BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI

ORIGINAL APPLICATION NO. 687 OF 2023 (PB)

IN THE MATTER OF :

"IN RE: AIR QUALITY INDEX IN VARIOUS CITIES"

I N D E X

Date: 02.05.2024
Place: Bhopal

RBobde

COUNSEL FOR
STATE OF MADHYA PRADESH

BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI

ORIGINAL APPLICATION NO. 687 OF 2023 (PB)

IN THE MATTER OF :

"IN RE: AIR QUALITY INDEX IN VARIOUS CITIES"

ACTION TAKEN REPORT ON BEHALF OF STATE OF MADHYA PRADESH IN COMPLIANCE OF ORDER DATED 19.02.2024

IT IS MOST RESEPCTFULLY SUBMITTED HEREINUNDER :

1. That the present original application is registered in suo-moto exercise of powers on the basis of the Air Quality Bulletins of CPCB posted on their website in respect of Air Quality Index (AQI) for different cities from 20.10.2023 to 01.11.2023. The said reports show that there are various cities where the air quality index has dipped to "very poor" or even to "severe" stage, wherein among the list of cities is Bhopal and Gwalior from the State of Madhya Pradesh with alleged poor air quality.

2. That this Hon'ble Tribunal vide Order dated 19.02.2024 directed the cities (53) to disclose contribution by each polluting source in terms of identified pollutant (PM10/PM2.5). That for the convenience of this Hon'ble

Tribunal, the relevant extract from the aforementioned order is reproduced hereinbelow :

> *'All the cities (53) should disclose contribution by each polluting source in terms of identified pollutant (PM10/PM2.5) as per source apportionment and progressive reduction on account of measures taken '.*

3. That in compliance of the aforementioned directions of this Hon'ble Tribunal, the Source Apportionment Study conducted in Bhopal and Gwalior, the respective contributions of each polluting source in terms of identified pollutants (PM10/PM2.5) are delineated as follows:

a. <u>Bhopal :</u>

i. That presently there are a total of seven Air Quality Monitoring Systems out of which three are Continuous Ambient Air Quality Monitoring Stations (CAAQMS) and four are Manual station, within the city of Bhopal.

ii. It is further submitted that a Source Apportionment Study for the city of Bhopal was conducted by the Automotive Research

Association of India, Pune. The Executive Summary of Source Apportionment Study for the city of Bhopal is marked and annexed herewith as **Annexure R-1**.

iii. That the aforementioned study carried out by Automotive Research Association of India, Pune, delineates the following pollutants for both PM10 and PM 2.5 :

1. Total PM10 emission load in the Bhopal city is estimated to be 10,309.3 tonnes per year. The top four contributors to PM10 emissions are :-
    a. Dust (62.2%),
    b. Transport (13.0%),
    c. Construction (12.1% each) and
    d. Open Waste Burning (2.9%).

2. Similarly, the total PM2.5 emission load in the Bhopal city is estimated to be 4121.1 tonnes per year. The top four contributors to PM2.5 emissions are :-
    a. Dust (37.7%),
    b. Transport (29.3%),

c. Construction (7.6%), and

d. Open Waste Burning (6.7%).

b. Gwalior :

i. That presently there are a total of four Continuous Ambient Air Quality Monitoring Stations (CAAQMS), within the city of Gwalior.

ii. It is further submitted that a Source Apportionment Study for the city of Gwalior was conducted by the Indian Institute of Technology, Kanpur (IIT Kanpur). The Executive Summary of Source Apportionment Study for the city of Gwalior is marked and annexed herewith as **Annexure R-2**.

iii. That the aforementioned study carried out by Indian Institute of Technology, Kanpur (IIT, Kanpur), delineates the following pollutants for both PM10 and PM 2.5 :

1. Total PM10 emission load in Gwalior is estimated to be 108 tonnes per day. The top 3 contributors to PM10 emissions are-

a. Road Dust (88%),

b. Vehicles (7%), and

c. Brick Kilns (2%).

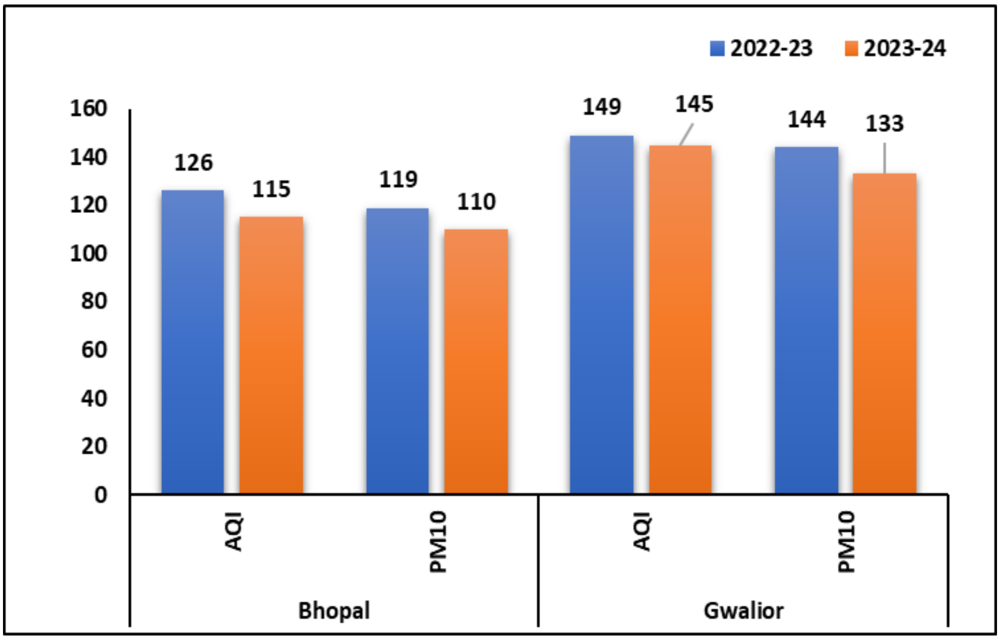
2. Similarly, PM2.5 emission load in Gwalior is estimated to be 32 tonnes per day. The top 3 contributors to PM2.5 emissions are-

a. Road Dust (67%),

b. Vehicles (22%), and

c. Brick Kilns (4%)

4. Furthermore, Air quality index (AQI) and Particulate Matter (PM10) of Bhopal and Gwalior for the year 2022-23 & 2023-24. It is observed from the chart that the AQI as well as PM10 of the current year of both cities (Bhopal and Gwalior) has been improved from the previous years. That for the convenience of this Hon'ble Tribunal the below mentioned flow chart enumerates the same :



5. That for the convenience of this Hon'ble Tribunal a tabular representation of Air Quality Index in the cities of Gwalior and Bhopal from 1st February, 2024 till 30th April, 2024 is marked and annexed herewith as **Annexure R-3**.

6. An affidavit in support is filed herewith.

Date: 02.05.2024
Place: Bhopal

RBobde

COUNSEL FOR
STATE OF MADHYA PRADESH

BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL

PRINCIPAL BENCH, NEW DELHI

ORIGINAL APPLICATION NO. 687 OF 2023 (PB)

IN THE MATTER OF :

"IN RE: AIR QUALITY INDEX IN VARIOUS CITIES"

AFFIDAVIT

I, Himanshu Singh, S/o Shri A.D. Singh, Joint Director and Officer-in-Charge, office at Directorate of Urban Development and Administration, Shivaji Nagar, Bhopal, M.P, do hereby solemnly affirm on oath as under :

1. That I am Officer in Charge for State of Madhya Pradesh in the present matter, and am fully conversant with the facts of the case and hence competent to swear on this affidavit.
2. That I am filing an Action Taken Report in the aforementioned matter before the Hon'ble Tribunal the contents of which are true and correct and no material fact has been concealed.
3. That the contents of the Action Taken Report are true and correct and no material fact is concealed or supressed.

DEPONENT

VERIFICATION

I the above-named deponent do hereby verify that the contents of the affidavit above are true and correct.

Signed and verified on this ___ Day of ________ 2024 at Bhopal (MP)

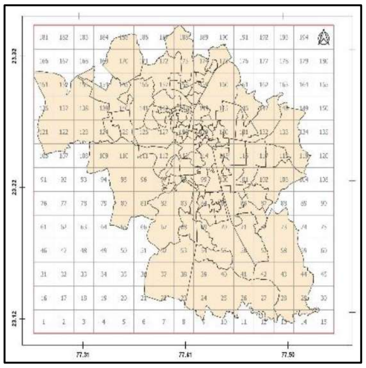
DEPONENT

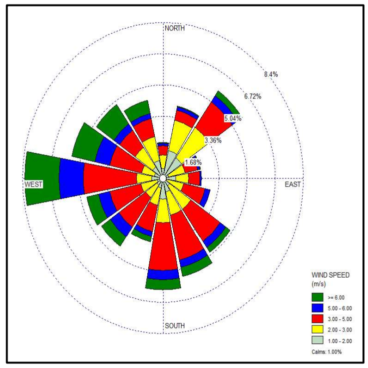
IDENTIFY BY ME

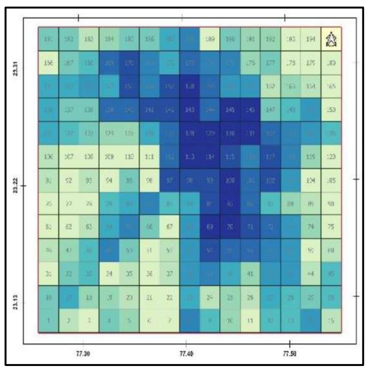
Report No.: ARAI/ERL/MPPCB_BHO/2022-23/DFR_V2.0

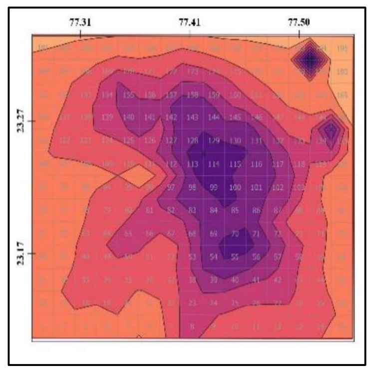
DRAFT FINAL REPORT

Emission Inventory and Source Apportionment Study of Bhopal City in Madhya Pradesh









Submitted to

Madhya Pradesh Pollution Control Board (MPPCB), Bhopal

Submitted by

Environment Research Laboratory

The Automotive Research Association of India (ARAI), Pune

March 2023

Suggested format for citation:

ARAI (2023), Emission Inventory and Source Apportionment Study of Bhopal City in Madhya Pradesh, The Automotive Research Association of India, Pune, M.S., India

Disclaimer

This report is the outcome of the project "Emission Inventory and Source Apportionment Study of Bhopal City in Madhya Pradesh" sponsored by Madhya Pradesh Pollution Control Board (MPPCB), Bhopal. The information in this report has been generated by The Automotive Research Association of India (ARAI), Pune, India, as per the scope of work in the above-referred project.

The inferences, analysis and projections made in this report are based on the data gathered physically at the identified locations in Bhopal during the project duration. Due care has been taken to validate the authenticity and correctness of the information.

ARAI disclaim any and all liability for the use that may be made of the information contained in this report. None of the information in this report may be reproduced, republished or re-disseminated in any manner or form without the prior written permission of competent authority.

Project Team

- Dr. Sukrut S. Thipse, Head – Environment Research Laboratory (ERL)
- Mr. Moqtik A. Bawase, Principal Investigator
- Mr. Yogesh V. Sathe, Co- Principal Investigator
- Dr. Yamini J. Patil
- Mr. Hemant L. Khandaskar
- Mr. Jeetendra Kumar Purohit
- Mr. Ajim R. Shaikh
- Mr. Aditya S. Sharma
- Mr. Harshvardhan V. Bhoite
- Mr. Mayur R. Ekhare
- Mr. Rohit N. Bacche
- Mr. Russell Sarkar
- Mr. Shrikant B. Jadhav
- Ms. Gauri A. Naik
- Mr. Rushant A. Nandkhile

Acknowledgements

The project "Emission Inventory and Source Apportionment Study of Bhopal City in Madhya Pradesh" was sponsored by Madhya Pradesh Pollution Control Board (MPPCB), Bhopal. We gratefully acknowledge assistance and guidance received from Chairman and Member Secretary, MPPCB during the project duration. We would like to express sincere thanks to The Regional Officer – Bhopal and their entire team for coordination, assistance and ground support during the execution of this project.

We express sincere thanks to the Central Pollution Control Board (CPCB), New Delhi, India for the real-time air quality monitoring data through their data portal. We would also like to thank National Centers for Environmental Information (NCEI) of National Oceanic and Atmospheric Administration (NOAA), USA for making available surface meteorological observations through Integrated Surface Database (ISD).

[THIS PAGE INTENTIONALLY LEFT BLANK]

Abbreviations

AERMOD: American Meteorological Society/Environmental Protection Agency Regulatory Model
AQI: Air Quality Index
ARAI: Automotive Research Association of India
BAU: Business-as-usual
BMC: Bhopal Municipal Corporation
BRTS: Bus rapid transit system
BS-X: Bharat Stage (I to VI)
CAAQM: Continuous Ambient Air Quality Monitoring Station
CM: crustal materials
CO: Carbon Monoxide
CPCB: Central Pollution Control Board
DG: Diesel Generators
EC: Elemental carbon
EF: Emission factors
EV: Electric Vehicle
FCBTK: Fixed chimney bull trench kiln
GCP: Good construction practices
GIS: Geographic Information System
GoI: Government of India
GoMP: Government of Madhya Pradesh
MoEFCC: Ministry of Environment, Forest and Climate Change
MPPCB: Madhya Pradesh Pollution Control Board
MRTS: Mass rapid transit system
MSL: Mean Sea Level
MSW: Municipal Solid Waste
NCAP: National Clean Air Project
NFC: No further control
NGO: Non-Governmental organisation
NMT: Non-motorised transport
NOx: Nitrogen Oxides
NMVOCs: Non-Methane Volatile Organic Compounds
NAAQ: National Ambient Air Quality Standards
OC: Organic carbon
PM: Particulate Matter
PM10: Particulate Matter having aerodynamic diameter less than or equal to 10 microns
PM2.5: Particulate Matter having aerodynamic diameter less than or equal to 2.5 microns
QA: Quality assurance
QC: Quality control
SC-I: Scenario I
SC-II: Scenario II
sL: Silt Loading
SNA: Sulphate, Nitrate and Ammonium
SO2: Sulfur Dioxide
SS: Sea salts
TE: Trace elements
TERI: The Energy and Resources Institute
TPY: Tonnes Per Year
USEPA: United States Environmental Protection Agency
VKT: Vehicle Kilometres Travelled
ZIF: Zone of influence

[THIS PAGE INTENTIONALLY LEFT BLANK]

Executive Summary

Air pollution has become a serious problem recently and it is considered as a major challenge for pollution and health regulatory agencies around the world. The Central Pollution Control Board (CPCB), New Delhi has identified 131 cities in India where the prescribed annual National Ambient Air Quality Standards (NAAQS) are violated. In this regard, Ministry of Environment, Forest and Climate Change (MoEFCC) have launched National Clean Air Program (NCAP) in 2019 which aims to reduce the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by year 2024, taking 2017 as the base year for the comparison of concentration.

In recent years, with rapid economic development and population growth, several cities in Madhya Pradesh have also witnessed an increase in air pollution and are getting reflected in the non-attainment cities. Six cities including Bhopal, Indore, Gwalior, Ujjain, Sagar and Dewas in Madhya Pradesh have also been identified by CPCB in the above list due to routine violation of NAAQS, mainly in terms of PM_{10}. There can be significant difference in the contribution of sources at the urban scales and hence the city-based clean air action plans must be dynamic and evolve, based on the available scientific evidence, including the information available through source apportionment studies (MoEFCC, 2019). Emission inventory and source apportionment study, which is primarily based on measurements and tracking down the sources through receptor modelling, helps in identifying the sources and extent of their contribution.

To address the air pollution issues of the city of Bhopal, Madhya Pradesh Pollution Control Board (MPPCB) has entrusted The Automotive Research Association of India (ARAI), Pune to carry out a detailed study on "Emission Inventory and Source Apportionment of Bhopal City (M. P.)". The main aim of this study is to identify and characterize various emission sources in Bhopal city of Madhya Pradesh and help the regulatory agencies in prioritizing the actions for improving the air quality. The major objectives of the study are:

- To carry out particulate matter (PM_{10} & $PM_{2.5}$) source apportionment using receptor modeling approach for Bhopal city.
- To develop emission inventory of air pollutants and conduct dispersion modelling analysis for Bhopal city.

This study has six major components 1. air quality sampling and chemical analysis, 2. receptor modelling, 3. emission inventory and hotspots identification, 4. dispersion modelling,

5. evaluation of control scenarios and air quality benefits and 6. action plan. The highlights of these components are presented below:

Air quality sampling and chemical analysis

Based on the reconnaissance surveys and inputs from MPPCB five sampling locations were identified for this study which represent various land-use patterns, and included one background, two residential, one commercial + traffic and an industrial site. These sites are located in different parts of Bhopal city and can provide an integrated insight into the characteristic of $PM_{2.5}$ and PM_{10} over Bhopal city. Table ES-1 and Fig. ES-1 provides details of the monitoring locations.

Table ES-1 Geographic information of the selected sampling sites in Bhopal city

Code	Location	Latitude	Longitude	Category
NIREH	National Institute for Research in Environmental Heath (NIREH), Bhauri Bypass Road	23°17'22.25"N	77°17'27.76"E	Background
GVDPR	Top N Town Ice-cream Factory, Govindpura Industrial Estate	23°16'11.20"N	77°26'35.66"E	Industrial
MPNGR	Sankalp Netralay, Zone-II M. P. Nagar	23°13'48.95"N	77°26'11.97"E	Commercial + Traffic
KOLRD	Anupam Hospital, Kolar Road	23°10'20.29"N	77°25'1.43"E	Residential
DIGBL	Muskan Children's and General Hospital, near DIG Bungalow, Berasiya Road	23°16'36.48"N	77°24'10.37"E	Residential

The ambient $PM_{2.5}$ and PM_{10} samples were collected in the study area, during two critical seasons i.e. winter (January 7 to 29, 2020) and summer (Apr 23 to May 11, 2022). It is important to note that, the summer season sampling could not be conducted in 2020 and 2021 due to the COVID-19 lockdown.

The ambient $PM_{2.5}$ and PM_{10} samples were collected using multi-channel speciation samplers for 24 hours at a flow rate of 16.7 LPM. Teflon filters were used for measurement of gravimetric mass, elemental concentrations, and water-soluble ions while the quartz-fiber filters were analysed for carbonaceous materials. The Teflon filters were subjected to analysis of elements using Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRF) method while the water-soluble inorganic ionic components were determined using ion chromatography method. Similarly, the quartz filter samples were used for the analysis of organic carbon (OC) and elemental carbon (EC) using a Thermal/Optical Carbon Analyzer (DRI Model 2015 Series 2; Desert Research Institute, USA) following IMPROVE_A protocol (Chow et al. 2007).

