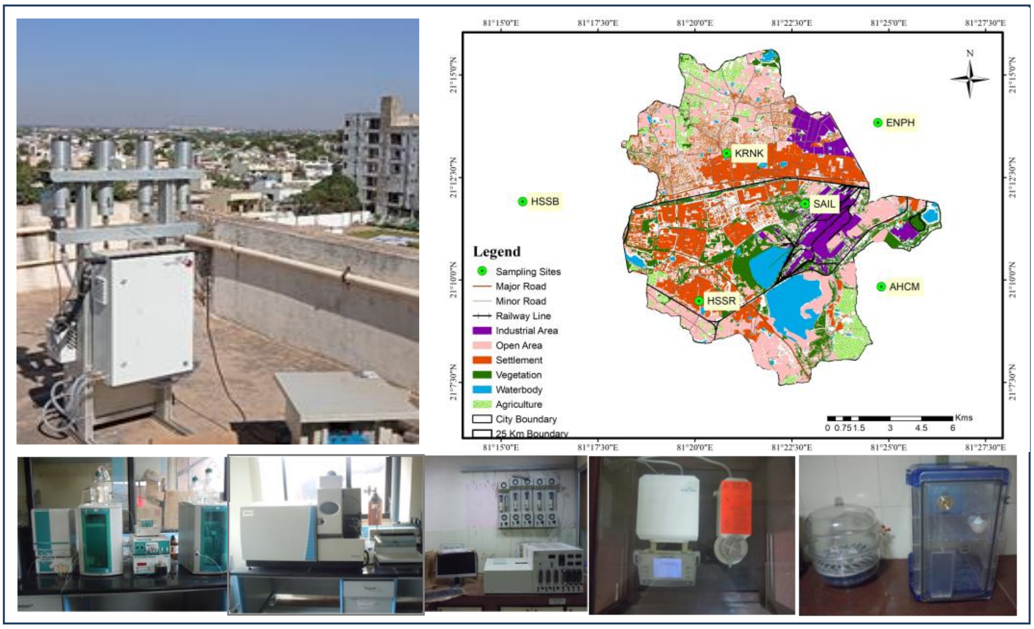
Source Apportion-based Action Plans for Maintaining and Restoring Air Quality in the Bhilai Region, Chhattisgarh

(Final Report)

Submitted to

Chhattisgarh Environment Conservation Board, Raipur



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Executive Summary

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

To address the air pollution issues of City of Bhilai, Chhattisgarh Environment Conservation Board, Raipur has sponsored the study “Source Apportion-based Action Plans for Maintaining and Restoring Air Quality in the Bhilai Region, Chhattisgarh” to the Indian Institute of Technology Kanpur (IITK). The study/project had commenced on November 22, 2019. The main objectives of the study are preparation of emission inventory, air quality monitoring in three seasons, chemical composition of PM_{10} and $PM_{2.5}$, apportionment of sources to ambient air quality, trend analysis in historical air quality data and development of pollution control plan. The project has the following specific major objectives:

- The study area includes a 25 km radius with Bhilai Steel Plant (main gate) as the epicenter.
- Identification and emission inventory of all sources i.e. Point, Line, and Area sources.
- Quantum of total air pollution load in the area generated from Point, Line and Area sources and their contribution (percent wise).
- Emission characterization in respective sources.
- Monitoring of ambient air quality for all three seasons i.e. summer, winter, and post-monsoon.
- Air quality modeling and source contribution assessment analysis.
- Delineation of air quality management plans for overall improvements and conforming to the ambient air quality standards in the region.

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

Air Quality: Measurements

A total of seven air quality sites were categorized based on the predominant land-use pattern (Table 1.1) to cover varying land-use prevailing in the city. PM_{10} (particulate matter of size less than and equal to 10 µm diameter), $PM_{2.5}$ (particulate matter of size less than and equal to 2.5 µm diameter), SO_2, NO_2, VOCs (volatile organic compounds), OC (organic carbon), EC (elemental carbon), Ions, Elements, PAHs (polyaromatic hydrocarbons) and molecular markers were considered for sampling and measurements. The air quality sampling was conducted for three seasons: winter, summer and post-monsoon.

Table 1.1: Description of Sampling Sites of Bhilai

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	Kripal Nagar, Kohka	KRNK	Residential	Domestic cooking, vehicle, road dust, garbage/waste burning, Restaurants
2.	SAIL Bhilai Steel Plant (BSP)	SAIL	Industrial	Industries, DG sets, vehicle, road dust, garbage/industrial waste burning, Restaurants
3.	Engineering Park, Hathkhoj	ENPH	Industrial	Industries, DG sets, vehicle, road dust, garbage/industrial waste burning, Restaurants
4.	Higher Secondary School, Risali	HSSR	Commercial	DG sets, vehicle, road dust, garbage/waste burning, Restaurants
5.	Higher Secondary School, Baghera	HSSB	Background /commercial	Soil and road dust, vehicle, garbage/agricultural waste burning, domestic cooking
6.	Ayushman Health Centre, Morid	AHCM	Residential	Domestic cooking, vehicle, road dust, garbage/waste burning, Industrial
7.	Atal Bhawan, Gudeli Village	ABGV	Residential	Domestic cooking, vehicle, road dust, garbage/waste burning, Industrial

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

- Particulate pollution is the main concern in the city where PM_{10} levels are 1.8 – 2.5 times higher than the national air quality standards (NAAQS) in summer and winter months and $PM_{2.5}$ levels are 1.5 – 2.4 times higher than the NAAQS in winter and summer months. PM_{10} and $PM_{2.5}$ levels were within the limit of the NAAQS in post-monsoon.

- 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 three seasons.

Winter - PM_{10}

The overall average concentration of PM_{10} in winter season is 250±62 $\mu g/m^3$ against the acceptable level of 100 $\mu g/m^3$. Highest levels were observed at SAIL (344±40 $\mu g/m^3$) and lowest at HSSB (181±54 $\mu g/m^3$).

The crustal component (Si + Al + Fe + Ca) accounts for about 23%. This suggests soil and road dust was significantly high in PM_{10} in winter. The coefficient of variation (CV) is about 0.36 (of fraction of crustal component) which suggests the crustal source contributes consistently to winter. though much less compared to summer season.

The other important component is the secondary particles (NO_3^{-} + SO_4^{-2} + NH_4^{+}), which account for about 13% of total PM_{10} and combustion related total carbon (TC = EC + OC) accounts for about 16% in winter.

The Cl^- content in PM_{10} in winter is consistent with an average of 3 percent, which is an indicator of burning of plastic solid waste; recall poly vinyl chloride (PVC) is a major part of solid waste. The highest Cl^- content is observed at HSSR at 11.36 $\mu g/m^3$ compared to overall city level of 7.64 $\mu g/m^3$. The high level at HSSR signifies some local burning of waste as a means of disposal of solid waste.

Winter - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 142±29 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at SAIL 196±32 µg/m^3 and lowest at HSSR 108±20 µg/m^3. The crustal component (20% in winter, 18% in summer and 20% in post-monsoon) is almost similar in all the three seasons.

The other important components are the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 15% of total $PM_{2.5}$ and combustion related total carbon (EC+OC) accounts for 21%; both secondary particles and combustion related carbon are consistent contributors to $PM_{2.5}$ at about 36%. Highest level of TC was observed at SAIL (39 µg/m^3).

The Cl^- content in $PM_{2.5}$ winter is consistent with an average of 4.47% which is an indicator of burning of solid waste.

Summer - PM_{10}

The overall average concentration of PM_{10} in summer season was 175±78 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 22 percent of total PM_{10} in summer. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.50, which suggests the sources are inconsistent all around the city forming a layer which envelopes the city. The areas of SAIL and ENPH have the highest crustal fraction (around 23% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Bhilai and are more prominent in summer when soil and dust are dry and high-speed winds make the particles airborne. It was observed that in summer the atmosphere looks light brownish which can be attributed to the presence of large amounts of soil dust particles in the atmosphere.

The second significant component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 15 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about 16 percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^-, SO_4^{-2}, and NH_4^+.

The Cl^- content in PM_{10} in summer is consistent at 4 percent, which is an indicator of burning of municipal solid waste and has a relatively similar contribution in summer and winter.

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer is 91±34 µg/m^3 against the acceptable level of 60 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 20% of total $PM_{2.5}$. This suggests airborne soil and road dust is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.40, which suggests the source is consistent all around the city.

The second important component is combustion related total carbon (EC+OC), which account for 25% of total $PM_{2.5}$ and secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$) accounts for 17%; both fractions of secondary particles and combustion related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles, and combustion contribute consistently to $PM_{2.5}$ in summer.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 4%, which is an indicator of burning of municipal solid waste and has a similar contribution to $PM_{2.5}$ and PM_{10}.

Post-monsoon - PM_{10}

The overall average concentration of PM_{10} in post-monsoon season was 93±40 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 23 percent of total PM_{10} in post-monsoon. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in post-monsoon. The coefficient of variation (CV) is about 0.49, which suggests the sources are inconsistent all around the city forming a layer which envelopes the city. The areas of HSSR and ENPH have the highest crustal fraction (around 24% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around Bhilai.

The second significant component is the secondary particles (NO_3^{-} + SO_4^{-2} + NH_4^{+}), which account for 17 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about 13 percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^{-}, SO_4^{-2}, and NH_4^{+}.

The Cl^- content in PM_{10} in post-monsoon is consistent at 3 percent, which is an indicator of burning of municipal solid waste and has a relatively equal contribution in summer and winter.

Post-monsoon - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in post-monsoon season is 50 µg/m^3 (except at ENPH and HSSR where level is 67 µg/m^3 and 74 µg/m^3) within the acceptable level of 60 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 16% of total $PM_{2.5}$. This suggests airborne soil and road dust is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.32, which suggests the source is consistent all around the city.

The second important component is combustion related total carbon (EC+OC), which account for 18% of total $PM_{2.5}$ and secondary particles (NO_3^{-} + SO_4^{-2} + NH_4^{+}) accounts for 17%; fractions of combustion related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles and combustion contribute consistently to $PM_{2.5}$ in post-monsoon.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 3 percent, which is an indicator of burning of solid waste and has a similar contribution to $PM_{2.5}$ and PM_{10}. This is similar in all the three seasons.

Potassium levels

In general potassium levels are high and variable for PM_{10} (3.4 to 6.4 µg/m^3) and $PM_{2.5}$ (1.3 to 4.0 µg/m^3) in winter, summer and post-monsoon. In general potassium level should be less than 2 µg/m^3 which achieved in post-monsoon in $PM_{2.5}$. Potassium is an indicator of biomass burning (includes agricultural residue, plant leaves, wood, dung cake) and high levels and variability show significant biomass burning and it is consistent in all three seasons.

NO_2 levels

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

General inferences

Levels of OC (at all locations), PM_{10}, $PM_{2.5}$ and NO_2 (all sites except at KRNK) are statistically higher in winter than in summer season. Levels of all pollutants at all locations (except SO_2 at HSSB) are statistically higher in winter than post-monsoon. In general air pollution levels in ambient air (barring traffic intersections) are uniform across the city suggesting entire city is stressed under high pollution; in a relative sense, SAIL is most polluted followed by HSSR and ENPH. HSSB is the least polluted area.

It is to be noted that OC3/TC ratio is above 0.20 and highest among ratio of fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed in atmosphere due to condensation and nucleation of volatile to semi volatile organic compounds, which suggests emissions within and outside of Bhilai.

Total PAH levels (17 compounds; particulate phase) in winter is high at 34 ng/m^3 the comparison with annual standard is not advisable due to different averaging times. However, PAH levels in summer and post-monsoon drop to about 28 ng/m^3 and 21 ng/m^3.

The concentrations of molecular markers in $PM_{2.5}$ (total of 6 compounds) are also higher in winter (96 ng/m^3) than in summer (71 ng/m^3) and post-monsoon (64 ng/m^3) indicating presence of common sources of emissions from coal, gasoline, and domestic fuel.

The total BTX levels are lesser in winter (9 µg/m^3) than in summer (18 µg/m^3) and post-monsoon (15 µg/m^3). The emission rate in summer is higher due to higher temperature. The average benzene level exceeded the annual national standard (5 µg/m^3) in winter.

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

Emission Inventory

Emission inventory (EI) is a necessity for planning air pollution control activities. The overall baseline EI for Bhilai City is developed for the base year 2022. The pollutant wise contribution is shown in Figure 1 to Figure 5. Spatial distribution of emissions from different sources is presented in Figure 6 to Figure 10.

The total PM_{10} emission load in the study area is estimated to be 122 tonnes/d. The top four contributors to PM_{10} emissions are industries (49%; break-up: Bhilai Steel Plant (BSP), 32% and others 17%), road dust (36%), brick kilns (4%), and domestic (4%); these are based on annual emissions. Seasonal and daily emissions could be variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources is required to obtain the desired air quality.

$PM_{2.5}$ emission load in the study area is estimated to be 53 tonnes/d. The top four contributors to $PM_{2.5}$ emissions are industries (58%; break up: BSP: 45% and others: 13%), road dust (19%), domestic (8%), and bick kilns (6%); these are based on annual emissions. Seasonal and daily emissions could be variable depending on the activities in progress.

SO_2 emission load in the study area is estimated to be 160 tonnes/d. Industries (95%; break-up: BSP: 53% and others: 42%), brick kilns (4%), and domestic (1%) are the main sources.

NO_x emissions load in the study area is estimated to be 196 tonnes/d. The majority of total emissions are attributed to industries (85%; break-up BSP: 47% and others: 38%), vehicles (13%), and domestic (1%).

The estimated CO emission is 74 tonnes/d. The major contributors to CO emissions are vehicles (35%), domestic (23%), and brick kilns (15%).

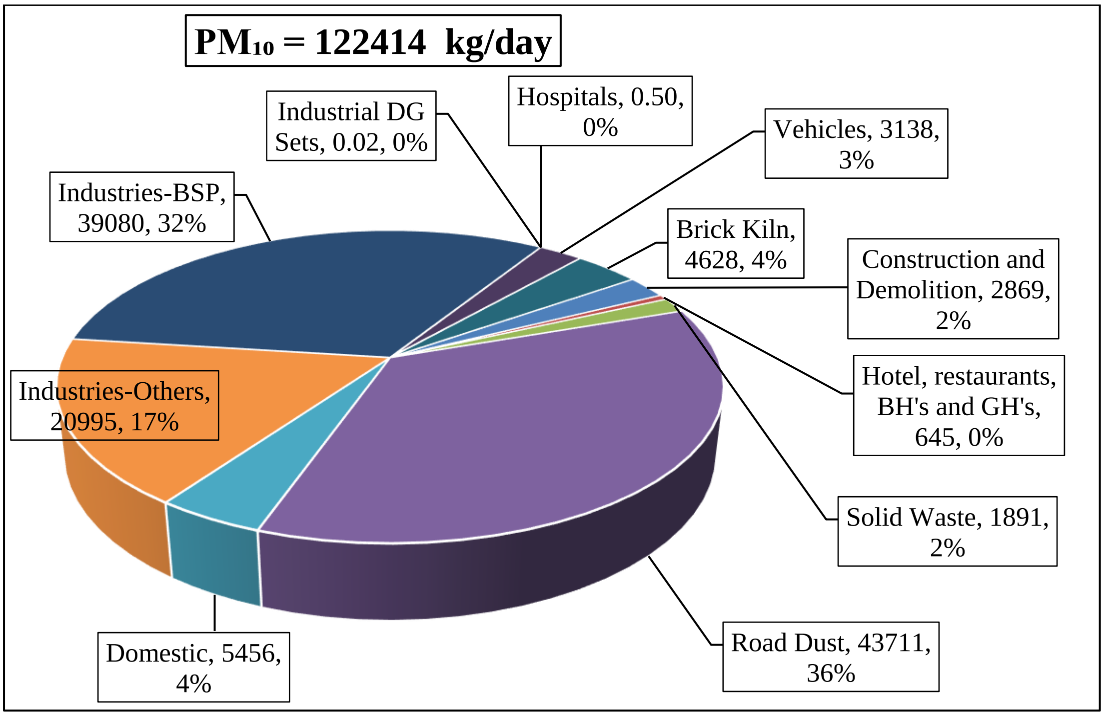


Figure 1: Emission Load Contribution of Different Sources in PM_{10} (kg/d)

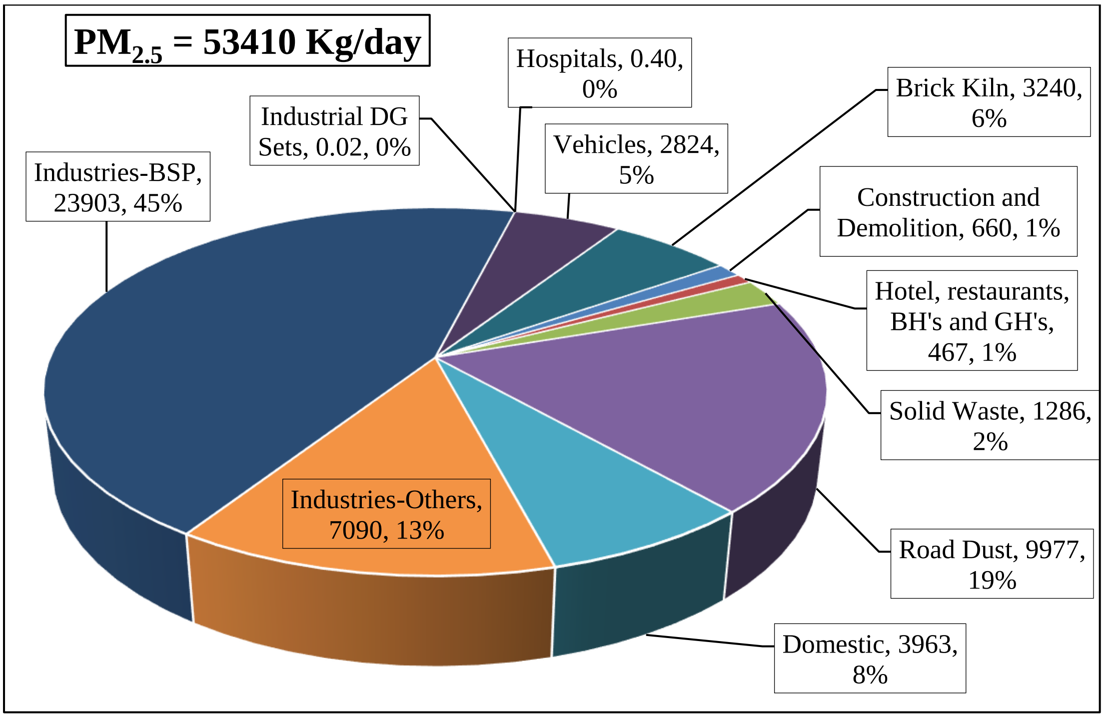


Figure 2: Emission Load Contribution of Different Sources in $PM_{2.5}$ (kg/d)

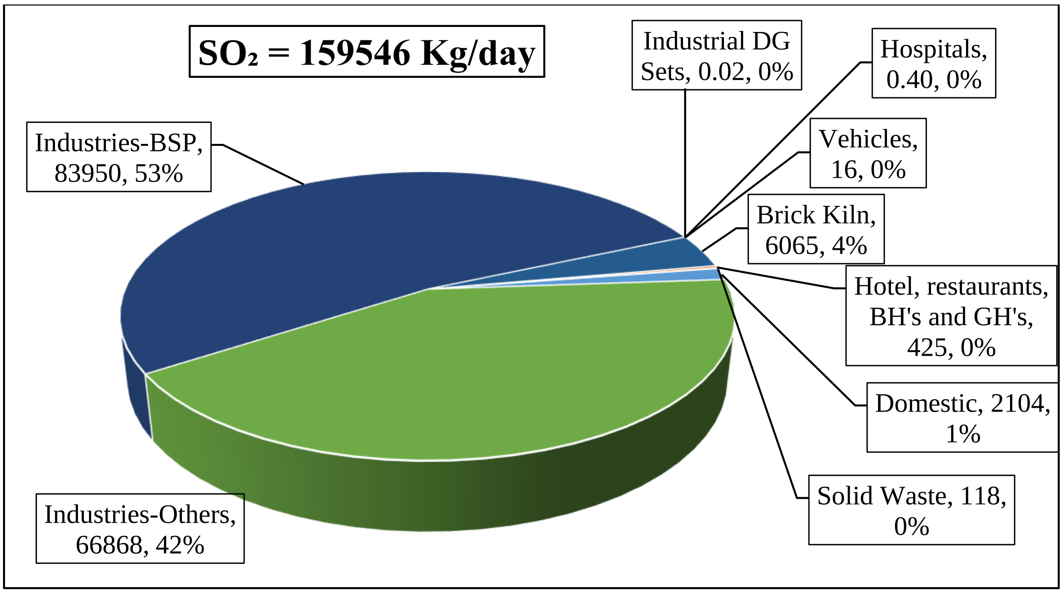


Figure 3: Emission Load Contribution of Different Sources in SO_2 (kg/d)

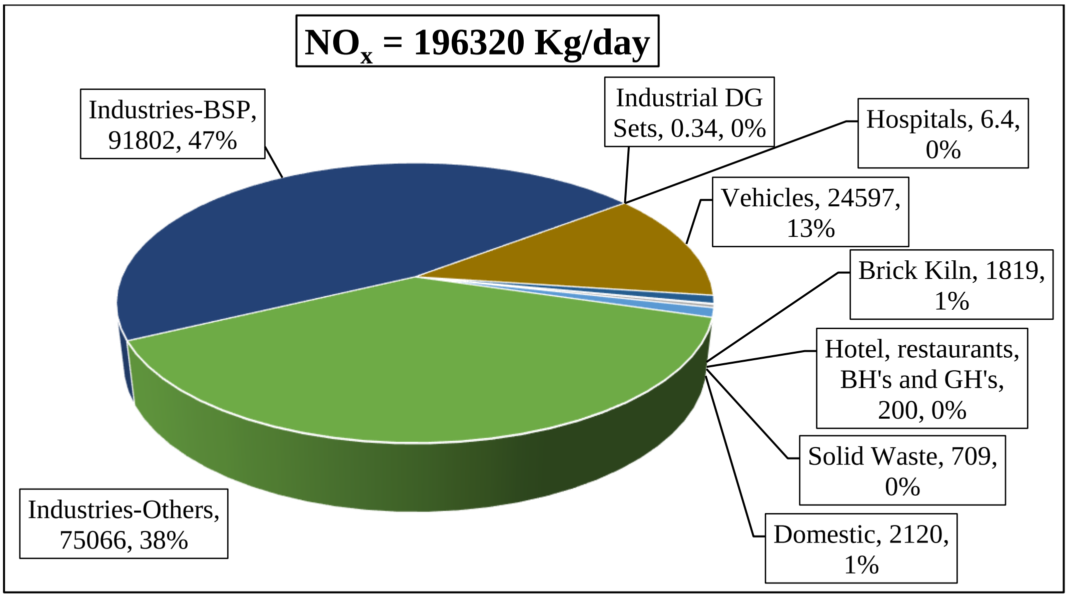


Figure 4: Emission Load Contribution of Different Sources in NO_x (kg/d)

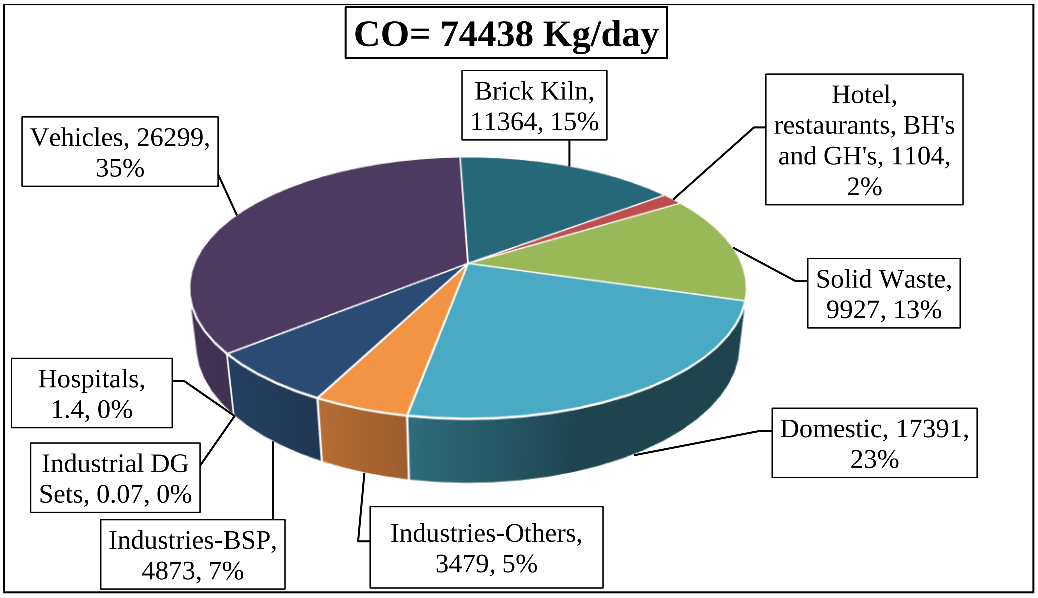


Figure 5: CO Emission Load Contribution of Different Sources (kg/d)

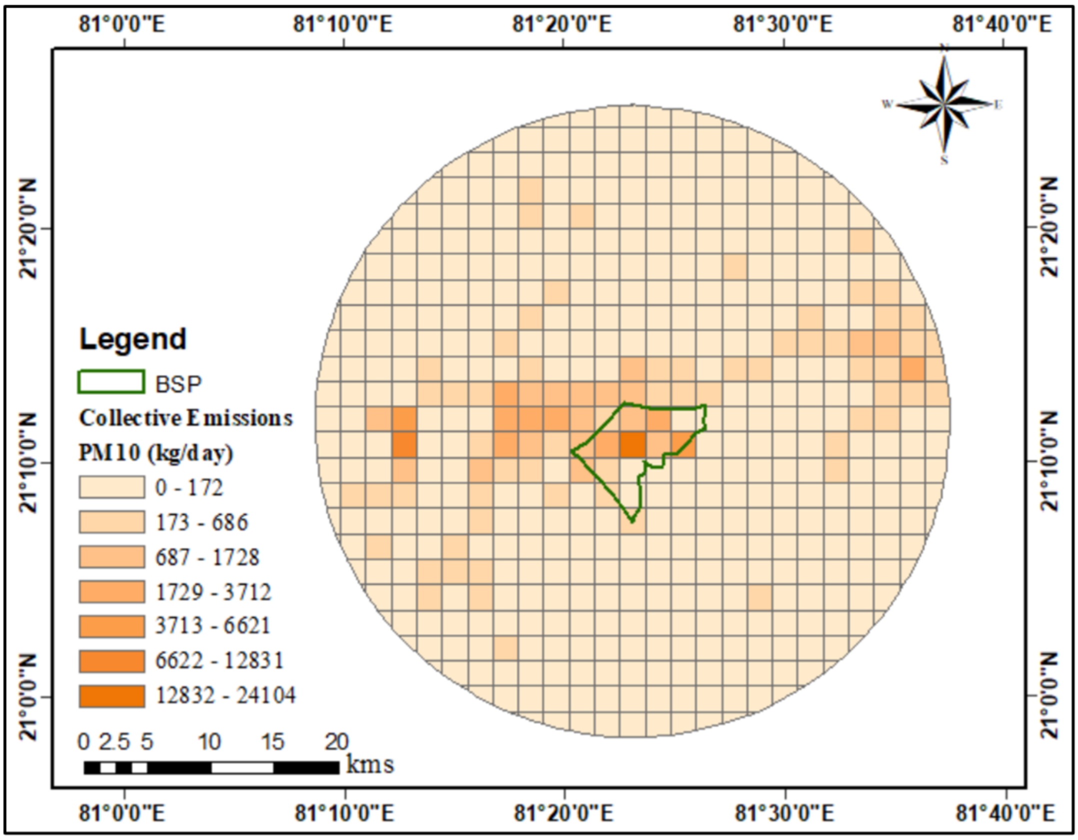


Figure 6: Spatial Distribution of PM_{10} Emissions in Bhilai

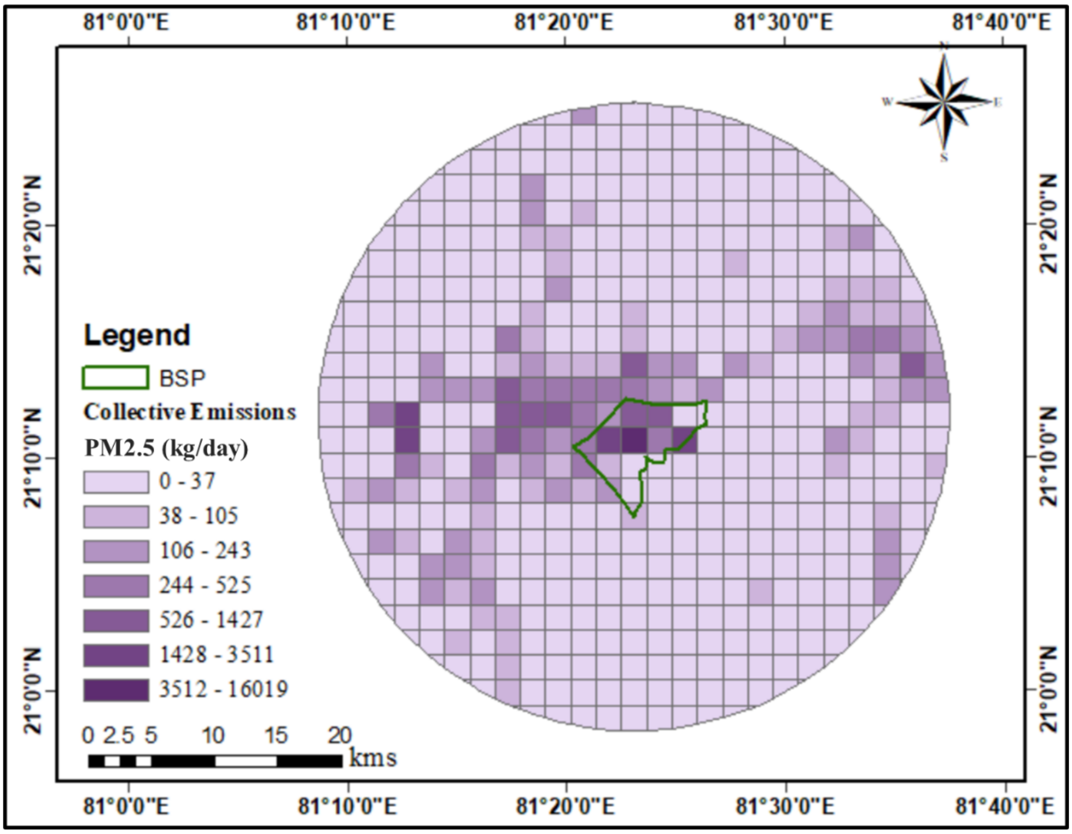


Figure 7: Spatial Distribution of $PM_{2.5}$ Emissions in Bhilai

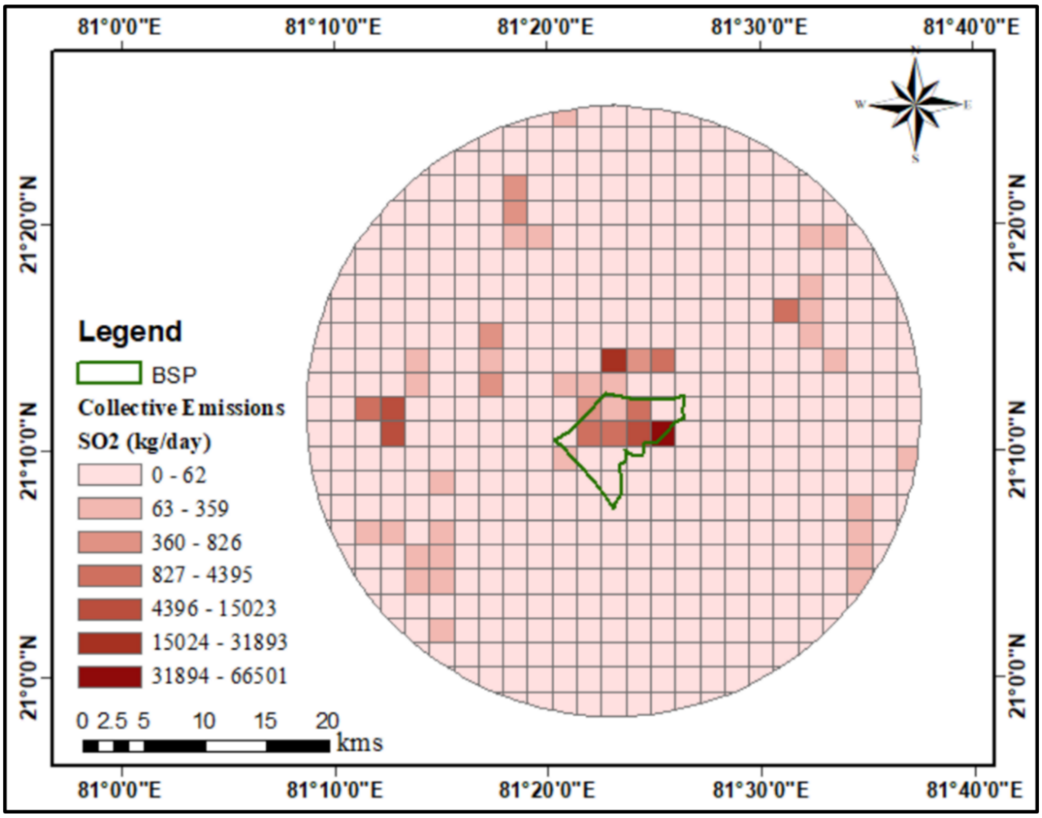


Figure 8: Spatial Distribution of SO_2 Emissions in Bhilai

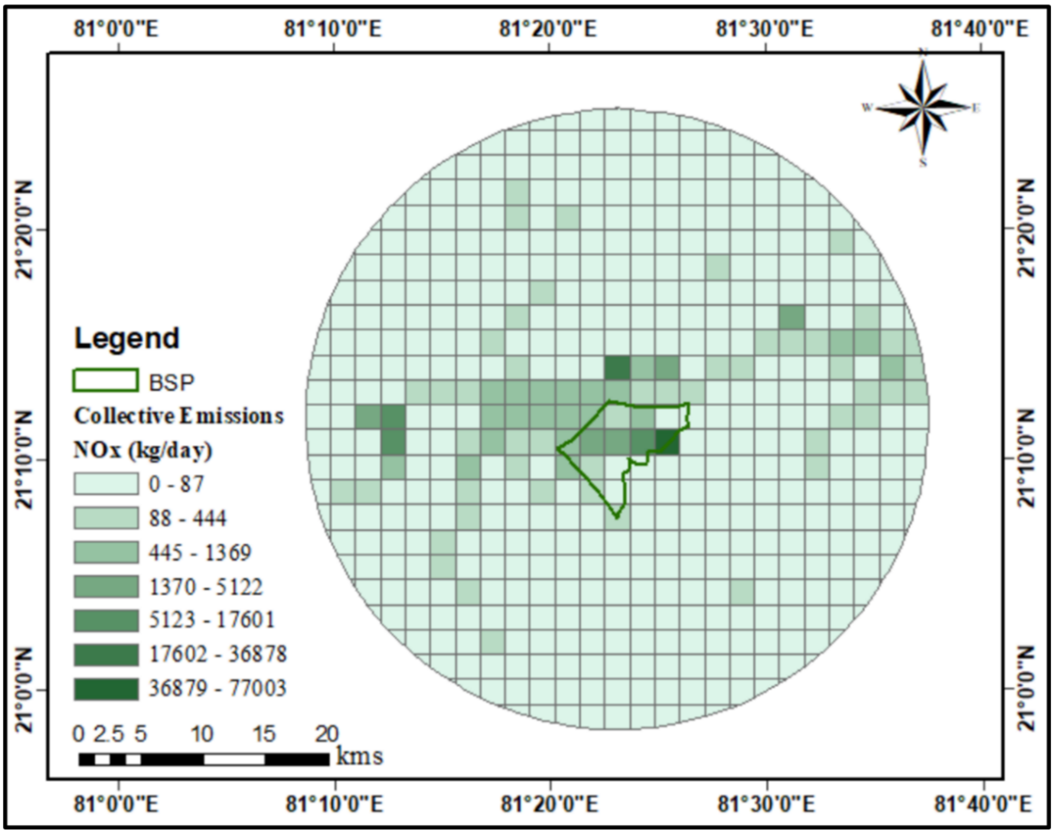


Figure 9: Spatial Distribution of NO_x Emissions in Bhilai

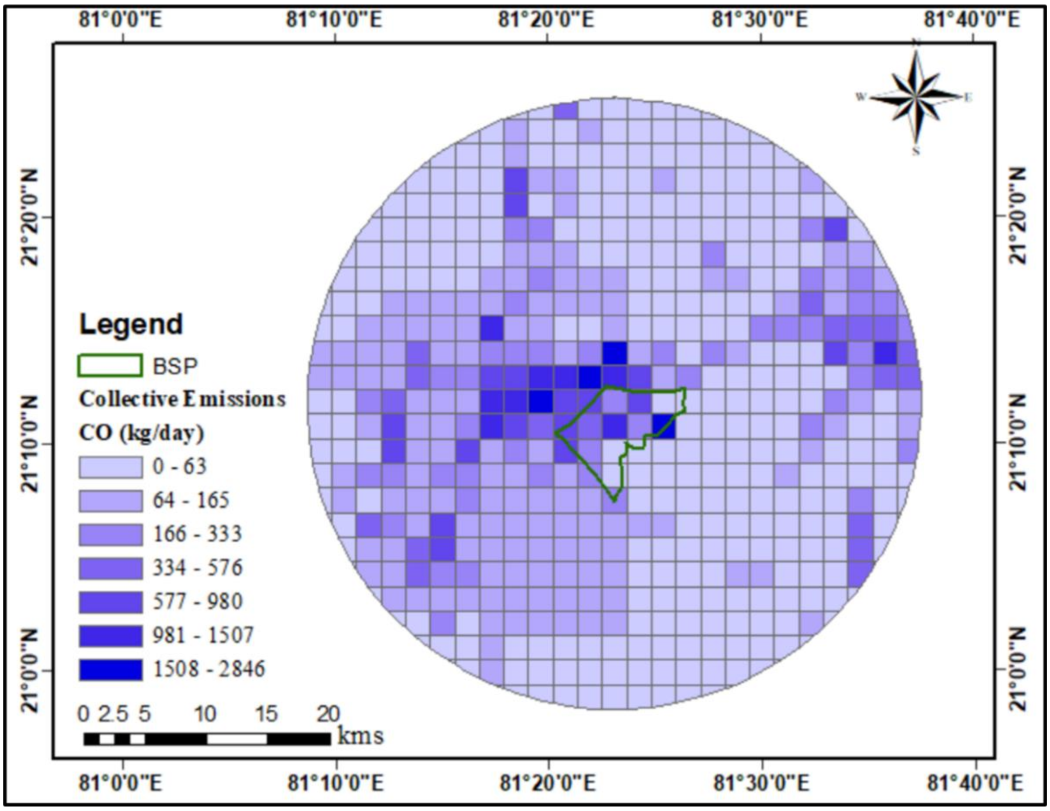


Figure 10: Spatial Distribution of CO Emissions in Bhilai

Air Quality Modeling

Receptor Modeling

Based on the CMB (chemical mass balance; USEPA 8.2 version) modeling results (Figure 11 and Figure 12) 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, winter and post-monsoon.
  - The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include coal and flyash (26 – 24%), soil and road dust (23 – 16%), SIA particles (8 - 7%), biomass burning (13 – 19%), vehicles (17 - 21%) and waste burning (7 - 6%). It is noteworthy that in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.
  - The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include coal and flyash (22 – 19%), soil and road dust (23 – 18%), biomass burning (11 - 17%), vehicles (19 – 22%), waste burning (6 – 5%), and SIA particles (12 - 13%). It is noteworthy that in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
  - The post-monsoon sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include soil and road dust (26 – 22%), biomass burning (12 - 14%), vehicles (18 – 25%), waste burning (4 – 4%), coal and flyash (24 - 20%) and SIA particles (8 - 8%). It is noteworthy, in post-monsoon also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

- The four most consistent sources for PM_{10} and $PM_{2.5}$ in all seasons are biomass burning, vehicles, coal and flyash and soil and road dust. The other sources on average may contribute more (or less) but their contributions are variable from one day to another.

