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BEFORE THE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI

ORIGINAL APPLICATION NO. 687/2023
AIR QUALITY INDEX IN VARIOUS CITIES

WITH

ORIGINAL APPLICATION NO. 1228/2024

NEWS ITEM TITLED "LANCET STUDY LINKS ALARMING MORTALITY RATES TO POOR AIR QUALITY 12 STRATEGIES TO COMBAT COUNTRY'S AIR POLLUTION CRISIS" APPEARING IN THE INDIAN EXPRESS DATED 13.09.2024

WITH

ORIGINAL APPLICATION NO. 646/2024

NEWS ITEM TITLED "HOW PARTIAL COMBUSTION FUELS YOUR BAD-AIR WOES" APPEARING IN THE TIMES OF INDIA DATED 02.05.2024

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THROUGH COUNSEL

Bpsjadon

BHANWAR PAL SINGH JADON
COUNSEL FOR STATE OF U.P.
Bhanwar09jadon09@gmail.com| 9639286572

Date: 19.01.2026

Place: NOIDA

NOTARIAL

NOTARIAL

S. No. 17

DATE 19.1.26

NOTARY INDIA

BEFORE THE NATIONAL GREEN TRIBUNAL

PRINCIPAL BENCH, NEW DELHI

ORIGINAL APPLICATION NO. 687/2023

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AFFIDAVIT ON BEHALF OF THE DISTRICT MAGISTRATE, VARANASI IN COMPLIANCE OF THE ORDER DT. 06.11.2025 PASSED BY THE HON'BLE TRIBUNAL

I, Satyendra Kumar , son of Radha Raman Jha , aged about 39 years, currently posted as the District Magistrate, Varanasi, do hereby solemnly affirm and state as under:

NOTARY

S. PATHAK

Advocate

Distt-Varanasi, UP

Regd. No. 13472/2017

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1. That I am the District Magistrate of Varanasi and in that capacity, I am fully conversant with the facts of the case. I am competent and duly authorized to swear this affidavit.

2. That this affidavit is being filed in compliance with the directions issued by this Hon'ble Tribunal in its order dated 06.11.2025. That vide the said order, this Hon'ble Tribunal impleaded several non-attainment cities, including Varanasi, as respondents. Furthermore, the Hon'ble Tribunal took on record the suggestions filed by the Learned Amicus Curiae and directed all respondents to consider the said suggestions, act upon them where feasible, and file a response thereto. This affidavit, therefore, details the status of air quality management in Varanasi and responds to the suggestions of the Learned Amicus Curiae.

I. Source Apportionment Study / Scientific Foundation for Air Quality Management

3. That the air quality scenario of Varanasi City has been scientifically assessed through a comprehensive *Source Apportionment Study and Clean Air Action Plan* conducted by the Indian Institute of Technology (IIT), Kanpur and

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submitted to the Uttar Pradesh Pollution Control Board (UPPCB) in March 2024.

A Copy of the Source Apportionment Study has been annexed herewith as **ANNEXURE R-1.**

4. That the said study establishes that particulate matter, namely PM_{10} and $PM_{2.5}$, is the major air pollutant in Varanasi City. The concentrations of PM_{10} and $PM_{2.5}$ were observed to exceed the National Ambient Air Quality Standards (NAAQS), particularly during the winter season, whereas gaseous pollutants such as SO_2 remain well within permissible limits and NO_2 is within standards but contributes to secondary particulate formation.

5. That as per the emission inventory and source apportionment results, the major contributing sources of air pollution in Varanasi City are:
    - Road dust and soil dust,
    - Vehicular emissions,
    - Biomass burning including domestic fuel use and regional residue burning,
    - Coal and fly ash usage in hotels, small industries and boilers,
    - Secondary Inorganic Aerosols formed from precursor gases,
    - Municipal solid waste burning and construction activities.

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Distt-Varanasi, UP

6. That the emission inventory prepared under the said study indicates:

   - Total PM_{10} emission load of approximately 33,823 kg/day, out of which road dust contributes about 84% and vehicular emissions about 9%.

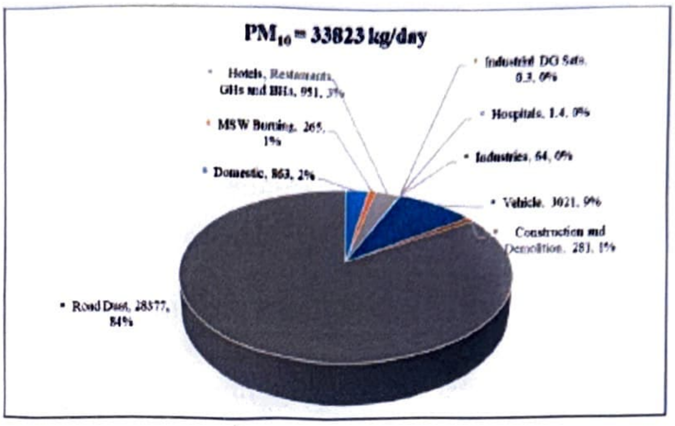

Figure1: PM_{10} Emission Load of Different Sources in Varanasi

- Total $PM_{2.5}$ emission load of approximately 10,877 kg/day, out of which road dust contributes about 60%, vehicles about 25%, and domestic fuel burning about 6%.

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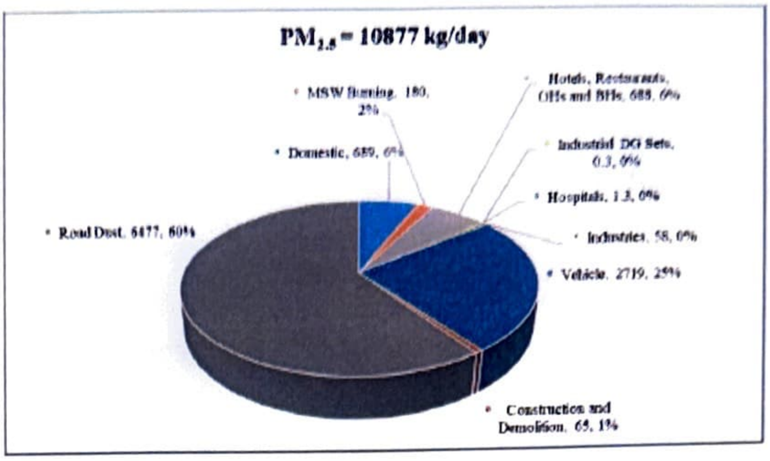

Figure2: $PM_{2.5}$ Emission Load of Different Sources in Varanasi

7. **That the aforesaid findings clearly establish that road dust and vehicular emissions are the dominant and most controllable sources of particulate pollution in the city, requiring priority intervention.**

II. City Action Plan and its implementation status:

8. That in pursuance of the recommendations of the Source Apportionment Study and in alignment with the National Clean Air Programme (NCAP), a comprehensive Clean Air Action Plan for Varanasi City has been prepared and is under active implementation by the District Administration, Varanasi Nagar Nigam, and UPPCB, in coordination with concerned line departments. A Copy of the City Action Plan has been annexed herewith as **ANNEXURE**

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9. That the major control measures undertaken and being implemented include:

   a. Regular mechanized vacuum sweeping and water sprinkling on major roads,

   b. Paving of unpaved roads and maintenance of pothole-free roads,

   c. Strict prohibition and monitoring against open burning of municipal solid waste,

   d. Strengthening of door-to-door waste collection and scientific disposal,

   e. Enforcement of construction and demolition dust control measures including wet suppression and covering of materials,

   f. Enforcement of vehicular emission norms, phasing out of old diesel vehicles and promotion of cleaner fuels and electric vehicles,

   g. Traffic decongestion and better traffic management at major junctions,

   h. Mandatory shift of hotels, restaurants and banquet halls from coal/wood to LPG, PNG or electric cooking,

   i. Promotion of LPG/PNG in the domestic sector and reduction of biomass fuel use,

   j. Enforcement of emission standards for industries and regulated use of diesel generator sets.

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10. That time-bound short-term and long-term action points have been formulated covering vehicular pollution control, dust suppression, prevention of waste burning, strengthening of solid waste management, industrial emission control, construction dust mitigation, real-time monitoring systems, AQI dissemination and public grievance redressal mechanisms.

11. Continuous monitoring, enforcement actions under the Air Act, 1981, and inter-departmental coordination are being strengthened to ensure progressive improvement in ambient air quality and compliance with the directions of the Hon'ble Tribunal.

III. Air Quality Monitoring Data (Ambient Air Quality Monitoring Data, Details of CAQM Stations):

12. That continuous ambient air quality monitoring is being carried out through CPCB/UPPCB stations and corrective measures are taken based on observed trends and exceedances.

13. The city of Varanasi is equipped with **four CAQM stations** located at **Ardhali Bazar, Maldahiya, Bhelupur, and IESD, BHU,** all of which are under the operation and maintenance of UPPCB. Along with the CAQM

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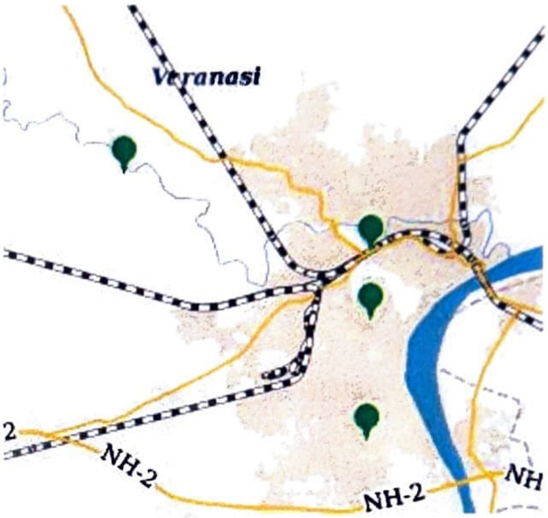
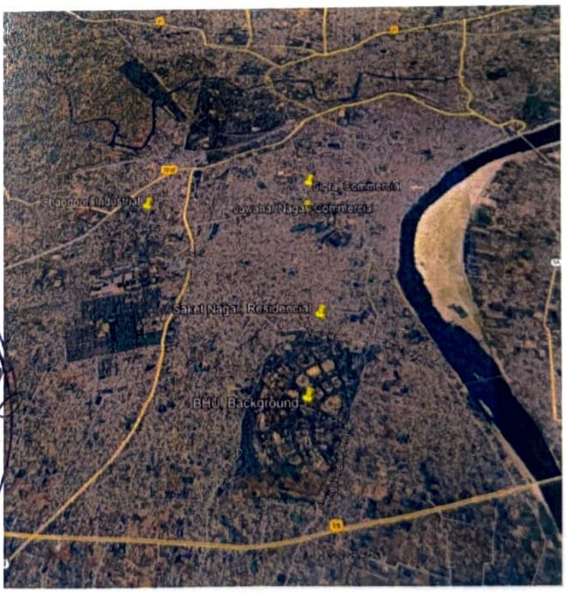
network, **five manual monitoring stations** are functioning in Varanasi, covering commercial, residential, industrial, and background locations at **Sigra, Jawahar Nagar, BHU, Saket Nagar, and Chandpur** respectively. That the data with respect to same is uploaded on the CPCB portal.


Varanasi
2
NH-2
NH-2
NH

CAQM stations locations


Sigra, Commercial
Chandpur, Industrial
Jawahar Nagar, Commercial
Saket Nagar, Residencial
BHU, Background

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Manual stations locations

A Copy of the air quality data for last three months at different stations has been annexed herewith as **ANNEXURE R-3**

14. That Varanasi City is a Non-Attainment City under the NCAP framework and is committed to achieving sustained reduction in PM_{10} and $PM_{2.5}$ concentrations through source-based interventions, infrastructure strengthening, behavioral change measures, and continuous monitoring.

15. It is respectfully submitted that substantial on-ground actions have been undertaken by Varanasi Nagar Nigam, District Administration, and UPPCB for effective control of air pollution and improvement of ambient air quality in Varanasi City. The present status of implementation is as follows:

a. Dust Control Measures

16. A total of 354 km of roads have been fully paved end-to-end, including black-topping, ensuring that the city's road network remains completely pothole-free.

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17. UPPCB has identified 30 hotspots in Varanasi city, which have been improved by Varanasi Nagar Nigam (VNN), resulting in a reduction in pollution caused by road dust and vehicular emissions.

18. Source-wise actions have been taken at each hotspot. To reduce road dust, VNN has deployed:

- 01 Mechanical Road Sweeping Vehicle
- 11 Water Sprinklers operating at identified hotspot sites
- 01 Anti-Smog Gun

Copies of photographs of Water Sprinklers, Vehicle and Anti-Smog Gun has been annexed herewith as **ANNEXURE R 4**

b. Solid Waste Management Actions

19. That **100% Door-to-Door (D2D) waste collection** coverage has been achieved across the city. Secondary collection points are monitored through GPS-based systems, ensuring timely lifting and prevention of waste accumulation. A Zero Tolerance Policy on open burning of garbage is strictly enforced. 100% solid waste processing is being ensured through scientific waste management facilities, eliminating open dumping. These actions have significantly minimized emissions from municipal solid waste burning.

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20. Processing Facilities:

- Waste-to-Compost Plant: 600 tons per day
- Waste-to-Charcoal Plant: 600 tons per day
- 03 Bio-methanation Plants: 15 tons per day

Copies of the photographs of the waste collection centres and Processing Facilities have been annexed herewith as **ANNEXURE R-5**

c. **Vehicular Pollution Control**

21. Electric Bus Fleet Expansion: A total of 50 electric buses are operational in the city, promoting clean public transport. No-Entry Zones have been implemented during peak hours to control congestion and vehicular emissions. PUC enforcement drives are conducted at 62 locations to check polluting vehicles and ensure compliance with emission norms. 21 major traffic intersections have been improved with Intelligent Traffic System (ITS), optimizing traffic flow and reducing idle emissions. These measures have effectively contributed to reduction in vehicular pollution load.

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d. Green Cover Enhancement

22. A cumulative green cover of 1,43,275 square meters has been developed across Varanasi city, including traffic corridors, open areas, public gardens, community spaces, school campuses and housing societies. For the year 2025–26, the plantation target is 2.5 lakh saplings. **A Miyawaki plantation target of 80 hectares has been set for 2025–26 to create dense urban forests and strengthen carbon sinks.** This sustained greening effort is aimed at improving air quality, microclimate and ecological balance.

e. Impact under NCAP

23. That the work undertaken under NCAP has led to a significant reduction in air pollution in Varanasi from 2019-2020 to the present. Under the National Clean Air Programme (NCAP, the PM_{10} concentration target for Varanasi city has been set at 60 $\mu g/m^3$ for the period from 2019–20 to 2025–26, and the city has approximately achieved this target through the sustained implementation of various air pollution control and mitigation measures. Reduction data has been shown in below picture-

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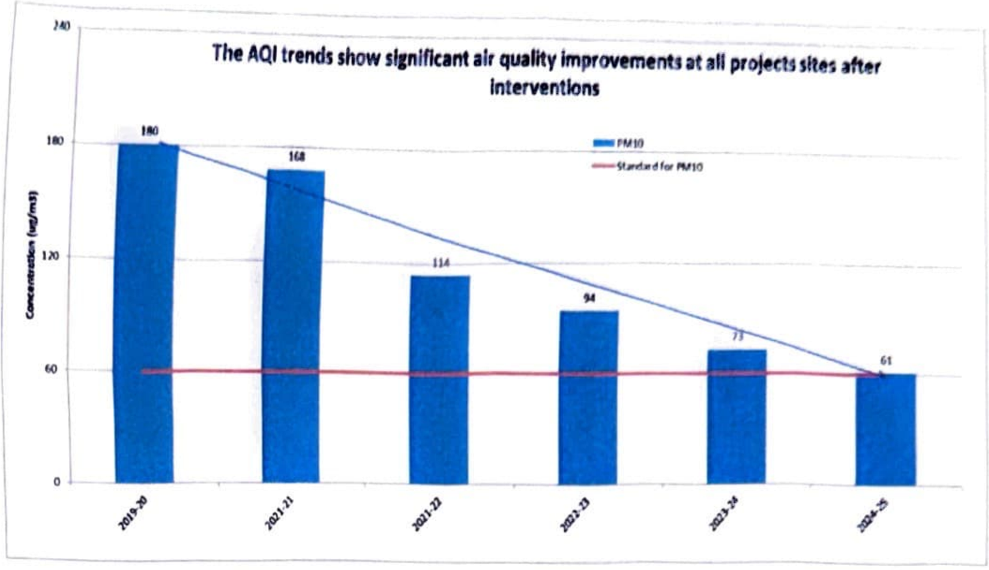

f. **Airshed Approach:**

24. It is respectfully submitted that the State of Uttar Pradesh has adopted a robust, science-based and airshed-oriented approach for air quality management through the Uttar Pradesh Clean Air Plan (UCAP), 2024. The Plan identifies particulate matter ($PM_{2.5}$ and PM_{10}) as the principal pollutants and recognizes that nearly 40% of $PM_{2.5}$ exposure is secondary in nature, with a significant contribution from sources outside the State. UCAP provides a comprehensive emission inventory, source apportionment, and time-bound sectoral action framework covering residential, transport, industrial, agricultural, waste management and dust control sectors. It projects that implementation of additional priority measures within Uttar Pradesh, along with cooperative action with neighboring states in the Indo-Gangetic Plain, can enable

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attainment of National Ambient Air Quality Standards of 40 μg/m³ for $PM_{2.5}$ and further progress towards 35 μg/m³.

The State is committed to full and effective implementation of UCAP in convergence with NCAP, CPCB guidelines and directions of the Hon'ble Tribunal to ensure sustained improvement in ambient air quality.

g. IEC Activities for Air Pollution Improvement and Cleanliness Drive

25. To strengthen cleanliness and air pollution control, Varanasi Nagar Nigam is regularly conducting effective IEC (Information, Education & Communication) activities on a daily basis to create public awareness and promote responsible environmental practices among citizens.

h. Stack Emission Report: UPPCB

26. That Stack Emission details with respect to the Industries situated in Varanasi (Within the Limit of Nagar Nigam) has been analysed by NABL Lab.

Copy of the stack Emission details with Industries name has been annexed herewith as

ANNEXURE R-6

Hence the present affidavit is being submitted for the kind perusal of the Hon'ble Tribunal. It is prayed that the same be taken on record

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Regd. No.-13472/2017

DEPONENT

VERIFICATION

Verified at Varanasi on this 19th day of January 2026, that the contents of the above affidavit from paragraphs 1 to 29 are believed to be true and correct to the best of my knowledge and belief. No part of it is false and nothing material has been concealed therefrom.

DEPONENT

S. PATHAK
Regd. No. 13472/2017
19/1/26

Sworn Before Me & Solemnly
Affirm Signature and Contents
Verified Today.

19/1/26

S. PATHAK Advocate
NOTARY GOVT. OF INDIA
Varanasi
Reg. No. 13472/2017

ANNEXURE R-1

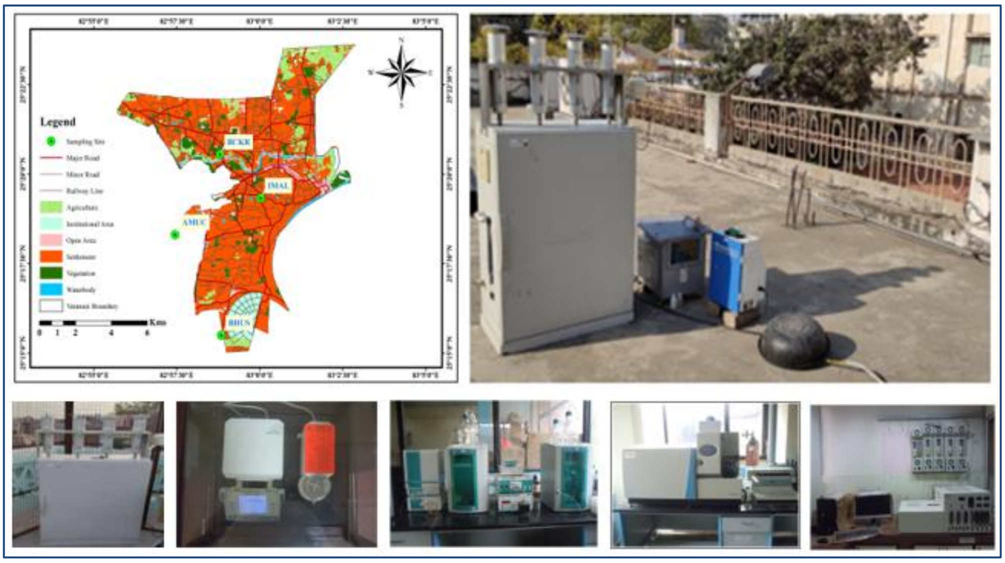
7723

Identification of Air Pollution Sources and their Contribution to Ambient Air in the City of Varanasi employing Source Apportionment Study and Developing Clean Air Action Plan

(Final Report)

Submitted to

Uttar Pradesh Pollution Control Board, Lucknow


Legend
Sampling Site
Major Road
Minor Road
Railway Line
Agriculture
Institutional Area
Open Area
Settlement
Vegetation
Waterbody
Varanasi Boundary
Kms
0 1 2 4 6
N
S
W
E
BCKR
IMAL
AMUC
BHUS

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

March 2024

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Disclaimer

This document is intended as the official report by Indian Institute of Technology (IIT), Kanpur on ‘Identification of Air Pollution Sources and their Contribution to Ambient Air in the City of Varanasi employing Source Apportionment Study and Developing Clean Air Action Plan’ submitted to the U.P. Pollution Control Board, Lucknow. While every effort has been made to ensure the correctness of data/information used in this Report, IIT Kanpur does not accept any legal liability for the accuracy or inferences drawn from the material contained therein or for any consequences arising from the use of this material. No part of this report may be reproduced in any form (electronic or mechanical) without prior permission from or intimation to the authors. No part of this report can be used for any scientific publications in any journal, conferences, seminars, workshops, etc., without written permission from the authors.

The full Report should be referenced as follows:

Sharma M and Nagar P K (2024) “Identification of Air Pollution Sources and their Contribution to Ambient Air in the City of Varanasi employing Source Apportionment Study and Developing Clean Air Action Plan” IIT Kanpur Report Submitted to Uttar Pradesh Pollution Control Board, Lucknow

Text from this Report can be quoted provided the source is acknowledged.

Executive Summary

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

To address the air pollution issues of the City of Varanasi, the Uttar Pradesh Pollution Control Board (UPPCB), Lucknow has sponsored the study "Identification of Air Pollution Sources and their Contribution to Ambient Air in the City of Varanasi employing Source Apportionment Study and Developing Clean Air Action Plan" to the Indian Institute of Technology Kanpur (IITK) through their letter No. H47212/CL/399/SAS/UNS PR4/2019-20 dt. 05-02-2020. The main objectives of the study were the preparation of emission inventory, air quality monitoring in two seasons, chemical composition of PM_{10} (particulate matter of size less than or equal to 10 µm diameter) and $PM_{2.5}$ (particulate matter of size less than or equal to 2.5 µm diameter), apportionment of sources to ambient air quality, trend analysis in historical air quality data and development of pollution control plan for the city. The project has the following specific objectives:

- Identify and inventorize emission sources (industry, traffic, power plants, local power generation, small-scale industries, household cooking, etc.);
- 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 control options in a time-bound manner.

This study had 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 four air quality sampling sites were selected and categorized based on the predominant land-use pattern (Table 1) to cover varying land-uses prevailing in the city. PM_{10}, $PM_{2.5}$, SO_2, NO_2, VOCs (volatile organic compounds), OC (organic carbon), EC (elemental carbon), ions, elements, and PAHs (polyaromatic hydrocarbons) were considered for sampling and analysis. The air quality sampling was conducted for two seasons: winter (2020-21) and summer (2021).

Table 1: Description of Sampling Sites of Varanasi

S. No.	**Sampling Location**	**Site Code**	**Description of the site**	**Type of sources**
1.	BENARES CLUB KACHERI ROAD	BCKR	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, Restaurants
2.	IMA LAHURABIR	IMAL	Commercial	DG sets, vehicle, road dust, garbage/waste burning, Restaurant
3.	AMAR UJALA CHANDPUR	AMUC	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, Restaurant
4.	BHU SUSUVAHI	BHUS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, Restaurants

Based on the air quality measurements in summer and winter 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 3.4 – 4.1 times higher than the national air quality standard (100 $\mu g/m^3$) in the winter season and 2.4 – 2.9 times in the summer season. $PM_{2.5}$ levels are 4.4 – 5.3 times higher than the national standard (60 $\mu g/m^3$) in the winter season. In the summer, $PM_{2.5}$ levels exceed by 1.6 – 2.1 times the national standard.

- 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.

PM_{10} (winter and summer)

The overall average concentration of PM_{10} was 367±29 µg/m^3 in winter and 287±21 µg/m^3 in summer against the acceptable level of 100 µg/m^3. The highest levels were observed at BCKR (401±105 µg/m^3) and lowest at AMUC (340±103 µg/m^3) in winter. In summer, the highest levels were at BCKR (314±112 µg/m^3) and the lowest at BHUS (266±48 µg/m^3).

In winter, crustal component (Si + Al + Fe + Ca) accounts for about 16% (much less compared to 30% in summer). This suggests soil and road dust have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.25 (of the fraction of crustal component), which suggests the crustal source contributes consistently even in winter, though much less than in summer.

In summer, the crustal component (Si + Al + Fe + Ca) accounts for about 30% of total PM_{10}. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.21 (of the fraction of crustal component), which suggests the sources are consistent and uniform all around the city, forming a layer that envelops the city. BCKR has the highest crustal fraction (around 36% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Varanasi 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.

In winter, the other important component is the combustion-related total carbon (TC = EC + OC), which account for about 26% of total PM_{10} and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for about 20%; both fractions of secondary particles and combustion-related carbons have increased and account for 46% of PM_{10}.

In summer, the combustion-related total carbon (EC+OC) account for 13% of total PM_{10} and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for about 7%.

The Cl^- content in PM_{10} in winter is consistent and varies between 2 –7%, an indicator of the burning of municipal and plastic solid waste (MSW); poly vinyl chloride (PVC) is a significant part of MSW. The highest Cl^- content is observed at IMAL at 25 µg/m^3 compared to the overall city level of 18 µg/m^3. The Cl^- content in PM_{10} in summer is consistent at 1.6 – 6%. The high level at IMAL signifies some local burning of waste either in industries or as means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ is 265±22 µg/m^3 in winter and 116±11 µg/m^3 in summer and against the acceptable level of 60 µg/m^3. The highest levels are observed at IMAL (285±107 µg/m^3) and lowest at BHUS (240±76 µg/m^3) in winter. In summer, the highest levels were at AMUC and the lowest at BHUS.

The crustal component (Si + Al + Fe + Ca) accounts for about 15% in winter and 16% in summer in total $PM_{2.5}$. The CV is about 0.25 in winter, which suggests the source is consistent all around the city though relatively small in summer.

In winter, the important components are the combustion-related total carbon (TC=EC+OC), which account for 26% of total $PM_{2.5}$ and secondary particles (NO_3^{-} + SO_4^{-2} + NH_4^{+}) accounts for 22%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 48%. The highest TC level was observed at IMAL (82 µg/m^3) and secondary particles at BHUS (about 66 µg/m^3).

In summer, the combustion-related total carbon (EC+OC) account for 23% and secondary particles accounts for 13%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 36%. The highest TC was at AMUC and secondary particles at IMAL.

The Cl^{-} content in $PM_{2.5}$ was consistent in the winter and summer seasons and varied between 2 - 8%, which is an indicator of the burning of MSW. This is relatively lower in summer than in winter.

Potassium levels

In general, potassium levels are high and variable for PM_{10} (6.4 to 8 µg/m^3) in winter and in summer 3.7 to 18 µg/m^3. In $PM_{2.5}$, potassium levels in winter vary between 5.4 to 6.4 µg/m^3. In general, the potassium levels are 2.0 µg/m^3 in urban areas. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.60) show day-to-day variation in winter.

NO_2 levels

NO_2 levels in winter are higher (30.20±9.04 $\mu g/m^3$) than those in summer (19.69±3.22 $\mu g/m^3$) and the levels meet the national air quality standard of 80 $\mu g/m^3$. The highest NO_2 levels were at BCKR in winter (40.17 $\mu g/m^3$) and summer (24.03 $\mu g/m^3$), a residential site. NO_2 is 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 (less than 6.0 $\mu g/m^3$) in the city were well within the air quality standard.

General inferences

In winter, $PM_{2.5}$, OC and EC levels are significantly higher ($p\text{-value} < 0.05$) than summer season at all sites, PM_{10} levels are higher at all sites except IMAL, NO_2 levels are higher at all sites except BCKR and SO_2 levels are higher at AMUC and BHUS. In general, air pollution levels in ambient air (barring traffic intersections) are uniform across the city, suggesting the entire city is stressed under high pollution.

It is to be noted that OC3/TC ratio (OC3 refers to carbon content of higher molecular weight in organic compounds) is above 0.20 and the highest among the ratio of the fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed in the atmosphere due to condensation and nucleation of volatile to semi-volatile organic compounds, which suggests emissions within and outside of Varanasi.

Total PAH levels (17 compounds; particulate phase) in winter is high at 88 ng/m^3 and B(a)P at 7.30 ng/m^3 (annual standard is 1.0 ng/m^3); the comparison with the annual standard is not advisable due to different averaging times. PAH levels in summer drop significantly to about 16 ng/m^3. The highest PAH levels were observed at AMUC (250 ng/m^3) in winter and in summer 19 ng/m^3 at BCKR.

The overall average of six molecular markers (17α(H)-22,29,30–Trisnorhopane, 17α(H),21 α(H)_hopane, 17α(H),21β(H)-hopane, Pentriacontane, Hentriacontane and Tritriacontane) was higher in winter (188 ng/m^3) than in summer (130 ng/m^3). The presence of significant quantities of molecular markers, especially alkanes and hopanes show the significant contribution of coal burning, gasoline and diesel combustion.

The total BTX levels are slightly higher in winter (18.6±6.7 $\mu g/m^3$) than in summer (11.4±2.1 $\mu g/m^3$). The emission rate of VOCs is expected to be high in summer due to high temperature, but no much difference in the concentration in two seasons due to better dispersion and large ventilation coefficient in summer season.

In a broad sense, combustion sources, vehicles, coal, biomass burning and MSW burning are the consistent sources and require a strategy to control these sources.

Emission Inventory

Emission inventory (EI) is a necessity for planning air pollution control activities. The overall baseline EI for Varanasi City is developed for the base year 2020. The pollutant-wise contribution is shown in Figures 1 to 5. The spatial distribution of pollutant emissions from all sources is presented in Figure 6.

The total PM_{10} emission load in the city is estimated to be 33823 kg/day. The top three contributors to PM_{10} emissions are road dust (84%), vehicles (9%), and hotels, restaurants, guest houses (GHs), and Banquet halls (BHs) (3%); 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 attain the desired air quality.

$PM_{2.5}$ emission load in the city is estimated to be 10877 kg/day. The top three contributors to $PM_{2.5}$ emissions are road dust (60%), vehicles (25%), and domestic (6%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO_2 emission load in the city is estimated to be 1104 kg/day. The top contributors are hotel, restaurants, GHs, and BHs (58%), industries (23%), and domestic (16%).

NO_x emissions load in the city is estimated to be 18694 kg/day. The majority of total emissions are attributed to vehicular (92%), domestic (4%), and hotels, restaurants, BHs & GHs (3%). 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 30490 kg/day. The major contributors to CO emissions are vehicles (79%), domestic (10%), and hotels, restaurants, BHs & GHs (5%). Vehicles could be the main target for controlling CO for improving air quality concerning CO.

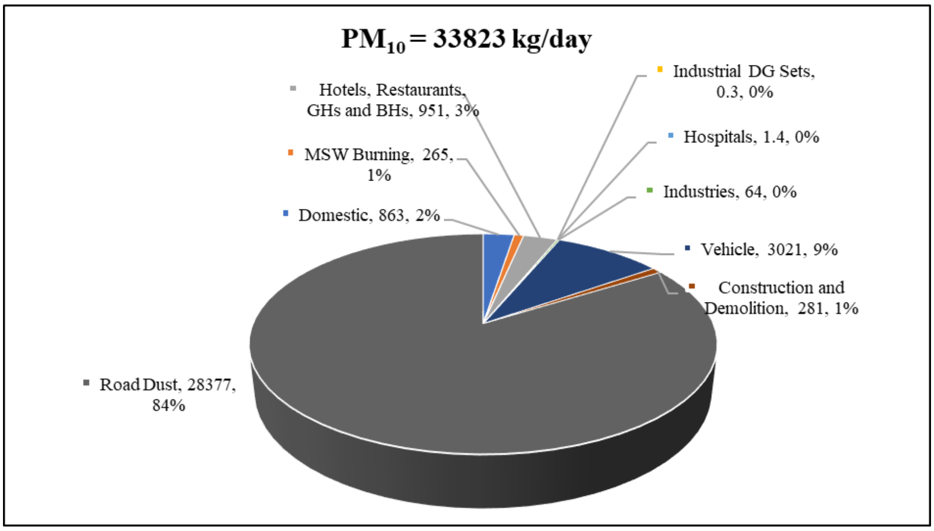


Figure 1: PM_{10} Emission Load of Different Sources in Varanasi

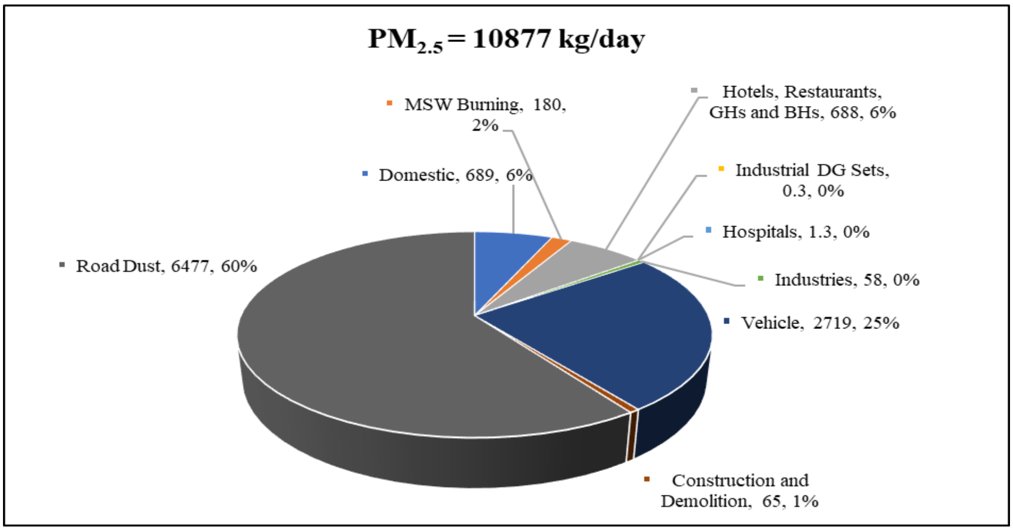


Figure 2: $PM_{2.5}$ Emission Load of Different Sources in Varanasi

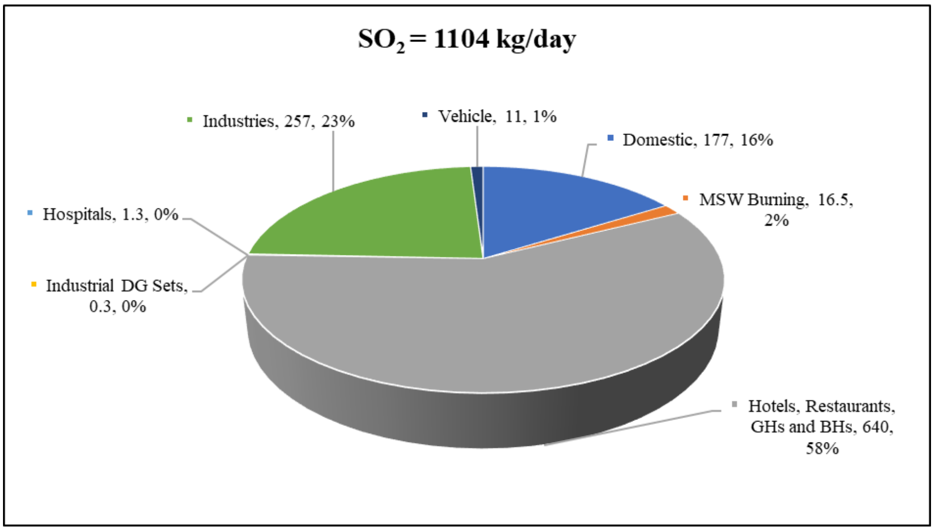


Figure 3: SO_2 Emission Load of Different Sources in Varanasi

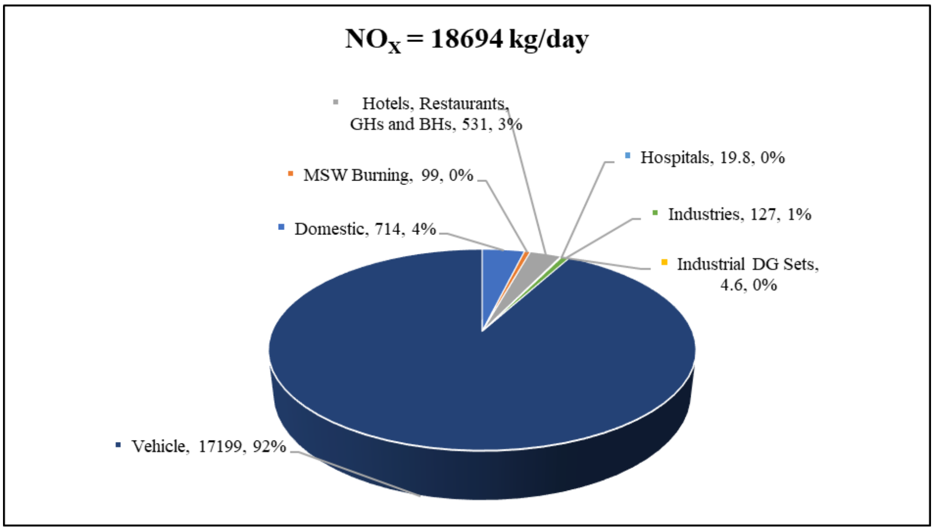


Figure 4: NOx Emission Load of Different Sources in Varanasi

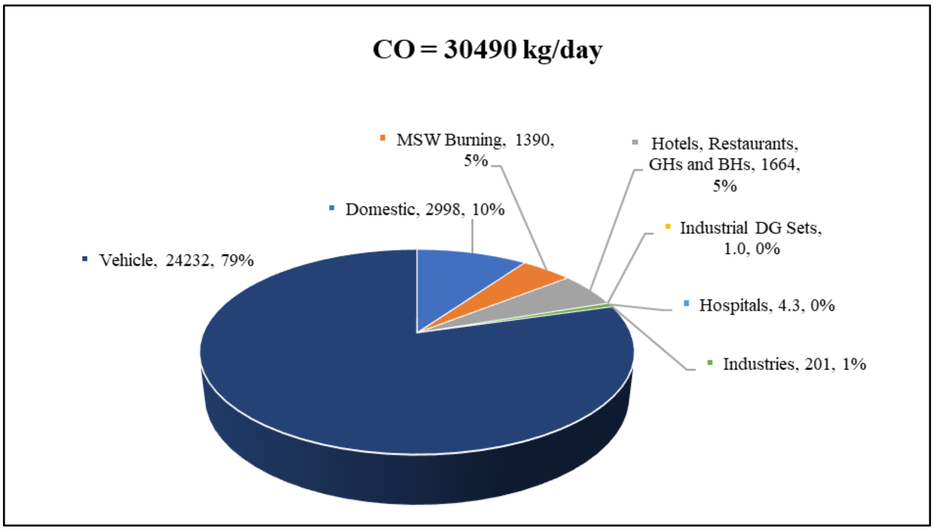
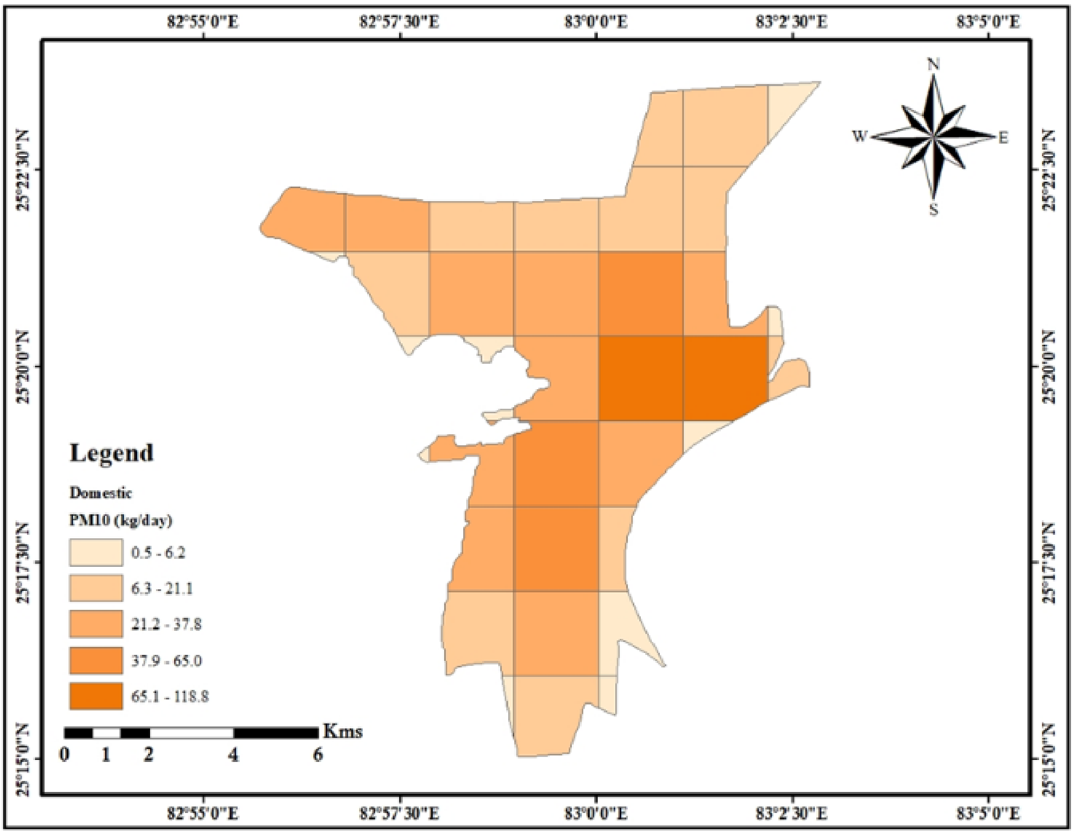
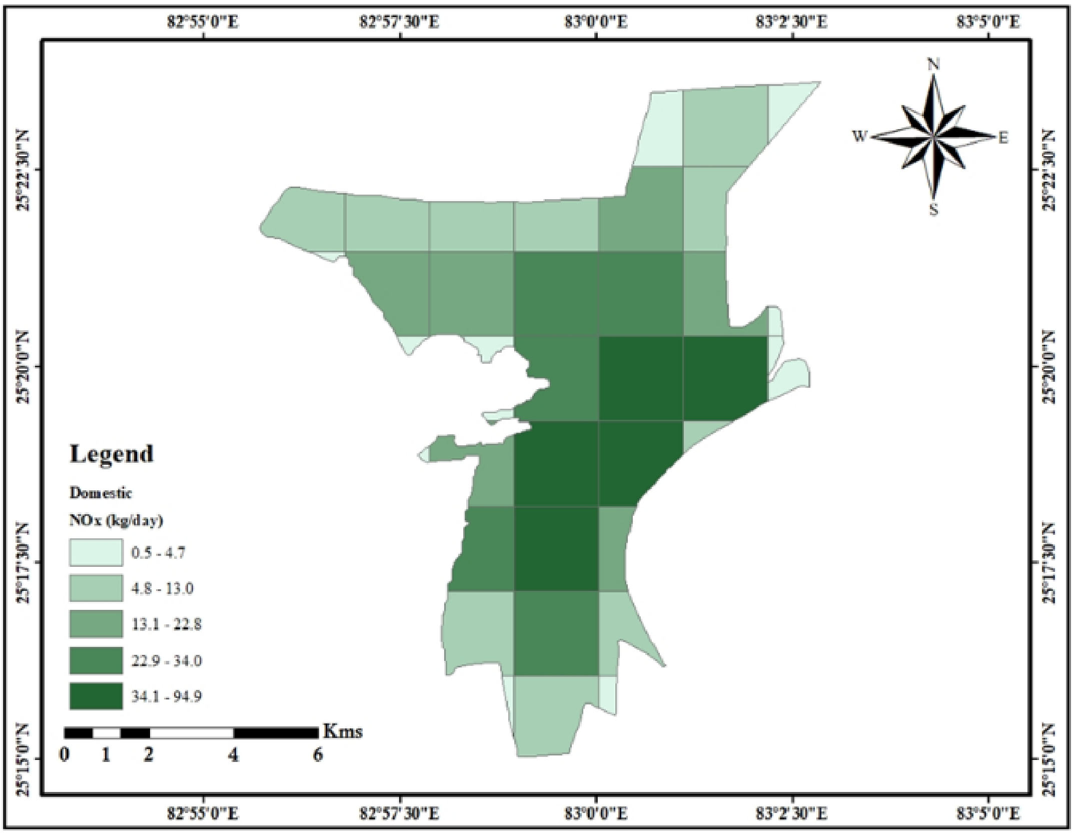


Figure 5: CO Emission Load Contribution of Different Sources in Varanasi


82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Domestic
PM10 (kg/day)
0.5 - 6.2
6.3 - 21.1
21.2 - 37.8
37.9 - 65.0
65.1 - 118.8
Kms
0
1
2
4
6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83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Domestic
NOx (kg/day)
0.5 - 4.7
4.8 - 13.0
13.1 - 22.8
22.9 - 34.0
34.1 - 94.9
Kms
0
1
2
4
6

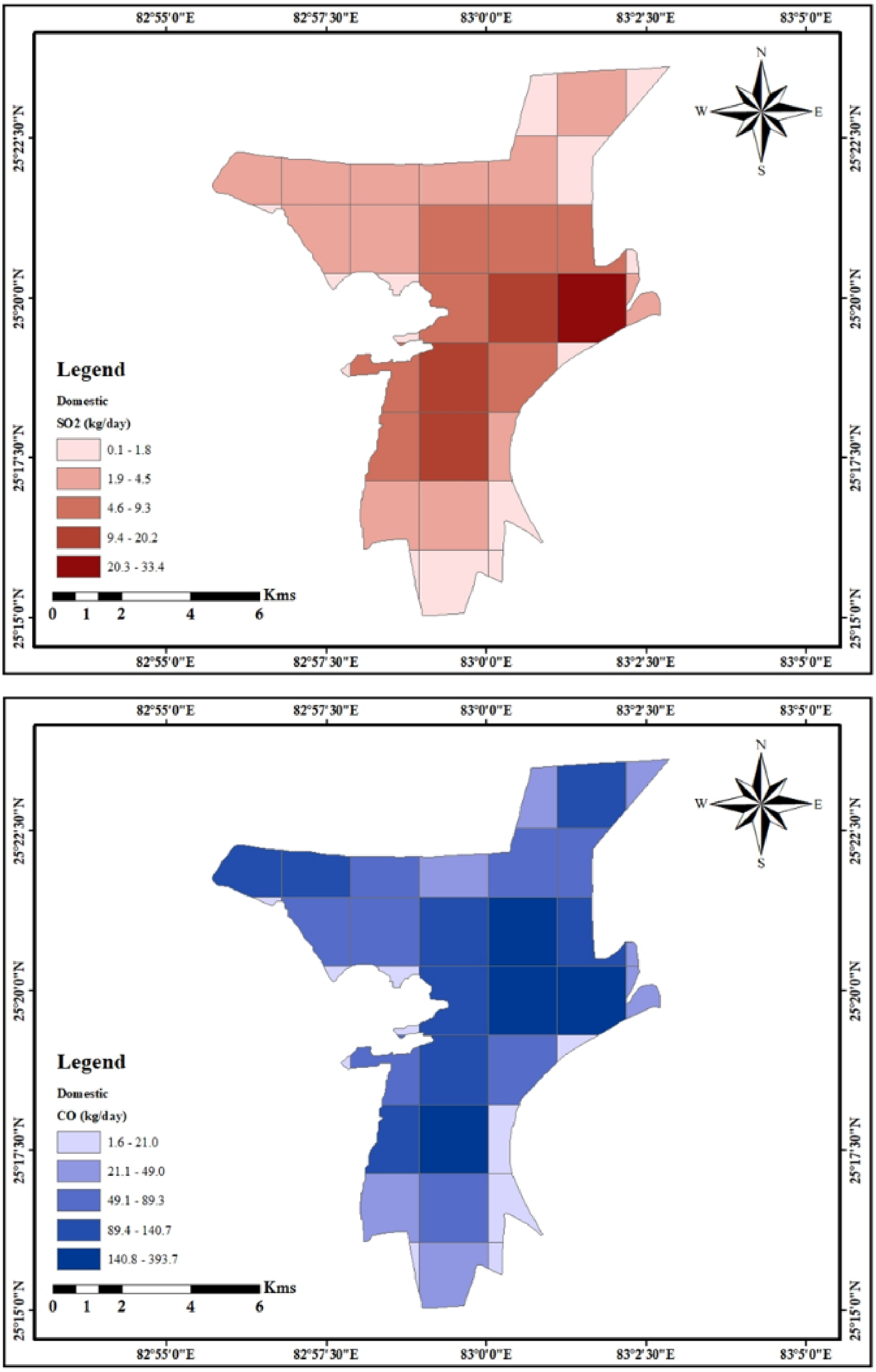
82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Domestic
SO2 (kg/day)
0.1 - 1.8
1.9 - 4.5
4.6 - 9.3
9.4 - 20.2
20.3 - 33.4
Kms
0
1
2
4
6
Legend
Domestic
CO (kg/day)
1.6 - 21.0
21.1 - 49.0
49.1 - 89.3
89.4 - 140.7
140.8 - 393.7

Figure 6: Spatial Distribution of PM$_{10}$, NO$_x$, SO$_2$ and CO Emissions in Varanasi City

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Air Quality Modeling for Source Apportionment: Receptor Modeling

Based on the CMB 8.2 model of USEPA (2004) modeling results (Figure 7) 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.
    - In winter, % contributions of PM_{10} – $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: biomass burning (27.9 – 29.8%), secondary inorganic aerosol (SIA; 18.7 – 20.1%), soil and road dust (17.9 – 17.7%), coal and fly ash (18.6 – 15.5%; includes ash from burning of residual oil), vehicles (12 – 14.1%), construction material (1.9 – 1%), MSW burning (1.8 – 0.8%), and industrial (1.3 – 1.2%).
    - In summer, % contribution of PM_{10} – $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: soil and road dust (51.1 – 29%), coal and fly ash (20.3 – 13%; includes burning of residual oil), biomass burning (12.7 – 28.1%), vehicles (9.4 – 17.6%), SIA (3.3 – 7%), construction material (2.1 – 3.1%), MSW burning (0.6 – 1.1%), and industrial (0.5 – 1.1%). It is noteworthy, in winter and summer, major sources for PM_{10} and $PM_{2.5}$ are generally the same
- The high contribution (in PM_{10} and $PM_{2.5}$) of soil and dust, biomass burning, coal and flyash and vehicles at most of the sites envelops the entire region with PM pollution.
- In summer, soil and road dust, vehicles and biomass burning activities contribute 73% to PM_{10} and 75% to $PM_{2.5}$. It is observed that in summer, the atmosphere looks greyish to brownish indicating the presence of large amounts of dust. In winter, the contributions of coal and fly ash, soil and road dust and construction material reduce significantly both in PM_{10} and $PM_{2.5}$ (by 58 and 62%) when winds are low and prevalent atmospheric conditions are calm.
- The contribution of the biomass burning in summer is at 28% (for $PM_{2.5}$) and 13% (for PM_{10}) and in winter at 28% (for PM_{10}) and 30% (for $PM_{2.5}$). The presence of sizeable biomass burning (including crop residue burning) is consistent in winter and summer, indicates the contribution from nearby areas and is impacted by meteorology.

- The contribution of the vehicles in summer is at 18% (for $PM_{2.5}$) and 9% (for PM_{10}) and in winter at 12% (for $PM_{2.5}$) and 14% (for PM_{10}). Vehicles (including domestic) that indicates the slow-moving traffic with high congestions on the major roads.
- The contribution of the SIA in summer is at 7% (for $PM_{2.5}$) and 3% (for PM_{10}) and in winter at 20% (for $PM_{2.5}$) and 19% (for PM_{10}). High and consistent contributions of secondary aerosols suggest the high emissions of precursors gases from different sectors, i.e., combustion sources, industries, brick kilns, biomass, MSW burning, domestic at far distances at regional levels from the receptor sites.

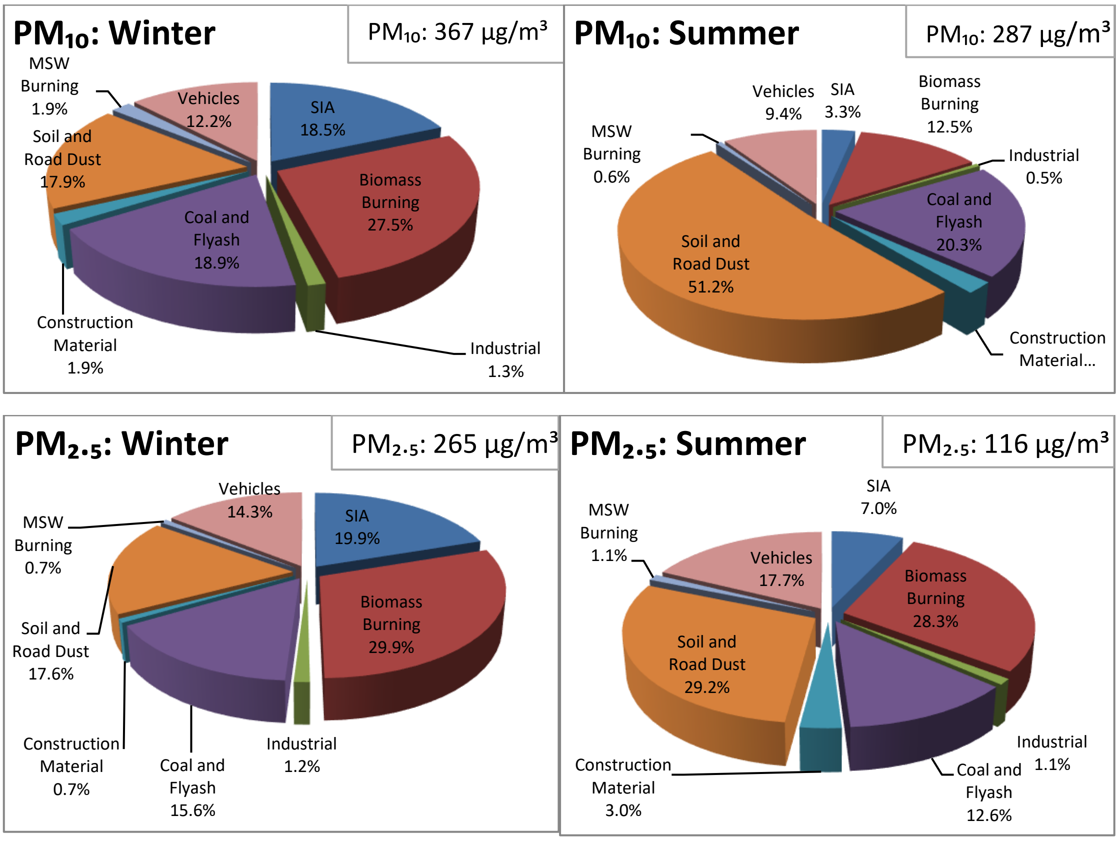

Figure 7: City level source contribution to ambient air PM_{10} and $PM_{2.5}$ levels

Air Quality Dispersion Modeling

From the annual average plots, it is seen that $PM_{2.5}$ envelops a large area that gets elongated along the prevailing wind direction (SW) within the City of Varanasi (Figure 8). The annual standard for $PM_{2.5}$ concentration (40 µg/m^3) is exceeded in the city. The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winter months (November and December) while the lowest was during the summer (June and July).

The high values of PM2.5 concentration were obtained from the sources of road dust, vehicular, domestic and hotels. Hospitals, DG sets and industries contributed the least to the PM2.5 concentration.

The overall, top contributors to PM2.5 at the hotspot location were road dust (63%), vehicle (24%), hotels (5%), domestic (5), MSW burning (2%), construction & demolition (1%), industries (< 1%), hospitals (< 1%) and DG sets (< 1%) on the critical day.

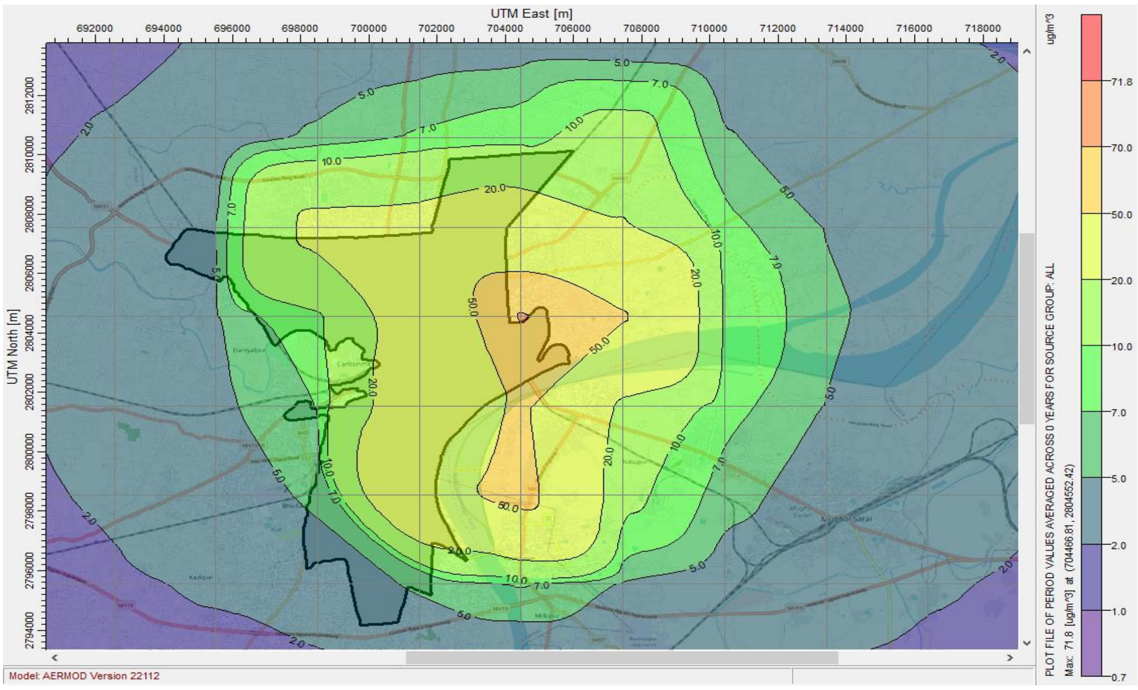
UTM East [m]
692000
694000
696000
698000
700000
702000
704000
706000
708000
710000
712000
714000
716000
718000
UTM North [m]
2812000
2810000
2808000
2806000
2804000
2802000
2800000
2798000
2796000
2794000
2.0
5.0
7.0
10.0
20.0
50.0
ug/m^3
71.8
70.0
50.0
20.0
10.0
7.0
5.0
2.0
1.0
0.7
PLOT FILE OF PERIOD VALUES AVERAGED ACROSS 0 YEARS FOR SOURCE GROUP: ALL
Max: 71.8 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112

Figure 8: Annual Average PM2.5 Levels from All Sources in the City

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: A Glance of Control Options and Action Plan for City of Varanasi

Source	Control Action	Responsible agencies	Time Frame
Hotels/ Restaurants/ Banquet Halls	All restaurants (sitting capacity of more than 15 persons) should not use coal in any form and shift to gas-based or electric cooking appliances.	Varanasi Municipal Corporation	1 year
	Link commercial license to clean fuel gas	Varanasi 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-off near the roadside – proper collection and disposal required.	Varanasi Municipal Corporation	1 year
Domestic Sector	LPG to all. About 10 - 15% of populations (including nearby villages) may still be using solid fuel (e.g., wood, biomass and dung) as cooking fuel and they should shift to LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	New building complexes or societies should have PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 years
	By 2030, the city may plan to partial shift to electric cooking or PNG at the minimum	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 -7 years

Source	Control Action	Responsible agencies	Time Frame
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance require improvements.	Varanasi Municipal Corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF only.	Varanasi Municipal Corporation, UPPCB	
	Desilting and cleaning of municipal drains on regular interval to stop ammonia, H_2S and VOC emissions	Varanasi Municipal Corporation	
	Waste burning (e.g., packing material, waste oil) in industrial areas should be stopped.	UPSIDC, UPPCB	
	Weekly and monthly mass balance of MSW generation, collection and disposal be undertaken.	Varanasi Municipal Corporation	
	Sensitize people and media through workshops and literature distribution as not to burn the waste.	Varanasi Municipal Corporation, UPPCB, and NGO	
Construction and Demolition	Wet suppression (maintain about 2% moisture in construction material except dry cement) in the area	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to construction and demolition processing facility	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	Immediate

Source	Control Action	Responsible agencies	Time Frame
	Proper handling and storage of raw material: covered storage and provide the windbreakers for large construction.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen throughout the height of construction all around.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	No storage of construction material near roadside (up to 10 m from the edge of the road)	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Builders should have an approved area for green belt in residential colonies.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops to minimize the emissions.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD, UPPCB, and NGO	

Source	Control Action	Responsible agencies	Time Frame
Road Dust	The silt load on each road should be reduced under 2 gm/m^2. Regular vacuum sweeping should be done on the roads having a silt load above 2 gm/m$^{2.}$	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, PWD, UPPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, PWD, UPPCB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, PWD	
	Increase green cover and plantation open areas, community places, schools, and housing societies.	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out at least four times a month on major roads with road washing. Road paving should extend up to shoulders	Varanasi Development Authority, Varanasi 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 (This option can be implemented with vehicles of BS-IV and BS-VI technology)	State Transportation Department	3 years

Source	Control Action	Responsible agencies	Time Frame
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for transportation of raw material 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 commercial vehicles operating in city	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Varanasi.	Transport Department, Traffic Police, Varanasi, NHAI, Toll agencies	Six-months
	Electric/Hybrid Vehicles should be encouraged with accelerated policy; New residential and commercial buildings to have charging facilities. All new city and school buses should be electric and explore conversion of existing buses into electric. Develop EV charging infrastructure as per NITI Aayog, MoUA and Govt. of UP guidelines (https://www.niti.gov.in/sites/default/files/2023-02/EV_Handbook_Final_14Oct.pdf; https://mohua.gov.in/upload/whatsnew/5c6e472b20d0aGuidelines%20(EVCI).pdf)	Transport Department, Varanasi City Transport Services Ltd	1 year

Source	Control Action	Responsible agencies	Time Frame
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should include well-equipped maintenance workshops. Adequate charging stations and infrastructure.	Transport Department, Varanasi City Transport Services Ltd	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Varanasi Municipal Corporation, Varanasi City Transport Services Ltd	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Varanasi Development Authority, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	1 year
	IT systems in buses, bus stops, and control centers, and passenger information systems for the reliability of bus services and monitoring.	Varanasi Development Authority, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	1 year
	Movement of materials (raw and product) within city should be allowed between 10 PM to 5 AM.	Transport Department, Varanasi, Varanasi Development Authority, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	1 year
Industries and DG Sets	Emission standard compliance in industries including shifting of highly polluting industries.	UPPCB, Industry Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and UPPCB	

Source	Control Action	Responsible agencies	Time Frame
	.		
	Industrial waste burning should be stopped immediately	Industrial Associations, UPSIDC, UPPCB	Immediate
	Following best practices to minimize fugitive emission within the industry premises, all leakages within the industry should be controlled	Industrial Associations, UPSIDC, UPPCB	Immediate
	Areas in front of the industry should be kept clean with no storage or disposed material	Industrial Associations, UPSIDC, UPPCB	
	Category A Industries (using coal and other dirty fuels)		
	Boilers and furnaces in Varanasi are running on coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity in a time-bound manner	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, UPPCB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that need to be shifted to natural gas and electricity	Industrial Associations, UPPCB	2 years
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, UPPCB	2 years
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, UPPCB	2 years

Source	Control Action	Responsible agencies	Time Frame
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, JVVNL	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
Decongestion of Roads at 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	Varanasi Development Authority, Varanasi Municipal Corporations, Varanasi City Transport Services Ltd, Traffic Police, Varanasi -	6 months
	Disciplined Public transport (designate one lane stop).	Varanasi City Transport Services Ltd., Traffic Police, Varanasi	
	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 on parking.	Varanasi Development Authority, Varanasi Municipal Corporation, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Varanasi Development Authority, Varanasi City Transport Services Ltd, NHAI, Traffic Police, Varanasi	

Source	Control Action	Responsible agencies	Time Frame
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Varanasi Development Authority, Varanasi City Transport Services Ltd, NHAI, Traffic Police, Varanasi	
	Mechanized multi-story parking at bus stands, railway stations, and big commercial areas. Remove at least 50 percent of on-street parking in the city	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi Municipal Corporations, NHAI, Traffic Police, Varanasi	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Kashi Chauraha, BHU Main Gate Chauraha, Pandeypur Chauraha, Chowkaghat Chauraha, Lahartara Chauraha, Girjaghar Chauraha and Atulanand Bus Stop Chauraha are the main bottlenecks for traffic and require decongestion and better traffic management.	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi Municipal Corporations, Traffic Police, Varanasi	
	Parking policy in congestion area (high parking cost, at city centers, consider parking is limited for physically challenged people, etc).	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi Municipal Corporations, NHAI, Traffic Police, Varanasi	
	Chaudhary Charan Singh Bus Stand causes extreme congestion and increased emissions and should be decongested at priority. It	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi	

Source	Control Action	Responsible agencies	Time Frame
	is recommended that the city should relocate these bus stations to the outskirts of the city at multiple locations.	Municipal Corporations, Traffic Police, Varanasi	
*The above steps should not only be implemented in Varanasi municipal limits rather these should be extended to up to at least 25 km beyond the boundary.			

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Acknowledgments

This project “Identification of Air Pollution Sources and Their Percentage Contribution to the Ambient Air through Source Apportionment Study and Remedial Measures for Non-Attainment City of Varanasi” was sponsored by Uttar Pradesh Pollution Control Board (UPPCB), Lucknow to the Indian Institute of Technology (IIT) Kanpur. The project was quite vast in terms of activities, including field sampling, data collection, laboratory analyses, computational work and interpretation of results. Support of different institutions and individuals at all levels is gratefully acknowledged. Although it will be an endeavor to remember and acknowledge all those who assisted in the project, we seek pardon in anticipation, if we err.

We gratefully acknowledge the assistance and guidance received from Shri Manoj Singh, Chairman, Shri J.P.S Rathore, Former Chairman, Shri Sanjeev Kumar Singh, Member Secretary and Shri Ajay Sharma and Shri Ashish Tiwari, Former Member Secretary, UPPCB, Lucknow and We are thankful to Shri Ram Gopal, Chief Environmental Officers who provided full support to this study at different times. We are also thankful Shri S. C. Shukla, Regional Officer, Varanasi and Shri Samrendra Singh, Assistant Scientific Officer, UPPCB, Lucknow for assisting in the day-to-day activities of the project.

The analytical facilities of Centre for Environmental Science and Engineering, IIT Kanpur (created under MPLADS, Govt of India) are gratefully acknowledged.

Dr. Pavan Kr Nagar, Post-Doctoral Fellow, IIT Kanpur worked tirelessly from field sampling to analysis and preparation of the report; thanks to Pavan for his inestimable support. I thank to Brajesh Singh, Project Engineer and Yuvraj Patidar, MTech student for assisting in the sampling, analysis, modeling and preparation of report. I also thank Shri Dhirendra Singh of Airshed Professionals for assisting in the preparation of emission inventory for the city. Sincere thanks are also due to the entire IITK team engaged in the project Anju, Arunima, Nitya, Ram Saroj, Reeta, Sana, Sahir, Shashank, Suyashi, Virendra, Vipin, Raju, Arun, Avinash, Kuldeep, Saurabh, Shivansh and Vakeel.

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1 Introduction

1.1 Background

Air pollution has emerged as a major challenge, particularly in urban areas. The problem becomes more complex due to the multiplicity and complexity of air polluting source mix (e.g., industries, automobiles, generator sets, domestic fuel burning, roadside dust, construction activities, etc.). The burgeoning population coupled with rapid growth in terms of vehicles, construction, and energy consumption has resulted in serious environmental concerns in Varanasi.

Varanasi is one of the old luminous cities, which is also a successful industrial city, a place of knowledge, philosophy, education, culture, music and Indian traditional arts and crafts. Industries in fine silks, silver and gold is said to be famous and renowned in their unique and purity in work.

Being a major Centre of Tourism, Textiles, Education, and small-scale industry units in Varanasi has experienced a phenomenal growth in recent years. The burgeoning population coupled with rapid growth in terms of vehicles for tourism and transportation, pharmaceuticals industries, construction, and energy consumption has resulted in serious environmental concerns in Uttar Pradesh.

The expanding population coupled with rapid growth in terms of vehicles for transportation of man, raw material and final goods, industries, construction, and energy consumption has resulted in air pollution issues in the both city, and cities becomes under the category of nonattainment of air quality standards.

Until recently, traditional approaches to the problem of apportioning source impacts have been limited to dispersion, or source, models which use emission inventory data (gathered at emission source) with meteorological data to estimate impacts at the receptor. Unlike source models, receptor models (especially for particulate matter) derive source impacts based on ambient particulate morphology, chemistry and variability information collected at the receptor. The increased interest in receptor models has resulted from the inability of dispersion models to assess short-term source impacts or identify sources, which collectively account for all of the measured mass (USEPA, 1991). These shortcomings are largely the result of the difficulty in developing accurate 24-hour particulate emission inventories and meteorological databases. Although traditional techniques using dispersion modelling for source impact apportionment will remain an important tool in air-shed management, recent advances in receptor-oriented techniques offer an additional useful tool.

Since the enactment of the Air Act 1981, air pollution control programs have focused on point and area source emissions, and many areas have benefited from these control programs. Nonetheless, most cities in the country still face continuing particulate non-attainment problems from particles of unknown origin (or those not considered for pollution control) despite the high level of control applied to many point sources. It is in the latter case that an improved understanding of source-receptor linkages is especially needed if cost-effective emission reductions are to be achieved. Determining the sources of airborne particulate matter is a difficult problem because of the complexity of the urban source mix. The problem is often compounded by the predominance of non-ducted and widely distributed area (fugitive) sources and the lack of understanding of the sources of secondary aerosol, their formation and transport. The advent of receptor modeling and recent developments in the areas of trace element analysis now permit a much more detailed analysis of ambient aerosol samples. By providing detailed information on the sources of the total, fine and inhalable particles, receptor models can play a major role in developing strategies for controlling airborne particulate matter.

It is evident from the above discussions that receptor modeling is a promising tool for source identification and apportionment in complex urban conditions. This is particularly true when many unorganized activities are releasing particulate into the atmosphere, which is typically true for our urban cities. In order to apply receptor modeling, it is essential to identify sources (small or large), generate emission profiles in terms of fingerprints and elemental composition. The next vital step is determining the chemical characterization of collected particulate matter on filter paper. In fact, it is easily conceivable that receptor and dispersion modeling can complement each other for better interpretations and decision making and can be applied in tandem.

To address the air pollution issues of the City of Varanasi, the Uttar Pradesh Pollution Control Board (UPPCB), Lucknow has sponsored the study "Identification of Air Pollution Sources and their Contribution to Ambient Air in the City of Varanasi employing Source Apportionment Study and Developing Clean Air Action Plan" to the Indian Institute of Technology Kanpur (IITK) through their letter No. H47212/CL/399/SAS/UNS PR4/2019-20 dt. 05-02-2020. 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 sources to ambient air quality, trend analysis in historical air quality data.

1.2 General Description of City

1.2.1 Geography and Demography

Varanasi city in the State of Uttar Pradesh situated in the center of the Ganges valley and in between the latitude 25.3176º N and longitude 82.9739º E and sprawling over an area of 83 sq km. Varanasi is worldwide renowned for tourism, center of handloom woven, embroidered textiles; the main products are zari-embroidery and brocade-work on silk sarees, diesel locomotive works and Bharat heavy electricals limited.

The population of Varanasi city is 1,198,491; of which male and female are 635,140 and 563,351 respectively as per the 2011 census (Census India, 2012). The city is governed by Municipal Corporation, which has 90 wards.

1.2.2 Climate

The climate of Varanasi features a humid subtropical nature and the temperature varies from 5°C in winter to 45 °C in peak summer. The city features mild winters, hot and dry summers and a monsoon season. In summers, the city witnesses a sudden surge in temperature and at times, mercury goes up to 45 °C. The total rainfall in the district varies from 680 mm to1500 mm with large proportion of it occurring during the months of June to September. The relative humidity in the city varies between 24% to 78%.

1.2.3 Emission Source Activities

The source activities for air pollution in the city of Varanasi can be broadly classified as: transport sector (motor vehicles and railways), commercial activities, industrial activities, domestic activities, institutional and office activities and fugitive non-point sources. For transport of men and transport, mostly public transport, tempos and taxies fulfil the transport requirement for the city. The combustion of fuels like coal, liquefied petroleum gas (LPG) and wood come under the source of domestic activities. As far as industrial activities are concerned, mostly small and medium scale industries are responsible for industrial air pollution. In most institutions and offices, diesel generators are used at the time of power failure.

1.3 Need for the Study

1.3.1 Air Pollution Levels: Earlier Studies

$PM_{2.5}$ and PM_{10} concentrations varied seasonally with atmospheric processes and the anthropogenic activities in Varanasi. A few studies on source apportionment of PM levels have been reported in Varanasi (Pandey et al., 1992; Mukherjee and Agrawal, 2018; Jain et al., 2019; Jain et al., 2021). Varanasi is ranked 30th among Indian cities based on PM_{10} levels of global cities (WHO 2016). These studies have employed trace element markers and principal component analysis at a few locations. (Mukherjee and Agrawal, 2018) have reported that air pollutant levels are 12 times higher than guidelines in Varanasi at PM monitoring station which is located at 25.3505°N latitude and 82.9783°E longitude in the northern sector of the city which is surrounded by heavy commercial and residential areas with monitoring period of 1066 days (July 2014–May 2017). Their study (Mukherjee and Agrawal, 2018) concluded that the PM_{10} levels exceed annual standard of Central Pollution Control Board, India (CPCB 2009), and World Health Organization (WHO 2005) by a factor of 4 – 12.2. After monsoon, PM_{10} concentration started to increase and showed peak concentration around January and then gradually declined from February to March and again showed elevation in April then followed a steep decline from May to July and remained constant up to August.

(Pandey et al., 1992) Ozone and TSP (total suspended particulate size 100 μm or less) concentrations reached a maximum of 160 (0.08 ppm) and 733 $\mu g/m^3$. The measured maximum concentrations (2-h average) were 150 and 231 $\mu g/m^3$ (0.078 and 0.086 ppm) for NO_2 and SO_2, respectively, for the winter season.

Chemical characteristics and sources of $PM_{2.5}$ and PM_{10} over Indo Gangetic Plain (IGP) of India from January 2015 to December 2016 for a seven-factor solution. Secondary aerosols contributed 18% to $PM_{2.5}$ and 16% to PM_{10}. vehicular emissions contributed 18.5% to $PM_{2.5}$ and 18% to the PM_{10}. vehicular emissions are a significant contributor to PM pollution in Varanasi since the problem of traffic congestion is severe in the city with many hotspots of traffic jams. Biomass burning contributed 19% and 18% to $PM_{2.5}$ and PM_{10}, respectively. Soil/road dust that contributed 14% to $PM_{2.5}$ and 21% to PM_{10}. The dominant presence of Soil/road dust source in this region could be attributed to the on-going construction activities across the city that causes serious problems of loose crustal soil and re-suspended dust city-wide. The higher concentration of Na^+, Mg^{2+}, $Ca^{2+,}$ and F^- identified as sodium and magnesium salt and accounted 8% of $PM_{2.5}$ and 8% of PM_{10}. Fossil fuel combustion is due to presence of markers like Cl^-, SO_4^{2-}, F^-, Al, and Cr (Sharma et al., 2014; Sharma et al., 2016b) and CMB results showed that it contributed around 13% to $PM_{2.5}$ and 8% to total PM_{10}. Many small and medium scale pulp and paper factories, handicraft industries, locomotive industries in and around Varanasi may have contributed to the receptor site. Industrial emission has contributed around 9% to $PM_{2.5}$ and 11% to PM_{10}. (Jain, Sharma et al. 2021).

Although Varanasi city faces air pollution problems due to the number of sources, no detailed study of the chemical composition of PM_{10} and $PM_{2.5}$ in recent years has been undertaken to identify the sources and their contributions to air pollution.

1.4 Objectives and Scope of Work

Objectively the project aims to achieve the following:

- Development of GIS-based gridded (2 km × 2 km resolution) emission inventory for air pollutants (particulate matter equal and less than 10μm diameter (PM_{10}), particulate matter equal and less than 2.5μm diameter ($PM_{2.5}$), sulphur dioxide (SO_2), carbon monoxide (CO), and oxides of nitrogen (NOx) for the base year, 2020.
- Compilation of emission factors for all sources, parking lot surveys through questionnaires for vehicle technology, model, engine capacity and measurement of driving patterns of various classes of vehicles operating on roads.
- Monitoring of air pollutants PM_{10}, $PM_{2.5}$, SO_2, NO_2, Benzene, Toluene, and Xylene. Analyze collected PM_{10} and $PM_{2.5}$ mass for elemental composition, ions, elemental carbon, organic carbon, PAHs (Di methyl Phthalate (DmP), Acenaphthylene (AcP), Di ethyl Phthalate (DEP), Fluorene (Flu), Phenanthrene (Phe), Anthracene (Ant), Pyrene (Pyr), Butyl benzyl phthalate (BbP), Bis(2-ethylhexyl) adipate (BeA), Benzo(a)anthracene (B(a)A), Chrysene (Chr), Benzo(b)fluoranthene (B(b)F), Benzo(k)fluoranthene (B(k)F), Benzo(a)pyrene (B(a)P), Indeno(1,2,3-cd)pyrene (InP), Dibenzo(a,h)anthracene (D(a,h)A) and Benzo(ghi)perylene (B(ghi)P)).
- Reconstruction of chemical species of PM and assessment for primary and secondary sources of air pollutants.
- Application of receptor model to establish source receptor linkages of PM_{10}, and $PM_{2.5}$ using state-of-the-art modeling to arrive at source apportionments at various sampling sites.

- Identification of various control options (e.g., adoption of EURO IV/V, diesel filter, etc.) and assessment of their efficacies for air quality improvements and development of control scenarios (in a techno-economical perspective) consisting of combinations of several control options.
- Selection of most effective control options for implementation and development of time-bound action plan.

1.5 Approach to the Study

The approach to the study is based on the attainment of its objectives within the scope of work, as explained in section 1.4. The summary of the approach to the study and major tasks are presented in Figure 1.1. The overall approach to the study is broadly described below.

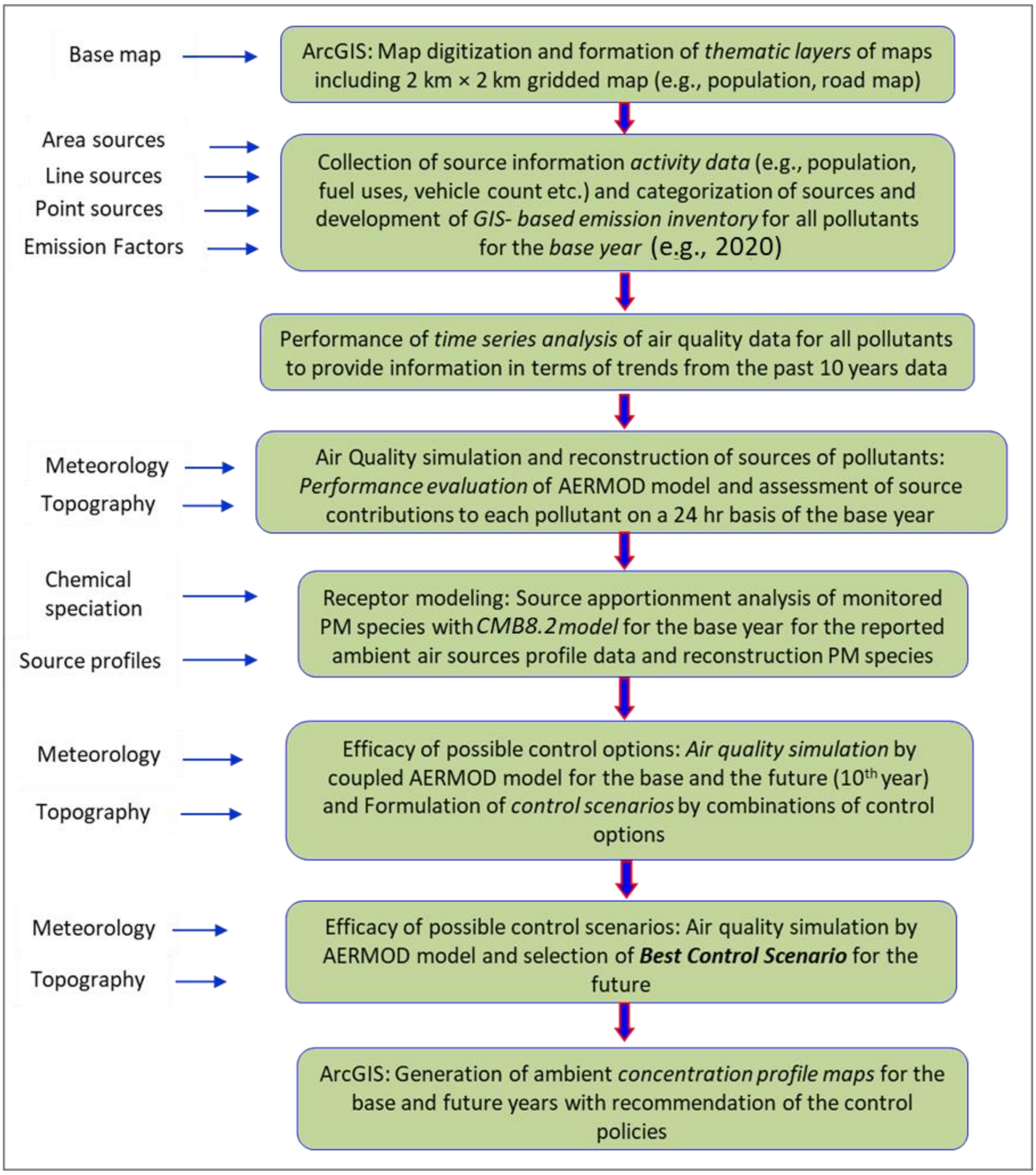
Base map
ArcGIS: Map digitization and formation of *thematic layers* of maps including 2 km × 2 km gridded map (e.g., population, road map)
Area sources
Line sources
Point sources
Emission Factors
Collection of source information *activity data* (e.g., population, fuel uses, vehicle count etc.) and categorization of sources and development of *GIS- based emission inventory* for all pollutants for the *base year* (e.g., 2020)
Performance of *time series analysis* of air quality data for all pollutants to provide information in terms of trends from the past 10 years data
Meteorology
Topography
Air Quality simulation and reconstruction of sources of pollutants: *Performance evaluation* of AERMOD model and assessment of source contributions to each pollutant on a 24 hr basis of the base year
Chemical speciation
Source profiles
Receptor modeling: Source apportionment analysis of monitored PM species with *CMB8.2 model* for the base year for the reported ambient air sources profile data and reconstruction PM species
Meteorology
Topography
Efficacy of possible control options: *Air quality simulation* by coupled AERMOD model for the base and the future (10th year) and Formulation of *control scenarios* by combinations of control options
Meteorology
Topography
Efficacy of possible control scenarios: Air quality simulation by AERMOD model and selection of ***Best Control Scenario*** for the future
ArcGIS: Generation of ambient *concentration profile maps* for the base and future years with recommendation of the control policies

Figure 1.1: Approach to the Study and Major Tasks

1.5.1 Selection of sampling sites: Representation of Urban Land-use

It was considered appropriate that four sites in a city like Varanasi can represent typical land-use patterns. It needs to be ensured that at all sites, there is a free flow of air without any obstruction (e.g., buildings, trees, etc.). In view of the safety of the stations, most public buildings could be better choices as sampling sites. Sites were finalized in consultation with the officials of UPPCB, Varanasi.

1.5.2 Identification and Grouping of Sources for Emission Inventory

An on-the-field exercise was taken up to physically identify all small and large sources around the sampling sites. This exercise included the presence of emission sources like refuses and biomass burning, road dust, and coal/coke burnt by street vendors/small restaurants to large units like power generation units and various vehicle types. It was necessary to group some of the similar sources to keep the inventory exercise manageable. It needs to be recognized that particulate emission sources change from one season to another. Finally, the collected data were developed into emission inventory for the following pollutants: SO_2, NOx, CO, PM_{10} and $PM_{2.5}$ on a GIS platform.

1.5.3 Emission Source Profiles

Since for $PM_{2.5}$, Indian or Varanasi specific source profiles are not available except for vehicular sources (ARAI, 2009), the source profiles for this study were taken from ‘SPECIATE version 3.2’ of USEPA (2006) and updated version 5.1 of SPECIATE (USEPA, 2020). For vehicular sources, profiles were taken from ARAI (2009). ‘SPECIATE’ is a repository of Total Organic Compound (TOC) and PM speciated profiles for a variety of sources for use in source apportionment studies (USEPA, 2006, 2020); care has been exercised in adopting the profiles for their applicability in the local environment of Varanasi city. For the sake of uniformity, source profiles for non-vehicular sources for PM_{10} and $PM_{2.5}$ were adopted from USEPA (2006, 2020).

1.5.4 Application of Receptor modeling

There are several methods and available commercial software that can be used for apportioning the sources if the emission profiles and measurements are available in the ambient air particulate in terms of elemental composition. The most common software is CMB 8.2 model of USEPA (2004). This model should be able to provide the contribution of each source in the particulate in ambient air. The modeling results should help identify major sources for pollution control. It was important to note that along with source contribution, the model could also provide the associated uncertainties in estimated source contributions.

1.5.5 Application of Dispersion Modeling

In addition to receptor modeling, dispersion modeling in the study area was undertaken. The hourly meteorological data were generated through WRF “Version 3.6” model (NCAR, 2012). The emission quantities coupled with predominant meteorological data of the city were used in the dispersion model in estimating the concentration of various pollutants and examining the contribution of each of the sources. AERMOD View “Version 9.0.” model (USEPA, 2015) was used for dispersion modeling.

1.6 Report Structure

The report is divided into six chapters. The brief descriptions of the chapters are given below.

Chapter 1

This chapter presents the background of the study, general description of the city, including geography and demography, climate and sources of air pollution. The current status of the city in terms of air pollution is described by reviewing the previous studies. The objectives, scope and approach to this study are also briefly described in this chapter.

Chapter 2

This chapter presents the air quality status of the city based on the monitoring and chemical characterization results of various air pollutants of all sampling sites for two seasons, i.e., winter and summer. In addition to the above information, this chapter also describes methodologies adopted for monitoring, laboratory analyses, quality assurance and quality control (QA/QC). Finally, this chapter also compares the results of all sites both diurnally and seasonally.

Chapter 3

This chapter describes the methodology of developing an emission inventory of pollutants at different grids of the city. The chapter also presents and compares the grid-wise results of emission inventory outputs for various pollutants. The contributions of various sources towards air pollution loads (pollutant-wise) are presented. The QA/QC approaches for emission inventory are also explained in this chapter.

Chapter 4

This chapter presents the methodology used for CMB 8.2 model of USEPA (2004) modeling for source apportionment study for PM_{10} and $PM_{2.5}$ in the summer and winter. The contribution of various sources at receptor sites and the overall scenario of sources that influences the air quality in the city is presented.

Chapter 5

This chapter presents the methodology used for dispersion modeling for source apportionment study for $PM_{2.5}$ in the summer and winter seasons. The pattern of $PM_{2.5}$ is described temporally and spatially at different receptor sites and the overall scenario of sources that influence the city's air quality is presented.

Chapter 6

This chapter describes, explores and analyzes emission control options and analysis for various sources based on the modeling results from Chapters 3, 4 and 5.

This chapter discusses alternatives for controlling the prominent sources in the city from the management, administrative and technology points of view.

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2 Air Quality: Measurements, Data Analyses and Inferences

2.1 Introduction

Air pollution continues to remain a public health concern despite various actions taken to control air pollution. There is a need to take stock of benefits that have accrued and ponder on 'Way Forward'. Further analysis of actions and future needs become even more important in view of the revised air quality standards that have been notified (http://www.cpcb.nic.in/National_Ambient_Air_Quality_ Standards.php (CPCB, 2009). The first step to accomplish future action is to assess the current air pollution status.

This chapter presents and discusses the current status of the air quality of Varanasi from the sampling and chemical analysis results for two seasons carried out under the present study.

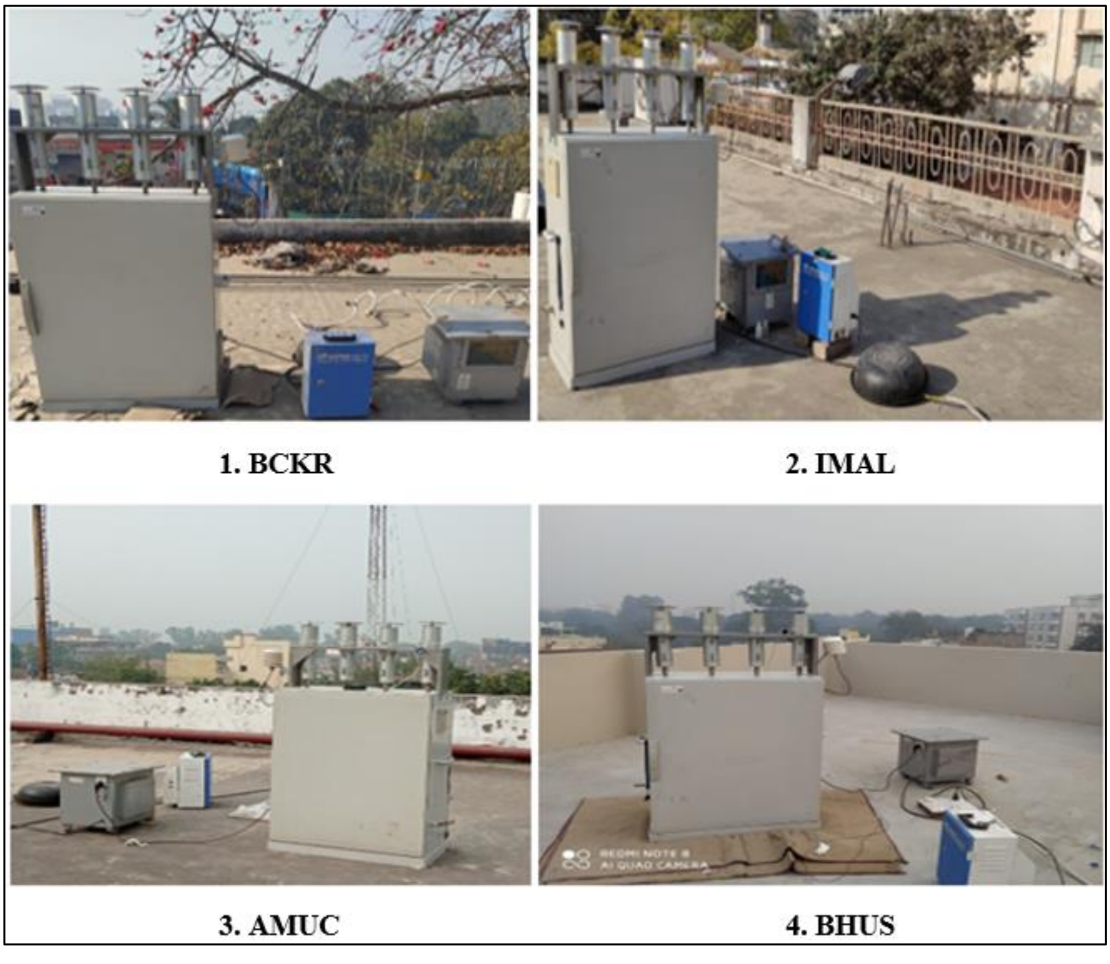
2.2 Methodology

2.2.1 Site selection and details

Total of four air quality sites have been selected to cover various land-use patterns prevailing in the city. It is ensured that at all sites, there was a free flow of air without any obstruction (e.g., buildings, trees etc.). In view of the safety of the stations, public buildings (institutions, office buildings, etc.) were selected. The sites were selected in consultation with UPPCB, Lucknow. Table 2.1 describes the sampling sites with prevailing land use and other features. Figure 2.1 shows the physical features (photographs) of the sampling sites. Figure 2.2 shows the locations of the sampling sites on the map and the overall land-use pattern of the city.

Table 2.1: Description of Sampling Sites of Varanasi

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	BENARES CLUB KACHERI ROAD	BCKR	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, Restaurants
2.	IMA LAHURABIR	IMAL	Commercial	DG sets, vehicle, road dust, garbage/waste burning, Restaurant
3.	AMAR UJALA CHANDPUR	AMUC	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning, Restaurant
4.	BHU SUSUVAHI	BHUS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, Restaurants



1. BCKR

2. IMAL

3. AMUC

4. BHUS

Figure 2.1: Photographs of Sampling Sites showing the physical features

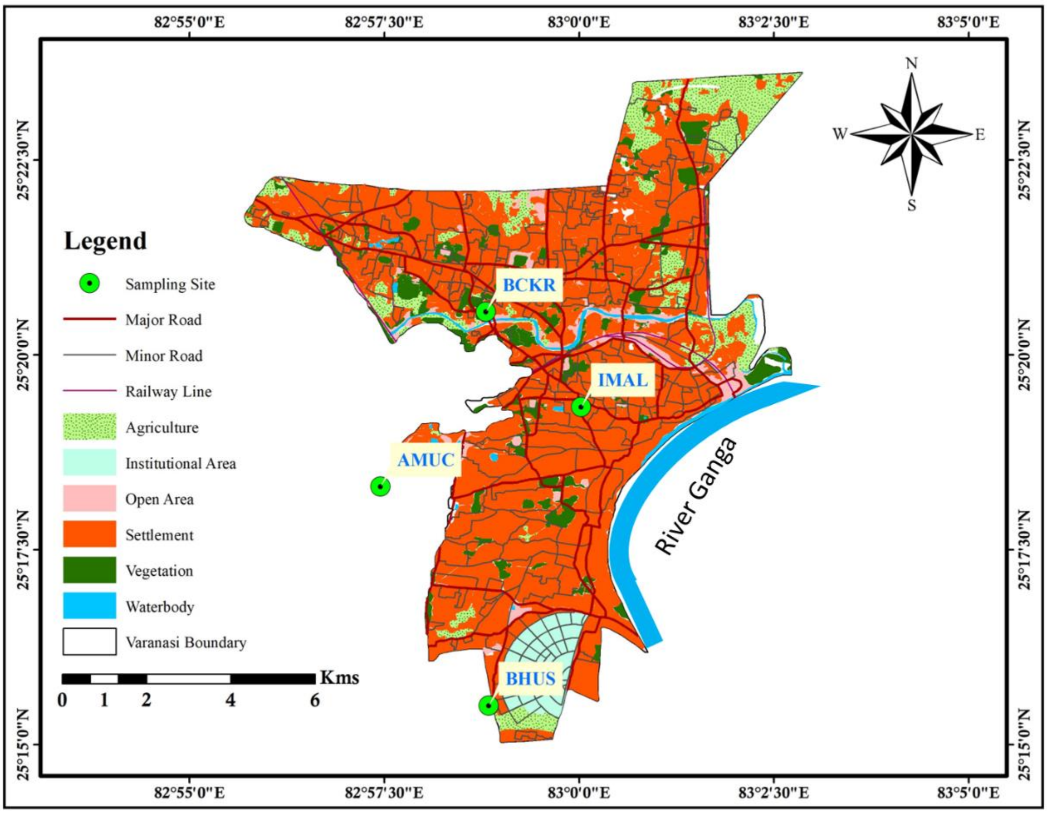

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Sampling Site
Major Road
Minor Road
Railway Line
Agriculture
Institutional Area
Open Area
Settlement
Vegetation
Waterbody
Varanasi Boundary
Kms
0 1 2 4 6
BCKR
IMAL
AMUC
BHUS
River Ganga

Figure 2.2: Land-use Pattern and Locations of Sampling Sites

The parameters for sampling and their monitoring methodologies, including the type of filter papers/chemicals and calibration protocols, are adopted from CPCB, Delhi (www.cpcb.nic.in). The entire monitoring programme is divided into two groups, i.e., (i) gaseous sampling and (ii) particulate matter (PM) sampling (PM_{10} and $PM_{2.5}$). Nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and volatile organic compounds (VOCs) are among the gaseous species. The monitoring parameters for this study along with sampling and analytical methods are presented in Table 2.2 and the chemical components (of PM) in Table 2.3.

Table 2.2: Details of Samplers/Analyzers and Methods

Sr. No.	Parameter	Sampler/Analyzing Instrument	Method
1.	PM_{10}	4-Channel Speciation Sampler (4-CSS)	Gravimetric
2.	$PM_{2.5}$	4-Channel Speciation Sampler (4-CSS)	Gravimetric
3.	SO_2	Bubbler/Spectrophotometer	West and Gaek
4.	NO_2	Bubbler/Spectrophotometer	Jacob &Hochheiser modified
5.	OC/EC	OC/EC Analyzer	Thermal Optical Reflectance
6.	Ions	Ion-Chromatograph	Ion-Chromatography
7.	Elements	ICP-MS	USEPA

8.	PAHs	GC-MS	Mass spectrophotometry
9.	VOCs	GC-MS with ATD	Mass spectrophotometry
10	Markers	GC-MS	Mass spectrophotometry

Table 2.3: **Target Chemical components for Characterization of PM**

Components	Required filter matrix	Analytical methods
$PM_{10}/PM_{2.5}$	Teflon filter paper.	Gravimetric
Elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba and Pb)	Teflon filter paper	ICP-MS
Ions (F^-, Cl^-, NO_3^-, SO_4^{2-}, K^+, NH_4^+, Na^+, Mg^{2+}, and Ca^{2+})	Teflon filter paper	Ion-chromatography
Carbon Analysis (OC, EC and Total Carbon)	Quartz filter (Prebaked at 600ºC)	TOR/TOT method

2.2.2 Instruments and Accessories

The 4-channel speciation samplers (Umwelttechnik MCZ GmbH, Germany) (with mass flow controller) are used in this study for monitoring particulate matter (Figure 2.3(a)). A flow rate is 16.7 LPM for PM_{10} and $PM_{2.5}$ is used in the sampler. Three channels of the sampler are utilized: First channel for PM_{10}, second channel for $PM_{2.5}$ (Teflon filters -Whatman grade PTFE filters of 47 mm diameter) and third for collection of $PM_{2.5}$ on quartz fiber filter (Whatman grade QM-A quartz filters of 47 mm Diameter). PTFE filters are used for the analysis of ions and elements and quartz filters are used for OC-EC and PAHs. The quartz filter papers, before sampling, were baked at 550 °C for 12 h to drive out any residual organics.

Ecotech AAS 118 (Ecotech, India; flow rate of 1.0 LPM) sampler was used for gaseous pollutants (SO_2 and NO_2) and a low flow pump (Pocket pump 210 series; SKC Inc, USA) was used for sampling of VOCs (flow rate – 50 ml/min).

PM_{10} and $PM_{2.5}$ concentrations are determined gravimetrically by weighing the PTFE filters before and after the sampling using a digital microbalance (Metler-Toledo MX-5, USA; sensitivity of 1µg; Figure 2.3(b)) in USEPA standard weighing and filter conditioning laboratory. The collected samples were stored in the refrigerator at 4 °C until further analyses. As per USEPA guidelines (USEPA, 1999a), before initial and final (after the sampling) weighing, Teflon filter papers were conditioned in a desiccator for 24 h in humidity (40 ± 5%) and temperature (20 ± 2 °C) controlled room.

Water-soluble ions are extracted from the Teflon filters in ultra-pure Milli-Q water following the reference method (USEPA, 1999a). Ions analysis of extracted sampled is carried out using Ion Chromatography (Merohm 882 compact IC, Switzerland; Figure 2.3(e)). Ion recovery efficiencies were determined by spiking the known quantity of ion mass and reproducibility tests were performed by replicate analysis. Recovery was found between 90% and 106%, which was within ±10% for all species analyzed.

In addition to conventional pollutants and parameters, this study has analyzed the fraction of organic carbon (OC) and elemental carbon (EC) by thermal optical transmittance (DRI Model 2001A Thermal/Optical Carbon Analyzer; Figure 2.3(c)). The explanation of fractions of EC and OC is given in below:

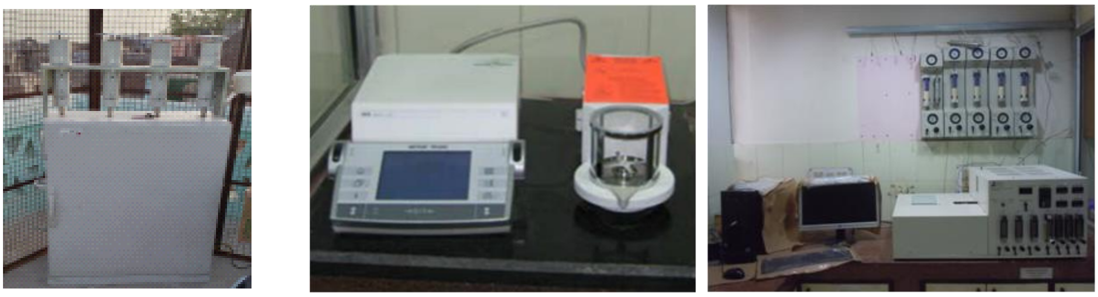
- OC1: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from ambient (~25 °C) to 140 °C.
- OC2: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 140 to 280 °C.
- OC3: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 280 to 480 °C.
- OC4: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 480 to 580 °C.
- EC1: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere at 580 °C.
- EC2: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere from 580 to 740 °C.
- EC3: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere from 740 to 840 °C.
- OP: The carbon evolved from the time that the carrier gas flow is changed from He to 98% He/2% O_2 at 580 °C to the time that the laser-measured filter reflectance (OPR) or transmittance (OPT) reaches its initial value. A negative sign is assigned if the laser split occurs before the introduction of O_2.
- OC: OC1 + OC2 + OC3 + OC4 +OP

- EC: EC1 +EC2 + EC3
- Total Carbon (TC): OC1 + OC2 + OC3 + OC4 + EC1 +EC2 + EC3; All carbon evolved from the filter punch between ambient and 840°C under He and 98% He /2% O_2 atmospheres.

For elemental analysis, PTFE filters were digested in hydrochloric/nitric acid solution using the microwave digestion system (Anton-Paar, Austria) as per the USEPA method (USEPA, 1999b). The digested samples were filtered and diluted to 25 mL with deionized (ultra-pure) water. The digested samples for elements were analyzed using ICP-MS (Thermo fisher Scientific Inc, USA; Figure 2.3(f)) (USEPA, 1999c).

PAHs were extracted in hexane and dichloromethane (DCM) solvent (1:1v/v) followed by passing it through silica cartridge (Rajput et al., 2011, USEPA, 1999d). The extracted samples were concentrated using the rotary evaporator (up to 10 mL) and Turbo Vap (Work Station-II, Caliper Life Sciences, Hopkinton, USA) for a final volume of 1 mL. Extracted samples were analyzed for PAHs using the Gas chromatography-Mass spectrophotometer (Model Clarus 600 S, Perkin Elmer, USA; Figure 2.3(d)). The pyrene-d_{10} standard was used as an internal standard.

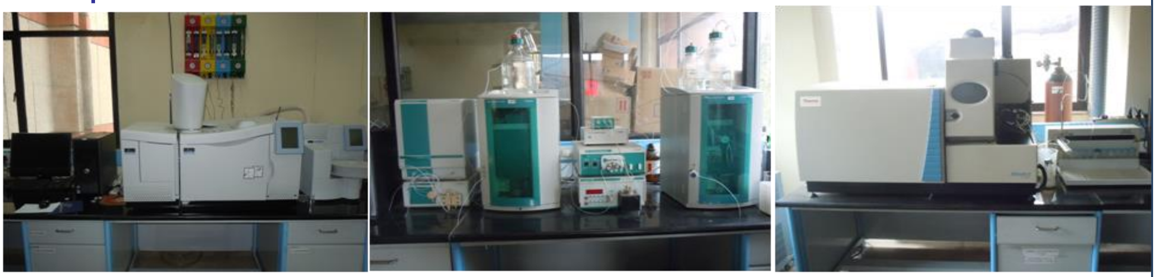
To analyze the molecular markers, QMA filters were used. In view of small quantity of molecular markers on filters, filter papers of seven days were combined and extracted. Extractions were carried out in DCM and acetone (1:1) solution in soxhlet apparatus followed by concentration of extract using a rotary evaporator and nitrogen purging on turbovap; the extract volume was reduced to 2 ml. The samples were analyzed for alkanes and hopanes on GCMS ((Zhang et al., 2009).



(a) 4-Channel Speciation Sampler

(b) Microbalance

(c) OC/EC Analyzer



(d) GC-MS with ATD

(e) Ion Chromatography

(f) ICP-MS

Figure 2.3: Instruments for Sampling and Characterization

2.3 Quality Assurance and Quality Control (QA/QC)

Quality assurance and quality control (QA/QC) in entire project planning and its implementation at all levels were designed and the hands-on training was imparted to the project team before the beginning of any sampling and analysis. During sampling and analysis, a coding system has been adopted to eliminate any confusion. Separate codes for seasons, site locations, parameters, time slots are adopted.

For SO_2, and NO_2, analyses were done regularly just after the sampling following the standard operating procedures (SOPs) in the laboratory at Kanpur. All other measurements and analyses were carried out at the laboratories of IIT Kanpur after completion of sampling. The calibrations for all samplers were done at regular intervals at the time of sampling. The calibrations of overall analyses were established by cross-checking with known concentrations of the pollutants. The major features of QA/QC are briefly described here.

- SOPs for entire project planning and implementation were developed, peer-reviewed by other experts and project personnel have been trained in the field and in the laboratory. Whenever necessary, the SOPs were adjusted to meet the field challenges.
- SOPs include type of equipment (with specifications), sampling and calibration methods with their frequency.
- SOPs for chemical analysis includes a description of methods, standards to be used,

laboratory and field blanks, internal and external standards, development of the database, screening of data, record-keeping including backups, traceability of calculations and standards.

There are dedicated computers for instruments and data storage with passwords. It ensures that computers do not get infected. These computers are not hooked to Internet connections.

Sampling periods: The ambient air sampling has been completed for 15 days at each site for winter (December 14, 2020 – January 14, 2021) and summer (March 05, 2021 - April 06, 2021). The analysis of SO_2 and NO_2 are carried out daily on a regular basis, while gravimetric analysis for particulate matters is done after the completion of the sampling at IIT Kanpur. All efforts were made for the 100% achievement of the sampling and analysis. The overall sampling was achieved over 95% of the time. Efforts were made to sample on extra days to cover the missing days of sampling. The details of sampling days for all pollutants at all monitoring sites are presented in Table 2.4 to Table 2.11 for the winter and summer seasons, respectively.

Table 2.4: Sampling days of various pollutants in winter (2020) at BCKR

BCKR-Benaras Club Kacheri Road, Varanasi (Winter)															
	14-Dec-20	15-Dec-20	16-Dec-20	17-Dec-20	18-Dec-20	19-Dec-20	20-Dec-20	21-Dec-20	22-Dec-20	23-Dec-20	24-Dec-20	25-Dec-20	26-Dec-20	27-Dec-20	28-Dec-20
PM_{10}	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫
$PM_{2.5}$	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
OC	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
EC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
VOC				🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		
NO_2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SO_2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

Table 2.5: Sampling days of various pollutants in winter (2020) at IMAL

IMAL-IMA Lahurabir, Varanasi (Winter)															
	14-Dec-20	15-Dec-20	16-Dec-20	17-Dec-20	18-Dec-20	19-Dec-20	20-Dec-20	21-Dec-20	22-Dec-20	23-Dec-20	24-Dec-20	25-Dec-20	26-Dec-20	27-Dec-20	28-Dec-20
PM_{10}	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫	🟫
$PM_{2.5}$	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
OC	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
EC	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
VOC			🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪			
NO_2	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SO_2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦

Table 2.6: Sampling days of various pollutants in winter (2020-21) at AMUC

AMUC-Amar Ujala Chandpur, Varanasi (Winter)															
	31-Dec-20	01-Jan-21	02-Jan-21	03-Jan-21	04-Jan-21	05-Jan-21	06-Jan-21	07-Jan-21	08-Jan-21	09-Jan-21	10-Jan-21	11-Jan-21	12-Jan-21	13-Jan-21	14-Jan-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC			■	■	■	■	■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.7: Sampling days of various pollutants in winter (2020-21) at BHUS

BHUS-BHU Susuvahi, Varanasi (Winter)															
	31-Dec-20	01-Jan-21	02-Jan-21	03-Jan-21	04-Jan-21	05-Jan-21	06-Jan-21	07-Jan-21	08-Jan-21	09-Jan-21	10-Jan-21	11-Jan-21	12-Jan-21	13-Jan-21	14-Jan-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC				■	■	■	■	■	■	■	■	■			
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.8: Sampling days of various pollutants in summer (2021) at BCKR

BCKR-Benaras Club Kacheri Road, Varanasi (Summer)															
	05-Mar-21	06-Mar-21	07-Mar-21	08-Mar-21	09-Mar-21	10-Mar-21	11-Mar-21	12-Mar-21	13-Mar-21	14-Mar-21	15-Mar-21	16-Mar-21	17-Mar-21	18-Mar-21	19-Mar-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC					■	■	■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

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Table 2.9: Sampling days of various pollutants in summer (2021) at IMAL

IMAL-IMA Lahurabir, Varanasi (Summer)															
	05-Mar-21	06-Mar-21	07-Mar-21	08-Mar-21	09-Mar-21	10-Mar-21	11-Mar-21	12-Mar-21	13-Mar-21	14-Mar-21	15-Mar-21	16-Mar-21	17-Mar-21	18-Mar-21	19-Mar-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC					■	■	■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.10: Sampling days of various pollutants in summer (2021) at AMUC

AMUC-Amar Ujala Chandpur, Varanasi (Summer)															
	23-Mar-21	24-Mar-21	25-Mar-21	26-Mar-21	27-Mar-21	28-Mar-21	29-Mar-21	30-Mar-21	31-Mar-21	01-Apr-21	02-Apr-21	03-Apr-21	04-Apr-21	05-Apr-21	06-Apr-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC					■	■	■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.11: Sampling days of various pollutants in summer (2021) at BHUS

BHUS-BHU Susuvahi, Varanasi (Summer)															
	23-Mar-21	24-Mar-21	25-Mar-21	26-Mar-21	27-Mar-21	28-Mar-21	29-Mar-21	30-Mar-21	31-Mar-21	01-Apr-21	02-Apr-21	03-Apr-21	04-Apr-21	05-Apr-21	06-Apr-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC					■	■	■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

2.4 Ambient Air Quality - Results

2.4.1 Benaras Club Kacheri Road (BCKR)

The sampling period was December 14 – 28, 2020 for winter and March 05 – 19, 2021 for summer.

2.4.1.1 Particulate Matter (PM_{10}, $PM_{2.5}$)

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ at BCKR are shown for winter (Figure 2.4) and summer (Figure 2.5). Average levels at this site were: $PM_{2.5}$: 281±86 (winter) and 121±24 μg/m^3 (summer) and PM_{10}: 401±105 (winter) and 314±112 μg/m^3 (summer). In winter, the $PM_{2.5}$ levels were 4.6 times higher than the national air quality standard (NAQS: 60 μg/m^3) and PM_{10} levels were 4 times higher than the NAQS (100 μg/m^3). In summer, the $PM_{2.5}$ levels slightly exceed by 2 times the standards, while PM_{10} is 3.1 times higher than the NAQS.

A statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of PM concentrations is presented in Table 2.16 to Table 2.19 for the winter and summer season. In summer, $PM_{2.5}$ levels drop significantly compared to PM_{10} levels that continued to be high in spite of improvement in meteorology and better dispersion. The particle airborne from the soil during dust storms in the dry months of summer can contribute significantly to a coarse fraction (i.e., $PM_{2.5-10}$).

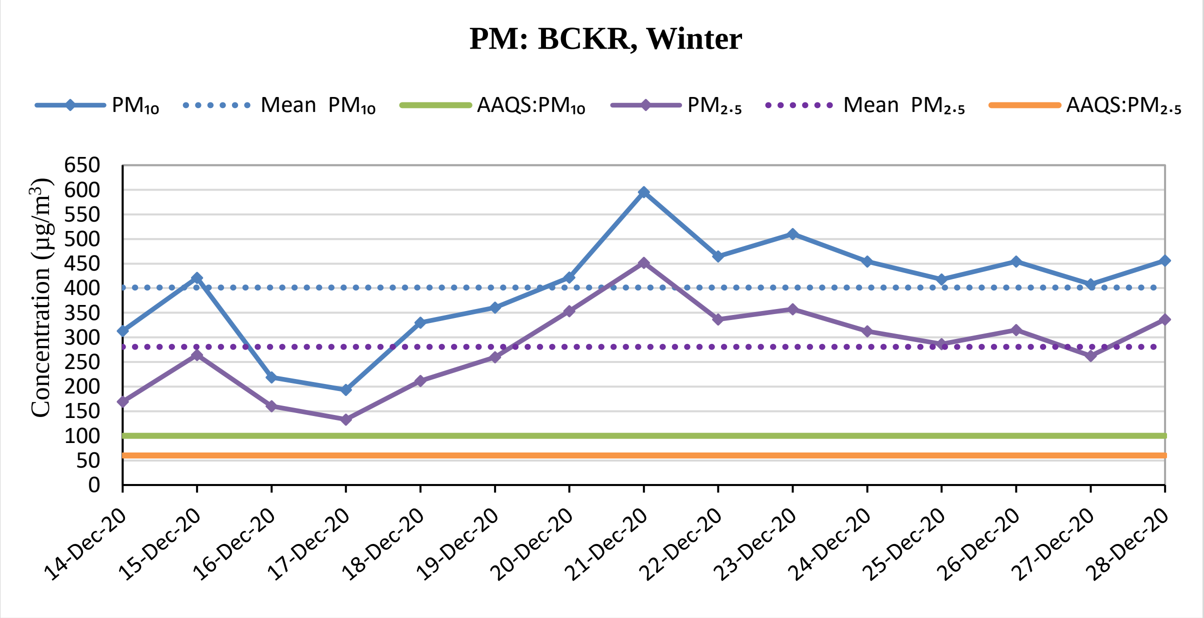


Figure 2.4: PM Concentrations at BCKR for Winter Season

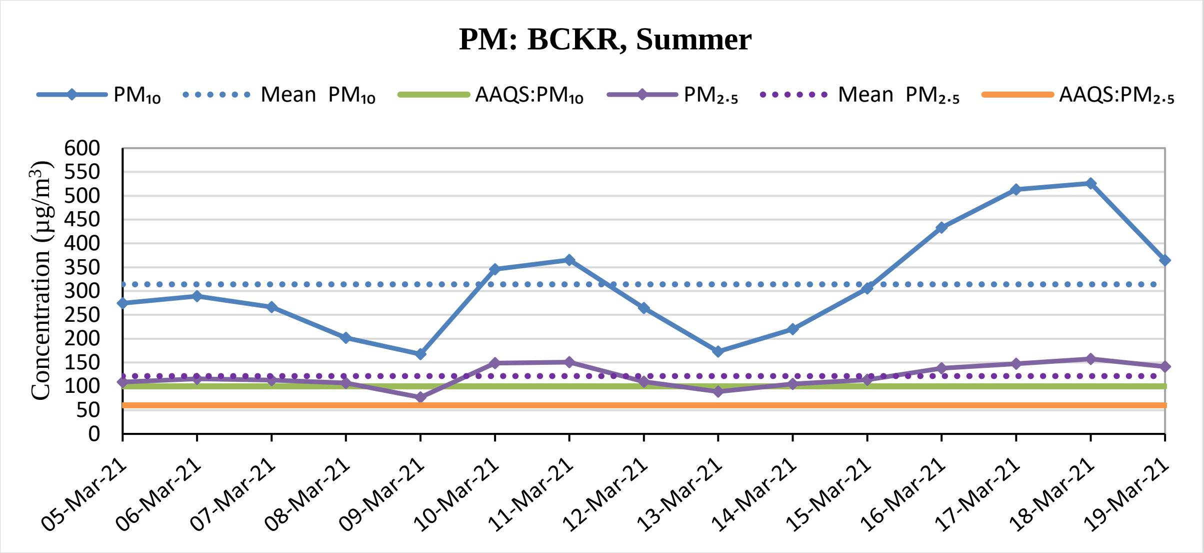


Figure 2.5: PM Concentrations at BCKR for Summer Season

2.4.1.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.6) and summer (Figure 2.7) seasons. It was observed that SO_2 concentrations were low (mostly < 5.0 µg/m^3) and met the air quality standard. NO_2 levels also meet the national standard (80 µg/m^3) with an average of 15 days at 40.17±4.79 µg/m^3 in winter and 24.03±6.22 µg/m^3 in summer season. The summer concentration of NO_2 dropped dramatically, as does the $PM_{2.5}$ levels. Although NO_2 levels are meeting the standard, it is a matter of concern as NO_2 is largely attributed to vehicular pollution, which is on the rise. Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams or local open burning, etc.

The Mean concentrations of benzene, toluene, p-xylene and o-xylene (BTX) are presented in Figure 2.8 and the statistical summary in Table 2.12. The total BTX level is observed 19.47±5.32 µg/m^3 (Benzene: 10.47 and Toluene: 2.81 µg/m^3) in winter and 16.44±4.46 µg/m^3 (Benzene: 8.44 and Toluene: 1.70 µg/m^3) in summer seasons. The BTX levels were higher during winter than in the summer.

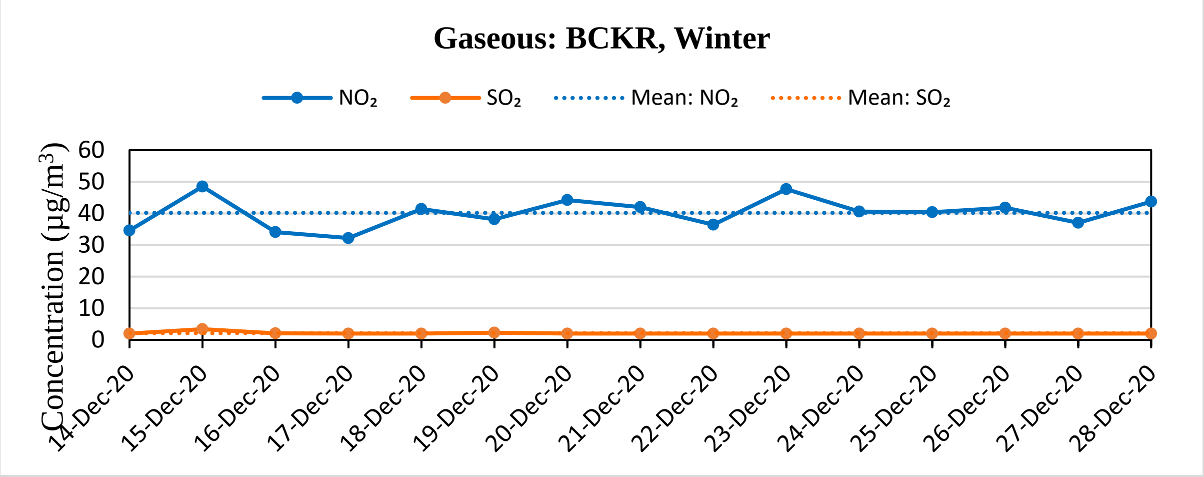


Figure 2.6: SO_2 and NO_2 Concentrations at BCKR for Winter Season

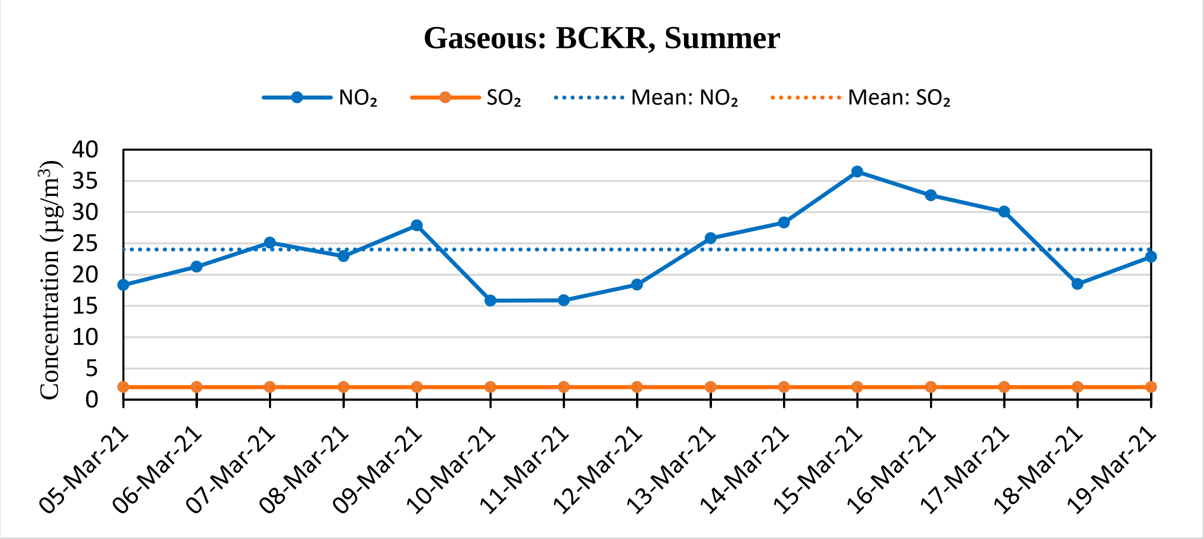


Figure 2.7: SO_2 and NO_2 Concentrations at BCKR for Summer Season

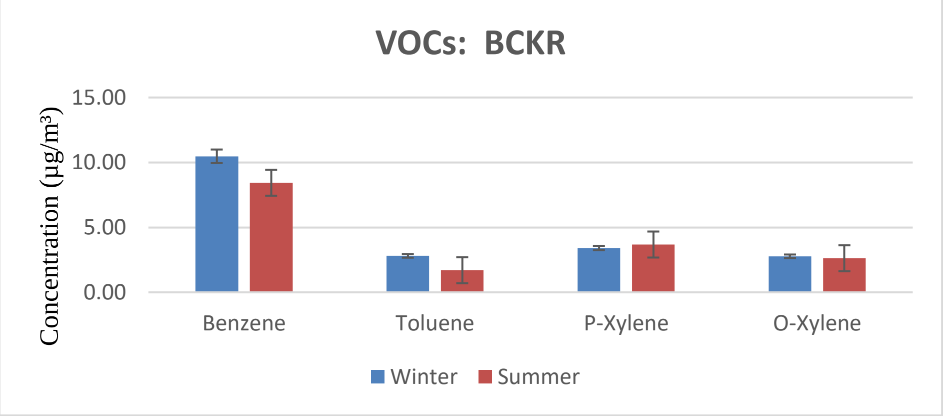


Figure 2.8: VOCs concentration at BCKR

2.4.1.3 Carbon Content (EC/OC) in PM$_{2.5}$

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and the ratio of OC fraction to TC are shown in Figure 2.9(a) and (b) for winter and summer seasons. Organic carbon is observed slightly higher (winter: 44.11±13.95 and summer: 9.86±4.16 μg/m^3) than the elemental carbon (winter: 25.52±8.20 and summer: 8.20±3.37 μg/m^3). It is also observed that the OC and EC are higher in the winter than in the summer. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.13 for winter and summer. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at BCKR.

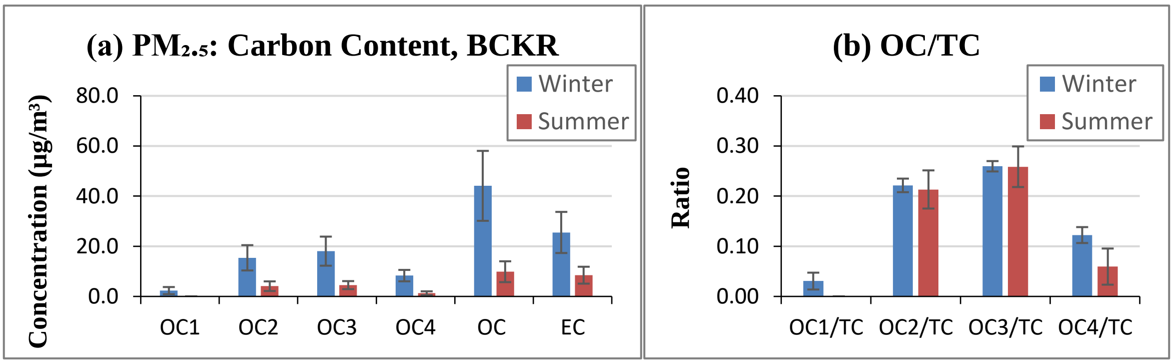


Figure 2.9: EC and OC Content in PM$_{2.5}$ at BCKR

TC typically present in an urban environment (i.e., 20–45% of PM$_{2.5}$) (Dinoi et al., 2017), and the results match as TC in PM$_{2.5}$ in winter is about 25% in winter and 15% in summer. It also suggests fresh nearby combustion and burning.

2.4.1.4 PAHs in PM$_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.10 shows the average measured concentration of PAHs at BCKR for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.14 for winter and summer seasons. The PAHs compounds analyzed were: (i) Di methyl Phthalate (DmP), (ii) Acenaphthylene (AcP), (iii) Di ethyl Phthalate (DEP), (iv) Fluorene (Flu), (v) Phenanthrene (Phe), (vi) Anthracene (Ant), (vii) Pyrene (Pyr), (viii) Butyl benzyl phthalate (BbP), (ix) Bis(2-ethylhexyl) adipate (BeA), (x) Benzo(a)anthracene (B(a)A), (xi) Chrysene (Chr), (xii) Benzo(b)fluoranthene (B(b)F), (xiii) Benzo(k)fluoranthene (B(k)F), (xiv) Benzo(a)pyrene (B(a)P), (xv) Indeno(1,2,3-cd)pyrene (InP), (xvi) Dibenzo(a,h)anthracene (D(a,h)A) and (xvii)

Benzo(ghi)perylene (B(ghi)P). It is observed that Total PAHs concentrations are higher in winter season (100±46 ng/m^3) compared to summer season (19±3 ng/m^3). Major PAHs (mostly higher molecular weight compounds) are B(ghi)P (10 ng/m^3), B(b)F (20 ng/m^3), Chr (8 ng/m^3) and DmP (13 ng/m^3) for winter season and B(ghi)P (2 ng/m^3), B(b)F (3 ng/m^3) and Phe (3 ng/m^3) for summer season.

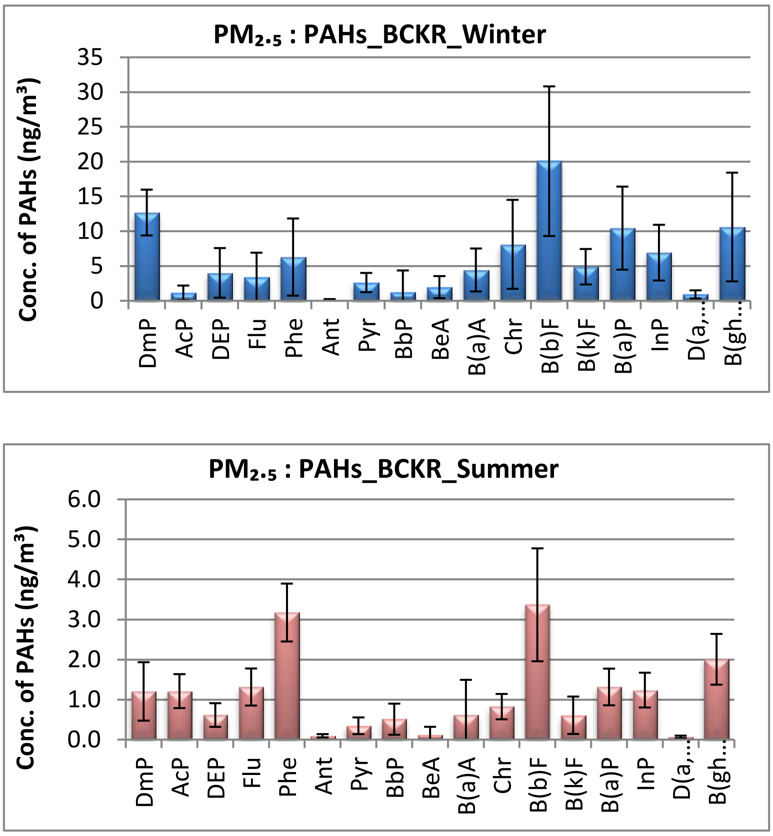


Figure 2.10: PAHs Concentrations in PM$_{2.5}$ at BCKR

2.4.1.5 Molecular Markers in PM$_{2.5}$

Total six molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21 α(H)_hopane, 17α(H),21β(H)-hopane, Pentriacontane, Hentriacontane and Tritriacontane. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D).

Figure 2.11 and Table 2.15 show the levels of six molecular markers. Total concentration of markers was 262.6±163.7 ng/m^3 in winter and 151.6±18.5 ng/m^3 in summer. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

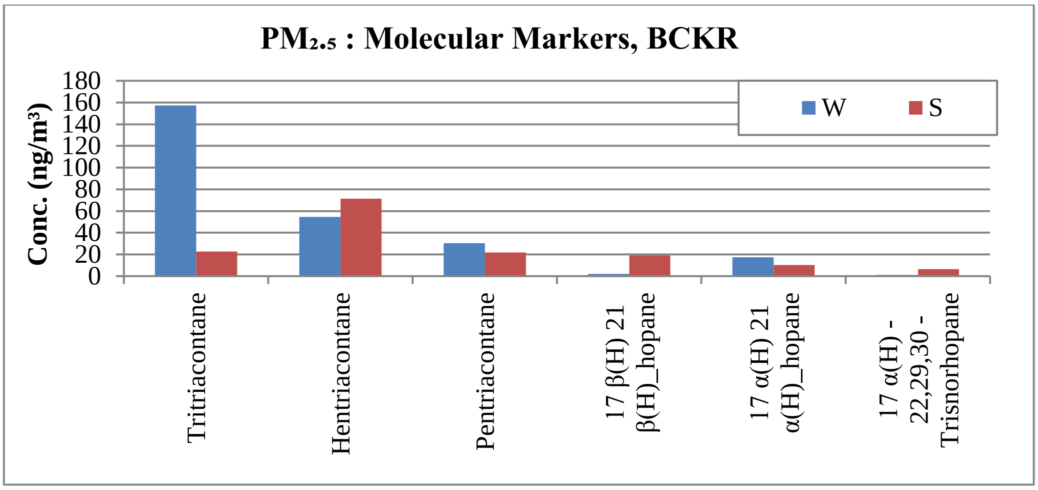


Figure 2.11: Molecular Markers in $PM_{2.5}$ at BCKR

2.4.1.6 Chemical Composition of PM_{10} and $PM_{2.5}$ and their correlation

Graphical presentations of chemical species are shown for the winter and summer seasons for PM_{10} (Figure 2.12) and $PM_{2.5}$ (Figure 2.13). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content (EC and OC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb)] along with mass percentage (% R) recovered from PM are presented in Table 2.16 to Table 2.19 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.20 to Table 2.23 for both seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituents of the PM are presented in Figure 2.14 (a) and (b) for the winter season and Figure 2.15 (a) and (b) for the summer season.