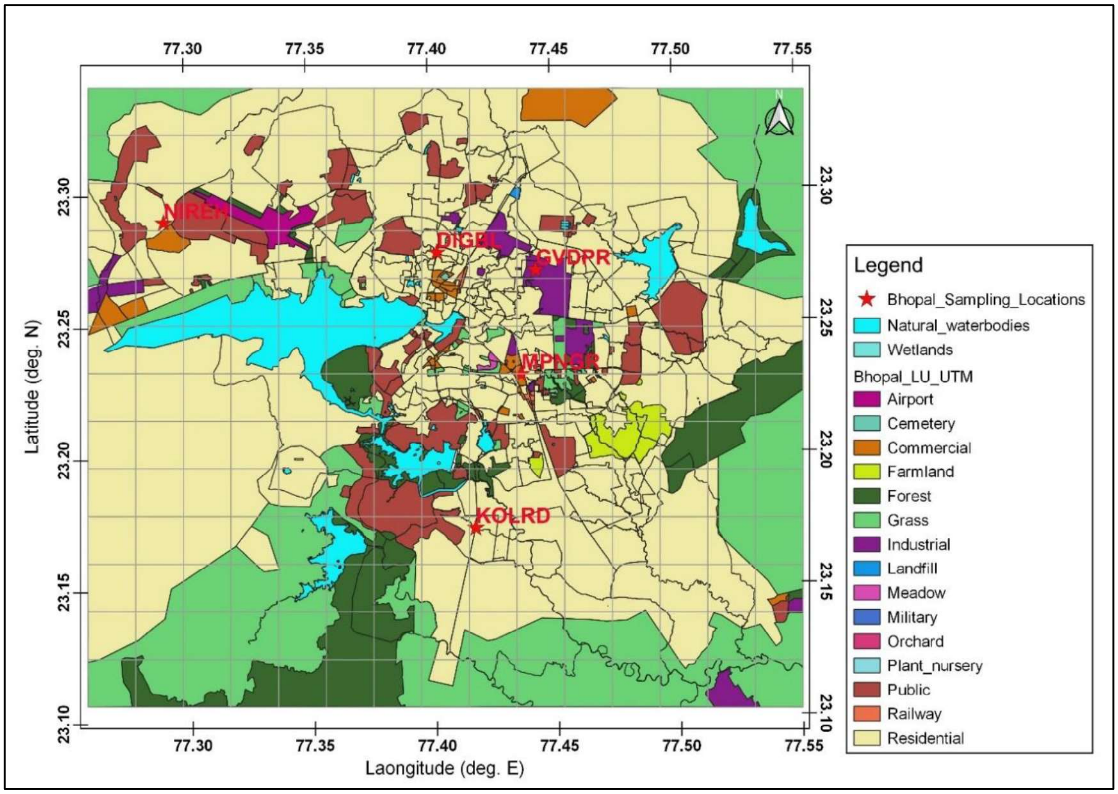


Figure ES-1 Bhopal city map showing different land-use classes. The red stars show the location of five sampling sites selected for source apportionment study

The mean $PM_{2.5}$ and PM_{10} mass concentrations during the winter season over all sites were 91.7 and 144.6 µg/m3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at M. P. Nagar (111.9 µg/m3) while the lowest were recorded at NIREH (52.3 µg/m3). Similarly, the highest seasonal mean PM_{10} concentrations were observed at DIG Bungalow (179.3 ± 55.6 µg/m^3) while the lowest were recorded at NIREH (74.3 ± 23.1 µg/m^3). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.65, varying from 0.40 to 0.93, which in turn indicates dominance of combustion sources.

The mean $PM_{2.5}$ and PM_{10} mass concentrations during the summer season over all sites were 45.1 and 138.1 µg/m^3, respectively. The highest seasonal mean $PM_{2.5}$ concentrations were observed at DIGBL (54.2 µg/m^3) while the lowest was recorded at NIREH (34.4 µg/m^3). The highest seasonal mean PM_{10} concentrations were observed at GVDPR (176.9 ± 45.3 µg/m^3) while the lowest were recorded at NIREH (96.8 ± 34.8 µg/m^3). The average value of $PM_{2.5}$ to PM_{10} ratios during the study period over all sites was found to be 0.33, varying from 0.30 to 0.39, which in turn indicates dominance of dusty sources.

Based on the chemical speciation analysis, the PM chemical components were grouped into six categories i.e. organic matter (OM), elemental carbon (EC), sulphate, nitrate and ammonium ions (together referred to as SNA), chloride ions, crustal materials (CM) and other trace elements (TE). The reconstructed PM mass is then calculated and compared with observed gravimetric mass. The reconstructed mass was significantly related to gravimetric mass in both winter and summer seasons. The squared correlation coefficient, R^2 is found to be 0.77 (winter) and 0.91 (summer) for $PM_{2.5}$ whereas it is found to be 0.84 (winter) and 0.87 (summer) for PM_{10}, respectively. During the winter season, the fractions of major chemical compositions followed the order of OM > SNA > EC > CM > SS > TE in $PM_{2.5}$ whereas this order changed to OM > CM > SNA > EC > SS > TE in PM_{10}. Similarly, during the summer season, the fractions of major chemical compositions followed the order of OM > SNA > CM > EC > TE > SS in $PM_{2.5}$ whereas this order changed to CM > OM > TE > SNA > EC > SS in PM_{10}. Additionally, chemical ratios such as OC/EC, Cl-/Na+, K+/OC, K+/EC, NO3-/SO4— and degree of neutralization (DON) were also used as indicators to qualitatively assess the contributions from air polluting sources.

Receptor modelling

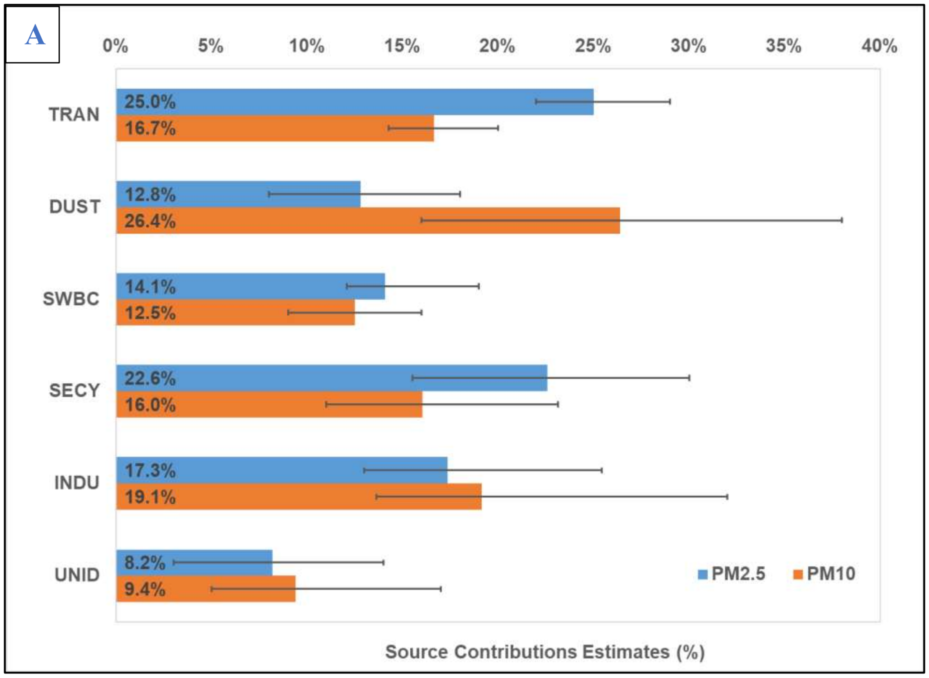
The data generated from chemical analysis along with source profiles is then used for receptor modelling assessment. In the present study, the US EPA-Chemical Mass Balance Model (CMB V8.2; Coulter 2004) is used to apportion the sources of $PM_{2.5}$ and PM_{10} particles in Bhopal city. The CMB model uses ambient pollutant concentrations, their chemical composition, and the chemical composition of sources i.e. source profiles, to estimate the relative contribution of each source to ambient concentrations at a given location.

Source contributions to fine and coarse particulate matter i.e. $PM_{2.5}$ and PM_{10} were calculated with the CMB model for the individual daily samples for five sampling sites in

Bhopal city. Five pollution sources were apportioned using the average concentration data including i) transport, ii) road and construction dust, iii) biomass burning, iv) industry and v) secondary aerosols. The residual/un-apportioned mass can be attributed to unknown sources as well as process and modelling uncertainties. The results from individual sites are averaged to calculate the city-level mean source contributions and are explained below.

Overall, the winter-time $PM_{2.5}$ mass at Bhopal (refer Fig. ES-2 (A)) are found to be dominated by transport sector with highest contribution of 25.0%. The other sources of $PM_{2.5}$ at Bhopal are identified as secondary aerosols (22.6%), industry (17.3%), transport (30.0%), solid waste and biomass combustion (14.1%), and dust (12.8%). Similarly, the winter-time PM_{10} mass at Bhopal is found to be dominated by dust (26.4%), followed by industries (19.1%), transport (16.7%), secondary aerosols (16.0%), and solid waste and biomass combustion (12.5%). Additionally, about 8.2% and 9.4% mass of PM2.5 and PM10 remained un-apportioned during the winter season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.

The summer-time $PM_{2.5}$ mass at Bhopal (refer Fig. ES-2 (B)) is found to be dominated by transport sector with highest contribution of 28.0%. The other summer-time sources of $PM_{2.5}$ at Bhopal are identified as dust (27.6%), solid waste and biomass combustion (18.6%), industry (13.4%), and secondary aerosols (10.8%). Similarly, the summer-time PM_{10} mass at Bhopal is also found to be dominated by dust (46.6%), followed by transport (12.6%), industries (11.5%), solid waste and biomass combustion (9.8%), and secondary aerosols (4.9%). Additionally, about 1.6% and 14.6% mass of $PM_{2.5}$ and PM_{10} remained un-apportioned during the summer season, respectively, which can be attributed to unknown sources as well as process and modelling uncertainties.



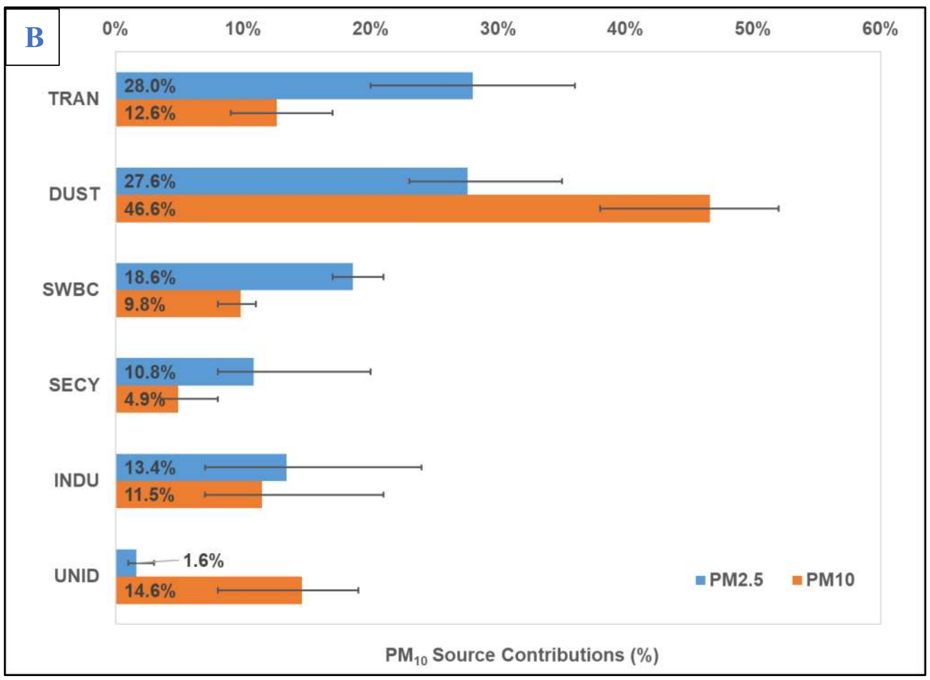


Figure ES-2 City-level source contribution estimates (SCE) for Bhopal city using CMB receptor model during winter (A) and summer (B) seasons

(Note-The horizontal blue and orange coloured bars represent the mean SCE percentage in $PM_{2.5}$ and PM_{10}, respectively while the error bars represent the range of estimated SCE among five sampling sites.)

Emission Inventory

The development of emission inventory for Bhopal city involved quantification of emission loads originating from sectors including: Transport, Re-suspended road dust, Open Waste Burning, Residential, Industries, Diesel generators, Hotels, Restaurants and Bakeries, Crematoria, Brick kilns, Aircraft and Construction activities. The air pollutants considered in this study includes: particulate matter having aerodynamic diameter less than or equal to 10 microns (PM_{10}), particulate matter having aerodynamic diameter less than or equal to 2.5 microns ($PM_{2.5}$), sulfur dioxide (SO_2), nitrogen oxides (NO_X), carbon monoxide (CO), and non-methane volatile organic compounds (NMVOCs). The spatial resolution of emission inventory is: 2 x 2 km^2 over the study area while the temporal resolution is monthly.

The emission inventory development stated with data collection activity. Two types of data collection approaches are used in this study i.e. primary and secondary data collection. The first approach i.e. primary data collection involves field surveys at identified locations for residential, commercial, and industrial fuel consumption, parking lot surveys to understand details of vehicle fleet, classified vehicle surveys to understand traffic count for various vehicle types. The second approach i.e. secondary data collection involves extracting relevant data from published reports, research papers, and government department website. The emission inventory development followed a bottom-up approach for estimation of emissions using activity rates for each sector and the measured emission factors (EFs) in India wherever possible. The bottom-up approach uses source-specific and category-specific data at the most refined spatial level to estimate emissions. The emissions estimated for individual sources are summed up to obtain a city-level inventory.

The overall baseline emission inventory (Year 2021) for the Bhopal city is presented in Fig. ES-3. The city level spatial distribution of the pollutants is provided in Fig. ES-4. The total PM_{10} emission load in the Bhopal city is estimated to be 10,309.3 tonnes per year. The top four contributors to PM_{10} emissions are dust (62.2%), transport (13.0%), construction (12.1% each) and open waste burning (2.9%). Similarly, the total $PM_{2.5}$ emission load in the Bhopal city is estimated to be 4121.1 tonnes per year. The top four contributors to $PM_{2.5}$ emissions are dust (37.7%), transport (29.3%), construction (7.6%), and open waste burning (6.7%). These emission loads are based on annual emissions whereas daily and seasonal emissions could be highly variable Daily and seasonal emissions could be highly variable.

The gaseous pollutants, included in the study were SO_2, NO_X, CO and NMVOC. The SO_2, NO_X, CO and NMVOC emission loads for year 2021 in the study domain are estimated to be 731.6, 10801.6, 44332.2, and 20803.7 tonnes per year, respectively.

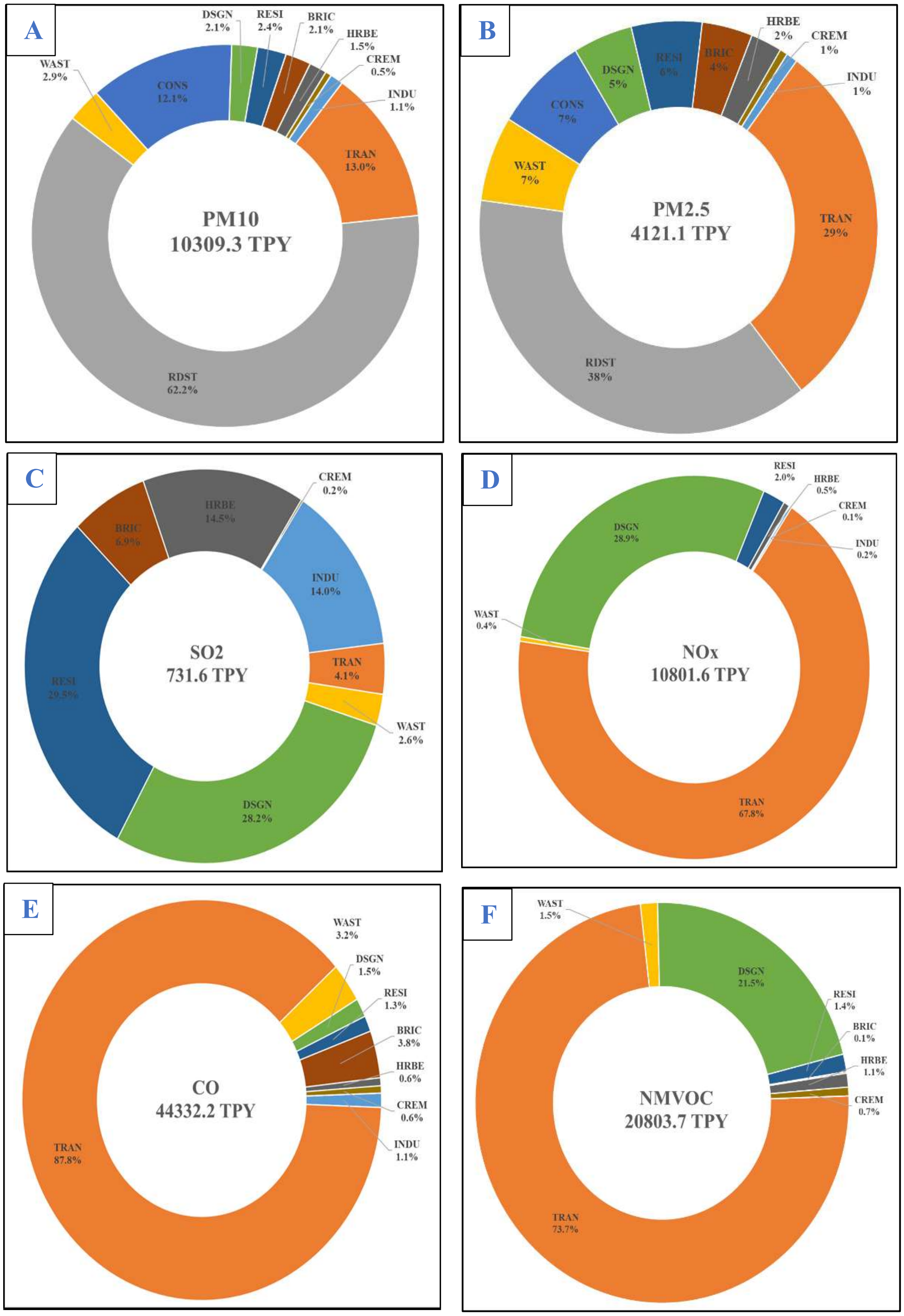


Figure ES-3 Sector-wise contribution to air pollutant emissions of A) PM10, B) PM2.5, C) SO2, D) NOX, E) CO and F) NMVOC in Bhopal city, 2021

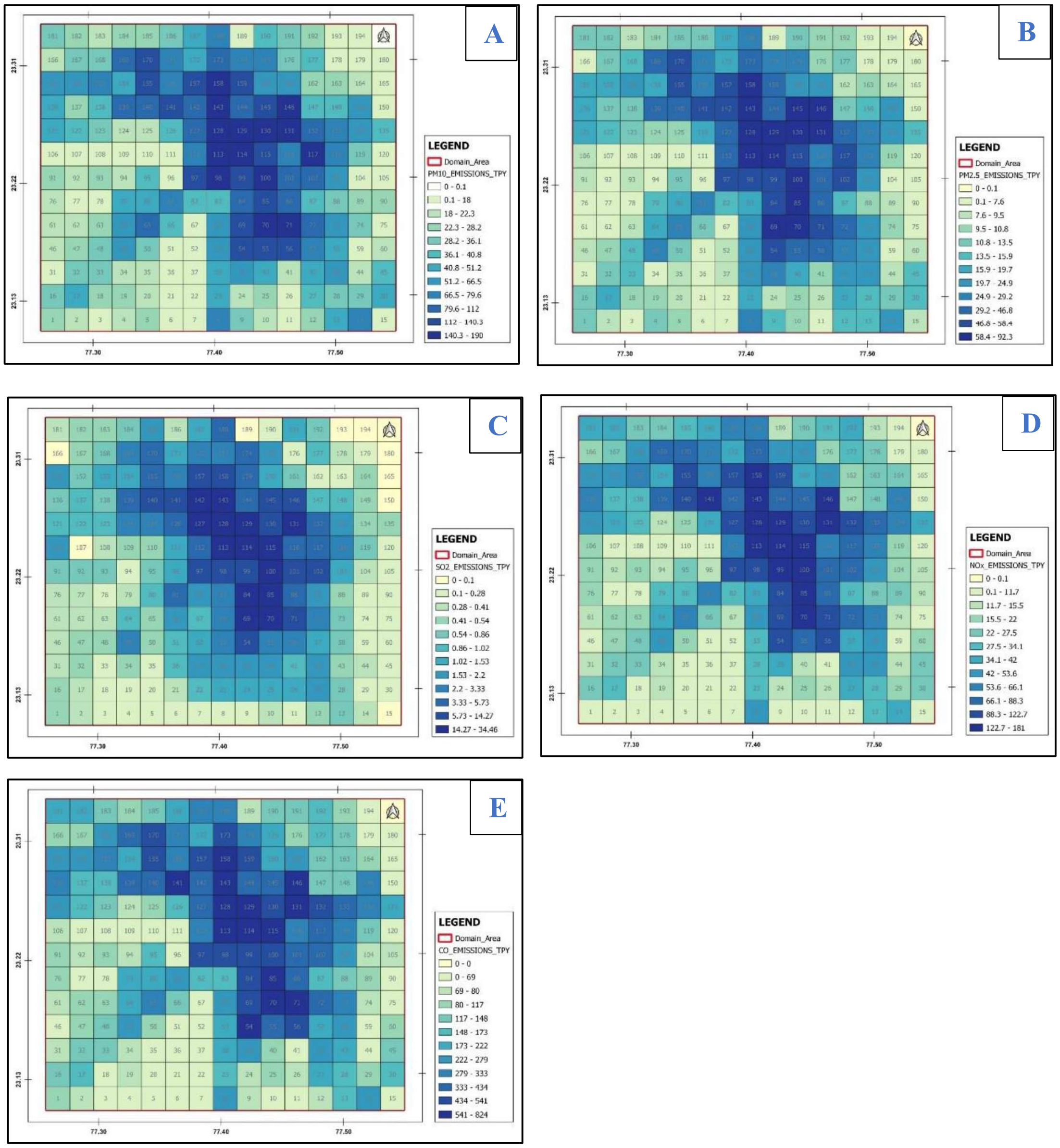


Figure ES-4 Spatial distribution of air pollutant emissions A) PM_{10}, B) $PM_{2.5}$, C) SO_2, D) NO_X, and E) CO (tonnes per year) in Bhopal city, 2021.

