted to estimate future CO_2 emissions in this study.

5.1.3 Estimation of SO_2 emissions by TPPs in 2021-22

The SO_2 emissions from the stacks of TPPs can be estimated using suitable emission factors in conjunction with coal consumption data (Varshney and Garg, 1978). Emission factors are developed based on previous stack gas sampling data and material balances for specific gaseous emissions from point sources. Considering the average sulfur content of domestic coal as 0.4%, the SO_2 emissions from the TPPs using domestic coal can be estimated using Equation (3).

$$SO_2\ emission\ (Mt) = 19 * 0.4 * \text{domestic coal amount (kt)} \times 10^{-6} \quad (3)$$

To estimate the SO_2 emissions from TPPs using imported coal, the average sulfur content of imported coal used by TPPs is considered to be 0.9%. For a plant installed with a FGD, it is assumed that about 90% of the SO_2 gas in the flue gas produced is captured and removed as gypsum. Hence only 10% of the estimated SO_2 emissions from the stack are considered as the actual emissions from a TPP fitted with a FGD.

5.1.4 Estimation of total freshwater consumption by TPPs in 2021-22

Water is one of the key requirements for power generation. It is required for the cooling process in the condenser, for ash disposal, to remove heat generated in plant auxiliaries, and other purposes. For inland TPPs water is drawn from the freshwater sources such as rivers, reservoirs, and barrages. For coastal areas, plants make use of seawater for cooling processes and auxiliaries and install desalination plants for other water requirements The water consumption of each TPP can be estimated using Equation (4) utilizing the specific water consumption value available in our database.

$$Water\ consumption(Bcm) = Gross\ gen.(GWh) \times Sp.consumption\ rate\left(\frac{m^3}{MWh}\right) \times 10^{-6} \quad (4)$$

The average specific water consumption levels for the sub-critical and super-critical TPPs are estimated separately (Table 5) to arrive at the overall water consumption of TPPs. This provides an estimate of freshwater consumption by all the operational TPPs.

5.2 Emission Modelling for FY 2023-24

To conduct a comparative analysis between the base year and current year FY 2023-24, the actual data on total installed capacity is collected from the capacity reports provided by National Power Portal. The details of new additions and retirements are considered from the power plant database provided by the 'Indian Climate and Energy Dashboard' portal. The database is modified for TPPs that have been retired or commissioned to ensure that the capacity information accurately reflects the current status. Using this updated capacity data, gross generation at an 85% PLF is estimated using Equation (1).

Given that the TPP-wise CO_2 emissions for FY 2023-24 have not yet been published by the CEA, our estimates are based on the estimated gross generation of each TPS (NPP, 2024). Utilizing the actual count of TPPs within each capacity range considered by the CEA for specific CO_2 emission levels, a weighted average of the specific emission levels across the operational TPPs is estimated and applied to Equation (2) to estimate the total CO_2 emissions from the operational TPPs in FY 2023-24.

To estimate the SO_2 emissions for FY 2023-24, the station-wise gross consumption estimates of both imported and domestic coal are obtained from CEA reports. Assuming a 90% capture efficiency for FGDs, the SO_2 emissions are computed separately for these two categories using Equation (3). The summation of the SO_2 generated from each TPP in the database is estimated to be the total SO_2 emitted from the thermal power utilities in India in FY 2023-24.

To estimate the freshwater consumption from TPPs in FY 2023-24, the average specific water consumption rates for the sub-critical and super-critical TPPs derived for FY 2021-22 (Table 5) are multiplied with the corresponding generation from individual TPPs in the FY 2023-24.

5.3 Emission Modelling for FY 2030-31

Our primary objective is to quantify the incremental CO_2 and decrease in SO_2 emissions resulting from the installations of FGDs in TPPs. Despite the mandate by MOEFCC for the installation of FGDs in all the operational and new TPPs, delays caused by various factors have hindered progress. Therefore, three realistic scenarios for the year 2030-31 based on the FGD implementation in TPPs have been proposed to assess the incremental or decremental emissions caused by the installation. Each scenario involves estimating plant-specific emissions followed by cumulating them to quantify the total volume of emissions attributable to FGD installations.

5.3.1 Preparation of the 2030-31 database

As previously stated, all the operational TPPs in 2021-22 are included in the 2030-31 database. The data on the progressive retirements of TPPs have been sourced from the DST final report on the Transition plans of TPPS provided by NIAS. The retirement is determined based on criteria such as obsolete technologies, higher auxiliary power consumption, significant declines in operational performance, increased specific fuel consumption & costs, and an increase in the emission intensity rates of the TPPs. For the TPPs that were retired between 2022 and 2024, the actual retirement year of the TPPs is updated in the database. For potential retirements in the period of 2024-2030, the projected retirement years as per the NIAS-DST report are recorded. This expansion of generation is planned based on the premise of meeting the peak demand and energy requirements for the period 2022-2032 at the lowest possible cost. Specifically, 170 TPPs (out of the 591 operational units in 2021-22) with a combined capacity of 32,143 MW are projected to retire, while 37 units (26,240 MW) are added. Consequently, there are 458 operational units included in our FY 2030-31 database. Among the 170 TPPs projected for retirement between March 2022 and March 2031, four TPPs are equipped with FGDs while four TPPs are equipped with CFBC technology.

The gross electricity generation of TPPs is estimated using equation (1) considering the installed generation capacity. As previously noted, the normative PLF at which the TPPs operate with optimum efficiency is 85%. In FY 2023-24, the All India PLF of coal-fired thermal power stations has escalated to 69.09% while the PLF of central sector TPS has surpassed 75% in FY 2023-24 (CEA, 2024a). Given the rapid growth in energy demand, the predominance of central sector TPPs with supercritical/ultra-supercritical technology in the TPPs under construction, and the preference for pithead locations for new TPPs, we foresee that the average PLF of TPPs will reach 85% by FY 2030-31 to fulfil the energy requirements in an efficient manner. To facilitate an accurate comparison of the various scenarios considered in each time horizon, gross generation is kept constant and the additional generation to offset the auxiliary power consumption of FGDs is not included in the estimation.

The CO_2 emissions from the TPPs are estimated using Equation (2), considering the specific CO_2 emission levels derived from the 2021-22 data. To compensate for the auxiliary power consumption of FGDs, we assume that an additional 2% of the absolute CO_2 emissions will be produced by the TPPs when FGDs are in operation. If a TPP is equipped with an FGD unit, 2% of the gross generation is utilized for its power requirements. Consequently, this necessitates a 2% additional coal consumption leading to a corresponding 2% increase in CO_2 emissions. For better comparison among the scenarios, the generation is maintained constant, and the changes in auxiliary power consumption due to FGDs are reflected in the incremental amount of coal consumed and the consequent increase in CO_2 emissions.

To estimate coal consumption by the individual TPPs, the normative coal consumption stipulated by the CERC on 27th March 2019 for various capacity ranges of power plants are utilized. The norms provide a specific coal consumption rate, which represents the annual coal consumption by a TPP of a particular capacity range per unit capacity (CEA, 2019b). The normative coal requirement for TPPs is also given at a normative PLF of 85%, aligning with our assumptions. The specific coal consumption rates used in the calculations for different capacity ranges of TPPs are detailed in Table 6.

Table 6 : Normative coal requirement of the TPPs in the period 2019-24 (CEA, 2019)

Unit Capacity (MW)	Annual Specific Coal Consumption Rate (t/MW)
< 100	5840
100 - 200	5840
200 - 250	5615
250 & above (subcritical)	5335
660 MW (supercritical)	5054

The annual coal consumption is estimated using Equation (5), with an additional 2% factored into the calculations for the coal consumed to meet the power requirements of FGDs.

$$Absolute\ coal\ consumption\ (Mt) = \frac{specific\ coal\ rate\ \left(\frac{t}{MW}\right) * Capacity(MW)}{10^6} \quad (5)$$

In FY 2023-24, only 8 percent of the coal used in TPPs was sourced through imports with the balance 92 percent supplied by domestic coal mines. In FY 2031-32, CEA (2023a) has projected that only 28.9 Mt (<3%) of imported coal will be used out of a total coal consumption of 1025.8 MT by TPPs to generate 1566 TWh of electricity. Given the decline in use of imported coal due to the higher landed costs and the increase in supply of coal from domestic mines after the commencement of commercial coal mining by the private sector, we assume that coal-fired baseload power generation in India will rely almost entirely on domestic coal beyond 2030. Knowing the changes in the technology mix of TPPs we can therefore estimate the annual coal consumption (and the associated emissions) by TPPs for future years based on the use of domestic coal and the future thermal power scenarios, while individual TPP-wise CO_2 & SO_2 emissions can also be assessed separately in the final report of this study.

Considering the sulfur content in domestic coal as 0.4%, the SO_2 emissions from the TPPs are computed using Equation (3). After the removal of SO_2 gas by FGDs, it is assumed that only 10% of the estimated emissions are released through the stack, thus, only 10% is accounted as the total SO_2 emissions. The total water consumption is estimated using the Equation (4) and the specific water consumption levels outlined in Table 7.

Table 7 : Specific water consumption values used to estimate overall water consumption by TPPs

Type	Specific Water Consumption (m^3/MWh)
Subcritical (< 660 MW)	4
Supercritical (≥ 660 MW)	2.5

These are derived based on the new water consumption norms set by the CEA. For TPPs installed with FGDs, an additional 0.4 m^3/MWh is incorporated into the basic specific water consumption rate to offset the additional water requirements of the FGDs. The total water consumption for TPPs with FGDs installed can be estimated using the Equation (6).

$$Water\ consumption\ (Bcm) = Gross\ gen.\ (GWh) \times (Sp.\ consumption\ rate + 0.4) \times 10^{-6} \quad (6)$$

6. Scenario Development for FY 2030-31 and FY 2040-41

To assess the projected impact of FGD unit installation on emissions and water consumption of the TPPs, three scenarios are delineated based on the number of FGD installations anticipated in the period 2021-2030. As per the latest timelines for the compliance of FGDs, all operating TPPs in India are mandated to install FGDs by the December 2026. However, the current data from the CEA indicates that the progress significantly lags behind these timelines. The current (September 2024) status of FGDs in TPPs categorised as per CPCB (2022) is summarised in Table 8.

As shown in Table 13, only 44 TPPs (22.6 GW) have installed FGDs out of the 537 TPPs identified for FGD retrofits by the Central Electricity Authority as of September 2024, after accounting for retirement of TPPs and TPPs using CFBC technology. Out of the 65 TPPs identified as Category A TPPs located within 10 km of the National Capital Region (NCR) or +1 million population cities, only 12 TPPs have installed TPPs while 20 more operating TPPs have awarded contracts for the procurement, installation, and commissioning of FGDs. As per the current guidelines, all these 65 TPPs are mandated to have FGDs retrofitted by 31 December 2024. Since less than 20 percent of the TPPs in Category A have installed FGDs till date, it is clear that an extension of the deadline will be required in any case.

As shown in Table 8, 233 TPPs (102 GW) have awarded contracts for FGDs besides the 44 FGDs already installed. The lag between the award of FGD contracts and the commissioning of FGDs in so many TPPs is mainly due to the lack of the requisite 45-60 days shut-down period necessary for hooking up the FGD to the TPP. It is worth noting that critical FGD components costing about 20-30% of the FGD contracts by value are still imported, largely from China (CEA, 2024d).

While all 39 TPPs under construction (all with supercritical/ultra-supercritical technology) with a total installed capacity of 28.4 GW will be progressively commissioned 2030 along with FGDs, 33 TPPs in Category A (7.3 GW capacity), 39 TPPs in Category B (11.9 GW), and 188 TPPs in Category C (60.3 GW) have not ordered FGDs till now. These 260 TPPs (79.6 GW) are forced to mobilise a capex of approximately Rs. 96,000 Crores for FGDs at the current average FGD cost of Rs.1.2 crores per MW of installed TPP capacity (CEA, 2024d). Many TPPs among these 260 TPPs are not in a position to justify the exorbitant investments in FGDs since they use obsolete & inefficient technology and are due for retirement within 10 years.

Table 8 : Status of FGD installations in Thermal Power Plants in India as of September 2024

Categorization of Thermal Power Plants as per CPCB and CEA	FGDs to be installed in (Excl. CFBC)	Timelines for Compliance		FGDs installed Nos./ (GW)	FGDs awarded Nos./ (GW)
		Other than SO2 emissions	SO2 emissions		
Category A TPPs (Within 10-km radius of cities with +1 million population)	65 TPPs (20.4 GW)	31 December 2022	31 December 2024	12 (4.9 GW)	20 (8.1 GW)
Category B TPPs (Within 10-km radius of a Critically Polluted Area or a Non-Attainment City)	66 TPPs (23.3 GW)	31 December 2023	31 December 2025	3 (1.8 GW)	24 (9.6 GW)
Category C TPPs (other than those in Category A & B)	406 TPPs (160.5 GW)	31 December 2024	31 December 2026	29 (15.9 GW)	189 (84.3 GW)
Total	537 TPPs (204.2 GW)			44 (22.6 GW)	233 (102 GW)

Notes (CPCB, 2022; CEA, 2024d):

1. Out of the 600 identified TPPs operated by utilities in India as of September 2024, 53 TPPs are equipped with Circulating Fluidised Bed Combustion (CFBC) technology and are not required to be equipped with FGDs since they can remove SO2 emissions directly.
2. Further, 10 more TPPs have retired between 2022 and 2024. This leaves a total of 537 operational TPPs (600 – 53-10) to be retrofitted with FGDs as of September 2024.

Lastly, the retrofit of FGDs will increase electricity tariffs of TPPs with power purchase agreements (PPAs) by 50-55 paise per kWh which the State-owned DISCOMs (power distribution companies) have to recover from the final consumer (CEA, 2024d; MOP, 2018).

To establish a baseline for CO_2 and SO_2 emissions from TPPs in 2030-31, Scenario 1 presumes no further FGDs will be retrofitted in currently operational TPPs beyond the current installations of 44 FGDs and all 39 TPPs currently under construction. This will result in a total of 83 units fitted with FGDs among the 458 TPPs likely to be operational by 2030. The projected generation of 1514 TWh from coal-based Thermal Power Plants (TPPs) in 2030-31in our study is higher than the projection for coal-based power in the National Electricity Plan (NEP) which is only 1335 TWh compared to the 1295 TWh of coal-fired generation in FY 2023-24 . However, CEA (2023a) also projects the coal requirements for power generation in FY 2031-32 based on a projection of 1566 TWh of thermal power generation, which is 63% of the total electricity requirement from utilities. Since the peak demand projection for FY 2031-32 has been hiked to 388 GW (Vol II NEP) from 366 GW (Vol 1 NEP) and 80 GW of new TPP capacity is being progressively set up, a 63% share of coal in India's electricity generation in FY 2031-32 appears to be reasonable (CEA, 2023a; 2024b; PIB, 2024).

Scenario 2 is predicated on the assumption that all 233 TPPs (102 GW) where FGD contracts have already been awarded will be retrofitted with FGDs besides the 39 coal-fired TPPs (28.4 GW) under

construction with FGDs (CEA, 2024c). Consequently, 272 more TPPs (130.40 GW) will be equipped with FGDs by 2030-31 compared to the current scenario where only 44 FGDs are retrofitted in TPPs with a total generation capacity of 22.6 GW. Overall, TPPs with a total generation capacity of 153 GW (22.6+102+28.4) will be fitted with FGDs by FY 2030-31 as per this scenario.

Scenario 3 is the final scenario where all the 458 operating TPPs in FY 2030-31 will be retrofitted with FGDs regardless of necessity, except for those being scheduled for decommissioning. Scenario 1 will provide the baseline emissions projected for 2030-31, while Scenarios 2 and 3 will elucidate the potential consequences of FGD installations on emissions from the TPPs and their water consumption.

Considering the three scenarios, gross generation, coal consumption, CO_2 and SO_2 emissions as well as water consumption are estimated using the pertinent equations. The emissions can be compared to quantify the additional emissions attributable to the installation of FGDs in TPPs.