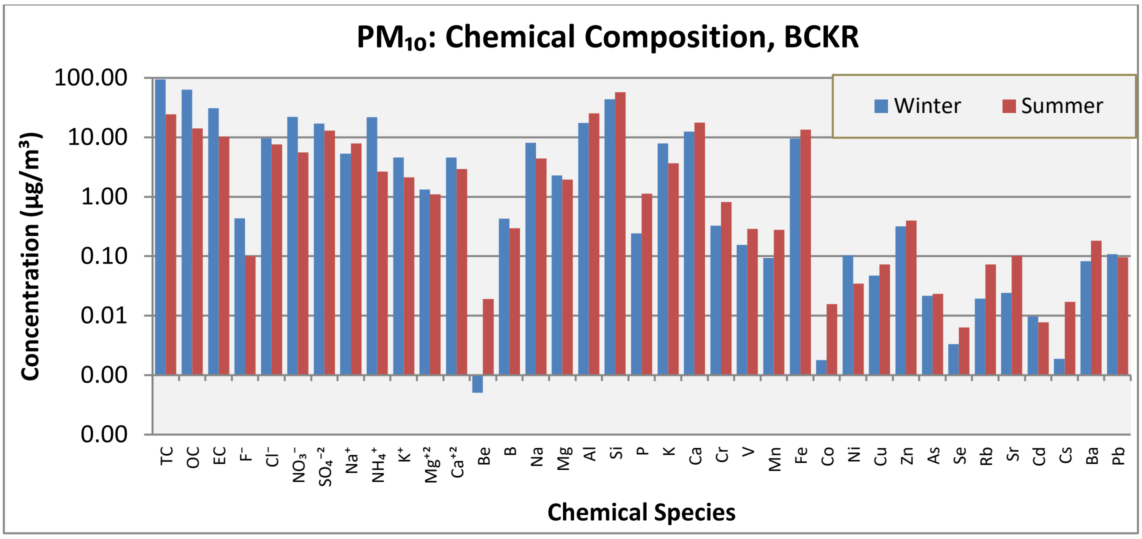


Figure 2.12: Concentrations of species in PM_{10} at BCKR

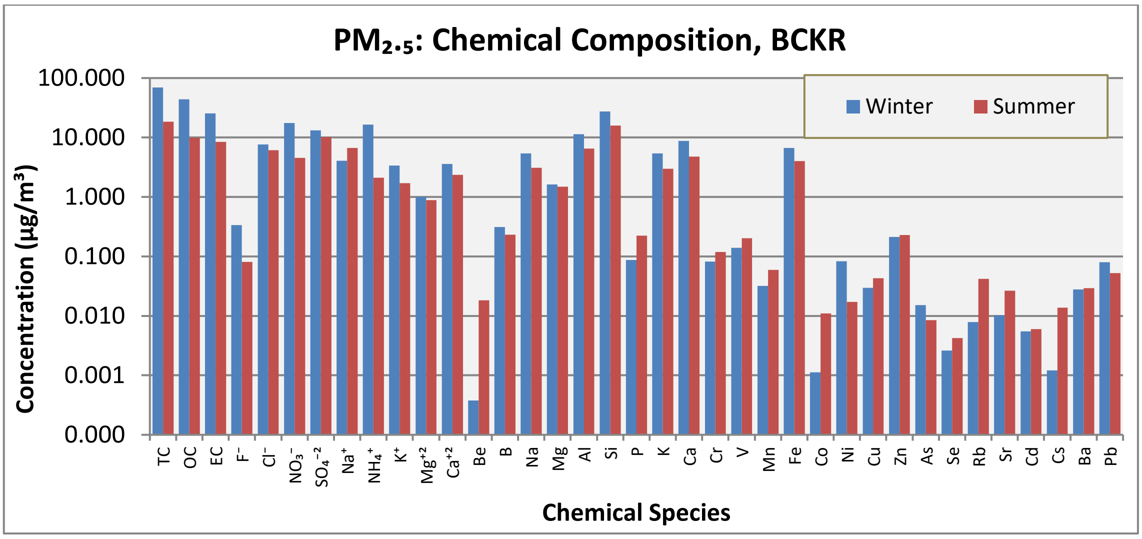
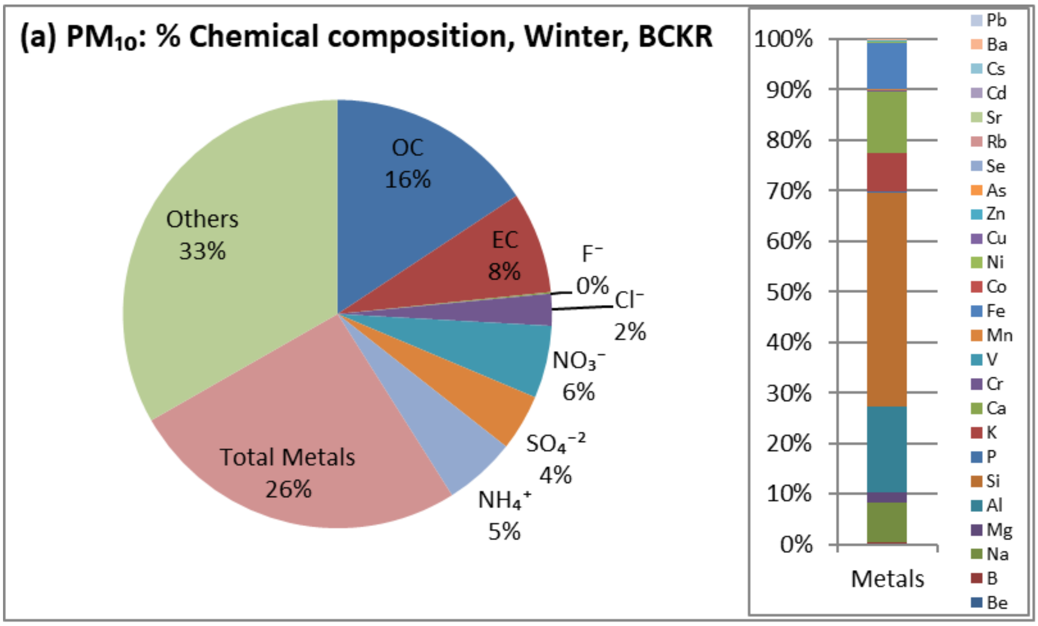


Figure 2.13: Concentrations of species in $PM_{2.5}$ at BCKR



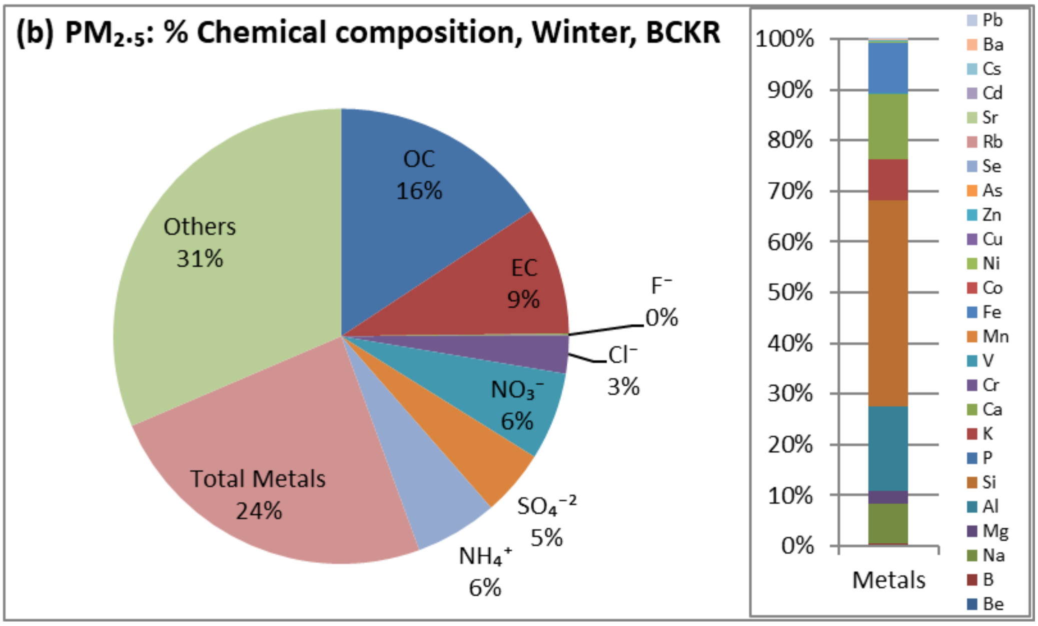


Figure 2.14: Percentage distribution of species in PM at BCKR for Winter Season

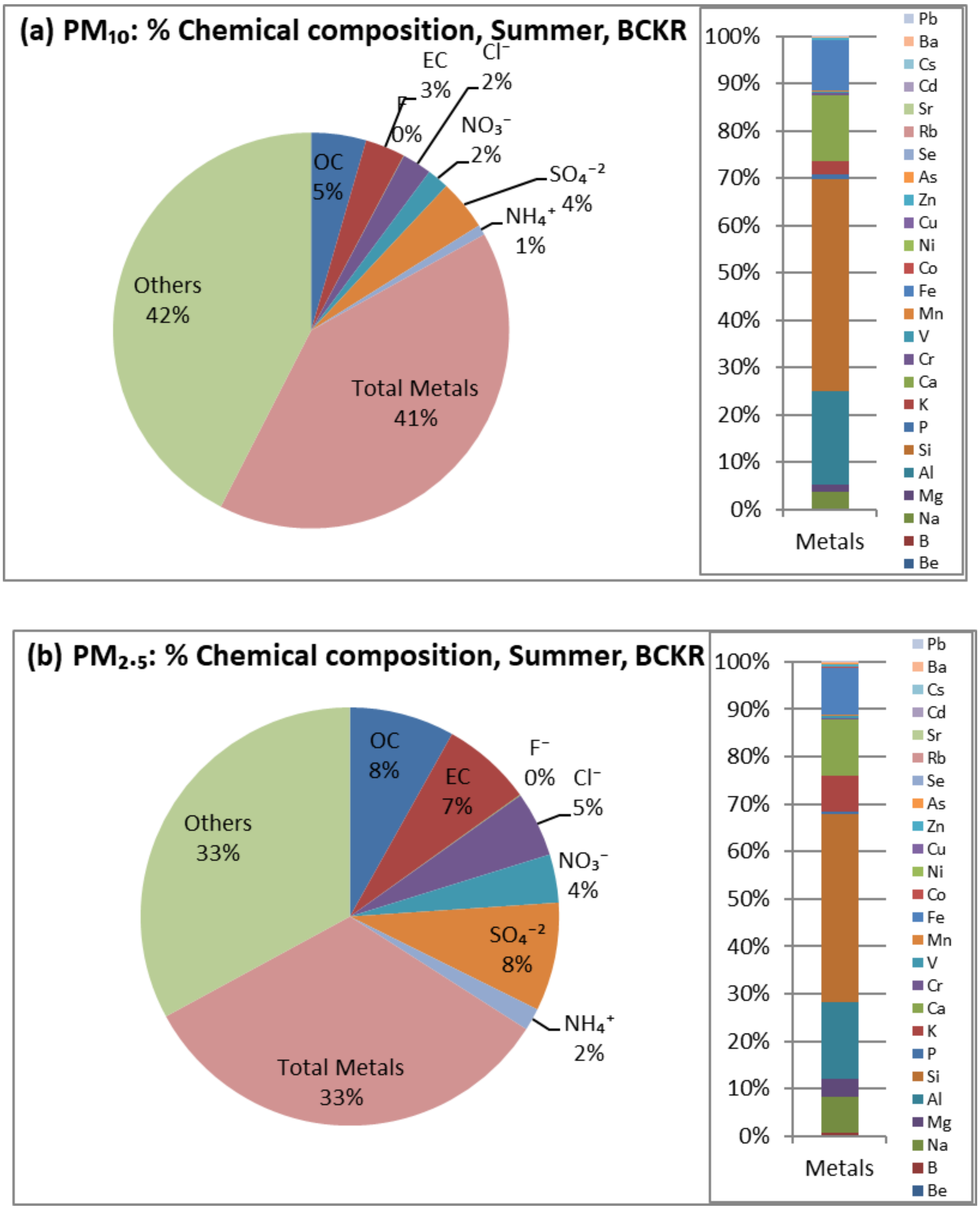


Figure 2.15: Percentage distribution of species in PM at BCKR for Summer Season

2.4.1.7 Comparison of PM_{10} and $PM_{2.5}$ Composition

This section presents some important observations from the experimental findings related to fine particles and PM_{10} concentrations. The graphical presentation is a better option for understanding the compositional variation. A compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.16) at BCKR.

The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (57%) than summer (30%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, K^+, B, V, Co, Zn, Cd and Pb; whereas, major species contributing in coarse mode are F^-, Mg^{2+}, Ca^{2+}, Na, Mg, Al, Si, P, Ca, Cr, Mn, Fe, Rb, Sr and Ba.

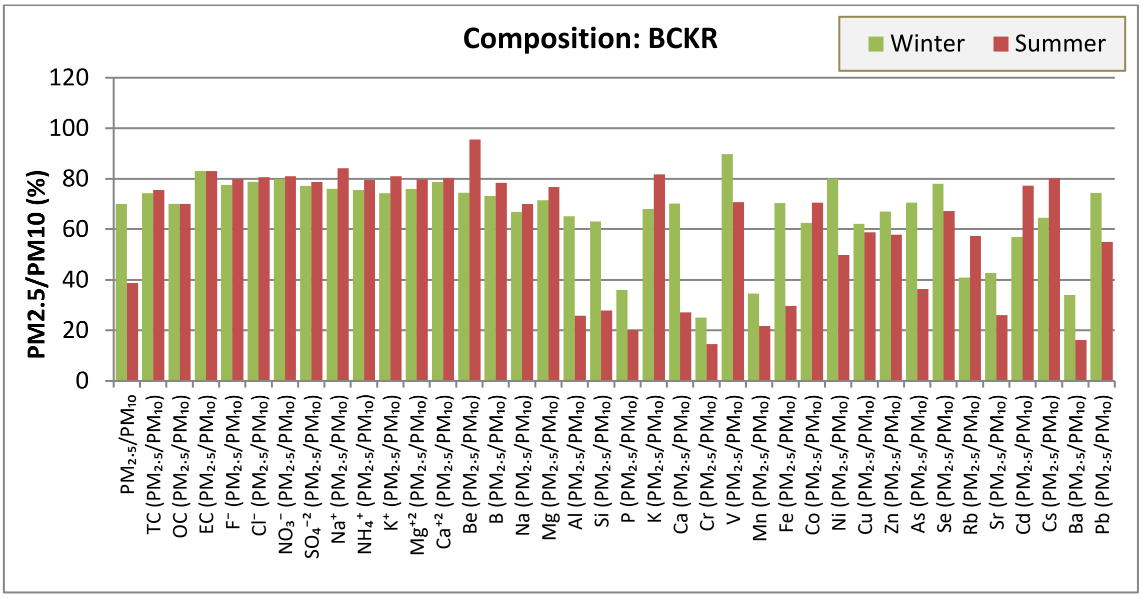


Figure 2.16: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at BCKR

Table 2.12: Statistical results of gaseous pollutants (µg/m^3) at BCKR for winter (W) and summer (S) seasons

BCKR(W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	40.17	2.11	2.09	0.42	0.85	1.39	4.76
SD	4.79	0.36	0.32	0.16	0.46	1.04	1.66
Max	48.49	3.40	2.70	0.66	1.82	3.95	8.50
Min	32.19	2.00	1.72	0.15	0.31	0.61	2.86
CV	0.12	0.17	0.15	0.37	0.54	0.75	0.35
BCKR (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.03	2.00	8.44	6.78	22.09	24.20	61.52
SD	6.22	0.00	1.05	4.10	10.93	14.27	29.24
Max	36.45	2.00	9.33	15.25	45.17	53.10	121.33
Min	15.83	2.00	7.10	3.37	11.92	12.07	34.46
CV	0.26	0.00	0.12	0.60	0.49	0.59	0.48

Table 2.13: Statistical results of carbon contents (µg/m^3) in PM$_{2.5}$ at BCKR for Winter (W) and summer (S) seasons

BCKR(W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	280.76	69.63	25.52	44.11	2.33	15.41	18.07	8.31	0.03	0.22	0.26	0.12
SD	85.85	22.09	8.20	13.95	1.43	5.04	5.80	2.27	0.02	0.01	0.01	0.02
Max	452.00	114.67	41.89	72.78	4.26	25.65	30.02	13.55	0.06	0.25	0.29	0.15
Min	133.00	31.10	11.11	19.98	0.21	6.88	8.21	4.66	0.00	0.20	0.25	0.10
CV	0.31	0.32	0.32	0.32	0.61	0.33	0.32	0.27	0.55	0.06	0.04	0.13
BCKR(S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	121.44	18.34	8.48	9.86	0.00	4.09	4.51	1.26	0.00	0.21	0.26	0.06
SD	24.23	7.39	3.37	4.16	0.00	1.93	1.60	0.78	0.00	0.04	0.04	0.04
Max	157.00	26.32	12.80	15.09	0.00	6.47	6.55	2.07	0.00	0.26	0.34	0.10
Min	77.00	3.06	1.66	1.40	0.00	0.38	1.01	0.00	0.00	0.13	0.22	0.00
CV	0.20	0.40	0.40	0.42	0.00	0.47	0.36	0.62	0.00	0.18	0.16	0.61

Table 2.14: **Statistical results of PAHs (ng/m^3) in PM$_{2.5}$ at BCKR for winter (W) and summer (S) seasons**

BCKR(W)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	12.69	1.14	4.02	3.38	6.29	0.15	2.62	1.25	1.96	4.43	8.11	20.06	4.90	10.44	6.92	0.92	10.60	99.88
SD	3.29	1.06	3.56	3.53	5.54	0.09	1.38	3.11	1.59	3.09	6.39	10.76	2.55	5.97	4.00	0.59	7.81	46.36
Max	18.42	3.48	11.71	11.13	18.36	0.31	4.23	8.30	4.63	9.17	18.33	35.91	8.42	19.31	13.01	2.01	25.60	154.95
Min	7.57	0.47	1.60	0.95	2.51	0.08	0.84	0.05	0.49	0.90	0.58	6.70	1.63	2.76	2.13	0.28	2.88	42.18
CV	0.26	0.93	0.89	1.04	0.88	0.58	0.53	2.49	0.81	0.70	0.79	0.54	0.52	0.57	0.58	0.64	0.74	0.46
BCKR(S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.20	1.21	0.61	1.31	3.17	0.10	0.35	0.51	0.12	0.61	0.82	3.37	0.61	1.32	1.24	0.07	2.01	18.63
SD	0.73	0.42	0.30	0.46	0.72	0.04	0.21	0.39	0.20	0.88	0.32	1.41	0.47	0.46	0.43	0.03	0.63	2.76
Max	1.88	1.82	1.16	1.95	4.21	0.18	0.76	1.38	0.42	2.61	1.25	5.89	1.63	1.87	1.79	0.11	2.78	23.02
Min	0.11	0.55	0.40	0.71	2.36	0.04	0.10	0.27	0.00	0.23	0.38	1.37	0.21	0.53	0.44	0.02	0.85	15.24
CV	0.61	0.35	0.48	0.35	0.23	0.45	0.60	0.76	1.65	1.43	0.38	0.42	0.77	0.35	0.35	0.46	0.32	0.15

Table 2.15: Statistical results of molecular markers (ng/m^3) in PM$_{2.5}$ at BCKR for winter (W) and summer (S) seasons

MNS(W)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	157.41	54.60	30.32	2.01	17.25	1.04	262.64
SD	171.64	8.98	2.63	0.58	5.34	0.53	163.71
CV	1.09	0.16	0.09	0.29	0.31	0.50	0.62

MNS(S)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	22.69	71.36	21.66	19.07	10.29	6.55	151.61
SD	4.10	12.99	4.52	5.18	3.43	5.88	18.51
CV	0.18	0.18	0.21	0.27	0.33	0.90	0.12

Table 2.16: Statistical results of chemical characterization (μg/m^3) of PM$_{10}$ at BCKR for winter (W) season

BCKR(W)	PM$_{10}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	401	63.0	30.8	0.4	9.7	22.0	17.1	5.3	21.8	4.6	1.3	4.5	5E-4	0.43	8.08	2.27	17.46	43.50	0.24
SD	105	19.9	9.9	0.1	4.3	11.6	5.0	2.2	8.8	1.5	0.4	1.5	1E-4	0.18	7.60	0.76	4.85	12.77	0.08
Max	595	104.0	50.5	0.7	19.2	56.0	24.5	10.1	33.2	6.7	2.1	6.8	7E-4	0.77	22.38	3.23	24.89	65.95	0.44
Min	193	28.5	13.4	0.3	2.9	10.8	9.5	2.3	5.3	1.9	0.7	2.1	4E-4	0.12	2.14	1.32	8.32	20.04	0.13
CV	0.26	0.32	0.32	0.28	0.45	0.53	0.29	0.42	0.40	0.32	0.34	0.33	0.21	0.41	0.94	0.33	0.28	0.29	0.33
BCKR(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	7.91	12.44	0.33	0.16	0.09	9.49	0.00	0.10	0.05	0.32	0.02	0.00	0.02	0.02	0.01	0.00	0.08	0.11	66.8
SD	3.00	3.62	0.09	0.02	0.03	2.79	0.00	0.03	0.02	0.07	0.00	0.00	0.01	0.01	0.01	0.00	0.03	0.02	3.1
Max	12.91	17.14	0.53	0.19	0.15	14.06	0.00	0.18	0.07	0.47	0.03	0.01	0.03	0.04	0.02	0.00	0.12	0.14	73.2
Min	3.03	6.00	0.17	0.13	0.05	4.15	0.00	0.07	0.02	0.17	0.01	0.00	0.01	0.01	0.00	0.00	0.04	0.07	61.4
CV	0.38	0.29	0.29	0.12	0.29	0.29	0.26	0.27	0.33	0.23	0.21	0.33	0.30	0.32	0.54	0.16	0.31	0.21	0.05

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.17: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at BCKR for winter (W) season

BCKR(W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	281	44.1	25.5	0.3	7.6	17.5	13.2	4.0	16.5	3.4	1.0	3.6	4E-4	0.31	5.40	1.62	11.38	27.43	0.09
SD	86	13.9	8.2	0.1	3.4	9.9	4.1	1.7	6.6	1.0	0.4	1.1	8E-5	0.14	6.05	0.60	4.25	11.37	0.05
Max	452	72.8	41.9	0.5	14.8	48.5	20.4	7.3	23.9	5.2	1.6	5.2	6E-4	0.57	21.52	2.70	20.07	44.11	0.16
Min	133	20.0	11.1	0.2	2.5	8.8	7.1	1.8	4.0	1.5	0.5	1.7	3E-4	0.11	1.37	0.84	5.00	11.53	0.00
CV	0.31	0.32	0.32	0.26	0.44	0.57	0.31	0.41	0.40	0.31	0.35	0.32	2E-1	0.44	1.12	0.37	0.37	0.41	0.54
BCKR(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.38	8.73	0.08	0.14	0.03	6.67	0.00	0.08	0.03	0.21	0.015	0.003	0.008	0.010	0.006	0.001	0.028	0.08	68.9
SD	1.66	3.49	0.04	0.02	0.02	3.03	0.00	0.02	0.01	0.06	0.005	0.001	0.003	0.004	0.002	0.000	0.017	0.03	4.2
Max	7.91	16.13	0.16	0.17	0.09	13.26	0.00	0.12	0.06	0.34	0.021	0.004	0.012	0.018	0.009	0.001	0.079	0.14	80.0
Min	2.23	3.01	0.03	0.11	0.01	2.43	0.00	0.04	0.01	0.12	0.003	0.001	0.003	0.007	0.003	0.001	0.009	0.05	64.0
CV	0.31	0.40	0.44	0.13	0.53	0.45	0.62	0.30	0.46	0.27	0.32	0.30	0.33	0.36	0.33	0.12	0.60	0.34	0.06

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.18: Statistical results chemical characterization (µg/m^3) of PM_{10} at BCKR for summer (S) season

BCKR(S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	314	14.1	10.2	0.1	7.6	5.6	12.9	7.9	2.6	2.1	1.1	2.9	2E-2	0.30	4.42	1.94	25.18	57.24	1.13
SD	112	5.9	4.1	0.1	2.8	2.0	2.9	3.9	1.4	0.6	0.4	1.1	1E-3	0.14	2.58	0.67	10.46	24.70	1.01
Max	526	21.6	15.4	0.4	11.6	9.6	19.2	15.6	5.0	3.2	1.9	5.2	2E-2	0.62	11.51	3.39	42.91	104.32	4.60
Min	167	2.0	2.0	0.1	2.8	2.2	6.5	2.2	0.5	1.0	0.6	1.3	2E-2	0.15	1.46	1.14	11.33	28.66	0.36
CV	0.36	0.42	0.40	0.86	0.36	0.37	0.22	0.49	0.52	0.27	0.36	0.38	0.06	0.46	0.58	0.35	0.42	0.43	0.90
BCKR(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.65	17.70	0.82	0.29	0.28	13.52	2E-2	3E-2	7E-2	0.40	0.02	6E-3	7E-2	1E-1	8E-3	2E-2	0.18	0.10	58.28
SD	0.99	8.01	0.36	0.07	0.15	6.54	3E-3	1E-2	2E-2	0.14	0.01	2E-3	3E-2	6E-2	3E-3	6E-3	0.08	0.03	3.36
Max	5.36	33.18	1.52	0.38	0.59	26.90	2E-2	6E-2	1E-1	0.68	0.04	1E-2	1E-1	2E-1	1E-2	4E-2	0.37	0.13	65.46
Min	1.57	8.32	0.39	0.18	0.12	6.70	1E-2	2E-2	4E-2	0.17	0.01	7E-4	4E-2	4E-2	3E-3	1E-2	0.08	0.04	54.24
CV	0.27	0.45	0.44	0.23	0.54	0.48	0.18	0.36	0.24	0.35	0.35	0.37	0.37	0.63	0.36	0.35	0.45	0.30	0.06

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.19: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at BCKR for summer (S) season

BCKR(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	121	9.9	8.5	0.1	6.1	4.5	10.2	6.6	2.1	1.7	0.9	2.3	2E-2	0.23	3.09	1.48	6.50	15.90	0.22
SD	24	4.2	3.4	0.1	2.5	1.7	2.7	3.4	1.1	0.5	0.4	0.9	1E-3	0.15	1.54	0.57	2.16	5.02	0.07
Max	157	15.1	12.8	0.4	10.5	8.4	16.1	12.7	4.3	2.6	1.7	4.4	2E-2	0.49	5.70	2.50	9.42	22.89	0.39
Min	77	1.4	1.7	0.0	2.1	1.7	5.7	1.6	0.4	0.8	0.4	1.0	2E-2	0.00	1.25	0.63	3.16	8.87	0.13
CV	0.20	0.42	0.40	1.00	0.40	0.37	0.26	0.51	0.54	0.29	0.43	0.40	0.08	0.63	0.50	0.39	0.33	0.32	0.32
BCKR(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.99	4.79	0.12	0.20	0.06	4.02	1E-2	2E-2	4E-2	0.23	9E-3	4E-3	4E-2	3E-2	6E-3	1E-2	3E-2	0.05	67.37
SD	0.68	1.41	0.04	0.03	0.02	1.27	7E-4	2E-3	1E-2	0.09	4E-3	2E-3	2E-2	9E-3	2E-3	5E-3	1E-2	0.02	3.84
Max	3.86	6.96	0.18	0.25	0.09	5.67	1E-2	2E-2	7E-2	0.37	2E-2	7E-3	1E-1	4E-2	9E-3	3E-2	5E-2	0.07	73.35
Min	1.40	2.65	0.05	0.16	0.03	2.39	1E-2	1E-2	3E-2	0.10	4E-3	2E-4	3E-2	2E-2	3E-3	1E-2	1E-2	0.02	62.04
CV	0.23	0.29	0.35	0.13	0.31	0.32	0.07	0.14	0.29	0.38	0.42	0.41	0.50	0.33	0.33	0.36	0.38	0.28	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.20: Correlation matrix for PM_{10} and its composition at BCKR for winter season

BCKR(W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.97	0.96	0.97	0.61	0.57	0.36	0.72	0.35	0.69	0.86	0.64	0.41	0.94
TC		1.00	1.00	1.00	0.71	0.56	0.24	0.68	0.40	0.71	0.86	0.67	0.44	0.86
OC			1.00	0.99	0.71	0.55	0.22	0.66	0.40	0.71	0.85	0.66	0.44	0.86
EC				1.00	0.70	0.57	0.28	0.70	0.39	0.72	0.87	0.67	0.44	0.87
NO_3^-					0.16	0.52	1.00	0.67	0.11	0.36	0.37	0.13	-0.10	0.25
SO_4^{-2}					0.51	0.67		1.00	0.49	0.64	0.82	0.57	0.25	0.56
NH_4^+					0.45	0.44			0.25	1.00	0.72	0.51	0.48	0.50
Metals					0.47	0.41			0.29		0.72	0.56	0.38	1.00

Table 2.21: Correlation matrix for $PM_{2.5}$ and its composition at BCKR for winter season

BCKR(W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.97	0.97	0.96	0.59	0.47	0.25	0.68	0.30	0.74	0.85	0.52	0.39	0.95
TC		1.00	1.00	1.00	0.69	0.58	0.21	0.67	0.41	0.73	0.87	0.60	0.49	0.88
OC			1.00	0.99	0.70	0.58	0.19	0.65	0.41	0.73	0.86	0.60	0.50	0.88
EC				1.00	0.68	0.58	0.25	0.69	0.42	0.74	0.89	0.59	0.48	0.87
NO_3^-					0.09	0.40	1.00	0.70	0.24	0.33	0.42	0.02	-0.17	0.06
SO_4^{-2}					0.53	0.65		1.00	0.52	0.63	0.82	0.46	0.16	0.48
NH_4^+					0.32	0.47			0.26	1.00	0.83	0.61	0.53	0.63
Metals					0.47	0.25			0.15		0.68	0.39	0.32	1.00

Table 2.22: Correlation matrix for PM_{10} and its composition at BCKR for summer season

BCKR (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.60	0.64	0.51	0.15	0.20	0.03	0.32	0.19	-0.43	0.84	0.65	0.95	0.99
TC		1.00	0.99	0.97	0.01	0.31	0.37	0.34	0.02	-0.12	0.61	0.37	0.61	0.51
OC			1.00	0.93	0.02	0.34	0.36	0.25	0.05	-0.24	0.63	0.41	0.65	0.56
EC				1.00	-0.02	0.24	0.37	0.45	-0.02	0.05	0.57	0.30	0.53	0.42
NO_3^-					0.57	0.45	1.00	0.14	0.13	-0.09	0.43	0.39	0.13	-0.02
SO_4^{-2}					0.13	0.25		1.00	0.30	0.45	0.48	0.37	0.33	0.26
NH_4^+					-0.52	-0.33			-0.28	1.00	-0.22	-0.55	-0.42	-0.46
Metals					0.15	0.16			0.18		0.81	0.63	0.94	1.00

Table 2.23: Correlation matrix for $PM_{2.5}$ and its composition at BCKR for summer season

BCKR(S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.63	0.63	0.61	0.02	0.17	-0.05	0.43	0.18	-0.10	0.80	0.55	0.84	0.88
TC		1.00	0.99	0.98	0.00	0.21	0.28	0.15	0.01	-0.06	0.59	0.32	0.59	0.27
OC			1.00	0.93	0.02	0.25	0.27	0.04	0.03	-0.19	0.59	0.35	0.64	0.29
EC				1.00	-0.02	0.16	0.27	0.28	-0.02	0.11	0.56	0.26	0.51	0.23
NO_3^-					0.67	0.40	1.00	0.22	0.22	-0.13	0.40	0.39	0.04	-0.39
SO_4^{-2}					0.21	0.30		1.00	0.32	0.58	0.49	0.34	0.20	0.26
NH_4^+					-0.48	-0.20			-0.26	1.00	-0.17	-0.50	-0.39	-0.15
Metals					-0.13	-0.09			0.04		0.56	0.38	0.71	1.00

2.4.2 IMA Lahurabir (IMAL)

The sampling period was December 14 – 28, 2020 for winter and March 05 – 19, 2021 for summer.

2.4.2.1 Particulate Matter (PM_{10}, $PM_{2.5}$)

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown at IMAL for winter (Figure 2.17) and summer (Figure 2.18). Average levels for winter and summer season were 285±107 and 118±25 $\mu g/m^3$ (for $PM_{2.5}$) and 380±124 and 275±88 $\mu g/m^3$ (for PM_{10}) respectively. The $PM_{2.5}$ levels are 4.7 times higher than the NAQS and PM_{10} is 3.8 times higher than the NAQS in winter. The $PM_{2.5}$ levels are 1.9 times higher and PM_{10} levels are 2.7 times higher than the NAQS in summer. A statistical summary of PM concentrations is presented in Table 2.28 to Table 2.31 for the winter and summer seasons. In summer, $PM_{2.5}$ levels drop significantly compared to PM_{10} levels that continued to be high despite improvement in meteorology and better dispersion. The particle airborne from the soil during dust storms in the dry months of summer can contribute significantly to a coarse fraction (i.e., $PM_{2.5-10}$).

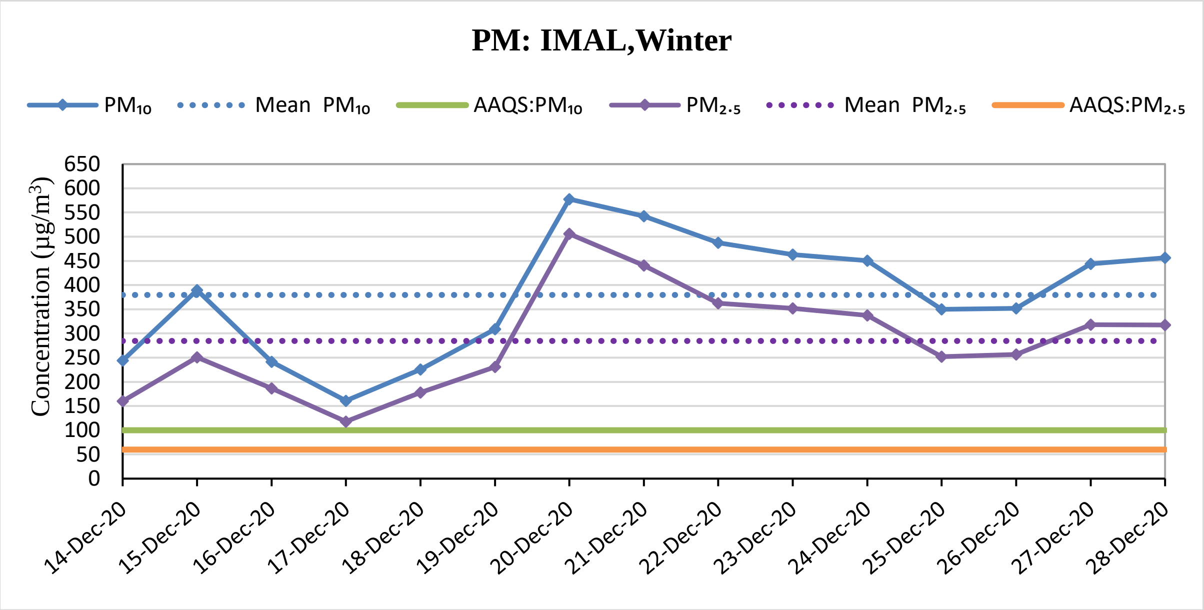


Figure 2.17: PM Concentrations at IMAL for Winter Season

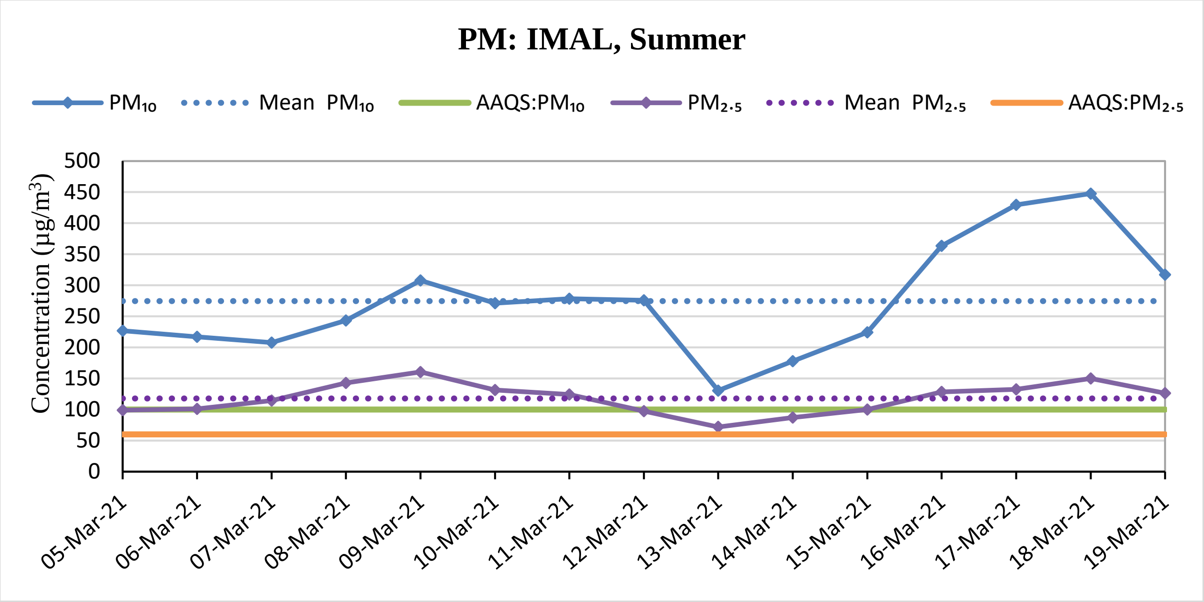


Figure 2.18: PM Concentrations at IMAL for Summer Season

2.4.2.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.19) and summer (Figure 2.20) seasons. It was observed that SO_2 concentrations were low (mostly < 5.0 µg/m^3) and met the air quality standard. NO_2 levels are also under the NAQS with an average of 15 days at 35.5±6.09 µg/m^3 in winter and 20.11±7.07 µg/m^3 in summer season (Table 2.24). The summer concentration of NO_2 dropped dramatically similarly $PM_{2.5}$ levels. Although the NO_2 is certainly a matter of concern in the winter season and these values can largely be attributed to vehicular pollution and DG sets. The Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams or local open and coal-burning etc.

The Mean concentrations of BTX were presented in Figure 2.21 and the statistical summary in Table 2.24. The total BTX level is observed 17.06±8.99 µg/m^3 (Benzene: 8.99 and Toluene: 2.87 µg/m^3) in winter and 8.76±1.19 µg/m^3 (Benzene: 3.87 and Toluene: 0.96 µg/m^3) in summer seasons. The BTX levels were high during winter than in the summer.

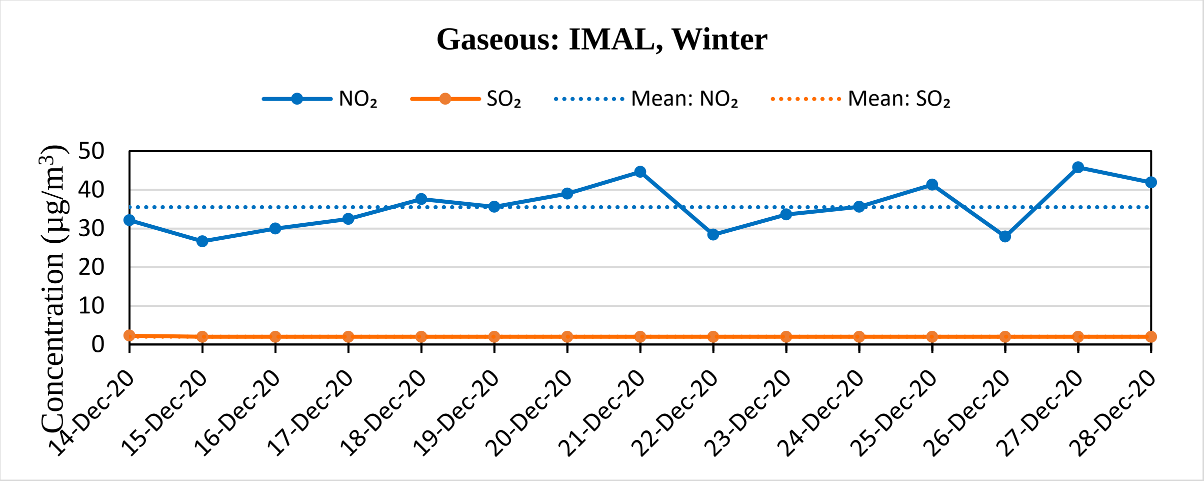


Figure 2.19: SO_2 and NO_2 Concentrations at IMAL for Winter Season

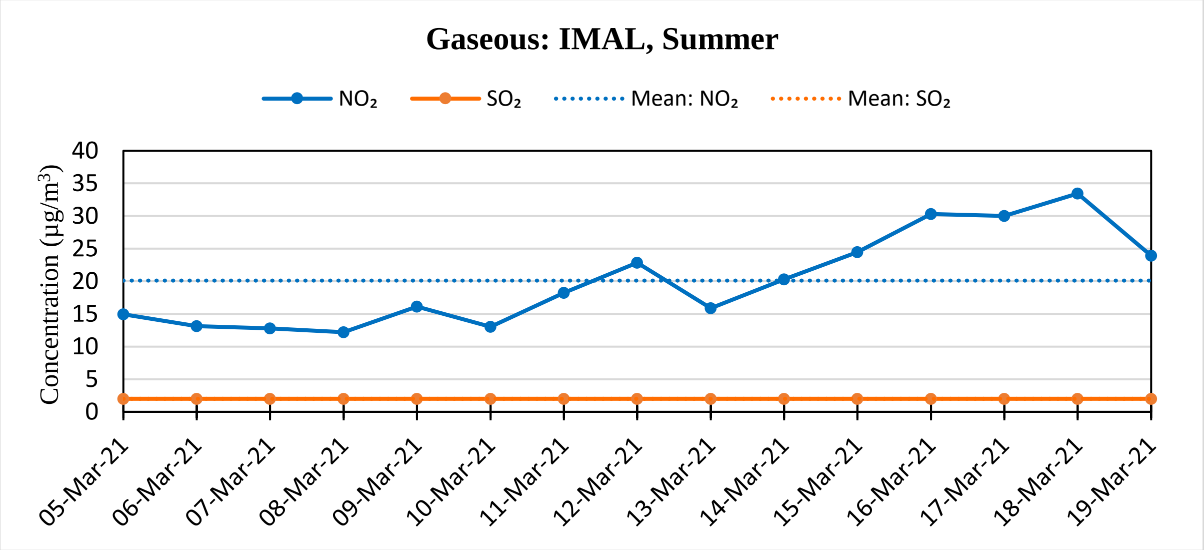


Figure 2.20: SO_2 and NO_2 Concentrations at IMAL for Summer Season

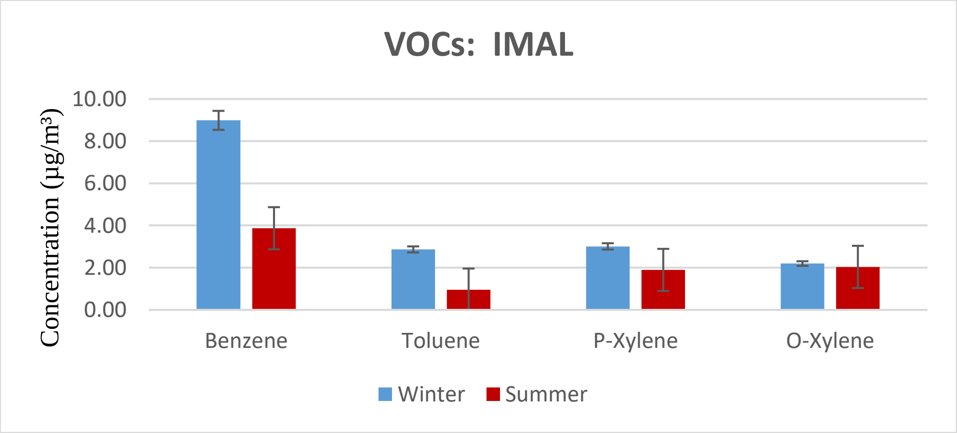


Figure 2.21: VOCs concentration at IMAL

2.4.2.3 Carbon Content (EC/OC) in $PM_{2.5}$

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and the ratio of OC fraction to TC are shown in Figure 2.22 (a) and (b) for winter and summer seasons. OC is observed higher (winter: 48.89±18.17 and summer: 19.06±2.87 μg/m^3) than the EC (winter: 32.83±13.75 and summer: 16.58±3.90 μg/m^3). It is also observed that the OC and EC are much higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.25 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at IMAL.

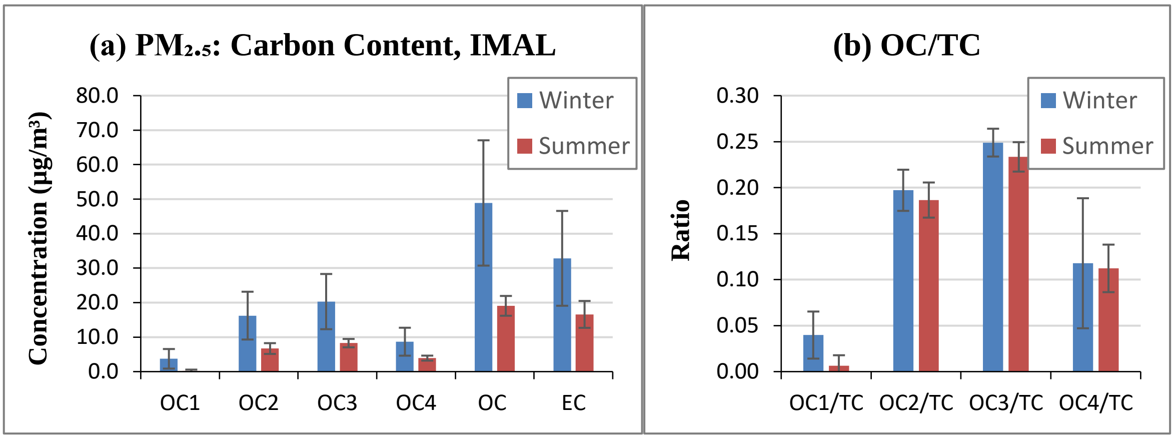


Figure 2.22: EC and OC Content in $PM_{2.5}$ at IMAL

2.4.2.4 PAHs in $PM_{2.5}$

Figure 2.23 shows the average measured concentration of PAHs at IMAL for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.26 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are higher in winter season (66±98 ng/m^3) compared to summer season (17±4 ng/m^3). Major PAHs are B(b)F (9.6 ng/m^3), Chr (8.3 ng/m^3), B(a)P (7.9 ng/m^3), B(ghi)P (7.6 ng/m^3) and DmP (6.8 ng/m^3) for winter season and DmP (10.7 ng/m^3) and B(b)F (1 ng/m^3) for summer season.

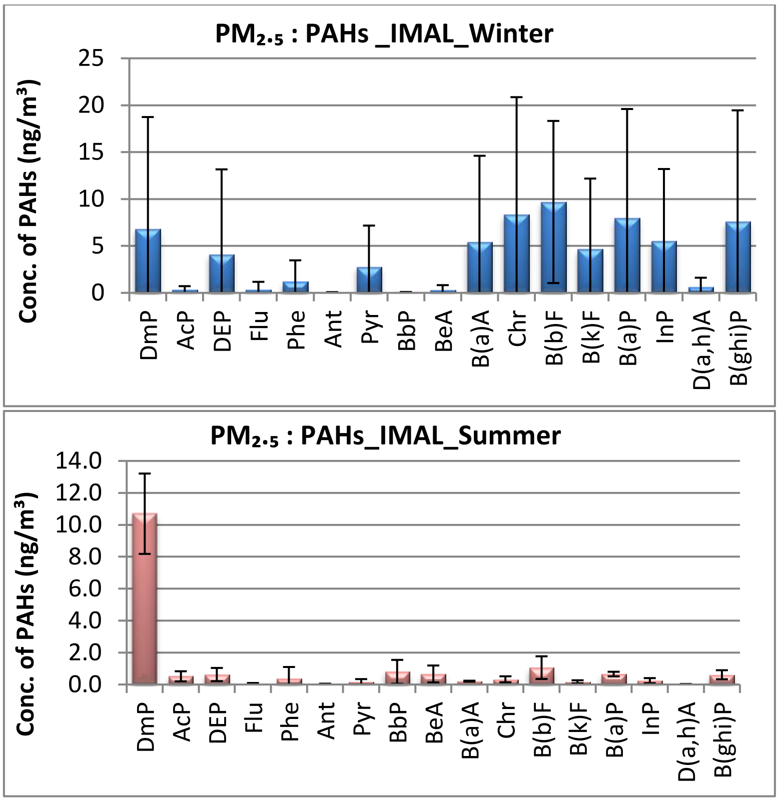


Figure 2.23: PAHs Concentrations in $PM_{2.5}$ at IMAL

2.4.2.5 Molecular Markers in $PM_{2.5}$

Total six molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21 α(H)_hopane, 17α(H),21β(H)-hopane, Pentriacontane, Hentriacontane and Tritriacontane. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D).

Figure 2.24 and Table 2.27 show the levels of six molecular markers. Total concentration of markers was 140.1±40 ng/m^3 in winter and 131.6±18.1 ng/m^3 in summer. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

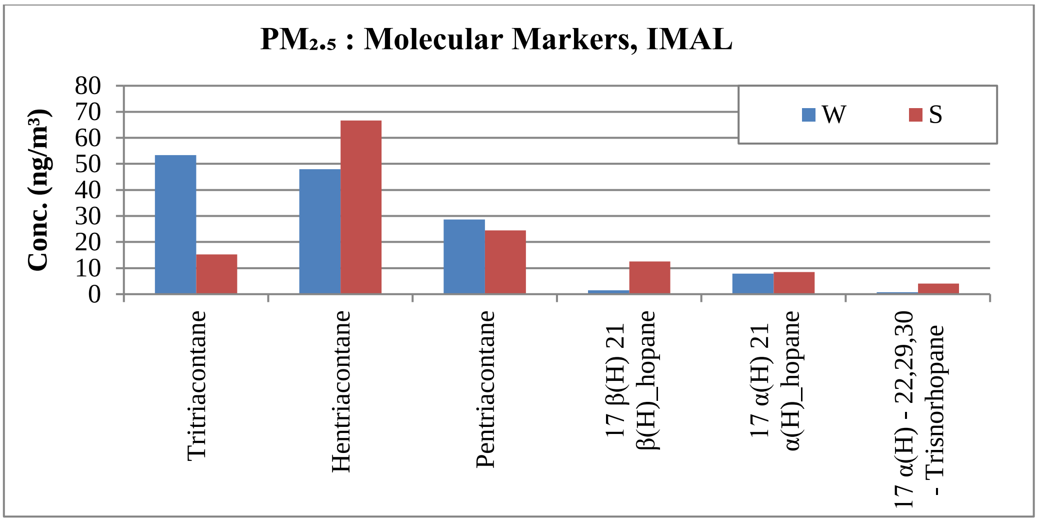


Figure 2.24: Molecular Markers in $PM_{2.5}$ at IMAL

2.4.2.6 Chemical composition of PM_{10} and $PM_{2.5}$ and their correlation matrix

Graphical presentations of chemical species are shown for the winter and summer seasons for PM_{10} (Figure 2.25) and $PM_{2.5}$ (Figure 2.26). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content, ionic species and elements] along with mass percentage (% R) recovered from PM are presented in Table 2.28 to Table 2.31 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.32 to Table 2.35 for both seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituents of the PM are presented in Figure 2.27(a) and (b) for the winter season and Figure 2.28 (a) and (b) for the summer season.

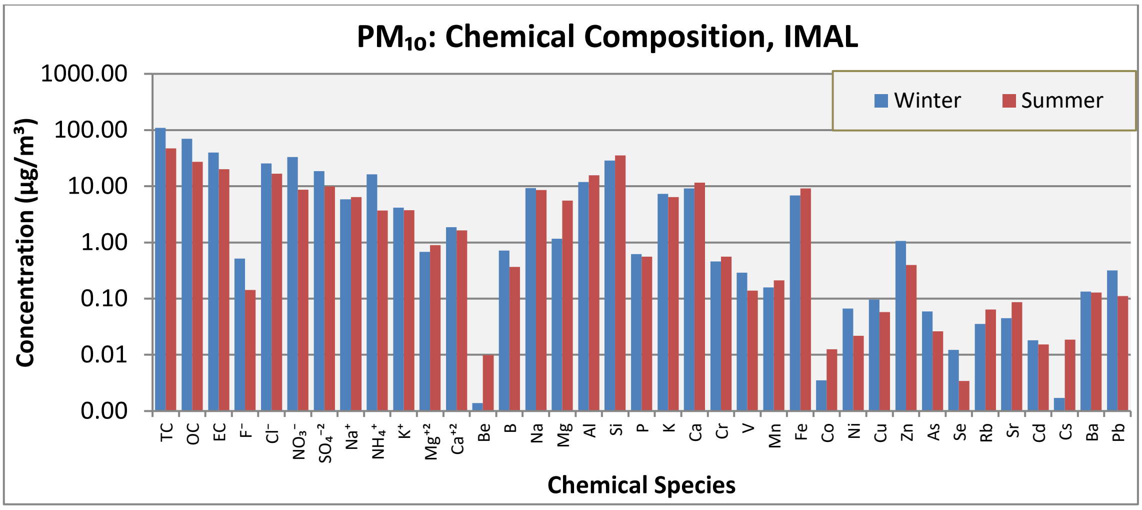


Figure 2.25: Concentrations of species in PM_{10} at IMAL

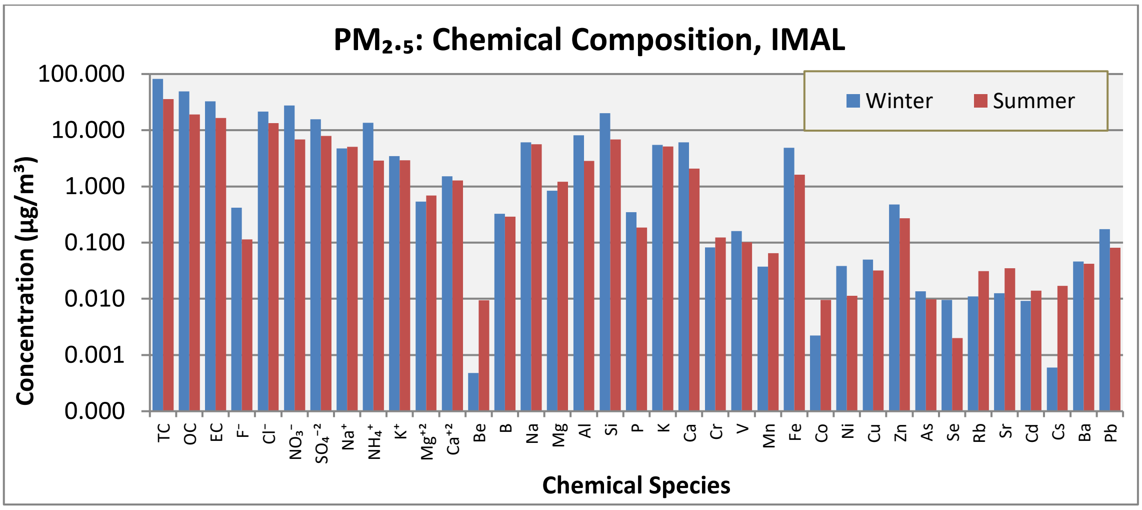


Figure 2.26: Concentrations of species in $PM_{2.5}$ at IMAL

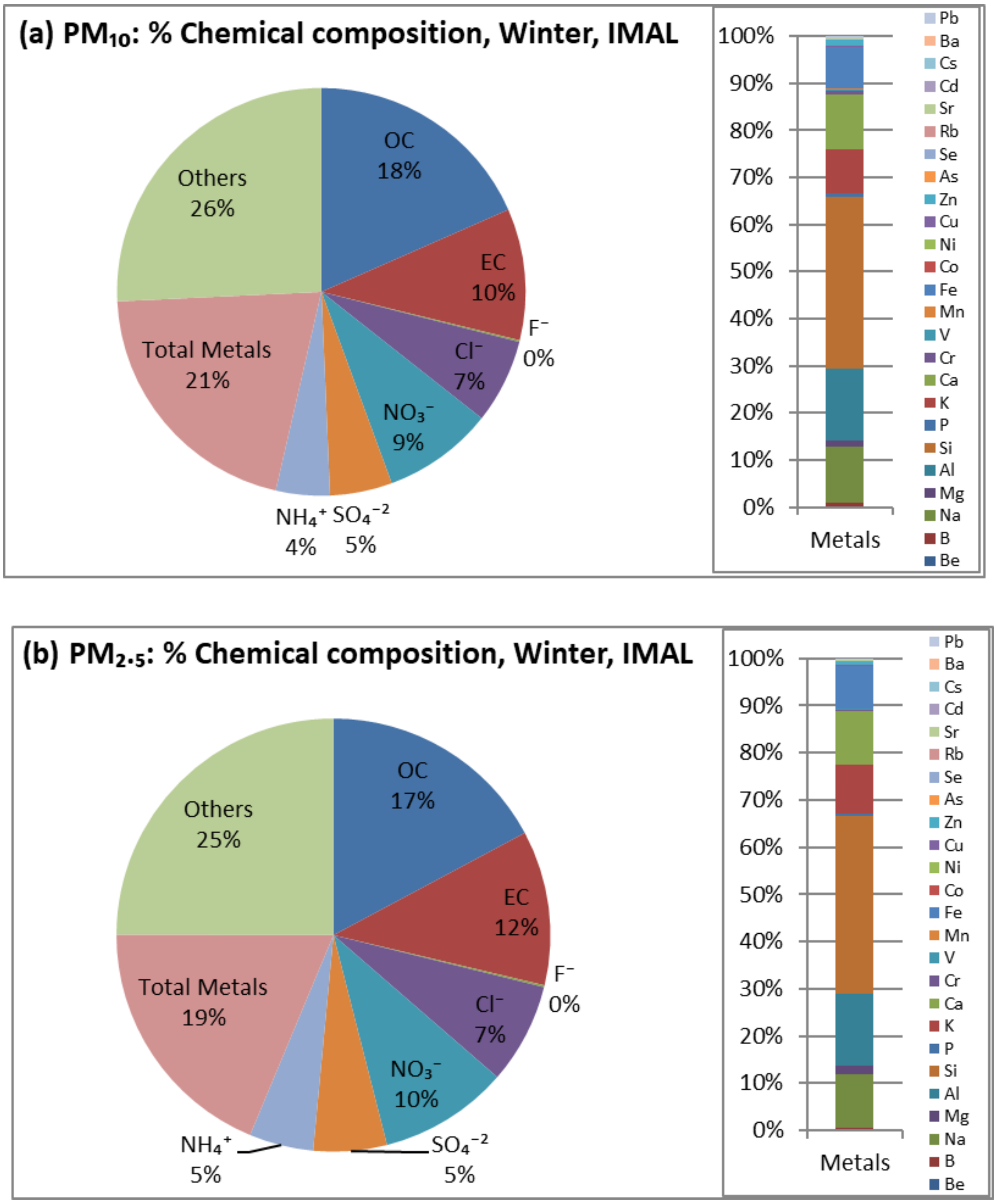


Figure 2.27: Percentage distribution of species in PM at IMAL for Winter Season

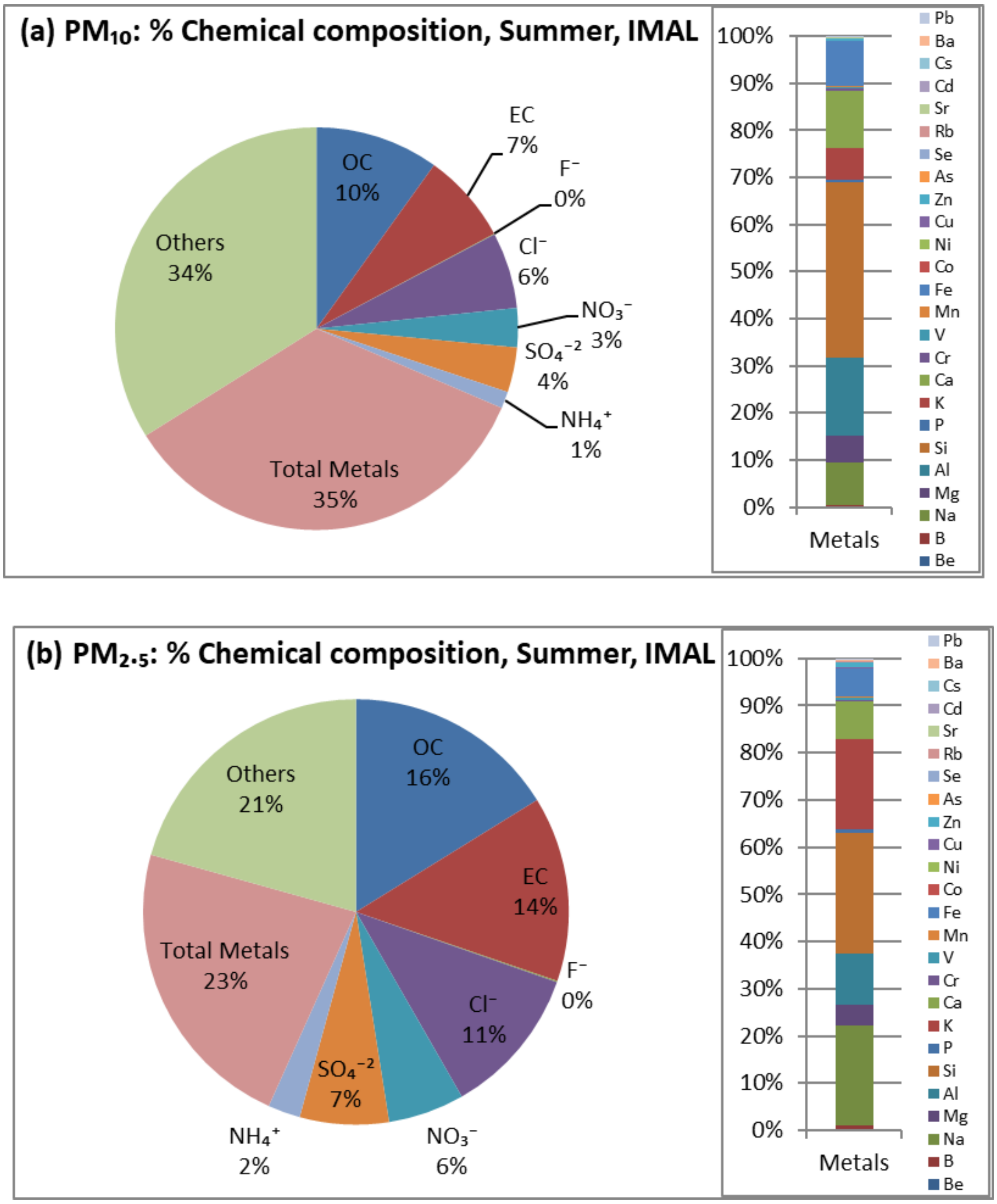


Figure 2.28: Percentage distribution of species in PM at IMAL for Summer Season

2.4.2.7 Comparison of PM_{10} and $PM_{2.5}$ Composition

The graphical presentation is the better option for understanding the compositional variation. A compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.29) at IMAL. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (66%) than summer (45%). The major species contributing to fine mode are TC, OC, EC, Cl^-,

NO_3^-, SO_4^{-2}, NH_4^+, B, V, Co, Zn and As; whereas major species contributing in coarse mode are K^+, Mg^{2+}, Ca^{2+}, Na, Mg, Al, Si, P, K, Ca, Cr, Mn, Fe and Ba.

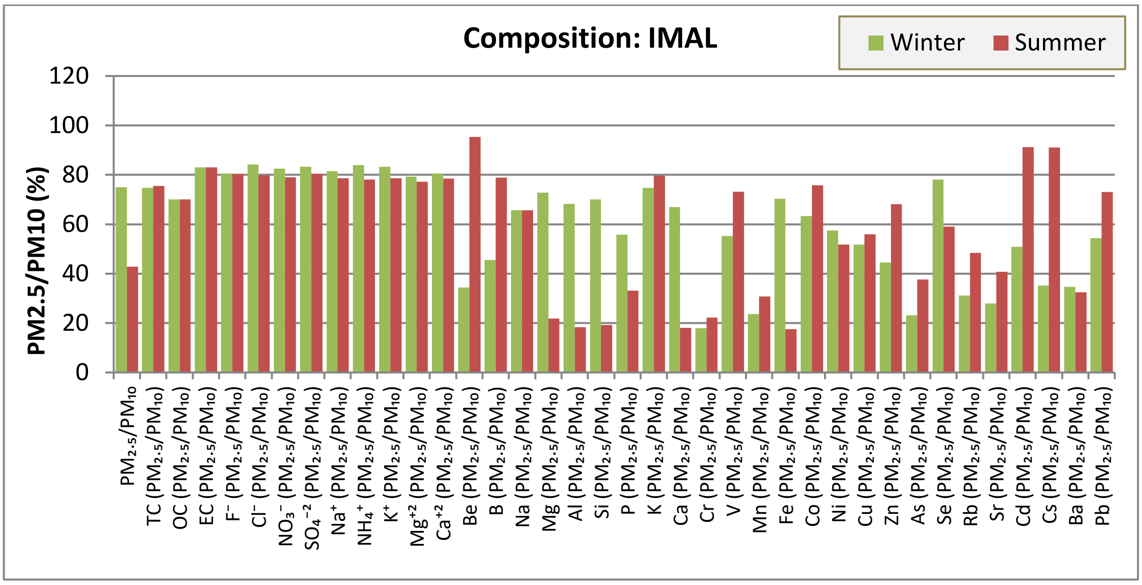


Figure 2.29: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at IMAL

Table 2.24: Statistical results of gaseous pollutants (µg/m^3) at IMAL for winter (W) and summer (S) seasons

IMAL (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	35.50	2.02	1.80	0.43	0.75	1.10	4.08
SD	6.09	0.06	0.82	0.32	0.51	0.93	2.30
Max	45.78	2.25	2.88	1.01	2.00	3.35	9.07
Min	26.69	2.00	0.29	0.01	0.28	0.00	0.71
CV	0.17	0.03	0.46	0.74	0.68	0.85	0.56
IMAL (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	20.11	2.00	3.87	1.92	5.68	5.09	16.56
SD	7.07	0.00	0.31	0.25	1.18	1.42	2.60
Max	33.45	2.00	4.46	2.39	7.32	7.38	21.21
Min	12.20	2.00	3.54	1.61	4.24	3.21	13.56
CV	0.35	0.00	0.08	0.13	0.21	0.28	0.16

Table 2.25: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at IMAL for winter (W) and summer (S) seasons

IMAL(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	284.54	81.72	32.83	48.89	3.71	16.23	20.29	8.66	0.04	0.20	0.25	0.12
SD	106.51	31.68	13.75	18.17	2.84	6.93	8.00	4.05	0.03	0.02	0.02	0.07
Max	506.00	131.93	54.54	77.39	9.52	27.12	34.57	21.48	0.08	0.23	0.27	0.36
Min	118.00	28.04	10.50	17.55	0.15	5.61	7.31	4.48	0.00	0.13	0.21	0.07
CV	0.37	0.39	0.42	0.37	0.76	0.43	0.39	0.47	0.64	0.11	0.06	0.60
IMAL (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	117.79	35.64	16.58	19.06	0.22	6.68	8.25	3.91	0.01	0.19	0.23	0.11
SD	24.70	6.59	3.90	2.87	0.36	1.57	1.21	0.72	0.01	0.02	0.02	0.03
Max	161.00	50.17	25.45	24.72	1.31	9.61	10.63	5.28	0.04	0.21	0.27	0.18
Min	72.00	23.13	8.86	14.27	0.04	3.82	6.29	2.87	0.00	0.15	0.21	0.08
CV	0.21	0.18	0.24	0.15	1.66	0.23	0.15	0.18	1.72	0.10	0.07	0.23

Table 2.26: **Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at IMAL for winter (W) and summer (S) seasons**

IMAL(W)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	6.81	0.34	4.12	0.36	1.21	0.05	2.75	0.08	0.30	5.44	8.35	9.68	4.63	7.98	5.52	0.62	7.60	65.84
SD	11.93	0.37	9.04	0.81	2.26	0.03	4.42	0.01	0.52	9.17	12.50	8.64	7.55	11.61	7.68	0.99	11.86	98.18
Max	33.81	1.18	24.61	2.20	6.31	0.11	12.52	0.10	1.37	25.68	35.70	26.41	21.50	33.46	22.27	2.82	34.04	284.03
Min	1.39	0.17	0.30	0.00	0.06	0.04	0.29	0.05	0.00	0.18	0.73	2.31	0.54	0.95	0.76	0.06	1.08	9.55
CV	1.75	1.07	2.20	2.27	1.88	0.51	1.61	0.19	1.76	1.69	1.50	0.89	1.63	1.45	1.39	1.61	1.56	1.49
IMAL (S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	10.69	0.51	0.62	0.03	0.36	0.04	0.17	0.79	0.66	0.21	0.33	1.06	0.17	0.65	0.24	0.02	0.61	17.18
SD	2.52	0.32	0.41	0.06	0.73	0.01	0.17	0.75	0.53	0.03	0.19	0.71	0.10	0.14	0.16	0.02	0.28	3.99
Max	15.02	1.19	1.50	0.17	1.98	0.06	0.48	1.97	1.54	0.25	0.69	2.13	0.36	0.90	0.48	0.04	1.12	24.51
Min	8.21	0.25	0.25	0.00	0.00	0.03	0.02	0.12	0.16	0.15	0.17	0.22	0.09	0.51	0.06	0.00	0.30	12.17
CV	0.24	0.61	0.66	2.07	2.02	0.27	1.01	0.94	0.80	0.16	0.57	0.67	0.58	0.22	0.65	1.21	0.46	0.23

Table 2.27: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at IMAL for winter (W) and summer (S) seasons

MNS(W)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	53.40	47.96	28.70	1.42	7.84	0.80	140.13
SD	11.01	19.50	8.99	0.42	4.68	0.40	40.07
CV	0.21	0.41	0.31	0.30	0.60	0.49	0.29

MNS(S)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	15.21	66.68	24.53	12.56	8.46	4.11	131.55
SD	5.85	7.09	1.95	12.18	6.48	2.69	18.11
CV	0.38	0.11	0.08	0.97	0.77	0.66	0.14

Table 2.28: Statistical results of chemical characterization (μg/m^3) of PM_{10} at IMAL for winter (W) season

IMAL(W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	380	69.8	39.6	0.5	25.4	33.3	18.7	5.8	16.2	4.2	0.7	1.9	1E-3	0.72	9.24	1.16	11.96	28.67	0.62
SD	124	25.9	16.6	0.1	8.6	11.7	4.7	1.3	5.3	1.4	0.2	0.6	2E-4	0.28	5.04	0.39	5.51	14.55	0.18
Max	578	110.6	65.7	0.7	39.1	51.9	26.4	7.3	25.3	7.0	1.2	3.2	2E-3	1.10	16.70	2.07	19.37	53.90	0.92
Min	161	25.1	12.7	0.3	9.3	14.5	11.6	2.6	7.5	1.9	0.3	0.8	1E-3	0.24	1.98	0.53	1.21	2.48	0.36
CV	0.33	0.37	0.42	0.19	0.34	0.35	0.25	0.23	0.33	0.33	0.35	0.31	0.17	0.40	0.55	0.34	0.46	0.51	0.28
IMAL(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	7.32	9.13	0.46	0.29	0.16	6.88	0.00	0.07	0.10	1.07	0.06	0.01	0.04	0.04	0.02	0.00	0.13	0.32	75.1
SD	2.16	4.48	0.24	0.06	0.07	3.59	0.00	0.02	0.04	0.50	0.02	0.00	0.01	0.02	0.01	0.00	0.06	0.14	4.6
Max	11.22	15.89	0.96	0.38	0.32	12.85	0.01	0.11	0.14	2.45	0.08	0.02	0.06	0.08	0.04	0.00	0.25	0.58	85.6
Min	3.27	0.97	0.09	0.20	0.08	0.58	0.00	0.03	0.03	0.45	0.01	0.00	0.01	0.02	0.01	0.00	0.05	0.12	66.3
CV	0.29	0.49	0.53	0.22	0.43	0.52	0.35	0.34	0.38	0.47	0.29	0.36	0.39	0.41	0.56	0.44	0.43	0.42	0.06

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.29: Statistical results of chemical characterization ($\mu g/m^3$) of $PM_{2.5}$ at IMAL for winter (W) season

IMAL(W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	285	48.9	32.8	0.4	21.4	27.4	15.6	4.8	13.6	3.5	0.5	1.5	5E-4	0.33	6.07	0.84	8.16	20.10	0.35
SD	107	18.2	13.7	0.1	7.6	10.0	3.9	1.2	4.6	1.1	0.2	0.5	1E-4	0.34	5.59	0.28	4.43	12.21	0.05
Max	506	77.4	54.5	0.5	34.4	45.5	21.9	6.7	21.9	5.6	1.0	2.4	7E-4	0.91	15.19	1.41	18.06	45.70	0.42
Min	118	17.6	10.5	0.3	6.7	11.7	9.7	2.0	6.0	1.7	0.3	0.6	3E-4	0.01	0.00	0.41	1.11	2.48	0.25
CV	0.37	0.37	0.42	0.16	0.36	0.36	0.25	0.26	0.34	0.32	0.40	0.30	3E-1	1.05	0.92	0.34	0.54	0.61	0.14
IMAL(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.46	6.11	0.08	0.16	0.04	4.84	0.00	0.04	0.05	0.47	0.014	0.010	0.011	0.013	0.009	0.001	0.046	0.17	76.0
SD	1.83	3.74	0.08	0.15	0.04	3.18	0.00	0.03	0.05	0.49	0.006	0.005	0.011	0.011	0.009	0.000	0.031	0.14	4.2
Max	8.89	14.84	0.20	0.34	0.10	12.30	0.00	0.09	0.13	1.37	0.019	0.018	0.034	0.033	0.024	0.001	0.107	0.43	82.5
Min	2.62	0.84	0.00	0.00	0.00	0.56	0.00	0.00	0.00	0.00	0.002	0.002	0.000	0.001	0.000	0.000	0.014	0.02	66.5
CV	0.33	0.61	0.97	0.91	0.99	0.66	0.35	0.90	0.93	1.02	0.42	0.52	0.95	0.88	0.94	0.54	0.67	0.83	0.06

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.30: Statistical results chemical characterization ($\mu g/m^3$) of PM_{10} at IMAL for summer (S) season

IMAL(S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	275	27.2	20.0	0.1	16.8	8.6	9.9	6.5	3.7	3.7	0.9	1.6	1E-2	0.37	8.54	5.55	15.58	35.51	0.56
SD	88	4.1	4.7	0.1	8.0	3.5	3.0	2.0	3.3	1.1	0.3	0.9	7E-4	0.07	2.31	3.26	8.08	18.36	0.14
Max	448	35.3	30.7	0.2	30.4	14.2	14.8	9.8	14.0	5.6	1.6	3.1	1E-2	0.49	13.00	12.61	32.67	73.28	0.74
Min	131	20.4	10.7	0.1	5.3	3.6	5.2	3.3	1.1	2.4	0.6	0.3	9E-3	0.25	5.06	1.37	5.01	10.31	0.19
CV	0.32	0.15	0.24	0.36	0.47	0.41	0.30	0.31	0.88	0.30	0.30	0.56	0.07	0.20	0.27	0.59	0.52	0.52	0.26
IMAL(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.44	11.56	0.56	0.14	0.21	9.15	1E-2	2E-2	6E-2	0.40	0.03	3E-3	6E-2	9E-2	2E-2	2E-2	0.13	0.11	66.97
SD	2.05	6.79	0.19	0.02	0.09	5.23	2E-3	7E-3	1E-2	0.14	0.01	1E-3	2E-2	4E-2	6E-3	2E-3	0.04	0.02	3.57
Max	10.45	26.38	0.94	0.18	0.40	20.91	2E-2	4E-2	9E-2	0.70	0.04	5E-3	1E-1	2E-1	4E-2	2E-2	0.21	0.15	72.71
Min	3.66	3.62	0.23	0.11	0.07	3.16	1E-2	1E-2	4E-2	0.24	0.02	1E-3	3E-2	4E-2	1E-2	2E-2	0.05	0.09	61.22
CV	0.32	0.59	0.34	0.16	0.43	0.57	0.16	0.34	0.21	0.34	0.24	0.31	0.34	0.50	0.42	0.08	0.34	0.14	0.05

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.31: Statistical results of chemical characterization (μg/m^3) of $PM_{2.5}$ at IMAL for summer (S) season

IMAL(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	118	19.1	16.6	0.1	13.4	6.8	8.0	5.1	2.9	2.9	0.7	1.3	9E-3	0.29	5.61	1.22	2.86	6.82	0.18
SD	25	2.9	3.9	0.0	6.3	2.6	2.5	1.6	2.5	0.9	0.2	0.7	7E-4	0.05	2.13	0.46	1.68	4.00	0.11
Max	161	24.7	25.5	0.2	24.1	11.5	12.2	7.7	10.8	4.9	1.1	2.3	1E-2	0.37	10.00	2.29	6.17	13.58	0.54
Min	72	14.3	8.9	0.0	3.9	3.3	4.4	2.5	0.8	1.9	0.4	0.3	9E-3	0.22	2.63	0.81	0.60	1.34	0.08
CV	0.21	0.15	0.24	0.38	0.47	0.38	0.32	0.31	0.86	0.30	0.28	0.54	0.08	0.17	0.38	0.38	0.59	0.59	0.59
IMAL(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.12	2.08	0.12	0.10	0.06	1.61	9E-3	1E-2	3E-2	0.27	1E-2	2E-3	3E-2	4E-2	1E-2	2E-2	4E-2	0.08	79.82
SD	1.71	1.19	0.06	0.01	0.03	0.93	7E-4	2E-3	8E-3	0.13	2E-3	1E-3	6E-3	1E-2	6E-3	1E-3	1E-2	0.02	5.65
Max	9.90	4.09	0.24	0.12	0.13	3.16	1E-2	2E-2	5E-2	0.61	1E-2	4E-3	4E-2	6E-2	3E-2	2E-2	6E-2	0.12	90.73
Min	3.29	0.45	0.06	0.08	0.04	0.35	9E-3	7E-3	2E-2	0.08	5E-3	3E-4	3E-2	2E-2	9E-3	2E-2	3E-2	0.04	70.39
CV	0.33	0.57	0.49	0.12	0.42	0.58	0.08	0.22	0.26	0.49	0.21	0.60	0.19	0.34	0.39	0.07	0.30	0.24	0.07

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.32: Correlation Matrix for PM_{10} and its composition at IMAL for winter season

IMAL(W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.95	0.93	0.97	0.53	0.39	0.53	0.60	-0.29	0.80	0.83	0.18	0.28	0.86
TC		1.00	1.00	0.99	0.54	0.38	0.62	0.65	-0.31	0.85	0.85	0.05	0.18	0.70
OC			1.00	0.97	0.54	0.38	0.63	0.63	-0.30	0.84	0.84	0.01	0.12	0.64
EC				1.00	0.51	0.36	0.58	0.65	-0.30	0.84	0.86	0.10	0.27	0.76
NO_3^-					0.56	0.55	1.00	0.74	-0.01	0.84	0.68	-0.22	-0.04	0.12
SO_4^{-2}					0.59	0.47		1.00	0.23	0.81	0.78	0.21	0.38	0.27
NH_4^+					0.64	0.54			-0.06	1.00	0.84	0.07	0.25	0.47
Metals					0.26	0.06			-0.35		0.54	0.32	0.41	1.00

Table 2.33: Correlation matrix for $PM_{2.5}$ and its composition at IMAL for winter season

IMAL(W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.97	0.95	0.97	0.69	0.33	0.67	0.69	-0.31	0.84	0.84	0.00	0.32	0.92
TC		1.00	0.99	0.99	0.69	0.35	0.64	0.68	-0.25	0.81	0.85	-0.02	0.33	0.83
OC			1.00	0.97	0.68	0.36	0.65	0.66	-0.26	0.80	0.83	-0.05	0.26	0.79
EC				1.00	0.69	0.33	0.61	0.69	-0.23	0.80	0.86	0.04	0.41	0.87
NO_3^-					0.68	0.57	1.00	0.82	-0.04	0.89	0.76	-0.27	0.04	0.43
SO_4^{-2}					0.69	0.45		1.00	0.27	0.87	0.88	0.07	0.51	0.49
NH_4^+					0.73	0.53			0.01	1.00	0.89	0.01	0.27	0.66
Metals					0.49	0.10			-0.44		0.65	0.10	0.33	1.00

Table 2.34: Correlation matrix for PM_{10} and its composition at IMAL for summer season

IMAL(S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.61	0.68	0.53	0.65	0.34	0.35	0.17	-0.15	-0.04	0.30	0.77	0.57	0.97
TC		1.00	0.97	0.98	0.24	0.17	0.40	0.71	0.06	0.55	0.75	0.52	0.43	0.44
OC			1.00	0.90	0.37	0.31	0.48	0.65	0.12	0.48	0.66	0.60	0.34	0.50
EC				1.00	0.11	0.05	0.32	0.73	0.01	0.58	0.79	0.42	0.49	0.37
NO_3^-					0.54	0.41	1.00	0.20	0.49	0.21	0.26	0.32	-0.16	0.23
SO_4^{-2}					0.05	0.01		1.00	0.05	0.58	0.87	0.21	0.26	0.01
NH_4^+					-0.40	-0.35			0.27	1.00	0.65	0.07	0.25	-0.14
Metals					0.63	0.22			-0.16		0.17	0.73	0.61	1.00

Table 2.35: Correlation matrix for $PM_{2.5}$ and its composition at IMAL for summer season

IMAL(S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.88	0.81	0.88	0.25	0.01	0.24	0.71	-0.29	0.45	0.77	0.51	0.76	0.87
TC		1.00	0.97	0.98	0.27	0.17	0.38	0.72	0.00	0.53	0.79	0.48	0.46	0.57
OC			1.00	0.90	0.40	0.30	0.46	0.62	0.05	0.45	0.70	0.60	0.35	0.48
EC				1.00	0.17	0.06	0.30	0.76	-0.04	0.57	0.82	0.38	0.51	0.60
NO_3^-					0.58	0.38	1.00	0.07	0.46	0.12	0.14	0.38	-0.17	-0.03
SO_4^{-2}					-0.06	-0.04		1.00	-0.12	0.62	0.91	0.13	0.39	0.48
NH_4^+					-0.44	-0.35			0.24	1.00	0.75	-0.01	0.26	0.28
Metals					0.09	-0.32			-0.42		0.55	0.36	0.95	1.00

2.4.3 Amar Ujala Chandpur (AMUC)

The sampling period was December 31, 2020 – January 14, 2021, for winter and March 23 – April 06, 2021 for summer.

2.4.3.1 Particulate Matter (PM$_{10}$, PM$_{2.5}$)

Time series of 24-hr average concentrations of PM$_{10}$ and PM$_{2.5}$ are shown for winter (Figure 2.30) and summer (Figure 2.31). Average levels for winter and summer season were 254±82 and 124±40 µg/m^3 (for PM$_{2.5}$) and 340±103 and 294±59 µg/m^3 (for PM$_{10}$) respectively. The PM$_{2.5}$ levels are 4.2 times higher than the NAQS and PM$_{10}$ is 3.4 times higher than the NAQS in winter The PM$_{2.5}$ levels are 2 times higher and PM$_{10}$ levels are 2.9 times higher than the NAQS in summer. A statistical summary of PM concentrations is presented in Table 2.40 to Table 2.43 for the winter and summer seasons. In summer, both PM$_{10}$ and PM$_{2.5}$ levels drop significantly but do not meet the national standards, however, PM$_{10}$ levels was not dropped in same manner as PM$_{2.5}$ and continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from the soil surface during dust storms in the dry months of summer can contribute significantly to a coarse fraction.

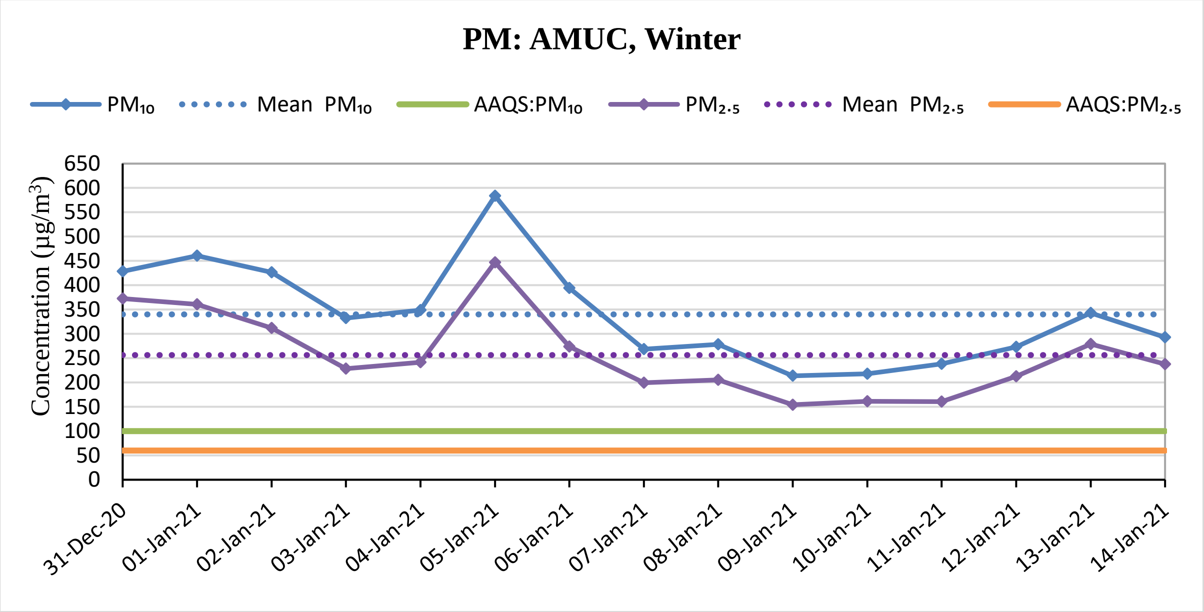


Figure 2.30: PM Concentrations at AMUC for Winter Season

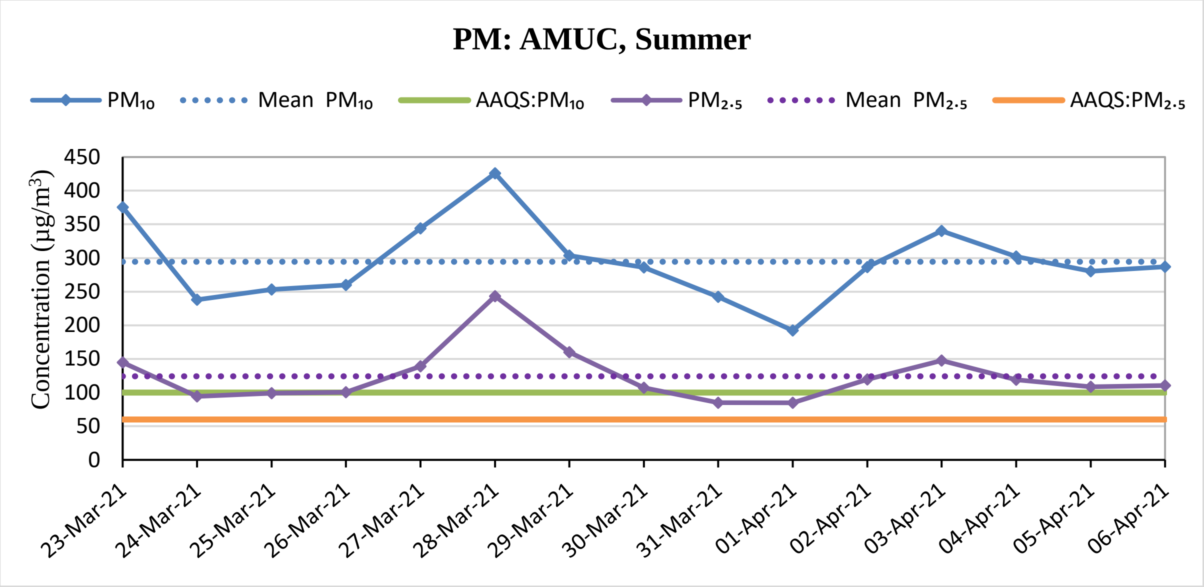


Figure 2.31: PM Concentrations at AMUC for Summer Season

2.4.3.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.32) and summer (Figure 2.33) seasons. It was observed that NO_2 and SO_2 levels were under the NAQ standards. The average of 15 days for winter and summer were 23.25±6.16 and 16.66±2.99 µg/m^3 (for NO_2). The summer concentration of NO_2 and SO_2 dropped significantly than in winter. Although, NO_2 and SO_2 are certainly a matter of concern and these values can largely be attributed to vehicular pollution, DG sets and coal combustion in industries. Variation in NO_2 and SO_2 are due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams, coal combustion or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.34 and the statistical summary in Table 2.36. The total BTX level is observed 19.41±7.36 µg/m^3 (Benzene: 8.78 and Toluene: 3.38 µg/m^3) in winter and 7.19±0.43 µg/m^3 (Benzene: 3.40 and Toluene: 0.72 µg/m^3) in summer seasons. The BTX levels were high during winter than in the summer.

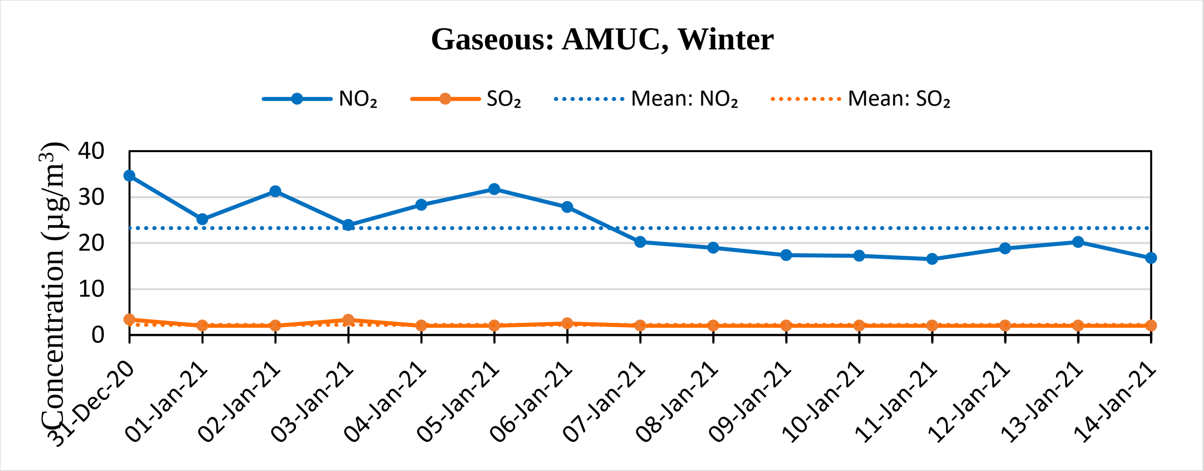


Figure 2.32: SO_2 and NO_2 Concentrations at AMUC for Winter Season

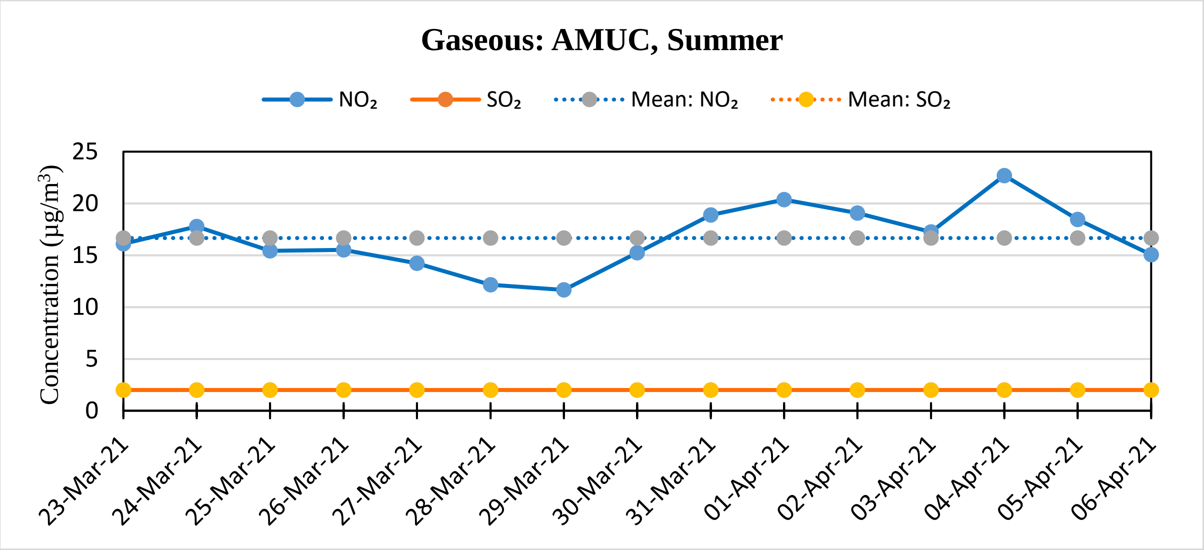


Figure 2.33: SO_2 and NO_2 Concentrations at AMUC for Summer Season

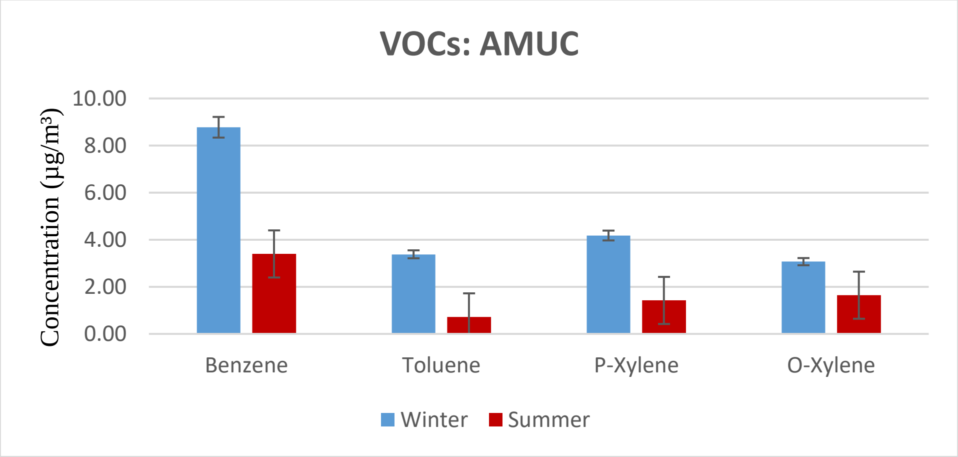


Figure 2.34: VOCs concentration at AMUC

2.4.3.3 Carbon Content (EC/OC) in $PM_{2.5}$

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and the ratio of OC fraction to TC are shown in Figure 2.35 (a) and (b) for winter and summer seasons. OC is observed slightly higher (winter: 46.11±18.85 and summer: 22.48±7.79 µg/m^3) than the EC (winter: 29.66±12.94 and summer: 17.00±6.65 µg/m^3). It is also observed that the OC and EC are higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.37 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at AMUC.

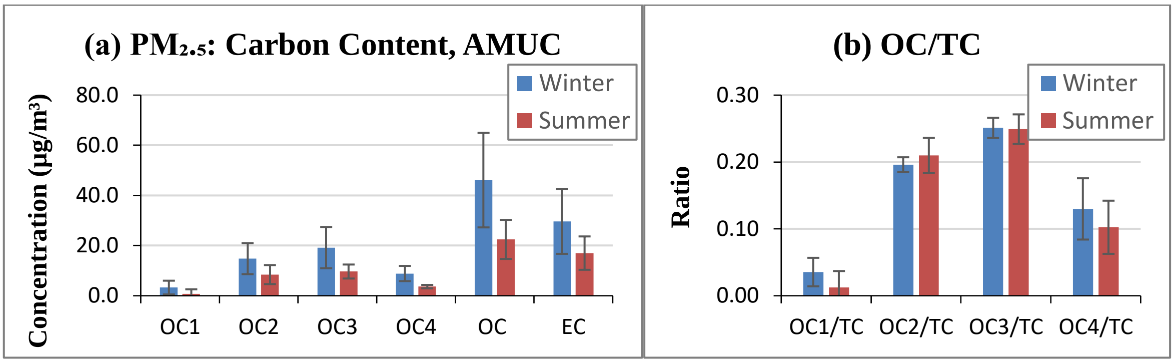


Figure 2.35: EC and OC Content in $PM_{2.5}$ at AMUC

2.4.3.4 PAHs in $PM_{2.5}$

Figure 2.36 shows the average measured concentration of PAHs at AMUC for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.38 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (168±47 ng/m^3) compared to summer season (17±8 ng/m^3). Major PAHs are DEP (56.9 ng/m^3), DmP (24.9 ng/m^3), B(b)F (18.6 ng/m^3), BeA (11.3 ng/m^3), and Chr (11 ng/m^3) for winter season B(b)F (4.6 ng/mb^3), B(ghi)P (2.4 ng/m^3) and Chr (1.3 ng/m^3) for summer season.

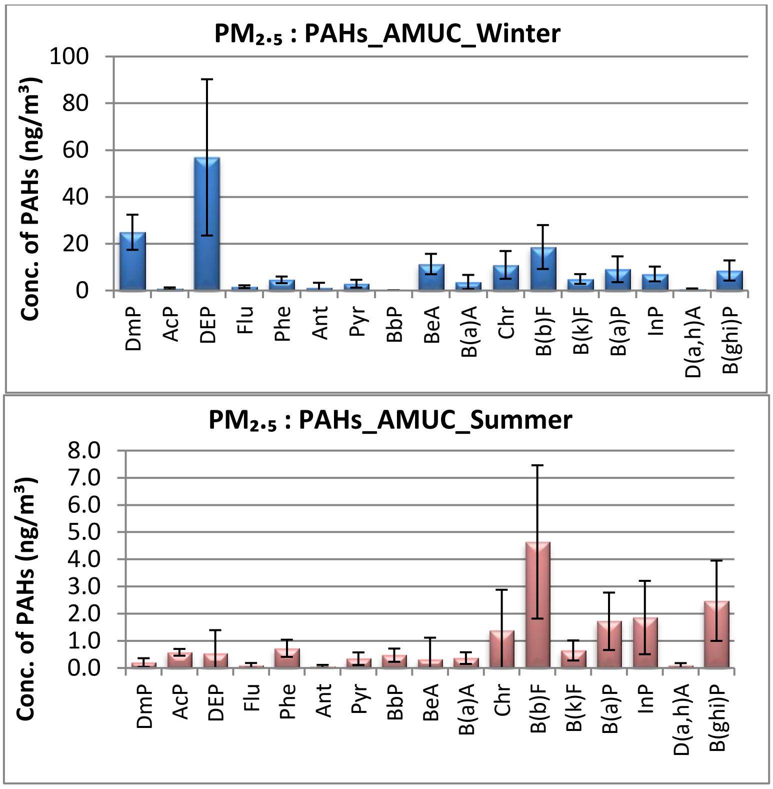


Figure 2.36: PAHs Concentrations in $PM_{2.5}$ at AMUC

2.4.3.5 Molecular Markers in $PM_{2.5}$

Total six molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21 α(H)_hopane, 17α(H),21β(H)-hopane, Pentriacontane, Hentriacontane and Tritriacontane. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D).

Figure 2.37 and Table 2.39 show the levels of six molecular markers. Total concentration of markers was 177.5±35.3 ng/m^3 in winter and 144.1±42.3 ng/m^3 in summer. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

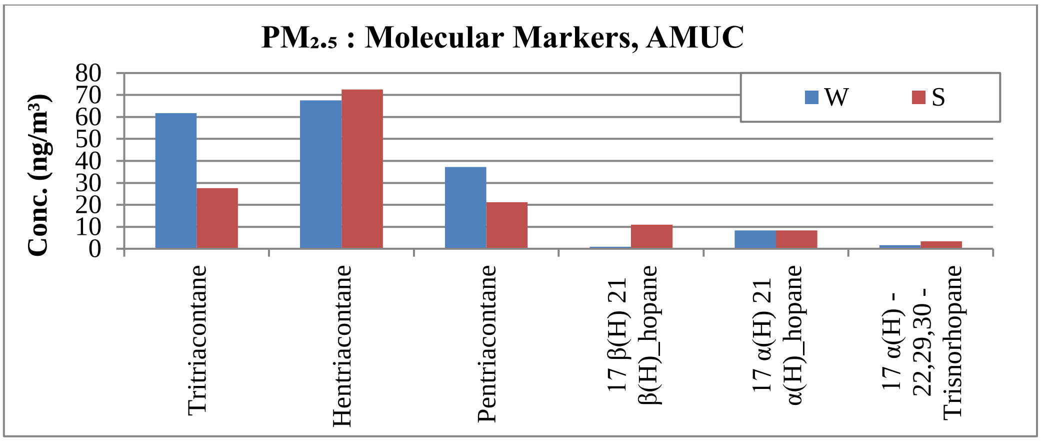


Figure 2.37: Molecular Markers in $PM_{2.5}$ at AMUC

2.4.3.6 Chemical Composition of PM_{10} and $PM_{2.5}$ and their correlation matrix

Graphical presentations of chemical species are shown for the winter and summer seasons for PM_{10} (Figure 2.38) and $PM_{2.5}$ (Figure 2.39). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content, ionic species and elements] along with mass percentage (%R) recovered from PM are presented in Table 2.40 to Table 2.43 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.44 to Table 2.47 for both seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituents of the PM are presented in Figure 2.40 (a) and (b) for the winter season and Figure 2.41 (a) and (b) for the summer season.

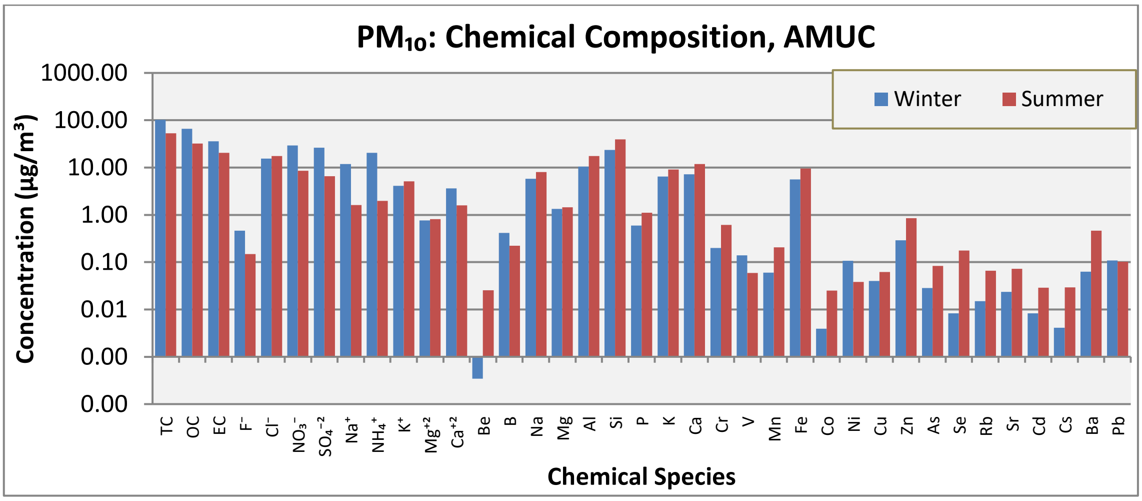


Figure 2.38: Concentrations of species in PM_{10} at AMUC

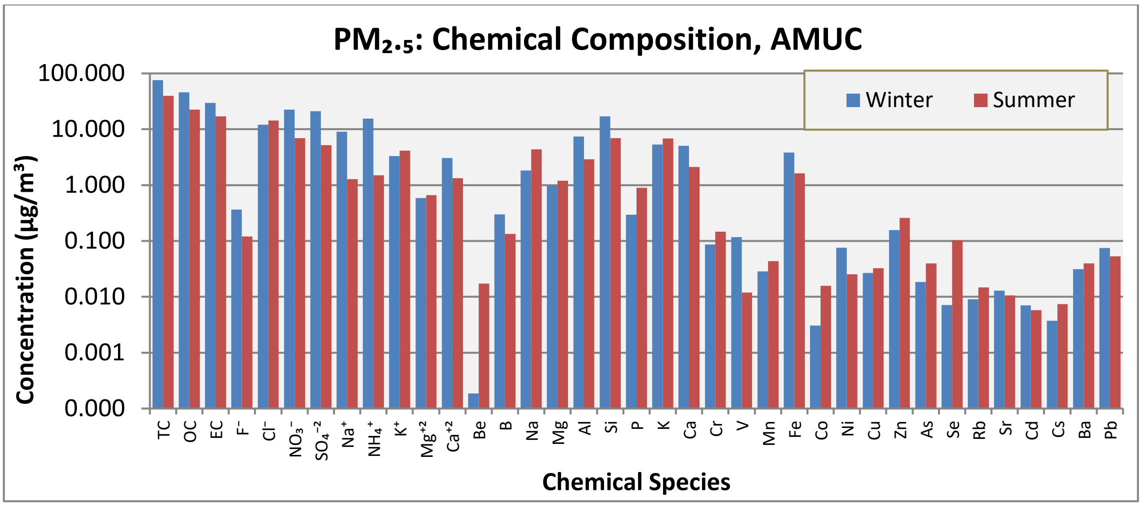


Figure 2.39: Concentrations of species in PM2.5 at AMUC

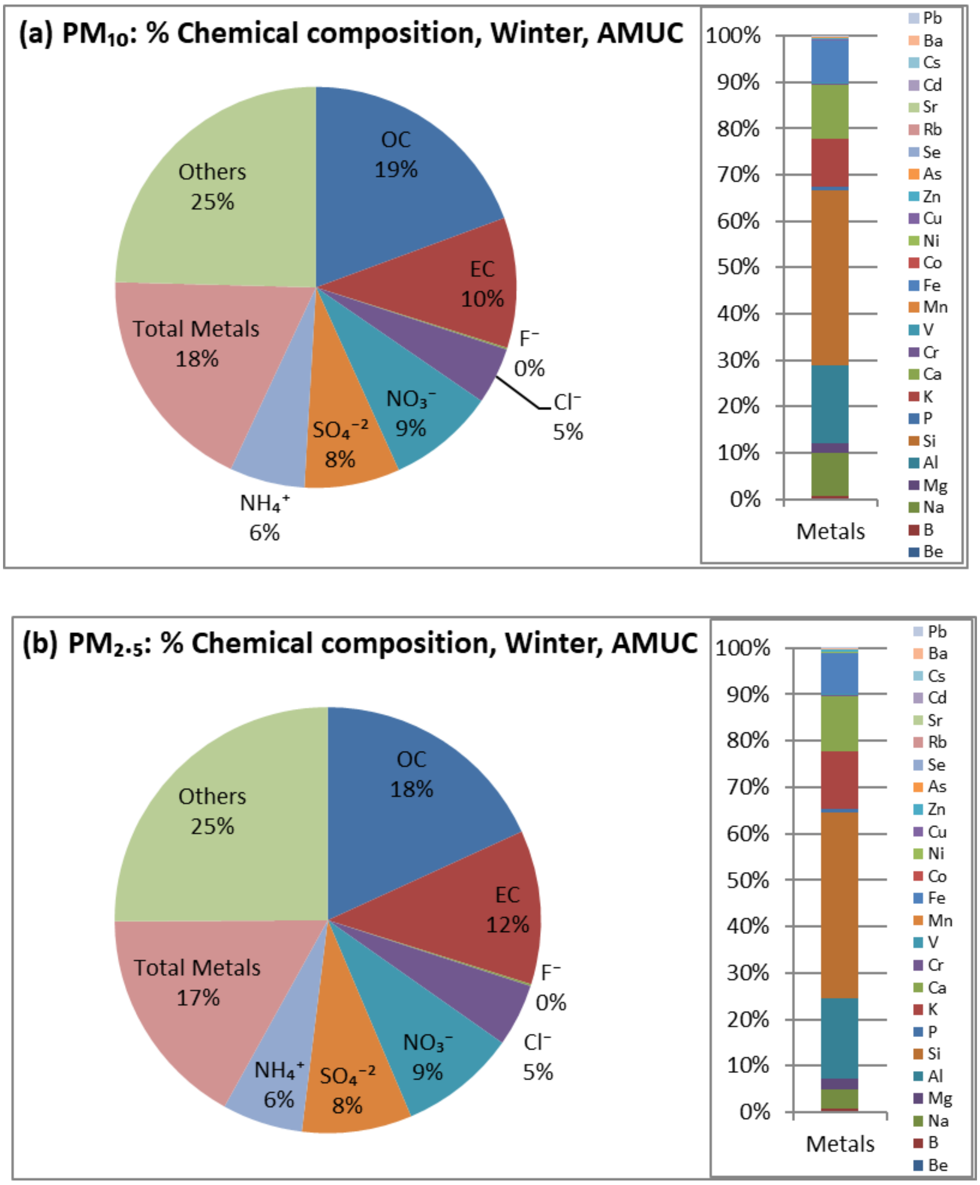


Figure 2.40: Percentage distribution of species in PM at AMUC for Winter Season

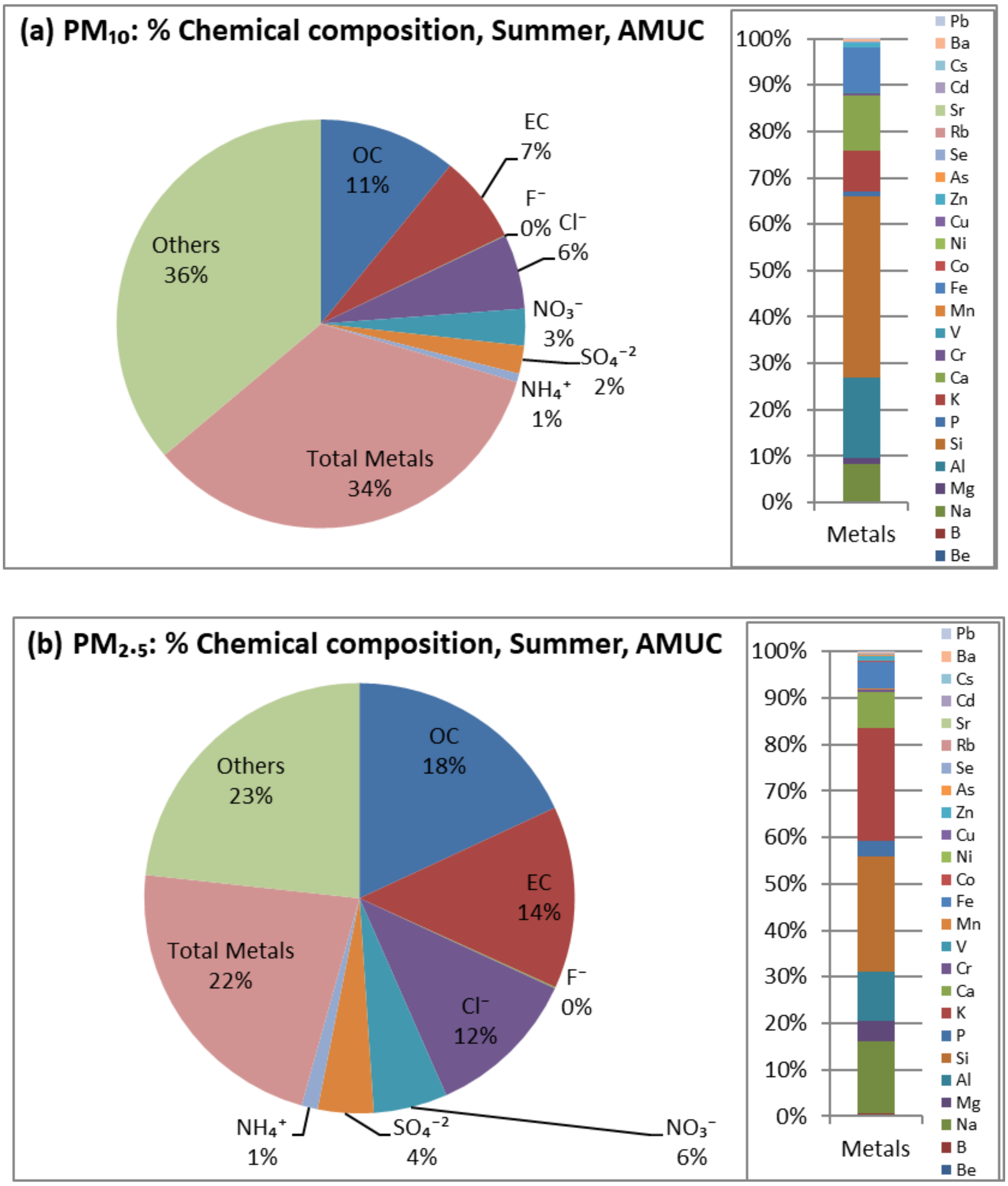


Figure 2.41: Percentage distribution of species in PM at AMUC for Summer Season

2.4.3.7 Comparison of PM_{10} and $PM_{2.5}$ Composition

The graphical compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.42) at AMUC. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that a significant portion of PM has fine mode during winter (65%) than summer (39%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Be, V, Cu and Cd; whereas, major species contributing in coarse mode are F^-, Mg^{+2}, Ca^{2+}, Mg, Al, Si, P, Ca, Cr, Fe, Sr and Ba.

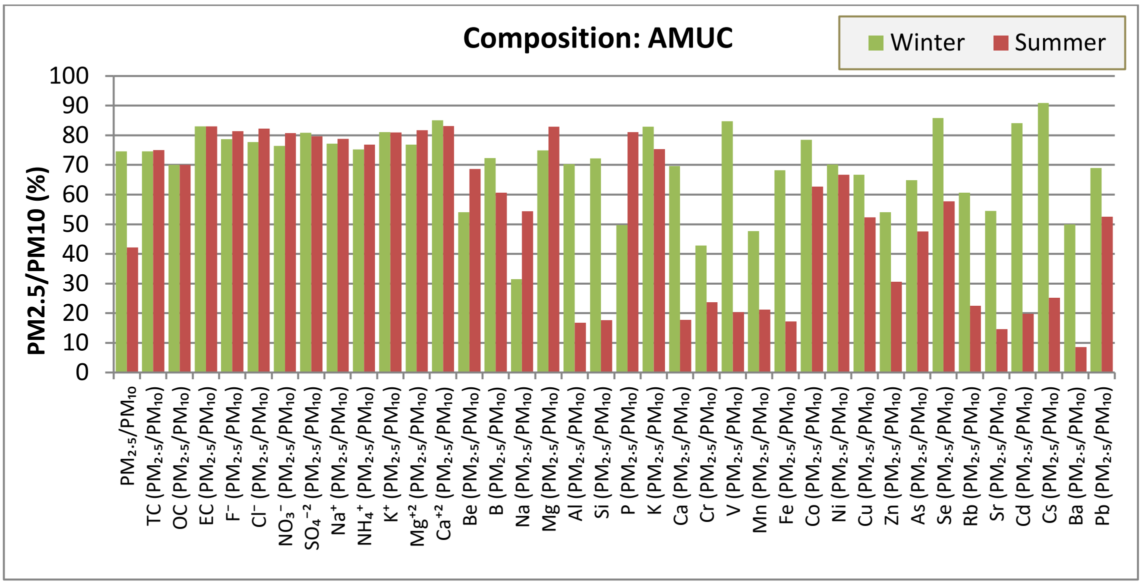


Figure 2.42: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at AMUC

Table 2.36: Statistical results of gaseous pollutants (µg/m^3) at AMUC for winter (W) and summer (S) seasons

AMUC (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	23.25	2.21	1.76	0.51	1.04	1.53	4.84
SD	6.16	0.47	0.67	0.45	0.53	0.74	1.69
Max	34.61	3.35	2.65	1.66	1.85	2.68	8.84
Min	16.50	2.00	0.29	0.17	0.42	0.61	2.93
CV	0.27	0.21	0.38	0.89	0.51	0.49	0.35
AMUC (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	16.66	2.00	3.40	1.45	4.27	4.11	13.22
SD	2.99	0.00	0.29	0.08	0.31	0.32	0.77
Max	22.70	2.00	3.73	1.58	4.68	4.51	14.50
Min	11.66	2.00	2.89	1.31	3.79	3.62	12.12
CV	0.18	0.00	0.08	0.06	0.07	0.08	0.06

Table 2.37: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at AMUC for winter (W) and summer (S) seasons

AMUC(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	256.38	75.77	29.66	46.11	3.26	14.79	19.19	8.87	0.04	0.20	0.25	0.13
SD	85.54	31.30	12.94	18.85	2.74	6.19	8.23	3.04	0.02	0.01	0.02	0.05
Max	447.00	129.94	52.99	79.39	9.18	26.50	33.52	18.34	0.07	0.22	0.28	0.21
Min	154.00	32.07	11.16	20.91	0.07	6.55	7.34	6.12	0.00	0.17	0.23	0.06
CV	0.33	0.41	0.44	0.41	0.84	0.42	0.43	0.34	0.60	0.06	0.06	0.35
AMUC (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	124.22	39.48	17.00	22.48	0.76	8.43	9.65	3.63	0.01	0.21	0.25	0.10
SD	40.11	14.21	6.65	7.79	1.81	3.79	2.79	0.69	0.02	0.03	0.02	0.04
Max	243.00	81.56	35.27	46.29	6.86	19.03	17.42	5.77	0.08	0.26	0.30	0.18
Min	85.00	23.42	8.09	15.33	0.04	4.58	6.55	2.78	0.00	0.17	0.21	0.04
CV	0.32	0.36	0.39	0.35	2.38	0.45	0.29	0.19	1.93	0.13	0.09	0.39

Table 2.38: **Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at AMUC for winter (W) and summer (S) seasons**

AMUC(W)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	24.90	0.86	56.88	1.64	4.56	1.10	2.92	0.08	11.31	3.62	10.94	18.59	4.92	9.08	7.06	0.60	8.56	167.62
SD	7.51	0.46	33.39	0.58	1.42	2.22	1.66	0.01	4.36	3.06	5.94	9.39	2.09	5.52	3.17	0.29	4.31	47.03
Max	35.26	1.77	113.33	2.37	5.75	6.12	5.45	0.10	18.92	10.07	20.46	34.47	8.82	19.34	11.91	1.07	15.59	242.27
Min	13.26	0.34	22.35	0.78	1.64	0.08	0.75	0.05	4.57	1.19	3.29	6.25	2.27	3.66	3.06	0.25	3.37	108.22
CV	0.30	0.53	0.59	0.35	0.31	2.02	0.57	0.18	0.39	0.85	0.54	0.51	0.42	0.61	0.45	0.48	0.50	0.28
AMUC (S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	0.20	0.58	0.53	0.10	0.73	0.07	0.34	0.47	0.32	0.36	1.38	4.64	0.65	1.72	1.86	0.09	2.47	16.51
SD	0.16	0.12	0.86	0.09	0.32	0.05	0.23	0.24	0.79	0.22	1.50	2.82	0.37	1.06	1.35	0.09	1.48	7.52
Max	0.39	0.77	2.20	0.25	1.32	0.16	0.73	0.96	2.12	0.83	4.69	9.77	1.27	3.50	3.95	0.26	4.63	31.00
Min	0.02	0.43	0.00	0.00	0.37	0.02	0.10	0.26	0.00	0.22	0.40	1.15	0.23	0.57	0.30	0.00	0.65	9.37
CV	0.80	0.22	1.61	0.92	0.44	0.74	0.69	0.52	2.46	0.59	1.08	0.61	0.57	0.62	0.73	0.94	0.60	0.46

Table 2.39: Statistical results of molecular markers (ng/m^3) in PM$_{2.5}$ at AMUC for winter (W) and summer (S) seasons

MNS(W)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	61.72	67.63	37.22	0.93	8.41	1.62	177.53
SD	25.41	4.16	1.28	0.41	3.67	1.26	35.26
CV	0.41	0.06	0.03	0.44	0.44	0.78	0.20

MNS(S)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	27.59	72.53	21.24	11.03	8.28	3.41	144.08
SD	6.44	30.59	9.10	7.47	1.93	2.14	42.27
CV	0.23	0.42	0.43	0.68	0.23	0.63	0.29

Table 2.40: Statistical results of chemical characterization (μg/m^3) of PM$_{10}$ at AMUC for winter (W) season

AMUC(W)	PM$_{10}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	340	65.9	35.7	0.5	15.5	29.4	26.2	11.8	20.6	4.1	0.8	3.6	3E-4	0.41	5.81	1.33	10.50	23.66	0.60
SD	103	26.9	15.6	0.1	6.2	7.8	4.4	3.5	4.3	1.1	0.3	1.5	1E-4	0.29	7.87	0.58	3.50	8.39	0.29
Max	584	113.4	63.8	0.6	26.7	53.5	34.0	17.8	32.8	5.9	1.5	8.0	7E-4	0.94	28.84	2.71	19.44	47.42	1.08
Min	214	29.9	13.4	0.3	8.0	21.6	19.1	4.1	16.1	2.3	0.3	2.1	2E-4	0.01	0.01	0.56	6.59	15.23	0.11
CV	0.30	0.41	0.44	0.17	0.40	0.27	0.17	0.30	0.21	0.28	0.39	0.41	0.32	0.69	1.35	0.44	0.33	0.35	0.49
AMUC(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.45	7.24	0.20	0.14	0.06	5.59	0.00	0.11	0.04	0.29	0.03	0.01	0.01	0.02	0.01	0.00	0.06	0.11	75.7
SD	1.90	2.78	0.19	0.05	0.04	2.30	0.00	0.05	0.03	0.23	0.01	0.00	0.01	0.02	0.00	0.00	0.07	0.07	2.2
Max	10.22	15.30	0.59	0.24	0.16	12.64	0.01	0.22	0.09	0.92	0.04	0.01	0.05	0.08	0.01	0.01	0.23	0.23	78.9
Min	3.76	4.42	0.00	0.06	0.02	3.14	0.00	0.06	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.01	71.8
CV	0.29	0.38	0.95	0.33	0.68	0.41	0.28	0.46	0.71	0.78	0.32	0.29	0.80	0.94	0.37	0.15	1.15	0.63	0.03

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.41: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at AMUC for winter (W) season

AMUC(W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	254	46.1	29.7	0.4	12.1	22.5	21.2	9.1	15.5	3.3	0.6	3.1	2E-4	0.30	1.83	1.00	7.38	17.09	0.30
SD	82	18.9	12.9	0.1	4.9	6.3	4.1	2.8	3.2	1.1	0.3	1.3	8E-5	0.23	1.57	0.47	2.88	7.28	0.14
Max	447	79.4	53.0	0.4	20.8	41.6	29.6	15.2	24.4	5.1	1.4	6.9	3E-4	0.82	5.95	2.39	14.99	36.97	0.56
Min	154	20.9	11.2	0.3	5.8	16.0	14.0	3.6	11.7	2.0	0.3	1.6	9E-5	0.00	0.00	0.49	3.96	9.85	0.01
CV	0.32	0.41	0.44	0.14	0.41	0.28	0.19	0.31	0.21	0.32	0.45	0.43	4E-1	0.78	0.86	0.47	0.39	0.43	0.47
AMUC(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.35	5.04	0.09	0.12	0.03	3.81	0.00	0.08	0.03	0.16	0.018	0.007	0.009	0.013	0.007	0.004	0.031	0.07	75.5
SD	1.86	2.52	0.08	0.04	0.02	1.48	0.00	0.03	0.02	0.08	0.009	0.002	0.005	0.013	0.002	0.000	0.053	0.05	2.9
Max	8.67	12.84	0.34	0.20	0.06	7.58	0.00	0.16	0.07	0.34	0.038	0.010	0.023	0.058	0.011	0.005	0.215	0.14	80.2
Min	3.36	2.83	0.00	0.04	0.00	2.13	0.00	0.04	0.00	0.00	0.002	0.005	0.003	0.003	0.004	0.003	0.002	0.01	71.3
CV	0.35	0.50	0.97	0.36	0.60	0.39	0.22	0.41	0.69	0.52	0.47	0.26	0.57	1.03	0.34	0.11	1.68	0.62	0.04

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.42: Statistical results chemical characterization (µg/m^3) of PM_{10} at AMUC for summer (S) season

AMUC(S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	294	32.1	20.5	0.1	17.4	8.5	6.5	1.6	2.0	5.1	0.8	1.6	3E-2	0.22	8.03	1.44	17.42	39.35	1.10
SD	59	11.1	8.0	0.1	10.9	3.3	2.9	0.5	2.8	1.7	0.4	0.7	8E-2	0.12	2.48	0.81	3.76	7.22	0.16
Max	426	66.1	42.5	0.3	35.9	14.4	11.4	2.7	11.3	10.1	1.8	3.0	3E-1	0.43	15.00	3.37	24.59	52.30	1.50
Min	192	21.9	9.7	0.1	3.7	3.3	2.8	0.8	0.3	3.2	0.4	0.3	3E-3	0.08	4.85	0.65	10.92	26.35	0.91
CV	0.20	0.35	0.39	0.51	0.63	0.39	0.45	0.29	1.40	0.33	0.51	0.47	3.00	0.55	0.31	0.56	0.22	0.18	0.15
AMUC(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	9.04	11.90	0.62	0.06	0.21	9.52	3E-2	4E-2	6E-2	0.85	0.08	2E-1	7E-2	7E-2	3E-2	3E-2	0.46	0.10	63.74
SD	2.74	2.83	0.22	0.06	0.08	2.49	7E-2	7E-2	6E-2	0.59	0.09	8E-2	7E-2	7E-2	8E-2	8E-2	0.99	0.09	2.90
Max	16.59	16.34	1.18	0.28	0.37	16.23	3E-1	3E-1	3E-1	2.00	0.38	4E-1	3E-1	3E-1	3E-1	3E-1	4.03	0.32	69.17
Min	5.84	7.61	0.25	0.02	0.03	6.08	2E-3	7E-3	1E-2	0.11	0.02	3E-2	1E-2	1E-2	3E-3	4E-3	0.02	0.00	58.92
CV	0.30	0.24	0.35	1.07	0.40	0.26	2.98	1.96	1.00	0.69	1.12	0.46	1.02	0.99	2.73	2.67	2.15	0.90	0.05

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.43: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at AMUC for summer (S) season

AMUC(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	124	22.5	17.0	0.1	14.3	6.9	5.2	1.3	1.5	4.2	0.7	1.3	2E-2	0.13	4.37	1.19	2.91	6.93	0.89
SD	40	7.8	6.6	0.1	9.1	2.6	2.5	0.3	2.1	1.4	0.4	0.7	6E-2	0.10	0.66	0.72	1.68	3.70	0.12
Max	243	46.3	35.3	0.2	30.6	10.9	9.8	2.0	8.7	8.6	1.6	2.6	2E-1	0.37	5.83	2.99	6.27	15.00	1.25
Min	85	15.3	8.1	0.0	2.7	2.5	2.3	0.7	0.2	2.7	0.3	0.2	1E-3	0.01	3.53	0.64	0.33	0.94	0.77
CV	0.32	0.35	0.39	0.55	0.64	0.37	0.48	0.27	1.39	0.35	0.57	0.49	3.22	0.73	0.15	0.60	0.58	0.53	0.14
AMUC(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.81	2.11	0.15	0.01	0.04	1.63	2E-2	3E-2	3E-2	0.26	4E-2	1E-1	1E-2	1E-2	6E-3	7E-3	4E-2	0.05	76.93
SD	1.81	1.20	0.18	0.01	0.05	0.81	5E-2	6E-2	4E-2	0.26	4E-2	4E-2	1E-2	9E-3	4E-3	8E-3	2E-2	0.06	5.78
Max	12.73	4.59	0.63	0.05	0.20	3.16	2E-1	2E-1	2E-1	1.07	2E-1	2E-1	4E-2	3E-2	1E-2	3E-2	8E-2	0.24	90.81
Min	5.21	0.26	0.02	0.00	0.00	0.20	1E-3	1E-3	4E-4	0.00	6E-3	1E-2	4E-3	1E-3	2E-3	2E-3	2E-3	0.00	67.96
CV	0.27	0.57	1.22	1.15	1.08	0.50	3.12	2.41	1.37	1.02	1.13	0.43	0.72	0.80	0.68	1.13	0.61	1.15	0.08

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.44: Correlation matrix for PM_{10} and its composition at AMUC for winter season

AMUC(W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.94	0.91	0.96	0.76	0.73	0.74	0.10	0.22	0.83	0.95	0.50	0.83	0.95
TC		1.00	0.99	0.97	0.82	0.68	0.52	-0.17	0.23	0.70	0.98	0.48	0.68	0.86
OC			1.00	0.94	0.78	0.65	0.46	-0.20	0.25	0.68	0.96	0.44	0.62	0.82
EC				1.00	0.85	0.71	0.61	-0.13	0.17	0.73	0.98	0.54	0.75	0.89
NO_3^-					0.47	0.63	1.00	0.39	0.33	0.80	0.56	0.51	0.74	0.72
SO_4^{-2}					-0.30	-0.07		1.00	-0.15	0.30	-0.15	-0.30	0.39	0.23
NH_4^+					0.62	0.60			0.00	1.00	0.68	0.31	0.82	0.76
Metals					0.68	0.71			0.17		0.90	0.42	0.85	1.00

Table 2.45: Correlation matrix for $PM_{2.5}$ and its composition at AMUC for winter season

AMUC(W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.93	0.91	0.94	0.68	0.64	0.76	0.35	0.10	0.91	0.94	0.35	0.87	0.95
TC		1.00	0.99	0.98	0.82	0.69	0.60	0.07	0.17	0.74	0.98	0.45	0.67	0.80
OC			1.00	0.94	0.78	0.66	0.54	0.06	0.22	0.70	0.97	0.41	0.61	0.77
EC				1.00	0.84	0.71	0.65	0.08	0.09	0.77	0.96	0.49	0.73	0.81
NO_3^-					0.32	0.49	1.00	0.50	0.32	0.78	0.63	0.40	0.74	0.73
SO_4^{-2}					-0.35	-0.02		1.00	0.10	0.55	0.16	-0.18	0.56	0.47
NH_4^+					0.49	0.57			-0.03	1.00	0.80	0.20	0.89	0.95
Metals					0.55	0.51			-0.06		0.82	0.16	0.94	1.00

Table 2.46: Correlation matrix for PM_{10} and its composition at AMUC for summer season

AMUC(S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.85	0.81	0.86	0.60	0.60	0.46	0.60	-0.11	0.71	0.25	0.34	0.57	0.77
TC		1.00	0.99	0.98	0.69	0.54	0.50	0.66	0.03	0.91	0.52	0.15	0.49	0.38
OC			1.00	0.94	0.66	0.47	0.43	0.59	0.05	0.91	0.54	0.09	0.57	0.37
EC				1.00	0.72	0.61	0.58	0.73	0.01	0.88	0.48	0.23	0.37	0.38
NO_3^-					0.47	0.59	1.00	0.33	-0.18	0.34	0.17	-0.08	-0.25	0.02
SO_4^{-2}					0.57	0.31		1.00	0.04	0.71	0.52	0.21	0.22	0.33
NH_4^+					0.54	0.48			0.15	1.00	0.39	0.08	0.49	0.22
Metals					0.25	0.19			-0.08		0.08	0.39	0.63	1.00

Table 2.47: Correlation matrix for $PM_{2.5}$ and its composition AMUC for summer season

AMUC(S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.98	0.98	0.96	0.72	0.47	0.37	0.72	0.01	0.91	0.39	0.14	0.61	0.78
TC		1.00	0.99	0.98	0.76	0.47	0.44	0.73	0.07	0.91	0.47	0.13	0.50	0.71
OC			1.00	0.94	0.73	0.39	0.35	0.66	0.12	0.91	0.49	0.07	0.59	0.76
EC				1.00	0.78	0.54	0.52	0.79	0.02	0.89	0.43	0.19	0.38	0.62
NO_3^-					0.44	0.64	1.00	0.37	-0.25	0.32	0.05	-0.08	-0.33	-0.17
SO_4^{-2}					0.69	0.41		1.00	0.05	0.73	0.43	0.32	0.20	0.42
NH_4^+					0.61	0.42			0.21	1.00	0.31	0.06	0.50	0.62
Metals					0.36	-0.08			-0.03		0.39	0.08	0.90	1.00

2.4.4 BHU Susuvahi (BHUS)

The sampling period was December 31, 2020 – January 14, 2021, for winter and March 23 – April 06, 2021 for summer.

2.4.4.1 Particulate Matter (PM_{10}, $PM_{2.5}$)

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.43) and summer (Figure 2.44). Average levels for winter and summer season were 240±76 and 100±34 $\mu g/m^3$ (for $PM_{2.5}$) and 347±110 and 266±48 $\mu g/m^3$ (for PM_{10}) respectively. The $PM_{2.5}$ levels are 4 times higher than the NAQS and PM_{10} is 3.4 times higher than the NAQS in winter The $PM_{2.5}$ levels are 1.6 times higher and PM_{10} levels are 2.6 times higher than the NAQS in summer. A statistical summary of PM concentrations is presented in Table 2.52 to Table 2.55 for the winter and summer seasons. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards. PM_{10} levels also decreased but slightly exceed NAQS. The particles airborne from the soil surface during dust storms in the dry months of summer can contribute significantly to a coarse fraction.

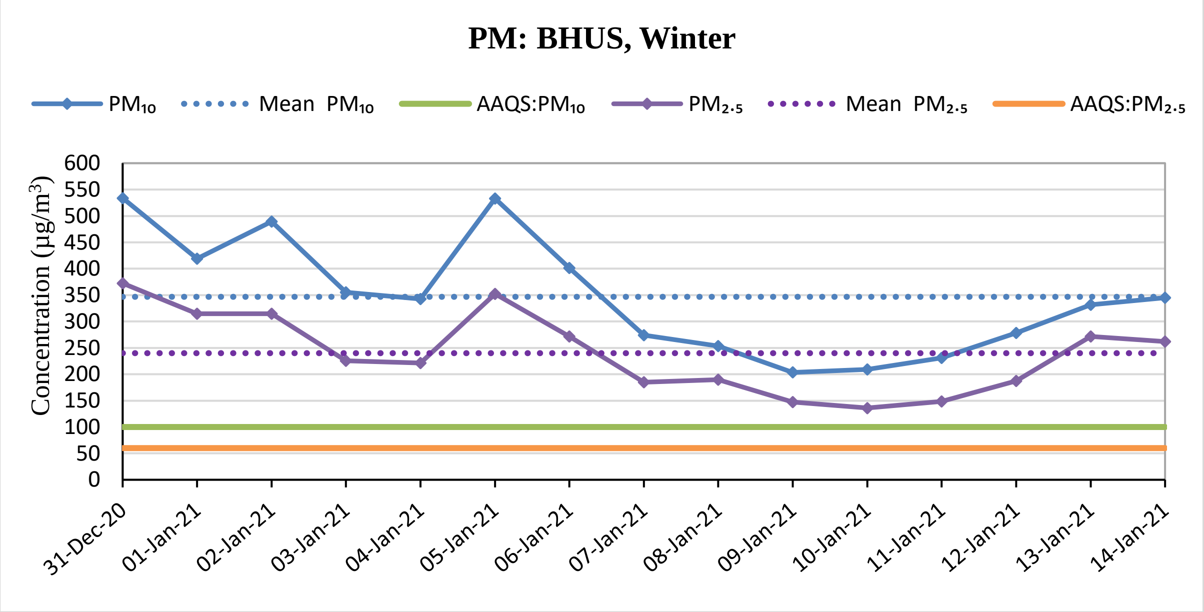


Figure 2.43: PM Concentrations at BHUS for Winter Season

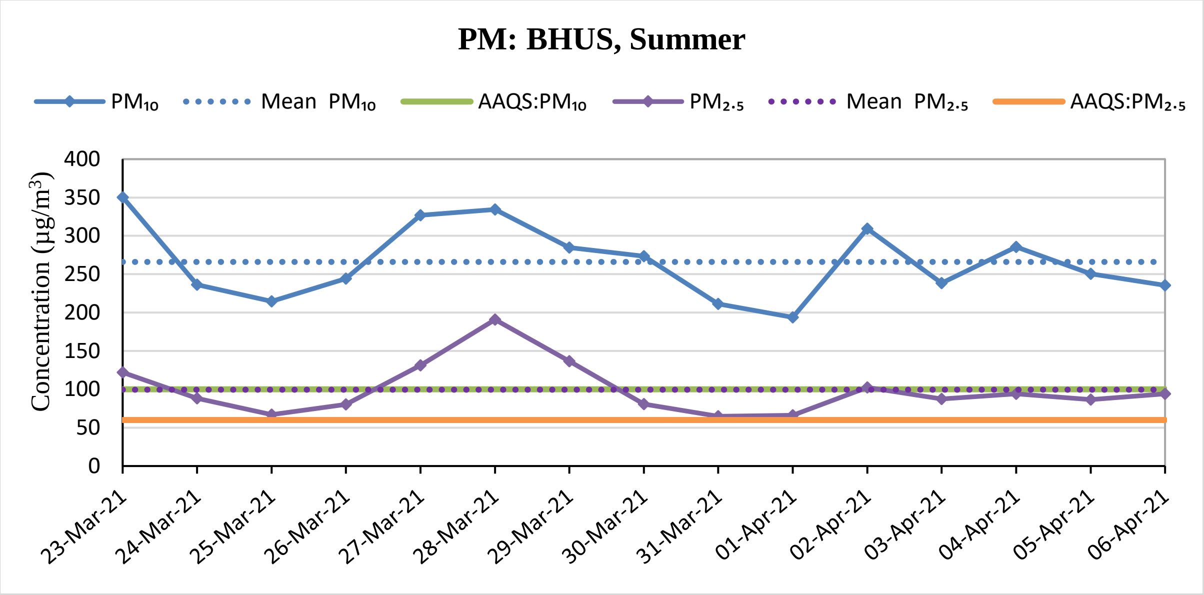


Figure 2.44: PM Concentrations at BHUS for Summer Season

2.4.4.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.45) and summer (Figure 2.46) seasons. It was observed that SO_2 concentrations were low (mostly < 6.0 µg/m^3) and met the air quality standard. NO_2 levels also under the national standard with an average of 15 days at 21.87±7.15 µg/m^3 in winter and 17.94±3.74 µg/m^3 in summer season. The summer concentration of NO_2 dropped significantly. Although the NO_2 is certainly a matter of concern, these values can largely be attributed to vehicular pollution and DG sets. Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.47 and the statistical summary in Table 2.48. The total BTX level is observed 18.57±5.16 µg/m^3 (Benzene: 7.51 and Toluene: 2.33 µg/m^3) in winter and 13.16±2.39 µg/m^3 (Benzene: 5.53 and Toluene: 1.31 µg/m^3) in summer seasons. The BTX levels were slightly high during winter than in the summer.