PM emissions hotspots

The preparation of emission inventory of Bhopal city followed the particulate matter emissions hotspot analysis i.e. analysis of grids with highest PM_{10} and $PM_{2.5}$ emissions in year 2021. In this study, top 20 grids with highest share to PM_{10} and $PM_{2.5}$ were identified for further analysis. Fig. ES-5 shows the PM emission hotspots identified in the study domain while Fig. ES-6 shows the sector-wise emissions of PM_{10} (A) and $PM_{2.5}$ (B) emissions (tonnes per year) in hotspot grids in Bhopal for baseline year 2021, respectively.

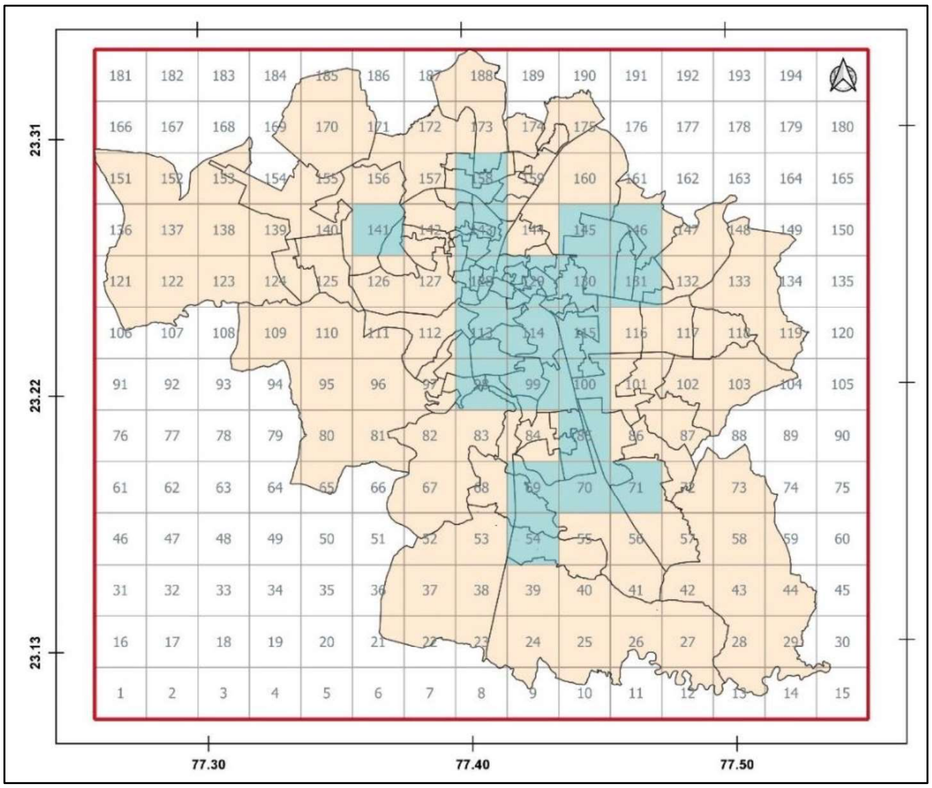


Figure ES-5 Map showing locations of $PM_{2.5}$ emission hotspots grids in Bhopal for year 2021

In general, the major contributing sectors to PM_{10} emissions in hotspot grids are re-suspended road dust (61.1%), followed by transport (12.0%), and construction (8.0%). Other sectors such as diesel generators, open waste burning, residential, hotels and restaurants, industries and crematoria have contributions less than 5%. Similarly, the major contributing sectors to $PM_{2.5}$ emissions in hotspot grids are re-suspended road dust (34.6%), followed by transport (25.2%), diesel generators (10.7%), open waste burning (8.9%), residential (7.3%), hotels and restaurants (5.3%). Other sectors such as construction, industries and crematoria have contributions less than 5%.

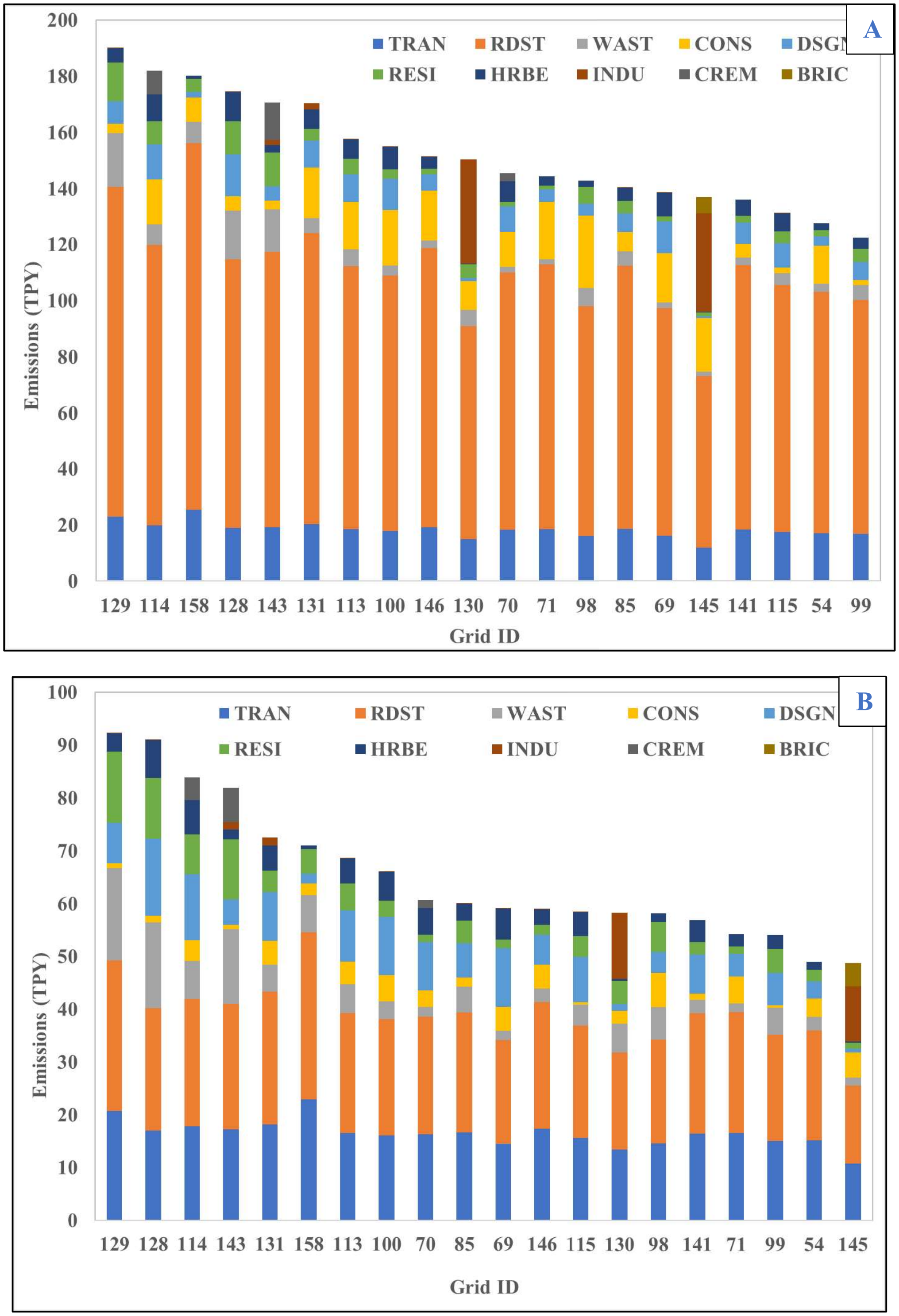


Figure ES-6 Sectoral PM10 (A) and PM2.5 (B) emissions (tonnes per year) in hotspot grids in Bhopal for baseline year 2021

Dispersion Modelling

In this study the AERMOD model is used to estimate the pollutant concentrations under different emission scenarios. AERMOD is configured to consider the local meteorology, emissions and terrain information to simulate the air pollutant concentrations at specified receptors in the study domain. The emissions from different sectors are modelled as area sources having dimensions 2 x 2 km^2, except selected industries, crematoria and brick kilns. The industries are divided into two types: i) industries having stack heights greater than or equal to 20 m are modelled as point sources and ii) remaining industries are modelled as area sources. Similarly, crematoria are modelled as point sources while clamp type brick kilns are modelled as volume sources.

The gridded receptors are placed at the vertex of each grid cell used in the emission inventorization, forming a network of 224 gridded receptors (refer Fig. ES-7). Additionally, one discrete receptor is also configured at location of T. T. Nagar CAAQM station operated by MPPCB for model validation purpose. The height of each receptor is set to 1.5 m above ground level i.e. average breathing level for humans. Further, the lowest daily concentration of a pollutant reported, in a particular season, at T. T. Nagar CAAQM station is used as the daily background concentration to reflect the regional-scale contributions from distant sources.

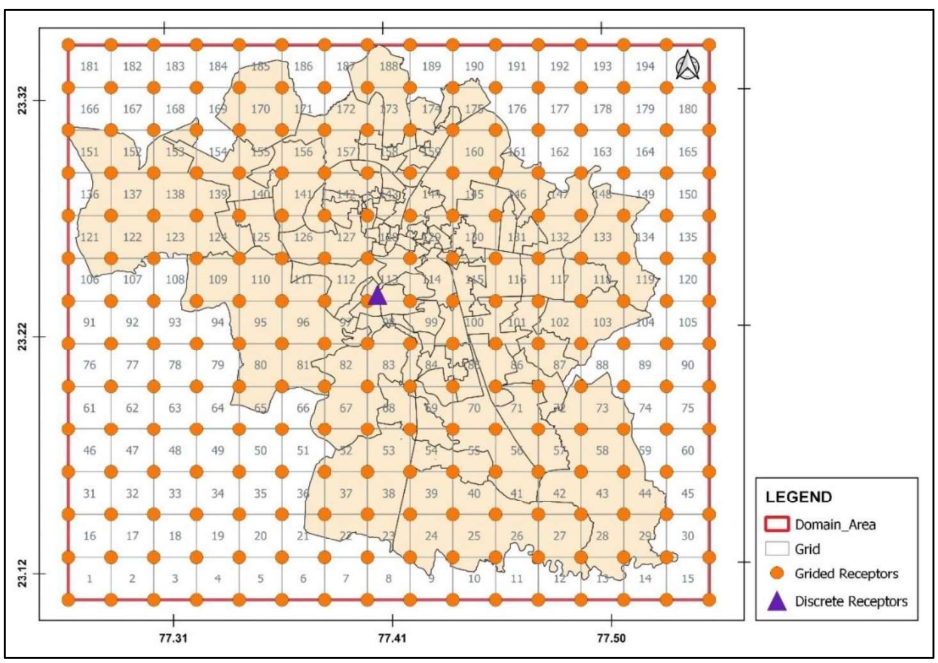


Figure ES-7 Map showing modelling domain overlaid by gridded and discrete receptors configured in this study. TTNGR refers to location of CAAQM station located at T. T. Nagar

In order to validate the dispersion modelling set-up, the AERMOD simulated daily averaged concentrations of pollutants including $PM_{2.5}$, PM_{10}, SO_2, NO2, and CO are compared against observations at CAAQM observations at T. T. Nagar for year 2021. The model performance is evaluated using six statistical measures including: mean, correlation coefficient (R), Mean Bias (MB), Root mean squared error (RMSE), Factor of two (FAC2) envelope and Fractional bias (FB). Based on the statistical analysis, the AERMOD model has been found to estimate the pollutant concentrations in Bhopal city, with a reasonable accuracy. Fig. ES-8 shows the spatial distribution of AERMOD simulated PM_{10} and $PM_{2.5}$ concentrations during summer and winter seasons of 2021, respectively.

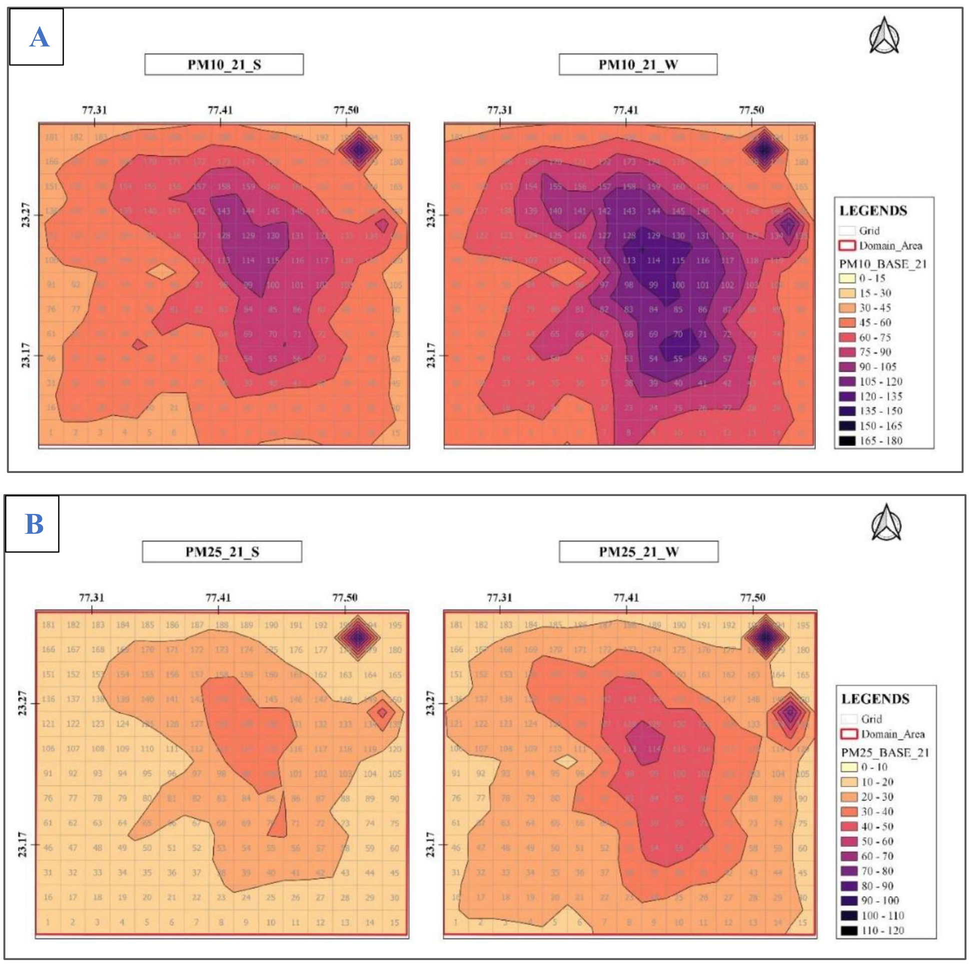


Figure ES-8 Map showing spatial distribution of PM_{10} (A) and $PM_{2.5}$ (B) concentrations ($\mu g/m^3$) during summer and winter seasons over Bhopal for year 2021

Future projections and air quality benefits

A key component of the present study is to project the emissions originating from different sectors for future years, based on baseline emission inventory developed for 2021. Four hypothetical emission scenarios viz. i) No further control (NFC), ii) Business-as-usual (BAU), iii) Scenario – I (SC-I) and iv) Scenario – II (SC-II); are developed for Bhopal city to include various existing and planned control interventions in each sector. These scenarios can be defined as given below:

i) **No further control (NFC):** No further control (NFC) scenario assume that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 but the control measures would be similar to present/current levels.

ii) **Business-as-usual (BAU):** Business-as-usual (BAU) scenarios consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be partially implemented.

iii) **Scenario – I (SC-I):** Scenario – I (SC-I) consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be implemented more aggressively compared to BAU scenarios.

iv) **Scenario – II (SC-II):** Scenario – II (SC-II) consider that there would be growth in the activities as per the sector-specific growth rates in 2026 and 2031 while the planned control measures would be implemented to the highest aggressive levels, possible.

These scenarios consider changes in technology and fuels which mainly include: faster EV adoption, implementation of BS VII, increase in penetration of natural gas based vehicles, roll-out of ethanol blended gasoline fuel (E20), reduction in silt loading on road surfaces, introduction of MRTS, improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, continuous supply of grid electricity, adoption of Zig-zag type brick kilns and various other control measures. The four emission scenarios defined above can be further categorized as mid-term (2026) and long term (2031). The details on sector-wise considerations and assumptions are provided in Chapter 5 of the report. Table ES-2 summarizes the estimated emissions (tonnes per year) of selected pollutants under four scenarios in Bhopal for years 2021, 2026 and 2031.

Table ES-2 Estimated emissions (tonnes per year) of selected pollutants under four scenarios in Bhopal for years 2021, 2026 and 2031

Year	Scenario	PM_{10}	$PM_{2.5}$	SO_2	NO_X	CO
2021	BASE	10,309	4,121	732	10,802	44,332
2026	NFC	12,940	4,596	692	16,390	75,292
	BAU	11,910	4,295	682	16,111	70,911
	SC_I	10,184	3,632	560	14,111	64,382
	SC_II	8,701	3,001	415	12,654	64,306
2031	NFC	14,687	5,040	752	17,264	1,03,301
	BAU	12,779	4,348	683	13,544	40,610
	SC_I	10,128	3,383	464	10,561	36,978
	SC_II	6,368	2,120	412	9,491	29,681

The NFC scenario projections in Bhopal indicate a potential increase in PM_{10} emissions to 12,940 tonnes per year in 2026 i.e. an increase of 25.5% w.r.t. baseline year 2021 and to 14,687 tonnes per year in 2031 i.e. an increase of 42.5% w.r.t. baseline year 2021. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to increase to 4,596 (11.5%) and 5,040 tonnes per year (i.e. 22.3%) in 2026 and 2031, respectively. The BAU projections in Bhopal indicate a potential decrease of PM_{10} emissions to 11,910 tonnes per year in 2026 i.e. a decrease of 8.0 % w.r.t. NFC_2026 and to 12,779 tonnes per year in 2031 i.e. a decrease of 13.0 % w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 4,295 (6.5%) and 4,348 tonnes per year (i.e. 13.7%) in 2026 and 2031, respectively.

The SC-I projections in Bhopal indicate a potential decrease of PM_{10} emissions to 10,184 tonnes per year in 2026 i.e. a decrease of 21.3% w.r.t. NFC 2026 and to 10,128 tonnes per year in 2031 i.e. a decrease of 31.0% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 3,632 (21.0%) and 3,383 tonnes per year (i.e. 32.9%) in 2026 and 2031, respectively. The SC-II projections in Bhopal indicate a potential decrease of PM_{10} emissions to 8,701 tonnes per year in 2026 i.e. a decrease of 32.8% w.r.t. NFC 2026 and to 6,368 tonnes per year in 2031 i.e. a decrease of 56.6% w.r.t. NFC 2031. The finer PM fraction i.e. $PM_{2.5}$ emissions are also estimated to decrease to 3,001 (i.e. 34.7%) and 2,120 tonnes per year (i.e. 57.9%) in 2026 and 2031, respectively. Fig. ES-9 presents the scenario-wise emission reduction potentials for BAU, SC-I and SC-II scenarios in Bhopal for future years.