- The consistent presence of SIA, biomass burning and vehicles in PM_{10} and $PM_{2.5}$ across all sites and in three seasons, suggests these particles encompass the entire Bhilai region as a layer.

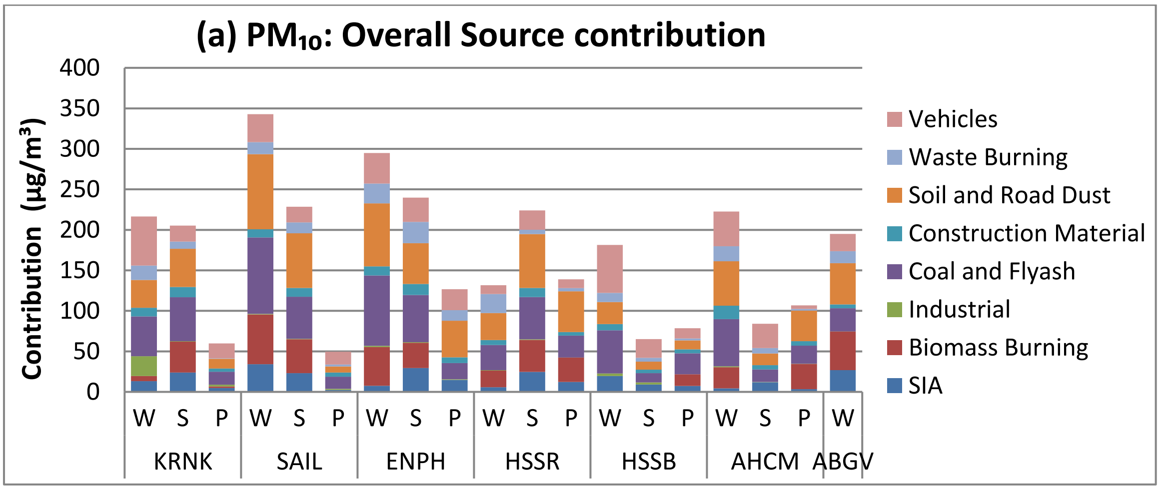
- Like the above point, in winter, the consistent presence of soil and road dust encompasses the entire Bhilai region as a layer.

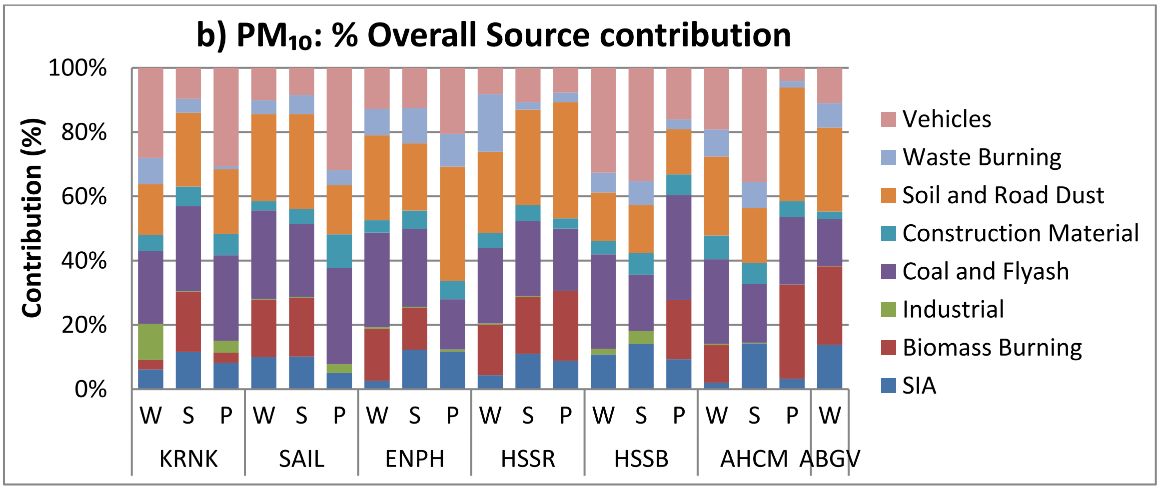
- Soil and road dust in summer contribute 23 – 18% and coal and flyash contribute 22 – 19% to PM_{10} and $PM_{2.5}$. It is observed that in summer the atmosphere looks whitish to grayish indicating the presence of large amounts of dust and; re-suspension of dust appears to be the cause of the large contribution of these sources.

- The contribution of biomass burning in winter is quite high at 13% (for PM_{10}) 19% (for $PM_{2.5}$). The presence of sizeable biomass is consistent in PM in winter, summer and post-monsoon indicated to local sources present in Bhilai and nearby areas. There is an immediate need to control or find alternatives to eliminate biomass emissions to observe any significant improvement in air quality in Bhilai.

- SIA particle levels are higher in summer compared to winter and post-monsoon.

- Vehicular emission contribution to PM_{10} (about 18%) and $PM_{2.5}$ (about 23%) is consistently similar in all the three seasons.


(a) PM_{10}: Overall Source contribution


b) PM_{10}: % Overall Source contribution

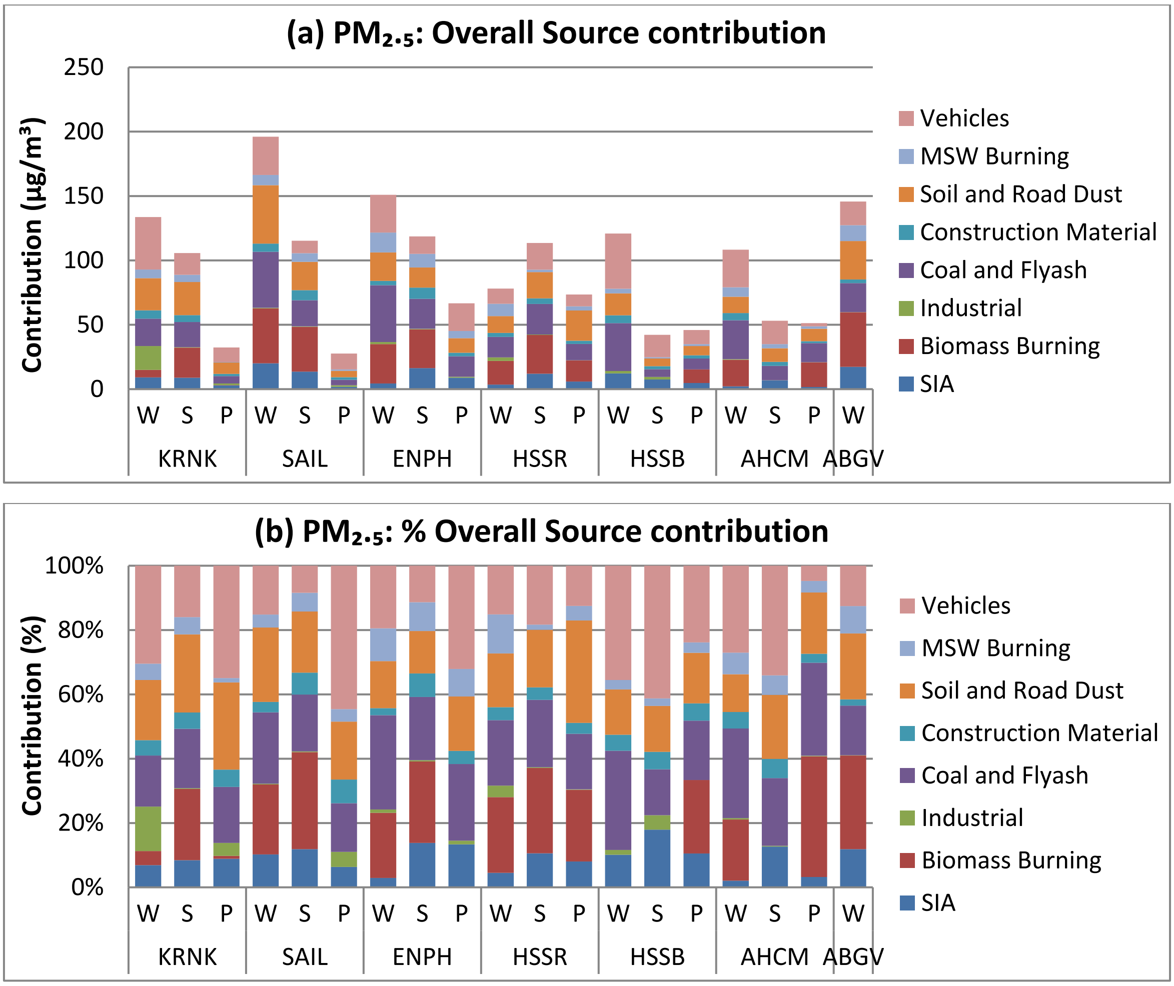
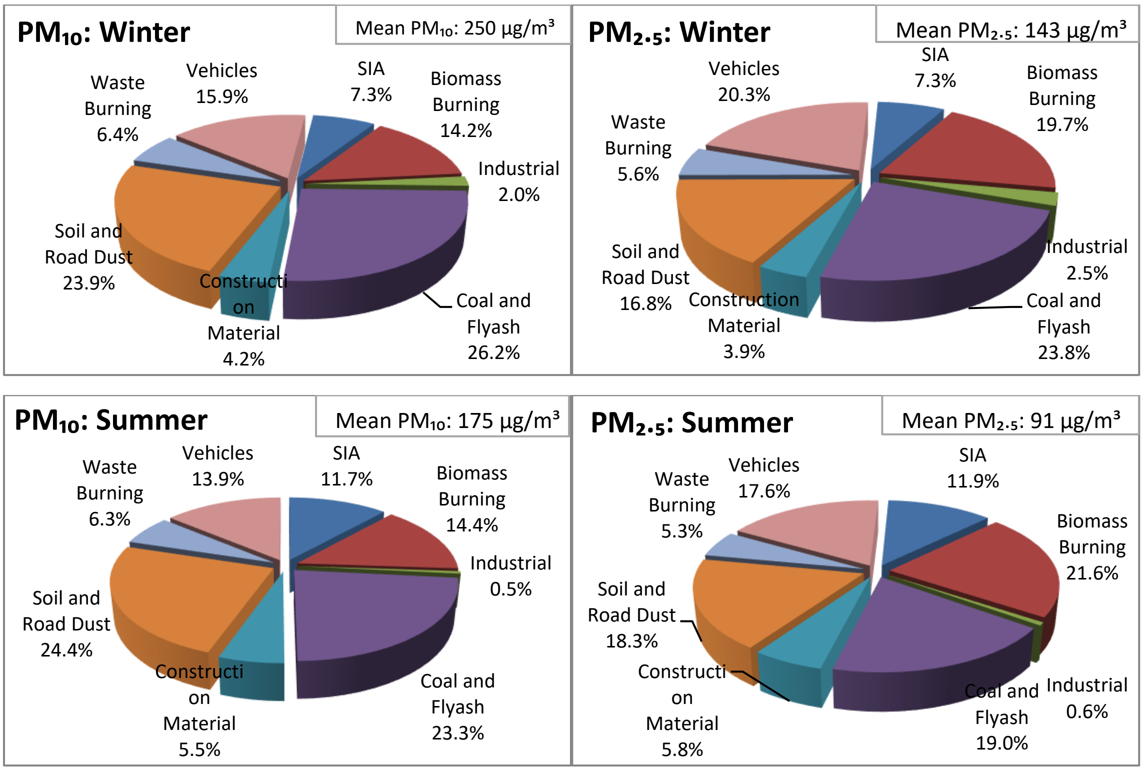


Figure 11: Overall Results of CMB Modeling for PM_{10} and $PM_{2.5}$ at seven sites



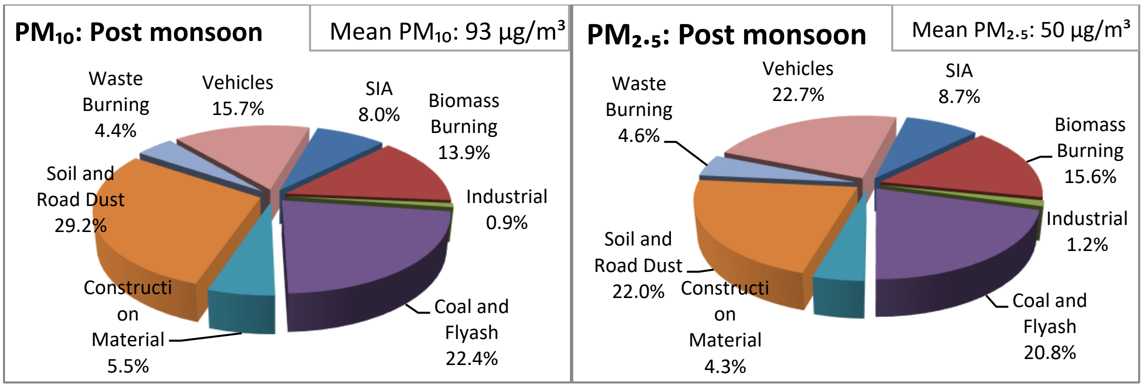


Figure 12: City level source contribution to ambient air PM_{10} and $PM_{2.5}$ levels (Industrial contribution excluding coal and flyash)

Control Options and Actions

A detailed analysis of control options for PM is given in Chapter 5. The proposed control options are summarized below and in Table 2

It may be noted that this study on air quality management is comprehensive and provides insight into air quality measurements, emission inventory, source-receptor impact analyses, identification of control options, their efficacies and action plans for attaining air quality standards.

Table 2: Action Plan for City of Bhilai

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Hotels/ Restaurants/ Banquet Halls	All Restaurants small or large should not use coal and shift to gas-based or electric (for a sitting capacity of more than 15 persons) appliances.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	1 year
	Link Commercial license to clean fuel	Municipal Corporations of Bhilai, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	Ash/residue from the tandoor and other activities should not be disposed of near the roadside. Requires ward-level surveillance.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	1 year
Domestic Sector	LPG to all. Slums and about 16% of the population are still using wood, coal, biomass, and dung cake as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	No new building complex or society be allowed without a PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year

Source	**Control Action**	**Responsible authorities**	**Time Frame (within a specified time)**
	By 2030, the city may plan to shift to electric cooking (common in Western countries) or PNG at the minimum.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 - 7 years
Solid Waste (SW) Burning	Develop the Scientific Treatment, Storage, and Disposal Facilities (TSDFs) at dumping sites.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	2-3 years
	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation., CECB, CGHB.	
	Desilting and cleaning of municipal drains	Bhilai Municipal Corporations	
	Waste burning in Industrial areas should be stopped.	CSIDC, CECB	
	Daily, Monthly mass balance of SW generation and disposal	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	

Source	**Control Action**	**Responsible authorities**	**Time Frame (within a specified time)**
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation., CECB, and NGO	
Construction and Demolition	Wet suppression	Chhattisgarh Housing Board (CGHB), Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation., Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to a construction and demolition processing facility.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	Immediate
	Proper handling and storage of raw material: cover the storage and provide the windbreakers.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road)	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD, CECB, and NGO	
Road Dust	The silt load in Bhilai varies from 8 to 17 g/m^2. The silt load on each road should be reduced to under 2 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 2 gm/m^2.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, PWD, CECB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, PWD, CECB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, State Forest Department, PWD	
	Vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	CGHB, MCB, MCR and Bhilai-Charoda MC, 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 the BS-IV category as well)	State Transportation Department	5 years
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products.	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10-year-old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Bhilai.	Transport Department, Traffic Police Bhilai, NHAI, Toll agencies	Six-months
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. All new city buses should be electric.	Transport Department, RTOs Bhilai	1 year
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should include well-equipped maintenance workshops. Adequate charging stations.	Transport Department, RTOs Bhilai	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	MCB, MCR and Bhilai-Charoda MC, RTOs Bhilai	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	CGHB, RTOs Bhilai, Traffic Police- Bhilai	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	CGHB, RTOs Bhilai, Traffic Police- Bhilai	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Movement of materials (raw and products) within the city should be allowed between 10 PM to 5 AM.	Transport Department -Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	1 year
	All the diesel-based city public transport (school and government/private buses) should be phased out completely in the next three years, and city transport should be operated only through metro, e-vehicle or on CNG. All new public transport should be CNG or electric buses.	Transport Department-Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	3 – 10 years
	Incentivise and aggressively implement e-mobility including required charging infrastructure. Strategic plan for EV charging infrastructure at each 3 km in urban areas, 25 km on highways (both sides) and 100 km for buses and trucks and swappable battery stations.	Transport Department-Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	2 years
	Adequate vehicle scrappage infrastructure should be developed in the next three years. Extended Producer Responsibility (EPR) may be considered for vehicle manufacturers, who will have to build required vehicle scrap plants.	Transport Department- Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Ensure that all heavy-duty vehicles entering in the city must undergo regular emission testing at state-monitored PUC centers to verify the compliance with the latest emission standards.	Transport Department-Bhilai, RTOs Bhilai, Traffic Police- Bhilai, CECB	1 year
	Implement low-emission zones in areas with high pollution levels, such as densely populated areas.	Transport Department-Bhilai, RTOs Bhilai, Traffic Police-Bhilai, CECB	2 - 5 years
	Public transport is to be strengthened with metro and/or adequate number of buses, route plan based on commute surveys and mobile-based ticketing and seating systems is developed in all major cities.	Transport Department-Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	2 – 5 years
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	CECB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal Council and CECB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, CGHB, CSIDC, Industries Department, CECB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, CSIDC, CECB	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Following best practices to minimize fugitive emissions within the industry premises, all leakages within the industry should be controlled.	Industrial Associations, CSIDC, CECB	Immediate
	The area and road in front of the industry should be the responsibility of the industry	Industrial Associations, CSIDC, CECB	
	Maintain the inventory of all the raw materials, fuel consumptions, solid waste, hazardous waste and wastewater generation and reclycling/treatment in the industries, and periodic updatations and reporting to CECB	Industrial Associations, CECB	1 year
	Periodic third-party audits need to be conducted to ensure the efficiency of air pollution control systems installed in industries as well as compliance with ambient air quality standards.	Industrial Associations, CECB	1 year
	All loose and dust generating fuel/raw materials like coal, ore, rice husk etc. must be kept under covered sheds or kept covered with large tarpaulin sheets within industrial premises, to reduce resuspension of loose materials in air with wind movement.	Industrial Associations, CECB	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Use eco-friendly dust suppressant chemicals on coal and ore stockpiles to form a crust over the piles, minimizing coal dust dispersion.	Industrial Associations, CECB	1 year
	Reduce the emissions in Bhilai Steel Plant from the operations in the bake oven, steel melting shop, sinter plant and raw material sotorage and handling.	BSP, CECB	2 year
	Category A Industries (using coal and other dirty fuels)		
	About 26 boilers, heaters and furnaces in Bhilai are running using Coal, Briquettes, Rise Husk, Wood, HSD, Furnace Oil, Waste, Firewood and other dirty solid fuels which should be shifted to natural gas and electricity wherever possible.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, CECB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity.	Industrial Associations, CECB	2 years
	Cyclones, multi-cyclones should be replaced by baghouses/ESP. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, CECB	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Category B Industries (Induction Furnace)		
	Fume gas capturing hood followed by baghouse should be used to control air pollution.	Industrial Associations, CECB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, HPSEBL	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 in high-traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane.	CGHB, MCB, MCR and Bhilai-Charoda MC, RTOs Bhilai, Traffic Police- Bhilai	1 year
	Disciplined Public transport (designate one lane stop).	RTOs Bhilai, Traffic Police-Bhilai	
	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.	CGHB, MCB, MCR and Bhilai-Charoda MC., RTOs Bhilai, Traffic Police- Bhilai	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	CGHB, RTOs Bhilai, NHAI, Traffic Police, Bhilai	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	CGHB, RTOs Bhilai, NHAI, Traffic Police, Bhilai	
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	CGHB, RTOs Bhilai, Greater Bhilai Municipal Corporation, NHAI, Traffic Police, Bhilai	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, ACC Chowk, Atal Chowk, Tatibandh chowk, Nankatti Minor Patan Road and Maharana Pratap Chowk are the main bottlenecks for traffic.	CGHB, RTOs Bhilai, Greater Bhilai Municipal Corporation, Traffic Police, Bhilai	
	Parking policy in congested areas (high parking cost, at city centres, only parking is limited for physically challenged people, etc).	CGHB, RTOs Bhilai, Greater Bhilai Municipal Corporation, NHAI, Traffic Police, Bhilai	
*The above steps should not only be implemented in Bhilai Corporation municipal, Risali Municipal Corporation and Bhilai-Charoda Municipal Corporation limits rather these should be extended up to outer city boundary.			

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Acknowledgments

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1 Introduction

1.1 Background of the Study

Air pollution poses a significant challenge, especially in urban areas, and is further complicated by a diverse and intricate mix of sources such as industries, vehicles, generator sets, domestic fuel burning, roadside dust, and construction activities. Bhilai has witnessed remarkable growth in recent years, with a burgeoning population and rapid developments in industries, vehicles, construction, and energy consumption, leading to heightened environmental concerns.

Traditionally, addressing the impact of pollution sources relied on dispersion or source models utilizing emission inventory and meteorological data. However, these models faced limitations in assessing short-term impacts or identifying sources comprehensively. Receptor models, particularly for particulate matter, analyze ambient particulate morphology, chemistry, and variability at the receptor, offering an alternative approach. While dispersion models remain crucial in air-shed management, recent advances in receptor-oriented techniques provide an additional valuable tool.

Despite air pollution control programs focusing on point and area sources since the Air Act of 1981, many cities still grapple with particulate non-attainment issues from unknown aerosol sources. Improved understanding of source-receptor linkages is essential for cost-effective emission reductions, given the complexity of urban source mixes, the prevalence of fugitive sources, and limited knowledge of secondary aerosol sources.

Receptor modelling, coupled with advancements in trace element analysis, allows for a detailed examination of ambient aerosol samples, offering valuable insights into total, fine, and inhalable particles sources. This approach proves promising for source identification and apportionment in complex urban settings, particularly when dealing with numerous unorganized activities releasing particulates into the atmosphere. To implement receptor modelling effectively, it is crucial to identify sources, create emission profiles, and determine the chemical composition of collected particulate matter on filter paper. Combining receptor and dispersion modelling can enhance interpretation and decision-making processes, providing a comprehensive approach to addressing air pollution challenges.

To address the air pollution issues of the City of Bhilai, Chhattisgarh Environment Conservation Board, Raipur has sponsored the study “Source Apportion-based Action Plans for Maintaining and Restoring Air Quality in the Bhilai Region, Chhattisgarh” to the Indian Institute of Technology Kanpur (IITK) (Letter No. 4986/Tech./HO/2019, dated 12.09.2019). The study has commenced on November 22, 2019. The main objectives of the study are the preparation of an emission inventory, air quality monitoring in three seasons, the chemical composition of PM_{10} and $PM_{2.5}$, apportionment of sources to ambient air quality, and the development of a pollution control plan.

1.2 General Description of City

1.2.1 Geography and Demography

Bhilai (latitudes 21.1938° N and longitudes 81.35119° E), Bhilai is situated in the eastern part of Chhattisgarh in the Durg district. It lies approximately 25 kilometres west of the state capital, Raipur. The topography of Bhilai is characterized by a mix of plains and undulating terrain. The city is situated on the eastern bank of the Shivnath River. Bhilai experiences a tropical climate. Summers are typically hot, with temperatures soaring, while winters are relatively mild. Monsoons bring substantial rainfall to the region. One of the defining features of Bhilai is its robust industrial infrastructure. The Bhilai Steel Plant, operated by the Steel Authority of India Limited (SAIL), is a major steel-producing facility and a key contributor to the city's economy.

Bhilai has experienced significant population growth in recent years, attributed in part to its industrial development. The population comprises a diverse mix of people from various cultural and ethnic backgrounds. The industrialization in Bhilai has led to a workforce engaged in manufacturing and related sectors. Steel Plants are the major employer, attracting people from various parts of the country.

As per the census of 2011 (Census of India, 2012), the population of the city is 6,25,629 with a literacy rate of 87.23% and the estimated population of Bhilai in 2023 is 7,20,000. The city is administered by the Bhilai Municipal Corporation.

1.2.2 Climate

The city experiences semi-arid climatic conditions with high temperatures in summer and winters are mild to moderate. The average annual rainfall in Bhilai is 1200 - 1400 mm, and most of the rainfall occurs in the monsoon months of July to September. The maximum temperature ranges are experienced in summer up to 40°C and the minimum temperature in the winter season is in the range of 10 – 25°C in the coldest period of December-January. The average monthly wind speed varies between 2.3 and 7.8 km/h with a maximum speed during monsoon and a minimum in winter as recorded in Raipur by Indian Meteorological Department.

1.2.3 Emission Source Activities

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

1.3 Need for the Study

1.3.1 Current Air Pollution Levels: Earlier Studies

$PM_{2.5}$ and PM_{10} concentrations varied seasonally with atmospheric processes and the anthropogenic activities in Bhilai.

The measured mean PM_{10} levels at commercial, industrial, and residential monitoring stations was 125 ± 52 $\mu g/m^3$ in 2015 (Guttikunda, et al., 2018). The average PM_{10} levels were 172 ± 43.0 (Industrial), 79.5 ± 9.1 (Residential/Rural/Other (RO)) and 98.8 ± 17.6 $\mu g/m^3$ (Residential/Rural/Other (Hostel)) during 2006 to 2015 at NAMP stations (Guttikunda, et al., 2018).

Although Bhilai city faces air pollution problems due to the number of sources, no detailed study of the chemical composition of PM_{10} and $PM_{2.5}$ has been undertaken to identify the sources and their contributions to air pollution. One of the common sources is industrial pollution and it significantly contributes to air pollution. Other sources are vehicular emissions, construction dust and unregulated sources that can be a major cause of air pollution.

1.4 Objectives and Scope of Work

Objectively the project aims to achieve the following:

- The study area includes a 25 km radius with Bhilai Steel Plant (main gate) as the epicentre.
- Development of GIS-based gridded (2 km × 2 km resolution) emission inventory for air pollutants (particulate matter equal and less than 10 µm 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 (NO_x), volatile organic compounds (VOCs) and polyaromatic hydrocarbons (PAHs) 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 (Iso Phorone (IsP), Di methyl Phthalate (DmP), Acenaphthylene (AcP), Di ethyl Phthalate (DEP), Fluorene (Flu), Hexachlorobenzene (HcB), 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 is presented in Figure 1.1. The overall approach to the study is broadly described below.

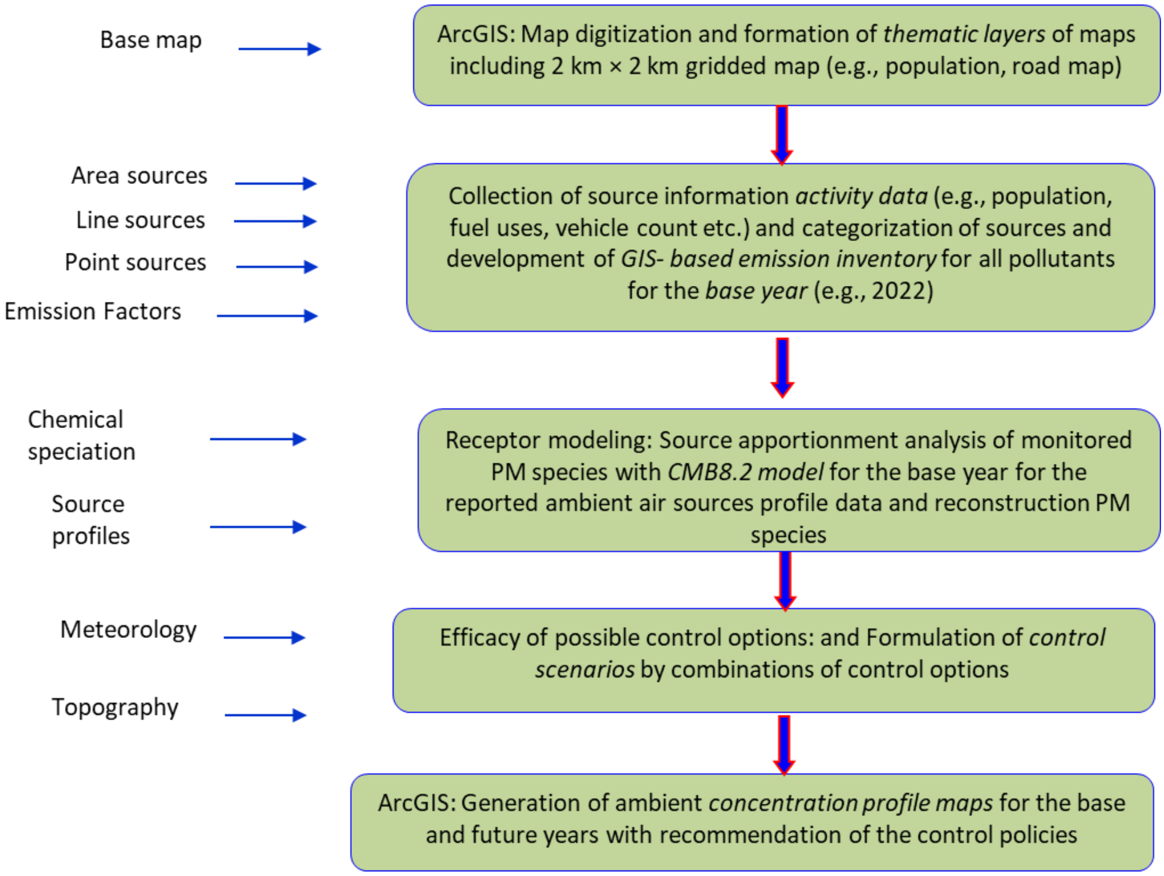


Figure 1.1: Approach to the Study and Major Tasks

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

It was considered appropriate that seven sites in a city like Bhilai 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, public buildings could be better choices as sampling sites. Sites were finalized in consultation with the officials of CECB, Raipur.

1.5.2 Identification and Grouping of Sources for Emission Inventory

An on-the-field exercise was taken to physically identify all small and large sources around the sampling sites. This exercise included the presence of emission sources like refuse 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 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 an 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 Bhilai-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 Bhilai 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 USEPA CMB 8.2 (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.

1.6 Report Structure

The overall framework of the study is presented in Figure 1.1. The report is divided into 5 chapters. The brief descriptions of the chapters are given below.

Chapter 1

This chapter presents the background of the study, and a 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 locations for three seasons, i.e., winter, summer and post-monsoon carried out in this study. In addition to the above information, this chapter also enumerates methodologies adopted for the monitoring, laboratory analyses, quality assessment and quality control (QA/QC). 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 CMB8.2 modeling for source apportionment study for PM_{10} and $PM_{2.5}$ in the summer and winter seasons. The contribution of various sources at receptor sites and the overall scenario of sources that influence the air quality in the city is presented.

Chapter 5

This chapter describes, explores and analyzes emission of control options and analysis for various sources based on the modeling results from Chapter 4. This chapter also discusses some alternatives for controlling the prominent sources in the city from the management point of view and explains the benefits to be achieved in future.

2 Air Quality: Measurements, Data Analyses, and Inferences

2.1 Introduction

Air pollution remains a persistent issue for public health, even considering multiple measures implemented to mitigate it. It is essential to evaluate the gains achieved and contemplate the path forward. This becomes increasingly crucial, given the recently updated air quality standards, as highlighted by the Central Pollution Control Board (CPCB) in 2009 (http://www.cpcb.nic.in/National_Ambient_Air_Quality_Standards.php). The initial phase of planning for future actions involves assessing the current state of air pollution.

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

2.2 Methodology

2.2.1 Site and analyzer details

A total seven 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 CECB, Raipur. 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 Bhilai

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	Kripal Nagar, Kohka	KRNK	Residential	Domestic cooking, vehicle, road dust, garbage/waste burning, Restaurants
2.	SAIL Bhilai Steel Plant (BSP)	SAIL	Industrial	Industries, DG sets, vehicle, road dust, garbage/industrial waste burning, Restaurants
3.	Engineering Park, Hathkhoj	ENPH	Industrial	Industries, DG sets, vehicle, road dust, garbage/industrial waste burning, Restaurants
4.	Higher Secondary School, Risali	HSSR	Commercial	DG sets, vehicle, road dust, garbage/waste burning, Restaurants
5.	Higher Secondary School, Baghera	HSSB	Background/ commercial	Soil and road dust, vehicle, garbage/agricultural waste burning, domestic cooking
6.	Ayushman Health Centre, Morid	AHCM	Residential	Domestic cooking, vehicle, road dust, garbage/waste burning, Industrial
7.	Atal Bhawan, Gudeli Village	ABGV	Residential	Domestic cooking, vehicle, road dust, garbage/waste burning, Industrial

1. KRNK

2. SAIL

3. ENPH

4. HSSR

5. HSSB

6. AHCM

7. ABGV

Figure 2.1: Photographs of Sampling Sites showing the physical features

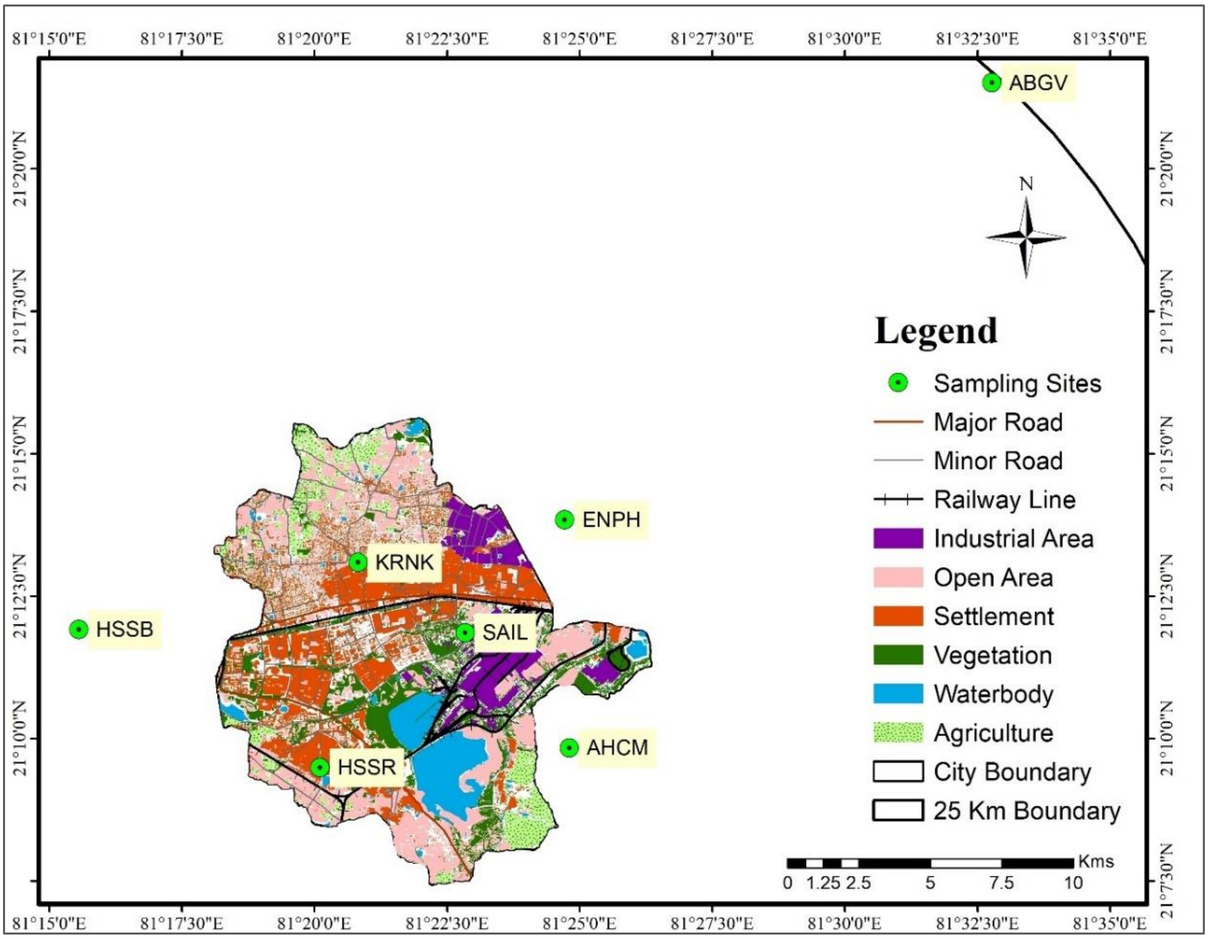


Figure 2.2: Land-use Pattern of City and Sampling Sites

The parameters for sampling and their monitoring methodologies including type of filter papers/chemicals and calibration protocols are adopted from CPCB, Delhi (www.cpcb.nic.in). The entire monitoring program 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), sulphur dioxide (SO_2) and volatile organic compounds (VOCs) are among the gaseous species. The monitoring parameters for this study along with their samplers and analytical methods are presented in Table 2.2 and the chemical components of PM are presented in Table 2.3.