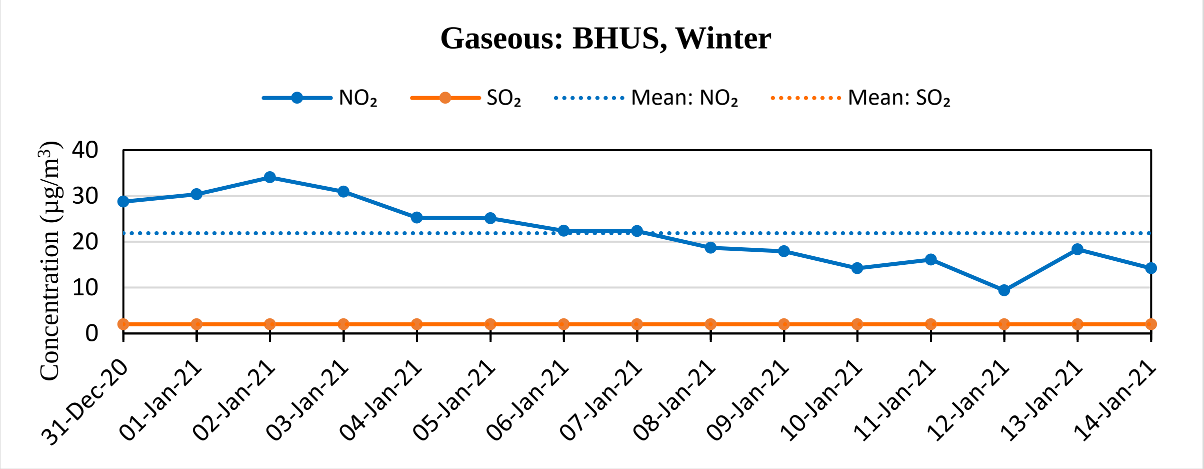


Figure 2.45: SO_2 and NO_2 Concentrations at BHUS for Winter Season

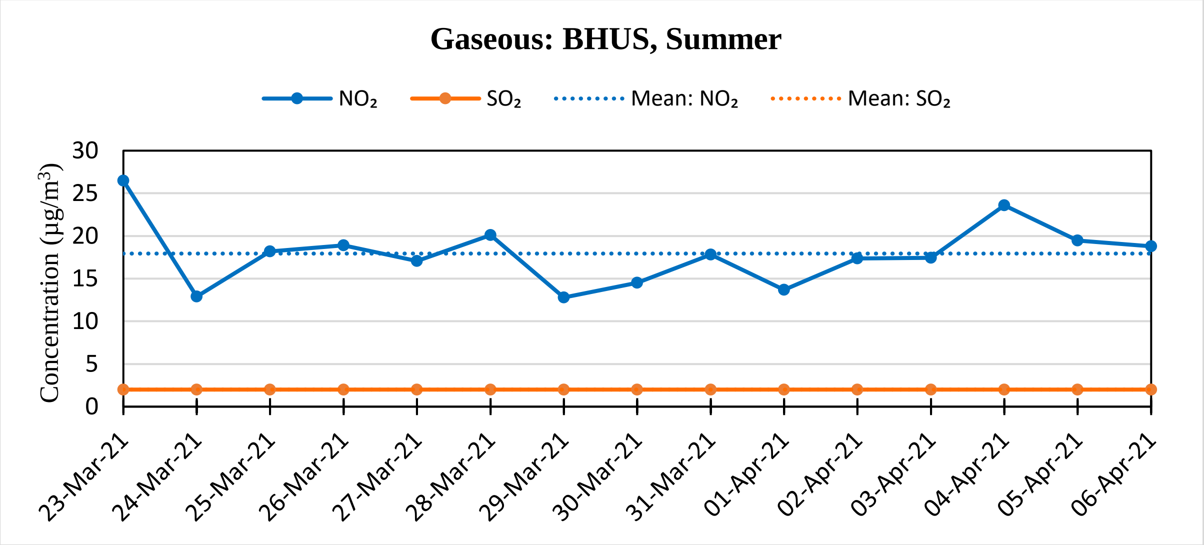


Figure 2.46: SO_2 and NO_2 Concentrations at BHUS for Summer Season

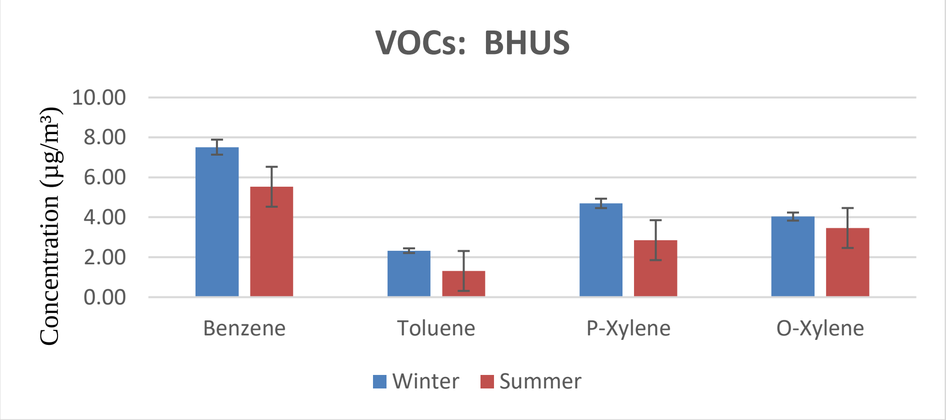


Figure 2.47: VOCs concentration at BHUS

2.4.4.3 Carbon Content (EC/OC) in $PM_{2.5}$

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and the ratio of OC fraction to TC are shown in Figure 2.48 (a) and (b) for winter and summer seasons. OC is observed higher (winter: 33.73±15.09 and summer: 9.50±5.34 μg/m^3) than the EC (winter: 18.96±9.79 and summer: 5.09±2.32 μg/m^3). It is also observed that the OC and EC are higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.49 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere at BHUS.

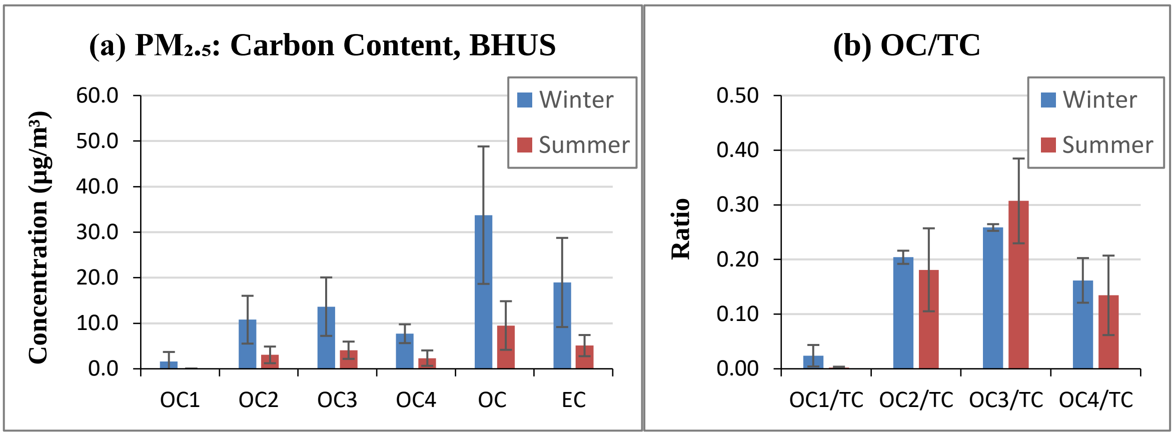


Figure 2.48: EC and OC Content in $PM_{2.5}$ at BHUS

2.4.4.4 PAHs in $PM_{2.5}$

Figure 2.49 shows the average measured concentration of PAHs at BHUS for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.50 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (19±13 ng/m^3) compared to summer season (13±4 ng/m^3). Major PAHs are DmP (5.3 ng/m^3), B(b)F (3.3 ng/m^3), B(a)P (1.7 ng/m^3) and Chr (1.6 ng/m^3) for winter season and BeA (2.5 ng/m^3), DmP (2.1 ng/m^3), DEP (1.5 ng/m^3), and Bbp (1.2 ng/m^3) for summer season.

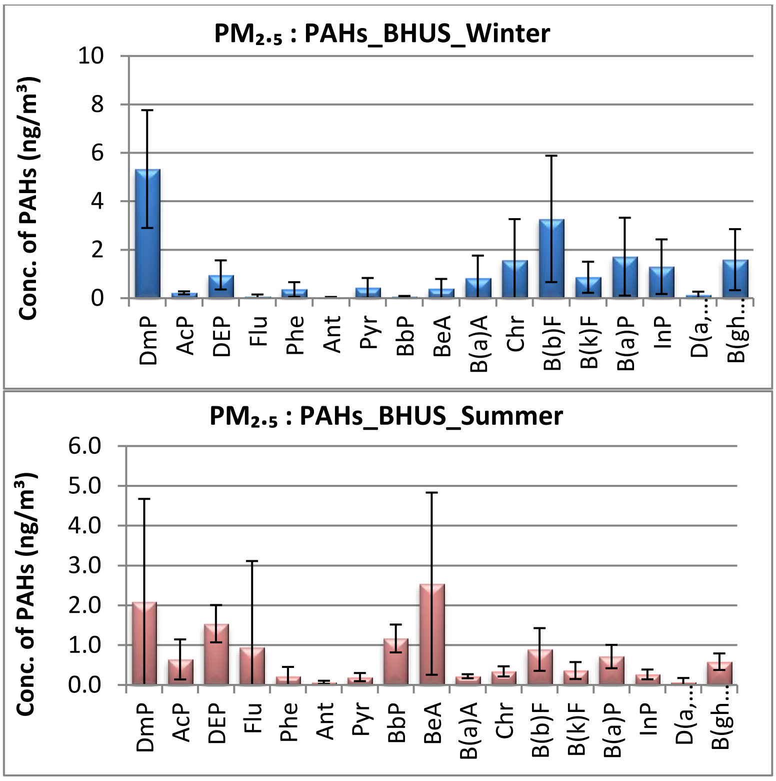


Figure 2.49: PAHs Concentrations in $PM_{2.5}$ at BHUS

2.4.4.5 Molecular Markers in $PM_{2.5}$

Total six molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21 α(H)_hopane, 17α(H),21β(H)-hopane, Pentriacontane, Hentriacontane and Tritriacontane. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D).

Figure 2.50 and Table 2.51 show the levels of six molecular markers. Total concentration of markers was 170±69.2 ng/m^3 in winter and 89.4±17 ng/m^3 in summer. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

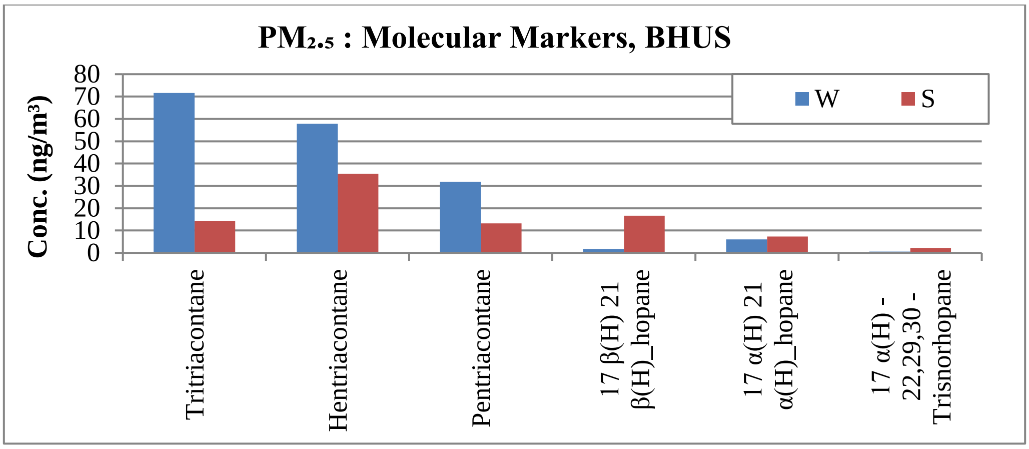


Figure 2.50: Molecular Markers in $PM_{2.5}$ at BHUS

2.4.4.6 Chemical Composition of PM_{10} and $PM_{2.5}$ and their correlation matrix

Graphical presentations of chemical species are shown for the winter and summer season at BHUS for PM_{10} (Figure 2.51) and $PM_{2.5}$ (Figure 2.52). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content, ionic species and elements] along with mass percentage (% R) recovered from PM are presented in Table 2.52 to Table 2.55 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.56 to Table 2.59 for both seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituents of the PM are presented in Figure 2.53 (a) and (b) for the winter season and Figure 2.54 (a) and (b) for the summer season.

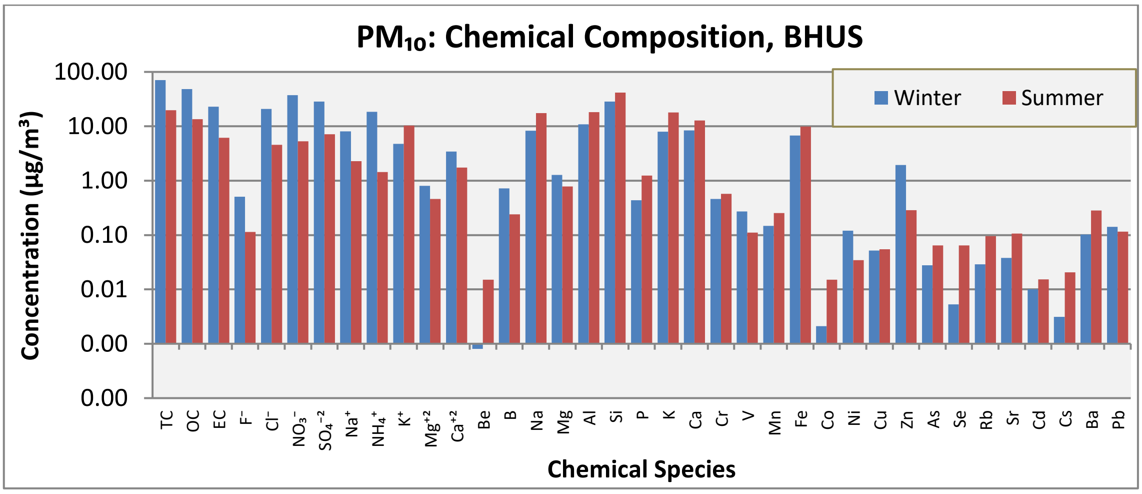


Figure 2.51: Concentrations of species in PM_{10} at BHUS

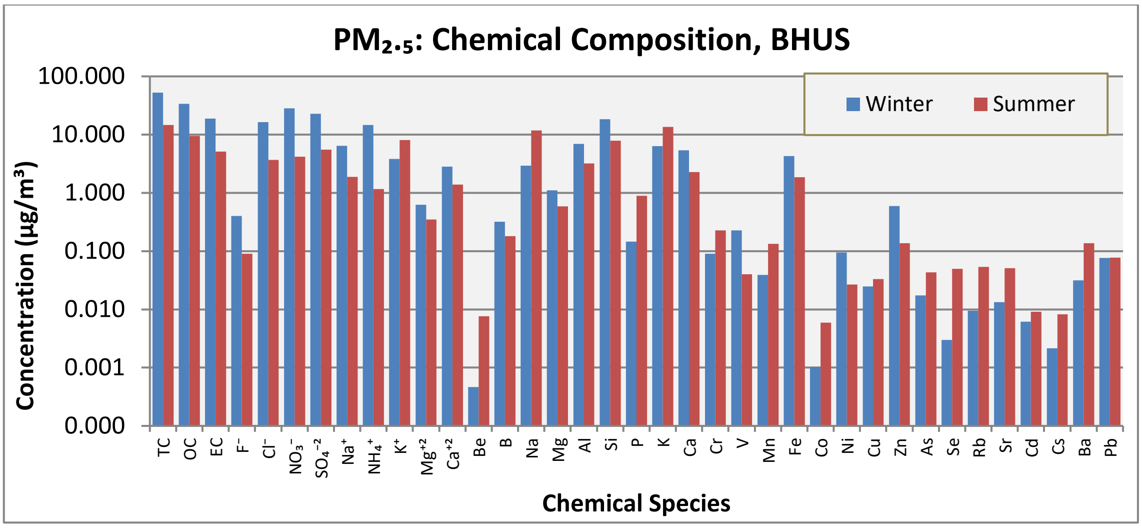


Figure 2.52: Concentrations of species in PM2.5 at BHUS

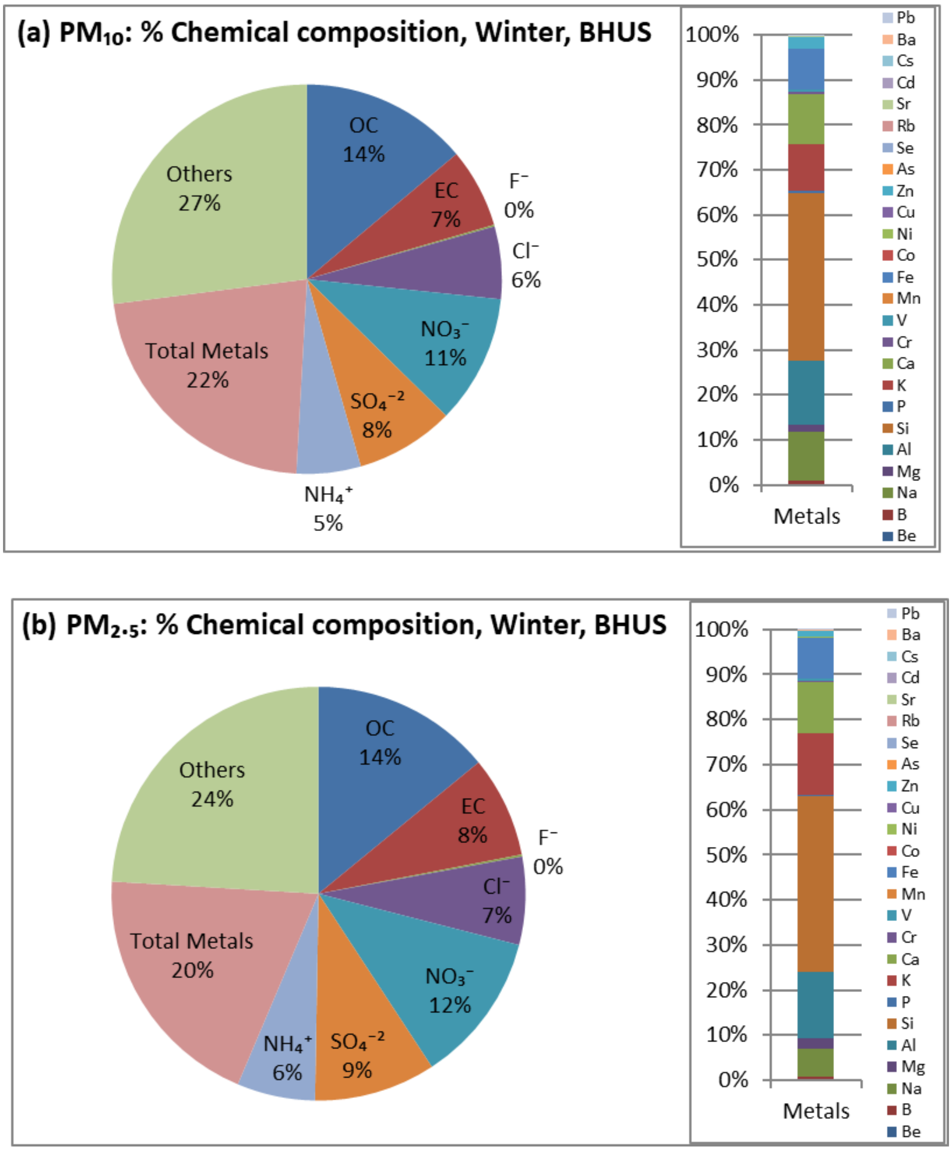


Figure 2.53: Percentage distribution of species in PM at BHUS for Winter Season

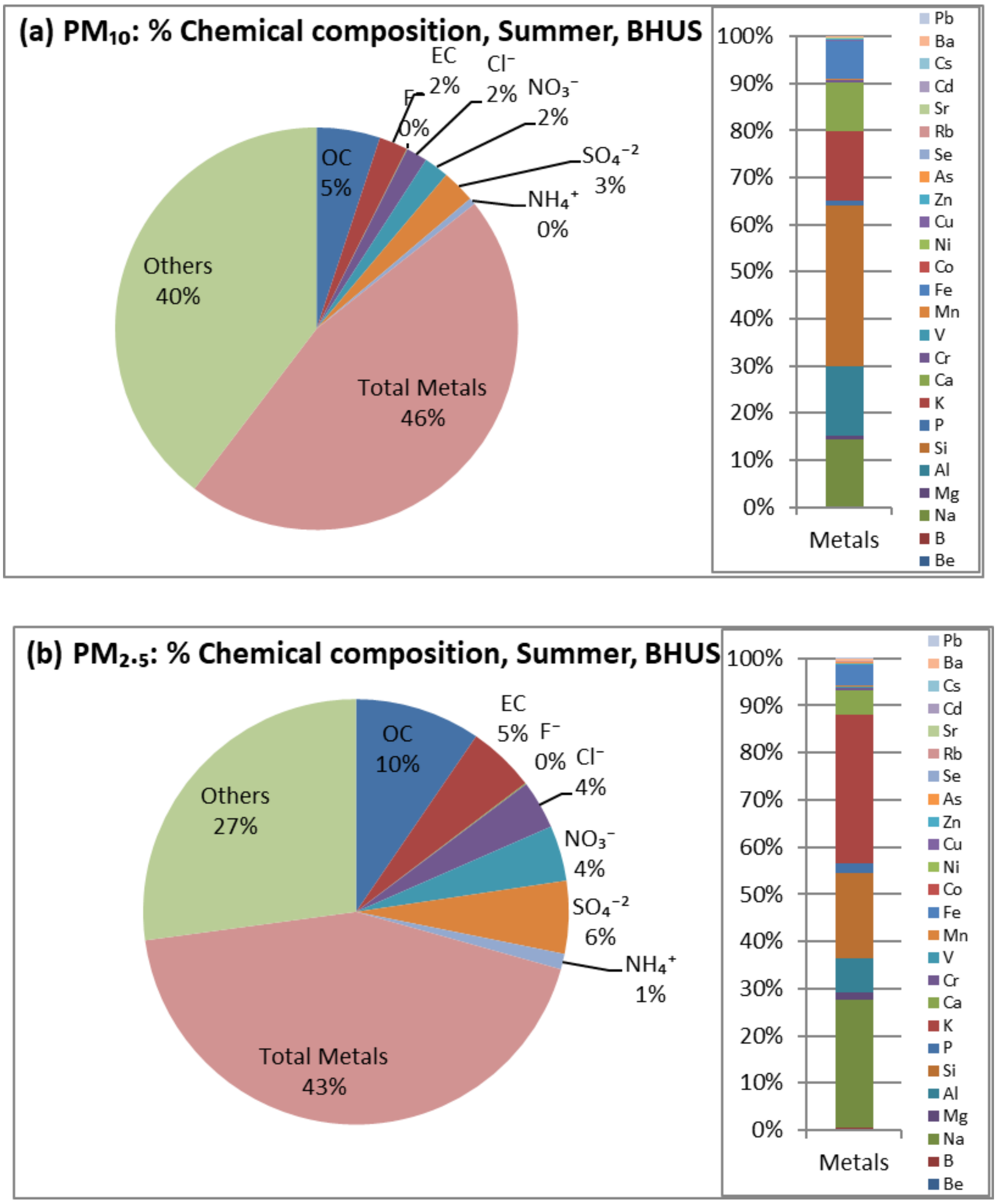


Figure 2.54: Percentage distribution of species in PM at BHUS for Summer Season

2.4.4.7 Comparison of PM_{10} and $PM_{2.5}$ Composition

The graphical compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.55) at BHUS. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (65%) than summer (43%). The major species contributing to fine mode are TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Be, V, Zn, As and Cd; whereas major species contributing in coarse mode are Ca^{+2}, Mg^{+2}, B, Mg, Al, Si, P, Ca, Cr, Mn, Fe, Sr and Ba.

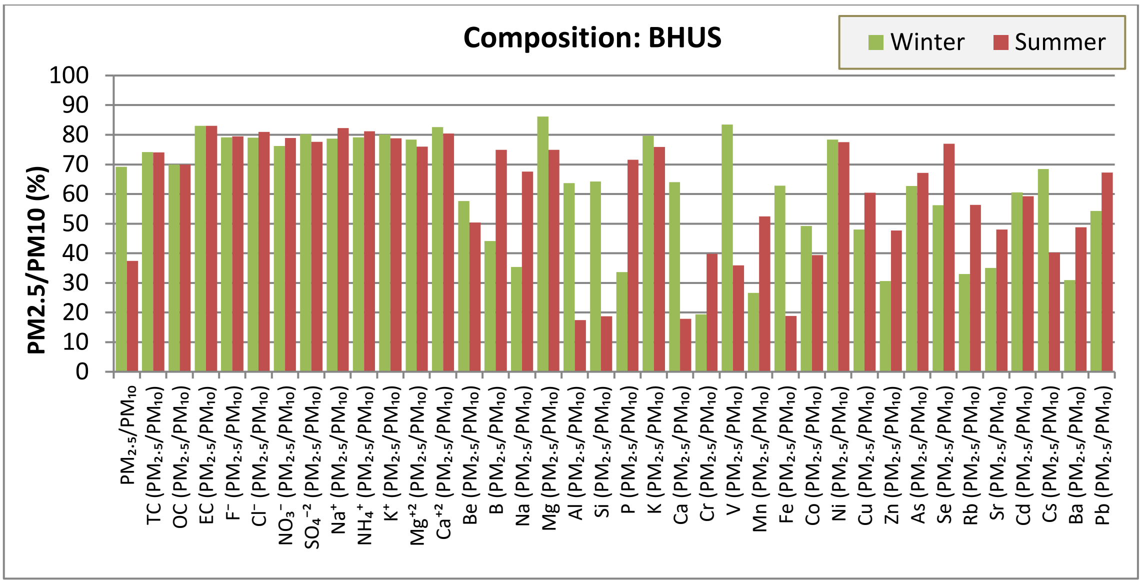


Figure 2.55: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at BHUS

Table 2.48: Statistical results of gaseous pollutants (µg/m^3) at BHUS for winter (W) and summer (S) seasons

BHUS(W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	21.87	2.00	1.50	0.35	1.17	2.02	5.04
SD	7.15	0.00	0.41	0.06	0.53	1.37	1.85
Max	34.04	2.00	1.95	0.48	2.16	5.17	8.87
Min	9.39	2.00	0.51	0.26	0.42	0.61	3.02
CV	0.33	0.00	0.28	0.18	0.45	0.68	0.37
BHUS (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	17.94	2.00	5.53	2.63	8.56	8.66	25.38
SD	3.74	0.00	0.88	0.36	1.69	2.16	4.90
Max	26.47	2.00	6.65	3.09	11.46	11.97	31.72
Min	12.79	2.00	4.42	2.25	7.05	6.71	20.88
CV	0.21	0.00	0.16	0.14	0.20	0.25	0.19

Table 2.49: Statistical results of carbon contents (µg/m^3) in PM$_{2.5}$ at BHUS for winter (W) and summer (S) seasons

BHUS (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	239.96	52.69	18.96	33.73	1.61	10.77	13.64	7.70	0.02	0.20	0.26	0.16
SD	75.85	24.79	9.79	15.09	2.08	5.25	6.42	2.06	0.02	0.01	0.01	0.04
Max	372.00	108.96	41.23	67.73	7.43	22.91	27.99	12.40	0.07	0.22	0.27	0.22
Min	136.00	22.21	7.06	15.16	0.11	4.53	5.50	4.69	0.00	0.18	0.25	0.09
CV	0.32	0.47	0.52	0.45	1.29	0.49	0.47	0.27	0.82	0.06	0.02	0.25
BHUS (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	99.50	14.59	5.09	9.50	0.03	3.05	4.07	2.34	0.00	0.18	0.31	0.13
SD	33.65	7.41	2.32	5.34	0.03	1.83	1.90	1.69	0.00	0.08	0.08	0.07
Max	191.00	28.98	8.64	21.70	0.07	6.94	8.34	6.35	0.01	0.24	0.52	0.22
Min	65.00	1.29	0.70	0.59	0.00	0.00	0.59	0.00	0.00	0.00	0.24	0.00
CV	0.34	0.51	0.46	0.56	0.84	0.60	0.47	0.72	0.92	0.42	0.25	0.54

Table 2.50: **Statistical results of PAHs (ng/m^3) in PM$_{2.5}$ at BHUS for winter (W) and summer (S) seasons**

BHUS (W)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	5.33	0.22	0.96	0.07	0.36	0.04	0.42	0.08	0.38	0.82	1.56	3.27	0.86	1.71	1.30	0.14	1.59	19.11
SD	2.43	0.06	0.60	0.08	0.30	0.01	0.41	0.01	0.41	0.94	1.70	2.61	0.64	1.61	1.13	0.13	1.26	13.10
Max	8.48	0.30	1.79	0.21	0.84	0.05	1.25	0.09	0.83	2.83	4.99	7.80	2.03	4.89	3.35	0.31	3.79	41.13
Min	2.20	0.12	0.11	0.00	0.00	0.03	0.03	0.05	0.00	0.23	0.29	0.78	0.23	0.45	0.26	0.01	0.42	6.04
CV	0.46	0.29	0.63	1.17	0.84	0.29	0.98	0.18	1.07	1.14	1.09	0.80	0.75	0.94	0.87	0.94	0.79	0.69
BHUS (S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	2.08	0.64	1.54	0.94	0.22	0.07	0.20	1.17	2.54	0.22	0.34	0.89	0.36	0.71	0.26	0.06	0.58	12.83
SD	2.59	0.50	0.47	2.17	0.24	0.04	0.10	0.35	2.29	0.05	0.13	0.54	0.21	0.29	0.12	0.11	0.21	4.20
Max	7.08	1.70	2.23	5.86	0.57	0.15	0.37	1.72	6.34	0.31	0.59	1.59	0.75	1.09	0.42	0.31	0.89	18.71
Min	0.11	0.24	0.74	0.00	0.00	0.03	0.06	0.72	0.46	0.14	0.19	0.32	0.14	0.35	0.11	0.01	0.39	7.43
CV	1.24	0.78	0.30	2.31	1.09	0.60	0.52	0.30	0.90	0.23	0.38	0.60	0.59	0.41	0.46	1.75	0.36	0.33

Table 2.51: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at BHUS for winter (W) and summer (S) seasons

MNS(W)	Tritriacontane	Hentriacontane	Pentriacontane	17 β(H) 21 β(H)_hopane	17 α(H) 21 α(H)_hopane	17 α(H) - 22,29,30 - Trisnorhopane	Total
Mean	71.66	57.83	31.90	1.81	6.10	0.66	169.96
SD	32.24	24.30	13.80	0.43	4.19	0.21	69.18
CV	0.45	0.42	0.43	0.24	0.69	0.32	0.41

MNS(S)	Tritriacontane	Hentriacontane	Pentriacontane	17 β(H) 21 β(H)_hopane	17 α(H) 21 α(H)_hopane	17 α(H) - 22,29,30 - Trisnorhopane	Total
Mean	14.41	35.51	13.20	16.69	7.40	2.15	89.35
SD	2.84	11.00	1.13	3.85	1.08	1.08	16.99
CV	0.20	0.31	0.09	0.23	0.15	0.50	0.19

Table 2.52: Statistical results of chemical characterization (µg/m^3) of PM_{10} at BHUS for winter (W) season

BHUS(W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	347	48.2	22.8	0.5	20.9	37.1	28.4	8.1	18.5	4.8	0.8	3.4	8E-4	0.72	8.26	1.28	10.92	28.44	0.43
SD	110	21.6	11.8	0.1	8.4	11.3	6.7	2.1	5.2	1.3	0.2	2.1	2E-4	0.47	5.57	0.36	4.99	13.03	0.16
Max	534	96.8	49.7	0.7	38.4	60.5	38.6	11.5	32.6	8.2	1.3	7.1	1E-3	1.60	23.30	1.87	17.70	49.04	0.73
Min	203	21.7	8.5	0.3	9.3	21.8	17.1	4.3	12.4	3.5	0.5	0.1	6E-4	0.12	3.46	0.79	2.73	7.38	0.13
CV	0.32	0.45	0.52	0.20	0.40	0.31	0.24	0.25	0.28	0.28	0.30	0.61	0.21	0.65	0.67	0.28	0.46	0.46	0.37
BHUS(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	8.00	8.40	0.46	0.27	0.15	6.79	0.00	0.12	0.05	1.93	0.03	0.01	0.03	0.04	0.01	0.00	0.10	0.14	74.1
SD	2.20	4.02	0.15	0.03	0.04	3.15	0.00	0.02	0.03	3.60	0.01	0.00	0.01	0.01	0.01	0.00	0.06	0.06	5.1
Max	14.02	14.37	0.70	0.31	0.21	11.78	0.00	0.15	0.17	14.86	0.05	0.01	0.04	0.06	0.03	0.00	0.26	0.27	85.7
Min	5.81	2.25	0.25	0.22	0.08	1.63	0.00	0.09	0.02	0.40	0.01	0.00	0.01	0.02	0.00	0.00	0.04	0.07	68.8
CV	0.27	0.48	0.33	0.11	0.27	0.46	0.29	0.15	0.66	1.87	0.33	0.37	0.32	0.31	0.74	0.17	0.59	0.39	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.53: Statistical results of chemical characterization (µg/m^3) of PM$_{2.5}$ at BHUS for winter (W) season

BHUS(W)	PM$_{2.5}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	240	33.7	19.0	0.4	16.5	28.3	22.8	6.4	14.6	3.8	0.6	2.8	5E-4	0.32	2.93	1.10	6.95	18.27	0.15
SD	76	15.1	9.8	0.1	6.7	8.7	5.5	1.8	4.2	1.1	0.2	1.7	9E-5	0.24	1.19	0.33	3.60	10.33	0.08
Max	372	67.7	41.2	0.5	30.5	46.7	32.9	10.0	25.3	6.6	0.9	5.6	6E-4	0.85	5.81	1.65	12.45	31.77	0.30
Min	136	15.2	7.1	0.3	7.9	17.4	13.5	3.3	9.3	2.7	0.4	0.1	3E-4	0.05	1.46	0.68	0.28	0.74	0.00
CV	0.32	0.45	0.52	0.16	0.41	0.31	0.24	0.29	0.29	0.28	0.28	0.61	2E-1	0.76	0.41	0.30	0.52	0.57	0.56
BHUS(W)	**K**	**Ca**	**Cr**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Rb**	**Sr**	**Cd**	**Cs**	**Ba**	**Pb**	**% R**
Mean	6.37	5.38	0.09	0.23	0.04	4.27	0.00	0.09	0.02	0.59	0.017	0.003	0.009	0.013	0.006	0.002	0.031	0.08	77.1
SD	1.60	3.05	0.06	0.02	0.02	2.39	0.00	0.02	0.01	0.39	0.008	0.002	0.006	0.005	0.006	0.000	0.039	0.03	6.5
Max	10.02	10.19	0.25	0.28	0.10	7.66	0.00	0.14	0.06	1.32	0.030	0.005	0.024	0.023	0.024	0.003	0.133	0.15	93.8
Min	4.71	0.19	0.03	0.18	0.02	0.16	0.00	0.08	0.01	0.14	0.007	0.000	0.002	0.006	0.002	0.002	0.005	0.04	69.2
CV	0.25	0.57	0.62	0.11	0.48	0.56	0.38	0.19	0.47	0.66	0.44	0.57	0.65	0.39	0.99	0.14	1.25	0.44	0.08

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.54: Statistical results chemical characterization (µg/m^3) of PM$_{10}$ at BHUS for summer (S) season

BHUS(S)	PM$_{10}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	266	13.6	6.1	0.1	4.5	5.3	7.1	2.3	1.4	10.3	0.5	1.7	2E-2	0.24	17.49	0.79	18.22	41.76	1.24
SD	48	7.6	2.8	0.1	3.5	4.0	3.5	1.2	1.3	2.5	0.1	0.8	2E-2	0.08	7.16	0.25	3.06	8.67	0.30
Max	350	31.0	10.4	0.3	13.4	14.3	13.9	6.0	5.3	15.2	0.9	3.2	8E-2	0.40	27.79	1.49	22.07	63.80	1.92
Min	194	0.8	0.8	0.1	1.7	2.1	3.1	1.1	0.3	6.9	0.3	0.4	9E-3	0.12	2.88	0.54	12.65	27.83	0.69
CV	0.18	0.56	0.46	0.64	0.76	0.75	0.50	0.54	0.93	0.25	0.32	0.44	1.25	0.33	0.41	0.32	0.17	0.21	0.24
BHUS(S)	**K**	**Ca**	**Cr**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Rb**	**Sr**	**Cd**	**Cs**	**Ba**	**Pb**	**% R**
Mean	17.93	12.74	0.57	0.11	0.25	9.92	2E-2	3E-2	5E-2	0.29	0.06	6E-2	1E-1	1E-1	2E-2	2E-2	0.28	0.11	60.22
SD	4.33	2.38	0.12	0.03	0.09	1.66	1E-2	3E-2	3E-2	0.12	0.05	5E-2	7E-2	5E-2	2E-2	7E-3	0.22	0.07	2.39
Max	26.53	16.49	0.86	0.18	0.53	12.89	5E-2	1E-1	2E-1	0.60	0.21	2E-1	4E-1	2E-1	7E-2	4E-2	0.86	0.33	63.86
Min	12.39	8.60	0.42	0.08	0.19	7.40	1E-2	2E-2	3E-2	0.15	0.01	2E-2	5E-2	6E-2	9E-3	2E-2	0.11	0.06	56.66
CV	0.24	0.19	0.21	0.24	0.34	0.17	0.72	0.93	0.60	0.42	0.74	0.77	0.78	0.48	0.99	0.33	0.76	0.57	0.04

% R is the % recovery of mass of collected particle through compositional analysis

Table 2.55: Statistical results of chemical characterization (μg/m^3) of $PM_{2.5}$ at BHUS for summer (S) season

BHUS(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	100	9.5	5.1	0.1	3.7	4.2	5.5	1.9	1.2	8.1	0.3	1.4	8E-3	0.18	11.81	0.59	3.19	7.83	0.89
SD	34	5.3	2.3	0.1	2.9	3.3	2.6	1.1	1.1	2.3	0.1	0.6	2E-2	0.07	5.19	0.15	1.67	4.17	0.37
Max	191	21.7	8.6	0.3	12.0	11.9	9.9	5.4	3.9	12.2	0.6	2.7	7E-2	0.28	18.38	0.91	7.07	17.01	1.26
Min	65	0.6	0.7	0.0	1.5	1.7	2.5	0.9	0.3	4.8	0.2	0.3	1E-3	0.06	0.19	0.40	0.45	1.30	0.00
CV	0.34	0.56	0.46	0.64	0.79	0.79	0.47	0.60	0.91	0.28	0.30	0.44	2.21	0.40	0.44	0.26	0.52	0.53	0.41
BHUS(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	13.62	2.28	0.23	0.04	0.13	1.87	6E-3	3E-2	3E-2	0.14	4E-2	5E-2	5E-2	5E-2	9E-3	8E-3	1E-1	0.08	73.64
SD	4.23	1.21	0.19	0.03	0.13	1.00	1E-2	3E-2	3E-2	0.09	4E-2	4E-2	8E-2	6E-2	1E-2	1E-2	1E-1	0.07	5.16
Max	23.83	5.00	0.57	0.14	0.42	4.33	4E-2	1E-1	1E-1	0.35	2E-1	2E-1	3E-1	2E-1	4E-2	4E-2	3E-1	0.29	85.76
Min	8.89	0.34	0.01	0.01	0.02	0.31	9E-4	6E-3	8E-3	0.01	5E-3	1E-2	8E-3	3E-3	1E-3	2E-3	2E-2	0.01	65.80
CV	0.31	0.53	0.85	0.84	0.96	0.53	1.71	1.10	0.90	0.66	0.88	0.88	1.47	1.09	1.06	1.30	0.73	0.91	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.56: Correlation Matrix for PM_{10} and its composition at BHUS for winter season

BHUS(W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.93	0.93	0.92	0.62	0.22	0.39	0.36	0.02	0.56	0.52	0.29	0.62	0.96
TC		1.00	1.00	0.99	0.62	0.16	0.20	0.11	0.05	0.36	0.32	0.12	0.60	0.84
OC			1.00	0.99	0.62	0.14	0.22	0.12	0.02	0.39	0.34	0.11	0.61	0.84
EC				1.00	0.62	0.20	0.17	0.09	0.10	0.31	0.29	0.13	0.58	0.84
NO_3^-					0.24	-0.06	1.00	0.80	-0.21	0.66	0.59	0.30	-0.13	0.29
SO_4^{-2}					0.05	0.16		1.00	-0.07	0.56	0.36	0.40	-0.01	0.28
NH_4^+					0.35	-0.12			-0.26	1.00	0.70	0.38	0.37	0.53
Metals					0.56	0.11			-0.01		0.54	0.30	0.69	1.00

Table 2.57: Correlation matrix for $PM_{2.5}$ and its composition at BHUS for winter season

BHUS(W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.92	0.93	0.90	0.64	0.17	0.19	0.28	-0.10	0.65	0.42	0.12	0.79	0.92
TC		1.00	1.00	0.99	0.63	0.22	0.05	0.06	-0.02	0.46	0.27	0.06	0.64	0.79
OC			1.00	0.99	0.63	0.20	0.06	0.07	-0.06	0.48	0.29	0.05	0.64	0.80
EC				1.00	0.63	0.25	0.03	0.04	0.04	0.42	0.25	0.07	0.62	0.76
NO_3^-					0.36	0.14	1.00	0.81	-0.18	0.49	0.47	0.19	-0.21	-0.03
SO_4^{-2}					0.36	0.17		1.00	-0.15	0.59	0.29	0.30	0.03	0.14
NH_4^+					0.51	-0.04			-0.34	1.00	0.58	0.38	0.40	0.57
Metals					0.46	-0.04			-0.12		0.44	0.12	0.92	1.00

Table 2.58: Correlation matrix for PM_{10} and its composition at BHUS for summer season

BHUS(S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.52	0.47	0.60	0.66	0.63	0.79	0.53	-0.46	0.55	0.71	0.37	0.64	0.92
TC		1.00	0.99	0.92	0.47	0.29	0.17	0.30	-0.35	0.57	0.76	0.07	0.40	0.17
OC			1.00	0.85	0.50	0.30	0.11	0.26	-0.33	0.58	0.72	0.03	0.37	0.11
EC				1.00	0.34	0.24	0.30	0.37	-0.37	0.49	0.80	0.19	0.43	0.30
NO_3^-					0.64	0.78	1.00	0.62	-0.25	0.52	0.58	0.52	0.55	0.80
SO_4^{-2}					0.65	0.34		1.00	-0.18	0.84	0.75	-0.11	0.70	0.43
NH_4^+					0.83	0.54			-0.21	1.00	0.86	-0.09	0.72	0.31
Metals					0.53	0.55			-0.39		0.45	0.40	0.51	1.00

Table 2.59: Correlation matrix for $PM_{2.5}$ and its composition at BHUS for summer season

BHUS(S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.68	0.68	0.63	0.88	0.61	0.66	0.65	-0.39	0.87	0.86	-0.02	0.84	0.91
TC		1.00	0.99	0.92	0.43	0.21	0.18	0.26	-0.33	0.55	0.73	0.04	0.39	0.45
OC			1.00	0.85	0.47	0.20	0.11	0.22	-0.30	0.54	0.67	-0.01	0.37	0.48
EC				1.00	0.30	0.22	0.33	0.33	-0.36	0.50	0.79	0.14	0.40	0.34
NO_3^-					0.63	0.82	1.00	0.53	-0.24	0.55	0.59	0.35	0.56	0.57
SO_4^{-2}					0.55	0.25		1.00	-0.07	0.86	0.72	-0.27	0.62	0.54
NH_4^+					0.78	0.46			-0.19	1.00	0.86	-0.20	0.73	0.74
Metals					0.91	0.55			-0.33		0.64	-0.12	0.76	1.00

2.4.5 Overall Summary and results

The sampling period for winter is November 08, 2020, to December 09, 2020, and April 10, 2021, to May 10, 2021, for the summer season

2.4.5.1 Particulate Matter (PM_{10}, $PM_{2.5}$)

The seasonal comparison is shown for PM_{10} (Figure 2.56), $PM_{2.5}$ (Figure 2.57) and the ratio of $PM_{2.5}$ to PM_{10} (Figure 2.58) for all sites. The overall summary of experimental results for PM is shown for the winter and summer seasons (Table 2.60).

Winter

The overall city average of $PM_{2.5}$ in winter was 265±21 µg/m^3 and PM_{10} was 367±29 µg/m^3. The $PM_{2.5}$ levels are about 4.4 times higher than the national air quality standard (60 µg/m^3) and PM_{10} about 3.7 times higher than the standard (100 µg/m^3). PM_{10} levels were highest at BCKR, the residential site at 401 µg/m^3, followed by levels at IMAL (380 µg/m^3), a commercial site. $PM_{2.5}$ levels were highest at IMAL, the commercial site at 285 µg/m^3, followed by levels at BCKR (281 µg/m^3), a residential site. The highest variability was seen at IMAL (CV: 0.37) for $PM_{2.5}$ followed by BHUS and AMUC (CV: 0.32). The highest variation for PM_{10} was seen at IMAL (CV: 0.33) and least at BCKR (CV: 0.26).

The ratio of $PM_{2.5}$ to PM_{10} is a useful parameter to indicate the relative abundance of fine particles (i.e., $PM_{2.5}$) and toxicity of particulate matter. The overall city ratio is 0.72 for winter and 0.40 for summer and it was highest at IMAL and AMUC (0.75), followed by BCKR (0.70) for winter and highest at IMAL (0.43), followed by AMUC (0.42). The relatively high $PM_{2.5}$ at these sites could be attributed by combustion sources and less road dust emission.

Summer

The overall city average of $PM_{2.5}$ levels in summer dropped to 116±11 µg/m^3 also PM_{10} dropped to 287±21 µg/m^3 compared to winter. The $PM_{2.5}$ levels slightly exceed by 1.9 times the standards, while PM_{10} is 2.9 times higher than the standard. PM_{10} levels were highest at BCKR, the residential site at 314 µg/m^3, followed by levels at AMUC (294 µg/m^3), industrial site. $PM_{2.5}$ levels were highest at AMUC, the industrial site at 124 µg/m^3, followed by levels at BCKR (121 µg/m^3), a residential site.

The highest variability in $PM_{2.5}$ was seen at BHUS (CV: 0.34) followed by AMUC (CV: 0.32). The highest variation for PM_{10} was seen at BCKR (CV: 0.36) and least at BHUS (CV: 0.18). The overall $PM_{2.5}$ to PM_{10} city ratio is 0.72 for winter 0.40 for summer and it was highest at IMAL and AMUC (0.75), followed by BCKR (0.70) for winter and highest at IMAL (0.43), followed by AMUC (0.42)

The time-series data also reveal that within winter, levels of PM_{10} and $PM_{2.5}$ may show increasing or decreasing patterns. It is seen that levels are highest and increase during the last week of December and the first week of January. In the later part of January, the levels drop rapidly.

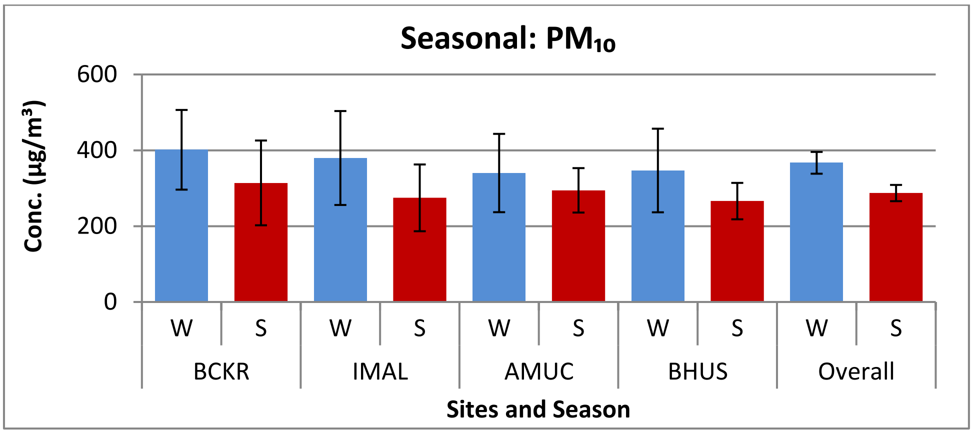


Figure 2.56: Seasonal comparison of PM_{10} levels for all Sites

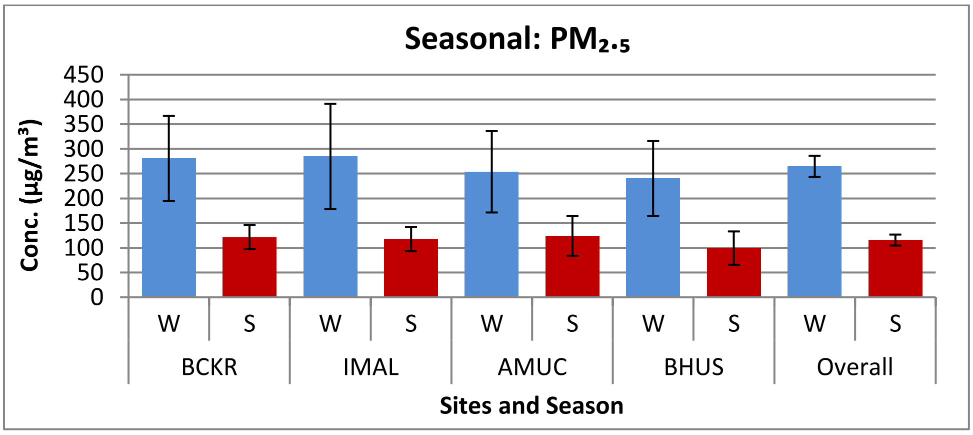


Figure 2.57: Seasonal comparison of $PM_{2.5}$ levels for all Sites

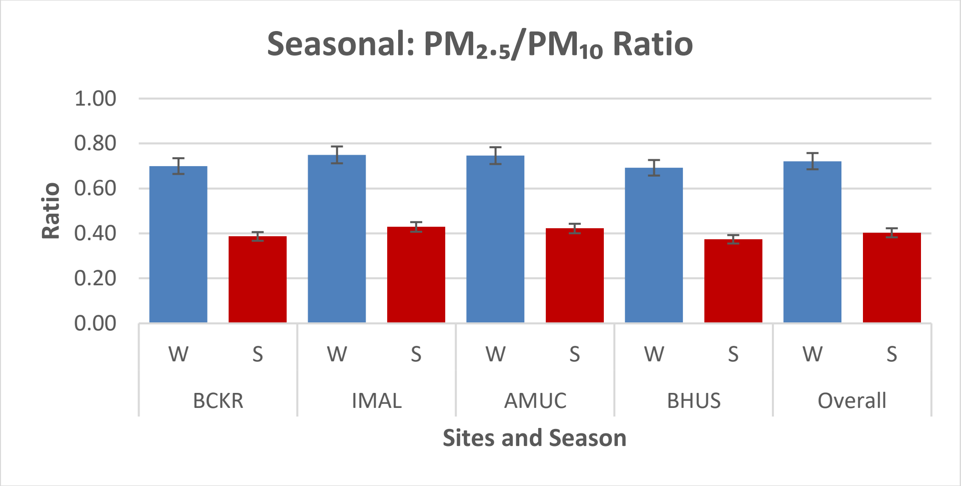


Figure 2.58: Seasonal comparison of $PM_{2.5}$ /PM_{10} ratio

2.4.5.2 Gaseous Pollutants (NO_2 and SO_2)

The seasonal comparison is shown for NO_2 and SO_2 (Figure 2.59). The overall average concentrations with statistical summary are presented in Table 2.61 and Table 2.62 for all sites for winter and summer seasons.

The SO_2 levels were quite low (mostly < 5.0 µg/m^3) and were always within the air quality standards (80 µg/m^3). The SO_2 levels being very low have not been further discussed.

It was observed that NO_2 levels were within the air quality standards (80 µg/m^3) during both seasons. The overall city-level average NO_2 levels are 30.20±9.04 µg/m^3 in winter and 19.69±3.22 µg/m^3 in summer. The highest NO_2 concentration was observed at BCKR in winter (40.17 µg/m^3) and at BCKR in summer (24.03 µg/m^3). NO_2 is an emerging pollutant that can largely be attributed to vehicular emissions. BCKR (residential area) and IMAL (commercial area) are having higher vehicular emissions of NO_2. Levels drop significantly in summer due to high wind speeds, convective conditions, large mixing height resulting in better dilution and dispersion of the NO_2.

Although the NO_2 levels meet the national air quality standard, efforts are required to improve the air quality for NO_2, particularly in the winter season, as it will be difficult to reduce the emission after the fact at a later stage.

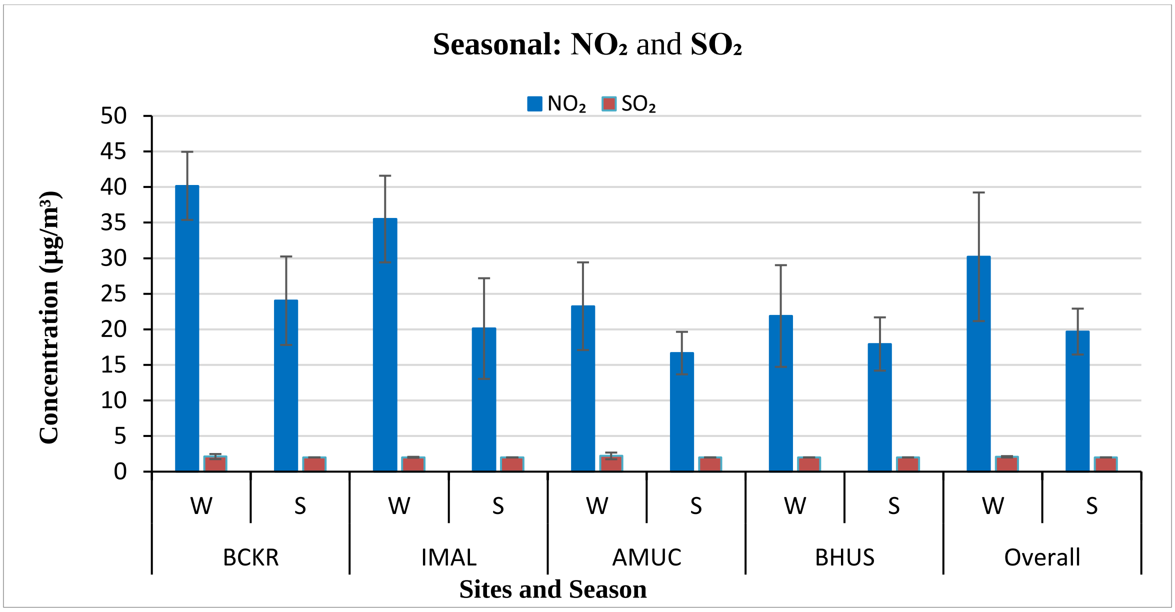


Figure 2.59: Seasonal Comparison of NO2 and SO2 levels for all Sites

2.4.5.3 Volatile Organic Compounds (VOCs: BTX)

The seasonal comparison for VOCs (BTX) is shown in Figure 2.60. The overall statistical summary is presented in Table 2.61 to Table 2.62 for all sites for the winter and summer seasons.

The overall city-level average of BTX levels is 18.63±1.12 µg/m^3 in winter and 11.39±4.21 µg/m^3 in summer. The highest BTX concentration was observed at BCKR in winter (19.47 µg/m^3) and summer (16.44 µg/m^3).

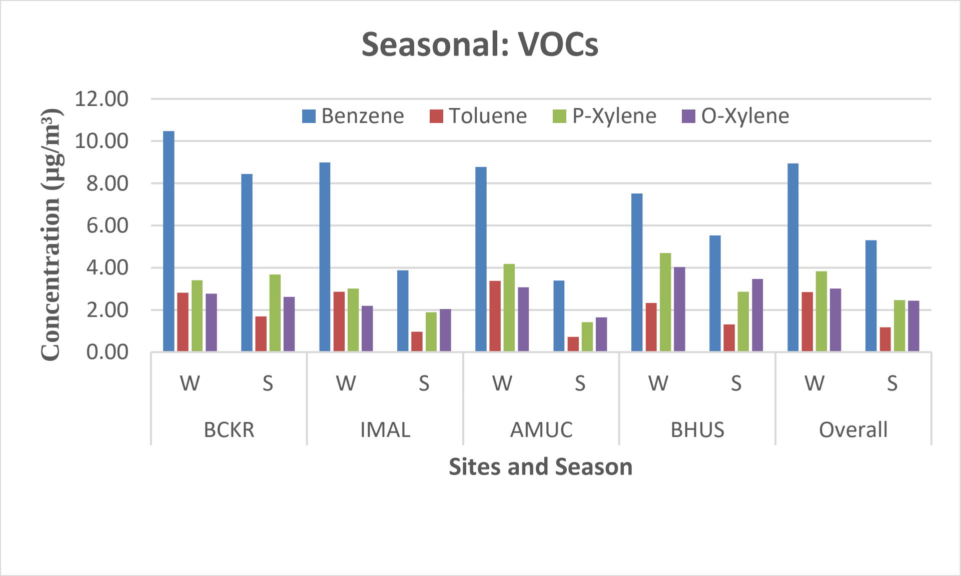


Figure 2.60: Seasonal comparison of VOCs for all Sites

2.4.5.4 Carbon Content (EC/OC) in $PM_{2.5}$

The seasonal comparison for OC and EC is presented in Figure 2.61 for PM_{10} and Figure 2.62 for $PM_{2.5}$. The $PM_{2.5}$ contained a high fraction of TC (OC+EC), 26% in winter and 27% in summer seasons. The OC is observed higher than the EC at each site during winter and summer; this is generally true that in the atmosphere volatile and semi-volatile organic compounds continuously undergo nucleation, oxidation, condensation and convert into organic particles, whereas EC remains unchanged, as a result, the ratio of OC to EC further increases. However, the ratio of OC3/TC is observed higher than other OCs; this indicates the formation of secondary organic carbon particles in the atmosphere is an important process. It is also observed that the OC and EC are higher in the winter season than in the summer season, probably because of poor dispersion in winter and more combustion sources, including biomass and municipal solid waste (MSW) burning. It is observed that the average TC to $PM_{2.5}$ ratio were maximum (29.9%) at AMUC followed by IMAL and minimum (22%) at BHUS in winter (Table 2.82) and maximum (31.8%) at AMUC and minimum (14.7%) at BHUS in summer (Table 2.84).

The overall summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.63 to Table 2.64 for winter and summer seasons.

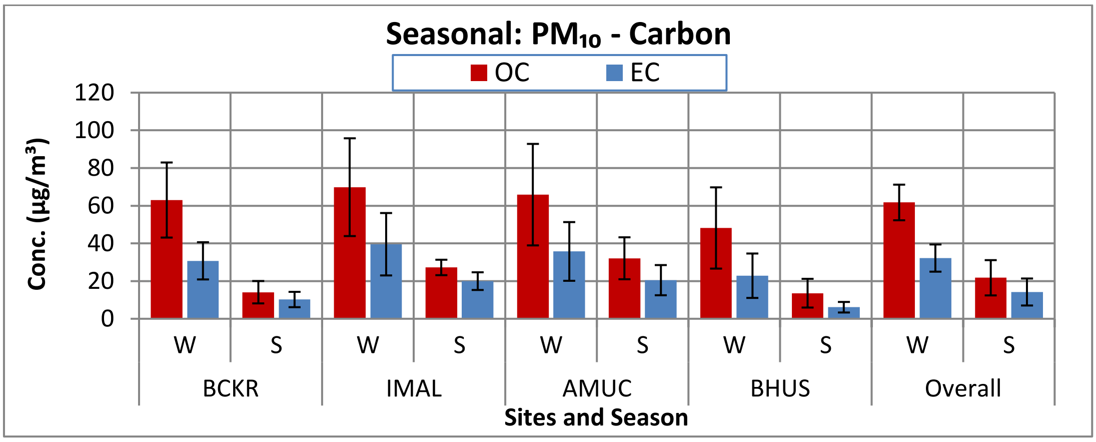


Figure 2.61: Seasonal Comparison of EC and OC in PM_{10} for all Sites

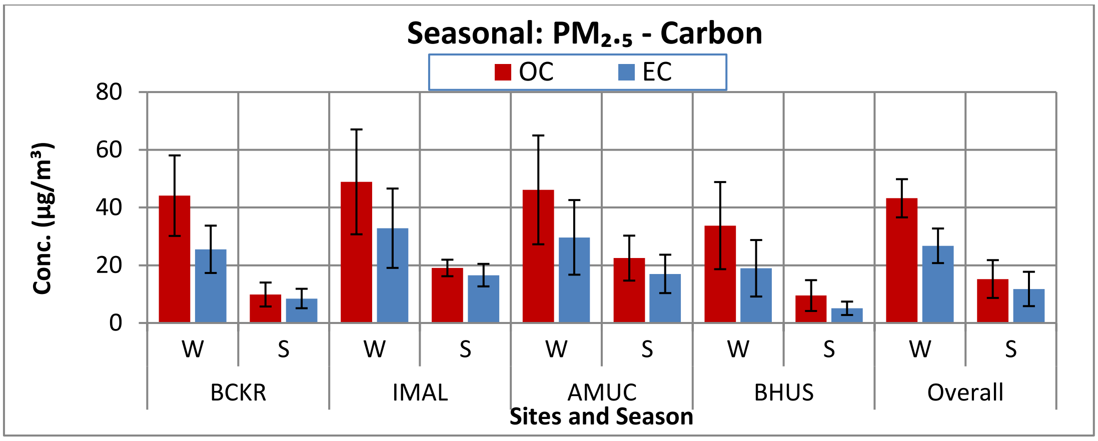


Figure 2.62: Seasonal Comparison of EC and OC in $PM_{2.5}$ for all Sites

2.4.5.5 PAHs in $PM_{2.5}$

The average concentrations of PAHs are shown graphically for the winter season (Figure 2.63) and summer season (Figure 2.64**Error! Reference source not found.**) for all sites along with the overall average concentration for Varanasi. Average concentrations are shown in Table 2.65 to Table 2.66 with the standard deviation and coefficient of variation CV for Varanasi City. The PAHs compounds analyzed are (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. Seasonal comparisons for PAHs are shown in Figure 2.65, indicating that the concentrations are significantly higher in the winter season than in the summer season. Major PAHs are DmP, InP, B(ghi)P, B(b)F, B(k)F and Chr. The overall average total PAHs were much higher in winter (88±51 ng/m^3) than in summer (16±5 ng/m^3). B(a)P, although has the annual standard of 1 ng/m^3 and we cannot compare it with levels of 15 days, however levels of B(a)P (winter mean: 7.3 and summer mean: 1.1 ng/m^3) were high and annual standard is most likely to exceed by a fair margin at all sites in the winter season and for summer season all except IMAL and BHUS sites.

Literature reported values for InP/(InP + B(ghi)P) ratio are 0.18, 0.37 and 0.56 for gasoline, diesel and coal respectively (Rajput and Lakhani, 2010). The ratio obtained in this study (0.54 in winter and 0.56 in summer) is comparable to the reported values for coal combustion in the winter and summer seasons. It is inferred that the major source of PAHs is coal combustion and other source is diesel vehicles.

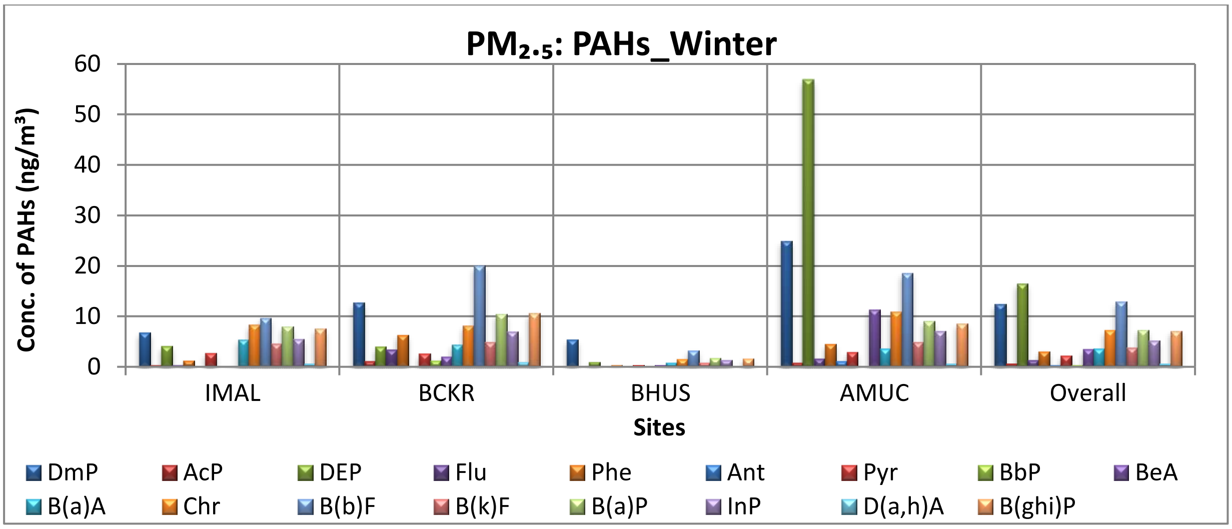


Figure 2.63: Variation in PAHs in $PM_{2.5}$ for winter season

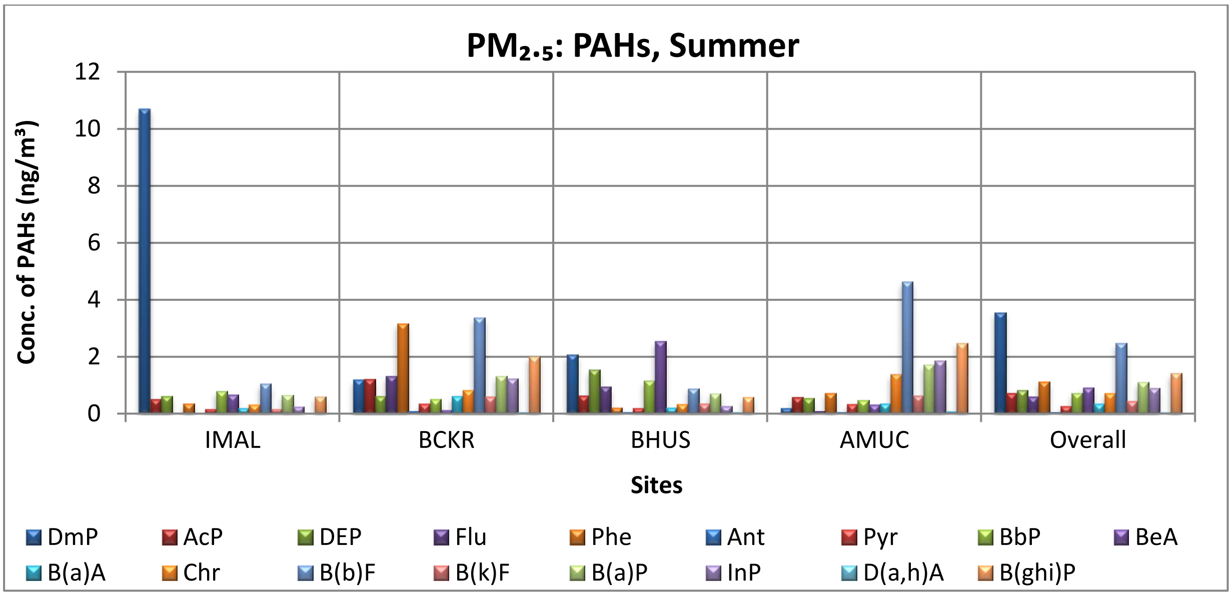


Figure 2.64: Variation in PAHs in $PM_{2.5}$ for summer season

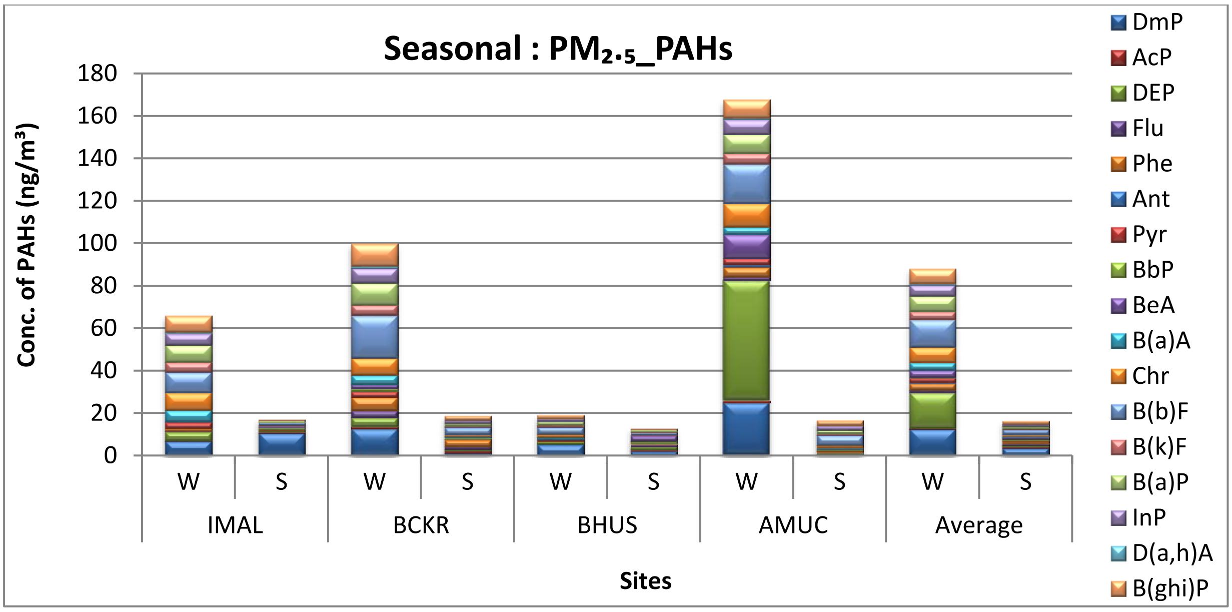


Figure 2.65: Seasonal comparison of PAHs in $PM_{2.5}$

2.4.5.6 Molecular Markers in $PM_{2.5}$

The average concentrations of molecular markers are shown graphically for winter season (Figure 2.66) and summer season (Figure 2.67) for all sites along with overall average concentration for Varanasi. Average concentrations are shown in Table 2.67 to Table 2.68 with the standard deviation and coefficient of variation CV for Varanasi. Seasonal comparison is shown in Figure 2.68 which indicates the concentrations of molecular markers are higher in winter compared to summer season compared to summer season. The overall average of molecular markers was measured higher in winter (188 ng/m^3) compared to summer (130 ng/m^3). The presence of significant quantities of molecular markers, especially alkanes and hopanes conclusively establishes contribution of coal burning, gasoline and diesel combustion in vehicles.

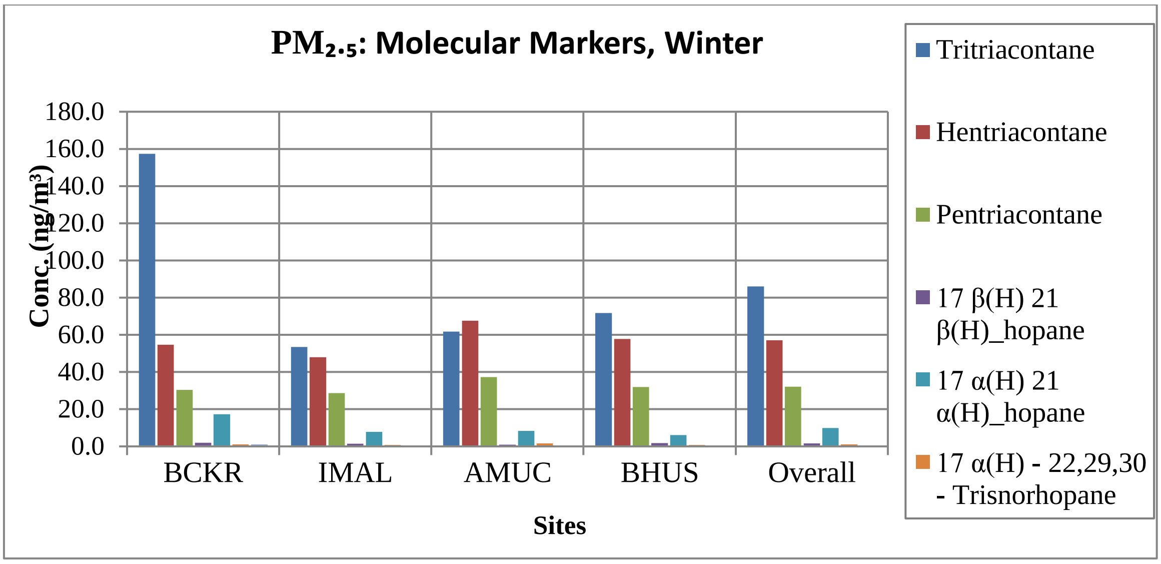


Figure 2.66: Variation in molecular markers in $PM_{2.5}$ for winter season

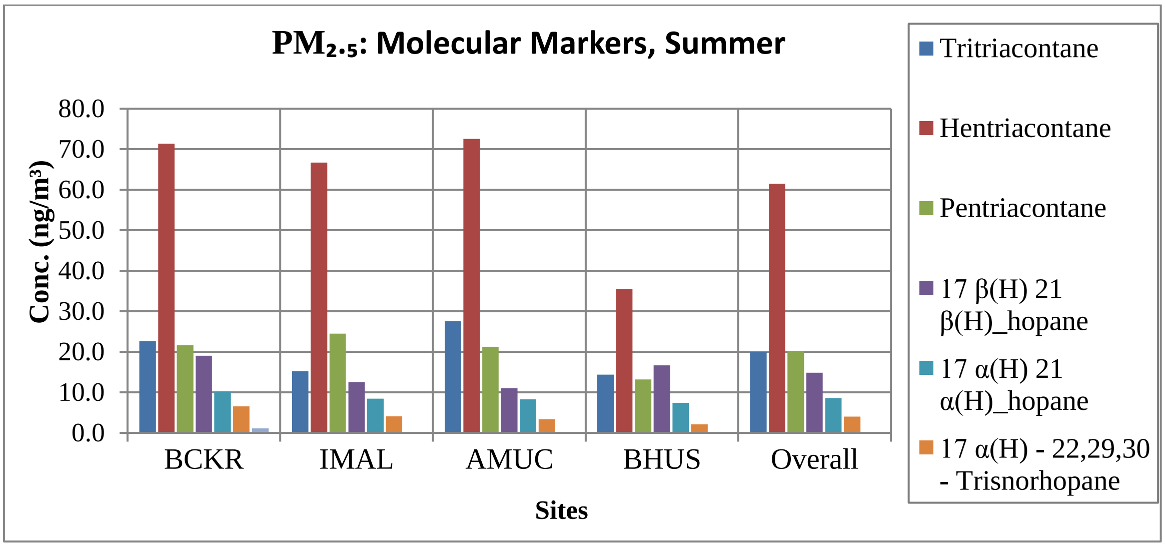


Figure 2.67: Variation in molecular markers in $PM_{2.5}$ for summer season

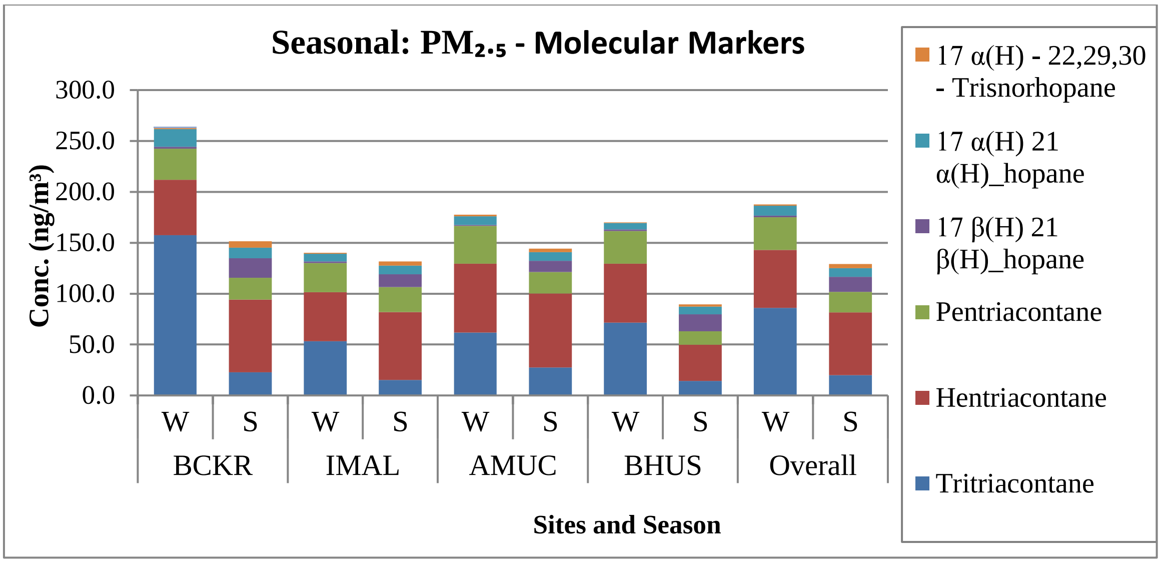


Figure 2.68: Seasonal comparison of molecular markers in $PM_{2.5}$

2.4.5.7 Chemical Composition of PM_{10} and $PM_{2.5}$

Graphical presentation for seasonal comparison for chemical species [(a) Anions, (b) Cations and (c) Elements) are shown for PM_{10} (Figure 2.69 (a), (b) and (c)) and $PM_{2.5}$ (Figure 2.70 (a), (b) and (c)). Overall summary of average concentrations for all sites along with overall average, standard deviation (SD) and coefficient of variation (CV) for PM (PM_{10} and $PM_{2.5}$), its composition [carbon content (EC and OC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb)] along with mass percentage (%R) estimated in composition are presented in Table 2.69 to Table 2.72 for winter and summer seasons.

The statistical summary of the major components (i.e., crustal elements – Si, Ai, Fe, Ca; Secondary ions - NO_3^-, SO_4^{-2}, NH_4^+; TC) in PM_{10} and $PM_{2.5}$ are presented in Table 2.74 to Table 2.77 for winter and summer seasons.

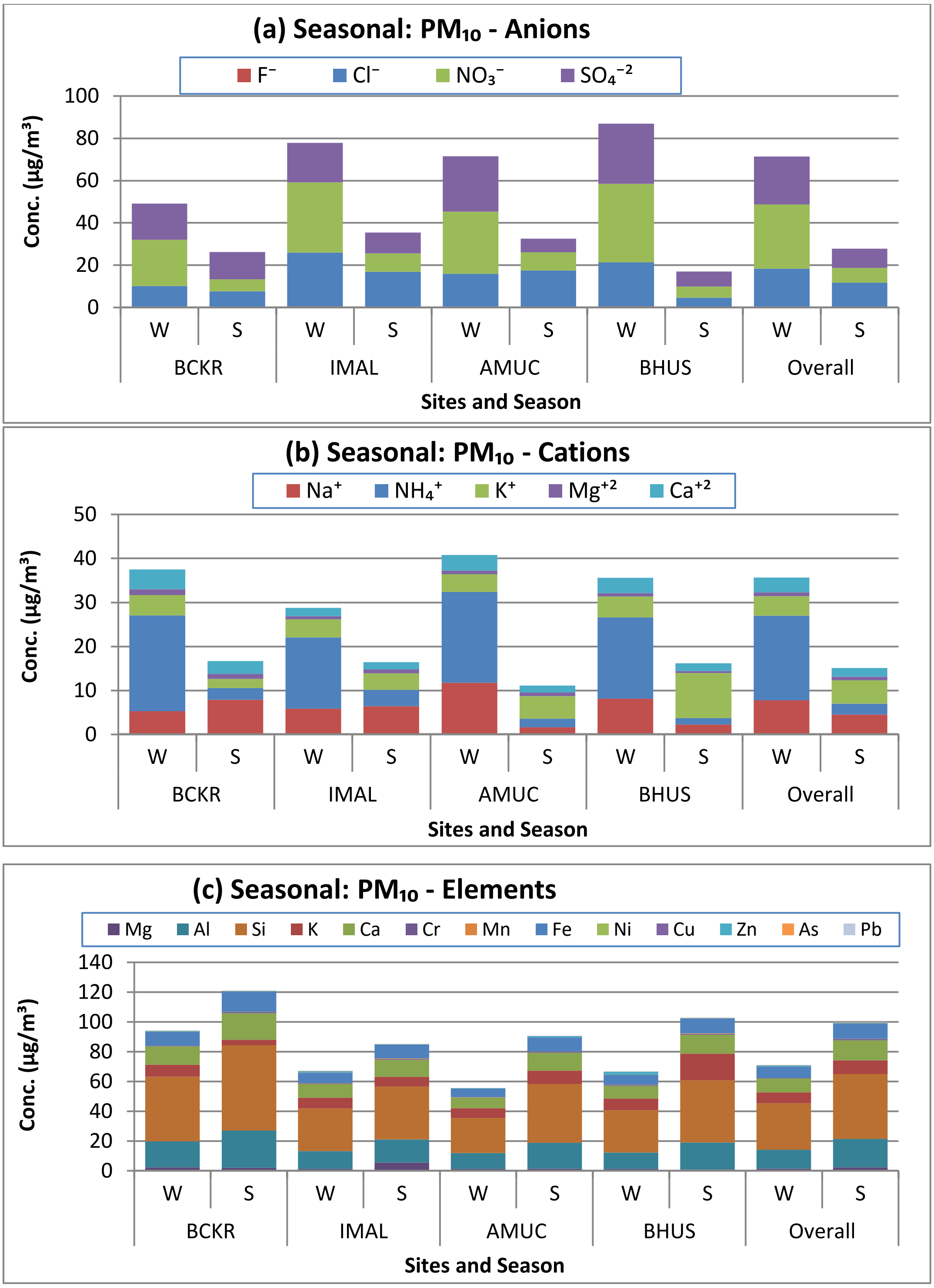
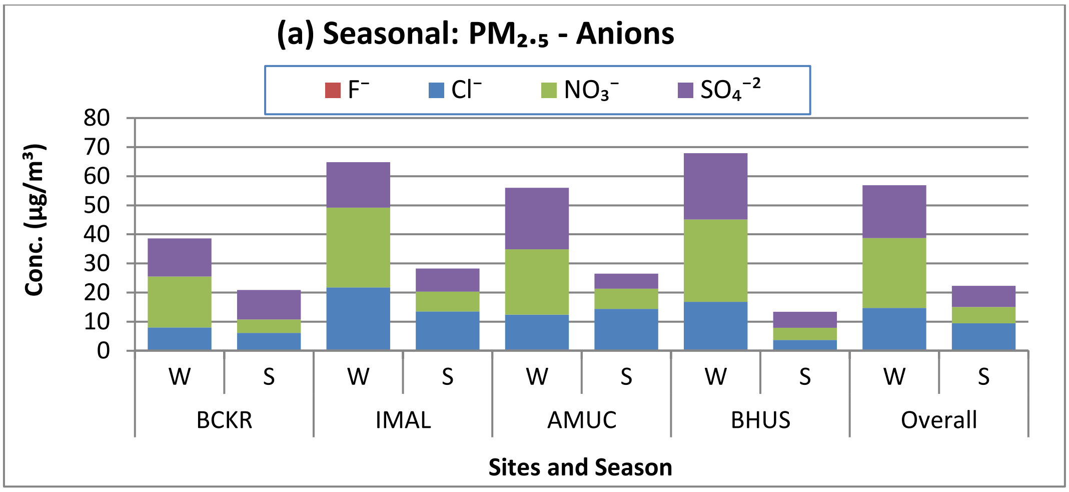
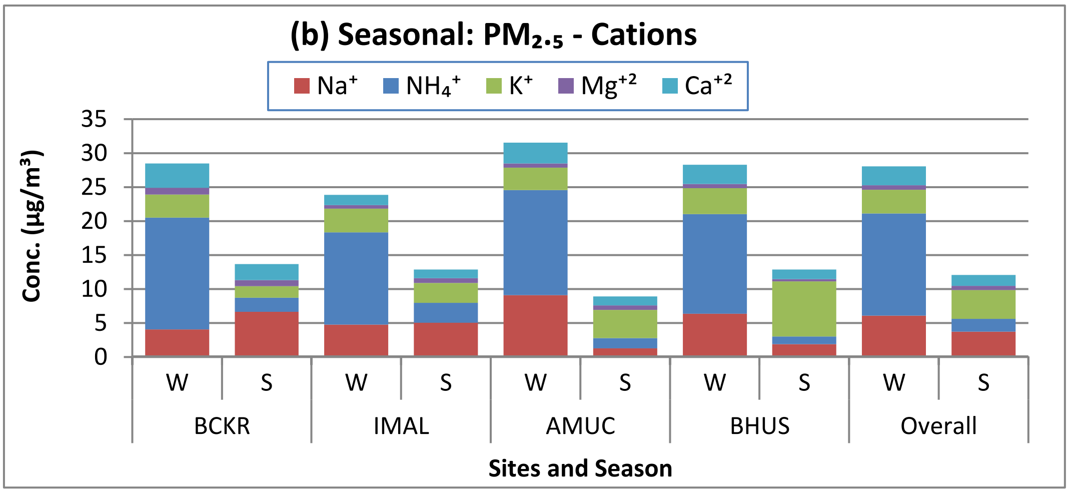


Figure 2.69: Seasonal comparison of ionic and elemental species concentrations in PM_{10} for all sites





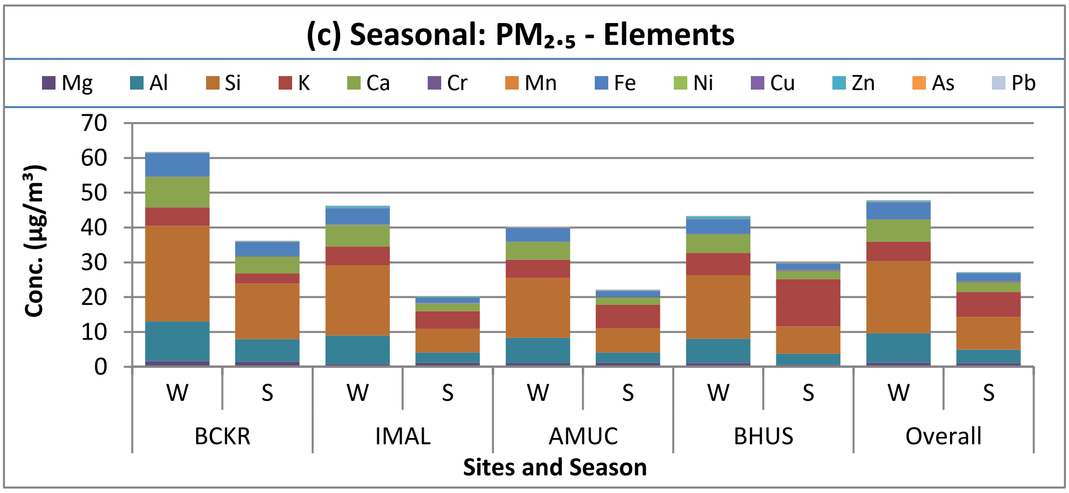


Figure 2.70: Seasonal comparison of ionic and elemental species concentrations in PM2.5 for all sites

2.4.5.8 Comparison of PM_{10} and $PM_{2.5}$ Composition

The graphical presentation is the better option for understanding the compositional variation. The major chemical species considered for overall compositional comparisons are carbon (OC and EC), ions (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}) and elements (Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Ni, Zn, As, Cd, Ba and Pb). Compositional comparison of $PM_{2.5}$ vs PM_{10} is shown for all major carbon, ions (Figure 2.71) and elements (Figure 2.72) for all sites and both seasons in Varanasi. The overall compositional comparison is also presented in Table 2.73 for all sites.

It is observed that a significant portion of PM has more fine-mode particles during winter (65%) than in summer (38%). The major species contributing to fine mode are TC, EC, OC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, K^+, Be, B, V, Cu and Cd; whereas, major species contributing in coarse mode are Mg^{+2}, Ca^{+2}, Mg, Al, Si, P, Ca, Cr, Mn, Fe, Sr and Ba (Figure 2.71 and Figure 2.72).

The average ratio ($PM_{2.5}/PM_{10}$) was taken from the previous studies (Puxbaum et al., 2004; Samara et al., 2014; Wang et al., 2014) for EC (0.70) and OC (0.83) to estimate the carbon content in PM_{10}. Therefore, the percentage of EC (70%) and OC (83%) are constant for all sites by converting from levels known in $PM_{2.5}$ and translating these into EC and OC levels of PM_{10}.

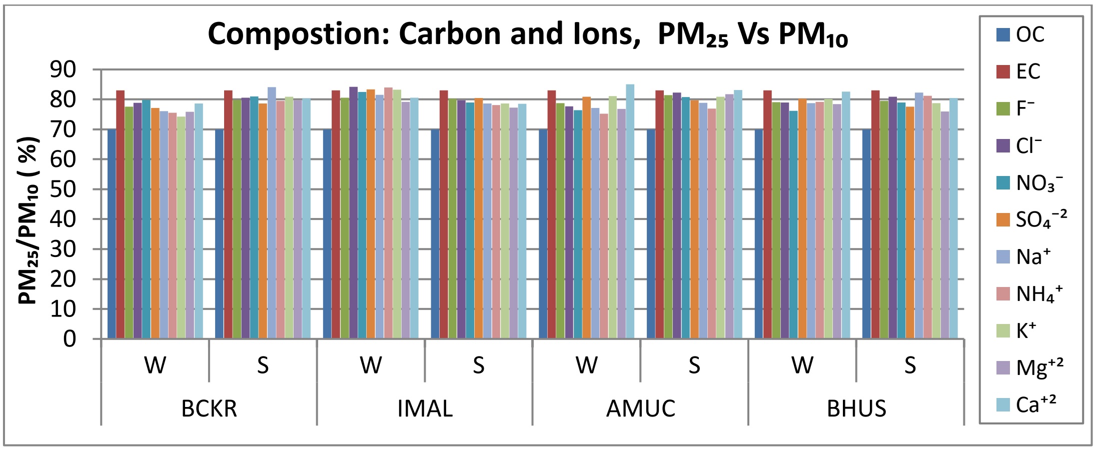


Figure 2.71: Compositional comparison of carbon and ions species in $PM_{2.5}$ Vs PM_{10}

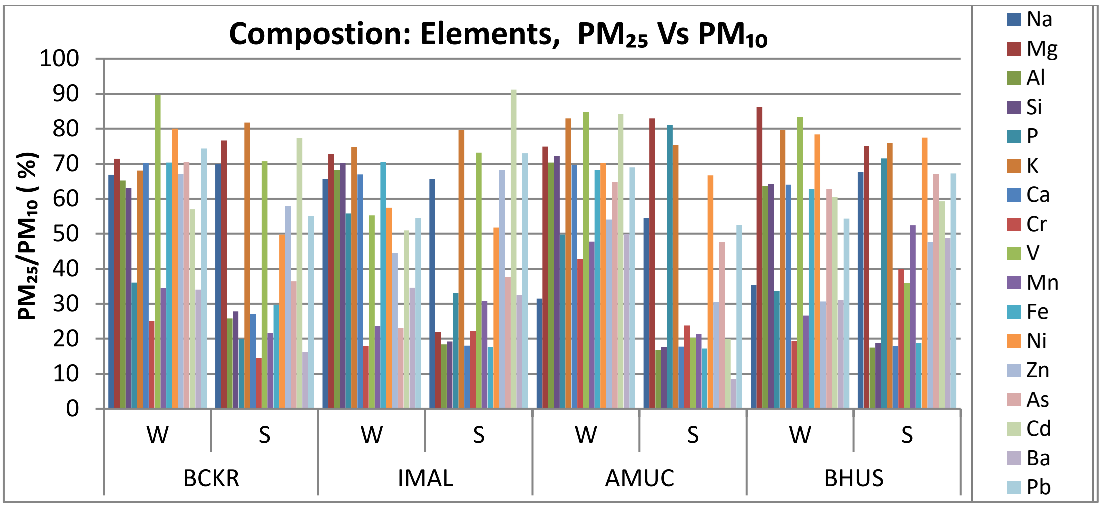


Figure 2.72: Ratio elemental components in $PM_{2.5}$ and PM_{10}

Table 2.60: Overall summary of experimental results of PM (mean±SD µg/m^3)

PM	PM_{10}		$PM_{2.5}$		$PM_{2.5}/PM_{10}$	
Sites	Winter	Summer	Winter	Summer	Winter	Summer
BCKR	401±105 (0.26)	314±112 (0.36)	281±86 (0.31)	121±24 (0.20)	0.69±0.07 (0.10)	0.41±0.07 (0.17)
IMAL	380±124 (0.33)	275±88 (0.32)	285±107 (0.37)	118±25 (0.21)	0.74±0.06 (0.08)	0.45±0.09 (0.19)
AMUC	340±103 (0.30)	294±59 (0.20)	256±86 (0.33)	124±40 (0.32)	0.75±0.05 (0.07)	0.42±0.06 (0.14)
BHUS	347±110 (0.32)	266±48 (0.18)	240±76 (0.32)	100±34 (0.34)	0.69±0.05 (0.08)	0.37±0.07 (0.20)
Overall	367±29 (0.08)	287±21 (0.07)	265±21 (0.08)	116±11 (0.10)	0.72±0.03 (0.04)	0.41±0.03 (0.08)
Values show in parenthesis are the coefficient of variation (CV)						

Table 2.61: Overall summary of average concentration (µg/m^3) of gaseous pollutants (SO_2, NO_2 and VOCs) for winter season

Winter	NO_2	SO_2	Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
BCKR	40.17	2.11	10.47	2.81	3.41	2.77	19.47
IMAL	35.50	2.02	1.62	1.04	1.85	2.08	5.32
AMUC	23.25	2.21	13.49	4.39	7.29	7.91	29.65
BHUS	21.87	2.00	7.51	2.33	4.70	4.04	18.57
Overall	30.20	2.09	8.27	2.64	4.31	4.20	18.25
SD	9.04	0.10	5.06	1.38	2.30	2.60	9.98
CV	0.30	0.05	0.61	0.52	0.53	0.62	0.55

Table 2.62: Overall summary of average concentration (µg/m^3) of gaseous pollutants (SO_2, NO_2 and VOCs) for summer season

Summer	NO_2	SO_2	Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
BCKR	24.03	2.00	8.44	1.70	3.68	2.62	16.44
IMAL	20.11	2.00	3.87	0.96	1.89	2.04	8.76
AMUC	16.66	2.00	0.31	0.13	0.39	0.57	1.19
BHUS	17.94	2.00	5.53	1.31	2.85	3.46	13.16
Overall	19.69	2.00	4.54	1.03	2.20	2.17	9.89
SD	3.23	0.00	3.39	0.67	1.41	1.22	6.60
CV	0.16	0.00	0.75	0.65	0.64	0.56	0.67

Table 2.63: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for winter Season

Winter	$PM_{2.5}$	TC	OC	EC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
BCKR	280.76	69.63	44.11	25.52	2.33	15.41	18.07	8.31	0.03	0.22	0.26	0.12
IMAL	284.54	120.42	87.59	32.83	3.71	54.92	20.29	8.66	0.04	0.24	0.24	0.11
AMUC	256.38	75.77	46.11	29.66	3.26	14.79	19.19	8.87	0.04	0.20	0.25	0.13
BHUS	239.96	77.34	58.39	18.96	1.61	10.77	13.64	32.35	0.02	0.19	0.24	0.21
Overall	265.41	85.79	59.05	26.74	2.73	23.98	17.80	14.55	0.03	0.21	0.25	0.14
SD	21.06	23.32	20.04	5.99	0.94	20.73	2.91	11.87	0.01	0.02	0.01	0.05
CV	0.08	0.27	0.34	0.22	0.34	0.86	0.16	0.82	0.20	0.11	0.04	0.31

Table 2.64: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for summer season

Summer	$PM_{2.5}$	TC	OC	EC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
BCKR	121.44	18.34	9.86	8.48	0.00	4.09	4.51	1.26	0.000	0.213	0.259	0.060
IMAL	117.79	35.64	19.06	16.58	0.22	6.68	8.25	3.91	0.007	0.186	0.233	0.112
AMUC	124.22	39.48	22.48	17.00	0.76	8.43	9.65	3.63	0.013	0.210	0.249	0.102
BHUS	99.50	14.59	9.50	5.09	0.03	3.05	4.07	2.34	0.002	0.181	0.307	0.134
Overall	115.74	27.01	15.23	11.79	0.25	5.56	6.62	2.79	0.005	0.198	0.262	0.102
SD	11.14	12.38	6.55	5.94	0.35	2.45	2.76	1.22	0.006	0.016	0.032	0.031
CV	0.10	0.46	0.43	0.50	1.39	0.44	0.42	0.44	1.059	0.082	0.121	0.307

Table 2.65: Overall summary of average concentration (ng/m^3) of PAHs in PM$_{2.5}$ all sites for winter season

Winter	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
BCKR	6.81	0.34	4.12	0.36	1.21	0.05	2.75	0.08	0.30	5.44	8.35	9.68	4.63	7.98	5.52	0.62	7.60	65.84
IMAL	12.69	1.14	4.02	3.38	6.29	0.15	2.62	1.25	1.96	4.43	8.11	20.06	4.90	10.44	6.92	0.92	10.60	99.88
AMUC	5.33	0.22	0.96	0.07	0.36	0.04	0.42	0.08	0.38	0.82	1.56	3.27	0.86	1.71	1.30	0.14	1.59	19.11
BHUS	24.90	0.86	56.88	1.64	4.56	1.10	2.92	0.08	11.31	3.62	10.94	18.59	4.92	9.08	7.06	0.60	8.56	167.62
Overall	12.43	0.64	16.49	1.36	3.10	0.34	2.18	0.37	3.49	3.58	7.24	12.90	3.83	7.30	5.20	0.57	7.09	88.11
SD	6.29	0.49	11.65	1.25	2.38	0.59	1.97	0.79	1.72	4.06	6.63	7.85	3.21	6.18	4.00	0.50	6.31	51.17
CV	0.51	0.76	0.71	0.92	0.77	1.75	0.90	2.13	0.49	1.14	0.92	0.61	0.84	0.85	0.77	0.88	0.89	0.58

Table 2.66: Overall summary of average concentration (ng/m^3) of PAHs in PM$_{2.5}$ for all sites for summer season

Summer	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
BCKR	10.69	0.51	0.62	0.03	0.36	0.04	0.17	0.79	0.66	0.21	0.33	1.06	0.17	0.65	0.24	0.02	0.61	17.18
IMAL	1.20	1.21	0.61	1.31	3.17	0.10	0.35	0.51	0.12	0.61	0.82	3.37	0.61	1.32	1.24	0.07	2.01	18.63
AMUC	2.08	0.64	1.54	0.94	0.22	0.07	0.20	1.17	2.54	0.22	0.34	0.89	0.36	0.71	0.26	0.06	0.58	12.83
BHUS	0.20	0.58	0.53	0.10	0.73	0.07	0.34	0.47	0.32	0.36	1.38	4.64	0.65	1.72	1.86	0.09	2.47	16.51
Overall	3.55	0.74	0.83	0.60	1.12	0.07	0.26	0.74	0.91	0.35	0.72	2.49	0.45	1.10	0.90	0.06	1.42	16.29
SD	1.50	0.34	0.51	0.70	0.50	0.04	0.18	0.43	0.95	0.29	0.53	1.37	0.29	0.49	0.52	0.06	0.65	4.62
CV	0.42	0.46	0.62	1.17	0.45	0.53	0.68	0.59	1.04	0.84	0.74	0.55	0.64	0.44	0.57	1.03	0.46	0.28

Table 2.67: Overall summary of average concentration (ng/m^3) of molecular markers in $PM_{2.5}$ for winter season

Winter	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
BCKR	157.41	54.60	30.32	2.01	17.25	1.04	262.64
IMAL	53.40	47.96	28.70	1.42	7.84	0.80	140.13
AMUC	61.72	67.63	37.22	0.93	8.41	1.62	177.53
BHUS	71.66	57.83	31.90	1.81	6.10	0.66	169.96
Overall	86.05	57.00	32.04	1.54	9.90	1.03	187.57
SD	60.07	14.24	6.67	0.46	4.47	0.60	77.06
CV	0.70	0.25	0.21	0.30	0.45	0.58	0.41

Table 2.68: Overall summary of average concentration (ng/m^3) of molecular markers in $PM_{2.5}$ for summer season

Summer	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21 α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
BCKR	22.69	71.36	21.66	19.07	10.29	6.55	151.61
IMAL	15.21	66.68	24.53	12.56	8.46	4.11	131.55
AMUC	27.59	72.53	21.24	11.03	8.28	3.41	144.08
BHUS	14.41	35.51	13.20	16.69	7.40	2.15	89.35
Overall	19.97	61.52	20.16	14.84	8.60	4.06	129.15
SD	4.81	15.42	4.17	7.17	3.23	2.95	23.97
CV	0.24	0.25	0.21	0.48	0.38	0.73	0.19

Table 2.69: Overall summary of average concentration of chemical species in PM$_{10}$ for all sites for winter season

Winter	PM$_{10}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
BCKR	401	93.8	63.0	30.8	0.4	9.7	22.0	17.1	5.3	21.8	4.6	1.3	4.5	0.00	0.43	8.08	2.27	17.5	43.5
IMAL	380	109	69.8	39.6	0.5	25.4	33.3	18.7	5.8	16.2	4.2	0.7	1.9	0.00	0.72	9.24	1.16	12	28.7
AMUC	340	101	65.9	35.7	0.5	15.5	29.4	26.2	11.8	20.6	4.1	0.8	3.6	0.00	0.41	5.81	1.33	10.5	23.7
BHUS	347	71.0	48.2	22.8	0.5	20.9	37.1	28.4	8.1	18.5	4.8	0.8	3.4	0.00	0.72	8.26	1.28	11	28.4
Overall	367	94	61.7	32.2	0.48	17.9	30.4	22.6	7.76	19.3	4.39	0.89	3.36	0.00	0.57	7.85	1.51	12.7	31.1
SD	29	16.6	9.45	7.22	0.04	6.79	6.47	5.54	2.94	2.46	0.32	0.29	1.11	0.00	0.17	1.45	0.51	3.23	8.60
CV	0.08	0.18	0.15	0.22	0.08	0.38	0.21	0.25	0.38	0.13	0.07	0.33	0.33	0.61	0.30	0.18	0.34	0.25	0.28
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
BCKR	7.91	12.4	0.33	0.16	0.09	9.49	0.00	0.10	0.05	0.32	0.02	0.00	0.02	0.02	0.01	0.00	0.08	0.11	66.8
IMAL	7.32	9.13	0.46	0.29	0.16	6.88	0.00	0.07	0.10	1.07	0.06	0.01	0.04	0.04	0.02	0.00	0.13	0.32	75.1
AMUC	6.45	7.24	0.20	0.14	0.06	5.59	0.00	0.11	0.04	0.29	0.03	0.01	0.01	0.02	0.01	0.00	0.06	0.11	75.7
BHUS	8.00	8.40	0.46	0.27	0.15	6.79	0.00	0.12	0.05	1.93	0.03	0.01	0.03	0.04	0.01	0.00	0.10	0.14	74.1
Overall	7.42	9.30	0.36	0.21	0.11	7.19	0.00	0.10	0.06	0.90	0.03	0.01	0.02	0.03	0.01	0.00	0.10	0.17	72.9
SD	0.71	2.23	0.12	0.08	0.05	1.64	0.00	0.02	0.03	0.77	0.02	0.00	0.01	0.01	0.00	0.00	0.03	0.10	4.16
CV	0.10	0.24	0.34	0.36	0.40	0.23	0.36	0.23	0.43	0.86	0.49	0.53	0.37	0.32	0.38	0.42	0.32	0.60	0.06

Table 2.70: Overall summary of average concentration of chemical species in PM$_{2.5}$ for all sites for winter season

Winter	PM$_{2.5}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
BCKR	281	69.6	44.1	25.5	0.3	7.6	17.5	13.2	4.0	16.5	3.4	1.0	3.6	0.00	0.31	5.40	1.62	11.4	27.4
IMAL	285	81.7	48.9	32.8	0.4	21.4	27.4	15.6	4.8	13.6	3.5	0.5	1.5	0.00	0.33	6.07	0.84	8.16	20.1
AMUC	254	75.8	46.1	29.7	0.4	12.1	22.5	21.2	9.1	15.5	3.3	0.6	3.1	0.00	0.30	1.83	1.00	7.38	17.1
BHUS	240	52.7	33.7	19.0	0.4	16.5	28.3	22.8	6.4	14.6	3.8	0.6	2.8	0.00	0.32	2.93	1.10	6.95	18.3
Overall	265	70.0	43.2	26.7	0.38	14.4	24.0	18.2	6.07	15.1	3.5	0.69	2.75	0.00	0.31	4.06	1.14	8.47	20.7
SD	21	12.5	6.62	5.99	0.04	5.90	4.99	4.55	2.24	1.21	0.22	0.21	0.88	0.00	0.01	2.01	0.34	2.00	4.64
CV	0.08	0.18	0.15	0.22	0.09	0.41	0.21	0.25	0.37	0.08	0.06	0.31	0.32	0.36	0.04	0.50	0.30	0.24	0.22
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
BCKR	5.38	8.73	0.08	0.14	0.03	6.67	0.00	0.08	0.03	0.21	0.02	0.00	0.01	0.01	0.01	0.00	0.03	0.08	68.9
IMAL	5.46	6.11	0.08	0.16	0.04	4.84	0.00	0.04	0.05	0.47	0.01	0.01	0.01	0.01	0.01	0.00	0.05	0.17	76.0
AMUC	5.35	5.04	0.09	0.12	0.03	3.81	0.00	0.08	0.03	0.16	0.02	0.01	0.01	0.01	0.01	0.00	0.03	0.07	75.5
BHUS	6.37	5.38	0.09	0.23	0.04	4.27	0.00	0.09	0.02	0.59	0.02	0.00	0.01	0.01	0.01	0.00	0.03	0.08	77.1
Overall	5.64	6.31	0.08	0.16	0.03	4.90	0.00	0.07	0.03	0.36	0.02	0.01	0.01	0.01	0.01	0.00	0.03	0.10	74.4
SD	0.49	1.67	0.00	0.05	0.00	1.26	0.00	0.02	0.01	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.05	3.71
CV	0.09	0.26	0.05	0.29	0.14	0.26	0.52	0.33	0.35	0.58	0.13	0.60	0.14	0.11	0.23	0.71	0.24	0.48	0.05

Table 2.71: Overall summary of average concentration of chemical species in PM$_{10}$ for all sites for summer season

Summer	PM$_{10}$	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
BCKR	314	24.3	14.1	10.2	0.1	7.6	5.6	12.9	7.9	2.6	2.1	1.1	2.9	0.02	0.30	4.42	1.94	25.2	57.2
IMAL	275	47.2	27.2	20.0	0.1	16.8	8.6	9.9	6.5	3.7	3.7	0.9	1.6	0.01	0.37	8.54	5.55	15.6	35.5
AMUC	294	52.6	32.1	20.5	0.1	17.4	8.5	6.5	1.6	2.0	5.1	0.8	1.6	0.03	0.22	8.03	1.44	17.4	39.4
BHUS	266	19.7	13.6	6.1	0.1	4.5	5.3	7.1	2.3	1.4	10.3	0.5	1.7	0.02	0.24	17.5	0.79	18.2	41.8
Overall	287	36	21.8	14.2	0.13	11.6	7.02	9.12	4.56	2.44	5.31	0.82	1.97	0.02	0.28	9.62	2.43	19.1	43.5
SD	21	16.4	9.36	7.16	0.02	6.49	1.81	2.95	3.08	0.98	3.52	0.27	0.63	0.01	0.06	5.56	2.14	4.20	9.54
CV	0.07	0.46	0.43	0.50	0.18	0.56	0.26	0.32	0.68	0.40	0.66	0.33	0.32	0.37	0.23	0.58	0.88	0.22	0.22
Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
BCKR	3.65	17.70	0.82	0.29	0.28	13.52	0.016	0.03	0.07	0.40	0.02	0.01	0.07	0.10	0.008	0.02	0.18	0.10	58.3
IMAL	6.44	11.56	0.56	0.14	0.21	9.15	0.013	0.02	0.06	0.40	0.03	0.00	0.06	0.09	0.015	0.02	0.13	0.11	67.0
AMUC	9.04	11.90	0.62	0.06	0.21	9.52	0.025	0.04	0.06	0.85	0.08	0.18	0.07	0.07	0.029	0.03	0.46	0.10	63.7
BHUS	17.93	12.74	0.57	0.11	0.25	9.92	0.015	0.03	0.05	0.29	0.06	0.06	0.10	0.11	0.015	0.02	0.28	0.11	60.2
Overall	9.26	13.48	0.64	0.15	0.24	10.52	0.02	0.03	0.06	0.48	0.05	0.06	0.07	0.09	0.02	0.02	0.26	0.11	62.30
SD	6.18	2.86	0.12	0.10	0.03	2.02	0.01	0.01	0.01	0.25	0.03	0.08	0.01	0.02	0.01	0.01	0.15	0.01	3.85
CV	0.67	0.21	0.19	0.66	0.14	0.19	0.32	0.22	0.13	0.52	0.60	1.29	0.19	0.17	0.52	0.26	0.56	0.08	0.06

Table 2.72: Overall summary of average concentration of chemical species in $PM_{2.5}$ for all sites for summer season

summer	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
BCKR	121	18.3	9.9	8.5	0.1	6.1	4.5	10.2	6.6	2.1	1.7	0.9	2.3	0.02	0.23	3.09	1.48	6.50	15.90
IMAL	118	35.6	19.1	16.6	0.1	13.4	6.8	8.0	5.1	2.9	2.9	0.7	1.3	0.01	0.29	5.61	1.22	2.86	6.82
AMUC	124	39.5	22.5	17.0	0.1	14.3	6.9	5.2	1.3	1.5	4.2	0.7	1.3	0.02	0.13	4.37	1.19	2.91	6.93
BHUS	100	14.6	9.5	5.1	0.1	3.7	4.2	5.5	1.9	1.2	8.1	0.3	1.4	0.01	0.18	11.81	0.59	3.19	7.83
Overall	116	27.0	15.23	11.79	0.10	9.37	5.61	7.21	3.72	1.92	4.22	0.65	1.59	0.01	0.21	6.22	1.12	3.87	9.37
SD	11	12.4	6.55	5.94	0.02	5.28	1.45	2.34	2.56	0.76	2.76	0.22	0.51	0.01	0.07	3.87	0.38	1.76	4.38
CV	0.10	0.46	0.43	0.50	0.19	0.56	0.26	0.32	0.69	0.39	0.65	0.34	0.32	0.41	0.32	0.62	0.34	0.46	0.47

Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
BCKR	2.99	4.79	0.12	0.20	0.06	4.02	0.011	0.017	0.04	0.23	0.009	0.00	0.042	0.026	0.006	0.01	0.029	0.05	67.4
IMAL	5.12	2.08	0.12	0.10	0.06	1.61	0.009	0.011	0.03	0.27	0.010	0.00	0.031	0.035	0.014	0.02	0.042	0.08	79.8
AMUC	6.81	2.11	0.15	0.01	0.04	1.63	0.016	0.025	0.03	0.26	0.040	0.10	0.015	0.011	0.006	0.01	0.039	0.05	76.9
BHUS	13.62	2.28	0.23	0.04	0.13	1.87	0.006	0.027	0.03	0.14	0.043	0.05	0.054	0.051	0.009	0.01	0.137	0.08	73.6
Overall	7.13	2.82	0.15	0.09	0.08	2.28	0.011	0.020	0.04	0.22	0.03	0.04	0.04	0.03	0.009	0.01	0.06	0.07	74.44
SD	4.59	1.32	0.05	0.08	0.04	1.16	0.004	0.007	0.01	0.06	0.02	0.05	0.02	0.02	0.004	0.00	0.05	0.02	5.35
CV	0.64	0.47	0.33	0.95	0.52	0.51	0.38	0.36	0.15	0.27	0.74	1.19	0.47	0.55	0.44	0.39	0.82	0.23	0.07

Table 2.73: Ratios of chemical species of PM$_{2.5}$ and PM$_{10}$ for all sites for winter (W) and summer (S) seasons

Sites	BCKR		IMAL		AMUC		BHUS		Overall	
Season	W	S	W	S	W	S	W	S	W	S
PM$_{10}$	401	314	380	275	340	294	347	266	367	287
PM$_{2.5}$	281	121	285	118	254	124	240	100	265	116
PM$_{2.5}$/PM$_{10}$	70	39	75	43	75	42	69	37	72	40
TC (PM$_{2.5}$/PM$_{10}$)	74	75	75	76	75	75	74	74	74	75
OC (PM$_{2.5}$/PM$_{10}$)	70	70	70	70	70	70	70	70	70	70
EC (PM$_{2.5}$/PM$_{10}$)	83	83	83	83	83	83	83	83	83	83
F$^-$ (PM$_{2.5}$/PM$_{10}$)	78	80	81	80	79	81	79	79	79	80
Cl$^-$ (PM$_{2.5}$/PM$_{10}$)	79	81	84	80	78	82	79	81	81	81
NO$_3^-$ (PM$_{2.5}$/PM$_{10}$)	80	81	83	79	76	81	76	79	79	80
SO$_4^{-2}$ (PM$_{2.5}$/PM$_{10}$)	77	79	83	80	81	80	80	78	80	79
Na$^+$ (PM$_{2.5}$/PM$_{10}$)	76	84	81	79	77	79	79	82	78	81
NH$_4^+$ (PM$_{2.5}$/PM$_{10}$)	76	79	84	78	75	77	79	81	78	79
K$^+$ (PM$_{2.5}$/PM$_{10}$)	74	81	83	79	81	81	80	79	80	79
Mg^{+2} (PM$_{2.5}$/PM$_{10}$)	76	80	79	77	77	82	78	76	77	79
Ca^{+2} (PM$_{2.5}$/PM$_{10}$)	79	80	81	79	85	83	83	80	82	81
Be (PM$_{2.5}$/PM$_{10}$)	75	96	34	95	54	69	58	50	49	76
B (PM$_{2.5}$/PM$_{10}$)	73	78	46	79	72	61	44	75	55	74
Na (PM$_{2.5}$/PM$_{10}$)	67	70	66	66	31	54	35	68	52	65
Mg (PM$_{2.5}$/PM$_{10}$)	71	77	73	22	75	83	86	75	76	46
Al (PM$_{2.5}$/PM$_{10}$)	65	26	68	18	70	17	64	17	67	20
Si (PM$_{2.5}$/PM$_{10}$)	63	28	70	19	72	18	64	19	67	22
P (PM$_{2.5}$/PM$_{10}$)	36	20	56	33	50	81	34	72	46	54
K (PM$_{2.5}$/PM$_{10}$)	68	82	75	80	83	75	80	76	76	77
Ca (PM$_{2.5}$/PM$_{10}$)	70	27	67	18	70	18	64	18	68	21
Cr (PM$_{2.5}$/PM$_{10}$)	25	14	18	22	43	24	19	40	23	24
V (PM$_{2.5}$/PM$_{10}$)	90	71	55	73	85	20	83	36	75	60
Mn (PM$_{2.5}$/PM$_{10}$)	35	22	24	31	48	21	27	52	30	32
Fe (PM$_{2.5}$/PM$_{10}$)	70	30	70	18	68	17	63	19	68	22
Co (PM$_{2.5}$/PM$_{10}$)	63	71	63	76	78	63	49	39	66	62
Ni (PM$_{2.5}$/PM$_{10}$)	80	50	57	52	70	67	78	77	73	62
Cu (PM$_{2.5}$/PM$_{10}$)	62	59	52	56	67	52	48	60	56	57
Zn (PM$_{2.5}$/PM$_{10}$)	67	58	44	68	54	31	31	48	40	47
As (PM$_{2.5}$/PM$_{10}$)	71	36	23	38	65	48	63	67	47	51
Se (PM$_{2.5}$/PM$_{10}$)	78	67	78	59	86	58	56	77	76	63
Rb (PM$_{2.5}$/PM$_{10}$)	41	57	31	48	61	23	33	56	38	47
Sr (PM$_{2.5}$/PM$_{10}$)	43	26	28	41	55	15	35	48	38	34
Cd (PM$_{2.5}$/PM$_{10}$)	57	77	51	91	84	20	61	59	60	52
Cs (PM$_{2.5}$/PM$_{10}$)	65	80	35	91	91	25	68	40	71	54
Ba (PM$_{2.5}$/PM$_{10}$)	34	16	35	32	50	9	31	49	36	24
Pb (PM$_{2.5}$/PM$_{10}$)	74	55	54	73	69	53	54	67	60	62

Table 2.74: Statistical summary of major components: PM_{10}, winter (µg/m^3)

Winter	PM_{10}	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/PM_{10}	Sec Ions (NO_3^- + SO_4^{-2} + NH_4^+)	Ratio Sec Ions/PM_{10}	TC	Ratio TC/PM_{10}
BCKR	401	82.9	0.207	60.8	0.152	93.8	0.234
IMAL	380	56.6	0.149	68.1	0.179	109.4	0.288
AMUC	340	47.0	0.138	76.2	0.224	101.6	0.299
BHUS	347	54.5	0.157	84.0	0.242	71.0	0.205
Overall	367	60.3	0.163	72.3	0.199	94.0	0.256
SD	29	15.6	0.030	10.0	0.041	16.6	0.045
CV	0.08	0.26	0.19	0.14	0.21	0.18	0.17

Table 2.75: Statistical summary of major components: $PM_{2.5}$, winter (µg/m^3)

Winter	$PM_{2.5}$	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/$PM_{2.5}$	Sec Ions (NO_3^- + SO_4^{-2} + NH_4^+)	Ratio Sec Ions/$PM_{2.5}$	TC	Ratio TC/$PM_{2.5}$
BCKR	281	54.22	0.193	47.15	0.168	69.6	0.248
IMAL	285	39.21	0.138	56.62	0.199	81.7	0.287
AMUC	254	33.33	0.131	59.12	0.233	75.8	0.299
BHUS	240	34.87	0.145	65.71	0.274	52.7	0.220
Overall	265	40.41	0.152	57.15	0.218	70.0	0.263
SD	21	9.54	0.028	7.69	0.045	12.5	0.036
CV	0.08	0.24	0.18	0.13	0.21	0.18	0.14

Table 2.76: Statistical summary of major components: PM_{10}, summer (µg/m^3)

Summer	PM_{10}	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/PM_{10}	Sec Ions (NO_3^- + SO_4^{-2} + NH_4^+)	Ratio Sec Ions/PM_{10}	TC	Ratio TC/PM_{10}
BCKR	314	113.6	0.362	21.2	0.067	24.3	0.077
IMAL	275	71.8	0.261	22.2	0.081	47.2	0.172
AMUC	294	78.2	0.266	17.0	0.058	52.6	0.179
BHUS	266	82.6	0.311	13.8	0.052	19.7	0.074
Overall	287	86.6	0.300	18.6	0.065	36.0	0.126
SD	21	18.6	0.047	3.9	0.013	16.4	0.058
CV	0.07	0.21	0.16	0.21	0.20	0.46	0.46

Table 2.77: Statistical summary of major components: $PM_{2.5}$, summer (µg/m^3)

Summer	$PM_{2.5}$	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/$PM_{2.5}$	Sec Ions (NO_3^- + SO_4^{-2} + NH_4^+)	Ratio Sec Ions/$PM_{2.5}$	TC	Ratio TC/$PM_{2.5}$
BCKR	121	31.2	0.257	16.8	0.138	18.3	0.151
IMAL	118	13.4	0.113	17.7	0.150	35.6	0.303
AMUC	124	13.6	0.109	13.6	0.109	39.5	0.318
BHUS	100	15.2	0.152	10.9	0.109	14.6	0.147
Overall	116	18.3	0.158	14.7	0.127	27.0	0.230
SD	11	8.6	0.069	3.1	0.021	12.4	0.093
CV	0.10	0.47	0.44	0.21	0.16	0.46	0.41

2.4.6 Statistical Summary

For the comparison of winter and summer air quality levels, box plots and Student t-test statistics were used. These are discussed in the following sections.

2.4.6.1 Box Plot Distribution

Statistical box plots are shown in Figure 2.73 to Figure 2.77 for all sites for $PM_{2.5}$, PM_{10}, NO_2 and SO_2, EC and OC for winter (W) and summer (S) season. These figures show the mean, median, 25% quartile, 75% quartile and outliers of the data distribution. The outlier values could be possibly due to the local activities (i.e., DG sets emission, biomass burning, traffic congestion etc.) near the monitoring stations. The BCKR and IMAL sites show the largest variability and high pollution level, whereas residential areas show low variability in PM_{10} and $PM_{2.5}$. The same trend and pattern are applicable for NO_2, OC and EC. It is to be noted that variability is much higher in winter than in summer. The probable reasons could be due to changes in meteorology, the presence of occasional local sources like DG sets, traffic jams or open burning, some episodic behaviour, etc.

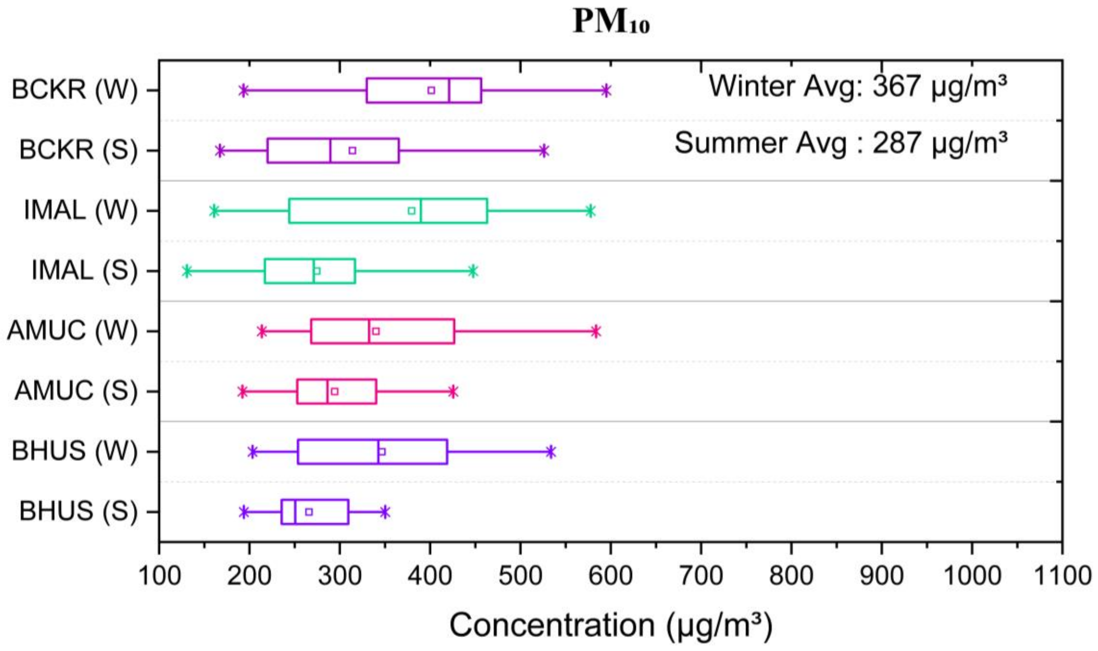


Figure 2.73: Box plot distribution for PM_{10} (winter and summer)

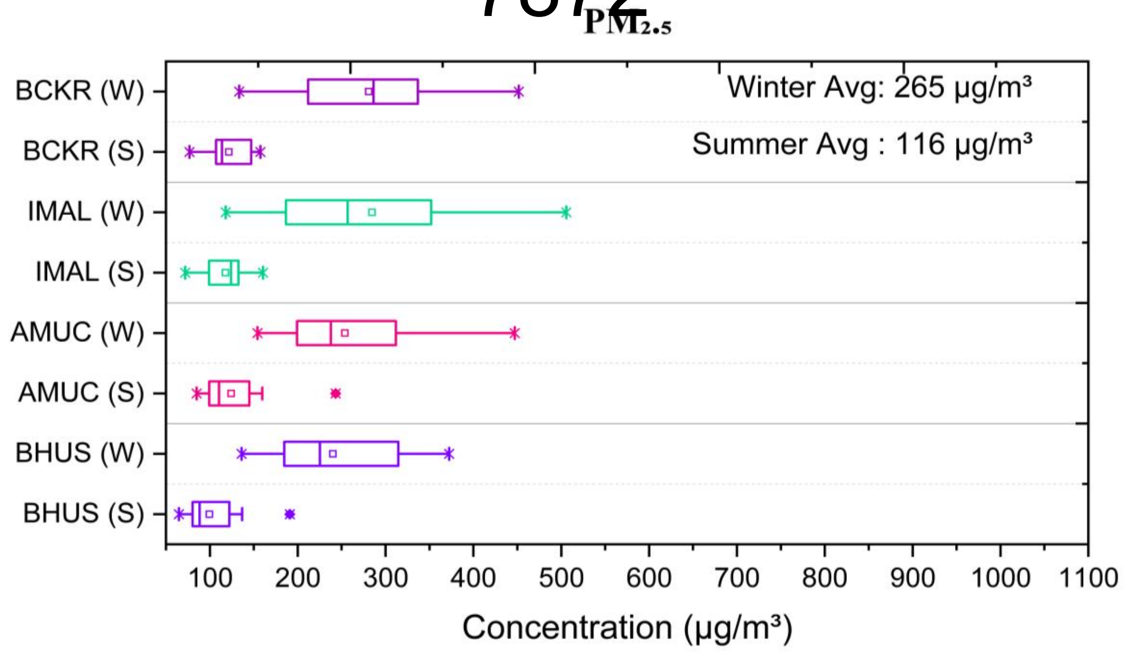


Figure 2.74: Box plot distribution for $PM_{2.5}$ (winter and summer)

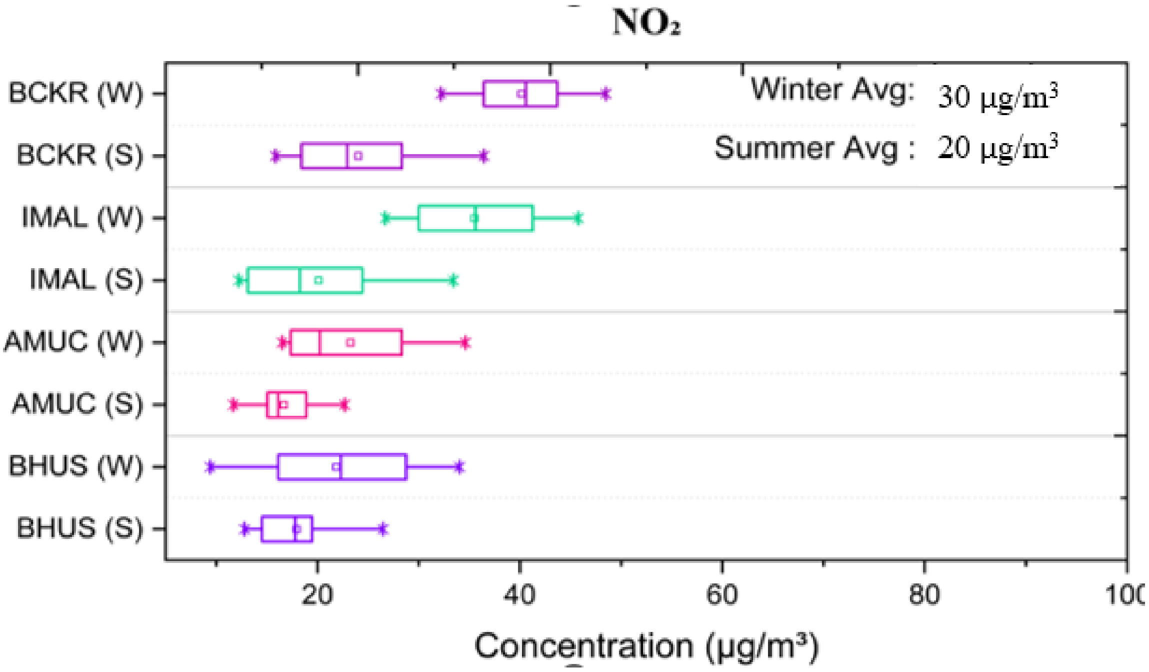


Figure 2.75: Box plot distribution for NO_2 (winter and summer)

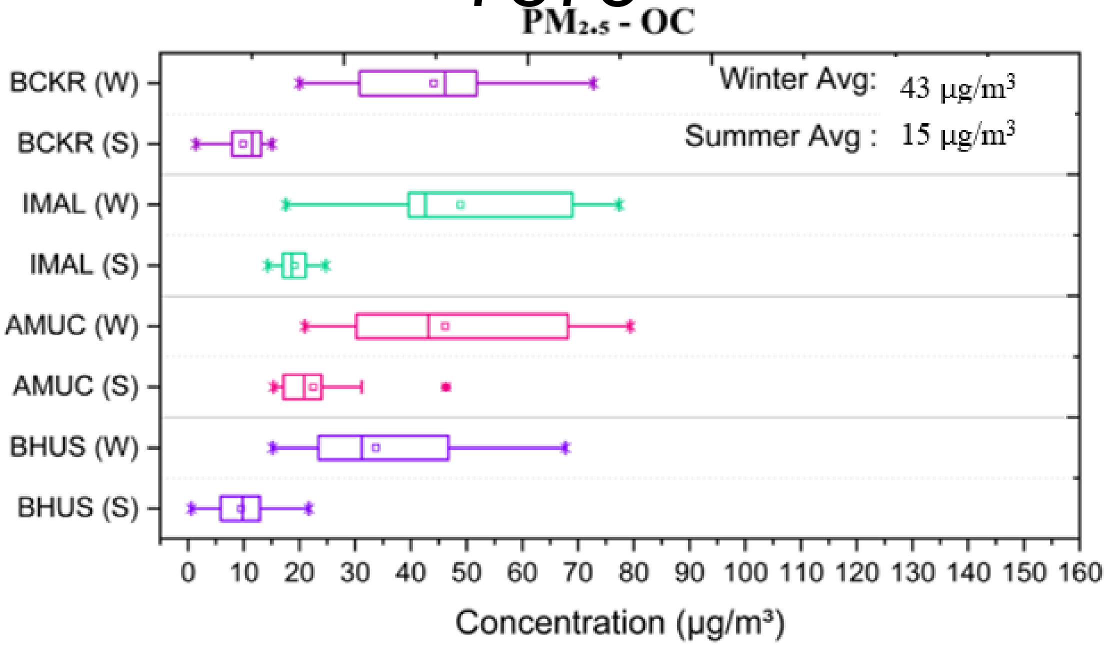


Figure 2.76: Box plot distribution for OC (winter and summer)

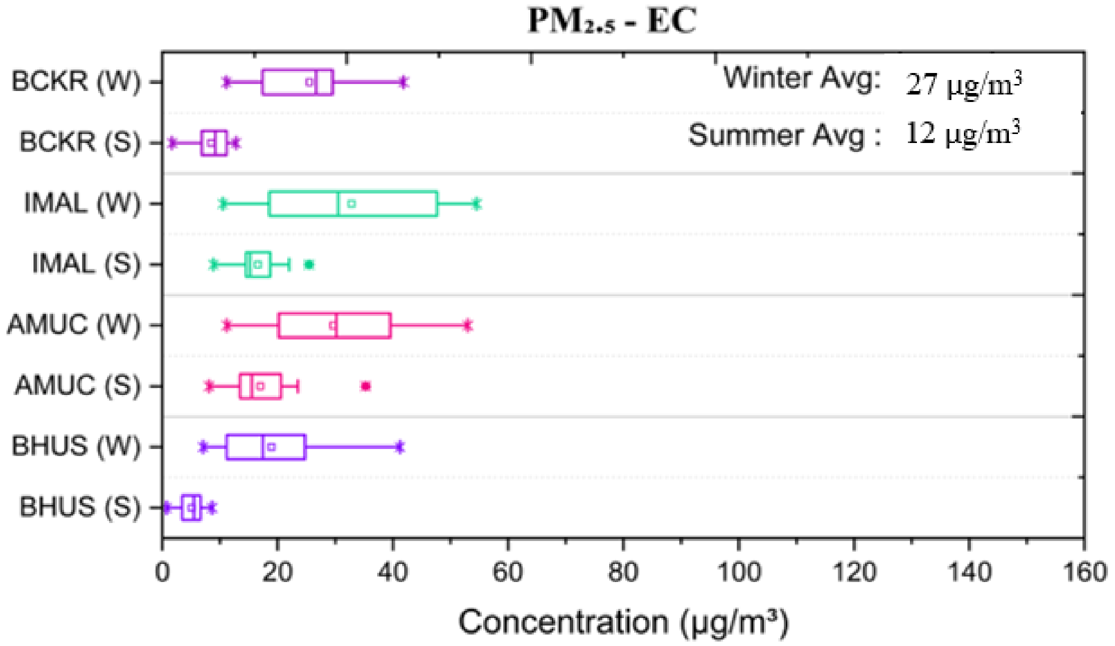


Figure 2.77: Box plot distribution for EC (winter and summer)

2.4.6.2 Statistics of t-Test for Seasonal Comparison

Student t-test statistics are performed at 5% level of significance to estimate if winter levels are higher (or lower) than summer levels for PM_{10}, $PM_{2.5}$, NO_2, SO_2 and carbon content (EC and OC). It is observed from Table 2.78 that in winter, $PM_{2.5}$, OC and EC levels are significantly higher (p-value < 0.05) than summer season at all sites, PM_{10} levels are higher at all sites except IMAL, NO_2 levels are higher at all sites except BCKR and SO_2 levels are higher at AMUC and BHUS. There is no significant difference in PM_{10} levels at IMAL, in NO_2 levels at BCKR and in SO_2 levels at BCKR and IMAL in summer and winter.

The information on the seasonal composition of PM can assist in identifying the various sources contributing to the ambient pollution level.

Table 2.78: Statistical Comparison Winter vs Summer

Parameter → Site ↓	PM_{10}	$PM_{2.5}$	OC	EC	NO_2	SO_2
BCKR	⬆	⬆	⬆	⬆	⬌	⬌
IMAL	⬌	⬆	⬆	⬆	⬆	⬌
AMUC	⬆	⬆	⬆	⬆	⬆	⬆
BHUS	⬆	⬆	⬆	⬆	⬆	⬆
⬌ No significant difference		⬆ (Levels higher in winter)			⬇ (Levels lower in winter)	
* No pollutant showed lower concentration in winter						

2.5 Interpretations and Inferences

Based on the extensive air quality measurements in the summer and winter months and critical analyses of air quality data, the following inferences and insights are drawn for developing a causal relationship between emission and impact through receptor modeling (Chapters 4). The season-wise, site-specific average air concentration of PM_{10}, $PM_{2.5}$ and their compositions and gaseous pollutants (Tables 2.69 – 2.79 and 2.81 – 2.85) 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 3.4 – 4.1 times higher than the national air quality standard (100 $\mu g/m^3$) in the winter season and 2.4 – 2.9 times in the summer season. $PM_{2.5}$ levels are 4.4 – 5.3 times higher than the national standard (60 $\mu g/m^3$) in the winter season. In the summer, $PM_{2.5}$ levels exceed by 1.6 – 2.1 times the national standard.

- 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.

PM_{10} (winter and summer)

The overall average concentration of PM_{10} was 367±29 $\mu g/m^3$ in winter and 287±21 $\mu g/m^3$ in summer against the acceptable level of 100 $\mu g/m^3$. The highest levels were observed at BCKR (401±105 $\mu g/m^3$) and lowest at AMUC (340±103 $\mu g/m^3$) in winter. In summer, the highest levels were at BCKR (314±112 $\mu g/m^3$) and the lowest at BHUS (266±48 $\mu g/m^3$).