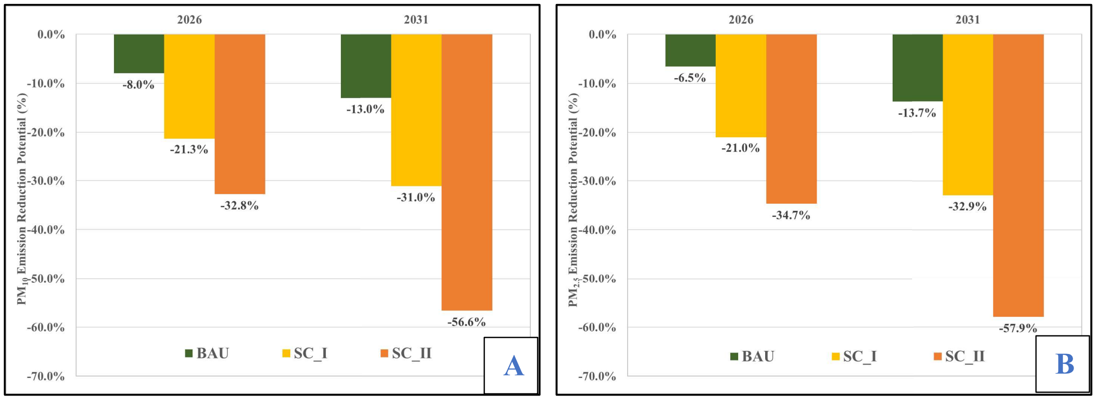


Figure ES-9 Estimated PM_{10} (A) and $PM_{2.5}$ (B) emission reduction potential (%) w.r.t. NFC in three scenarios (BAU, SC-I, and SC-II of 2026 and 2031)

Air quality benefits of four designed scenarios were assessed for years 2026 and 2031 using AERMOD simulated seasonal average pollutant concentrations in Bhopal city. A gradual reduction in pollutant concentrations is visible for BAU, SC-I and SC-II scenarios in 2026 and 2031 due to changes in technology and fuels such as EV adoption, implementation of BS VII, increase in penetration of natural gas based vehicles, reduction in silt loading on road surfaces, introduction of MRTS, improvement in NMT & public transport, usage of clean fuel for cooking, improved waste collection efficiency, adoption of Zig-zag type brick kilns and various other control strategies considered in different scenarios.

With implementation of control measures considered in different scenarios, the PM_{10} concentrations are estimated to reduce by 4.1%, 9.9% and 14.4% during summer and by 4.2%, 10.8% and 16.0% during winter seasons, in 2026 for BAU, SC-I and SC-II scenarios, respectively. Similarly, for 2031, the PM_{10} concentrations are estimated to reduce by 6.5%, 14.9% and 27.7% during summer and by 7.2%, 16.2% and 29.8% during winter seasons, for BAU, SC-I and SC-II scenarios, respectively. In case of $PM_{2.5}$, with implementation of control measures considered in different scenarios, an estimated reduction of 3.6%, 9.2% and 13.7% during summer and 6.7%, 14.6% and 26.3% during winter seasons, could be achieved in 2026 for BAU, SC-I and SC-II scenarios, respectively. Similarly, for 2031, the reduction during summer season is estimated to be 3.7%, 10.5% and 16.1% while the same during winter season is estimated to be 8.0%, 16.8% and 29.9%, for BAU, SC-I and SC-II scenarios, respectively.

This study also extracted location -specific air quality benefits due to implementation of different scenarios in 2026 and 2031. Six representative locations, i.e. T.T. Nagar CAAQMS and five ARAI sampling locations, were selected to understand the impact of controls measures on air quality. Tables ES-3 presents the percentage change in air quality concentrations during summer and winter seasons, w.r.t. corresponding NFC scenarios in 2026 and 2031 at T. T. Nagar CAAQMS location in Bhopal.

Table ES-3 Percentage change in air quality concentrations during summer and winter seasons, w.r.t. corresponding NFC scenarios in 2026 and 2031 at T. T. Nagar CAAQMS location

	2026			2031		
	BAU	SC-I	SC-II	BAU	SC-I	SC-II
SUMMER						
PM_{10}	-7.3%	-16.7%	-25.4%	-11.9%	-26.0%	-46.3%
$PM_{2.5}$	-6.3%	-15.9%	-24.4%	-12.1%	-25.0%	-43.5%
SO_2	-0.2%	-4.1%	-7.9%	-3.1%	-5.7%	-11.5%
NO2	-0.9%	-3.2%	-4.2%	-19.9%	-19.9%	-27.2%
CO	-4.2%	-8.2%	-9.0%	-57.0%	-57.3%	-59.1%
WINTER						
PM_{10}	-7.7%	-18.3%	-28.1%	-13.2%	-27.9%	-49.2%
$PM_{2.5}$	-6.3%	-17.9%	-28.1%	-14.1%	-27.7%	-47.7%
SO_2	-0.5%	-6.9%	-13.6%	-5.1%	-11.2%	-18.8%
NO2	-0.8%	-3.3%	-4.7%	-20.0%	-20.2%	-28.0%
CO	-3.9%	-8.4%	-9.3%	-54.0%	-54.7%	-56.6%

The air quality benefits are also translated to improvement in Air quality index (AQI). AQI is a measure that relates air quality to human health exposure and is derived by translating the weighted concentrations of individual pollutants (Ott, 1978). It is important to note that, the AQI values are calculated using the AERMOD estimated pollutant concentrations, only. The air quality situation can gradually improve with implementation of proposed scenarios. The combined proportion of Good and Satisfactory AQI classes are estimated to be substantially higher compared to the corresponding do-nothing or NFC scenario. For example, the combined proportion of Good and Satisfactory AQI classes in BAU (2026: 46%, 2031: 44%), SC-I (2026: 53%, 2031: 57%), and SC-II (2026: 62%, 2031: 84%). Fig ES-10 and ES-11 represents the distribution of AQI categories at T.T Nagar CAAQMS station for year 2026 and 2031 rspectively

It is important to note that, the AQI changes presented here are location specific and a similar improvement is expected in other locations of Bhopal region as well. These findings are very important from the perspectives of the National Clean Air Program (NCAP) launched recently by Govt. of India (MoEFCC, 2019). NCAP is primarily aimed at reducing the national level $PM_{2.5}$ and PM_{10} concentrations by 20-30% by the year 2024, as compared to 2017 i.e. base year.

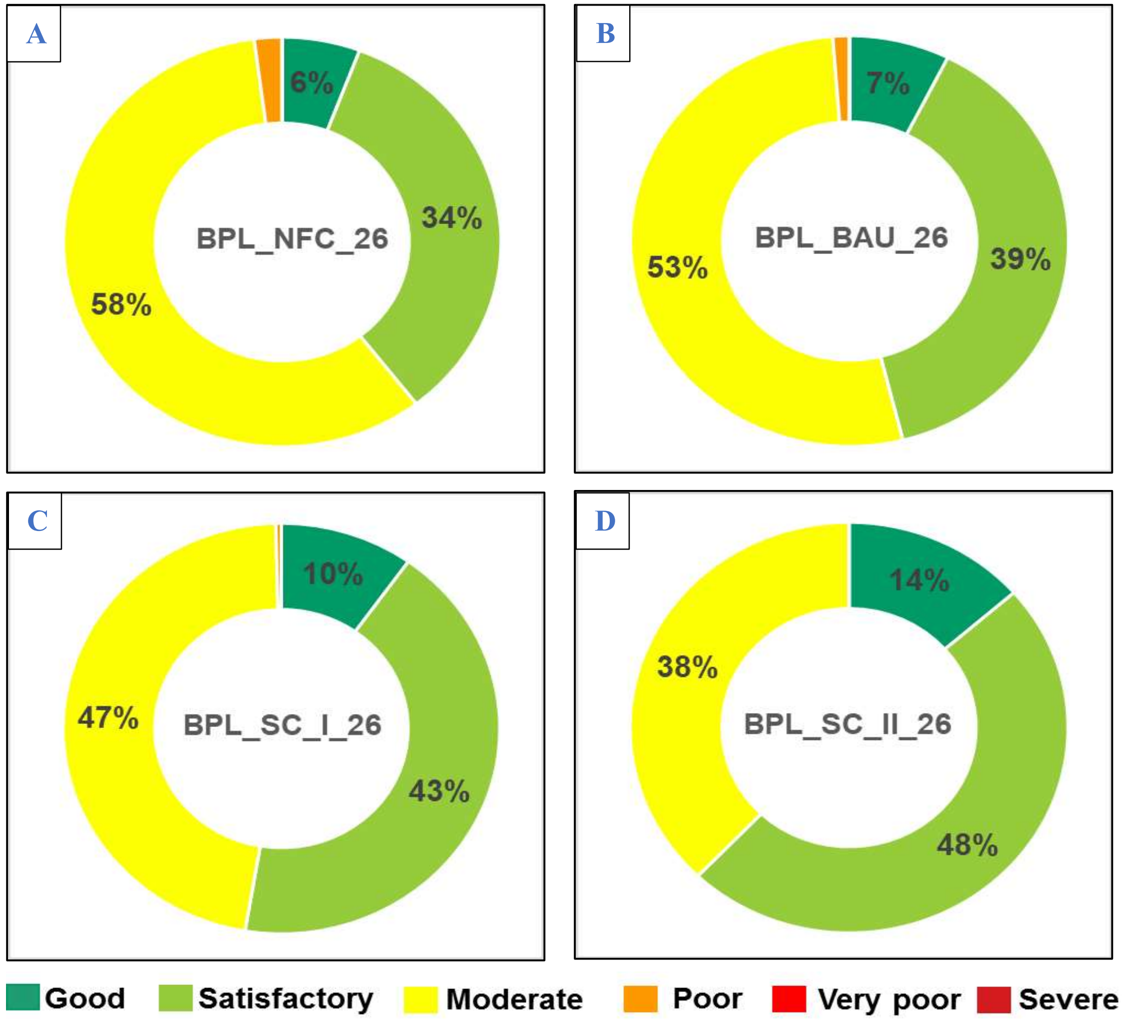


Figure ES-10 Distribution of six AQI categories at T. T. Nagar CAAQMS location in Bhopal for different scenarios in 2026

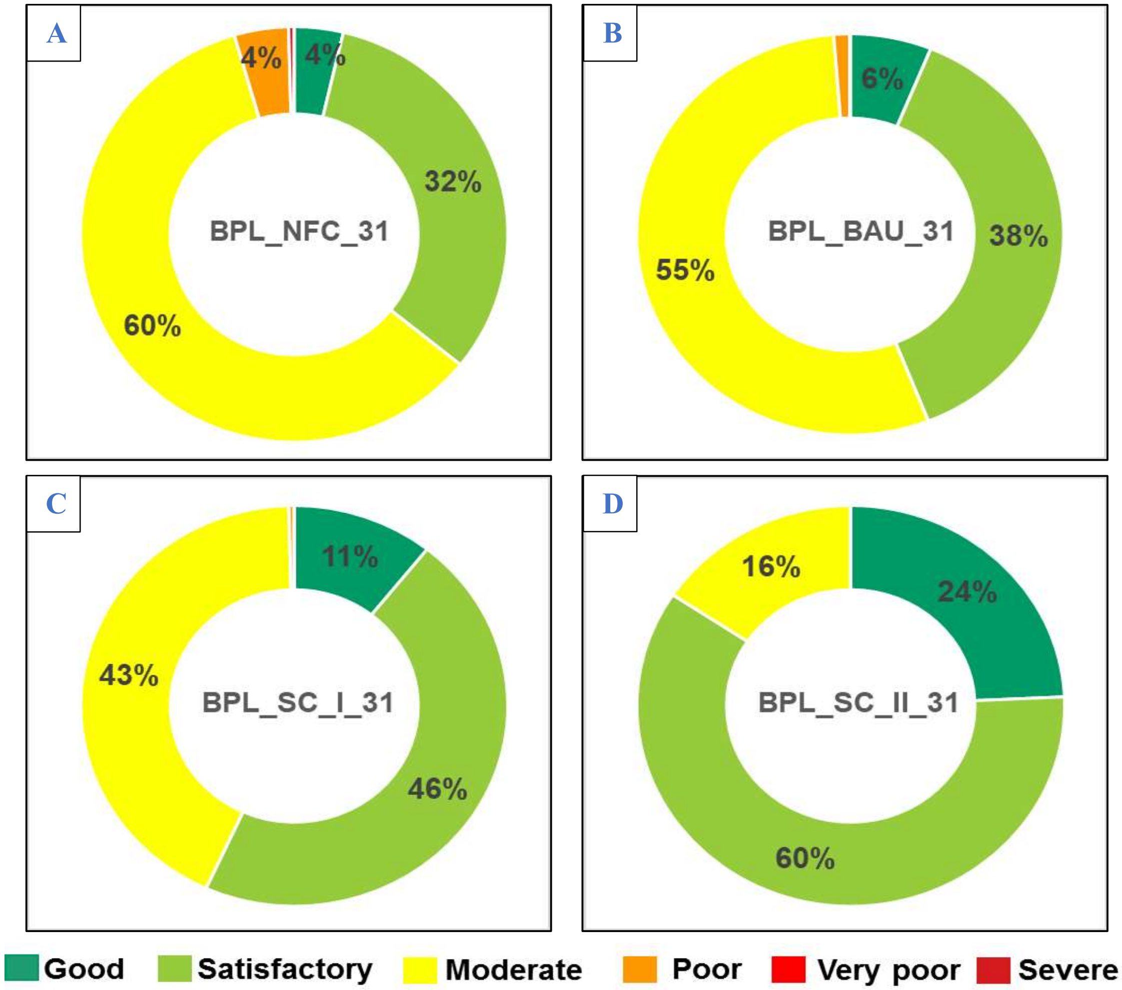


Figure ES-11 Distribution of six AQI categories at T. T. Nagar CAAQMS location in Bhopal for different scenarios in 2031

Action Plan

Table ES-4 presents the proposed air quality action plan for Bhopal city. The action plan constitutes sector wise suggestions along with executing agency / authority for immediate and short to mid-term actions

Table ES-4 Proposed Air quality action plan for Bhopal

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Transport	**A) Management**		
	TR1. Congestion Management: Identify the hotspot locations of traffic congestion. Introduce traffic actuated signals at such locations. Consider the one-way routes during peak hours at these locations. Also, regulate eateries along the kerb side, especially small ones to avoid traffic congestions.	RTO, Bhopal	Immediate
	TR2. Parking Policy: Formulate vehicle parking policy and ensure its effective implementation. Provide parallel parking system along the major roads of the town. Enforce strict action and penalty for vehicles parked in non-parking areas.	BMC / RTO, Bhopal	6 months
	TR3. Public transport: Improve the public transport infrastructure such as strengthening and modernization of fleet of buses (procurement of new buses), implementation of plan for metro and increase coverage as per plan.	BMC, MPMRCL	3 years
	TR4. Prepare and implement zonal plans to develop an NMT network. Introducing cycle tracks along with the roads	BMC	1-2 years
	TR5. Declare NO-vehicle zones in hot-spots, university / school premises.	BMC / University / School	6 months
	TR6. Strict actions against visibly polluting vehicles (i.e. vehicles without PUC certificates) impose penalty and launch extensive awareness drive against polluting vehicles.	RTO, Bhopal	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	TR7. Examine existing framework for removing broken down buses or trucks from roads and create a system for speedy removal and ensuring minimal disruption to traffic from such buses or trucks.	BMC	6 months
	B) Technology		
	TR8. Improve and strengthen PUC program. (SMS based system to alerts, Linking of PUC centres with remote server and elimination of manual intervention in PUC testing, Fitness and calibration audits of PUC centres adopted with defined team for verification, Integration of on-board diagnostic (OBD) system fitted in new vehicles with vehicle inspection, Linking of PUC certificates with annual vehicle insurance, etc.)	RTO, Bhopal	1 year
	TR9. Encourage adoption of cleaner fuels (CNG). CNG infrastructure for auto gas supply in the city and transition of public transport vehicles to CNG mode	BMC / Oil Companies/ GAIL / State Government	3 years
	TR10. The EV adoption initiative for public transport vehicles (buses) and government office-vehicles	BMC, Government Offices	3 years
	TR11. Encouraging EV adoption for personal and commercial vehicles through incentivization or tax relaxation.	State Government, RTO	3 years
Road Dust	RD1. End-to-end paving of roads along with black-topping and maintaining potholes free roads.	PWD / BMC	Immediate / Continuous
	RD2. Road design: The road design should strictly comply with URDPFI / IRC guidelines for urban roads	PWD / BMC	Immediate / Continuous
	RD3. Repair the defects in road to keep them pot holes free as per the PWD guidelines.	PWD / BMC	Immediate / Continuous
	RD4. Immediate lifting of solid waste generated from desilting and cleaning of municipal drains for its disposal	BMC	Immediate / Continuous
	RD5. Implement truck loading guidelines; use of appropriate enclosures for haul trucks; gravel paving for all haul routes	BMC	6 months

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	RD6. All the canals/nallah's side roads should be concrete / brick lined.	BMC	1 year
	Regular cleaning of roads and water spraying to suppress the dust. Remove road dust/silt regularly by using mechanical sweepers.	BMC	Immediate / Continuous
	RD7. Identify road stretches with high dust generation and use Foggers to suppress the dust.	BMC	6 months
	RD8. Greening of traffic corridors, open areas, gardens, community places, schools and housing societies	BMC	1 year
Industries	IN1. All potential industries to be implemented with Continuous Emission Monitoring System (CEMS). Ensure regular calibration and working of this system and its online reporting is required.	MPPCB	1 year
	IN2. Assess the number of industrial units that are non-compliant and prepare unit/plant wise action plan for time bound compliance.	MPPCB	Immediate and Continuous
	IN3. Intensive polluting industries to be restricted from operations within urban zone. Restriction of any new red category industry to open within urban zone.	MPPCB	Immediate
	IN4. Strict compliance to be followed on industrial open waste burning.	MPPCB	Immediate
	IN5. Control of Fugitive Emissions: • Use of hoods and enclosure for all process equipment, • Scrap management program for the prevention or minimization of waste and other feed materials. • Use of covered or enclosed conveyors and transfer points	MPPCB	Immediate
	IN6. Adoption of Cleaner Fuels: • Cleaner fuel implementation to be encouraged and incentivized. • Discourage the fuels with high sulphur content. • A favourable taxation and pricing policy for mass adoption.	MPPCB	1 year
	IN7. Ensuring installation/Up-gradation and operation of air pollution control devices in industries	MPPCB	6 months
	WB1. Improving door to door waste collection efficiency to 100%.	BMC	1 year