To maintain a consistent interval between the study periods, FY 2040-41 has been chosen as the next time horizon following FY 2030-31. Recent generation planning studies by CEA indicate that the coal-based installed capacity must reach 283 GW by FY 2031-32 from the level of 259.6 GW projected in the NEP (CEA, 2023a; PIB, 2024). We anticipate the additional capacity to come fully on stream only in the mid-2030s since only 18.4 GW of thermal capacity has been awarded till October 2024 besides the 29.2 GW of capacity under construction, while another 47 GW of thermal capacity is still at various stages of planning & development today (MoP, 2024a). The new thermal power projects will take time to achieve financial closure and secure all clearances before commencing construction.

The impact of adhering to the FGD implementation mandate in FY 2040-41 can be analysed by estimating the incremental CO_2 emissions and reductions in SO_2 emissions for this particular year. The three scenarios formulated for FY 2030-31, based on the implementation strategy of FGDs, are also considered for the FY 2040-41 period. The potential retirements during the period 2030-40 are not documented in any government reports. Therefore, the first objective is to project the capacity and energy demand for 2040-41, followed by the identification of potential retirements and additions.

Given this context, it is necessary to adopt a plausible scenario where the energy requirement is satisfied despite possible retirement. The TPPs older than 25-30 years and those with lower capacities (< 490 MW) must be retired due to their lower efficiency compared to the supercritical and ultra-supercritical TPPs that will dominate the power sector in the 2030s. While all TPPs with obsolete sub-critical technology below 490 MW of unit capacity are projected to retire, 135 efficient TPPs with sub-critical technology with unit capacities ranging between 490 MW and 600 MW are projected to be operating up to 2040 by when some of them would be 40 years old (Table 14).

The 20th Electric Power Survey (20th EPS) projects a robust demand growth of 4.06% - 4.59% (CAGR) in the electrical energy required between 2031-32 and 2041-42, and a CAGR of 4.30% - 4.91% in the peak demand during the same period (CEA, 2022a). The All-India peak demand is projected to increase from 388 GW (updated projection in Vol II of the NEP) in 2031-32 to 466 GW (20th EPS)

in FY 2036-37 and 575 GW (20th EPS) in FY 2041-42 (CEA, 2022a; 2024b). Further, the electrical energy required to be generated by utilities is projected to increase from 1734 TWh in FY 2023-24 to 2378 TWh in FY 2030-31 (20th EPS baseline scenario) and 3776 TWh (20th EPS baseline scenario) in FY 2040-41 (CEA, 2022a). We project that coal-based generation will rise to about 1548 TWh in 2030 and 2068 TWh in FY 2040, with 34 TWh of lignite-based generation in all scenarios studied. This implies that the share of coal in India's total electricity generation by utilities will come down from the current (FY 2023-24) level of 75% to about 65% in 2030 and 57% in 2040 even if the coal-fired generation increases in absolute terms till 2040. Therefore, India's coal generation will peak beyond 2040 by which renewable (backed with adequate storage), hydro and nuclear energy should be ramped up to taper down coal.

Table 9 : Technology-wise projections of TPPs and Coal-fired generation by utilities

Year	No. of Coal-fired Units (after retirement of obsolete & inefficient TPPs & addition of new TPPs with supercritical/ultra-supercritical technology)			Coal-based (excluding lignite) Electricity Generation (TWh)	Electrical Energy Requirement as per the 20th Electricity Power Survey (TWh)
	Sub-critical < 490 MW	Sub-critical 490 - 600 MW	Supercritical 660 - 800 MW		
2022 (actual)	333	132	90	1041	1380
2024 (actual)	359	135	108	1261	1626
2030 (projected)	196	135	127	1514	2378
2040 (projected)	NIL	138	288	2034	3776

Notes: The 2030 and 2040 projections may be seen in the light of the following facts:

1. The lignite generation in India is assumed to be constant @34 TWh (at the FY 2023-24 level) between now and 2040 over & above the above the projections of coal-based generation.
2. As per the National Electricity Plan (NEP), CEA (2023a) has projected a requirement of 1566 TWh of coal-based power generation in FY 2031-32 as a contingency plan against any deficit in meeting the ambitious targets for non-fossil fuel (VRE sources, hydro, and nuclear) sources in that year.
3. More recently, Vol II of the NEP (CEA, 2024b) projects the peak demand in FY 2031-32 to be 388 GW versus the NEP-Vol I estimate of 366 GW (CEA, 2023a).
4. Recent generation planning studies by CEA indicate that the coal-based installed capacity must reach 283 GW by FY 2031-32 from the level of 259.6 GW projected in the NEP (PIB, 2024).

7. Findings and Conclusions

This chapter presents a comparison of installed capacity, gross generation, CO_2 and SO_2, emissions as well as water consumption of base year FY 2021-22 and the projected scenarios of 2030 and 2040. The variations between FY 2023-24 and 2030 Scenario 1 can be attributed to the increased generation, higher PLF adopted for all TPPs, and a rise in the share of electricity generation from modern & more efficient supercritical TPPs compared to older, subcritical TPPs. The differences among the three scenarios in the same year (either 2030 or 2040) is primarily due to the varying number of FGDs retrofitted in the 537 operational TPPs (Table 8) since we have assumed for the purpose of this study that all new TPPs under construction now or being awarded will be commissioned with FGDs. This assumption is more conservative compared to a scenario where the TPPs awarded in the last 12 months (18.4 GW) and the TPPs yet to be awarded (47 GW) are not fitted with FGDs during actual construction depending on the nature & scope of any amendment of the Stack emission mandate by MOEFC.

The major difference between the 2030 and 2040 scenarios is the progressive retirement of the inefficient and obsolete sub-490 MW TPPs operated by utilities once the additional 80 GW capacity in the form of new supercritical/ultra-supercritical TPPs is progressively commissioned in the 1st half of the 2030s (PIB, 2024). These changes help us to understand the changes in CO_2 emissions intensity and specific water consumption in TPPs due to the impact of FGDs in partly masking the higher efficiencies of supercritical and ultra-supercritical technology.

Table 10 provides the comparative analysis of key metrics for the base year and the three scenarios each in 2030 and 2040 based on the status of FGD installation and the projected increase in coal- and lignite-fired electricity generation from 1295 TWh in FY 2023-24 to 1548 TWh in the year 2030 and 2068 TWh in the year 2040. This table is explained based on two extreme scenarios:

7.1 Impact of FGDs on CO2 emissions:

7.1.1 Scenario 1

Other than the 44 TPPs already retrofitted with FGDs, none of the remaining 493 (537-44) operating TPPs are retrofitted with FGDs due to an amendment in MOEFCC's SO_2 stack emission mandate (MOEFCC, 2015). However, the 39 supercritical TPPs (28.4 GW) under construction are assumed to be progressively commissioned with FGDs between now and 2030 while all TPPs that have not yet commenced site construction are not equipped with FGDs. On the other hand, all operating TPPs (old & new) are equipped with High-Efficiency Electrostatic Precipitators (ESPs) to reduce the Particulate Matter (PM) concentration in the stack to 50 mg/Nm^3 (milligrams per Normal m^3) irrespective of age. This requires tightening the norms for PM emissions from the current level of 100 mg/Nm^3 for the pre-2003 TPPs and the relaxation of the norm to 50 mg/Nm^3 from the current standard of 30 mg/Nm^3 for post-2016 TPPs which requires usage of washed coal to reduce the ash which is critical to increase the efficiency of the ESPs beyond the level of 99.97%.

Table 10 : Impact of FGDs on key parameters for different scenarios

Scenario	Gross Generation from TPPs (TWh)	Coal + Lignite consumption (Mt)	CO_2 emissions (Mt)	SO_2 emissions (Mt)	Water Consumption (Billion Cubic Meters, Bm^3)
2021-22	1079	743	977	5.27	2.96
2023-24	1295	907	1174	6.45	3.79
2030-Sc1	1548	1110	1427	6.66	4.63
2030-Sc2		1120	1440	3.42	4.87
2030-Sc3		1128	1450	0.82	5.07
2040-Sc1	2068	1458	1835	5.62	
2040-Sc2		1467	1847	2.68	
2040-Sc3		1472	1853	1.09	

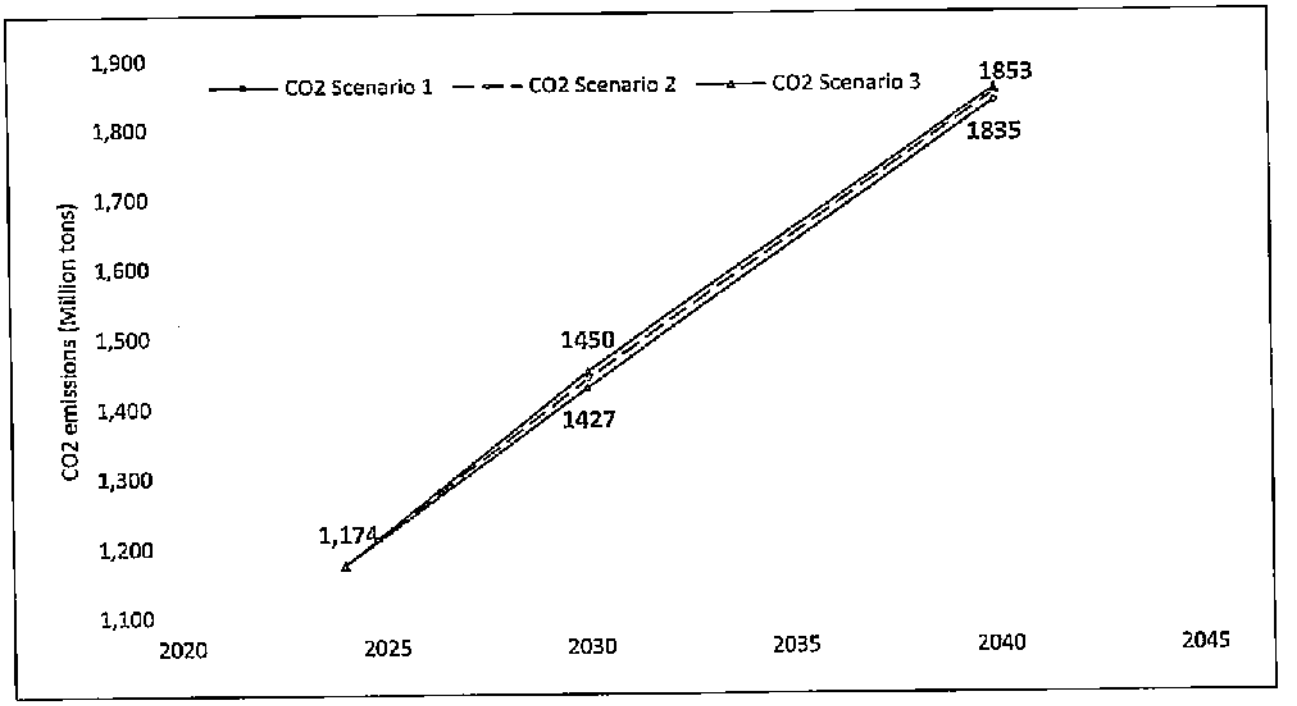
In this scenario, the coal & lignite required for power generation by utilities is projected to increase from the FY 2023-24 level of 907 Mt to 1110 Mt in 2030 and 1458 Mt in 2040 due to the increase in auxiliary power consumption by approximately 2% due to the operation of the FGDs. In this scenario, the CO_2 emissions are projected to increase from 1174 Mt in FY 2023-24 to 1427 and 1835 Mt in 2030 and 2040, respectively. However, the SO_2 emissions from TPPs are projected to increase marginally from 6.45 Mt in FY 2023-24 to 6.66 Mt in 2030 (due to the increase in coal generation) before reducing to 5.62 Mt in 2040 due to the progressive retirement of the obsolete & inefficient sub-490 MW TPPs with the addition of 65.4 (18.4 GW awarded and 47 GW to be awarded) of additional TPP capacity based on supercritical/ultra-supercritical technology. The freshwater consumption of TPPs is projected to increase from 3.79 million cubic meters (Mm^3) to 4.63 Mm^3 in 2030.

7.1.2 Scenario 3

In this scenario, all the 537 operating TPPs are projected to retrofitted with FGDs irrespective of the sulfur content of coal or the size, age, and location of the TPP. In this case, the coal & lignite required for power generation by utilities is projected to increase from the FY 2023-24 level of 907 Mt to 1128 Mt in 2030 and 1472 Mt in 2040 with a concomitant increase in CO_2 emissions from 1174 Mt in FY 2023-24 to 1450 and 1853 Mt in 2030 and 2040, respectively. The impact of FGDs on CO2 emissions in each of the three scenarios during FY 2023-24, 2030, and 2040 is depicted in Figure 6.

This significant increase in emissions each year will accumulate over time due to the longevity of CO_2 in the atmosphere, typically considered as 100-1000 years. Hence, to quantify the total CO_2 emissions from the TPPs over three decades, a cumulative approach is employed. The average emissions of FY 2023-24 and FY 2030-31 are estimated and multiplied by six to estimate the cumulative emissions for the intervening six years. For the next decade (2030 – 2040) the average emissions are computed and multiplied by ten to obtain the cumulative emission for that period.

Figure 6 : CO_2 emissions from TPPs projected in the three scenarios



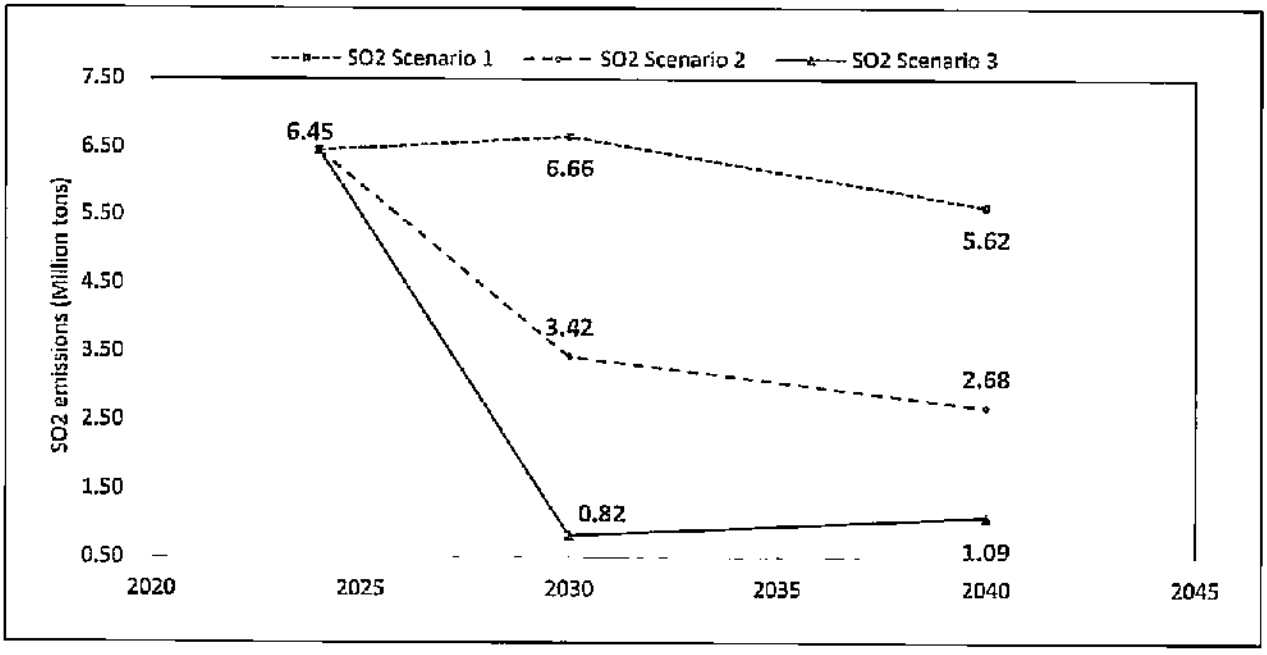
By completing the above computation, we estimate that, installing all the procured 233 FGDs (Scenario 2) will add 158 Mt of CO_2 between 2024 and 2040 compared to no more retrofit of FGDs (Scenario 1), while installing FGDs in all TPPs (old & new) will add 272 Mt of CO2 between 2024 & 2040 compared to Scenario 1. These accumulations of CO2 will increase the global warming by trapping more long wave radiation and thus increasing the global temperature. Increase in global mean temperature have devastating effects on climate, including climate extremes, sea level rise, and much more. This highlights the adverse impacts of FGD installation in terms of incremental CO_2 emissions with its knock-on effects on global warming, extreme weather events, sea level rise, etc.