In winter, crustal component (Si + Al + Fe + Ca) accounts for about 16% (much less compared to 30% in summer). This suggests soil and road dust have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.25 (of the fraction of crustal component), which suggests the crustal source contributes consistently even in winter, though much less than in summer.

In summer, the crustal component (Si + Al + Fe + Ca) accounts for about 30% of total PM_{10}. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.21 (of the fraction of crustal component), which suggests the sources are consistent and uniform all around the city, forming a layer that envelops the city. BCKR has the highest crustal fraction (around 36% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Varanasi 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.

In winter, the other important component is the combustion-related total carbon (TC = EC + OC), which account for about 26% of total PM_{10} and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for about 20%; both fractions of secondary particles and combustion-related carbons have increased and account for 46% of PM_{10}.

In summer, the combustion-related total carbon (EC+OC) account for 13% of total PM_{10} and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for about 7%.

The Cl^- content in PM_{10} in winter is consistent and varies between 2 –7%, an indicator of the burning of municipal and plastic solid waste (MSW); poly vinyl chloride (PVC) is a significant part of MSW. The highest Cl^- content is observed at IMAL at 25 $\mu g/m^3$ compared to the overall city level of 18 $\mu g/m^3$. The Cl^- content in PM_{10} in summer is consistent at 1.6 – 6%. The high level at IMAL signifies some local burning of waste either in industries or as means of disposal of solid waste.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ is 265±22 µg/m^3 in winter and 116±11 µg/m^3 in summer and against the acceptable level of 60 µg/m^3. The highest levels are observed at IMAL (285±107 µg/m^3) and lowest at BHUS (240±76 µg/m^3) in winter. In summer, the highest levels were at AMUC and the lowest at BHUS.

The crustal component (Si + Al + Fe + Ca) accounts for about 15% in winter and 16% in summer in total $PM_{2.5}$. The CV is about 0.25 in winter, which suggests the source is consistent all around the city though relatively small in summer.

In winter, the important components are the combustion-related total carbon (TC=EC+OC), which account for 26% of total $PM_{2.5}$ and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for 22%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 48%. The highest TC level was observed at IMAL (82 µg/m^3) and secondary particles at BHUS (about 66 µg/m^3).

In summer, the combustion-related total carbon (EC+OC) account for 23% and secondary particles accounts for 13%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 36%. The highest TC was at AMUC and secondary particles at IMAL.

The Cl^- content in $PM_{2.5}$ was consistent in the winter and summer seasons and varied between 2 - 8%, which is an indicator of the burning of MSW. This is relatively lower in summer than in winter.

Potassium levels

In general, potassium levels are high and variable for PM_{10} (6.4 to 8 µg/m^3) in winter and in summer 3.7 to 18 µg/m^3. In $PM_{2.5}$, potassium levels in winter vary between 5.4 to 6.4 µg/m^3. In general, the potassium levels are 2.0 µg/m^3 in urban areas. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.60) show day-to-day variation in winter.

NO_2 levels

NO_2 levels in winter are higher (30.20±9.04 µg/m^3) than those in summer (19.69±3.22 µg/m^3) and the levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 levels were at BCKR in winter (40.17 µg/m^3) and summer (24.03 µg/m^3), a residential site. NO_2 is 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 (less than 6.0 µg/m^3) in the city were well within the air quality standard.

General inferences

In winter, $PM_{2.5}$, OC and EC levels are significantly higher (p-value < 0.05) than summer season at all sites, PM_{10} levels are higher at all sites except IMAL, NO_2 levels are higher at all sites except BCKR and SO_2 levels are higher at AMUC and BHUS. In general, air pollution levels in ambient air (barring traffic intersections) are uniform across the city, suggesting the entire city is stressed under high pollution.

It is to be noted that OC3/TC ratio (OC3 refers to carbon content of higher molecular weight in organic compounds) is above 0.20 and the highest among the ratio of the fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed in the atmosphere due to condensation and nucleation of volatile to semi-volatile organic compounds, which suggests emissions within and outside of Varanasi.

Total PAH levels (17 compounds; particulate phase) in winter is high at 88 ng/m^3 and B(a)P at 7.30 ng/m^3 (annual standard is 1.0 ng/m^3); the comparison with the annual standard is not advisable due to different averaging times. PAH levels in summer drop significantly to about 16 ng/m^3. The highest PAH levels were observed at AMUC (250 ng/m^3) in winter and in summer 19 ng/m^3 at BCKR.

The overall average of six molecular markers (17α(H)-22,29,30–Trisnorhopane, 17α(H),21 α(H)_hopane, 17α(H),21β(H)-hopane, Pentriacontane, Hentriacontane and Tritriacontane) was higher in winter (188 ng/m^3) than in summer (130 ng/m^3). The presence of significant quantities of molecular markers, especially alkanes and hopanes show the significant contribution of coal burning, gasoline and diesel combustion.

The total BTX levels are slightly higher in winter (18.6±6.7 µg/m^3) than in summer (11.4±2.1 µg/m^3). The emission rate of VOCs is expected to be high in summer due to high temperature, but no much difference in the concentration in two seasons due to better dispersion and large ventilation coefficient in summer season.

In a broad sense, combustion sources, vehicles, coal, biomass burning and MSW burning are the consistent sources in winter and require a strategy to control these sources. In summer, air quality cannot be improved unless we find effective control solutions for soil and road dust, fly ash re-suspension. The possible effective mixture of control options is discussed in Chapter 6.

3 Emission Inventory

3.1 Introduction

Emission inventory (EI) is a basic necessity for planning air pollution control activities. EI provides a reliable estimate of total emissions of different pollutants, their spatial and temporal distribution, and identification and characterization of main sources. This information on EI is an essential input to air quality models for developing strategies and policies. In this chapter, the emission inventory of Varanasi city for the year 2020 is presented.

3.2 Methodology

The stepwise methodology adopted for this study is presented in Figure 3.1.

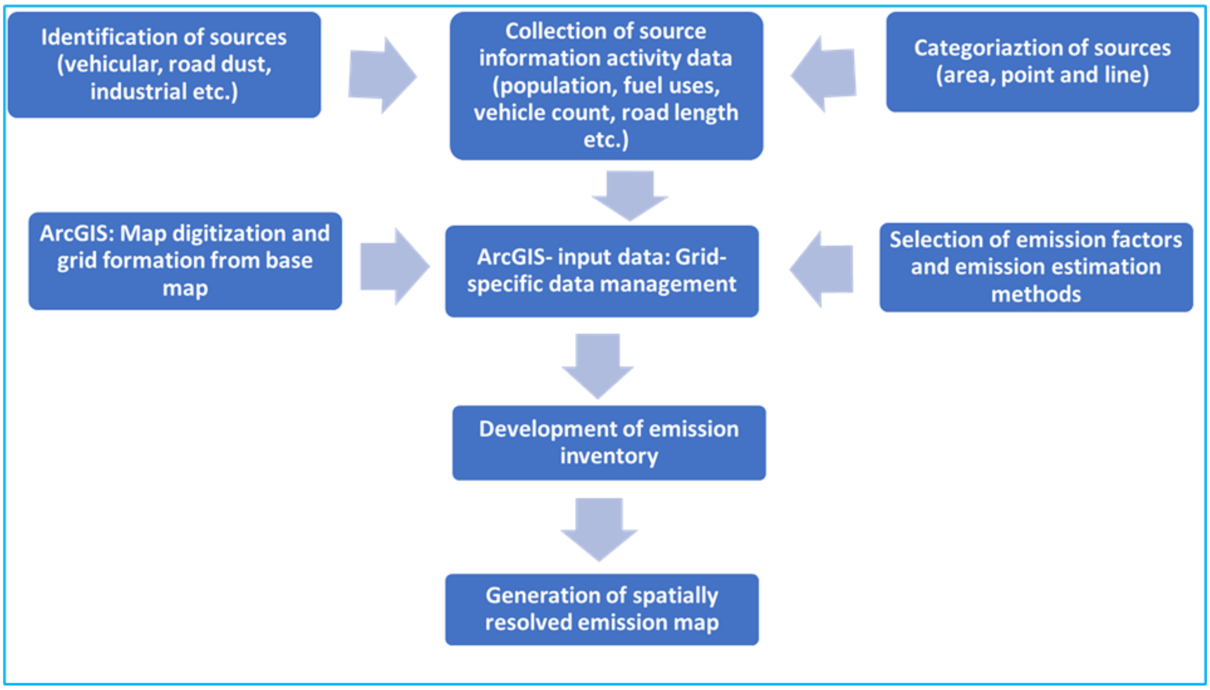

Identification of sources (vehicular, road dust, industrial etc.)
Collection of source information activity data (population, fuel uses, vehicle count, road length etc.)
Categoriaztion of sources (area, point and line)
ArcGIS: Map digitization and grid formation from base map
ArcGIS- input data: Grid-specific data management
Selection of emission factors and emission estimation methods
Development of emission inventory
Generation of spatially resolved emission map

Figure 3.1: Stepwise Methodology adopted for the Study

3.2.1 Categorization of Sources

The air quality of a region is affected by emissions from different sources. Depending upon the emissions from sources, their contribution to air quality varies. It is important to identify and quantify these sources to control the emission and thereby improve the air quality. Air pollution sources are widely categorized as area (domestic and fugitive combustion type emission sources), industrial (point and area) sources and vehicular (line) sources. The source category and type of sources are shown in Figure 3.2 .

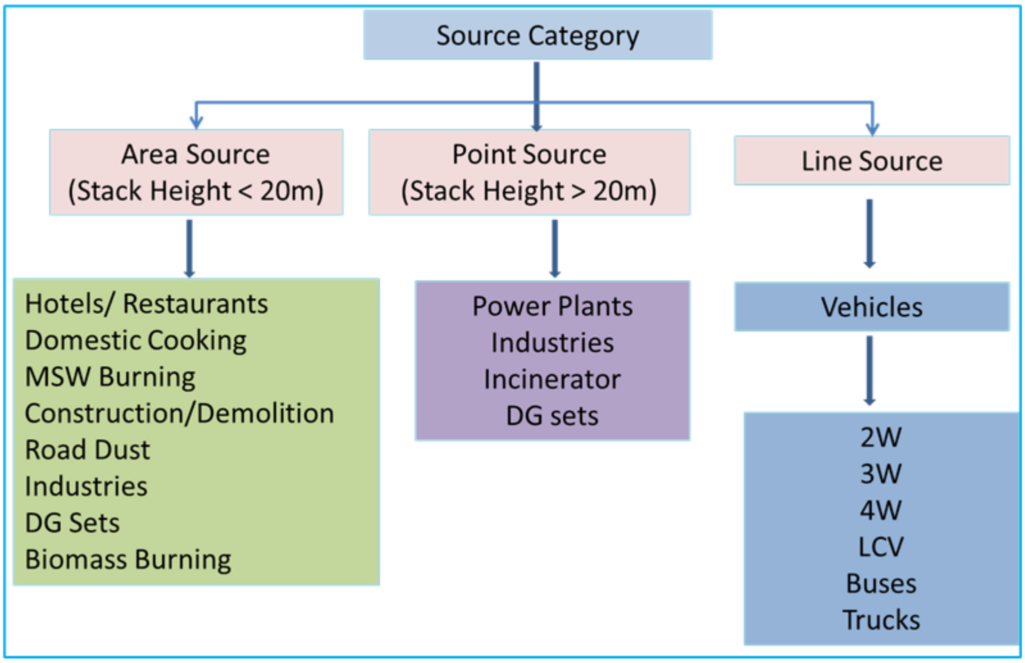

Source Category
Area Source
(Stack Height < 20m)
Point Source
(Stack Height > 20m)
Line Source
Hotels/ Restaurants
Domestic Cooking
MSW Burning
Construction/Demolition
Road Dust
Industries
DG Sets
Biomass Burning
Power Plants
Industries
Incinerator
DG sets
Vehicles
2W
3W
4W
LCV
Buses
Trucks

Figure 3.2: Source Category and type of sources

3.2.2 Data Collection

The primary and secondary data were collected by the IITK team. For example, construction and demolition data were collected by field survey and validated by satellite imagery. Road dust sampling at seven locations was conducted. A physical survey of industrial areas was also done. The main sources of secondary data collection are from UPPCB, Census of India, CPCB website, Transport Department, and Toll Plazas. The information has also been collected through the Internet by visiting various websites. Although all possible efforts have been made to collect the data, some information/data could be missing.

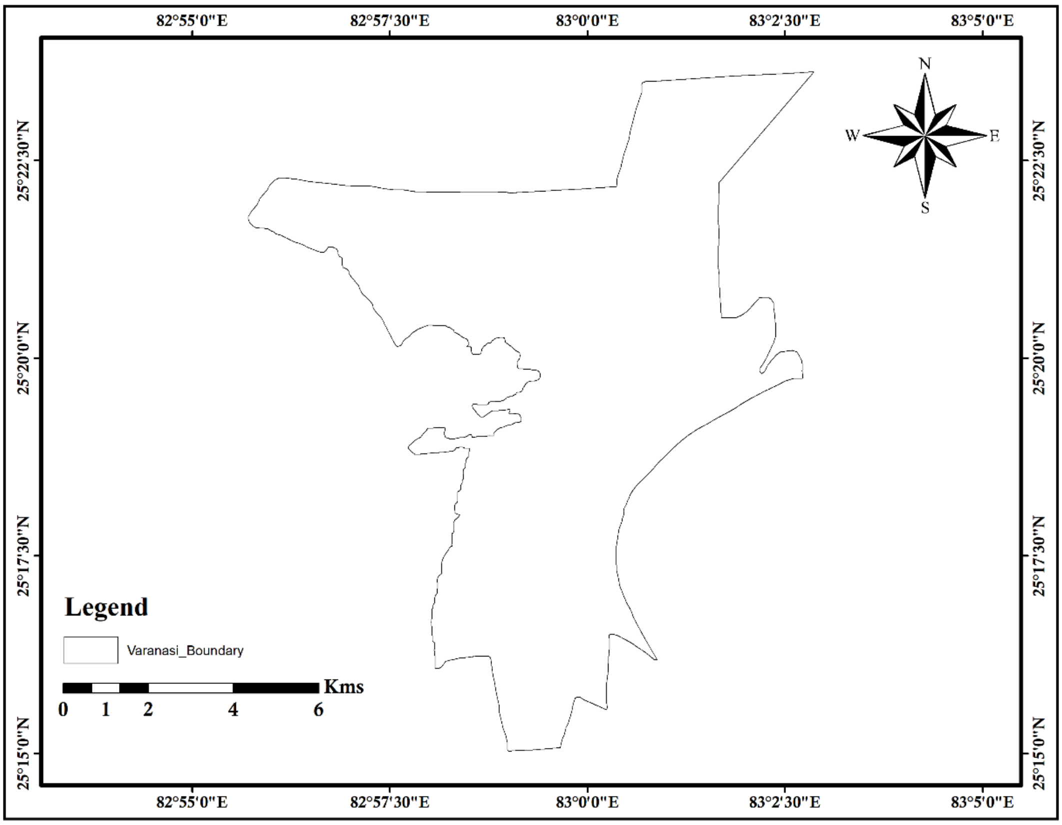
The period for the primary surveys is given below in the table.

Varanasi **Data Collection Period: October – November 2020**		
Sources	Primary	Secondary
Domestic	On-field ward-wise survey	Census of India
Construction and Demolition	On-filed Survey of construdtion site	Satellite Google Imagery, PWD, CPWD, Development Authority
Hotels, Restaurants, GHs and BHs	Onfield Survey	

Brick Kilns	On-field Survey	Satellite Google Imagery
MSW Burning	On-field Survey	
Hospitals	On-field Survey	
Industries	Geotagged	Consent Data
DG sets	Geotagged	Consent Data
Vehicle	Video Recording	
Road Dust	On-field Sampling	

3.2.3 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, agriculture, road network, water bodies, etc. (Figure 3.3 to Figure 3.13).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83°5'0"E
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25°15'0"N
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Legend
Varanasi_Boundary
Kms
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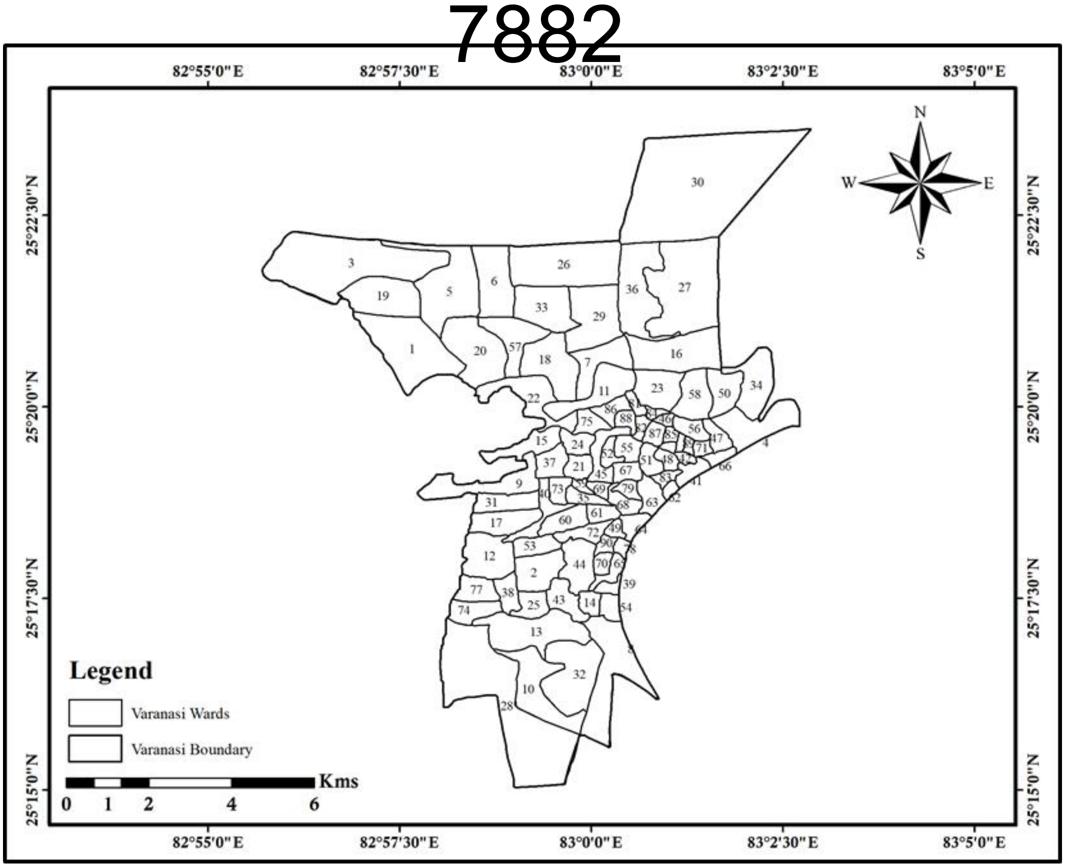
Figure 3.3: Varanasi City Boundary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20
57
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7
16
11
23
58
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34
22
86
88
84
46
56
47
4
75
87
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15
24
52
55
71
51
48
66
37
21
45
67
83
41
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40
73
69
79
31
68
63
62
17
60
61
72
49
64
53
90
78
12
44
70
65
2
39
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43
14
54
74
13
32
10
28
Legend
Varanasi Wards
Varanasi Boundary
Kms
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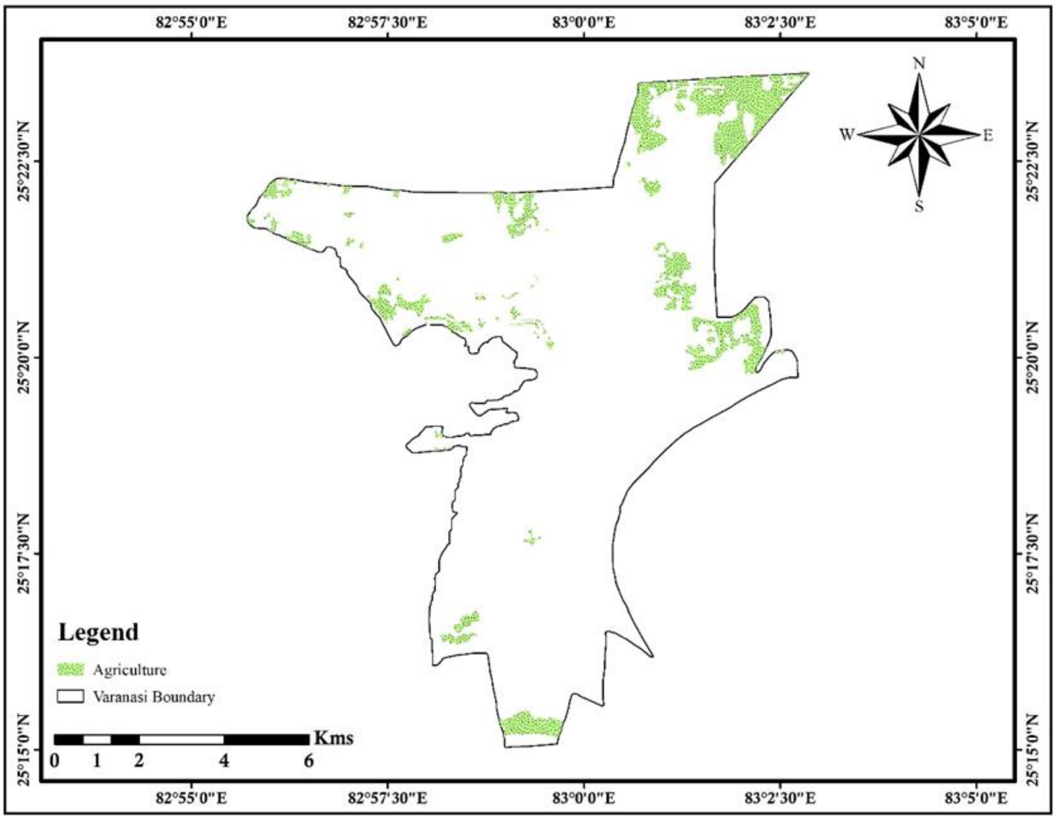
Figure 3.4: Ward Map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Legend
Agriculture
Varanasi Boundary
Kms
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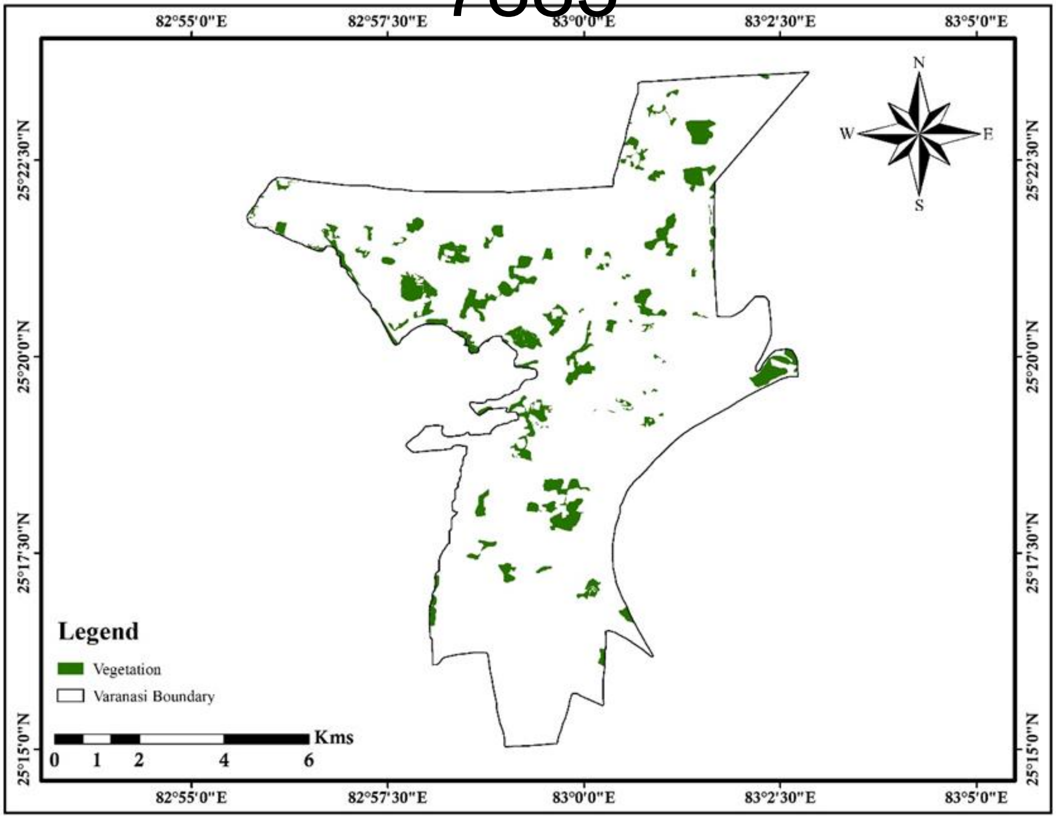
Figure 3.5: Agricultural Area Map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Legend
Vegetation
Varanasi Boundary
Kms
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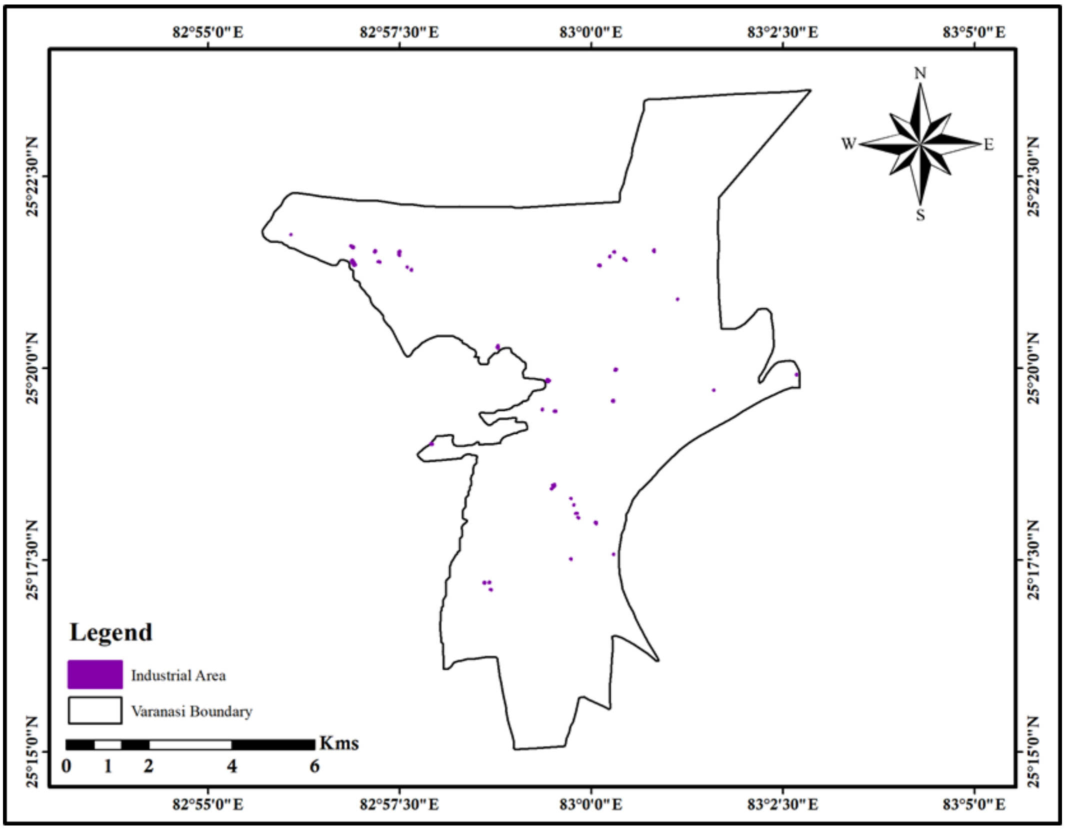
Figure 3.6: Green Area (Vegetation) Map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Legend
Industrial Area
Varanasi Boundary
Kms
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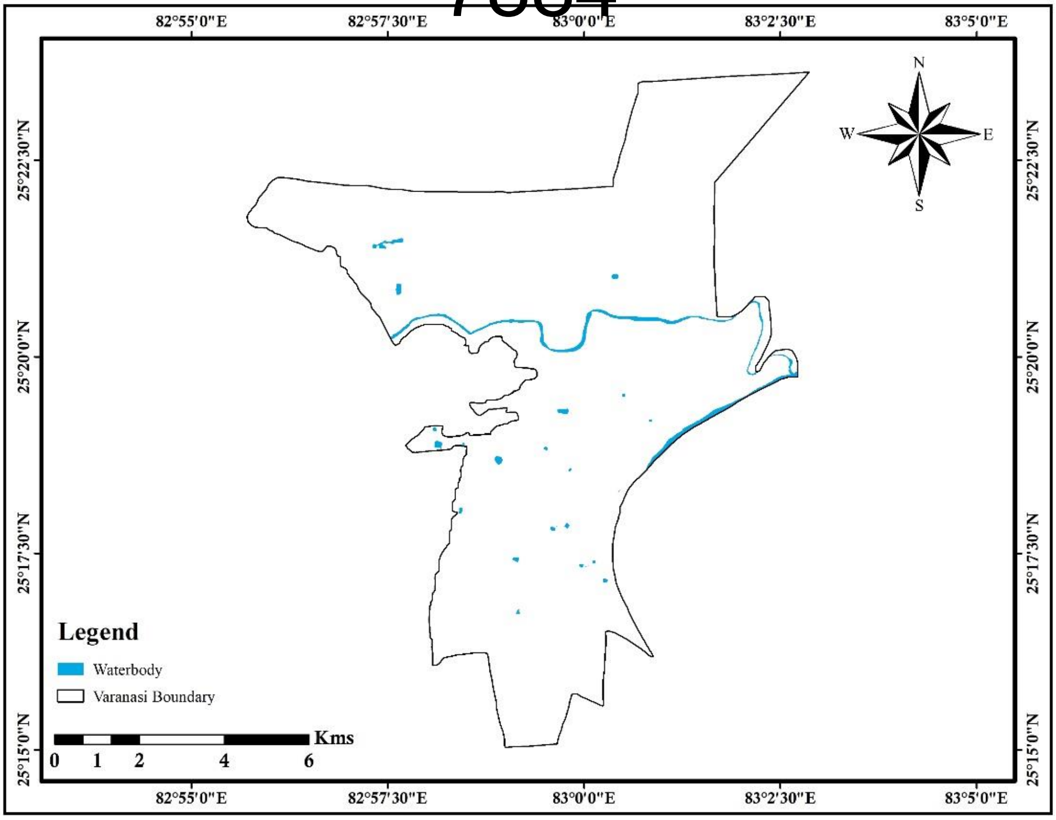
Figure 3.7: Industrial Area Map

7884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Legend
Waterbody
Varanasi Boundary
Kms
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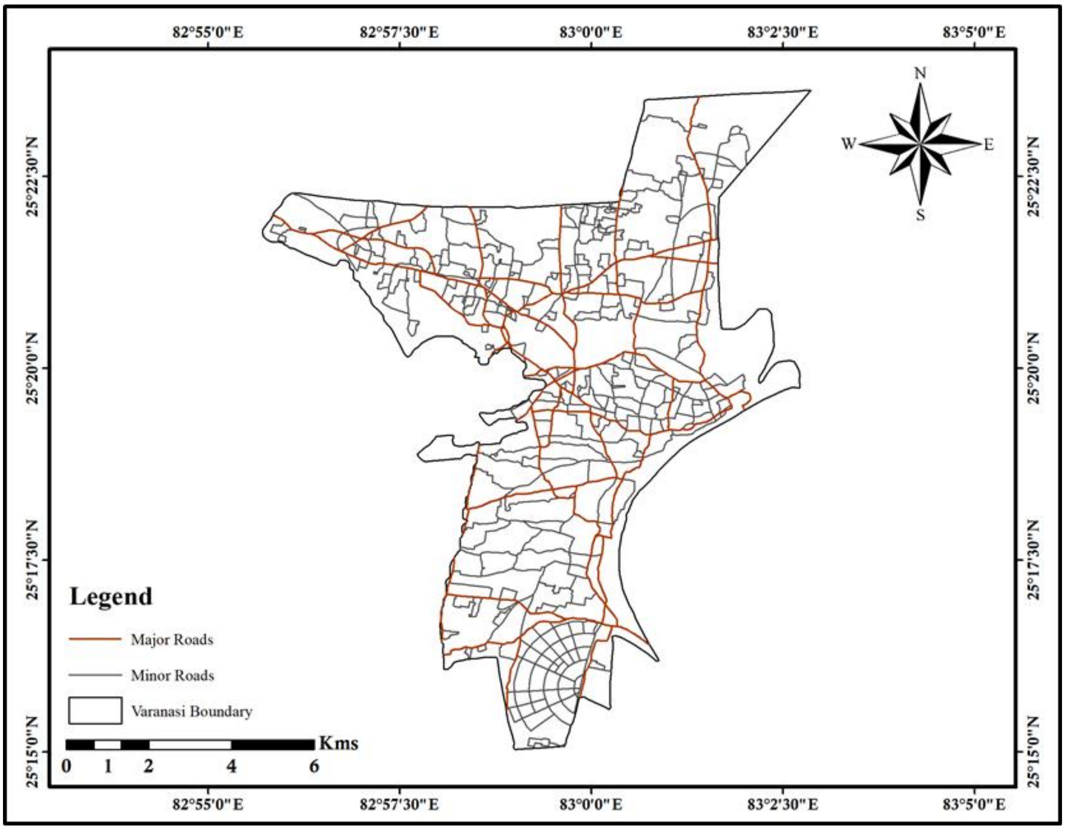
Figure 3.8: Waterbodies Area Map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Legend
Major Roads
Minor Roads
Varanasi Boundary
Kms
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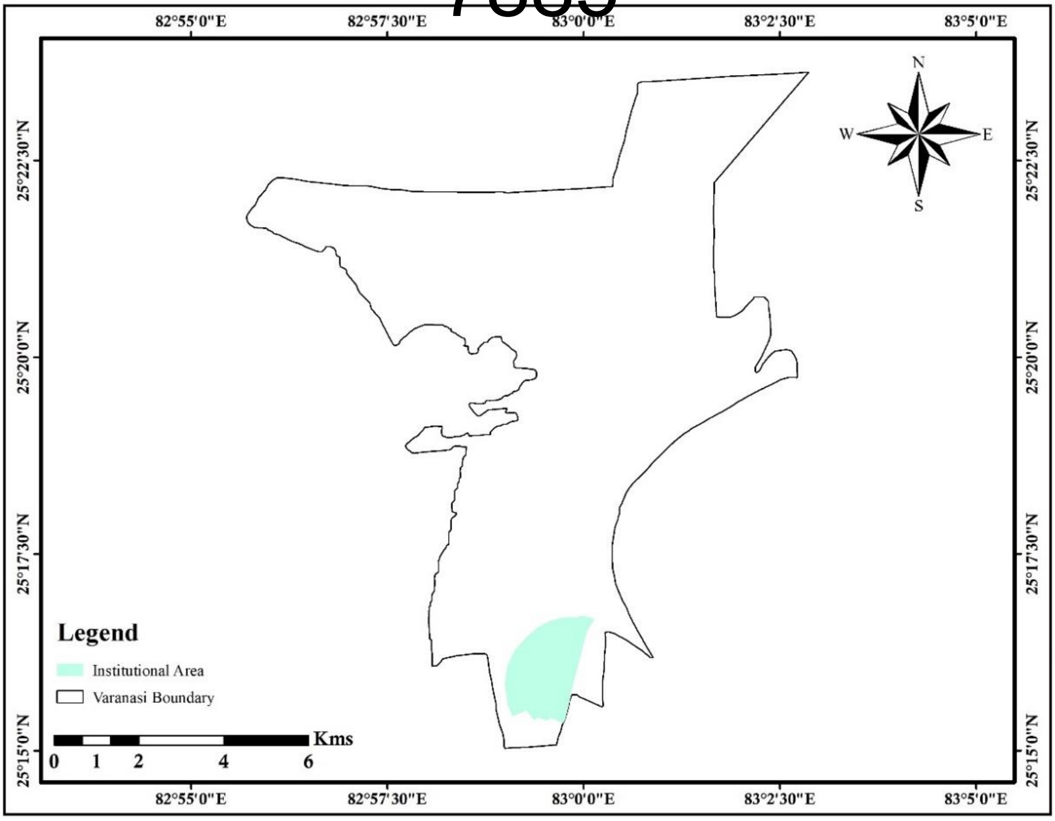
Figure 3.9: Major Road Network Map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Institutional Area
Varanasi Boundary
Kms
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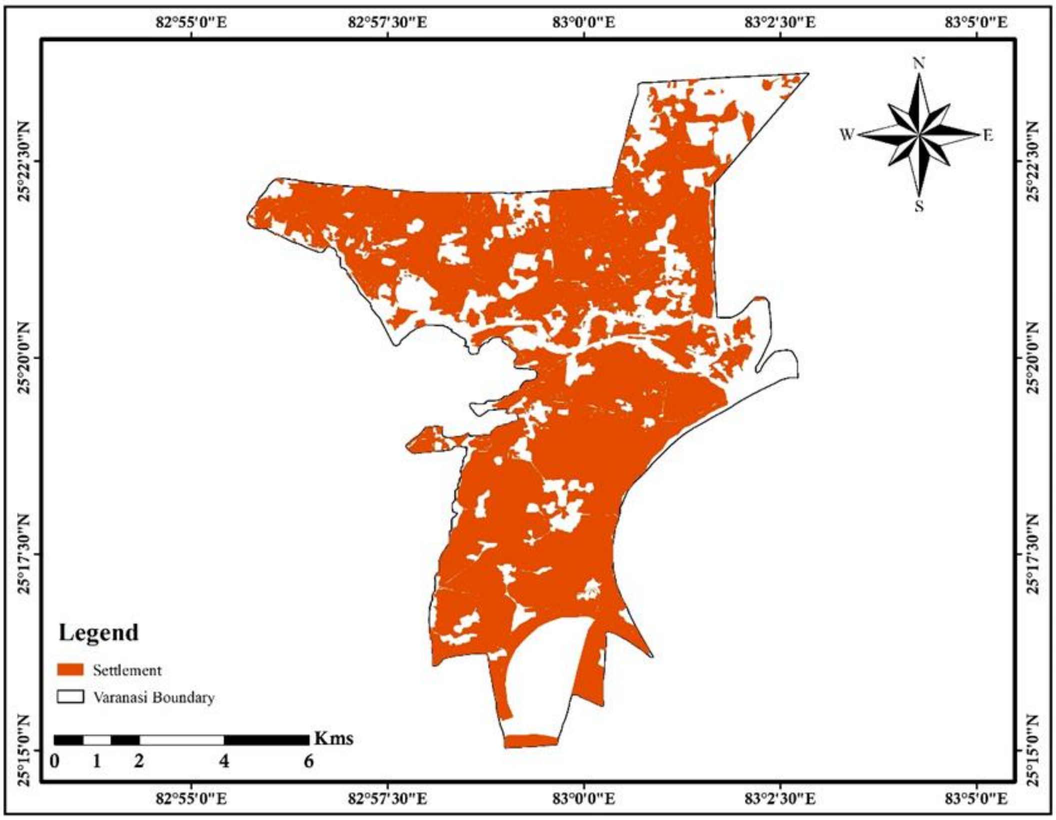
Figure 3.10: Institutional Area Map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25°15'0"N
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Legend
Settlement
Varanasi Boundary
Kms
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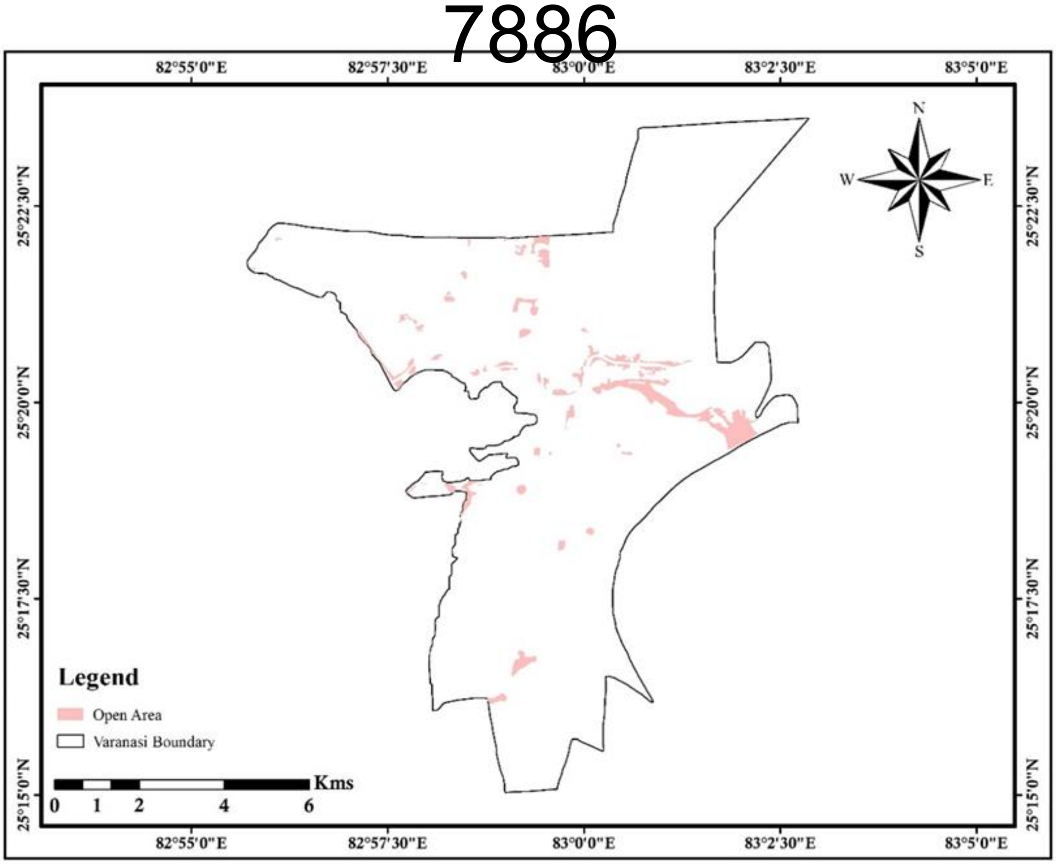
Figure 3.11: Settlement Area Map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25°15'0"N
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Legend
Open Area
Varanasi Boundary
Kms
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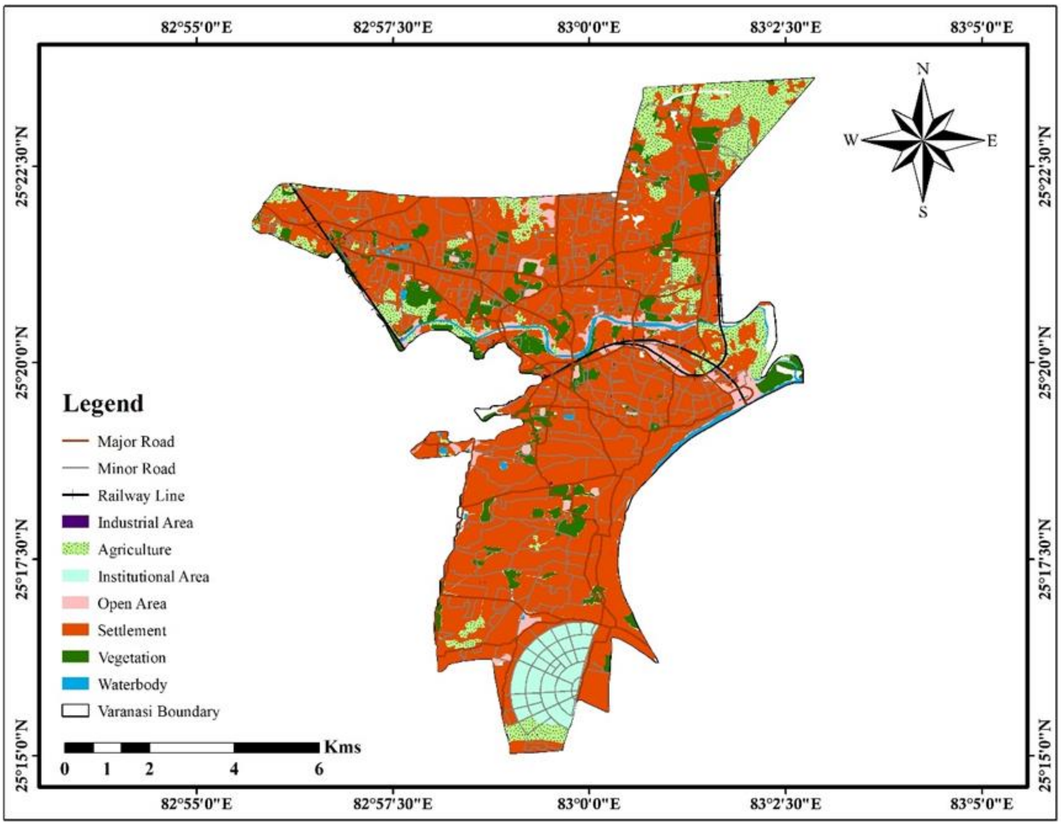
Figure 3.12: Open Area Map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25°20'0"N
25°17'30"N
25°15'0"N
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W
Legend
Major Road
Minor Road
Railway Line
Industrial Area
Agriculture
Institutional Area
Open Area
Settlement
Vegetation
Waterbody
Varanasi Boundary
Kms
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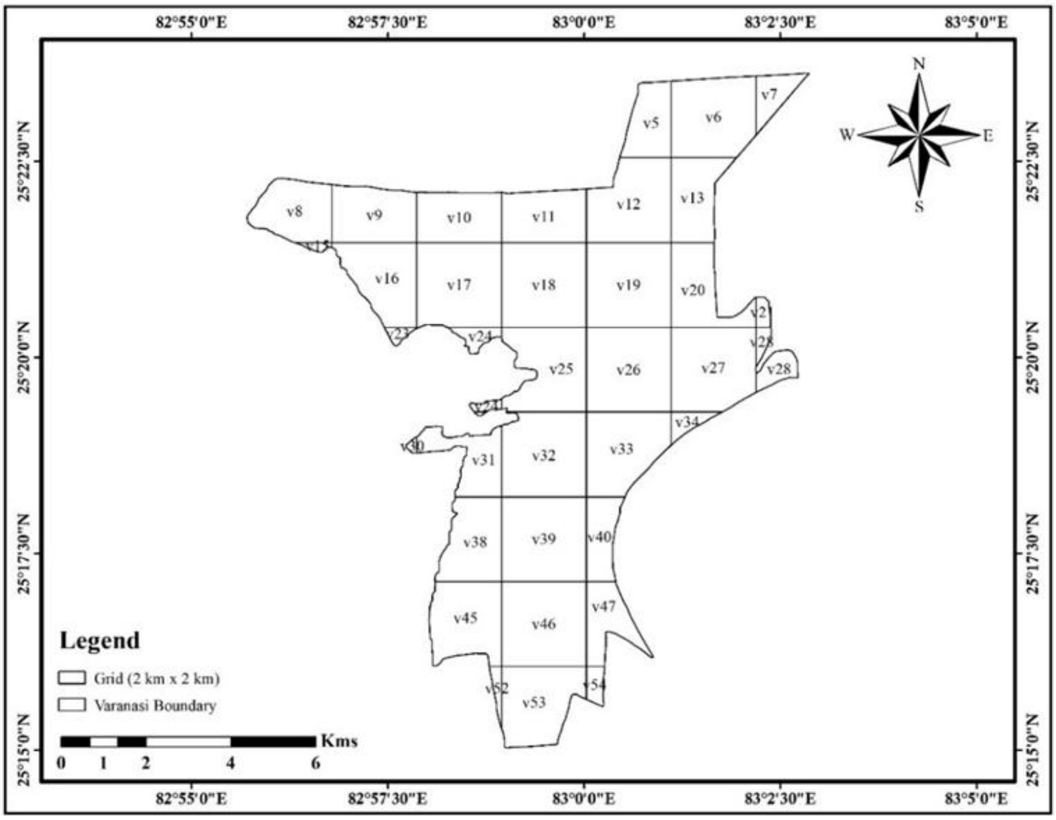
Figure 3.13: Land-use Map of Varanasi city

At the time of the development of the emission inventory, a suitable coding system was adopted to avoid confusion and misrepresentation of results and interpretation. The emissions have been calculated for Varanasi city. The Grid map of Varanasi with grid identity numbers is shown in Figure 3.14. The entire study area was divided into grid cells of 2 km x 2 km.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v47
v52
v53
v54
Legend
Grid (2 km x 2 km)
Varanasi Boundary
Kms
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6

Figure 3.14: Grid Map of Varanasi showing Grid Identity Numbers

3.2.4 Emission Factor

An emissions factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the mass of pollutant per unit mass of raw material, volume, distance traveled, or duration of the activity (e.g., grams of particulate emitted per kilogram of coal burnt). Such factors facilitate the estimation of emissions from various sources of air pollution. In most cases, these factors are simply averaging of all available data of acceptable quality and are generally assumed to be representative of long-term averages for all facilities in the source category. The emission factors used in the report are mentioned in Annexure 1.

The general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100) \qquad (3.1)$$

Where:

E = Emissions;
A = Activity rate;
EF = Emission factor, and
ER = Overall emission reduction efficiency, %

The CPCB-prescribed emission factors (mostly adopted from USEPA – AP42) are used to bring uniformity in emission estimates, thus facilitating comparison in the emission inventories of different cities. The emission reductions from air pollution control devices (APCD) were duly accounted for. As regards vehicle emissions, factors revised by ARAI were used and for BS-VI vehicles, prescribed limits were taken as the emission factor.

3.2.5 Domestic Sector

The interior boundaries in the map with 90 wards (Figure 3.15) show the administrative boundaries of wards in Varanasi City. The projected population of Varanasi city for the year 2020 is approximately 1630000 and the emission from the domestic sector for the same is calculated. The fuel consumption pattern shows LPG (85%) consumption (CEEW Report, 2020), Wood (3.2%), Kerosene (1.2%), Dung (0.7%), Coal (0.6%), and Crop Residue (0.4%). During the field survey, it was observed that most of the economically weaker/ slum areas are using wood and dung as fuel for cooking. Although they have been given LPG cylinders, due to their economic condition, refilling of cylinders is irregular.

The area of wards was calculated using GIS, and the emission density for each ward is calculated for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO). The emission factors are given by CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

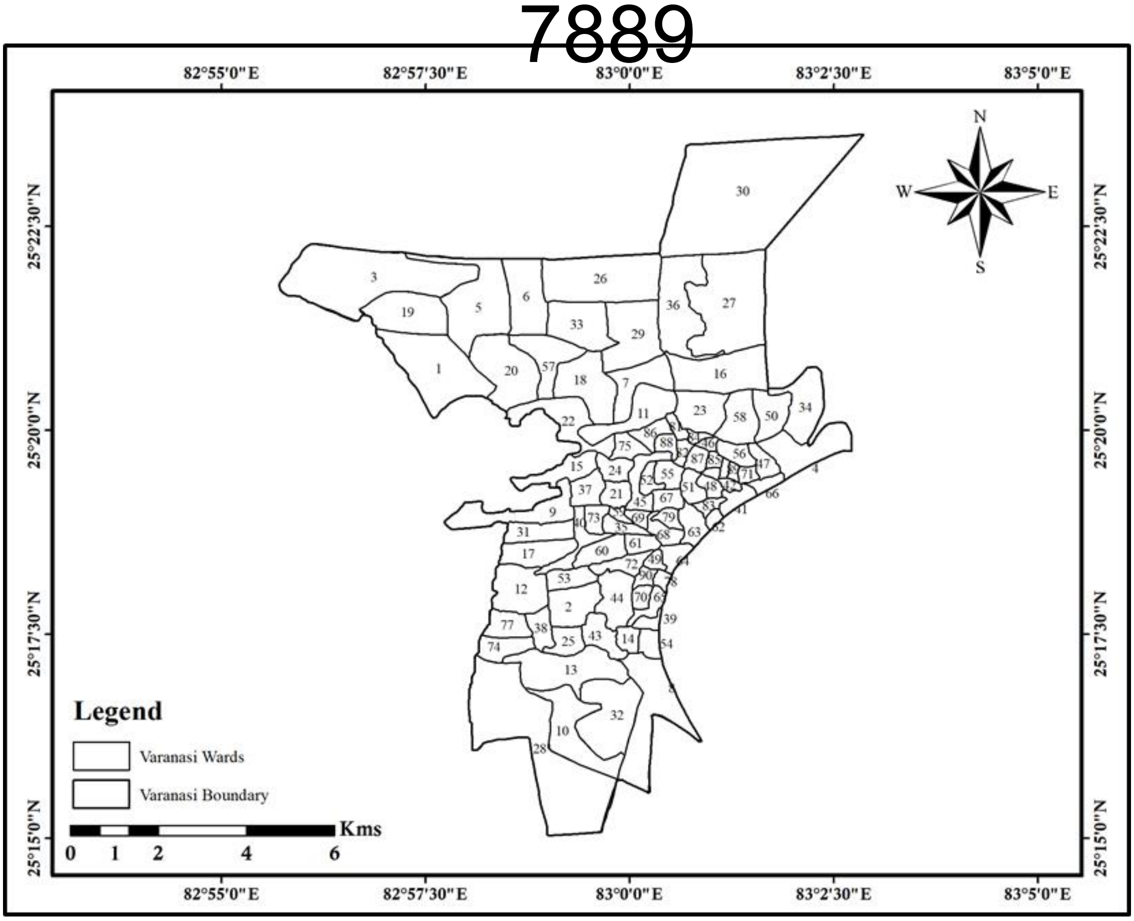

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Varanasi Wards
Varanasi Boundary
Kms
0 1 2 4 6

Figure 3.15: Wards in Varanasi City

The overall emission from domestic sources is presented in Figure 3.16. The emission contribution from different fuel types to different pollutants is shown in Figure 3.17 to Figure 3.21. For spatial distribution of different pollutants (Figure 3.22 to Figure 3.26), emission per capita, in each ward was calculated, as activity data was available based on per capita.

The emission density in terms of kg/day/m^2 in each ward was calculated based on the population and area of the ward for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO); see below.

Emission Density (kg/day/m^2) = Emission of Ward (kg/day) / Ward Area (m^2). . . . . (3.2)

For calculating emissions in a grid that may contain more than one ward, the area of the fraction of each ward falling inside that grid was calculated, and with the help of the emission density of the ward, the emissions were calculated, see below.

7890

$$Grid\ Emissions = \sum_{i=1}^{N} \begin{pmatrix} area\ of\ fraction\ ward\ i\ in\ grid \times \\ emission\ density\ of\ ward, i \end{pmatrix} \qquad …….(3.3)$$

Where N= no. of wards in the grid

i = ith ward in the grid

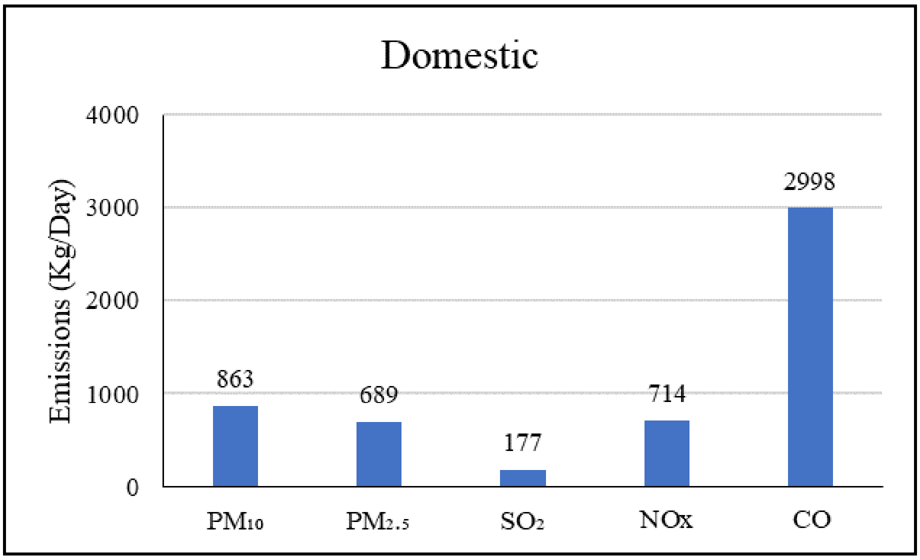


Figure 3.16: Emission Load from Domestic Sector (kg/day)

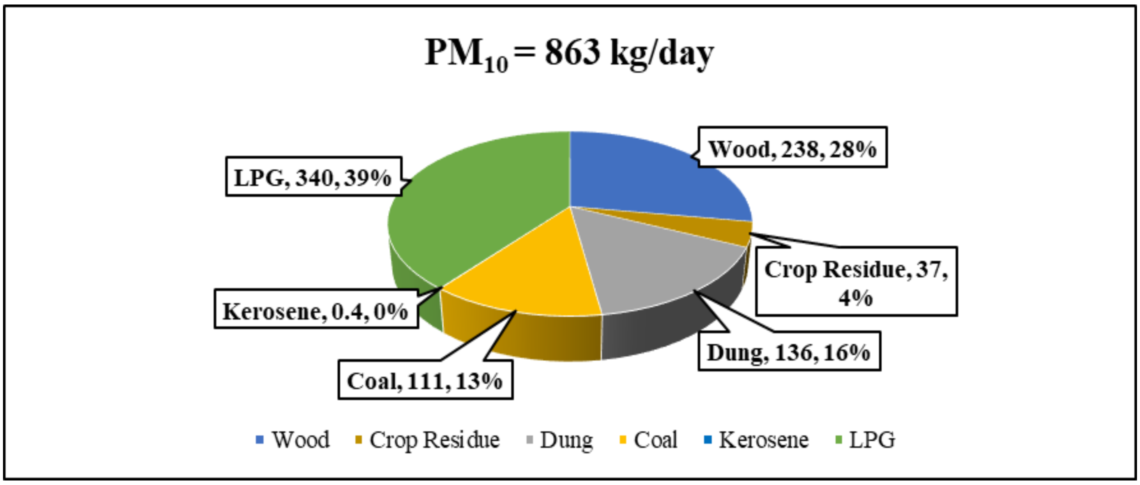


Figure 3.17: PM$_{10}$ Emission load from Domestic Sector (Kg/day, %)

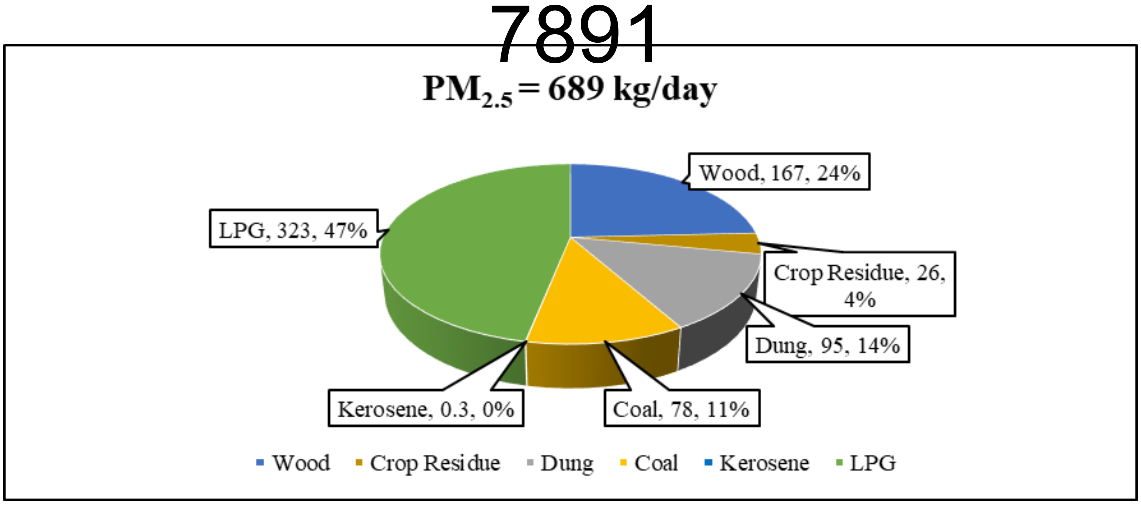


Figure 3.18: $PM_{2.5}$ Emission load from Domestic Sector (Kg/day, %)

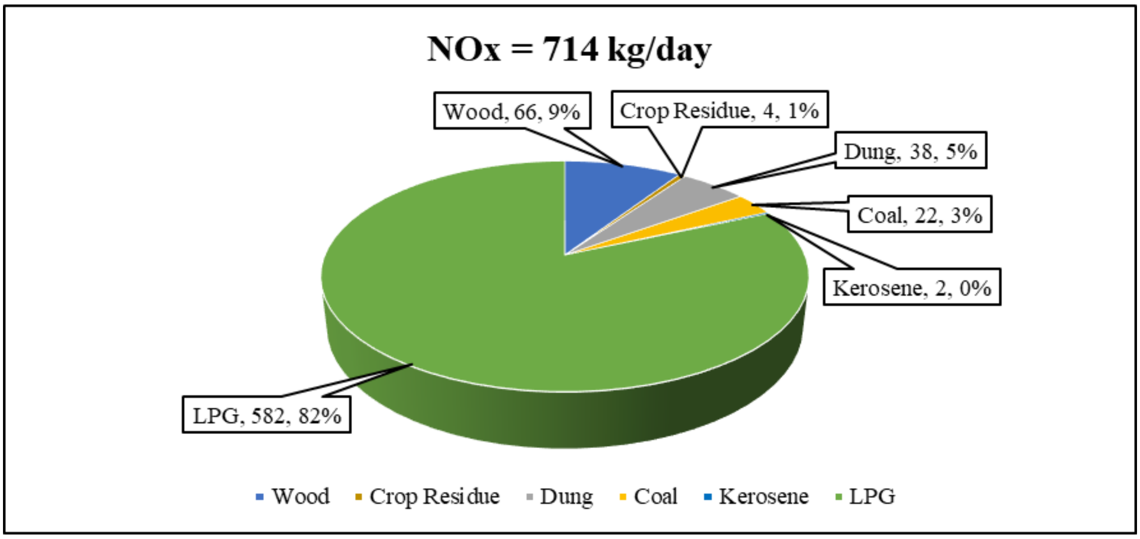


Figure 3.19: NOx Emission load from Domestic Sector (Kg/day, %)

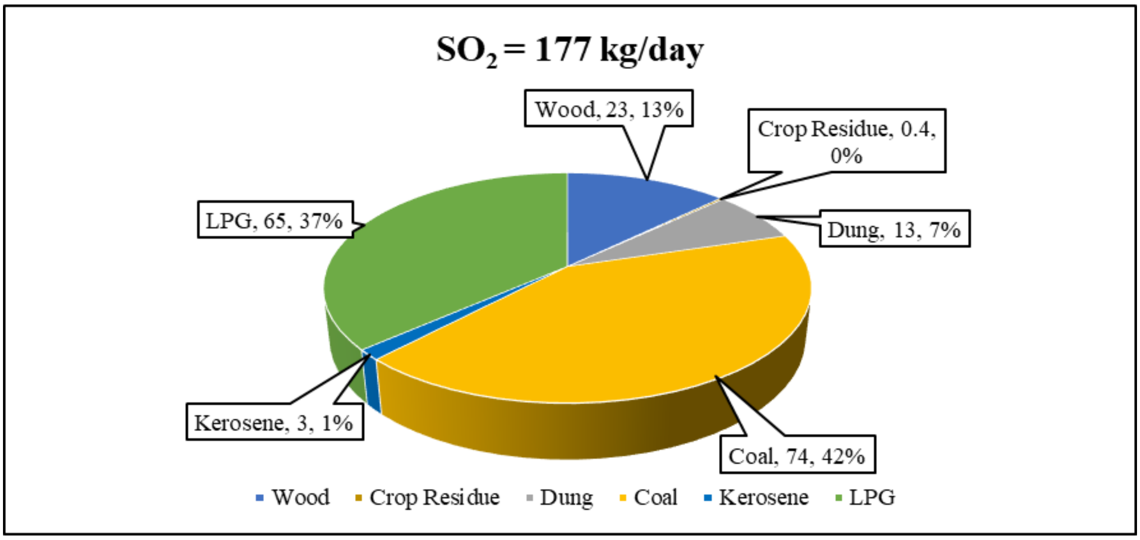


Figure 3.20: SO_2 Emission load from Domestic Sector (Kg/day, %)

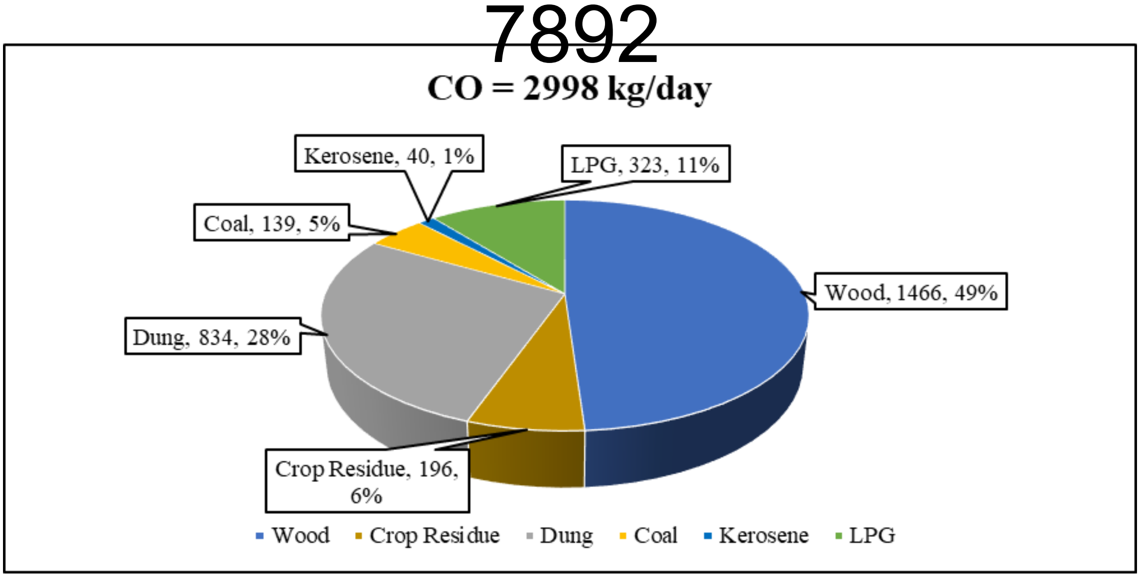
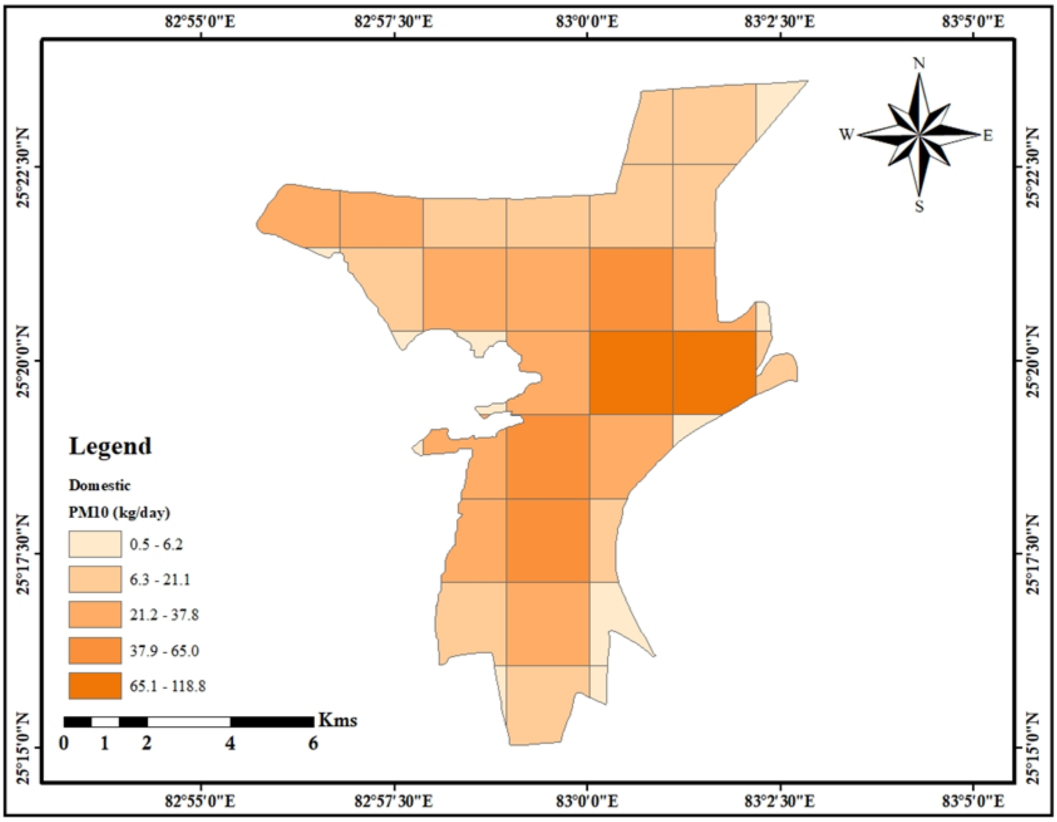


Figure 3.21: CO Emission load from Domestic Sector (Kg/day, %)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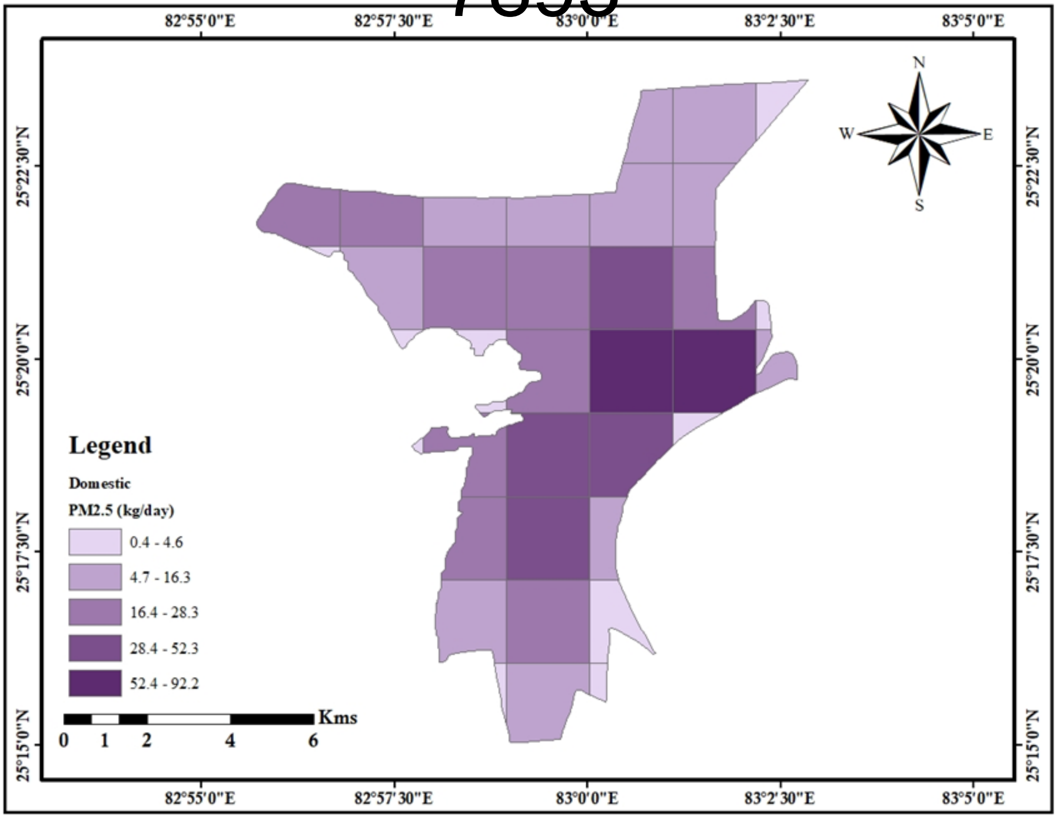
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Domestic
PM10 (kg/day)
0.5 - 6.2
6.3 - 21.1
21.2 - 37.8
37.9 - 65.0
65.1 - 118.8
Kms
0
1
2
4
6

Figure 3.22: Spatial Distribution of PM_{10} Emissions from Domestic Sector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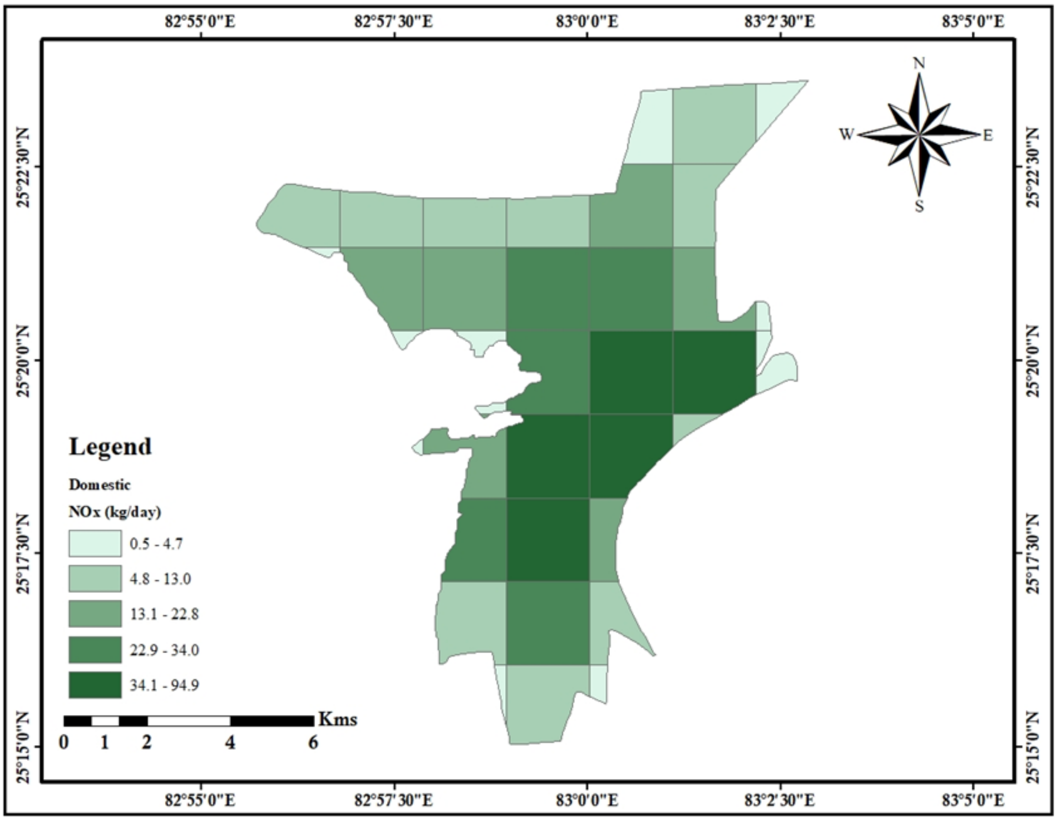
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Domestic
PM2.5 (kg/day)
0.4 - 4.6
4.7 - 16.3
16.4 - 28.3
28.4 - 52.3
52.4 - 92.2
Kms
0
1
2
4
6

Figure 3.23: Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector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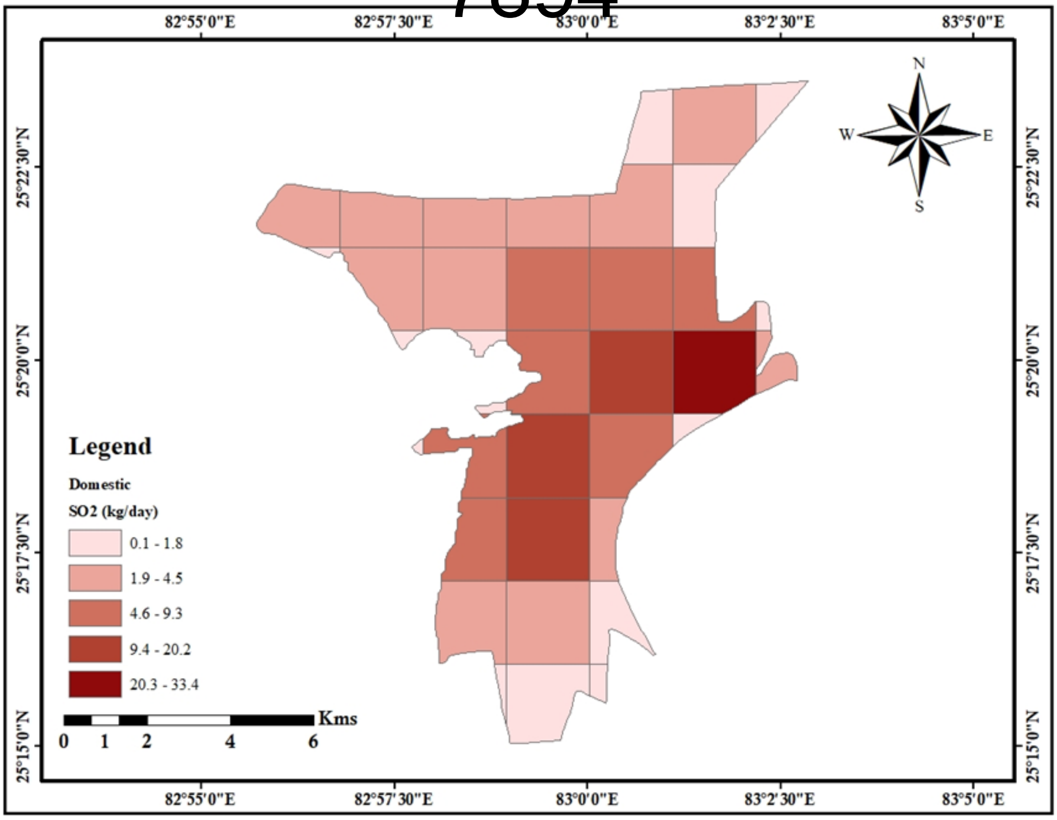
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Domestic
NOx (kg/day)
0.5 - 4.7
4.8 - 13.0
13.1 - 22.8
22.9 - 34.0
34.1 - 94.9
Kms
0
1
2
4
6

Figure 3.24: Spatial Distribution of NOx Emissions from Domestic Sector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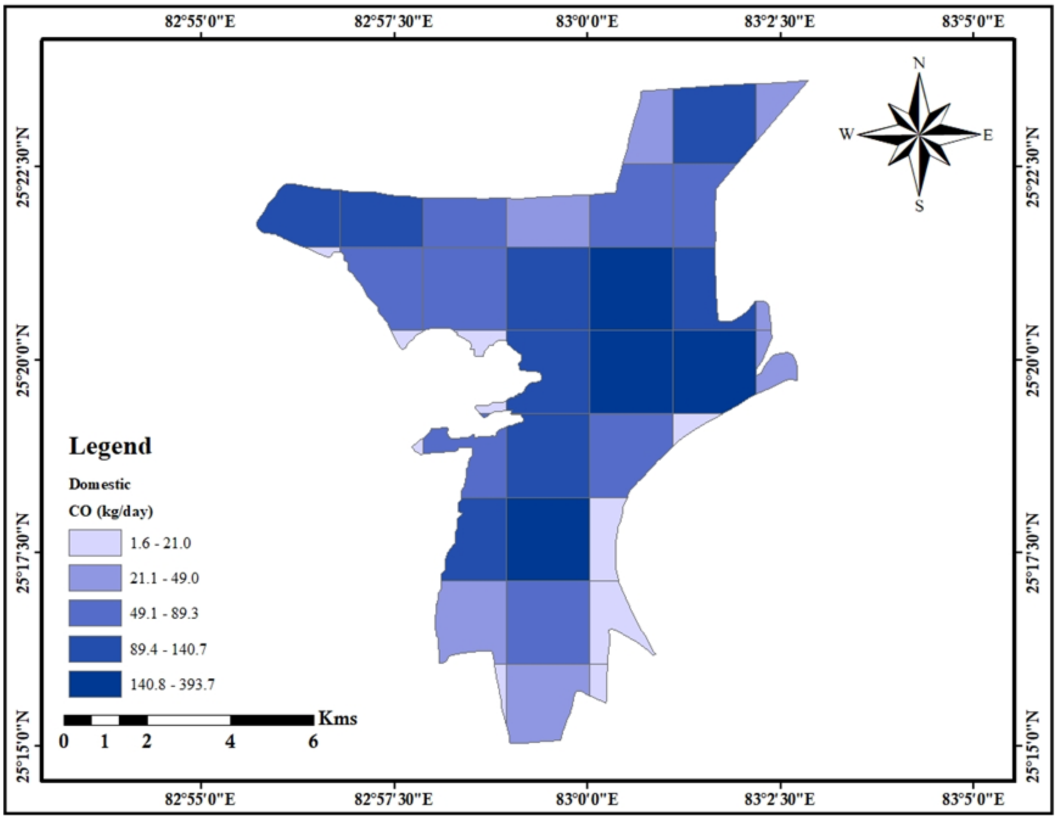
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Domestic
SO2 (kg/day)
0.1 - 1.8
1.9 - 4.5
4.6 - 9.3
9.4 - 20.2
20.3 - 33.4
Kms
0
1
2
4
6

Figure 3.25: Spatial Distribution of SO₂ Emissions from Domestic Sector


82°55'0"E
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83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Domestic
CO (kg/day)
1.6 - 21.0
21.1 - 49.0
49.1 - 89.3
89.4 - 140.7
140.8 - 393.7
Kms
0
1
2
4
6

Figure 3.26: Spatial Distribution of CO Emissions from Domestic Sector

3.2.6 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. Satellite imagery was also used to identify the construction activities. The major construction activities include buildings (including residential housing and apartments) information was obtained from Varanasi Nagar Nigam, PWD, CPWD, and a detailed survey were done. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road (Figure 3.27). The areas under construction activities were calculated based on survey data and GIS. The location of construction and demolition sites at Varanasi is given in Figure 3.28.

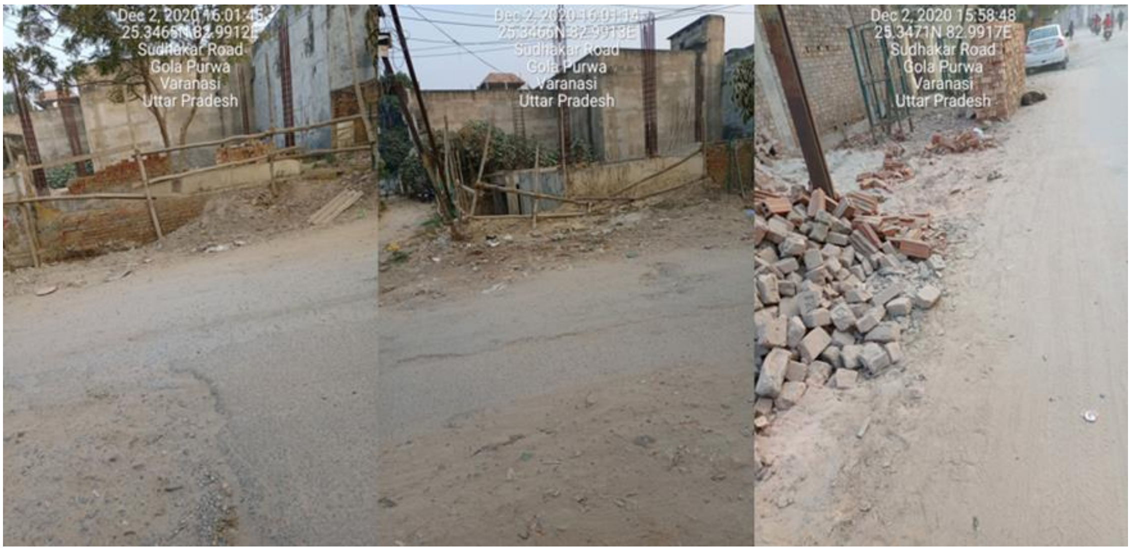
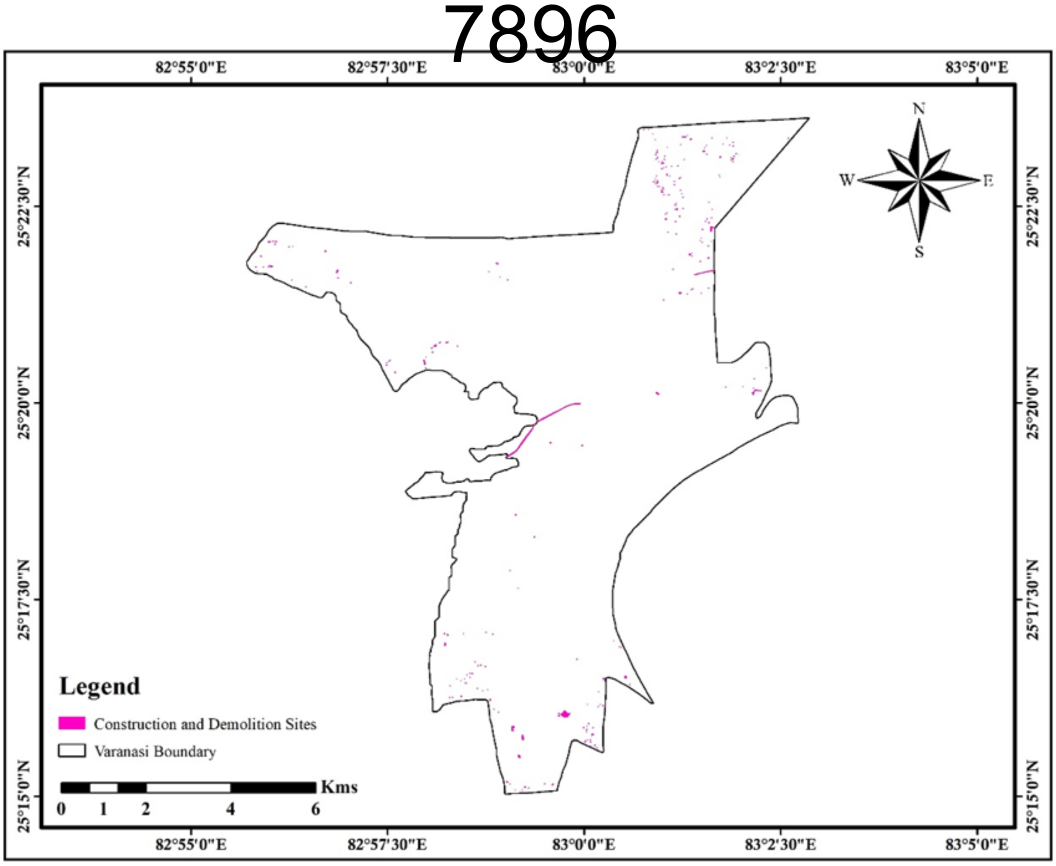

Dec 2, 2020 16:01:45
25.3465N 82.9912E
Sudhakar Road
Gola Purwa
Varanasi
Uttar Pradesh
Dec 2, 2020 16:01:14
25.3466N 82.9913E
Sudhakar Road
Gola Purwa
Varanasi
Uttar Pradesh
Dec 2, 2020 15:58:48
25.3471N 82.9917E
Sudhakar Road
Gola Purwa
Varanasi
Uttar Pradesh

Figure 3.27: Construction material and debris near constructuion sites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83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Construction and Demolition Sites
Varanasi Boundary
Kms
0
1
2
4
6

Figure 3.28: Location of Construction and Demolition sites at Varanasi city

Total emissions from construction and demolition activities are presented in Figure 3.29. The spatially resolved map of construction and demolition activities is shown in Figure 3.30 and Figure 3.31. The Emission load of PM_{10} and $PM_{2.5}$ from construction and demolition is 281 kg/day and 65 kg/day.

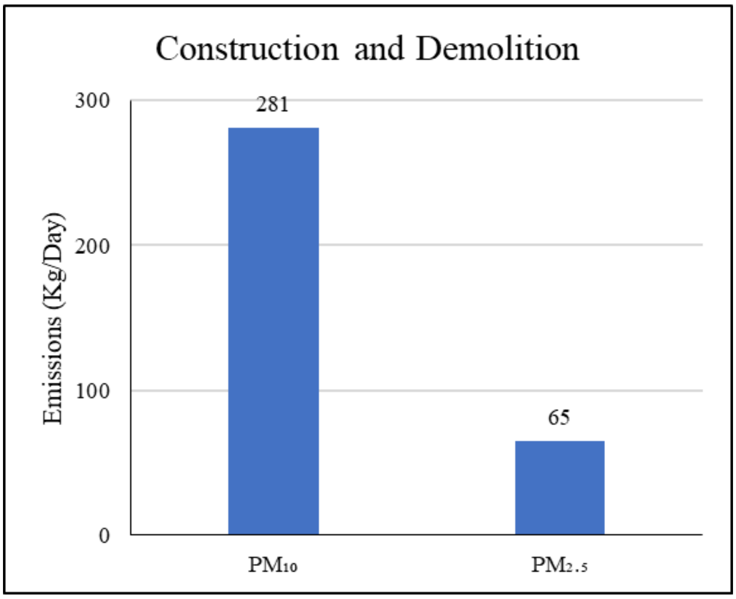


Figure 3.29: Emission Load from Construction and Demolition activities (kg/day)

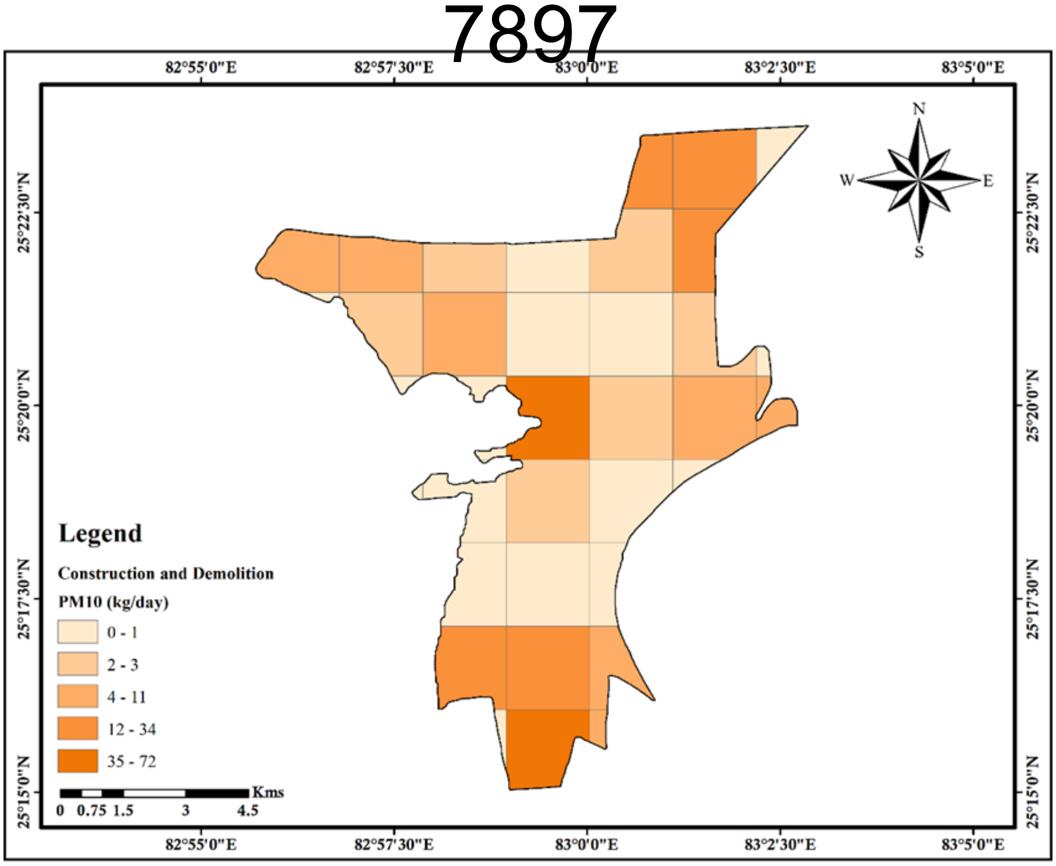
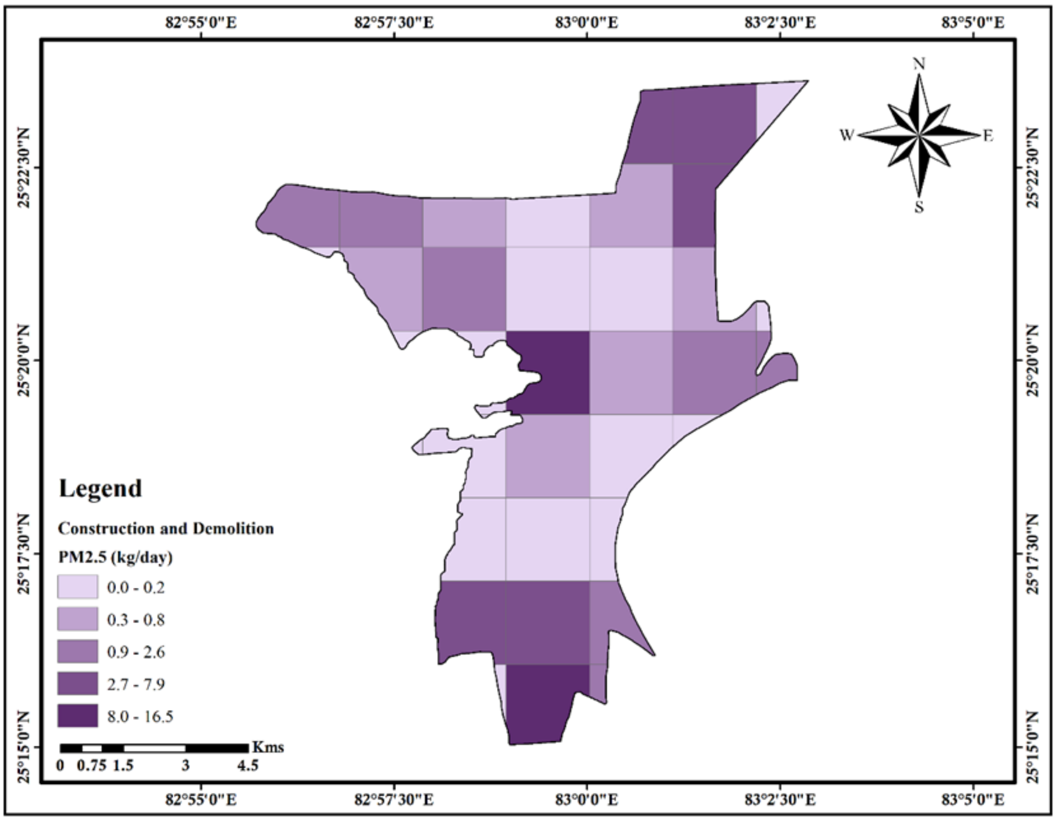

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Construction and Demolition
PM10 (kg/day)
0 - 1
2 - 3
4 - 11
12 - 34
35 - 72
Kms
0 0.75 1.5 3 4.5

Figure 3.30: Spatial Distribution of PM_{10} Emissions from Construction/Demolition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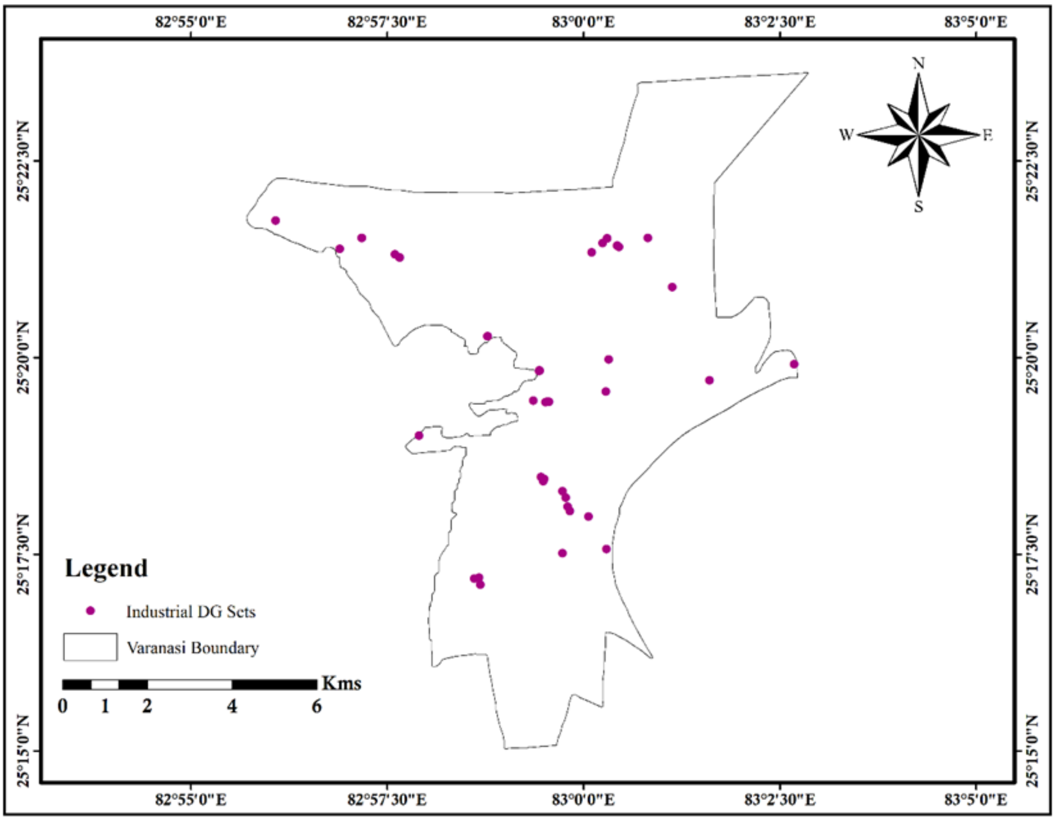
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Construction and Demolition
PM2.5 (kg/day)
0.0 - 0.2
0.3 - 0.8
0.9 - 2.6
2.7 - 7.9
8.0 - 16.5
Kms
0 0.75 1.5 3 4.5

Figure 3.31: Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition

7898

3.2.7 Industrial Diesel Generator Sets (Industrial DG sets)

The location of the DG set is shown in Figure 3.32. The industries use DG sets as a backup, approximately 42 DG sets are installed in industries that inside of the city boundary (source: consent data). The capacities of DG sets are in the range of 5 KVA to 750 KVA with an average capacity of 180 KVA. During the industrial survey, it was found that these DG sets operate for two hours per day. Most industries use diesel as fuel for generator sets. The calculation is based on Eq (3.1), where ER, overall efficiency reduction was taken as zero. The CPCB (2011) emission factors were used for emission estimation. The total emissions from DG sets are shown in Figure 3.33, the spatial distribution of emissions from DG Sets is shown in Figure 3.34 to Figure 3.38.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83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
E
S
W
Legend
● Industrial DG Sets
Varanasi Boundary
Kms
0 1 2 4 6

Figure 3.32: Location of Industrial DG Sets

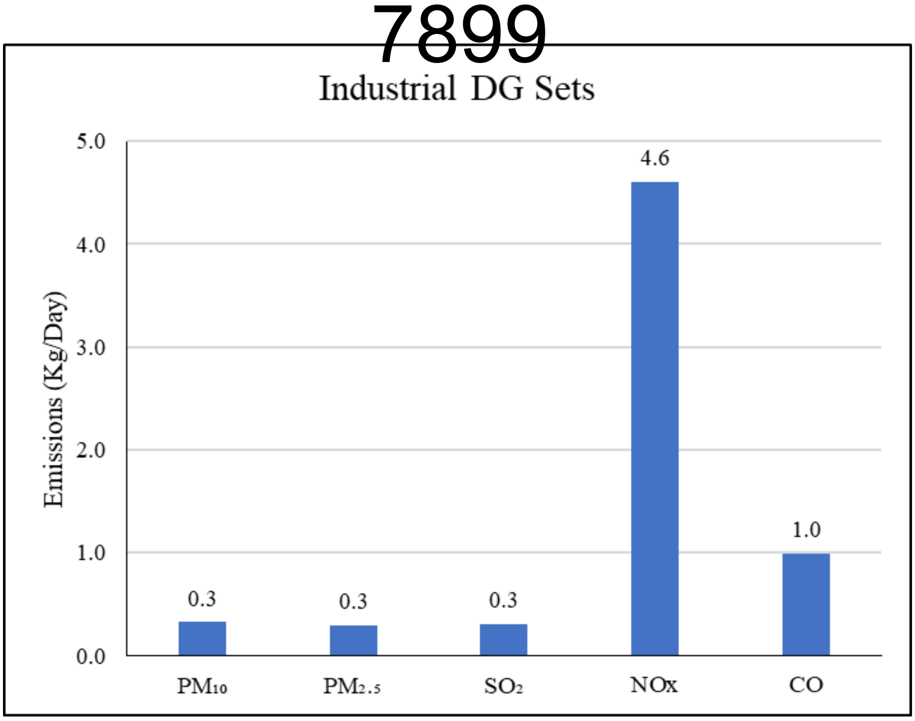


Figure 3.33: Emission Load (kg/day) from DG sets

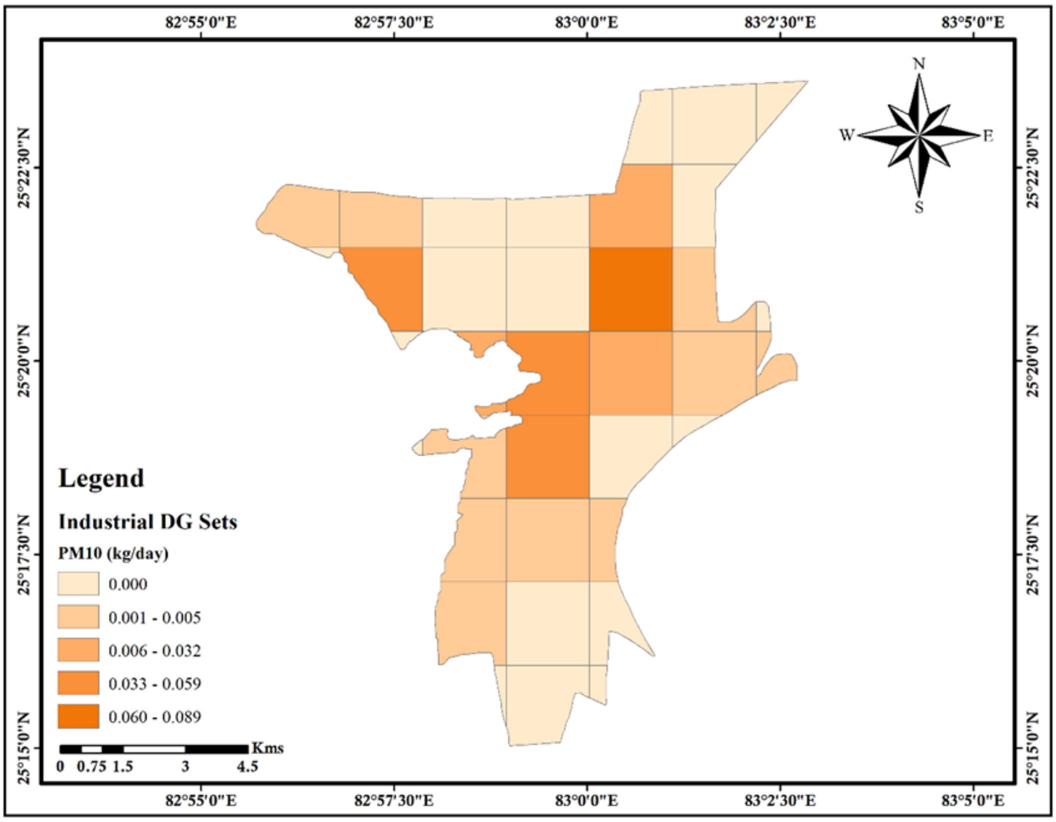
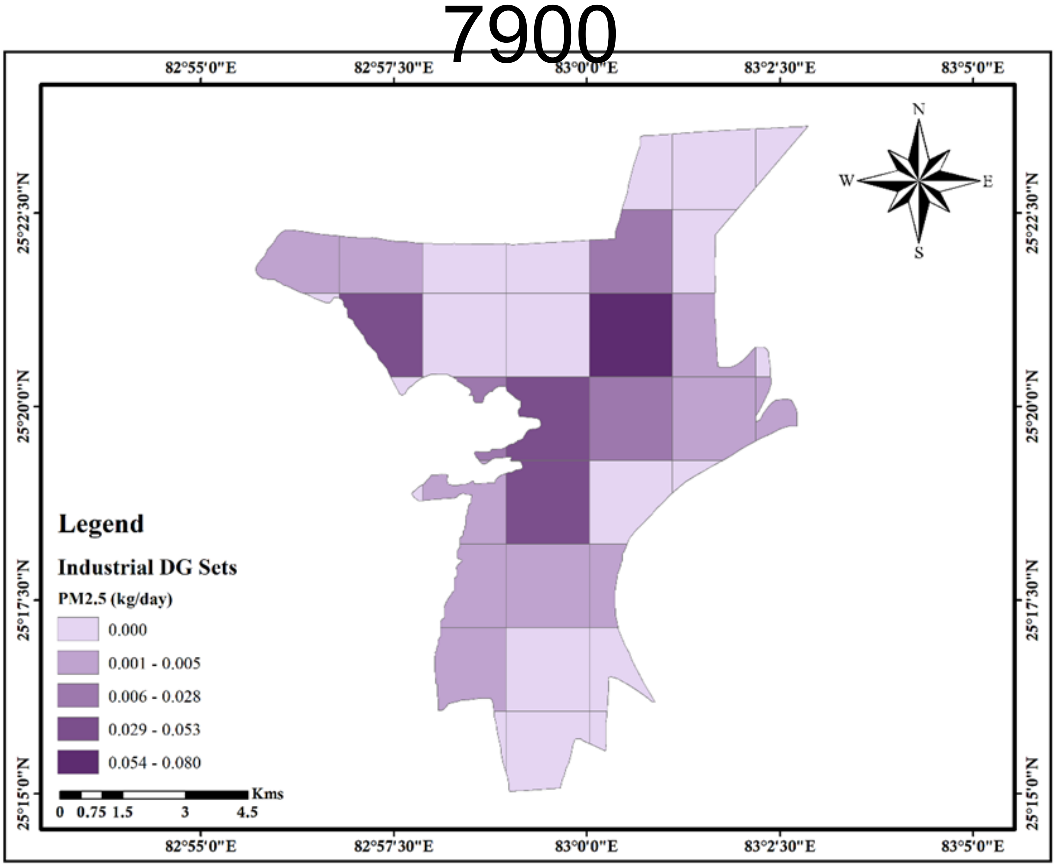

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industrial DG Sets
PM10 (kg/day)
0.000
0.001 - 0.005
0.006 - 0.032
0.033 - 0.059
0.060 - 0.089
Kms
0 0.75 1.5 3 4.5

Figure 3.34: Spatial Distribution of PM_{10} Emissions from DG Sets

7900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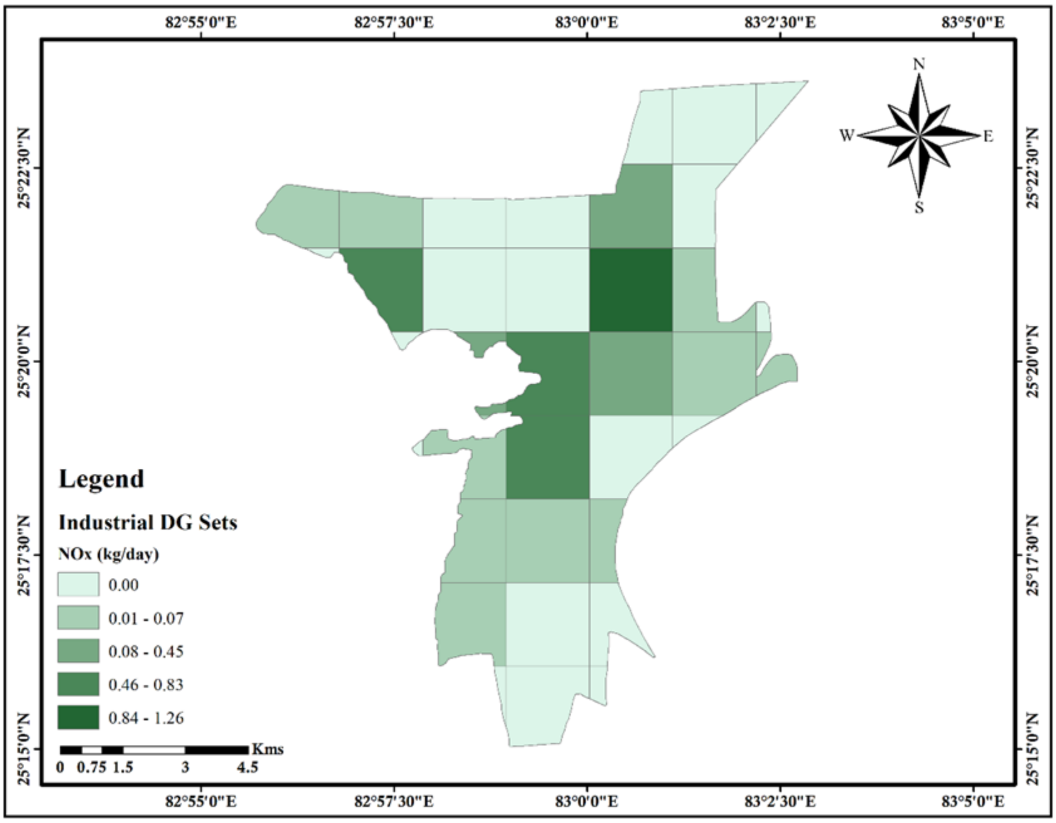
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industrial DG Sets
PM2.5 (kg/day)
0.000
0.001 - 0.005
0.006 - 0.028
0.029 - 0.053
0.054 - 0.080
Kms
0 0.75 1.5 3 4.5

Figure 3.35: Spatial Distribution of $PM_{2.5}$ Emissions from DG Sets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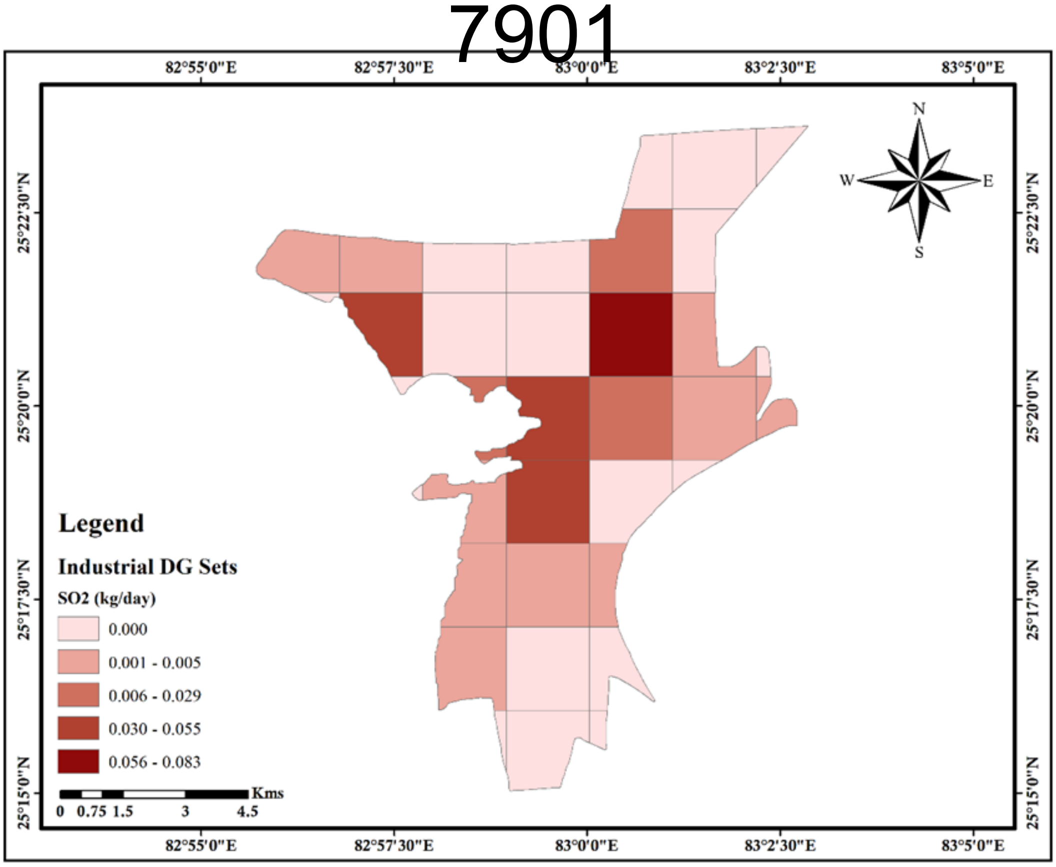
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industrial DG Sets
NOx (kg/day)
0.00
0.01 - 0.07
0.08 - 0.45
0.46 - 0.83
0.84 - 1.26
Kms
0 0.75 1.5 3 4.5

Figure 3.36: Spatial Distribution of NOx Emissions from DG Set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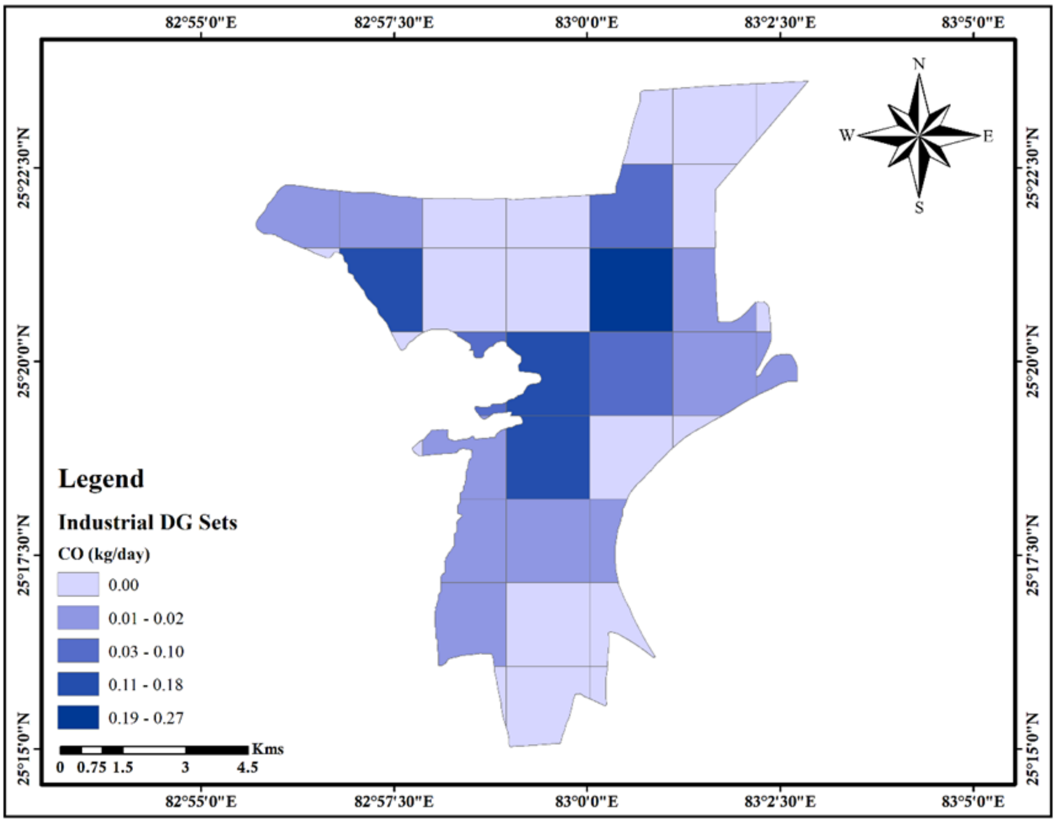
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industrial DG Sets
SO2 (kg/day)
0.000
0.001 - 0.005
0.006 - 0.029
0.030 - 0.055
0.056 - 0.083
Kms
0 0.75 1.5 3 4.5

Figure 3.37: Spatial Distribution of SO_2 Emissions from DG Set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83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industrial DG Sets
CO (kg/day)
0.00
0.01 - 0.02
0.03 - 0.10
0.11 - 0.18
0.19 - 0.27
Kms
0 0.75 1.5 3 4.5

Figure 3.38: Spatial Distribution of CO Emissions from DG Sets

3.2.8 Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs)

The primary survey was conducted by the IITK team to identify the hotels and restaurants of more than sitting capacity of ten persons and other eating joints

During the field survey, it was observed that hotels, restaurants, etc. use coal as fuel in tandoors. The total number of Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) is found to be approximately 880 (Figure 3.39). It was observed that coal/wood is being used as fuel in the tandoor, the common fuel other than wood is LPG. The average consumption of wood/coal in each establishment is estimated to be 80 kg per day based on a primary survey. The fuel consumption for each fuel type was estimated for each grid. In most of the cases, it was found that there were no control devices installed during these activities. The emissions of various parameters such as PM_{10}, $PM_{2.5}$, SO_2, NO_x, and CO were estimated from the activity data from each fuel type and then summed up in each grid cell. The overall emission from this area source (Hotels, Restaurants, GHs, and BHs) is shown in Figure 3.40. The spatial distribution of emissions from Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) lying within the boundary is shown in Figure 3.41 to Figure 3.45.

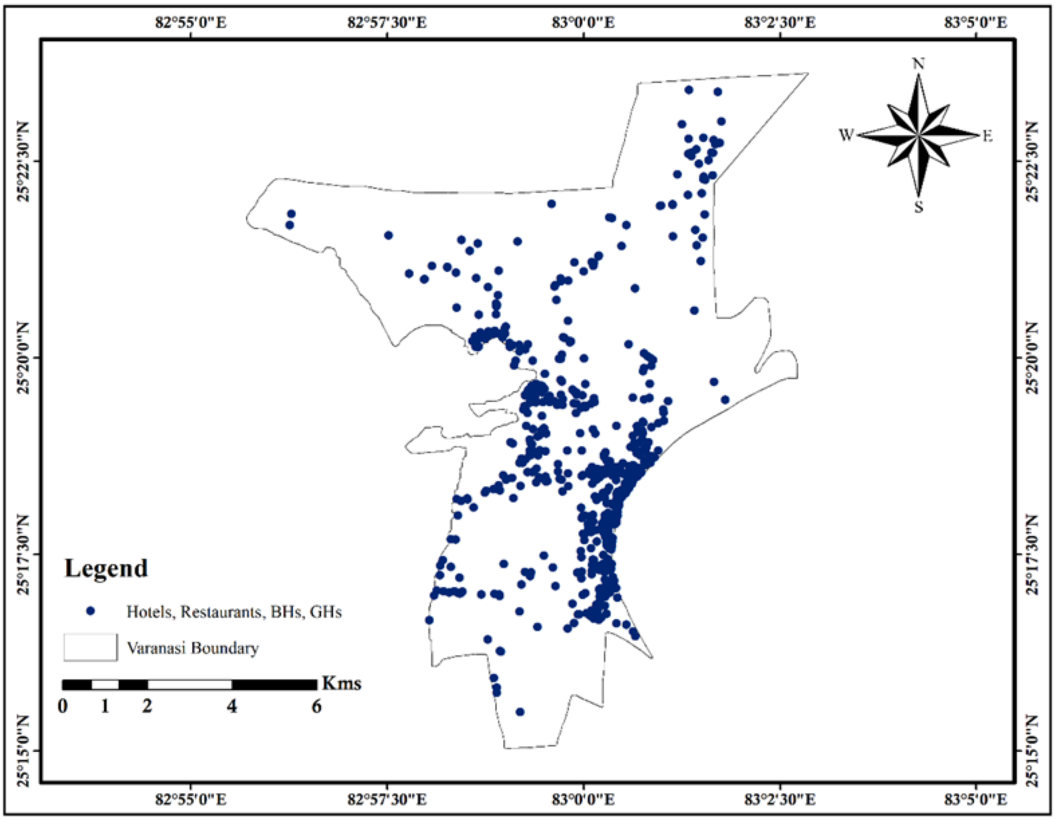


Figure 3.39: Location of Hotels, Restaurants, GHs and BHs

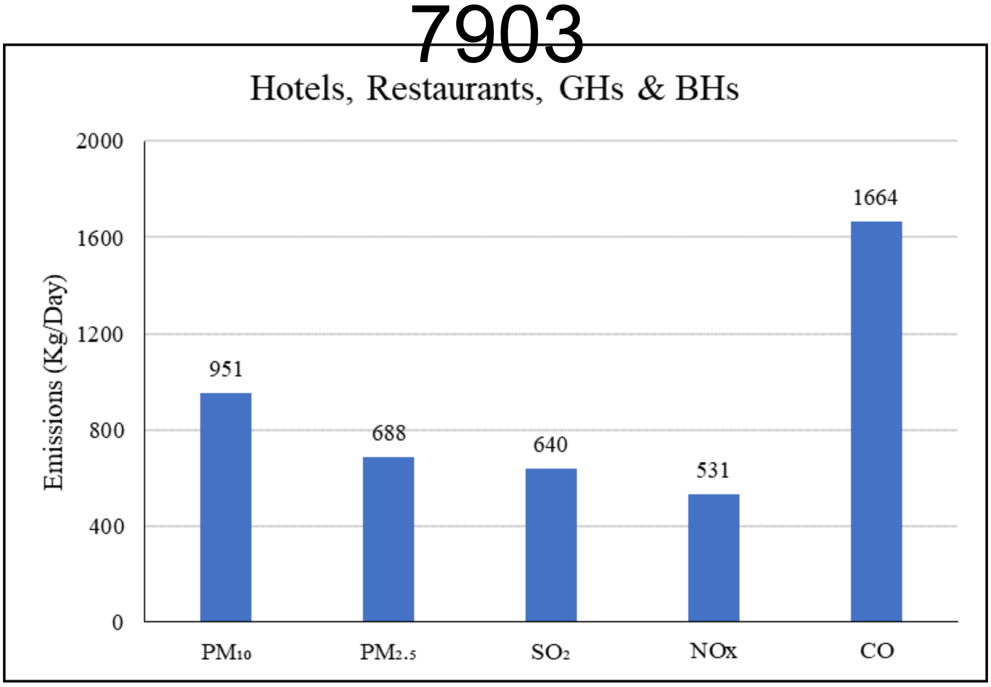
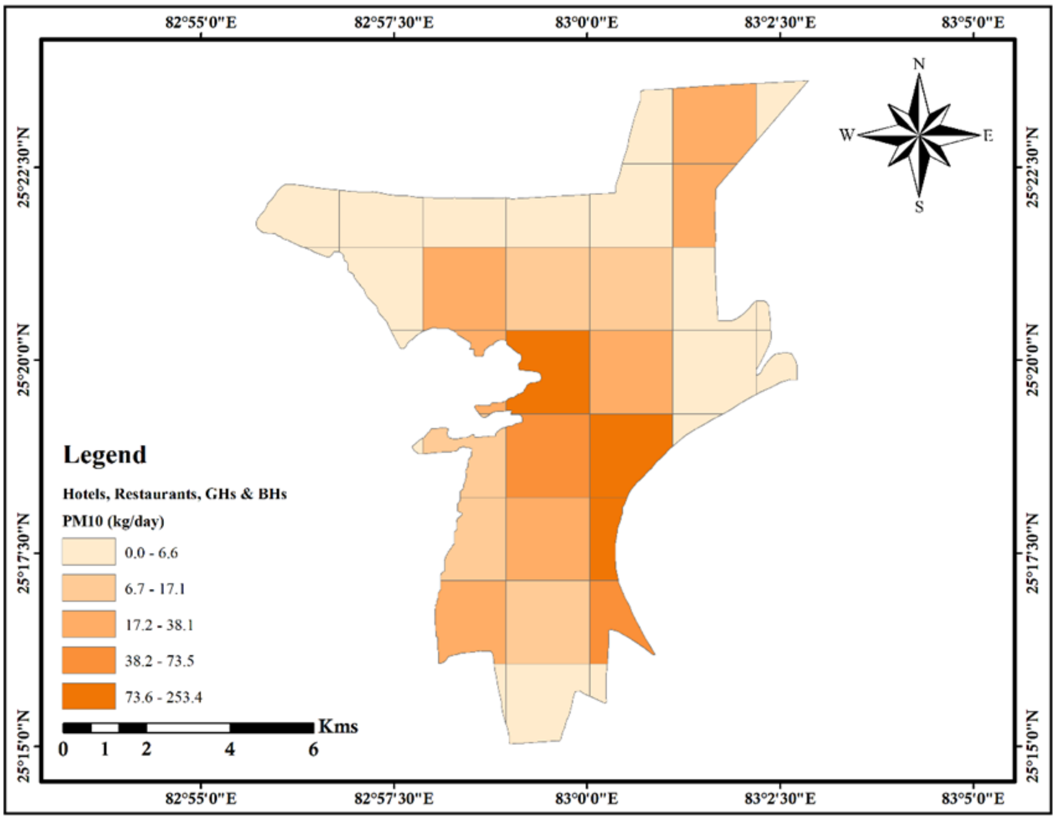


Figure 3.40: Emission Load from Hotels, Restaurants, GHs and BHs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83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
E
S
W
Legend
Hotels, Restaurants, GHs & BHs
PM10 (kg/day)
0.0 - 6.6
6.7 - 17.1
17.2 - 38.1
38.2 - 73.5
73.6 - 253.4
Kms
0
1
2
4
6

Figure 3.41: Spatial Distribution of PM10 Emissions from Hotels, Restaurants, GHs and BHs

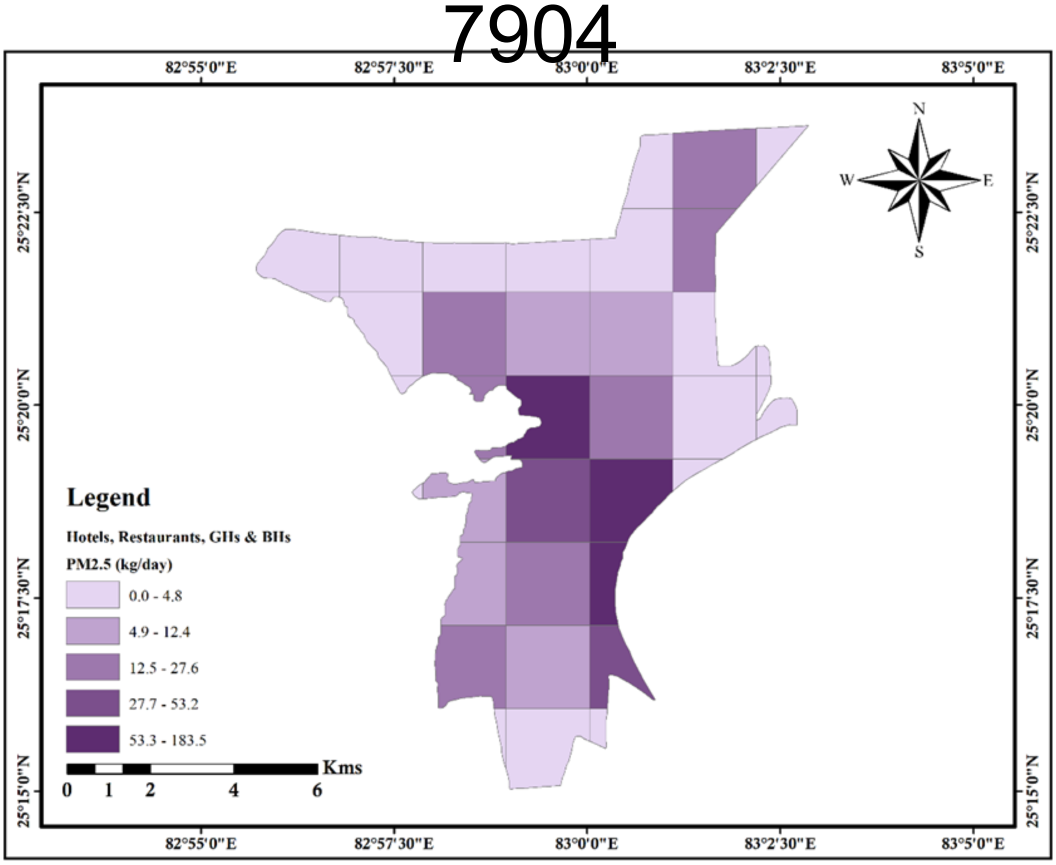
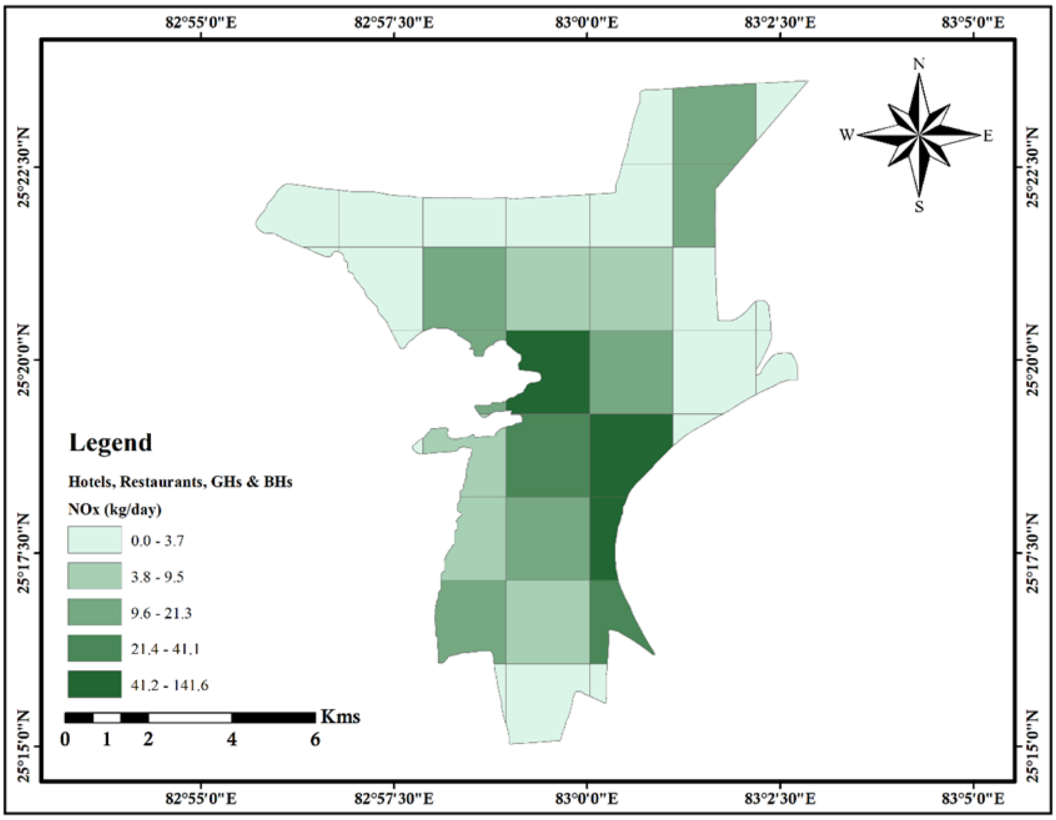

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Hotels, Restaurants, GHs & BHs
PM2.5 (kg/day)
0.0 - 4.8
4.9 - 12.4
12.5 - 27.6
27.7 - 53.2
53.3 - 183.5
Kms
0
1
2
4
6

Figure 3.42: Spatial Distribution of $PM_{2.5}$ Emissions from Hotels, Restaurants, GHs and BHs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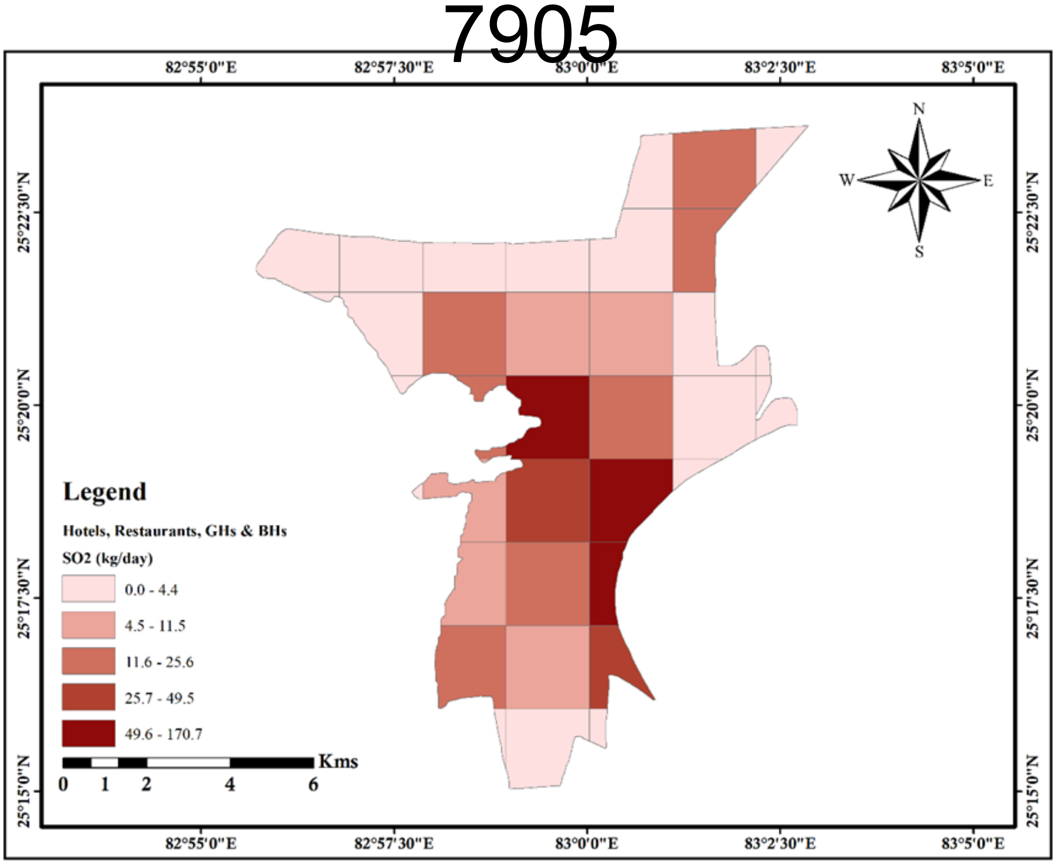
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Hotels, Restaurants, GHs & BHs
NOx (kg/day)
0.0 - 3.7
3.8 - 9.5
9.6 - 21.3
21.4 - 41.1
41.2 - 141.6
Kms
0
1
2
4
6

Figure 3.43: Spatial Distribution of NO_X Emissions from Hotels, Restaurants, GHs and BHs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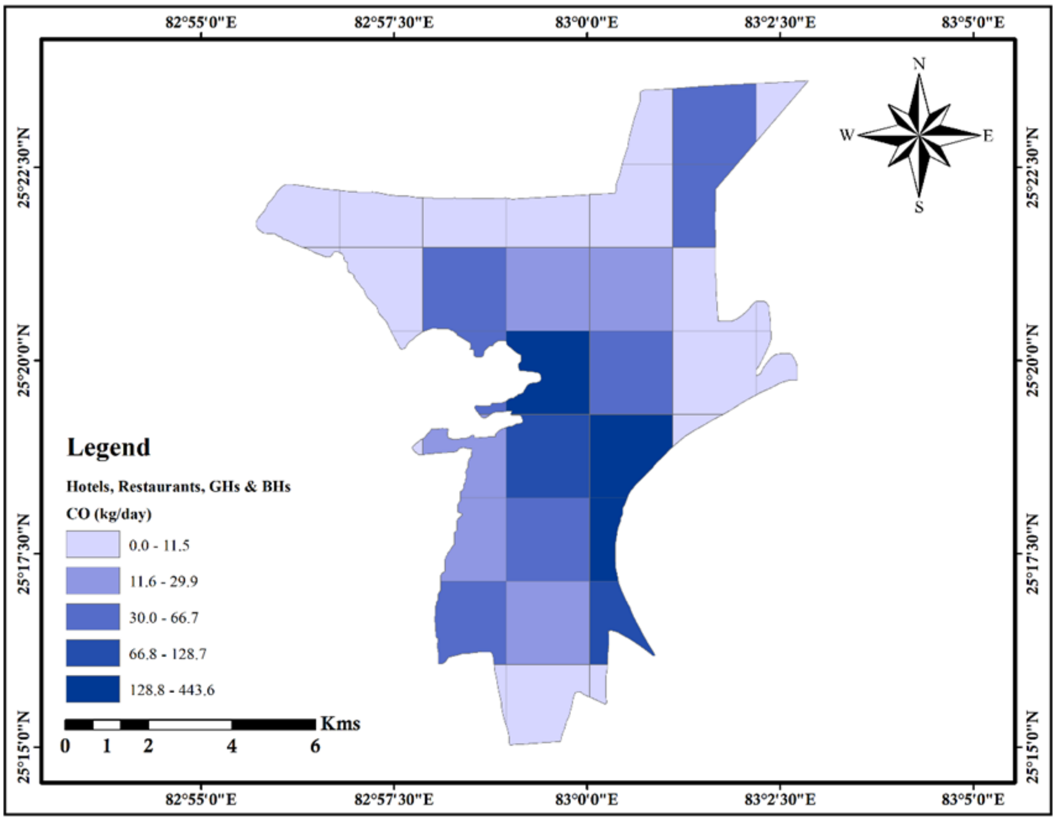
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Hotels, Restaurants, GHs & BHs
SO2 (kg/day)
0.0 - 4.4
4.5 - 11.5
11.6 - 25.6
25.7 - 49.5
49.6 - 170.7
Kms
0
1
2
4
6

Figure 3.44: Spatial Distribution of SO_2 Emissions from Hotels, Restaurants, GHs and BHs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83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Hotels, Restaurants, GHs & BHs
CO (kg/day)
0.0 - 11.5
11.6 - 29.9
30.0 - 66.7
66.8 - 128.7
128.8 - 443.6
Kms
0
1
2
4
6

Figure 3.45: Spatial Distribution of CO Emissions from Hotels, Restaurants, GHs and BHs

3.2.9 Municipal Solid Waste burning

Open burning activities are broadly classified into refuse and biomass burning. The refuse or municipal solid waste (MSW) burning depends on solid waste generation and the extent of disposal and infrastructure for collection. The Solid waste generation is around 945 MT/day and the waste collected is approx. 912 MT/day. This emission is expected to be large in the regions of economically lower strata of the society which do not have proper infrastructure for collection and disposal of MSW. The MSW collection efficiency is 96.5% in Varanasi city (UPPCB SWM Annual Report 2019-20) and several events of MSW burning have been observed during the city survey. The survey was conducted on weekdays and weekends and the frequency of MSW events is calculated in the low-, middle- and higher-income areas. The MSW burning at different locations in Varanasi city is shown in Figure 3.46.