Sector	Control Actions	Responsible Agency / Authority	Time Frame
Open Waste Burning	WB2. Enforcing a complete ban on open waste burning. A heavy penalty and stringent action against such activities.	BMC	Immediate
	WB3. Non-recyclable waste with a calorific value of 1,500 kcal or more must not be disposed of into landfills and must be used solely to generate energy	MPPCB, BMC	Immediate / Continuous
	WB4. Collection of horticulture waste (biomass) and its disposal as per SWM rules, 2016, following composting and gardening approach	BMC	Immediate / Continuous
	WB5. Encouraging the reduce, recycle and reuse policy for waste in city	BMC / State Government	Immediate / Continuous
	WB6. Organic waste conversion (OWC) units can be installed in the city at a decentralized scale especially in more prominent societies and colonies based on the MSW characteristics of the area.	BMC	1 year
	WB7. Effective management of landfill sites through increasing the recycling rate, installing waste to energy conversion plants, restricting illegal waste dumping, proper disposal of hazardous waste, as per Hazardous waste management rule 2016, to prevent greenhouse gas emissions from site	BMC	1 year
	WB8. Reduce the VKT of waste collection vehicles with route optimization technique.	BMC	6 months
Construction	CN1. Adoption of Good Construction Practices (GCP) to minimize the waste generation. Promote recycling of materials. Encourage the use of environmentally friendly material. Ensure compliance check for GCP regularly	BMC / MPPCB	Immediate
	CN2. Strict enforcement of CPCB guidelines for construction activity such as use of green screens, side covering of digging sites, etc.	BMC / MPPCB	Continuous
	CN3. Ensure transportation of construction materials in covered vehicles.	BMC / Site Developer	Immediate
	CN4. Restriction on storage of construction materials along the road side.	BMC	Immediate
	CN5. Provide a control measures against fugitive emissions such as a use of covered or enclosed conveyors while conveying the material.	BMC / MPPCB	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	CN6. To maintain facility of tar road inside the construction site for movement of vehicles carrying construction material	BMC / Site Developer	Immediate
	CN7. Develop mechanism for ensuring periodic maintenance of construction equipment and vehicles.	BMC / Site Developer	3 months
	CN8. Develop and implement dust control measures such as site covering, fugitive emission control, installing air pollution controlling devices for all types of construction activities i.e. buildings and infrastructure.	BMC	1 year
	CN9. C&D waste should be sent to construction and demolition processing facility only. Strict action against non-compliance of the same on any individual or developers.	BMC	Immediate
	CN10. Mandatory use of RMC plants at large construction sites and preparation of guidelines for dust control measures for operation of RMC plants.	BMC / MPPCB	1 Year
DG sets	DG1. Ensure uninterrupted electric supply to avoid the use of DG sets, especially in commercial and industrial zones.	State Electricity Board	1 Year
	DG2. Curtail use of DG Sets in social events by providing temporary electric connections	BMC / State Electricity Board	Immediate
	DG3. Discourage use of DG sets in cellular towers and encourage use of alternate power (e.g. Battery)	BMC	6 months
	DG4. Develop the city into a Renewable Energy Hub with a focus on creation of RE Equipment Manufacturing Eco-system as per Madhya Pradesh Renewable energy policy	BMC / State Government	5 years
	DG5. Leverage rooftop solar program to reduce dependence on DG sets	BMC	1 year
	DG6. Installation of Retrofitted Emission Control Devices (RECD) to diesel generators as per CPCB guidelines	MPPCB	1 year
Residential	RS1. Ensure easy availability of affordable cleaner cooking fuels (LPG/ PNG/biogas) for all to achieve 100% LPG adoption.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP/BP, etc.)	1-3 years

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	RS2. Expanding coverage of LPG under Pradhan Mantri Ujjwala Yojana (PMUY).	State / Central Government	1-2 years
	RS3. Introduce schemes for providing subsidized LPG connections as well as providing means of finance to small tea vendors/hawkers who are using kerosene stoves in order to reduce emissions from burning of kerosene	State / Central Government	1-2 years
	RS4. Introduction of improved *Chullahs* (low emission *Chullahs*) in rural areas	BMC, NGOs	1 year
	RS5. Encouraging use of electricity for domestic cooking. (for example: Induction cooktops)	Department of Food, Civil Supplies and Consumer Affairs	2 year
	RS6. Provide centralized solar based hot water in slum areas to avoid solid fuel usage for water heating purposes	BMC	1 year
Hotel, restaurant and bakeries	HR1. Coal and wood-based cooking in restaurants to be shifted to electricity and LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1-2 years
	HR2. Promoting mini LPG cylinders to small open eateries.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
Brick kilns	BK1. Ensure the compliance checking routinely. Provide design specifications for improved kilns.	MPPCB / BMC	Immediate
	BK2. Enforce restrictions for the operations of brick kilns in urban zone. Zig-zag technology to be encouraged and promoted.	MPPCB / BMC	1-3 years
	BK3. Closure of unauthorized brick kilns, if any.	MPPCB	Immediate
Crematoria	CR1. Convert all existing traditional crematoria (wood based) to electric. Installing new electric crematoria as per requirement.	BMC	1 year
Public awareness	PA1. Launch Public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicle, lane discipline, etc.	BMC, MPPCB, NGOs	Immediate
	PA2. Encourage the use of public transport for daily commute.	BMC, MPPCB, NGOs	Immediate

Sector	Control Actions	Responsible Agency / Authority	Time Frame
	PA3. Education program to create awareness among citizens through various mass media tools, such as local newspapers, local news channels on TV or radio, street plays, social media platforms, citizen engagement events, recording announcements through waste collection vehicle, organizing awareness seminars at the community level	BMC, MPPCB, NGOs	Immediate
IT enabled services	IT1. Use of mobile application for complaint registration and grievance redressal regarding air pollution	BMC	1 year
CAAQMS	MS1. Increase the number of air quality monitoring stations	MPPCB	1-2 year

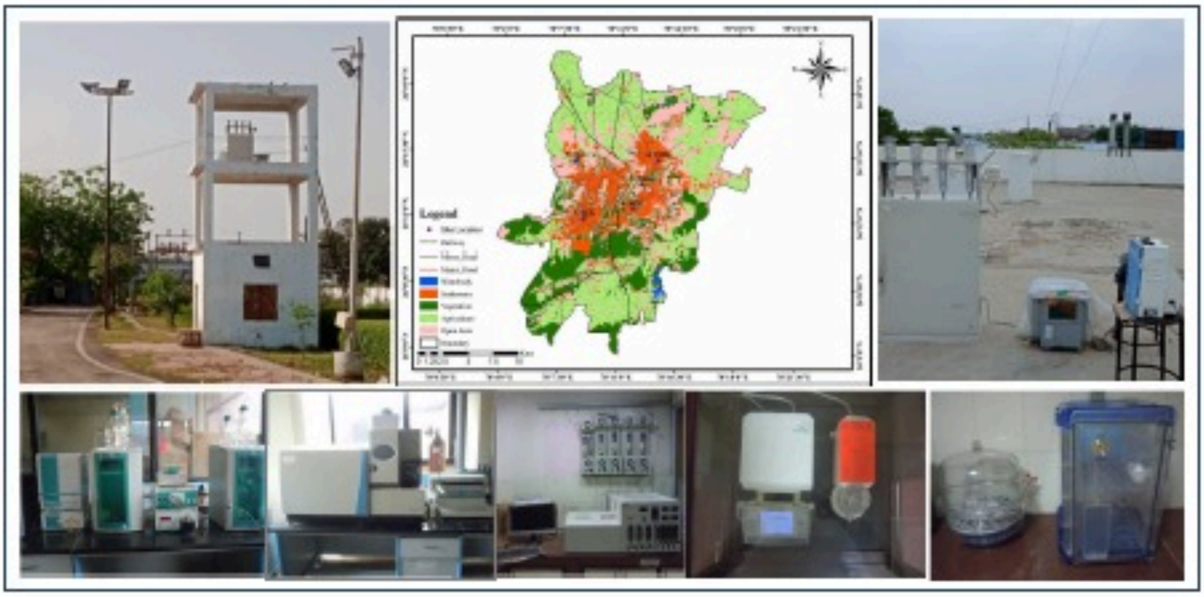
Annexure R-2

Source Apportionment Study and Emission Inventory of Gwalior City

(Final Report)

Submitted to

Madhya Pradesh Pollution Control Board, Bhopal



Mukesh Sharma, PhD and Pavan K. Nagar, PhD

Department of Civil Engineering

Centre for Environmental Science and Engineering

Indian Institute of Technology Kanpur, Kanpur- 208016

January 2024

Executive Summary

Since the enactment of the Air Act 1981, air pollution control programs have focused on point and area source emissions, and many communities have benefited from these control programs. Nonetheless, most cities in the country still face continuing particulate non-attainment problems from aerosols of unknown origin (or those not considered for pollution control) despite the high level of control applied to many point sources.

To address the air pollution issues of the City of Gwalior, the Madhya Pradesh Pollution Control Board (MPPCB), Bhopal has sponsored the study "Source Apportionment Study and Emission Inventory of Gwalior City" to the Indian Institute of Technology Kanpur (IITK). The study/project commenced on March 19, 2020. The main objectives of the study are preparation of emission inventory, air quality monitoring in two seasons, chemical composition of PM_{10} and $PM_{2.5}$, apportionment of sources to ambient air quality, and development of pollution control plan. The project has the following specific major objectives:

- Identify and inventories emission sources (industry, traffic, power plants, local power generation, small scale industries, etc.) in Gwalior.
- Chemical speciation of particulate matter (PM) and measurement of other air pollutants.
- Perform receptor modeling to establish the source-receptor linkages for PM in ambient air.
- Identification of various control options and assessment of their efficacies for air quality improvements and development of control scenarios consisting of combinations of several control options; and
- Selection of best control options from the developed control scenarios and recommend implementation of control options in a time-bound manner.

This study has five major components (i) air quality measurements, (ii) emission inventory, (iii) air quality modeling, (iv) control options and (v) action plan. The highlights of these components are presented below.

Air Quality: Measurements

A total of five air quality sites were categorized based on the predominant land-use pattern (Table 1) to cover varying land-use prevailing in the city. PM_{10} (particulate matter of size less than and equal to 10 µm diameter), $PM_{2.5}$ (particulate matter of size less than and equal to 2.5 µm diameter), SO_2, NO_2, OC (organic carbon), EC (elemental carbon), Ions, Elements, PAHs (polyaromatic hydrocarbons) and molecular markers were considered for sampling and measurements. The air quality sampling was conducted for two seasons: summer (2021) and winter (2021-2022).

Table 1: Description of Sampling Sites of Gwalior

S. No.	Sampling Site	Site Code	Land-use	Type of Sources
1	Hargovind Puram, Gwalior	**HPG**	Residential	Domestic cooking, vehicle, road dust, garbage/MSW burning, Restaurants.
2	Moti Jheel, Gwalior	**MJG**	Residential (Background)	Domestic cooking, vehicle, road dust, garbage/MSW burning, Restaurants.
3	Bada Circle, Gwalior	**BCG**	Commercial	DG sets, vehicle, road dust, garbage/waste burning, Restaurants
4	Surya Maharajpura, Gwalior	**SMG**	Industrial	Industries, DG sets, vehicle, road dust, garbage/industrial waste burning, Restaurants
5	Madhav Institute, Gwalior	**MIG**	Industrial cum Commercial	Industries, DG sets, vehicle, road dust, garbage/industrial waste burning, Restaurants

Based on the air quality measurements in summer and winter months and critical analyses of air quality data (Chapter 2), the following inferences and insights are drawn for understanding the current status of air quality. The season-wise, site-specific average air concentrations of PM_{10}, $PM_{2.5}$ and their compositions have been referred to bring the important inferences to the fore.

- Particulate pollution is the main concern in the city where PM_{10} levels are 1.5 – 2.8 times higher than the national air quality standards in summer and winter months and

$PM_{2.5}$ levels are within limit of NAAQS in summer and 2.9 times higher than the national standard in winter months.

- The chemical composition of PM_{10} and $PM_{2.5}$ carries the signature of sources and their harmful contents. The chemical composition is variable depending on the size fraction of particles and the season. The PM levels and chemical composition are discussed separately for two seasons.

Winter - PM_{10}

The overall average concentration of PM_{10} in winter season is 275±65 µg/m^3 against the acceptable level of 100 µg/m^3 (24-hourly mean). Highest levels were observed at SMG and lowest at HPG.

The crustal component (Si + Al + Fe + Ca) accounts for about 22% (much less compared to 32% in summer). This suggests soil and road dusts have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.34 (of fraction of crustal component) which suggests the crustal source contributes consistently even to winter though much less compared to summer season.

The other important component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for about 16% of total PM_{10} and combustion related total carbon (TC = EC + OC) accounts for about 19%; both fractions of secondary particles and combustion related carbons have increased in winter and account for 35% of PM_{10}.

The Cl^- content in PM_{10} in winter is consistent with the average of 2.6 percent, which is an indicator of burning of municipal and plastic solid waste (MSW); recall poly vinyl chloride (PVC) is a major part of MSW. The highest Cl^- content is observed at SMG at 9.91 µg/m^3 compared to overall city level of 7 µg/m^3. The high level at SMG signifies some local burning of waste in industrial processes of as a means of disposal of solid waste.

Winter - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 172±33 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at SMG 215±58 µg/m^3

and lowest at HPG 140±32 µg/m^3. The crustal component is reduced to 19% in $PM_{2.5}$ in winter compared to 23% in summer.

The other important components are the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for 16% of total $PM_{2.5}$ and combustion related total carbon (EC+OC) accounts for 23%; both secondary particles and combustion related carbon are consistent contributors to $PM_{2.5}$ at about 39%. Highest level of TC was observed at VKI and SMG at about 53 µg/m^3.

The Cl^- content in $PM_{2.5}$ winter is consistent at an average of 2.5 percent which is an indicator of burning of municipal solid waste (MSW).

Summer - PM_{10}

The overall average concentration of PM_{10} in summer season was 147±75 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 32 percent of total PM_{10} in summer. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.54, which suggests the sources are inconsistent all around the city forming a layer which envelopes the city. The areas of HPG and MJG have the highest crustal fraction. It is difficult to pinpoint the crustal sources as these are widespread and present all around Gwalior and are more prominent in summer when soil and dust are dry and high speed winds make the particles airborne. It was observed that in summer the atmosphere looks light brownish which can be attributed to the presence of large amounts of soil dust particles in the atmosphere.

The second significant component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for 9 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about 8 percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^-, SO_4^{-2}, and NH_4^+. The combustion related contribution is relatively less in PM_{10} in summer.

The Cl^- content in PM_{10} in summer is consistent at 1.5 – 3.5 percent, which is an indicator of burning of municipal solid waste (MSW) and has a relatively lower contribution in summer than winter.

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer season is 41 µg/m^3 within the acceptable level of 60 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 23% of total $PM_{2.5}$. This suggests airborne soil and road dust is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.23, which suggests the source is consistent all around the city.

The second important component is combustion related total carbon (EC+OC), which account for 22% of total $PM_{2.5}$ and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for 10%; both fractions of secondary particles and combustion related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles, and combustion contribute consistently to $PM_{2.5}$ in summer.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 2.7 percent except at SMG (4.4%), which is an indicator of burning of municipal solid waste (MSW) and has a similar contribution to $PM_{2.5}$ and PM_{10}.

Potassium levels

In general potassium levels are high and variable for PM_{10} and $PM_{2.5}$ in winter (8.4 and compared to summer (2.5 and 0.7 µg/m^3). In general potassium level should be less than 2 µg/m^3. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.60) show significant biomass burning and it is consistent both in summer and winter.

NO_2 levels

NO_2 levels in winter are higher than those in summer at all sites (except at HPG) and the levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 levels were at SMG, a traffic and industrial site. In addition, high levels of NO_2 are expected to undergo chemical transformation to form fine secondary particles in the form of nitrates, adding to high levels of existing PM_{10} and $PM_{2.5}$. SO_2 levels in the city were well within the air quality standard.

General inferences

$PM_{2.5}$, OC and EC levels are significantly higher at all sites, PM_{10} is significantly higher at BCG, MIG and SMG in winter than summer and no significance difference at HPG and SMG in winter compared to summer. SO_2 and NO_2 levels are also higher at all sites except at HPG in winter compared to summer. In general air pollution levels in ambient air (barring traffic intersections) are uniform across the city suggesting entire city is stressed under high pollution; in a relative sense, SMG is most polluted followed by MJG. HPG is the least polluted area.

It is to be noted that OC3/TC ratio is above 0.24 and highest among ratio of fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed in atmosphere due to condensation and nucleation of volatile to semi volatile organic compounds, which suggests emissions within and outside of Gwalior.

Total PAH levels (17 compounds; particulate phase) in winter is very high at 74.92 ng/m^3 and B(a)P at 5.38 ng/m^3 (annual standard is 1 ng/m^3); the comparison with annual standard is not advisable due to different averaging times. However, PAH levels in summer drop significantly to about 26.88 ng/m^3. The highest PAH levels observed at SMG (winter 117 ng/m^3) and at MJG (summer 43 ng/m^3).

The concentrations of molecular markers in $PM_{2.5}$ (total of 6 compounds) are also higher in winter (98 ng/m^3) than in summer (62 ng/m^3) indicating presence of common sources of emissions from coal, gasoline and domestic fuel.

In a broad sense, air is more toxic in winter than in summer as it contains much larger contribution of combustion products in winter than in summer months.

Emission Inventory

Emission inventory (EI) is a basic necessity for planning air pollution control activities. The overall baseline EI for Gwalior City is developed for the base year 2022. The pollutant wise contribution is shown in Figures 1 to 5. Spatial Distribution of pollutant emissions from all sources is presented in Figure 6.

The total PM_{10} emission load in Gwalior is estimated to be 108 t/d. The top three contributors to PM_{10} emissions are road dust (88%), vehicles (7%), and brick kiln (2%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to obtain the desired air quality.

$PM_{2.5}$ emission load in Gwalior is estimated to be 32 t/d. The top three contributors to $PM_{2.5}$ emissions are road dust (67 %), vehicles (22 %), and brick kiln (4%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO_2 emission load in Gwalior is estimated to be 4 t/d. brick kiln contribute 35% followed by domestic (33%) and industries (19%)

NOx emissions load in Gwalior is estimated to be 47 t/d. Nearly 93% of emissions are attributed to vehicular emissions followed by domestic (2.4%) and industries (2.1%). Vehicular emissions that occur at ground level, probably make it the most important emission. NOx apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates) and ozone. NOx from vehicles and industry are potential sources for controlling NOx emissions.

The estimated CO emission is about 80 t/d. Nearly 63% emission of CO is from vehicles, followed by industries (19%), and about 12% by domestic.