Table 2.2: Details of Samplers/Analysers 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	Mass spectrometry
8.	Molecular Markers	Gas chromatography- mass spectrometry (GC-MS)	Mass spectrometry
9.	PAHs	GC-MS	Mass spectrometry
10.	VOCs	GC-MS	Mass spectrometry

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, Hg 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: The first channel for PM_{10}, the second channel for $PM_{2.5}$ (Teflon filters -Whatman grade PTFE filters of 47 mm diameter) and the third for collection of $PM_{2.5}$ on quartz fibre 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 hours 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 the extracted samples is carried out using Ion Chromatography (Merohm 882 compact IC, Switzerland; Figure 2.3(e)). Ion recovery efficiencies and reproducibility were determined by spiking the known quantity of ion mass on the unexposed filter paper, extracting the ion mass and analyzing it on IC. Ion recovery for all species was between 90 and 106% and reproducibility was within ± 10% of known concentration.

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)). EC-OC analyzer was calibrated using 5% CO_2 as per the operating manual of the carbon analyzer (DRI, 2012). Each run is followed by a run-end calibration with 5% CH_4. The explanation of fractions of EC and OC is given 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 IO-3.1 (USEPA, 1999b). The digested samples were filtered and diluted to 25 mL with deionized (ultra-pure) water. For elements, digested samples were analyzed on inductively coupled plasma mass spectrometry (ICP-MS; Thermo Fisher Scientific Inc, USA; Figure 2.3(f)) (USEPA, 1999c) for the following 25 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.

The ICP-MS was calibrated at five levels using periodic table mix1, 33 elements for ICP (Sigma-Aldrich). Element recovery efficiencies were determined by spiking the known quantity of elemental mass on the filter paper and extracting and analyzing it as per the developed standard operating procedures (SOPs) on ICPMS. The recoveries for the elements were in the range of 80–95% except for Si (65%). A correction factor was applied for each element concentration according to its recovery efficiency. All chemicals and reagents were of an analytical or higher grade.

PAHs were extracted in hexane and dichloromethane (DCM) solvent (1:1v/v) followed by passing it through a 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 the 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 a 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 the entire project planning and its implementation at all levels were designed and 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, and 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 which was set up in Bhilai. All other measurements and analyses were carried out at the laboratories of IIT Kanpur. 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 include a description of methods, standards to be used, laboratory and field blanks, internal and external standards, development of database, screening of data, record keeping including backups, traceability of calculations and standards.

There are dedicated computers for instruments and data storage with passwords. To ensure that the 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 12, 2020 - February 07, 2021), summer (March 05, 2021 – May 10, 2021) and post-monsoon (September 09, 2021 - October 26, 2021) except at AHCM (7 days sampling). In addition, the sampling for all parameters was carried out at ABGV in winter (December 18, 2022 - January 01, 2023) at a distance of about 25 km from the SAIL office. The analysis of SO_2 and NO_2 are carried out daily regularly while gravimetric analysis for particulate matters was done after completion of the sampling in the season. All efforts were made for the 100% achievement of the sampling and analysis. 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 - Table 2.10 for all the three seasons respectively.

Table 2.4: Sampling days of various pollutants at KRNK

KRNK-Kripal Nagar Kohka (Winter, Summer and Post Monsoon)

	12-Dec-20	13-Dec-20	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
PM$_{10}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM$_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC							■	■	■	■	■	■	■		
NO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

	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$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

	09-Sep-21	10-Sep-21	11-Sep-21	12-Sep-21	13-Sep-21	14-Sep-21	15-Sep-21	16-Sep-21	17-Sep-21	18-Sep-21	19-Sep-21	20-Sep-21	21-Sep-21	22-Sep-21	23-Sep-21
PM$_{10}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM$_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC						■	■	■	■	■	■	■			
NO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.5: Sampling days of various pollutants at SAIL

SAIL-SAIL Steel Plant (Winter, Summer and Post Monsoon)

	25-Dec-20	26-Dec-20	27-Dec-20	28-Dec-20	29-Dec-20	30-Dec-20	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
PM$_{10}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM$_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC						■	■	■	■	■	■	■			
NO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

	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$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

	09-Sep-21	10-Sep-21	11-Sep-21	12-Sep-21	13-Sep-21	14-Sep-21	15-Sep-21	16-Sep-21	17-Sep-21	18-Sep-21	19-Sep-21	20-Sep-21	21-Sep-21	22-Sep-21	23-Sep-21
PM$_{10}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM$_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC						■	■	■	■	■	■	■			
NO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO$_2$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.6: Sampling days of various pollutants at ENPH

ENPH-Engineering Park Hathkhoj (Winter, Summer and Post Monsoon)

	11-Jan-21	12-Jan-21	13-Jan-21	14-Jan-21	15-Jan-21	16-Jan-21	17-Jan-21	18-Jan-21	19-Jan-21	20-Jan-21	21-Jan-21	22-Jan-21	23-Jan-21	24-Jan-21	25-Jan-21
PM_{10}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$PM_{2.5}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VOC					✓	✓	✓	✓	✓	✓	✓				
NO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	22-Mar-21	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
PM_{10}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$PM_{2.5}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VOC						✓	✓	✓	✓	✓	✓	✓			
NO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	26-Sep-21	27-Sep-21	28-Sep-21	29-Sep-21	30-Sep-21	01-Oct-21	02-Oct-21	03-Oct-21	04-Oct-21	05-Oct-21	06-Oct-21	07-Oct-21	08-Oct-21	09-Oct-21	10-Oct-21
PM_{10}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$PM_{2.5}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VOC					✓	✓	✓	✓	✓						
NO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 2.7: Sampling days of various pollutants at HSSR

HSSR-Higher Secondary School Rishali (Winter, Summer and Post Monsoon)

	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	15-Jan-21	16-Jan-21	17-Jan-21
PM_{10}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$PM_{2.5}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VOC						✓	✓	✓	✓	✓	✓	✓			
NO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	22-Mar-21	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
PM_{10}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$PM_{2.5}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VOC						✓	✓	✓	✓	✓	✓	✓			
NO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

	13-Oct-21	14-Oct-21	15-Oct-21	16-Oct-21	17-Oct-21	18-Oct-21	19-Oct-21	20-Oct-21	21-Oct-21	22-Oct-21	23-Oct-21	24-Oct-21	25-Oct-21	26-Oct-21
PM_{10}	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$PM_{2.5}$	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
OC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
VOC					✓	✓	✓	✓	✓	✓	✓			
NO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SO_2	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 2.8: Sampling days of various pollutants at HSSB

HSSB-Higher Secondary School Baghera (Winter, Summer and Post Monsoon)

	24-Jan-21	25-Jan-21	26-Jan-21	27-Jan-21	28-Jan-21	29-Jan-21	30-Jan-21	31-Jan-21	01-Feb-21	02-Feb-21	03-Feb-21	04-Feb-21	05-Feb-21	06-Feb-21	07-Feb-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC					■	■	■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

	01-May-21	02-May-21	03-May-21	04-May-21	05-May-21	06-May-21	07-May-21	08-May-21	09-May-21	10-May-21
PM_{10}	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■
VOC					■	■	■	■	■	■
NO_2	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■

	27-Sep-21	28-Sep-21	29-Sep-21	30-Sep-21	01-Oct-21	02-Oct-21	03-Oct-21	04-Oct-21	05-Oct-21	06-Oct-21	07-Oct-21	08-Oct-21	09-Oct-21	10-Oct-21	11-Oct-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
VOC							■	■	■	■	■				
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.9: Sampling days of various pollutants at AHCM

AHCM-Ayushman Health Centre Morid, Bhilai (Winter, Summer and Post Monsoon)

	01-Feb-21	02-Feb-21	03-Feb-21	04-Feb-21	05-Feb-21	06-Feb-21	07-Feb-21	29-Apr-21	30-Apr-21	01-May-21	02-May-21	03-May-21	04-May-21	05-May-21	17-Oct-21	18-Oct-21	19-Oct-21	20-Oct-21	21-Oct-21	22-Oct-21	23-Oct-21
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.10: Sampling days of various pollutants at ABGV

ABGV-Atal Bhavan (Winter)															
	18-Dec-22	19-Dec-22	20-Dec-22	21-Dec-22	22-Dec-22	23-Dec-22	24-Dec-22	25-Dec-22	26-Dec-22	27-Dec-22	28-Dec-22	29-Dec-22	30-Dec-22	31-Dec-22	01-Jan-23
PM_{10}	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
$PM_{2.5}$	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO_2			■	■	■	■	■	■	■	■	■	■	■	■	■
SO_2			■	■	■	■	■	■	■	■	■	■	■	■	■
	31-Dec-22	04-Jan-23	05-Jan-23												
VOC	■	■	■												

2.4 Ambient Air Quality - Results

2.4.1 Kripal Nagar, Kohka (KRNK)

The sampling period was December 12- 26, 2020 for winter, March 05 – 19, 2021 for summer and September 08 – 23, 2021 for post-monsoon.

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

A time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ at KRNK is shown for winter (Figure 2.4), summer (Figure 2.5) and post-monsoon (Figure 2.6). Average levels at this site were: $PM_{2.5}$: 129±42 (winter), 106±22 µg/m^3 (summer) and 32±15 µg/m^3 (post-monsoon) and PM_{10}: 216±67 (winter), 205±46 µg/m^3 (summer) and 60±29 µg/m^3 (post-monsoon). In winter, the $PM_{2.5}$ levels were about two times higher than the national air quality standard (NAAQS: 60 µg/m^3) and PM_{10} levels were 2.16 times higher than the NAAQS (100 µg/m^3). In summer, the $PM_{2.5}$ levels were 1.77 times NAAQS while PM_{10} is 2.0 times higher than the NAAQS. In post-monsoon, both the $PM_{2.5}$ and PM_{10} levels were within the limit of NAAQS.

A statistical summary of PM concentrations is presented in Table 2.15 - Table 2.20 for winter, summer and post-monsoon seasons. In post-monsoon, both $PM_{2.5}$ and PM_{10} levels drop below NAAQS. In summer $PM_{2.5}$ and PM_{10} are quite high and above NAAQS despite improvement in meteorology and better dispersion. The particles airborne from soil during dust storms in the dry months of summer can contribute significantly to coarse fraction (i.e., $PM_{2.5-10}$).

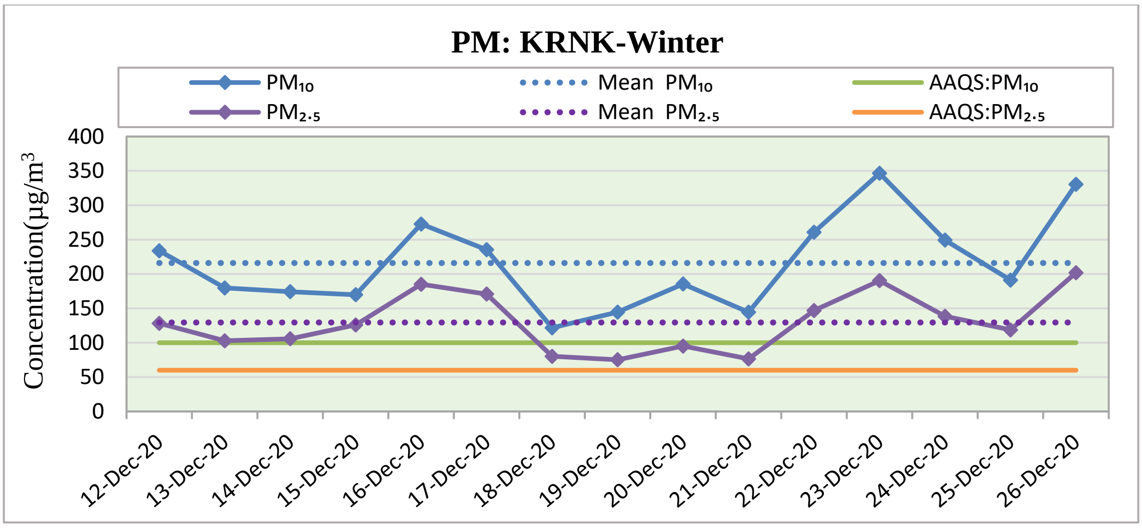


Figure 2.4: PM Concentrations at KRNK for Winter Season

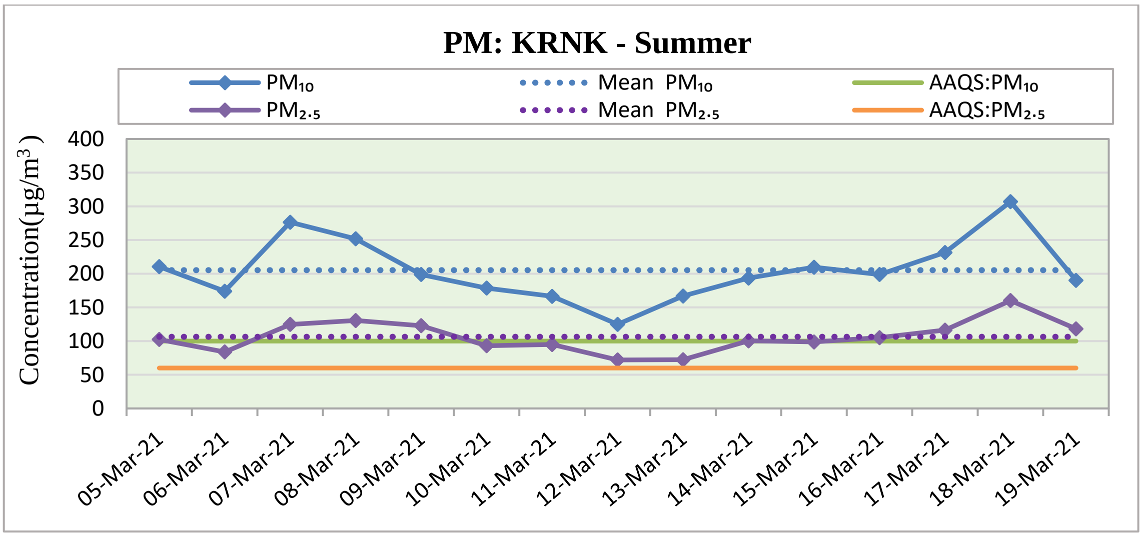


Figure 2.5: PM Concentrations at KRNK for Summer Season

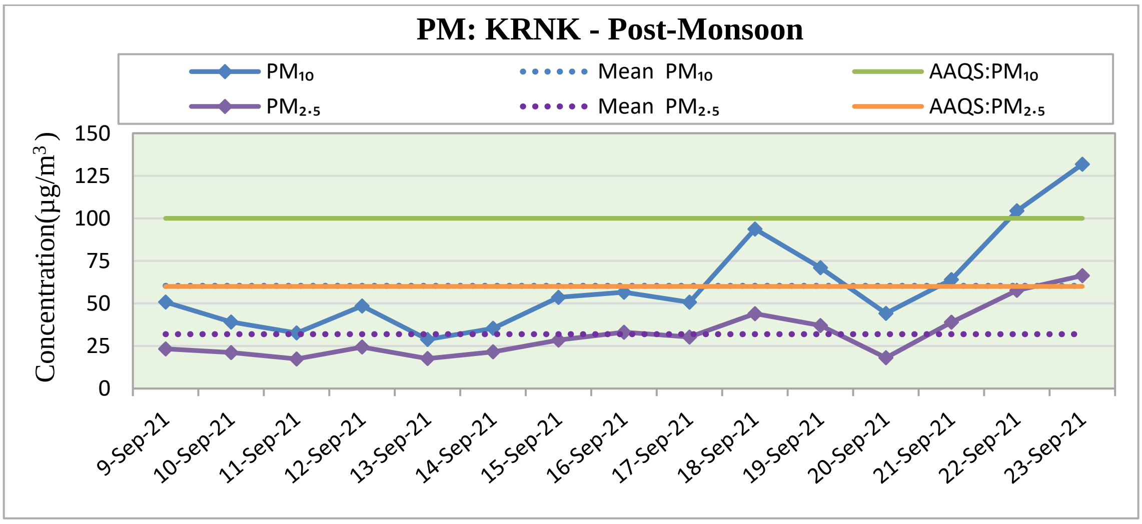


Figure 2.6: PM Concentrations at KRNK for Post-monsoon Season

2.4.1.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.7), summer (Figure 2.8) and post-monsoon (Figure 2.9) seasons. It was observed that SO_2 concentrations meet the air quality standard with an average of 11±8 µg/m^3 in winter, 6±4 µg/m^3 in summer and 2.2±0.5 µg/m^3 in post-monsoon µg/m^3. NO_2 levels also meet the national standard (80 µg/m^3) but are higher than SO_2 with an average of 25±7 µg/m^3 in winter, 24±6 µg/m^3 in summer and 13±5 µg/m^3 in post-monsoon season (Table 2.11). 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 local open burning etc.

The mean concentrations of benzene, toluene, p-xylene, and o-xylene (BTX) are presented in Figure 2.10 and the statistical summary in Table 2.11. The total BTX level is observed 13.75±8.47 µg/m^3 (Benzene: 9.61 and Toluene: 0.27 µg/m^3) in winter, 22.43±6.26 µg/m^3 (Benzene: 4.82 and Toluene: 0.95 µg/m^3) in summer and 33.28±4.41 µg/m^3 (Benzene: 7 µg/m^3, Toluene: 1.34 µg/m^3, p-xylene: 10.51 µg/m^3 and o-xylene: 14.43 µg/m^3) in post-monsoon seasons. The maximum BTX concentration was observed at 32 µg/m^3 in winter, 35 µg/m^3 in summer and 47 µg/m^3 in post-monsoon seasons. The Xylene levels were higher during post-monsoon than in the winter and summer.

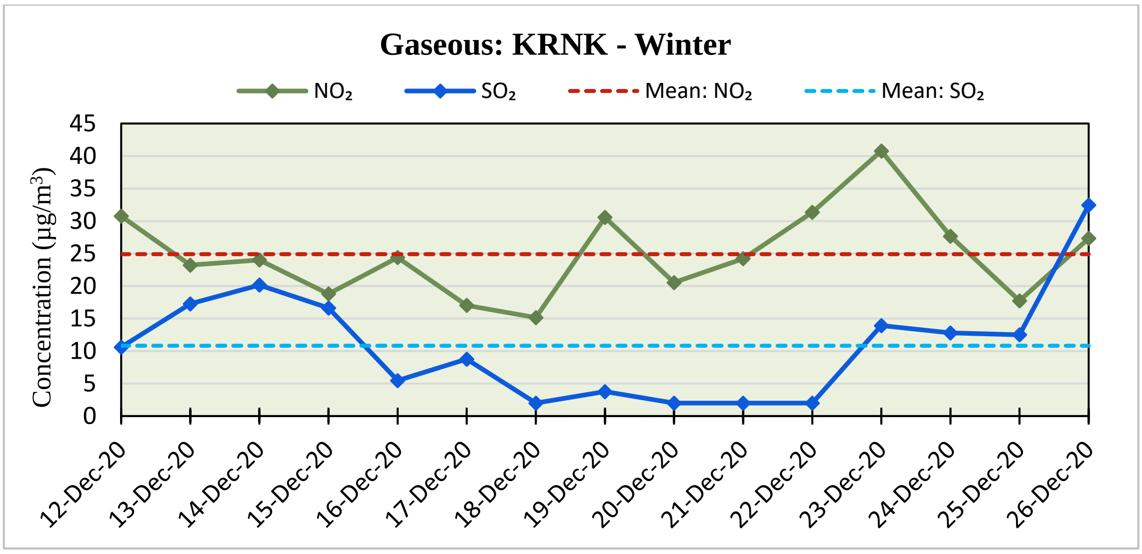


Figure 2.7: SO_2 and NO_2 Concentrations at KRNK for Winter Season

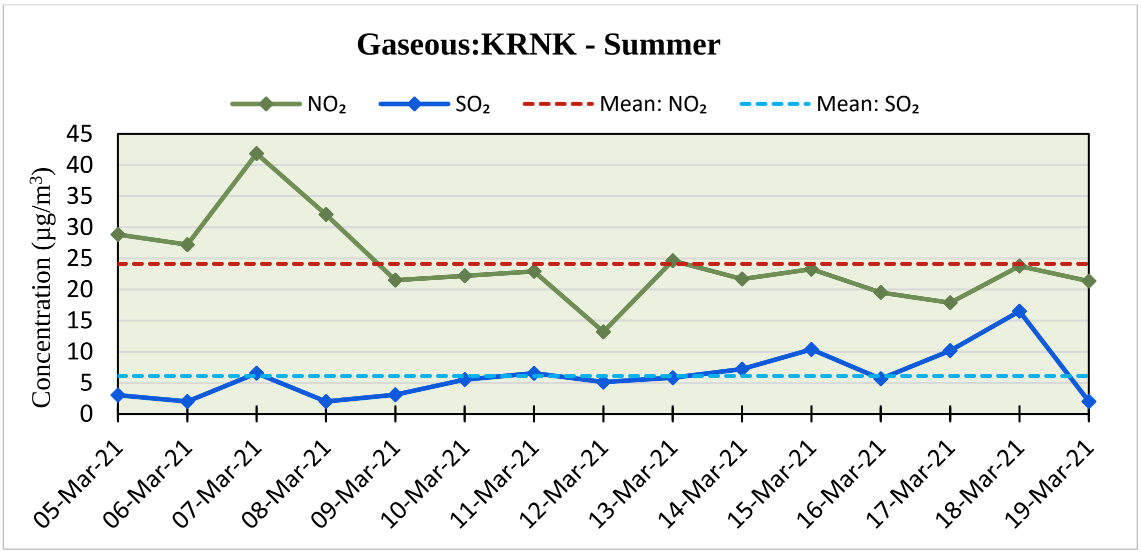


Figure 2.8: SO$_2$ and NO$_2$ Concentrations at KRNK for Summer Season

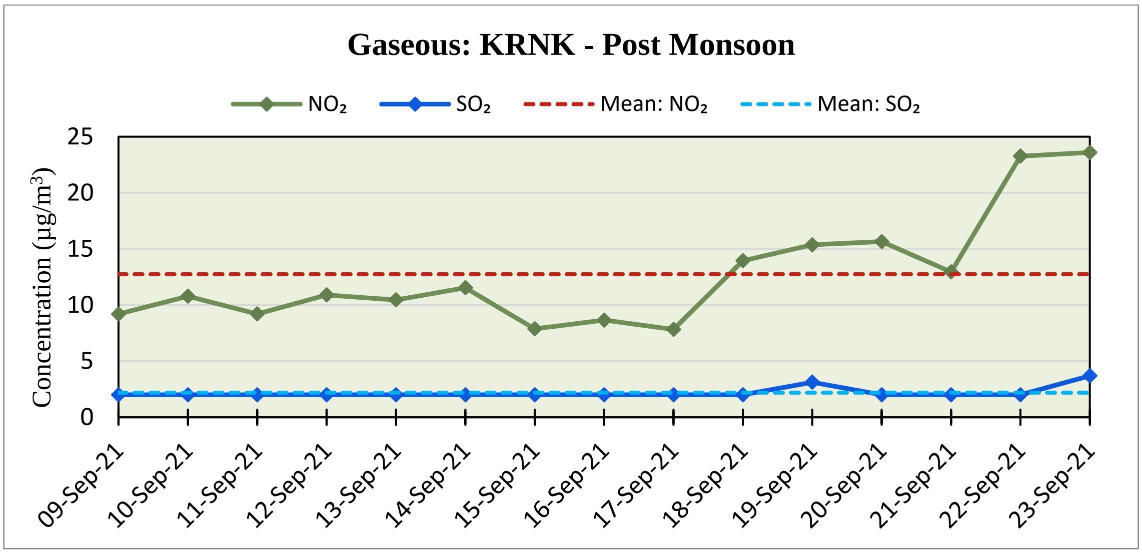


Figure 2.9: SO$_2$ and NO$_2$ Concentrations at KRNK for Post -monsoon Season

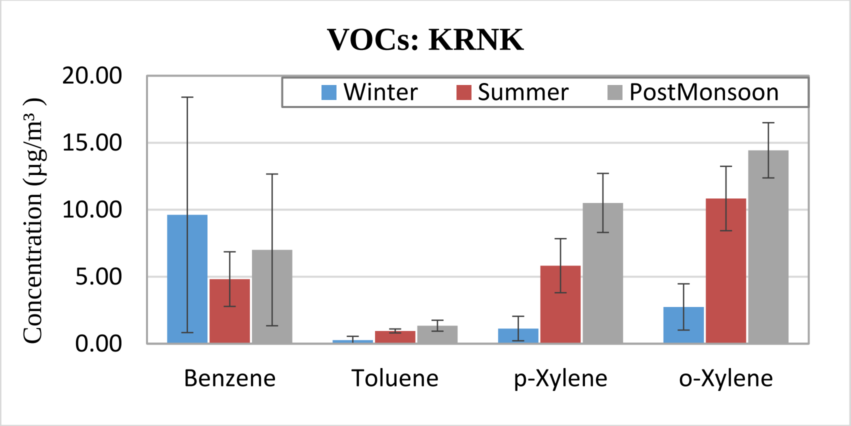


Figure 2.10: VOCs concentration at KRNK

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.11 (a) and (b) for winter, summer, and post-monsoon seasons. Organic carbon is observed slightly higher (winter: 19.08±7.02, summer: 14.12±2.98 and post-monsoon: 3.48±1.27 µg/m^3) than the elemental carbon (winter: 10.66±5.77, summer: 10.53±3.70 and post-monsoon: 1.82±0.90 µg/m^3). However, the ratio of OC3/TC is observed higher indicating the formation of secondary organic carbon in the atmosphere. It is also observed that the OC and EC are higher in the winter 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 2.12 for winter, summer, and post-monsoon seasons.

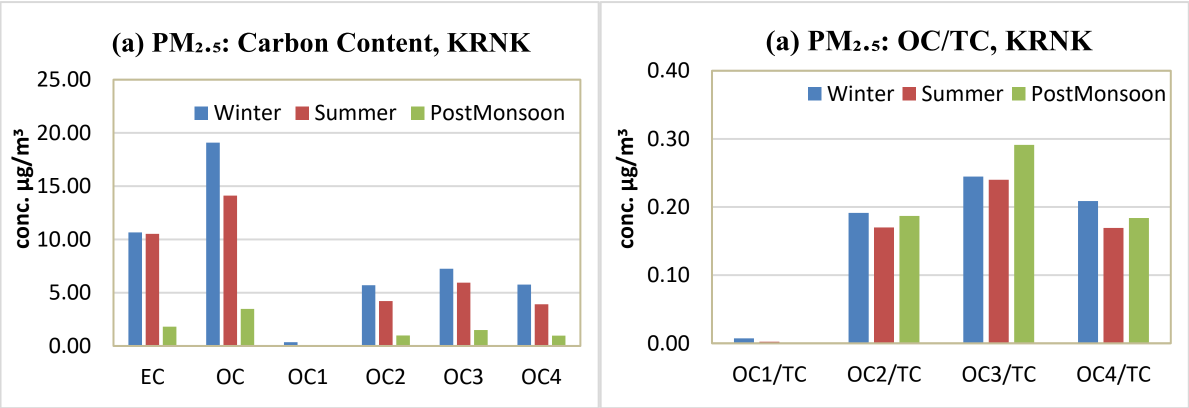


Figure 2.11: EC and OC Content in PM$_{2.5}$ at KRNK

2.4.1.4 PAHs in PM$_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.12 shows the average measured concentration of PAHs at KRNK for winter, summer, and post-monsoon seasons. A statistical summary of PAHs is presented in Table 2.13 for winter, summer, and post-monsoon 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 PAH concentrations in winter were 18.1±10.9 ng/m^3, in summer: 17.6±5.5 ng/m^3 and in post-monsoon: 20.2±3.5 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are

(i) B(b)F (4 ng/m^3), B(ghi)P (2 ng/m^3), BaP (2 ng/m^3) and Chr (1 ng/m^3) for winter season; (ii) B(b)F (3.6 ng/m^3), BaP (1.47 ng/m^3), B(ghi)P (2.57 ng/m^3), AcP (1.29 ng/m^3) and DEP (1.10 ng/m^3) for summer season; and (iii) Flu (1.29 ng/m^3), Phe (5.55 ng/m^3), Ant (1.59 ng/m^3), AcP (2.42 ng/m^3), B(b)F (1.24 ng/m^3), BaP (1.17 ng/m^3), and DmP (1.05 ng/m^3) for post-monsoon.

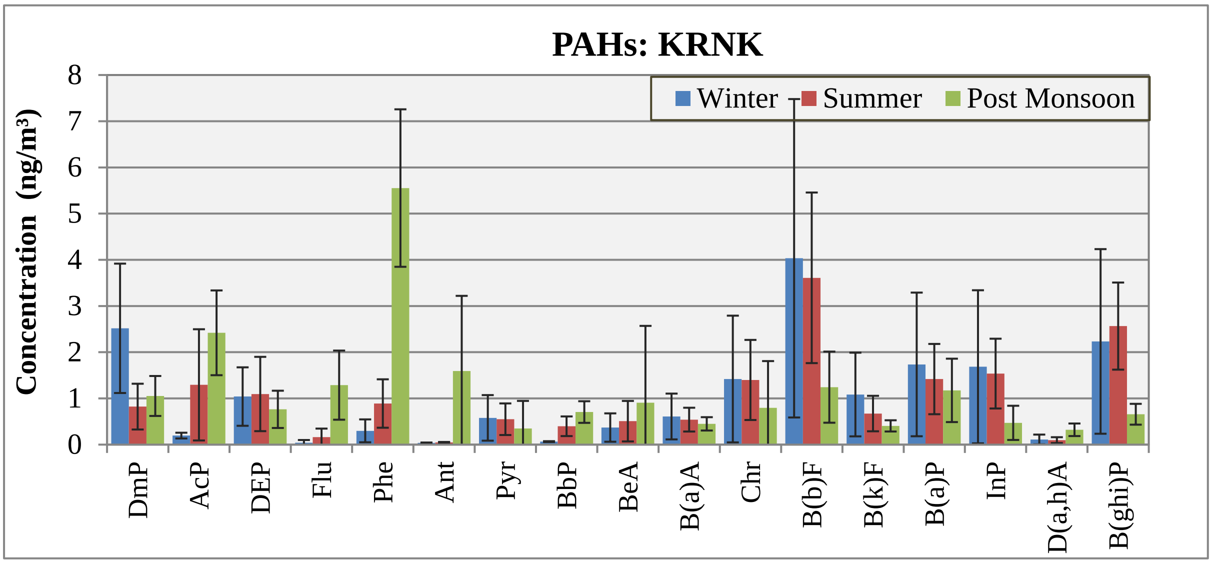


Figure 2.12: PAH Concentrations in PM$_{2.5}$ at KRNK

2.4.1.5 Molecular Markers in PM$_{2.5}$

Total six molecular markers analysed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, 17 β(H) 21 β(H)_hopane, n-Hentriacontane, n-Tritriacontane and n-Pentatriacontane. 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 2.13 and Table 2.14 show the levels of six molecular markers. The total concentration of markers was 93.93±34.10 ng/m^3 in winter, 89.73±45.60 ng/m^3 in summer and 86.43±8.0 ng/m^3 in post-monsoon. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

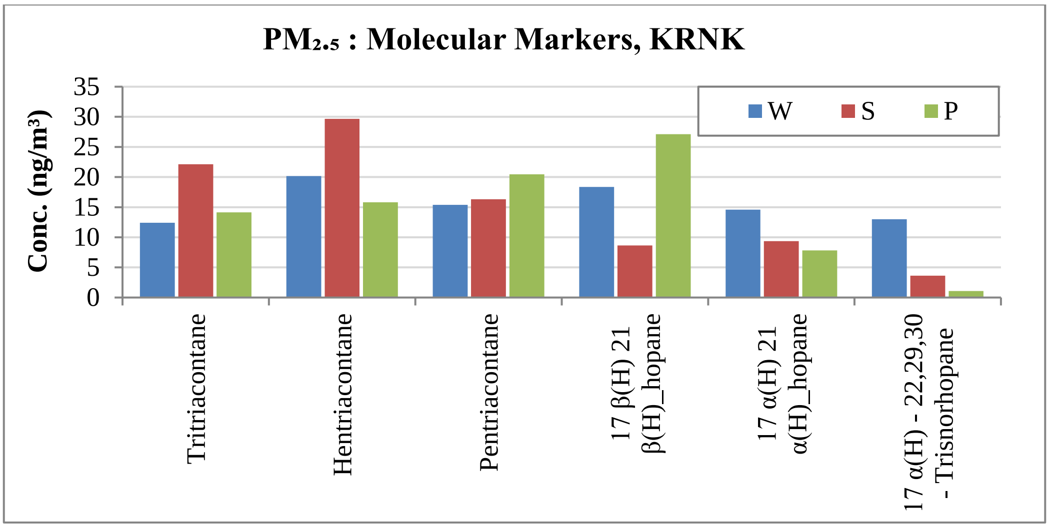


Figure 2.13: Molecular Markers in $PM_{2.5}$ at KRNK

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

Graphical presentations of chemical species at KRNK are shown for winter, summer and post-monsoon seasons for PM_{10} (Figure 2.14) and $PM_{2.5}$ (Figure 2.15). Statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) 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 the Table 2.15 - Table 2.20 for winter, summer and post-monsoon seasons.

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 2.21 - Table 2.26 for all three seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM is presented in Figure 2.16 (a) and (b) for winter, Figure 2.17 (a) and (b) for summer and Figure 2.18 (a) and (b) for post-monsoon seasons.