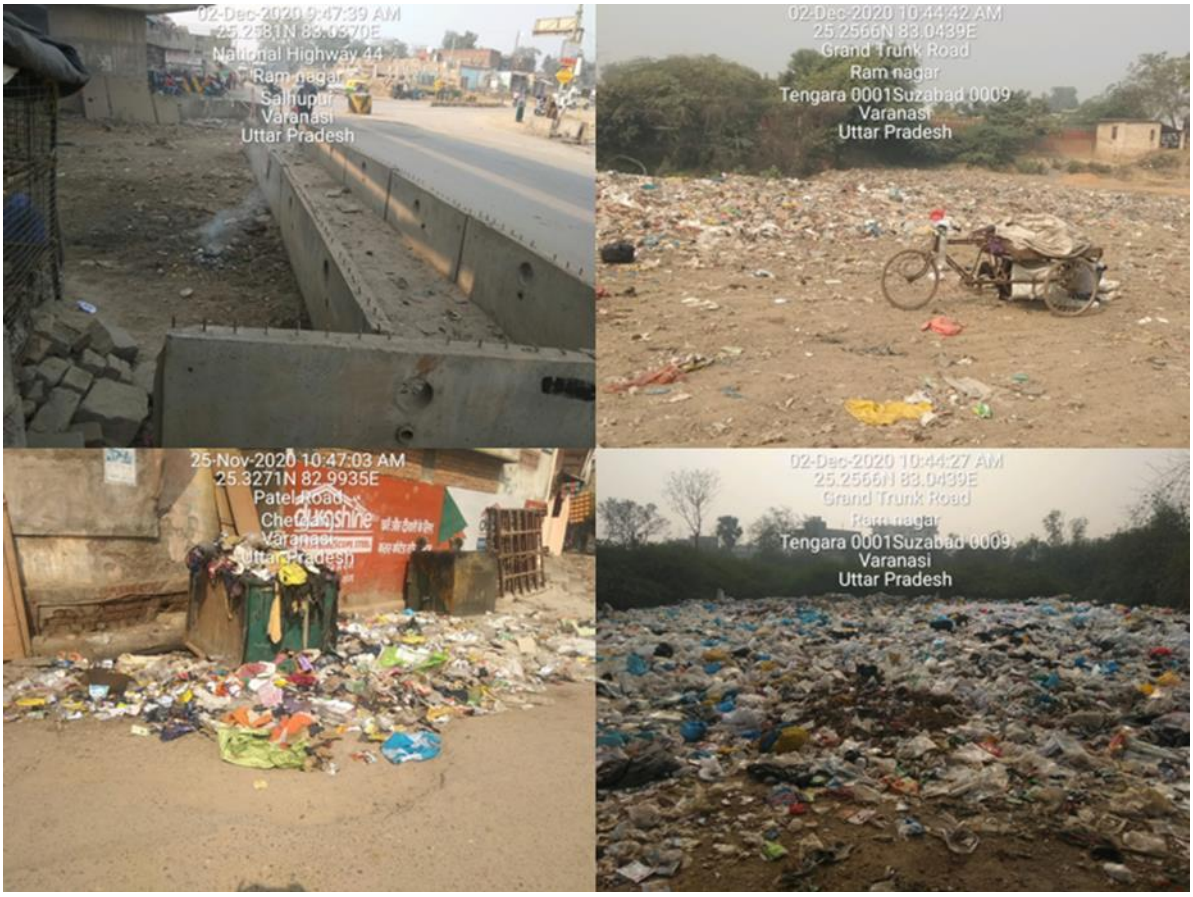

02-Dec-2020 9:47:39 AM
25.2581N 83.0370E
National Highway 44
Ram nagar
Salhupur
Varanasi
Uttar Pradesh
02-Dec-2020 10:44:42 AM
25.2566N 83.0439E
Grand Trunk Road
Ram nagar
Tengara 0001Suzabad 0009
Varanasi
Uttar Pradesh
25-Nov-2020 10:47:03 AM
25.3271N 82.9935E
Patel Road
Chetganj
Varanasi
Uttar Pradesh
02-Dec-2020 10:44:27 AM
25.2566N 83.0439E
Grand Trunk Road
Ram nagar
Tengara 0001Suzabad 0009
Varanasi
Uttar Pradesh

Figure 3.46: MSW Burning in several parts of Varanasi city

The emission factors are given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emission from MSW burning using the same procedure of emission density in a ward or village. The emissions from MSW burning are presented in Figure 3.47 and spatial distribution in Figure 3.48 to Figure 3.52.

7907

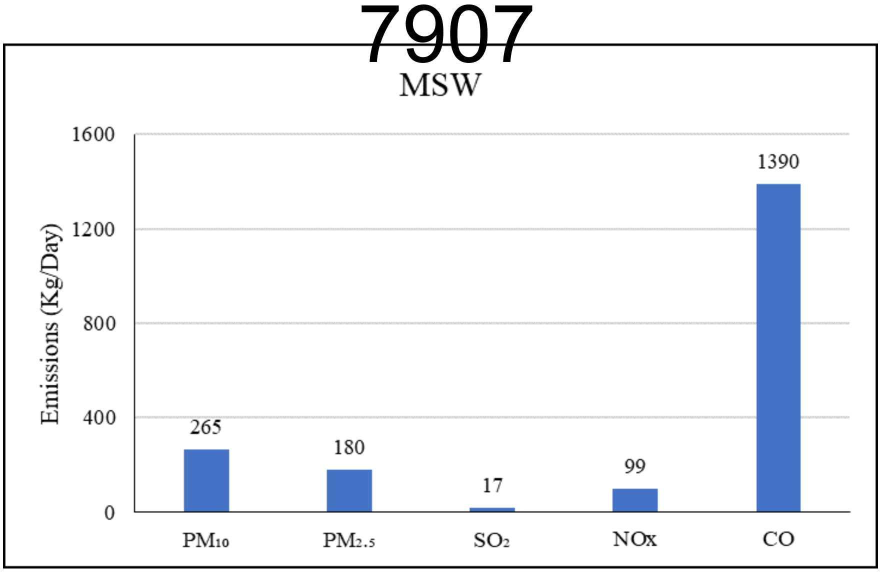
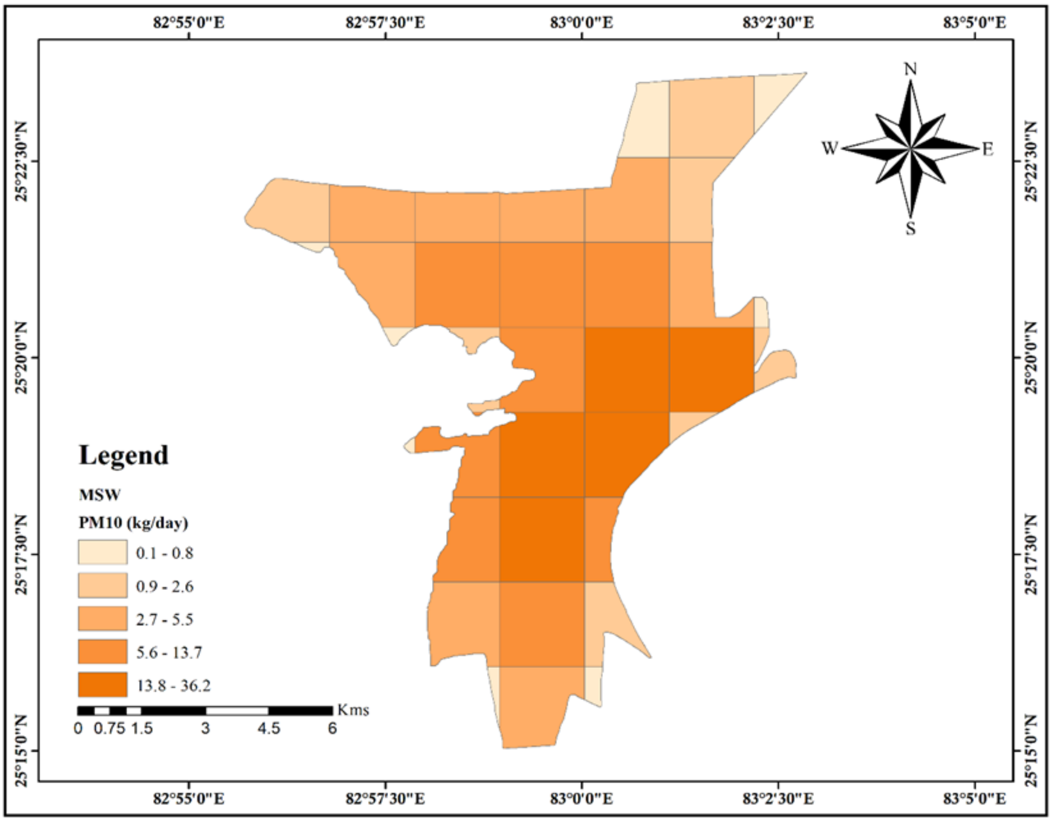


Figure 3.47: Emission Load from MSW Burning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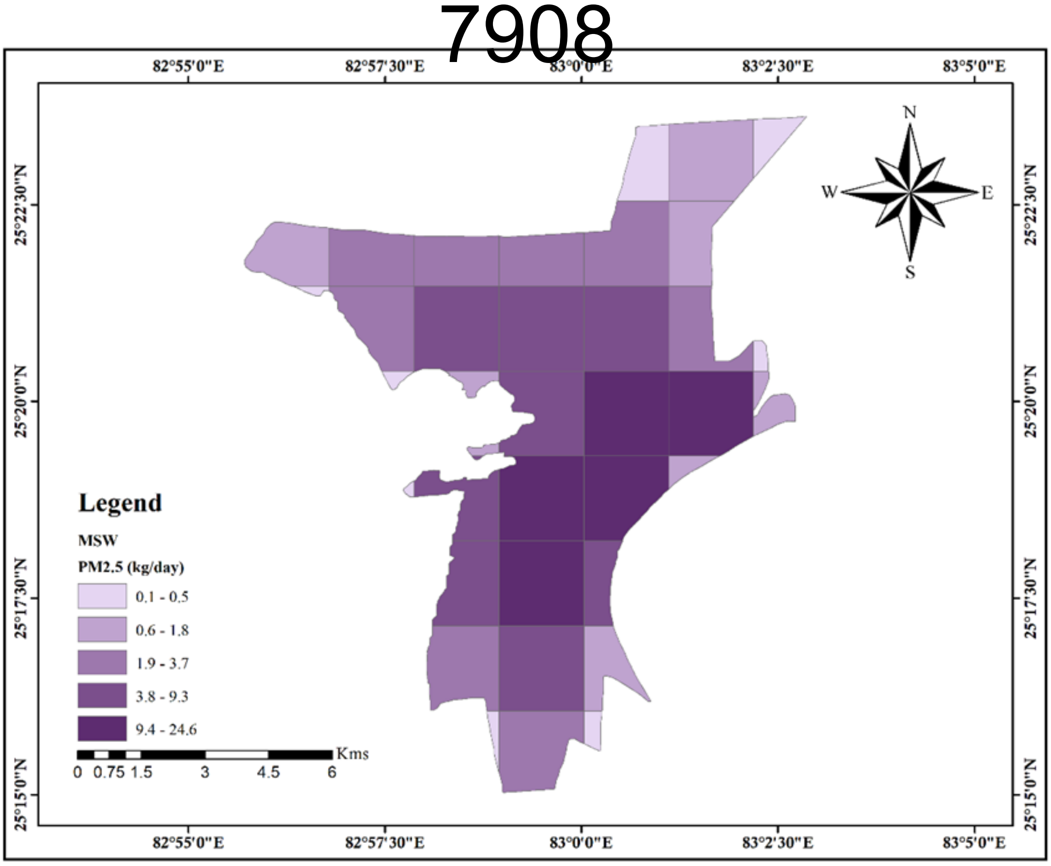
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
MSW
PM10 (kg/day)
0.1 - 0.8
0.9 - 2.6
2.7 - 5.5
5.6 - 13.7
13.8 - 36.2
Kms
0 0.75 1.5 3 4.5 6

Figure 3.48: Spatial Distribution of PM_{10} Emissions from MSW Burning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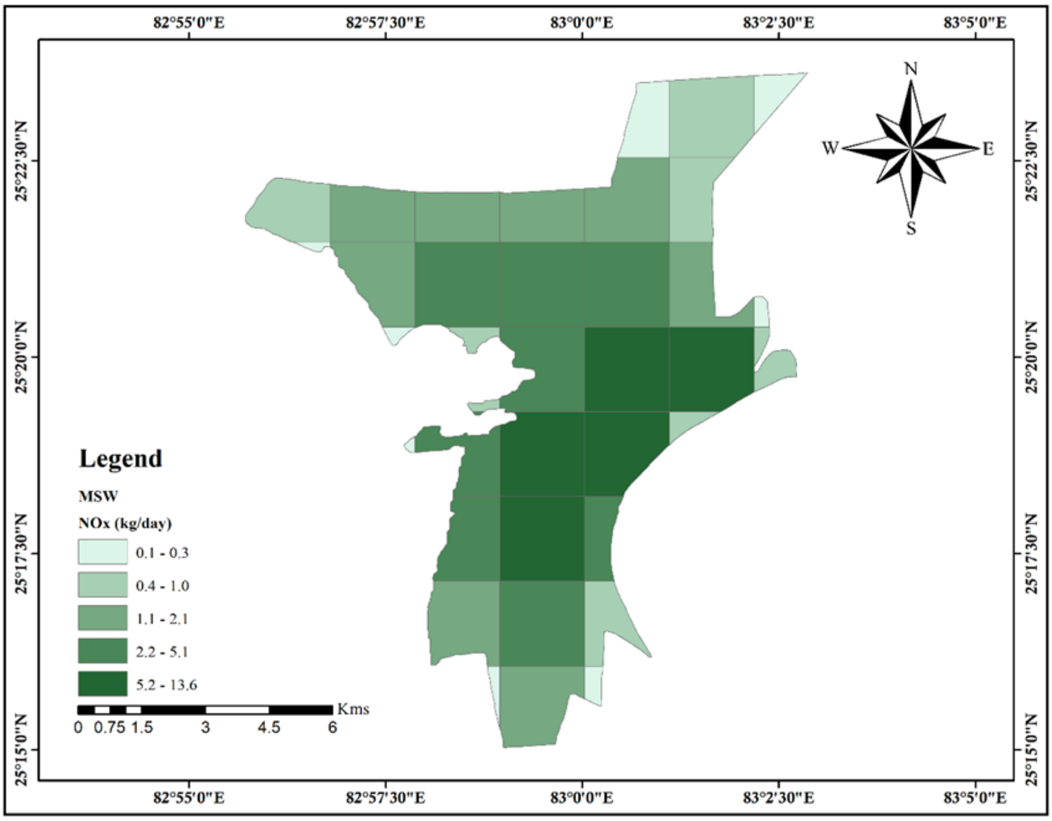
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
MSW
PM2.5 (kg/day)
0.1 - 0.5
0.6 - 1.8
1.9 - 3.7
3.8 - 9.3
9.4 - 24.6
Kms
0 0.75 1.5 3 4.5 6

Figure 3.49: Spatial Distribution of $PM_{2.5}$ Emissions from MSW Burning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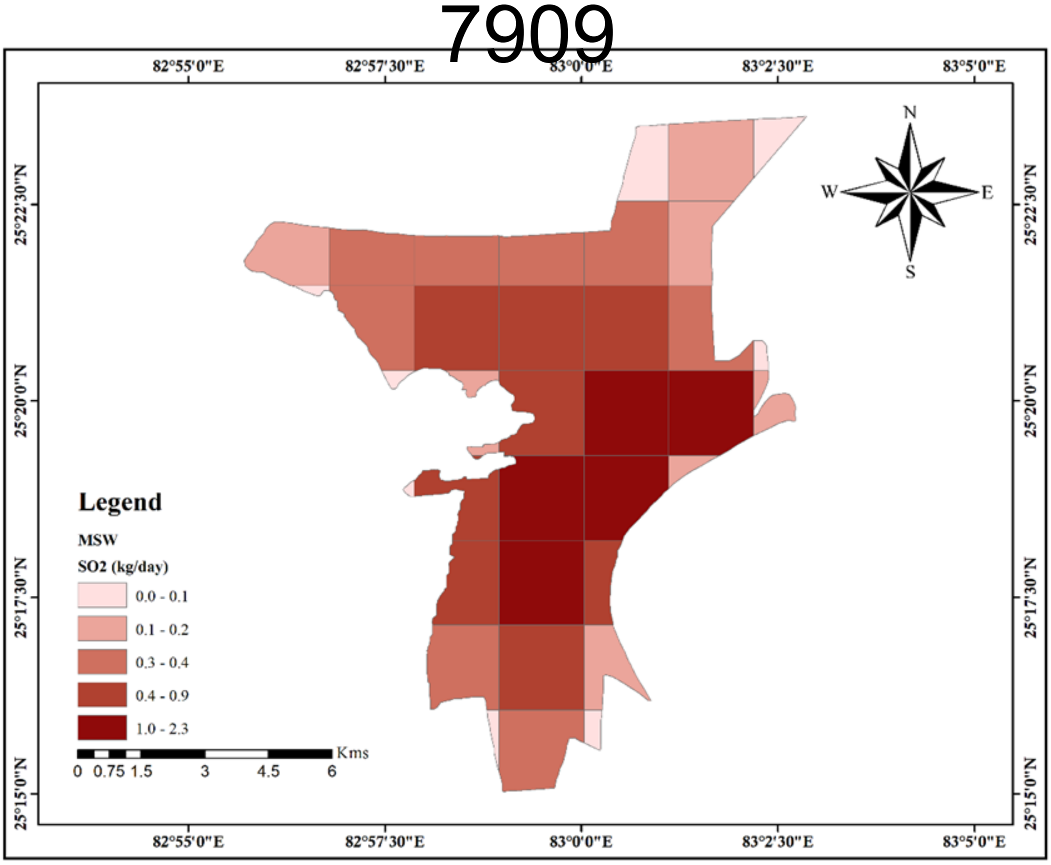
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
MSW
NOx (kg/day)
0.1 - 0.3
0.4 - 1.0
1.1 - 2.1
2.2 - 5.1
5.2 - 13.6
Kms
0 0.75 1.5 3 4.5 6

Figure 3.50: Spatial Distribution of NO_X Emissions from MSW Burning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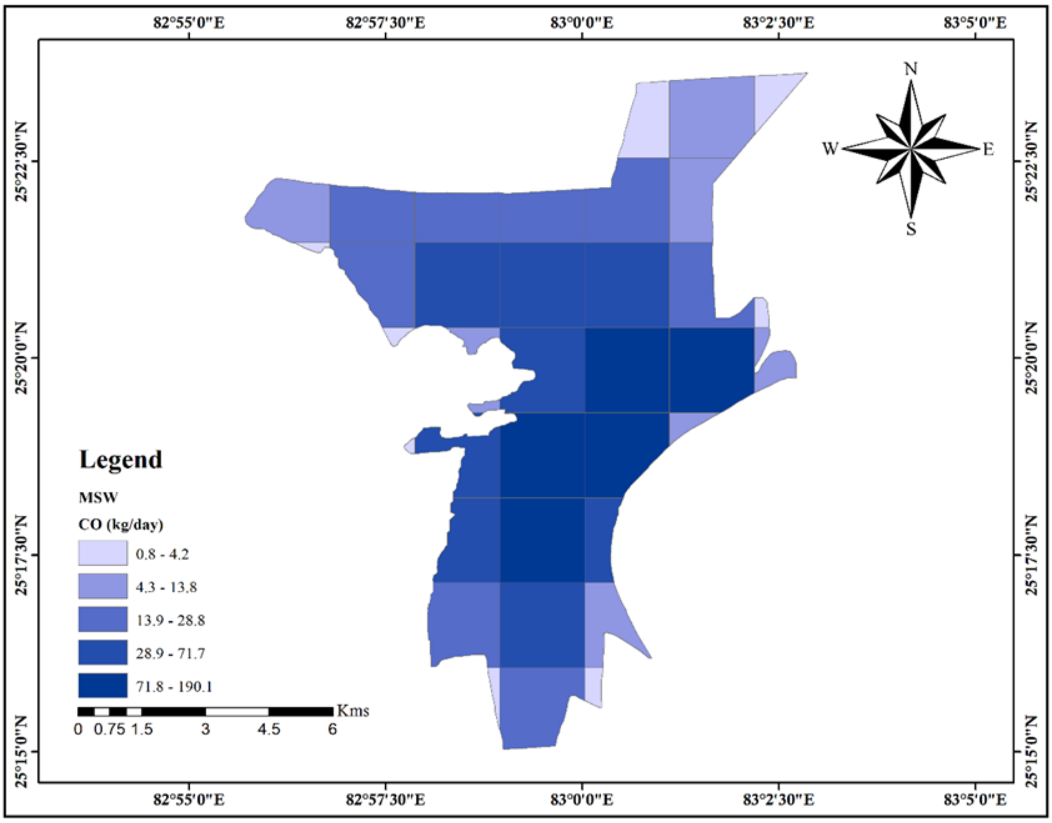
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
E
S
W
Legend
MSW
SO2 (kg/day)
0.0 - 0.1
0.1 - 0.2
0.3 - 0.4
0.4 - 0.9
1.0 - 2.3
0 0.75 1.5 3 4.5 6
Kms

Figure 3.51: Spatial Distribution of SO$_2$ Emissions from MSW Burning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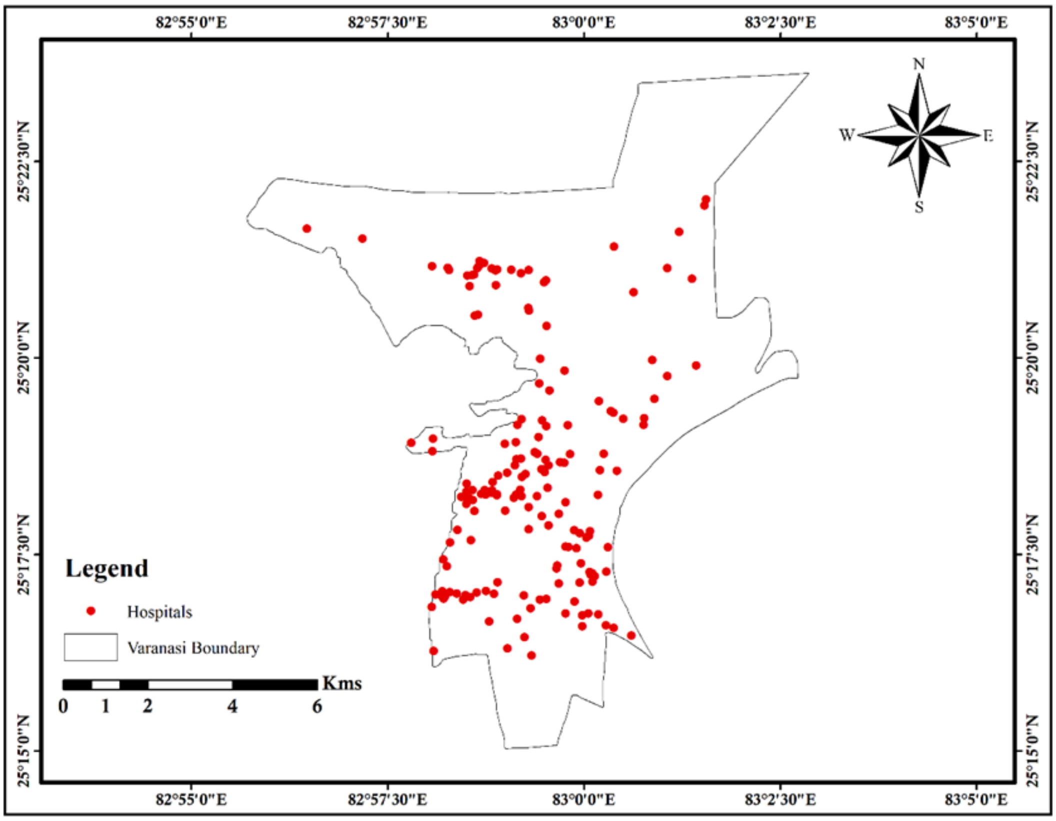
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
E
S
W
Legend
MSW
CO (kg/day)
0.8 - 4.2
4.3 - 13.8
13.9 - 28.8
28.9 - 71.7
71.8 - 190.1
0 0.75 1.5 3 4.5 6
Kms

Figure 3.52: Spatial Distribution of CO Emissions from MSW Burning

3.2.10 Hospitals

A detailed survey was undertaken to estimate the emission from hospitals in Varanasi City. There are approximately 308 hospitals present in the city. The locations of Hospitals in Varanasi are given in Figure 3.53. The emission load from hospitals is given in Figure 3.54. The Spatial distribution of emissions from Hospitals is given in Figure 3.55 to Figure 3.59. The overall emissions from hospitals along with their average 110 KVA DG set capacity and running two hours are presented in Table 3.1.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83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Hospitals
Varanasi Boundary
Kms
0
1
2
4
6

Figure 3.53: Locations of Hospitals in Varanasi City

Table 3.1: Hospitals Details in Varanasi city (emissions in kg/day)

No. of Hospitals	**DG set Average Capacity**		**PM$_{10}$**	**PM$_{2.5}$**	**SO$_2$**	**NOx**	**CO**
	KVA	Running Hour	(kg/d)	(kg/d)	(kg/d)	(kg/d)	(kg/d)
308	110	2	1.4	1.3	1.3	19.8	4.3

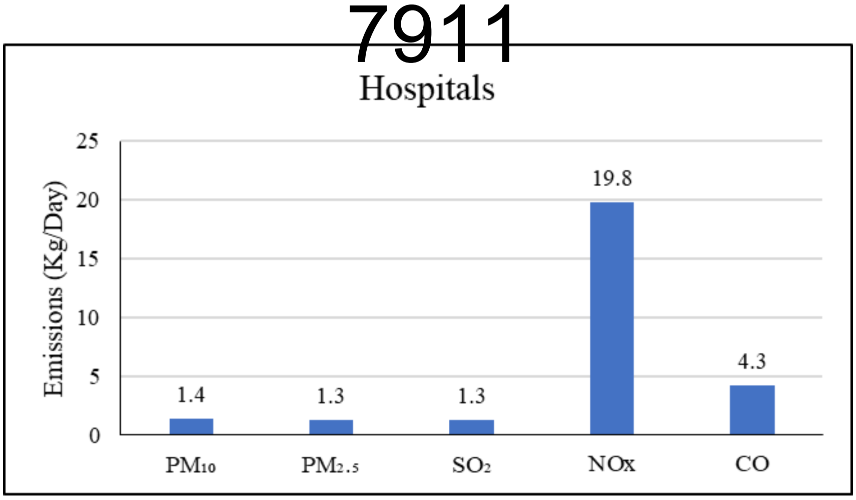
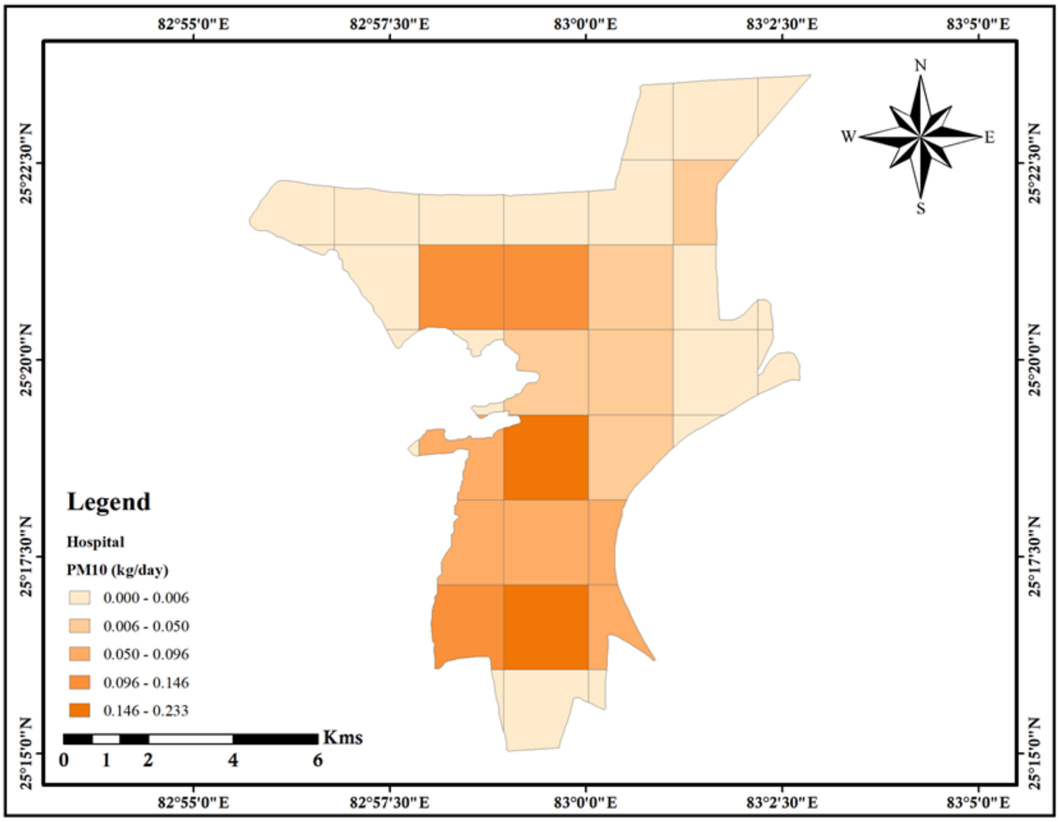


Figure 3.54: Emission Load from Hospitals (kg/day)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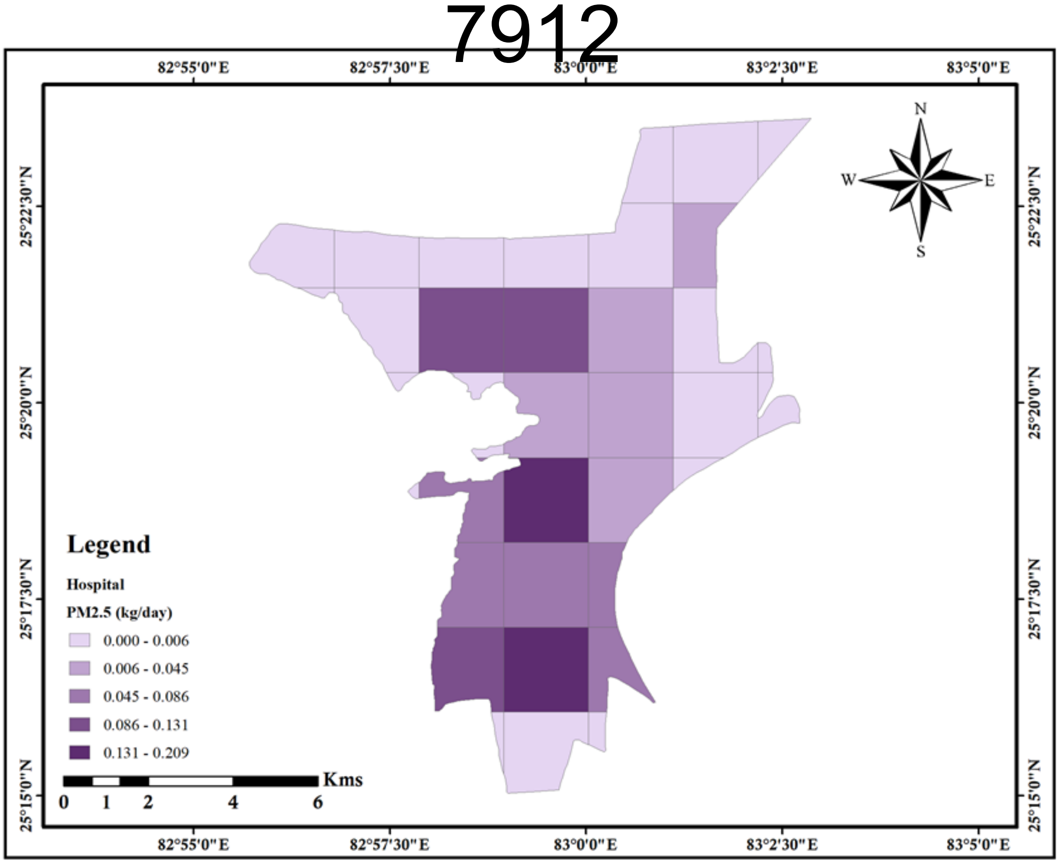
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Hospital
PM10 (kg/day)
0.000 - 0.006
0.006 - 0.050
0.050 - 0.096
0.096 - 0.146
0.146 - 0.233
Kms
0
1
2
4
6

Figure 3.55: Spatial Distribution of PM_{10} Emissions from Hospitals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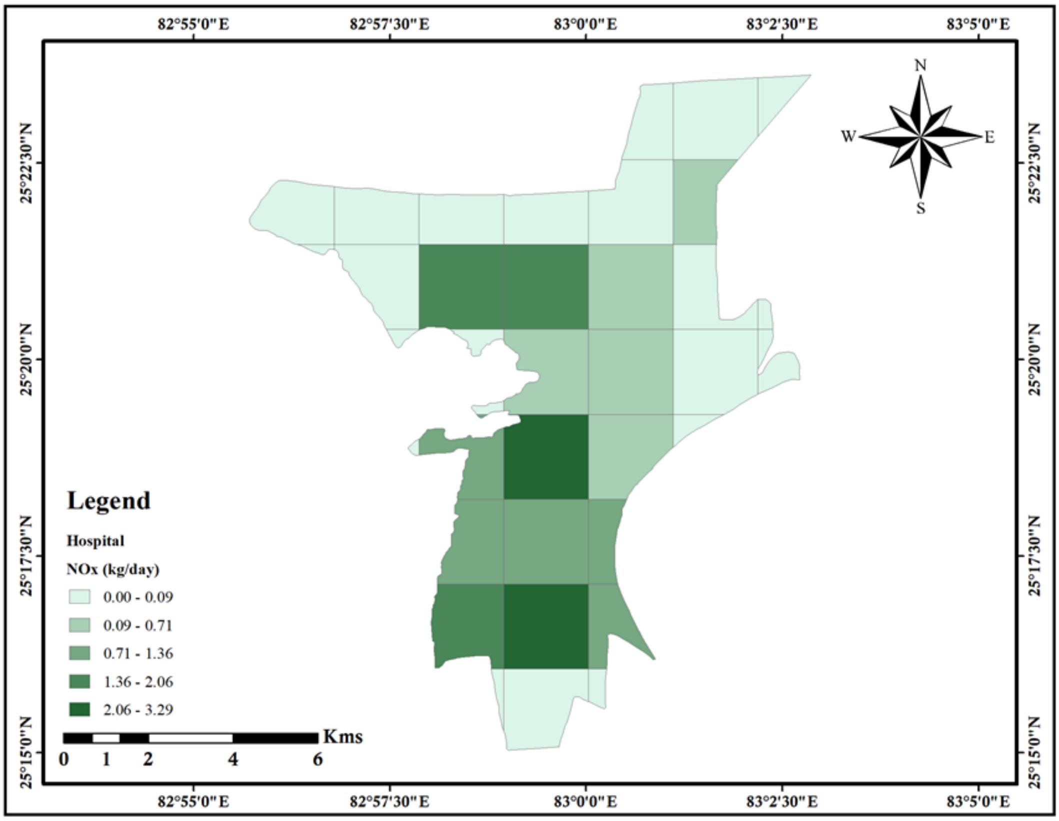
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Hospital
PM2.5 (kg/day)
0.000 - 0.006
0.006 - 0.045
0.045 - 0.086
0.086 - 0.131
0.131 - 0.209
Kms
0
1
2
4
6

Figure 3.56: Spatial Distribution of PM$_{2.5}$ Emissions from Hospitals


82°55'0"E
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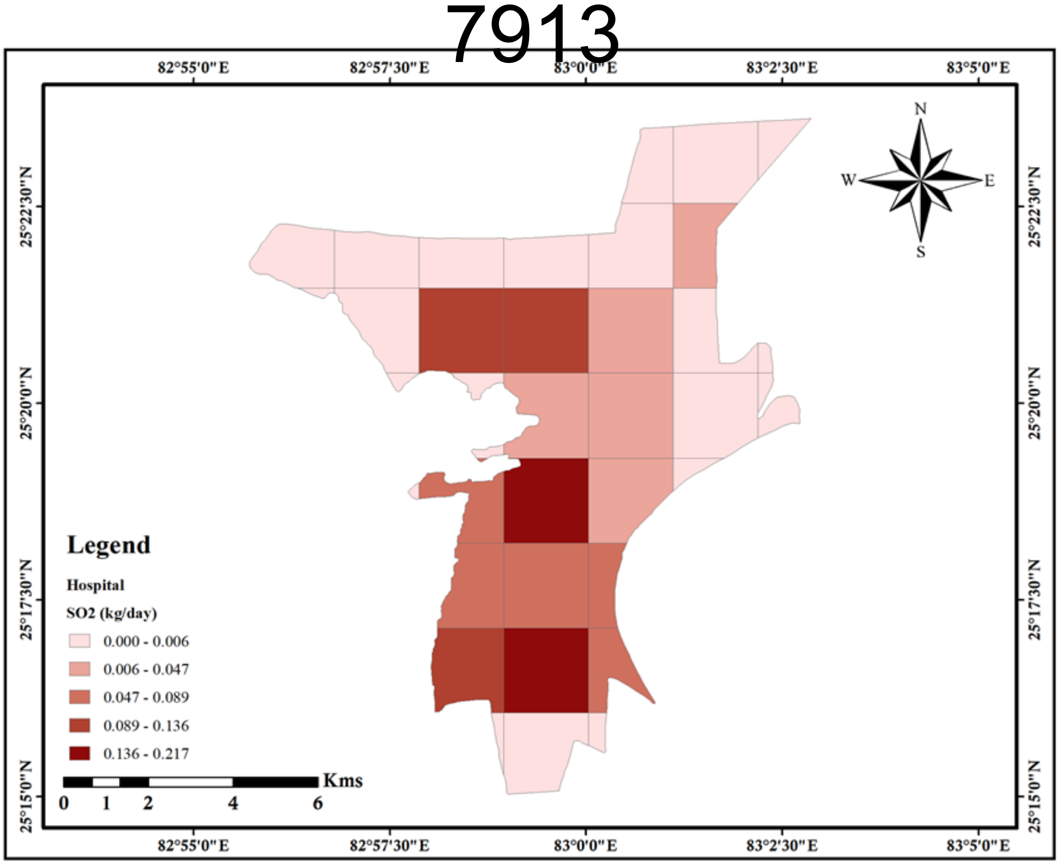
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Hospital
NOx (kg/day)
0.00 - 0.09
0.09 - 0.71
0.71 - 1.36
1.36 - 2.06
2.06 - 3.29
Kms
0
1
2
4
6

Figure 3.57: Spatial Distribution of NOx Emissions from Hospitals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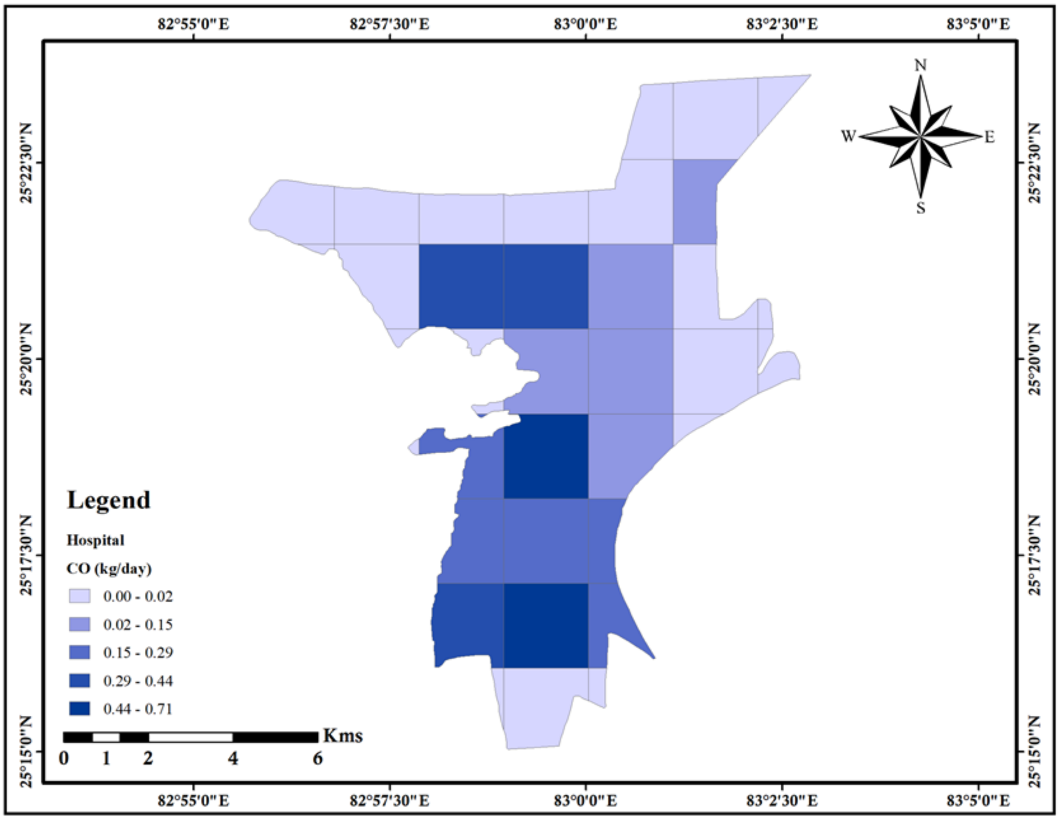
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Hospital
SO2 (kg/day)
0.000 - 0.006
0.006 - 0.047
0.047 - 0.089
0.089 - 0.136
0.136 - 0.217
Kms
0
1
2
4
6

Figure 3.58: Spatial Distribution of SO2 Emissions from Hospitals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83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
S
E
W
Legend
Hospital
CO (kg/day)
0.00 - 0.02
0.02 - 0.15
0.15 - 0.29
0.29 - 0.44
0.44 - 0.71
Kms
0
1
2
4
6

Figure 3.59: Spatial Distribution of CO Emissions from Hospitals

3.2.11 Industries

There are approximately 23 industrial units in Varanasi City (Table 3.2) having boilers, baby boilers, furnaces and thermic fluid heaters, and other air-polluting units, that contribute to particulate as well as gaseous emissions out of 39 total industrial units that inside of the city boundary (consent data). Major fuels that contribute to emissions are Coal, HSD, Fuel Oil, Wood, Hard coke, and Rice Husk. The industrial locations are given in Figure 3.60. The information on stacks, fuel, and their consumption was obtained from UPPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. For further analysis, the industries are categorized based on stack height as an area source (stack height < 20 m) and as a point source (stack height > 20 m) (PriyaDarshini et. al, 2016; Sharma and Dikshit, 2016).

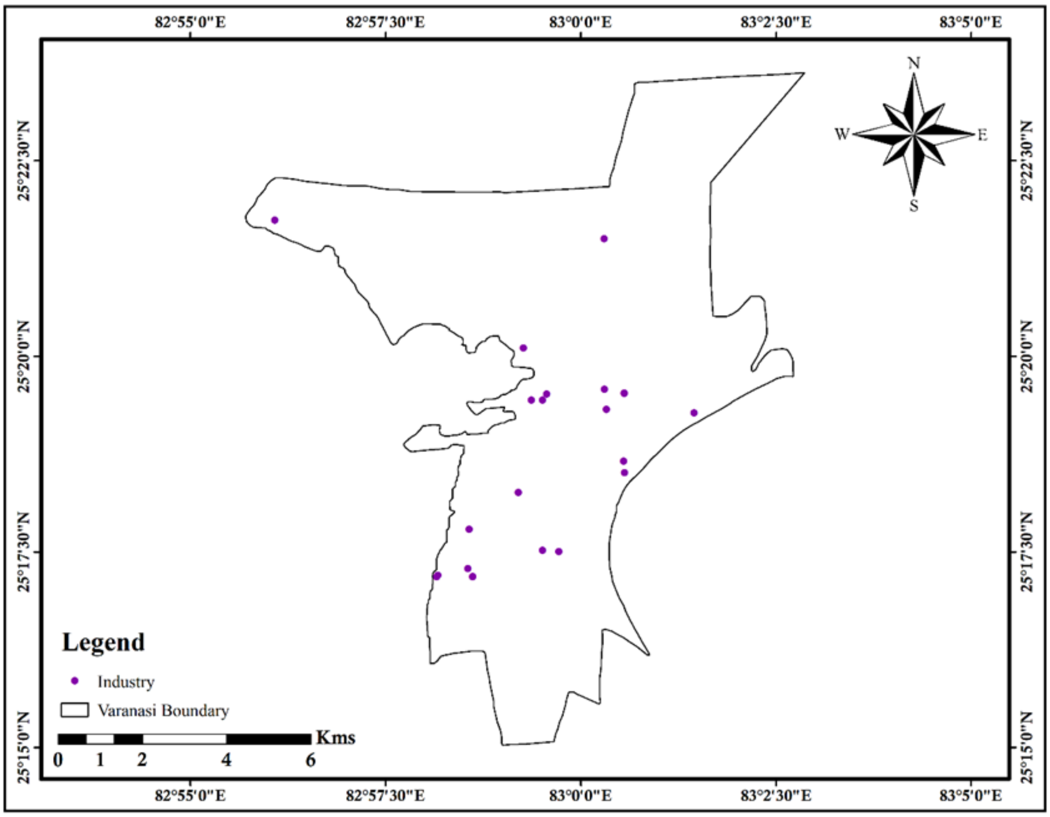


Figure 3.60: Location of Industries in Varanasi city

Table 3.2: Furnace/Boiler Details in Varanasi City (emissions in kg/day)

(Source: Consent Data, UPPCB)

Boiler/Furnace Type	Fuel used in Boiler/Furnace	No of Furnaces/ Boilers	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
			kg/day	kg/day	kg/day	kg/day	kg/day

Baby Boiler	Coal, Bio Briquette, HSD	8	1.4	1.3	3.1	3.8	0.2
Boiler	Wood, Coal, Rice Husk, Bio Briquette	5	45.8	41.2	201.3	83.6	177.9
Cupola Furnace	Coal & HSD	2	8.5	7.6	15.8	18.3	0.4
Furnace	Coal, Fuel Oil, Hard Coke	2	3.5	3.2	10.9	8.2	0.2
Incinerator	HSD	2	0.6	0.5	3.6	5.1	0.5
Oil Fired Furnace	HSD & Fuel Oil	1	0.7	0.6	19.5	3.8	0.3
Thermic Fluid Heater	Coal, Wood, Rice Husk	2	2.9	2.6	3.2	3.8	13.1
Bhatti	Bio Disel	1	0.6	0.5	0.0	0.1	8.4
Total		**23**	**64**	**58**	**257**	**127**	**201**

Industries as Area Source

Figure 3.61 presents the overall emissions from industries (stack height < 20 m) as an area source. There are around six industrial units categorized as area sources in Varanasi city. The boiler/baby boilers are majorly falling under this category. The spatial distribution of emissions from industries (area source) lying within the boundary is shown in Figure 3.62 to Figure 3.66.

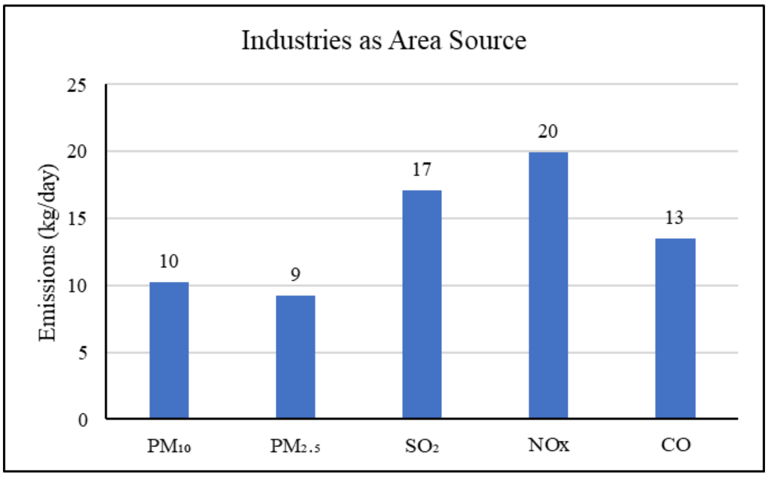
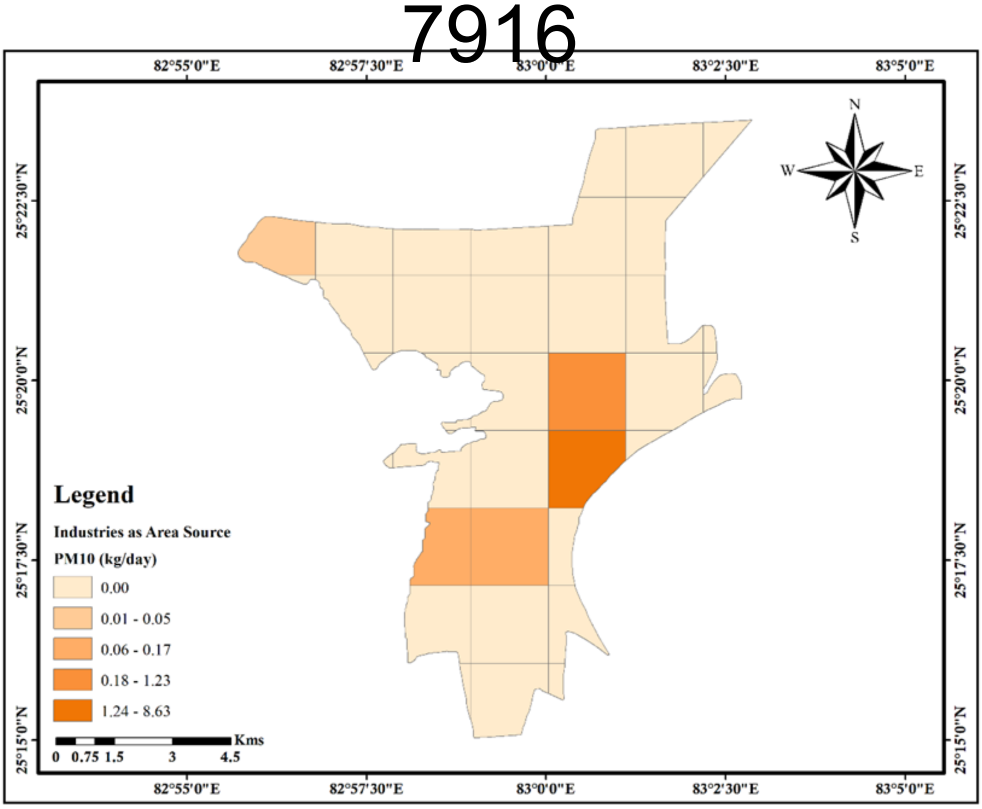


Figure 3.61: Emission Load from Industries as Area Source (kg/day)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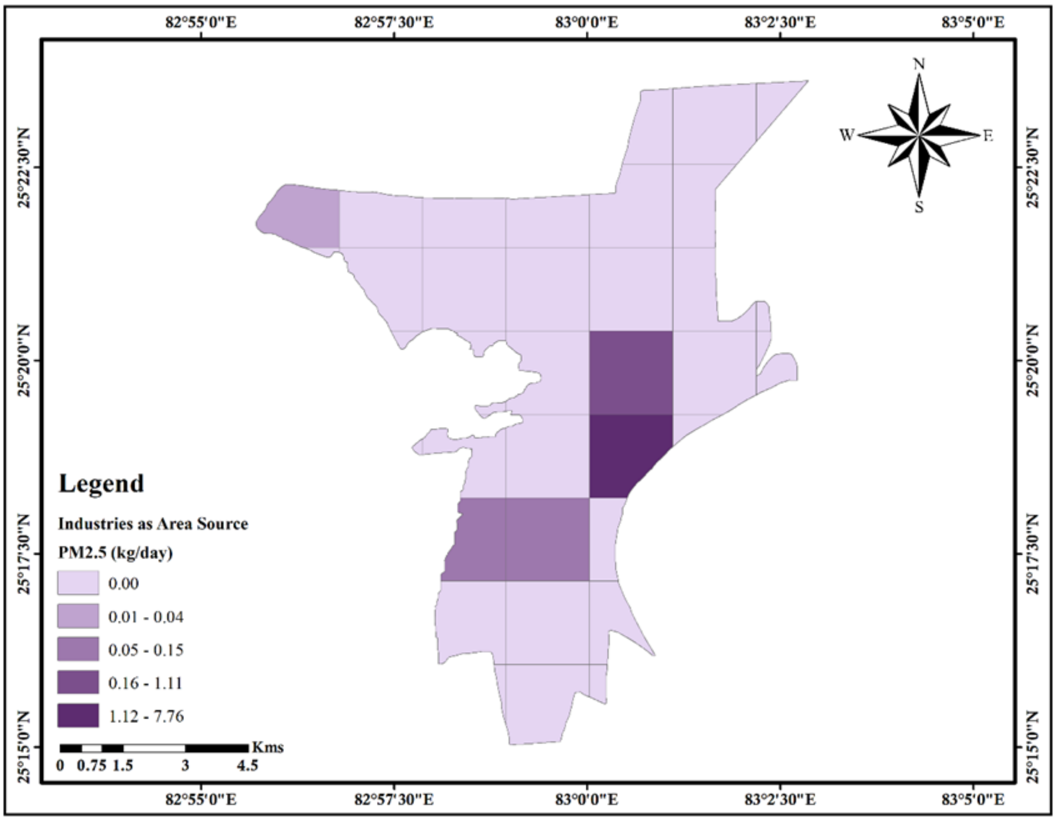
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Area Source
PM10 (kg/day)
0.00
0.01 - 0.05
0.06 - 0.17
0.18 - 1.23
1.24 - 8.63
Kms
0 0.75 1.5 3 4.5

Figure 3.62: Spatial Distribution of PM_{10} Emissions from Industries as area source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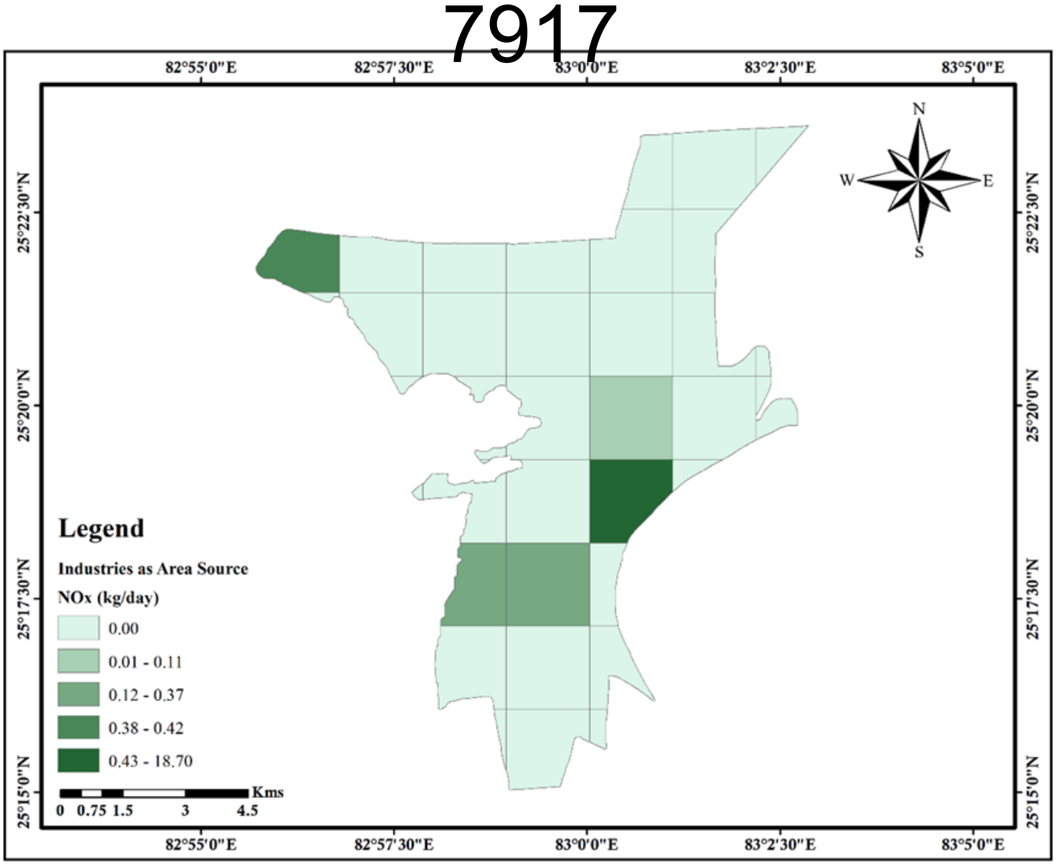
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Area Source
PM2.5 (kg/day)
0.00
0.01 - 0.04
0.05 - 0.15
0.16 - 1.11
1.12 - 7.76
Kms
0 0.75 1.5 3 4.5

Figure 3.63: Spatial Distribution of $PM_{2.5}$ Emissions from Industries as area source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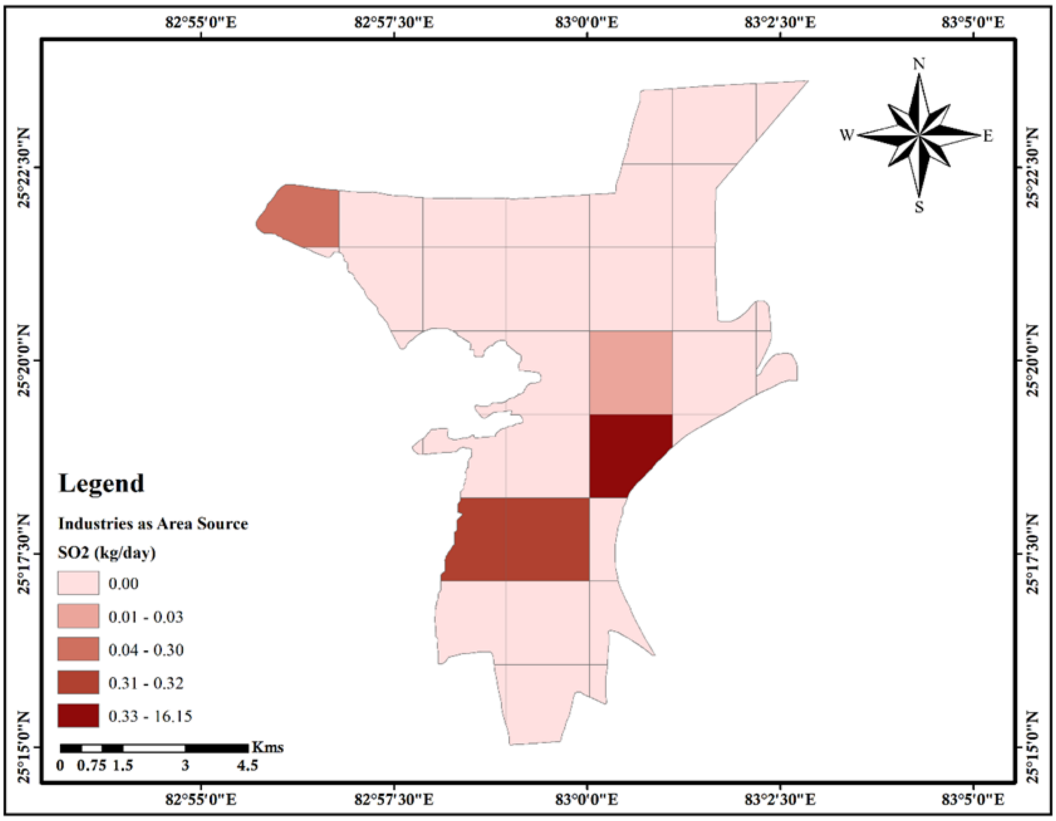
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Area Source
NOx (kg/day)
0.00
0.01 - 0.11
0.12 - 0.37
0.38 - 0.42
0.43 - 18.70
Kms
0 0.75 1.5 3 4.5

Figure 3.64: Spatial Distribution of NO_x Emissions from Industries as area source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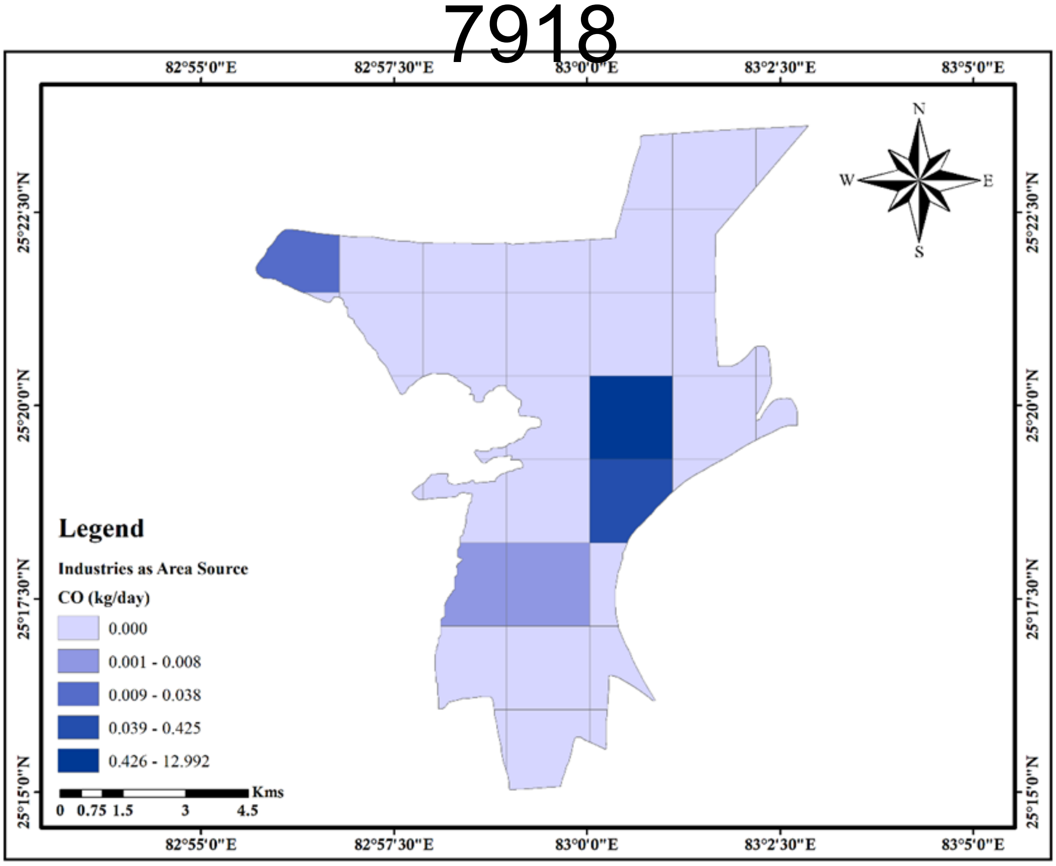
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Area Source
SO2 (kg/day)
0.00
0.01 - 0.03
0.04 - 0.30
0.31 - 0.32
0.33 - 16.15
Kms
0 0.75 1.5 3 4.5

Figure 3.65: Spatial Distribution of SO_2 Emissions from Industries as area source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82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Area Source
CO (kg/day)
0.000
0.001 - 0.008
0.009 - 0.038
0.039 - 0.425
0.426 - 12.992
Kms
0 0.75 1.5 3 4.5

Figure 3.66: Spatial Distribution of CO Emissions from Industries as area source

Industries as Point Source

There are approximately 17 industries that are having chimney height equal to or more than 20 meters. The industries having a stack height of more than 20 m have been taken as a point source. There are approximately 17 industries that are having stack heights of more than 20 meters. The emission of pollutants from industries as a point source is shown in Figure 3.67.

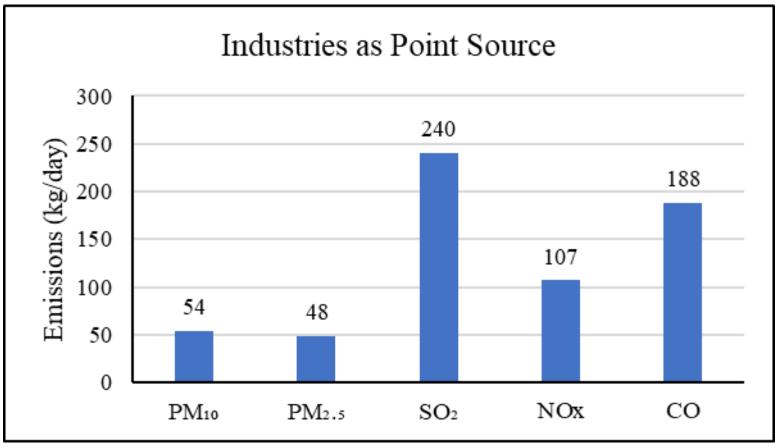
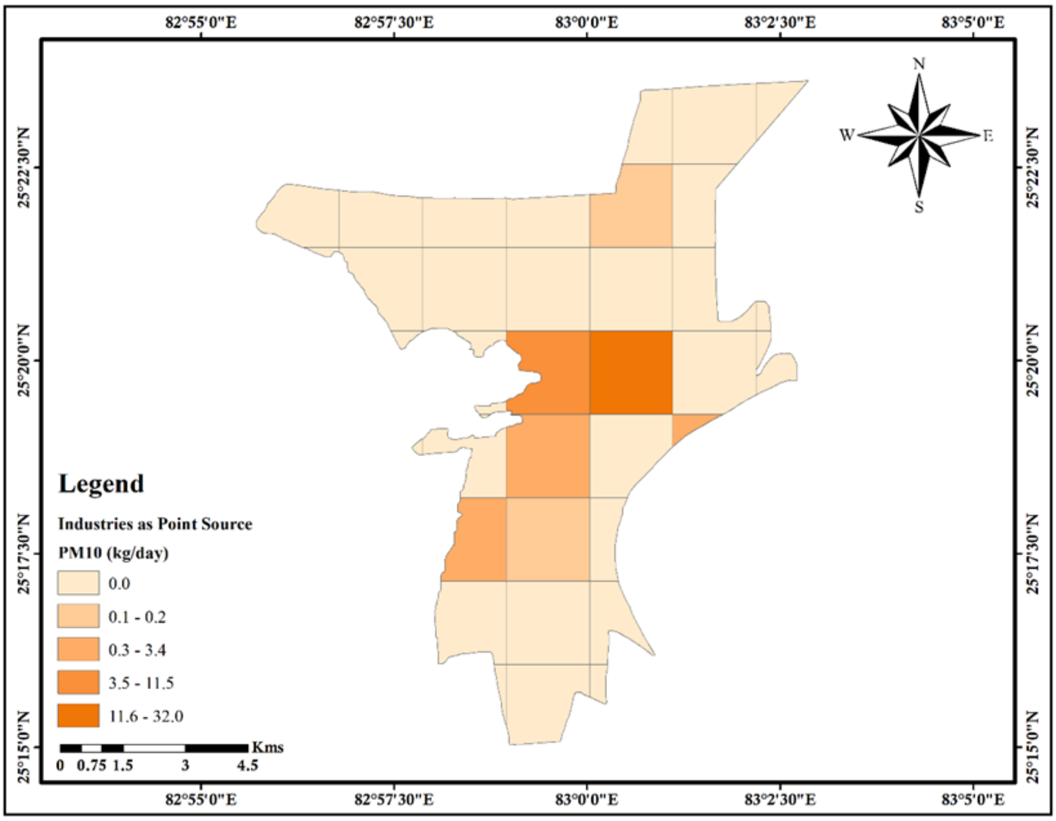


Figure 3.67: Emission Load from Industrial Point Source

The spatial distribution of emissions from industries as point source is presented in Figure 3.68 to Figure 3.72.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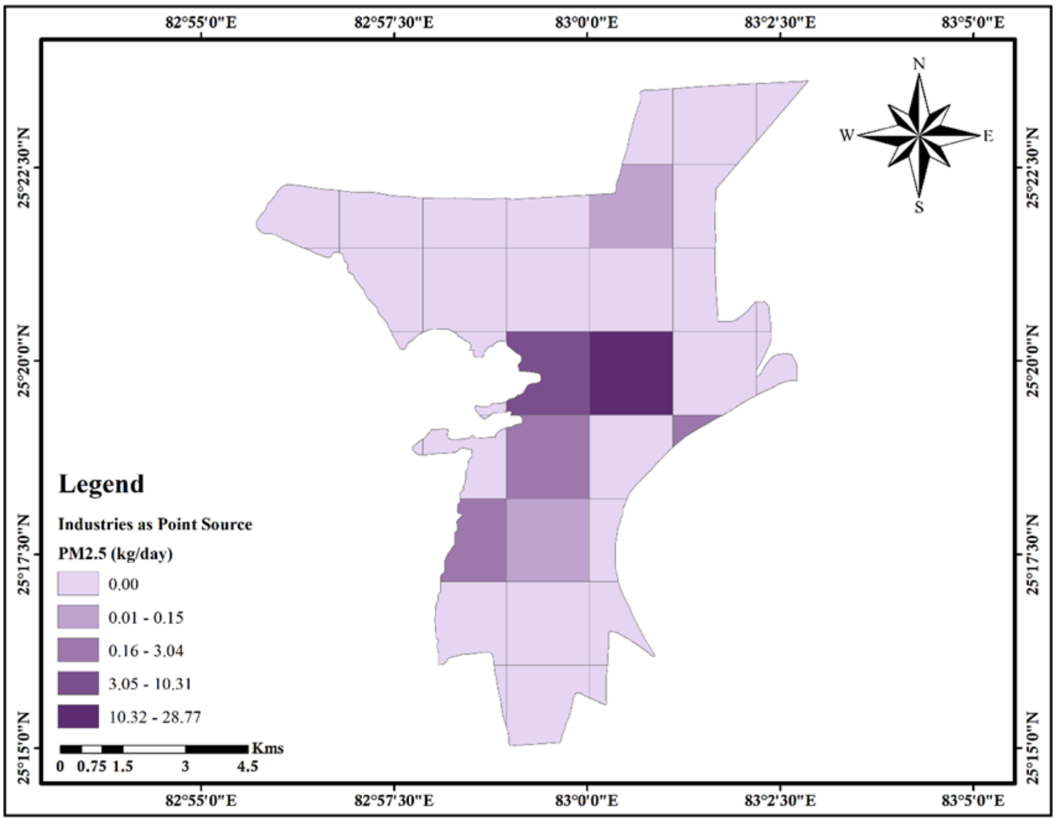
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Point Source
PM10 (kg/day)
0.0
0.1 - 0.2
0.3 - 3.4
3.5 - 11.5
11.6 - 32.0
Kms
0 0.75 1.5 3 4.5

Figure 3.68: Spatial Distribution of PM_{10} Emissions from Industries as point source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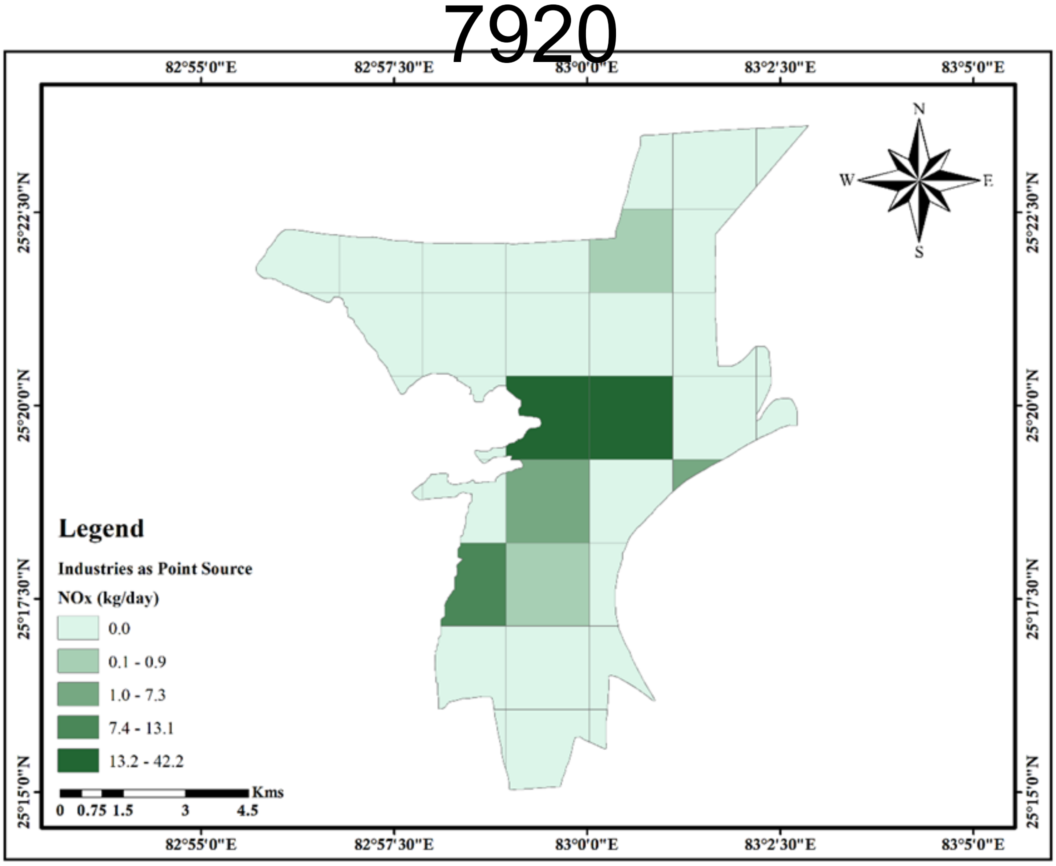
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Point Source
PM2.5 (kg/day)
0.00
0.01 - 0.15
0.16 - 3.04
3.05 - 10.31
10.32 - 28.77
Kms
0 0.75 1.5 3 4.5

Figure 3.69: Spatial Distribution of $PM_{2.5}$ Emissions from Industries as point source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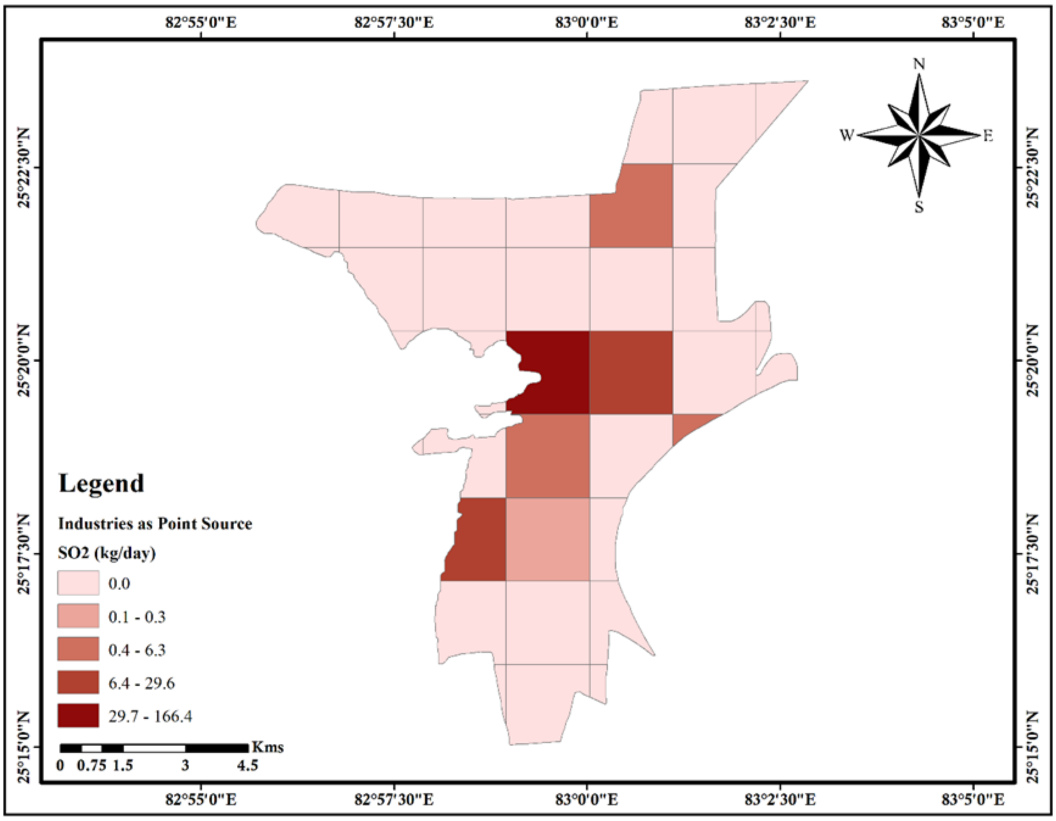
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Point Source
NOx (kg/day)
0.0
0.1 - 0.9
1.0 - 7.3
7.4 - 13.1
13.2 - 42.2
Kms
0 0.75 1.5 3 4.5

Figure 3.70: Spatial Distribution of NOx Emissions from Industries as point source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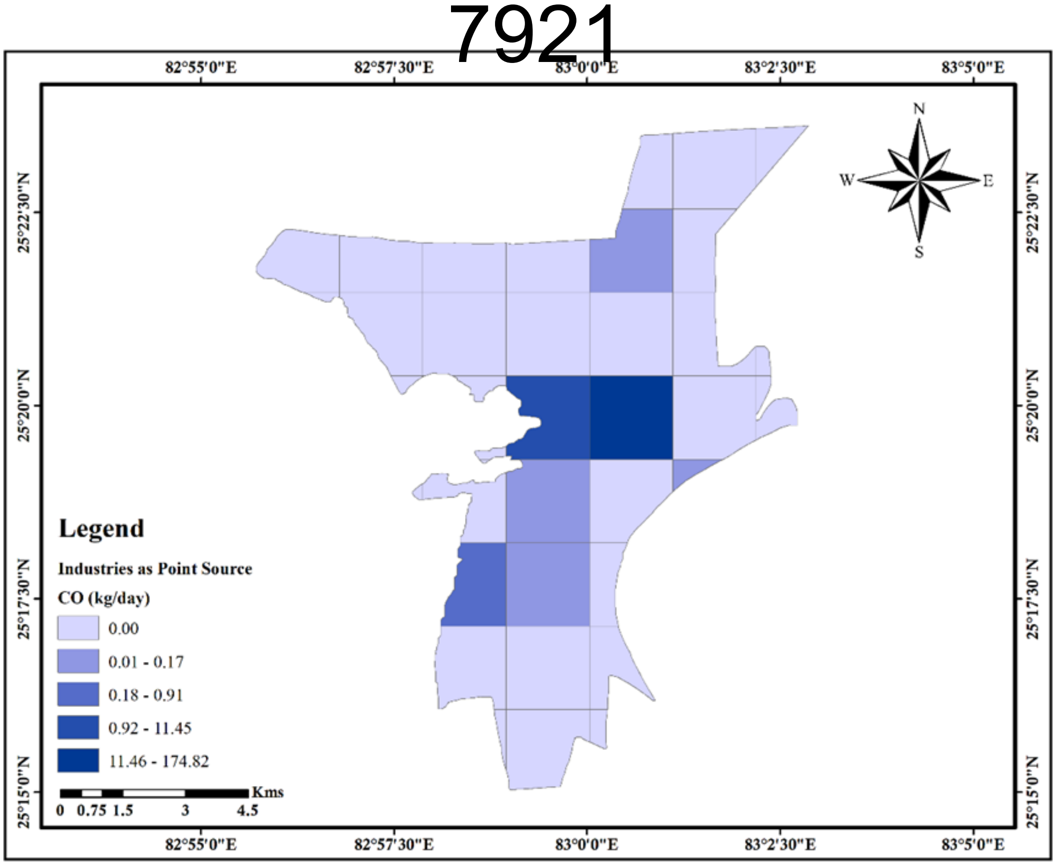
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Point Source
SO2 (kg/day)
0.0
0.1 - 0.3
0.4 - 6.3
6.4 - 29.6
29.7 - 166.4
Kms
0 0.75 1.5 3 4.5

Figure 3.71: Spatial Distribution of SO_2 Emissions from Industries as point source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83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Industries as Point Source
CO (kg/day)
0.00
0.01 - 0.17
0.18 - 0.91
0.92 - 11.45
11.46 - 174.82
Kms
0 0.75 1.5 3 4.5

Figure 3.72: Spatial Distribution of CO Emissions from Industries as point source

3.2.12 Parking Lot Survey

To obtain the prevalence of vehicle technology types operating in the city and fuel used, parking lot questionnaire surveys (engine technology and capacity, vehicle age, fuel use, etc.) were done at 7 locations (Pandeypur Chauraha, Atulanand Bus Stop Chauaraha, BHU Main Gate Chauraha, Chokaghat Chauraha, Girjaghar Chauraha, Kashi Chauraha, Lahartara Chauraha) in the city of Varanasi. ARAI (2011) and CPCB (2011) emission factors were used to calculate the emissions. The parking lane survey results for 2Ws, 3Ws, and 4Ws in terms of engine size and year of manufacturing is presented in Figure 3.73 to Figure 3.75. This information is vital in calculating the emission from vehicles on the road. The emission factors vary considerably for engine size, fuel uses, and age of the vehicles.

7922

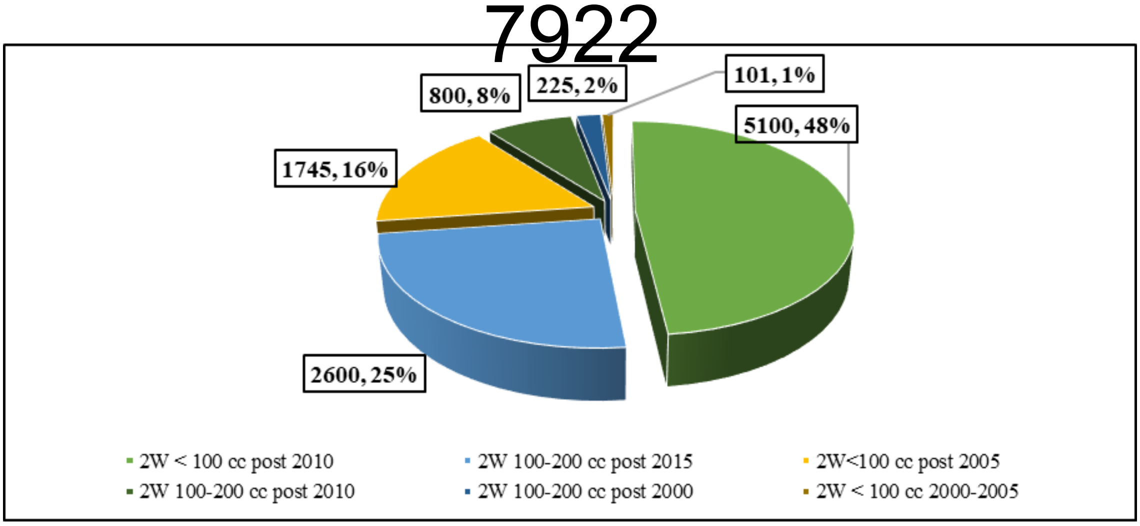


Figure 3.73: Distribution of 2-Ws in the study area (parking lot survey)

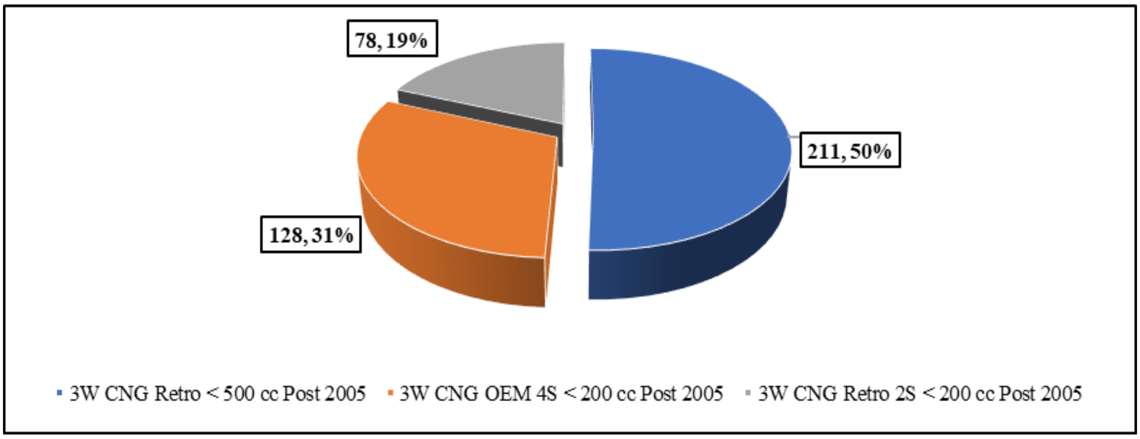


Figure 3.74: Distribution of 3-Ws in the study area (parking lot survey)

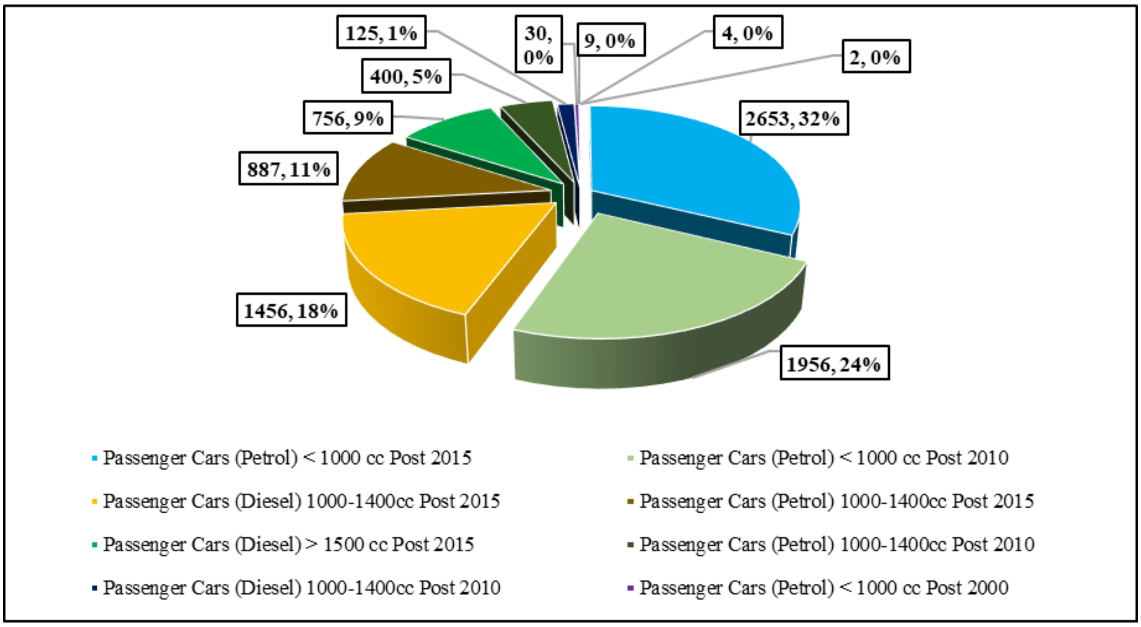
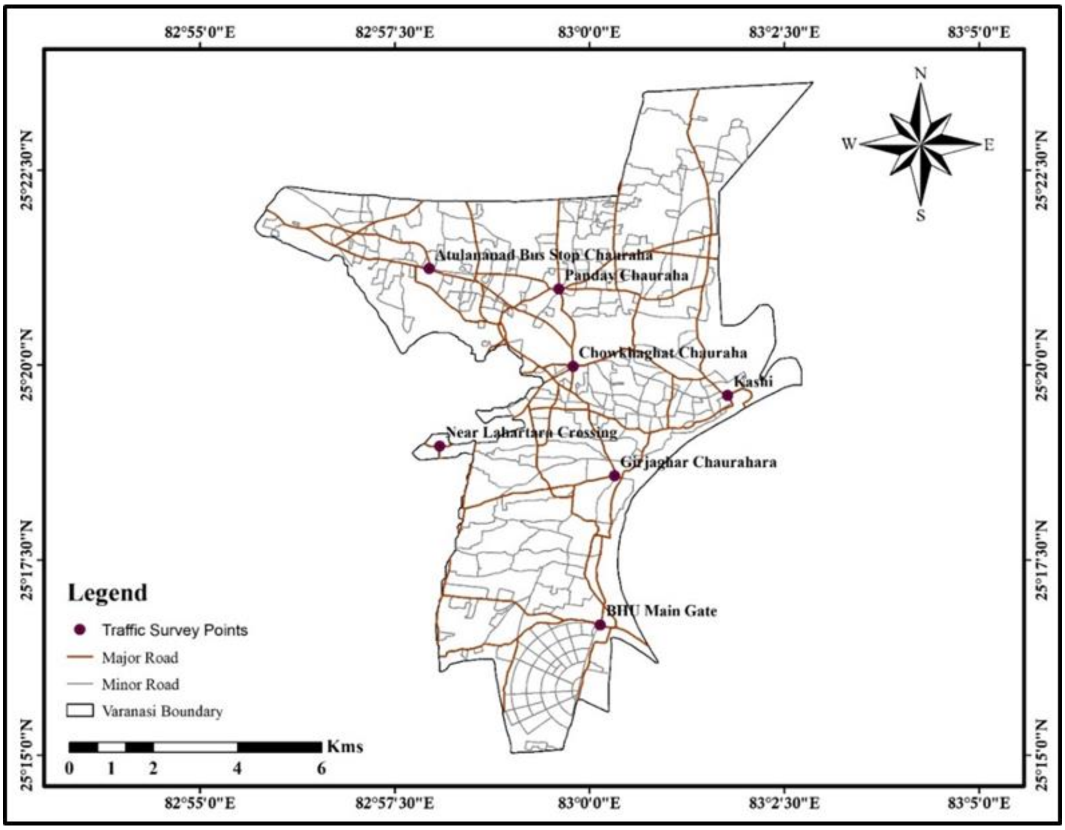


Figure 3.75: Distribution of 4-Ws in the study area (parking lot survey)

3.2.13 Vehicular - Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, Buses, and Trucks at 7 locations were obtained by video recording at crossings (Figure 3.76). From these 7 traffic locations, the data were extrapolated for the remaining grid cells. Road lengths in each cell for major and minor roads were calculated from the digitized maps using the ArcGIS tool, ArcMap, and extracted into the grids. The information on traffic flow from traffic counts was translated into the vehicles on the roads in each grid. Wherever it was feasible, either traffic flow was taken directly from the traffic data, and for interior grids, traffic from medium roads going the highways was taken to flow in the interior part of the city. The emissions from each vehicle category for each grid are estimated and summed up.


82°55'0"E
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83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Atulananad Bus Stop Chauraha
Panday Chauraha
Chowkhaghat Chauraha
Kashi
Near Lahartara Crossing
Girjaghar Chaurahara
BHU Main Gate
Legend
Traffic Survey Points
Major Road
Minor Road
Varanasi Boundary
Kms
0
1
2
4
6

Figure 3.76: Traffic location considered for vehicle emission in the city of Varanasi.

The emissions from railway locomotives are not taken into considerations, as the emissions are negligible in comparison with the vehicles and other sources.

The emission contribution of each vehicle type in the city of Varanasi city is presented in Figure 3.77 to Figure 3.81.

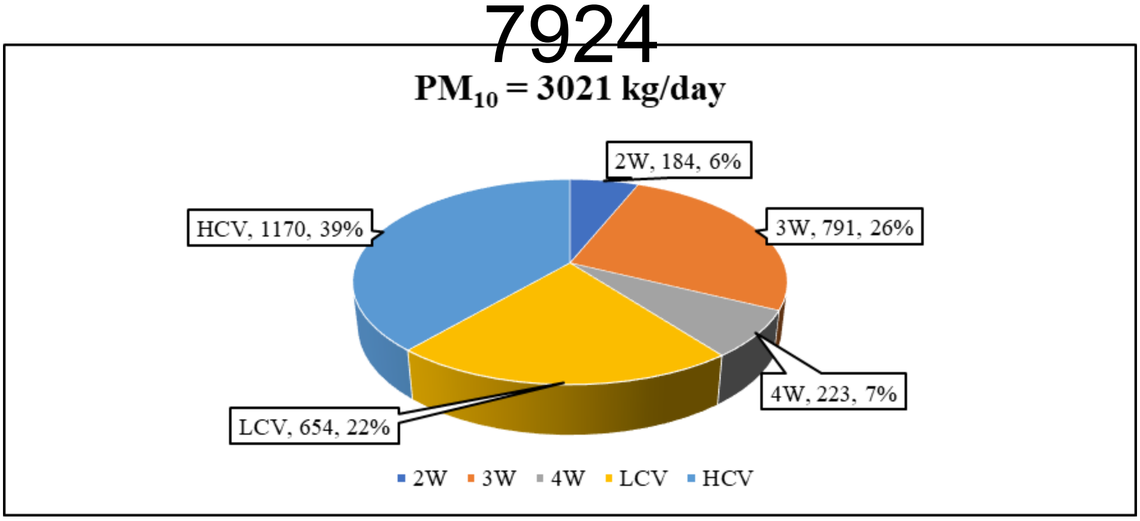


Figure 3.77: PM$_{10}$ Emission Load contribution of each vehicle type (kg/day)

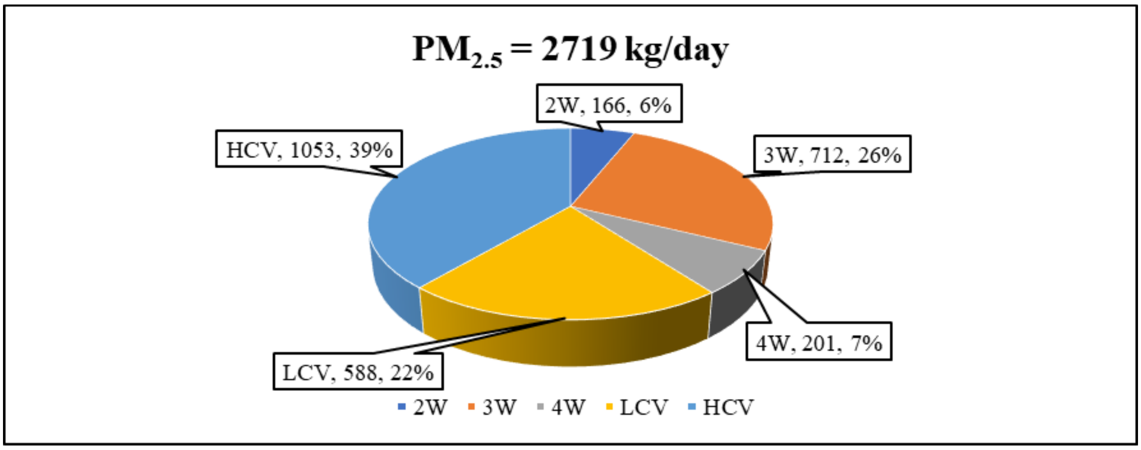


Figure 3.78: PM$_{2.5}$ Emission Load contribution of each vehicle type (kg/day)

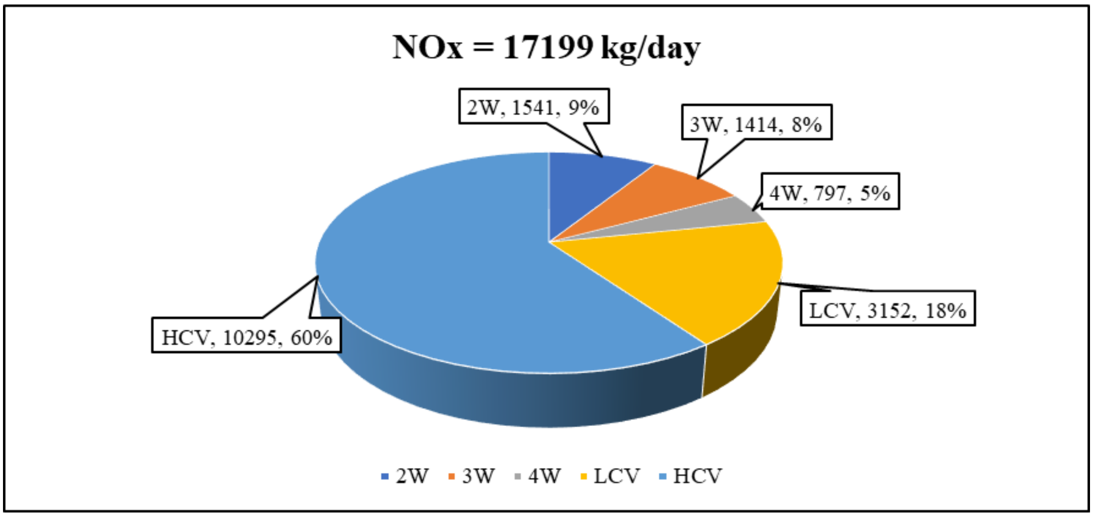


Figure 3.79: NO$_x$ Emission Load contribution of each vehicle type (kg/day)

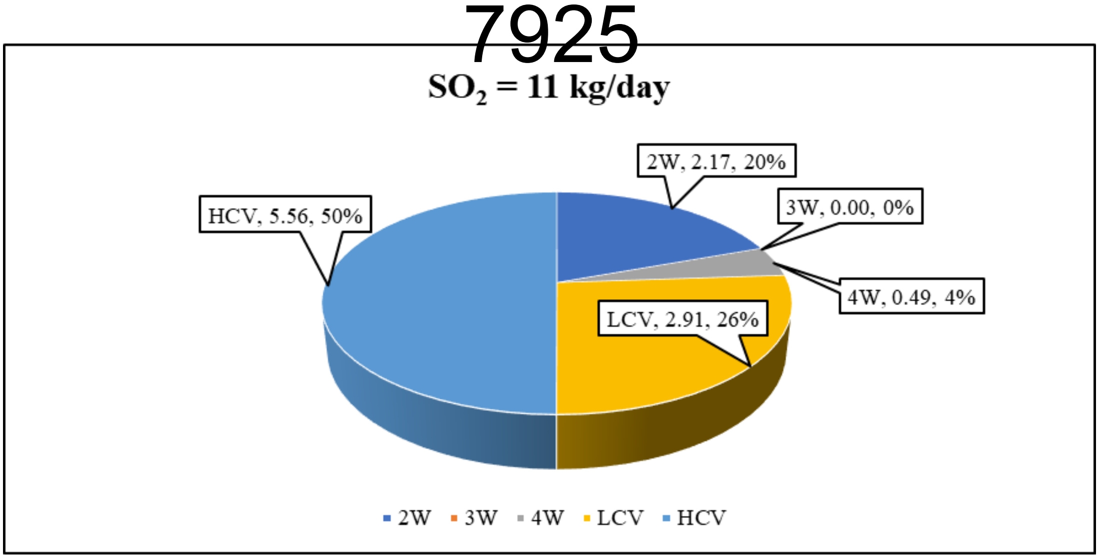


Figure 3.80: SO_2 Emission Load contribution of each vehicle type (kg/day)

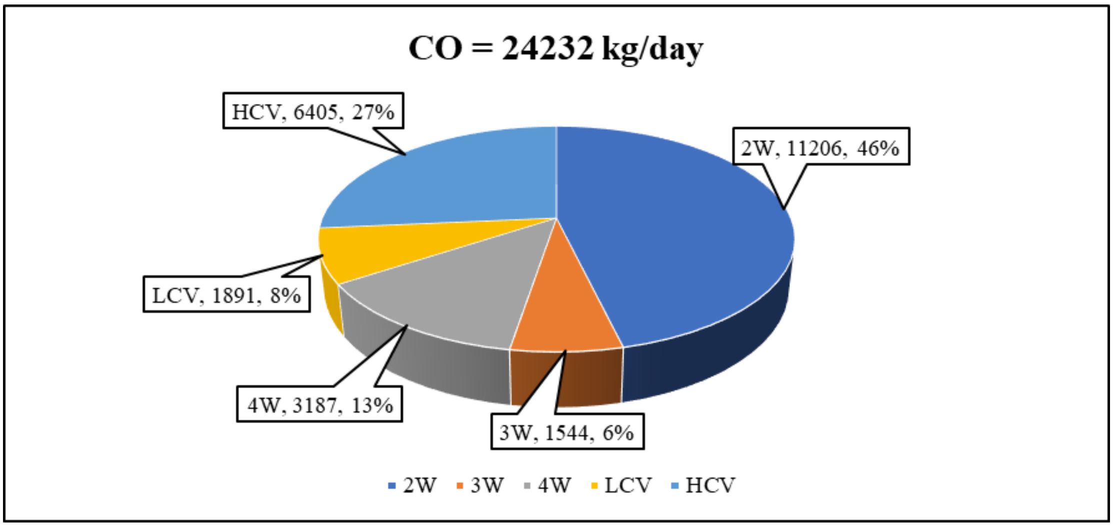


Figure 3.81: CO Emission Load contribution of each vehicle type (kg/day)

The emission from vehicles is shown in Figure 3.82. The spatial distribution of emissions from vehicles is presented in Figure 3.83 to Figure 3.87.

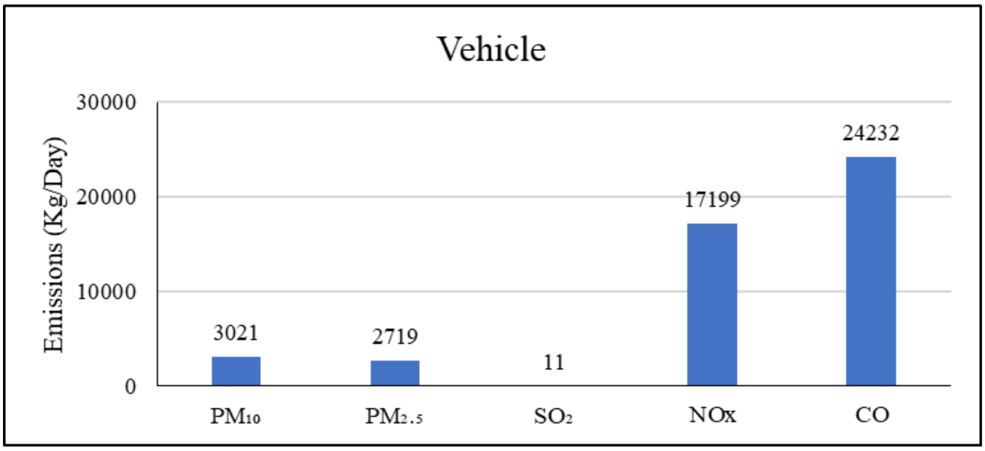
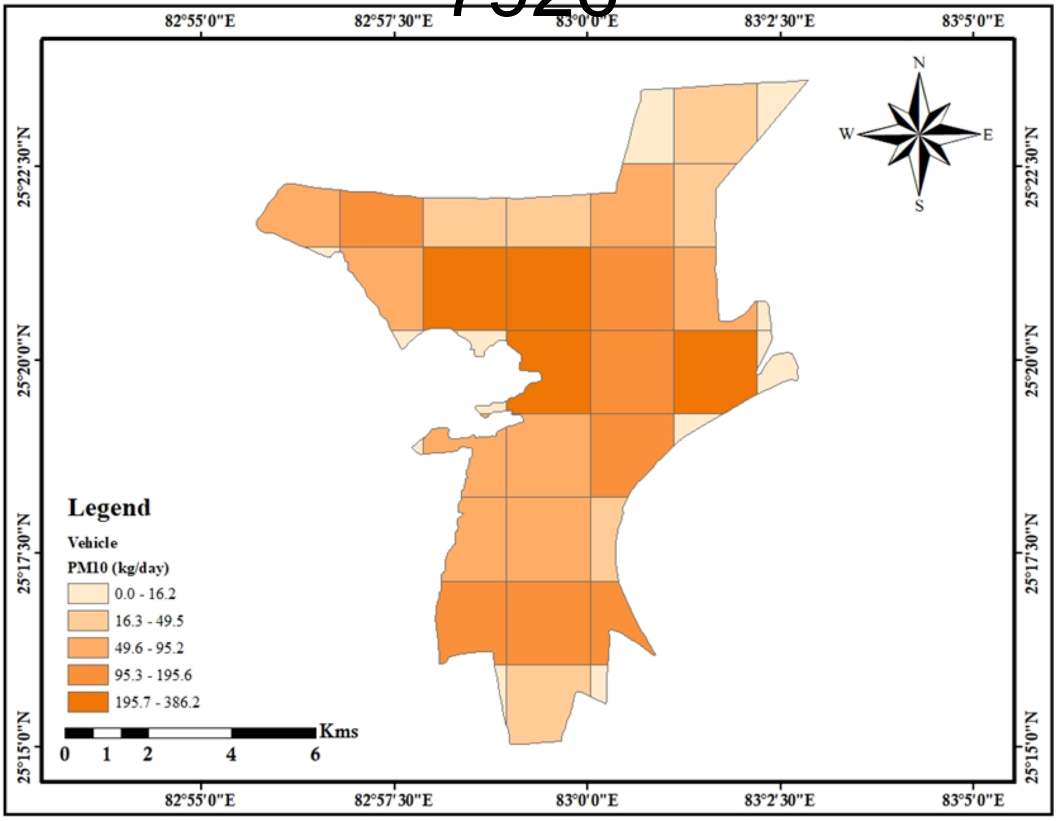


Figure 3.82: Emission Load from Vehicles (kg/day)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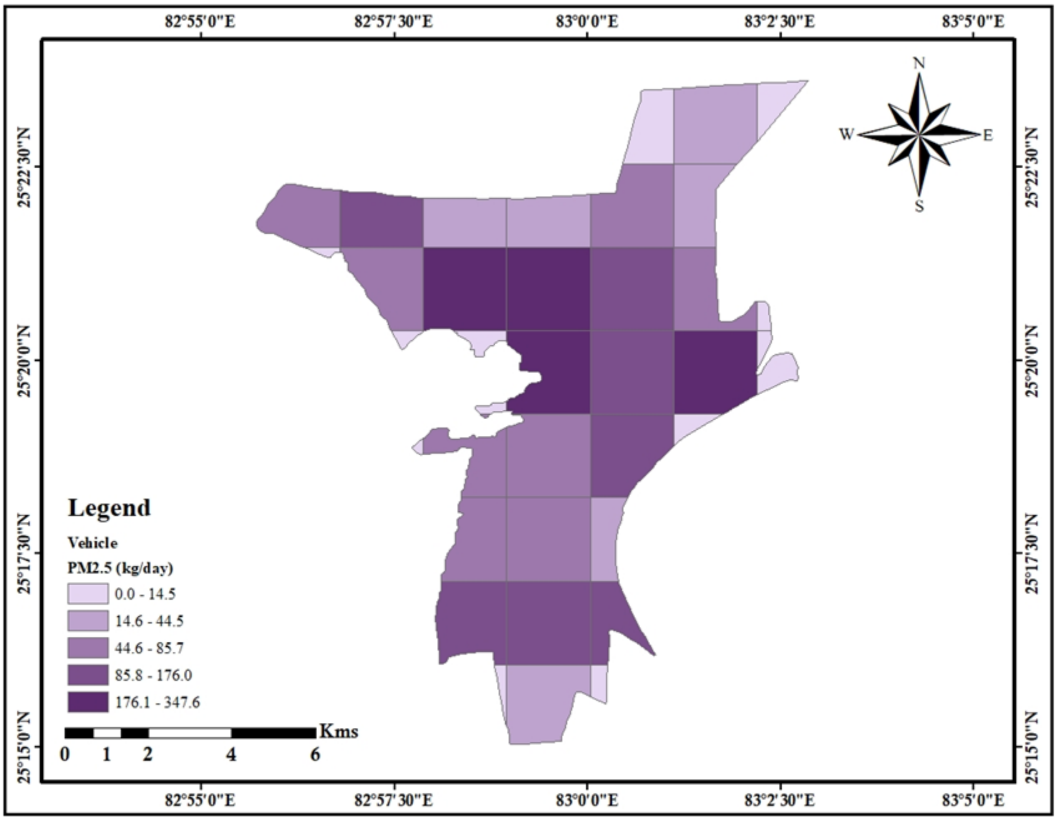
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Vehicle
PM10 (kg/day)
0.0 - 16.2
16.3 - 49.5
49.6 - 95.2
95.3 - 195.6
195.7 - 386.2
Kms
0
1
2
4
6

Figure 3.83: Spatial Distribution of PM_{10} Emissions from Vehicles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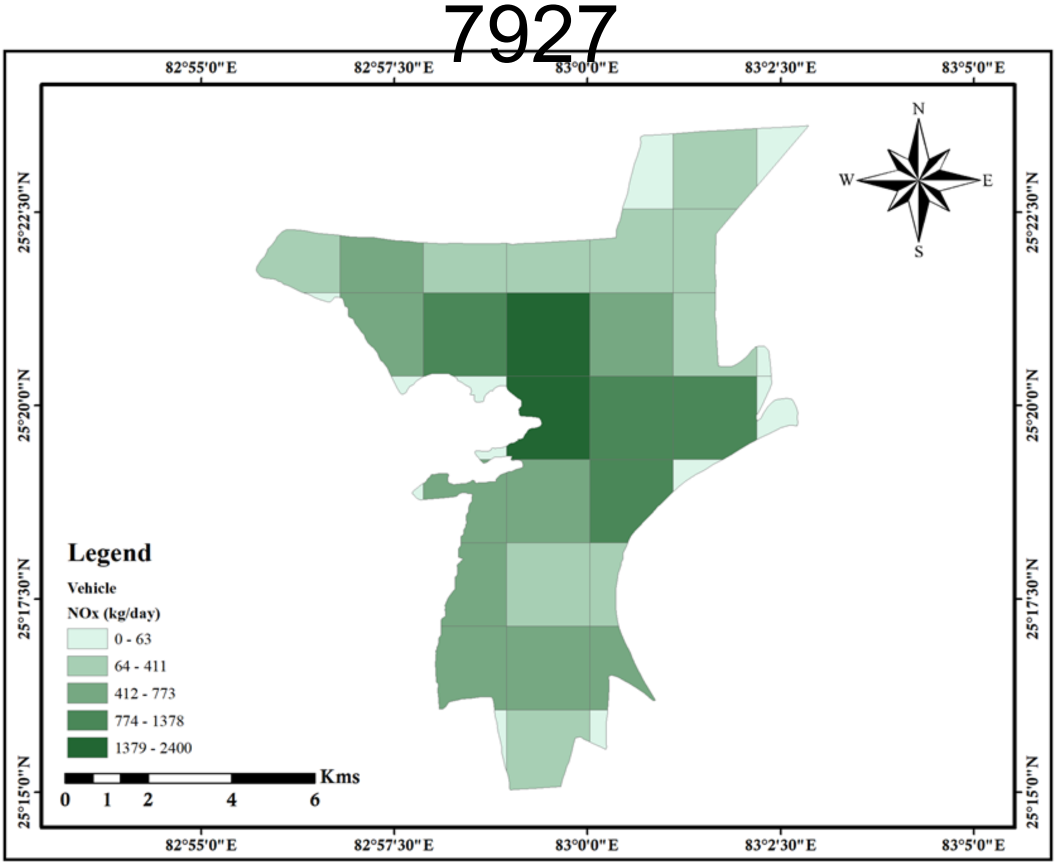
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Vehicle
PM2.5 (kg/day)
0.0 - 14.5
14.6 - 44.5
44.6 - 85.7
85.8 - 176.0
176.1 - 347.6
Kms
0
1
2
4
6

Figure 3.84: Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles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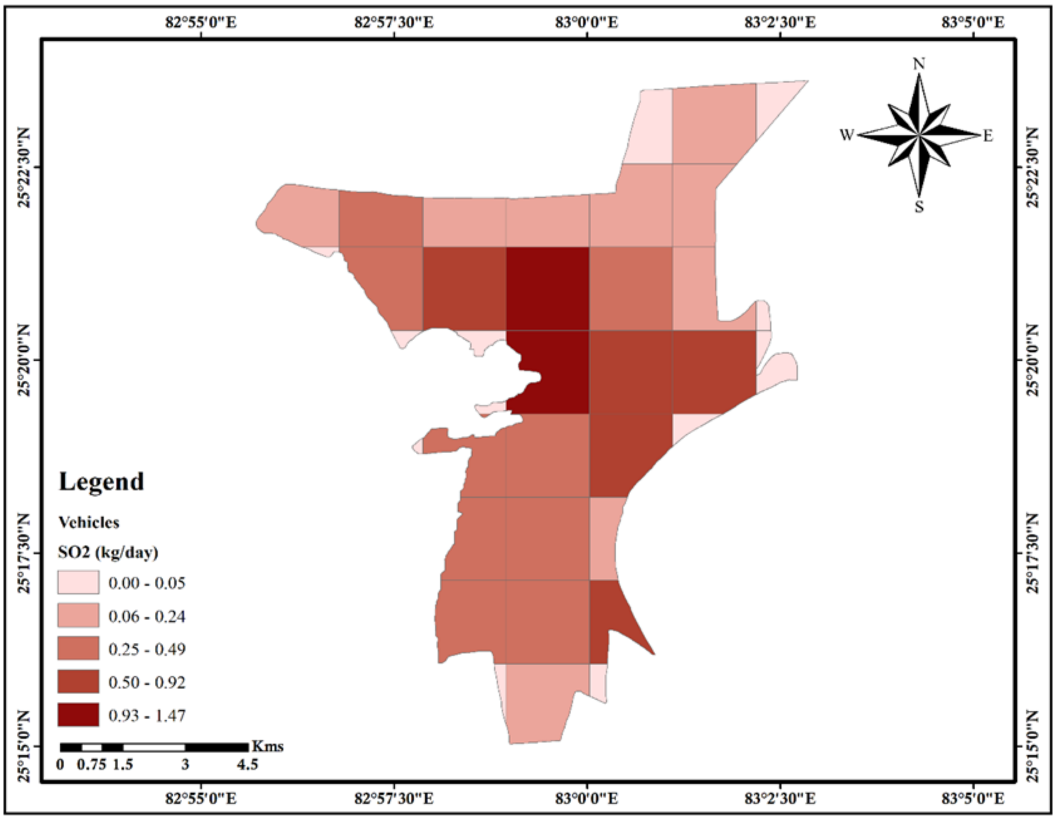
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Vehicle
NOx (kg/day)
0 - 63
64 - 411
412 - 773
774 - 1378
1379 - 2400
Kms
0
1
2
4
6

Figure 3.85: Spatial Distribution of NOx Emissions from Vehicles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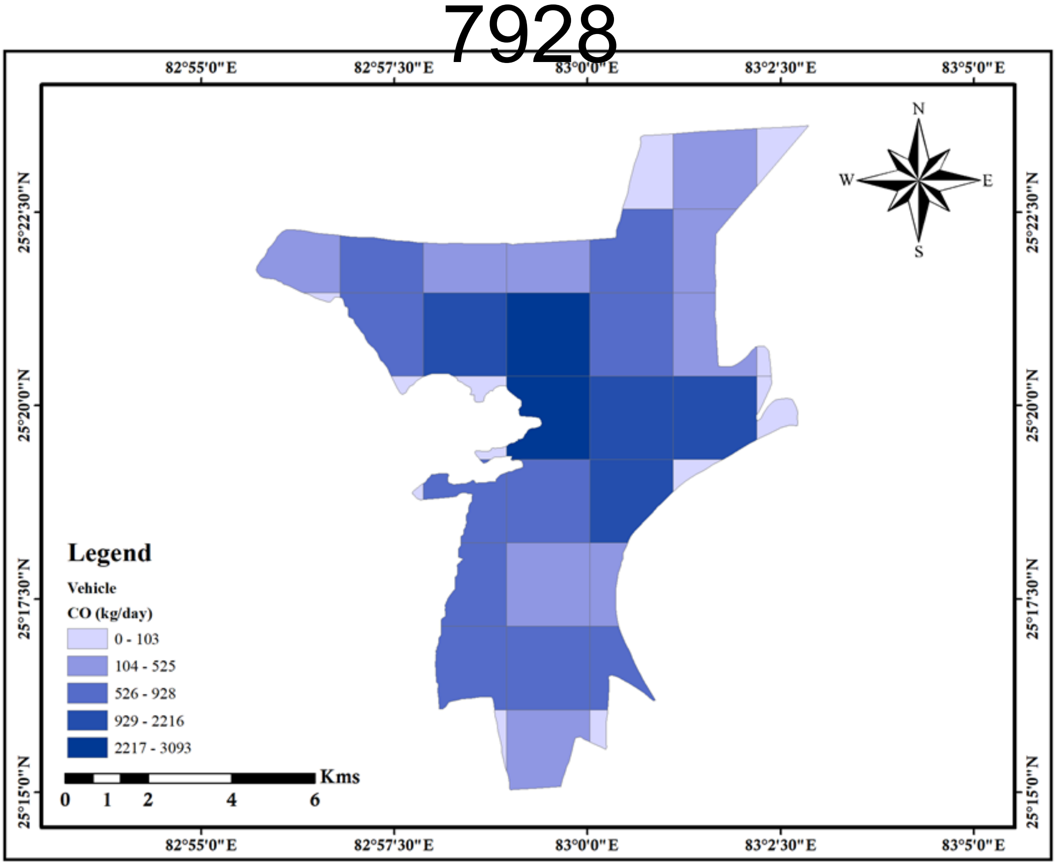
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Vehicles
SO2 (kg/day)
0.00 - 0.05
0.06 - 0.24
0.25 - 0.49
0.50 - 0.92
0.93 - 1.47
Kms
0
0.75
1.5
3
4.5

Figure 3.86: Spatial Distribution of SO_2 Emissions from Vehicles


82°55'0"E
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83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Vehicle
CO (kg/day)
0 - 103
104 - 525
526 - 928
929 - 2216
2217 - 3093
Kms
0
1
2
4
6

Figure 3.87: Spatial Distribution of CO Emissions from Vehicles

3.2.14 Traffic Congestion

Major Traffic Bottleneck at Varanasi City are given in Figure 3.88. Consequently, the major Traffic bottlenecks are mentioned in Table 3.3. The figure depicts the traffic report of Varanasi for seven traffic hotspots of the city for the seven days of the week. The color coding used here is Red, Orange, and Green indicating the slow traffic to fast traffic movement respectively. Chowkaghat Chauraha, Girjaghar Chauraha, Pandeypur Chauraha, and BHU Main Gate Chauraha have been seeing most of the traffic in the morning span on the weekdays, resulting in most of the people accessing roads for the conveyance to their respective working spaces.

Table 3.3: Major Traffic Bottleneck at Varanasi City

Kashi Chauraha	BHU Main Gate Chauraha	Pandeypur Chauraha
Chowkaghat Chauraha	Lahartara Chauraha	Girjaghar Chauraha
Atulanand Bus Stop Chauraha		

S.NO	DATE	Kashi	BHU Main Gate	Pandeypur	Chowkaghat	Lahartara	Girjaghar	Atulanand Bus Stop
1	Sunday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟥 8am-10am	🟩 8am-10am
		🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟩 10am-12pm
		🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟥 2pm-4pm	🟩 2pm-4pm
		🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟩 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
2	Monday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟥 8am-10am	🟧 8am-10am	🟥 8am-10am	🟧 8am-10am
		🟧 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
		🟩 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm
		🟧 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟩 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
3	Tuesday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟥 8am-10am	🟧 8am-10am	🟧 8am-10am	🟧 8am-10am
		🟧 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
		🟧 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm	🟩 2pm-4pm
		🟧 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟩 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
4	Wednesday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟥 8am-10am	🟧 8am-10am	🟧 8am-10am	🟧 8am-10am
		🟧 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
		🟧 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm	🟩 2pm-4pm
		🟧 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟩 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
5	Thursday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟧 8am-10am	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am
		🟧 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
		🟧 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm	🟩 2pm-4pm
		🟧 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟩 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
6	Friday	🟩 8am-10am	🟥 8am-10am	🟧 8am-10am	🟧 8am-10am	🟩 8am-10am	🟧 8am-10am	🟩 8am-10am
		🟩 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
		🟩 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm
		🟧 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟩 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
7	Saturday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟧 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
		🟧 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
		🟧 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
		🟩 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm	🟩 2pm-4pm
		🟧 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
		🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm

Green = smooth traffic
Orange = slow-moving traffic
Red = Heavy traffic with congestion

Figure 3.88: Typical Traffic conditions at different locations in Varanasi City

7930

3.2.15 Paved and Unpaved Road Dust

Dust emissions from paved and unpaved roads have been found that vary with the ‘silt loading’ present on the road surface and the average weight of vehicles travelling on the road. The term silt loading (sL) refers to the mass of the silt-sized material (equal to or less than 75 µm in physical diameter) per unit area of the travel surface. The quantity of dust emissions from the movement of vehicles on a paved or unpaved road can be estimated using the following empirical expression:

$$E = \frac{\left[k\left(\frac{sL}{2}\right)^{0.65} \times \left(\frac{W}{3}\right)^{1.5} \times VKT\right]}{1000} \qquad (3.4)$$

Where

E = emission from road dust (kg/day)

VKT = vehicle kilometer travel

sL = road surface silt loading (grams per square meter) (g/m2), and

W = average weight (tons) of the vehicles travelling the road.

k = constant (a function of particle size) in g VKT-1 (vehicle kilometer travel)

The road dust sampling locations are given in Figure 3.89. The silt loads (sL) samples from 7 locations were collected (Figure 3.90). Then mean weight of the vehicle fleet (W) was estimated by giving the weightage to the percentage of vehicles of all types with their weight. Then emission rate (g VKT^{-1}) was calculated based on Eq (3.4). VKT for each grid was calculated by considering the tonnage of each road. Then finally, the emission loads from paved and unpaved roads were found out by using Eq (3.4). There is a need to clean the road on regular basis. The road dust deposition can be seen in Figure 3.91. In the winter and monsoon season, it is less due to moisture and dew atmospheric conditions. The emission load from road dust in Varanasi city is given in Figure 3.92. The Spatial distribution of Emissions from Road Dust Re-suspension is presented in Figure 3.93 and Figure 3.94.

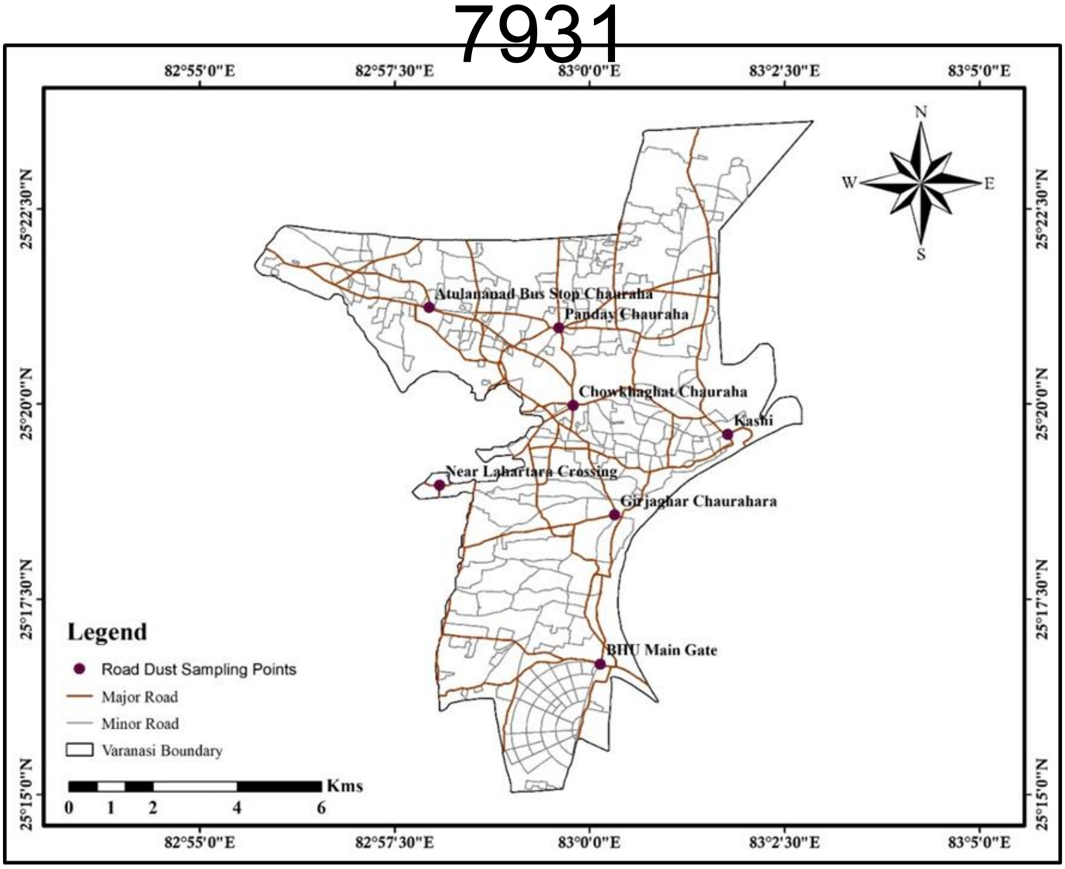

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Atulananad Bus Stop Chauraha
Panday Chauraha
Chowkhaghat Chauraha
Kashi
Near Lahartara Crossing
Girjaghar Chaurahara
BHU Main Gate
Legend
● Road Dust Sampling Points
Major Road
Minor Road
Varanasi Boundary
Kms
0 1 2 4 6

Figure 3.89: Road Dust Sampling Location

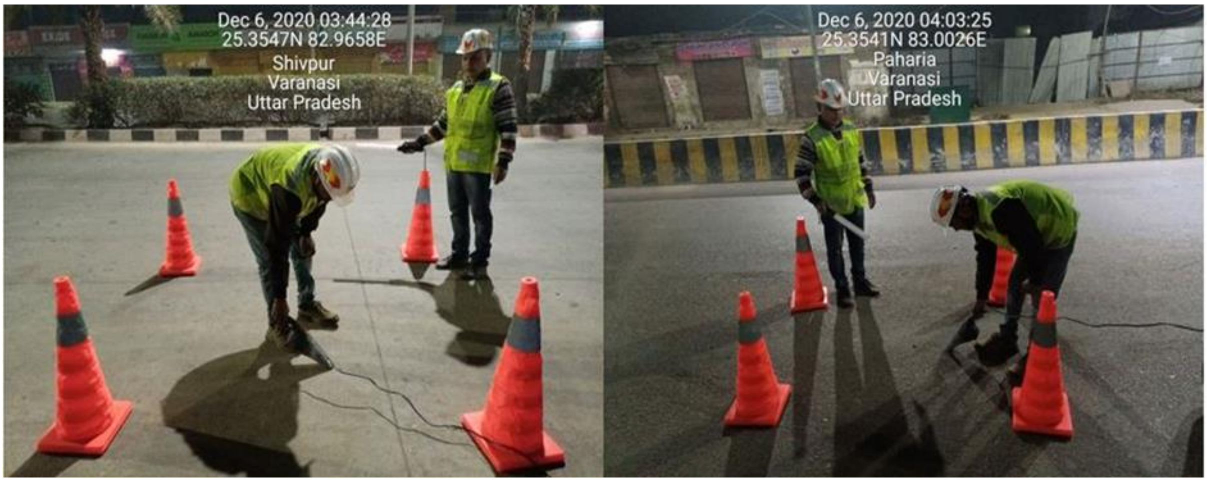

Dec 6, 2020 03:44:28
25.3547N 82.9658E
Shivpur
Varanasi
Uttar Pradesh
Dec 6, 2020 04:03:25
25.3541N 83.0026E
Paharia
Varanasi
Uttar Pradesh

Figure 3.90: Road Dust Sampling in the City of Varanasi

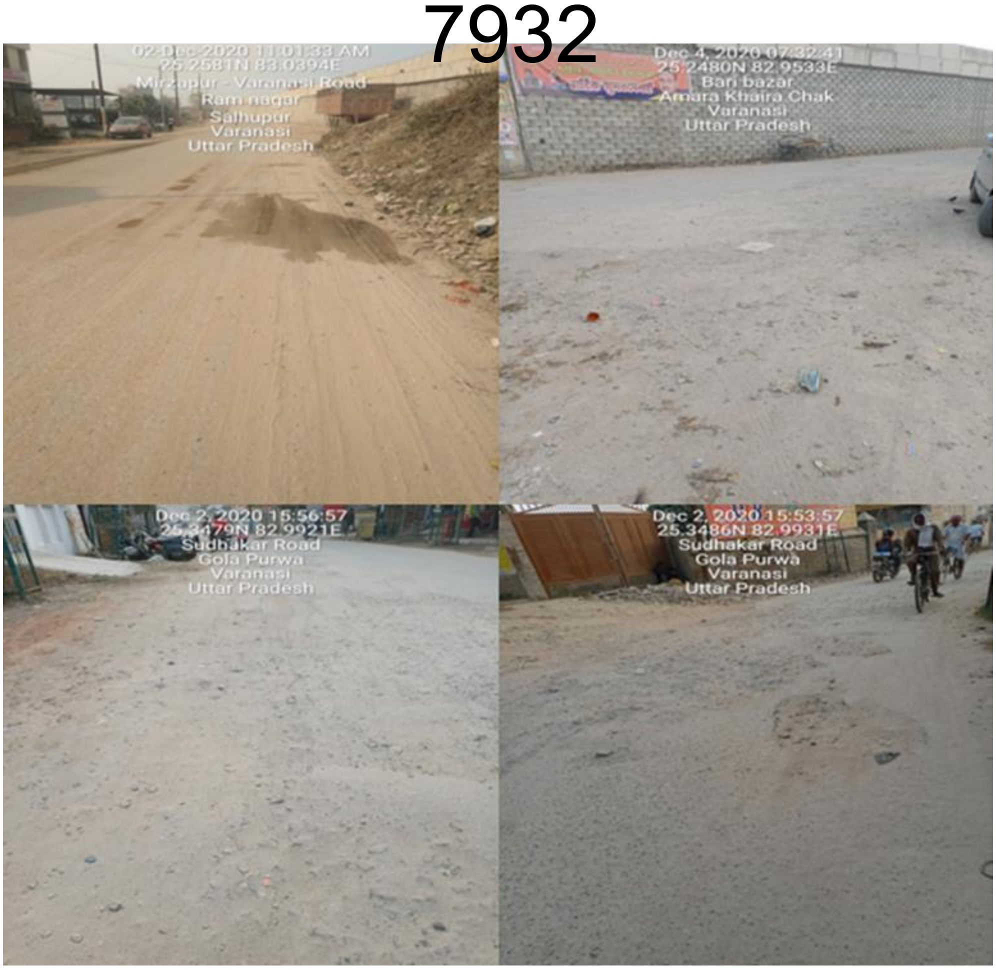

02-Dec-2020 11:01:33 AM
25.2581N 83.0394E
Mirzapur - Varanasi Road
Ram nagar
Salhupur
Varanasi
Uttar Pradesh
Dec 4, 2020 07:32:41
25.2480N 82.9533E
Bari bazar
Amara Khaira Chak
Varanasi
Uttar Pradesh
Dec 2, 2020 15:56:57
25.3479N 82.9921E
Sudhakar Road
Gola Purwa
Varanasi
Uttar Pradesh
Dec 2, 2020 15:53:57
25.3486N 82.9931E
Sudhakar Road
Gola Purwa
Varanasi
Uttar Pradesh

Figure 3.91: Road dust deposition on the paved road

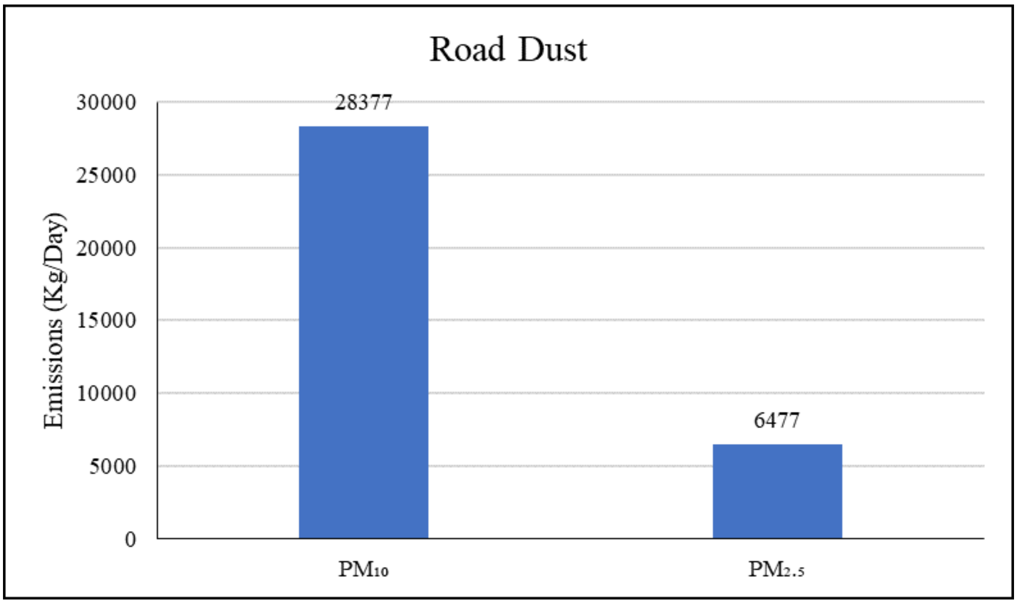


Figure 3.92: Emissions from road dust in Varanasi city (Kg/day)

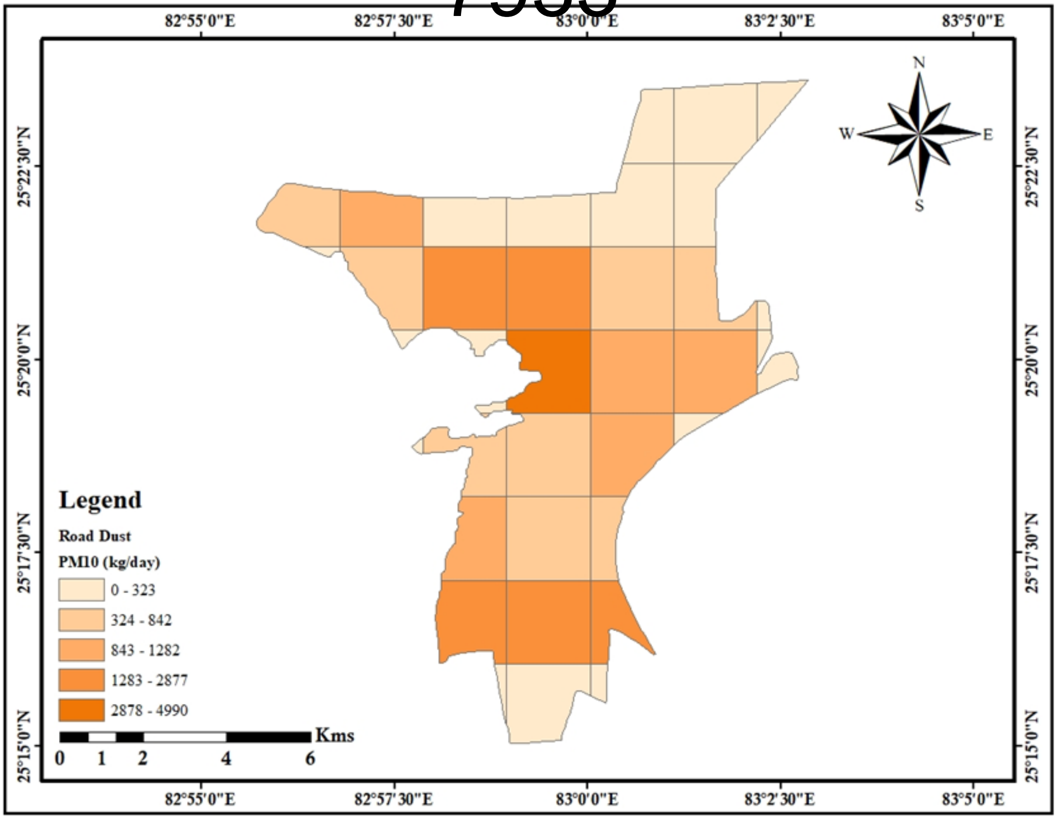

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Road Dust
PM10 (kg/day)
0 - 323
324 - 842
843 - 1282
1283 - 2877
2878 - 4990
Kms
0
1
2
4
6

Figure 3.93: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

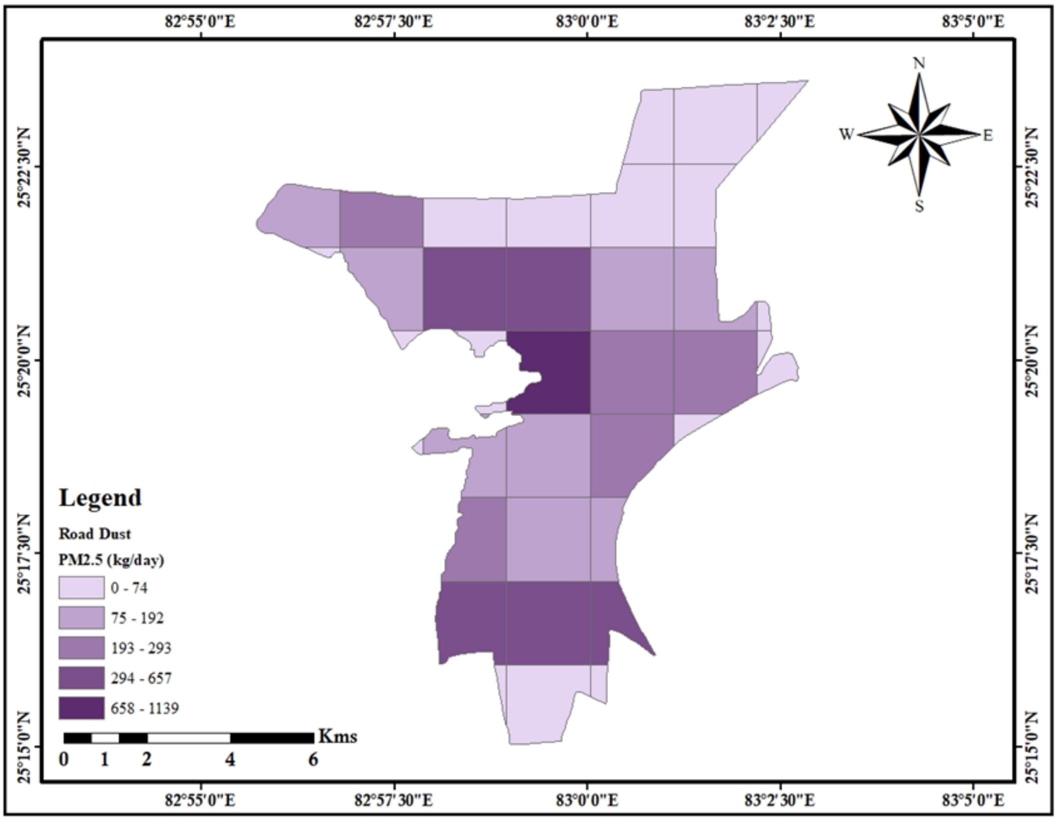

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Road Dust
PM2.5 (kg/day)
0 - 74
75 - 192
193 - 293
294 - 657
658 - 1139
Kms
0
1
2
4
6

Figure 3.94: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

3.2.16 Crematoriums

The number of cremations in Varanasi can vary from one day to another. Harischandra Ghat and Manikarnika Ghat are main ghats for cremation. On average, approximately 160 dead bodies per day are cremated in Varanasi. The wood required for the cremation is 216 kg/dead body. The emission factors for each pollutant for cremation were taken from CPCB (2011). The estimated emissions from wood burning in crematoriums are PM_{10}: 174 kg/day, $PM_{2.5}$: 122 kg/day, SO_2: 17 kg/day, NO_x: 48 kg/day and CO: 1071 kg/day.