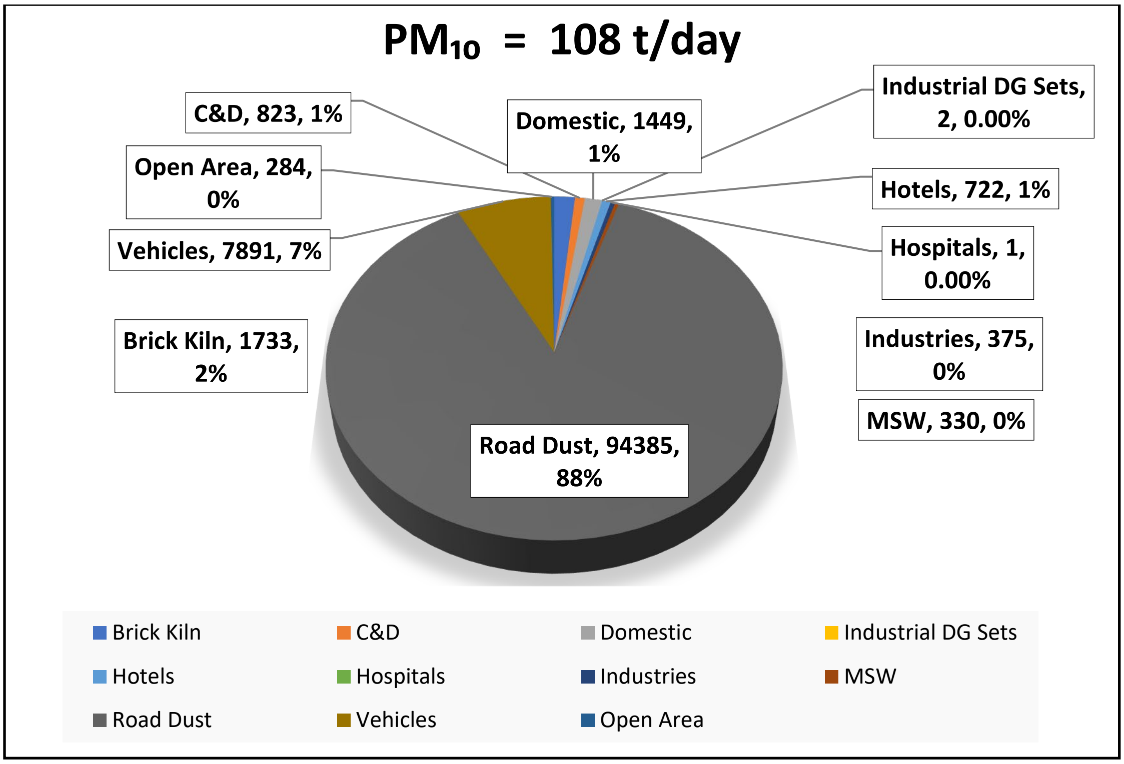


Figure 1: PM_{10} emission Inventory of different sources in the city of Gwalior (kg/d)

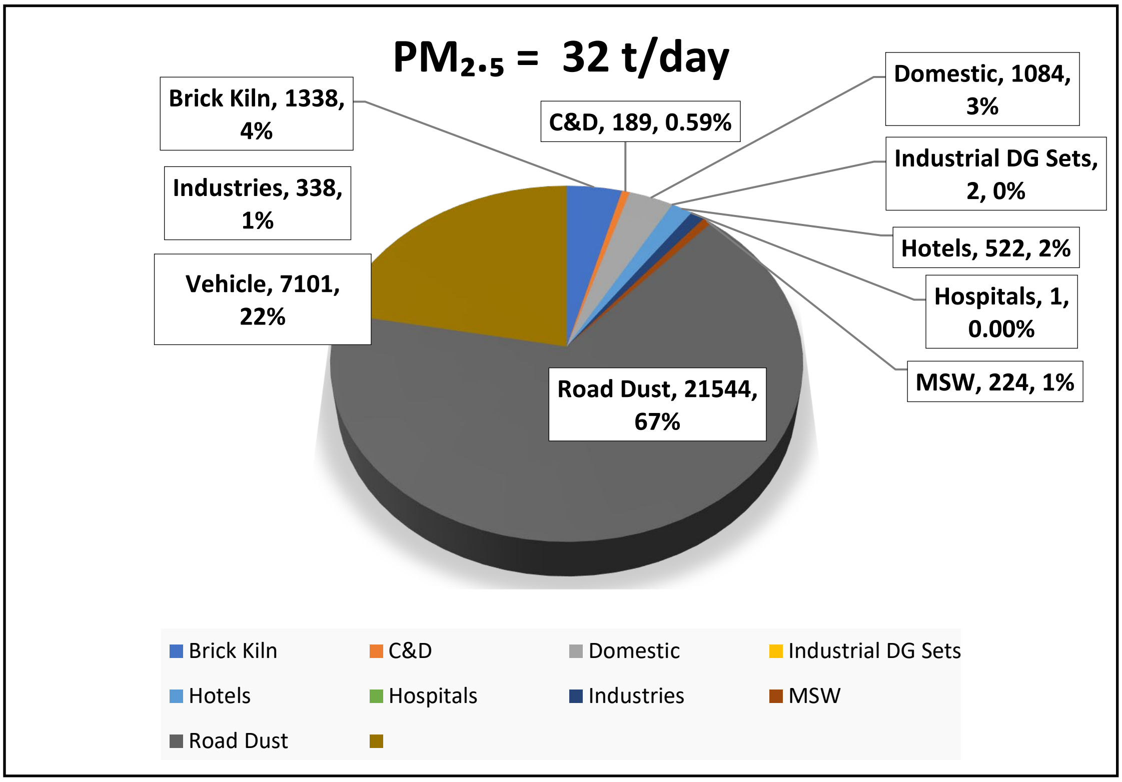


Figure 2: $PM_{2.5}$ emission load of different sources in the city of Gwalior (kg/d)

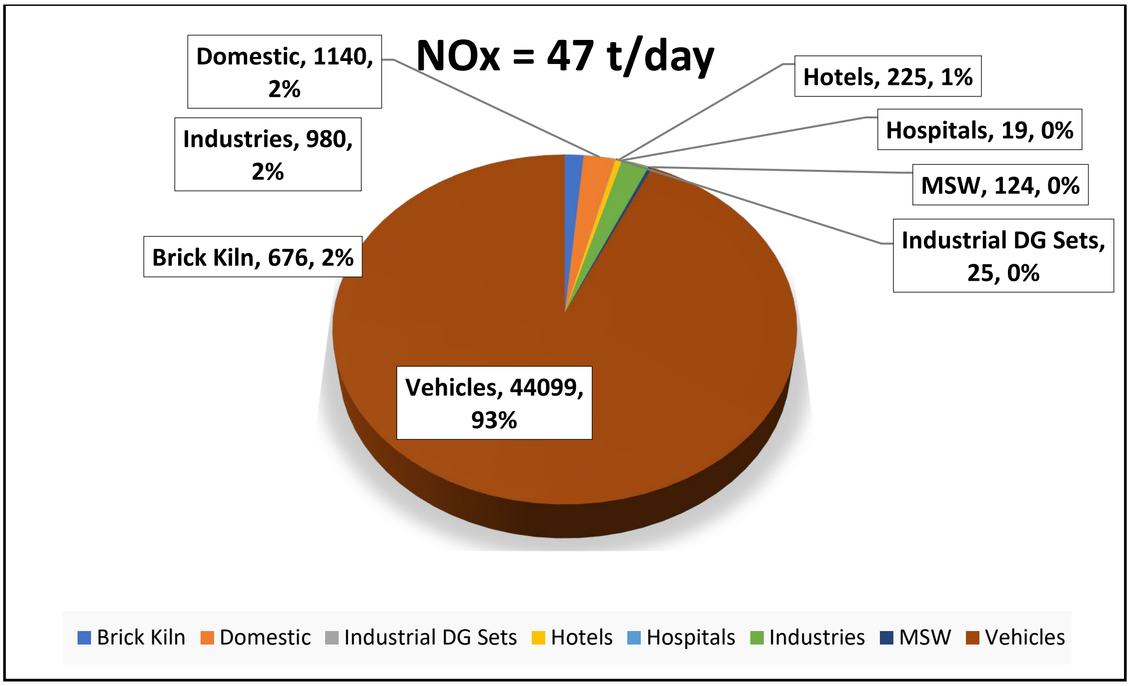


Figure 3: NO_x emission load of different sources in the city of Gwalior (Kg/d)

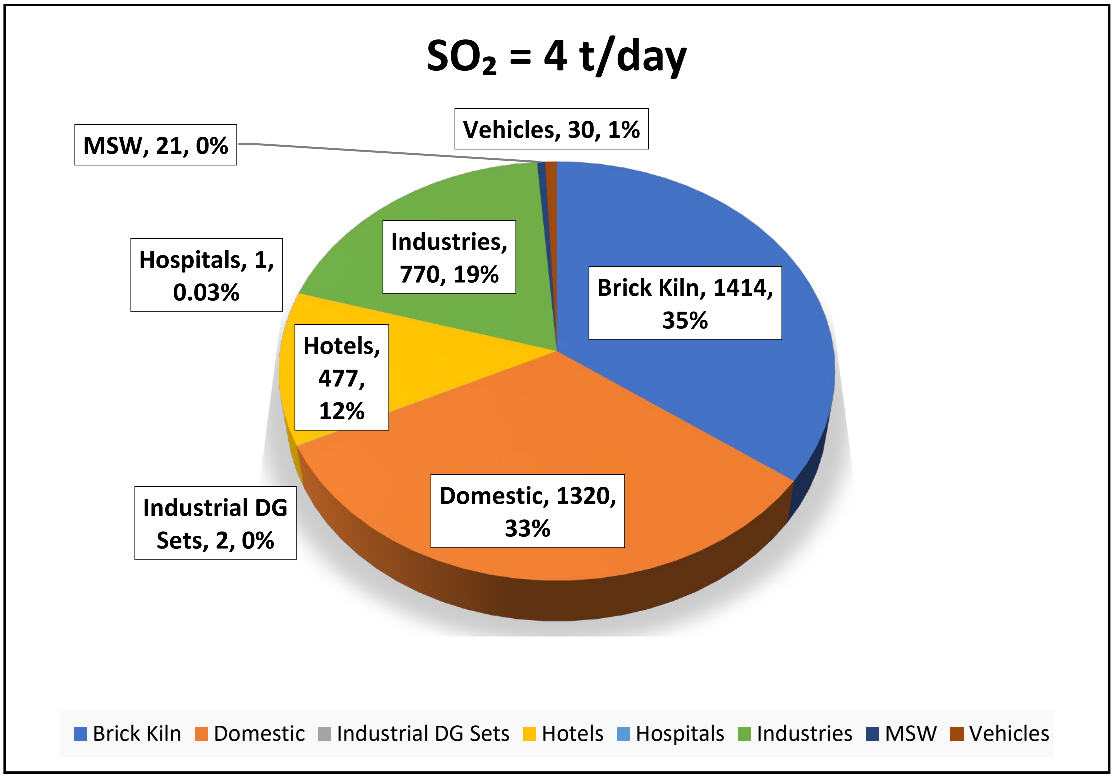


Figure 4: SO_2 emission load of different sources in the city of Gwalior (kg/d)

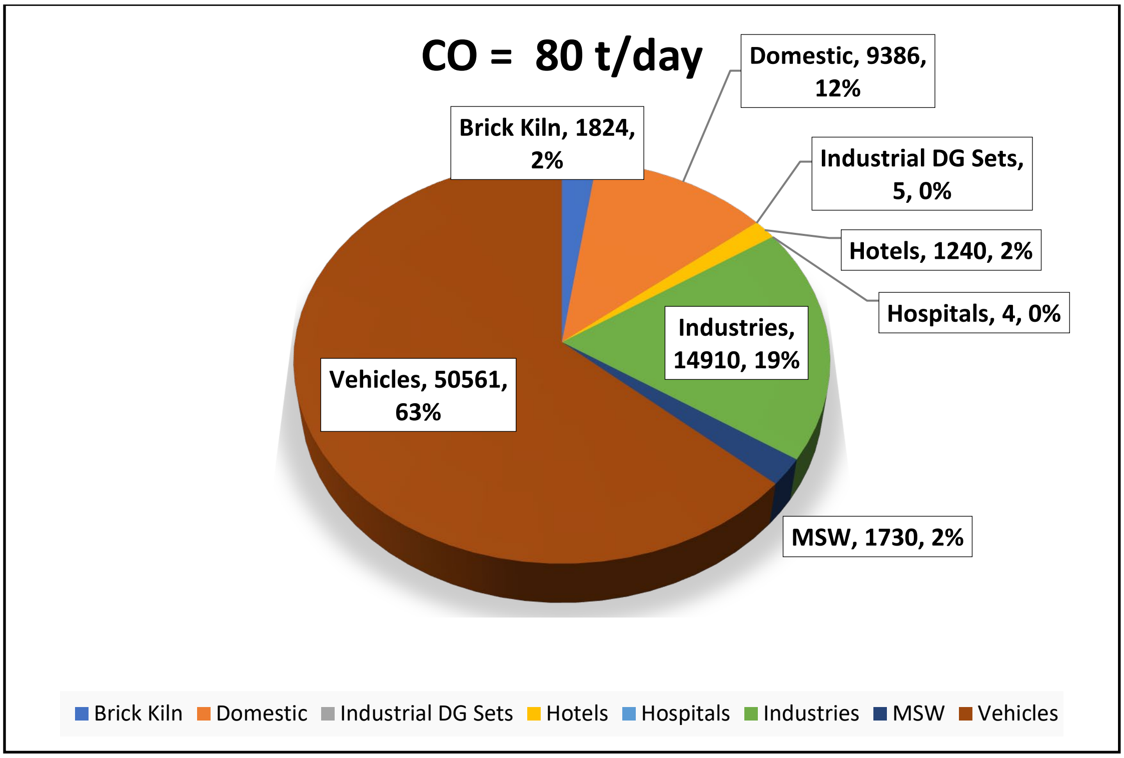
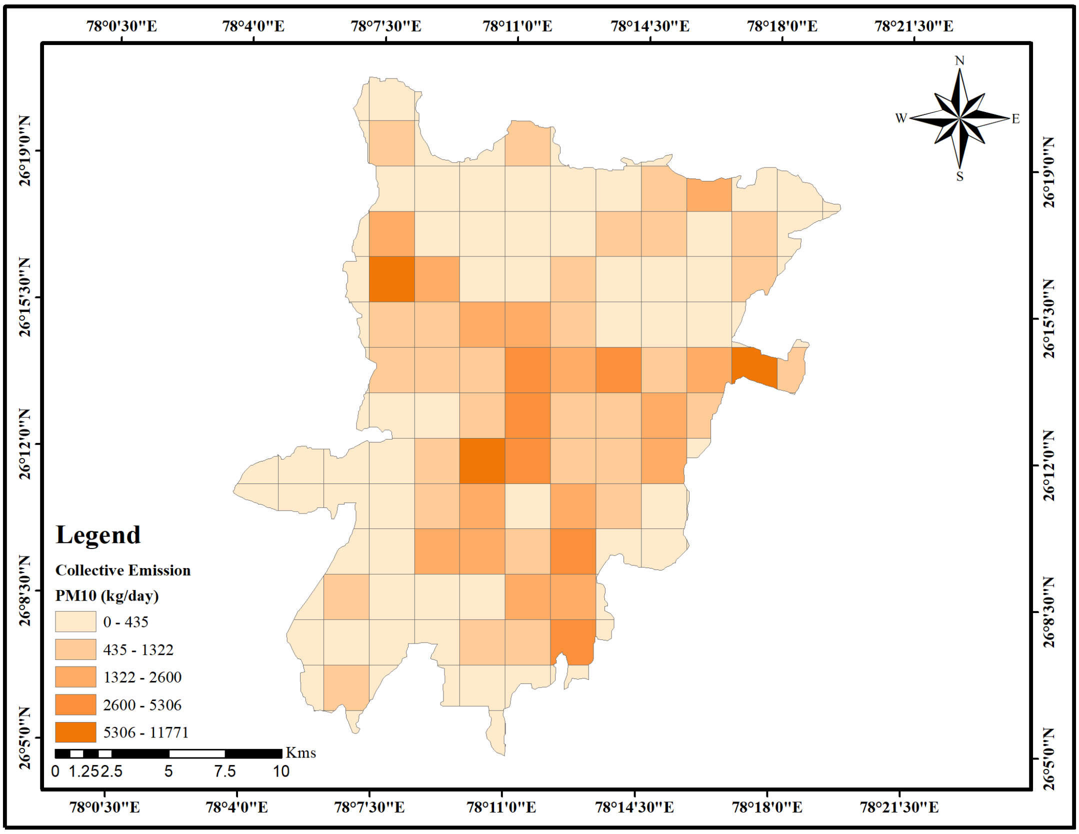
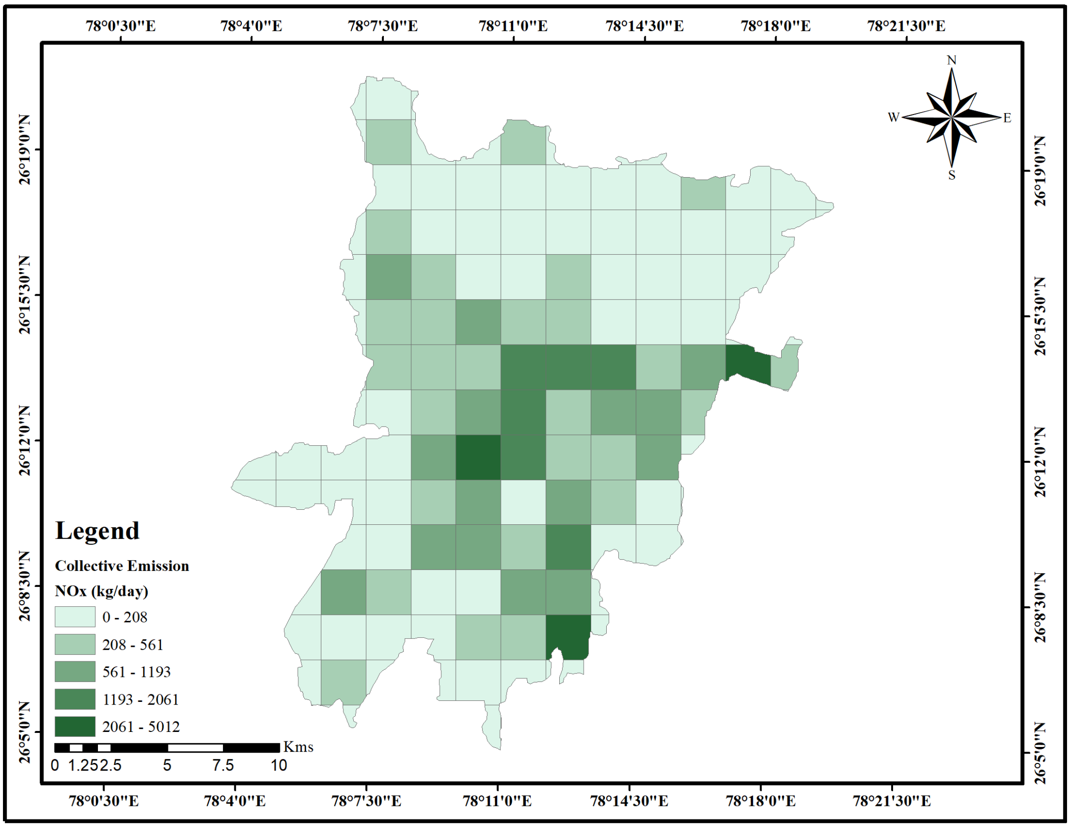
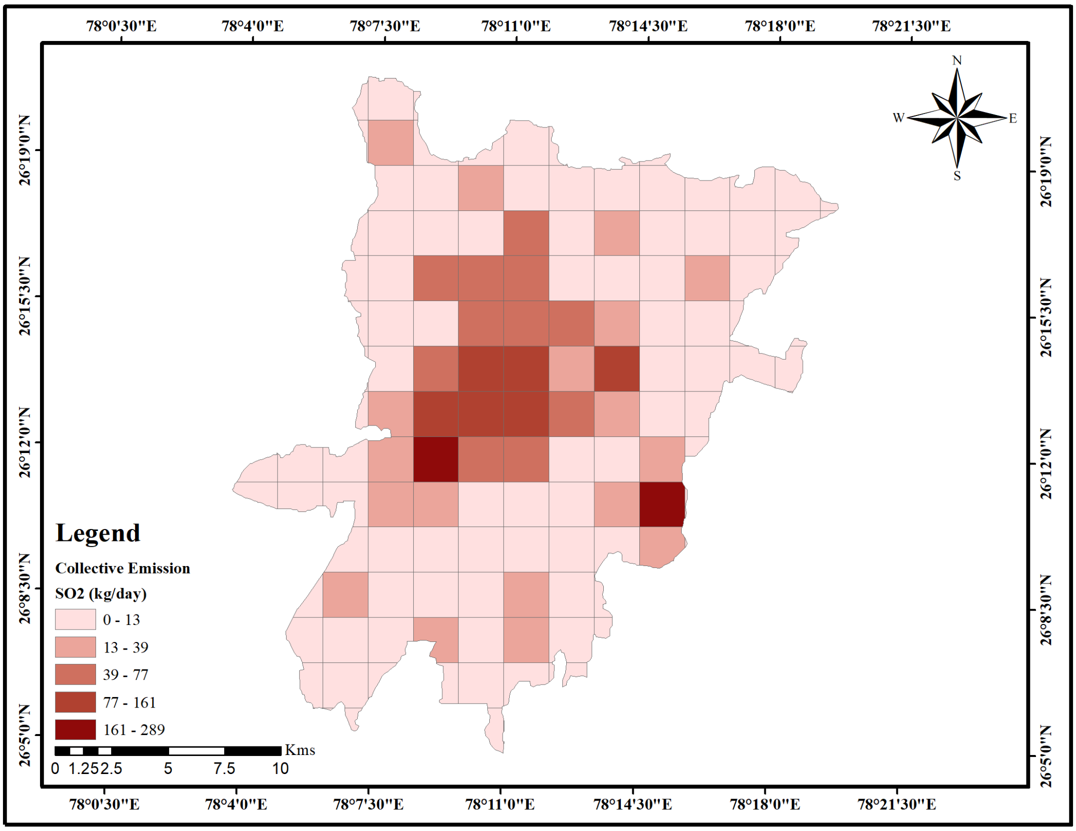


Figure 5: CO emission load of different sources in the city of Gwalior (kg/d)




78°0'30"E
78°4'0"E
78°7'30"E
78°11'0"E
78°14'30"E
78°18'0"E
78°21'30"E
26°19'0"N
26°15'30"N
26°12'0"N
26°8'30"N
26°5'0"N
N
S
W
E
Legend
Collective Emission
NOx (kg/day)
0 - 208
208 - 561
561 - 1193
1193 - 2061
2061 - 5012
Kms
0 1.252.5 5 7.5 10