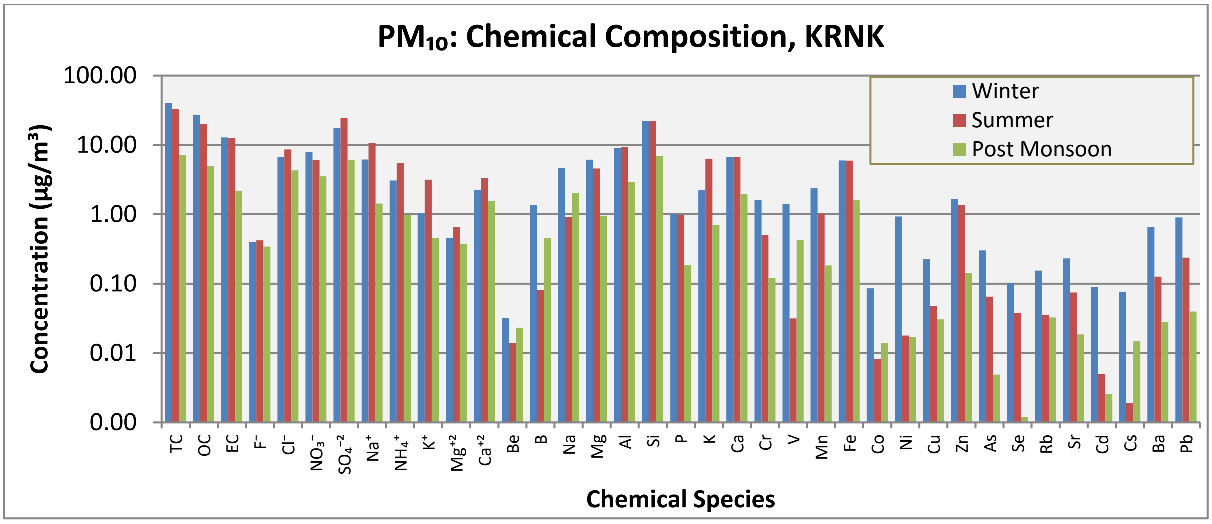


Figure 2.14: Concentrations of species in PM_{10} at KRNK

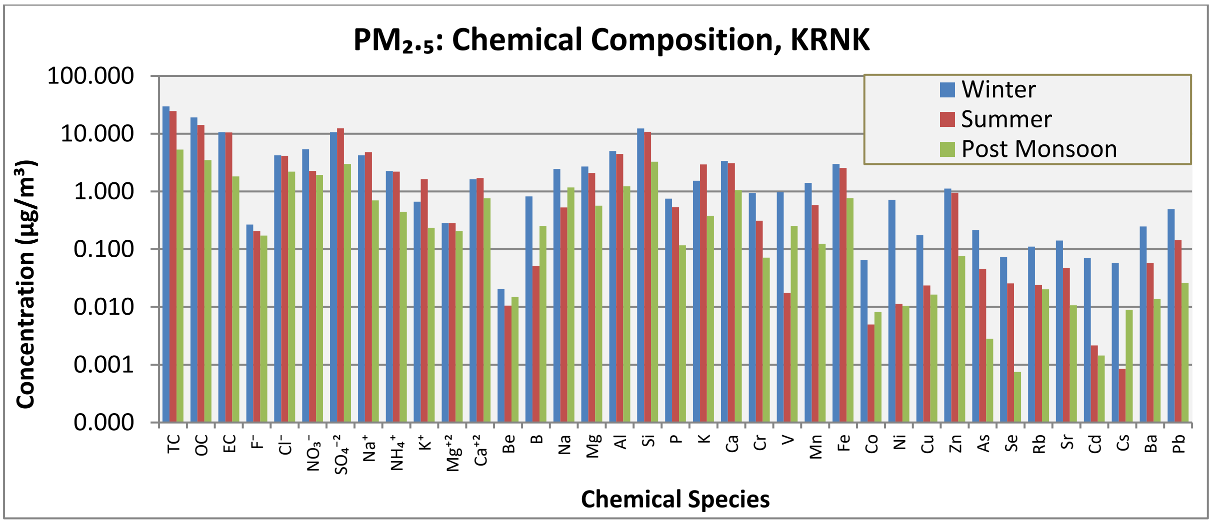
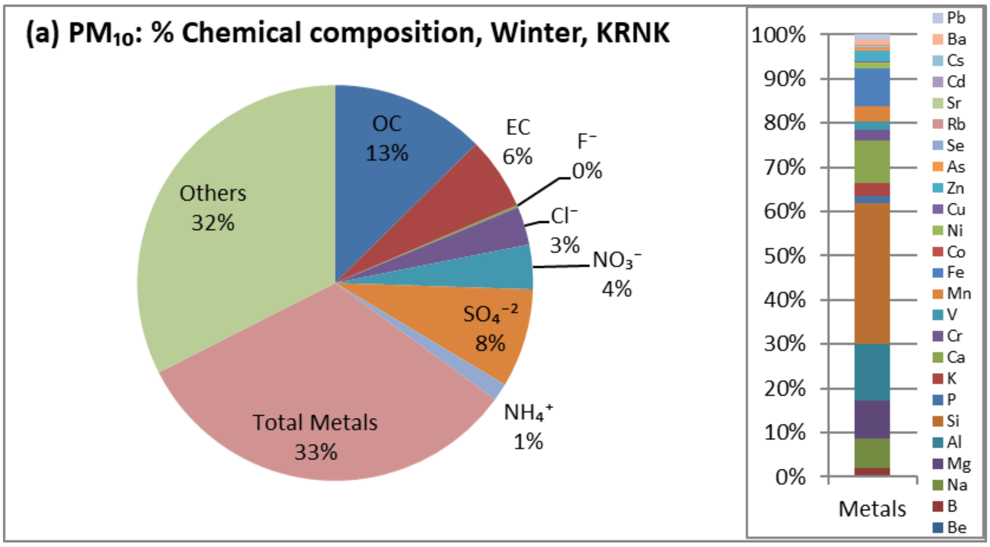


Figure 2.15: Concentrations of species in $PM_{2.5}$ at KRNK



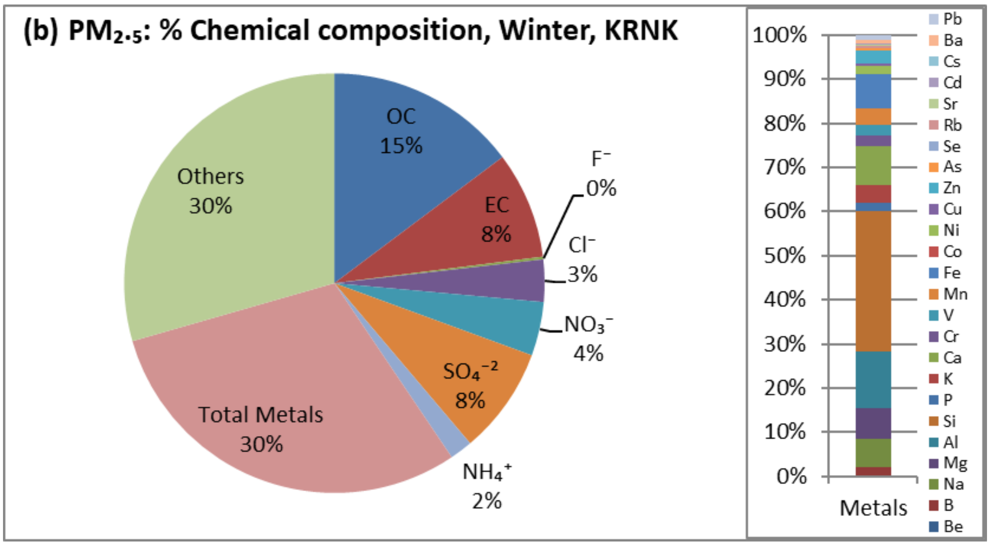


Figure 2.16: Percentage distribution of species in PM at KRNK for Winter Season

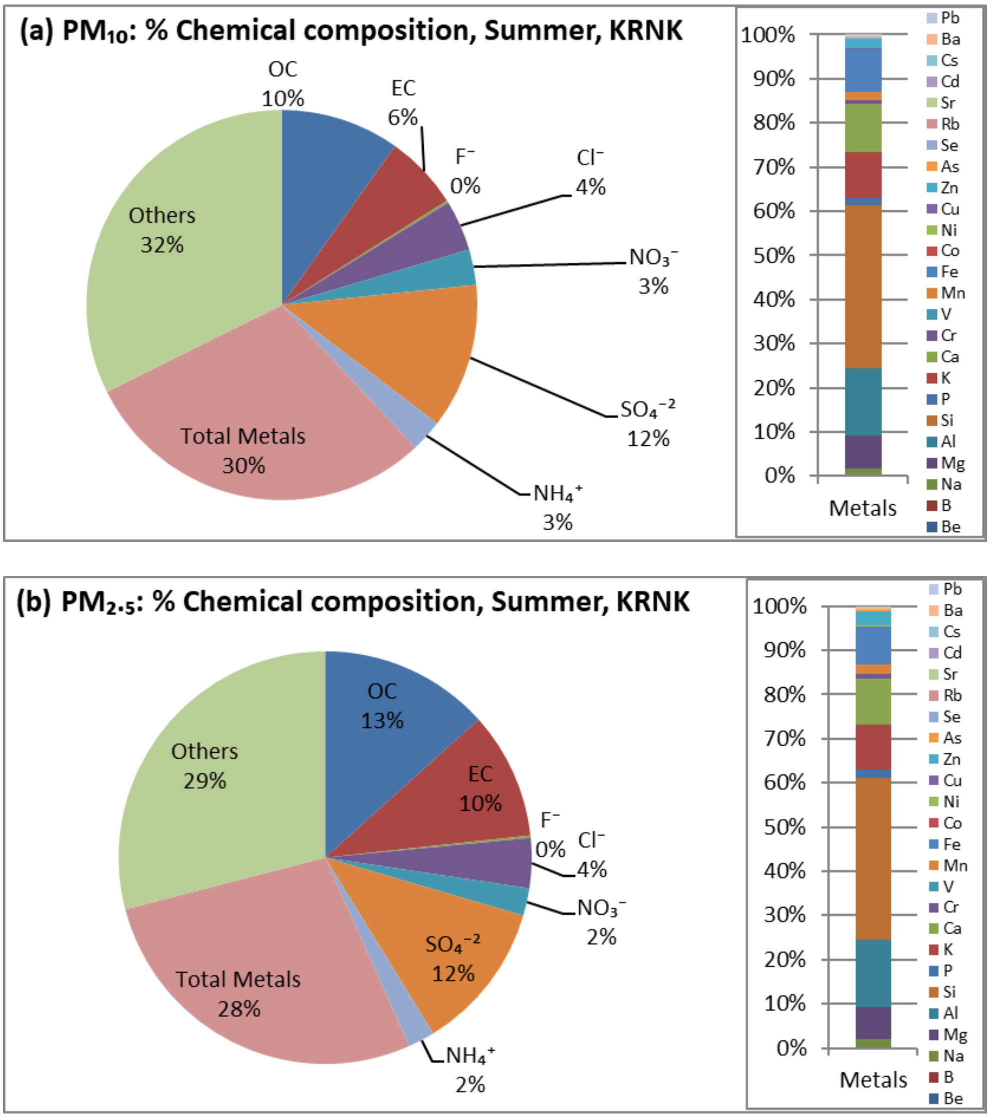


Figure 2.17: Percentage distribution of species in PM at KRNK for Summer Season

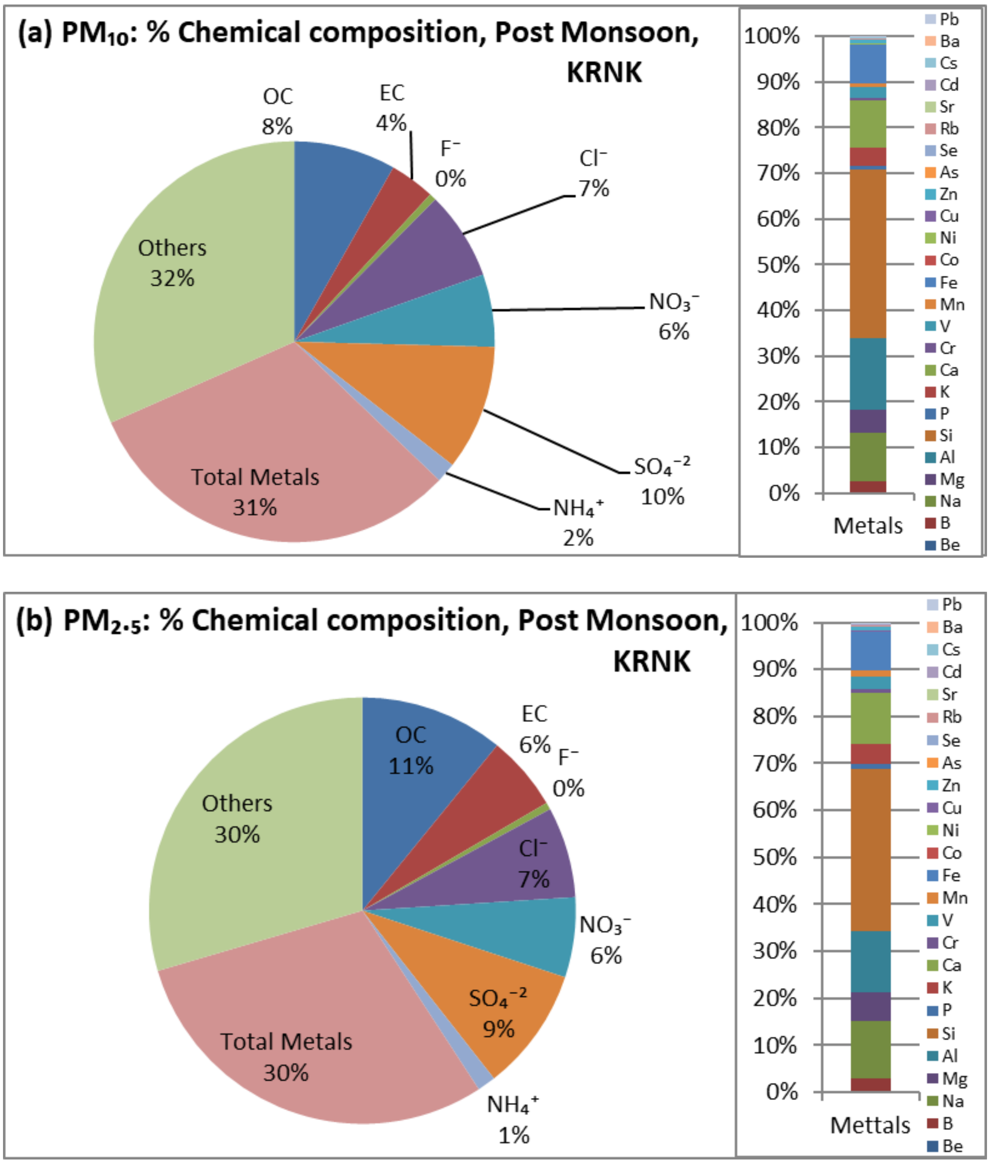


Figure 2.18: Percentage distribution of species in PM at KRNK for Post-monsoon Season

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, summer, and post-monsoon seasons (Figure 2.19) at KRNK.

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 is having fine mode during winter (60 %), summer (52%) and post-monsoon (53%). The major species contributing to fine mode are TC, OC, EC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Zn and Pb whereas, the major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Ca, Cr, Fe and Ni.

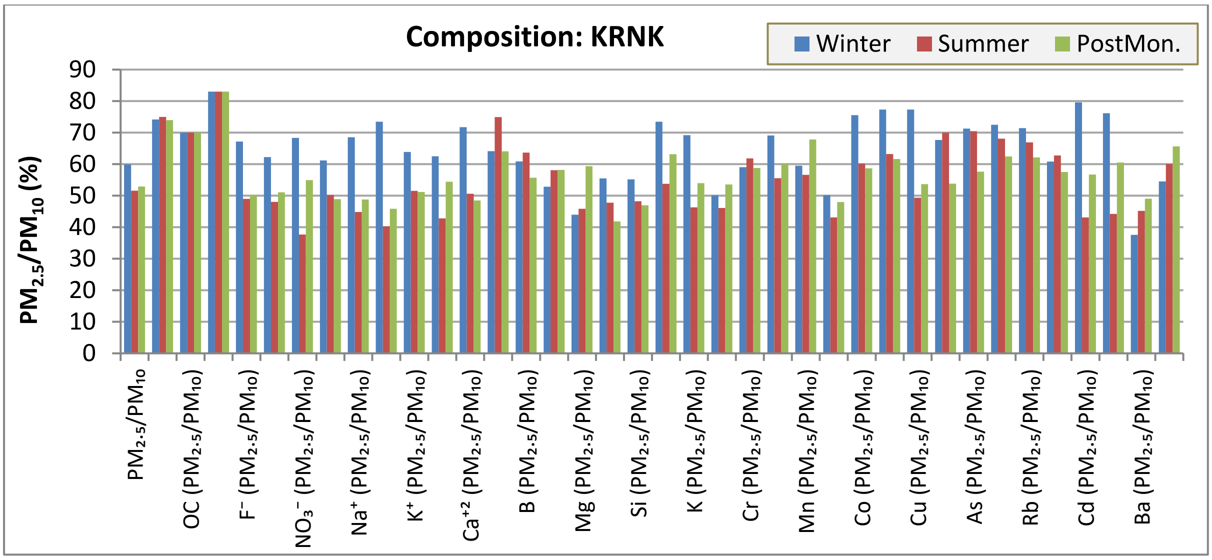


Figure 2.19: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at KRNK

Table 2.11: Statistical results of gaseous pollutants (μg/m^3) at KRNK for winter (W), summer (S) and post-monsoon (P) seasons

KRNK (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.90	10.82	9.61	0.27	1.13	2.74	13.75
SD	6.54	8.33	8.78	0.28	0.91	1.73	8.47
Max	40.78	32.45	28.33	0.89	3.15	6.08	30.51
Min	15.15	2.00	3.76	0.05	0.50	0.79	6.03
CV	0.26	0.77	0.91	1.07	0.81	0.63	0.62
KRNK (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.13	6.10	4.82	0.95	5.82	10.84	22.43
SD	6.40	3.79	2.04	0.15	2.02	2.40	6.26
Max	41.84	16.51	9.42	1.20	10.15	14.66	35.43
Min	13.20	2.00	3.81	0.77	4.13	7.63	16.38
CV	0.27	0.62	0.42	0.16	0.35	0.22	0.28
KRNK (P)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	12.75	2.19	7.00	1.34	10.51	14.43	33.28
SD	4.82	0.49	5.66	0.41	2.20	2.06	7.41
Max	23.60	3.69	19.78	2.05	12.85	17.49	47.19
Min	7.83	2.00	4.11	0.93	7.11	12.17	24.82
CV	0.38	0.22	0.81	0.30	0.21	0.14	0.22

Table 2.12: Statistical results of carbon contents ($\mu g/m^3$) in $PM_{2.5}$ at KRNK for winter (W), summer (S) and post-monsoon (P) seasons

KRNK (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	129.42	29.74	10.66	19.08	0.36	5.70	7.25	5.76	0.01	0.19	0.24	0.21
SD	40.75	12.60	5.77	7.02	0.73	2.38	2.97	1.51	0.01	0.01	0.02	0.05
Max	201.87	56.66	23.39	33.26	1.99	10.53	13.14	8.17	0.04	0.21	0.28	0.26
Min	75.00	15.52	5.32	10.20	0.00	2.93	3.45	3.59	0.00	0.18	0.21	0.12
CV	0.31	0.42	0.54	0.37	2.01	0.42	0.41	0.26	1.94	0.05	0.08	0.23
KRNK (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	106.35	24.65	10.53	14.12	0.06	4.21	5.94	3.92	0.00	0.17	0.24	0.17
SD	23.26	6.46	3.70	2.98	0.02	1.24	1.75	0.67	0.00	0.01	0.02	0.05
Max	160.06	37.67	17.13	20.55	0.09	6.97	9.84	5.01	0.00	0.19	0.28	0.25
Min	71.99	14.38	5.20	9.18	0.03	2.29	3.33	2.61	0.00	0.16	0.21	0.10
CV	0.22	0.26	0.35	0.21	0.32	0.30	0.29	0.17	0.31	0.07	0.08	0.31
KRNK (P)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	31.95	5.30	1.82	3.48	0.01	0.99	1.50	0.98	0.00	0.19	0.29	0.18
SD	14.75	2.11	0.90	1.27	0.02	0.41	0.49	0.43	0.00	0.02	0.05	0.01
Max	66.36	10.42	4.26	6.43	0.08	1.94	2.45	2.15	0.01	0.25	0.38	0.22
Min	17.40	2.83	0.84	1.99	0.00	0.53	0.91	0.55	0.00	0.16	0.22	0.17
CV	0.46	0.40	0.49	0.37	3.29	0.42	0.33	0.44	3.20	0.12	0.18	0.07

Table 2.13: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at KRNK for winter (W), summer (S) and post-monsoon (P) seasons

KRNK (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	2.52	0.20	1.04	0.04	0.30	0.04	0.58	0.07	0.37	0.61	1.42	4.03	1.08	1.74	1.68	0.11	2.23	18.05
SD	1.40	0.06	0.63	0.06	0.25	0.01	0.49	0.01	0.31	0.50	1.37	3.45	0.91	1.55	1.66	0.11	2.00	10.91
Max	4.32	0.29	2.13	0.15	0.77	0.05	1.36	0.07	0.76	1.40	3.67	10.01	2.65	4.10	4.70	0.30	5.89	36.39
Min	0.82	0.13	0.25	0.00	0.07	0.03	0.11	0.05	0.00	0.22	0.32	0.90	0.22	0.37	0.24	0.02	0.48	8.08
CV	0.56	0.32	0.61	1.46	0.83	0.24	0.85	0.14	0.83	0.81	0.97	0.85	0.83	0.90	0.98	0.95	0.89	0.60
KRNK (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	0.82	1.29	1.10	0.16	0.89	0.05	0.55	0.40	0.51	0.54	1.40	3.61	0.67	1.42	1.54	0.10	2.57	17.61
SD	0.50	1.20	0.80	0.18	0.52	0.01	0.34	0.21	0.44	0.26	0.87	1.85	0.38	0.76	0.76	0.06	0.94	5.49
Max	1.86	2.91	2.62	0.55	1.97	0.06	1.14	0.71	1.34	0.86	2.65	6.41	1.19	2.63	2.65	0.18	4.02	27.24
Min	0.37	0.28	0.19	0.03	0.50	0.03	0.20	0.13	0.08	0.24	0.55	1.75	0.26	0.59	0.81	0.04	1.46	10.27
CV	0.60	0.93	0.73	1.12	0.59	0.22	0.62	0.54	0.86	0.48	0.62	0.51	0.57	0.54	0.49	0.65	0.37	0.31
KRNK (P)	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	1.05	2.42	0.76	1.29	5.55	1.59	0.35	0.71	0.91	0.45	0.79	1.24	0.41	1.17	0.47	0.32	0.66	20.15
SD	0.43	0.92	0.40	0.75	1.70	1.63	0.60	0.23	1.66	0.14	1.01	0.77	0.12	0.69	0.37	0.14	0.23	3.51
Max	1.44	3.60	1.32	2.19	7.07	4.39	1.69	1.01	4.66	0.76	3.06	2.76	0.55	2.39	1.24	0.48	1.06	25.60
Min	0.50	1.51	0.19	0.44	2.88	0.58	0.00	0.44	0.04	0.33	0.17	0.55	0.23	0.46	0.17	0.12	0.40	15.19
CV	0.41	0.38	0.53	0.58	0.31	1.02	1.71	0.33	1.84	0.32	1.27	0.62	0.30	0.58	0.79	0.42	0.34	0.17

Table 2.14: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at KRNK for winter (W), summer (S) and post-monsoon (P) seasons

KRNK(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	12.42	20.17	15.39	18.36	14.59	13.00	93.93
SD	7.53	12.98	5.35	10.68	8.89	11.47	34.10
CV	0.61	0.64	0.35	0.58	0.61	0.88	0.36
KRNK(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	22.13	29.67	16.31	8.64	9.36	3.62	89.73
SD	29.61	12.02	7.78	3.55	2.83	0.47	45.60
CV	1.34	0.41	0.48	0.41	0.30	0.13	0.51
KRNK(P)	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	14.13	15.80	20.45	27.13	7.83	1.08	86.43
SD	5.18	8.99	1.34	3.66	4.56	0.16	8.00
CV	0.37	0.57	0.07	0.13	0.58	0.15	0.09

Table 2.15: Statistical results of chemical characterization (μg/m^3) of PM_{10} at KRNK for winter (W) season

KRNK	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	216	27.26	12.84	0.40	6.76	7.86	17.43	6.16	3.08	1.04	0.46	2.26	0.03	1.35	4.64	6.12	9.02	22.31	1.02
SD	67	10.04	6.95	0.13	3.39	3.86	12.11	3.08	1.95	0.43	0.22	1.43	0.02	0.59	2.51	2.65	2.97	7.86	0.46
Max	347	47.52	28.18	0.76	13.98	14.43	43.25	14.63	6.97	1.85	0.79	4.62	0.07	2.72	12.61	12.52	15.40	38.59	1.75
Min	122	14.57	6.41	0.27	1.92	1.40	4.19	2.18	1.00	0.41	0.19	0.07	0.01	0.61	1.88	2.27	5.00	12.12	0.37
CV	0.31	0.37	0.54	0.32	0.50	0.49	0.70	0.50	0.63	0.41	0.47	0.63	0.52	0.44	0.54	0.43	0.33	0.35	0.45
KRNK	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.22	6.74	1.60	1.41	2.37	5.96	0.09	0.93	0.23	1.66	0.30	0.10	0.15	0.23	0.09	0.08	0.66	0.90	68.08
SD	0.55	3.26	0.65	0.56	0.88	3.04	0.03	0.31	0.10	0.82	0.19	0.04	0.06	0.11	0.04	0.04	0.42	0.68	5.00
Max	2.78	14.70	2.63	2.72	4.18	13.91	0.16	1.64	0.49	3.16	0.68	0.17	0.30	0.50	0.19	0.19	1.60	2.75	75.07
Min	0.95	3.31	0.71	0.57	0.64	2.65	0.06	0.52	0.08	0.61	0.08	0.05	0.09	0.10	0.05	0.06	0.06	0.08	60.31
CV	0.25	0.48	0.41	0.40	0.37	0.51	0.31	0.33	0.43	0.49	0.62	0.39	0.40	0.49	0.40	0.46	0.64	0.75	0.07

Table 2.16: Statistical results of chemical characterization (µg/m^3) of PM$_{2.5}$ at KRNK for winter (W) season

KRNK	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	129	19.08	10.66	0.27	4.21	5.37	10.66	4.22	2.26	0.67	0.29	1.62	0.02	0.82	2.45	2.69	5.01	12.31	0.75
SD	42	7.02	5.77	0.13	2.01	2.54	7.44	1.74	1.53	0.34	0.14	1.17	0.01	0.40	2.06	1.83	2.11	5.36	0.39
Max	202	33.26	23.39	0.67	8.53	8.68	24.91	9.09	5.92	1.08	0.57	4.21	0.06	1.97	9.32	7.64	9.18	23.55	1.24
Min	75	10.20	5.32	0.15	1.42	0.86	2.27	1.94	0.71	0.15	0.11	0.05	0.00	0.38	0.73	0.61	1.95	4.45	0.15
CV	0.33	0.37	0.54	0.49	0.48	0.47	0.70	0.41	0.67	0.51	0.48	0.72	0.70	0.49	0.84	0.68	0.42	0.44	0.52
KRNK	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.54	3.38	0.95	0.97	1.41	2.99	0.06	0.72	0.17	1.12	0.22	0.07	0.11	0.14	0.07	0.06	0.25	0.49	71.17
SD	0.52	1.38	0.62	0.41	0.88	1.23	0.02	0.23	0.10	0.73	0.15	0.03	0.05	0.05	0.03	0.03	0.18	0.55	4.36
Max	2.06	5.97	2.13	1.49	3.17	4.85	0.10	1.09	0.43	2.38	0.46	0.16	0.22	0.25	0.17	0.17	0.77	2.29	80.40
Min	0.32	1.24	0.29	0.32	0.31	1.08	0.04	0.29	0.04	0.31	0.03	0.03	0.06	0.08	0.05	0.03	0.03	0.07	65.91
CV	0.34	0.41	0.66	0.42	0.62	0.41	0.27	0.32	0.58	0.65	0.70	0.46	0.44	0.37	0.45	0.59	0.74	1.11	0.06

Table 2.17: Statistical results chemical characterization (µg/m^3) of PM$_{10}$ at KRNK for summer (S) season

KRNK	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	205	20.18	12.68	0.42	8.60	6.04	24.69	10.68	5.48	3.16	0.66	3.37	0.01	0.08	0.91	4.57	9.33	22.32	0.99
SD	46	4.25	4.46	0.14	2.72	2.65	9.11	3.70	2.52	1.15	0.25	1.81	0.00	0.03	0.33	0.90	3.11	7.35	0.43
Max	307	29.35	20.63	0.71	12.87	11.06	42.29	19.30	9.47	5.43	1.12	7.66	0.02	0.13	1.83	6.53	15.47	37.53	1.72
Min	125	13.11	6.27	0.21	3.73	1.82	14.38	5.49	1.46	1.16	0.34	1.42	0.01	0.01	0.50	3.55	6.14	13.93	0.33
CV	0.23	0.21	0.35	0.33	0.32	0.44	0.37	0.35	0.46	0.36	0.38	0.54	0.16	0.41	0.36	0.20	0.33	0.33	0.44
KRNK	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.34	6.71	0.50	0.03	1.03	5.93	0.01	0.02	0.05	1.36	0.06	0.04	0.04	0.07	0.01	0.00	0.13	0.24	68.04
SD	2.49	2.38	0.11	0.01	0.25	2.24	0.00	0.01	0.03	0.54	0.04	0.01	0.01	0.02	0.00	0.00	0.04	0.20	2.95
Max	12.27	11.46	0.75	0.05	1.39	10.21	0.02	0.05	0.12	2.57	0.21	0.05	0.05	0.11	0.01	0.01	0.21	0.84	74.22
Min	3.11	4.11	0.37	0.01	0.48	3.49	0.00	0.00	0.01	0.68	0.03	0.02	0.02	0.04	0.00	0.00	0.06	0.01	63.94
CV	0.39	0.35	0.21	0.40	0.24	0.38	0.50	0.71	0.62	0.40	0.64	0.20	0.26	0.26	0.33	1.35	0.35	0.85	0.04

Table 2.18: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at KRNK for summer (S) season

KRNK	$PM_{2.5}$	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	106	14.12	10.53	0.21	4.13	2.28	12.39	4.79	2.21	1.63	0.28	1.70	0.01	0.05	0.53	2.10	4.46	10.77	0.53
SD	22	2.98	3.70	0.06	1.54	0.89	4.93	1.63	0.86	0.56	0.11	0.83	0.00	0.03	0.23	0.67	1.21	2.85	0.18
Max	153	20.55	17.13	0.32	7.33	3.99	23.75	7.59	3.99	2.77	0.58	3.42	0.01	0.11	0.97	3.25	6.32	15.33	0.78
Min	72	9.18	5.20	0.11	1.32	1.14	7.37	2.38	1.20	0.82	0.14	0.67	0.00	0.00	0.21	1.22	2.64	6.64	0.22
CV	0.21	0.21	0.35	0.28	0.37	0.39	0.40	0.34	0.39	0.34	0.40	0.49	0.22	0.55	0.44	0.32	0.27	0.26	0.34
KRNK	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.93	3.09	0.31	0.02	0.58	2.56	0.00	0.01	0.02	0.95	0.05	0.03	0.02	0.05	0.00	0.00	0.06	0.14	71.08
SD	1.32	0.88	0.09	0.01	0.19	0.89	0.00	0.01	0.02	0.45	0.02	0.01	0.01	0.02	0.00	0.00	0.02	0.15	1.75
Max	6.31	4.47	0.49	0.03	0.92	4.22	0.01	0.04	0.08	1.84	0.11	0.04	0.04	0.07	0.01	0.00	0.09	0.63	75.39
Min	1.14	1.77	0.20	0.00	0.28	1.47	0.00	0.00	0.01	0.49	0.02	0.01	0.01	0.03	0.00	0.00	0.02	0.01	68.47
CV	0.45	0.28	0.28	0.38	0.33	0.35	0.56	0.96	0.79	0.47	0.48	0.28	0.32	0.34	0.58	1.00	0.36	1.08	0.02

Table 2.19: Statistical results chemical characterization (µg/m^3) of PM_{10} at KRNK for post-monsoon (P) season

KRNK	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	60	4.97	2.19	0.34	4.31	3.53	6.11	1.43	0.97	0.46	0.38	1.56	0.02	0.46	2.01	0.96	2.93	6.97	0.18
SD	29	1.81	1.08	0.11	1.83	1.37	3.68	0.65	0.68	0.30	0.23	0.89	0.00	0.25	0.58	0.70	1.64	3.77	0.08
Max	132	9.18	5.14	0.54	7.61	6.38	13.09	2.70	2.73	1.16	0.89	3.12	0.03	1.01	2.96	2.53	6.86	15.93	0.36
Min	29	2.84	1.01	0.17	1.52	1.66	1.57	0.64	0.48	0.15	0.09	0.34	0.02	0.13	1.24	0.24	1.12	2.90	0.09
CV	0.48	0.37	0.49	0.33	0.43	0.39	0.60	0.45	0.70	0.66	0.62	0.57	0.15	0.54	0.29	0.74	0.56	0.54	0.45
KRNK	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.70	1.96	0.12	0.42	0.18	1.59	0.01	0.02	0.03	0.14	0.00	0.00	0.03	0.02	0.00	0.01	0.03	0.04	69.78
SD	0.34	1.14	0.12	0.07	0.23	0.97	0.00	0.00	0.03	0.12	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.06	3.60
Max	1.57	4.67	0.48	0.53	0.90	3.89	0.02	0.03	0.11	0.44	0.02	0.00	0.05	0.04	0.00	0.02	0.08	0.25	75.43
Min	0.41	0.69	0.02	0.30	0.04	0.53	0.01	0.01	0.01	0.04	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.01	60.66
CV	0.49	0.58	1.02	0.16	1.23	0.61	0.20	0.26	0.95	0.83	0.79	0.63	0.23	0.49	0.30	0.16	0.86	1.52	0.05

Table 2.20: Statistical results of chemical characterization (μg/m^3) of $PM_{2.5}$ at KRNK for post-monsoon (P) season

KRNK	$PM_{2.5}$	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	32	3.48	1.82	0.17	2.20	1.94	2.99	0.70	0.45	0.23	0.21	0.76	0.01	0.25	1.17	0.57	1.23	3.27	0.12
SD	15	1.27	0.90	0.06	1.09	0.79	1.84	0.35	0.29	0.21	0.15	0.50	0.00	0.14	0.58	0.35	0.64	1.61	0.05
Max	66	6.43	4.26	0.27	4.34	3.16	6.99	1.54	1.27	0.75	0.58	1.79	0.02	0.57	2.34	1.25	2.51	5.89	0.19
Min	17	1.99	0.84	0.06	0.94	1.02	0.94	0.27	0.25	0.07	0.05	0.18	0.01	0.08	0.53	0.14	0.43	1.47	0.04
CV	0.46	0.37	0.49	0.35	0.49	0.41	0.62	0.50	0.65	0.88	0.73	0.66	0.28	0.54	0.50	0.62	0.52	0.49	0.40
KRNK	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.38	1.05	0.07	0.25	0.12	0.76	0.01	0.01	0.02	0.08	0.00	0.00	0.02	0.01	0.00	0.01	0.01	0.03	71.55
SD	0.23	0.74	0.07	0.08	0.18	0.49	0.00	0.00	0.01	0.05	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.05	3.53
Max	0.93	2.89	0.22	0.40	0.73	1.97	0.01	0.01	0.05	0.20	0.01	0.00	0.04	0.02	0.00	0.01	0.04	0.19	76.25
Min	0.17	0.30	0.01	0.15	0.02	0.25	0.00	0.01	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	61.58
CV	0.62	0.70	0.93	0.30	1.44	0.64	0.23	0.26	0.85	0.67	0.76	0.74	0.36	0.47	0.33	0.22	0.85	1.81	0.05

Table 2.21: Correlation matrix for PM_{10} and its composition at KRNK for winter season

KRNK	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	0.89	0.42	0.21	0.53	0.08	-0.29	-0.08	0.78	0.77	0.48	0.98
TC		1.00	0.99	0.98	0.23	0.13	0.23	-0.22	-0.21	-0.36	0.65	0.60	0.62	0.90
OC			1.00	0.94	0.25	0.15	0.23	-0.21	-0.16	-0.32	0.64	0.66	0.56	0.91
EC				1.00	0.18	0.10	0.23	-0.23	-0.26	-0.39	0.63	0.50	0.69	0.85
NO_3^-					0.66	0.27	1.00	0.57	-0.20	0.36	0.50	0.61	0.00	0.51
SO_4^{-2}					0.00	-0.22		1.00	-0.22	0.78	0.35	0.13	-0.05	0.06
NH_4^+					0.09	0.10			-0.23	1.00	0.20	0.04	-0.16	-0.02
Metals					0.46	0.25			-0.32		0.74	0.78	0.41	1.00

Table 2.22: Correlation matrix for $PM_{2.5}$ and its composition at KRNK for winter season

KRNK	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.79	0.78	0.77	0.35	0.19	0.62	0.32	-0.35	0.19	0.70	0.48	0.55	0.94
TC		1.00	0.99	0.98	0.17	0.33	0.21	-0.28	-0.18	-0.35	0.36	0.40	0.73	0.64
OC			1.00	0.94	0.24	0.33	0.21	-0.29	-0.15	-0.32	0.36	0.47	0.66	0.65
EC				1.00	0.07	0.31	0.21	-0.27	-0.21	-0.38	0.34	0.31	0.79	0.60
NO_3^-					0.45	0.21	1.00	0.63	0.02	0.30	0.53	0.46	-0.08	0.59
SO_4^{-2}					0.09	-0.14		1.00	-0.15	0.77	0.46	0.02	-0.13	0.35
NH_4^+					0.34	0.01			-0.15	1.00	0.42	0.12	-0.15	0.34
Metals					0.47	0.09			-0.41		0.73	0.57	0.39	1.00

Table 2.23: Correlation matrix for PM_{10} and its composition at KRNK for summer season

KRNK	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	0.69	0.65	0.70	0.80	-0.23	0.41	0.48	-0.14	0.12	0.51	0.69	0.84	0.97
TC		1.00	0.97	0.97	0.33	0.05	0.26	0.04	0.02	-0.23	0.54	0.24	0.46	0.60
OC			1.00	0.87	0.33	0.03	0.36	-0.06	-0.01	-0.41	0.47	0.17	0.45	0.57
EC				1.00	0.32	0.07	0.15	0.13	0.05	-0.04	0.57	0.29	0.43	0.60
NO_3^-					0.36	-0.14	1.00	0.12	-0.27	-0.07	0.54	0.07	0.29	0.37
SO_4^{-2}					0.43	-0.58		1.00	-0.27	0.69	0.35	0.29	0.29	0.35
NH_4^+					0.12	-0.29			-0.22	1.00	0.18	0.14	-0.06	0.03
Metals					0.81	-0.18			-0.09		0.37	0.74	0.88	1.00

Table 2.24: Correlation matrix for $PM_{2.5}$ and its composition at KRNK for summer season

KRNK	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.69	0.57	0.75	0.24	0.03	0.38	0.51	0.12	0.46	0.52	0.33	0.62	0.96
TC		1.00	0.96	0.97	0.06	-0.06	0.39	-0.09	-0.28	-0.01	0.49	0.05	0.40	0.54
OC			1.00	0.87	-0.05	-0.21	0.46	-0.24	-0.43	-0.19	0.45	-0.01	0.35	0.45
EC				1.00	0.14	0.07	0.32	0.04	-0.15	0.14	0.50	0.10	0.41	0.59
NO_3^-					0.00	-0.49	1.00	-0.21	-0.13	-0.22	0.44	-0.06	0.12	0.47
SO_4^{-2}					0.23	0.04		1.00	0.52	0.83	-0.08	0.52	0.45	0.49
NH_4^+					0.51	0.14			0.36	1.00	0.00	0.60	0.47	0.40
Metals					0.17	-0.05			0.09		0.56	0.27	0.54	1.00

Table 2.25: Correlation matrix for PM_{10} and its composition at KRNK for post-monsoon season

KRNK	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.84	0.79	0.86	0.32	0.82	0.55	0.89	0.90	0.00	0.94	0.84	0.93	0.99
TC		1.00	0.98	0.96	0.37	0.61	0.51	0.70	0.72	-0.14	0.86	0.66	0.65	0.78
OC			1.00	0.89	0.31	0.53	0.51	0.62	0.66	-0.18	0.80	0.64	0.57	0.72
EC				1.00	0.44	0.70	0.49	0.78	0.76	-0.06	0.89	0.66	0.73	0.81
NO_3^-					-0.03	0.39	1.00	0.30	0.55	0.26	0.68	0.32	0.47	0.50
SO_4^{-2}					0.25	0.78		1.00	0.88	0.15	0.82	0.82	0.91	0.88
NH_4^+					-0.05	-0.07			0.04	1.00	0.14	0.01	0.15	-0.04
Metals					0.31	0.83			0.88		0.90	0.83	0.95	1.00

Table 2.26: Correlation matrix for $PM_{2.5}$ and its composition at KRNK for post-monsoon season

KRNK	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.84	0.78	0.88	0.43	0.79	0.54	0.90	0.92	0.03	0.90	0.56	0.95	0.98
TC		1.00	0.98	0.96	0.23	0.54	0.51	0.73	0.89	-0.08	0.89	0.38	0.80	0.73
OC			1.00	0.89	0.15	0.42	0.50	0.62	0.87	-0.15	0.82	0.37	0.72	0.65
EC				1.00	0.32	0.68	0.50	0.84	0.87	0.03	0.93	0.37	0.87	0.79
NO_3^-					0.43	0.39	1.00	0.31	0.66	0.17	0.66	0.09	0.52	0.47
SO_4^{-2}					0.48	0.89		1.00	0.78	0.07	0.81	0.56	0.93	0.89
NH_4^+					0.29	0.10			-0.03	1.00	0.16	0.07	0.16	0.03
Metals					0.44	0.80			0.85		0.83	0.58	0.93	1.00

2.4.2 SAIL Steel Plant (SAIL)

The sampling period was December 25, 2020- January 08, 2021, for winter, March 05 – 19, 2021 for summer and September 09 – 23, 2021 for post-monsoon.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ at SAIL is shown for winter (Figure 2.21), summer (Figure 2.21) and post-monsoon (Figure 2.22). Average levels at this site were: $PM_{2.5}$: 196±33 (winter), 114±23 µg/m^3 (summer) and 28±13 µg/m^3 (post-monsoon) and PM_{10}: 344±42 (winter), 229±54 µg/m^3 (summer) and 51±30 µg/m^3 (post-monsoon). In winter, the $PM_{2.5}$ levels were about 3.27 times higher than the NAAQS (60 µg/m^3) and PM_{10} levels were 3.44 times higher than the NAAQS (100 µg/m^3). In summer, the $PM_{2.5}$ levels were 1.9 times NAAQS while PM_{10} is 2.3 times higher than the NAAQS. In post-monsoon, both the $PM_{2.5}$ and PM_{10} levels were under the standards.