7.2 Impact of FGDs on SO2 emissions

The trends in SO_2 emission from the TPPs in the three scenarios explained above are shown in Figure 7. Though there will be a reduction in SO_2 emissions by the retrofit of FGDs in all operating TPPs that have not yet done so, this will only be accomplished at the cost of a significant increase in CO_2 emissions (Figure 6) and freshwater consumption (Figure 8).

As shown in Figure 7, the SO_2 emissions from TPPs are projected to reduce sharply from 6.45 Mt in FY 2023-24 to 0.82 Mt in 2030 with a marginal increase to 1.09 Mt in 2040 despite the increase of 33.6% in coal-fired power generation between 2030 and 2040. This is due to the change in technology mix with the progressive retirement of all sub-490 MW obsolete & inefficient TPPs after completing their useful economic lives and the addition of High-Efficiency, Low-Emission TPPs (HELE) with supercritical/ultra-supercritical technology.

Figure 7 : SO_2 emissions from TPPs projected in the three scenarios



In 2040, considering the significant number of TPP additions to meet the growing demand for 24x7 baseload electricity, the SO_2 emission will increase from the FY 2030 estimates in all three scenarios. Overall, Scenario 3 can be considered as an extreme reduction path compared to Scenario 2. However, this substantial reduction in SO_2 can be realized at the expense of escalated CO_2 emissions, augmented coal consumption, and increased water usage. This trade-off underscores the complexity of environmental management and the need for balanced strategies. Since SO_2 has a short atmospheric lifetime measured in days, it cannot accumulate when emitted from the tall (220 – 275 m) stacks in TPPs in India because of the excellent dispersion of stack emissions under the climatic conditions generally prevalent in India.

7.3 Impact of FGDs on freshwater consumption

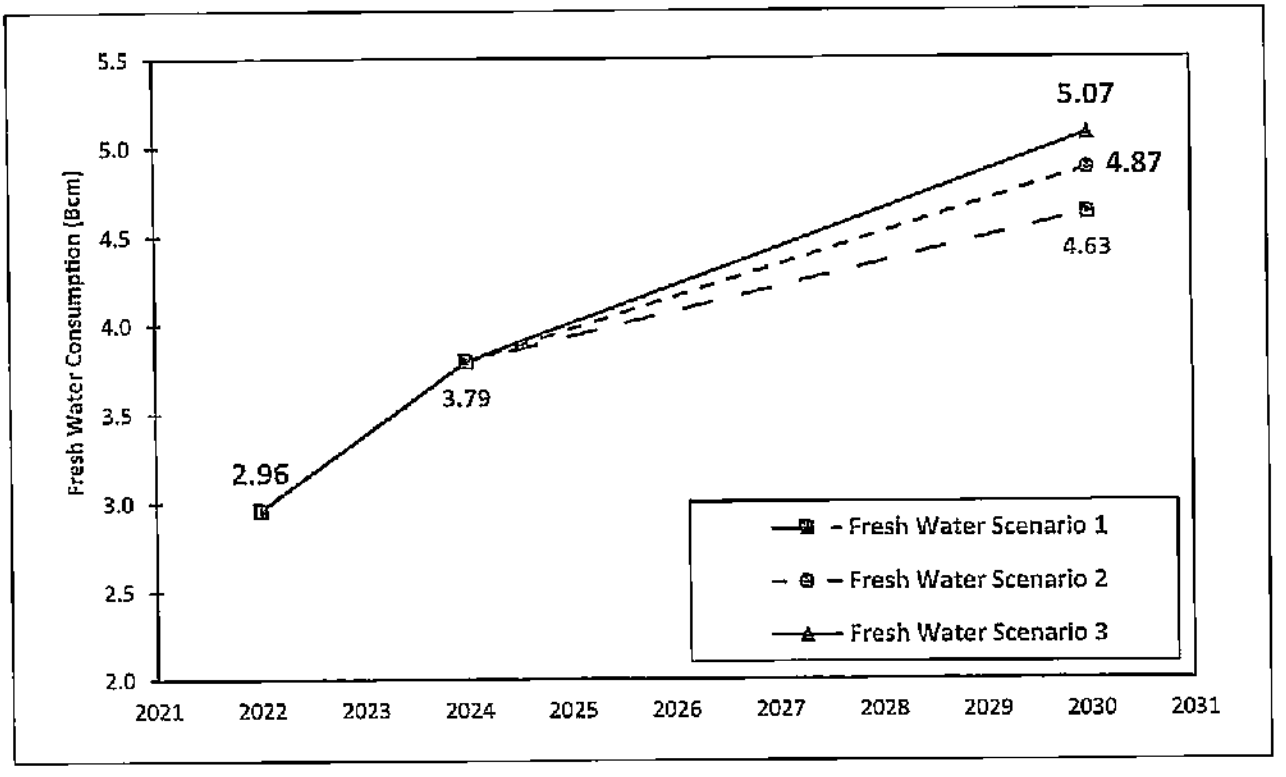
For the estimation of freshwater consumption, the TPPs are categorized into non-coastal (inland) and coastal TPPs, with the assumption that coastal TPPs utilize only seawater to meet their water requirements. The actual specific water consumption data for inland TPPs is procured from the CEA report, and the total water consumption is computed based on their gross generation for FY 2021-22. The database includes 516 inland TPPs, of which 435 are subcritical and 81 are supercritical units. Using the average specific water consumption of 3.4 m^3/MWh for subcritical TPPs and 2.69 m^3/MWh for supercritical TPPs, the water consumption for all operational TPPs is estimated.

For FY 2023-24, the gross generation data for individual stations, obtained from the NPP report, is distributed among the TPPs according to their capacity. By applying the formula and average specific water consumption rate from FY 2021-22, the total water consumption for FY 2023-24 is projected.

The specific water consumption norm of each class of TPPs is used to estimate the total freshwater consumption of TPPs based on their generation in 2030.

The trend in freshwater consumption by TPPs from the base year (FY 2021-22) to 2030, for each of the three scenarios is shown in Figure 8. In FY 2021-22, the total freshwater consumption by all operational TPPs is estimated to be 2.96 billion cubic meters (Bcm). This is likely to have increased to 3.79 Bcm in FY 2023-24 due to the increase in coal-fired power generation from 1079 to 1295 TWh between FY 2021-22 and FY 2023-24.

Figure 8 : Freshwater consumption by the TPPs in the base year and future scenarios.



Since coal-fired power generation is projected to increase further to 1548 TWh in FY 2030-31, all three scenarios (in relation to FGD retrofits) involve further increases in freshwater requirements to operate these FGDs. The total consumption in 2030 (**Scenario 1**) is estimated to be 4.63 billion cubic meters (Bcm), reflecting a 30% growth over eight years due to increased generation. This is expected to increase further to 4.87 Bcm in **Scenario 2**, which is an additional increase of 0.24 Bcm from **Scenario 1**. The freshwater consumption by TPPs is projected to increase further to 5.07 Bcm in Scenario 3 due to the installation of FGDs across all TPPs irrespective of location, coal characteristics, and age.

The freshwater consumption in 2040 will go up further due to the projected increase in coal-fired power generation from 1548 TWh in 2030 to approximately 2068 TWh in 2040. In the 2030s, all the 196 sub-490 MW TPPs operated by utilities are projected to progressively retire after outliving their

useful economic lives. They will be replaced with 161 supercritical/ultra-supercritical TPPs with higher capacities (660/800 MW each) and lower specific coal and water consumptions. As per MOP (2024a), an aggregate capacity of 65.64 GW of such TPPs is under bidding/consideration today. In case these TPPs are also fitted with FGDs, the total freshwater consumption in 2040 on this count alone will increase by 0.20 BCM. Therefore, it is recommended that these HELE TPPs not be saddled with FGDs.

8. Policy Recommendations

Coal-based power plants remain the cornerstone of India's power sector, significantly contributing to the country's energy generation due to the abundant availability of indigenous coal and the current limitations of renewable energy technologies and storage solutions. India's updated Nationally Determined Contributions (NDCs) submitted to UNFCCC in August 2022 include a commitment to *reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level* (MOEFCC, 2022). Since the installation of FGDs impacts the energy efficiency and emissions intensity of TPPs, a blanket implementation will adversely affect India's performance concerning its updated NDCs. Further, three independent studies conducted by NIAS, NEERI, and IIT Delhi demonstrate with different case studies and methods that, FGDs hardly have any impact on Particulate Matter (PM) pollution which is the major problem attributed to TPPs using high-ash Indian coal. PM (not SO2) is also the criteria pollutant in all non-attainment cities in India. Therefore, the authors submit the following recommendations based on this study:

- PM pollution from TPP stacks can be addressed quickly and cost-effectively by retrofitting indigenous High-efficiency Electrostatic Precipitators (ESPs) in all TPPs irrespective of their size or location. This will enable all TPPs to reduce PM pollution by 99.97% in a cost-effective manner without shutdowns while complying with the MOEFCC (2015) stack emission norms for PM (50 mg/m^3 for TPPs installed up to December 2016). Controlling PM emissions from TPP stacks at this level will make the maximum impact on air pollution from TPPs even without FGDs.
- Bharat Heavy Electricals Ltd. (BHEL) has retrofitted High-efficiency ESPs even in older TPPs with space constraints. Installation of such ESPs will cost only Rs. 25 Lakhs per MW compared to Rs. 120 Lakhs per MW for wet FGDs based on imported technology. Further, retrofitting High-efficiency ESPs in operating TPPs requires only 2 days of boiler shutdown for hookup, unlike FGDs which require ~45-day boiler shutdowns during FGD commissioning.
- Since 32 of the 65 TPPs within 10 km of cities with +1 million population have either installed or awarded FGDs, the impacts of FGDs in terms of PM pollution reduction in these cities must be assessed before any future FGDs are awarded.
- TPPs retiring by 2030 to be exempted from SO_2 stack emission norms since these will normally be the obsolete stations with a proportionately lesser contribution to the total electricity generation in the country. This will avoid saddling paying electricity consumers with large tariff hikes to recover the cost of the FGDs within a short period.
- There is no tangible benefit of fitting FGDs in TPPs not located within 10 km of cities with +1 million population if they are using low-Sulfur coal. Rather, they must be equipped with High-efficiency ESPs for the reasons explained earlier.
- The Environmental (Protection) Rules notified on December 7, 2015, to be amended to limit the SO2 stack emission norms only to TPPs using Imported coal and/or High (> 0.5%) Sulfur coal.

- Since all new TPPs are (i) based on domestic low-Sulfur coal, (ii) designed with High-efficiency ESPs, and (iii) located more than 10 km away from any city with +1 million population, FGDs to be avoided in TPPs awarded from January 2024 onwards.
- Implementation of these decisions will reduce PM pollution without the adverse impacts of FGDs (higher levels of water consumption & CO_2 emissions), while limiting the financial burden on the power sector thereby minimizing electricity tariff hikes on account of FGD installations.
- The impact on global warming by installing FGDs in all TPPs in India must be assessed.
- The effect on India's NDCs if FGDs are installed in all TPPs must be quantified.
- Since coal supplied from domestic coal mines accounts for 92% of the power generated in India, and this reliance is going to increase in future, there should be a greater thrust on the enablers required to use high-ash, low-Sulfur Indian coal more efficiently.
- Using coal washed at the pithead will not only reduce air pollution from TPPs & coal transportation but will also enhance ESP performance as well as boiler efficiency thereby reducing CO_2 emissions. Using washed coal will also reduce water consumption in TPPs.
- An integrated cost-benefit analysis of using washed coal in TPPs in India must be conducted since the dependence on high-ash domestic coal for power generation will continue in India.
- CO_2 emissions from TPPs can be minimized by burning coal more efficiently compared to the current levels of efficiency achieved in the super-critical power plants of India. Integrated Gasification Combined Cycle (IGCC) power plants use coal and water more efficiently and enable CO2 capture in an efficient manner. Coal gasification projects are being pursued by the Ministry of Coal (MOC). Integrated Gasification Combined Cycle (IGCC) technology should be mandated for TPPs applying for Environmental Clearance from 2027 onwards, as this technology is CO_2 capture-ready and utilizes both coal and water more efficiently.
- Escalating demands for freshwater use in all industries in general and TPPs in particular is a cause of great concern for India when large parts of India face water stress. To address this concern, the Ministry of Power (MOP, 2020) mandated all TPPs located within 50 km of a municipality or any Urban Local Body (ULB) to use the treated sewage water produced by the municipality/ULB with the "associated cost to be allowed as pass-through in the tariff." However, the cost of the Sewage Treatment Plant (STP) as well as the sewage water supply system are to be borne by the ULB as per MOP (2020).
- Even before this mandate was issued, the Koradi TPP of MAHAGENCO started procuring 130 million liters per day (MLD) of sewage water from the Nagpur Municipal Corporation (NMC) and using it in the TPP after secondary and tertiary treatment in a dedicated STP. This STP was constructed, operated, and maintained by MAHEGENCO for which the land was provided by the NMC who also passed through (to MAHAGENCO) a GOI grant to cover about 50% of the capital cost of the STP (MOP, 2019; Sharma, 2013).
- However, very few TPPs are complying with this mandate because most ULBs in India lack the expertise and financial strength to construct such large & modern STPs which require several synergies between the TPP and the ULB as well as the State Government (World Bank, 2020).

Therefore, Das et al. (2024) have recommended that the STP for secondary & tertiary treatment should also be constructed and operated by the TPP at its own cost (to be passed through in the tariff) while the ULB is responsible for constructing and maintaining the underground sewage system. MOP may like to amend their mandate (MOP, 2020) accordingly since this will enhance the sustainability of the thermal power sector and enable the achievement of SDG 6 ("Clean water & sanitation)" in ULBs.

- Finally, to provide reliable base load power at an affordable cost, India's nuclear power capacity should be increased to at least 100 GW by 2050. This is critical to reduce India's dependence on coal for baseload power and achieve Net Zero emissions by 2070.

In conclusion, the strategic implementation of FGDs, coupled with advancements in cleaner coal technologies and a balanced energy mix including a higher share for clean & firm non-fossil fuel energy source like atomic energy, will enable India to address the environmental impacts of coal-based TPPs without compromising on energy security and economic growth.

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DOCUMENT CONTROL SHEET

1	Document No and Year	:	NIAS/NSE/EECP/U/RR/15/2024
2	Title	:	Economic, Environmental, and Climate Impacts of FGDs in Thermal Power Plants in India
3	Type of Document	:	Research Report
4	No. of Pages and Figures	:	53 + viii pages, 10 tables and 14 figures
5	No. of References	:	42
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11 Abstract:

India's Nationally Determined Contributions (NDCs) submitted to the United Nations Framework Convention on Climate Change in November 2022 include a commitment to reduce the emissions intensity of the country's GDP by 45 percent by 2030 from the 2005 level. Since coal-fired Thermal Power Plants (TPPs) produce ~50% of India's CO_2 emissions, it is critical to enhance the efficiency of TPPs and reduce their emissions to achieve India's NDCs.

However, installing Flue Gas Desulfurizers (FGDs) in all TPPs by 2030 will increase the Auxiliary Power Consumption (APC) of the TPPs and add approximately 272 Mt of CO2 emissions to the atmosphere between now and 2040. While CO_2 accumulations in the atmosphere contribute to global warming, the Intergovernmental Panel on Climate Change (IPCC) report (AR 6) states that anthropogenic SO_2 emissions have masked global warming by ~0.5°C in the 2010-2019 period relative to the 1850-1900 period. Therefore, adding long-lived CO_2 emissions while removing short-lived SO_2 emissions by installing FGDs indiscriminately in all TPPs in India despite the very low Sulfur content of Indian coal and the low ambient SO_2 concentrations around the TPPs will enhance global warming.