78°0'30"E
78°4'0"E
78°7'30"E
78°11'0"E
78°14'30"E
78°18'0"E
78°21'30"E
26°19'0"N
26°15'30"N
26°12'0"N
26°8'30"N
26°5'0"N
N
S
W
E
Legend
Collective Emission
SO2 (kg/day)
0 - 13
13 - 39
39 - 77
77 - 161
161 - 289
Kms
0 1.252.5 5 7.5 10

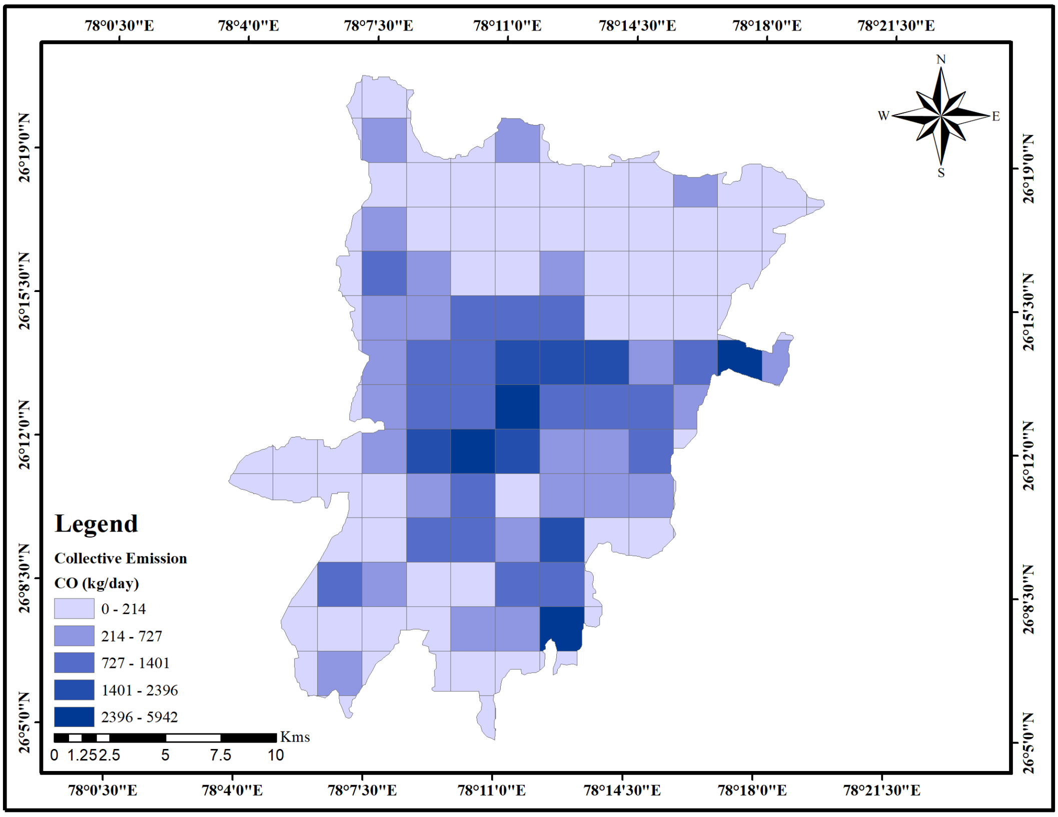


Figure 6: Spatial Distribution of PM_{10}, NOx, SO_2 and CO Emissions in the City

Air Quality Modeling

Receptor Modeling

Based on the CMB (chemical mass balance; USEPA 8.2 version) modeling results (Figures 7 and 8) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for the preparation of action plan. The important inferences are:

- The sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter.
    - The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include: soil and road dust (25.3 – 21.7%), biomass burning (16.8 – 19.0%), coal and flyash (18.4 – 19.9%), vehicles (15.7 – 18.7%), secondary inorganic aerosol (SIA) particles (11.6 – 11.5%), MSW burning (6.2

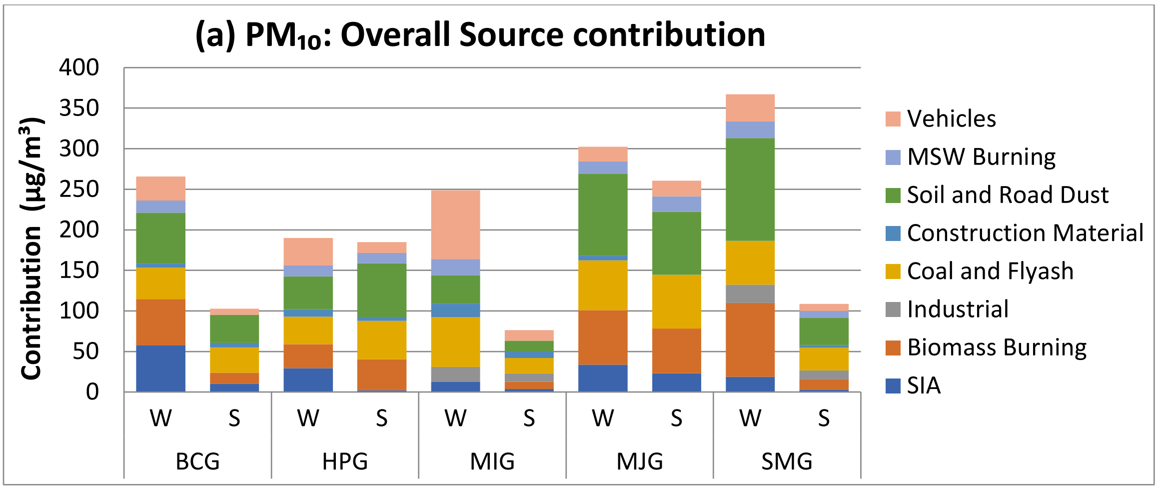
– 5.2%), construction material (3.2 – 1.9%) and industries (2.7 – 1.9%). It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.

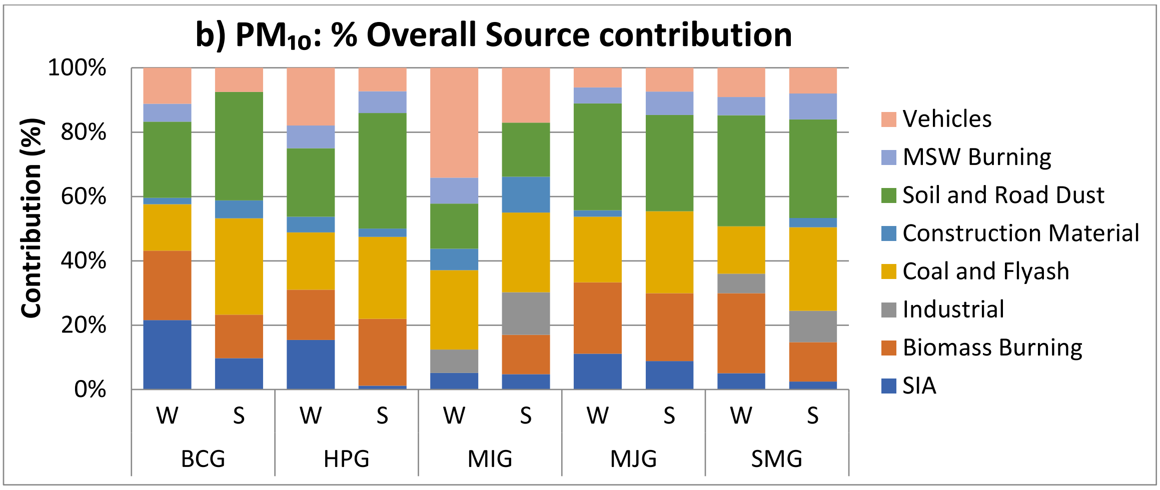
- The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include; soil and road dust (29.4 – 30.2%), coal and flyash (26.3 – 24.3%), biomass burning (16.0 – 17.3%), vehicles (9.5 – 10.8%), SIA particles (5.4 – 5.2%), MSW burning (4.4 – 4.5%), construction material (4.4 – 3.6%) and industries (4.6 – 4.8%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

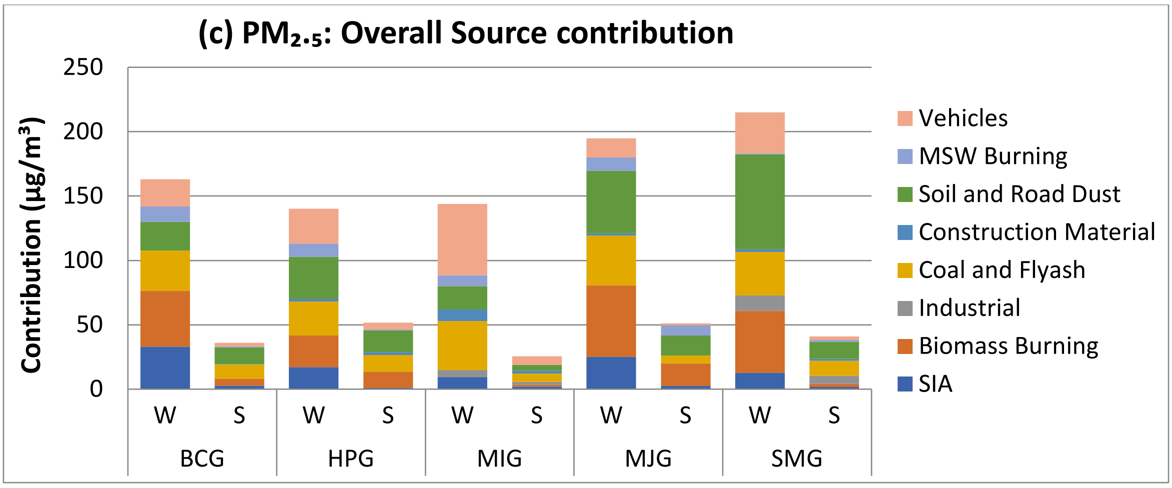
- The most consistent sources for PM_{10} and $PM_{2.5}$ in both the seasons are soil and road dust, and coal and flyash.
- The third most consistent source in winter season is MSW burning while in summer is biomass burning.
- The other sources on average may contribute more (or less) but their contributions are variable from one day to another. Industrial and construction emission sources were least contributor with high variability in the city in both seasons in PM_{10} and $PM_{2.5}$.
- The moderate presence of SIA and vehicles in PM_{10} and $PM_{2.5}$ across all sites and in two seasons, suggests these particles encompass entire Gwalior region as a layer.
- Like the above point, in winter, consistent presence of soil and road dust encompass entire Gwalior region as a layer.
- Soil and road dust in summer contribute 29 – 30% and the coal and flyash contribute 24 – 26% to PM_{10} and $PM_{2.5}$. It is observed that in summer the atmosphere looks whitish to grayish indicating presence of large amounts of dust; re-suspension of dust appears to be the cause of large contribution of these sources. This hypothesis can be argued from the fact that the contribution of coal and flyash, and soil and road dust reduce both in PM_{10} and $PM_{2.5}$ in winter when winds are low and prevalent atmospheric conditions are calm. The coal and fly ash could be due to coal uses in brick kiln and cement (having high content of flyash) uses in construction work.
- The contribution of the biomass burning in both the seasons is quite high (16 - 17% in PM_{10} and about 17 -19% in $PM_{2.5}$). The presence of sizeable biomass is consistent in winter and summer indicates to local sources present in Gwalior and nearby areas.

There is an immediate need to control or find alternatives to eliminate biomass emissions to observe any significant improvement in air quality in Gwalior.

- Industrial emission contribution is quite low (<3% in winter and about 5% in summer for both PM) in the city. MIG and SMG are the two industrial sites majorly contributing to the ambient air.
- The contribution of MSW burning is 4 to 6% in both seasons in PM_{10} and $PM_{2.5}$ that is reasonably low but consistent in winter season. This source emission is expected to be large in the regions of economically lower strata of the society which does not have proper infrastructure for collection and disposal of MSW.
- In industrial area, large trucks ferrying raw material and finishes products over poor road conditions were spotted due to dumping and burning of MSW and plastic waste along the roadsides in both winter and summer season that indicates irregular management of waste generated from industries which succeeds for open burning.







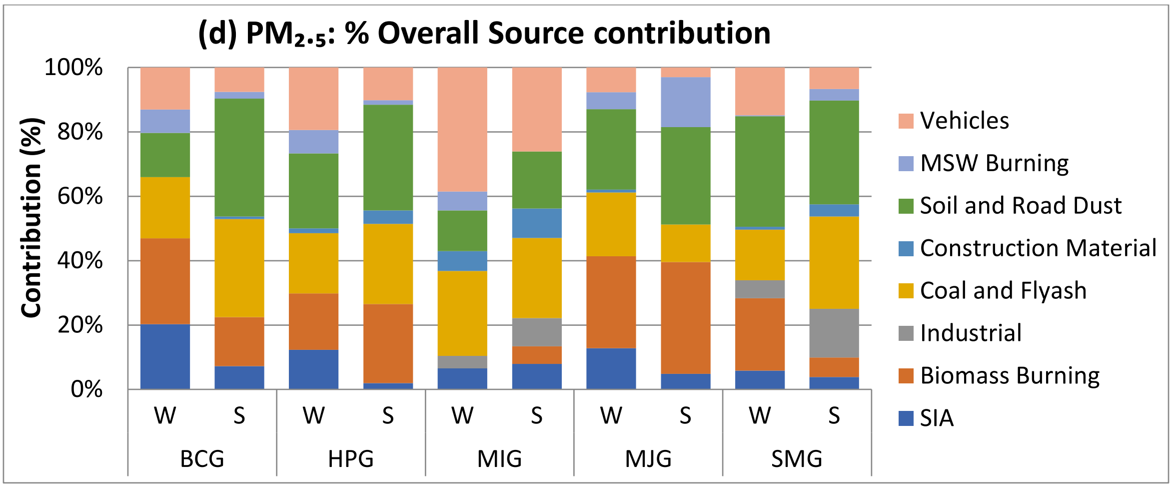
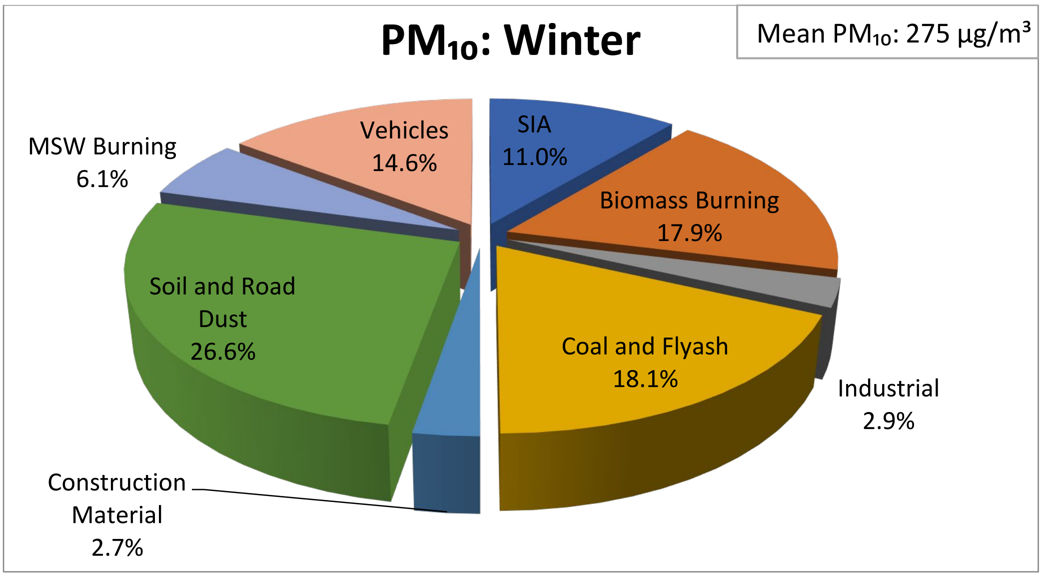


Figure 7: Overall Results of CMB Modeling for PM_{10} and $PM_{2.5}$ at five sites



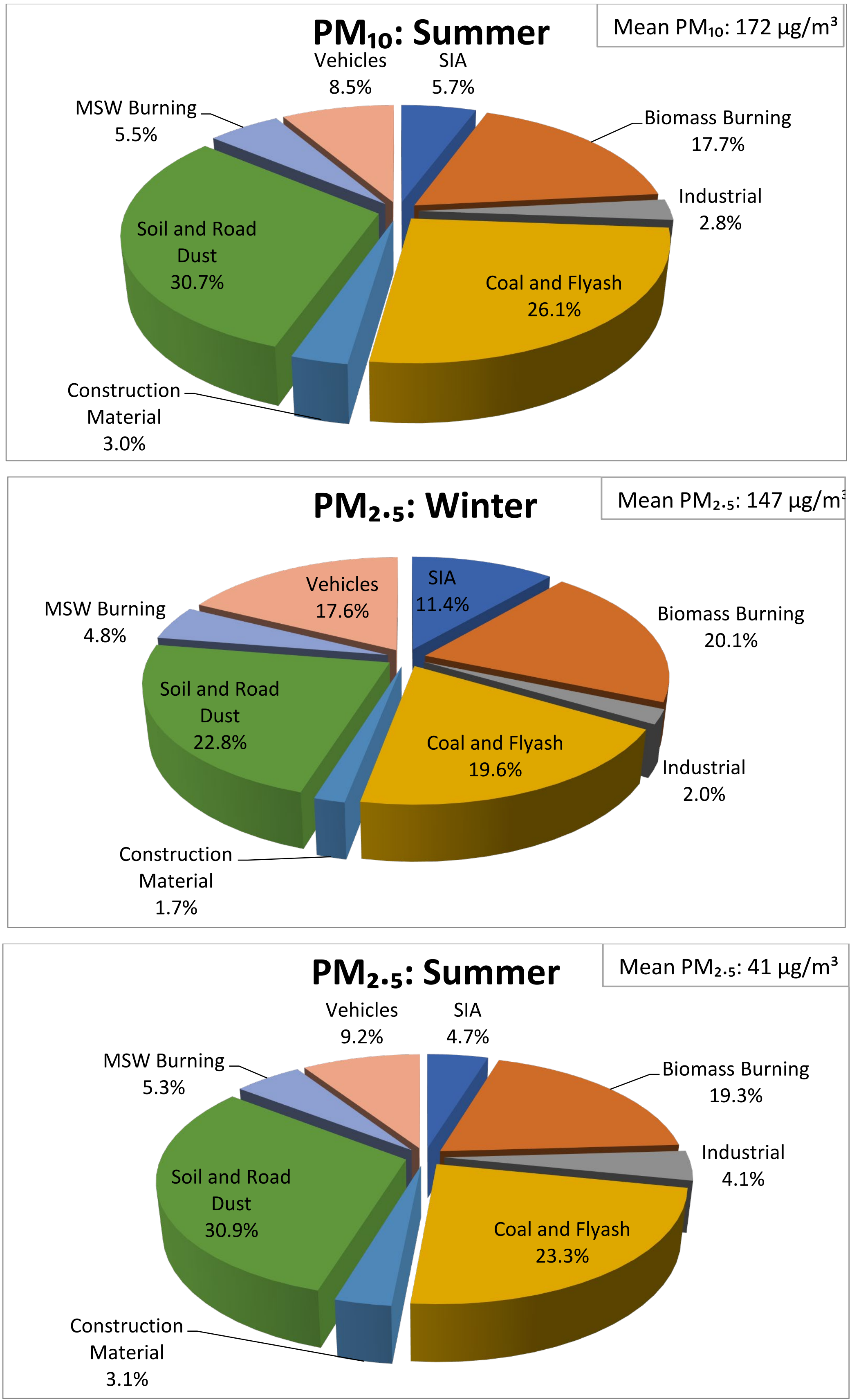


Figure 8: City level source contribution to ambient air PM_{10} and $PM_{2.5}$ levels

Dispersion Air Quality Modelling

The spatial pattern of annual mean levels of $PM_{2.5}$ is shown in Figure 9. The major findings from the dispersion modeling are summarized:

The predominant wind blowing direction was observed to be NW in most of the months and SE in some months. Also, a relatively high wind speed was observed in the summer season.

highest 24-hour average was 491.8 µg/m^3 (28th October 2022), monthly average $PM_{2.5}$ levels for the critical month was 316 µg/m^3 (November) and the annual average was 210.79 µg/m^3.