A statistical summary of PM concentrations is presented in Table 2.31 - Table 2.36 for the winter, and summer seasons. In summer $PM_{2.5}$ and PM_{10} both drop but are still quite higher than NAAQS despite improvement in meteorology and better dispersion in summer. The particles airborne from soil during dust storms in the dry months of summer can contribute significantly to coarse fraction (i.e., $PM_{2.5-10}$). In post-monsoon, both $PM_{2.5}$ and PM_{10} levels drop below NAAQS.

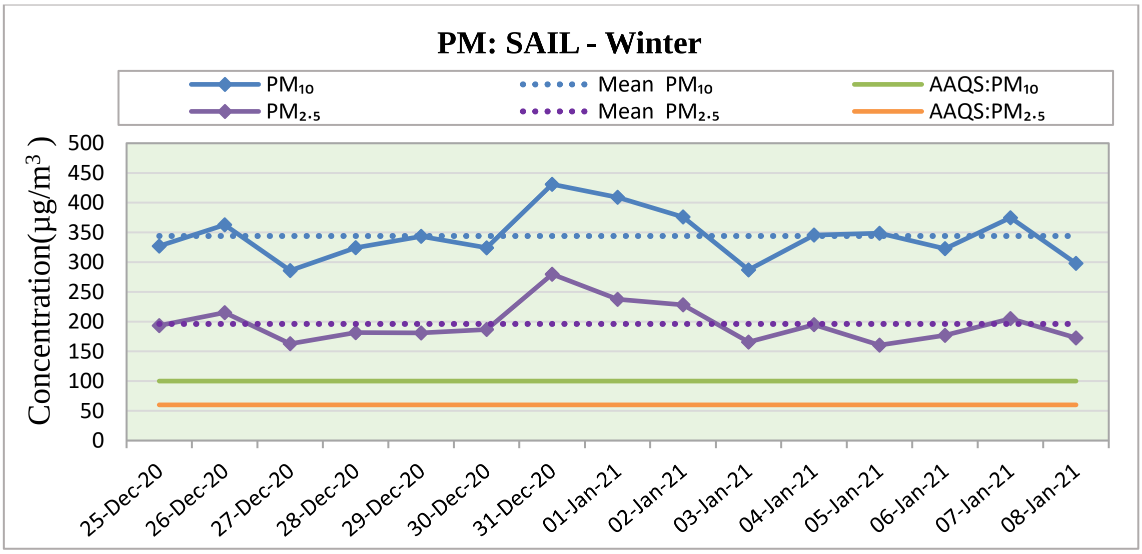


Figure 2.20: PM Concentrations at SAIL for Winter Season

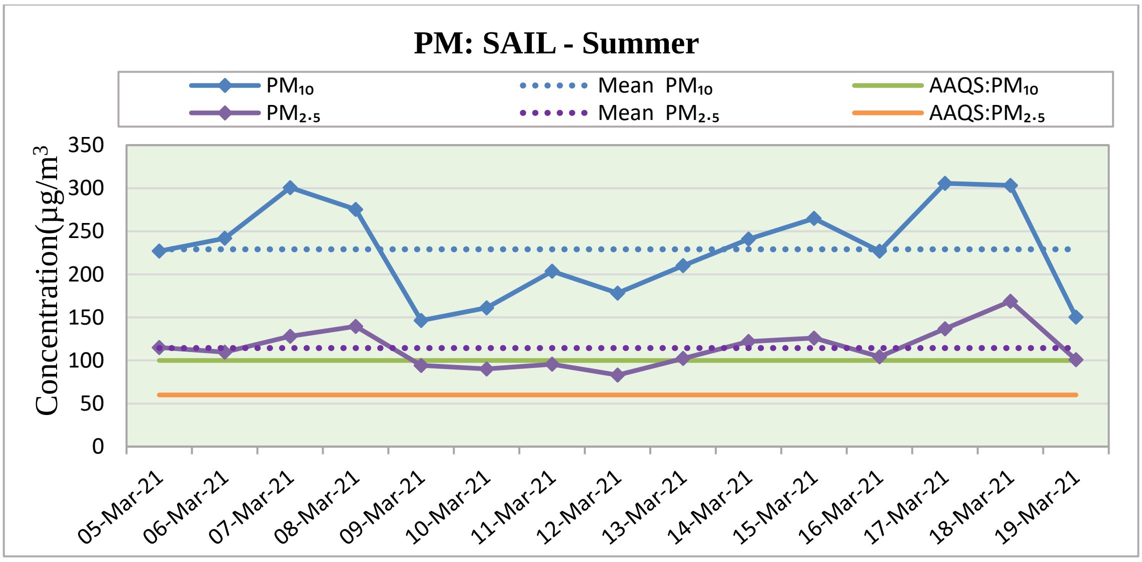


Figure 2.21: PM Concentrations at SAIL for Summer Season

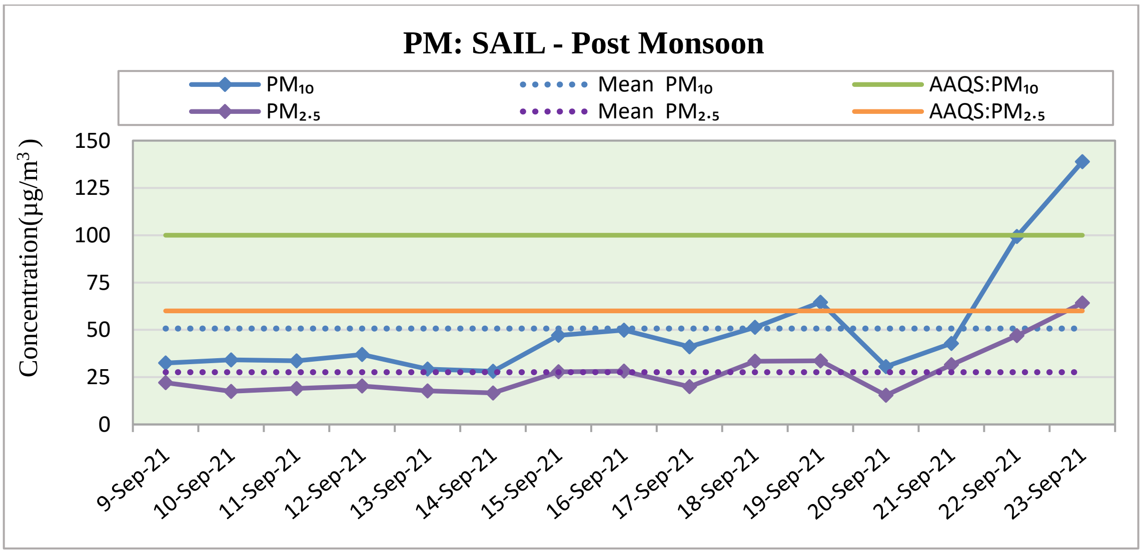


Figure 2.22: PM Concentrations at SAIL for Post-monsoon Season

2.4.2.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.23), summer (Figure 2.24) and post-monsoon (Figure 2.25) seasons. It was observed that SO_2 levels were higher in winter (17±10 µg/m^3) than in other seasons and met the NAAQS. NO_2 levels were also under the NAAQS with an average of 15 days at 40.6±5.5 µg/m^3 in winter, 33.9±6.9 µg/m^3 in summer and 8.2±3.9 µg/m^3 in post-monsoon seasons (Table 2.27). The summer concentration of SO_2 and NO_2 dropped similarly to $PM_{2.5}$ levels. Although NO_2 and

SO_2 levels are certainly a matter of concern in the winter season their higher values in the summer season can largely be attributed to vehicular pollution, DG sets and coal combustion. The variation in NO_2 and SO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams, local open and coal burning etc.

The mean concentrations of BTX are presented in Figure 2.26 and the statistical summary is in Table 2.27. The total BTX level is observed 7.04±2.43 µg/m^3 (Benzene: 3.70 and Toluene: 0.12 µg/m^3) in winter, 21.21±2.14 µg/m^3 (Benzene: 4.04 and Toluene: 1.00 µg/m^3) in summer and 14.80±7.04 µg/m^3 (Benzene: 2.53 and Toluene: 0.64 µg/m^3) in post-monsoon seasons. The maximum BTX concentration was observed at 10 µg/m^3 in winter, 24 µg/m^3 in summer and 21 µg/m^3 in post-monsoon seasons. The higher concentration of p-xylene and o-xylene can be due to coal-burning motor vehicle emissions and the high consumption of xylene-based solvents in the region.

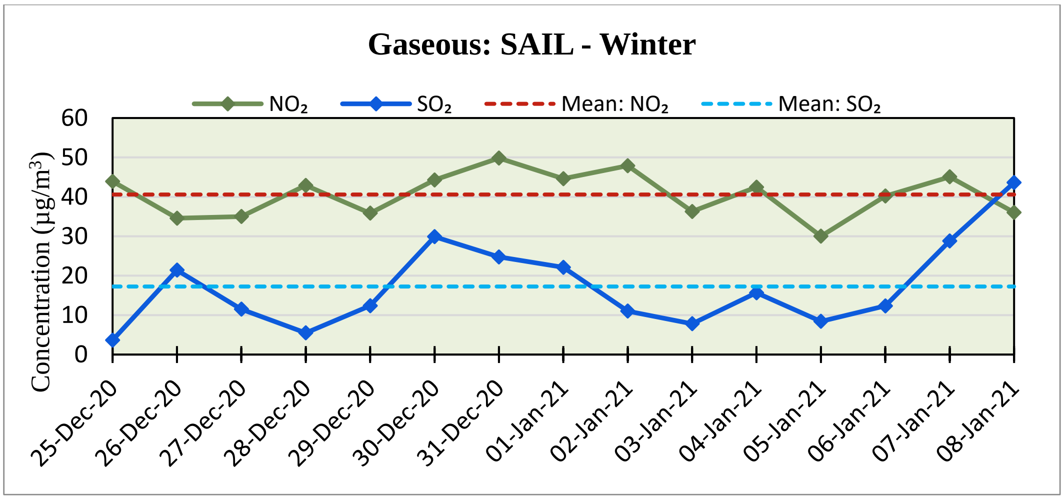


Figure 2.23: SO_2 and NO_2 Concentrations at SAIL for Winter Season

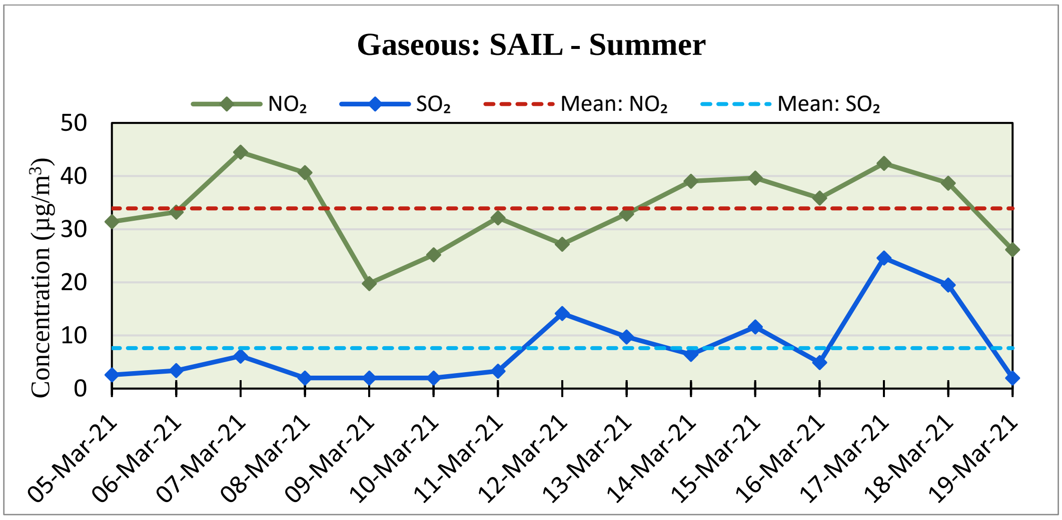


Figure 2.24: SO_2 and NO_2 Concentrations at SAIL for Summer Season

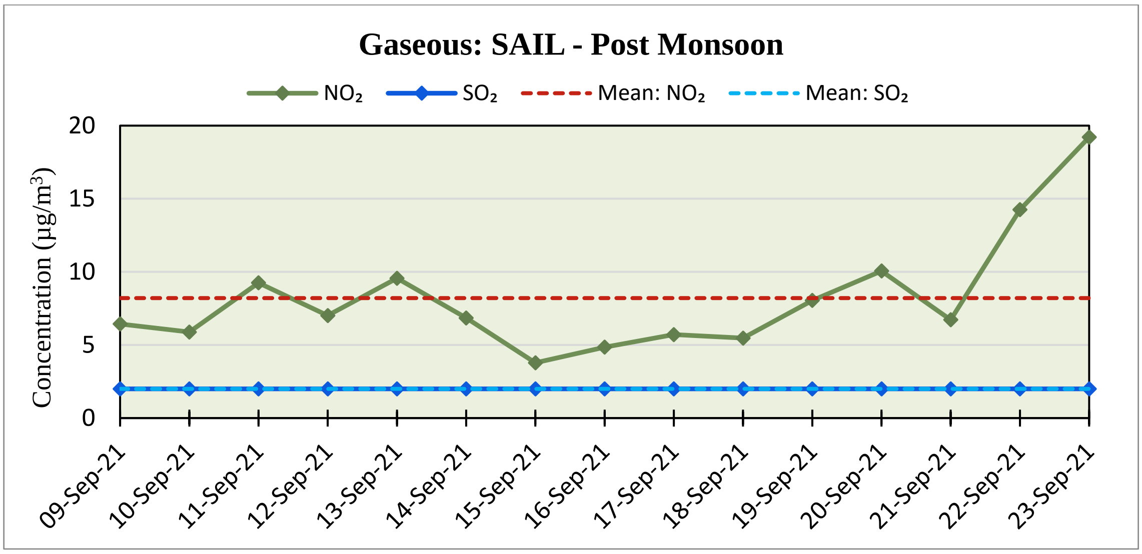


Figure 2.25: SO_2 and NO_2 Concentrations at SAIL for Post-monsoon Season

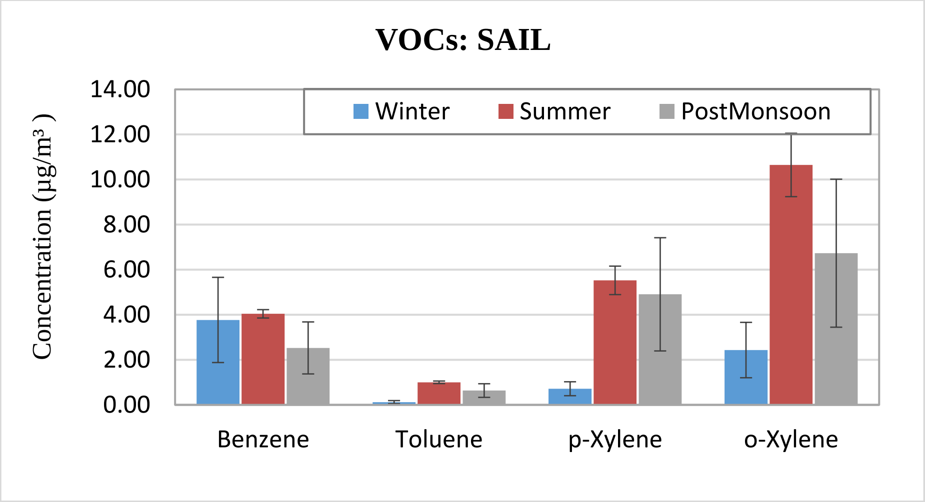


Figure 2.26: VOC concentration at SAIL

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 2.27 (a) and (b) for winter, summer, and post-monsoon seasons. Organic carbon is observed slightly higher (winter: 24.24±3.53, summer: 15.09±2.50 and post-monsoon: 2.78±1.27 µg/m^3) than the elemental carbon (winter: 15.29±3.42 summer: 11.87±3.13 and post-monsoon: 1.39±1.03 µg/m^3). However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere. It is also observed that the OC and EC are higher in the winter 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 2.28 for winter, summer and post-monsoon seasons.

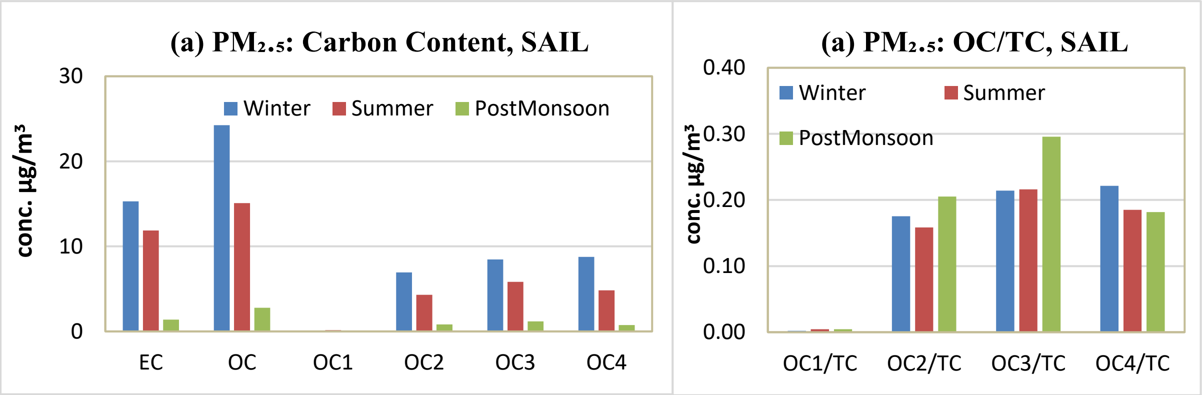


Figure 2.27: EC and OC Content in $PM_{2.5}$ at SAIL

2.4.2.4 PAHs in $PM_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.28 shows the average measured concentration of PAHs at KRNK for winter, summer, and post-monsoon seasons. A statistical summary of PAHs is presented in Table 2.29 for winter, summer, and post-monsoon 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 PAH concentration in winter was 47.8±18.2 ng/m^3, in summer: 52.8±21.8 ng/m^3 and in post-monsoon: 14.4±2.8 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are (i) B(b)F (11 ng/m^3), B(k)F (3 ng/m^3), InP (4 ng/m^3), B(a)A (3 ng/m^3), B(ghi)P (5 ng/m^3), BaP (5 ng/m^3) and Chr (7 ng/m^3) for winter season; (ii) B(b)F (9 ng/m^3), B(k)F (4 ng/m^3), InP (6 ng/m^3), B(a)A (2 ng/m^3), B(ghi)P (4 ng/m^3), BaP (8 ng/m^3) and Chr (4 ng/m^3) for summer season; and (iii) DmP (1 ng/m^3), AcP (3 ng/m^3), DEP (2 ng/m^3) and BbP (3 ng/m^3) for post-monsoon season.

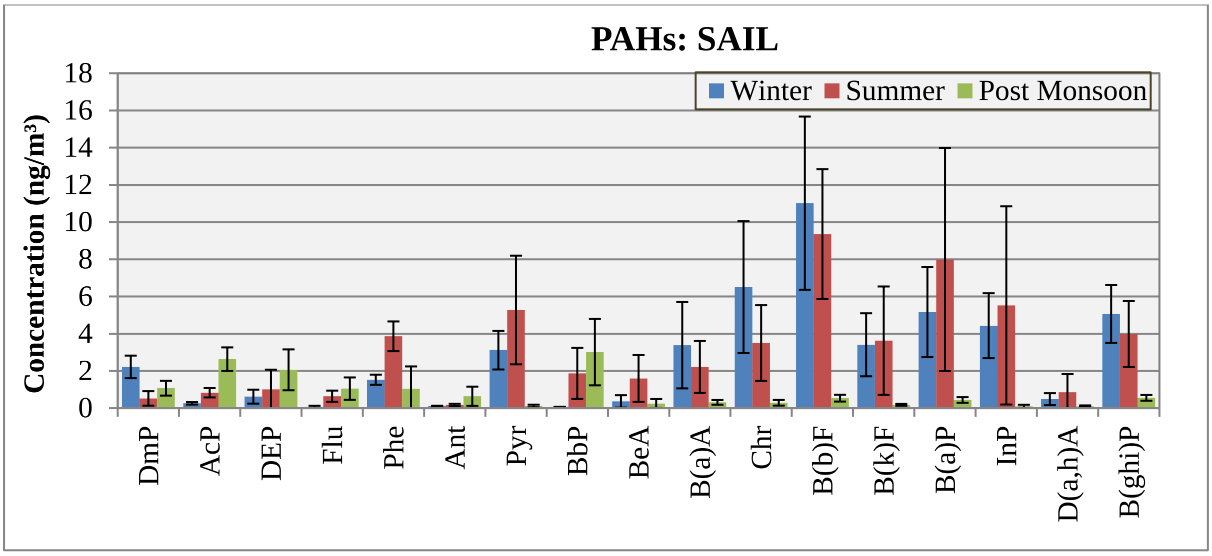


Figure 2.28: PAHs Concentrations in $PM_{2.5}$ at SAIL

2.4.2.5 Molecular Markers in $PM_{2.5}$

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

Figure 2.29 and Table 2.30 show the levels of six molecular markers. The total concentration of markers was 89.43±36.92 ng/m^3 in winter, 73.37±20.93 ng/m^3 in summer and 54.07±14.39 ng/m^3 in post-monsoon. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

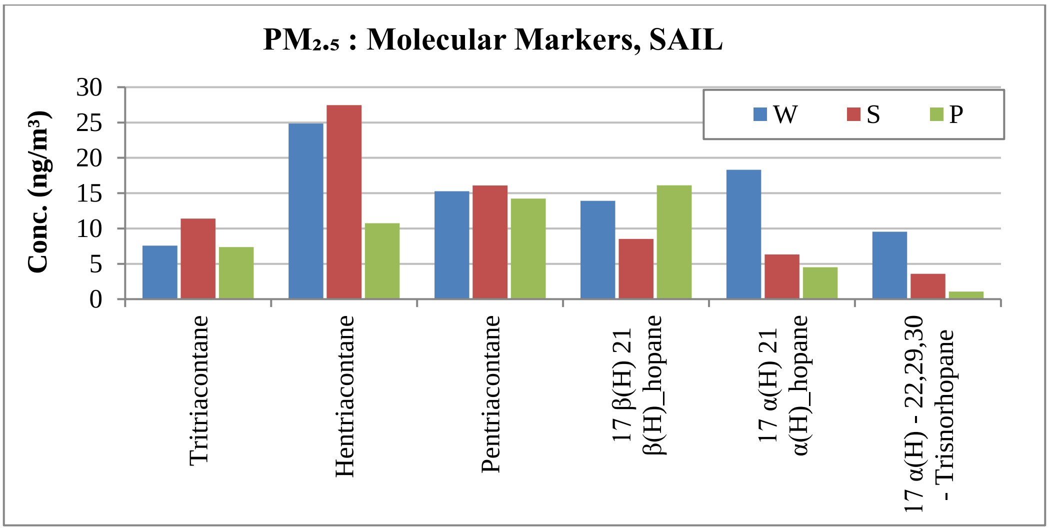


Figure 2.29: Molecular Markers in $PM_{2.5}$ at SAIL

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 winter, summer and post-monsoon season for PM_{10} (Figure 2.30) and $PM_{2.5}$ (Figure 2.31). 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 2.31 - Table 2.36 for winter, summer and post-monsoon seasons.

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 2.37 - Table 2.42 for all three seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM is presented in Figure 2.32(a) and (b) for winter, Figure 2.33(a) and (b) for summer and Figure 2.34 (a) and (b) for post-monsoon seasons.

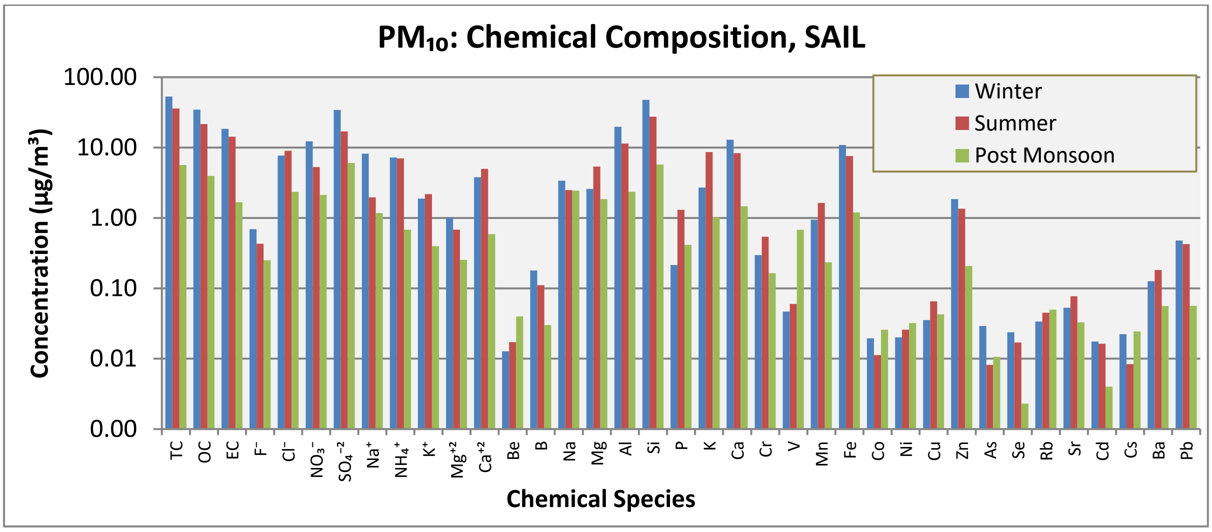


Figure 2.30: Concentrations of species in PM_{10} at SAIL

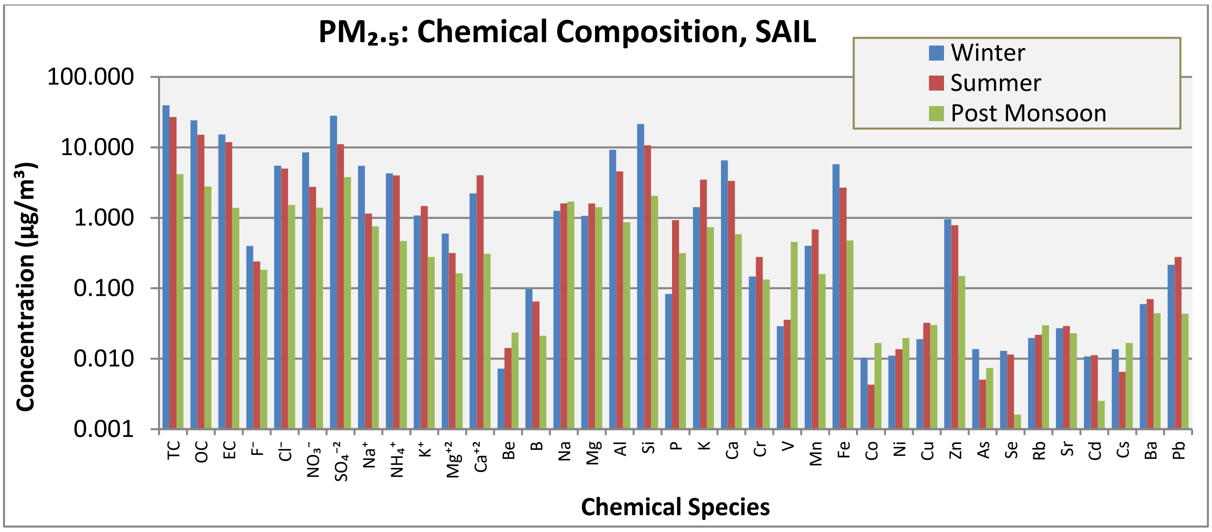


Figure 2.31: Concentrations of species in $PM_{2.5}$ at SAIL

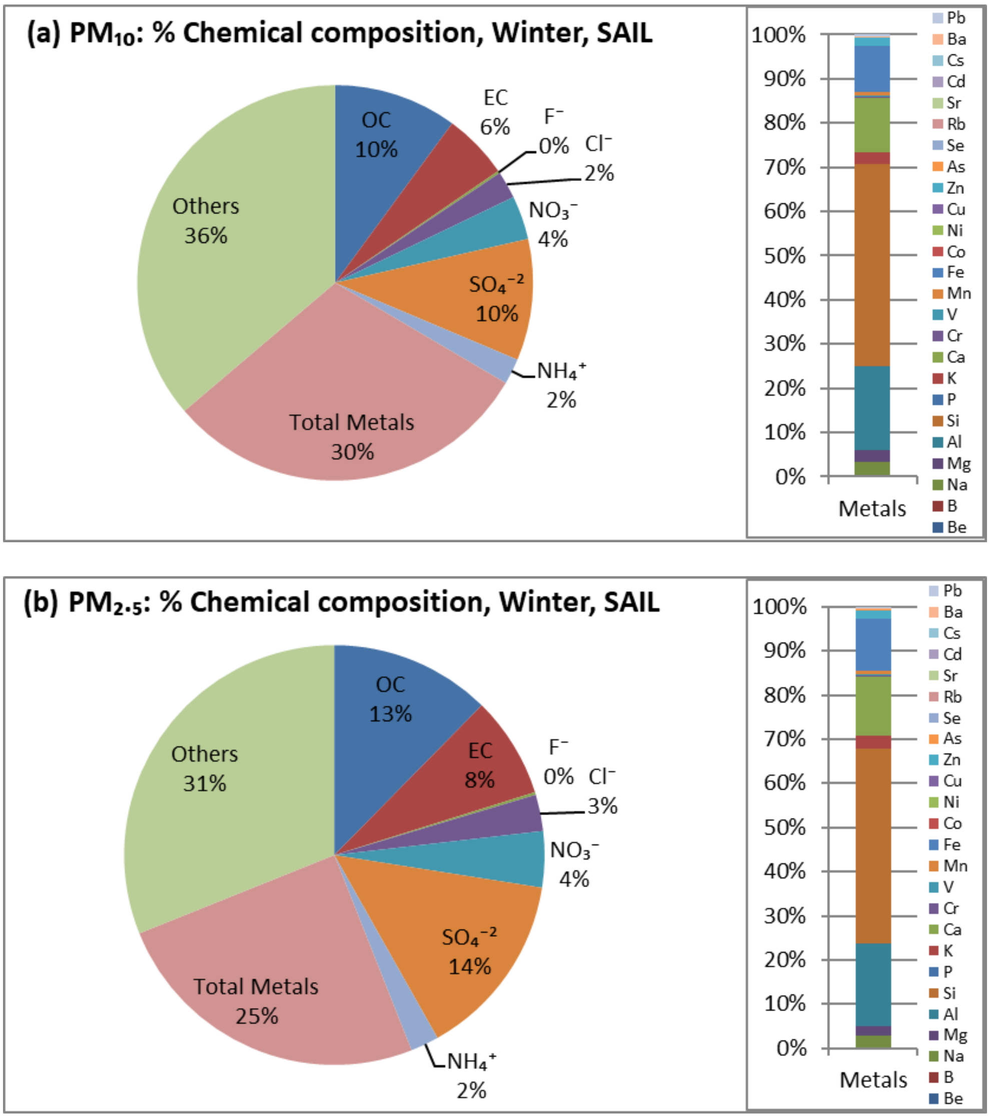


Figure 2.32: Percentage distribution of species in PM at SAIL for Winter Season

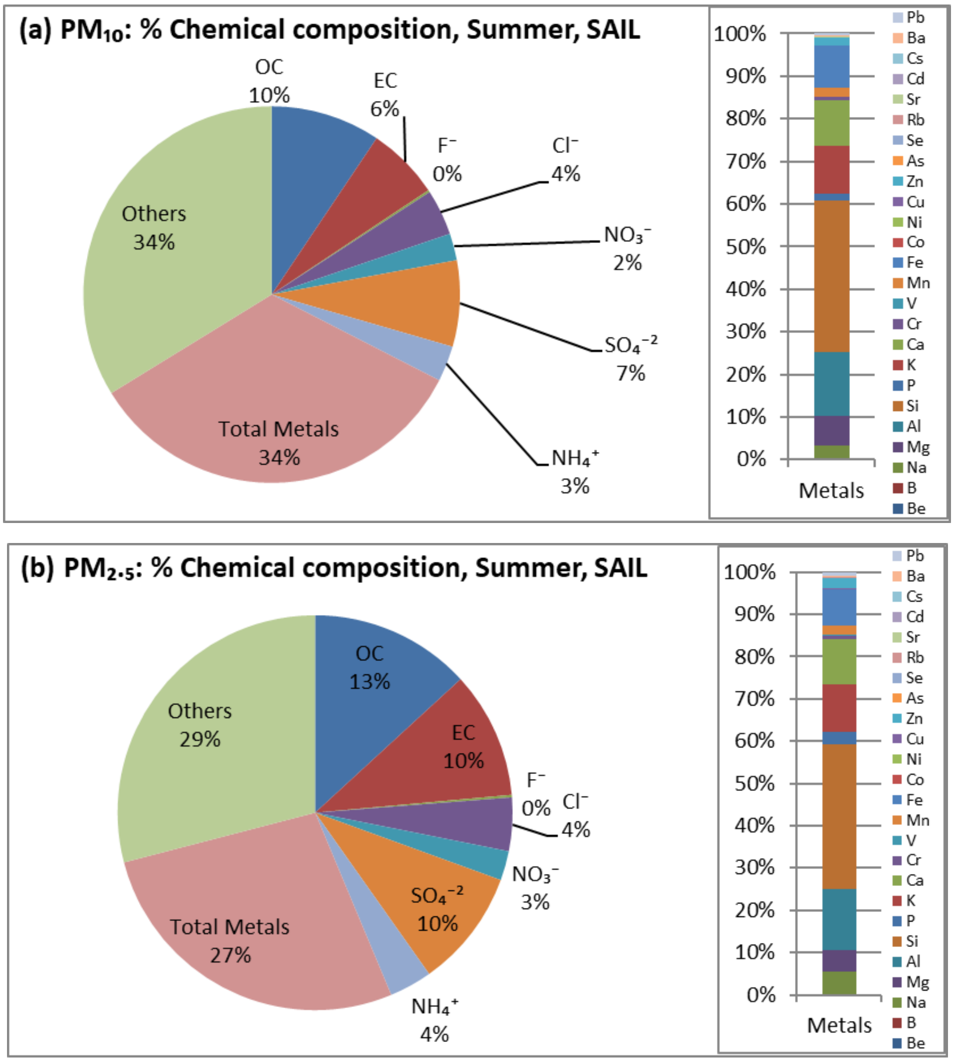
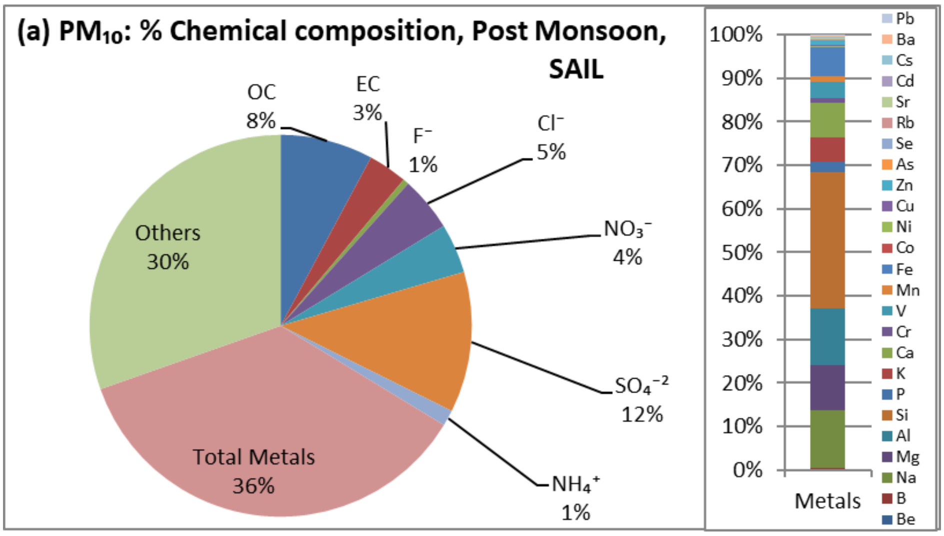


Figure 2.33: Percentage distribution of species in PM at SAIL for Summer Season



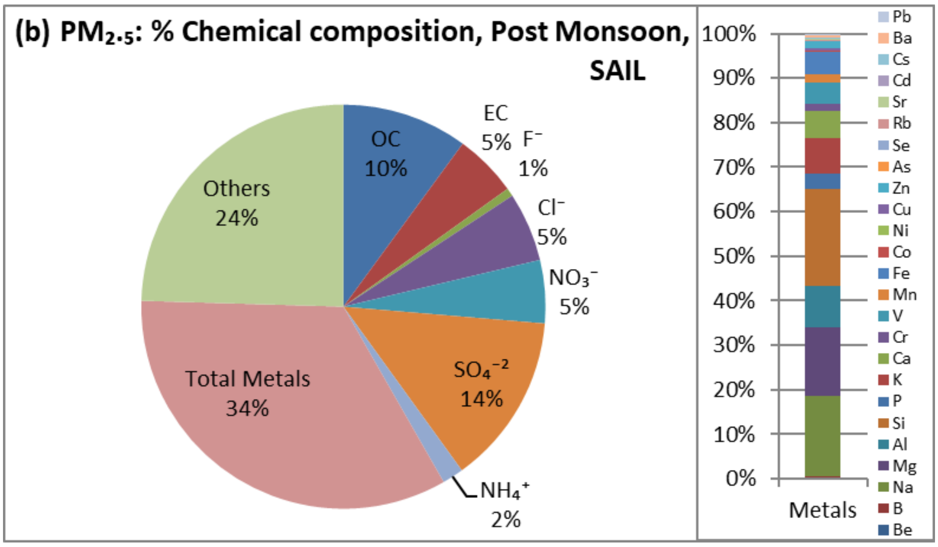


Figure 2.34: Percentage distribution of species in PM at SAIL for Post-monsoon Season

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, summer and post-monsoon seasons (Figure 2.35) at SAIL. 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 major portion of PM is having fine mode during winter (57%), summer (50%) and post-monsoon (55%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, K^+, Mg^{2+}, V, Zn and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Al, Si, Ca, Cr, Fe and Ni.