Considering the low-sulfur Indian coals, the 220-275 m tall TPP stacks, and the tropical climate around TPPs in India, future FGD installations must be postponed till impact assessment studies of the FGDs installed (or to be installed) in 32 TPPs located within 10 km of cities are completed. For TPPs in other areas, the Ministry of Environment, Forest and Climate Change (MOEFCC) can exempt the TPPs using Indian coal with less than 0.5% Sulfur content from complying with the SO_2 stack emission norms while limiting PM emissions from the stacks to 50 mg per Normal m^3.

Particulate Matter (PM) pollution is the major problem attributed to TPPs using high-ash Indian coal. PM pollution from TPP stacks can be addressed quickly and cost-effectively by retrofitting indigenous High-efficiency Electrostatic Precipitators (ESPs) in all TPPs to reduce the stack emissions of PM by 99.97%. This will enable TPPs using low-sulfur Indian coal to minimize ambient air pollution even without FGDs. This will also eliminate the incremental requirements of freshwater and limestone required to operate the FGDs.

12 Keywords:
Electrostatic Precipitators (ESPs); Flue Gas Desulfurizers (FGDs);
Nationally Determined Contributions (NDCs); SO2 emissions; Global Warming.

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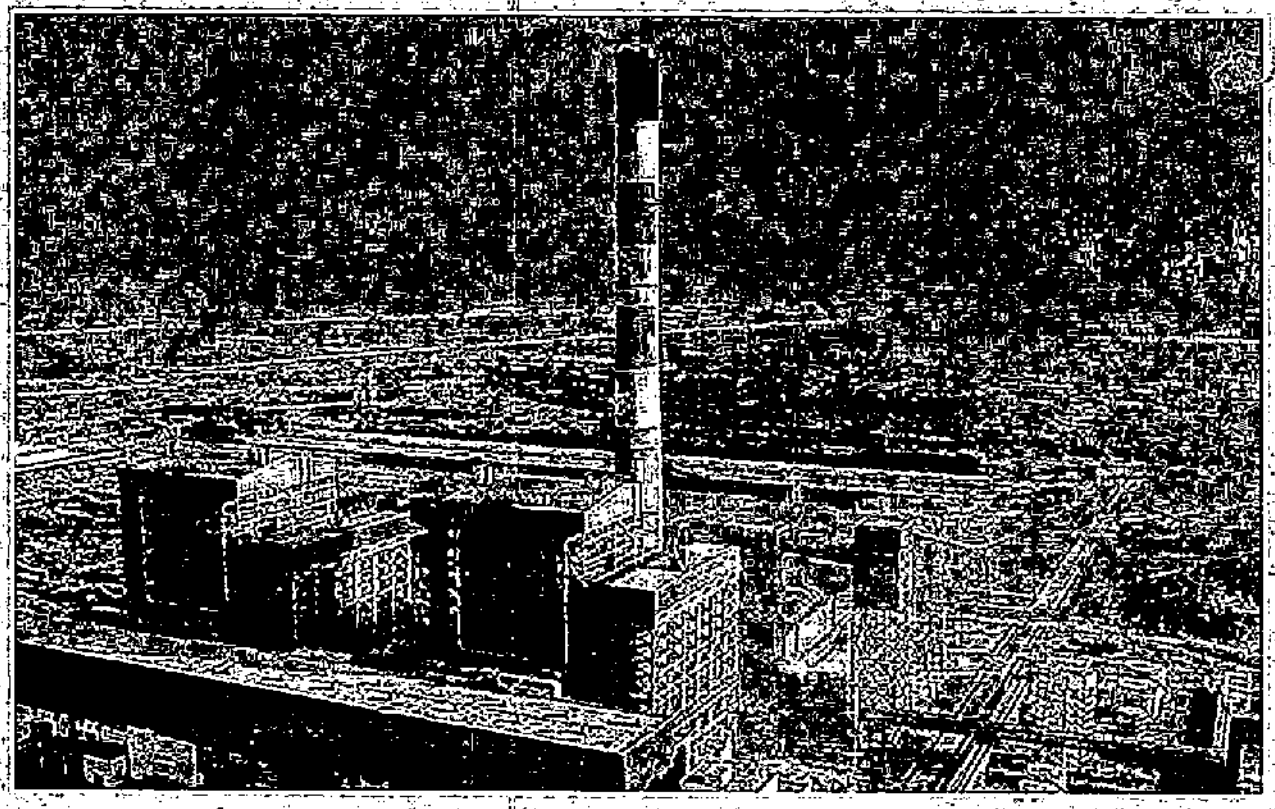

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Annexure - III

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अधिसूचना

नई दिल्ली, 11 जुलाई, 2025

सा.का.नि. 465(अ).— जबकि देश में कोयला और लिग्नाइट आधारित ताप विद्युत संयंत्रों के लिए सल्फर डाइऑक्साइड उत्सर्जन मानक केन्द्र सरकार अधिसूचना सं. का.आ. 3305(अ) दिनांक 7 दिसंबर 2015 के तहत प्रकाशित किए गए थे, जिनमें कुछ समय-सीमाएं भी निर्धारित की गई थीं, जिन्हें बाद में समय-समय पर संशोधित किया गया था;

और जबकि प्रौद्योगिकी प्रदाताओं की सीमित उपलब्धता, इसकी तकनीकी-आर्थिक व्यवहार्यता, आपूर्ति श्रृंखला पर कोविड-19 महामारी के नकारात्मक प्रभाव, अधिक मांग और कम आपूर्ति के कारण मूल्य वृद्धि, परिवेशी वायु में सल्फर डाइऑक्साइड की कम सांद्रता और बिजली की कीमतों में वृद्धि के कारण उपभोक्ता पर भारी बोझ आदि के कारण इन उत्सर्जन मानकों की समय-सीमा में छूट या ढील के संबंध में कई अभ्यावेदन प्राप्त हुए थे और इस संबंध में विद्युत मंत्रालय की स्पष्ट सिफारिश प्राप्त हुई थी;

और जबकि अनुसंधान संस्थानों द्वारा इन मानकों के पीछे की प्रभावशीलता और औचित्य तथा क्षेत्र के समग्र परिवेशी वायु प्रदूषण में इसकी भूमिका के संबंध में कई अध्ययन किए गए थे;

और इन उत्सर्जन मानकों और इसकी समय-सीमा के संबंध में उद्योग, विद्युत मंत्रालय, केंद्रीय प्रदूषण नियंत्रण बोर्ड, वैज्ञानिक संस्थानों और अन्य हितधारकों के साथ कई हितधारक परामर्श किए गए थे;

और जबकि केन्द्रीय प्रदूषण नियंत्रण बोर्ड में इस मुद्दे की समग्र जांच करने, उपलब्ध अध्ययन रिपोर्टों, अन्य प्रासंगिक सामग्रियों और अन्य संबंधित कारकों का आकलन करने और इन मानकों और इसकी समय-सीमा की प्रयोज्यता पर सिफारिश करने के लिए एक समिति का गठन किया गया था और जबकि केन्द्रीय प्रदूषण नियंत्रण बोर्ड ने विस्तृत विश्लेषण के बाद, देश के अधिकांश क्षेत्रों में सल्फर डाइऑक्साइड के राष्ट्रीय परिवेशी वायु गुणवत्ता मानकों; जल, सहायक बिजली और चूना पत्थर की अतिरिक्त खपत से बचने के लिए संसाधन संरक्षण; नियोजित किए जाने वाले नियंत्रण उपायों के लागू होने के कारण वातावरण में कार्बन फुटप्रिंट या कार्बन डाइआक्साइड उत्सर्जन में वृद्धि, और इन नियंत्रण उपायों के लिए अपेक्षित चूना पत्थर का खनन और परिवहन; सभी कोयला या लिग्नाइट आधारित ताप विद्युत संयंत्र में ऐसे नियंत्रण उपायों के कार्यान्वयन की तकनीकी-आर्थिक व्यवहार्यता; और घनी आबादी वाले क्षेत्रों और अन्य वायु प्रदूषण संवेदनशील क्षेत्रों में वायु प्रदूषण के नियंत्रण और उन्मूलन के लिए एहतियाती सिद्धांत को लागू करने के संबंध में अपने अध्ययन के आधार अपनी सिफारिश प्रस्तुत की है;

अब, इसलिए पर्यावरण (संरक्षण) अधिनियम, 1986 (1986 का 29) की धारा 6 और 25 द्वारा प्रदत्त शक्तियों का प्रयोग करते हुए केन्द्र सरकार पर्यावरण (संरक्षण) नियम, 1986 को और संशोधित करने के लिए निम्नलिखित नियम बनाती है, नामत: -

1. (1) इन नियमों का संक्षिप्त नाम पर्यावरण (संरक्षण) चतुर्थ संशोधन नियम, 2025 है।

(2) ये सरकारी राजपत्र में प्रकाशन की तारीख से प्रवृत्त होंगे।

2. पर्यावरण (संरक्षण) नियम, 1986 के अनुसूची-I में क्रम संख्या 25 में, "* (i) से शुरू होने वाली प्रविष्टियों के लिए केंद्रीय प्रदूषण नियंत्रण बोर्ड (सीपीसीबी) द्वारा एक टास्क फोर्स का गठन किया जाएगा" और "** से समाप्त होने वाली सभी टीपीपी (इकाइयां) शामिल हैं जिन्हें पर्यावरणीय मंजूरी दी गई है और निर्माणाधीन हैं" के स्थान पर निम्नलिखित को प्रतिस्थापित किया जाएगा, अर्थात:-

"(क) केंद्रीय प्रदूषण नियंत्रण बोर्ड द्वारा एक टास्क फोर्स का गठन किया जाएगा जिसमें पर्यावरण, वन और जलवायु परिवर्तन मंत्रालय, विद्युत मंत्रालय, केंद्रीय विद्युत प्राधिकरण और केंद्रीय प्रदूषण नियंत्रण बोर्ड के प्रतिनिधि शामिल होंगे, जो उत्सर्जन मानकों के अनुपालन के लिए उक्त तालिका के कॉलम (3) में निर्दिष्ट उनकी अवस्थिति के आधार पर नीचे दी गई तालिका-I के कॉलम (2) में निर्दिष्ट तीन ताप विद्युत संयंत्रों की श्रेणी में वर्गीकृत करेगा : -

तालिका I

क्र.सं.	वर्ग	अवस्थिति/क्षेत्र
(1)	(2)	(3)
1	श्रेणी क	राष्ट्रीय राजधानी क्षेत्र के 10 किलोमीटर के दायरे में या मिलियन से अधिक आबादी वाले शहरों में[1]।
2	श्रेणी ख	गंभीर रूप से प्रदूषित क्षेत्रों[2] अथवा अनुपालन न करने वाले क्षेत्र[2] के 10 किमी के दायरे के भीतर
3	श्रेणी ग	श्रेणी क और ख में शामिल संयंत्रों के अलावा

[1]भारत की 2011 की जनगणना के अनुसार।

[2]जैसा कि केन्द्रीय प्रदूषण नियंत्रण बोर्ड द्वारा परिभाषित किया गया है।

(ख) (i) सल्फर डाइऑक्साइड उत्सर्जन के अलावा अन्य मापदंडों के लिए उत्सर्जन मानकों की प्रयोज्यता समय-सीमा निम्नानुसार होगी:

(537)
754

तालिका-II

क्र.सं.	वर्ग	अनुपालन के लिए समयसीमा (बंद न की जाने वाली इकाइयाँ)	अनुपालन से छूट के लिए इकाइयों को बंद करने की अंतिम तिथि
(1)	(2)	(3)	(4)
1	श्रेणी क	31 दिसंबर 2022 तक	31 दिसंबर 2022 तक
2	श्रेणी ख	31 दिसंबर 2023 तक	31 दिसंबर 2025 तक
3	श्रेणी ग	31 दिसंबर 2024 तक	31 दिसंबर 2025 तक

(ii) तालिका-II के कालम (4) में निर्दिष्ट तिथि से पहले बंद घोषित किए गए ताप विद्युत संयंत्र को सल्फर डाइऑक्साइड उत्सर्जन के अलावा अन्य मापदंडों के लिए निर्दिष्ट मानकों को पूरा करना अपेक्षित नहीं होगा, यदि ऐसे संयंत्र बंद होने के आधार पर छूट के लिए केन्द्रीय प्रदूषण नियंत्रण बोर्ड और केन्द्रीय विद्युत प्राधिकरण को एक वचनबद्धता प्रस्तुत करते हैं:

बशर्ते कि ऐसे संयंत्रों का संचालन वचनबद्धता में निर्दिष्ट तारीख से आगे जारी रहता है तथा यदि थर्मल पावर प्लांट/यूनिट निर्दिष्ट मानकों को पूरा नहीं करता है, तो उनसे तालिका-II के स्तंभ (4) में निर्दिष्ट तारीखों से पर्यावरण क्षतिपूर्ति वसूल की जाएगी;

(ग) ताप विद्युत संयंत्रों में सल्फर डाइऑक्साइड के लिए उत्सर्जन मानकों की प्रयोज्यता निम्नानुसार होगी:

(i) 31 दिसंबर 2030 से पहले बंद होने की घोषणा करने वाले ताप विद्युत संयंत्रों द्वारा सल्फर डाइऑक्साइड उत्सर्जन के लिए निर्दिष्ट मानकों को पूरा करना अपेक्षित नहीं होगा, यदि ऐसे संयंत्र बंद होने के आधार पर छूट के लिए केन्द्रीय प्रदूषण नियंत्रण बोर्ड और केन्द्रीय विद्युत प्राधिकरण को वचनबद्धता प्रस्तुत करते हैं:

बशर्ते कि इन संयंत्रों पर 31 दिसंबर 2030 से उत्पादित विद्युत पर 0.40 रुपये प्रति यूनिट की दर से पर्यावरण क्षतिपूर्ति लगाई जाएगी, यदि उनका प्रचालन निर्दिष्ट मानकों को पूरा किए बिना उपक्रम में निर्दिष्ट तिथि के बाद भी जारी रहता है;

(ii) मौजूदा श्रेणी 'क' के ताप विद्युत संयंत्र 31 दिसम्बर, 2027 तक सल्फर डाइऑक्साइड उत्सर्जन मानकों का अनुपालन करेंगे। चालू होने वाले श्रेणी 'क' ताप विद्युत संयंत्रों को भी 31 दिसम्बर, 2027 से पहले इन मानकों का अनुपालन करना होगा। और 31 दिसम्बर, 2027 के बाद चालू होने वाले श्रेणी 'क' के अन्य संयंत्र इन मानकों का अनुपालन सुनिश्चित करने के बाद ही प्रचालन करेंगे;

(iii) वर्तमान अथवा शुरू किए जाने वाले श्रेणी 'ख' के सभी संयंत्रों/एककों के लिए सल्फर डाइऑक्साइड उत्सर्जन मानकों की प्रयोज्यता, केंद्र सरकार द्वारा पर्यावरण प्रभाव आकलन अधिसूचना 2006 के तहत गठित थर्मल पावर परियोजनाओं के प्रभारी विशेषज्ञ मूल्यांकन समिति की सिफारिशों के आधार पर निम्नलिखित प्रक्रिया के अनुसार उपयुक्त वैज्ञानिक अध्ययनों के आधार पर मामले दर मामले के अनुसार तय की जाएगी:

(क क) यदि पर्यावरणीय स्वीकृति पहले ही दी जा चुकी है, तो ऐसे संयंत्र या एककों सल्फर डाइऑक्साइड मानकों की प्रयोज्यता की समीक्षा का विकल्प चुन सकते हैं, बशर्ते कि संबंधित परियोजना प्रस्तावक इस अधिसूचना के जारी होने की तिथि से छह महीने के भीतर परिवेश पोर्टल पर इस समीक्षा के लिए आवेदन करें। यदि सल्फर डाइऑक्साइड मानकों को लागू माना जाता है, तो वे 31 दिसम्बर, 2028 से प्रभावी होंगे। अन्य सभी मामलों में, ताप विद्युत संयंत्र को अधिसूचना संख्या सा.का.नि. 742 (अ) 30 अगस्त, 1990 द्वारा अधिसूचित स्टैक ऊँचाई मानदंडों का 31 दिसम्बर, 2028 तक अनुपालन करना होगा;