3.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 3.4. The pollutant-wise contribution is shown in Figure 3.95 to Figure 3.99. The spatial distribution of pollutant Emissions from all sources is presented in Figure 3.100 to Figure 3.104.

Table 3.4: Varanasi City Level Inventory (kg/day)

Sources	**PM_{10}**	**$PM_{2.5}$**	**SO_2**	**NOx**	**CO**
Domestic	863	689	177	714	2998
MSW Burning	265	180	17	99	1390
Hotels, Restaurants, GHs and BHs	951	688	640	531	1664
Construction and Demolition	281	65			
Industrial DG Sets	0.3	0.3	0.3	4.6	1
Hospitals	1.4	1.3	1.3	19.8	4.3
Industries	64	58	257	127	201
Vehicle	3021	2719	11	17199	24232
Road Dust	28377	6477			
Total	**33823**	**10877**	**1104**	**18694**	**30490**
Note: Emissions from wood burning in crematoriums is less than 1%.					

The total PM_{10} emission load in the city is estimated to be 33823 kg/day. The top three contributors to PM_{10} emissions are road dust 28%), vehicles (9%), and hotels, restaurants, guest houses (GHs), and Banquet halls (BHs) (3%); 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 attain the desired air quality.

$PM_{2.5}$ emission load in the city is estimated to be 10877 kg/day. The top three contributors to $PM_{2.5}$ emissions are road dust (60%), vehicles (25%), and domestic (6%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO_2 emission load in the city is estimated to be 1104 kg/day. The top contributors are hotel, restaurants, GHs, and BHs (58%), industries (23%), and domestic (16%).

NO_x emissions load in the city is estimated to be 18694 kg/day. The majority of total emissions are attributed to vehicular (92%), domestic (4%), and hotels, restaurants, BHs & GHs (3%). 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 30490 kg/day. The major contributors to CO emissions are vehicles (79%), domestic (10%), and hotels, restaurants, BHs & GHs (5%). Vehicles could be the main target for controlling CO for improving air quality concerning CO.

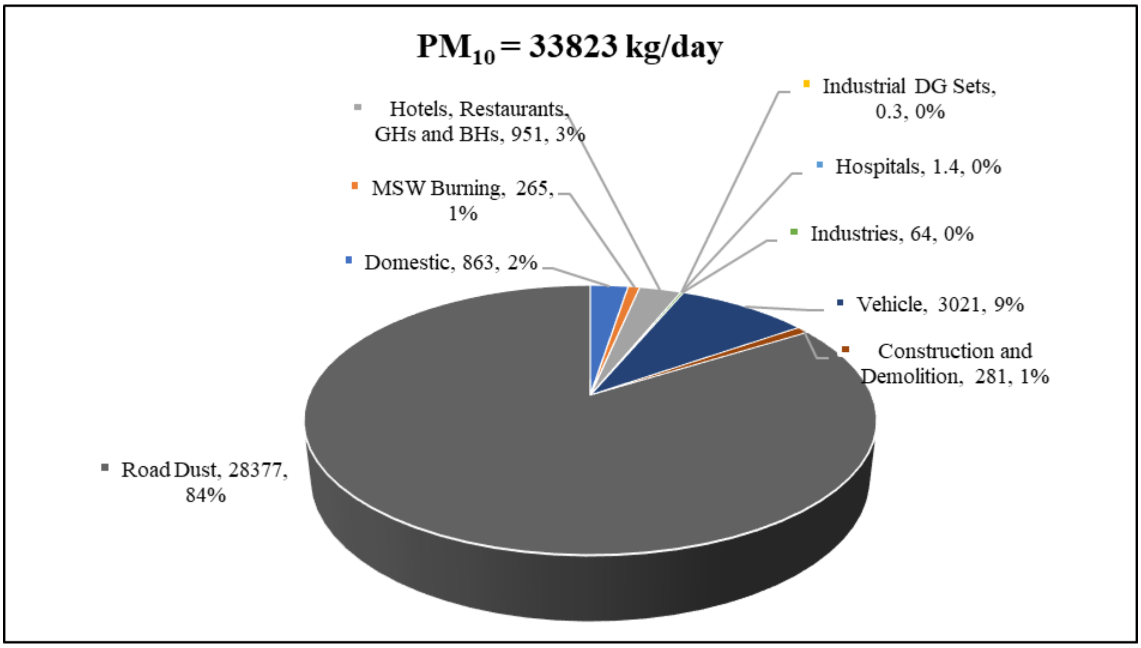


Figure 3.95: PM_{10} Emission Contribution of Different Sources

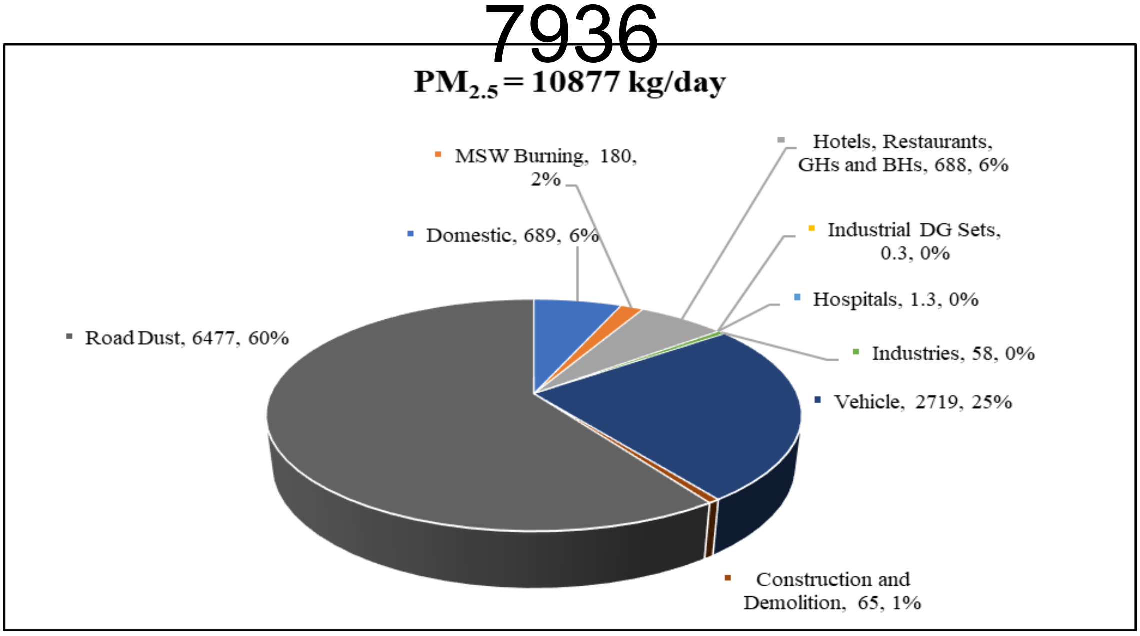


Figure 3.96: $PM_{2.5}$ Emission Load Contribution of Different Sources

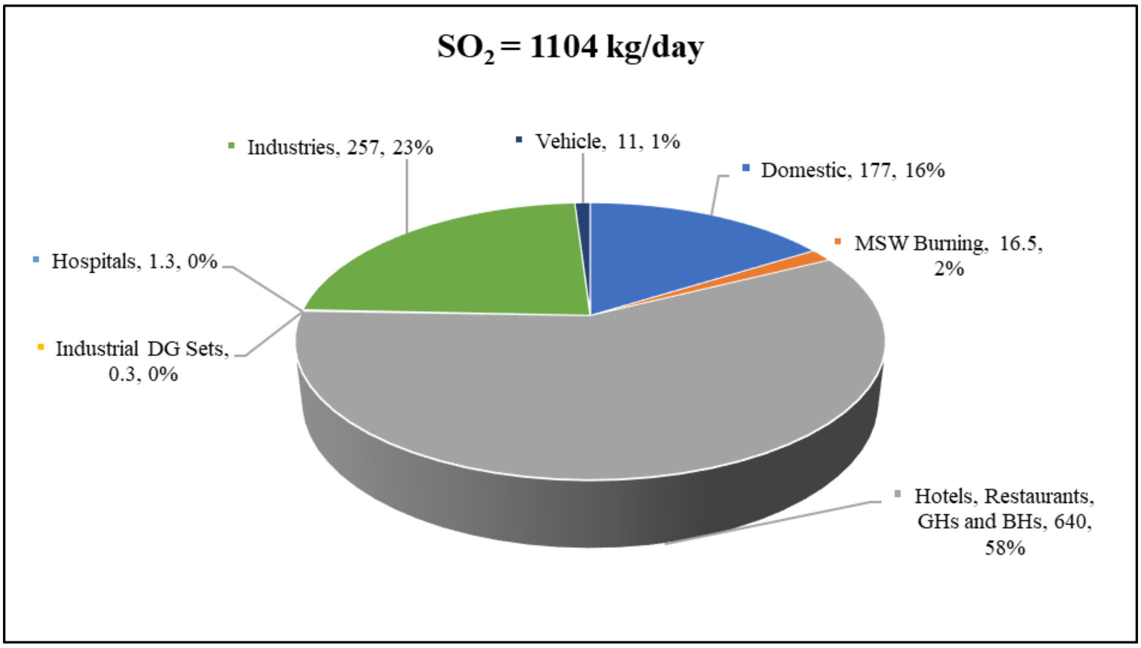


Figure 3.97: SO_2 Emission Load Contribution of Different Sources

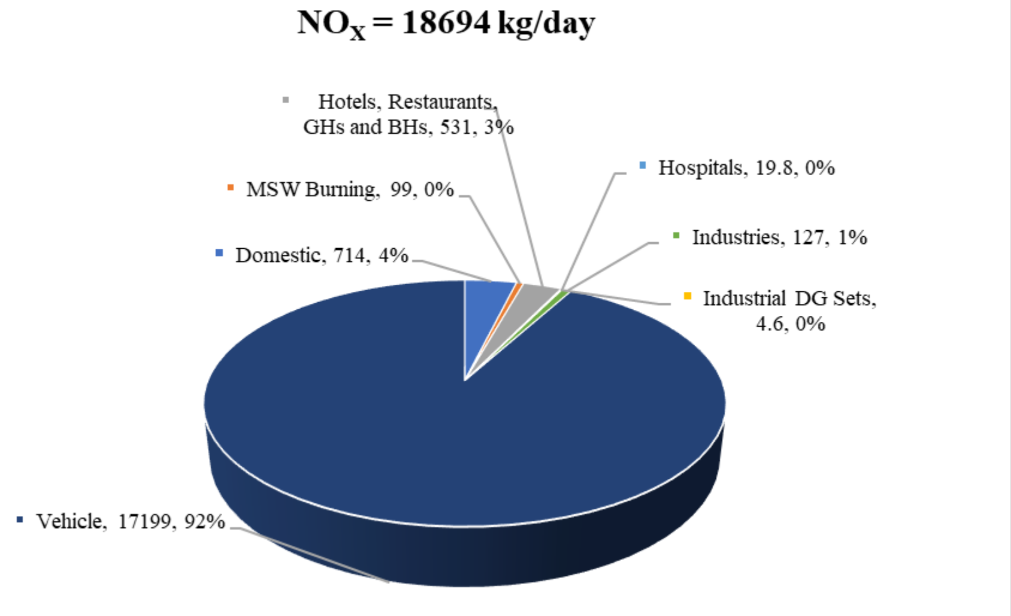


Figure 3.98: NOx Emission Load Contribution of Different Sources

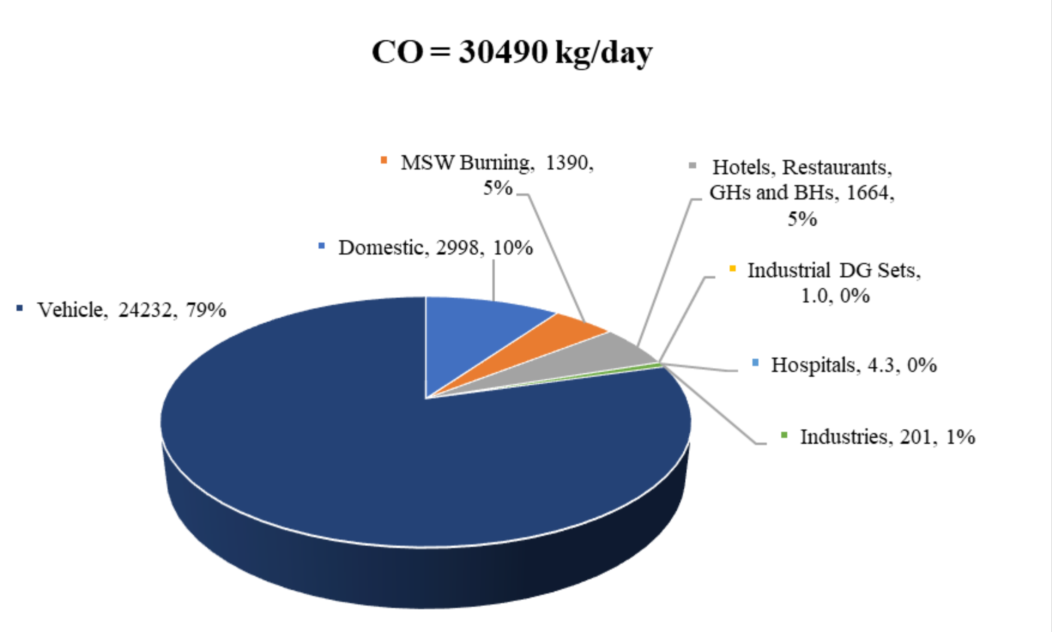


Figure 3.99: CO Emission Load Contribution of Different Sources

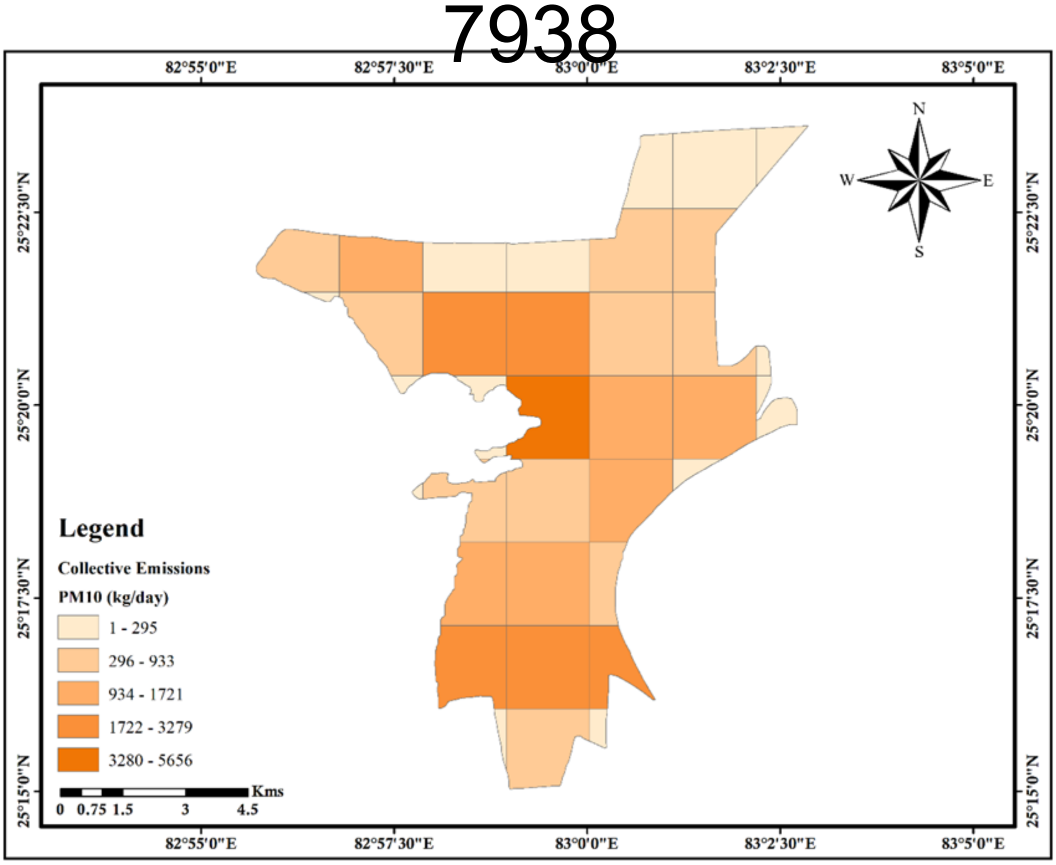

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Collective Emissions
PM10 (kg/day)
1 - 295
296 - 933
934 - 1721
1722 - 3279
3280 - 5656
Kms
0 0.75 1.5 3 4.5

Figure 3.100: Spatial Distribution of PM_{10} Emissions in the City of Varanasi

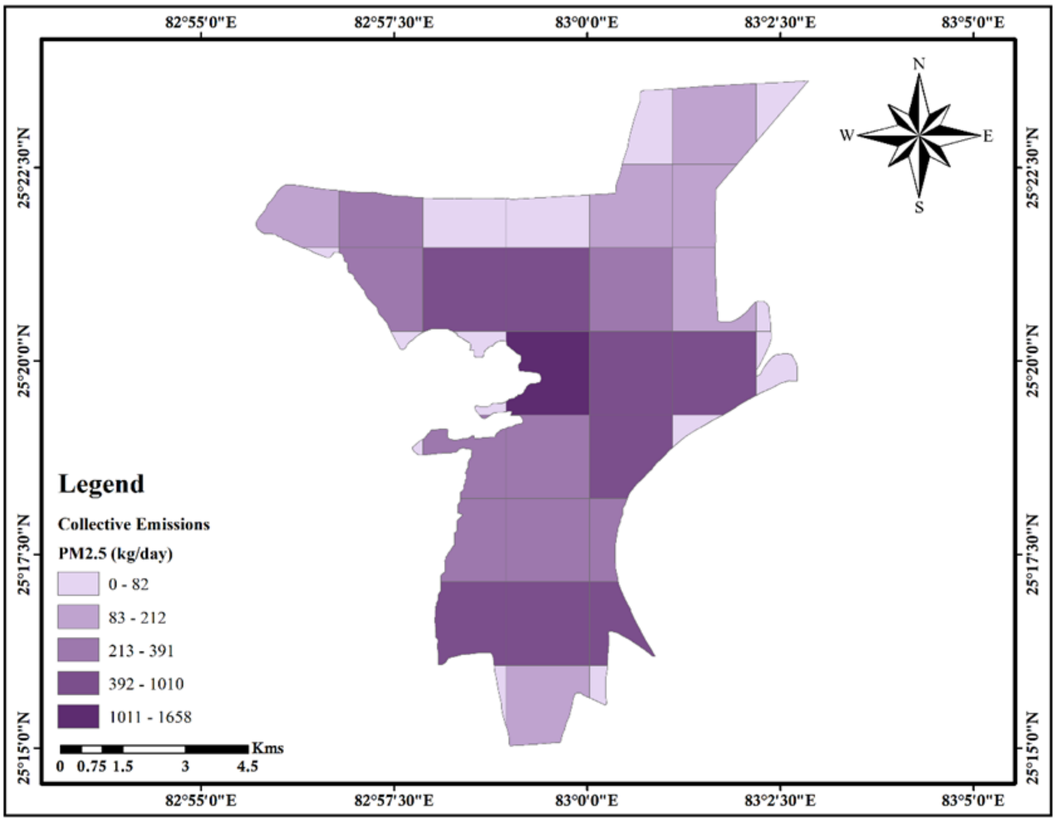

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Collective Emissions
PM2.5 (kg/day)
0 - 82
83 - 212
213 - 391
392 - 1010
1011 - 1658
Kms
0 0.75 1.5 3 4.5

Figure 3.101: Spatial Distribution of $PM_{2.5}$ Emissions in the City of Varanasi

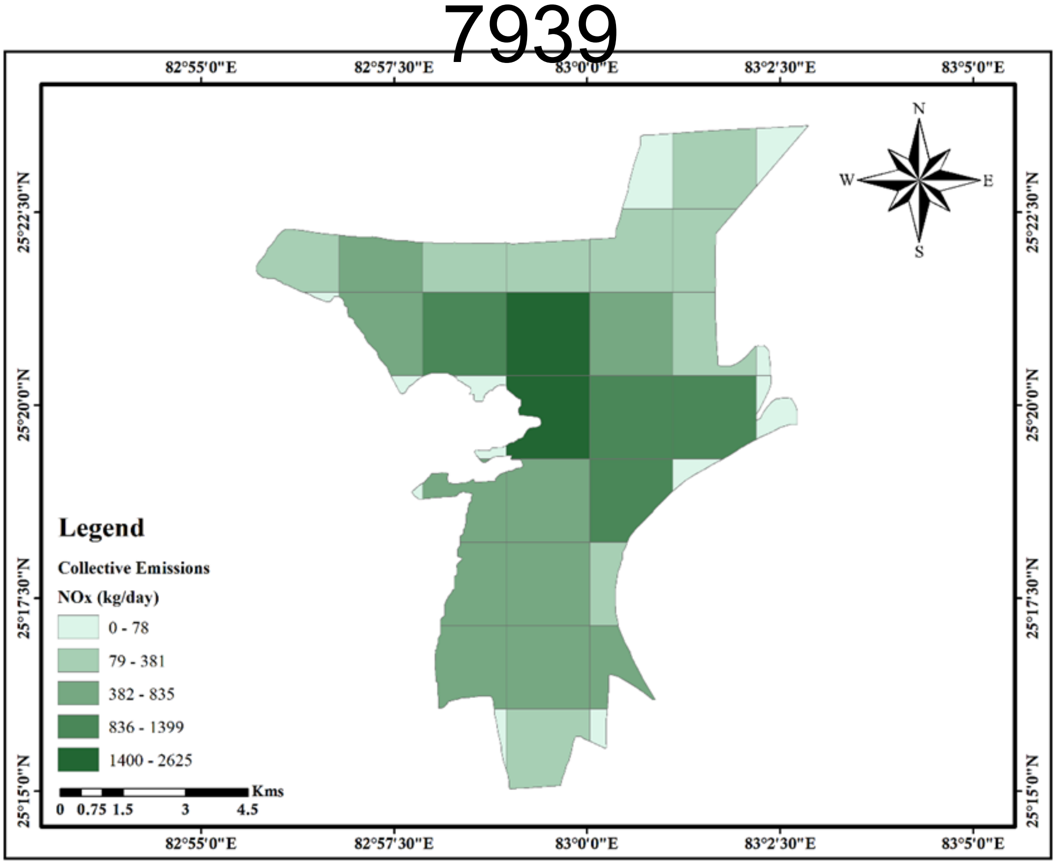

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Collective Emissions
NOx (kg/day)
0 - 78
79 - 381
382 - 835
836 - 1399
1400 - 2625
Kms
0 0.75 1.5 3 4.5

Figure 3.102: Spatial Distribution of NOx Emissions in the City of Varanasi

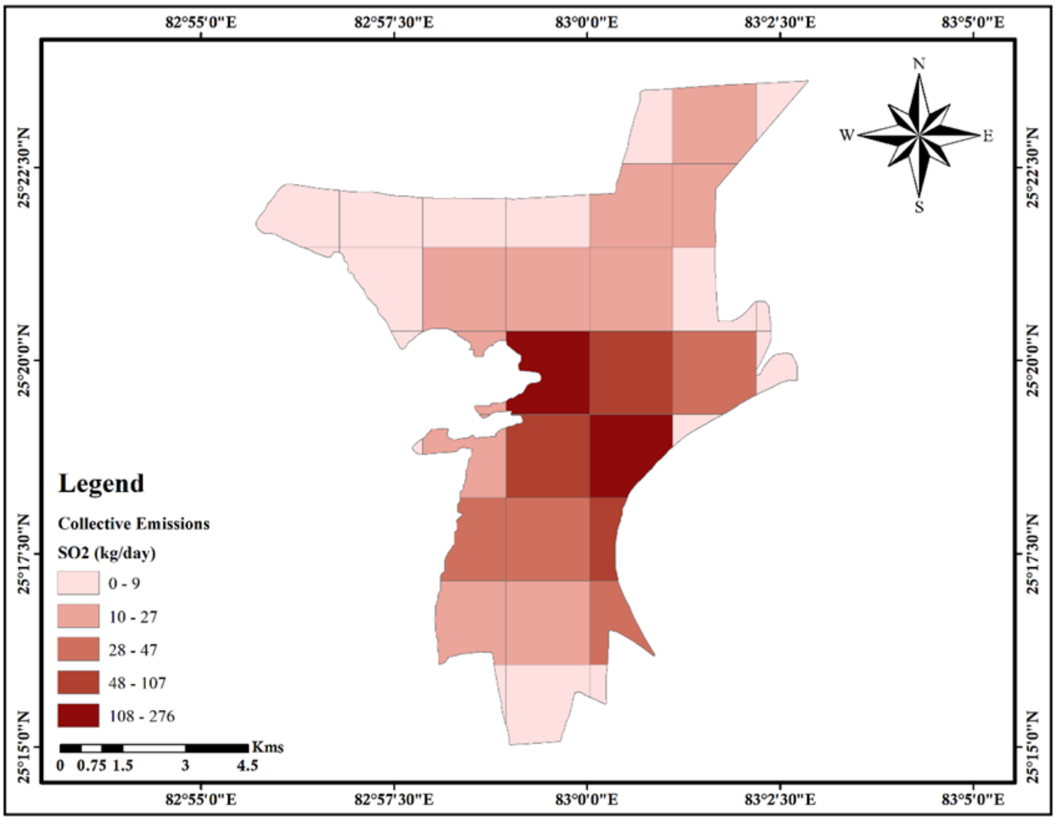

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Collective Emissions
SO2 (kg/day)
0 - 9
10 - 27
28 - 47
48 - 107
108 - 276
Kms
0 0.75 1.5 3 4.5

Figure 3.103: Spatial Distribution of SO_2 Emissions in the City of Varanasi

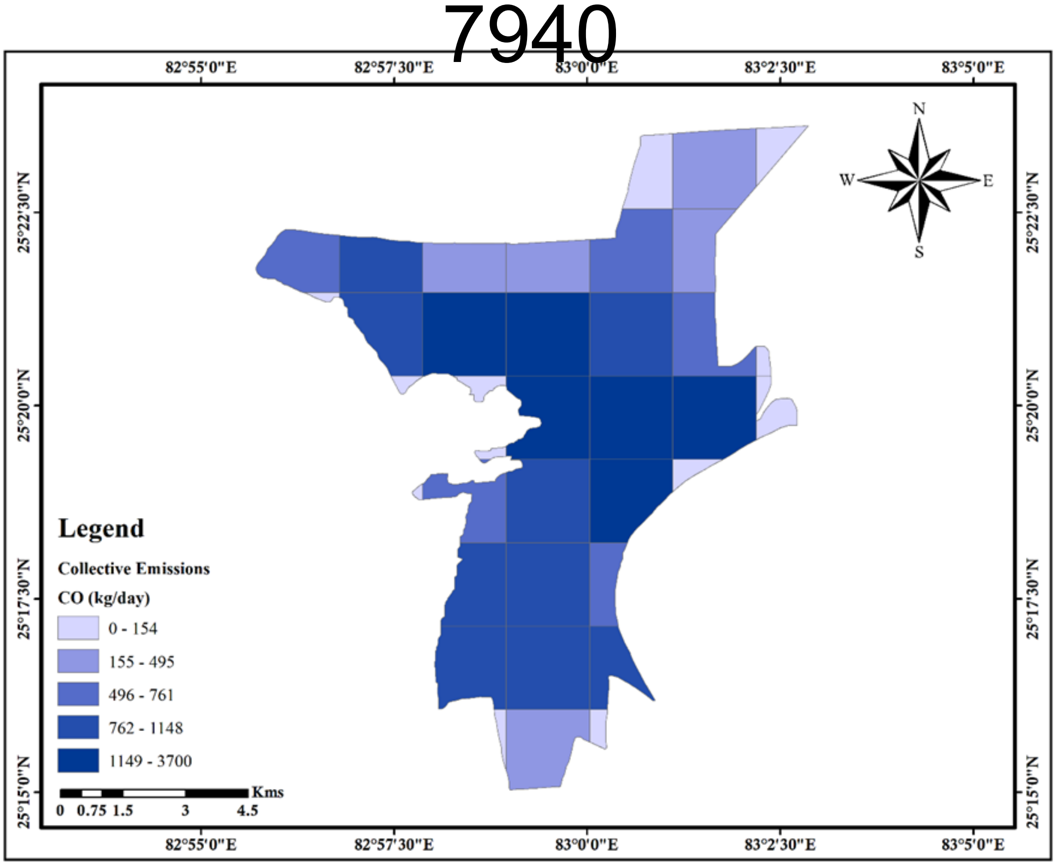

82°55'0"E
82°57'30"E
83°0'0"E
83°2'30"E
83°5'0"E
25°22'30"N
25°20'0"N
25°17'30"N
25°15'0"N
N
W
E
S
Legend
Collective Emissions
CO (kg/day)
0 - 154
155 - 495
496 - 761
762 - 1148
1149 - 3700
Kms
0 0.75 1.5 3 4.5

Figure 3.104: Spatial Distribution of CO Emissions in the City of Varanasi

3.3.1 Comparison of Emissions with other Cities

The contribution of road dust in emission load in the Agra city was estimated for PM_{10} (82%) and $PM_{2.5}$ (68%); these are based on annual emissions. The road dust emissions in Prayagraj and Varanasi are similar in PM_{10}: 82% in Prayagraj and 84% in Varanasi and in $PM_{2.5}$: 58% in Prayagraj and 60% in Varanasi. The source apportionment results for PM_{10} and $PM_{2.5}$ were similar to Agra City (Ghosh et al, 2023). The comparison of emission load in different cities is given in Table 3.5.

Table 3.5: Comparison of source-wise emission loads in different cities for $PM_{2.5}$ (kg/day)

S. No.	Emission Source	Agra	Kanpur	Jaipur	Prayagraj	Varanasi
1	Domestic	901	1857	1612	1265	689
2	MSW Burning	343	1408	1015	327	180
3	Hotels, Restaurants, GHs and BHs	683	393	727	517	688
4	Construction and Demolition	194	486	794	162	65
5	Industrial DG Sets	7	287	262	0.8	0.3
6	Hospitals	42	24	20	0.4	1.3

7	Industries	551	3960	6575	5	58
8	Vehicle	1649	6066	6879	1999	2719
9	Road Dust	9227	19930	15960	5879	6477
10	**Total**	**13596**	**34411**	**33844**	**10154**	**10877**
Other information						
1	Population (in million)	2.0	3.5	2.0	2.0	2.0
2	City area (sq. km)	120	260	485	365	165
3	Mean silt load (g/m^2)	31.2	35.5	18	22.5	22

7942

4 Receptor Modelling and Source Apportionment

4.1 Receptor Modeling

In a complicated urban atmosphere, to identify and quantify the contribution of multiple emitting sources to air quality is challenging. However, recent advancements in the chemical characterization of PM have made it possible to apportion the sources contributing to air pollution, especially that of PM. Receptor modeling using source fingerprinting (chemical composition) can be applied quantitatively to know the sources of origin of particles. Mathematical models are frequently used to identify and to adopt the source reductions of environmental pollutants. There are two types of modeling approaches to establish source receptor linkages:

1. Dispersion Modeling and
2. Receptor source Modeling.

The focus of modeling in this chapter is receptor modeling. The receptor model begins with observed ambient airborne pollutant concentrations at a receptor and seeks to apportion the observed concentrations between several source types based on the knowledge of the compositions of the sources and receptor materials (Cooper and Watson, 1980; Watson, 1984; Javitz et al., 1988). There are two generally recognized classes of receptor Models:

- Chemical elemental balance or chemical mass balance (CEM/CMB), and
- Multivariate or a statistical.

In this Chapter, CMB technique has been attempted to fully understand the contribution of each source to ambient air PM_{10} and $PM_{2.5}$ concentrations. However, the extensive emission inventory undertaken in this study gave a good idea of possible sources in the study area.

While (CEM/CMB) methods apportion sources using extensive quantitative source emission profiles, statistical approaches infer source contribution without a prior need of quantitative source composition data (Watson et al., 1994). The CMB method assumes that there is linearity in the concentration of aerosol and their mass is conserved from the time a chemical species is emitted from its source to the time it is measured at a receptor. That is, if p sources are contributing M_j mass of particulates to the receptor (Watson et al., 2004),

$$m = \sum_{j=1}^{p} M_j$$

$$F'_{ij} = F_{ij}$$

Where, m is the total mass of the particulate collected on a filter at a receptor site, F'_{ij} is the fraction of chemical species *i* in the mass from source j collected at the receptor and F_{ij} is the fraction of chemical i emitted by source *j* as measured at the source. The mass of the specific species, m_i, is given by the following:

$$m_i = \sum_{i=1}^{p} M_{ij} = \sum_{i=1}^{p} F'_{ij} M_j$$

Where, M_{ij} is the mass of element *i* contributed to the receptor from source *j*. Dividing both sides of the equation by the total mass of the deposit collected at the receptor site, it follows that

$$C_i = \sum_{j=1}^{p} F_{ij} S_j$$

Where, C_i is the concentration of chemical component i measured at the receptor (air filter) and S_j is the source contribution; that is, the ratio of the mass contributed from source j to the total mass collected at the receptor site.

If the C_i and F_{ij} at the receptor for all p of the source types suspected of affecting the receptor are known, and $p \leq n$ (n = number of the species), a set of n simultaneous equations exist from which the source type contribution S_j may be calculated by least square methods. The software used for apportioning the sources is CMB 8.2, developed by USEPA (2004).

4.2 CMB Modeling: Analysis of Source Apportionment of PM_{10} and $PM_{2.5}$

Since for $PM_{2.5}$, Indian or Varanasi specific source profiles are not available except for vehicular sources (ARAI, 2009), the source profiles for this study were taken from 'SPECIATE version 3.2' of USEPA (2006) and updated version 5.1 of SPECIATE (USEPA, 2020). For vehicular sources, profiles were taken from ARAI (2009). 'SPECIATE' is a repository of Total Organic Compound (TOC) and PM speciated profiles for a variety of sources for use in source apportionment studies (USEPA, 2006, 2020); care has been exercised in adopting the profiles for their applicability in the local environment of Varanasi city. For the sake of uniformity, source profiles for non-vehicular sources for PM_{10} and $PM_{2.5}$ were adopted from USEPA (2006, 2020).

The PM_{10} and $PM_{2.5}$ monitoring data along with results of chemical speciation (described in Chapter 2) have been used in the application of CMB 8.2 model of USEPA (2004). The CMB model was run for each site for each day of sampling for two seasons (summer and winter) for PM_{10} and $PM_{2.5}$ separately. The model results were analyzed in terms of R-square (model fitting) and model-computed percent mass (compared to the measured mass). The CMB results for most measurements (over 85 percent) showed the R-square was above 0.60. Model-computed mass accounted for more than 80 percent of measured mass. In this study, the degree of freedom (number species – number of sources) being more than 24, modeling results which gave R-square more than 0.65 were considered for further analyses. The results of CMB 8.2 at each location for each season are described in Section 4.3.

HYSPLIT Model (NOAA, 2013) was run for back trajectory analysis to assist in interpretation of results and to indicate how the sources located in the upwind of Prayagraj could impact air quality in Prayagraj.

4.3 CMB Modeling Results and interpretation

It may be noted that vehicular sources include all vehicles powered by gasoline, diesel and CNG. Secondary particles include ammonium sulfates and ammonium nitrates which are formed in atmosphere from precursor gases (SO_2, NO_x and NH_3). The CMB model could provide contribution of vehicles as a single entity. However, the model could not fully resolve the source contribution from various vehicular fuels due to colinearity in source profiles. We have worked out vehicle fuel specific contribution based on emission inventory of PM_{10} and $PM_{2.5}$ from gasoline, diesel and CNG specific to the grid where measurements were done.

4.3.1 Benaras Club Kacheri Road (BCKR)

4.3.1.1 Winter Season [sampling period: Dec 14 –Dec 28, 2020]

PM_{10} (winter)

The average PM_{10} concentration was 401 µg/m^3. Figure 4.1 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average of about 15 days) in terms of concentration and percentage, respectively, at BCKR. It is observed that the major source contributing to PM_{10} was coal and fly ash (104 µg/m^3 ~ 26%) followed by biomass burning (81 µg/m^3 ~ 20%), vehicles (67 µg/m^3 ~ 17%), soil and road dust (67 µg/m^3 ~ 17%). The other significant sources are secondary inorganic aerosols SIA (14%), municipal solid waste (MSW) burning (3%), construction material (2%) and industrial emission (1%)

$PM_{2.5}$ (winter)

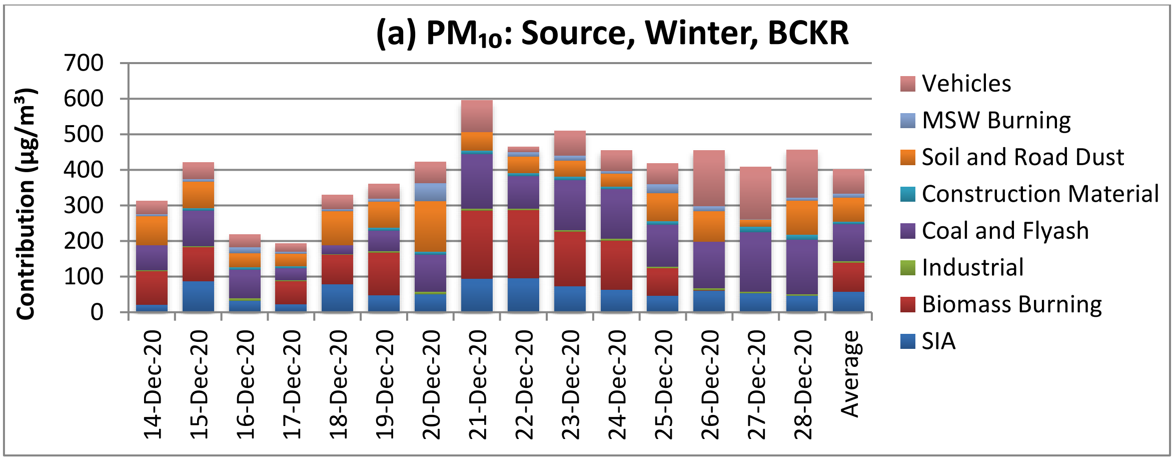
The average $PM_{2.5}$ concentration was 281 µg/m^3 (i.e., about 0.70 of PM_{10}). Figure 4.2 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at BCKR. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (71 µg/m^3 ~ 25.5%) followed by soil and road dust (60 µg/m^3 ~ 22%) and coal and fly ash (51 µg/m^3 ~ 18%). Other sources are secondary inorganic aerosols SIA (17%), vehicles (16%), industrial emissions (1%), municipal solid waste (MSW) burning (0.5%) and construction material (0%).

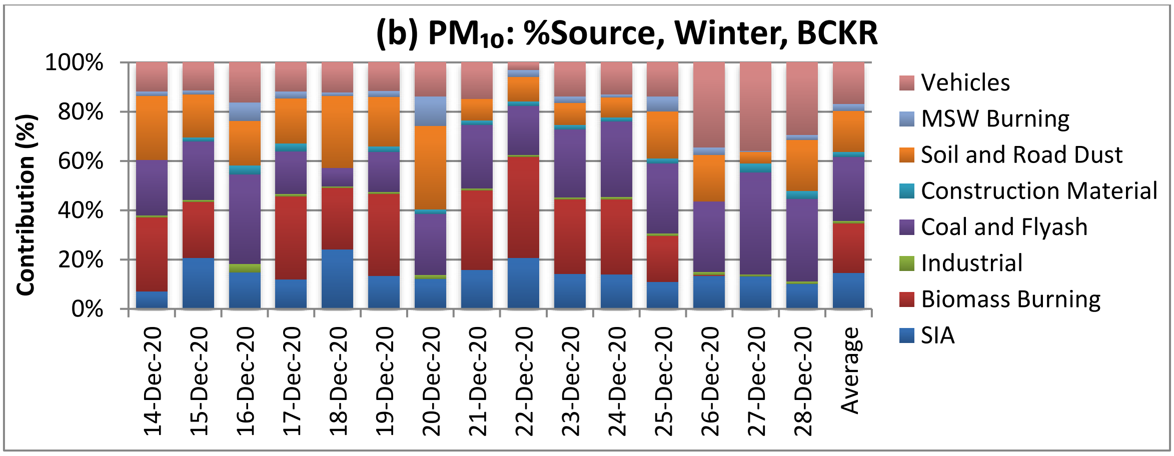
HYSPLIT back trajectories (Figure 4.3) indicate that wind is flowing mostly from the NW direction. Winds can pick up the pollutants on the way, especially from large sources and tall emitting sources, but these contributions have not been quantified.

Inferences

- Coal and fly ash contribute to PM_{10} (26%) and $PM_{2.5}$ (18%).
- Biomass burning contributes to PM_{10} (20%) and $PM_{2.5}$ (25.5%). This emission is expected from regions of economically lower strata of society where they used wood/dungs for cooking the food and crop residue burning in the nearby areas.
- Soil and road dust contribution is higher in $PM_{2.5}$ (22%) compared to PM_{10} (17%). The consistent levels during the winter season may be due to low wind speed (more calm conditions). It can be seen the high fraction of $PM_{2.5}$ in PM_{10} (about 0.70 of PM_{10}).
- The vehicles contribute significantly to PM_{10} (17%) and $PM_{2.5}$ (16%). It includes gasoline, diesel, natural gas, DGs, LPG from domestic cooking.

- The SIA contributes to PM_{10} (15%) and $PM_{2.5}$ (17%). These particles are expected to source from precursor gases (SO_2 and NO_x) emitted from far distances. However, the contribution of NO_x from local sources, especially vehicles and power plants, can also contribute to nitrates. For sulfates, the major contribution can be attributed to large power plants and refineries from long distances.
- The MSW burning has a contribution to PM_{10} (3%) and $PM_{2.5}$ (0.5%) at BCKR. This emission is expected to be large from regions of economically lower strata of society that do not have proper infrastructure for the collection and disposal of solid waste.





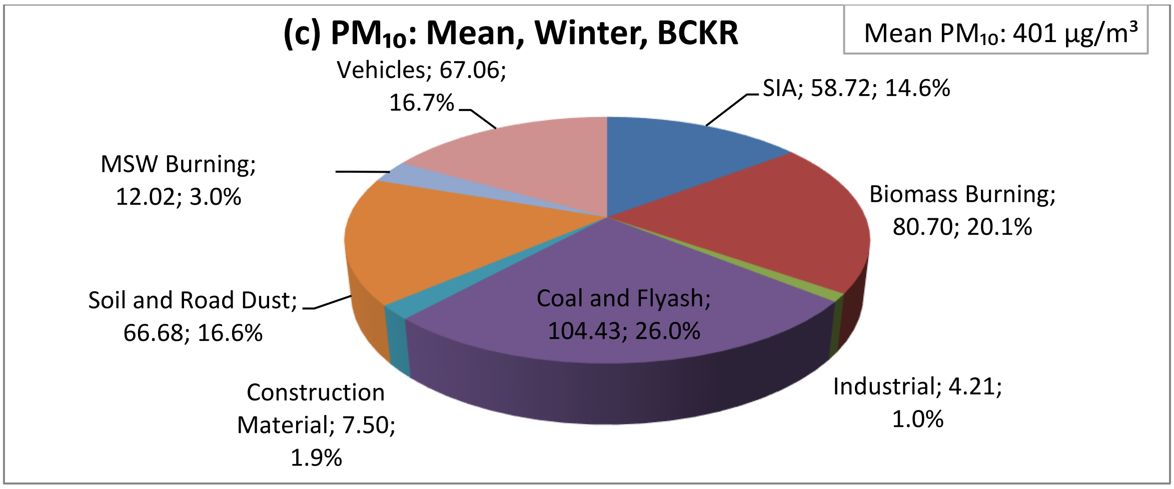
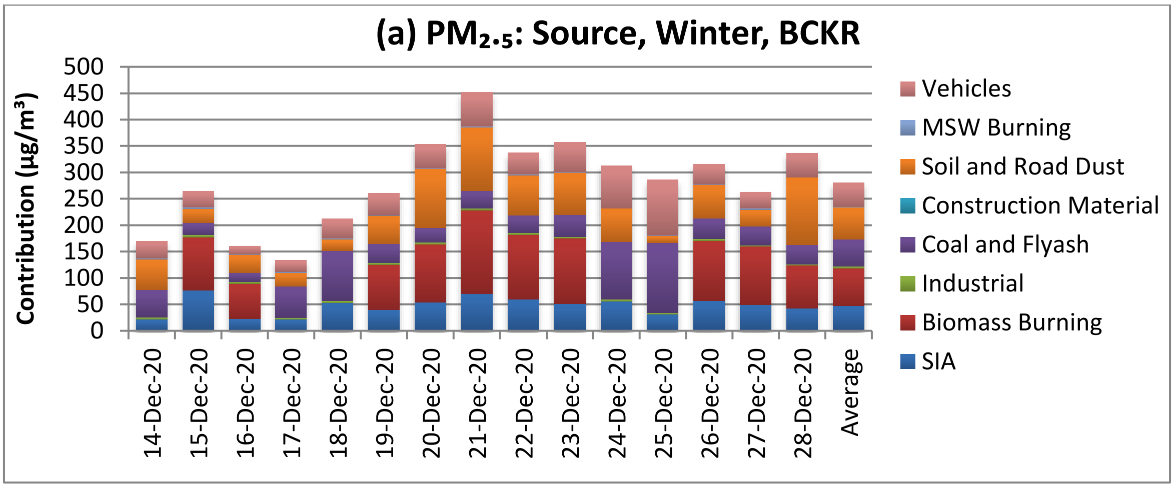
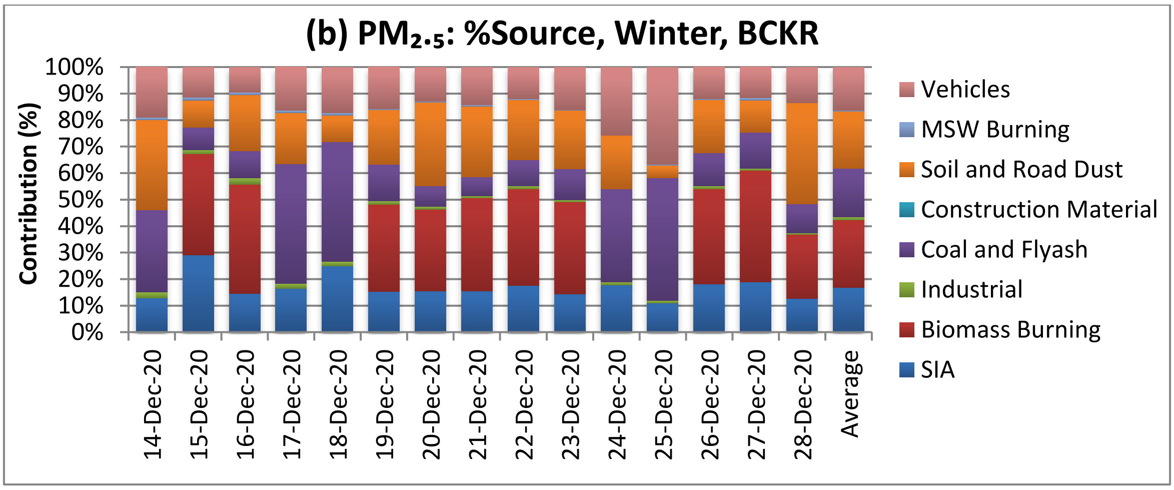


Figure 4.1: CMB modeling for PM$_{10}$ at BCKR for winter season





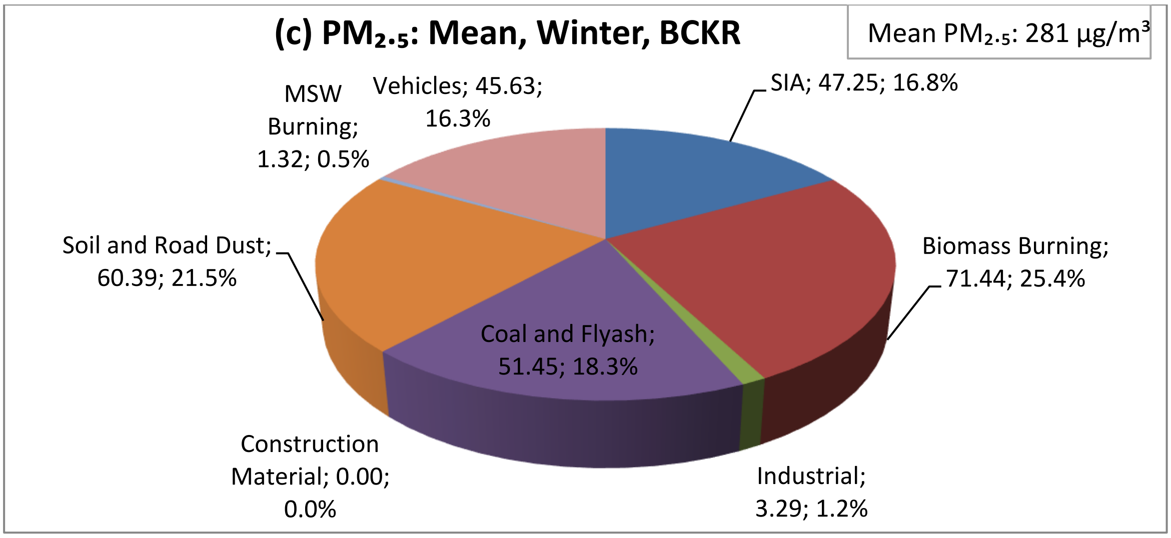


Figure 4.2: CMB modeling for $PM_{2.5}$ at BCKR for winter season (MSW burning includes burning of plastic core wires to recover metal)

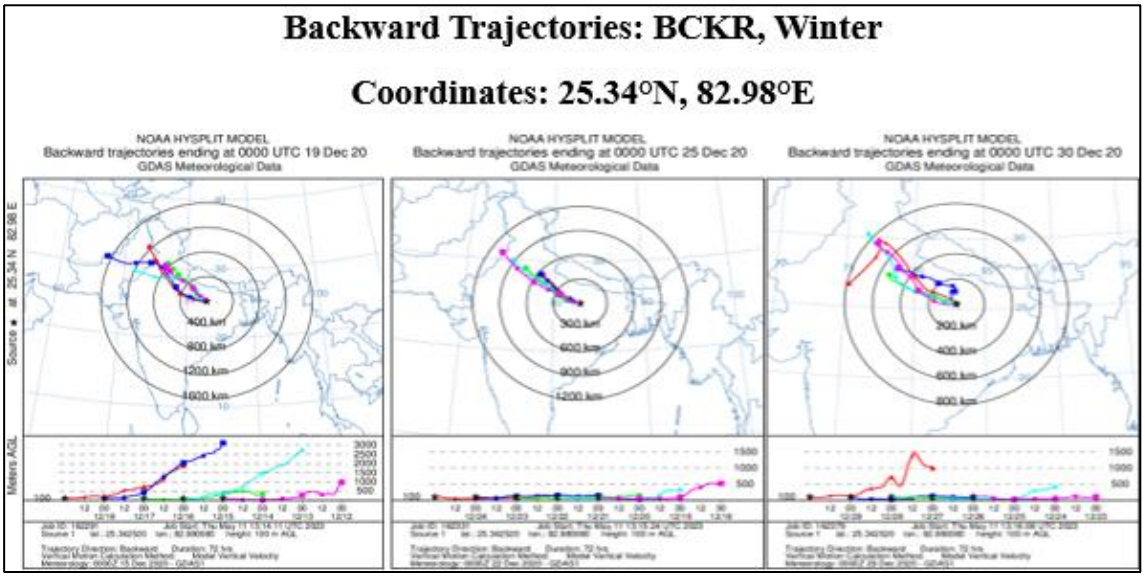

Backward Trajectories: BCKR, Winter
Coordinates: 25.34°N, 82.98°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 19 Dec 20
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 25 Dec 20
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 30 Dec 20
GDAS Meteorological Data
400 km
800 km
1200 km
1600 km
300 km
600 km
900 km
1200 km
200 km
400 km
600 km
800 km
Source ★ at 25.34 N 82.98 E
Meters AGL

Figure 4.3: Backward trajectories at BCKR for winter season

4.3.1.2 Summer Season [sampling period: Mar 05 – Mar 19, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 314 µg/m^3. Figure 4.4 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at BCKR. It is observed that the major source contributing to PM_{10} was soil and road dust (185 µg/m^3 ~ 59%) followed by coal and fly ash (65 µg/m^3 ~ 21%) and vehicles (27 µg/m^3 ~ 8.5%). Other sources are biomass burning (5%), SIA (3.5%), construction material (2%), MSW burning (0.5%) and industrial (0.5%).

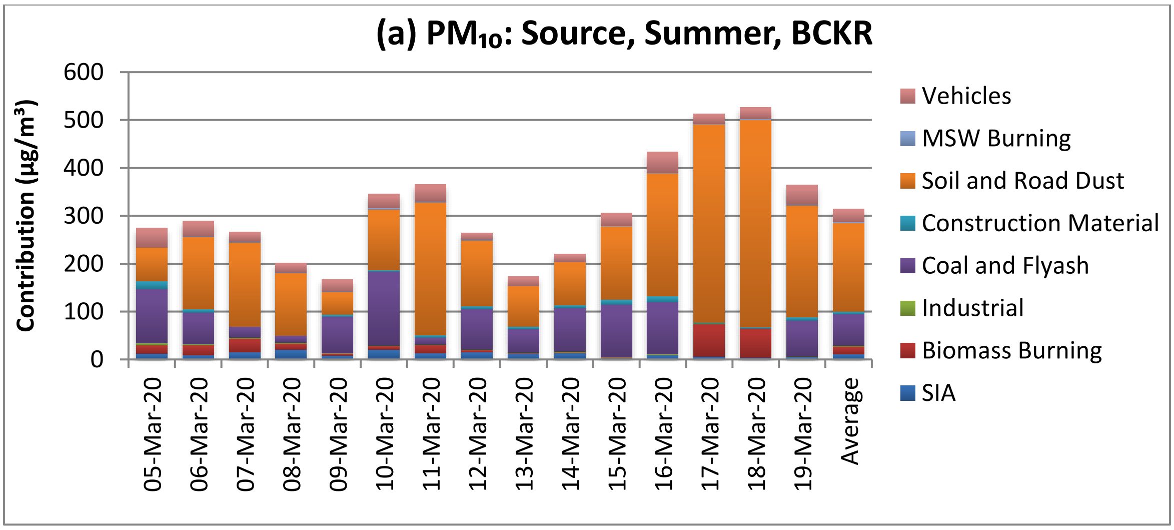
$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 121 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.39. Figure 4.5 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at BCKR. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (62 µg/m^3 ~ 51%) followed by vehicles (18 µg/m^3 ~ 15%) and biomass burning (15 µg/m^3 ~ 12.5%). Other significant sources are coal and fly ash (10.5%), SIA (8.5%), industrial (1%), MSW burning (1%) and construction material (0.5%).

HYSPLIT back trajectories (Figure 4.6) show that most of the time wind is mostly from NW, W and SW. These winds pick up the pollutants on the way, especially from tall emitting sources.

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Soil and road dust and construction have become the major PM_{10} and $PM_{2.5}$ sources. It was observed that the atmosphere in summer looked white to gray, indicating the presence of large amounts of dust which may be due to high speeds of wind and very dry conditions, which makes the dust airborne. The occasional dust storm can also contribute to road/soil dust resuspension.



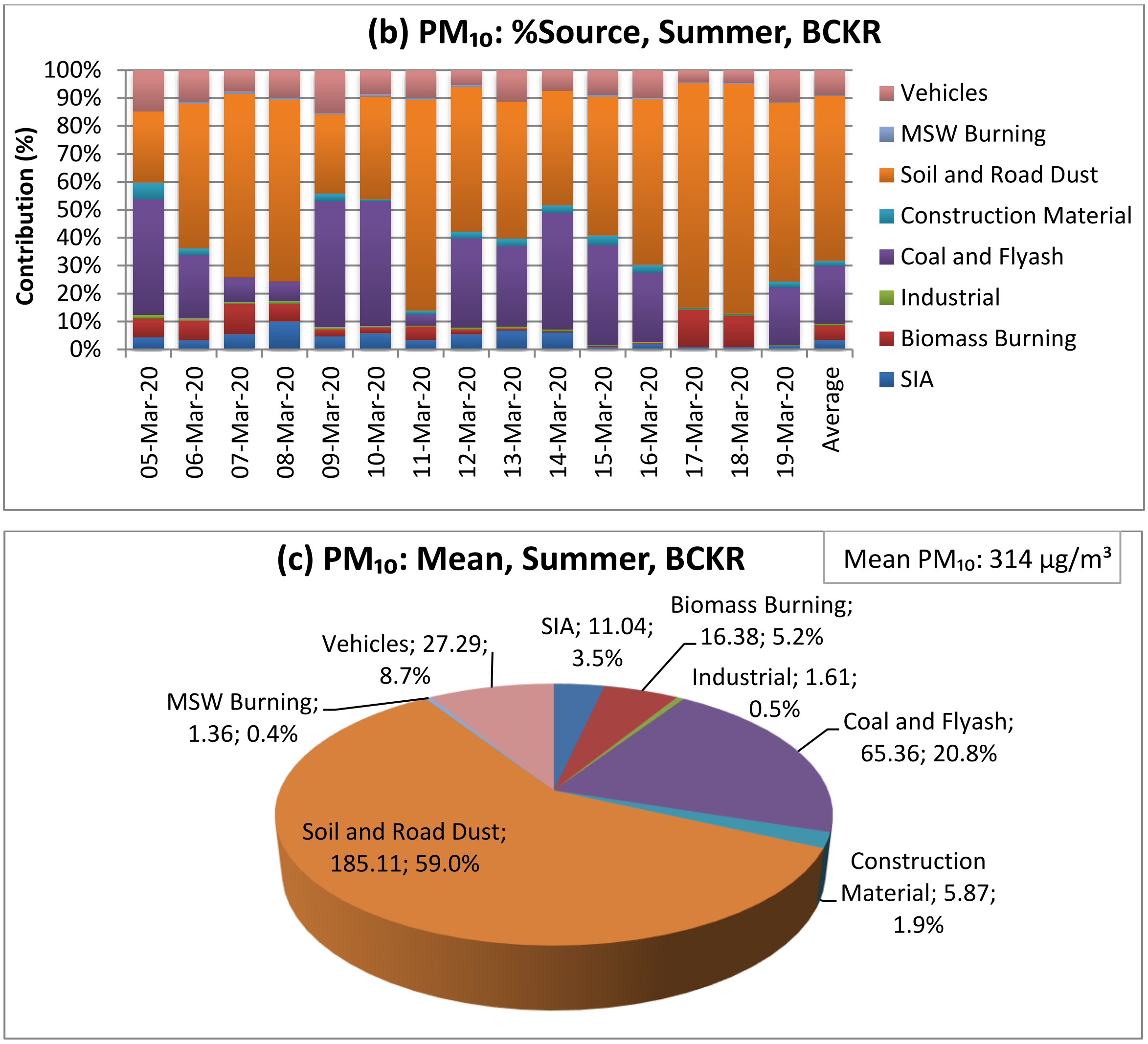
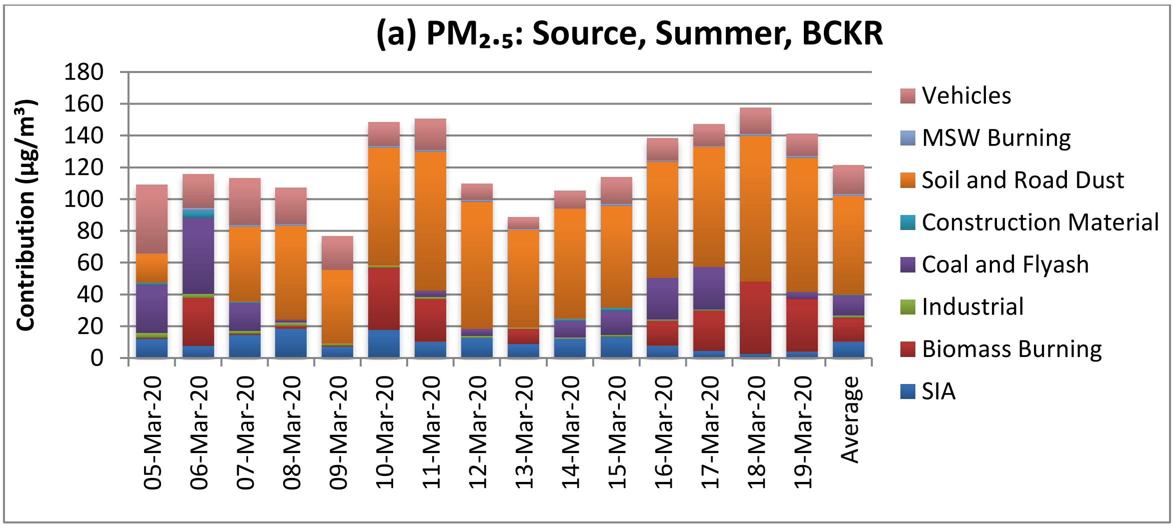


Figure 4.4: CMB modeling for PM$_{10}$ at BCKR for summer season



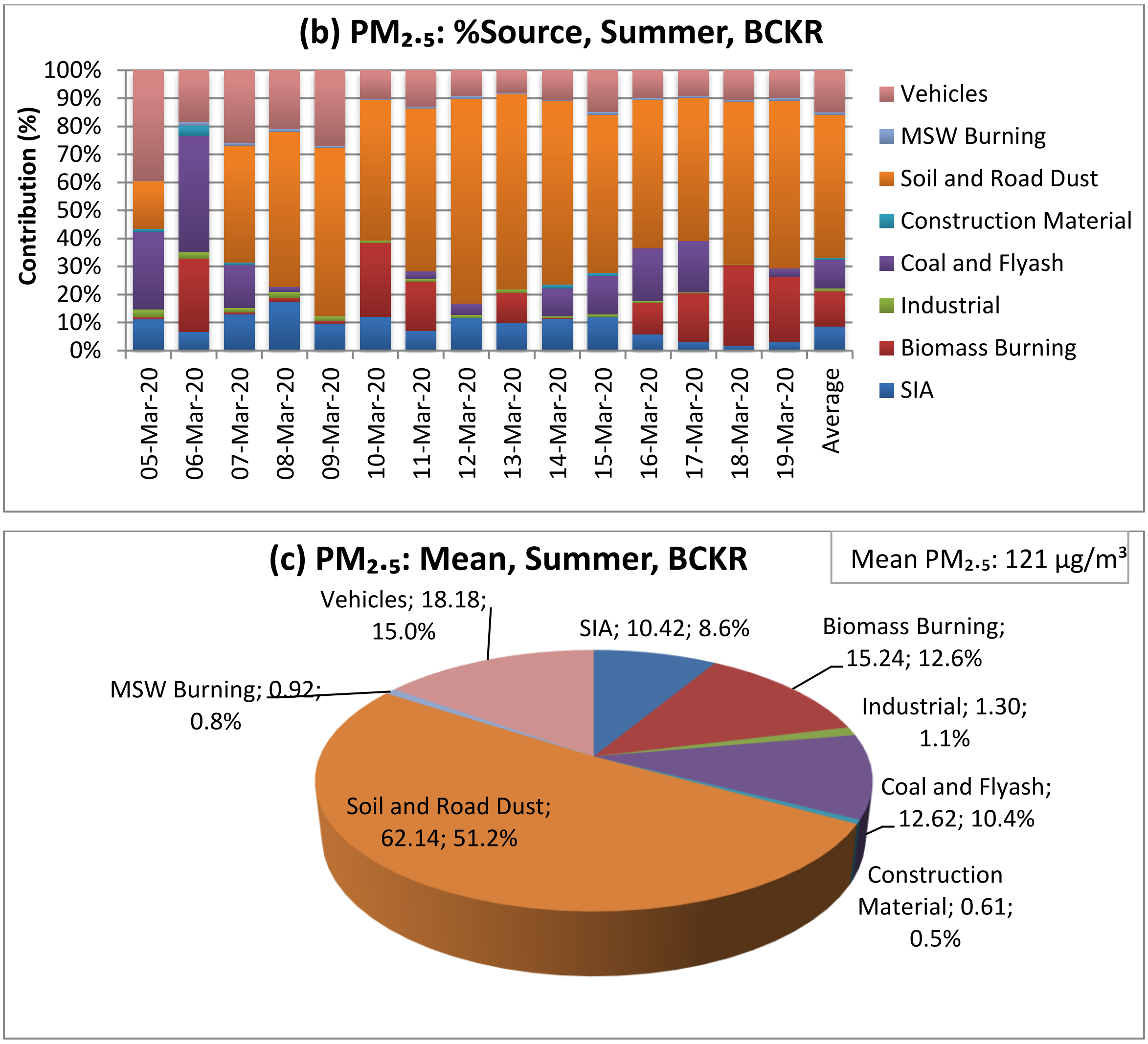


Figure 4.5: CMB modeling for $PM_{2.5}$ at BCKR for summer season

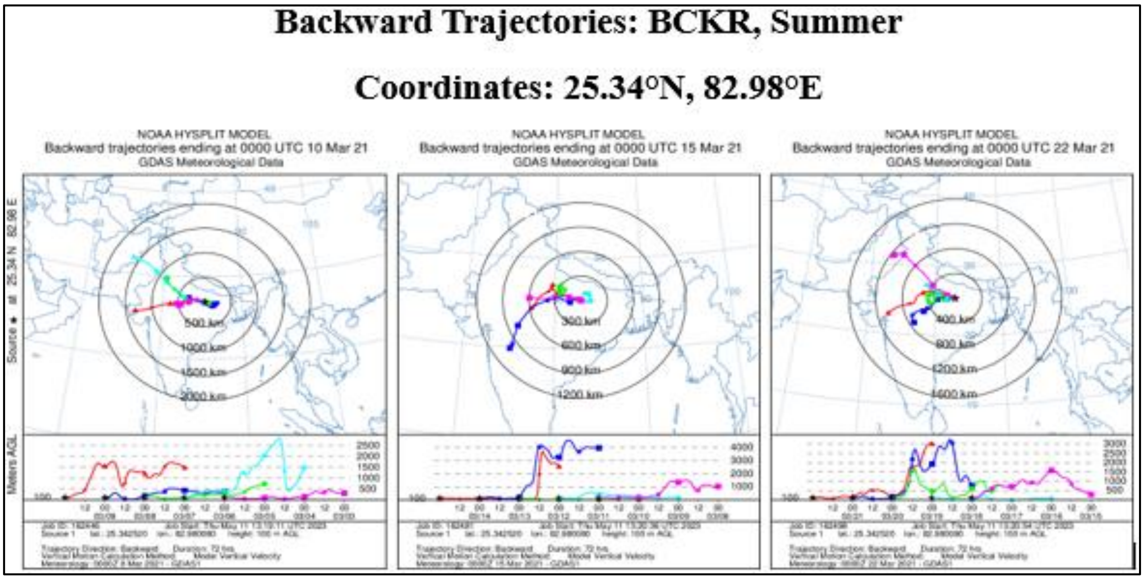

Backward Trajectories: BCKR, Summer
Coordinates: 25.34°N, 82.98°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 10 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 15 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 22 Mar 21
GDAS Meteorological Data
500 km
1000 km
1500 km
2000 km
300 km
600 km
900 km
1200 km
400 km
800 km
1200 km
1600 km
Source ★ at 25.34 N 82.98 E
Meters AGL

Figure 4.6: Backward trajectories at BCKR for summer season

4.3.2 IMA Lahurabir (IMAL)

4.3.2.1 Winter Season [sampling period: Dec 14 –Dec 28, 2020]

PM_{10} (winter)

The average PM_{10} concentration was 380 µg/m^3. Figure 4.7 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at IMAL. It is observed that the major source contributing to PM_{10} was biomass burning (105 µg/m^3 ~ 27.5%) followed by soil and road dust (73 µg/m^3 ~ 19%) and coal and fly ash (65 µg/m^3 ~ 17%). The other significant sources are SIA (16.5%), vehicles (14%), MSW burning (3%) and construction material (2%). The contribution of industrial emission ash was the lowest at about 1% in PM_{10}.

$PM_{2.5}$ (winter)

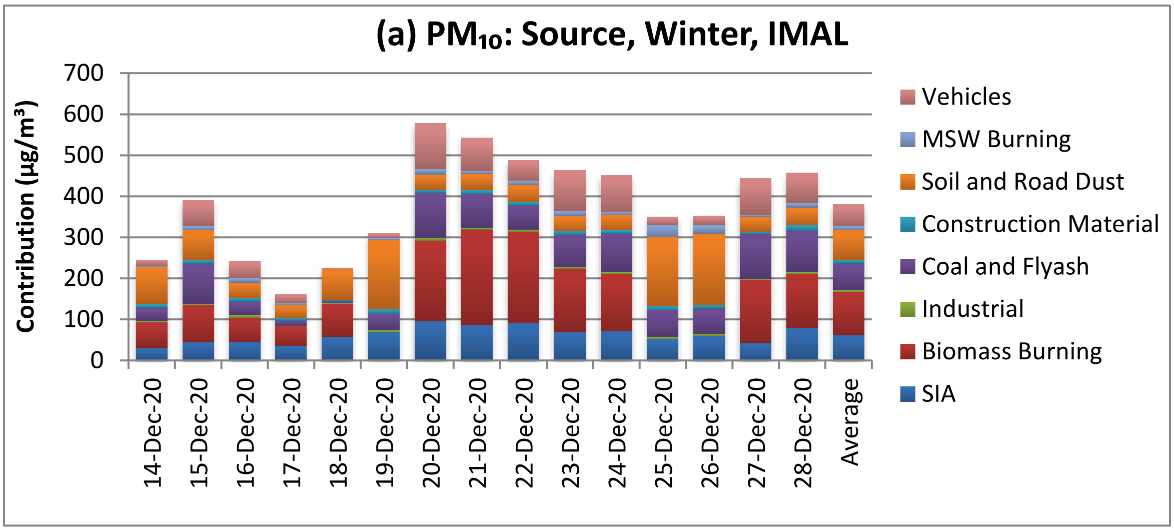
The average $PM_{2.5}$ concentration was 285 µg/m^3 (i.e., about 0.75 of PM_{10}). Figure 4.8 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at IMAL. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (91.5 µg/m^3 ~ 32%) followed by SIA (52 µg/m^3 ~ 18%) and vehicles (47 µg/m^3 ~ 16.5%). The other significant sources are soil and road dust (15.5%), coal and fly ash (14%), MSW burning (1.5%) and construction material (1.5%). The contribution of industrial emission was estimated at about 1% in $PM_{2.5}$.

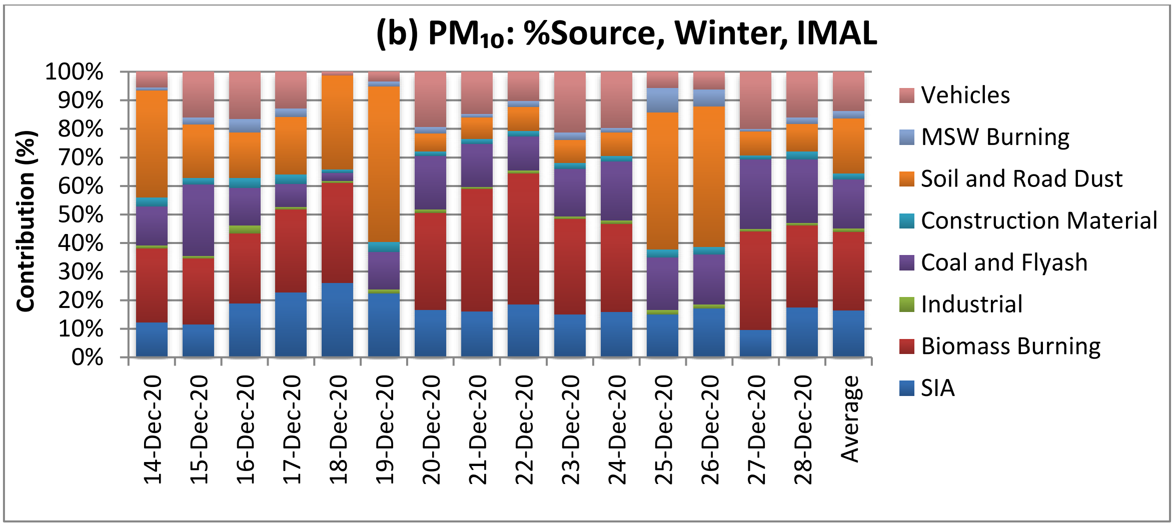
HYSPLIT back trajectories (Figure 4.9) show that wind is mostly from NW and wind mass travels over the states of Punjab, Haryana, Delhi and part of Rajasthan before entering Varanasi. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Biomass burning and coal and fly ash emissions are the major contributing sources to both PM_{10} and

$PM_{2.5}$. SIA, soil/road dust and vehicles are the consistent sources contributing to PM_{10} and $PM_{2.5}$ and slightly changed. The biomass burning and coal and fly ash are exceptionally high at IMAL, indicating that this emission is expected from regions of economically lower strata of society where they used wood/dungs for cooking the food and crop residue burning in the nearby areas.





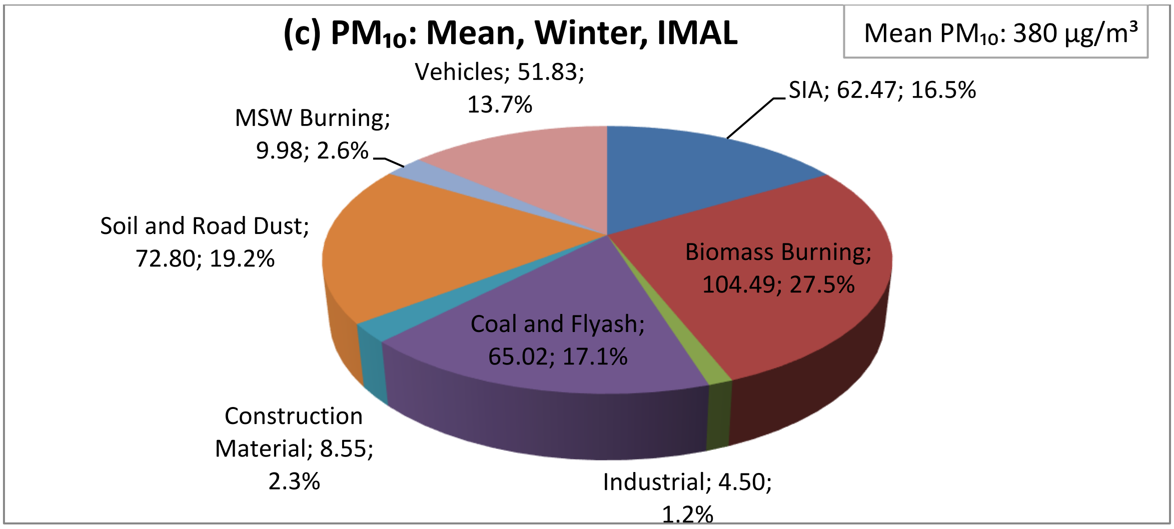
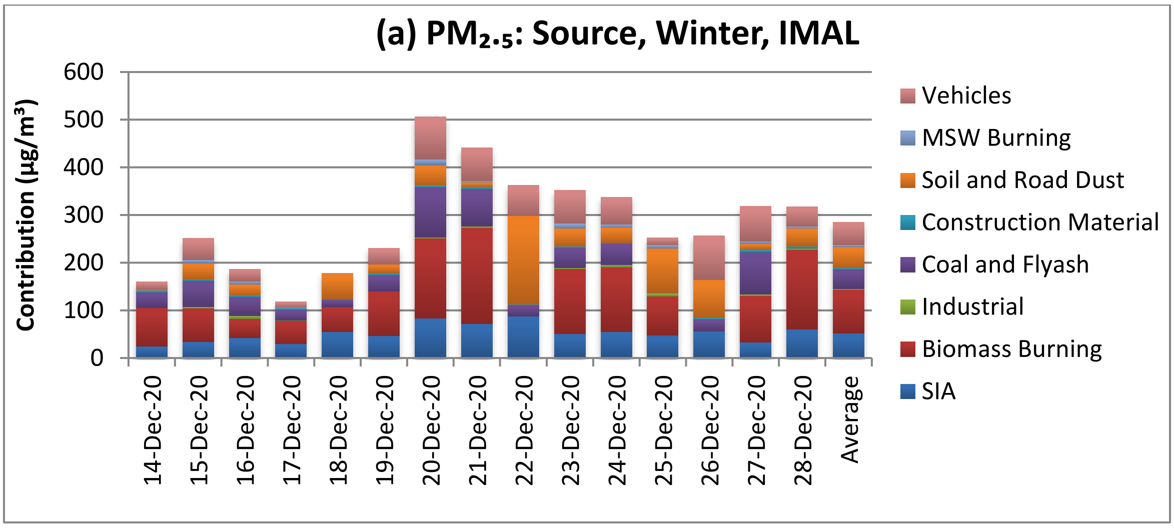
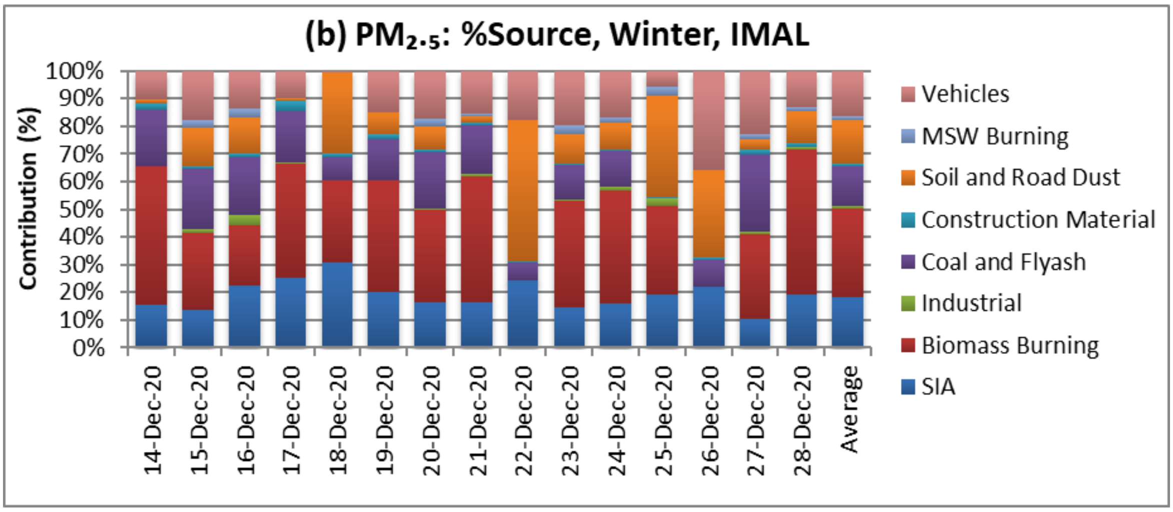


Figure 4.7: CMB modeling for PM_{10} at IMAL for winter season





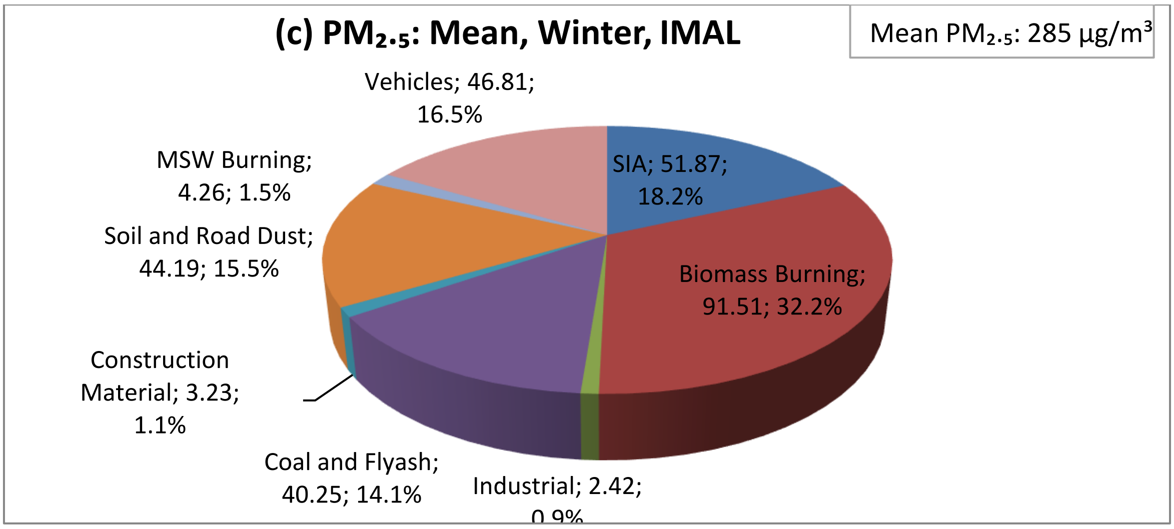


Figure 4.8: CMB modeling for $PM_{2.5}$ at IMAL for winter season

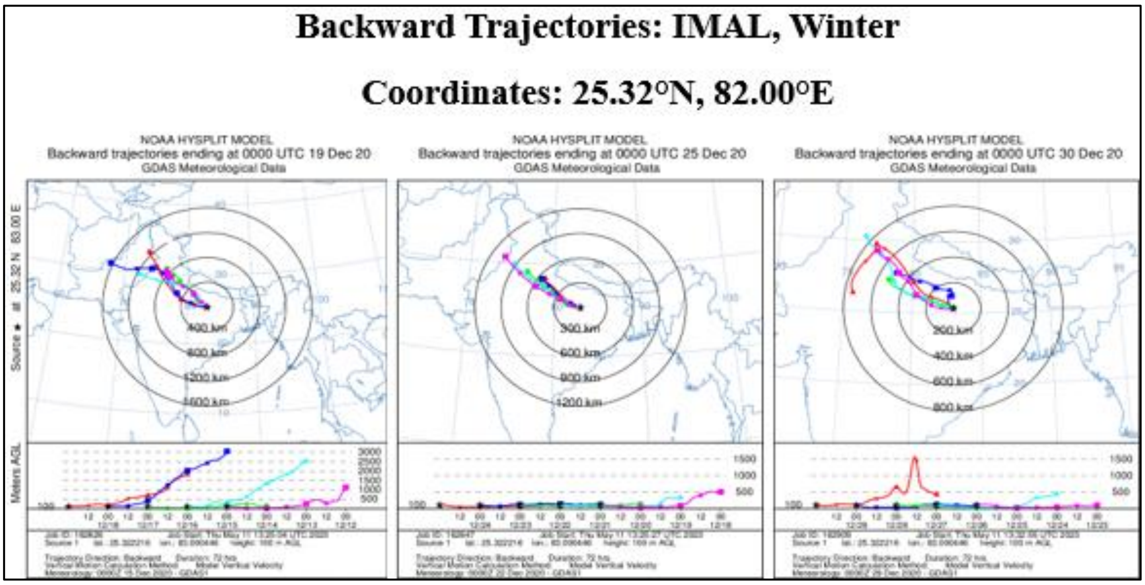

Backward Trajectories: IMAL, Winter
Coordinates: 25.32°N, 82.00°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 19 Dec 20
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 25 Dec 20
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 30 Dec 20
GDAS Meteorological Data
Meters AGL

Figure 4.9: Backward trajectories at IMAL for winter season

4.3.2.2 Summer Season [sampling period: Mar 05 – Mar 19, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 275 µg/m^3. Figure 4.10 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at IMAL. It is observed that the major source contributing to PM_{10} was soil and road dust (119 µg/m^3 ~ 43.4%) followed by coal and fly ash (58 µg/m^3 ~ 21%) and biomass burning (20 µg/m^3 ~ 14%). The other significant sources are vehicles (13%), SIA (5%), construction material (2%) and MSW burning (1%). The contribution of industrial emissions is lowest at 0.6% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 118 µg/m^3 ($PM_{2.5}/PM_{10}$ is 0.43). Figure 4.11 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at IMAL. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (38 µg/m^3 ~ 32.5%) followed by vehicles (31.5 µg/m^3 ~ 27%) and soil and road dust (19 µg/m^3 ~ 16%). Other significant sources are coal and fly ash (11.5%), SIA (9%), construction material (1.3%) and MSW burning (1.5%). The contribution of industrial emissions is lowest at 1.2% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.12) show that wind is mostly from NW and SW. Wind mass travels over the Thar Desert in Rajasthan and part of states of Punjab and Haryana before entering Varanasi. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inferences

Soil/Road dust and biomass burning are the major contributors in summer both for PM_{10} and $PM_{2.5}$; at the same time, vehicles, coal and fly ash and SIA are prominent both in PM_{10} and $PM_{2.5}$. In winter, the wind speed is generally low and mostly about to calm conditions. Therefore, fine mode particles retain in the atmosphere. In the area of about 50 km radius, there are several brick kiln units operated and caused emissions.

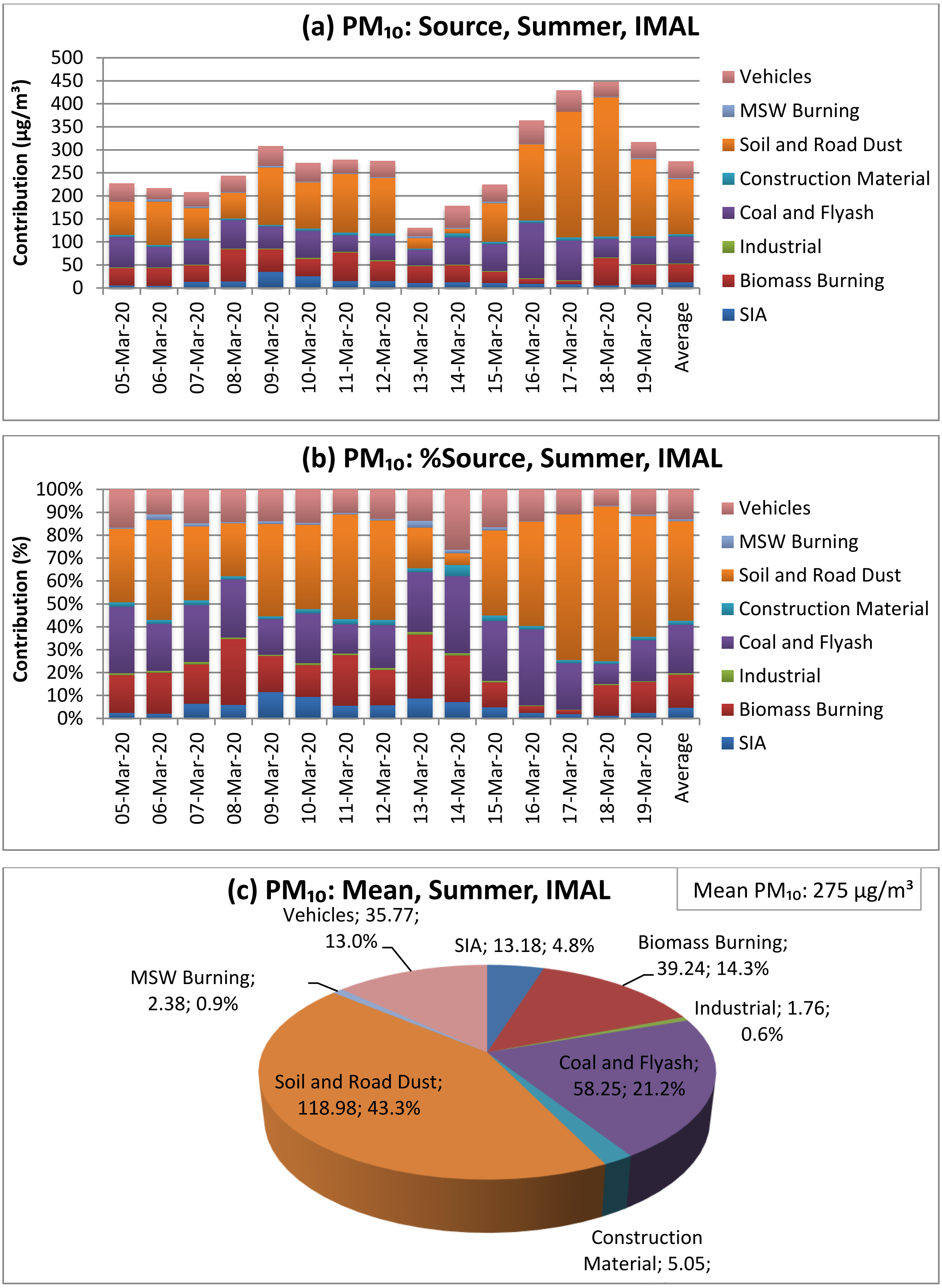


Figure 4.10: CMB modeling for PM$_{10}$ at IMAL for summer season

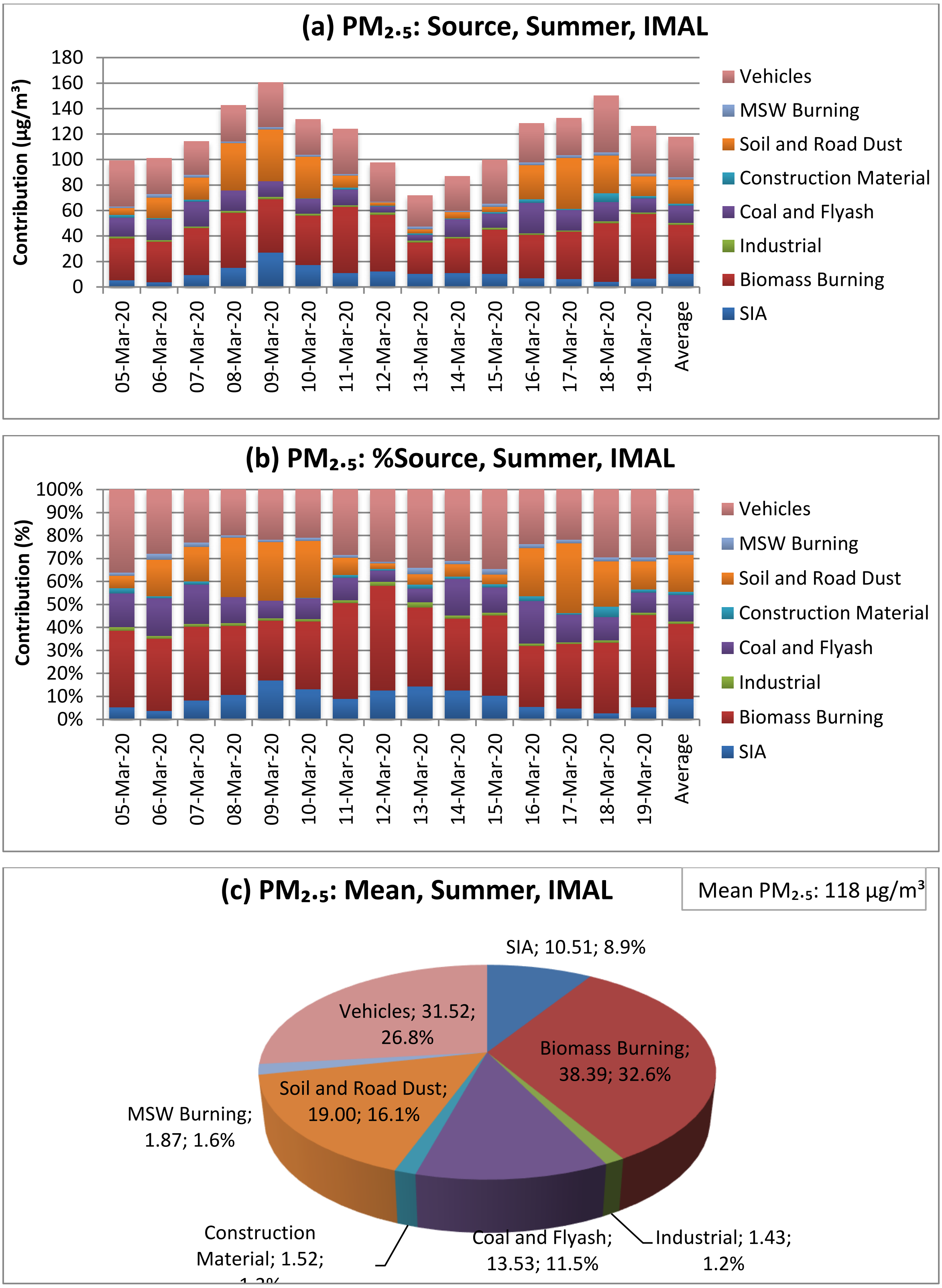


Figure 4.11: CMB modeling for PM2.5 at IMAL for summer season

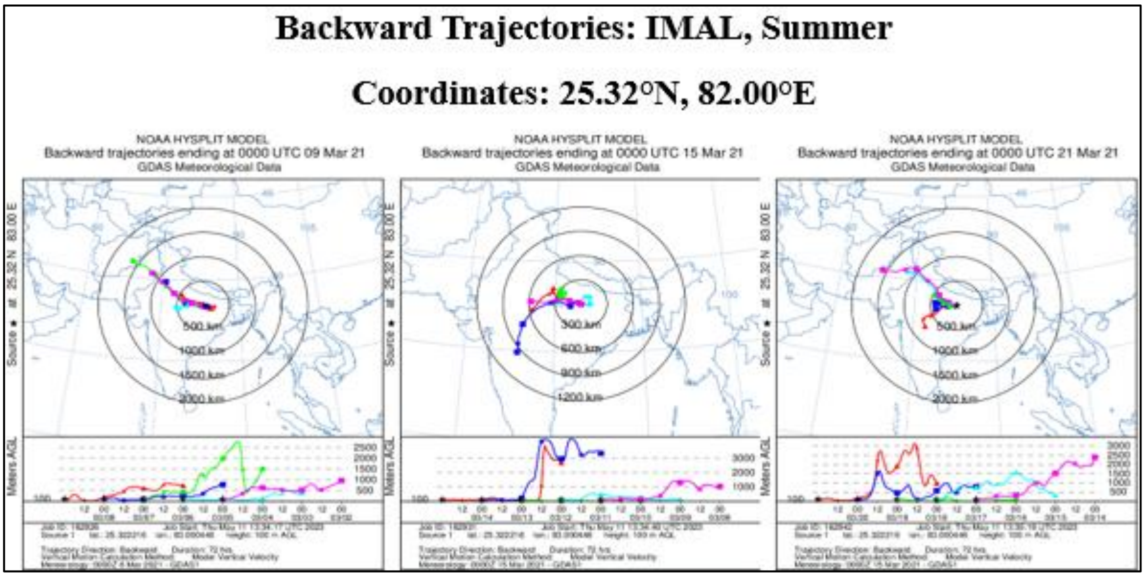

Backward Trajectories: IMAL, Summer
Coordinates: 25.32°N, 82.00°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 09 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 15 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 21 Mar 21
GDAS Meteorological Data
500 km
1000 km
1500 km
2000 km
300 km
600 km
900 km
1200 km
Meters AGL

Figure 4.12: Backward trajectories at IMAL for Summer Season

4.3.3 Amar Ujala Chandpur (AMUC)

4.3.3.1 Winter Season [sampling period: Dec 31, 2020 – Jan 14, 2021]

PM_{10} (winter)

The average PM_{10} concentration was 340 µg/m^3. Figure 4.13 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at AMUC. It is observed that the major source contributing to PM_{10} was biomass burning (138.5 µg/m^3 ~ 41%) followed by SIA (72 µg/m^3 ~ 21%) and coal and fly ash (57µg/m^3 ~ 17%). The other significant contributing sources are vehicles (11%), soil and road dust (6%), construction material (2.5%), industrial emission (1%) and MSW burning (0.5%).

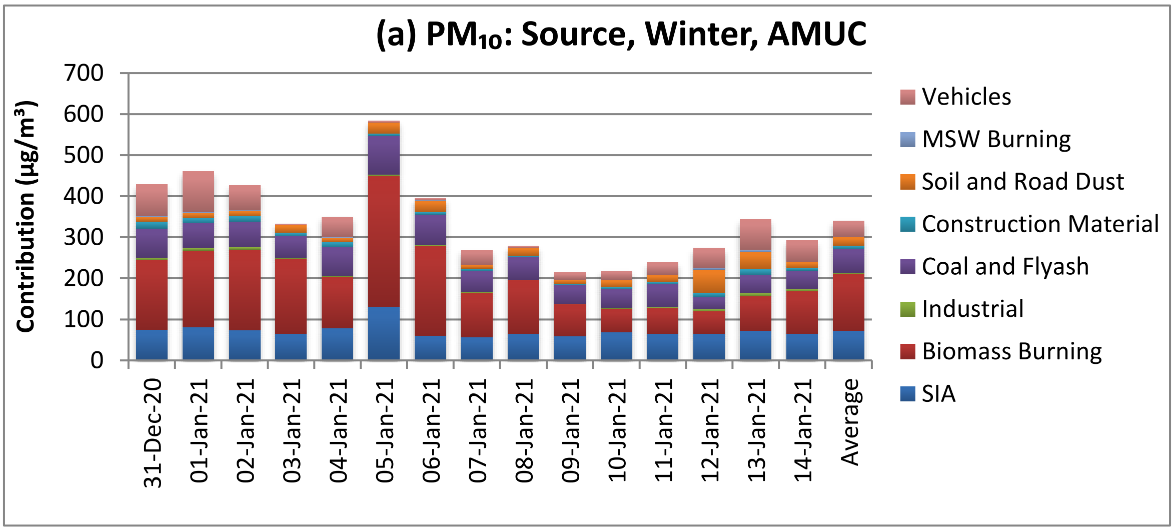
$PM_{2.5}$ (winter)

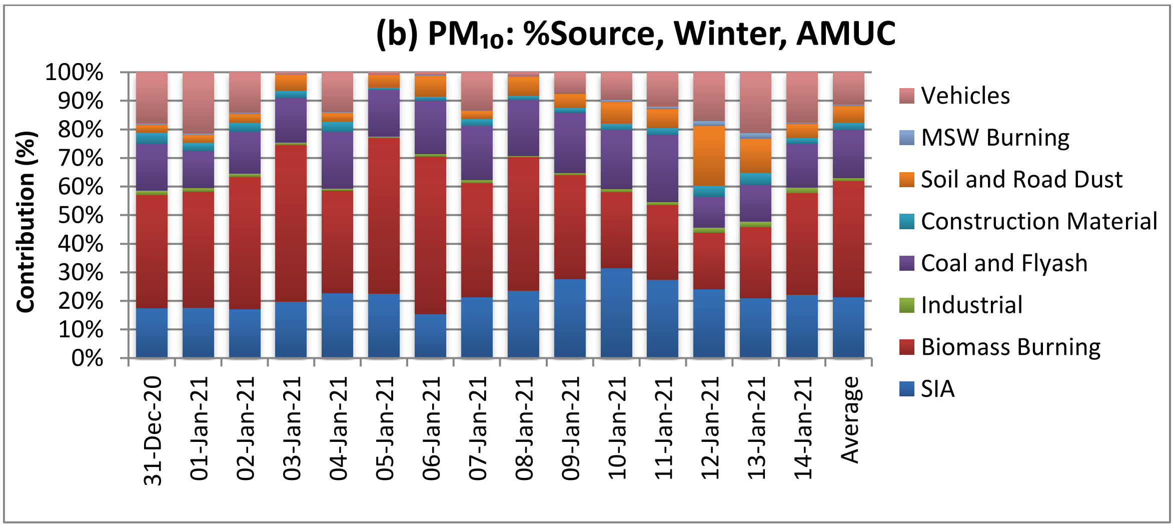
The average $PM_{2.5}$ concentration was 254 µg/m^3 (i.e., about 0.75 of PM_{10}). Figure 4.14 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at AMUC. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (101 µg/m^3 ~ 40%) followed by SIA (52 µg/m^3 ~ 21%) and coal and fly ash (46 µg/m^3 ~ 18%). Other major sources are vehicles (14%), soil and road dust (4.5%), construction material (1.4%) and industrial emission (1%). The contribution of the MSW burning was lowest at 0.1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.15) show that most of the time wind is mostly from NW and N direction. The wind mass travels over Punjab, Haryana, Delhi and part of Rajasthan before entering Varanasi. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. SIA emissions are the second most contributor at AMUC after biomass burning, indicating that this emission is expected from regions of economically lower strata of society where they used wood/dungs for cooking the food and crop residue burning in the nearby areas. The coal and fly ash and vehicular emissions also contribute a significant amount at AMUC.





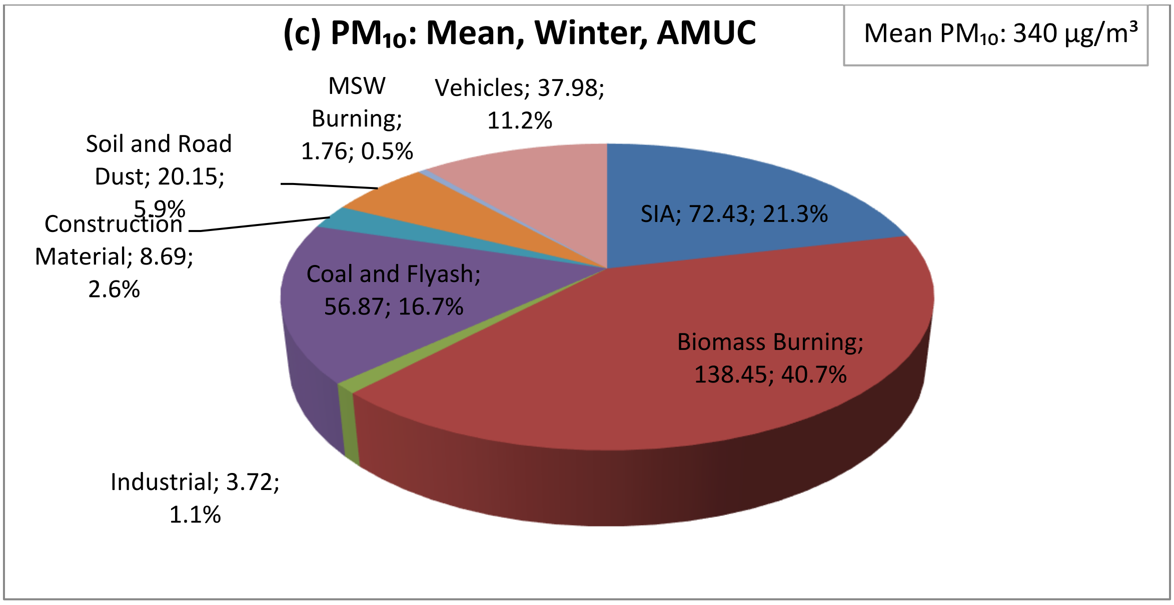
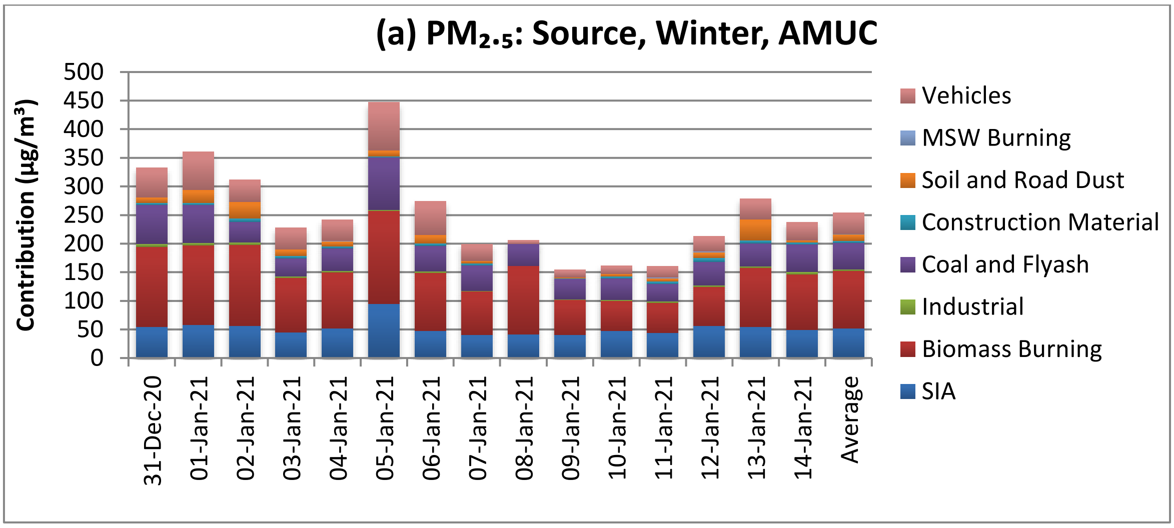
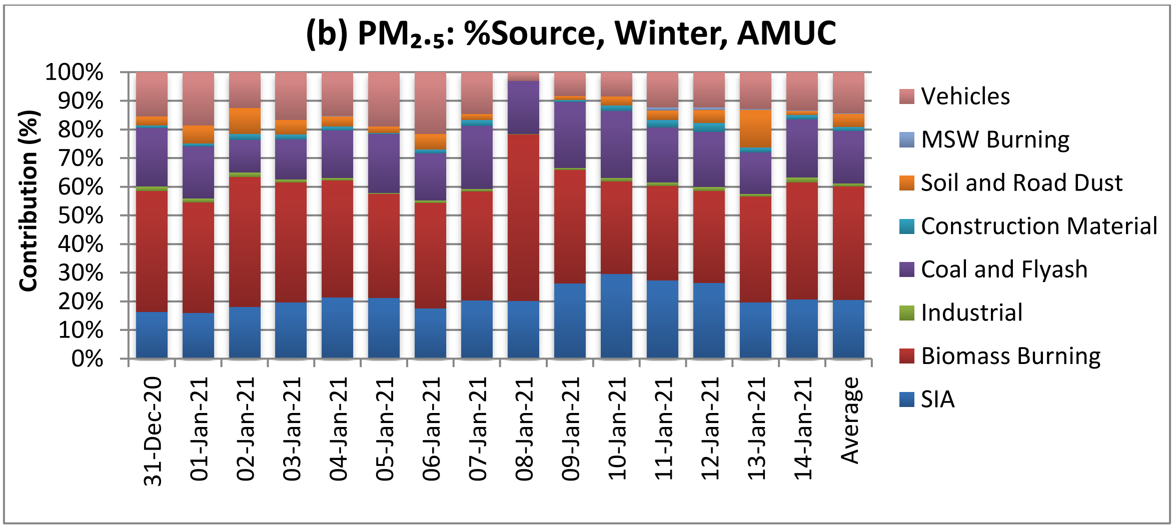


Figure 4.13: CMB modeling for PM$_{10}$ at AMUC winter season





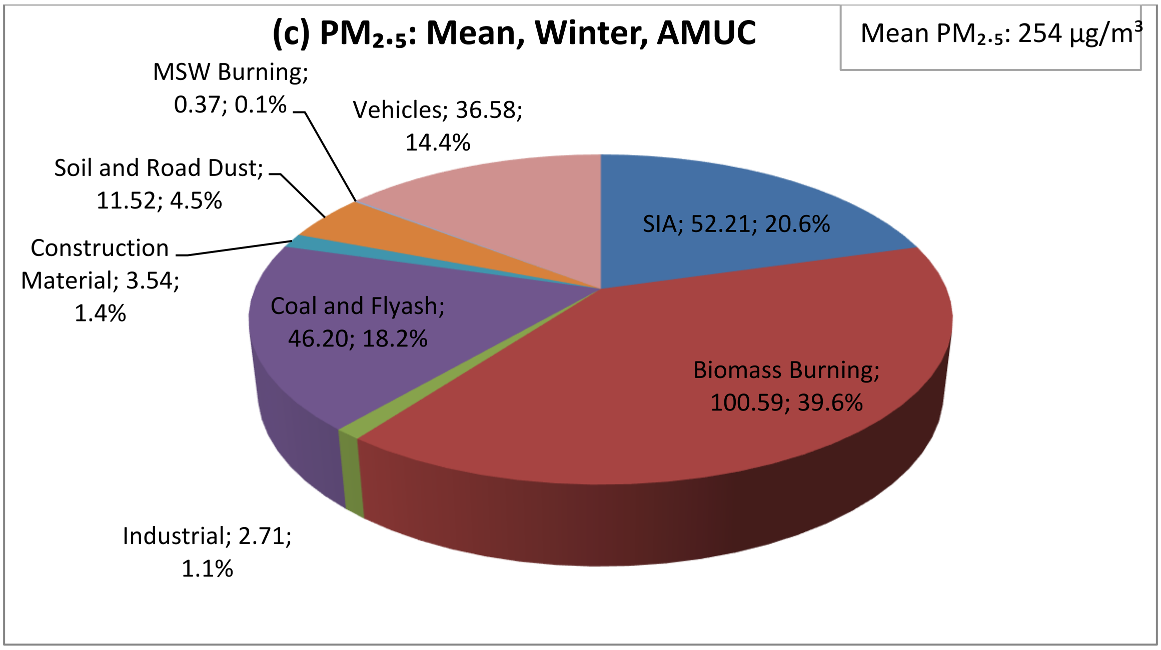


Figure 4.14: CMB modeling for $PM_{2.5}$ at AMUC, winter season

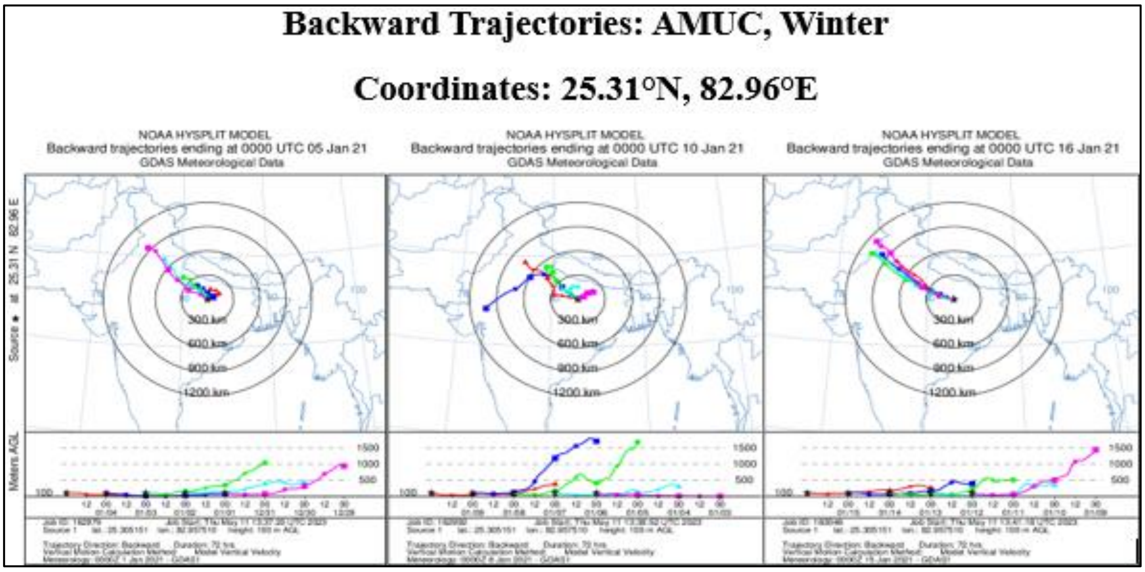

Backward Trajectories: AMUC, Winter
Coordinates: 25.31°N, 82.96°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 05 Jan 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 10 Jan 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 16 Jan 21
GDAS Meteorological Data
300 km
600 km
900 km
1200 km
Meters AGL
1500
1000
500
100

Figure 4.15: Backward trajectories at AMUC for winter season

4.3.3.2 Summer Season [sampling period: Mar 23 – April 06, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 294 µg/m^3. Figure 4.16 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at AMUC. It is observed that the major source contributing to PM_{10} was soil and road dust (126 µg/m^3 ~ 43%) followed by biomass burning (60 µg/m^3 ~ 20%) and coal and fly ash (29 µg/m^3 ~ 20%). The other significant sources are vehicles (11%), construction material (2.6%), SIA (2.5%) and MSW burning (0.5%). The contribution of industrial emission the was lowest at 0.4%in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 124 µg/m^3 (i.e., about 0.42 of PM_{10}). Figure 4.17 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage, respectively, at AMUC. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (52 µg/m^3 ~ 42%) followed by soil and road dust (28 µg/m^3 ~ 22.5%) and vehicles (18 µg/m^3 ~ 15%). Other significant sources are coal and fly ash (9%), construction material (5.3%), SIA (4.5%) and MSW burning (1%). The contribution of industrial emission the was lowest at 0.7% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.18) show that wind is mainly from NW to SW and sometimes from the east. The wind mass travels over different states and the Thar Desert and Rajasthan before entering Varanasi. These winds pick up the pollutants on the way, especially from large sources.

Inference

Soil and road dust is major contributors in summer both for PM_{10} and $PM_{2.5}$. Biomass burning is the second major contributor to PM_{10} and $PM_{2.5}$ followed by vehicular and coal and fly ash emission. The loose particles are airborne with high-speed wind from the desert, open barren fields, open dumping sites of fly ash, caused the high contribution to PM. The sampling site was in the middle of the industrial area, which had large trucks ferrying raw material and finishes products.

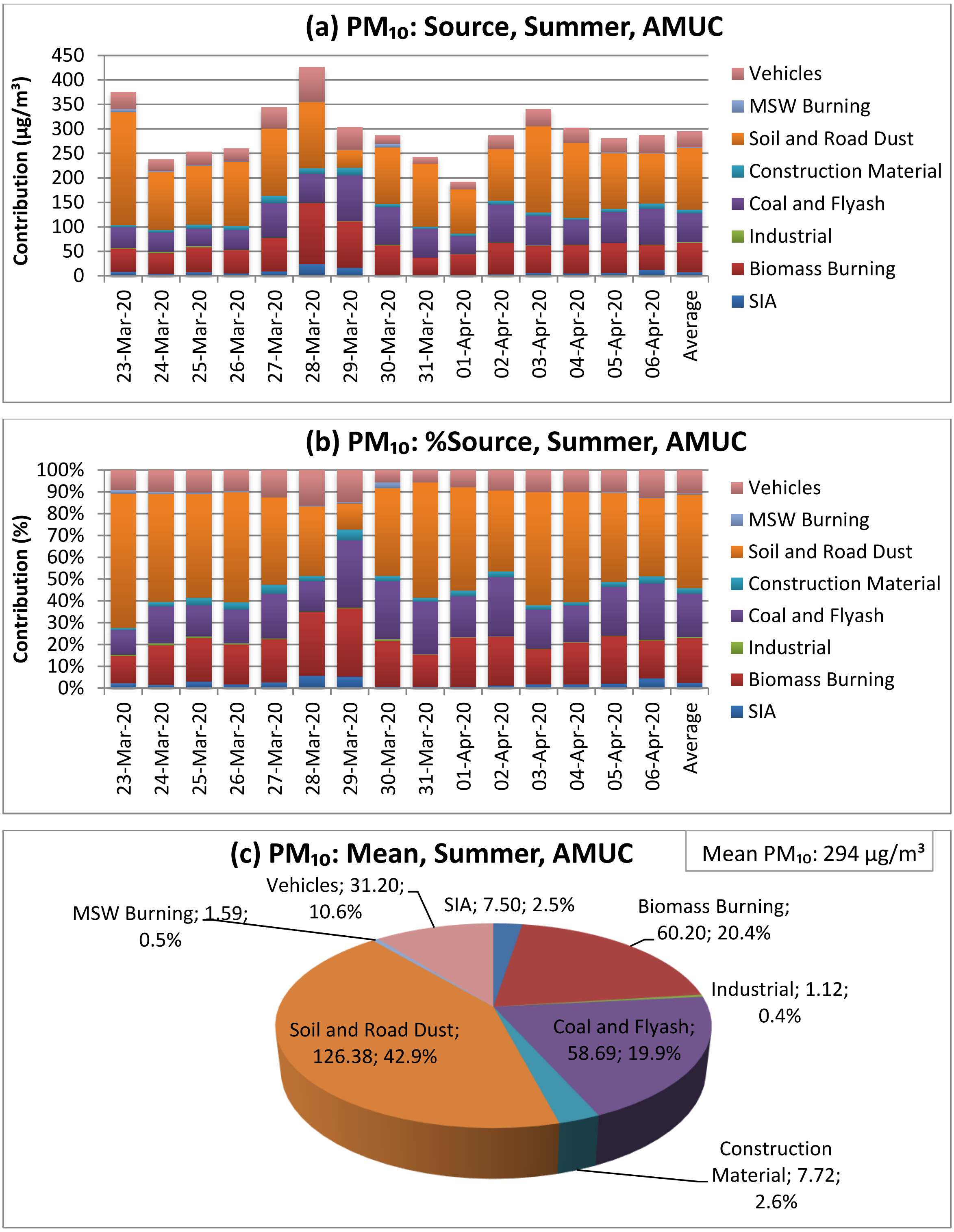


Figure 4.16: CMB modeling for PM_{10} at AMUC for summer season

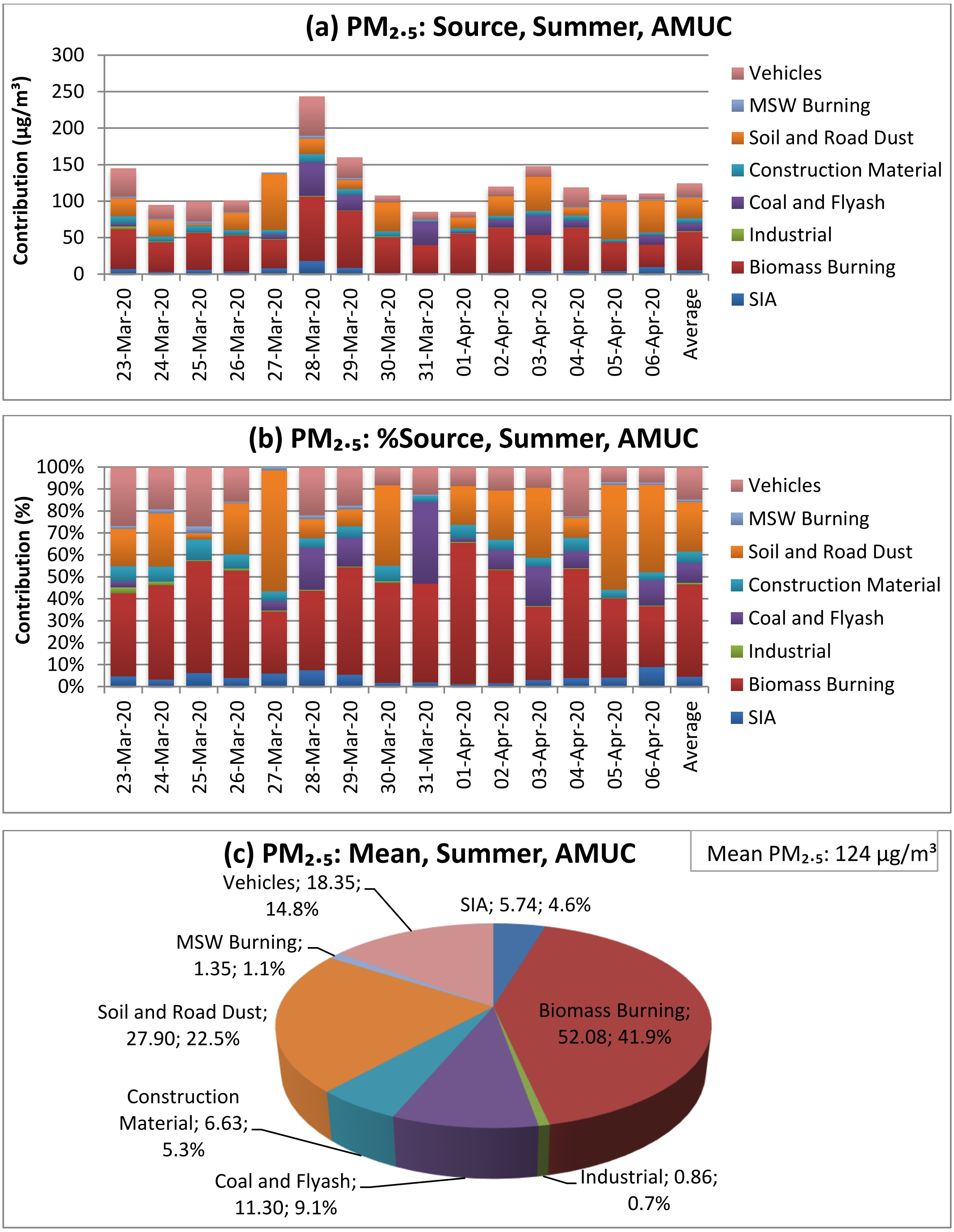


Figure 4.17: CMB modeling for PM2.5 at AMUC for summer season

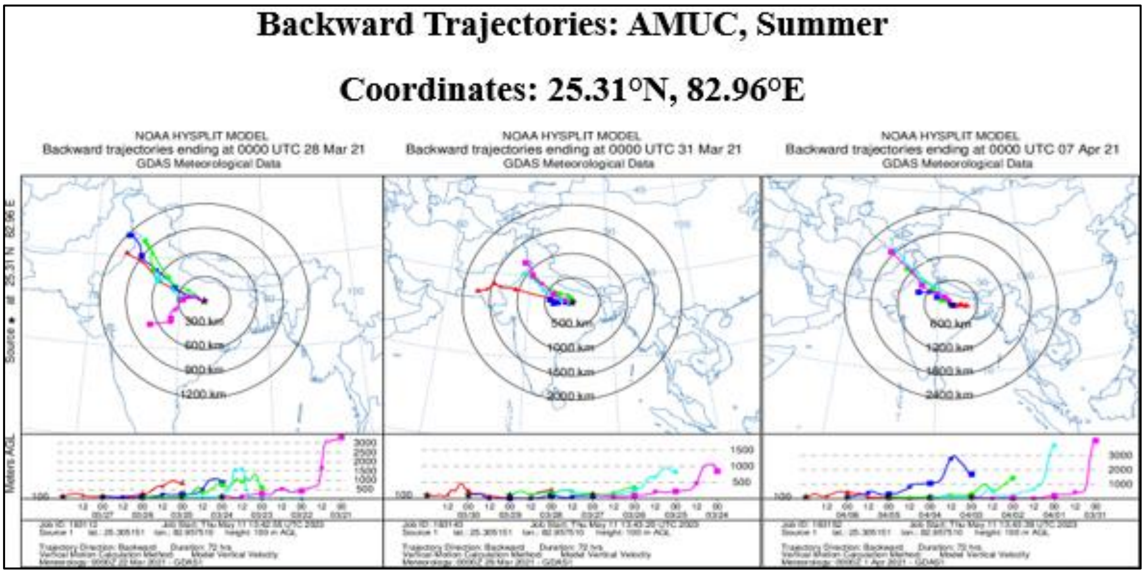

Backward Trajectories: AMUC, Summer
Coordinates: 25.31°N, 82.96°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 28 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 31 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 07 Apr 21
GDAS Meteorological Data
Source ★ at 25.31 N 82.96 E
300 km
600 km
900 km
1200 km
500 km
1000 km
1500 km
2000 km
600 km
1200 km
1800 km
2400 km
Meters AGL

Figure 4.18: Backward trajectories at AMUC for summer season

4.3.4 BHU Susuvahi (BHUS)

4.3.4.1 Winter Season [sampling period: Dec 31, 2020 – Jan 14, 2021]

PM_{10} (winter)

The average PM_{10} concentration was 347 µg/m^3. Figure 4.19 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at BHUS. It is observed that the major contributing source to PM_{10} was soil and road dust (102 µg/m^3 ~ 29.5%) followed by biomass burning (80 µg/m^3 ~ 23%) and SIA (78 µg/m^3 ~ 22%). The other significant contributing sources are coal and fly ash (15%), vehicles (6.5%), industrial emission (2%), construction material (1%) and MSW burning (1%).

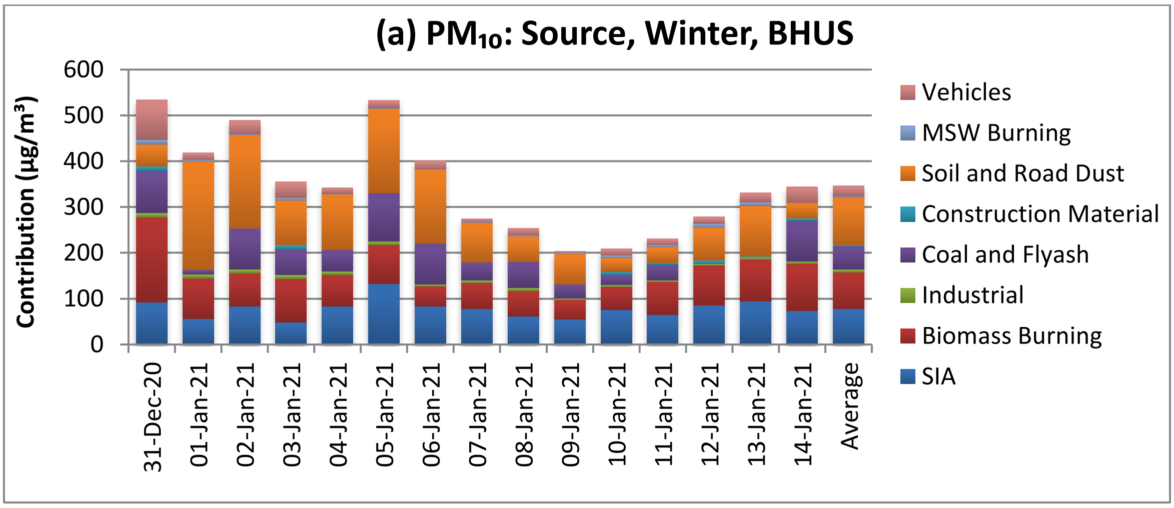
$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 240 µg/m^3 (i.e., about 0.69 of PM_{10}). Figure 4.20 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at BHUS. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (70 µg/m^3 ~ 29%) followed by SIA (59 µg/m^3 ~ 25%) and biomass burning (53 µg/m^3 ~ 22%). Other significant sources are coal and fly ash (11%), vehicles (9%), industrial emission (2%) and coal and MSW burning (1%). The contribution of the construction material was less than 0.5% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.21) show that wind is mostly from NW. Wind mass travels over to neighboring districts, states of Punjab, Haryana, Delhi and Rajasthan before entering into Varanasi. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inference

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. It is to be noted that at BHUS, biomass burning, coal and fly ash and SIA contribute about 60% in both PM_{10} and $PM_{2.5}$ and soil and road dust about 29% are consistent. The biomass burning and coal and fly ash are exceptionally high at BHUS, indicating that this emission is expected from regions of economically lower strata of society where they used wood/dungs for cooking the food and crop residue burning in the nearby areas.