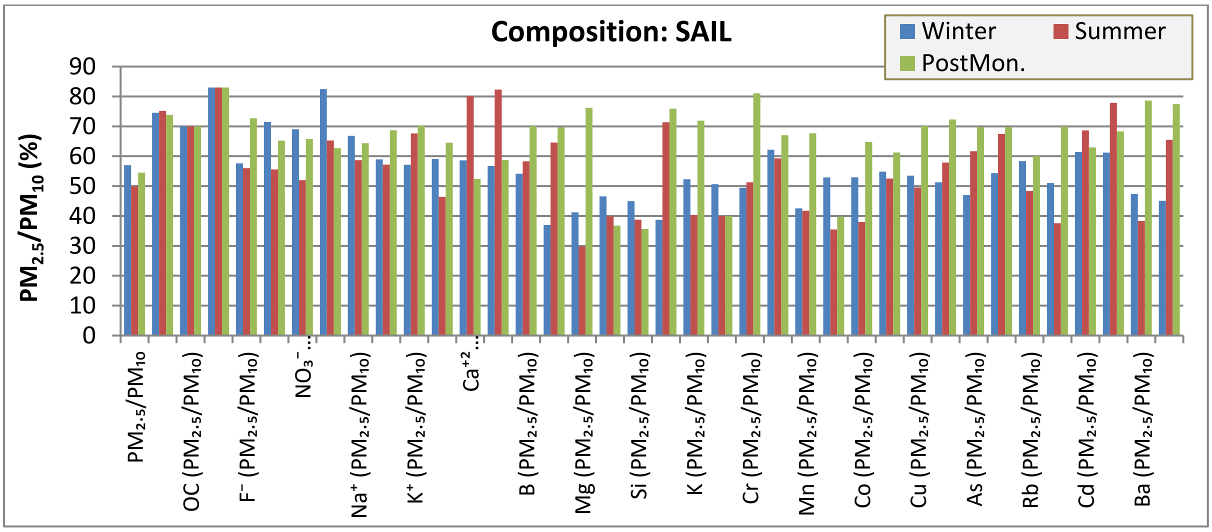


Figure 2.35: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at SAIL

Table 2.27: Statistical results of gaseous pollutants (μg/m^3) at SAIL for winter (W), summer (S) and post-monsoon (P) seasons

SAIL (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	40.59	17.26	3.77	0.12	0.72	2.43	7.04
SD	5.48	10.64	1.89	0.07	0.31	1.23	2.43
Max	49.83	43.62	5.57	0.19	1.16	4.56	9.94
Min	30.01	3.65	0.01	0.00	0.35	1.52	2.23
CV	0.13	0.62	0.50	0.55	0.43	0.51	0.35
SAIL (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	33.91	7.62	4.04	1.00	5.53	10.65	21.21
SD	6.87	6.79	0.19	0.06	0.63	1.41	2.14
Max	44.50	24.58	4.33	1.06	6.64	12.96	24.09
Min	19.78	2.00	3.78	0.92	5.00	9.28	19.09
CV	0.20	0.89	0.05	0.06	0.11	0.13	0.10
SAIL(P)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	8.21	2.00	2.53	0.64	4.91	6.73	14.80
SD	3.85	0.00	1.15	0.30	2.51	3.28	7.04
Max	19.21	2.00	3.30	0.87	7.32	9.77	21.12
Min	3.78	2.00	0.00	0.00	0.00	0.00	0.00
CV	0.47	0.00	0.46	0.48	0.51	0.49	0.48

Table 2.28: Statistical results of carbon contents (μg/m^3) in $PM_{2.5}$ at SAIL for winter (W), summer (S) and post-monsoon (P) seasons

SAIL(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	196.12	39.54	15.29	24.24	0.08	6.93	8.47	8.76	0.00	0.18	0.21	0.22
SD	31.56	6.38	3.42	3.53	0.05	1.62	1.70	1.13	0.00	0.02	0.02	0.04
Max	279.71	51.72	22.59	29.13	0.18	10.20	10.87	11.61	0.00	0.21	0.25	0.28
Min	160.00	28.83	9.24	18.69	0.02	4.95	6.01	7.03	0.00	0.15	0.17	0.16
CV	0.16	0.16	0.22	0.15	0.57	0.23	0.20	0.13	0.52	0.10	0.09	0.18
SAIL(S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	114.46	26.96	11.87	15.09	0.14	4.30	5.82	4.82	0.00	0.16	0.22	0.19
SD	22.76	5.06	3.13	2.50	0.29	1.00	1.29	0.79	0.01	0.01	0.02	0.05
Max	168.76	35.59	16.62	18.97	1.19	5.85	8.18	6.07	0.04	0.18	0.25	0.26
Min	83.10	17.73	6.72	11.01	0.01	2.62	3.80	3.58	0.00	0.14	0.17	0.12
CV	0.20	0.19	0.26	0.17	2.15	0.23	0.22	0.16	1.96	0.07	0.12	0.25
SAIL(P)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	27.62	4.17	1.39	2.78	0.02	0.83	1.18	0.75	0.00	0.21	0.30	0.18
SD	13.32	2.27	1.03	1.27	0.04	0.37	0.49	0.42	0.01	0.03	0.04	0.02
Max	64.17	9.46	3.72	5.73	0.12	1.74	2.32	1.78	0.03	0.30	0.37	0.21
Min	15.40	2.08	0.53	1.56	0.00	0.37	0.75	0.44	0.00	0.16	0.23	0.15
CV	0.48	0.55	0.74	0.46	1.72	0.45	0.42	0.55	1.97	0.16	0.15	0.08

Table 2.29: Statistical results of PAHs (ng/m^3) in PM$_{2.5}$ at SAIL for winter (W), summer (S) and post-monsoon (P) seasons

SAIL (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	2.22	0.26	0.62	0.06	1.53	0.12	3.12	0.07	0.36	3.38	6.50	11.02	3.41	5.16	4.43	0.48	5.07	47.82
SD	0.61	0.06	0.38	0.07	0.27	0.02	1.04	0.01	0.33	2.32	3.55	4.65	1.69	2.42	1.74	0.32	1.56	18.17
Max	3.22	0.33	1.23	0.17	1.89	0.14	4.72	0.07	0.94	6.60	11.22	16.18	5.54	7.97	6.81	0.96	7.16	68.62
Min	1.70	0.18	0.29	0.00	1.16	0.09	1.94	0.05	0.05	1.02	2.77	5.48	1.59	2.30	2.63	0.16	3.48	26.32
CV	0.27	0.25	0.60	1.04	0.18	0.15	0.33	0.13	0.91	0.69	0.55	0.42	0.50	0.47	0.39	0.67	0.31	0.38
SAIL (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	0.53	0.83	1.01	0.64	3.86	0.17	5.28	1.87	1.60	2.21	3.50	9.36	3.63	7.99	5.52	0.86	3.99	52.83
SD	0.39	0.25	1.06	0.30	0.80	0.06	2.92	1.38	1.26	1.40	2.03	3.49	2.91	6.00	5.32	0.97	1.78	21.81
Max	1.17	1.13	3.14	1.14	5.06	0.27	10.62	4.46	3.29	4.82	6.39	14.27	9.08	18.81	16.38	2.82	6.90	97.43
Min	0.20	0.55	0.05	0.30	2.52	0.06	2.68	0.49	0.09	0.51	1.03	3.52	0.83	1.53	0.81	0.07	1.88	28.49
CV	0.74	0.30	1.06	0.47	0.21	0.37	0.55	0.74	0.79	0.63	0.58	0.37	0.80	0.75	0.96	1.13	0.45	0.41
SAIL (P)	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	1.08	2.63	2.06	1.05	1.05	0.64	0.12	3.02	0.25	0.31	0.29	0.54	0.18	0.44	0.10	0.10	0.56	14.42
SD	0.40	0.63	1.10	0.60	1.20	0.52	0.07	1.79	0.24	0.12	0.15	0.18	0.05	0.15	0.08	0.05	0.15	2.83
Max	1.49	3.27	3.58	1.88	3.54	1.31	0.24	6.01	0.65	0.55	0.51	0.78	0.25	0.67	0.25	0.16	0.84	18.08
Min	0.42	1.67	0.63	0.31	0.09	0.07	0.03	0.82	0.00	0.20	0.14	0.27	0.13	0.29	0.01	0.04	0.39	8.83
CV	0.37	0.24	0.53	0.57	1.14	0.81	0.60	0.59	0.96	0.39	0.52	0.34	0.28	0.34	0.81	0.46	0.27	0.20

Table 2.30: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at SAIL for winter (W), summer (S) and post-monsoon (P) seasons

SAIL(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	7.57	24.85	15.27	13.91	18.31	9.55	89.46
SD	2.08	11.92	7.36	7.26	10.18	4.50	36.92
CV	0.28	0.48	0.48	0.52	0.56	0.47	0.41
SAIL(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	11.39	27.45	16.09	8.53	6.33	3.58	73.37
SD	5.71	9.42	4.55	5.50	1.59	2.36	20.93
CV	0.50	0.34	0.28	0.65	0.25	0.66	0.29
SAIL(P)	**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	7.37	10.75	14.24	16.11	4.52	1.07	54.07
SD	4.98	4.07	4.72	6.65	1.94	0.37	14.39
CV	0.68	0.38	0.33	0.41	0.43	0.34	0.27

Table 2.31: Statistical results of chemical characterization (µg/m^3) of PM_{10} at SAIL for winter (W) season

SAIL	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	344	34.63	18.43	0.69	7.69	12.29	34.14	8.20	7.24	1.89	1.01	3.79	0.01	0.18	3.39	2.59	19.78	47.70	0.21
SD	42	5.04	4.13	0.21	1.52	2.65	16.26	2.22	4.22	0.40	0.31	0.63	0.00	0.04	1.56	0.92	3.24	6.10	0.09
Max	431	41.61	27.22	1.17	10.70	17.17	68.38	12.22	16.76	2.62	1.72	5.40	0.02	0.25	7.84	3.89	23.85	56.09	0.39
Min	286	26.70	11.14	0.43	5.30	7.54	17.39	4.54	2.83	1.15	0.68	2.99	0.01	0.10	1.69	0.92	15.00	37.81	0.07
CV	0.12	0.15	0.22	0.31	0.20	0.22	0.48	0.27	0.58	0.21	0.30	0.17	0.27	0.23	0.46	0.36	0.16	0.13	0.43
SAIL	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.70	12.89	0.30	0.05	0.94	10.87	0.02	0.02	0.04	1.85	0.03	0.02	0.03	0.05	0.02	0.02	0.13	0.48	63.75
SD	0.63	2.21	0.15	0.01	0.44	1.84	0.01	0.01	0.02	1.01	0.01	0.01	0.01	0.02	0.01	0.01	0.08	0.23	2.49
Max	3.61	17.26	0.60	0.08	1.86	14.37	0.04	0.04	0.08	3.88	0.05	0.04	0.07	0.10	0.03	0.04	0.35	0.92	67.86
Min	1.62	10.15	0.09	0.03	0.35	8.01	0.01	0.01	0.02	0.39	0.01	0.01	0.02	0.03	0.01	0.01	0.04	0.16	59.00
CV	0.23	0.17	0.50	0.28	0.47	0.17	0.36	0.46	0.46	0.54	0.29	0.30	0.44	0.46	0.41	0.35	0.64	0.49	0.04

Table 2.32: Statistical results of chemical characterization (µg/m^3) of PM$_{2.5}$ at SAIL for winter (W) season

SAIL	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	196	24.24	15.29	0.40	5.49	8.48	28.15	5.48	4.26	1.08	0.60	2.22	0.01	0.10	1.26	1.07	9.21	21.46	0.08
SD	33	3.53	3.42	0.09	1.24	1.93	15.80	1.52	3.19	0.19	0.20	0.36	0.00	0.05	0.82	0.38	1.08	2.66	0.05
Max	280	29.13	22.59	0.64	7.15	11.48	64.15	8.63	11.83	1.67	1.17	3.15	0.01	0.20	3.59	1.63	11.19	25.86	0.20
Min	160	18.69	9.24	0.29	2.86	5.53	11.75	3.19	1.42	0.92	0.38	1.65	0.01	0.04	0.53	0.67	7.60	17.13	0.04
CV	0.17	0.15	0.22	0.23	0.23	0.23	0.56	0.28	0.75	0.17	0.33	0.16	0.06	0.52	0.65	0.35	0.12	0.12	0.56
SAIL	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.41	6.53	0.15	0.03	0.40	5.75	0.01	0.01	0.02	0.95	0.01	0.01	0.02	0.03	0.01	0.01	0.06	0.22	68.72
SD	0.29	0.97	0.05	0.01	0.14	0.84	0.00	0.00	0.01	0.57	0.00	0.00	0.00	0.01	0.00	0.00	0.03	0.11	2.78
Max	2.20	8.23	0.27	0.05	0.69	7.05	0.01	0.02	0.04	2.55	0.02	0.02	0.03	0.05	0.01	0.02	0.13	0.42	73.39
Min	1.12	4.81	0.07	0.02	0.22	4.38	0.01	0.01	0.01	0.32	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.09	63.53
CV	0.21	0.15	0.36	0.23	0.34	0.15	0.09	0.29	0.36	0.60	0.18	0.13	0.20	0.25	0.12	0.06	0.50	0.51	0.04

Table 2.33: Statistical results chemical characterization (µg/m^3) of PM$_{10}$ at SAIL for summer (S) season

SAIL	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	229	21.55	14.31	0.43	9.00	5.29	16.95	1.96	6.99	2.18	0.68	5.00	0.02	0.11	2.49	5.36	11.40	27.50	1.30
SD	54	3.57	3.78	0.17	2.67	1.83	5.40	0.47	2.17	0.56	0.31	2.07	0.00	0.05	0.52	1.88	4.09	10.30	0.84
Max	306	27.11	20.02	0.81	13.61	9.23	30.67	2.55	10.81	3.26	1.24	8.13	0.03	0.26	3.58	8.79	17.28	46.14	3.51
Min	146	15.73	8.09	0.16	4.52	2.90	9.54	1.03	3.10	1.29	0.16	1.33	0.01	0.07	1.60	1.45	4.60	11.02	0.63
CV	0.24	0.17	0.26	0.39	0.30	0.35	0.32	0.24	0.31	0.26	0.46	0.41	0.19	0.47	0.21	0.35	0.36	0.37	0.65
SAIL	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	8.65	8.35	0.54	0.06	1.64	7.57	0.01	0.03	0.07	1.35	0.01	0.02	0.05	0.08	0.02	0.01	0.18	0.43	66.87
SD	3.12	3.22	0.17	0.01	0.75	3.16	0.00	0.01	0.03	0.52	0.00	0.00	0.01	0.03	0.01	0.00	0.07	0.34	3.67
Max	15.51	12.88	0.98	0.08	3.53	12.08	0.02	0.06	0.13	2.45	0.02	0.02	0.06	0.13	0.05	0.01	0.29	1.06	73.27
Min	3.12	3.03	0.29	0.04	0.58	2.57	0.00	0.01	0.03	0.59	0.00	0.01	0.02	0.03	0.01	0.01	0.03	0.06	61.15
CV	0.36	0.39	0.31	0.17	0.46	0.42	0.30	0.49	0.46	0.39	0.57	0.24	0.23	0.33	0.72	0.15	0.40	0.79	0.05

Table 2.34: Statistical results of chemical characterization ($\mu g/m^3$) of $PM_{2.5}$ at SAIL for summer (S) season

SAIL	$PM_{2.5}$	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	114	15.09	11.87	0.24	5.00	2.75	11.07	1.15	4.00	1.47	0.32	4.01	0.01	0.06	1.61	1.59	4.54	10.66	0.93
SD	23	2.50	3.13	0.07	1.72	1.27	4.80	0.34	1.36	0.50	0.17	1.66	0.00	0.03	0.36	0.57	1.22	2.84	0.62
Max	169	18.97	16.62	0.36	8.57	5.02	24.13	1.94	6.69	2.39	0.73	6.54	0.02	0.13	2.23	2.99	7.08	16.84	2.60
Min	83	11.01	6.72	0.08	2.16	0.96	6.44	0.67	2.01	0.70	0.08	0.90	0.01	0.01	0.86	0.70	2.87	6.86	0.47
CV	0.20	0.17	0.26	0.30	0.34	0.46	0.43	0.30	0.34	0.34	0.53	0.41	0.18	0.48	0.23	0.36	0.27	0.27	0.67
SAIL	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.49	3.34	0.28	0.04	0.68	2.69	0.00	0.01	0.03	0.78	0.01	0.01	0.02	0.03	0.01	0.01	0.07	0.28	71.10
SD	0.89	1.21	0.09	0.01	0.37	0.85	0.00	0.01	0.01	0.37	0.00	0.00	0.01	0.01	0.01	0.00	0.03	0.23	2.03
Max	4.92	6.07	0.49	0.05	1.74	4.68	0.01	0.03	0.06	1.50	0.01	0.02	0.04	0.06	0.04	0.01	0.15	0.83	73.80
Min	1.89	2.05	0.17	0.02	0.17	1.68	0.00	0.00	0.02	0.22	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.05	66.82
CV	0.26	0.36	0.31	0.24	0.54	0.32	0.25	0.48	0.42	0.48	0.73	0.36	0.34	0.48	0.84	0.17	0.47	0.83	0.03

Table 2.35: Statistical results chemical characterization ($\mu g/m^3$) of PM_{10} at SAIL for post-monsoon (P) season

SAIL	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	51	3.97	1.67	0.25	2.34	2.12	6.04	1.17	0.68	0.40	0.25	0.59	0.04	0.03	2.44	1.86	2.36	5.74	0.41
SD	30	1.82	1.24	0.13	1.02	0.85	4.83	0.59	0.53	0.36	0.15	0.21	0.01	0.01	1.07	1.55	1.76	4.16	0.26
Max	139	8.19	4.49	0.67	4.93	4.77	20.45	1.92	2.13	1.47	0.65	0.99	0.06	0.06	3.94	6.21	7.36	16.90	0.98
Min	28	2.22	0.64	0.15	1.29	1.27	1.03	0.33	0.07	0.10	0.11	0.35	0.03	0.02	0.55	0.27	1.00	2.40	0.14
CV	0.60	0.46	0.74	0.51	0.44	0.40	0.80	0.50	0.77	0.91	0.58	0.36	0.24	0.45	0.44	0.84	0.75	0.72	0.62
SAIL	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.02	1.46	0.16	0.68	0.23	1.20	0.03	0.03	0.04	0.21	0.01	0.00	0.05	0.03	0.00	0.02	0.06	0.06	70.46
SD	0.81	0.94	0.18	0.17	0.28	0.70	0.01	0.02	0.03	0.21	0.01	0.00	0.01	0.02	0.00	0.01	0.08	0.06	3.76
Max	3.27	4.34	0.47	0.99	0.96	3.25	0.04	0.09	0.12	0.89	0.03	0.01	0.08	0.08	0.01	0.04	0.27	0.19	80.60
Min	0.35	0.67	0.01	0.46	0.04	0.56	0.02	0.02	0.02	0.03	0.00	0.00	0.04	0.01	0.00	0.02	0.00	0.01	65.72
CV	0.80	0.64	1.09	0.26	1.18	0.58	0.28	0.51	0.65	1.02	0.87	0.79	0.26	0.62	0.30	0.31	1.46	1.02	0.05

Table 2.36: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at SAIL for post-monsoon (P) season

SAIL	$PM_{2.5}$	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	28	2.78	1.39	0.18	1.53	1.40	3.78	0.76	0.47	0.28	0.16	0.31	0.02	0.02	1.70	1.41	0.87	2.05	0.31
SD	13	1.27	1.03	0.11	0.61	0.75	2.49	0.52	0.43	0.23	0.13	0.10	0.01	0.01	1.00	1.34	0.39	0.96	0.25
Max	64	5.73	3.72	0.56	2.87	3.92	8.99	1.84	1.72	0.95	0.60	0.55	0.04	0.05	3.25	4.75	1.95	4.80	0.86
Min	15	1.56	0.53	0.11	0.88	0.87	0.43	0.16	0.03	0.06	0.05	0.17	0.01	0.01	0.29	0.18	0.47	1.14	0.09
CV	0.48	0.46	0.74	0.61	0.40	0.54	0.66	0.69	0.91	0.82	0.82	0.33	0.30	0.57	0.59	0.95	0.45	0.47	0.79
SAIL	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.73	0.58	0.13	0.45	0.16	0.48	0.02	0.02	0.03	0.15	0.01	0.00	0.03	0.02	0.00	0.02	0.04	0.04	74.96
SD	0.68	0.26	0.16	0.21	0.18	0.19	0.01	0.01	0.02	0.16	0.01	0.00	0.01	0.02	0.00	0.01	0.06	0.05	2.85
Max	2.56	1.28	0.45	0.89	0.72	0.96	0.03	0.07	0.08	0.66	0.02	0.01	0.06	0.08	0.01	0.04	0.19	0.18	81.60
Min	0.23	0.31	0.00	0.20	0.02	0.26	0.01	0.01	0.01	0.02	0.00	0.00	0.02	0.01	0.00	0.01	0.00	0.00	70.41
CV	0.92	0.45	1.21	0.46	1.16	0.40	0.49	0.75	0.83	1.10	0.84	0.97	0.37	0.90	0.45	0.48	1.45	1.18	0.04

Table 2.37: Correlation Matrix for PM_{10} and its composition at SAIL for winter season

SAIL (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	0.27	0.05	0.48	0.66	0.34	0.50	0.66	-0.04	0.61	0.32	0.24	0.37	0.81
TC		1.00	0.93	0.90	-0.32	0.55	0.14	-0.16	-0.36	-0.02	0.24	-0.40	-0.24	0.10
OC			1.00	0.69	-0.37	0.44	0.01	-0.33	-0.35	-0.19	0.27	-0.40	-0.15	-0.04
EC				1.00	-0.21	0.59	0.27	0.09	-0.30	0.18	0.17	-0.34	-0.30	0.25
NO_3^-					0.24	0.36	1.00	0.36	-0.09	0.39	-0.25	0.32	0.15	0.39
SO_4^{-2}					0.64	-0.01		1.00	-0.15	0.83	-0.05	-0.07	0.19	0.26
NH_4^+					0.60	0.16			-0.22	1.00	-0.24	-0.15	0.31	0.19
Metals					0.59	0.29			0.23		0.45	0.61	0.41	1.00

Table 2.38: Correlation matrix for $PM_{2.5}$ and its composition at SAIL for winter season

SAIL (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	0.46	0.21	0.64	0.67	0.44	0.63	0.83	-0.12	0.84	0.11	-0.06	0.47	0.77
TC		1.00	0.92	0.92	0.04	0.33	0.69	0.01	-0.35	0.03	-0.02	-0.36	-0.04	0.48
OC			1.00	0.69	-0.05	0.18	0.56	-0.21	-0.39	-0.19	-0.01	-0.35	-0.05	0.25
EC				1.00	0.13	0.42	0.71	0.23	-0.26	0.26	-0.02	-0.31	-0.02	0.63
NO_3^-					0.20	0.54	1.00	0.34	-0.32	0.41	0.23	-0.27	-0.15	0.59
SO_4^{-2}					0.52	0.26		1.00	-0.05	0.98	0.01	-0.08	0.51	0.41
NH_4^+					0.56	0.21			-0.09	1.00	0.02	0.00	0.51	0.47
Metals					0.65	0.46			-0.11		0.38	0.20	0.27	1.00

Table 2.39: Correlation matrix for PM_{10} and its composition at SAIL for summer season

SAIL (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	0.63	0.38	0.74	0.85	0.50	-0.19	0.52	0.56	0.46	0.79	0.91	0.86	0.99
TC		1.00	0.89	0.90	0.20	0.38	-0.20	0.11	0.11	0.34	0.45	0.54	0.33	0.58
OC			1.00	0.61	-0.09	0.39	-0.17	-0.17	-0.06	0.12	0.27	0.35	0.14	0.33
EC				1.00	0.43	0.30	-0.19	0.35	0.25	0.48	0.53	0.61	0.43	0.70
NO_3^-					-0.21	-0.23	1.00	-0.10	0.33	0.27	0.08	-0.34	-0.16	-0.14
SO_4^{-2}					0.72	-0.09		1.00	0.25	0.32	0.57	0.43	0.49	0.48
NH_4^+					0.39	0.06			0.74	1.00	0.43	0.37	0.54	0.40
Metals					0.84	0.48			0.53		0.77	0.89	0.85	1.00

Table 2.40: Correlation matrix for $PM_{2.5}$ and its composition at SAIL for summer season

SAIL (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	0.76	0.46	0.85	0.45	0.33	0.04	0.64	0.23	0.67	0.64	0.53	0.66	0.98
TC		1.00	0.87	0.92	0.17	0.26	0.04	0.13	0.03	0.36	0.30	0.33	0.27	0.70
OC			1.00	0.61	0.01	0.20	0.07	-0.13	-0.10	0.03	0.08	0.25	0.07	0.38
EC				1.00	0.26	0.26	0.00	0.31	0.13	0.56	0.42	0.32	0.38	0.83
NO_3^-					-0.10	-0.35	1.00	0.18	-0.02	0.15	0.25	-0.38	-0.20	-0.04
SO_4^{-2}					0.42	0.01		1.00	0.20	0.48	0.81	0.24	0.44	0.63
NH_4^+					0.40	0.05			0.61	1.00	0.51	0.20	0.59	0.66
Metals					0.40	0.28			0.24		0.57	0.50	0.64	1.00

Table 2.41: Correlation matrix for PM_{10} and its composition at SAIL for post-monsoon season

SAIL(P)	PM_{10}	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	0.86	0.88	0.77	0.66	0.86	0.96	0.16	0.29	0.84	0.89	-0.39	0.99
TC		1.00	0.99	0.98	0.64	0.46	0.74	0.76	0.00	0.20	0.86	0.73	-0.47	0.83
OC			1.00	0.95	0.65	0.45	0.75	0.73	0.03	0.19	0.83	0.74	-0.46	0.81
EC				1.00	0.61	0.46	0.70	0.79	-0.04	0.21	0.88	0.69	-0.45	0.83
NO_3^-					0.92	0.65	1.00	0.83	0.15	0.49	0.63	0.86	-0.20	0.86
SO_4^{-2}					0.73	0.64		1.00	0.09	0.42	0.72	0.84	-0.32	0.96
NH_4^+					0.33	0.24			-0.18	1.00	0.10	0.18	-0.01	0.26
Metals					0.76	0.66			0.26		0.82	0.91	-0.37	1.00

Table 2.42: Correlation matrix for $PM_{2.5}$ and its composition at SAIL for post-monsoon season

SAIL (P)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.84	0.82	0.85	0.73	0.53	0.90	0.93	0.21	0.42	0.77	0.89	0.10	0.98
TC		1.00	0.99	0.99	0.73	0.33	0.76	0.70	-0.11	0.15	0.82	0.81	-0.02	0.76
OC			1.00	0.95	0.74	0.33	0.77	0.65	-0.11	0.12	0.79	0.80	0.04	0.74
EC				1.00	0.70	0.33	0.73	0.74	-0.10	0.18	0.85	0.80	-0.10	0.76
NO_3^-					0.88	0.63	1.00	0.73	0.01	0.40	0.61	0.93	0.04	0.87
SO_4^{-2}					0.50	0.38		1.00	0.32	0.52	0.74	0.73	0.18	0.92
NH_4^+					0.24	0.37			-0.14	1.00	0.09	0.25	0.36	0.35
Metals					0.69	0.52			0.35		0.73	0.87	0.09	1.00

2.4.3 Engineering Park Hathkhoj (ENPH)

The sampling period was January 11- 25, 2021 for winter, March 22, 2021- April 05, 2021, for summer and September 26, 2021 - October 10, 2021, for post-monsoon.

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

Time series of 24-hour average concentrations of PM_{10} and $PM_{2.5}$ at ENPH is shown for winter (Figure 2.36), summer (Figure 2.37) and post-monsoon (Figure 2.38). Average levels at this site were: $PM_{2.5}$: 151±34 (winter), 119±21 µg/m^3 (summer) and 67±31 µg/m^3 (post-monsoon) and PM_{10}: 295±75 (winter), 240±63 µg/m^3 (summer) and 127±58 µg/m^3 (post-monsoon). In winter, the $PM_{2.5}$ levels were about 2.5 times higher than the NAAQS (60 µg/m^3) and PM_{10} levels were 3 times higher than the NAAQS (100 µg/m^3). In summer, the $PM_{2.5}$ levels were 1.98 times NAAQS while PM_{10} is 2.40 times higher than the NAAQS. In post-monsoon, both the $PM_{2.5}$ and PM_{10} levels were 1.2 times higher than the NAAQS.

A statistical summary of PM concentrations is presented in Table 2.47 - Table 2.52 for the winter, and summer seasons. In summer $PM_{2.5}$ and PM_{10} are quite high and above NAAQS despite improvement in meteorology and better dispersion. The particles airborne from soil during dust storms in the dry months of summer can contribute significantly to coarse fraction (i.e., $PM_{2.5-10}$). In post-monsoon, $PM_{2.5}$ levels dropped below NAAQS whereas PM_{10} levels were higher than standards.

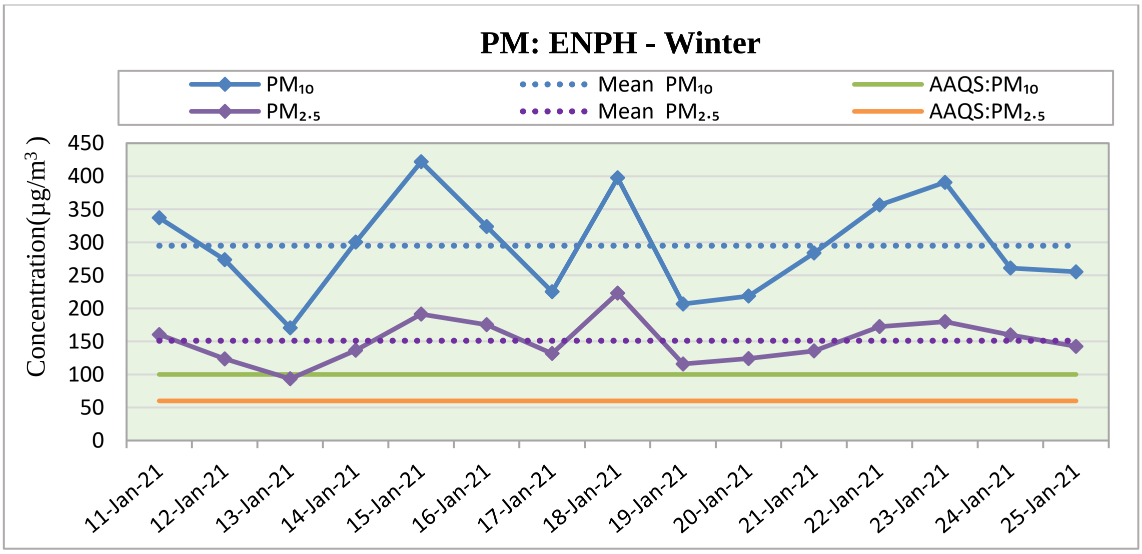


Figure 2.36: PM Concentrations at ENPH for Winter Season

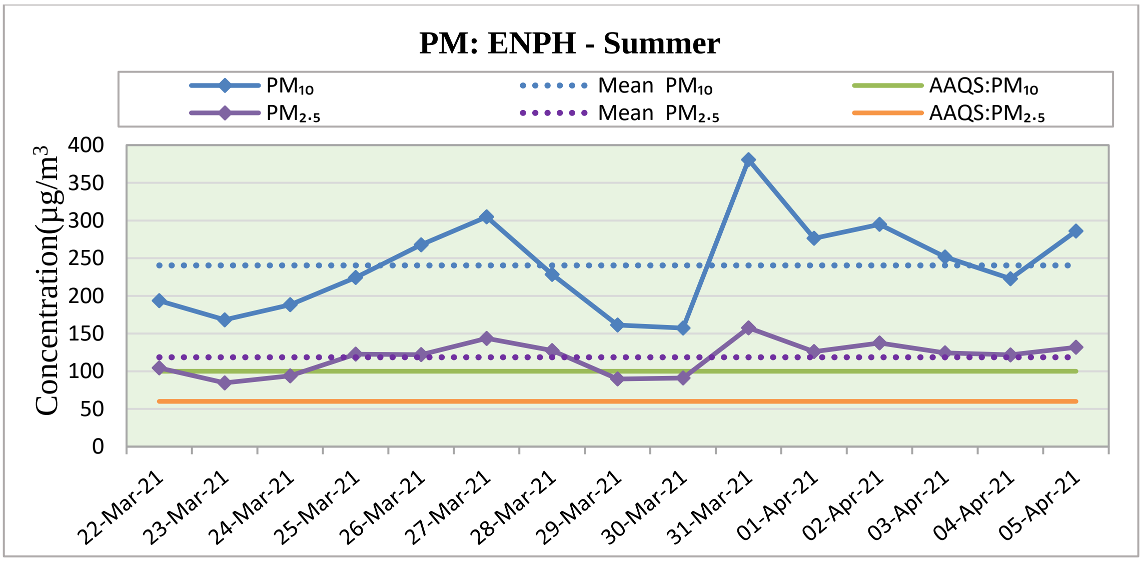


Figure 2.37: PM Concentrations at ENPH for Summer Season

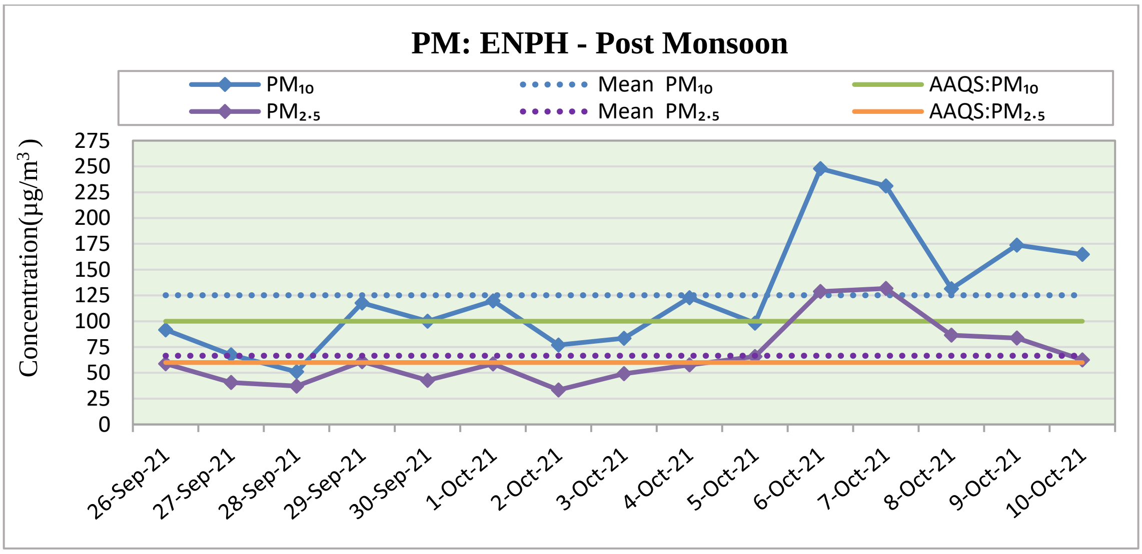


Figure 2.38: PM Concentrations at ENPH for Post-monsoon Season

2.4.3.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.39), summer (Figure 2.40) and post-monsoon (Figure 2.41) seasons. It was observed that SO_2 concentrations meet the air quality standard with an average of 20±8 µg/m^3 in winter, 10±7 µg/m^3 in summer and 3±2 µg/m^3 in post-monsoon. NO_2 levels were also under the national standard with an average of 32±8 µg/m^3 in winter, 24±4 µg/m^3 in summer and 18±6 µg/m^3 in post-monsoon seasons (Table 2.43). The summer and post-monsoon levels of NO_2 dropped similarly to $PM_{2.5}$ levels. The NO_2 is a matter of concern and these values can largely be attributed to vehicular, DG sets and industrial coal combustion pollution. Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams coal combustion etc.