(ख ख) यदि शुरू किए जाने वाले संयंत्रों को पर्यावरण स्वीकृति नहीं दी गई है, तो सल्फर डाइऑक्साइड मानकों की प्रयोज्यता और उनके लागू होने की तिथि या अन्यथा, समय-समय पर संशोधित, जैसा कि पर्यावरण प्रभाव आकलन अधिसूचना 2006 में निर्धारित प्रक्रिया के अनुसार, ऐसी प्रत्येक परियोजना को दी गई पर्यावरणीय मंज़ूरी में निर्दिष्ट अनुसार होगी और जिन मामलों में सल्फर डाइऑक्साइड मानक लागू नहीं किए गए हैं, वहाँ ताप विद्युत संयंत्रों को अधिसूचना संख्या सा.का.नि. 742 (अ) 30 अगस्त, 1990 द्वारा अधिसूचित स्टैक ऊँचाई मानदंडों का पालन करना होगा;

(ग ग) सल्फर डाइऑक्साइड उत्सर्जन के लिए ये मानक उन सभी संयंत्रों/इकाइयों के संबंध में 31 दिसम्बर, 2028 से लागू होंगे, जिन्होंने उपरोक्त पैरा (i) में निर्दिष्ट समय सीमा के भीतर समीक्षा का विकल्प नहीं चुना है;

(iv) सल्फर डाइऑक्साइड उत्सर्जन मानक श्रेणी ग के सभी ताप विद्युत संयंत्रों पर लागू नहीं होंगे, बशर्ते कि अधिसूचना संख्या सा.का.नि. 742 (अ) 30 अगस्त, 1990 द्वारा अधिसूचित स्टैक ऊँचाई मानदंडों का अनुपालन सुनिश्चित किया गया हो। श्रेणी ग के मौजूद ताप विद्युत संयंत्रों द्वारा स्टैक ऊँचाई मानदंडों का अनुपालन सुनिश्चित करने की समय-सीमा 31 दिसंबर, 2029 है;

(घ) केन्द्र सरकार केन्द्रीय प्रदूषण नियंत्रण बोर्ड (सीपीसीबी) की सिफारिशों पर, आदेश द्वारा ताप विद्युत संयंत्रों को सल्फर डाइऑक्साइड उत्सर्जन मानकों के अनुपालन से संबंधित समय-सीमा को बढ़ा दें।

(ङ) तालिका-II के कॉलम (4) में निर्दिष्ट तिथि और पैरा (ख), (ग) और (घ) में निर्दिष्ट तिथि के बाद, बंद होने वाले और अनुपालन न करने वाले ताप विद्युत संयंत्रों पर तालिका-III में निर्दिष्ट दरों के अनुसार पर्यावरण प्रतिपूर्ति लगाई जाएगी, अर्थात:-

तालिका-III

समय-सीमा के बाद अनुपालन न करने वाले संयंत्रों का संचालन	पर्यावरण क्षतिपूर्ति (प्रति यूनिट उत्पादित बिजली के लिए रु.)
0-180 दिन	0.20
181-365 दिन	0.30
366 दिन और उससे आगे	0.40"

[फा. सं. क्यू-15017/40/2007- सीपीडब्ल्यू]

नीलेश कुमार साह, संयुक्त सचिव

नोट: मुख्य नियमों को दिनांक 19 नवंबर, 1986 के आदेश संख्या 844(ई) के द्वारा भारत का राजपत्र, असाधारण के भाग-II, खंड 3, उप-खंड (i) में प्रकाशित किया गया और दिनांक 3 जुलाई, 2005 की अधिसूचना संख्या जीएसआर-446(ई) के माध्यम से संशोधित किया गया।

556

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 11th July, 2025

G.S.R. 465(E).— Whereas Sulphur dioxide emission standards were published by the Central Government *vide* SO 3305(E) dated the 7th December, 2015 for coal and lignite based thermal power plants in the country, also prescribing certain timelines, which were amended subsequently from time to time;

And whereas many representations were received regarding exemption or relaxation in timelines of these emission standards due to limited availability of technology providers, its techno-economic feasibility, negative impact of COVID19 pandemic on supply chain, price escalation due to high demand and low supplies, low Sulphur dioxide concentration in ambient air and heavy burden on consumer due to increase in electricity prices etc., and explicit recommendation of the Ministry of Power was received in this regard;

And whereas several studies were conducted by research institutions regarding effectiveness and rationale behind these standards and its role in overall ambient air pollution of the region;

And whereas several stakeholder consultations were done with Industry, Ministry of Power, Central Pollution Control Board, scientific institutions and other stakeholders regarding these emission standards and its timeline.;

And whereas a committee in the Central Pollution Control Board was constituted to examine the issue in totality, assess the available study reports, other relevant materials and other related factors and make a recommendation on applicability of these standards and its timeline;

And whereas the Central Pollution Control Board, after detailed analysis, has submitted its recommendation based on its study on National Ambient Air Quality Standards of Sulphur dioxide across most of the regions of the country; resource conservation in terms of avoiding additional consumption of water, auxiliary power, and limestone; increase in carbon footprint or Carbon dioxide emission into the atmosphere due to operation of control measures being deployed, and mining and transportation of limestone required for these control measures; the techno-economic feasibility of implementation of such control measures in all coal or lignite based Thermal Power Plants; and also applying the precautionary principle for control and abatement of air pollution in densely populated areas and other air pollution sensitive areas.

Now therefore, in exercise of the powers conferred by sections 6 and 25 of the Environment (Protection) Act,1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely: -

1. (1) These rules may be called the Environment (Protection) Fourth Amendment Rules, 2025.

(2) They shall come into force on the date of their publication in the Official Gazette.

2. In the Environment (Protection) Rules, 1986, in Schedule - I, in serial number 25, for the entries beginning with "* (i) A task force shall be constituted by Central Pollution Control Board (CPCB)" and ending with "**Includes all the TPPs (units) which have been accorded environmental clearance and are under construction" the following shall be substituted, namely:-

" (a) A task force shall be constituted by Central Pollution Control Board comprising of representative from the Ministry of Environment, Forest and Climate Change, Ministry of Power, Central Electricity Authority and the Central Pollution Control Board to categorise the thermal power plants in three categories as specified in column (2) of the Table-I below, on the basis of their location specified in column (3) of the said table, to comply with the emission standards:-

757 (554)

TABLE -I

Sl. No.	Category	Location/area
(1)	(2)	(3)
1	Category A	Within 10 km radius of National Capital Region or cities having million plus population[1].
2	Category B	Within 10 km radius of Critically Polluted Areas[2] or Non-attainment cities[2]
3	Category C	Other than those included in category A and B

[1] As per 2011 census of India.

[2] as defined by the Central Pollution Control Board.

(b) (i) The timelines for applicability of emission standards for parameters other than Sulphur dioxide emissions shall be as follows:-

TABLE-II

Sl. No.	Category	Timelines for compliance (Non-retiring units)	Last date for retirement of units for exemption from compliance
(1)	(2)	(3)	(4)
1	Category A	Upto 31st December 2022	Upto 31st December 2022
2	Category B	Upto 31st December 2023	Upto 31st December 2025
3	Category C	Upto 31st December 2024	Upto 31st December 2025

(ii) the thermal power plant declared to retire before the date as specified in column (4) of Table-II shall not be required to meet the specified standards for parameters other than Sulphur dioxide emissions in case such plants submit an undertaking to Central Pollution Control Board and Central Electricity Authority for exemption on ground of retirement of such plant:

Provided that such plants shall be levied environment compensation from the dates as specified in column (4) of Table –II, at the rate of rupees 0.40 per unit electricity generated in case their operation is continued beyond the date as specified in the undertaking in case the Thermal Power Plant or Unit do not meet the specified standards.

(c) The Applicability of emission standards for Sulphur dioxide in thermal power plants shall be as follows:

i. the thermal power plants declared to retire before 31st December, 2030 shall not be required to meet the specified standards for Sulphur dioxide emissions in case such plants submit an undertaking to Central Pollution Control Board and Central Electricity Authority for exemption on ground of retirement of such plant:

Provided that such plants shall be levied environment compensation from the 31st December 2030, at the rate of rupees 0.40 per unit electricity generated in case their operation is continued beyond the date as specified in the undertaking without meeting the specified standards;

ii. the existing Category A thermal power plants shall comply with the Sulphur dioxide emission standards by 31st December, 2027 and the Category A thermal power plants under commissioning shall also comply with the standards before 31st December, 2027. Other category A plants to be commissioned after 31st December, 2027 will operate only after ensuring compliance of these standards;

iii. for all Category B Plants or Units, whether existing or upcoming, the applicability of Sulphur dioxide emission standards, shall be decided on a case to case basis by the Central Government based upon the

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recommendations of the Expert Appraisal Committee in charge of Thermal Power Projects constituted under Environment Impact Assessment notification 2006 based on the appropriate scientific studies as per the following procedure:

(a a) in case environmental clearance has already been granted, such plants or units may opt for review of the applicability of Sulphur dioxide standards provided that concerned project proponent applies for such review on the PARIVESH portal within six months of the date of issue of this notification, in case Sulphur dioxide standards are decided as applicable, the same shall be effective from 31st December, 2028 and in all other cases, the thermal power plant shall comply with the stack height criteria notified *vide* notification number GSR 742 (E) dated the 30th August, 1990 by 31st December, 2028;

(b b) in cases of upcoming plants where EC has not been granted, the applicability of Sulphur dioxide standards and the date of its coming into force or otherwise will be as specified in environmental clearance granted to each such projects following the procedure as laid down in Environment Impact Assessment notification 2006 as amended from time to time and in cases, where the Sulphur dioxide standards are not made applicable, the thermal power plants shall comply with the stack height criteria notified *vide* notification number GSR 742 (E) dated the 30th August, 1990;

(c c) these standards for Sulphur dioxide emissions shall be applicable with effect from the 31st December, 2028 in respect of all those plants or units which have not opted for review within the given timeframe as specified in para (i) above;

iv. the Sulphur dioxide emission standards shall not be applicable to all Category C thermal power plants subject to ensuring compliance of stack height criteria notified *vide* notification number GSR 742 (E), dated the 30th August, 1990 and the time line for ensuring compliance by the existing Category C Thermal Power Plants of stack height criteria by the 31st December, 2029.

(d) The Central Government may, on the recommendations of the Central Pollution Control Board, by an order grant extension of timelines to thermal power plants from compliance of Sulphur dioxide emission standards.

(e) There shall be levied environment compensation on the non-retiring and non-compliant thermal power plants, after the date as specified in column (4) of Table-II and the date specified in paragraph (b), (c) & (d), as per the rates specified in Table-III.

TABLE -III

Non-Compliant operation beyond the Timeline	Environmental Compensation (Rs. per unit electricity generated)
0-180 days	0.20
181-365 days	0.30
366 days and beyond	0.40".

[F. No. Q-15017/40/2007-CPW]

NEELESH KUMAR SAH, Jt. Secy.

Note: The Principal rules were published in the Gazette of India, Extraordinary, Part-II, Section 3, Sub-section (i) *vide* number S.O. 844(E), dated the 19th November, 1986 and last amended *vide* notification number G.S.R 446(E) dated the 3rd July, 2025.

True copy

Uploaded by Dte. of Printing at Government of India Press, Ring Road, Mayapuri, New Delhi-110064
and Published by the Controller of Publications, Delhi-110054. KUMER CHAND MEENA

ANNEXURE R2/4 (COLLY)

ITEM NO.47 COURT NO.4 SECTION PIL-W

S U P R E M E C O U R T O F I N D I A
RECORD OF PROCEEDINGS

Writ Petition(s)(Civil) No(s). 13029/1985

M.C. MEHTA Petitioner(s)

VERSUS

UNION OF INDIA & ORS. Respondent(s)

(1) In Re: REPORT NO. 71 AND 78 FILED BY EPCA (REGARDING COMPREHENSIVE ACTION PLAN FOR AIR POLLUTION CONTROL AND SUPPLEMENTARY REPORT ON THE COMPREHENSIVE ACTION PLAN WITH TIMELINES)

2) IN Re: REPORT NO. 73 AND 75 FILED BY EPCA(ON THE ASSESSMENT OF POLLUTION UNDER CONTROL (PUC) PROGRAMME IN DELHI AND NCR)

Date : 17-11-2017 These applications were called on for hearing today.

CORAM : HON'BLE MR. JUSTICE MADAN B. LOKUR
HON'BLE MR. JUSTICE DEEPAK GUPTA

For Petitioner(s) Mr. Harish N. Salve, Sr. Advocate (A.C.)

Ms. Aparajita Singh, Advocate (A.C.)

Mr. A.D.N. Rao, Advocate (A.C.)[Np]

Mr. Siddhartha Chowdhury, Advocate (A.C.)[Np]

Petitioner-In-Person

For Respondent(S) Mr. A.N.S. Nadkarni, ASG
Mr. S.Wasim A. Qadri, Adv.
Mr. D.L. Chidanand, Adv.
Mr. Ritesh Kumar, Adv.
Mr. Zaid Ali, Adv.
Mr. Saeed Qadri, Adv.
Mr. S.S. Rebello, Adv.
Ms. Nivedita Nair, Adv.
Mr. Abhisehk Bharadwaj, Adv.
Mr. Jai Dehadrai, Adv.
Ms. Divya Prakash Pandey, Adv.
Mr. Ajit Yadav, Adv.
Ms. Saudamini Sharma, Adv.
Ms. Pallavi Chopra, Adv.
Mr. G.S. Makker, Advocate.

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Date: 2017.11.17 14:52:38 IST
Reason:

	Mr. Ajit Yadav, Adv.
CPCB	Mr. Vijay Panjwani, Advocate
U.P.	Ms. Aishwarya Bhati, AAG Ms. Rachna Gupta, Adv. Mr. Siddhant S. Malik, Adv.
Haryana	Mr. Anil Grover, AAG Ms. Noopur Singhal, Adv. Mr. Satish Kumar, Adv. Mr. Ajay Bansal, Adv. Mr. Gaurav Yadav, Adv. Mr. Sanjay Kr. Visen, Advocate Mr. Samir Ali Khan, Advocate
Rajasthan	Mr. S.S. Shamshery, AAG Mr. Amit Sharma, Adv. Mr. Ankit Raj, Adv. Ms. Indira Bhakar, Adv. Ms. Ruchi Kohli, Advocate
NCT	Mr. Chirag M. Shroff, Adv. Ms. Neha Sangwan, Adv. Mr. B.K. Prasad, Advocate. M/S S Narain
Mercedes Benz	Mr. Gopal Subramanium, Sr. Adv. Mr. Akshat Hansaria, Adv. Mr. Amit K. Mishra, Adv. Mr. Pavan Bhushan, Adv. Mr. Ritesh Bajaj, Adv.

UPON hearing the counsel the Court made the following

O R D E R

Report Nos. 72 and 76

On 13.11.2017, we had reserved orders on various applications filed for recall of the order dated 24.10.2017 regarding the ban on use of furnace oil and pet coke in the States of U.P., Haryana and Rajasthan.

Today, the learned ASG has placed before us a decision taken

by the Ministry of Environment, Forests and Climate Change of the Government of India on 15.11.2017 requiring the Central Pollution Control Board to issue a direction under Section 5 of the Environment (Protection) Act 1986 to the States of U.P., Haryana and Rajasthan prohibiting any industry, operation or processes using pet coke and furnace oil as fuel with immediate effect until further orders. It is clarified by the learned ASG that this is with respect to entire State and not only NCR region.

Pursuant to the communication dated 15.11.2017, a direction has been issued on the same date i.e. 15.11.2017 by the Chairman, CPCB under Section 5 of the Environment (Protection) Act, 1986. The direction is to the effect that there will be a prohibition on the use of pet coke and furnace oil by any industry, operation or processes within the the States of U.P., Haryana and Rajasthan with immediate effect until further orders.

It is submitted by the learned Amicus that a prohibition on the use of pet coke and furnace oil will solve only a part of the problem. A direction should also be issued to the effect there is a ban on the sale of pet coke and furnace oil in all these three States for being used as fuel.