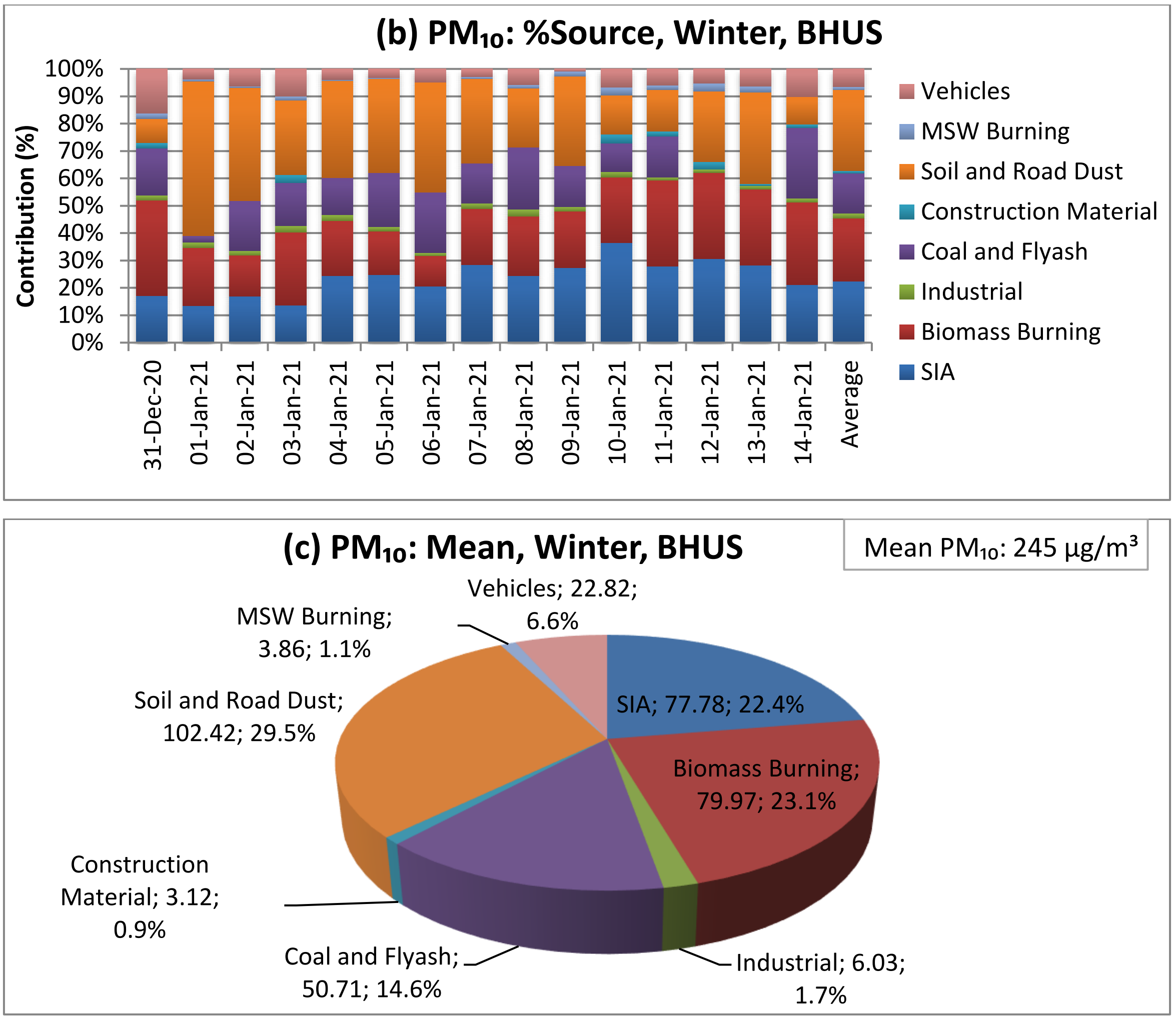
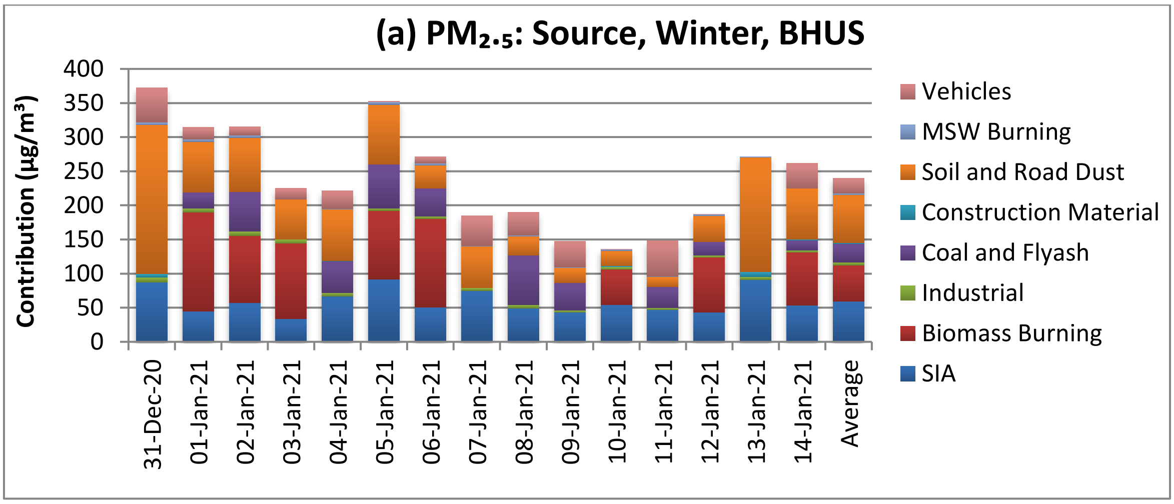
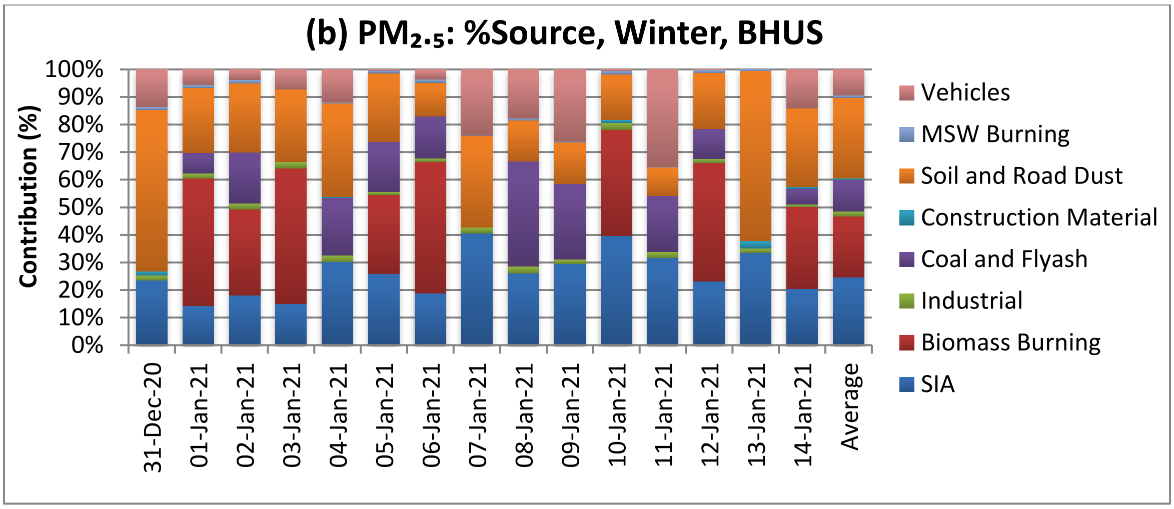


Figure 4.19: CMB modeling for PM_{10} at BHUS for winter season




(b) $PM_{2.5}$: %Source, Winter, BHUS

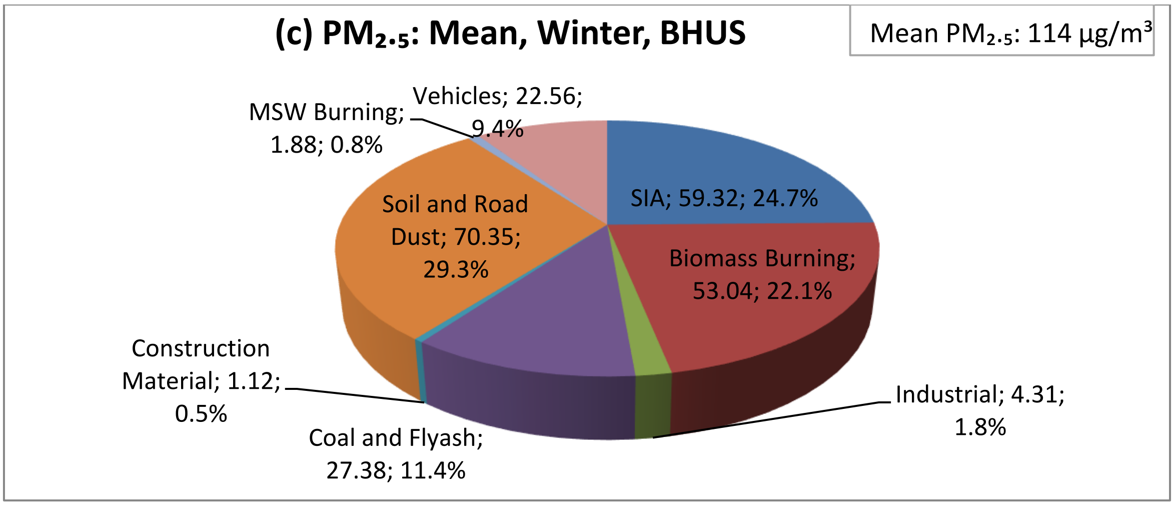
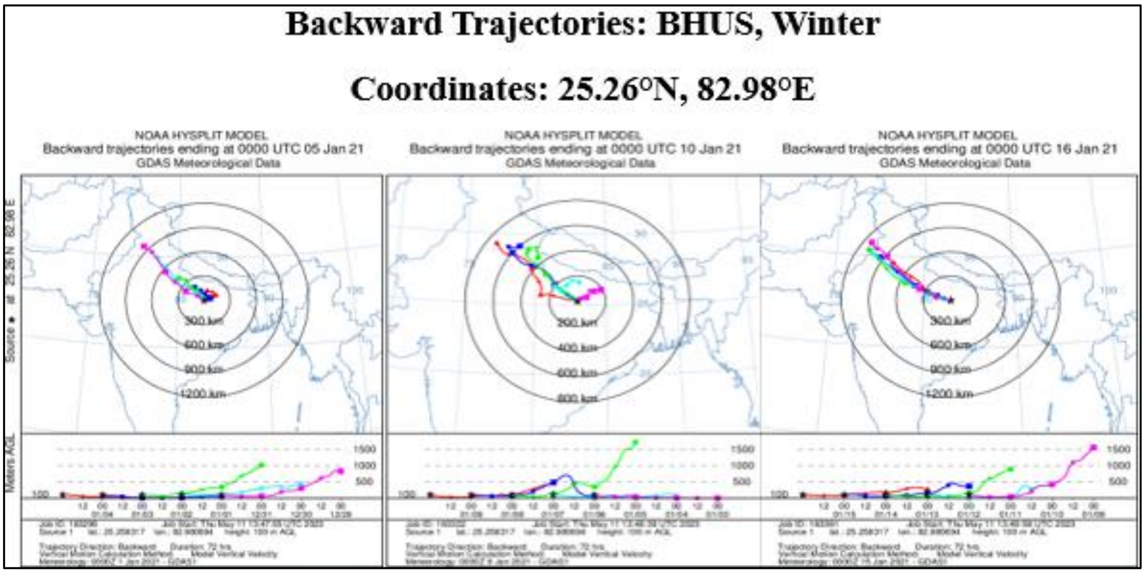

(c) $PM_{2.5}$: Mean, Winter, BHUS

Figure 4.20: CMB modeling for $PM_{2.5}$ at BHUS for winter season


Backward Trajectories: BHUS, Winter

Coordinates: 25.26°N, 82.98°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 05 Jan 21
GDAS Meteorological Data
300 km
600 km
900 km
1200 km
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 10 Jan 21
GDAS Meteorological Data
200 km
400 km
600 km
800 km
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 16 Jan 21
GDAS Meteorological Data
300 km
600 km
900 km
1200 km
Meters AGL
1500
1000
500
100

Figure 4.21: Backward trajectories at BHUS for winter season

4.3.4.2 Summer Season [sampling period: Mar 23 – April 06, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 266 µg/m^3. Figure 4.22 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at BHUS. It is observed that the major source contributing to PM_{10} was soil and road dust (157 µg/m^3 ~ 59%) followed by coal and fly ash (51 µg/m^3 ~ 19%) and biomass burning (28 µg/m^3 ~ 11%). The other significant sources are vehicles (5%), SIA (2.5%), construction material (2%), MSW burning (0.5%) and industrial emissions (0.5%).

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 100 µg/m^3 (i.e., about 0.37 of PM_{10}). Figure 4.23 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 15 days) in terms of concentration and percentage respectively at BHUS. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (26 µg/m^3 ~ 26%) followed by biomass burning (25 µg/m^3 ~ 25%) and coal and fly ash (21 µg/m^3 ~ 21%). Other significant sources are vehicles (14%), SIA (6%), construction material (5.5%), industrial emissions (1.5%) and MSW burning (1%).

HYSPLIT back trajectories (Figure 4.24) show that wind is mostly from NW to SW direction and wind mass travel over to neighboring districts and the state of Rajasthan before entering into Varanasi. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inference

Soil and road dust and coal and fly ash are major contributors in summer both for PM_{10} and $PM_{2.5}$. The loose particles are airborne with high-speed wind from the desert, open barren fields, open dumping sites of fly ash, no control at construction sites caused the high contribution to PM. The biomass burning and vehicles contribute a significant amount at BHUS that indicates irregular management of waste generated from commercial activities that succeed for open burning. It may be noted that this site is near a traffic junction which having high traffic load and congestion that caused high emissions.

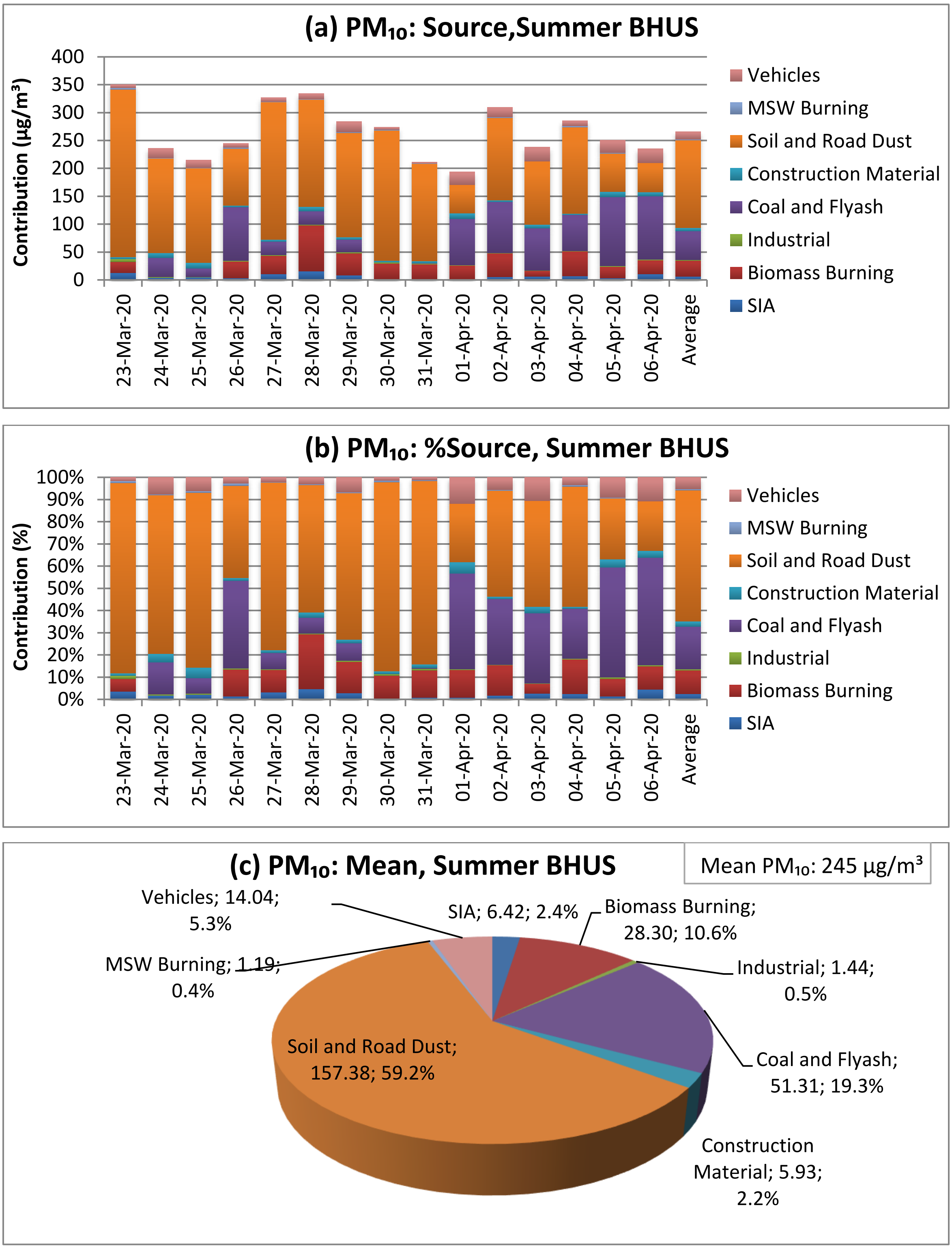


Figure 4.22: CMB modeling for PM_{10} at BHUS for summer season

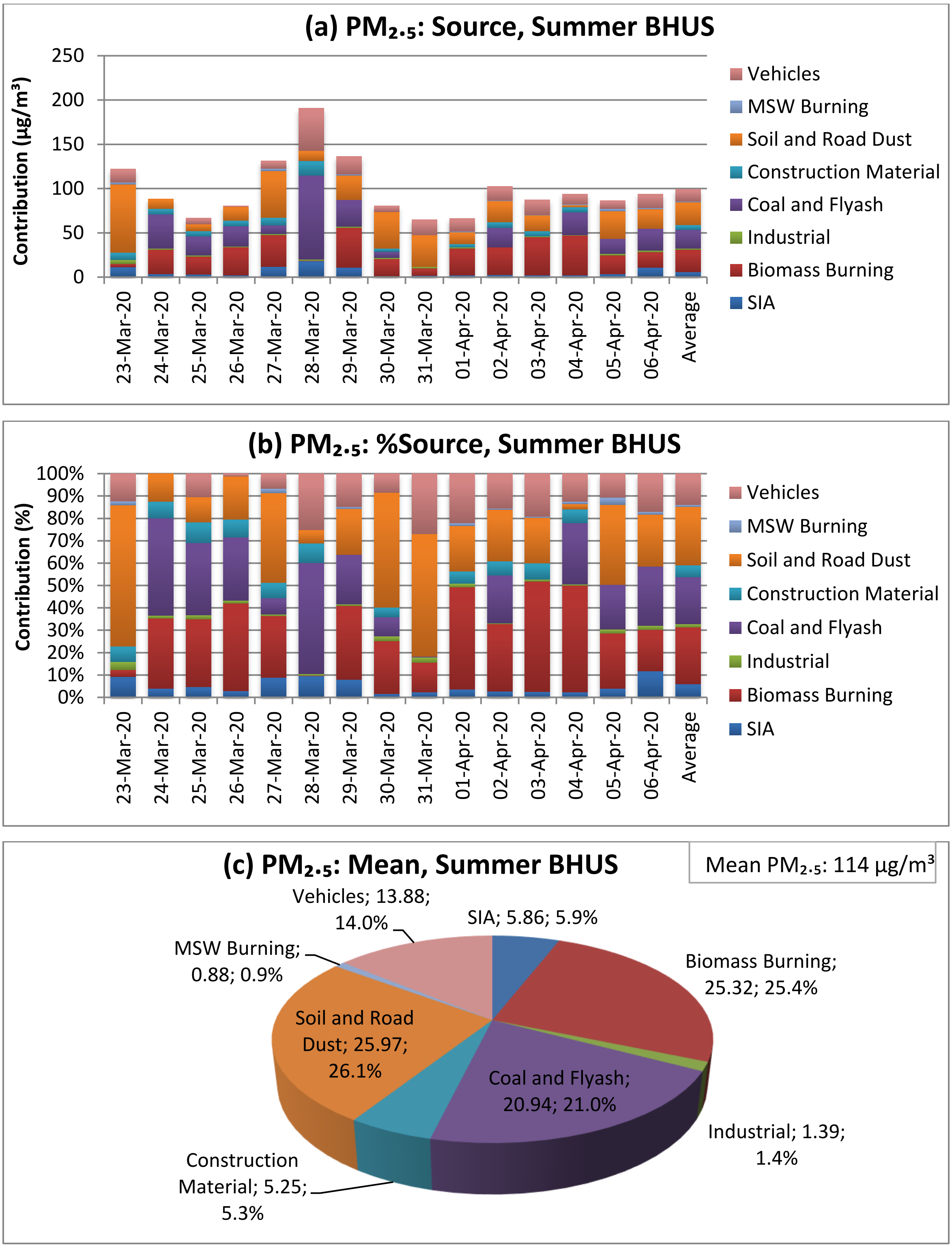


Figure 4.23: CMB modeling for $PM_{2.5}$ at BHUS for summer season

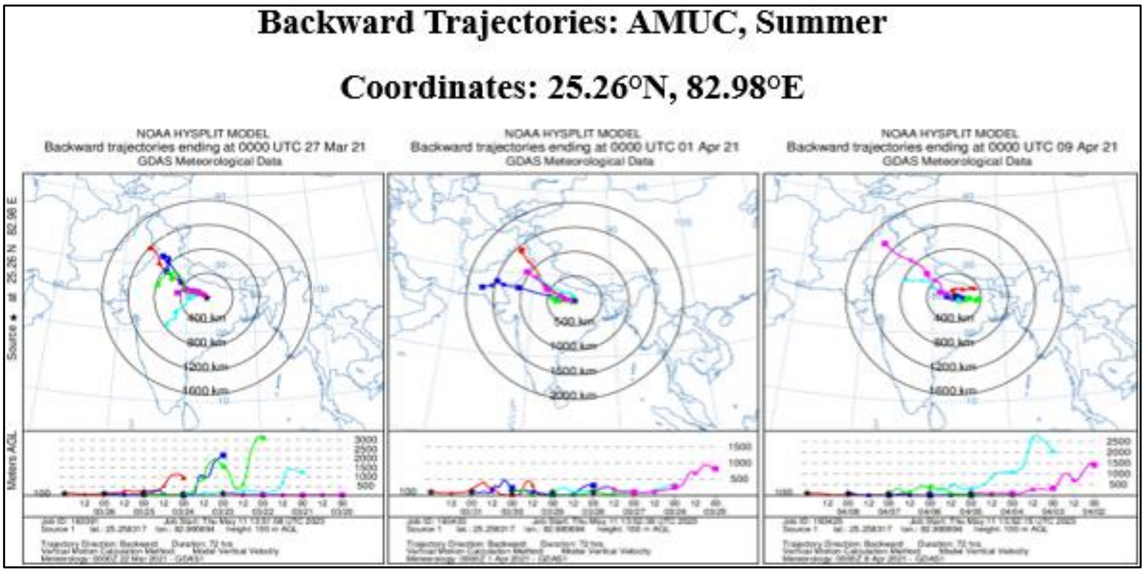

Backward Trajectories: AMUC, Summer
Coordinates: 25.26°N, 82.98°E
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 27 Mar 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 01 Apr 21
GDAS Meteorological Data
NOAA HYSPLIT MODEL
Backward trajectories ending at 0000 UTC 09 Apr 21
GDAS Meteorological Data
400 km
800 km
1200 km
1600 km
500 km
1000 km
1500 km
2000 km
Meters AGL

Figure 4.24: Backward trajectories at BHUS for summer season

4.4 Long-range transport and contribution

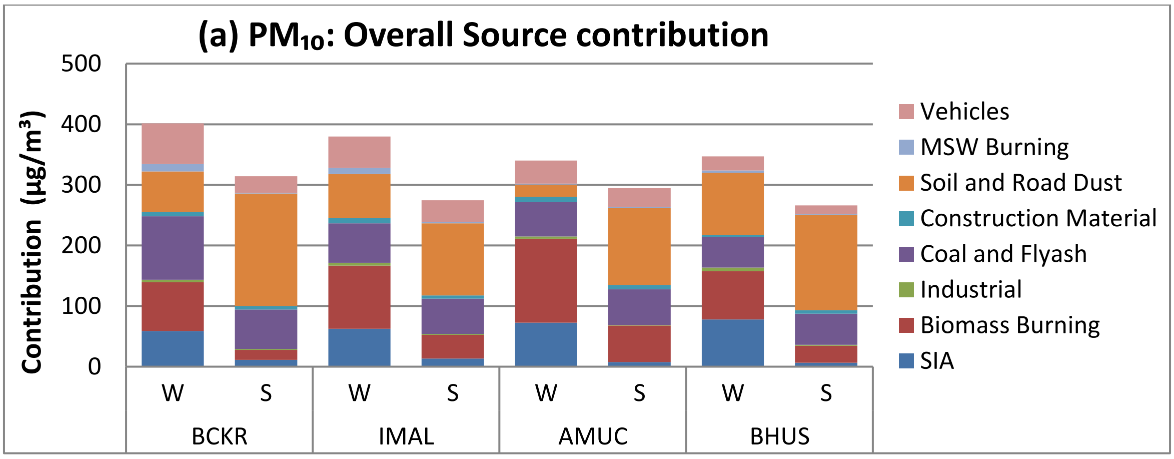
HYSPLIT back trajectories show that most of the time wind is from north-west (winter) and north-west and east (summer) and sometimes from south-west. Wind mass as it travels over some part of Thar desert and states of Punjab, Haryana, Delhi before entering Varanasi may pick up the pollutants on the way, especially from large sources (e.g., soil, brick kilns and CRB) and tall emitting sources (industries and power plants); however, these contributions have not been quantified. There is no assessment made on emissions upstream of Varanasi and their contribution in Varanasi.

4.5 Overall Summary and Source Apportionment at a Glance

The overall summary of CMB modeling results is shown in Figure 4.25 to Figure 4.28. Table 4.1 to Table 4.4 provide a summary with overall statistics. The main highlights of CMB results are summarized below.

- Ranges of source contributions to PM_{10} are: soil and road dust (5.9 – 59.2%), coal and fly ash (14.6 – 26.0%), vehicles (5.3 – 16.7%), MSW burning (0.4 – 3.0%), biomass burning (5.2 – 40.7%), industrial (0.4 – 1.7%), construction material (0.9 – 2.6%) and secondary inorganic aerosol (SIA; 2.4 – 22.4%).

- Ranges of source contributions to $PM_{2.5}$ are: soil and road dust (4.5 – 51.2%), coal and fly ash (9.1 – 21%), vehicles (9.4 – 26.8%), MSW burning (0.1 – 1.6%), biomass burning (12.6 – 41.9%), industrial (0.7 – 1.8%), construction material (0 – 5.3%) and SIA (4.6 – 24.7%).
- Percent contribution (winter – summer) of soil and road dust (PM_{10}: 17.8– 51.1% and $PM_{2.5}$: 17.7 – 29.0%), and construction material (PM_{10}: 1.9 – 2.1% and $PM_{2.5}$: 0.7 – 3.1%) are higher during summer season compared to winter season.
- Percent contribution (winter – summer) of biomass burning (PM_{10}: 27.9 – 12.6% and $PM_{2.5}$: 29.8 – 28.1%), SIA (PM_{10}: 18.7 – 3.3% and $PM_{2.5}$: 20.1 – 7.0%), and industrial (PM_{10}: 1.3 – 0.5% and $PM_{2.5}$: 1.2 –1.1%) are higher during winter season compared to summer season.
- Percent contribution (winter – summer) of coal and fly ash (PM_{10}: 18.6 – 20.3%), MSW burning ($PM_{2.5}$: 0.7 – 1.1%) and vehicles ($PM_{2.5}$: 14.1 – 17.6%) are higher in summer season compared to winter season.
- Percent contribution (winter – summer) of vehicles (PM_{10}: 12.0 – 9.4%), MSW burning (PM_{10}: 1.8 – 0.6%), and coal and fly ash ($PM_{2.5}$: 15.5 – 13.0%) are higher in winter season compared to summer season.



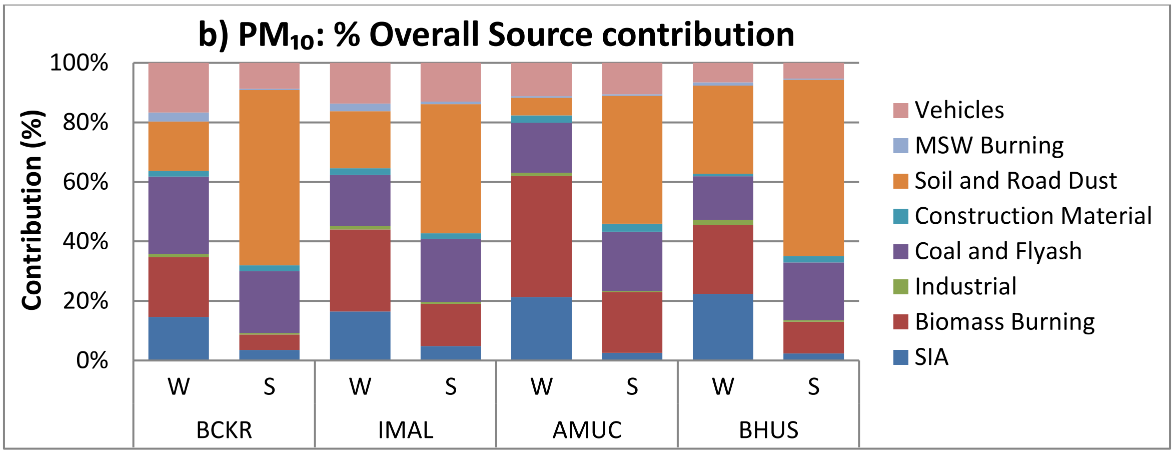


Figure 4.25: Overall results of CMB modeling for PM_{10}

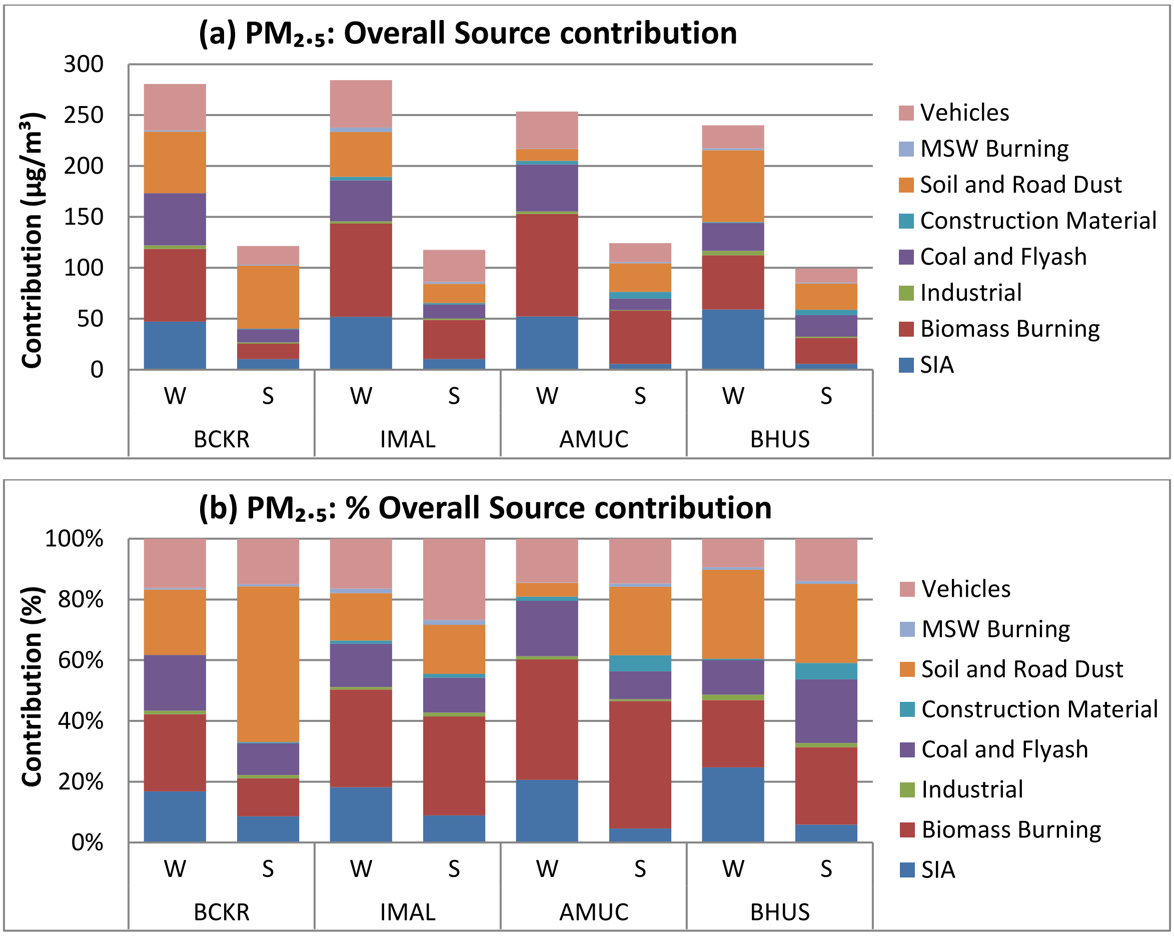


Figure 4.26: Overall results of CMB modeling for $PM_{2.5}$

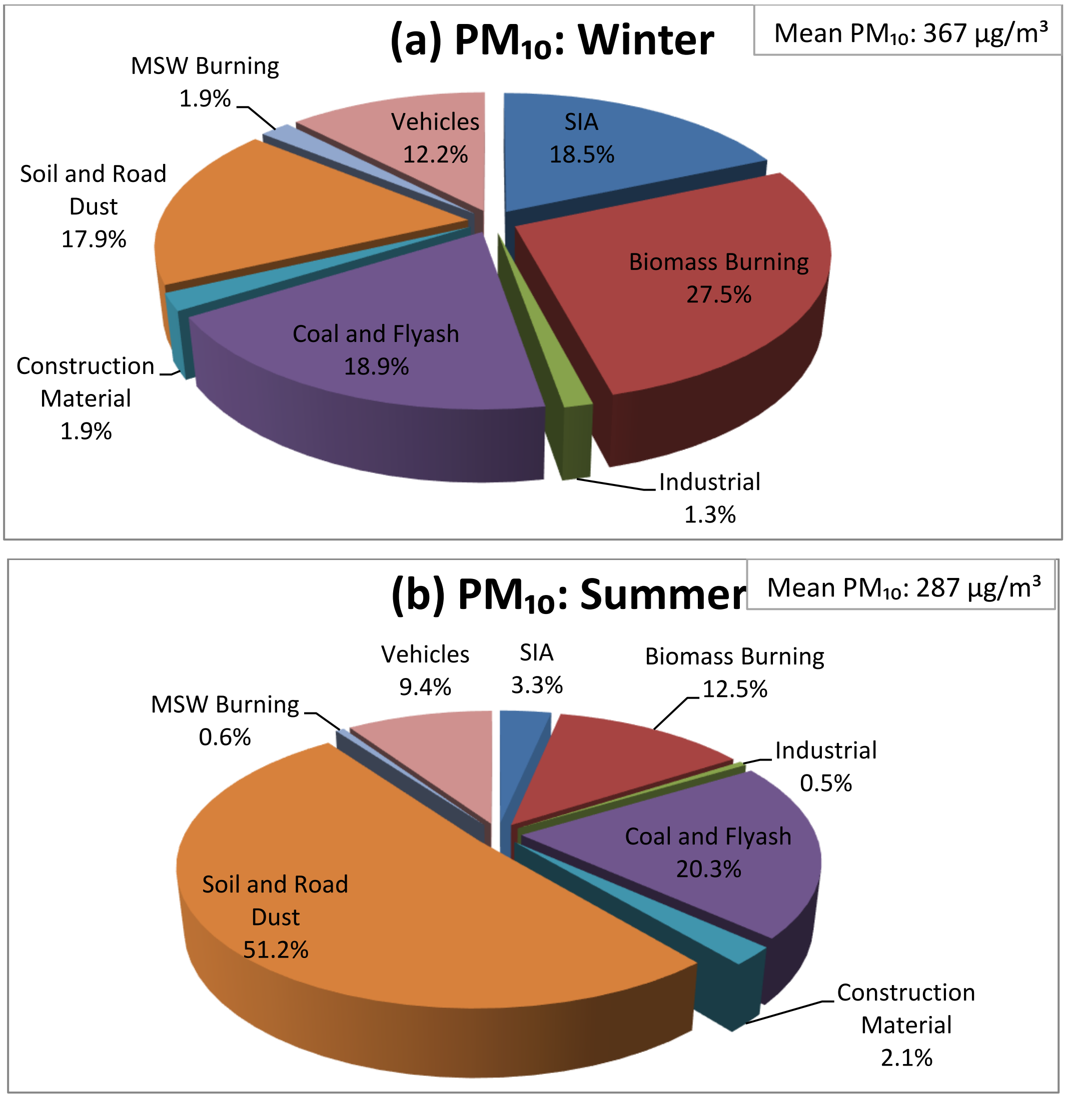
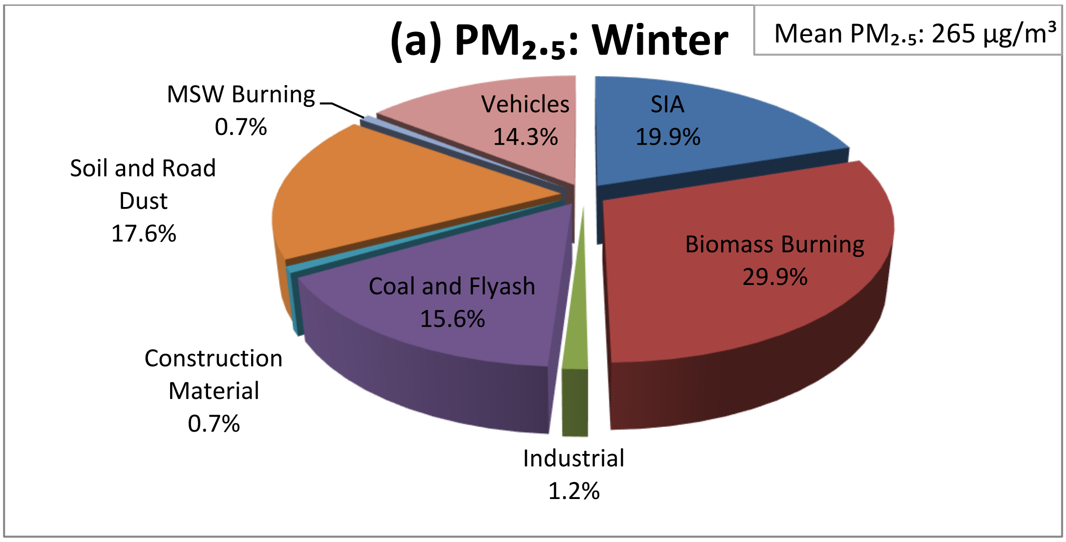


Figure 4.27: Overall source contribution to PM$_{10}$ in (a) winter and (b) summer



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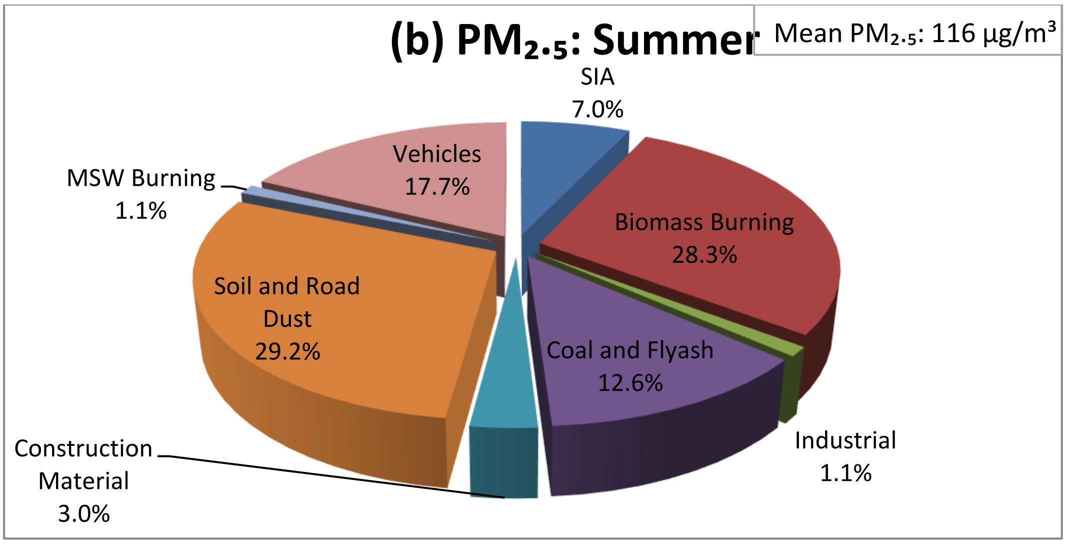

Figure 4.28: Overall source contribution to $PM_{2.5}$ in (a) winter and (b) summer

Table 4.1: Statistical summary of the source apportionment in PM_{10} for winter season

Site location	Parameter	Measured PM_{10} ($\mu g/m^3$)	Calculated PM_{10} ($\mu g/m^3$)	% Mass	% Source Contribution							
					SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	Mean	401	409	101.9	14.6	20.1	1.0	26.0	1.9	16.6	3.0	16.7
	SD	105	107	5.3	4.4	15.3	0.7	8.5	1.2	8.3	3.1	9.3
	CV	0.26	0.26	0.1	0.3	0.8	0.6	0.3	0.0	0.5	1.0	0.6
	Max	595	587	109.3	24.1	41.1	3.4	41.2	3.6	33.8	12.0	35.8
	Min	193	189	90.3	7.1	0.0	0.5	7.6	0.0	4.8	0.0	3.1
IMAL	Mean	380	389	103.5	16.5	27.5	1.2	17.1	2.3	19.2	2.6	13.7
	SD	124	119	5.9	4.4	14.7	0.5	6.0	0.8	17.4	2.2	6.7
	CV	0.33	0.31	0.06	0.3	0.5	0.4	0.4	0.4	0.9	0.8	0.5
	Max	578	582	110.7	26.1	45.8	2.9	25.0	3.6	54.4	8.5	21.2
	Min	161	172	92.0	9.6	0.0	0.8	2.8	1.2	6.3	0.0	1.3
AMUC	Mean	340	353	104.5	21.3	40.7	1.1	16.7	2.6	5.9	0.5	11.2
	SD	103	98	4.6	4.4	11.3	0.5	3.5	1.0	4.7	0.6	7.5
	CV	0.30	0.28	0.04	0.2	0.3	0.5	0.2	0.4	0.8	1.2	0.7
	Max	584	544	111.1	31.5	55.2	1.9	23.5	4.1	20.8	1.9	21.5
	Min	214	222	93.2	15.4	19.8	0.3	11.0	0.9	2.6	0.0	0.7
BHUS	Mean	347	340	98.4	22.4	23.1	1.7	14.6	0.9	29.5	1.1	6.6
	SD	110	105	4.4	6.5	6.8	0.5	8.0	1.3	13.0	1.0	3.7
	CV	0.32	0.31	0.04	0.3	0.3	0.3	0.5	1.4	0.4	0.9	0.6
	Max	534	516	106.9	36.5	34.8	2.6	25.7	3.4	56.5	3.0	16.2
	Min	203	196	88.9	13.5	11.0	1.1	0.0	0.0	8.9	0.0	0.9

Table 4.2: Statistical summary of the source apportionment in PM_{10} for summer season

Site location	Parameter	Measured PM_{10} ($\mu g/m^3$)	Calculated PM_{10} ($\mu g/m^3$)	% Mass	% Source Contribution							
					SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	Mean	314	319	101.7	3.5	5.2	0.5	20.8	1.9	59.0	0.4	8.7
	SD	112	112	5.4	2.7	4.5	0.3	16.5	1.6	17.6	0.3	3.3
	CV	0.36	0.35	0.1	0.8	0.9	0.7	0.8	0.9	0.3	0.6	0.4
	Max	526	525	110.9	10.2	13.2	1.3	45.2	6.1	82.2	0.9	15.5
	Min	167	155	89.8	0.8	0.2	0.1	0.0	0.0	25.4	0.0	4.0
IMAL	Mean	275	292	106.2	4.8	14.3	0.6	21.2	1.8	43.3	0.9	13.0
	SD	88	95	4.6	3.1	7.4	0.3	7.0	0.9	16.2	0.8	4.3
	CV	0.32	0.33	0.04	0.7	0.5	0.4	0.3	0.5	0.4	0.9	0.3
	Max	448	469	114.7	11.6	28.7	1.2	33.5	4.9	67.5	2.9	26.3
	Min	131	138	98.4	1.3	1.7	0.3	8.8	1.3	5.2	0.1	7.0
AMUC	Mean	294	300	102.3	2.5	20.4	0.4	19.9	2.6	42.9	0.5	10.6
	SD	59	63	9.5	1.6	4.9	0.2	5.8	1.0	11.7	0.7	2.9
	CV	0.20	0.21	0.1	0.64	0.24	0.57	0.29	0.38	0.27	1.32	0.27
	Max	426	437	116.6	5.7	31.3	0.8	31.0	4.7	61.4	2.6	16.3
	Min	192	209	84.8	0.7	12.6	0.2	11.4	1.1	12.1	0.0	5.6
BHUS	Mean	266	277	104.8	2.4	10.6	0.5	19.3	2.2	59.2	0.4	5.3
	SD	48	44	7.4	1.3	6.2	0.3	18.3	1.4	22.0	0.3	3.7
	CV	0.18	0.16	0.07	0.54	0.59	0.50	0.95	0.65	0.37	0.73	0.71
	Max	350	361	117.1	4.7	24.6	1.3	49.5	5.2	85.7	1.1	11.9
	Min	194	215	92.4	0.5	0.0	0.2	0.0	0.8	22.3	0.0	1.2

Table 4.3: Statistical summary of the source apportionment in $PM_{2.5}$ for winter season

Site location	Parameter	Measured PM_{10} ($\mu g/m^3$)	Calculated PM_{10} ($\mu g/m^3$)	% Mass	% Source Contribution							
					SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	Mean	281	280	99.5	16.8	25.4	1.2	18.3	0.0	21.5	0.5	16.3
	SD	86	91	9.6	4.7	17.6	0.6	15.2	0.0	9.3	0.4	6.9
	CV	0.31	0.32	0.1	0.28	0.69	0.47	0.83	0.00	0.43	0.79	0.43
	Max	452	443	111.8	29.1	42.0	2.3	46.3	0.0	38.2	1.1	36.8
	Min	133	120	80.4	11.0	0.0	0.5	7.2	0.0	4.7	0.0	9.6
IMAL	Mean	285	293	103.2	18.2	32.2	0.9	14.1	1.1	15.5	1.5	16.5
	SD	107	110	6.8	5.2	15.6	1.1	8.1	0.8	14.9	1.3	8.0
	CV	0.37	0.37	0.07	0.3	0.5	1.3	0.6	0.7	1.0	0.9	0.5
	Max	506	509	111.9	30.9	52.4	3.7	27.9	3.4	51.3	3.2	36.0
	Min	118	124	91.1	10.3	0.0	0.0	0.0	0.3	1.0	0.0	0.5
AMUC	Mean	254	275	109.5	20.6	39.6	1.1	18.2	1.4	4.5	0.1	14.4
	SD	82	80	6.7	4.2	6.4	0.4	3.4	0.8	3.3	0.3	4.7
	CV	0.32	0.29	0.06	0.2	0.2	0.4	0.2	0.6	0.7	2.4	0.3
	Max	447	433	123.2	29.6	58.1	1.8	23.2	3.2	13.2	1.1	21.4
	Min	154	174	96.7	16.1	32.1	0.2	11.4	0.0	0.0	0.0	3.0
BHUS	Mean	240	238	99.4	24.7	22.1	1.8	11.4	0.5	29.3	0.8	9.4
	SD	76	76	9.7	8.2	21.1	0.5	11.8	0.8	15.3	0.5	10.9
	CV	0.32	0.32	0.10	0.3	1.0	0.3	1.0	1.7	0.5	0.6	1.2
	Max	372	361	112.6	40.7	49.2	2.6	38.1	2.7	61.7	1.3	35.2
	Min	136	143	81.7	14.3	0.0	1.0	0.0	0.0	10.2	0.0	0.0

Table 4.4: Statistical summary of the source apportionment in $PM_{2.5}$ for summer season

Site location	Parameter	Measured PM_{10} ($\mu g/m^3$)	Calculated PM_{10} ($\mu g/m^3$)	% Mass	% Source Contribution							
					SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	Mean	121	126	103.7	8.6	12.6	1.1	10.4	0.5	51.2	0.8	15.0
	SD	24	28	6.3	4.4	11.3	0.8	12.3	1.0	19.3	0.4	9.0
	CV	0.20	0.22	0.1	0.5	0.9	0.7	1.2	2.0	0.4	0.5	0.6
	Max	158	164	111.8	17.5	28.9	2.9	41.6	3.5	73.0	1.5	39.4
	Min	77	77	90.7	1.8	0.0	0.1	0.0	0.0	0.0	0.2	8.2
IMAL	Mean	118	127	107.2	8.9	32.6	1.2	11.5	1.3	16.1	1.6	26.8
	SD	25	32	8.6	4.3	5.6	0.4	4.2	1.1	9.4	0.6	5.4
	CV	0.21	0.25	0.1	0.5	0.2	0.3	0.4	0.9	0.6	0.4	0.2
	Max	161	177	125.4	16.9	45.5	2.2	18.6	4.6	30.3	2.7	36.1
	Min	72	73	90.5	2.8	26.1	0.9	4.9	0.0	2.5	0.7	19.9
AMUC	Mean	124	127	102.6	4.6	41.9	0.7	9.1	5.3	22.5	1.1	14.8
	SD	40	39	8.4	2.3	10.0	0.7	10.4	1.8	16.5	0.9	8.0
	CV	0.32	0.30	0.1	0.49	0.24	1.02	1.14	0.33	0.74	0.82	0.54
	Max	243	231	116.7	9.0	64.3	2.8	37.2	9.6	55.2	3.1	26.9
	Min	85	84	88.9	1.3	27.6	0.1	0.0	2.6	0.0	0.0	0.0
BHUS	Mean	100	93	94.0	5.9	25.4	1.4	21.0	5.3	26.1	0.9	14.0
	SD	34	30	9.3	3.3	14.8	0.9	16.1	3.4	18.2	1.0	7.8
	CV	0.34	0.32	0.1	0.56	0.58	0.62	0.76	0.64	0.70	1.11	0.56
	Max	191	173	113.3	11.7	49.3	3.7	49.8	9.1	63.0	3.3	26.9
	Min	65	54	80.0	1.5	0.1	0.4	0.0	0.0	2.4	0.0	0.0

Table 4.5: Concentration apportionment: winter PM_{10} (Concentration in µg/m^3)

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	401	58.7	80.7	4.2	104.4	7.5	66.7	12.0	67.1
IMAL	380	62.5	104.5	4.5	65.0	8.6	72.8	10.0	51.8
AMUC	340	72.4	138.4	3.7	56.9	8.7	20.1	1.8	38.0
BHUS	347	77.8	80.0	6.0	50.7	3.1	102.4	3.9	22.8
Overall	367	67.9	100.9	4.6	69.3	7.0	65.5	6.9	44.9
SD	29	8.8	27.5	1.0	24.2	2.6	34.0	4.9	18.9

Table 4.6: Percentage apportionment: winter PM_{10}

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	401	14.6	20.1	1.0	26.0	1.9	16.6	3.0	16.7
IMAL	380	16.5	27.5	1.2	17.1	2.3	19.2	2.6	13.7
AMUC	340	21.3	40.7	1.1	16.7	2.6	5.9	0.5	11.2
BHUS	347	22.4	23.1	1.7	14.6	0.9	29.5	1.1	6.6
Overall	367	18.7	27.9	1.3	18.6	1.9	17.8	1.8	12.0
SD	29	3.8	9.1	0.3	5.1	0.7	9.7	1.2	4.3

Table 4.7: Concentration apportionment: winter $PM_{2.5}$ (Concentration in $\mu g/m^3$)

Site location	$PM_{2.5}$ ($\mu g/m^3$)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	281	47.2	71.4	3.3	51.4	0.0	60.4	1.3	45.6
IMAL	285	51.9	91.5	2.4	40.3	3.2	44.2	4.3	46.8
AMUC	254	52.2	100.6	2.7	46.2	3.5	11.5	0.4	36.6
BHUS	240	59.3	53.0	4.3	27.4	1.1	70.3	1.9	22.6
Overall	265	52.7	79.1	3.2	41.3	2.0	46.6	2.0	37.9
SD	21	5.0	21.2	0.8	10.4	1.7	25.8	1.7	11.2

Table 4.8: Percentage apportionment: winter $PM_{2.5}$

Site location	$PM_{2.5}$ ($\mu g/m^3$)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	281	16.8	25.4	1.2	18.3	0.0	21.5	0.5	16.3
IMAL	285	18.2	32.2	0.9	14.1	1.1	15.5	1.5	16.5
AMUC	254	20.6	39.6	1.1	18.2	1.4	4.5	0.1	14.4
BHUS	240	24.7	22.1	1.8	11.4	0.5	29.3	0.8	9.4
Overall	265	20.1	29.8	1.2	15.5	0.7	17.7	0.7	14.1
SD	21	3.5	7.8	0.4	3.4	0.6	10.4	0.6	3.3

Table 4.9: Concentration apportionment: summer PM_{10} (Concentration in µg/m^3)

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	314	11.0	16.4	1.6	65.4	5.9	185.1	1.4	27.3
IMAL	275	13.2	39.2	1.8	58.3	5.0	119.0	2.4	35.8
AMUC	294	7.5	60.2	1.1	58.7	7.7	126.4	1.6	31.2
BHUS	266	6.4	28.3	1.4	51.3	5.9	157.4	1.2	14.0
Overall	287	9.5	36.0	1.5	58.4	6.1	147.0	1.6	27.1
SD	21	3.1	18.6	0.3	5.7	1.1	30.4	0.5	9.4

Table 4.10: Percentage apportionment: summer PM_{10}

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	314	3.5	5.2	0.5	20.8	1.9	59.0	0.4	8.7
IMAL	275	4.8	14.3	0.6	21.2	1.8	43.3	0.9	13.0
AMUC	294	2.5	20.4	0.4	19.9	2.6	42.9	0.5	10.6
BHUS	266	2.4	10.6	0.5	19.3	2.2	59.2	0.4	5.3
Overall	287	3.3	12.6	0.5	20.3	2.1	51.1	0.6	9.4
SD	21	1.1	6.4	0.1	0.9	0.4	9.2	0.2	3.3

Table 4.11: Concentration apportionment: summer $PM_{2.5}$ (Concentration in µg/m^3)

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
BCKR	121	10.4	15.2	1.3	12.6	0.6	62.1	0.9	18.2
IMAL	118	10.5	38.4	1.4	13.5	1.5	19.0	1.9	31.5
AMUC	124	5.7	52.1	0.9	11.3	6.6	27.9	1.3	18.3
BHUS	100	5.9	25.3	1.4	20.9	5.3	26.0	0.9	13.9
Overall	116	8.1	32.8	1.2	14.6	3.5	33.8	1.3	20.5
SD	11	2.7	16.0	0.3	4.3	2.9	19.3	0.5	7.6

Table 4.12: Percentage apportionment: summer $PM_{2.5}$

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
-BCKR	121	8.6	12.6	1.1	10.4	0.5	51.2	0.8	15.0
IMAL	118	8.9	32.6	1.2	11.5	1.3	16.1	1.6	26.8
AMUC	124	4.6	41.9	0.7	9.1	5.3	22.5	1.1	14.8
BHUS	100	5.9	25.4	1.4	21.0	5.3	26.1	0.9	14.0
Overall	116	7.0	28.1	1.1	13.0	3.1	29.0	1.1	17.6
SD	11	2.1	12.4	0.3	5.4	2.6	15.4	0.4	6.1

4.6 Interpretations and Inferences

Based on the CMB modeling results (Figure 4.25 to Figure 4.28) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and pave the path for preparing an action plan. Table 4.5 to Table 4.12 show season-wise, site-specific average source contribution to PM_{10} and $PM_{2.5}$, and these tables are frequently referred to bring the important inferences to the fore.

- The sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter.
  - In winter, % contribution of PM_{10} – $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: biomass burning (27.9 – 29.8%), secondary inorganic aerosol (SIA; 18.7 – 20.1%), soil and road dust (17.9 – 17.7%), coal and fly ash (18.6 – 15.5%; includes ash from burning of residual oil), vehicles (12 – 14.1%), construction material (1.9 – 1%), MSW burning (1.8 – 0.8%), and industrial (1.3 – 1.2%).
  - In summer, % contribution of PM_{10} - $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: soil and road dust (51.1 – 29%), coal and fly ash (20.3 – 13%; includes burning of residual oil), biomass burning (12.7 – 28.1%), vehicles (9.4 – 17.6%), SIA (3.3 – 7%), construction material (2.1 – 3.1%), MSW burning (0.6 – 1.1%), and industrial (0.5 – 1.1%). It is noteworthy, in winter and summer, major sources for PM_{10} and $PM_{2.5}$ are generally the same
- The high presence of soil and dust, biomass burning, coal and flyash and vehicles (in PM_{10} and $PM_{2.5}$) at most the sites envelop the entire region.
- In summer, soil and road dust, vehicles and biomass burning activities contribute 73% to PM_{10} and 75% to $PM_{2.5}$. It is observed that in summer, the atmosphere looks brownish indicating the presence of large amounts of dust. In winter, the contributions of coal and fly ash, soil and road dust and construction material reduce significantly both in PM_{10} and $PM_{2.5}$ (by 58 and 62%) when winds are low and prevalent atmospheric conditions are calm.
- The contribution of the biomass burning in summer is at 28% (for $PM_{2.5}$) and 13% (for PM_{10}) and in winter at 28% (for PM_{10}) and 30% (for $PM_{2.5}$). The presence of sizeable

biomass is inconsistent in winter and summer, indicates the contribution from nearby areas and is impacted by meteorology.

- The contribution of the vehicles in summer is at 18% (for $PM_{2.5}$) and 9% (for PM_{10}) and in winter at 12% (for $PM_{2.5}$) and 14% (for PM_{10}). Vehicles (including domestic) that indicates the slow-moving traffic with high congestions on the major roads.
- The contribution of the SIA in summer is at 7% (for $PM_{2.5}$) and 3% (for PM_{10}) and in winter at 20% (for $PM_{2.5}$) and 19% (for PM_{10}). High and consistent contributions of secondary aerosols suggest the high emissions of precursors gases from different sectors, i.e., combustion sources, industries, brick kilns, biomass, MSW burning, domestic at far distances at regional levels from the receptor sites.

Directions for PM control

- Soil and road dust

  In summer, this source contributes about 51% to PM_{10}. The silt load on most of the roads is very high and silt can become airborne with the movement of vehicles. The estimated PM_{10} emission from road dust is about 28 tons per day. Similarly, soil from the open fields gets airborne in summer. The potential control options can be sweeping and watering of roads, better construction and maintenance, growing plants, grass, etc., to prevent re-suspension of dust.

- Biomass burning

  Biomass burning should be minimized if not completely stopped. Possibly, it could be switched to cleaner fuel for domestic fuel, local bakeries and hotels, industries, and other local thermal energy-consuming industries. All biomass burning in varanasi should be banned and strictly implemented.

- Coal and fly ash

  Coal and fly ash contribute about 19% to PM_{10} and unless sources contributing to fly ash are controlled, one cannot expect improvement in air quality. It appears these sources are more fugitive than regular point sources. Fly ash emissions from hotels, restaurants, tandoors and brick kilns within a 50 km radius also cause large emissions and require better housekeeping, fly ash disposal and improved zigzag technologies in brick kilns.

- Vehicular pollution

  This source is the largest source in winter and the most consistently contributing source to PM_{10} and $PM_{2.5}$ in winter and summer. Various control options include the implementation of BS-VI, introduction of electric and hybrid vehicles, traffic planning and restriction of movement of vehicles, retro-fitment in diesel exhaust, improvement in public transport, etc. These options are further discussed in Chapter 6.

- MSW burning

  One of the reasons for the burning of MSW/plastic waste is the lack of infrastructure for timely collection of MSW and people conveniently burn or it may smolder slowly for a long time. In this regard, infrastructure for collection and disposal of MSW has to improve and the burning of MSW should be completely banned.

- Secondary particles

  These particles are expected to source from precursor gases (organic gases, SO_2 and NO_x) which are chemically transformed into particles in the atmosphere. Mostly the precursor gases are emitted from far distances from large sources. For sulfates, the major contribution can be attributed to large power plants, refineries and brick kilns. However, the contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. Any particulate control strategy should also include control of primary precursor gases.

The effectiveness of the pollution control options and selection of an optimal mix of control options are analyzed in Chapter 6.

4.6.1 Comparison of Source contribution in different cities

It has been observed that the winter levels of $PM_{2.5}$ are very high in all the cities, comparable with cities in the state of UP and significantly higher in Delhi and the lowest in Jaipur (Table 4.13). It is noteworthy that $PM_{2.5}$ significantly reduces in summer in all cities except Delhi demonstrating the role of improved meteorology, where emissions in summer and winter may not vary as much as do the $PM_{2.5}$ concentration. It suggests that it is relatively easy to attain the air quality standards in summer, especially by controlling the road and soil dust which has high emissions.

Since all cities are major urban hubs, the vehicular contribution in winter is consistent at 15 - 35% (Kanpur). Contribution of secondary inorganic aerosol are consistent contributors in all cities (20 – 30 % in winter and 7 – 15% in summer) suggesting that the emissions from far areas influence the air quality in the cities and regional air quality action plan is a necessity. Industrial contributions are low (highest in Kanpur at 6%), as several actions have been taken by industries and there may not be very large industry in city limits. The source apportionment results for PM_{10} and $PM_{2.5}$ from Varanasi and Prayagraj were comparable to Agra city (Ghosh et al, 2023; Table 4.13) and there is a similarity in emission sources, especially in the three cities of UP. Biomass burning in winter is high (except Agra) in all cities 15 - 30% (maximum in Jaipur) which is indicative of burning of wood, dung, leaves, crop residue and other organic waste. Road dust, biomass burning, vehicles and secondary $PM_{2.5}$ are the common and important sources in all cities.

Table 4.13: Comparison of source contribution in different cities

Cities	Approximate Population (millions)	Area (Sq. Kms)	Season	$PM_{2.5}$ ($\mu g/m^3$)	(% Source Contribution							
					SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
Delhi	17.0	1483	Winter	363	29.88	25.84	0.78	4.79	1.52	4.29	7.75	25.14
			Summer	292	14.89	12.16	1.19	25.95	3.0	27.07	7.23	8.5
Agra	2.0	120	Winter	259	19.1	7.6	6.1	15.6	1.0	14	13.7	22.8
			Summer	67	5.5	9.9	2.9	22.9	2.9	34.5	7	14.4
Kanpur*	3.5	260	Winter	238	18.7	15.4	5.5	3.5	1.1	11.7	8.8	35.3
			Summer	78	9.7	22.5	5.3	3.5	11.9	21.9	10.3	14.9
Jaipur	3.5	485	Winter	114	22.6	32	1.7	1	0.6	18	7.5	16.6
			Summer	55	5.7	29.6	2.2	5.4	0.9	35.9	6.2	14
Prayagraj	2.0	365	Winter	196	16.6	26.6	5	12.7	1.6	9.6	5.5	22.3
			Summer	71	8.3	19.4	0.8	13.1	4.9	40.7	1	11.9
Varanasi	2.0	165	Winter	265	20.1	29.8	1.2	15.5	0.7	17.7	0.7	14.1
			Summer	116	7	28.1	1.1	13	3.1	29	1.1	17.6
*Secondary organic aerosol (SOA) estimated for Kanpur is equally distributed to biomass and vehicles contribution												

4.6.2 Emission Inventory Versus SA Results

The discussions here refer to the source strength of emission sources versus their contribution to ambient air as seen by SA results. The soil and road dust emissions are the highest and it indeed it has higher emissions in summer and lower in winter due to high-speed winds and dry conditions in summer. It is known that the atmosphere is very dusty in summer and this fact is reflected in the source apportionment results; contribution of soil and road dust is; (i) Varanasi: PM_{10}: 51% (summer), and 18% (winter); $PM_{2.5}$: 29% (summer) and 18% (winter) and (ii) Prayagraj: PM_{10}: 53% (summer), and 13% (winter); and $PM_{2.5}$: 41% (summer) and 10%

(winter). The soil and road dust contribution to PM_{10} or $PM_{2.5}$ levels is maximum in summer season compared to other sources as also seen in the emission inventory having maximum emission from road and soil dust.

Further, other combustion sources in winter become significant, therefore, the contribution of soil and road dust becomes less. It may further be noted that the maximum contribution of road and soil dust will be seen near the roads and open areas and purposefully the sampling site for measurements and SA study was kept far from the roads which may provide a disproportionate contribution of road dust and mask other important sources.

The other reason for variation in SA results compared to EI is the fact that while EI is limited to municipal boundaries, the air pollution levels are significantly influenced by outside air and long-range transport of primary and secondary particles, mostly not so much from road and soil dust.

The linkage between the source strength in emission inventory and its contribution to ambient air level can be at variance. The SA results depend on land-use pattern, traffic, road density, micrometeorological conditions, proximity of sampling site to a particular source(s), emission release height, and long-range transport of pollutants. This, in fact, signifies a need for both emission inventory and source apportionment studies.

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5 Dispersion Modeling

5.1 Introduction

The current state-of-the-science, comprehensive meteorological and regulatory air dispersion modeling systems have been used in the study to conduct the dispersion modeling. The American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD) has been used to assess the impact from short-range transport (<50 km) on $PM_{2.5}$ emitting from the sources within the Varanasi City,

5.1.1 AERMOD

AERMOD is a dispersion model having the ability to characterize the planetary boundary layer (PBL) through both surface and mixed layer scaling. This model is a complete and powerful air dispersion modeling package that seamlessly incorporates the following popular United States Environmental Protection Agency (EPA) air dispersion models into one integrated interface:

- AERMOD
- ISCST3
- ISC-PRIME

The AERMOD modeling system consists of one main program (AERMOD) and two pre-processors (AERMET and AERMAP). AERMOD uses terrain, boundary layer, and source data to model pollutant transport and dispersion for calculating temporally averaged air pollution concentrations.

The approach for modeling using AERMOD is shown in Figure 5.1. Onsite hourly meteorological data was generated by the WRF model. The model run was performed for a defined study period (the year 2020). The output of the WRF model was fed as the input of AERMOD in the pre-processor RAMMET and AERMET of the model. The observed meteorological data was collected from the UPPCB monitoring station located at Sanjay Palace, Varanasi and compared with the WRF results for validation.

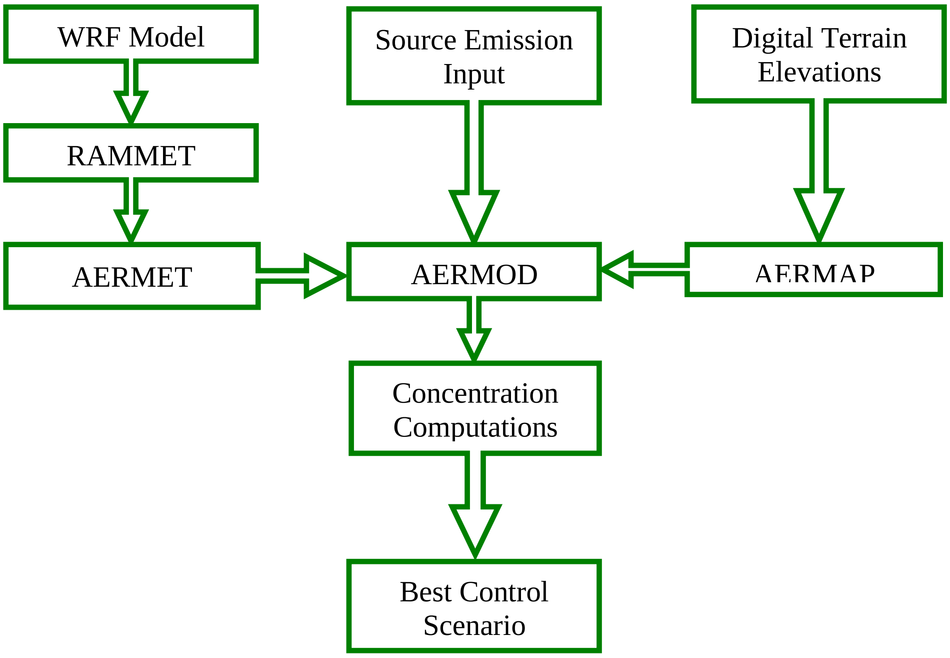


Figure 5.1: Approach for Dispersion Modelling using AERMOD

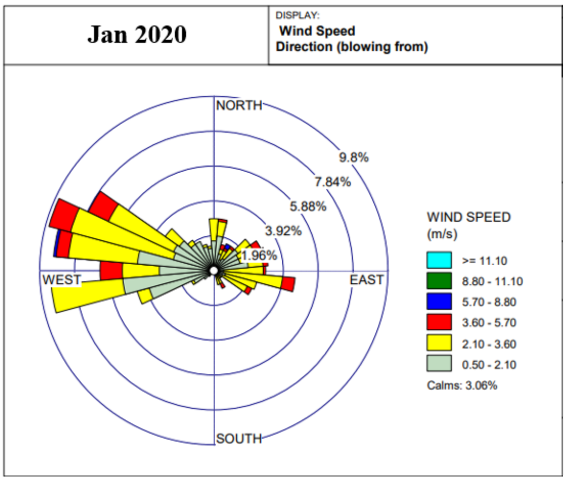
The meteorological parameters from the WRF model (wind speed, wind direction, rainfall, temperature, humidity, pressure, ceiling height, global horizontal radiation, and cloud cover) with one-hour resolution were organized in a spreadsheet. This spreadsheet was reprocessed in AERMET, which is the meteorological pre-processor of AERMOD. The terrain data at 90 m resolution of Shuttle Radar Topography Mission (SRTM) was used in AERMAP, which is also the pre-processor of AERMOD. This provided a physical relationship between terrain features and the behaviour of air pollution plumes and generated location and height data for each receptor location. AERMOD was further used to model air quality in the study for the prediction of pollutants concentration from different sources within Varanasi City.

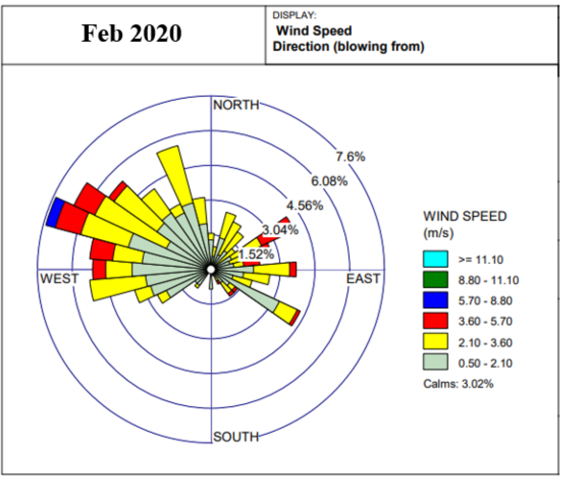
5.2 Meteorological Data

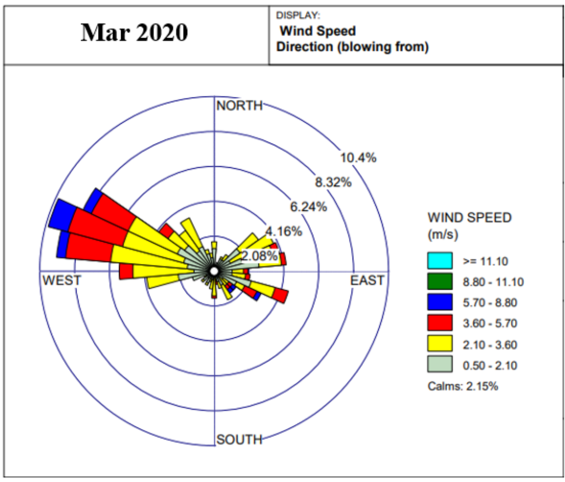
In evaluating the emission dispersion using the AERMOD, the meteorological dataset was generated using the WRF model (version 3.6.1) (Wang et al., 2007; Peckham et al., 2015) from January 01, 2020, to December 31, 2020. The frequency distribution and frequency count data were obtained by processing the hourly surface file in AERMET. The AERMET program is a meteorological pre-processor that prepares hourly surface data and upper-air data for use in the USEPA air quality dispersion model, AERMOD.

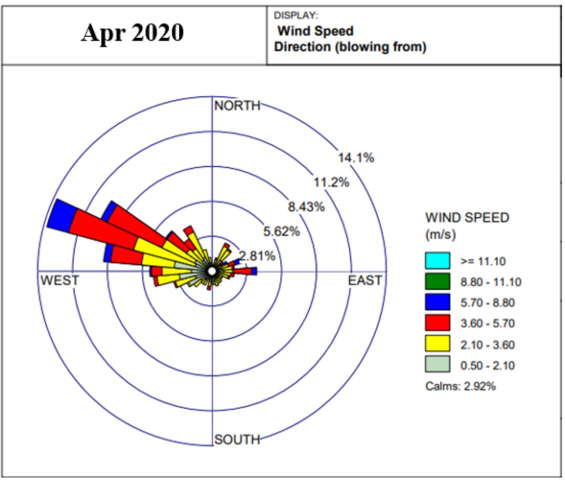
Dispersion modeling in the study area was undertaken for source apportionment and to evaluate the efficacies of various control options in improving air quality. The meteorological data generated continuously at sampling sites or IMD (India Meteorology Department)/WRF (Weather Research Forecast) model was utilized in dispersion modeling. The emission quantities coupled with meteorological data of the area were used in the dispersion model in estimating the concentration of various pollutants (as per the scope of work) and examining the contribution of each of the sources. Attempts were made to validate the model as measured concurrent concentrations at some air quality stations were available. The USEPA regulatory model AERMOD (2006) was used that considers topographical features like water bodies and terrain elevations. It may be noted that the model performance was tested with comprehensive statistical analyses by comparing the observed and predicted pollutant concentrations for other cities Kanpur (Sharma M. 2021) and Agra in the state (IIT Kanpur and UPPCB (2021).

The wind rose plots for all months of 2020 are shown in Figure 5.2. The predominant wind blowing direction was observed to be northwest in all the months. Also, a relatively high wind speed was observed in the summer season.









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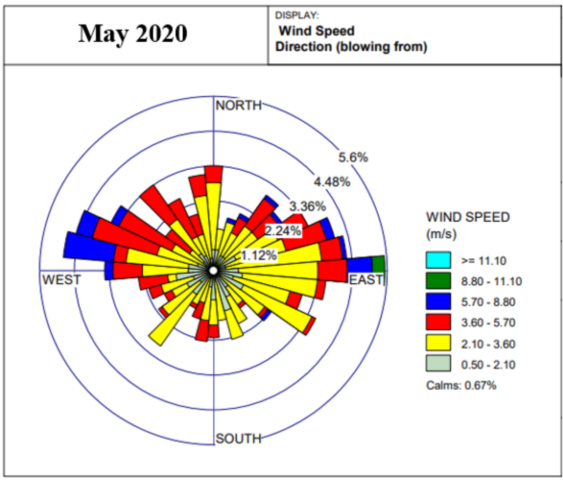
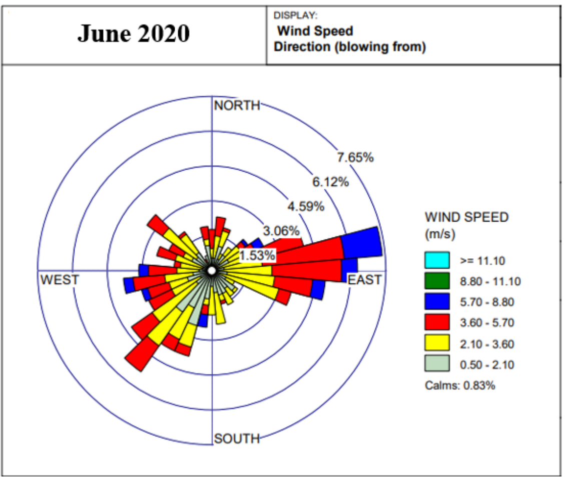
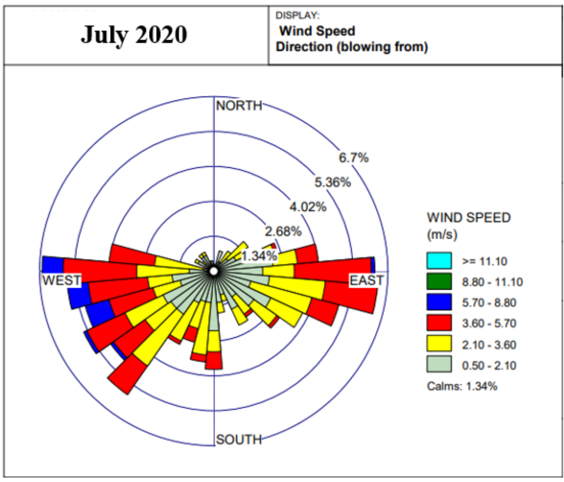
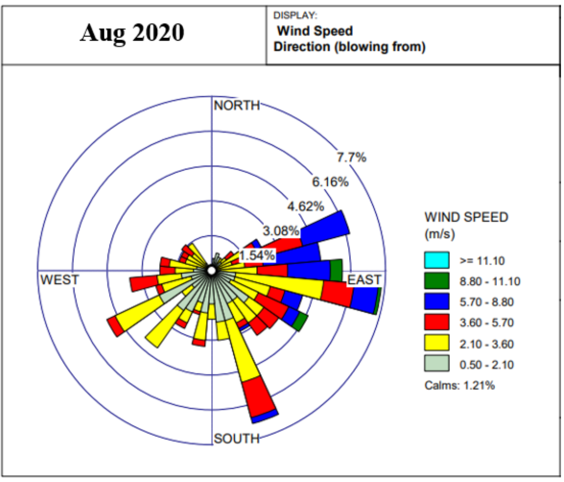
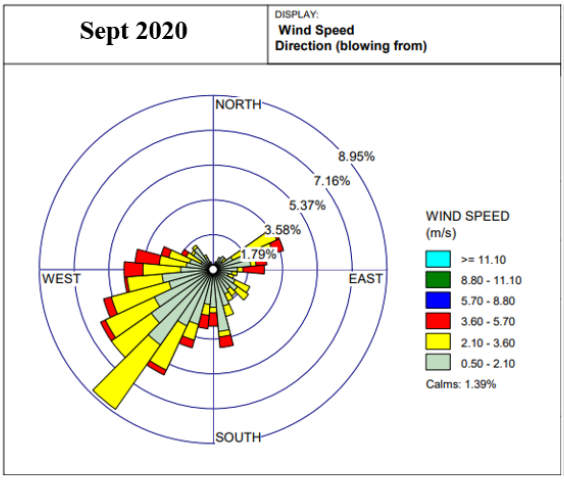
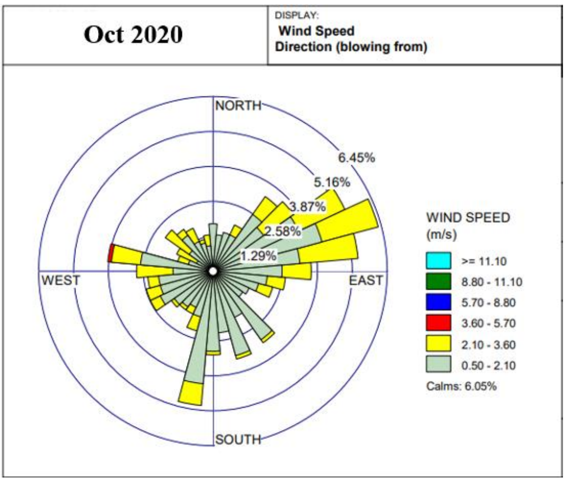

May 2020
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
SOUTH
WEST
EAST
5.6%
4.48%
3.36%
2.24%
1.12%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 0.67%


June 2020
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
SOUTH
WEST
EAST
7.65%
6.12%
4.59%
3.06%
1.53%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 0.83%


July 2020
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
SOUTH
WEST
EAST
6.7%
5.36%
4.02%
2.68%
1.34%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 1.34%


Aug 2020
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
SOUTH
WEST
EAST
7.7%
6.16%
4.62%
3.08%
1.54%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 1.21%


Sept 2020
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
SOUTH
WEST
EAST
8.95%
7.16%
5.37%
3.58%
1.79%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 1.39%


Oct 2020
DISPLAY:
Wind Speed
Direction (blowing from)
NORTH
SOUTH
WEST
EAST
6.45%
5.16%
3.87%
2.58%
1.29%
WIND SPEED
(m/s)
>= 11.10
8.80 - 11.10
5.70 - 8.80
3.60 - 5.70
2.10 - 3.60
0.50 - 2.10
Calms: 6.05%

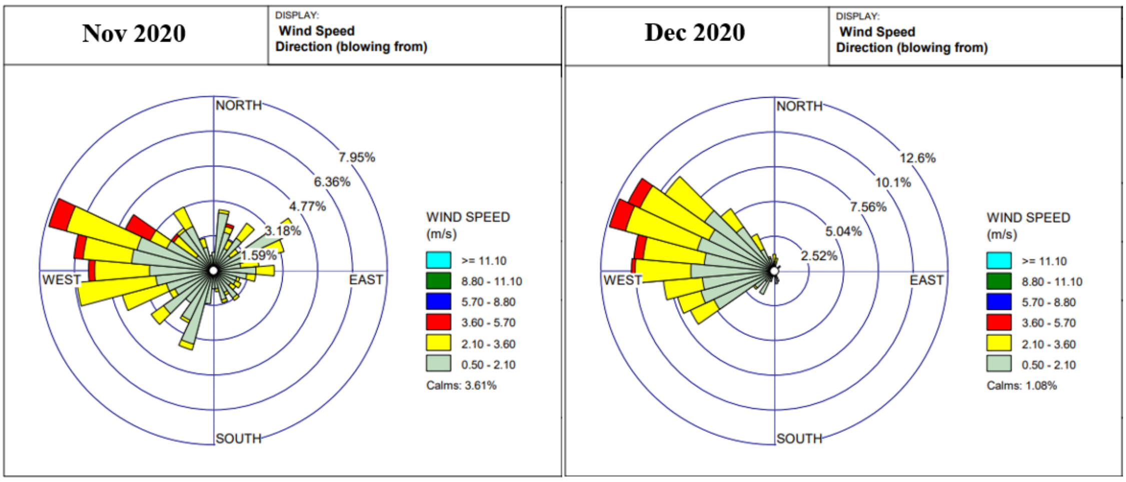


Figure 5.2: Wind Rose Plots for months of 2020

5.3 Digital Elevation Model (DEM) and receptor grid network

The Digital Terrain Elevation Model (DEM) is the most critical information required for complex terrain. The terrain affects the dispersion significantly. DEM is required to predict wind flow patterns and dispersion. AERMOD processes DEM data and creates an elevation and height scale (the terrain height and location that has the greatest influence on dispersion) for each receptor in the domain. The terrain is the vertical dimension of the land surface. Gridded terrain elevations for the proposed modeling domain were derived from 3 arc-second digital elevation models (DEMs) produced by the United States Geological Survey (USGS). The processed terrain elevation data is shown in Figure 5.3. Receptor locations were defined using a set of uniform cartesian grid networks. Uniform cartesian grid networks (Figure 5.4) were employed to assess the impact within the Varanasi City boundary.

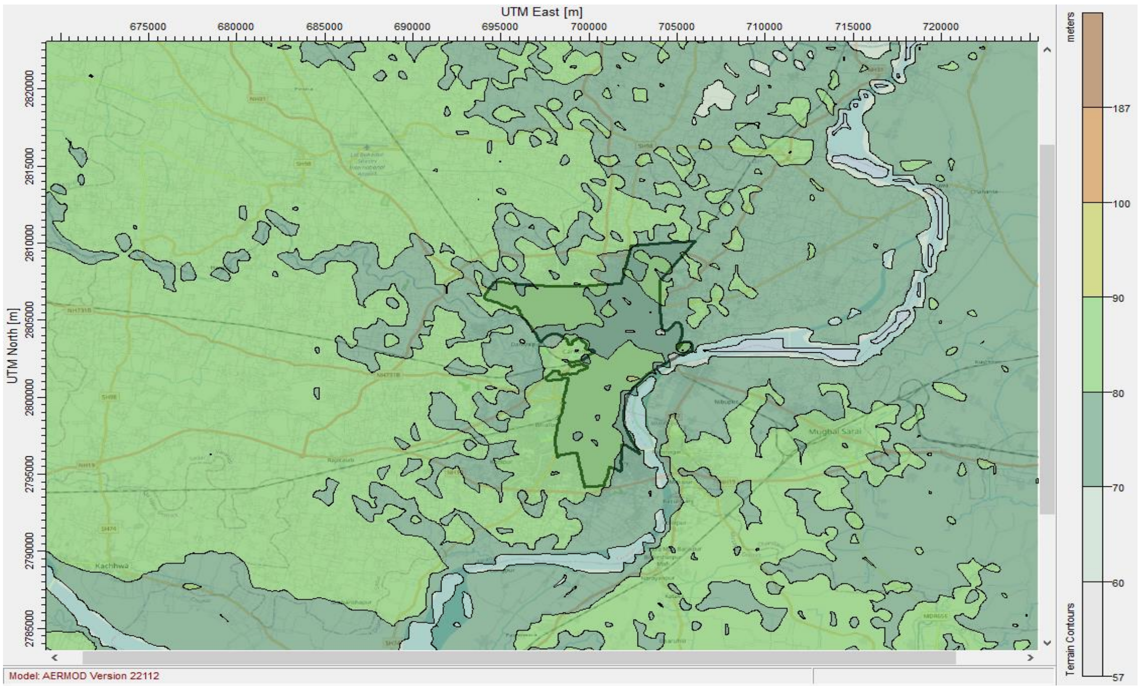

UTM East [m]
675000
680000
685000
690000
695000
700000
705000
710000
715000
720000
UTM North [m]
2820000
2815000
2810000
2805000
2800000
2795000
2790000
2785000
meters
187
100
90
80
70
60
57
Terrain Contours
Model: AERMOD Version 22112

Figure 5.3: Terrain Contour Map of the Varanasi City

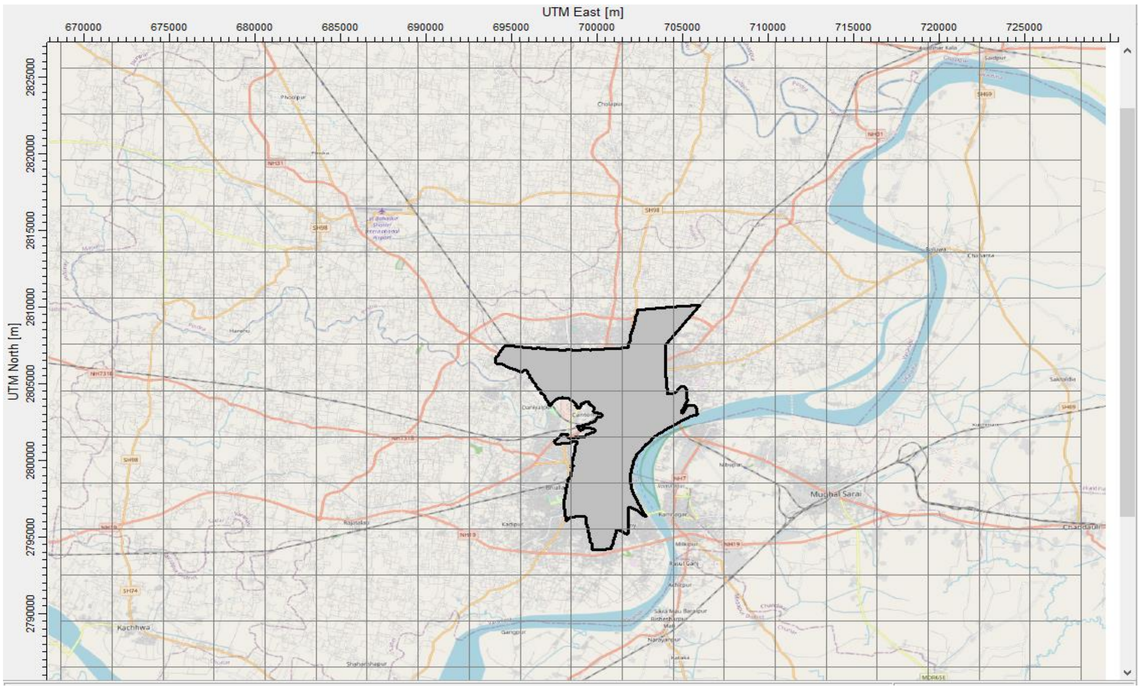

UTM East [m]
670000
675000
680000
685000
690000
695000
700000
705000
710000
715000
720000
725000
UTM North [m]
2825000
2820000
2815000
2810000
2805000
2800000
2795000
2790000

Figure 5.4: Uniform Cartesian Grid Receptor Network

5.4 Evaluation of Dispersion Modeling Results

The air dispersion modeling was done with complex terrain (using the elevation heights in Varanasi city). By this approach, all the elevations of terrain were accounted for, and the air dispersion reflected more accurate results as compared to flat terrain. The model was run considering only the sources within Varanasi city. Dispersion modeling was carried out using state-of-the-art models to apportion the contribution of collective sources and sector-wise; domestic, construction, hotels, hospitals, industries, vehicles, and road dust for the city.

5.4.1 The combined impact of all the sources

The highest 24-hour average, monthly average, and period average $PM_{2.5}$ concentration plots for all sources in the Varanasi City are given in Figure 5.5 to Figure 5.7. The high values of $PM_{2.5}$ concentration were obtained from the sources of road dust, vehicular, domestic and hotels. Hospitals, DG sets and industries contributed the least to the $PM_{2.5}$ concentration.

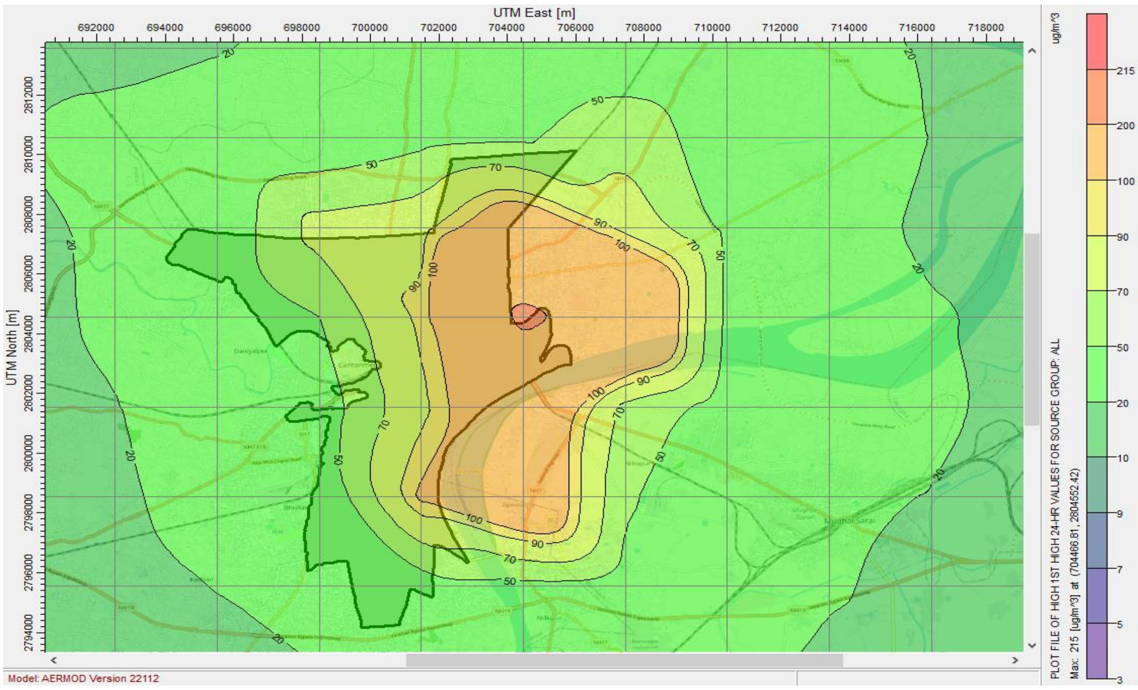
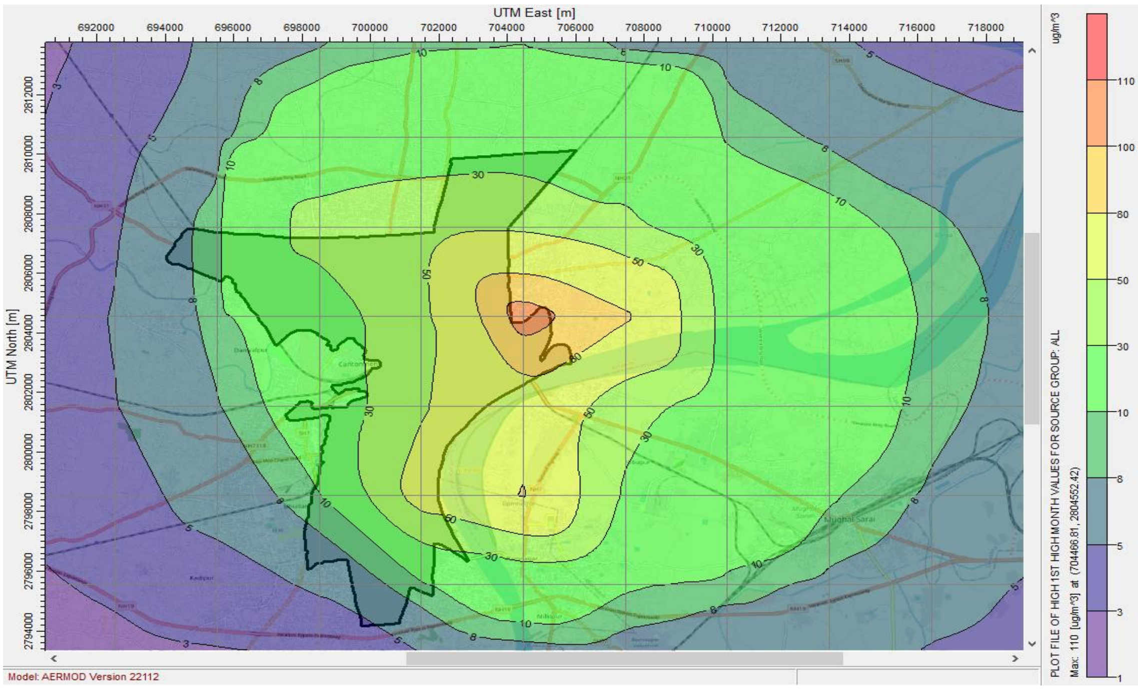

UTM East [m]
692000
694000
696000
698000
700000
702000
704000
706000
708000
710000
712000
714000
716000
718000
UTM North [m]
2812000
2810000
2808000
2806000
2804000
2802000
2800000
2798000
2796000
2794000
20
50
70
90
100
ug/m^3
215
200
100
90
70
50
20
10
9
7
5
3
PLOT FILE OF HIGH 1ST HIGH 24-HR VALUES FOR SOURCE GROUP: ALL
Max: 215 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112

Figure 5.5: Highest 24-hour Average $PM_{2.5}$ Levels from All Sources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2812000
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2800000
2798000
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ug/m^3
110
100
80
50
30
10
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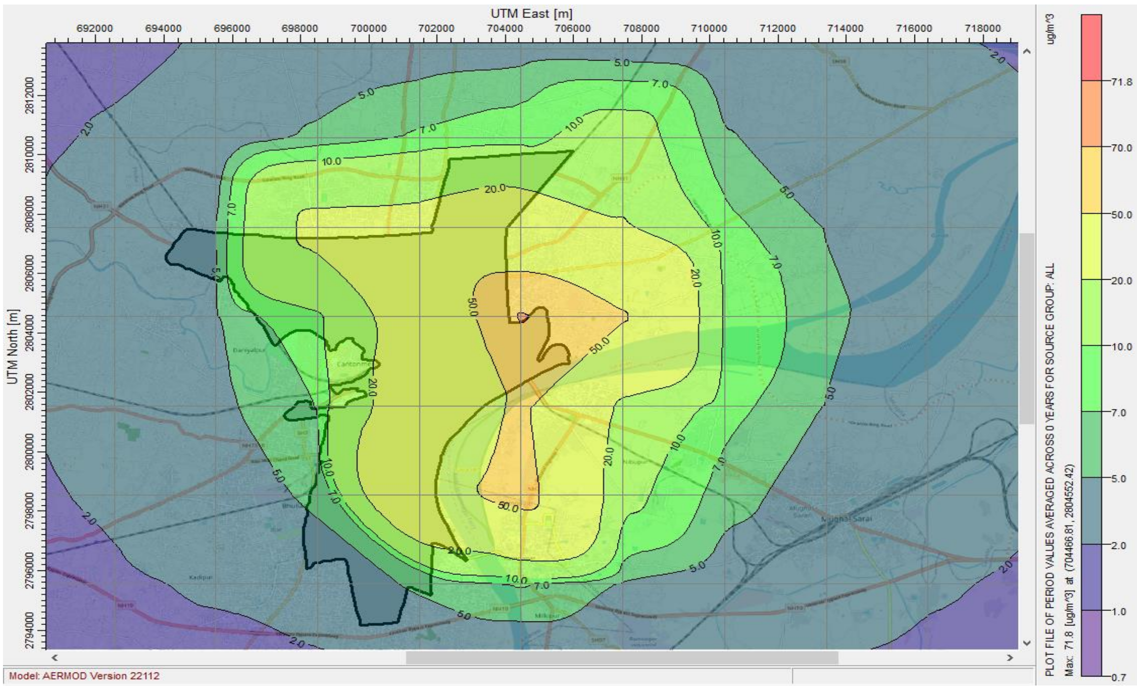
1
PLOT FILE OF HIGH 1ST HIGH MONTH VALUES FOR SOURCE GROUP: ALL
Max: 110 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112

Figure 5.6: Monthly Average $PM_{2.5}$ Levels for critical month (All Sources)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71.8
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PLOT FILE OF PERIOD VALUES AVERAGED ACROSS 0 YEARS FOR SOURCE GROUP: ALL
Max: 71.8 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112

Figure 5.7: Annual Average $PM_{2.5}$ Levels from All Sources

5.4.2 Sector-wise impact of all the sources

The AERMOD dispersion modeling was performed sector-wise to observe the impact of each source separately. The source-wise peak concentration based on daily, monthly, and annual (periods average for 2021) is shown in Table 5.1. The table presents the maximum contribution in $PM_{2.5}$ from Industry, vehicle and road dust sources.

Table 5.1: Maximum $PM_{2.5}$ levels (different time averages) from all sources

Source	Maximum $PM_{2.5}$ Levels ($\mu g/m^3$)		
	24-hr average	Monthly average	Annual average
Road dust	135	68.3	44.3
Vehicle	53.6	28	18.9
Domestic	18.1	9.27	6.19
Hotel	25.9	15.8	11.2
Construction	1.45	0.7	0.5
MSW burning	4.19	2.49	1.68
DG sets	0.007	0.003	0.002
Hospital	0.029	0.016	0.009
Industry	0.9	0.5	0.4

5.5 Scenario Analysis

(Develop and demonstrate control measures (three scenarios) on air quality improvements)

The study has considered three scenarios to assess the improvement in the air quality of Varanasi City. Maximum 24-hour average $PM_{2.5}$ concentration is the parameter considered to analyze different scenarios. In recent years CPCB focused on all types of pollution sources and tried to cut down the concentration of pollution sources as they are the contributors to $PM_{2.5}$ concentration in the city. The three scenarios are presented below.

5.5.1 Scenario: Baseline Scenario

Table 5.2 represents the current status of modeled air quality (maximum $PM_{2.5}$ concentration) in Varanasi city when no intervention has been taken. Maximum 24-hour average $PM_{2.5}$ concentration is the parameter considered to analyze different scenarios.

We considered total 3 scenarios to improvement air quality in the city:

5.5.2 Scenario 1: 25% Reduction in All Sources Emissions

Below table represents the status of air quality (maximum $PM_{2.5}$ concentration) in Varanasi city when the emissions from all sources are reduced by 25%.

5.5.3 Scenario 2: 50% Reduction in All Sources Emissions

Below table represents the status of air quality (maximum $PM_{2.5}$ concentration) in Varanasi city when the emissions from all sources are reduced by 50%.

5.5.4 Scenario 3: 75% Reduction in All Sources Emissions

Below table represents the status of air quality (maximum $PM_{2.5}$ concentration) in Varanasi city when the emissions from all sources are reduced by 75%.

Table 5.2: Highest 24-hour Average $PM_{2.5}$ Levels (µg/m^3) in different scenario

Months	**Scenario- Concentration (µg/m^3)**			
	Baseline	**Scenario 1**	**Scenario 2**	**Scenario 3**
January	149.0	111.73	74.48	37.23
February	141.8	106.34	70.90	35.44
March	124.9	93.64	62.43	31.21
April	124.3	93.24	62.17	31.08
May	85.6	64.21	42.82	21.41
June	93.3	69.99	46.66	23.33
July	113.4	85.05	56.71	28.35
August	109.2	81.88	54.59	27.29
September	136.1	102.03	68.04	34.02
October	154.6	115.99	77.32	38.66
November	179.9	134.92	89.97	44.98
December	214.8	161.03	107.38	53.68

The overall improvement in air quality for $PM_{2.5}$ under the three scenarios will be close to 25% in Scenario 1, 50% in Scenario 2 and 75% in Scenario 3 in the peak 24- hourly concentration (Figure 5.8). Since the maximum contribution is from road dust, the maximum advantage will be by improving road conditions. Sweeping, road washing and paved shoulders will be effective ways to control road dust emissions.

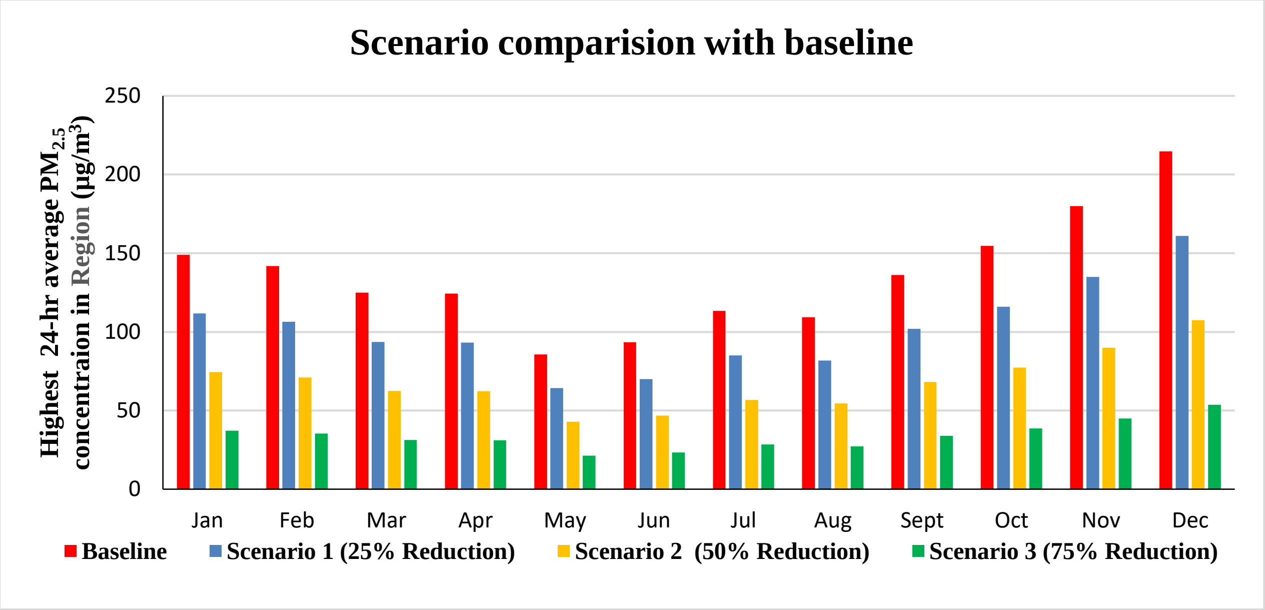
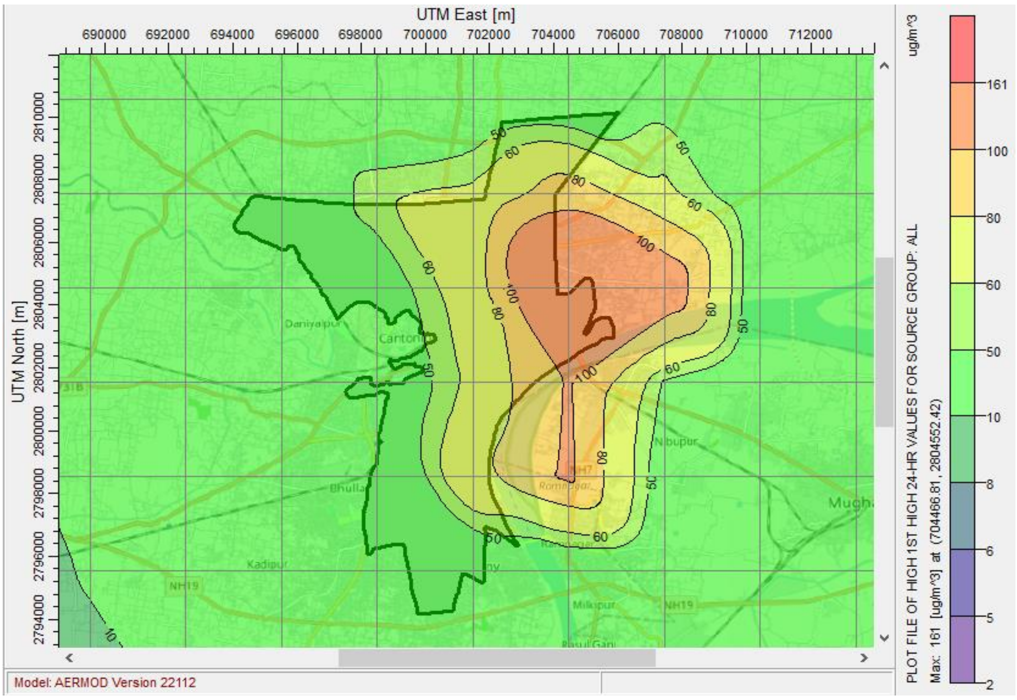


Figure 5.8: Air Quality Improvement in Scenarios 1, 2 and 3 in Peak 24-hour Average PM2.5 Levels

The highest 24-hour average $PM_{2.5}$ concentration plots for all sources with air quality improvement in Scenarios 1, 2 and 3 are given in Figure 5.9 to Figure 5.11.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2806000
2804000
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2798000
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60
80
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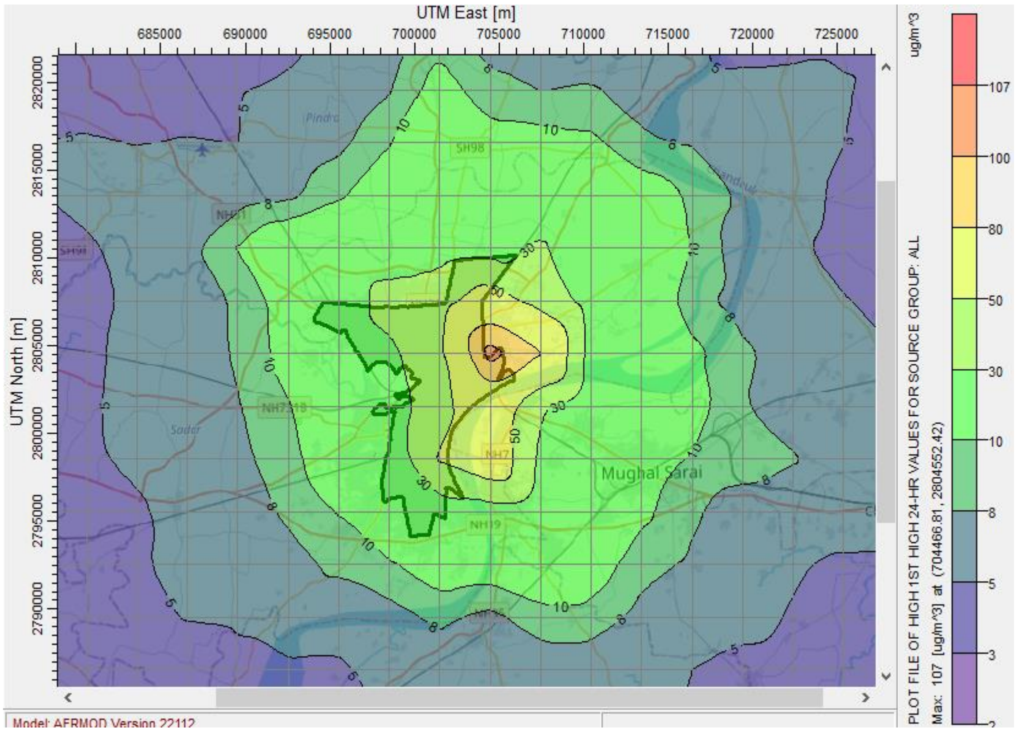
ug/m^3
161
100
80
60
50
10
8
6
5
2
PLOT FILE OF HIGH 1ST HIGH 24-HR VALUES FOR SOURCE GROUP: ALL
Max: 161 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112

Figure 5.9: Highest 24-hour Average PM2.5 Levels from All Sources (Scenarios 1)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UTM North [m]
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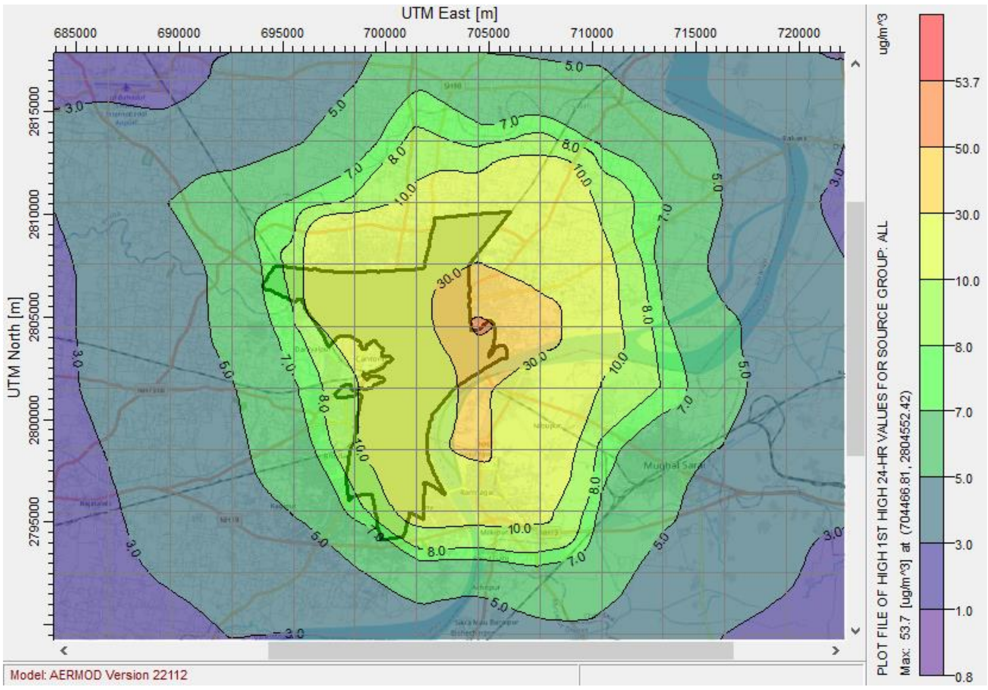
2800000
2795000
2790000
ug/m^3
107
100
80
50
30
10
8
5
3
2
PLOT FILE OF HIGH 1ST HIGH 24-HR VALUES FOR SOURCE GROUP: ALL
Max: 107 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112
Mughal Sarai
5
8
10
30
50

Figure 5.10: Highest 24-hour Average $PM_{2.5}$ Levels from All Sources (Scenarios 2)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ug/m^3
53.7
50.0
30.0
10.0
8.0
7.0
5.0
3.0
1.0
0.8
PLOT FILE OF HIGH 1ST HIGH 24-HR VALUES FOR SOURCE GROUP: ALL
Max: 53.7 [ug/m^3] at (704466.81, 2804552.42)
Model: AERMOD Version 22112
Mughal Sarai
3.0
5.0
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8.0
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30.0

Figure 5.11: Highest 24-hour Average $PM_{2.5}$ Levels from All Sources (Scenarios 3)

The city's highest contributing source is road dust followed by vehicular emissions and hotels. The rank of different sources based on their $PM_{2.5}$ contribution to the city is given in Table 5.3.

Table 5.3: Rank of sources in the city based on their contribution to $PM_{2.5}$

8003

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Sources	Road dust	Vehicle	Hotel	Domestic	MSW burning	Construction	Industry	Hospital	DG sets

The overall, top contributors to $PM_{2.5}$ at the hotspot location were road dust (63%), vehicle (24%), hotels (5%), domestic (5), MSW burning (2%), construction & demolition (1%), industries (< 1%), hospitals (< 1%) and DG sets (< 1%) on the critical day (Figure 5.12).

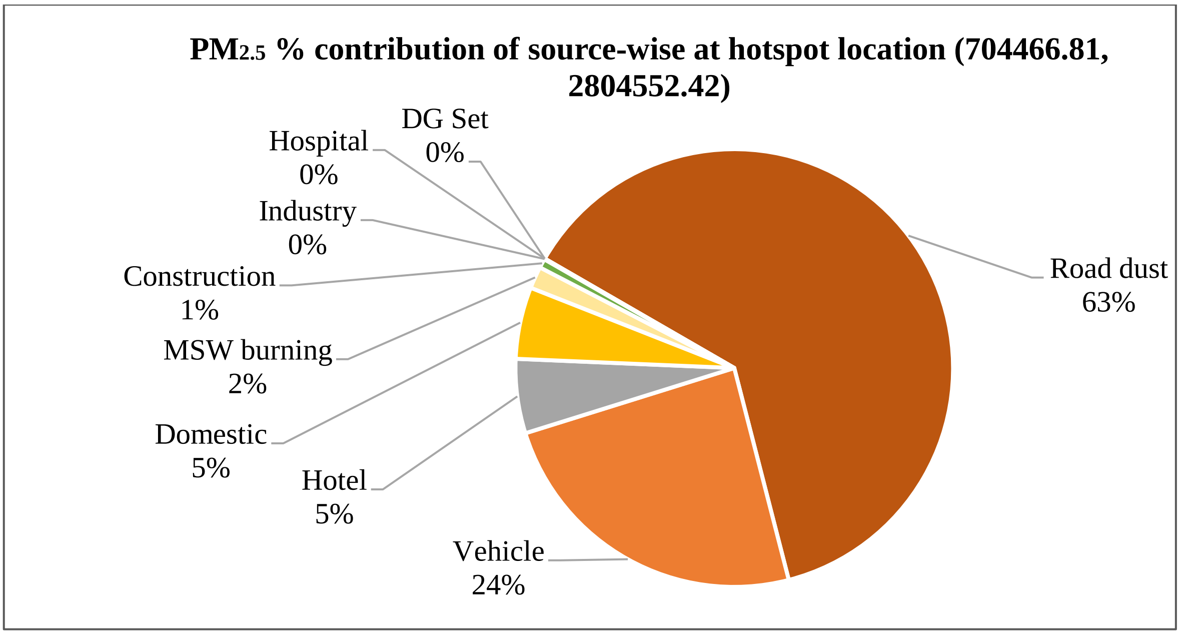

Figure 5.12: $PM_{2.5}$ percentage contribution of source-wise (24-Hr)

5.6 Summary of the Dispersion Modeling and interpretations

The major findings from the dispersion modeling are summarized below:

From the annual average plots, it is seen that $PM_{2.5}$ envelops a large area that gets elongated along the prevailing wind direction (SW) within the City of Varanasi (Figure 5.7). The annual standard for $PM_{2.5}$ concentration (40 µg/m^3) is exceeded in the city. The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winter months (November and December) while the lowest was during the summer (June and July).

The high values of $PM_{2.5}$ concentration were obtained from the sources of road dust, vehicular, domestic and hotels. Hospitals, DG sets and industries contributed the least to the $PM_{2.5}$ concentration.

The overall, top contributors to $PM_{2.5}$ at the hotspot location were road dust (63%), vehicle (24%), hotels (5%), domestic (5), MSW burning (2%), construction & demolition (1%), industries (< 1%), hospitals (< 1%) and DG sets (< 1%) on the critical day.

6 Control options, Analyses and Prioritization for Actions

6.1 Air Pollution Scenario in the City of Varanasi

The city of Varanasi has a complex urban environment concerning air pollution sources and faces severe air pollution of PM_{10} and $PM_{2.5}$. There are several prominent sources within and outside Varanasi city contributing to PM_{10} and $PM_{2.5}$ in ambient air. Chapter 3 presents the emission inventory and Chapter 4 describes the contributions of sources to the ambient air concentrations. Based on the comprehensive source apportionment study, the sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter. The highlights of the source apportionment study are presented below.

In winter, % contribution of PM_{10} – $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: biomass burning (27.9 – 29.8%), secondary inorganic aerosol (SIA; 18.7 – 20.1%), soil and road dust (17.9 – 17.7%), coal and fly ash (18.6 – 15.5%; includes ash from burning of residual oil), vehicles (12 – 14.1%), construction material (1.9 – 1%), MSW burning (1.8 – 0.8%), and industrial (1.3 – 1.2%).

In summer, % contribution of PM_{10} - $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: soil and road dust (51.1 – 29%), coal and fly ash (20.3 – 13%; includes burning of residual oil), biomass burning (12.7 – 28.1%), vehicles (9.4 – 17.6%), SIA (3.3 – 7%), construction material (2.1 – 3.1%), MSW burning (0.6 – 1.1%), and industrial (0.5 – 1.1%). It is noteworthy, in winter and summer, major sources for PM_{10} and $PM_{2.5}$ are generally the same.

Although sources contributing to summer and winter air pollution are different, the overall action plan should include control of all sources regardless of the season. This chapter presents various air pollution control options and their effectiveness in improving air quality. At the end of the chapter, a time-sensitive action plan is presented.

6.2 Controlling of sources within the city

6.2.1 Hotels/Restaurants/Guest Houses/Banquet Halls

The total number of Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) is found to be approximately 880. It was observed that coal/wood is being used as fuel in the tandoor, the common fuel other than wood is LPG. The PM emission in the form of flyash contributes to air pollution from this source. It is proposed that all restaurants of sitting capacity more than 15 should not use coal and shift to electric or gas-based appliances. A 70 % reduction of PM_{10} (666 kg/d) and $PM_{2.5}$ (466 kg/d) emission from this source can be achieved by stopping uses of coal.

It is also seen that the ash/residue from the tandoor/barbeques and other activities are indiscriminately disposed of near the roadside. This contributes to road dust emissions also. The Municipal Corporation may enforce coal-free cooking in hotels and restaurants, BHs, and marriage places. The ash must be stored in non-porous impervious bags and properly disposed-off. One may consider linking the commercial license to clean fuel, which may be enforced by Varanasi Municipal Corporation, Department of Food, Civil Supplies and Consumer Affairs, and oil Companies (Indian Oil, HP, etc.).

6.2.2 Domestic Sector

Although in Varanasi, 85% of the households use LPG for cooking, the remaining 15% uses wood, crop residue, cow dung, and coal for cooking (Census-India, 2012). The LPG should be made available to remaining 15% households to make the city 100% LPG-fuelled. This action is expected to reduce 85% of PM_{10} (1009 kg/day) and 84% of $PM_{2.5}$ (764 kg/d) emissions from domestic sector. The Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil, HP, etc.) may formulate a time-bound plan for every household.

By 2030, planning should be done that as many households as possible shift to electric cooking. For new societies, buildings should have a good infrastructure for PNG or provision for electric cooking – this will avoid transport and use of LPG cylinders.

6.2.3 Municipal Solid Waste (MSW) Burning

Any form of garbage burning should be strictly stopped and monitored for its compliance. It will require the development of infrastructure (including access to remote and congested areas) for effective collection of MSW and disposal at the scientific landfill site. The Varanasi Municipal Corporation should have the provision of penalty and fine to deter the people from burning any residue and improve the collection and disposal of the MSW.

The Varanasi municipal corporation should prioritize the MSW collection mechanism starting in a systematic manner in each ward. Special attention is required for fruits, vegetable markets and commercial areas and high-rise residential buildings, where MSW burning is common. A mechanism should be developed to carry out mass balance of MSW generation and disposal on daily and monthly basis. Any type of garbage burning should be stopped and ensured by Varanasi Municipal Corporation.

Desilting and cleaning of municipal drains by Varanasi Municipal Corporation should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H_2S, NH_3, VOCs, etc.

Proper disposal of MSW will require the development of infrastructure (including access to remote and congested areas) for effective collection of MSW and disposal at the scientific landfill site. The Varanasi municipal corporation should prioritize the MSW collection mechanism starting systematically in each ward with an emphasis on public awareness. Special attention is required for fruits and vegetable markets, commercial areas, mandis and high-rise residential buildings. Industrial waste burning is dealt with separately. Some of the MSW burning incidences are shown in Figure 6.1.

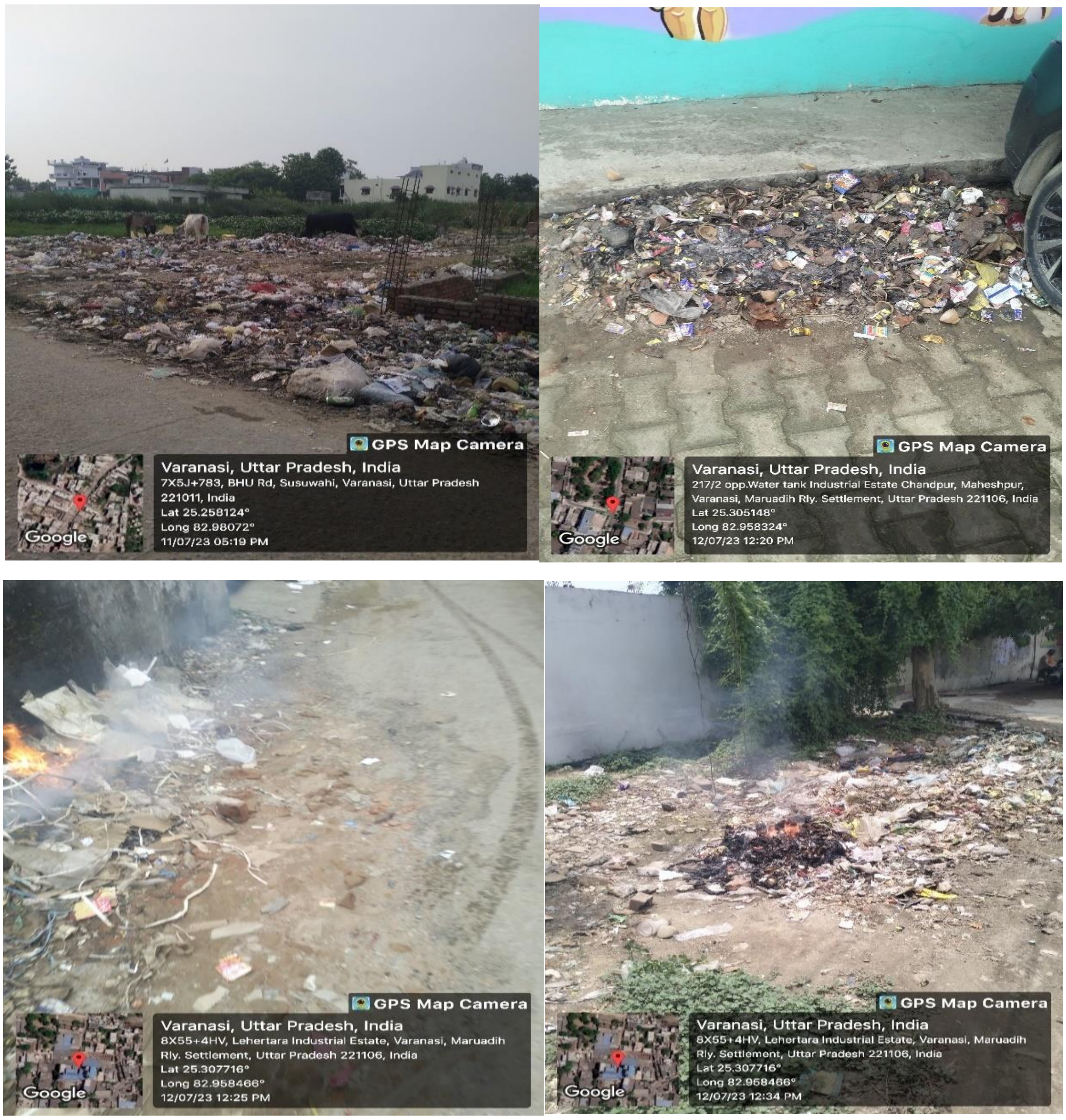
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Figure 6.1: Solid waste burning in the Varanasi

During the study period, it was discovered that Industrial Estate Lehertara Chandpur was burning large amounts of solid trash every 100 to 200 meters. However, small residue burning is a common practice at several locations in Varanasi.

Desilting and cleaning of municipal drains by Varanasi Municipal Corporation should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H_2S, NH_3, VOCs, etc.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Varanasi Municipal Corporation, UPPCB, and NGOs and municipal corporators.

The banning of MSW waste burning can reduce the emissions by 100% of PM_{10} (265 kg/d) and $PM_{2.5}$ (180 kg/d).

Helpline Number (For reporting complaints pertaining to air pollution viz., open burning, fugitive emission due to construction activities, etc.) should be created and advertised.

6.2.4 Construction and Demolition

The construction and demolition (C&D) emission can be classified as temporary or short-term. In a developing urban area, these temporary or short-term construction activities are frequent. This source is one of the significant ground-level emission sources. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road (Figure 6.2 and Figure 6.3).

Regions such as BHUS and AMUC, which are undergoing rapid urbanisation and are expected to attract settlers from neighbouring towns and villages, a large number of new dwellings are being built. As Varanasi is an old city, many of the buildings there are unsafe for people to live in; as a result, the government and the people living there are demolishing the older structures and constructing new ones in their place. Additionally, other ghats were repaired and developed during the study period, and the Kashi Vishwanath Corridor was also finished.

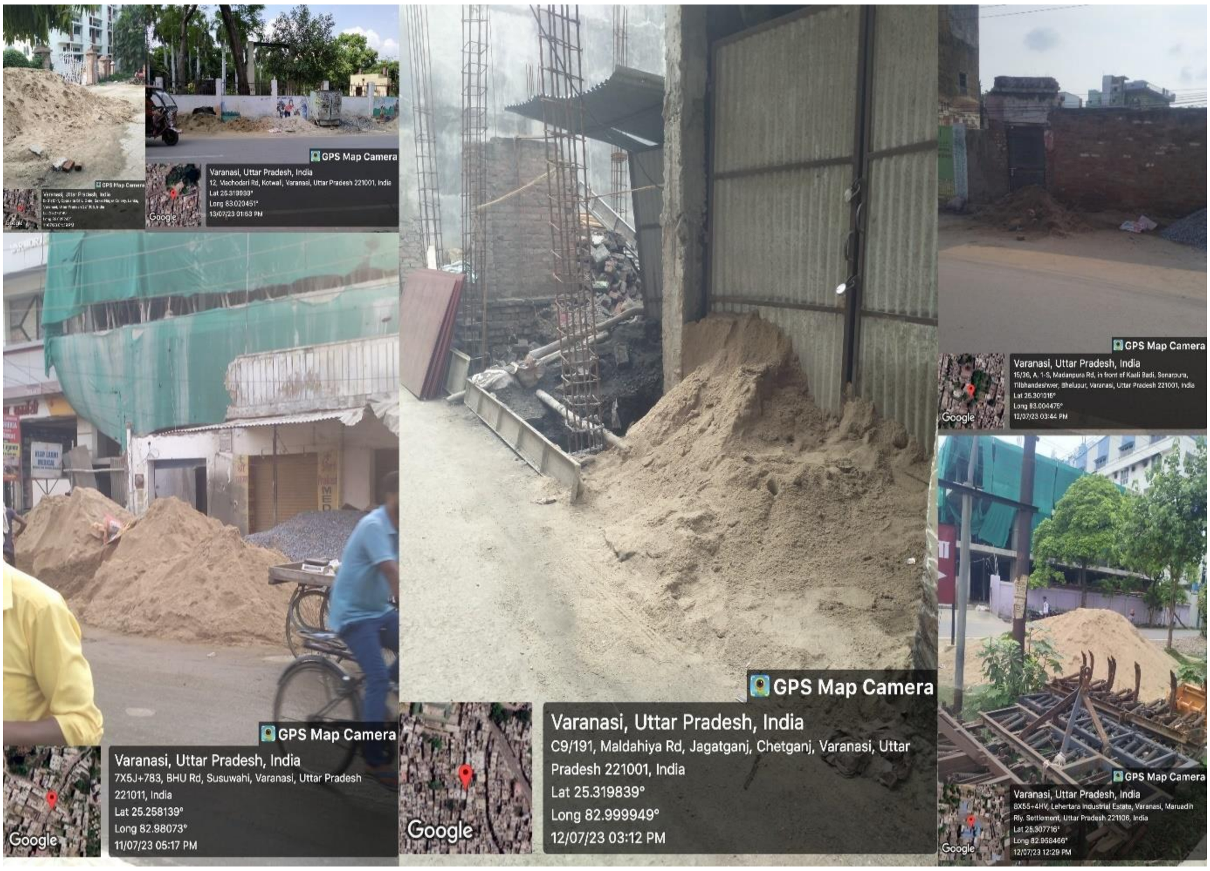
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Figure 6.2: Construction material and debris near construction sites

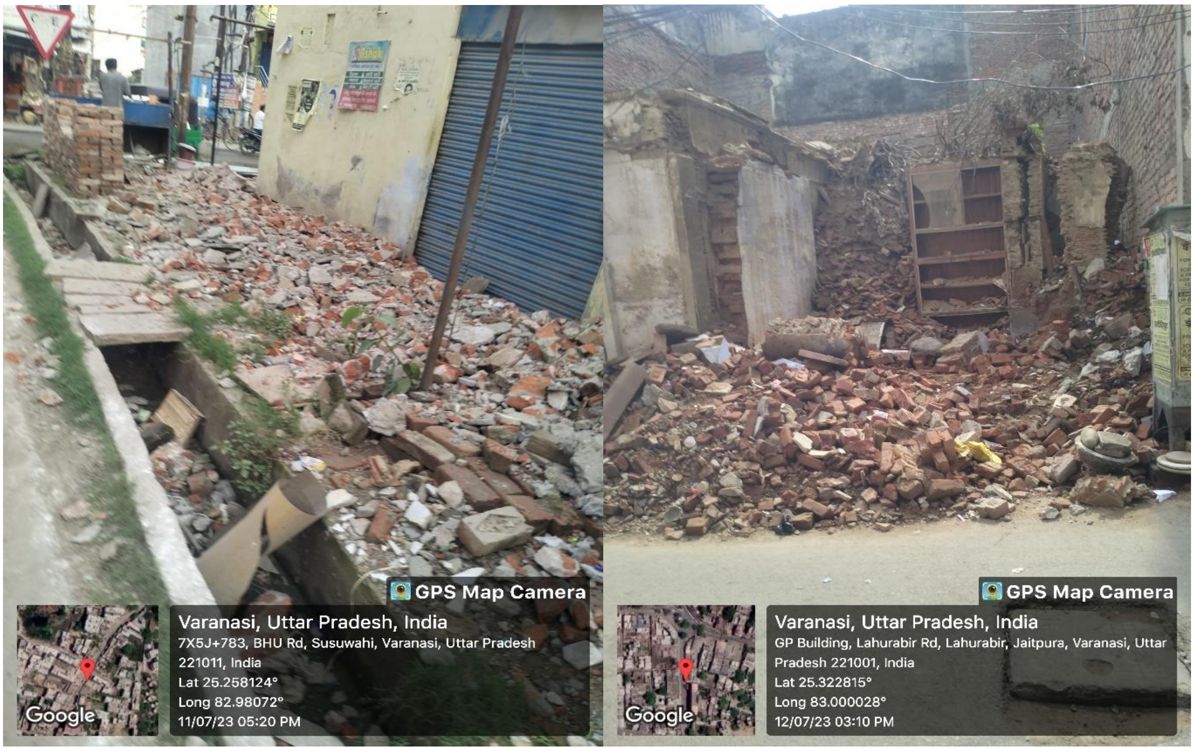
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Figure 6.3: Demolition debris near construction sites

Every C&D activity should fully comply with C&D Waste Management Rules, 2016. A C&D waste recycling facility must be created, which is a common practice in large cities. The control measures for emission should include:

- Wet suppression
- wind speed reduction (for large construction sites)
- Waste should be properly disposed of and not stored on the premises or on the roadside.
- Proper handling and storage of raw material: covered the storage and provide the windbreakers.
- Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.
- The actual construction area is covered by a fine screen.
- No storage (no matter how small) of construction material near roadside (up to 10 m from the edge of the road).

The above control measures should be coordinated and supervised under Varanasi Development Authority, Uttar Pradesh Housing Board, Varanasi Municipal Corporation, Urban Development Department, PWD, and UPPCB.

The suggested control measures will reduce the emission by 50% in PM_{10} (140 kg/day) and 72% in $PM_{2.5}$ (47 kg/day). This will also reduce the road dust and fly ash contribution to ambient air concentration.

6.2.5 Soil and Road Dust

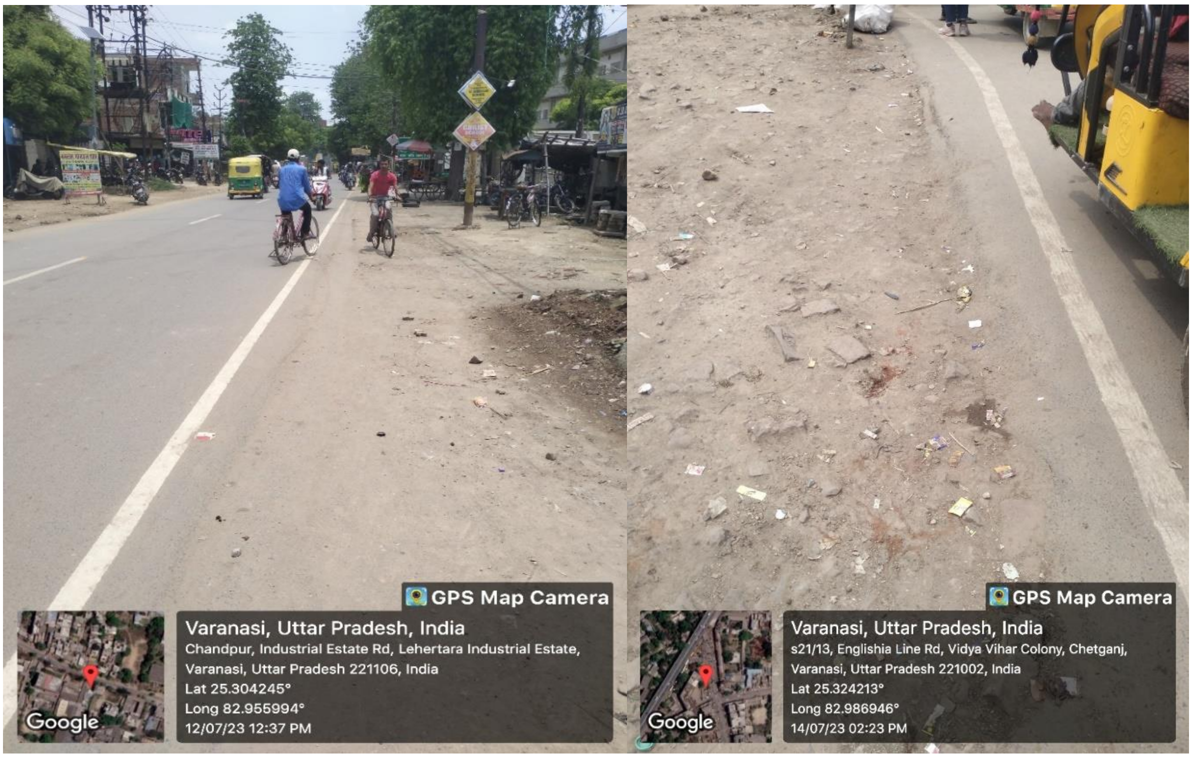
It has been observed that the soil and road dust emission and its contribution to ambient air concentration are consistent and it is one of the largest sources of PM_{10} and $PM_{2.5}$ emissions. The silt load, important factor PM emissions from the road varied from 18 to 26 g/m^2 which is very high. The industrial area, where heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for the pedestrians, proper drainage from the road, shrubs should be planted on-road divider. Some visuals of roads are shown in Figure 6.4.

The following control measures are suggested to reduce the dust emissions from the major roads:

1. Convert all unpaved, partially paved roads to fully paved roads. PWD (Public

Works Department) and city administration should act immediately to reduce the pollution load from road dust.