The Mean concentrations of BTX are presented in Figure 2.42 and the statistical summary is in Table 2.43. The total BTX level is observed 11±6 µg/m^3 (Benzene: 7.4 and Toluene: 0.13 µg/m^3) in winter, 23±2 µg/m^3 (Benzene: 4, Toluene: 1.0, p-xylene: 6.0 and o-xylene: 12.0 µg/m^3) in summer and 17±5 µg/m^3 (Benzene: 3.6, Toluene: 0.92, p-xylene: 5 and o-xylene: 7 µg/m^3) in post-monsoon seasons. The maximum BTX concentration was observed at 21 µg/m^3 in winter, 25 µg/m^3 in summer and 27 µg/m^3 in post-monsoon seasons.

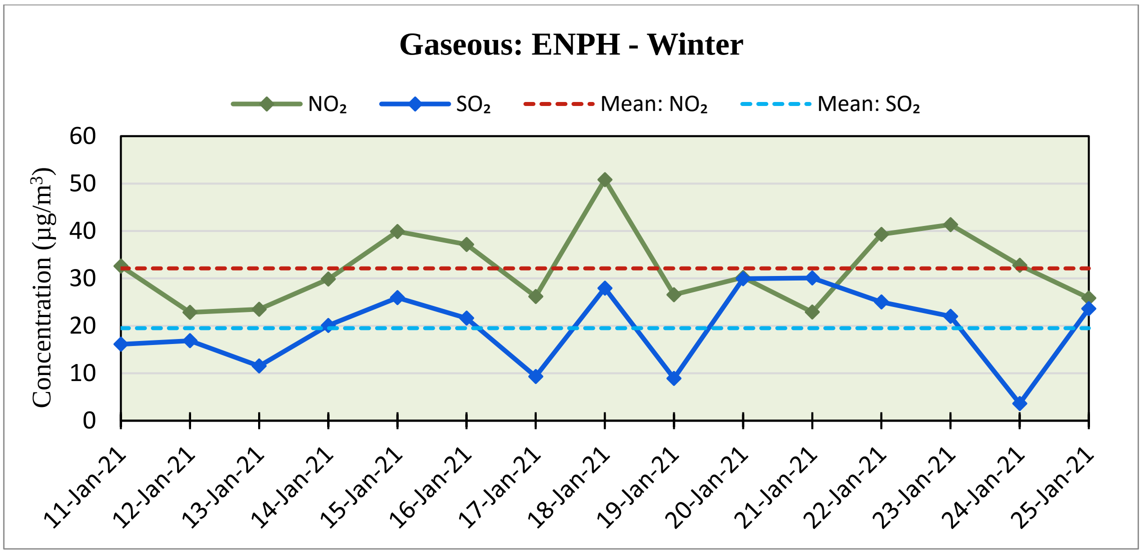


Figure 2.39: SO_2 and NO_2 Concentrations at ENPH for Winter Season

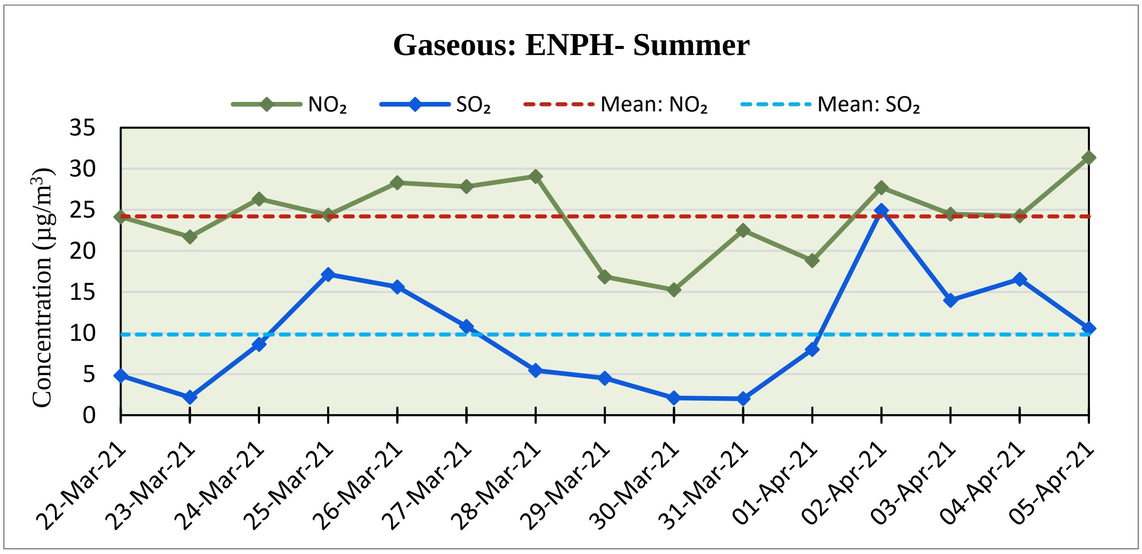


Figure 2.40: SO_2 and NO_2 Concentrations at ENPH for Summer Season

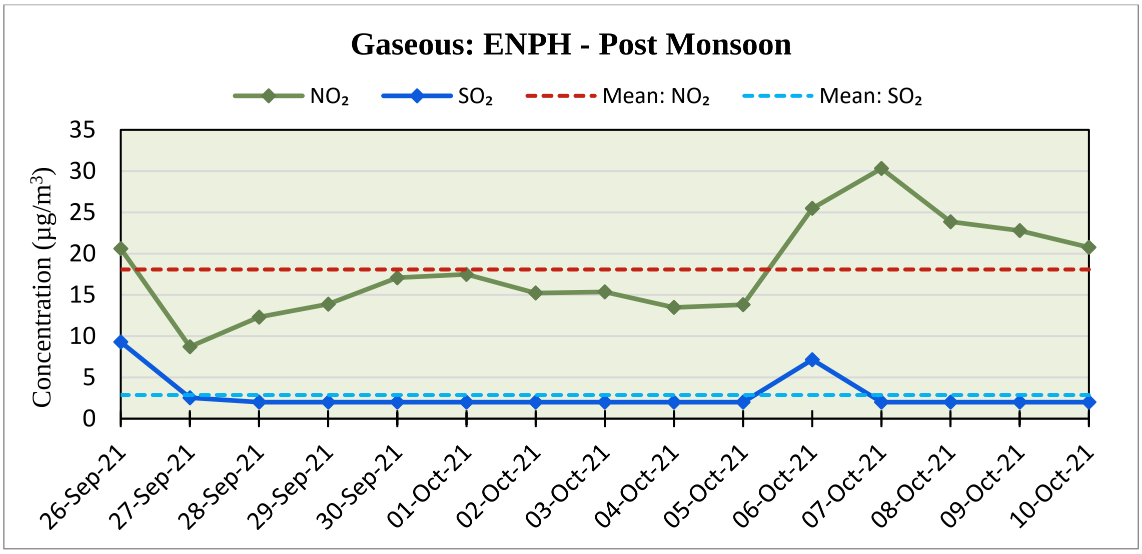


Figure 2.41: SO_2 and NO_2 Concentrations at ENPH for Post-monsoon Season

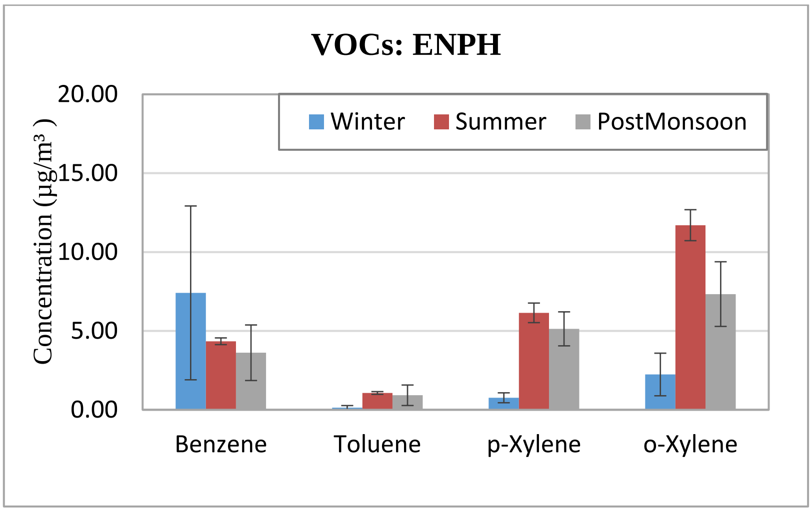


Figure 2.42: VOCs concentration at ENPH

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 2.27 (a) and (b) for winter, summer, and post-monsoon seasons. Organic carbon is observed slightly higher (winter: 20.91±4.99, summer: 15.31±2.46 and post-monsoon: 6.51±4.70 µg/m^3) than the elemental carbon (winter: 13.20±4.64 summer: 14.05±4.08 and post-monsoon: 4.91±1.90 µg/m^3). However, the ratio of OC3/TC is observed higher indicating the formation of secondary organic carbon in the atmosphere. It is also observed that the OC levels are higher in winter than in other seasons and EC levels are higher in summer than in other seasons. 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 2.44 for winter, summer and post-monsoon seasons.

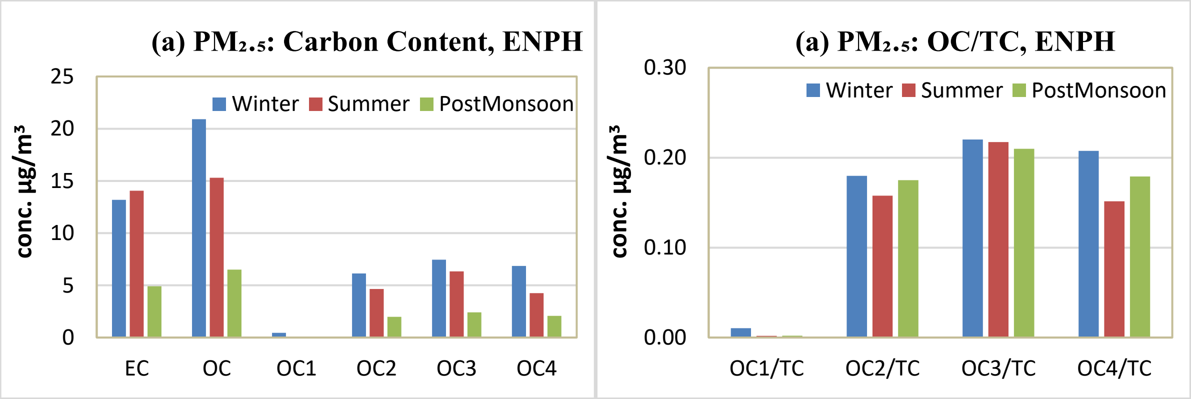


Figure 2.43: EC and OC Content in $PM_{2.5}$ at ENPH

2.4.3.4 PAHs in $PM_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.44 shows the average measured concentration of PAHs at ENPH for winter, summer and post-monsoon seasons. A statistical summary of PAHs is presented in Table 2.45 for winter, summer, and post-monsoon 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 PAH concentrations in winter were 58±22 ng/m^3, in summer: 45±26 ng/m^3 and in post-monsoon: 44±18 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are B(b)F (12 ng/m^3), B(ghi)P (7.75 ng/m^3), BaP (6 ng/m^3) and Chr (8 ng/m^3) for winter season and B(b)F (12 ng/m^3), BaP (12 ng/m^3), Chr (6 ng/m^3), B(ghi)P (6 ng/m^3), AcP (1 ng/m^3) for summer season. For post-monsoon Phe (4 ng/m^3), Ant (4 ng/m^3), Chr (2 ng/m^3) AcP (5 ng/m^3), B(b)F (9 ng/m^3) and BaP (5 ng/m^3).

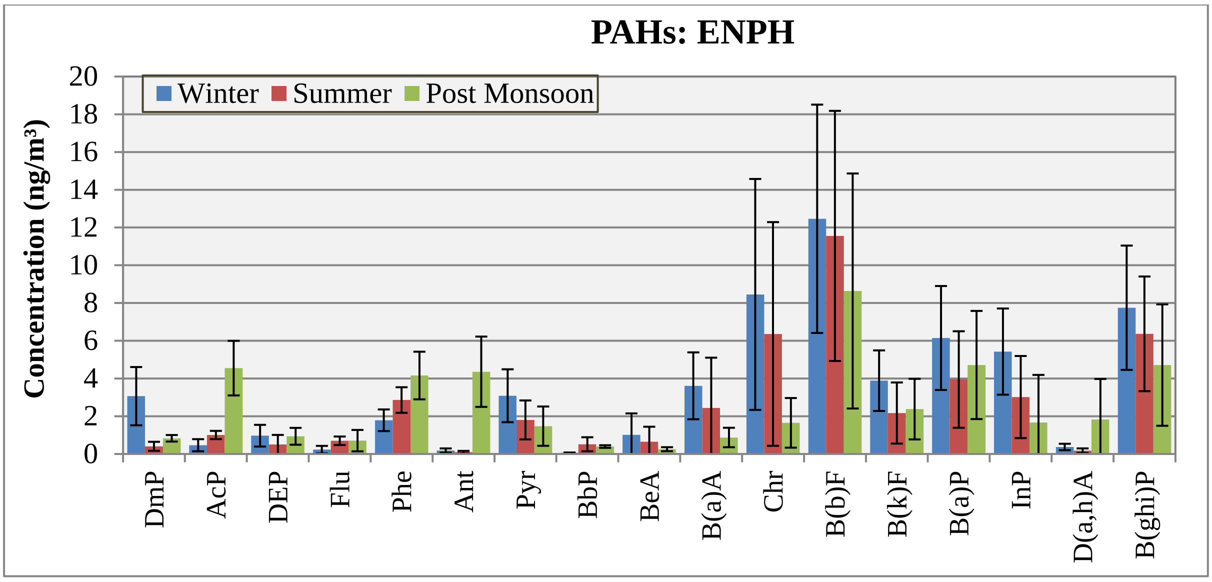


Figure 2.44: PAHs Concentrations in $PM_{2.5}$ at ENPH

2.4.3.5 Molecular Markers in $PM_{2.5}$

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

Figure 2.45 and Table 2.46 show the levels of six molecular markers. The total concentration of markers was 116.53±31.40 ng/m^3 in winter, 69.543±5.46 ng/m^3 in summer and 45.52±38.85 ng/m^3 in post-monsoon. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

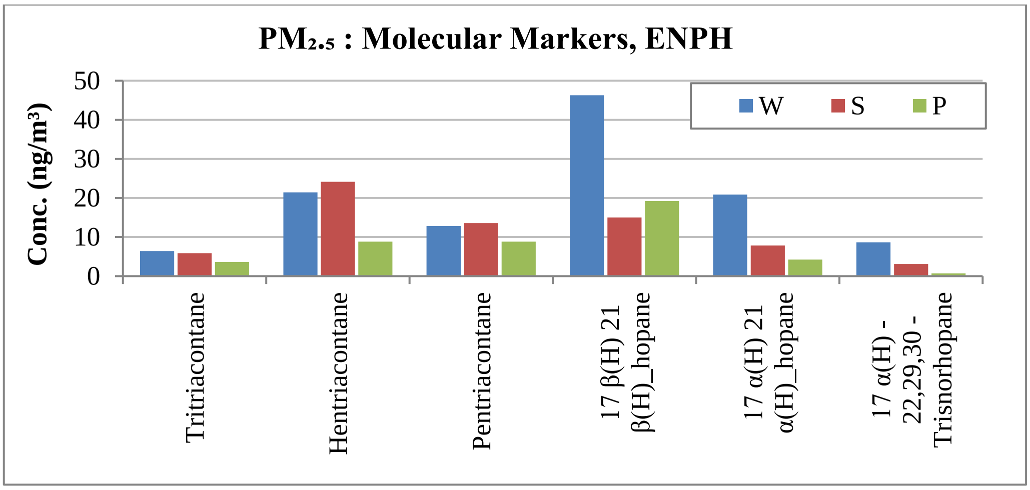


Figure 2.45: Molecular Markers in $PM_{2.5}$ at ENPH

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 winter, summer and post-monsoon seasons for PM_{10} (Figure 2.46) and $PM_{2.5}$ (Figure 2.47). 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 2.47 - Table 2.52 for winter, summer and post-monsoon seasons.

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 2.53 - Table 2.58 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 constituent of the PM is presented in Figure 2.48(a) and (b) for winter, Figure 2.49 (a) and (b) for summer and Figure 2.50 (a) and (b) for post-monsoon seasons.

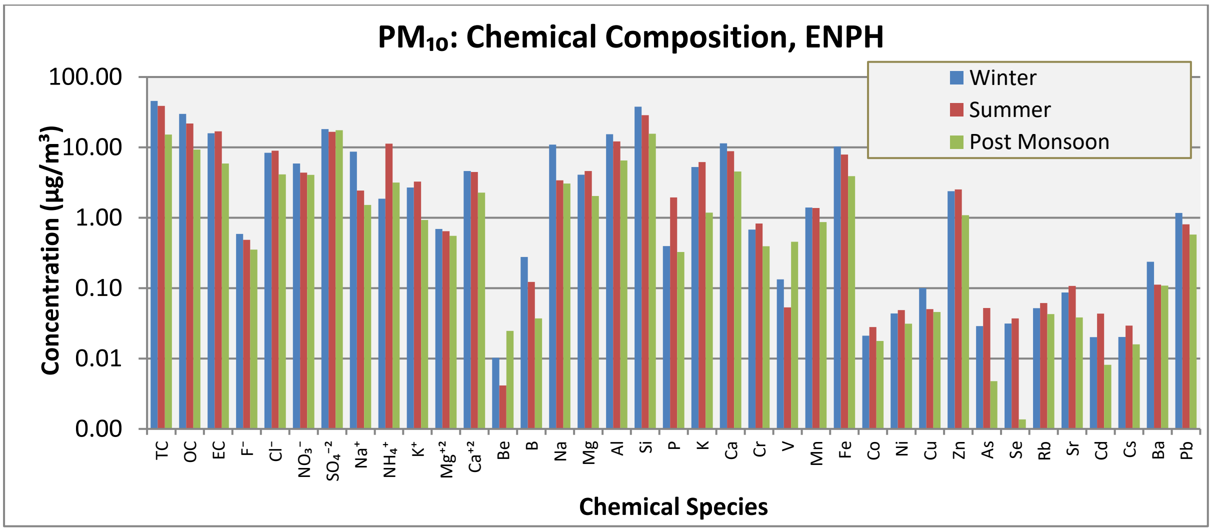


Figure 2.46: Concentrations of species in PM_{10} at ENPH

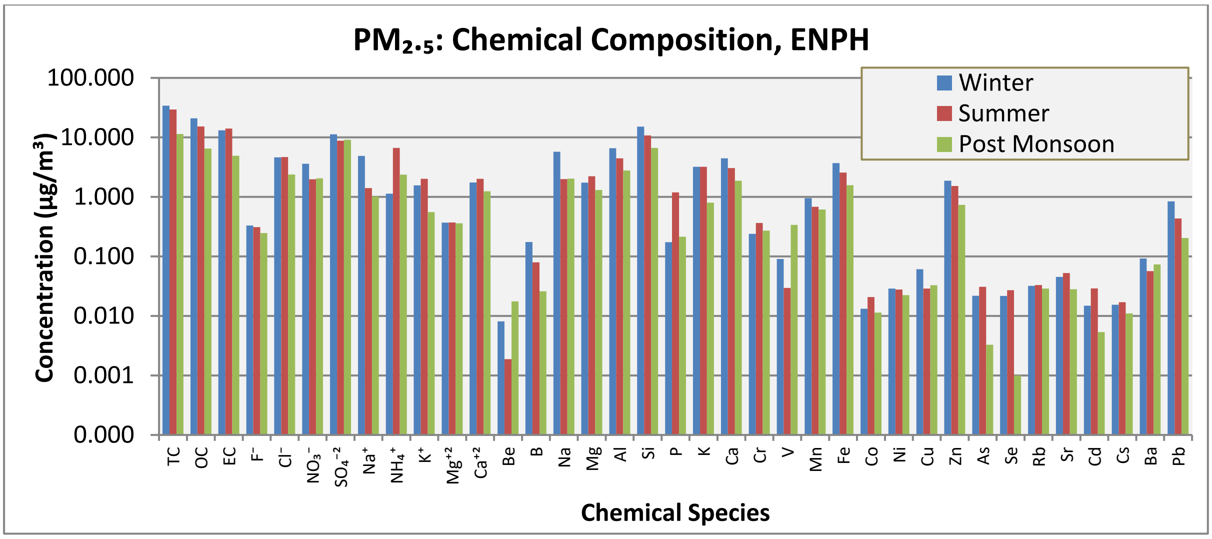


Figure 2.47: Concentrations of species in $PM_{2.5}$ at ENPH

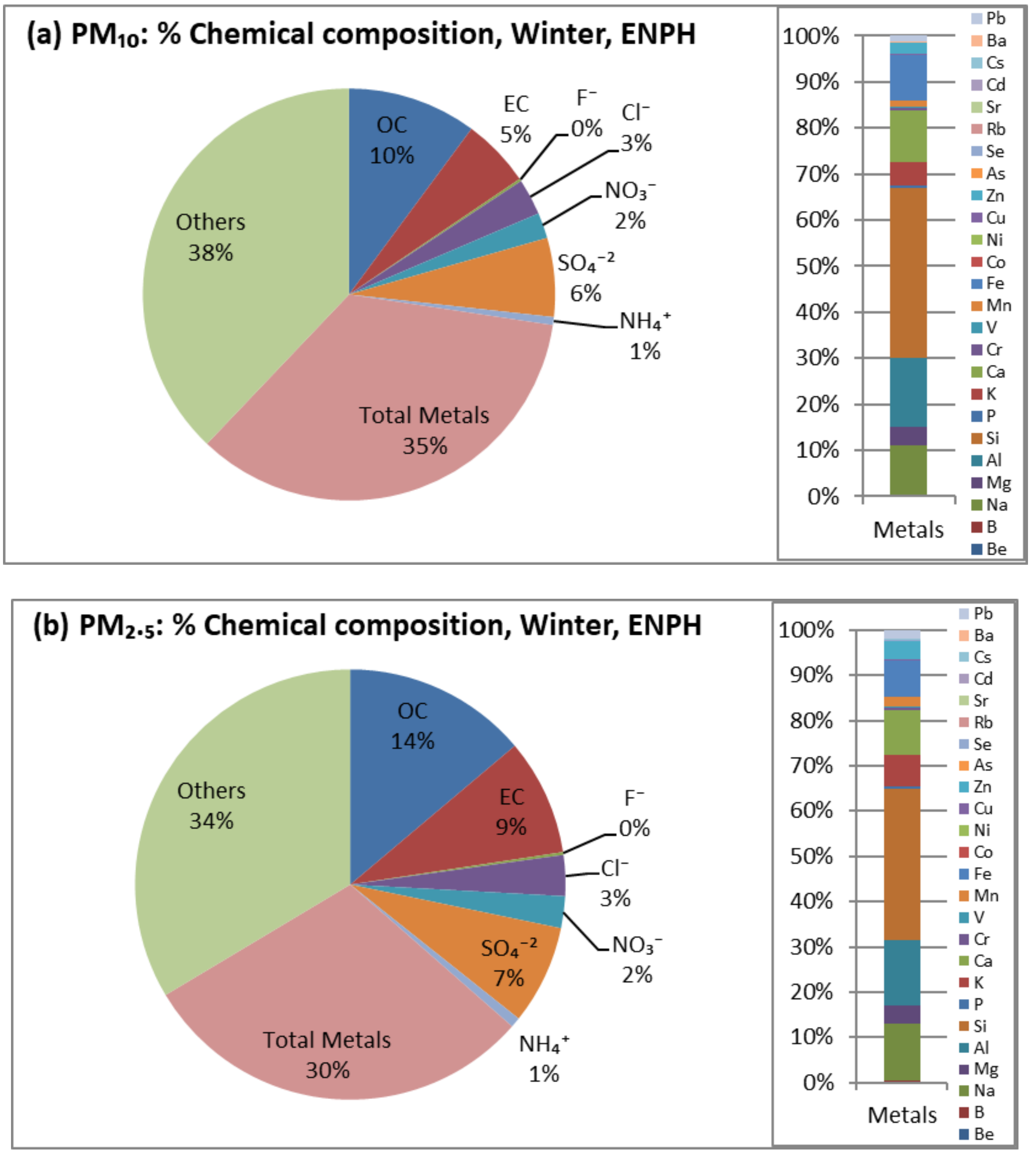


Figure 2.48: Percentage distribution of species in PM at ENPH for Winter Season

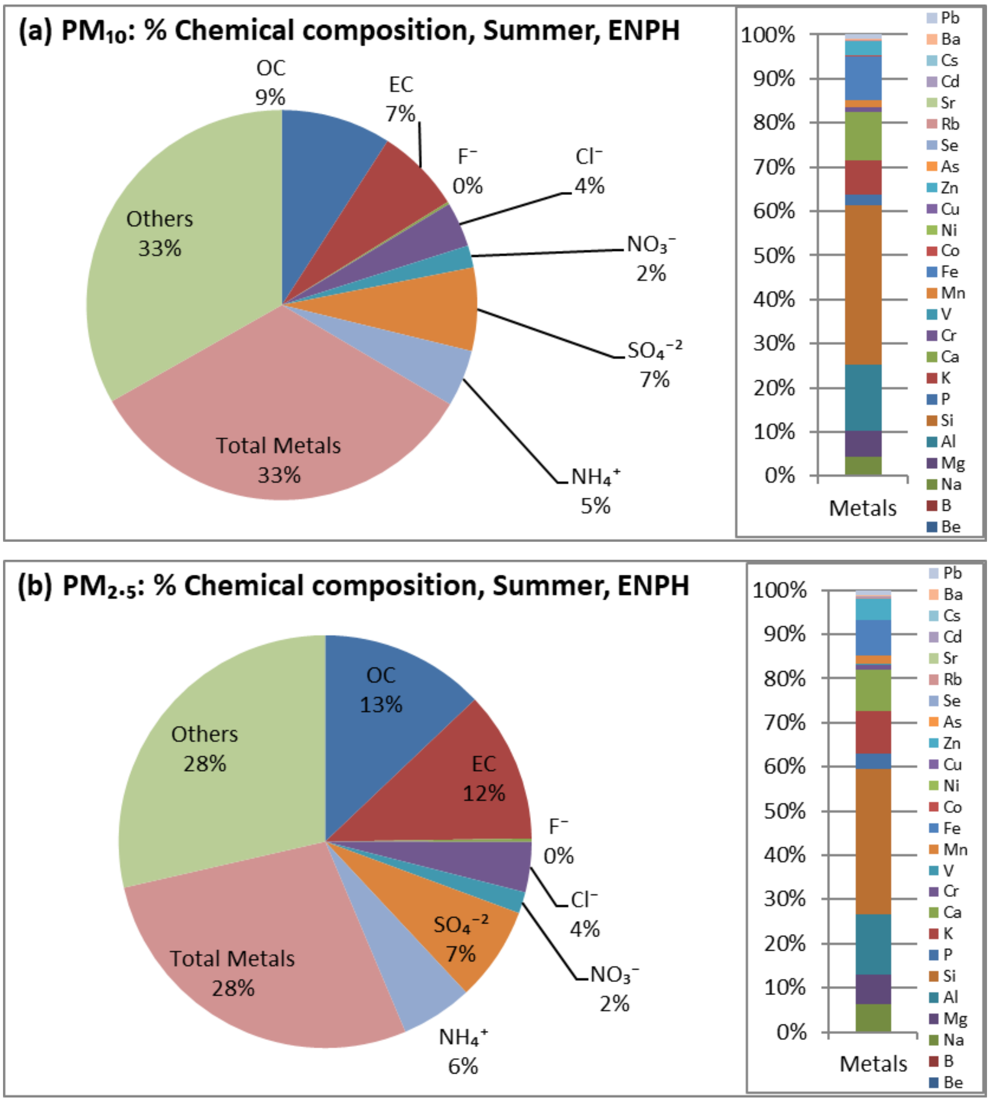
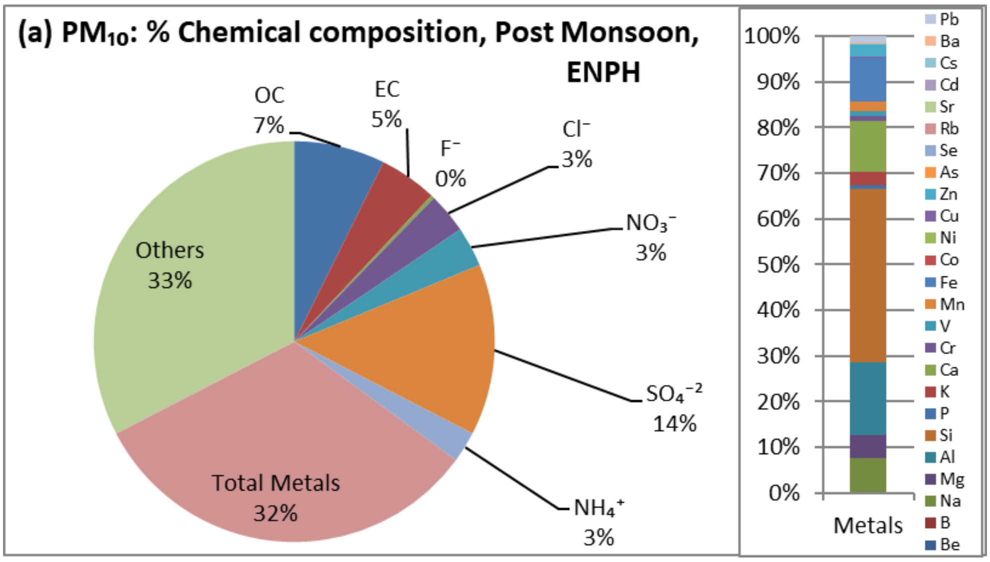


Figure 2.49: Percentage distribution of species in PM at ENPH for Summer Season



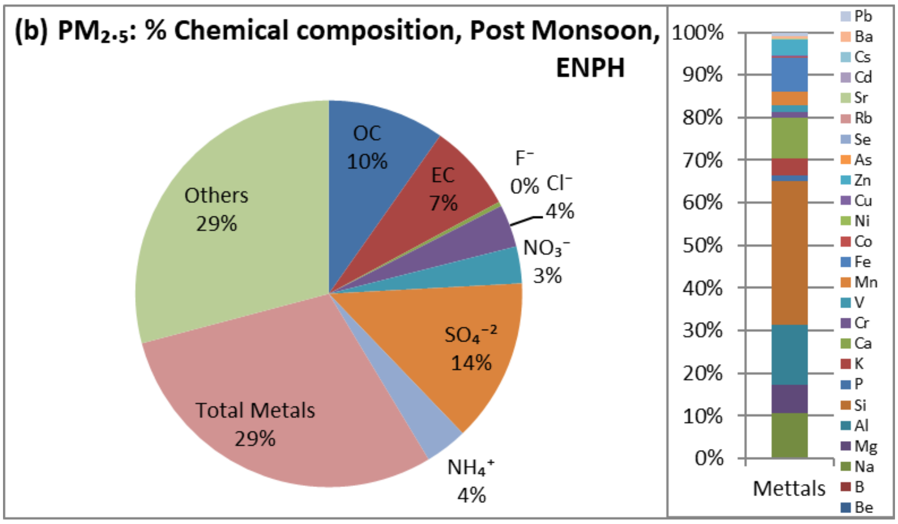


Figure 2.50: Percentage distribution of species in PM at ENPH for Post-monsoon Season

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, summer and post-monsoon seasons (Figure 2.51) at ENPH. 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 major portion of PM is having fine mode during winter (51 %), summer (49%) and post-monsoon (53%). The major species contributing to fine mode are TC, OC, EC, SO_4^{-2}, NH_4^+, K^+, B, V, Zn and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg, Al, Si, Ca, Cr, Mn, Fe and Ni.

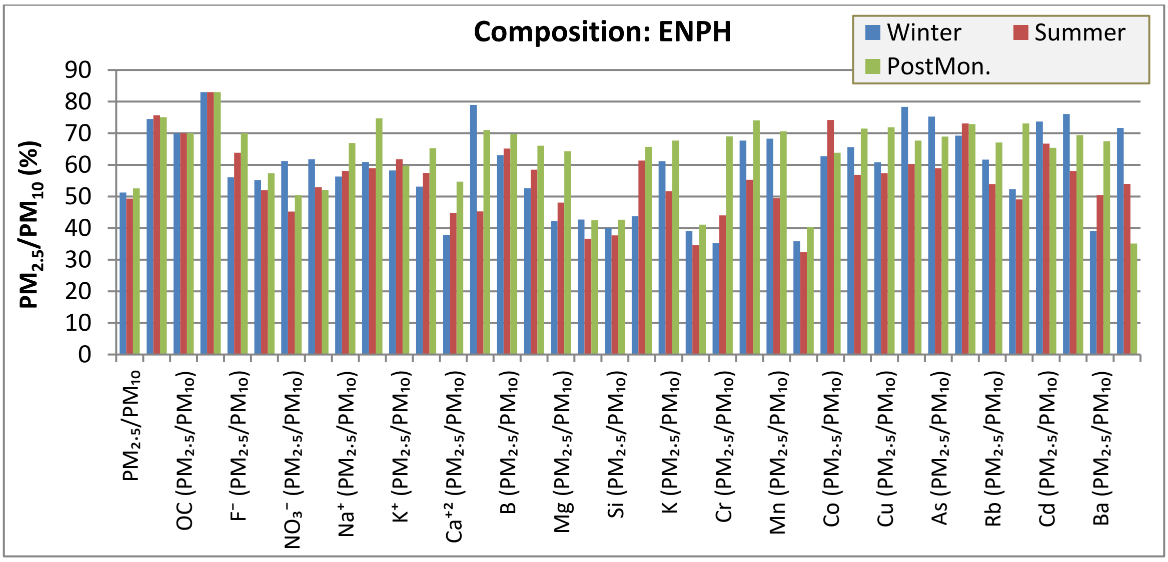


Figure 2.51: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at ENPH

Table 2.43: Statistical results of gaseous pollutants (μg/m^3) at ENPH for winter (W), summer (S) and post-monsoon (P) seasons

ENPH (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	32.12	19.51	7.41	0.13	0.76	2.24	10.54
SD	7.88	7.92	5.51	0.14	0.31	1.35	5.62
Max	50.82	30.09	17.65	0.42	1.40	5.02	20.69
Min	22.84	3.62	0.00	0.00	0.35	1.52	2.23
CV	0.25	0.41	0.74	1.03	0.41	0.60	0.53
ENPH(S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.20	9.82	4.34	1.07	6.15	11.70	23.26
SD	4.43	6.51	0.21	0.09	0.62	0.98	1.78
Max	31.36	24.94	4.73	1.19	6.98	12.62	25.08
Min	15.26	2.00	4.02	0.91	4.92	9.61	19.46
CV	0.18	0.66	0.05	0.08	0.10	0.08	0.08
ENPH (P)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	18.08	2.87	3.62	0.92	5.13	7.33	17.00
SD	5.59	2.14	1.76	0.65	1.08	2.05	5.48
Max	30.31	9.29	6.73	2.06	6.93	10.94	26.66
Min	8.72	2.00	2.56	0.50	4.07	6.02	13.88
CV	0.31	0.75	0.49	0.71	0.21	0.28	0.32

Table 2.44: Statistical results of carbon contents ($\mu g/m^3$) in $PM_{2.5}$ at ENPH for winter (W), summer (S) and post-monsoon (P) seasons

ENPH(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	151.01	34.10	13.20	20.91	0.45	6.14	7.45	6.86	0.01	0.18	0.22	0.21
SD	32.45	9.09	4.64	4.99	0.79	1.77	1.82	1.35	0.02	0.02	0.02	0.04
Max	223.01	52.08	24.51	28.25	2.70	9.32	9.73	9.50	0.06	0.21	0.27	0.25
Min	93.00	22.44	7.40	14.34	0.02	3.71	5.01	4.96	0.00	0.14	0.19	0.14
CV	0.21	0.27	0.35	0.24	1.73	0.29	0.24	0.20	1.55	0.10	0.10	0.17
ENPH(S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	118.60	29.36	14.05	15.31	0.06	4.66	6.34	4.25	0.00	0.16	0.22	0.15
SD	21.45	5.57	4.08	2.46	0.03	1.30	1.43	0.60	0.00	0.02	0.04	0.04
Max	157.57	38.43	22.29	20.45	0.13	7.83	8.85	5.29	0.00	0.21	0.26	0.25
Min	84.63	20.49	7.57	12.04	0.03	3.23	3.98	3.34	0.00	0.10	0.13	0.10
CV	0.18	0.19	0.29	0.16	0.57	0.28	0.22	0.14	0.46	0.14	0.16	0.29
ENPH(P)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	66.56	11.42	4.91	6.51	0.03	1.99	2.42	2.07	0.00	0.17	0.21	0.18
SD	29.96	4.70	1.90	2.93	0.04	0.88	1.14	0.95	0.00	0.03	0.03	0.02
Max	131.77	19.36	8.19	11.23	0.10	3.49	4.41	3.72	0.01	0.22	0.25	0.20
Min	33.42	5.44	2.17	3.28	0.00	0.99	1.11	1.02	0.00	0.12	0.15	0.13
CV	0.45	0.41	0.39	0.45	1.34	0.44	0.47	0.46	1.30	0.15	0.14	0.10

Table 2.45: Statistical results of PAHs (ng/m^3) in PM$_{2.5}$ at ENPH for winter (W), summer (S) and post-monsoon (P) seasons