The learned ASG says that he will look into the matter and will get back to us within a week or so.

We may note that pollution caused by pet coke and furnace oil is not a problem confined only to the NCR region but appears to be a problem faced by almost all the States and Union Territories in the country.

For the present, we do not propose to give any direction to

any other State and Union Territory but we request all the State Governments and Union Territories to consider taking similar measures as have been taken by the Government of India and the Chairman of the Central Pollution Control Board under Section 5 of the Environment (Protection) Act, 1986.

List on 4th December, 2017.

Report Nos. 71 and 78 (REGARDING COMPREHENSIVE ACTION PLAN FOR AIR POLLUTION CONTROL AND SUPPLEMENTARY REPORT ON THE COMPREHENSIVE ACTION PLAN WITH TIMELINES)

List on 4th December, 2017 for final orders.

Report Nos.73 and 75 (ON THE ASSESSMENT OF POLLUTION UNDER CONTROL (PUC) PROGRAMME IN DELHI AND NCR)

List on 4th December, 2017 for final orders.

Application for Direction by the Amicus Curiae

Learned Amicus has moved an application in which it is prayed as follows:

a) Direct the collection of a compensatory sum on petrol and diesel in NCR to be used for measures to deal with pollution in the NCR region.

b) Direct that the charge so collected should be utilized by the Union of India to procure the requisite agricultural equipments for the farmers of Punjab and Haryana.

c) Further direct that the Ministry of Petroleum and Natural Gas examine the feasibility of existing technologies and present a workable scheme on the use and disposal of the crop stubble to this

Hon'ble Court.

It is our impression that a prayer similar to prayer (c) has already been made in a writ petition filed and is perhaps pending before Hon'ble the Chief Justice.

On the request of the learned Amicus , we take the application on record but do not pass any orders since the learned Amicus says that he will move Hon'ble the Chief Justice.

Application for Direction by the Amicus Curiae

The learned Amicus has moved another application in which it is prayed as follows:

a) Direct that sufficeint gas supply be made available so that all power generation in the NCR region is from power plants using gas as their principal fuel.

b) Direct a ban on import of pet coke and furnace oil and confine the use of domestic pet coke for the sole purpose of feedstock.

c) Direct the implementation of the 2015 emission standards for power plants as per schedule i.e. by December 2017

d) Direct the review of the status of existing coal based power plants and a timebound switch over to natural gas.

e) Direct the Union to oversee measures to strengthen the distribution of electricity in the NCR region to ensure that there is no shortfall in availability of electricity on 24/7 basis.

Issue notice returnable on 04.12.2017.

Mr. Qadri, learned counsel accepts notice.

Learned ASG seeks some time to have instructions and file a response, if necessary.

Several amounts running into hundreds if not thousand crores have been collected under various heads/accounts pursuant to various orders passed by this Court from time to time. We request the learned ASG appearing for the Union of India, Mr. Vijay Panjwani, learned counsel for CPCB and Ms. Aprajita Singh, the learned Amicus before us to sit together and identify all the heads and the amounts lying under those heads / accounts so that there can be proper utilization of these funds. The Registry is directed to give access to the relevant records, if necessary.

The learned ASG, Mr. Vijay Panjwani and Ms. Aprajita Singh, the learned Amicus may take the assistance of any other person that they feel necessary.

(MEENAKSHI KOHLI)
COURT MASTER

(KAILASH CHANDER)
COURT MASTER

REVISED

ITEM NO.302 COURT NO.4 SECTION PIL-W

S U P R E M E C O U R T O F I N D I A
RECORD OF PROCEEDINGS

Writ Petition (Civil) No.13029/1985

M.C. MEHTA Petitioner(s)

VERSUS

UNION OF INDIA & ORS. Respondent(s)

(1) IN RE: REPORT NOS. 81 AND 84 SUBMITTED BY EPCA(IMPLEMENTATION OF THE DECEMBER, 2015 STANDARDS FOR THERMAL POWER PLANTS WHICH WERE TO BE IMPLEMENTED BY DECEMBER, 2017)

(2) IA NO. 39539 AND 39541/2019 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON BEHALF OF NTPC LTD.)

(3) IA NO. 34/1999 (APPLN. FOR DIRECTIONS ON B/O GAUTAM NAGAR WELFARE ASSOCIATION FILED BY A.C.)

(4) IN RE: ISSUE OF COMPREHENSIVE PLAN FOR AIR POLLUTION CONTROL (REPORT NO. 87, 93 , 94 AND 96 SUBMITTED BY EPCA) - REGIONAL RAPID TRANSPORT SYSTEM, PARKING POLICY AND REFORMS OF DTC AND CLUSTER BUS OPERATION

(5) IN RE: ALLOCATION OF NATURAL GAS TO M/S INDRAPRASTHA GAS LIMITED
(i) I.A. NO. 346/2013 (FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.
(ii) I.A. NO. 104664/2017 (APPLICATION FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.)
(iii) IA NO. 45387/2019 (APPLN. FOR DIRECTIONS ON BEHALF OF HARYANA CITY GAS DISTRIBUTION LTD.)“ONLY” IN W.P.(C) NO. 13029/1985

Date : 08-04-2019 These applications were called on for hearing today.

CORAM :
HON'BLE MR. JUSTICE ARUN MISHRA
HON'BLE MR. JUSTICE DEEPAK GUPTA

Mr. Harish N. Salve, Sr. Advocate (A.C.) [N.P.]
Ms. Aparajita Singh, Sr. Advocate (A.C.)
Mr. A.D.N. Rao, Advocate (A.C.)
Mr. Siddhartha Chowdhury, Advocate (A.C.)

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Mr. Rohan Jaitley, Adv.
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Mr. Vibhu Anshuman, Adv.

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Mr. Praveen Swaroop, Adv.
Mr. Gaurav Yadava, Adv.
Ms. Veena Bansal, Adv.

Mr. Rajesh Katyal, Adv.
Mr. Kuldip Singh, Adv.

Mr. Aniket Prasoon, Adv.
Mr. Samyak Mishra, Adv.
Mr. E.C. Aggarwala, Adv.

Mr. Mahesh Agarwal, Adv.
Mr. Aniket Prasoon, Adv.
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Mr. Samyak Mishra, Adv.
Mr. E.C. Aggarwala, Adv.

Ms. Suruchi Aggarwal, Adv.
Ms. Priyata Chakraborty, Adv.

Mr. Achyuth Ajith Kumar, Adv.
Mr. Talha Abdul Rahman, Adv.

Mr. Vijay Panjwani, Adv.

Ms. Kiran Bhardwaj, Adv.

Dr. Monika Gusain, Adv.

Mr. B.K. Prasad, Adv

Mr. Sanjay Kr. Visen, Adv

Mr. Abhishek, Adv

Ms. Ruchi Kohli, Advocate

Mr. B.V. Balramdas, Adv

M/S S Narain And Co.

Mr. Rohit K. Singh, Adv

Mr. Ritwik Dutta, Adv

Mr. Arvind Kumar Sharma, Adv

Ms. Nishtha Kumar, Adv

Ms. Sakya Singh Chaudhuri, Adv

Ms. Suruchi Aggarwal, Adv

Mr. Preshit Surshe, Adv

Mr. Rajiv Yadav, Adv

Mr. Guntur Prabhakar, Adv

Mr. Gaurav Shrivastava, Adv

Mr. Pradeep Misra, Adv

Mr. Kuldip Singh, Adv

Mr. S.K. Bhattcharya, Adv

Mr. R.D. Upadhyay, Adv

Mr. Ajit Pudussery, Adv

Ms. Bina Gupta, Advocate

UPON hearing the counsel the Court made the following

O R D E R

(1) IN RE: REPORT NOS. 81 AND 84 SUBMITTED BY EPCA(IMPLEMENTATION OF THE DECEMBER, 2015 STANDARDS FOR THERMAL POWER PLANTS WHICH WERE TO BE IMPLEMENTED BY DECEMBER, 2017)

Mr. A.N.S. Nadkarni, learned Solicitor General as well as Ms. Aparajita Singh, learned senior counsel submit that a new technology is being tested which is reported to be in the last

phase.

A prayer for grant of some time is made to report the outcome of the same, whether it can be adopted by the thermal plants.

As prayed, list in the second week of July, 2019.

(2) IA NO. 39539 AND 39541/2019 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON BEHALF OF NTPC LTD.)

IA NO.39539

Application for impleadment is allowed only for the purpose of IA No.39541/2019.

IA NO.39541/2019

This application has been filed to extend the time to switchover to the alternate fuels from Furnace Oil by a further period of two years from the date of the order of this Court for the 2 units of Meja Super Thermal Power Plant situated in the State of Uttar Pradesh.

As the prayer is quite reasonable, the same is allowed.

Consequently, the application is allowed.

(3) IA NO. 34/1999 (APPLN. FOR DIRECTIONS ON B/O GAUTAM NAGAR WELFARE ASSOCIATION FILED BY A.C.)

It is submitted by learned counsel appearing for the Government of NCT of Delhi that 11 interim Nazirs have been appointed.

Let an affidavit be filed in this regard.

With respect to the allotment of land, let a copy be furnished by Delhi Development Authority to Delhi Police. Let further progress be reported and affidavit in this regard be filed.

List on 06.05.2019.

COMPLETION OF TASKS IN 'A', 'B' AND 'C' CATEGORIES CORRIDORS

Let an affidavit be filed by the Delhi Police in terms of order dated 04.02.2019 by 30.04.2019.

List on 06.05.2019.

(4) IN RE: ISSUE OF COMPREHENSIVE PLAN FOR AIR POLLUTION CONTROL (REPORT NO. 87, 93 , 94 AND 96 SUBMITTED BY EPCA) - REGIONAL RAPID TRANSPORT SYSTEM, PARKING POLICY AND REFORMS OF DTC AND CLUSTER BUS OPERATION

IN RE: ISSUE OF COMPREHENSIVE PLAN FOR AIR POLLUTION CONTROL (REPORT NO. 87, 93, 94 AND 96 SUBMITTED BY EPCA)

DELHI-ALWAR REGIONAL RAPID TRANSPORT SYSTEM

In the submissions placed by Mr. A.N.S. Nadkarni, learned Additional Solicitor General of India on behalf of the Ministry of Housing and Urban Affairs, following facts have been pointed out:

> **"i. The NCRTC vide letter dated 22.01.2019 conveyed that the Board of Directors of NCRTC considered and approved the DPR of Delhi-Gurugram-SNB (Shahjahanpur-Neemrana-Behror) RRTS corridor i.e. the first part of the Delhi-Alwar corridor in accordance with the decision taken at the 36th meeting of the National Capital Region Planning Board.**
>
> **ii. In December, 2018 and in January, 2019 NCRTC has submitted the DPR to the concerned State Governments, i.e. the Government of Haryana/Government of Rajasthan and to the Government of National Capital Territory of Delhi respectively for their approval.**
>
> **iii. The NCRTC further informed the Government of India that the Government of Haryana has approved the DPR on 22.02.2019.**
>
> **iv. Approval from the Government of Rajasthan and Government of National Capital Territory of Delhi is awaited."**

It is submitted that approval from State of Rajasthan and Government of National Capital Territory of Delhi is awaited.

Let the Government of Rajasthan and Government of NCT of Delhi decide the matter and approve the Corridor by 30.04.2019.

List for consideration on 06.05.2019.

DELHI-PANIPAT REGIONAL RAPID TRANSPORT SYSTEM

Let the National Capital Regional Transport Corporation (NCRTC) expedite the process with regard to the Delhi-Panipat Regional Rapid Transport Corridor and duly indicate the status to the Ministry of Housing and Urban Affairs by 30.04.2019.

List on 06.05.2019

PARKING POLICY

Let the parties respond to the note with respect to the parking policy by 30.04.2019

List on 06.05.2019.

REFORMS OF DTC AND CLUSTER BUS OPERATION

List along with Action Plan Point 2.3.1 – Improvement in Bus Numbers And Services in Delhi in the month of July, 2019.

(5) IN RE: ALLOCATION OF NATURAL GAS TO M/S INDRAPRASTHA GAS LIMITED

(i) I.A. NO. 346/2013 (FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.

(ii) I.A. NO. 104664/2017 (APPLICATION FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.)

(iii) IA NO. 45387/2019 (APPLN. FOR DIRECTIONS ON BEHALF OF HARYANA CITY GAS DISTRIBUTION LTD.)"ONLY" IN W.P.(C) NO. 13029/1985

A prayer has been made in IA NO.45387/2019 for recall of order dated 31.10.2018 along with subsequent orders dated 06.12.2018, 04.02.2019 and 06.03.2019 passed by this Court regarding the valuation of the applicants for distribution of gas in geographical area of Gurugram.

It was submitted on behalf of the applicants that agreement was reached on 31.10.2018 between the parties that distribution/supply of natural gas by Haryana City Gas Distribution Ltd.(HCGDL) can be taken over by Indraprastha Gas Ltd.(IGL) in Gurugram (Gurgaon) District as an ongoing concern. It was agreed between the parties that valuation of the ongoing concern including the infrastructure (pipeline etc.) may be valued by an independent valuer such as Deloitte Haskins and Sells LLP.

Following order was passed on 31.10.2018:

> **"During the course of hearing, learned Additional Solicitor General suggested that it might be worth considering whether the supply of natural gas by Haryana City Gas Distribution Limited (HCGDL) can be taken over by**

Indraprastha Gas Limited (IGL) in Gurgaon District as an ongoing concern so that the entire dispute can be resolved amicably.

Learned counsel for the HCGDL and learned counsel for IGL are agreeable to this suggestion given by learned Additional Solicitor General.

It is also agreed between the parties that the valuation of the ongoing concern including the infrastructure (pipeline, etc.) may be valued by an independent valuer such as Deloitte Haskins and Sells LLP."

Thereafter, on 06.12.2018, following order was passed by this Court.

"We have gone through the additional affidavit filed on behalf of Indraprastha Gas Limited (IGL).

Payment to Deloitte Haskins and Sells LLP will be considered during the course of hearing on the next date.

The matter is released from the part heard.

List the applications on 29.01.2019 for final disposal.

Mr. Anil Grover, learned counsel for the State of Haryana says that there is no objection if IGL continues with their activities in Gurgaon District."

Thereafter on 04.02.2019, the matter came up for consideration and this Court directed Deloitte to submit a report as per order passed by this Court on 06.12.2018 and in addition to it assets to be valued separately.

The order was repeated again on 06.03.2019 and following order was passed by this Court:

"<u>IN RE : ALLOCATION OF GAS TO M/S INDRAPRASTHA GAS LIMITED</u>

It appears that Haryana City Gas Distribution Ltd. has not furnished the information as it was under the impression as stated by the learned counsel that valuation has to be made in the capacity of the ongoing concern.

The order of this Court is clear that apart from ongoing concern, valuation of the assets has to be made separately also. For that purpose, certain information has been sought from the Haryana City Gas Distribution Ltd. by Deloitte.

Let the said information be furnished within seven

days from today by the Haryana City Gas Distribution Ltd. to Deloitte.

Let Deloitte submit a report, within 15 days thereafter, as ordered by this Court on both aforesaid basis. This valuation is without prejudice to the rights available to the Haryana City Gas Distribution Ltd. to claim the compensation on ongoing basis.

List for consideration on 02.04.2019."

It is clear from the aforesaid orders and even in the initial orders, it was ordered by this Court that valuation be made of ongoing concern including infrastructure. This Court has further clarified that valuation has to be made as ongoing concern as well as of assets. Meaning thereby that infrastructure also has to be valued. Thus, it is clear that the valuation has to be made by the Haryana City Gas Distribution Ltd. of the ongoing concern as well as that of assets. In the application for recall of the order, it has been pointed out that agreement recorded in the order dated 31.10.2018 was confined to the valuation in the capacity of ongoing concern, and not of assets and infrastructure separately.

This Court has not diluted the order, even if the understanding of the Haryana city Gas Distribution Ltd. is that as an ongoing concern, the valuation as to be made, that is still intact. This Court simply clarified that all the assets be valued independently also. The parties cannot wriggle out of the same, as order was passed after hearing the parties on several dates.