2. Mechanical sweeping with water wash: The road dust PM_{10} emission estimated is 79 ton/day and it depends on the season and moisture on the road. This emission will be maximum in summer and least in monsoon. Efficiency of mechanical sweeping has been reported as 55% (Amato et al., 2010). If the sweeping of the main roads is done twice a month, the road dust emission will be reduced by 23% and if the frequency is increased to four times in a month, then the road dust emission will be reduced by 52%. This reduction is likely to reduce the ambient air concentration of PM_{10} by 71 $\mu g/m^3$ in summer.
3. Municipal Council should carry out vacuum-assisted sweeping. The efficiency of vacuum-assisted sweeping should be 90% (Amato et al., 2010) and this should be part of the specification with no leakages of collected dust vacuum trucks. If the sweeping is done twice a month, the road dust emission will be reduced by 42% (PM_{10}= 16460 kg/day and $PM_{2.5}$= 3760 kg/day).
4. If the silt road is greater than 2 gm/m^2, the vacuum-assisted sweeping should be carried out along with washing by the municipal council and the UPPCB should have the surveillance of this action.
5. The condition of the roads must be maintained properly with no potholes and shoulders paved by interlocking concrete to have a proper sidewalk.
6. The truck carrying construction material, or any airborne material should be covered.
7. Shrubs and perennial forages, or grass covers should be planted on the medians wherever possible.
8. Vacuum sweeping of roads with high silt load locations Snt Atulanand to BHU, Lanka via Circuit House Maqbool Alam road-Andrapul, MariMai, Maldahiya, Sajan Tiraha, Rathyatra-Kamachha-Ravindra puri-Lanka, Mahmoorganj, Cantt. Stationat Chaukaghat and Pandeypur.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Long 82.986946°
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Figure 6.4: Road Dust prominent on various roads

The above control measures should be coordinated and supervised by Varanasi Development Authority, Uttar Pradesh Housing Board, Varanasi Municipal Corporation, National Highway Authority, PWD, and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

6.2.6 Vehicle Emission Control, Congestion and Traffic Management

The vehicle emission contribution is significant for CO, NOx, PM_{10}, and $PM_{2.5}$. There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM_{10}, $PM_{2.5}$ and NOx. The source apportionment results show that BCKR, IMAL, and AMUC have very large vehicle contributions (14 – 26% in summer in $PM_{2.5}$) with an overall contribution of vehicles in the city is 18% of $PM_{2.5}$ in summer. Out of about 12.8 tonne/d emission of $PM_{2.5}$ from vehicles, over 80% is from diesel vehicles, especially from trucks and buses. Therefore, control measures have to focus on advanced technological intervention for diesel vehicles like Diesel Particulate Filter (DPF). The general recommendations for vehicular emission control are enumerated below (specific recommendations are discussed later).

1. Retro-fitment of DPF: These filters have a PM emission reduction efficiency of 60-

90%. If the diesel vehicles entering and those in the city are equipped with DPF, there is a possible reduction of 40% of $PM_{2.5}$ emissions. This option must be explored as Bharat stage VI fuel is available and this technology can be adopted.

2. Industries should encourage employing trucks and heavy-duty vehicles of Bharat stage VI or IV with DPF for transportation of the raw and finished products at and from the industry.
3. By the end of 2030, a target of 50% of the total registration of vehicles in the city should be EVs in the sector of 2Ws, 3Ws and passenger cars. A suitable subsidy or tax break may be considered to the individuals opting for EVs. Charging infrastructure should come up quickly at multiple places, including public buildings and parking lots and battery swapping facilities should be planned to avoid long charging periods especially for two-wheelers.
4. PUC checks are the means to check emissions from on-road vehicles; this should be strengthened. Emissions from in-use vehicles also depend on the maintenance and upkeep of vehicles. In this regard, it is suggested that each vehicle manufacturing company should have its own service centers in sufficient number to cater to the need of their vehicles in the city. The automobiles manufacturing company owned service centers (AMCOSC) should be fully equipped for complete inspection and maintenance of vehicles ensuring vehicles conforming to emission norms and fuel economy after servicing.
5. The current official PUC centres in Varanasi are 105 as per the Transport Department. 4 - 8 PUC Centres are required per 1,00,000 vehicles (5 mins/vehicle and 12 hrs/day). Proper maintenance and calibration of equipment must be ensured by regular surveillance.
6. The existing PUC system may be upgraded to an Infrared based system/Remote Sensing device (RSD) for on-road emissions monitoring at major traffic zones to identify the polluting vehicles from fleet as per the guideline of the Ministry of Road Transport and Highways, Government of India (https://morth.nic.in/sites/default/files/ASI/Draft%20AIS-170%20-%20RSD_DF_Sep_20200930_C.pdf).
7. Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.
8. Check the overload vehicles: Use weigh-in-motion bridges/machines (WIM) and Weigh-bridges at entry points to the city and at the toll plaza to check the payload

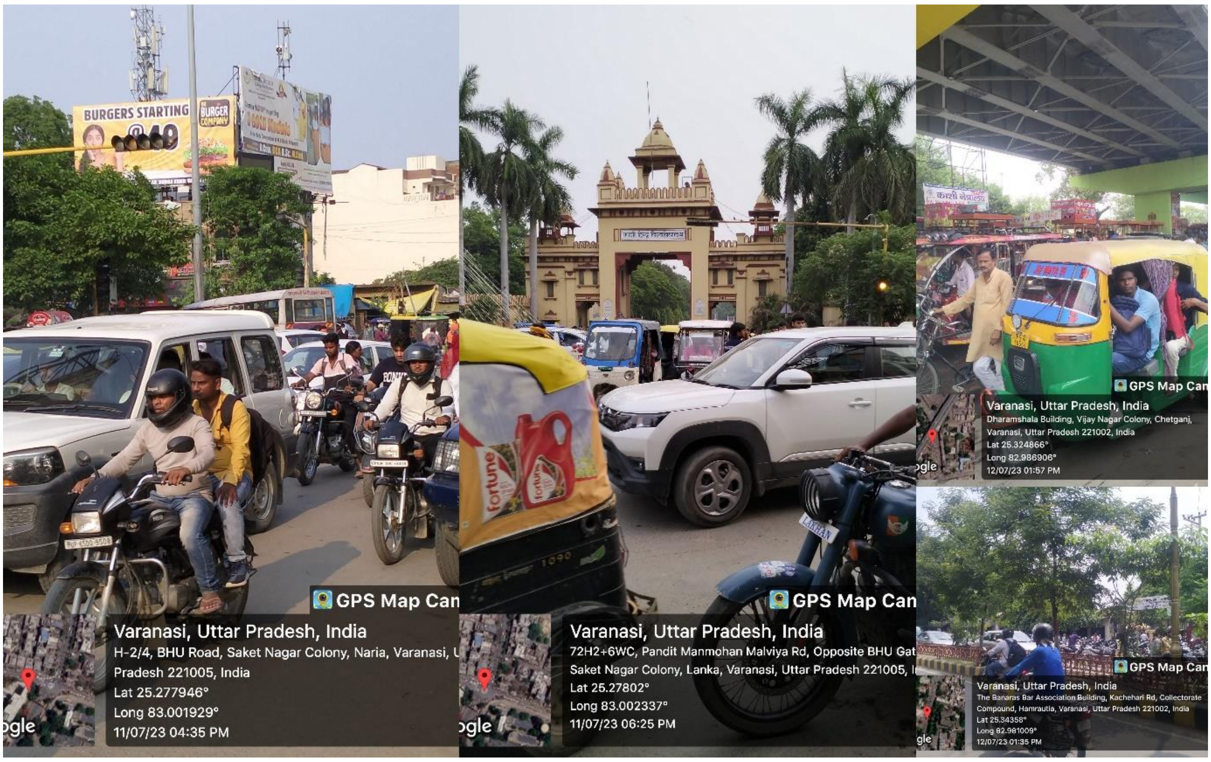
of commercial vehicles. As per CMVR, a penalty of 10 times the applicable rate for an overloaded truck is applicable.

9. UPSRTC should plan and install multiple electric charging facilities in its depots (in Varanasi and other destinations) to quickly move towards electric buses.
10. All local public transport in the city should also move to electric buses. It is suggested that buses should be medium size of 30 seating capacity and provide better frequency for easy maundering in the city to avoid difficult turning and congestion.
11. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications.
12. Information Technology (IT) systems in buses, bus stops, and control centre and passenger information systems should be introduced for the reliability of bus services and monitoring.
13. The public transport system is inadequate. The large intracity passenger demand is met mostly by tempos and autorickshaws. The tempo movements are undisciplined, and they form multiple lanes, stop as per their will in the middle of the road and hardly follow any traffic rules; this leads to congestion and safety hazard. There should be designated places where tempos can stop to drop and take passengers/commuters. There is no tempo terminal facility thus these mushroomed up at one place completely blocking the road at the terminus.
14. The intersections are very poorly designed. There is a need to improve the intersections of roads at many places of Varanasi City. The traffic signal, wherever installed, does not function properly which leads to slow traffic movement and reduced road safety. Steps shall be taken to install traffic signals on all the major intersections and traffic police shall enforce smooth traffic.
15. Other than a few roads, there is a lack of footpath availability and marking of zebra crossing for the pedestrian movements and people are forced to walk on the road. Proper footpaths and ease of crossing should be available for the pedestrians.
16. 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.
17. Public transport is to be strengthened with metro and/or an adequate number of buses, route plan based on commute surveys, and Mobile App based ticketing and seating system is developed in all major cities.

It is proposed that above control options may be coordinated under the supervision of State Transport Department.

Decongestion of Roads

Varanasi is the main centre of commercial and industrial activities in the state. A chaotic, undisciplined, and poorly managed traffic is the norm in the city (Figure 6.5). Driving in the opposite direction of main traffic, a culture of me first, parking in no-parking areas and on-street parking are the major causes of traffic congestion and pose a safety hazard. The slow movement of vehicles results in much higher emissions than vehicles at smooth cruising speed. The large vehicles (Trailers and Trucks) majorly operate in the areas of NH-2 GT road from Mughal Sarai to Allahabad SH-87, NH-7 Hyderabad gate in Varanasi to Jabalpur, Hyderabad, Madurai, etc SH-73, NH-29 Varanasi to Gorakhpur, Kushinagar. SH-74, NH-56 Varanasi to Jaunpur Lucknow. SH-98 require specific attention including installation of DPF.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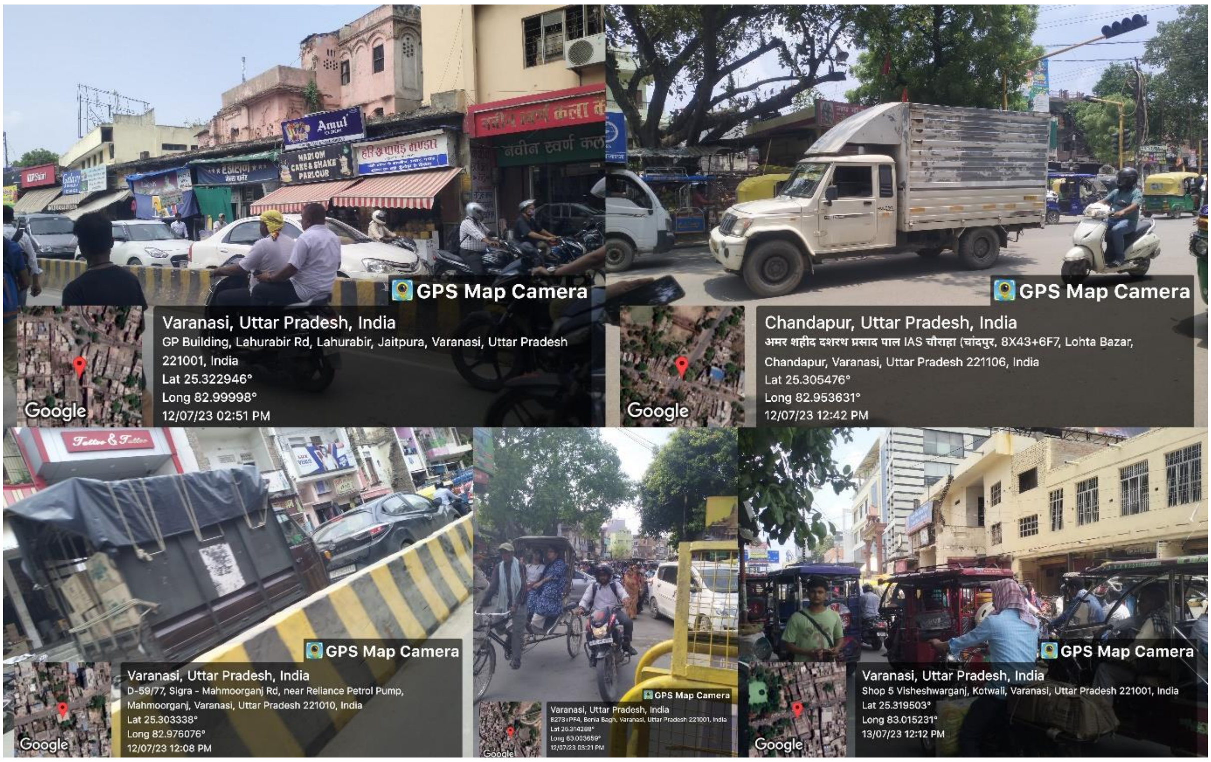
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Figure 6.5: Traffic Chaos and Congestion on the roads

The low speeds lead to a longer time on road causing large emissions. Further, under such driving conditions, emissions are often much higher than specified BS norms.

To increase the average speed and get full advantage of BS-VI, decongestion, removing encroachments from the roads, stopping unauthorized and improper parking is essential. The off-street parking is inadequate in the city causing jams and permanent congestion because of on-street haphazard parking.

The specific points that will help in decongestion are elaborated below.

- Heavy encroachment by shopkeepers and street vendors is observed in the commercial area and in residential areas, and vehicles are parked on the road. The parked vehicles take up to 40% of the road width, although one-third of the roads are more than 30 m wide. This reduces road utilization by about 50 percent.
- The unauthorized vehicle service centres located near the road make things worse as the vehicle is parked on-road while servicing and repairing and oil and grease spillage can be seen.
- Chaudhary Charan Singh bus stand is located in the center of the city (near Varanasi

Junction Railway Station), inter and intra city bus movements become heavy in this area and there is heavy traffic congestion because of road configuration. The nearby area of this bus stand is tightly jammed as the buses used to stop on-roads and within 10-15 minutes, traffic jam reaches 400-500 meters on all sides.

It is recommended that the Chaudhary Charan Singh bus stand is shifted to some other location at the outer periphery of city limits.

- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Varanasi city and create heavy congestion. As a result of connecting flyovers, other major connecting routes within the city will also decongest.
- Areas that are adjacent to the market centres like Chowk, Gyan Vapi, Vishwanath Gali or Lane, Thatheri Bazaar, Lahurabir, Godowlia, Dal Mandi Market and Golghar. experience heavy traffic congestion due to the unregulated parking and encroachment by local shop owners. The Godowlia and some other areas are commercial and mixed-use areas and encroachments along the road and of corridors are common and leave no space even for pedestrians. The on-street parking has to be removed and if required multistorey parking is developed (discussed later).

During the traffic recording and survey done by IIT kanpur, the following major intersections are identified as traffic bottlenecks (Table 6.1)

Table 6.1: Major Traffic Bottleneck at Varanasi City

Kashi Chauraha	BHU Main Gate Chauraha	Pandeypur Chauraha
Chowkaghat Chauraha	Lahartara Chauraha	Girjaghar Chauraha
Atulanand Bus Stop Chauraha		

The surveyed areas for traffic congestion were Lahartara Chauraha, Manduadih Chauraha, Chandpur Chauraha, Maidagin Chauraha, Visheshwarganj Chauraha, Vishwanath Temple, Godauliya Chauraha, Sigra Chauraha, RathYatra Chauraha, Trauma Centre, Ramnagar Chauk, Parav Chauraha, TengraMorhChauraha, Kajjakpura Chauraha, Sankat mochan Temple, Laxa Road, Beniabag Chauraha, Pt. Madan Mohan Malviya Chauraha, Cantt Railway Station, City Railway Station, Manduadih Raiway Station, Cantt Bus Station, PiliKothi Bus Station, KacheháriChauraha, Sarnath Chauraha, Chaukaghat Chauraha, MaldahiyaChauraha, Andharapull Chauraha which also need decongestion for smooth traffic operation.

Parking spaces

The off-street parking is inadequate in the city. Probably similar to the city of Agra, over 55% of major roads are taken by on-street parking causing jams and permanent congestion.

There must be no Parking zone (up to 50 m including auto, electric and hand-pulled rickshaw) near the intersections (Figure 6.6) it will help the smooth traffic flow. Certain parking policies in congestion areas (high parking costs, at city centers, only parking should be limited for physically challenged people.

The city should strictly follow Recommendations from IRC 12-2015 of prohibiting on-street parking as detailed below:

- Near Intersections: the capacity of an intersection is greatly reduced if vehicles are allowed to park on the approaches. Visibility is also adversely affected & safety is reduced. It is the general practice to prohibit parking for a distance of about 50 m on the approaches to a major intersection.
- Narrow Streets: Narrow streets with heavy traffic require that all possible measures should be taken to remove obstacles to traffic flow. Prohibition of parking can have a salutary effect on traffic flow & congestion. In the busy street of the central area, it is generally desirable to prohibit parking on two-way streets with less than 5.75 m width & one-way streets less than 4 m width.
- Pedestrian Crossings: Desirable to prohibit parking within about 8.0 m from the pedestrian crossings.
- Structures: Structures such as bridges, tunnels and underpasses generally have a road way width less than the highway and for this reason, it is desirable to prohibit parking on them.

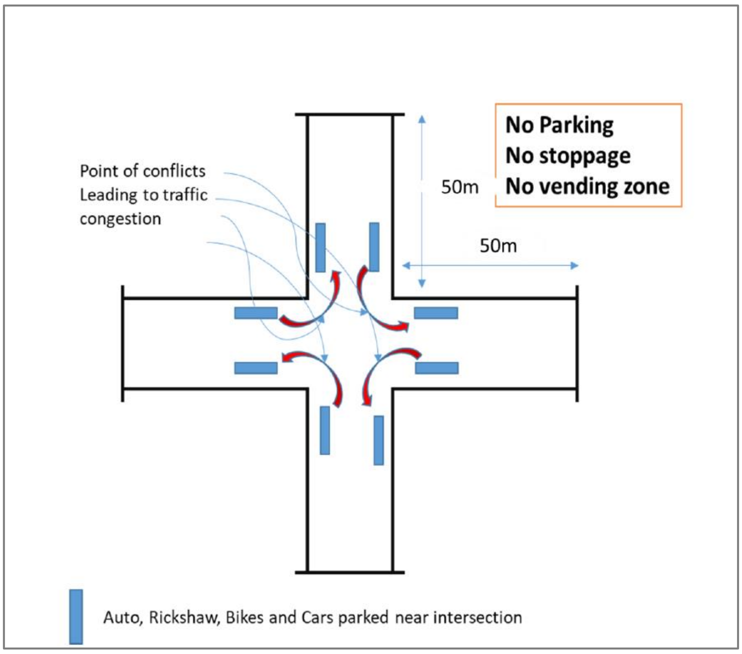
No Parking
No stoppage
No vending zone
Point of conflicts
Leading to traffic
congestion
50m
50m
Auto, Rickshaw, Bikes and Cars parked near intersection

Figure 6.6: Conflicts due to on-street parking near intersections

There are modern technologies to facilitate multilevel car parking systems and the city should consider multilevel car parking systems in near future.

Automated Multilevel Car Parking Systems

Automated Car Parking Systems are much in vogue - a method of automatically parking and retrieving cars that typically use a system of pallets and lifts and signaling devices for retrieval. They serve advantages like safety, saving of space, time and fuel (since one does not have to drive around for locating space) but also need to have an extra and a very detailed assessment of the parking required, space availability and traffic flow. These can be further categorized into fully automatic or semi-automatic systems.

People parked their bikes on the road near the civil court (Kachehari Road), which may finally cover the flow of vehicles (Figure 6.7). It is advised to create a bike parking system as well in that area.

Dependent/Stack System: This allows two passenger cars to be parked one above the other (Figure 6.8.) Its single post saves space and offers flexibility. Besides a platform (curved at the ends to allow the car to roll on/roll off conveniently) there is an operating control pendant that can be located anywhere in the garage, basement, and outdoor structure for operation from a safe distance.

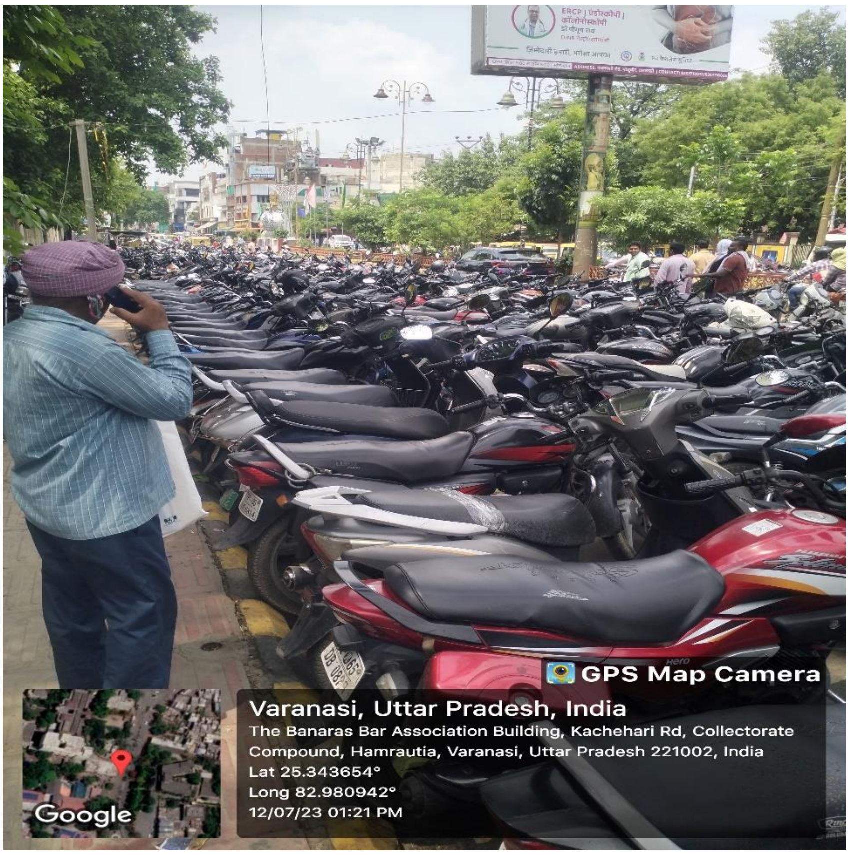
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Figure 6.7: Vehicles are parked at Kachehari Road

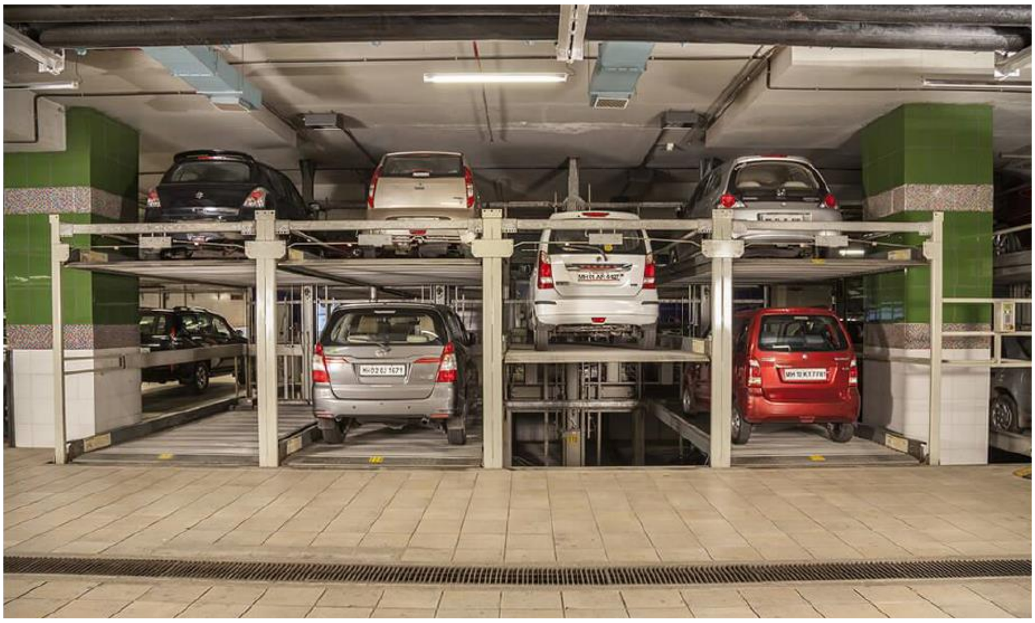

Figure 6.8: Multi-level car parking (example)

Puzzle Car Parking Systems: Here the cars move vertically and horizontally like a puzzle, till the car required comes to the lower level where it is driven out (Figure 6.9). Installed in basements, rooftops, under stilts, open grounds, terraces, driveways, etc the system is designed in the form of a matrix of rows and columns such as 2 x 2 or 2 x 3, etc in which out of the total number of available spots, a certain number of spots are kept vacant to enable horizontal and vertical movement of remaining spots.

Available in the range of two to six levels, all the cars are independent of each other, and the system can be installed in a phased manner.

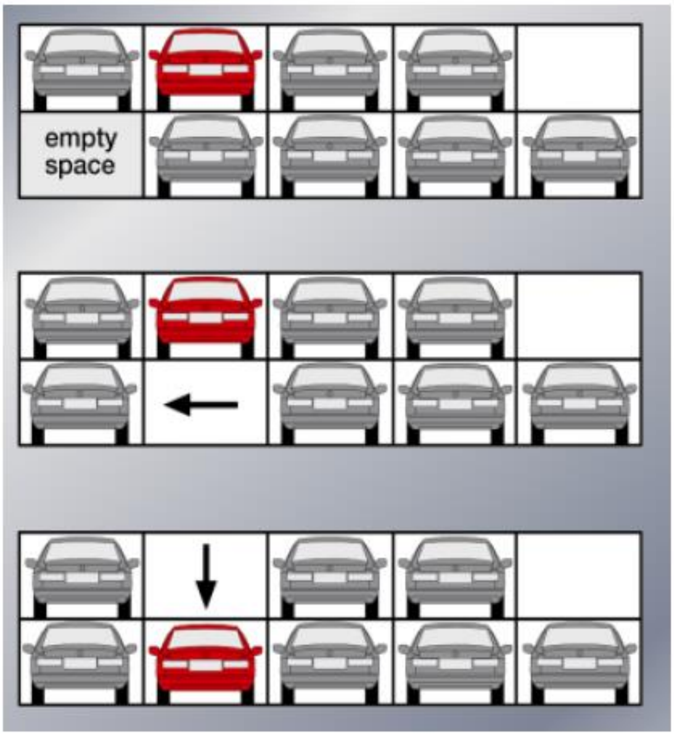

Figure 6.9:Puzzle Car parking system

Parking prices

Since on-street parking has been a major concern within the region, strict guidelines need to be adopted to discourage private vehicles in the settlements. In some areas, parking charges of Rs. 50 per hour needs to be introduced in the city. Also, the building norms must have the mandatory provision of parking at everyone's house. Unauthorized on-street parking must be penalized and strict monitoring of compliance of defined rules to be enforced. "No parking zone” and no-vending zones signs should be placed at required locations exhibiting parking issues and they should also be painted on roads with clear markings.

The introduction of one-way traffic in Varanasi has their effective road widths reduced due to on-street parking (Figure 6.10). Mostly, the parking is done on the walkways, and there is insufficient street space for pedestrians, cyclists, and public transport. At some places, there do exist parking places but still, people prefer to park on-street because of lower convenience and high prices at designated parking.

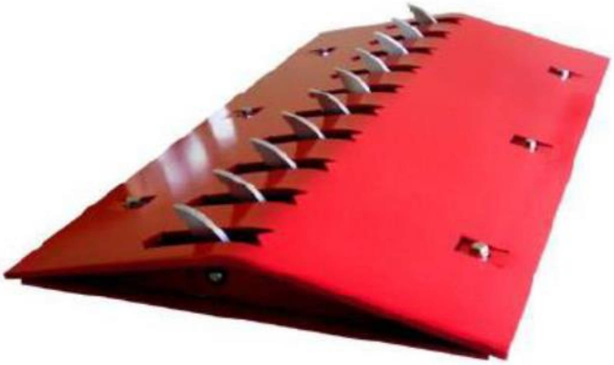

Figure 6.10: One-way traffic spike strips

Promoting Public Transport Travel

Increasing the efficiency of public transport can deliver benefits of enhanced road capacities, accessibility and safety, and security. Thus, it is proposed to improve the efficiency of the existing public transport system and bring in a new fleet of low-floor electric buses. The size of these buses (e.g. a 30-seater minibusses) should be decided to keep in mind the limited road width available at several locations in the city. Since the oversized buses tend to occupy most of the carriageway and further leads to congestion at bottlenecks while turning.

6.2.7 Industries

There are approximately 23 industrial units in Varanasi City having boilers, baby boilers, furnaces and thermic fluid heaters, and other air-polluting units, that contribute to particulate as well as gaseous emissions inside of the city boundary. Major fuels that contribute to emissions are Coal, HSD, Fuel Oil, Wood, Hard coke, and Rice Husk. The information on stacks, fuel, and their consumption was obtained from UPPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission.

It is also observed that the majority of industries use coal as fossil fuel in the industries. Since the industrial area is in the middle of the city, the industry should shift to PNG or LDO or other cleaner fuels in a time-bound manner possibly in one year.

In the Varanasi City, the prominent locations of Industries were Chandauli, Chandpur, Karkhiyaon, Ramnagar and Phoolpur. Although there were small industries scattered all around Varanasi City.

A coordinated effort under the supervision of UPPCB and Industries Departments is suggested to implement the following control measures:

- The majority of industries use multi-cyclones as air pollution control devices. It is recommended that these cyclones should be replaced by baghouses for effective control of particulate emission.
- Ensuring compliance with emission standards in industries: All industries causing Air, Water, and Noise pollution shall be made compliant w.r.t environmental regulations.
- Strict action to stop unscientific disposal of industrial waste in the surrounding area.
- Industrial waste burning should be stopped immediately which is seen in the industrial area especially packing materials.
- The area and road in front of the industry should be free from any storage or disposal of any waste or raw material.
- The industry should follow best practices to minimize fugitive emission within the industry premises; all leakages, transfer points, loading and unloading, material handling within the industry should be controlled.
- Adequate and quality electric supply should be available to the industries for an effective industrial operation and avoidance of the DG sets.
- It is seen that industrial waste (hazardous) is mixed with MSW and burnt in several parts of Varanasi. It is recommended that no industrial waste should be mixed with MSW rather disposed of at TSDF for hazardous waste disposal.
- There are industries with induction furnaces, which is a very pollution process, with almost no pollution control devices. The maximum emissions occur when the furnace lids and doors are opened during charging, back charging, alloying, oxygen lancing (if

done), poking, slag removal, and tapping operations. These emissions escape from sides and top the building.

- To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and commercially available. A side-based suction (Figure 6.11 to Figure 6.13) is far more effective than top suction, which interferes with the movement of the crane.

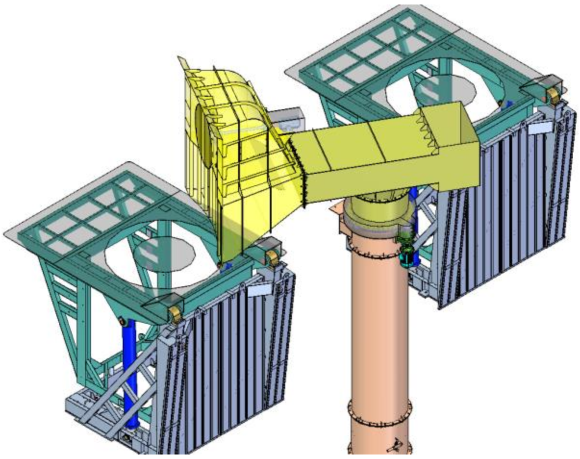

Figure 6.11: Proposed Suction Hood (Pic courtesy: Electrotherm)

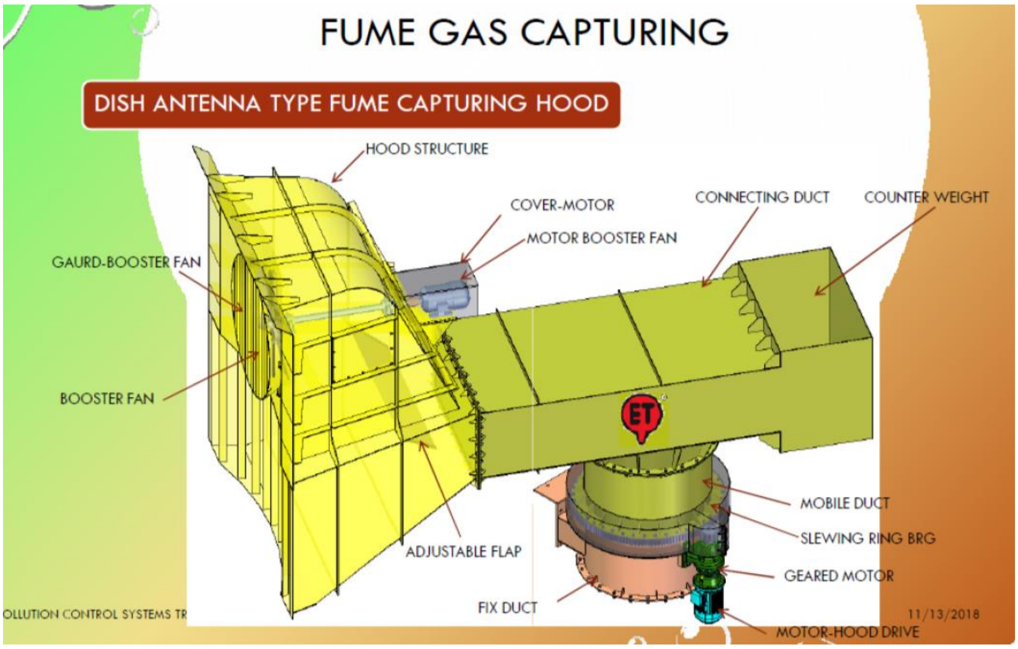
FUME GAS CAPTURING
DISH ANTENNA TYPE FUME CAPTURING HOOD
HOOD STRUCTURE
COVER-MOTOR
MOTOR BOOSTER FAN
CONNECTING DUCT
COUNTER WEIGHT
GAURD-BOOSTER FAN
BOOSTER FAN
ET
MOBILE DUCT
SLEWING RING BRG
GEARED MOTOR
ADJUSTABLE FLAP
FIX DUCT
MOTOR-HOOD DRIVE
OLLUTION CONTROL SYSTEMS TR
11/13/2018

Figure 6.12: Side-based Suction Hood (Pic courtesy: Electrotherm)

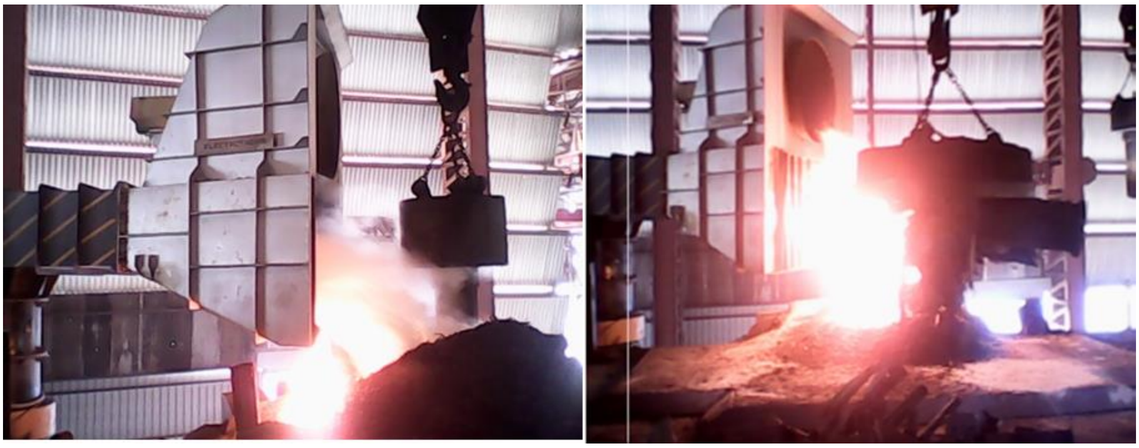

Figure 6.13: Working of side-based Suction Hood

- It is recommended that fume gas capturing hood followed by baghouse should be used to control air pollution.

The economics of the side-based suction hood for an induction furnace:

Assume capacity 8 tons per batch
Running time = 8 hrs.
Capital Cost of Suction Hood= Rs. 40 lakhs
Electricity cost for Running for one year = Rs. 26.5 lakhs
Running + Capital Cost for ten years = Rs. 3.0 crore
Per year operational cost (including maintenance) = Rs. 30 lakhs
Turnover of the company per year = Rs. 3 crore

Pollution control cost is 10% of turnover. Which is somewhat high and may raise the question of the economic viability of the industry, especially when other such industries in the country do not do such a level of investment. The industry will need some support in terms of soft loans or even some subsidies.

Industrial waste burning must be stopped under the supervision of UPPCB. It is also seen that solid waste (all types) is dumped and stored just outside the premises of the industry; this is not acceptable and it looks unpleasant and at times spills over the road. It is recommended that there should be a separate industrial non-hazardous dumpsite for industrial waste, and they should not be allowed to dispose of the waste on roads or in front of the industry. Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Varanasi Municipal Corporation and UPPCB.

6.2.8 Biomass Burning

India being an agrarian country produces a huge amount of crop residue annually, both on field and off-field, which is estimated to be about 500-550 million tons (Mt) (Indian Agricultural Research Institute, 2012). Rice crop contributes 36% of total crop residue whereas wheat contributes 22%. Traditionally, these residues are used for feeding cattle, 278 composting, thatching roofs in rural areas, and fuel for domestic and industrial uses. Uttar Pradesh (60 Mt) is the largest generator of crop residue followed by Punjab (51 Mt) and Haryana (28 Mt). According to a study conducted by Pathak et al. (2010) and from the calculations based on IPCC coefficients, total crop residue burnt per year in the country is estimated to be over 90 million tonnes.

Consequently, huge amount of paddy straw is burned on the open field during October-November. The practice is known as stubble burning. Though crop residue burning (CRB) is banned in these regions, practice still continues. The thick cloud of smoke emitted causes atmospheric pollution and poor air quality at local, global and regional scale and poses serious threat to human health (Kaskaoutis, 2014). This emission of CRB can certainly impact air quality in Varanasi and other cities in the Gangetic plane. The CMB modelling has clearly identified biomass burning as an important contributor to Varanasi’s PM_{10} and $PM_{2.5}$.

Alternatives to biomass burning

Alternatives to biomass burning include removal of the straw from the field and its use for other economic activities: energy production, biogas generation, commercial feedstock for cattle, composting, conversion in biochar, raw material for industry (John A., 2013).

6.2.9 Coal and Fly Ash

This study has identified that Coal and fly ash contribute more than 10% in Varanasi. This implies that there is more windborne fly ash in the atmosphere. In the earlier discussions in this chapter, control at other sources (Hotels, Restaurants, Guest Houses, and Banquet Halls) 880 were the analysed. In use or abandoned fly ash ponds are also contributing to PM pollution. There is a possibility of contribution of flyash from brick kilns operating outside Varanasi. The following actions are proposed to reduce the fly ash emissions.

Preventing the wind from entraining the dust particles can be accomplished by keeping the wind from blowing over the material. This can be done by confinement or by wind control or by developing a dense green belt all around the ash pond.

Reduction in wind speed, and therefore reduction in emissions can be achieved using one or more of the many diverse forms of windscreen in addition to enclosing the dust area. Commercial windscreens are portable and can be placed in front, on top, or any desired position in respect to a source.

The most effective was to avoid fly ash getting airborne is to keep the entire pond moist and possibly maintained about 1mm of water layer over the entire fly ash pond.

6.3 Environmental Surveillance

1. A system should be developed for monitoring environmental quality in order to detect areas of pollution concentration in time for remedial measures.
2. GRAP System (Graded Response Action Plan) should be developed: It is an emergency plan through which pollution control strategize to act according to air quality status suitable and rapid action that can be implemented quickly.
3. Pollution Control Board should take regularly do visits to check the status of road dust as it is seen that road dust is a major emission source for particulate matter.
4. Visual emissions must be informed and properly documented so that data of industries or sector is causing pollution can be identified.
5. For doing the above steps manpower must be increased in the respective departments so that the surveillance can be conducted uninterrupted.
6. Industries illegally running night shifts must be checked through surveillance. At night dispersion is more difficult that will cause more impact of pollution.
7. Solar power should be installed in Varanasi to reduce the running hours of Diesel Generators as well as to power infrastructural facilities in the commercial area.

6.4 Summary of Actions and Control Options

It may be noted that air polluting sources are plenty and efforts are required for every sector/source. In addition, there is a need to explore and implement various options for controlling air pollutants. A list of potential control options (technical, administrative and management) based on the above discussion that includes interventions is presented in Table 6.2 for $PM_{2.5}$ and PM_{10}.

6.5 Strengthening of UPPCB Varanasi Regional Office

The following measures may be taken to strengthen Regional Office of UPPCB

- Additional manpower for sampling, analysis, assessment, action plan implementation and surveillance.
- Coordination with other implanting agencies.
- Upgradation of emission inventory every two year and assess emission reduction.
- Capacity-building through regular training; and
- Laboratory upgradation for analysis different pollutants.

8030

Table 6.2: A Glance of Control Options and Action Plan for City of Varanasi (for details read section 6.2)

Source	Control Action	Responsible agencies	Time Frame
Hotels/ Restaurants/ Banquet Halls	All restaurants (sitting capacity of more than 15 persons) should not use coal in any form and shift to gas-based or electric cooking appliances.	Varanasi Municipal Corporation	1 year
	Link commercial license to clean fuel gas	Varanasi 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-off near the roadside – proper collection and disposal required.	Varanasi Municipal Corporation	1 year
Domestic Sector	LPG to all. About 10 - 15% of populations (including nearby villages) may still be using solid fuel (e.g., wood, biomass and dung) as cooking fuel and they should shift to LPG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	New building complexes or societies should have PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 years
	By 2030, the city may plan to partial shift to electric cooking or PNG at the minimum	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 -7 years

Source	Control Action	Responsible agencies	Time Frame
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance require improvements.	Varanasi Municipal Corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF only.	Varanasi Municipal Corporation, UPPCB	
	Desilting and cleaning of municipal drains on regular interval to stop ammonia, H_2S and VOC emissions	Varanasi Municipal Corporation	
	Waste burning (e.g., packing material, waste oil) in industrial areas should be stopped.	UPSIDC, UPPCB	
	Weekly and monthly mass balance of MSW generation, collection and disposal be undertaken.	Varanasi Municipal Corporation	
	Sensitize people and media through workshops and literature distribution as not to burn the waste.	Varanasi Municipal Corporation, UPPCB, and NGO	
Construction and Demolition	Wet suppression (maintain about 2% moisture in construction material except dry cement) in the area	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to construction and demolition processing facility	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	Immediate

Source	Control Action	Responsible agencies	Time Frame
	Proper handling and storage of raw material: covered storage and provide the windbreakers for large construction.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen throughout th height of construction all around.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	No storage of construction material near roadside (up to 10 m from the edge of the road)	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Builders should have an approved area for green belt in residential colonies.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops to minimize the emissions.	Varanasi Development Authority, Varanasi Municipal Corporation, Urban Development Department, PWD, UPPCB, and NGO	

Source	Control Action	Responsible agencies	Time Frame
Road Dust	The silt load on each road should be reduced under 2 gm/m^2. Regular vacuum sweeping should be done on the roads having a silt load above 2 gm/m$^{2.}$	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, PWD, UPPCB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, PWD, UPPCB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, PWD	
	Increase green cover and plantation open areas, community places, schools, and housing societies.	Varanasi Development Authority, Varanasi Municipal Corporation, National Highway Authority, State Forest Department, PWD	
	vacuum-assisted sweeping is carried out at least four times a month on major roads with road washing. Road paving should extend up to shoulders	Varanasi Development Authority, Varanasi 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 (This option can be implemented with vehicles of BS-IV and BS-VI technology)	State Transportation Department	3 years

Source	Control Action	Responsible agencies	Time Frame
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for transportation of raw material 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 commercial vehicles operating in city	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Varanasi.	Transport Department, Traffic Police, Varanasi, NHAI, Toll agencies	Six-months
	Electric/Hybrid Vehicles should be encouraged with accelerated policy; New residential and commercial buildings to have charging facilities. All new city and school buses should be electric and explore conversion of existing buses into electric. Develop EV charging infrastructure as per NITI Aayog, MoUA and Govt. of UP guidelines (https://www.niti.gov.in/sites/default/files/2023-02/EV_Handbook_Final_14Oct.pdf; https://mohua.gov.in/upload/whatsnew/5c6e472b20d0aGuidelines%20(EVCI).pdf)	Transport Department, Varanasi City Transport Services Ltd	1 year

Source	Control Action	Responsible agencies	Time Frame
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should include well-equipped maintenance workshops. Adequate charging stations and infrastructure.	Transport Department, Varanasi City Transport Services Ltd	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Varanasi Municipal Corporation, Varanasi City Transport Services Ltd	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Varanasi Development Authority, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	1 year
	IT systems in buses, bus stops, and control centers, and passenger information systems for the reliability of bus services and monitoring.	Varanasi Development Authority, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	1 year
	Movement of materials (raw and product) within city should be allowed between 10 PM to 5 AM.	Transport Department, Varanasi, Varanasi Development Authority, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	1 year
Industries and DG Sets	Emission standard compliance in industries including shifting of highly polluting industries.	UPPCB, Industry Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and UPPCB	

Source	Control Action	Responsible agencies	Time Frame
	.		
	Industrial waste burning should be stopped immediately	Industrial Associations, UPSIDC, UPPCB	Immediate
	Following best practices to minimize fugitive emission within the industry premises, all leakages within the industry should be controlled	Industrial Associations, UPSIDC, UPPCB	Immediate
	Areas in front of the industry should be kept clean with no storage or disposed material	Industrial Associations, UPSIDC, UPPCB	
	Category A Industries (using coal and other dirty fuels)		
	Boilers and furnaces in Varanasi are running on coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity in a time-bound manner	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, UPPCB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that need to be shifted to natural gas and electricity	Industrial Associations, UPPCB	2 years
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, UPPCB	2 years
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, UPPCB	2 years

Source	Control Action	Responsible agencies	Time Frame
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, JVVNL	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
Decongestion of Roads at 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	Varanasi Development Authority, Varanasi Municipal Corporations, Varanasi City Transport Services Ltd, Traffic Police, Varanasi -	6 months
	Disciplined Public transport (designate one lane stop).	Varanasi City Transport Services Ltd., Traffic Police, Varanasi	
	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 on parking.	Varanasi Development Authority, Varanasi Municipal Corporation, Varanasi City Transport Services Ltd, Traffic Police, Varanasi	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Varanasi Development Authority, Varanasi City Transport Services Ltd, NHAI, Traffic Police, Varanasi	

Source	Control Action	Responsible agencies	Time Frame
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Varanasi Development Authority, Varanasi City Transport Services Ltd, NHAI, Traffic Police, Varanasi	
	Mechanized multi-story parking at bus stands, railway stations, and big commercial areas. Remove at least 50 percent of on-street parking in the city	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi Municipal Corporations, NHAI, Traffic Police, Varanasi	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, Kashi Chauraha, BHU Main Gate Chauraha, Pandeypur Chauraha, Chowkaghat Chauraha, Lahartara Chauraha, Girjaghar Chauraha and Atulanand Bus Stop Chauraha are the main bottlenecks for traffic and require decongestion and better traffic management.	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi Municipal Corporations, Traffic Police, Varanasi	
	Parking policy in congestion area (high parking cost, at city centers, consider parking is limited for physically challenged people, etc).	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi Municipal Corporations, NHAI, Traffic Police, Varanasi	
	Chaudhary Charan Singh Bus Stand causes extreme congestion and increased emissions and should be decongested at priority. It	Varanasi Development Authority, Varanasi City Transport Services Ltd, Varanasi	

Source	Control Action	Responsible agencies	Time Frame
	is recommended that the city should relocate these bus stations to the outskirts of the city at multiple locations.	Municipal Corporations, Traffic Police, Varanasi	
*The above steps should not only be implemented in Varanasi municipal limits rather these should be extended to up to at least 25 km beyond the boundary.			

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ANNEXURE 1

Table showing the Emission Factors (EF) used while estimating the emissions:

Source		Units	PM$_{10}$	PM$_{2.5}$	NOx	SO$_2$	CO
Cremation		g/kg	6.53	5.88	1.81	0.62	40.18
Domestic	Wood	g/kg	5.04	4.54	1.40	0.48	31.00
	Crop residue	kg/ton	11.00	9.90	0.49	0.12	58.00
	Dung	g/kg	5.04	4.54	1.40	0.48	31.00
	Coal	g/kg	13.20	4.60	3.99	13.30	24.92
	Kerosene	g/lit	0.61	0.55	2.50	4.00	62.00
	LPG	g/lit	2.10	2.10	3.60	0.40	2.00
Medical Incinerators		g/kg	2.33	2.10	1.78	1.09	2.95
DG Set		g/kwh	1.33	1.20	18.80	1.24	4.06
Industrial Area	LDO	g/lit	2.37	2.13	6.60	33.91	0.60
	HSD	g/lit	1.49	1.34	6.60	18.84	0.60
	LPG	g/kg	2.1	1.89	1.80	0.4	0.252
	Natural gas	kg/ (10)^6 m^3	121.6	109.4	1600	9.6	1344
	Coal(cyclone)	g/kg	10.15	1.05	11.00	9.50	0.25
	Coal(scrubber)	g/kg	7.35	5.25	11.00	9.50	0.25
	Dal mill	kg/hr	85.00	-	-	-	-
Industrial Stack	LDO	g/lit	2.37	2.13	6.60	33.91	0.60
	HSD	g/lit	1.49	1.34	6.60	18.84	0.60
	LPG	g/kg	2.1	1.89	1.80	0.4	0.252
	Natural gas	kg/(10)^6 m^3	121.6	109.4	1600	9.6	1344
	Coal(cyclone)	g/kg	10.15	1.05	11.00	9.50	0.25
	Coal(scrubber)	g/kg	7.35	5.25	11.00	9.50	0.25
Vehicle	2 wheelers (BS-iii)	g/km	0.0365	0.03285	0.0107	0.00	2.37
	2 wheelers (BS-iv)	g/km	0.0365	0.03285	0.0107	0.00	1.00
	3 wheelers (IMAL)	g/km	0.0096	0.00864	0.2550	0.00	1.00
	4 wheelers (BS-iii) (p)	g/km	0.0016	0.00144	0.0477	0.00	0.84
	4 wheelers (BS-iv) (p)	g/km	0.0013	0.00117	0.0358	0.00	0.06
	4 wheelers (BS-iii) (d)	g/km	0.0083	0.00747	0.14	0.00	0.3
	4 wheelers (BS-iv) (d)	g/km	0.0008	0.00072	0.1008	0.00	0.06
	4 wheelers (IMAL)	g/km	0.0038	0.00342	0.2942	0.00	0.06
	LCV(IMAL)	g/km	0.0297	0.02673	0.4549	0.00	3.66
	LCV(Diesel)	g/km	0.0339	0.03051	0.1692	0.00	3.66
	Bus (IMAL)	g/km	0.0225	0.02025	0.4956	0.00	3.72
	Bus (Diesel)	g/km	0.0214	0.01926	0.5211	0.00	3.92
	Truck	g/km	0.03	0.027	0.6887	0.00	4.13
Power Plant	Coal	kg/ton	0.95	0.42	11.00	9.50	0.25
	Natural Gas	kg/(10)^6 m^3	121.60	109.40	4480	9.60	1344
	LDO	g/lit	2.37	2.13	6.60	33.91	0.60
	HSD	g/lit	1.49	1.34	6.60	18.84	0.60
Tandoor		kg/day	14.00	7.00	3.99	9.50	24.92
Construction		ton/acre/mth	1.2	1.08	-	-	-

ANNEXURE R-2

Action Plan

For

The Control of Air Pollution
in .0
Varanasi City

REGIONAL OFFICE
UTTAR PRADESH POLLUTION CONTROL BOARD
AVAS VIKAS OFFICE CUM COMMERCIAL COMPLEX, JAWAHAR NAGAR,
BHELUPUR, VARANASI

8047

1. INTRODUCTION

Varanasi, also known as **Benares**, **Banaras** or **Kashi** , is a city on the banks of the river Ganga in the Uttar Pradesh state of North India, 320 kilometers south-east of the state capital, Lucknow, and 121 kilometers east of Allahabad. Varanasi lies along National Highway 2, which connects it to Kolkata, Kanpur, Agra, and Delhi, and is served by Varanasi Junction railway station and Lal Bahadur Shastri International Airport. Varanasi is also one of 72 districts in the Indian state of Uttar Pradesh. At the time of the 2011 census, there were a total of 8 blocks and 1329 villages in this district. The main native languages of Varanasi are Hindi and Bhojpuri.

Varanasi grew as an important industrial centre, famous for its muslin and silk fabrics, perfumes, ivory works, and sculpture. Buddha is believed to have founded Buddhism here around 528 BCE when he gave his first sermon, "The Setting in Motion of the Wheel of Dharma", at nearby Sarnath. The city's religious importance continued to grow in the 8th century, when Adi Shankara established the worship of Shiva as an official sect of Varanasi. During the Muslim rule through middle Ages, the city continued as an important centre of Hindu devotion, pilgrimage, mysticism and poetry which further contributed to its reputation as a centre of cultural importance and religious education. Guru Nanak visited Varanasi for Maha Shivaratri in 1507, a trip that played a large role in the founding of Sikhism.

The Kingdom of Benares was given official status by the Mughals in 1737, and continued as a dynasty-governed area until Indian independence in 1947. The city is governed by the Varanasi Nagar Nigam (Municipal Corporation). Silk weaving, carpets and crafts and tourism employ a significant number of the local population, as do the Diesel Locomotive Works.

Varanasi is known worldwide for its many ghats, embankments made in steps of stone slabs along the river bank where pilgrims perform ritual ablutions. Of particular note are the Dashashwamedh Ghat, the Panchganga Ghat, the Manikarnika Ghatand the Harishchandra Ghat, the last two being where Hindus cremate their dead and the Hindu genealogy registers at Varanasi are kept here.

2. ACTION TAKEN BY THE BOARD

Board has issued directions to Principal Secretary Urban Development, Principal Secretary Forests, Principal Secretary Transport, Principal Secretary Agriculture, Managing Director Central U.P. Gas Ltd., Managing Director Indraprastha Gas Ltd, and Managing Director Green Gas Ltd. under section 31 (A) of the Air (Prevention and Control of Pollution) Act, 1981 regarding prevention and control of air pollution in Varanasi city on dated 05.09.2016 in compliance of directions issued by Central Pollution Control Board, Delhi under section 18(1)(b) of the Air (Prevention and Control of Pollution) Act, 1981. Board has also issued directions under section31(A) of the Air (Prevention and Control of Pollution) Act, 1981 as amended regarding prevention and control of air pollution in Varanasi city on dated 14.11.2017.

Ambient Air is being monitored regularly by the Board. At source emission monitoring i.e. stack monitoring of industries is also being done regularly and action is being taken accordingly on the basis of analysis report. If any industry is found violating the standards firstly show-cause notice is issued to the industry followed by closure under Air (Prevention and Control of Pollution) Act, 1981.

3. ANNUAL AVERAGE DATA OF AMBIENT AIR QUALITY PM_{10} ($\mu g/m^3$) OF VARANASI CITY (YEAR 2013-2018)

U.P. Pollution Control Board is monitoring ambient air quality of Varanasi city manually at 05 locations viz Jawahar nagar, Sigra, BHU campus, Saketnagar, Chandpur for PM_{10}, SO_2 and NO_2 parameters. Annual Average data of Ambient Air Quality particularly PM_{10} (Particulate Matter size less than 10 microns) were observed during the year 2013-18 are as given below.

S.No.	Name of Location	Category	2013	2014	2015	2016	2017	2018
1	Jawahar nagar	Residential	145.1	142.2	144.1	195.5	242.1	202.09
2	Sigra	Commertial	150.7	142.7	146.2	203.0	233.4	202.33
3	BHU campus	Residential	-	190.2	178.1	218.1	222.9	171.65
4	Saketnagar	Residential	-	235.3	179.9	254.3	261.0	200.89
5	Chandpur	Industrial	-	239.2	226.7	199.7	294.9	226.65
	STANDARD (annual average)	60 $\mu g/m^3$						

4. SOURCES OF POLLUTION IN VARANASI

Based on Spatial and Temporal GIS Based Emission Inventory of Air Pollutants and Green House Gases in Three Major Cities of Uttar Pradesh, the main sources of air pollution in Varanasi city are Vehicular (2%),Road dust (92%), Domestic Cooking (3%), Industries (Point source & Areas source), Garbage burning (2%) & Agriculture waste burning (2%) etc. Data obtained from Continuous Ambient Air Quality Monitoring System (2018) at Varanasi showed values of CO 1.00 (mg/m^3); O_3 24.80 ($\mu g/m^3$); NO_2 45.20($\mu g/m^3$); SO_2 9.3 ($\mu g/m^3$); $PM_{2.5}$ 95.0 ($\mu g/m^3$); and Benzene 0.9($\mu g/m^3$), Toluene 1.93($\mu g/m^3$), Xylene 0.49($\mu g/m^3$).

5. Short term & Long term Action Plan

(A) **Vehicle emission control**

(a)Long Term Action Plan: Reduce congestion

Sl. No	Action Points	Timeframe for implementation	Action Required to be Taken by Responsible Departments
i	Plying of electric buses for public transport including establishment of sufficient charging stations.	360 days	Transport Department
ii	Prepare plan for construction of expressways/bypasses to avoid	360 days	N.H.A.I. /PWD

	congestion due to non-destined vehicles.		
iii	Construction of peripheral road around the city to avoid congestion.	360 days	N.H.A.I./PWD
iv	Arrangement of Multilevel Parking Facilities	360 days	Nagar Nigam/Development Authorities
vi	Development/Strengthening of Bike zone/Cycle zone at metro/railways/bus stations from where travelers hire bi-cycle to reach the destination.	360 days	Nagar Nigam/Development Authorities
vii	Initiate steps for retrofitting of particulate filters in diesel vehicles, when BS-VI fuels are available	360 days	Vehicle Manufacturing Companies/Ministry of Road Transport & Highways (MoRTH)
viii	Use of Bio-Ethanol in the city/urban transport system/waste to energy.	360 days	Transport Department

(b)Short Term Action Plan

Sl. No	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i	Launch extensive drive against polluting vehicles for ensuring strict compliance	As regular activity	R.T.O/Traffic Police
ii	Launch public awareness campaign for air pollution control, vehicle maintenance, minimizing use of personal vehicles, lane discipline, etc.	As regular activity	R.T.O/ Traffic Police
iii	Prevent parking of vehicles in the non-designated areas	As regular activity	Traffic Police/ Nagar Nigam
iv	Prepare & implement action plan to check fuel adulteration and random	30 days	District Supply Officer/Oil companies

	monitoring of fuel quality data		
v	Prepare & implement plan for widening of roads and improvement of infrastructure for decongestion of road	90 days	Nagar Nigam
vi	Steps for promoting battery operated vehicles including establishment of charging stations.	120 days	Transport Department/Nagar Nigam & Development Authorities
vii	Install weigh in motion bridges at the borders of cities/towns and States to prevent overloading of vehicles	180 days	Transport Department
viii	Synchronize traffic movements/Introduce intelligent traffic systems for lane-driving	180 days	Traffic Police
ix	Installation of remote sensor based PUC system	180 days	Traffic Police

(B) Suspension of road dust and other fugitive emissions control

(a)Long Term Action Plan

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	All the canals/nullah's side roads should be brick lined. Proper plantation also carried out.	360 days	Irrigation Department/ Forest department
ii)	Implementation of maintaining at least 33% forest cover area in the city in master plan.	180 days	Nagar Nigam/VDA/Forest Department

(b)Short Term Action Plan

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	Prepare plan for creation of green buffers along the traffic corridors. Plantation of	90 days	Forest Department/Nagar

	specific types of species of plants which are helpful in pollution control.		Nigam & Development Authorities
ii)	Maintain potholes free roads for free-flow of traffic	90 days & as regular activity afterwards.	Nagar Nigam/ Development Authorities
iii)	Introduce water fountains at major traffic intersection, wherever feasible	90 days	Nagar Nigam
iv)	Greening of open areas, gardens, community places, schools and housing societies	90 days	Forest Department
v)	Blacktopping of metalled road including pavement of road shoulders	180 days	Nagar Nigam
vi)	Use of treated effluent of STPs in Pollution Control Measure such as watering of Plants, sprinkling for dust suppression purposes.	90 days	Nagar Nigam
vii)	Wall to Wall pavement for control of dust from road. Design the footpath pavement/tiles having capacity to grow grass in between.	180 days	Nagar Nigam

(C) Control of emissions from biomass/crop residue/garbage/municipal solid waste burning

(b) Short Term Action Plan

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	Launch extensive drive against open burning of bio-mass, crop residue, garbage, leaves, etc.	90 days	Nagar Nigam
ii)	Regular check and control of burning of municipal solid wastes and use of fire extinguisher for control of fire in municipal solid waste and bio mass.		Nagar Nigam
iii)	Proper collection of horticulture waste (bio-mass) and its disposal following composting-cum-gardening approach		Nagar Nigam
iv)	Ensure ban on burning of agriculture waste and crop residues and its	180 days	Agriculture Department & U.P.

	implementation		Pollution Control Board
v)	Door to Door collection of segregated waste by agency and then its disposal directly in plant without dumping it on land.	90 days	Nagar Nigam
vi)	Establishment of composting pits in Parks/ residential societies etc for management of biodegradable waste.	90 days	Nagar Nigam/VDA
vii)	No plot should be left open more than 02 years and planting of trees must be mandatory on vacant plots.	90 days	Nagar Nigam/VDA

(D) **Control of industrial emissions**

(a) Long Term Action Plan

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	Conversion of natural draft brick kilns to induced draft using zigzag technique in a phased manner.	360 days	U.P. Pollution Control Board
ii)	Installation of Electrostatic precipitators and appropriate air pollution control devices in factory units/industries.	180 days	U.P. Pollution Control Board
iii)	Development of mobile facility/van for continuous ambient air quality monitoring for different localities.	360 days	Nagar Nigam

(b) Short Term Action Plan

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	Identification of brick kilns and their regular monitoring including use of designated fuel, and closure of unauthorized units	60 days	U.P. Pollution Control Board

ii)	Conversion of natural draft brick kilns to induced draft	120 days	U.P. Pollution Control Board
iii)	Monitoring of industrial emission including real time online monitoring through OCEMS (Online Continuous Emission Monitoring System) and live camera feed and to take action against non-complying industrial units	60 days, and thereafter, regular activity	U.P. Pollution Control Board
iv)	Bank guarantee should be taken for the compliance of conditions imposed in CTO/CTE for control of Environmental Pollution from industries. The bank guarantee shall be forfeited in case of any violation. Verification of these conditions to be carried out by UPPCB/selected Third Party Institutions/Quality control agencies etc.	60 days, and thereafter, regular activity	U.P. Pollution Control Board
v)	Installation of web cams and OCEMS in Grossly Polluting Industries.	60 days	U.P. Pollution Control Board

(E) **Control of air pollution from constructions and demolition activities**

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	Enforcement of Construction & Demolition Rules2016. Fine should be imposed on defaulting units.	15 days , and thereafter, continue as regular activity	Urban Development/Development Authorities
ii)	Control measures for fugitive emissions from material handling, conveying and screening operations through water sprinkling, curtains, barriers and dust suppression units;		Urban Development/Development Authorities
iii)	Ensure carriage of construction material in closed/covered vessels		Development authorities/ Regional Transport Department
iv)	Environmental aspects should be included during preparation of master plan for development of city.	Proposed Master Plan for Varanasi City 2021	Urban Development/Development Authorities

v)	Builders should leave 33% area for green belt in residential colonies. Plantation should be done as per Office order No. H16405/220/2018/02 dated 16.02.2018 available on website of the Board .i.e.,www.uppcb.com.	Within a reasonable timeframe	Urban Development/Development Authorities/ housing companies
vi)	All construction areas must be covered to avoid dispersion of particulate matter	30 days	Nagar Nigam/ Traffic Police
vii)	Street vendors are to be controlled strictly in respect of removing their wastes and debris before leaving the site of operation	30 days	Nagar Nigam/ Traffic Police
viii)	Street vendors are to be controlled strictly in respect of removing their wastes and debris before leaving the site of operation	30 days	Nagar Nigam/ Traffic Police

(F) Other Steps to control Air Pollution

(a)Long Term Action Plan

(G)

Sl. No.	**Action Points**	**Timeframe for implementation**	**Action Required to be Taken by Responsible Departments**
i)	Dead Bodies of Animals should be disposed through proper treatment facility like rendering plant etc	360 days	Nagar Nigam
ii)	Installation of CAAQMS by polluting units/institutions etc. under "Polluters Pay Principles".	360 days	U.P. Pollution Control Board

(b)Short Term Action Plan

Sl. No.	Action Points	Timeframe for implementation	Action Required to be Taken by Responsible Departments
i)	Air Quality Index to be calculated and disseminated to the people through website and other media (on maximum fortnightly basis for manually operated monitoring stations and real time basis for continuous monitoring stations	15days, and thereafter, continue as regular activity	U.P. Pollution Control Board
ii)	Establish an Air Quality Management Division at SPCB/PCC Head Quarters to oversee air quality management activities in the State and interact with CPCB	30 days	U.P. Pollution Control Board
iii)	Set-up and publicize helpline in the city/town as well as SPCB/PCC HQ for complaints against reported non-compliance	30 days	U.P. Pollution Control Board
iv)	Engage with concerned authorities on continual basis for maximizing coverage of LPG/PNG for domestic and commercial cooking with target of 100% coverage	30 days	District Supply Officer
v)	Monitoring of DG sets and action against violations. Fine should be imposed on defaulters.	30 days	U.P. Pollution Control Board/ Nagar Nigam
vi)	Street vendors are to be controlled strictly in respect of removing their wastes and debris before leaving the site of operation	30 days	Nagar Nigam /Development Authorities
vii)	Complete ban on littering of streets with municipal solid wastes (MSW). Segregation & source collection at source of MSW to be implemented.	30 days	Nagar Nigam /Development Authorities
viii)	If Air Quality Index found severe or above grade, ensure availability of masks to public for protection.	90 days	Nagar Nigam

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ANNEXURE R-3

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station : IESD BHU Varanasi

Monthly Report on Pollutant

Oct-25

Date	CO	SO$_2$	NO	NO2	NOX	NH3	O$_3$	PM$_{2.5}$	PM$_{10}$	BEN.	Eth-Ben	MP-XYL
	mg/m^3	µg/m^3	µg/m^3	µg/m^3	ppb	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3
01-10-2025	0.10	21.26	6.65	1.79	11.38	4.72	12.13	12.56	27.29	0.02	0.01	0.06
02-10-2025	0.09	21.11	6.65	1.73	11.35	3.62	12.87	10.23	24.44	0.02	0.01	0.05
03-10-2025	0.08	24.82	6.66	1.71	11.32	11.32	17.76	3.45	7.40	0.01	0.01	0.05
04-10-2025	0.10	25.49	6.60	1.69	11.22	3.24	18.21	3.12	8.51	0.02	0.01	0.06
05-10-2025	0.16	26.69	6.59	1.69	11.21	5.81	19.16	15.21	36.21	0.03	0.02	0.10
06-10-2025	0.17	23.94	6.64	1.69	11.28	4.75	18.26	23.51	56.97	0.04	0.02	0.11
07-10-2025	0.21	25.98	6.59	1.72	11.23	5.03	19.84	21.32	55.63	0.04	0.02	0.13
08-10-2025	0.23	32.63	6.53	1.65	11.07	7.25	17.78	26.12	59.43	0.05	0.02	0.14
09-10-2025	0.20	18.62	6.64	1.77	11.35	5.79	11.10	30.25	70.32	0.04	0.02	0.12
10-10-2025	0.18	19.00	6.65	1.78	11.36	5.48	11.54	35.32	119.89	0.04	0.02	0.11
11-10-2025	0.19	18.81	6.65	1.79	11.37	5.14	13.21	33.12	104.48	0.04	0.02	0.11
12-10-2025	0.18	19.76	6.67	1.79	11.41	5.66	13.82	28.24	96.41	0.04	0.02	0.11
13-10-2025	0.27	19.16	6.68	1.77	11.40	6.05	20.14	30.26	110.19	0.05	0.03	0.16
14-10-2025	0.26	19.22	6.67	1.75	11.37	5.67	25.65	29.32	96.72	0.05	0.03	0.16
15-10-2025	0.31	19.49	6.66	1.74	11.36	6.91	27.52	35.42	68.25	0.06	0.03	0.19
16-10-2025	0.37	32.20	6.67	1.74	11.37	7.23	34.29	46.09	117.47	0.07	0.04	0.22
17-10-2025	0.36	19.49	6.69	1.76	11.41	6.52	36.48	50.66	113.10	0.07	0.04	0.22
18-10-2025	0.30	18.91	6.64	1.75	11.34	7.41	29.37	46.88	116.52	0.06	0.03	0.17
19-10-2025	0.24	13.88	6.64	1.79	11.36	5.83	28.22	41.04	105.91	0.05	0.03	0.15
20-10-2025	0.26	15.40	6.64	1.77	11.34	32.39	32.39	68.29	149.44	0.05	0.03	0.15
21-10-2025	0.26	22.61	6.65	1.69	11.28	6.08	31.67	85.65	172.85	0.05	0.03	0.15
22-10-2025	0.26	19.94	6.64	1.74	11.31	6.38	21.85	47.38	95.24	0.05	0.03	0.16
23-10-2025	0.28	20.89	6.65	1.77	11.38	6.51	22.83	65.40	93.77	0.06	0.03	0.17
24-10-2025	0.23	22.34	6.61	1.74	11.28	5.65	20.01	34.76	76.24	0.05	0.02	0.14
25-10-2025	0.26	21.18	6.66	1.75	11.36	6.31	16.30	37.28	84.88	0.05	0.03	0.16
26-10-2025	0.30	21.57	6.68	1.77	11.40	7.04	16.96	36.78	86.74	0.06	0.03	0.18
27-10-2025	0.32	22.84	6.66	1.76	11.37	6.12	23.48	46.11	95.32	0.06	0.03	0.19
28-10-2025	0.16	21.89	6.65	1.76	11.35	3.74	14.19	18.33	44.62	0.03	0.02	0.10
29-10-2025	0.16	22.05	6.66	1.80	11.40	4.88	11.33	18.30	34.75	0.03	0.02	0.10
30-10-2025	0.10	22.91	6.64	1.77	11.36	3.15	8.12	8.51	17.31	0.02	0.01	0.06
31-10-2025	0.13	24.47	6.66	1.70	11.31	4.53	5.43	1.15	2.09	0.03	0.01	0.08
Average	**0.22**	**21.89**	**6.64**	**1.75**	**11.33**	**6.65**	**19.74**	**31.94**	**75.75**	**0.04**	**0.02**	**0.13**
Min.	**0.08**	**13.88**	**6.53**	**1.65**	**11.07**	**3.15**	**5.43**	**1.15**	**2.09**	**0.01**	**0.01**	**0.05**
Max.	**0.37**	**32.63**	**6.69**	**1.80**	**11.41**	**32.39**	**36.48**	**85.65**	**172.85**	**0.07**	**0.04**	**0.22**

Kashish

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station : IESD BHU Varanasi

Monthly Report on Pollutant

Nov-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m³	µg/m³	µg/m³	µg/m³	ppb	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
01-11-2025	0.17	22.85	6.65	1.77	11.37	5.97	5.09	4.76	9.56	0.04	0.02	0.11
02-11-2025	0.24	21.92	6.67	1.84	11.45	4.99	11.43	0.00	0.00	0.05	0.02	0.15
03-11-2025	0.27	20.36	6.71	1.86	11.53	11.53	20.69	30.57	126.33	0.05	0.03	0.16
04-11-2025	0.33	22.37	6.66	1.77	11.37	6.05	17.79	25.10	91.75	0.07	0.03	0.20
05-11-2025	0.28	22.62	6.65	1.73	11.33	4.50	23.10	30.26	90.60	0.06	0.03	0.17
06-11-2025	0.30	23.43	6.63	1.77	11.34	4.91	22.26	13.89	85.48	0.06	0.03	0.18
07-11-2025	0.29	21.88	6.66	1.74	11.34	4.76	22.60	32.44	101.35	0.06	0.03	0.18
08-11-2025	0.25	19.99	6.71	1.84	11.53	3.83	17.36	34.92	91.74	0.05	0.03	0.15
09-11-2025	0.31	19.45	6.74	1.85	11.57	3.35	23.68	50.55	120.57	0.06	0.03	0.19
10-11-2025	0.36	22.25	6.63	1.81	11.39	5.95	25.61	40.03	106.21	0.07	0.04	0.22
11-11-2025	0.38	22.76	6.66	1.74	11.35	5.42	30.59	49.63	134.40	0.08	0.04	0.22
12-11-2025	0.37	23.53	6.65	1.76	11.35	5.80	27.32	48.71	133.47	0.08	0.04	0.22
13-11-2025	0.41	23.26	6.65	1.75	11.35	7.50	27.89	44.66	127.41	0.08	0.04	0.25
14-11-2025	0.48	23.39	6.67	1.78	11.40	8.40	32.60	55.17	152.36	0.10	0.05	0.29
15-11-2025	0.46	23.70	6.68	1.78	11.43	9.11	32.20	35.42	68.25	0.09	0.05	0.28
16-11-2025	0.48	32.20	6.69	1.74	11.40	9.43	26.72	53.76	148.70	0.10	0.05	0.29
17-11-2025	0.51	24.06	6.68	1.78	11.41	11.10	26.21	55.16	147.47	0.10	0.05	0.31
18-11-2025	0.47	24.32	6.69	1.75	11.41	10.06	25.93	48.85	129.77	0.09	0.05	0.28
19-11-2025	0.58	24.91	6.69	1.79	11.45	13.35	27.26	56.73	141.94	0.12	0.06	0.35
20-11-2025	0.64	25.46	6.72	1.77	11.47	36.60	36.60	73.25	166.52	0.13	0.07	0.38
21-11-2025	0.57	24.16	6.72	1.82	11.53	12.12	32.54	77.58	164.74	0.12	0.06	0.34
22-11-2025	0.50	24.79	6.68	1.74	11.38	9.50	28.61	68.85	156.84	0.10	0.05	0.30
23-11-2025	0.47	23.48	6.74	1.81	11.54	8.68	23.89	67.93	148.98	0.09	0.05	0.28
24-11-2025	0.54	23.95	6.71	1.83	11.51	14.38	26.39	69.08	154.04	0.11	0.06	0.32
25-11-2025	0.43	23.86	6.69	1.75	11.41	10.74	22.30	46.32	128.19	0.09	0.04	0.26
26-11-2025	0.41	23.01	6.71	1.82	11.50	8.69	19.01	45.68	121.86	0.08	0.04	0.24
27-11-2025	0.54	24.54	6.71	1.79	11.46	10.65	33.84	63.40	152.88	0.11	0.06	0.33
28-11-2025	0.55	24.60	6.68	1.76	11.39	9.75	34.44	66.90	164.28	0.11	0.06	0.33
29-11-2025	0.35	24.51	6.66	1.77	11.38	7.08	22.10	49.15	125.59	0.07	0.04	0.21
30-11-2025	0.32	24.84	6.65	1.78	11.38	7.50	20.15	46.77	112.81	0.07	0.03	0.20
Average	**0.41**	**23.55**	**6.68**	**1.78**	**11.42**	**9.06**	**24.87**	**46.18**	**120.14**	**0.08**	**0.04**	**0.25**
Min.	**0.17**	**19.45**	**6.63**	**1.73**	**11.33**	**3.35**	**5.09**	**0.00**	**0.00**	**0.04**	**0.02**	**0.11**
Max.	**0.64**	**32.20**	**6.74**	**1.86**	**11.57**	**36.60**	**36.60**	**77.58**	**166.52**	**0.13**	**0.07**	**0.38**

Kashish

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Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station : IESD BHU Varanasi

Monthly Report on Pollutant

Dec-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m³	µg/m³	µg/m³	µg/m³	ppb	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
01-12-2025	0.43	25.67	6.71	1.87	11.54	12.90	21.68	55.16	131.89	0.09	0.05	0.26
02-12-2025	0.45	22.22	6.75	1.94	11.67	17.85	21.82	54.03	126.67	0.09	0.05	0.27
03-12-2025	0.55	28.75	6.62	1.72	11.27	11.27	31.19	43.76	132.73	0.11	0.06	0.33
04-12-2025	0.47	31.47	6.58	1.62	11.13	10.39	24.19	38.95	122.59	0.06	0.05	0.28
05-12-2025	0.41	32.68	6.61	1.65	11.19	8.73	23.36	34.81	113.26	0.08	0.04	0.25
06-12-2025	0.43	34.33	6.62	1.65	11.20	14.33	24.66	12.92	124.59	0.04	0.04	0.26
07-12-2025	0.40	39.93	6.56	1.59	11.06	8.52	21.56	36.01	114.31	0.08	0.04	0.24
08-12-2025	0.47	38.30	6.58	1.63	11.13	14.42	26.66	46.93	147.56	0.09	0.05	0.28
09-12-2025	0.41	31.59	6.62	1.62	11.18	12.51	23.33	41.07	131.01	0.08	0.04	0.25
10-12-2025	0.45	25.31	6.63	1.65	11.21	20.74	21.52	35.16	112.75	0.09	0.05	0.27
11-12-2025	0.45	22.71	6.63	1.68	11.25	13.80	24.00	39.04	122.53	0.09	0.05	0.27
12-12-2025	0.61	23.22	6.66	1.65	11.27	19.64	32.91	63.56	171.35	0.12	0.06	0.36
13-12-2025	0.81	20.70	6.71	1.71	11.40	18.92	40.94	95.68	225.11	0.16	0.09	0.49
14-12-2025	0.86	20.49	6.67	1.78	11.40	19.97	42.79	89.67	205.86	0.17	0.09	0.52
15-12-2025	0.65	21.23	6.66	1.75	11.35	11.34	32.33	35.42	68.25	0.13	0.07	0.39
16-12-2025	0.49	32.20	6.61	1.67	11.22	14.35	23.76	43.50	128.58	0.10	0.05	0.29
17-12-2025	0.47	22.31	6.63	1.69	11.26	10.50	25.50	50.95	144.47	0.09	0.05	0.28
18-12-2025	0.51	23.55	6.58	1.64	11.14	9.45	20.00	47.28	163.76	0.10	0.05	0.30
19-12-2025	0.51	25.53	6.59	1.59	11.12	9.83	22.87	52.75	158.34	0.10	0.05	0.31
20-12-2025	0.48	24.51	6.62	1.71	11.27	21.48	21.48	47.83	147.25	0.10	0.05	0.29
21-12-2025	0.45	27.57	6.58	1.60	11.10	10.82	18.54	38.33	122.72	0.09	0.05	0.27
22-12-2025	0.60	28.43	6.58	1.63	11.14	12.20	33.22	54.05	153.57	0.12	0.06	0.36
23-12-2025	0.61	28.55	6.56	1.62	11.11	12.60	25.82	42.92	125.49	0.12	0.06	0.37
24-12-2025	0.50	30.10	6.86	1.60	11.43	10.60	16.87	39.78	135.01	0.10	0.05	0.30
25-12-2025	0.49	30.30	6.54	1.58	11.03	12.16	13.64	33.07	100.42	0.10	0.05	0.30
26-12-2025	0.52	27.66	7.31	1.63	12.09	13.30	19.18	35.97	95.10	0.10	0.05	0.31
27-12-2025	0.43	28.93	6.58	1.62	11.12	10.68	13.44	36.30	106.95	0.09	0.04	0.26
28-12-2025	0.42	29.90	6.56	1.65	11.12	11.27	13.12	40.67	113.62	0.08	0.04	0.24
29-12-2025	0.37	27.62	6.61	1.68	11.22	9.56	9.23	41.58	110.58	0.07	0.04	0.22
30-12-2025	0.57	25.26	6.70	1.76	11.42	11.90	20.82	59.46	162.19	0.11	0.06	0.34
31-12-2025	0.56	24.50	6.71	1.71	11.38	10.46	22.52	64.46	197.63	0.11	0.06	0.34
Average	**0.51**	**27.60**	**6.65**	**1.67**	**11.27**	**13.11**	**23.64**	**46.81**	**136.00**	**0.10**	**0.05**	**0.31**
Min.	**0.37**	**20.49**	**6.54**	**1.58**	**11.03**	**8.52**	**9.23**	**12.92**	**68.25**	**0.04**	**0.04**	**0.22**
Max.	**0.86**	**39.93**	**7.31**	**1.94**	**12.09**	**21.48**	**42.79**	**95.68**	**225.11**	**0.17**	**0.09**	**0.52**

Kashish

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station :Jal Kal Sansthan Bhelupur Varanasi

Monthly Report on Pollutant

Oct-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m^3	µg/m^3	µg/m^3	µg/m^3	ppb	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3
01-10-2025	0.20	22.30	2.67	6.24	9.83	4.14	4.37	14.91	38.35	0.04	0.02	0.12
02-10-2025	0.17	22.18	2.65	6.24	9.82	4.14	3.63	10.44	26.84	0.03	0.02	0.10
03-10-2025	0.15	22.65	2.62	6.25	9.80	9.80	2.94	6.06	15.60	0.03	0.02	0.09
04-10-2025	0.22	22.71	2.67	6.21	9.81	4.11	2.53	7.68	19.74	0.04	0.02	0.13
05-10-2025	0.26	22.25	2.67	6.18	9.81	4.13	4.59	14.99	38.55	0.05	0.03	0.16
06-10-2025	0.37	22.27	2.63	6.26	9.81	4.11	9.60	2.06	70.47	0.08	0.04	0.23
07-10-2025	0.43	21.84	2.66	6.22	9.82	4.12	6.57	26.16	67.28	0.09	0.04	0.26
08-10-2025	0.44	23.16	2.61	6.18	9.69	4.07	9.64	30.54	78.53	0.09	0.05	0.27
09-10-2025	0.41	22.14	2.68	6.19	9.81	4.13	5.96	36.97	95.07	0.08	0.04	0.25
10-10-2025	0.25	21.79	2.67	6.20	9.79	4.12	5.84	51.90	133.45	0.05	0.03	0.15
11-10-2025	0.28	21.75	2.68	6.22	9.83	4.13	7.67	50.67	130.32	0.06	0.03	0.17
12-10-2025	0.25	21.48	2.68	6.23	9.83	4.12	6.44	48.03	123.50	0.05	0.03	0.15
13-10-2025	0.48	21.34	2.68	6.20	9.80	4.11	8.95	62.98	161.94	0.10	0.05	0.29
14-10-2025	0.51	21.02	2.71	6.17	9.81	4.21	7.34	55.05	141.55	0.10	0.05	0.31
15-10-2025	0.48	21.42	2.69	6.21	9.82	4.11	6.12	65.85	169.33	0.10	0.05	0.29
16-10-2025	0.59	32.20	2.69	6.21	9.82	4.10	1.82	68.20	229.75	0.12	0.06	0.36
17-10-2025	0.74	22.33	2.70	6.23	9.85	4.13	1.06	60.65	160.69	0.15	0.08	0.44
18-10-2025	0.60	22.24	2.71	6.20	9.85	4.13	1.90	43.22	102.38	0.11	0.06	0.33
19-10-2025	0.36	22.00	2.71	6.21	9.85	4.12	1.88	35.46	83.98	0.07	0.04	0.22
20-10-2025	0.37	22.31	2.68	6.19	9.80	1.67	1.67	39.20	92.83	0.07	0.04	0.22
21-10-2025	0.35	21.99	2.68	6.22	9.83	4.10	1.04	44.76	106.00	0.07	0.04	0.21
22-10-2025	0.35	22.55	2.70	6.17	9.80	4.14	1.55	34.99	82.88	0.07	0.04	0.21
23-10-2025	0.42	22.67	2.69	6.18	9.80	4.15	1.30	39.59	93.75	0.08	0.04	0.25
24-10-2025	0.30	22.47	2.96	6.19	10.09	4.14	2.56	32.79	77.65	0.06	0.03	0.18
25-10-2025	0.34	22.06	2.70	6.21	9.83	4.11	1.37	32.94	78.01	0.07	0.04	0.20
26-10-2025	0.40	21.70	2.71	6.23	9.87	4.14	1.03	36.52	86.49	0.08	0.04	0.24
27-10-2025	0.48	21.73	2.70	6.23	9.86	4.12	0.36	36.10	85.51	0.10	0.05	0.29
28-10-2025	0.30	21.32	2.69	6.25	9.86	4.14	0.52	21.61	51.17	0.06	0.03	0.18
29-10-2025	0.29	21.72	2.68	6.25	9.85	4.11	0.09	16.56	39.22	0.06	0.03	0.17
30-10-2025	0.15	21.94	2.71	6.20	9.86	4.12	0.12	8.80	20.85	0.03	0.02	0.09
31-10-2025	0.24	21.90	2.69	6.20	9.85	4.11	0.08	92.58	10.89	0.05	0.02	0.14
Average	**0.36**	**22.37**	**2.69**	**6.21**	**9.83**	**4.23**	**3.57**	**36.39**	**87.50**	**0.07**	**0.04**	**0.22**
Min.	**0.15**	**21.02**	**2.61**	**6.17**	**9.69**	**1.67**	**0.08**	**2.06**	**10.89**	**0.03**	**0.02**	**0.09**
Max.	**0.74**	**32.20**	**2.96**	**6.26**	**10.09**	**9.80**	**9.64**	**92.58**	**229.75**	**0.15**	**0.08**	**0.44**

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station :Jal Kal Sansthan Bhelupur Varanasi

Monthly Report on Pollutant

Nov-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m³	µg/m³	µg/m³	µg/m³	ppb	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
01-11-2025	0.33	22.13	2.68	6.22	9.83	4.12	0.08	8.68	20.55	0.07	0.03	0.20
02-11-2025	0.44	21.60	2.70	6.24	9.87	4.14	0.11	30.59	72.45	0.09	0.05	0.26
03-11-2025	0.44	21.18	2.67	6.21	9.82	9.82	1.28	40.01	94.77	0.09	0.05	0.26
04-11-2025	0.56	21.10	2.67	6.19	9.81	4.11	1.96	54.09	128.11	0.11	0.06	0.34
05-11-2025	0.58	22.57	2.63	6.23	9.78	4.08	2.22	47.15	111.67	0.12	0.06	0.35
06-11-2025	0.51	27.42	2.51	6.35	9.71	4.05	0.18	23.61	110.64	0.10	0.05	0.31
07-11-2025	0.49	30.74	2.52	6.32	9.69	4.04	0.01	52.16	123.53	0.10	0.05	0.29
08-11-2025	0.43	30.84	2.53	6.28	9.67	4.04	0.05	44.70	105.88	0.09	0.05	0.26
09-11-2025	0.50	31.29	2.51	6.33	9.68	4.03	0.07	52.66	124.73	0.10	0.05	0.30
10-11-2025	0.73	31.71	2.51	6.31	9.68	4.05	0.09	64.58	152.97	0.15	0.08	0.44
11-11-2025	0.69	27.15	2.60	6.25	9.74	4.10	1.20	66.08	156.50	0.14	0.07	0.42
12-11-2025	0.69	23.74	2.69	6.18	9.81	4.13	2.10	71.01	168.18	0.14	0.07	0.41
13-11-2025	0.79	24.26	2.67	6.25	9.84	4.13	2.07	74.29	175.94	0.16	0.08	0.48
14-11-2025	0.96	24.84	2.69	6.18	9.80	4.14	2.43	87.37	206.93	0.19	0.10	0.58
15-11-2025	1.14	24.70	2.69	6.16	9.78	4.13	1.69	81.68	159.47	0.23	0.12	0.68
16-11-2025	1.16	32.20	2.69	6.21	9.83	4.13	1.63	70.65	117.74	0.23	0.12	0.69
17-11-2025	1.12	24.51	2.69	6.21	9.84	4.14	3.80	68.67	114.44	0.22	0.12	0.67
18-11-2025	0.98	23.87	2.67	6.16	9.77	4.13	4.68	77.74	129.57	0.22	0.12	0.67
19-11-2025	1.38	24.37	2.68	6.20	9.81	4.14	2.61	68.09	113.48	0.28	0.14	0.83
20-11-2025	1.50	24.81	2.69	6.26	9.88	2.22	2.22	70.71	117.85	0.30	0.16	0.90
21-11-2025	1.25	24.26	2.67	6.24	9.84	4.15	1.21	64.20	126.72	0.25	0.13	0.75
22-11-2025	1.30	23.77	2.70	6.20	9.85	4.13	1.17	34.82	129.12	0.26	0.13	0.78
23-11-2025	1.30	23.30	2.69	6.23	9.85	4.13	0.93	42.56	120.84	0.26	0.14	0.78
24-11-2025	1.42	22.46	2.71	6.22	9.86	4.15	1.11	67.14	131.40	0.28	0.15	0.85
25-11-2025	0.93	21.44	2.67	6.24	9.84	4.13	1.11	56.13	101.73	0.19	0.10	0.56
26-11-2025	0.93	20.23	2.70	6.19	9.84	4.15	1.09	60.46	100.77	0.19	0.10	0.55
27-11-2025	1.15	20.87	2.68	6.20	9.81	4.14	1.22	68.79	114.64	0.23	0.12	0.69
28-11-2025	1.15	22.13	2.67	6.25	9.84	4.14	1.08	65.72	109.54	0.22	0.12	0.66
29-11-2025	0.62	21.84	2.70	6.23	9.87	4.15	1.30	47.91	79.85	0.12	0.06	0.37
30-11-2025	0.65	21.92	2.68	6.22	9.82	4.14	1.34	48.21	80.36	0.13	0.07	0.39
Average	**0.87**	**24.58**	**2.65**	**6.23**	**9.80**	**4.24**	**1.40**	**57.01**	**120.01**	**0.17**	**0.09**	**0.52**
Min.	**0.33**	**20.23**	**2.51**	**6.16**	**9.67**	**2.22**	**0.01**	**8.68**	**20.55**	**0.07**	**0.03**	**0.20**
Max.	**1.50**	**32.20**	**2.71**	**6.35**	**9.88**	**9.82**	**4.68**	**87.37**	**206.93**	**0.30**	**0.16**	**0.90**

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station :Jal Kal Sansthan Bhelupur Varanasi

Monthly Report on Pollutant

Dec-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m³	µg/m³	µg/m³	µg/m³	ppb	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
01-12-2025	0.85	23.42	2.63	6.26	9.81	4.11	1.71	56.33	93.88	0.17	0.09	0.51
02-12-2025	0.87	22.60	2.64	6.27	9.80	4.10	1.37	58.16	96.94	0.17	0.09	0.52
03-12-2025	0.88	21.74	2.72	6.20	9.86	9.86	2.23	54.65	91.09	0.17	0.09	0.53
04-12-2025	0.62	21.23	2.72	6.22	9.88	4.14	1.22	50.45	84.08	0.12	0.06	0.37
05-12-2025	0.59	20.11	2.70	6.21	9.85	4.15	1.28	50.43	84.06	0.12	0.06	0.35
06-12-2025	0.63	20.49	2.70	6.20	9.84	4.16	1.63	29.90	90.69	0.13	0.07	0.38
07-12-2025	0.50	20.55	2.69	6.24	9.86	4.15	1.57	47.39	78.98	0.10	0.05	0.30
08-12-2025	0.81	21.96	2.71	6.23	9.87	4.12	1.61	62.59	104.32	0.16	0.08	0.49
09-12-2025	0.65	22.39	2.70	6.23	9.87	4.15	1.41	54.87	91.46	0.13	0.07	0.39
10-12-2025	0.81	22.09	2.70	6.21	9.85	4.15	1.27	56.48	48.59	0.16	0.08	0.49
11-12-2025	0.81	21.95	2.71	6.20	9.86	4.13	1.13	55.85	38.65	0.16	0.08	0.49
12-12-2025	1.14	22.72	2.68	6.21	9.82	4.13	1.10	75.37	125.61	0.23	0.12	0.69
13-12-2025	1.71	24.76	2.70	6.21	9.86	4.15	0.91	100.35	167.25	0.34	0.18	1.02
14-12-2025	1.99	25.05	2.68	6.23	9.84	4.15	1.05	98.32	163.85	0.40	0.21	1.19
15-12-2025	1.25	23.75	2.69	6.24	9.86	4.14	0.96	79.95	133.26	0.25	0.13	0.75
16-12-2025	0.87	32.20	2.71	6.20	9.84	4.13	0.83	61.13	101.89	0.17	0.09	0.52
17-12-2025	0.75	22.65	2.67	6.25	9.85	4.12	0.77	56.66	94.44	0.15	0.08	0.45
18-12-2025	0.71	23.00	2.68	6.27	9.87	4.16	0.55	58.96	98.27	0.14	0.07	0.42
19-12-2025	0.73	22.36	2.68	6.25	9.86	4.15	0.86	62.76	104.60	0.15	0.08	0.44
20-12-2025	0.67	22.06	2.71	6.23	9.88	0.68	0.68	49.29	82.15	0.13	0.07	0.40
21-12-2025	0.60	21.88	2.69	6.24	9.87	4.14	0.63	46.85	78.09	0.12	0.06	0.36
22-12-2025	0.83	22.43	2.70	6.23	9.86	4.14	0.66	58.95	98.26	0.17	0.09	0.50
23-12-2025	0.88	22.48	2.71	6.21	9.86	4.13	0.67	56.57	94.28	0.18	0.09	0.53
24-12-2025	0.67	22.25	2.70	6.23	9.87	4.16	0.69	55.57	92.62	0.13	0.07	0.40
25-12-2025	0.73	22.64	2.68	6.25	9.85	4.15	0.64	51.79	86.32	0.15	0.08	0.44
26-12-2025	0.92	22.73	2.68	6.25	9.85	4.15	0.58	59.99	99.98	0.18	0.10	0.55
27-12-2025	0.62	22.30	2.71	6.23	9.88	4.14	0.61	53.93	89.88	0.13	0.06	0.38
28-12-2025	0.57	22.26	2.68	6.21	9.83	4.14	0.58	48.73	81.21	0.11	0.06	0.33
29-12-2025	0.52	21.14	2.70	6.25	9.88	4.15	0.57	47.36	78.93	0.11	0.05	0.31
30-12-2025	1.00	21.72	2.71	6.20	9.85	4.15	0.65	75.84	126.40	0.20	0.10	0.60
31-12-2025	1.06	22.01	2.70	6.21	9.84	4.14	0.73	92.58	114.83	0.21	0.11	0.63
Average	**0.85**	**22.61**	**2.69**	**6.23**	**9.85**	**4.21**	**1.00**	**60.26**	**97.25**	**0.17**	**0.09**	**0.51**
Min.	**0.50**	**20.11**	**2.63**	**6.20**	**9.80**	**0.68**	**0.55**	**29.90**	**38.65**	**0.10**	**0.05**	**0.30**
Max.	**1.99**	**32.20**	**2.72**	**6.27**	**9.88**	**9.86**	**2.23**	**100.35**	**167.25**	**0.40**	**0.21**	**1.19**

Kashish

8063

Regional Office
Pollution Control Board
Varanasi

Oct-25
CAAQMS Air Pollutant Data at Orderly Bazar, Varanasi

Pollutant		CO	O_3	NO_2	SO_2	PM 2.5	PM 10	BEN.	TOL.	XYL.
Unit		mg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m³	µg/m³	µg/m³
01-10-2025		0.17	Maint.	28.5	5.5	14	28	0.42	1.28	0.91
02-10-2025		0.17	Maint.	29.5	5.5	10	20	0.41	1.28	0.91
03-10-2025		0.22	Maint.	29.7	5.6	8	14	0.54	1.39	1.03
04-10-2025		0.23	Maint.	28.6	5.6	7	12	0.58	1.47	1.13
05-10-2025		0.18	Maint.	29.4	5.5	18	41	0.44	1.31	0.95
06-10-2025		0.19	Maint.	29.9	5.5	25	58	0.45	1.27	0.90
07-10-2025		0.16	Maint.	30.0	5.4	23	54	0.40	1.20	0.82
08-10-2025		0.18	Maint.	30.2	5.5	25	57	0.43	1.30	0.93
09-10-2025		0.19	Maint.	25.7	5.5	23	53	0.47	1.35	0.99
10-10-2025		0.17	Maint.	22.0	5.5	35	82	0.42	1.29	0.92
11-10-2025		0.20	Maint.	22.1	5.6	39	91	0.48	1.36	1.00
12-10-2025		0.19	Maint.	22.0	5.5	32	74	0.46	1.33	0.97
13-10-2025		0.19	Maint.	22.5	5.5	45	106	0.46	1.34	0.98
14-10-2025		0.18	Maint.	22.2	5.5	47	110	0.42	1.25	0.88
15-10-2025		0.18	Maint.	21.9	5.5	48	113	0.45	1.33	0.96
16-10-2025		0.18	Maint.	22.0	5.5	60	142	0.45	1.27	0.92
17-10-2025		0.19	Maint.	22.7	5.5	64	151	0.46	1.30	0.94
18-10-2025		0.18	Maint.	21.8	5.6	57	134	0.44	1.31	0.94
19-10-2025		0.20	Maint.	21.7	5.5	66	155	0.41	1.27	0.90
20-10-2025		0.26	Maint.	22.2	6.0	86	199	0.43	1.30	0.93
21-10-2025		0.19	Maint.	22.1	5.5	84	188	0.41	1.27	0.90
22-10-2025		0.20	Maint.	22.1	5.5	75	168	0.42	1.29	0.92
23-10-2025		0.17	Maint.	21.7	5.5	55	122	0.41	1.28	0.91
24-10-2025		0.22	Maint.	21.9	5.5	42	95	0.43	1.30	0.93
25-10-2025		0.24	Maint.	22.5	5.5	36	83	0.45	1.33	0.96
26-10-2025		0.26	Maint.	22.7	5.5	38	88	0.44	1.25	0.88
27-10-2025		0.18	Maint.	22.7	5.5	41	95	0.43	1.30	0.93
28-10-2025		0.27	Maint.	23.0	5.5	24	54	0.45	1.33	0.96
29-10-2025		0.24	Maint.	22.2	5.7	21	47	0.48	1.32	0.96
30-10-2025		0.26	Maint.	22.1	5.5	11	25	0.44	1.31	0.94
31-10-2025		0.27	Maint.	20.7	5.5	7	15	0.43	1.29	0.92
Average		0.20	Maint.	24.1	5.5	38	86	0.45	1.31	0.94
Minimum		0.16	Maint.	20.7	5.4	7	12	0.40	1.20	0.82
Maximum		0.27	Maint.	30.2	6.0	86	199	0.58	1.47	1.13
Std.	1 Hr.	4.00	180.0	NA	NA	NA	NA			
	8 Hr.	2.00	100.0	NA	NA	NA	NA			
	24Hr.	NA	NA	80.0	80.0	60	100	5(Annual)		

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Regional Office
Pollution Control Board
Varanasi

Nov-25
CAAQMS Air Pollutant Data at Orderly Bazar, Varanasi

Pollutant	CO	O_3	NO_2	SO_2	PM 2.5	PM 10	BEN.	TOL.	XYL.
Unit	mg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m^3	µg/m³	µg/m³	µg/m³
01-11-2025	0.22	Maint.	19.5	5.5	10	22	0.43	1.30	0.93
02-11-2025	0.25	Maint.	15.0	5.5	30	68	0.43	1.29	0.93
03-11-2025	0.27	Maint.	15.6	5.5	40	91	0.46	1.26	0.88
04-11-2025	0.26	Maint.	15.3	5.5	38	88	0.45	1.33	0.96
05-11-2025	0.24	Maint.	14.7	5.5	45	103	0.42	1.29	0.92
06-11-2025	0.27	Maint.	15.2	5.5	44	102	0.40	1.26	0.89
07-11-2025	0.19	Maint.	17.1	5.5	69	104	0.47	1.34	0.98
08-11-2025	0.17	Maint.	16.9	5.5	48	111	0.42	1.29	0.92
09-11-2025	0.17	Maint.	16.9	5.5	67	154	0.42	1.29	0.92
10-11-2025	0.25	Maint.	16.1	5.7	64	147	0.40	1.26	0.89
11-11-2025	0.19	Maint.	18.0	5.5	76	176	0.45	1.33	0.96
12-11-2025	0.19	Maint.	14.4	5.8	75	173	0.41	1.28	0.91
13-11-2025	0.21	Maint.	2.3	5.6	74	172	0.53	1.42	1.06
14-11-2025	Maint.	Maint.	Maint.	Maint.	88	204	Maint.	Maint.	Maint.
15-11-2025	0.18	18.2	3.1	2.4	63	168	0.02	0.12	0.06
16-11-2025	0.24	18.8	2.1	3.0	69	196	0.03	0.14	0.08
17-11-2025	0.25	18.7	21.4	3.1	53	158	0.03	0.14	0.08
18-11-2025	0.24	14.5	44.0	3.0	55	163	0.03	0.13	0.08
19-11-2025	0.23	8.0	40.0	3.1	52	157	0.03	0.15	0.09
20-11-2025	0.24	7.2	39.5	3.0	53	160	0.02	0.13	0.08
21-11-2025	0.27	7.5	40.1	3.1	52	158	0.03	0.14	0.08
22-11-2025	0.25	7.3	40.8	3.1	60	180	0.03	0.15	0.09
23-11-2025	0.25	7.1	40.0	3.2	56	168	0.03	0.15	0.09
24-11-2025	0.24	7.4	40.1	3.0	53	157	0.03	0.14	0.08
25-11-2025	0.24	8.2	40.2	3.2	47	140	0.03	0.17	0.10
26-11-2025	0.21	6.8	39.0	3.2	43	129	0.03	0.16	0.10
27-11-2025	0.23	6.6	40.0	3.1	59	176	0.03	0.15	0.09
28-11-2025	0.22	7.7	39.3	3.3	59	178	0.04	0.18	0.11
29-11-2025	0.26	7.5	40.0	3.4	46	139	0.04	0.21	0.12
30-11-2025	0.23	7.2	39.9	3.3	39	115	0.04	0.18	0.10
Average	0.23	9.9	25.7	4.2	54	142	0.21	0.67	0.47
Minimum	0.17	6.6	2.1	2.4	10	22	0.02	0.12	0.06
Maximum	0.27	18.8	44.0	5.8	88	204	0.53	1.42	1.06

Std.	1 Hr.	4.00	180.0	NA	NA	NA	NA			
	8 Hr.	2.00	100.0	NA	NA	NA	NA			
	24Hr.	NA	NA	80.0	80.0	60	100	5(Annual)		

Kashish

8065

Regional Office
Pollution Control Board
Varanasi

Dec-25
CAAQMS Air Pollutant Data at Orderly Bazar, Varanasi

Pollutant		CO	O_3	NO_2	SO_2	PM 2.5	PM 10	BEN.	TOL.	XYL.
Unit		mg/m^3	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$
01-12-2025		0.26	17.4	75.5	3.3	43	129	0.03	0.18	0.10
02-12-2025		0.34	14.0	73.3	3.1	50	150	0.03	0.16	0.09
03-12-2025		0.26	14.5	75.3	3.3	50	150	0.04	0.18	0.10
04-12-2025		0.26	14.3	74.6	3.3	45	134	0.04	0.19	0.12
05-12-2025		0.27	15.0	74.6	3.3	45	134	0.04	0.19	0.11
06-12-2025		0.27	16.0	75.7	3.3	49	146	0.04	0.18	0.11
07-12-2025		0.25	14.6	74.9	3.4	44	133	0.04	0.19	0.12
08-12-2025		0.26	16.0	76.3	3.3	54	163	0.03	0.19	0.11
09-12-2025		0.25	16.6	74.4	3.3	52	157	0.04	0.19	0.12
10-12-2025		0.27	16.3	75.0	3.2	47	140	0.03	0.17	0.10
11-12-2025		0.27	16.5	73.5	3.2	52	155	0.03	0.17	0.10
12-12-2025		0.26	14.6	74.2	3.2	82	246	0.03	0.16	0.10
13-12-2025		0.26	14.6	75.3	3.1	103	289	0.03	0.15	0.09
14-12-2025		0.27	14.2	72.7	3.1	102	255	0.03	0.15	0.09
15-12-2025		0.35	15.8	75.1	3.2	82	205	0.03	0.17	0.11
16-12-2025		0.24	14.5	74.6	3.3	70	174	0.03	0.19	0.11
17-12-2025		0.25	15.5	75.0	3.4	68	171	0.04	0.21	0.12
18-12-2025		0.27	15.6	74.1	3.6	64	160	0.04	0.24	0.14
19-12-2025		0.37	16.0	75.1	3.4	69	173	0.04	0.21	0.12
20-12-2025		0.29	15.1	75.3	3.7	44	111	0.05	0.26	0.15
21-12-2025		0.27	15.4	74.7	3.6	47	117	0.04	0.23	0.13
22-12-2025		0.34	15.8	74.2	3.5	71	183	0.04	0.22	0.13
23-12-2025		0.32	18.1	74.6	3.5	70	163	0.04	0.23	0.13
24-12-2025		0.27	16.7	73.9	3.4	51	129	0.04	0.21	0.12
25-12-2025		0.27	15.9	74.5	3.3	51	127	0.04	0.18	0.11
26-12-2025		0.28	15.4	74.8	3.3	48	119	0.04	0.18	0.11
27-12-2025		0.33	15.8	74.4	3.4	48	121	0.04	0.21	0.12
28-12-2025		0.31	14.2	74.8	3.4	45	113	0.04	0.20	0.12
29-12-2025		0.28	13.1	75.1	3.3	37	92	0.04	0.19	0.12
30-12-2025		0.30	15.0	74.5	3.2	47	119	0.03	0.16	0.10
31-12-2025		0.28	15.6	74.1	3.7	42	97	0.05	0.25	0.14
Average		0.28	15.4	74.7	3.3	57	153	0.04	0.19	0.11
Minimum		0.24	13.1	72.7	3.1	37	92	0.03	0.15	0.09
Maximum		0.37	18.1	76.3	3.7	103	289	0.05	0.26	0.15
Std.	1 Hr.	4.00	180.0	NA	NA	NA	NA			
	8 Hr.	2.00	100.0	NA	NA	NA	NA			
	24Hr.	NA	NA	80.0	80.0	60	100	5(Annual)		

Kashish

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station : Rajkiya Queens College Varanasi

Monthly Report on Pollutant

Oct-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m³	µg/m³	µg/m³	µg/m³	ppb	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
01-10-2025	0.42	23.28	1.92	1.34	4.11	1.00	2.36	27.95	25.09	0.08	0.04	0.26
02-10-2025	0.48	23.26	1.92	1.35	4.12	1.01	2.24	105.56	22.35	0.10	0.05	0.29
03-10-2025	0.21	23.74	1.90	1.32	4.04	4.04	2.05	5.80	14.40	0.04	0.02	0.13
04-10-2025	0.23	23.40	1.92	1.34	4.10	1.01	2.05	3.12	8.68	0.05	0.02	0.14
05-10-2025	0.41	23.34	1.93	1.35	4.13	0.99	2.53	9.25	26.34	0.08	0.04	0.25
06-10-2025	0.56	25.60	1.86	1.23	3.89	1.03	2.39	16.23	44.12	0.11	0.06	0.34
07-10-2025	0.59	31.87	1.64	1.06	3.49	1.00	2.23	12.29	40.48	0.12	0.06	0.35
08-10-2025	0.53	33.43	1.59	1.06	3.40	0.99	2.33	12.46	44.47	0.11	0.06	0.32
09-10-2025	0.40	28.07	1.77	1.26	3.85	1.03	4.51	13.74	49.48	0.08	0.04	0.24
10-10-2025	0.26	23.79	1.92	1.36	4.12	1.02	4.32	20.44	82.64	0.05	0.03	0.16
11-10-2025	0.31	24.06	1.91	1.33	4.09	1.00	3.22	22.41	79.34	0.06	0.03	0.19
12-10-2025	0.25	24.09	1.91	1.31	4.07	1.03	3.42	18.32	72.77	0.05	0.03	0.15
13-10-2025	0.41	24.02	1.91	1.31	4.07	1.01	5.05	23.79	89.74	0.08	0.04	0.25
14-10-2025	0.56	24.07	1.91	1.30	4.07	0.98	3.56	26.14	95.10	0.11	0.06	0.33
15-10-2025	0.49	23.65	1.92	1.33	4.11	1.01	3.61	25.83	100.72	0.10	0.05	0.29
16-10-2025	0.54	32.20	1.98	1.40	4.24	1.01	4.13	27.65	98.03	0.11	0.06	0.32
17-10-2025	0.56	22.24	1.97	1.41	4.23	1.01	4.76	29.77	104.93	0.11	0.06	0.34
18-10-2025	0.71	22.26	1.98	1.42	4.24	1.03	2.80	30.17	114.28	0.15	0.08	0.44
19-10-2025	0.59	22.30	1.98	1.43	4.26	1.03	3.27	28.70	104.59	0.12	0.06	0.35
20-10-2025	0.59	22.56	1.96	1.40	4.21	3.27	3.27	48.02	145.41	0.12	0.06	0.35
21-10-2025	0.49	23.90	1.91	1.29	4.06	1.00	3.07	57.57	164.65	0.10	0.05	0.29
22-10-2025	0.59	26.42	1.84	1.18	3.82	0.98	2.44	40.79	118.98	0.12	0.06	0.36
23-10-2025	0.83	32.01	1.65	1.05	3.48	1.00	2.16	37.53	117.48	0.16	0.09	0.49
24-10-2025	0.71	33.10	1.59	1.05	3.41	1.00	2.20	28.79	95.55	0.14	0.07	0.42
25-10-2025	0.74	33.56	1.58	1.05	3.38	0.99	2.35	22.58	42.68	0.15	0.08	0.44
26-10-2025	0.65	33.68	1.58	1.05	3.35	1.01	2.51	27.80	92.92	0.13	0.07	0.39
27-10-2025	0.73	28.66	1.98	1.26	3.60	1.02	3.04	32.58	100.28	0.14	0.08	0.44
28-10-2025	0.42	24.12	1.99	1.35	4.50	1.03	2.82	19.78	58.94	0.08	0.04	0.25
29-10-2025	0.45	24.08	1.59	1.20	3.58	1.01	2.08	17.32	48.80	0.09	0.05	0.27
30-10-2025	0.29	24.06	1.91	1.32	4.07	1.02	2.10	9.57	26.45	0.06	0.03	0.17
31-10-2025	0.32	23.61	1.94	1.34	4.13	1.00	1.89	4.89	12.01	0.06	0.03	0.19
Average	**0.49**	**26.08**	**1.85**	**1.27**	**3.94**	**1.18**	**2.93**	**26.03**	**72.31**	**0.10**	**0.05**	**0.30**
Min.	**0.21**	**22.24**	**1.58**	**1.05**	**3.35**	**0.98**	**1.89**	**3.12**	**8.68**	**0.04**	**0.02**	**0.13**
Max.	**0.83**	**33.68**	**1.99**	**1.43**	**4.50**	**4.04**	**5.05**	**105.56**	**164.65**	**0.16**	**0.09**	**0.49**

Kashish

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station : Rajkiya Queens College Varanasi

Monthly Report on Pollutant

Nov-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m^3	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	ppb	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$	$\mu g/m^3$
01-11-2025	0.32	23.26	1.95	1.39	4.19	1.03	1.74	5.26	19.79	0.07	0.03	0.19
02-11-2025	0.43	23.05	1.96	1.38	4.20	1.02	2.56	21.55	67.32	0.09	0.05	0.26
03-11-2025	0.48	23.08	1.96	1.38	4.19	4.19	3.39	29.43	93.89	0.09	0.05	0.29
04-11-2025	0.47	23.06	1.96	1.35	4.17	1.03	2.92	26.72	95.20	0.09	0.05	0.28
05-11-2025	0.53	22.95	1.96	1.38	4.19	1.02	3.40	31.28	105.52	0.11	0.06	0.32
06-11-2025	0.48	23.35	1.94	1.35	4.13	1.00	3.44	19.83	101.50	0.10	0.05	0.29
07-11-2025	0.44	22.87	1.96	1.39	4.20	1.03	3.95	33.18	109.72	0.09	0.05	0.27
08-11-2025	0.44	22.98	1.95	1.39	4.19	1.02	4.11	32.57	105.83	0.09	0.05	0.27
09-11-2025	0.51	22.92	1.95	1.37	4.18	1.03	4.08	47.54	135.01	0.10	0.05	0.31
10-11-2025	0.68	22.93	1.95	1.37	4.18	1.01	5.87	46.50	142.90	0.14	0.07	0.41
11-11-2025	0.69	22.40	1.98	1.42	4.25	1.03	5.51	55.66	158.58	0.14	0.07	0.41
12-11-2025	0.69	23.70	1.93	1.32	4.04	1.02	6.36	54.16	163.46	0.14	0.07	0.41
13-11-2025	0.72	24.94	1.88	1.30	3.95	1.01	6.06	52.89	165.73	0.15	0.07	0.44
14-11-2025	0.88	22.85	1.95	1.41	4.21	1.00	3.30	65.56	195.19	0.18	0.09	0.53
15-11-2025	1.00	22.83	1.95	1.41	4.21	1.02	3.28	57.84	139.74	0.20	0.11	0.60
16-11-2025	0.99	32.20	1.99	1.43	4.25	1.03	3.26	66.70	112.49	0.20	0.10	0.60
17-11-2025	1.45	22.90	1.96	1.40	4.21	1.00	2.86	61.80	118.77	0.29	0.15	0.87
18-11-2025	1.25	21.66	2.03	1.47	4.33	1.04	4.10	65.36	116.19	0.25	0.13	0.76
19-11-2025	1.62	22.28	2.00	1.42	4.26	1.02	2.55	65.04	119.91	0.32	0.17	0.97
20-11-2025	1.65	22.95	1.97	1.38	4.21	2.65	2.65	24.91	47.01	0.33	0.17	0.99
21-11-2025	0.96	23.42	1.93	1.34	4.12	1.02	3.80	60.16	95.50	0.19	0.10	0.58
22-11-2025	0.90	22.40	1.98	1.43	4.25	1.02	3.65	66.13	105.72	0.18	0.09	0.54
23-11-2025	0.98	21.79	2.02	1.45	4.31	1.01	3.50	65.46	112.67	0.20	0.10	0.59
24-11-2025	1.37	22.54	1.98	1.39	4.23	1.00	3.06	62.87	113.33	0.27	0.14	0.82
25-11-2025	0.95	22.99	1.96	1.36	4.19	1.01	2.88	22.58	42.68	0.19	0.10	0.57
26-11-2025	0.94	23.28	1.94	1.35	4.15	1.02	4.38	56.44	98.68	0.19	0.10	0.56
27-11-2025	1.63	24.43	1.89	1.27	3.96	1.01	2.05	66.50	115.08	0.33	0.17	0.98
28-11-2025	1.32	27.57	1.79	1.10	3.63	1.00	2.67	63.02	107.33	0.25	0.13	0.75
29-11-2025	0.71	25.40	1.87	1.27	3.94	1.02	5.17	49.76	86.38	0.14	0.07	0.42
30-11-2025	0.61	22.83	1.96	1.45	4.24	1.03	3.18	43.78	72.99	0.12	0.06	0.36
Average	**0.87**	**23.53**	**1.95**	**1.37**	**4.16**	**1.18**	**3.66**	**47.35**	**108.80**	**0.17**	**0.09**	**0.52**
Min.	**0.32**	**21.66**	**1.79**	**1.10**	**3.63**	**1.00**	**1.74**	**5.26**	**19.79**	**0.07**	**0.03**	**0.19**
Max.	**1.65**	**32.20**	**2.03**	**1.47**	**4.33**	**4.19**	**6.36**	**66.70**	**195.19**	**0.33**	**0.17**	**0.99**

Uttar Pradesh Pollution Control Board

Continuous Ambient Air Quality Monitoring Station : Rajkiya Queens College Varanasi

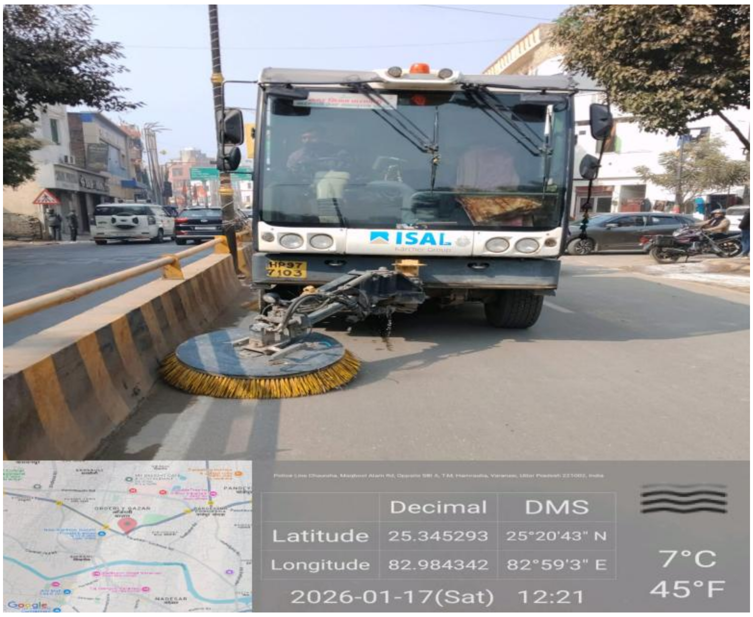
Monthly Report on Pollutant

Dec-25

Date	CO	SO_2	NO	NO2	NOX	NH3	O_3	$PM_{2.5}$	PM_{10}	BEN.	Eth-Ben	MP-XYL
	mg/m³	µg/m³	µg/m³	µg/m³	ppb	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³	µg/m³
01-12-2025	0.66	22.68	1.97	1.43	4.24	1.02	4.83	61.63	82.32	0.13	0.07	0.40
02-12-2025	0.92	22.91	1.97	1.40	4.22	1.00	3.25	53.40	98.30	0.19	0.10	0.55
03-12-2025	1.13	22.88	1.97	1.39	4.22	4.22	3.14	52.39	93.64	0.23	0.12	0.68
04-12-2025	0.57	23.40	1.94	1.35	4.13	1.02	3.94	50.14	85.28	0.12	0.06	0.34
05-12-2025	0.58	23.86	1.91	1.33	4.06	1.02	5.44	48.64	84.88	0.12	0.06	0.35
06-12-2025	0.64	24.80	1.87	1.28	3.93	1.00	4.89	29.67	93.09	0.13	0.07	0.39
07-12-2025	0.57	22.73	1.96	1.43	4.23	1.02	3.59	51.34	86.11	0.11	0.06	0.34
08-12-2025	0.86	22.77	1.96	1.41	4.22	1.03	2.96	63.73	108.26	0.17	0.09	0.52
09-12-2025	0.85	23.36	1.94	1.36	4.14	1.01	3.29	58.06	97.23	0.17	0.09	0.51
10-12-2025	0.77	22.89	1.96	1.38	4.19	1.02	2.98	50.73	93.65	0.15	0.08	0.46
11-12-2025	0.70	22.49	1.99	1.41	4.23	1.01	3.55	53.91	90.59	0.14	0.07	0.42
12-12-2025	0.92	22.92	1.95	1.37	4.17	1.01	2.49	83.25	131.75	0.18	0.10	0.55
13-12-2025	1.59	22.83	1.96	1.36	4.19	1.04	2.33	107.94	173.87	0.32	0.17	0.96
14-12-2025	2.15	22.76	1.96	1.40	4.21	1.02	2.12	104.17	58.55	0.43	0.22	1.29
15-12-2025	0.93	23.26	1.93	1.36	4.14	1.02	2.36	84.68	61.25	0.19	0.10	0.56
16-12-2025	0.40	32.20	2.02	1.46	4.31	1.04	2.76	63.56	99.95	0.08	0.04	0.24
17-12-2025	0.39	22.47	1.99	1.40	4.23	1.03	3.30	68.03	99.35	0.08	0.04	0.24
18-12-2025	0.45	22.76	1.97	1.39	4.21	1.01	1.89	68.64	106.93	0.09	0.05	0.27
19-12-2025	0.35	22.77	1.97	1.38	4.21	1.01	2.63	69.98	110.54	0.07	0.04	0.21
20-12-2025	0.40	22.59	1.96	1.39	4.21	2.04	2.04	55.60	82.44	0.08	0.04	0.24
21-12-2025	0.27	22.59	1.97	1.39	4.21	1.01	2.04	55.21	81.10	0.05	0.03	0.16
22-12-2025	0.53	22.59	2.41	1.65	5.10	1.00	2.01	76.93	108.34	0.11	0.06	0.31
23-12-2025	0.59	22.87	1.97	1.36	4.20	1.02	2.19	71.35	99.93	0.12	0.06	0.36
24-12-2025	0.44	22.72	1.98	1.37	4.21	0.99	2.22	61.62	88.54	0.09	0.05	0.26
25-12-2025	0.40	22.70	1.97	1.36	4.20	1.01	2.03	22.58	42.68	0.08	0.04	0.24
26-12-2025	0.62	24.11	1.91	1.26	4.00	0.99	2.91	61.64	86.88	0.13	0.06	0.37
27-12-2025	0.40	26.16	1.98	1.26	3.60	0.99	3.01	57.77	86.25	0.08	0.04	0.24
28-12-2025	0.45	26.12	1.99	1.35	4.50	1.02	2.29	57.66	87.04	0.08	0.04	0.25
29-12-2025	0.20	24.64	1.59	1.20	3.58	1.02	2.83	51.48	76.81	0.04	0.02	0.12
30-12-2025	0.55	22.53	1.97	1.45	4.25	1.02	2.29	83.12	122.71	0.11	0.06	0.33
31-12-2025	0.73	22.26	1.99	1.46	4.29	1.02	2.04	87.20	129.50	0.15	0.08	0.44
Average	**0.68**	**23.50**	**1.96**	**1.38**	**4.19**	**1.15**	**2.89**	**63.42**	**95.09**	**0.14**	**0.07**	**0.41**
Min.	**0.20**	**22.26**	**1.59**	**1.20**	**3.58**	**0.99**	**1.89**	**22.58**	**42.68**	**0.04**	**0.02**	**0.12**
Max.	**2.15**	**32.20**	**2.41**	**1.65**	**5.10**	**4.22**	**5.44**	**107.94**	**173.87**	**0.43**	**0.22**	**1.29**

ANNEXURE R-4

Copies of photographs of Water Sprinklers, Vehicle and Anti-Smog Gun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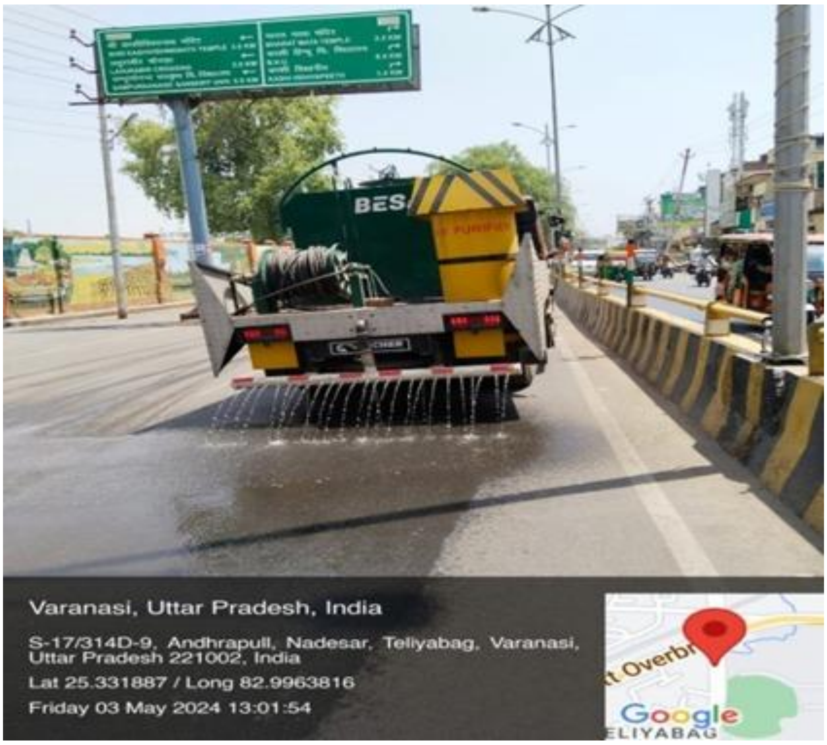
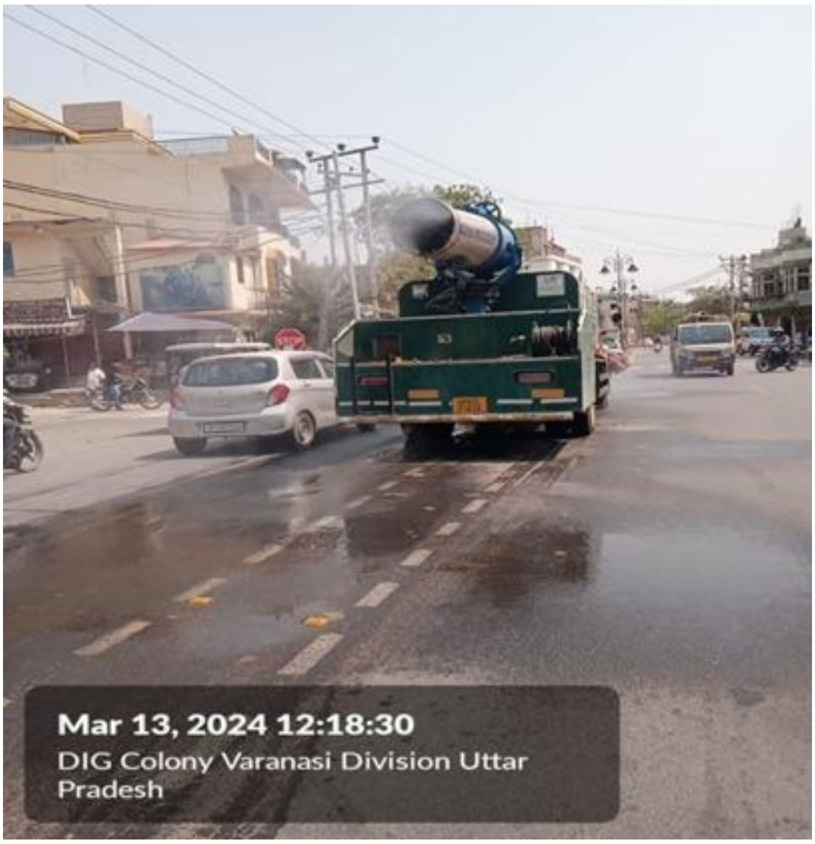
HP97 7103
Decimal
DMS
Latitude
25.345293
25°20'43" N
Longitude
82.984342
82°59'3" E
2026-01-17(Sat) 12:21
7°C
45°F
Google

Mechanical Road Sweeping Vehicle


BES
Varanasi, Uttar Pradesh, India
S-17/314D-9, Andhrapull, Nadesar, Teliyabag, Varanasi, Uttar Pradesh 221002, India
Lat 25.331887 / Long 82.9963816
Friday 03 May 2024 13:01:54
t Overbr
Google
ELIYABAG

Water Sprinkler

8070

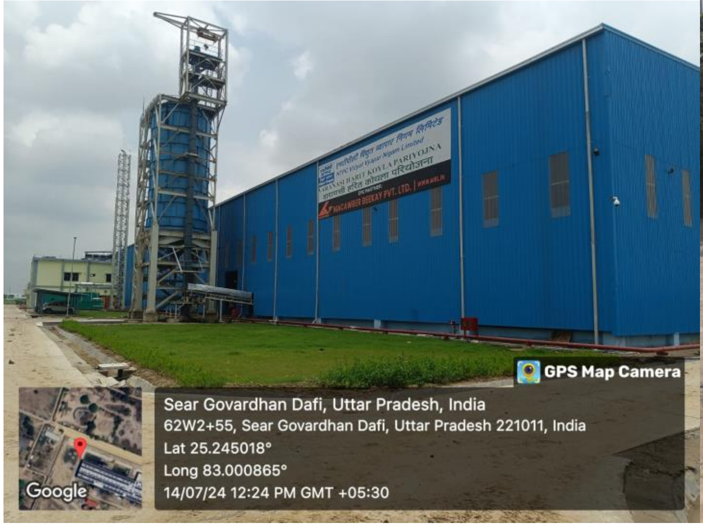

Mar 13, 2024 12:18:30
DIG Colony Varanasi Division Uttar Pradesh

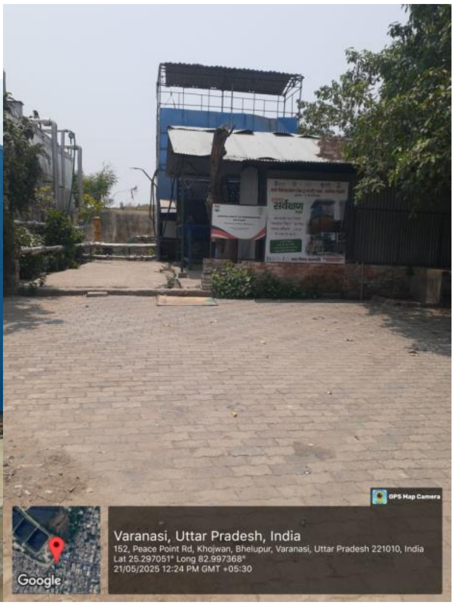
Anti-Smog Gun

ANNEXURE R--5

Photographs of Waste Collection Centres, Waste to Energy Plant and Processing Facilities

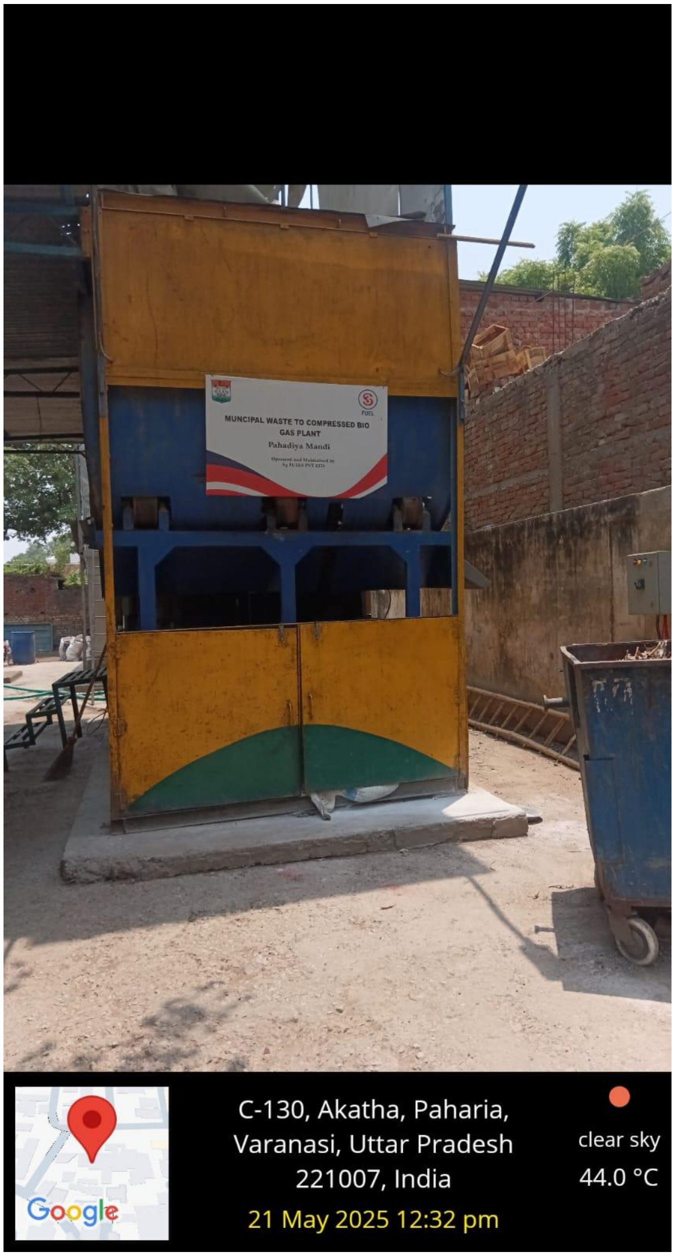
स्वच्छ सर्वेक्षण 2024
नगर निगम वाराणसी
सुरक्षा प्रहरी कक्ष
वेस्ट टू कम्पोस्ट प्लान्ट
(करसड़ा वाराणसी)
क्षमता : 600TPD
सर्वेक्षण 2024


एनटीपीसी विद्युत व्यापार निगम लिमिटेड
NTPC Vidyut Vyapar Nigam Limited
VARANASI HARIT KOYLA PARIYOJNA
वाराणसी हरित कोयला परियोजना
EPC PARTNER
MACAWBER BEEKAY PVT. LTD.
GPS Map Camera
Sear Govardhan Dafi, Uttar Pradesh, India
62W2+55, Sear Govardhan Dafi, Uttar Pradesh 221011, India
Lat 25.245018°
Long 83.000865°
14/07/24 12:24 PM GMT +05:30
Google


सर्वेक्षण
GPS Map Camera
Varanasi, Uttar Pradesh, India
152, Peace Point Rd, Khojwan, Bhelupur, Varanasi, Uttar Pradesh 221010, India
Lat 25.297051° Long 82.997368°
21/05/2025 12:24 PM GMT +05:30
Google

Waste to Charcoal Plant

8072


MUNCIPAL WASTE TO COMPRESSED BIO GAS PLANT
Pahadiya Mandi
FUEL
Google
C-130, Akatha, Paharia, Varanasi, Uttar Pradesh 221007, India
21 May 2025 12:32 pm
clear sky
44.0 °C

Biomethanation Plant

ANNEXURE R-6

Regional Office
UP Pollution Control Board
Varanasi

Stack emission Details with Industries name and address Situated in Varanasi (Within the Limit of Nagar Nigam)

S. No.	Name of Industry	Sector (for Example-Sugar, Distillery etc.)	Operational Status (Yes/No)	Consent Status (Yes/No)	Emission Source	Fuel Use	Test Report date	Particula Matter (PM) in mg/Nm3	Remark
1	AISEWARYA CREATIONS 310 G, Chandpur Crossing, Varanasi	Saree Printing & Washing	Yes	Yes	Boiler-600 Kg/day	Coal-500 Kg/day	29-11-2025	199	Complying
2	Lakhi Creation Pvt. Ltd., D-34, Industrial Estate, Chandpur, Varanasi	Saree Printing & Washing-100 Pcs/day.	Yes	Yes	Boiler-600 Kg/day	Coal-200 Kg/day	06-12-2025	214	Complying
3	Pushpanjali Sarees Pvt. Ltd. A-6, Industrial Estate, Extention, Chandpur, Varanasi	Saree Printing & Washing-375 Pcs/day.	Yes	Yes	Boiler-600 Kg/day	Coal-150 Kg/day	04-12-2025	230	Complying
4	Pushpanjali Sarees Pvt. Ltd. (Unit-III), B-1, B-2, B-1E, B-2E, Industrial Estate, Chandpur, Varanasi	Light Carpet Printing-100 Pcs/day and Silk Sarees Screen & Block Printing 50 Pcs/day.	Yes	Yes	Boiler-1.0 Ton/hour	Coal-500 Kg/day	04-12-2025	244	Complying
[illegible]	S N D Dyeing & Processing Co. Pvt. Ltd. A-7, Industrial Estate, Chandpur, Varanasi	Saree Printing & Washing-100 Pcs/day	Yes	Yes	Steam Generator-300 Kg/day	HSD-5 Ltr/Hr	29-11-2025	145	Complying
[illegible]	Samyak Creation Pvt. Ltd. P-8, Big Industrial Estate, Chandpur, Maheshpur, Varanasi	Silk, Cotton, Polyster Saree Printing, Washing and Embrodery200 Pcs/day	Yes	Yes	Boiler-0.6 Ton/day	Coal-200 Kg/day	03-12-2025	202	Complying
7	Swastik Dyeing & Processing Co Pvt. Ltd. P-3, Big Industrial Estate, Chandpur, Varanasi	Silk, Cotton, Polyster Saree Printing, Washing and Embrodery200 Pcs/day	Yes	Yes	Boiler-0.6 Ton/hour	Coal-100 Kg/day	28-11-2025	196	Complying

Note:-Data is analysed by NABL acrecdiated Laboratory

S.A.

ASO

8073

Scanned with OKEN Scanner