From the annual average plots, it is seen that $PM_{2.5}$ envelops a large area that gets elongated along the prevailing downwind direction (N-E) within Gwalior city. The annual standard for $PM_{2.5}$ concentration (40 µg/m^3) is exceeded in the area.

The city's highest contributing source for critical day (28th October 2022) is road dust followed by vehicular emissions. Domestic sources are where the residential population is concentrated. Overall, the top contributors to $PM_{2.5}$ were road dust (73%) followed by vehicles (24%) and domestic sources (2%).

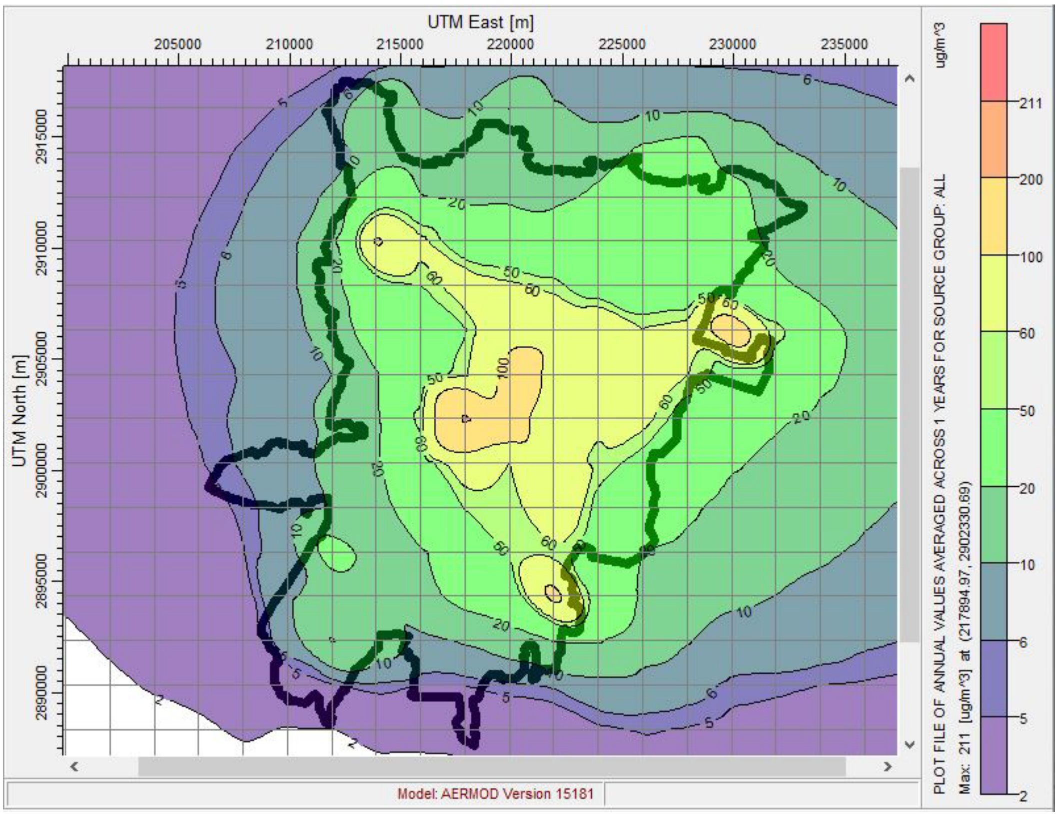


Figure 9: Iso-Concentration plot of annual average $PM_{2.5}$ levels

Control Options and Actions

A detailed analysis of control options for PM is given in Chapter 6. The proposed control options are summarized below in Table 2.

Table 2: Action Plan for City of Gwalior

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Hotels/ Restaurants/ Banquet Halls	All Restaurants small or large should not use coal and shift to gas-based or electric (for sitting capacity of more than 15 persons) appliances.	Gwalior municipal corporation	1 year
	Link Commercial license to clean fuel	Gwalior municipal corporation, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	Ash/residue from the tandoor and other activities should not be disposed of near the roadside. Requires ward-level surveillance.	Gwalior municipal corporation	1 year
Domestic Sector	LPG to all. Slums and about 2% of the population are still using wood, biomass, and dung cake as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	No new building complex or society be allowed without a PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	By 2030, the city may plan to shift to electric cooking (common in western countries) or PNG at the minimum	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 - 7 years
Municipal Solid Waste (SW) Burning	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Gwalior municipal corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Gwalior municipal corporation, MPPCB and MPHIDB.	
	Desilting and cleaning of municipal drains	Gwalior Municipal Corporations	
	Waste burning in Industrial areas should be stopped.	MPIDC, MPPCB	
	Daily, Monthly mass balance of SW generation and disposal	Gwalior municipal corporation.	
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Gwalior municipal corporation, MPPCB, and NGOs	
Construction and Demolition	Wet suppression	MP housing board (MPHIDB), Gwalior municipal corporation, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	MPHIDB, Gwalior municipal corporation, Urban Development Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Enforcement of C&D Waste Management Rules. The waste should be sent to a construction and demolition processing facility	MPHIDB, Gwalior municipal corporation, Urban Development Department, PWD	Immediate
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	MPHIDB, Gwalior municipal corporation, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	MPHIDB, Gwalior municipal corporation, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	MPHIDB, Gwalior Municipal corporation, Urban Development Department, PWD	
	No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road)	MPHIDB, Gwalior Municipal corporation, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	MPHIDB, Gwalior Municipal corporation, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	MPHIDB, Gwalior Municipal corporation, Urban Development Department, PWD, MPPCB, and NGO	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Road Dust	The silt load in Gwalior varies from 10.5 to 14.3 g/m^2. The silt load on each road should be reduced to under 2 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 2 gm/m^2.	MPHIDB, Gwalior Municipal corporation, National Highway Authority, PWD, MPPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	MPHIDB, Gwalior Municipal corporation, National Highway Authority, PWD, MPPCB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	MPHIDB, Gwalior Municipal corporation, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	MPHIDB, Gwalior Municipal corporation, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	MPHIDB, Gwalior Municipal corporation, National Highway Authority, PWD	
Vehicles	Diesel vehicles entering the city should be equipped with DPF which will bring a reduction of 40% in emissions	State Transportation Department	5 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	(This option can be implemented with vehicles of the BS-IV category as well)		
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Gwalior.	Transport Department, Traffic Police Gwalior, NHAI, Toll agencies	Six-months
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. All new city buses should be electric.	Transport Department, RTO Gwalior	1 year
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should	Transport Department, RTO Gwalior	1year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	include well-equipped maintenance workshops. Adequate charging stations.		
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Gwalior Municipal corporation, RTO Gwalior	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	MPHIDB, RTO Gwalior, Traffic Police-Gwalior	1 year
	IT systems in buses, bus stops, control centres, and passenger information systems for the reliability of bus services and monitoring.	MPHIDB, RTO Gwalior, Traffic Police-Gwalior	1 year
	Movement of materials (raw and product) within the city should be allowed between 10 PM to 5 AM.	Transport Department -Gwalior, MPHIDB, RTO Gwalior, Traffic Police- Gwalior	1 year
	All the diesel-based city public transport (school and government/private buses) should be phased out completely in next three years, and city transport should be operated only through metro, e-vehicle or on CNG. All new public transport should be CNG or electric buses.	Transport Department-Gwalior, MPHIDB, RTO Gwalior, Traffic Police- Gwalior	3 – 10 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Incentivise and aggressively implement e-mobility including required charging infrastructure. Strategic plan for EV charging infrastructure at each 3 km in urban areas, 25 km on highways (both sides) and 100 km for buses and trucks and swappable battery stations.	Transport Department-Gwalior, MPHIDB, RTO Gwalior, Traffic Police- Gwalior	2 years
	Adequate vehicle scrappage infrastructure should be developed in the next three years. Extended Producer Responsibility (EPR) may be considered for vehicle manufacturers, who will have to build required vehicle scrap plants.	Transport Department- Gwalior, MPHIDB, RTO Gwalior, Traffic Police- Gwalior	2 years
	Public transport to be strengthened with metro and/or adequate number of buses, route plan based on commute surveys and Mobile App based ticketing and seating system is developed in all major cities	Transport Department-Gwalior, MPHIDB, RTO Gwalior, Traffic Police- Gwalior	2 – 5 years
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	MPPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal Council and MPPCB	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, MPHIDB, MPIDC, Industries Department, MPPCB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, MPIDC, MPPCB	Immediate
	Following best practices to minimize fugitive emissions within the industry premises, all leakages within the industry should be controlled	Industrial Associations, MPIDC, MPPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, MPIDC, MPPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 118 boilers, Heater and furnaces in Gwalior are running by using Coal, Briquettes, Rise Husk, Wood, HSD, Furnace Oil, Waste, Firewood and other dirty solid fuels which should be shifted to natural gas and electricity.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, MPPCB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity.	Industrial Associations, MPPCB	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, MPPCB	2 years
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution.	Industrial Associations, MPPCB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, MPMKVVCL	2 years
	Renewable energy should be used to cater to the need of office requirements in the absence of power failure to stop the use of DG Set.	Industrial Associations	2 years
	Efficient recovery system for solvents in chemical industries: The technologies suggest 95% recovery of VOCs is feasible and same may be adopted	Industrial Associations	1 year
Decongestion of Roads in high traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane.	MPHIDB, Gwalior Municipal corporation, RTO Gwalior, Traffic Police- Gwalior	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Disciplined Public transport (designate one lane stop).	RTO Gwalior, Traffic Police-Gwalior	
	Removal of the free parking zone. No parking within 50 m of any major crossing and or chaurahs, rotaries. Strictly follow Indian Road Congress guidelines.	MPHIDB, Gwalior Municipal corporation., RTO Gwalior, Traffic Police- Gwalior	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	MPHIDB, RTO Gwalior, NHAI, Traffic Police, Gwalior	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	MPHIDB, RTO Gwalior, NHAI, Traffic Police, Gwalior	
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	MPHIDB, RTO Gwalior, Greater Gwalior Municipal Corporation, NHAI, Traffic Police, Gwalior	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Shikroda Tihara, Shivpur Tihara, Maharaj Bada, Swami Vivekanand Statue, Jiwaji University, Phool Bagh, Kampoo, Hazira Thana, Gole Ka Mandir, 7. No. Chowk, Gwalior-Chitora	MPHIDB, RTO Gwalior, Greater Gwalior Municipal Corporation, Traffic Police, Gwalior	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Chauraha, Tansen Chowk and Dabra Passare the main bottlenecks for traffic.		
	Parking policy in congested areas (high parking cost, at city centres, only parking is limited for physically challenged people, etc).	MPHIDB, RTO Gwalior, Greater Gwalior Municipal Corporation, NHAI, Traffic Police, Gwalior	
	The important points of congestion are Gole ka mandir, kampoo and 7 No. chowk. Parking on these Roads, should be strictly prohibited.	RTO Gwalior, Traffic Police	2 years
*The above steps should not only be implemented in Gwalior municipal Corporation area but these should be extended up to Outer city boundary.			

AIR QUALITY INDEX (AQI) OF BHOPAL AND GWALIOR CITIES OF MADHYA PRADESH (CAAQMS DATA)

(WITH PROMINENT POLLUTANT)

Month: February-2024

S. No.	Date	Bhopal	Gwalior
1.	01/02/24	MODERATE (140) PM10, PM2.5	MODERATE (161) PM10, PM2.5
2.	02/02/24	MODERATE (106) PM10	MODERATE (188) PM10, PM2.5
3.	03/02/24	MODERATE (139) PM2.5	MODERATE (154) PM10, PM2.5
4.	04/02/24	MODERATE (139) PM10	MODERATE (177) PM10, PM2.5
5.	05/02/24	MODERATE (102) PM10	MODERATE (132) PM10, PM2.5
6.	06/02/24	MODERATE (117) PM10	MODERATE (143) PM10, PM2.5
7.	07/02/24	MODERATE (107) PM10	MODERATE (168) O3, PM2.5
8.	08/02/24	MODERATE (102) PM10	MODERATE (110) PM10, O3
9.	09/02/24	MODERATE (112) PM10, O3	MODERATE (116) PM10, PM2.5
10.	10/02/24	SATISFACTORY (94) PM10, O3	MODERATE (161) PM10, PM2.5
11.	11/02/24	SATISFACTORY (96) PM10	POOR (223) PM2.5
12.	12/02/24	MODERATE (127) PM10, PM2.5	POOR (257) PM2.5
13.	13/02/24	POOR (215) PM2.5	POOR (266) PM2.5
14.	14/02/24	POOR (232) PM2.5	POOR (210) PM2.5
15.	15/02/24	MODERATE (183) PM2.5	POOR (264) PM2.5
16.	16/02/24	MODERATE (131) PM10, PM2.5	POOR (266) PM2.5
17.	17/02/24	MODERATE (132) PM10, PM2.5	POOR (205) PM2.5
18.	18/02/24	MODERATE (126) PM10, PM2.5	MODERATE (161) PM10, PM2.5
19.	19/02/24	MODERATE (125) PM10	MODERATE (124) PM10, O3
20.	20/02/24	SATISFACTORY (91) PM10	SATISFACTORY (100) PM10
21.	21/02/24	SATISFACTORY (100) PM10	MODERATE (130) PM10
22.	22/02/24	MODERATE (108) PM10	MODERATE (136) PM10, PM2.5
23.	23/02/24	MODERATE (125) PM10	SATISFACTORY (100) PM10, CO
24.	24/02/24	MODERATE (101) PM10	MODERATE (132) PM10
25.	25/02/24	MODERATE (114) PM10	MODERATE (120) PM10, O3

Dr. Neeraj Verma
Chief Chemist
M.P. Pollution Control Board
Bhopal

1594

S. No.	Date	Bhopal	Gwalior
26.	26/02/24	SATISFACTORY (98) PM10	MODERATE (125) PM10
27.	27/02/24	MODERATE (115) PM10	MODERATE (145) PM2.5, O3
28.	28/02/24	-	MODERATE (148) PM10, PM2.5, O3
29.	29/02/24	MODERATE (125) PM10	MODERATE (131) PM10

Month: March-2024

S. No.	Date	Bhopal	Gwalior
1.	01/03/24	MODERATE (113) PM10	MODERATE (138) PM10
2.	02/03/2024	SATISFACTORY (76) PM10	SATISFACTORY (63) PM10, CO
3.	03/03/2024	SATISFACTORY (76) PM10	GOOD (49) PM10, CO, O3
4.	04/03/2024	SATISFACTORY (85) O3	SATISFACTORY (99) PM10
5.	05/03/2024	SATISFACTORY (93) PM10, O3	MODERATE (150) PM10, O3
6.	06/03/2024	SATISFACTORY (96) PM10, O3	MODERATE (183) PM10, PM2.5
7.	07/03/2024	MODERATE (102) PM10, O3	MODERATE (162) PM10
8.	08/03/2024	MODERATE (102) PM10, O3	MODERATE (153) PM10, PM2.5
9.	09/03/2024	SATISFACTORY (96) PM10, O3	MODERATE (151) O3, PM2.5
10.	10/03/2024	SATISFACTORY (99) PM10, O3	MODERATE (179) PM10, PM2.5, O3
11.	11/03/2024	MODERATE (101) PM10, O3	MODERATE (146) PM10, O3
12.	12/03/2024	MODERATE (126) PM10	MODERATE (159) PM10, O3
13.	13/03/2024	SATISFACTORY (81) PM10	MODERATE (154) PM10, O3
14.	14/03/2024	SATISFACTORY (100) PM10	MODERATE (142) PM10, O3
15.	15/03/2024	MODERATE (109) PM10	MODERATE (133) PM10
16.	16/03/2024	MODERATE (116) PM10	MODERATE (155) PM10, O3
17.	17/03/2024	MODERATE (106) PM10	MODERATE (164) PM10
18.	18/03/2024	MODERATE (105) PM10	MODERATE (169) PM10, PM2.5, O3
19.	19/03/2024	MODERATE (105) PM10	MODERATE (161) PM10, O3
20	20/03/2024	SATISFACTORY (92) PM10, O3	MODERATE (184) PM10, O3
21	21/03/2024	MODERATE (107) PM10, O3	MODERATE (155) PM10, O3
22	22/03/2024	MODERATE (106) PM10	MODERATE (122) PM10, O3

Dr. Neeraj Verma
Chief Chemist
M.P. Pollution Control Board
Bhopal

S. No.	Date	Bhopal	Gwalior
23	23/03/2024	MODERATE (122) PM10	MODERATE (130) PM10
24	24/03/2024	MODERATE (108) PM10	MODERATE (143) PM10
25	25/03/2024	MODERATE (138) PM10	MODERATE (188) PM10, PM2.5
26	26/03/2024	MODERATE (102) PM10	MODERATE (143) PM10, PM2.5
27	27/03/2024	MODERATE (112) PM10	MODERATE (120) PM10
28	28/03/2024	MODERATE (150) PM10	MODERATE (148) PM10
29	29/03/2024	MODERATE (116) PM10	MODERATE (138) PM10
30	30/03/2024	MODERATE (115) PM10	MODERATE (106) PM10
31	31/03/2024	SATISFACTORY (98) PM10	MODERATE (118) PM10

Month: April-2024

S. No.	Date	Bhopal	Gwalior
1.	01/04/24	MODERATE (106) PM10	MODERATE (133) PM10
2.	02/04/24	MODERATE (129) PM10	MODERATE (128) PM10
3.	03/04/24	MODERATE (136) PM10	MODERATE (149) PM10
4.	04/04/24	MODERATE (108) PM10	MODERATE (147) PM10, O3
5.	05/04/24	MODERATE (110) PM10	MODERATE (133) PM10
6.	06/04/24	MODERATE (110) PM10	MODERATE (122) O3, PM10
7.	07/04/24	MODERATE (117) PM10	MODERATE (134) PM10
8.	08/04/24	SATISFACTORY (86) PM10	MODERATE (120) PM10
9.	09/04/24	SATISFACTORY (93) O3, PM10	MODERATE (128) PM10
10.	10/04/24	SATISFACTORY (80) PM10	MODERATE (129) O3, PM10
11.	11/04/24	SATISFACTORY (68) O3	SATISFACTORY (88) PM10
12.	12/04/24	SATISFACTORY (75) O3, PM10	MODERATE (137) PM10
13.	13/04/24	SATISFACTORY (68) O3, PM10	SATISFACTORY (89) O3, CO
14.	14/04/24	SATISFACTORY (69) O3, PM10	MODERATE (132) O3, PM10
15.	15/04/24	MODERATE (104) PM10	MODERATE (154) PM10
16.	16/04/24	SATISFACTORY (85) PM10	MODERATE (130) PM10
17.	17/04/24	SATISFACTORY (90) O3, PM10	SATISFACTORY (96) PM2.5, PM10
18.	18/04/24	MODERATE (102) O3, PM10	MODERATE (121) PM10

Dr. Neeraj Verma
Chief Chemist
M.P. Pollution Control Board
Bhopal

S. No.	Date	Bhopal	Gwalior
19.	19/04/24	SATISFACTORY (93) PM10	MODERATE (116) PM10
20.	20/04/24	SATISFACTORY (91) PM10	MODERATE (110) PM10
21.	21/04/24	SATISFACTORY (82) O3, PM10	MODERATE (107) O3, PM10
22.	22/04/24	SATISFACTORY (81) O3, PM10	SATISFACTORY (99) O3, PM10
23.	23/04/24	SATISFACTORY (80) O3, PM10	MODERATE (113) PM10, O3
24.	24/04/24	SATISFACTORY (87) O3, PM10	MODERATE (102) PM10, O3
25.	25/04/24	SATISFACTORY (79) PM10	MODERATE (128) PM10, O3
26.	26/04/24	SATISFACTORY (79) PM10, O3	MODERATE (138) PM10, O3
27.	27/04/24	SATISFACTORY (76) O3	MODERATE (104) PM10
28.	28/04/24	SATISFACTORY (99) PM10	MODERATE (120) PM10
29.	29/04/24	SATISFACTORY (87) PM10	MODERATE (143) PM10, PM2.5
30.	30/04/24	MODERATE (105) PM10	MODERATE (128) PM10, PM2.5, O3

2/5/24

Dr. Neeraj Verma
Chief Chemist
M.P. Pollution Control Board
Bhopal

***