We find that there is non-cooperation on the part of the Haryana City Gas Distribution Ltd. to furnish requisite information in spite of the various orders passed by this Court. That clearly amounts to non-compliance of the order passed by this Court. Now they have filed an application for recall of the order dated 31.10.2018 along with subsequent orders dated 06.12.2018, 04.02.2019 and 06.03.2019.

It was submitted that later on it has come to the notice of Haryana City Gas Distribution Ltd. that Deloitte was a statutory auditor for Indraprastha Gas Ltd. which is a public limited company. The apprehension raised on behalf of Haryana City Gas

Distribution Ltd. as to the bias of Deloitte is baseless and has absolutely no foundation.

Let valuation be made by the Deloitte Haskins and Sells LLP. Valuation from other valuer is not considered appropriate at this stage.

Let Haryana City Gas Distribution Ltd. now comply with the order passed by this Court and supply requisite information. It is made clear that this is the last opportunity granted to Haryana City Gas Distribution Ltd. to furnish the information. In case they do not co-operate and fail to supply the requisite information to Deloitte within seven days from today, that shall be treated as blatant violation of the directions of this Court and shall be dealt with appropriately, in accordance with law.

In case compliance is not made, all the Directors of Haryana City Gas Distribution Ltd. be kept present in the Court on 22.04.2019.

We have no hesitation in rejecting the application that has been filed for recall of the order dated 31.10.2018 along with subsequent orders dated 06.12.2018, 04.02.2019 and 06.03.2019 passed by this Court.

The Indraprastha Gas Limited is also desisted from issuing any advertisement showing that it has taken over the Haryana City Gas Distribution Ltd.

List the matter to report compliance on 22.04.2019.

(ASHA SUNDRIYAL)
COURT MASTER

(JAGDISH CHANDER)
BRANCH OFFICER

ITEM NO.302 COURT NO.4 SECTION PIL-W

S U P R E M E C O U R T O F I N D I A
RECORD OF PROCEEDINGS

Writ Petition (Civil) No.13029/1985

M.C. MEHTA Petitioner(s)

VERSUS

UNION OF INDIA & ORS. Respondent(s)

(1) IN RE: REPORT NOS. 81 AND 84 SUBMITTED BY EPCA(IMPLEMENTATION OF THE DECEMBER, 2015 STANDARDS FOR THERMAL POWER PLANTS WHICH WERE TO BE IMPLEMENTED BY DECEMBER, 2017)

(2) IA NO. 39539 AND 39541/2019 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON BEHALF OF NTPC LTD.)

(3) IA NO. 34/1999 (APPLN. FOR DIRECTIONS ON B/O GAUTAM NAGAR WELFARE ASSOCIATION FILED BY A.C.)

(4) IN RE: ISSUE OF COMPREHENSIVE PLAN FOR AIR POLLUTION CONTROL (REPORT NO. 87, 93 , 94 AND 96 SUBMITTED BY EPCA) - REGIONAL RAPID TRANSPORT SYSTEM, PARKING POLICY AND REFORMS OF DTC AND CLUSTER BUS OPERATION

(5) IN RE: ALLOCATION OF NATURAL GAS TO M/S INDRAPRASTHA GAS LIMITED
(i) I.A. NO. 346/2013 (FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.
(ii) I.A. NO. 104664/2017 (APPLICATION FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.)
(iii) IA NO. 45387/2019 (APPLN. FOR DIRECTIONS ON BEHALF OF HARYANA CITY GAS DISTRIBUTION LTD.)“ONLY” IN W.P.(C) NO. 13029/1985

Date : 08-04-2019 These applications were called on for hearing today.

CORAM :
HON'BLE MR. JUSTICE ARUN MISHRA
HON'BLE MR. JUSTICE DEEPAK GUPTA

Mr. Harish N. Salve, Sr. Advocate (A.C.)
Ms. Aparajita Singh, Sr. Advocate (A.C.)
Mr. A.D.N. Rao, Advocate (A.C.)
Mr. Siddhartha Chowdhury, Advocate (A.C.)

Counsel for the parties:-

Mr. Tushar Mehta, SG
Mr. Adarsh Tripathi, Adv.
Ms. Swati Ghildiyal, Adv.

Mr. Gaurav, Adv.

Mr. A.N.S. Nadkarni, ASG
Mr. Rajesh K. Singh, Adv.
Ms. Suhasini Sen, Adv.
Mr. D.L. Chidananda, Adv.
Mr. Raj Bahadur, Adv.
Ms. Shraddha Deshmukh, Adv.
Ms. Pinky Anand, ASG
Ms. Snidha Mehra, Adv.
Mr. B.V. Balramdas, Adv.
Ms. Archana Pathak, Adv.
Mrs. Anil Katiyar, Adv.
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Mr. B.V. Balram Das, Adv.

Mr. Gopal Jain, Sr. Adv.
Mr. Saurav Agrawal, Adv.
Mr. Rohan Jaitley, Adv.
Mr. Bimal Roy Jad, Adv.
Mr. Anshuman Choudhary, Adv.
Mr. Vibhu Anshuman, Adv.

Mr. Gopal Shankar Narayanan, Sr. Adv.
Mr. Sanjeet Singh, Adv.
Mr. Surjeet Singh, Adv.
Ms. Divya Roy, Adv.

Mr. Sanjiv Sen, Sr. Adv.
Mr. Praveen Swarup, Adv.
Mr. Sayan Roy, Adv.
Mr. Soumo Palit, Adv.

Mr. S. Wasim A. Qadri, Sr. Adv.
Mr. Pravin Swaroop, Adv.
Mr. Zaid Ali Subzposh, Adv.
Mr. Saeed Qadri, Adv.

Petitioner-In-Person

Mr. Anil Grover, AAG
Mr. Satish Kumar, Adv.
Mr. Sanjay Kr. Visen, Adv.

Mr. Balaji Srinivasan, AAG
Mr. B. Vinodh Kanna, Adv.
Ms. S. Valar Mathi, Adv.

Mr. G. Prakash, Adv.

Mr. Jishnu M.L., Adv.
Mrs. Priyanka Prakash, Adv.
Mrs. Beena Prakash, Adv.

Ms. Garima Prashad, Adv.
Mr. G.S. Oberoi, adv.

Mr. Prashant Bezboruah, Adv.
Mr. Munawwar Naseem, Adv.

Ms. Uttara Babbar, Adv.
Ms. Bhavana Duhoon, Adv.
Mr. Manan Bansal, Adv.

Mr. Abhishek Sharma, Adv.
Ashley Cherian, Adv.
Ms. Shreya Jad, Adv.

Mr. Ajay Bansal, Adv.
Mr. Praveen Swaroop, Adv.
Mr. Gaurav Yadava, Adv.
Ms. Veena Bansal, Adv.

Mr. Rajesh Katyal, Adv.
Mr. Kuldip Singh, Adv.

Mr. Aniket Prasoon, Adv.
Mr. Samyak Mishra, Adv.
Mr. E.C. Aggarwala, Adv.

Mr. Mahesh Agarwal, Adv.
Mr. Aniket Prasoon, Adv.
Ms. Parul Shukla, Adv.
Mr. Samyak Mishra, Adv.
Mr. E.C. Aggarwala, Adv.

Ms. Suruchi Aggarwal, Adv.
Ms. Priyata Chakraborty, Adv.

Mr. Achyuth Ajith Kumar, Adv.
Mr. Talha Abdul Rahman, Adv.

Mr. Vijay Panjwani, Adv.

Ms. Kiran Bhardwaj, Adv.

Dr. Monika Gusain, Adv.

Mr. B.K. Prasad, Adv

Mr. Sanjay Kr. Visen, Adv

Mr. Abhishek, Adv

Ms. Ruchi Kohli, Advocate

Mr. B.V. Balramdas, Adv

M/S S Narain And Co.

Mr. Rohit K. Singh, Adv

Mr. Ritwik Dutta, Adv

Mr. Arvind Kumar Sharma, Adv

Ms. Nishtha Kumar, Adv

Ms. Sakya Singh Chaudhuri, Adv

Ms. Suruchi Aggarwal, Adv

Mr. Preshit Surshe, Adv

Mr. Rajiv Yadav, Adv

Mr. Guntur Prabhakar, Adv

Mr. Gaurav Shrivastava, Adv

Mr. Pradeep Misra, Adv

Mr. Kuldip Singh, Adv

Mr. S.K. Bhattcharya, Adv

Mr. R.D. Upadhyay, Adv

Mr. Ajit Pudussery, Adv

Ms. Bina Gupta, Advocate

UPON hearing the counsel the Court made the following

O R D E R

(1) IN RE: REPORT NOS. 81 AND 84 SUBMITTED BY EPCA(IMPLEMENTATION OF THE DECEMBER, 2015 STANDARDS FOR THERMAL POWER PLANTS WHICH WERE TO BE IMPLEMENTED BY DECEMBER, 2017)

Mr. A.N.S. Nadkarni, learned Solicitor General as well as Ms. Aparajita Singh, learned senior counsel submit that a new technology is being tested which is reported to be in the last phase.

A prayer for grant of some time is made to report the outcome

of the same, whether it can be adopted by the thermal plants.

As prayed, list in the second week of July, 2019.

(2) IA NO. 39539 AND 39541/2019 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON BEHALF OF NTPC LTD.)

IA NO.39539

Application for impleadment is allowed only for the purpose of IA No.39541/2019.

IA NO.39541/2019

This application has been filed to extend the time to switchover to the alternate fuels from Furnace Oil by a further period of two years from the date of the order of this Court for the 2 units of Meja Super Thermal Power Plant situated in the State of Uttar Pradesh.

As the prayer is quite reasonable, the same is allowed.

Consequently, the application is allowed.

(3) IA NO. 34/1999 (APPLN. FOR DIRECTIONS ON B/O GAUTAM NAGAR WELFARE ASSOCIATION FILED BY A.C.)

It is submitted by learned counsel appearing for the Government of NCT of Delhi that 11 interim Nazirs have been appointed.

Let an affidavit be filed in this regard.

With respect to the allotment of land, let a copy be furnished by Delhi Development Authority to Delhi Police. Let further progress be reported and affidavit in this regard be filed.

List on 06.05.2019.

COMPLETION OF TASKS IN 'A', 'B' AND 'C' CATEGORIES CORRIDORS

Let an affidavit be filed by the Delhi Police in terms of order dated 04.02.2019 by 30.04.2019.

List on 06.05.2019.

(4) IN RE: ISSUE OF COMPREHENSIVE PLAN FOR AIR POLLUTION CONTROL

(REPORT NO. 87, 93 , 94 AND 96 SUBMITTED BY EPCA) - REGIONAL RAPID TRANSPORT SYSTEM, PARKING POLICY AND REFORMS OF DTC AND CLUSTER BUS OPERATION

IN RE: ISSUE OF COMPREHENSIVE PLAN FOR AIR POLLUTION CONTROL (REPORT NO. 87, 93, 94 AND 96 SUBMITTED BY EPCA)

DELHI-ALWAR REGIONAL RAPID TRANSPORT SYSTEM

In the submissions placed by Mr. A.N.S. Nadkarni, learned Additional Solicitor General of India on behalf of the Ministry of Housing and Urban Affairs, following facts have been pointed out:

> **"i. The NCRTC vide letter dated 22.01.2019 conveyed that the Board of Directors of NCRTC considered and approved the DPR of Delhi-Gurugram-SNB (Shahjahanpur-Neemrana-Behror) RRTS corridor i.e. the first part of the Delhi-Alwar corridor in accordance with the decision taken at the 36th meeting of the National Capital Region Planning Board.**
>
> **ii. In December, 2018 and in January, 2019 NCRTC has submitted the DPR to the concerned State Governments, i.e. the Government of Haryana/Government of Rajasthan and to the Government of National Capital Territory of Delhi respectively for their approval.**
>
> **iii. The NCRTC further informed the Government of India that the Government of Haryana has approved the DPR on 22.02.2019.**
>
> **iv. Approval from the Government of Rajasthan and Government of National Capital Territory of Delhi is awaited."**

It is submitted that approval from State of Rajasthan and Government of National Capital Territory of Delhi is awaited.

Let the Government of Rajasthan and Government of NCT of Delhi decide the matter and approve the Corridor by 30.04.2019.

List for consideration on 06.05.2019.

DELHI-PANIPAT REGIONAL RAPID TRANSPORT SYSTEM

Let the National Capital Regional Transport Corporation (NCRTC) expedite the process with regard to the Delhi-Panipat Regional Rapid Transport Corridor and duly indicate the status to the Ministry of Housing and Urban Affairs by 30.04.2019.

List on 06.05.2019

PARKING POLICY

Let the parties respond to the note with respect to the parking policy by 30.04.2019

List on 06.05.2019.

REFORMS OF DTC AND CLUSTER BUS OPERATION

List along with Action Plan Point 2.3.1 – Improvement in Bus Numbers And Services in Delhi in the month of July, 2019.

(5) IN RE: ALLOCATION OF NATURAL GAS TO M/S INDRAPRASTHA GAS LIMITED

(i) I.A. NO. 346/2013 (FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.

(ii) I.A. NO. 104664/2017 (APPLICATION FOR DIRECTIONS ON B/O INDRAPRASTHA GAS LTD.)

(iii) IA NO. 45387/2019 (APPLN. FOR DIRECTIONS ON BEHALF OF HARYANA CITY GAS DISTRIBUTION LTD.)"ONLY" IN W.P.(C) NO. 13029/1985

A prayer has been made in IA NO.45387/2019 for recall of order dated 31.10.2018 along with subsequent orders dated 06.12.2018, 04.02.2019 and 06.03.2019 passed by this Court regarding the valuation of the applicants for distribution of gas in geographical area of Gurugram.

It was submitted on behalf of the applicants that agreement was reached on 31.10.2018 between the parties that distribution/supply of natural gas by Haryana City Gas Distribution Ltd.(HCGDL) can be taken over by Indraprastha Gas Ltd.(IGL) in Gurugram (Gurgaon) District as an ongoing concern. It was agreed between the parties that valuation of the ongoing concern including the infrastructure (pipeline etc.) may be valued by an independent valuer such as Deloitte Haskins and Sells LLP.

Following order was passed on 31.10.2018:

> **"During the course of hearing, learned Additional Solicitor General suggested that it might be worth considering whether the supply of natural gas by Haryana City Gas Distribution Limited (HCGDL) can be taken over by Indraprastha Gas Limited (IGL) in Gurgaon District as an ongoing concern so that the entire dispute can be resolved**

amicably.

Learned counsel for the HCGDL and learned counsel for IGL are agreeable to this suggestion given by learned Additional Solicitor General.

It is also agreed between the parties that the valuation of the ongoing concern including the infrastructure (pipeline, etc.) may be valued by an independent valuer such as Deloitte Haskins and Sells LLP."

Thereafter, on 06.12.2018, following order was passed by this Court.

"We have gone through the additional affidavit filed on behalf of Indraprastha Gas Limited (IGL).

Payment to Deloitte Haskins and Sells LLP will be considered during the course of hearing on the next date.

The matter is released from the part heard.

List the applications on 29.01.2019 for final disposal.

Mr. Anil Grover, learned counsel for the State of Haryana says that there is no objection if IGL continues with their activities in Gurgaon District."

Thereafter on 04.02.2019, the matter came up for consideration and this Court directed Deloitte to submit a report as per order passed by this Court on 06.12.2018 and in addition to it assets to be valued separately.

The order was repeated again on 06.03.2019 and following order was passed by this Court:

"<u>IN RE : ALLOCATION OF GAS TO M/S INDRAPRASTHA GAS LIMITED</u>

It appears that Haryana City Gas Distribution Ltd. has not furnished the information as it was under the impression as stated by the learned counsel that valuation has to be made in the capacity of the ongoing concern.

The order of this Court is clear that apart from ongoing concern, valuation of the assets has to be made separately also. For that purpose, certain information has been sought from the Haryana City Gas Distribution Ltd. by Deloitte.

Let the said information be furnished within seven days from today by the Haryana City Gas Distribution Ltd. to Deloitte.

Let Deloitte submit a report, within 15 days thereafter, as ordered by this Court on both aforesaid basis. This valuation is without prejudice to the rights available to the Haryana City Gas Distribution Ltd. to claim the compensation on ongoing basis.

List for consideration on 02.04.2019."

It is clear from the aforesaid orders and even in the initial orders, it was ordered by this Court that valuation be made of ongoing concern including infrastructure. This Court has further clarified that valuation has to be made as ongoing concern as well as of assets. Meaning thereby that infrastructure also has to be valued. Thus, it is clear that the valuation has to be made by the Haryana City Gas Distribution Ltd. of the ongoing concern as well as that of assets. In the application for recall of the order, it has been pointed out that agreement recorded in the order dated 31.10.2018 was confined to the valuation in the capacity of ongoing concern, and not of assets and infrastructure separately.

This Court has not diluted the order, even if the understanding of the Haryana city Gas Distribution Ltd. is that as an ongoing concern, the valuation as to be made, that is still intact. This Court simply clarified that all the assets be valued independently also. The parties cannot wriggle out of the same, as order was passed after hearing the parties on several dates.

We find that there is non-cooperation on the part of the Haryana City Gas Distribution Ltd. to furnish requisite information in spite of the various orders passed by this Court. That clearly amounts to non-compliance of the order passed by this Court. Now they have filed an application for recall of the order dated 31.10.2018 along with subsequent orders dated 06.12.2018, 04.02.2019 and 06.03.2019.

It was submitted that later on it has come to the notice of Haryana City Gas Distribution Ltd. that Deloitte was a statutory auditor for Indraprastha Gas Ltd. which is a public limited company. The apprehension raised on behalf of Haryana City Gas Distribution Ltd. as to the bias of Deloitte is baseless and has absolutely no foundation.

Let valuation be made by the Deloitte Haskins and Sells LLP. Valuation from other valuer is not considered appropriate at this stage.

Let Haryana City Gas Distribution Ltd. now comply with the order passed by this Court and supply requisite information. It is made clear that this is the last opportunity granted to Haryana City Gas Distribution Ltd. to furnish the information. In case they do not co-operate and fail to supply the requisite information to Deloitte within seven days from today, that shall be treated as blatant violation of the directions of this Court and shall be dealt with appropriately, in accordance with law.

In case compliance is not made, all the Directors of Haryana City Gas Distribution Ltd. be kept present in the Court on 22.04.2019.

We have no hesitation in rejecting the application that has been filed for recall of the order dated 31.10.2018 along with subsequent orders dated 06.12.2018, 04.02.2019 and 06.03.2019 passed by this Court.

The Indraprastha Gas Limited is also desisted from issuing any advertisement showing that it has taken over the Haryana City Gas Distribution Ltd.

List the matter to report compliance on 22.04.2019.

(ASHA SUNDRIYAL)
COURT MASTER

(JAGDISH CHANDER)
BRANCH OFFICER

ITEM NO.1 Court 2 (Video Conferencing) SECTION PIL-W

S U P R E M E C O U R T O F I N D I A
RECORD OF PROCEEDINGS

Writ Petition(s)(Civil) No(s). 13029/1985

M.C. MEHTA Petitioner(s)

VERSUS

UNION OF INDIA & ORS. Respondent(s)

((1) REPORT NO. 106 SUBMITTED BY EPCA (SPECIAL REPORT ON POLLUTION HOT SPOTS IN NCR WITH REQUEST FOR URGENT DIRECTIONS TO IMPROVE ENFORCEMENT AND POLLUTION CONTROL)(2) IN RE: STUBBLE BURNING AND SMOG IN DELHI(i) IA NO. 127792/2017 (DISPOSED OF) (APPLN. FOR DIRECTIONS FILED BY A.C.)(ii) IA NOS. 158128 AND 158129/2019 (APPLNS. FOR INTERVENTION AND DIRECTIONS ON BEHALF OF DR. KAUSHAL KANT MISHRA)(iii) IA NOS. 56487 AND 56489/2020 (APPLNS. FOR EXTENSION OF TIME AND EXEMPTION FROM FILING ATTESTED AFFIDAVIT ON BEHALF OF CENTRAL POLLUTION CONTROL BOARD)(iv) IA NO. 181745/2019 AND IA NO. 46339/2020(APPLNS. FOR INTERVENTION AND DIRECTIONS ON BEHALF OF HARSHITA SINGHAL)(v) REPORT NO. 110 SUBMITTED BY EPCA REGARDING HOSPITAL WASTE MANAGEMENT IN COMPLIANCE OF DIRECTIONS DT. 06.3.2020)AND(2) IN RE: REPORT NOS. 81 AND 84 SUBMITTED BY EPCA(IMPLEMENTATION OF THE DECEMBER, 2015 STANDARDS FOR THERMAL POWER PLANTS WHICH WERE TO BE IMPLEMENTED BY DECEMBER, 2017)(2)I.A. NOS. 53959 AND 53962/2020 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON B/O NTPC)(3)I.A. NOS. 52536, 52538 AND 53358/2020 (APPLNS. FOR IMPLEADMENT, DIRECTIONS AND EXEMPTION FROM NOTARIZATION ON B/O ARAVALI POWER CO. LTD.)(4)I.A. NOS. 58771 AND 58772/2020 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON B/O TELANGANA STATE POWER GENERATION CORP. LTD.)(5) I.A. NOS. 59929 AND 59930/2020 (APPLNS. FOR IMPLEADMENT AND DIRECTIONS ON B/O U.P. RAJYA VIDYUT UTPADAN NIGAM LTD.)(6) I.A. NOS. 64205, 64206 AND 64207/2020 (APPLNS. FOR DIRECTIONS, PERMISSION AND EXEMPTION FROM FILING COURT FEE AND ATTESTED AFFIDAVIT ON B/O SINGARENI COLLIERIES CO. LTD.)"ONLY" NAME OF THE FOLLOWING ADVOCATES MAY BE TREATED TO HAVE BEEN SHOWN IN THE LIST:MR. HARISH N. SALVE, SR. ADVOCATE (A.C.)MS. APARAJITA SINGH, SR. ADVOCATE (A.C.)MR. A.D.N. RAO, ADVOCATE (A.C.)MR. SIDDHARTHA CHOWDHURY, ADVOCATE (A.C.)PETITIONER-IN-PERSONMR. G.S. MAKKER, MR. SANJAY KR. VISEN, MR. KAMLENDRA MISHRA, MR. SANDEEP KR. JHA, MS. UTTARA BABBARMR. B.V. BALRAMDAS, MR. CHIRAG M. SHROFF, MR. PRAVEEN SWARUP, MR. ABHISHEK, ADVOCATEMR. SENTHIL JAGDEESANMR. D.N. GOBURDHUN,MS. RUCHI KOHLI,M/S KHAITAN AND CO.MS. DIVYA ROYMS. ANUKA MUKHERJEE, MR. SANTOSH KUMAR 1, MR. JOGY SCARIA, MR. TAPESH SINGH, MR. SHUVODEEP ROY, MR. NARENDRA KUMAR, MR. V.G. PRAGASAM, MR. M. SHOEB ALAM,MR. V.N. RAGHUPATHY, MR. M. YOGESH KANNA, MR. ASHUTOSH DUBEY, MR. SHOVAN MISHRA, MR. VINAY GARG,MR. VINOD SHARMA,MR. SAMEER SHRIVASTAVA, MR. R.C. KOHLI, MS. K. ENATOLI SEMAMR. VIPIN NAIRMS. ASTHA SHARMA, MS. MADHUMITA BHATTACHARJEE,MR. ANUJ BHANDARI,MS. G. INDIRA,MR. YASH PAL DHINGRA,MR. YOGINDER

Signature Not Verified
Digitally signed by GULSHAN KUMAR ARORA
Date: 2020.07.29 18:00:31 IST
Reason:

HANDOO,MR. SUBHRO SANYAL, MR. GAURAV SRIVASTAVA, MR. MAHFOOZ AHSAN NAZKI, ADVOCATESMR. KULDIP SINGH, ADVOCATEMR. RAHUL NARAYAN, ADVOCATEMR. ROHIT K. SINGH, ADVOCATEMR. RITWIK DUTTA, ADVOCATEMR. ARVIND KUMAR SHARMA, ADVOCATEMR. E.C. AGRAWALA, ADVOCATEMR. TALHA ABDUL RAHMAN, ADVOCATEMS. NISHTHA KUMAR, ADVOCATEMS. SAKYA SINGH CHAUDHURI, ADVOCATEMS. SURUCHI AGGARWAL, ADVOCATEMR. PRESHIT SURSHE, ADVOCATEMR.RAJIV YADAV, ADVOCATEMR. B. VINODH KHANNA, ADVOCATEMR. GUNTUR PRABHAKAR, ADVOCATEMR. PRADEEP MISRA, ADVOCATEMR. GAURAV SHRIVASTAVA, ADVOCATEMR. P. PARMESWARAN, ADVOCATEMR. D. ABHINAV RAO, ADVOCATEMR. CHIRAG M. SHROFF, ADVOCATEMS. ANIL KATIYAR, ADVOCATEM/S S NARAIN AND CO. , ADVOCATESMS. GARIMA PRASHAD, ADVOCATE)

WITH

SMW(C) No. 3/2019 (PIL-W)
(FOR ADMISSION)

W.P.(C) No. 1333/2019 (PIL-W)
(FOR ADMISSION and IA No.170316/2019-EX-PARTE STAY and IA No.170317/2019-PERMISSION TO APPEAR AND ARGUE IN PERSON)

T.C.(C) No. 42/2019 (XVI-A)

T.C.(C) No. 41/2019 (XVI-A)

W.P.(C) No. 1426/2019 (PIL-W)
(FOR ADMISSION)

Date : 29-07-2020 This petition was called on for hearing today.

CORAM : HON'BLE MR. JUSTICE ARUN MISHRA
HON'BLE MR. JUSTICE VINEET SARAN
HON'BLE MR. JUSTICE M.R. SHAH

Counsel for the parties **Mr. Harish N. Salve, Sr. Advocate (A.C.) (NP)**

Ms. Aparajita Singh, Sr. Advocate (A.C.)

Mr. A.D.N. Rao, Advocate (A.C.)

Mr. Siddhartha Chowdhury, Advocate (A.C.)

Mr. Tushar Mehta, Solicitor General
Ms. Aishwarya Bhati, ASG
Ms. Suhasini Sen, Advocate
Mr. D.L.Chidananda, Advocate
Mr. S.S.Rebello, Adv.
Mr. Rajat Nair, Adv.
Mr. G.S. Makker, Adv.
Mr. Rajesh Kumar Singh,Adv.
Mr. Raj Bahadur Yadav,Adv.

Mr. Vibhu Shankar Mishra,Adv.
Mr. Prashant Rawat, Adv.
Mr. B.V. Balram Das,Adv.

Mr. Tushar Mehta,SG
Mr. Anil Grover, Sr. AAG/Haryana
Ms. Noopur Singhal,Adv.
Mr. Rahul Khurana,Adv.
MR. Sanjay Kumar Visen, Adv.

Mr. Tushar Mehta,SG
Mr. V. Shekhar,Sr.Adv.
Mr. Rajeev Kumar Dubey,Adv.
Mr. Kamlendra Mishra, Adv.

Mr. Chandra Prakash, Adv.

Mr. Tushar Mehta, SG
Mr. Sanjay Jain, ASG
Mr. Adarsh Tripathi, Advocate
Mr. Anish Gupta, Advocate
Mr. Nikhil Kandpal, Advocate
Mr. Gaurav Srivastava, AOR

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Mr. Jai Dehadrai, Adv.
Mr. Siddharth Arora, Adv.
Mr. Rishi Raj Sharma, Adv.
Mr. Sameer Shrivastava, Adv.

Mr. Dinesh Dwivedi,Sr.Adv.
Ms. Jyoti Mendiratta,Adv.

Mr. Mohit Chaudhary, Adv.
Mr. Imran Ali, Adv.
Ms. Puja Sharma, Adv.
Mr. Kunal Sachdeva, Adv.
Mr. Shyam Singh Yadav, Adv.
Mr. Balwinder Singh Suri, Adv.
Mr. Parveen Kumar, Adv.
Mr. Garima Sharma, Adv.
Ms. Srishti Gupta, Adv.

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Applicant-in-person

Petitioner(s)-in-person

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Applicant-in-person, AOR
Petitioner-in-person
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Mr. Rishi Matoliya, Advocate
Mr. Rishi Malhotra,Adv.
Ms. Nidhi Mohan Parashar, Advocate
Mr. Aakarshan Aditya, Advocate

UPON hearing the counsel the Court made the following

O R D E R

REPORT NO. 106 SUBMITTED BY EPCA
(Special Report on pollution hot spots in NCR with request for urgent directions to improve enforcement and pollution control)

IN RE: STUBBLE BURNING AND SMOG IN DELHI

IA NO. 127792/2017(DISPOSED OF)
(Application for direction submitted in Court by A.C. on 17.11.2017)

IA NOS. 158128 AND 158129/2019
(Applns. For intervention and directions on behalf of Dr. Kaushal Kant Mishra)

IN RE : COMPLIANCE OF ORDER DATED 13.01.2020

It was stated by Mr. Tushar Mehta, learned Solicitor General, that they have not been able to enter into any agreement with the IIT Bombay. IIT has now backed out. This is dilly-dallying tactics and violation of the order passed by this Court has already been committed at least by IIT.

We have to proceed against the IIT, Bombay as well as against the concerned persons for violating the order of this Court and backing out from the basis of the order which was passed by this Court. This is not expected of such institutions to act in the manner it is projected in the matter relating to public interest, it is shocking that such conduct is projected by such a public functionary. We are not at all happy with the state of affairs. We direct that the order to be complied with forthwith, otherwise it would be taken seriously.

As prayed for by Mr. Tushar Mehta, learned Solicitor General, list the matter tomorrow i.e. on 30.07.2020.

IN RE : WATER QUALITY

List tomorrow along with the Report filed by EPCA.

IA NOS. 56487 AND 56489/2020
(Applns. For extension of time and exemption from filing attested affidavit on behalf of Central Pollution Control Board)

List on 30.07.2020.

IA NOS. 181745/2019 AND 46339/2020
(Applications for Intervention and Directions on behalf of Harshita Singhal)
WITH
REPORT NO. 110 SUBMITTED BY EPCA
(Regarding Hospital Waste Management in compliance of Directions dt. 06.3.2020)
with
REPORT NO. 112 SUBMITTED BY EPCA
(Regarding Hosiptal waste management for Covid-19 in compliance ofdirections dt. 21.07.2020)

List tomorrow i.e. on 30.07.2020.

IN RE: REPORT NOS. 81 AND 84 SUBMITTED BY EPCA
(Implementation of the December, 2015 standards for Thermal Power Plants which were to be implemented by December, 2017)

Let the EPCA consider the affidavit filed on 13.02.2020 filed on behalf of the MoEF and Climate Change and submit its opinion within three weeks.

Let the EPCA, Central Pollution Control Board, Ministry of Power and MoEF convene a joint meeting in this regard and sort out the issue.

List in the last week of August, 2020.

IA NOS. 64205, 64206 AND 64207/2020

Issue notice.

There shall be interim stay on recovery till the next date of hearing.

Tag with I.A.No. 53959 of 2020.

IA NOS. 53959 AND 53962/2020
(Applns. for Impleadment and Directions on b/o NTPC)
IA NOS. 52536, 52538 AND 53358/2020
(Applns. for Impleadment, Directions and exemption from filing notarized affidaviton b/o Aravali Power Co. Ltd.)
IA D. NOS. 58771 AND 58772/2020
(Applns. for Impleadment and Directions on b/o Telangana State Power Generation Corporation Ltd.)
IA NOS. 59929 AND 59930/2020
(Applications for Impleadment and Directions on behalf of Uttar Pradesh Rajya Vidyut Utpadan Nigam Ltd. (Harduaganj Thermal Power Station)

Interim stay to continue till the next date of hearing.

These applications be taken up on receipt of the opinion of EPCA. List the applications in the last week of August, 2020.

(GULSHAN KUMAR ARORA)
AR-CUM-PS

(JAGDISH CHANDER)
ASSISTANT REGISTRAR