ENPH (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	3.06	0.46	0.97	0.23	1.79	0.18	3.09	0.07	1.01	3.61	8.45	12.46	3.88	6.15	5.43	0.37	7.75	58.98
SD	1.54	0.32	0.58	0.20	0.57	0.11	1.40	0.01	1.14	1.77	6.12	6.05	1.60	2.75	2.28	0.17	3.29	22.40
Max	5.20	1.17	2.18	0.67	2.97	0.39	5.65	0.08	2.76	5.78	19.91	21.10	6.04	9.39	8.51	0.62	12.63	88.17
Min	0.86	0.28	0.47	0.13	1.20	0.08	1.70	0.05	0.15	1.55	2.11	5.98	1.62	2.50	2.12	0.15	3.04	26.49
CV	0.50	0.69	0.59	0.85	0.32	0.62	0.45	0.10	1.12	0.49	0.72	0.49	0.41	0.45	0.42	0.46	0.42	0.38
ENPH (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	0.41	1.01	0.50	0.70	2.86	0.10	1.81	0.52	0.65	2.44	6.36	11.55	2.17	3.95	3.02	0.18	6.37	44.58
SD	0.24	0.22	0.51	0.23	0.68	0.06	1.03	0.37	0.79	2.66	5.93	6.63	1.62	2.56	2.18	0.12	3.04	25.90
Max	0.82	1.33	1.61	1.06	4.24	0.21	2.99	1.16	2.10	7.72	16.94	20.59	4.80	8.88	7.45	0.39	11.35	86.85
Min	0.20	0.71	0.10	0.48	2.24	0.03	0.34	0.24	0.00	0.24	0.49	1.91	0.25	0.71	0.47	0.08	2.73	12.37
CV	0.59	0.22	1.01	0.32	0.24	0.64	0.57	0.72	1.22	1.09	0.93	0.57	0.75	0.65	0.72	0.67	0.48	0.58
ENPH (P)	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	0.83	4.55	0.94	0.71	4.16	4.36	1.48	0.40	0.25	0.87	1.65	8.64	2.38	4.71	1.67	1.83	4.71	44.13
SD	0.17	1.45	0.45	0.57	1.26	1.86	1.04	0.07	0.11	0.52	1.31	6.23	1.60	2.87	2.53	2.14	3.22	18.79
Max	1.13	7.33	1.77	1.86	6.13	5.96	3.07	0.49	0.43	1.72	3.70	17.12	4.71	8.89	7.12	5.33	9.64	66.76
Min	0.59	2.86	0.38	0.23	2.34	0.33	0.08	0.28	0.13	0.24	0.14	1.24	0.25	1.00	0.17	0.01	0.70	18.40
CV	0.21	0.32	0.48	0.80	0.30	0.43	0.71	0.17	0.42	0.59	0.80	0.72	0.67	0.61	1.52	1.17	0.68	0.43

Table 2.46: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at ENPH for winter (W), summer (S) and post-monsoon (P) seasons

ENPH(W)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	6.43	21.43	12.84	46.29	20.88	8.66	116.53
SD	3.91	8.50	5.82	12.78	14.83	5.46	31.40
CV	0.61	0.40	0.45	0.28	0.71	0.63	0.27
ENPH(S)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	5.89	24.13	13.58	15.02	7.84	3.08	69.54
SD	1.25	3.06	2.33	2.77	2.97	0.91	5.46
CV	0.21	0.13	0.17	0.18	0.38	0.30	0.08
ENPH(P)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21 β(H)_hopane**	**17 α(H) 21α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	3.63	8.83	8.85	19.24	4.24	0.74	45.52
SD	2.42	4.27	4.62	26.64	3.78	0.45	38.85
CV	0.67	0.48	0.52	1.38	0.89	0.61	0.85

Table 2.47: Statistical results of chemical characterization (µg/m^3) of PM_{10} at ENPH for winter (W) season

ENPH	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	295	29.87	15.90	0.59	8.39	5.91	18.22	8.71	1.87	2.69	0.69	4.61	0.01	0.28	10.94	4.10	15.40	37.89	0.40
SD	75	7.13	5.59	0.18	4.13	2.63	6.64	4.00	1.31	0.98	0.34	1.28	0.00	0.10	6.66	2.04	4.45	11.11	0.19
Max	422	40.36	29.53	0.88	15.22	11.13	34.49	15.18	4.56	5.30	1.40	7.00	0.01	0.47	27.61	8.25	23.93	58.22	0.75
Min	170	20.48	8.91	0.32	2.97	2.63	8.51	3.94	0.13	1.33	0.25	2.22	0.01	0.15	3.17	1.46	8.33	21.61	0.11
CV	0.26	0.24	0.35	0.30	0.49	0.45	0.36	0.46	0.70	0.37	0.48	0.28	0.24	0.36	0.61	0.50	0.29	0.29	0.47
ENPH	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.25	11.40	0.68	0.13	1.40	10.29	0.02	0.04	0.10	2.38	0.03	0.03	0.05	0.09	0.02	0.02	0.24	1.17	62.36
SD	2.55	3.28	0.32	0.03	0.50	3.14	0.01	0.02	0.03	1.15	0.01	0.01	0.02	0.04	0.00	0.00	0.14	1.55	3.27
Max	11.67	16.79	1.38	0.19	2.23	15.22	0.03	0.09	0.15	4.43	0.06	0.04	0.09	0.16	0.03	0.03	0.53	5.94	67.84
Min	2.87	5.57	0.27	0.09	0.63	5.32	0.01	0.02	0.05	0.95	0.01	0.02	0.03	0.04	0.01	0.01	0.11	0.21	58.36
CV	0.49	0.29	0.47	0.22	0.36	0.31	0.31	0.42	0.34	0.48	0.37	0.19	0.36	0.42	0.19	0.25	0.59	1.32	0.05

Table 2.48: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at ENPH for winter (W) season

ENPH	$PM_{2.5}$	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	151	20.91	13.20	0.33	4.63	3.61	11.25	4.90	1.14	1.57	0.37	1.74	0.01	0.17	5.75	1.73	6.57	15.14	0.17
SD	34	4.99	4.64	0.06	2.64	1.67	6.45	2.55	0.85	0.54	0.17	0.56	0.00	0.05	3.21	0.81	1.37	3.50	0.07
Max	223	28.25	24.51	0.46	10.87	5.92	31.62	11.59	2.68	2.61	0.83	3.60	0.01	0.26	14.57	2.79	9.17	22.83	0.27
Min	93	14.34	7.40	0.20	1.20	1.09	6.25	2.34	0.05	0.71	0.15	1.14	0.01	0.10	2.25	0.54	4.08	8.44	0.09
CV	0.22	0.24	0.35	0.17	0.57	0.46	0.57	0.52	0.75	0.34	0.47	0.32	0.18	0.27	0.56	0.46	0.21	0.23	0.38
ENPH	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.21	4.45	0.24	0.09	0.95	3.69	0.01	0.03	0.06	1.87	0.02	0.02	0.03	0.05	0.01	0.02	0.09	0.84	66.49
SD	1.49	0.98	0.07	0.02	0.45	0.94	0.00	0.01	0.01	1.08	0.01	0.00	0.01	0.02	0.00	0.00	0.04	0.98	3.93
Max	6.57	6.09	0.38	0.11	1.82	5.32	0.02	0.05	0.08	4.03	0.04	0.03	0.04	0.07	0.02	0.02	0.17	3.32	74.62
Min	1.44	2.69	0.11	0.07	0.25	1.99	0.01	0.01	0.04	0.62	0.01	0.02	0.02	0.02	0.01	0.01	0.03	0.12	61.66
CV	0.46	0.22	0.31	0.17	0.47	0.26	0.19	0.29	0.24	0.58	0.33	0.16	0.24	0.34	0.21	0.17	0.42	1.17	0.06

Table 2.49: Statistical results chemical characterization (µg/m^3) of PM_{10} at ENPH for summer (S) season

ENPH	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	240	21.87	16.93	0.49	8.98	4.39	16.61	2.43	11.29	3.27	0.65	4.48	0.00	0.12	3.41	4.62	12.13	28.72	1.94
SD	63	3.51	4.92	0.15	4.81	2.27	4.59	0.86	3.35	1.30	0.41	1.10	0.00	0.05	1.10	1.85	3.68	9.02	1.21
Max	381	29.22	26.85	0.74	23.64	10.58	25.62	4.91	17.81	6.57	1.84	6.66	0.01	0.22	6.08	7.20	20.26	48.98	4.73
Min	157	17.21	9.13	0.31	4.76	1.43	10.03	1.54	6.98	1.83	0.34	3.11	0.00	0.06	2.00	1.76	6.79	15.63	0.47
CV	0.26	0.16	0.29	0.30	0.54	0.52	0.28	0.36	0.30	0.40	0.64	0.25	0.23	0.44	0.32	0.40	0.30	0.31	0.62
ENPH	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.20	8.84	0.83	0.05	1.37	7.92	0.03	0.05	0.05	2.52	0.05	0.04	0.06	0.11	0.04	0.03	0.11	0.81	67.39
SD	2.35	2.93	0.65	0.06	0.63	2.96	0.06	0.06	0.05	1.33	0.04	0.08	0.08	0.12	0.08	0.07	0.09	0.46	2.95
Max	10.82	15.49	2.19	0.26	2.54	14.88	0.25	0.23	0.22	4.50	0.17	0.31	0.27	0.42	0.32	0.29	0.29	1.84	73.31
Min	3.08	4.71	0.20	0.01	0.32	3.76	0.00	0.00	0.01	0.17	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.27	62.97
CV	0.38	0.33	0.79	1.17	0.46	0.37	2.22	1.14	1.03	0.53	0.83	2.12	1.23	1.09	1.78	2.54	0.78	0.56	0.04

Table 2.50: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at ENPH for summer (S) season

ENPH	$PM_{2.5}$	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	119	15.31	14.05	0.31	4.67	1.98	8.79	1.41	6.65	2.02	0.37	2.01	0.00	0.08	1.99	2.22	4.44	10.82	1.19
SD	21	2.46	4.08	0.07	1.80	0.68	3.12	0.24	1.27	0.77	0.14	0.71	0.00	0.03	0.36	0.62	1.32	3.33	0.71
Max	158	20.45	22.29	0.53	8.39	3.10	16.97	1.67	9.20	3.81	0.73	4.16	0.00	0.14	2.85	3.50	7.35	18.27	2.80
Min	85	12.04	7.57	0.24	2.78	0.86	5.50	0.95	4.29	0.92	0.21	1.14	0.00	0.03	1.31	1.40	2.71	6.41	0.26
CV	0.18	0.16	0.29	0.21	0.39	0.34	0.35	0.17	0.19	0.38	0.37	0.35	0.23	0.41	0.18	0.28	0.30	0.31	0.60
ENPH	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.20	3.06	0.37	0.03	0.68	2.56	0.02	0.03	0.03	1.52	0.03	0.03	0.03	0.05	0.03	0.02	0.06	0.44	71.76
SD	0.83	0.97	0.20	0.03	0.35	0.84	0.06	0.04	0.04	0.94	0.03	0.06	0.05	0.05	0.06	0.05	0.05	0.19	2.78
Max	4.55	5.35	0.79	0.13	1.68	4.79	0.22	0.15	0.15	3.31	0.11	0.23	0.21	0.17	0.23	0.18	0.19	0.85	77.15
Min	1.84	1.92	0.10	0.00	0.31	1.51	0.00	0.00	0.00	0.15	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.16	67.36
CV	0.26	0.32	0.56	1.08	0.52	0.33	2.69	1.33	1.25	0.62	0.93	2.19	1.51	0.98	1.99	2.66	0.81	0.43	0.04

Table 2.51: Statistical results chemical characterization (µg/m^3) of PM_{10} at ENPH for Post-monsoon (P) season

ENPH	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	125	9.30	5.91	0.35	4.14	4.08	17.52	1.52	3.16	0.93	0.55	2.28	0.02	0.04	3.07	2.04	6.54	15.63	0.33
SD	58	4.18	2.29	0.14	2.26	2.77	9.30	0.42	1.88	0.30	0.26	1.04	0.00	0.03	0.69	1.12	3.44	8.16	0.11
Max	248	16.04	9.87	0.72	8.09	10.02	41.00	2.35	6.23	1.60	1.27	4.02	0.03	0.08	4.50	3.98	13.39	31.09	0.56
Min	51	4.68	2.61	0.18	0.86	0.65	5.50	0.80	0.62	0.40	0.26	0.77	0.02	0.00	1.96	0.71	2.43	5.75	0.19
CV	0.46	0.45	0.39	0.40	0.55	0.68	0.53	0.28	0.60	0.32	0.47	0.46	0.15	0.70	0.23	0.55	0.53	0.52	0.35
ENPH	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.18	4.55	0.39	0.46	0.87	3.91	0.02	0.03	0.05	1.09	0.00	0.00	0.04	0.04	0.01	0.02	0.11	0.58	67.85
SD	0.37	2.52	0.21	0.15	0.54	2.30	0.00	0.01	0.02	0.86	0.00	0.00	0.01	0.02	0.01	0.00	0.08	0.73	2.04
Max	1.82	9.58	0.88	0.85	1.67	8.77	0.03	0.08	0.11	2.74	0.01	0.01	0.06	0.07	0.04	0.02	0.31	3.03	71.87
Min	0.61	1.51	0.13	0.33	0.25	1.37	0.01	0.02	0.02	0.24	0.00	0.00	0.03	0.02	0.00	0.01	0.03	0.08	65.65
CV	0.31	0.55	0.53	0.33	0.62	0.59	0.23	0.47	0.52	0.79	0.86	1.21	0.25	0.41	1.29	0.16	0.71	1.27	0.03

Table 2.52: Statistical results of chemical characterization (μg/m^3) of PM$_{2.5}$ at ENPH for Post-monsoon (P) season

ENPH	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	67	6.51	4.91	0.25	2.37	2.06	9.12	1.02	2.36	0.56	0.36	1.25	0.02	0.03	2.03	1.31	2.78	6.67	0.21
SD	31	2.93	1.90	0.12	0.96	1.40	5.12	0.50	1.76	0.24	0.18	0.75	0.00	0.02	0.67	0.95	1.22	2.92	0.09
Max	141	11.23	8.19	0.60	4.32	5.31	20.69	2.29	5.71	1.02	0.81	2.80	0.03	0.06	3.63	3.84	5.95	14.20	0.37
Min	33	3.28	2.17	0.12	0.73	0.44	4.59	0.43	0.49	0.24	0.16	0.53	0.01	0.00	1.11	0.35	1.38	3.75	0.10
CV	0.47	0.45	0.39	0.48	0.40	0.68	0.56	0.49	0.74	0.43	0.50	0.60	0.21	0.74	0.33	0.72	0.44	0.44	0.40
ENPH	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.80	1.87	0.27	0.34	0.61	1.58	0.01	0.02	0.03	0.74	0.00	0.00	0.03	0.03	0.01	0.01	0.07	0.20	71.39
SD	0.37	0.88	0.18	0.15	0.47	0.86	0.00	0.01	0.02	0.65	0.00	0.00	0.01	0.01	0.01	0.00	0.06	0.11	2.48
Max	1.49	4.00	0.68	0.83	1.56	3.69	0.02	0.07	0.08	2.26	0.01	0.01	0.06	0.06	0.02	0.02	0.21	0.42	75.98
Min	0.34	0.90	0.09	0.19	0.14	0.69	0.01	0.01	0.01	0.09	0.00	0.00	0.02	0.01	0.00	0.01	0.02	0.06	66.18
CV	0.46	0.47	0.66	0.44	0.76	0.55	0.24	0.61	0.65	0.89	0.79	1.50	0.46	0.48	1.08	0.30	0.78	0.53	0.03

Table 2.53: Correlation matrix for PM$_{10}$ and its composition at ENPH for winter season

ENPH (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	0.80	0.78	0.72	0.86	0.75	0.85	0.35	0.37	-0.18	0.65	0.81	0.70	0.94
TC		1.00	0.96	0.93	0.63	0.71	0.74	0.13	0.29	-0.12	0.69	0.72	0.37	0.67
OC			1.00	0.78	0.67	0.79	0.72	0.11	0.43	-0.22	0.58	0.65	0.43	0.58
EC				1.00	0.49	0.53	0.68	0.13	0.08	0.02	0.75	0.71	0.24	0.69
NO$_3^-$					0.68	0.62	1.00	0.45	0.24	-0.01	0.58	0.70	0.47	0.76
SO$_4^{-2}$					0.14	-0.09		1.00	-0.21	0.71	0.16	0.13	0.15	0.34
NH$_4^+$					-0.34	-0.50			-0.48	1.00	-0.07	-0.24	-0.29	-0.12
Metals					0.79	0.59			0.23		0.64	0.79	0.69	1.00

Table 2.54: Correlation matrix for $PM_{2.5}$ and its composition at ENPH for winter season

ENPH (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	0.91	0.87	0.86	0.57	0.46	0.63	0.16	0.11	0.15	0.63	0.34	0.27	0.92
TC		1.00	0.95	0.94	0.52	0.69	0.55	0.02	0.27	-0.02	0.60	0.29	0.17	0.80
OC			1.00	0.78	0.63	0.73	0.58	-0.01	0.34	-0.15	0.51	0.32	0.31	0.69
EC				1.00	0.35	0.57	0.45	0.06	0.17	0.12	0.63	0.22	0.01	0.81
NO_3^-					0.52	0.45	1.00	0.48	0.26	-0.05	0.48	0.00	0.46	0.37
SO_4^{-2}					-0.04	-0.18		1.00	-0.08	0.64	0.11	-0.16	-0.06	-0.05
NH_4^+					-0.17	-0.36			-0.08	1.00	0.05	-0.20	-0.21	0.19
Metals					0.43	0.27			-0.07		0.58	0.39	0.16	1.00

Table 2.55: Correlation matrix for PM_{10} and its composition at ENPH for summer season

ENPH (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	0.49	0.53	0.33	0.41	0.73	0.79	0.55	0.66	0.68	0.77	0.81	0.47	0.99
TC		1.00	0.78	0.89	-0.01	0.02	-0.06	-0.28	-0.18	0.00	0.23	0.05	0.13	0.49
OC			1.00	0.41	0.00	0.14	0.10	-0.10	-0.08	0.06	0.53	0.31	0.27	0.53
EC				1.00	-0.01	-0.07	-0.16	-0.34	-0.20	-0.05	-0.04	-0.15	0.00	0.34
NO_3^-					0.45	0.75	1.00	0.81	0.89	0.82	0.67	0.88	0.40	0.78
SO_4^{-2}					0.55	0.66		1.00	0.73	0.77	0.65	0.76	0.57	0.49
NH_4^+					0.61	0.74			0.89	1.00	0.70	0.79	0.69	0.60
Metals					0.35	0.67			0.61		0.70	0.77	0.39	1.00

Table 2.56: Correlation matrix for $PM_{2.5}$ and its composition ENPH for summer season

ENPH (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	0.66	0.61	0.54	0.55	0.73	0.62	0.10	0.00	0.04	0.52	0.72	0.77	0.98
TC		1.00	0.74	0.92	-0.11	0.28	0.11	-0.37	-0.25	-0.25	0.02	0.11	0.21	0.63
OC			1.00	0.41	0.08	0.40	0.23	-0.26	-0.13	-0.23	0.41	0.45	0.44	0.61
EC				1.00	-0.19	0.14	0.01	-0.35	-0.26	-0.20	-0.22	-0.12	0.02	0.49
NO_3^-					0.51	0.78	1.00	0.25	-0.03	0.11	0.41	0.63	0.57	0.59
SO_4^{-2}					0.22	0.13		1.00	0.30	0.12	0.44	0.25	0.14	-0.03
NH_4^+					0.29	-0.02			0.66	1.00	0.24	0.20	0.29	0.09
Metals					0.64	0.74			0.02		0.51	0.74	0.82	1.00

Table 2.57: Correlation matrix for PM_{10} and its composition at ENPH for Post-monsoon season

ENPH (P)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.82	0.85	0.69	0.41	0.35	0.74	0.89	0.28	0.82	0.35	0.77	0.58	0.99
TC		1.00	0.99	0.95	0.40	0.47	0.80	0.64	0.30	0.55	0.17	0.66	0.54	0.75
OC			1.00	0.88	0.41	0.48	0.83	0.67	0.25	0.59	0.19	0.71	0.56	0.79
EC				1.00	0.37	0.44	0.69	0.52	0.35	0.43	0.13	0.52	0.45	0.62
NO_3^-					0.25	0.60	1.00	0.45	0.27	0.55	0.19	0.60	0.51	0.68
SO_4^{-2}					0.38	0.00		1.00	0.07	0.81	0.24	0.67	0.45	0.88
NH_4^+					0.17	0.05			0.00	1.00	0.13	0.47	0.24	0.83
Metals					0.39	0.33			0.31		0.41	0.75	0.55	1.00

Table 2.58: Correlation matrix for $PM_{2.5}$ and its composition ENPH for Post-monsoon season

ENPH (P)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.82	0.82	0.75	0.57	0.41	0.95	0.97	0.35	0.74	0.50	0.76	0.69	0.99
TC		1.00	0.98	0.96	0.57	0.47	0.83	0.72	0.37	0.53	0.30	0.74	0.62	0.73
OC			1.00	0.88	0.56	0.45	0.80	0.73	0.33	0.57	0.32	0.78	0.62	0.74
EC				1.00	0.53	0.46	0.81	0.66	0.41	0.43	0.26	0.63	0.58	0.66
NO_3^-					0.53	0.45	1.00	0.94	0.43	0.61	0.47	0.72	0.67	0.93
SO_4^{-2}					0.54	0.36		1.00	0.31	0.65	0.51	0.72	0.70	0.98
NH_4^+					0.39	0.22			0.25	1.00	0.42	0.60	0.52	0.76
Metals					0.56	0.39			0.36		0.56	0.75	0.68	1.00

2.4.4 HSS Risali (HSSR)

The sampling period was January 03-17, 2021 for winter, March 22, 2021 - April 05, 2021, for summer and October 13-26, 2021- for post-monsoon.

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

Time series of 24-hour average concentrations of PM_{10} and $PM_{2.5}$ at HSSR is shown for winter (Figure 2.52), summer (Figure 2.53) and post-monsoon (Figure 2.54). Average levels at this site were: $PM_{2.5}$: 150±29 (winter), 114±23 µg/m^3 (summer) and 74±39 µg/m^3 (post-monsoon) and PM_{10}: 298±55 (winter), 224±67 µg/m^3 (summer) and 140±62 µg/m^3 (post-monsoon). In winter, the $PM_{2.5}$ levels were about 2.5 times higher than the NAAQS (60 µg/m^3) and PM_{10} levels were 3 times higher than the NAAQS (100 µg/m^3). In summer, the $PM_{2.5}$ levels were 1.89 times higher than the NAAQS and PM_{10} was 2.24 times higher than the NAAQS. In post-monsoon, the $PM_{2.5}$ levels were 1.15 times higher than the NAAQS and PM_{10} levels were 1.39 times higher than the standards.

A statistical summary of PM concentrations is presented in Table 2.63 - Table 2.68 for winter, summer and post-monsoon seasons. In post-monsoon, both $PM_{2.5}$ and PM_{10} levels dropped but maximum levels were above NAAQS. In summer $PM_{2.5}$ and PM_{10} level drop compared to winter were still quite high and above NAAQS despite improvement in meteorology and better dispersion in summer. The particles airborne from soil during dust storms in the dry months of summer can contribute significantly to coarse fraction (i.e., $PM_{2.5-10}$).

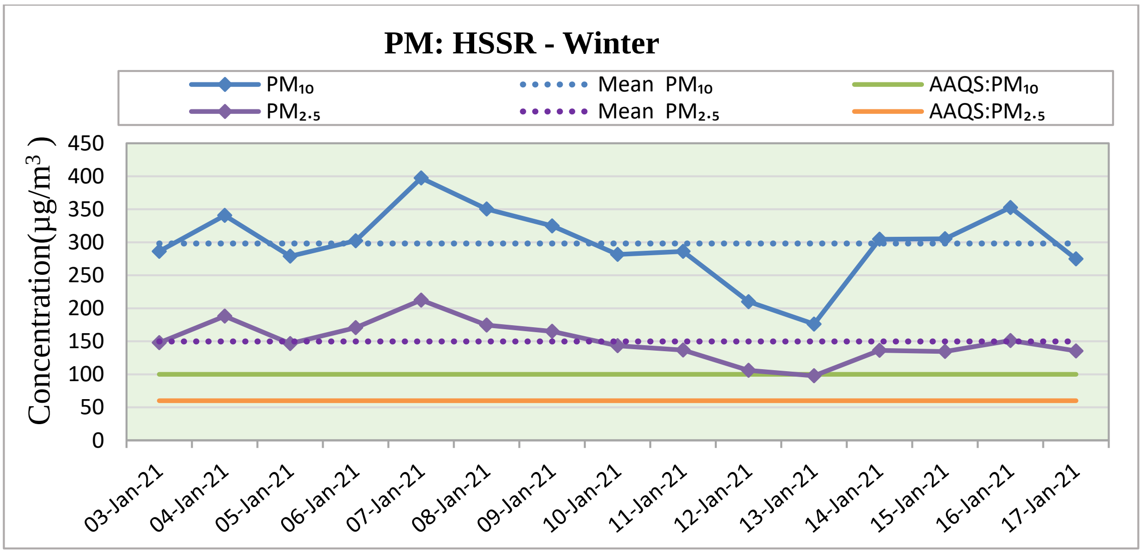


Figure 2.52: PM Concentrations at HSSR for Winter Season

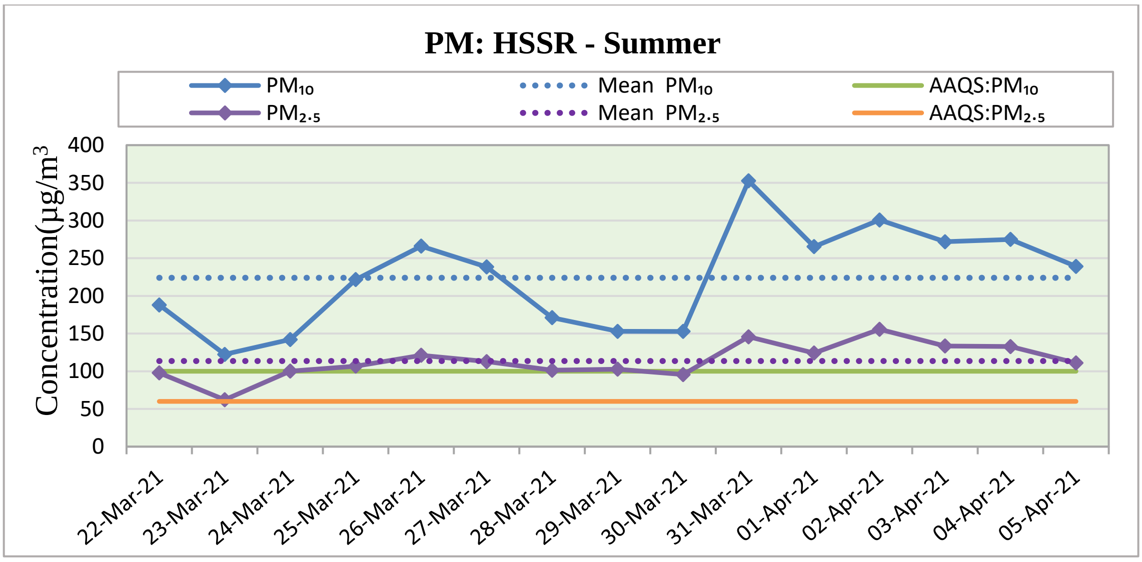


Figure 2.53: PM Concentrations at HSSR for Summer Season

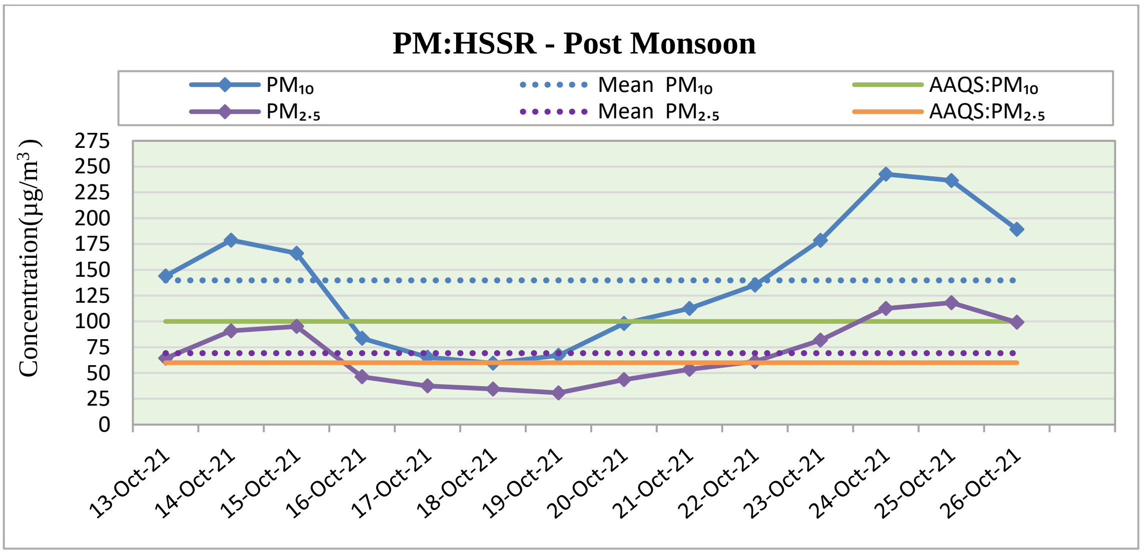


Figure 2.54: PM Concentrations at HSSR for Post Monsson Season

2.4.4.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.71), summer (Figure 2.72) and post-monsoon (Figure 2.73) seasons. It was observed that SO_2 concentrations meet the air quality standard with an average of 11.8±6.3 µg/m^3 in winter, 4.7±3.2 µg/m^3 in summer and 3.5±2.6 µg/m^3 in post-monsoon. NO_2 levels were also under the national standard with an average of 32.2±6.9 µg/m^3 in winter, 18.6±7.0 µg/m^3 in summer and 18.4±7.3 µg/m^3 in post-monsoon season (Table 2.43). The summer concentration of NO_2 dropped similarly to $PM_{2.5}$ levels. The NO_2 is a matter of concern and these values can largely be attributed to vehicular pollution and industrial emissions. 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, coal combustion etc.

The mean concentrations of BTX are presented in Figure 2.58 and the statistical summary is in Table 2.59. The total BTX level is observed 20.02±10 µg/m^3 (Benzene: 15.8 and Toluene: 0.13 µg/m^3) in winter, 21±2.7 µg/m^3 (Benzene: 4.0, Toluene: 1.0, p-xylene: 6.0 and o-xylene: 11.0 µg/m^3) in summer and 16±1.5 µg/m^3 (Benzene: 2.7, Toluene: 0.68, p-xylene: 5.38 and o-xylene: 7.39 µg/m^3) in post-monsoon seasons. The maximum BTX concentration was observed at 41 µg/m^3 in winter, 25 µg/m^3 in summer and 19 µg/m^3 in post-monsoon seasons.

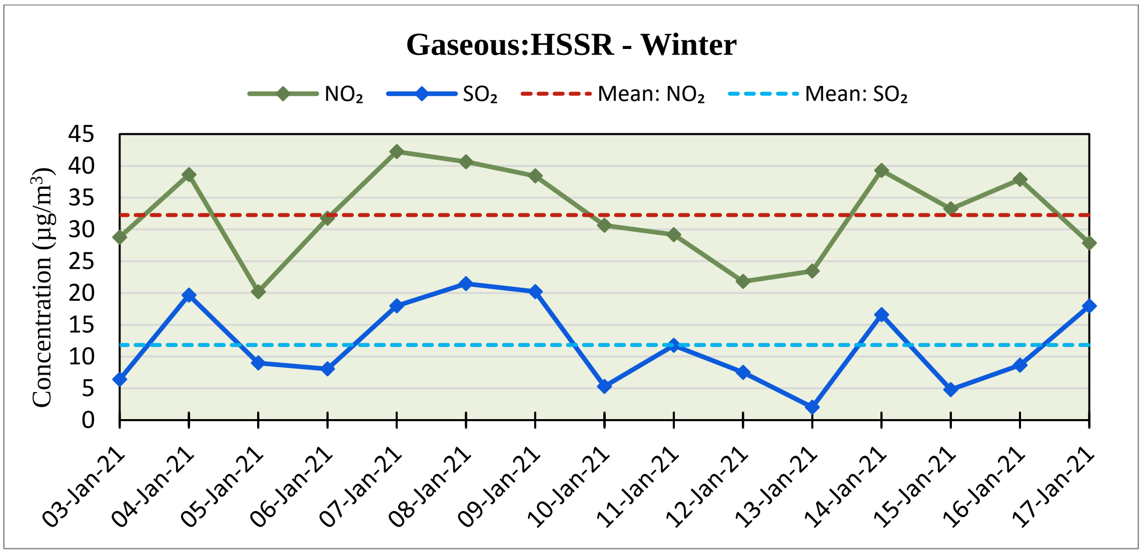


Figure 2.55: SO_2 and NO_2 Concentrations at HSSR for Winter Season

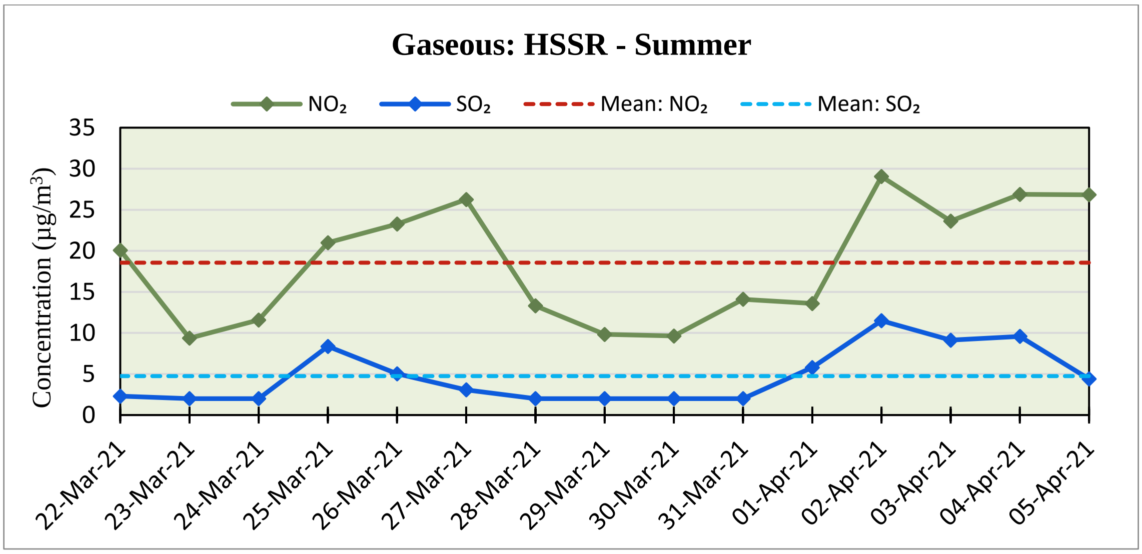


Figure 2.56: SO_2 and NO_2 Concentrations at HSSR for Summer Season

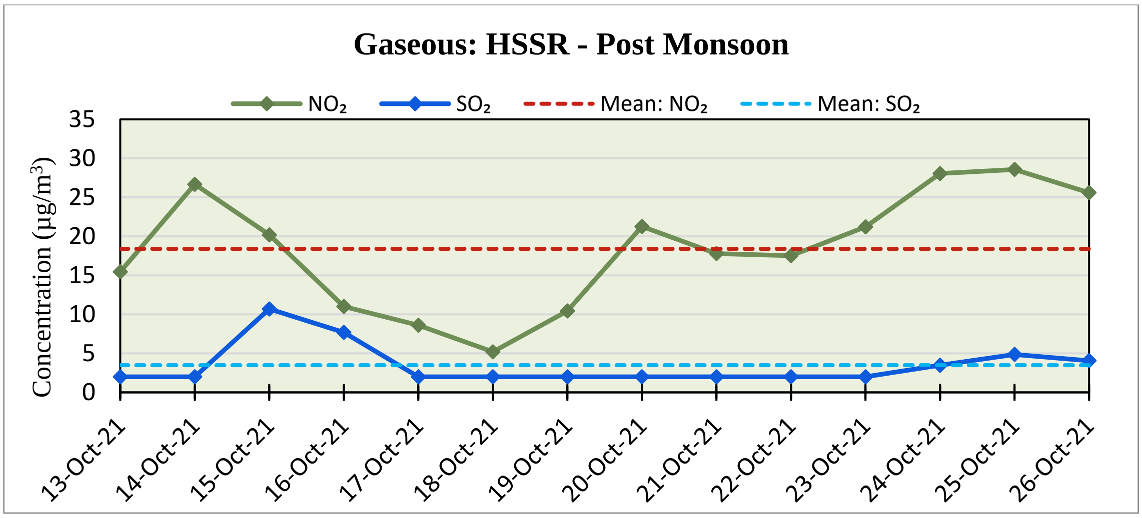


Figure 2.57: SO_2 and NO_2 Concentrations at HSSR for Summer Season

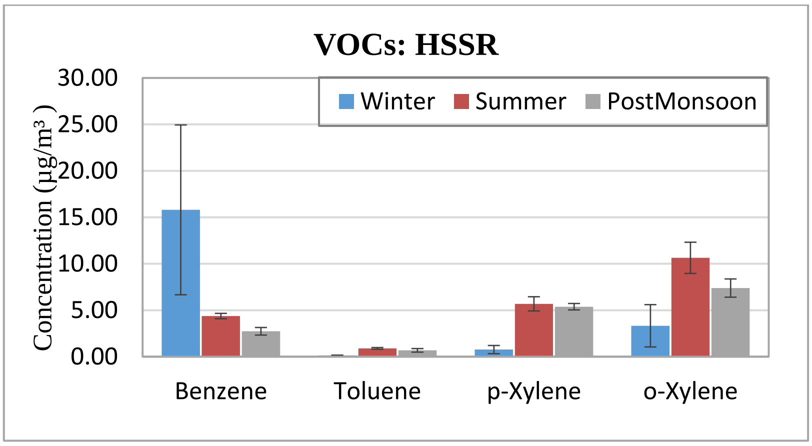


Figure 2.58: VOCs concentration at HSSR

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 2.59 (a) and (b) for winter, summer, and post-monsoon seasons. Organic carbon is observed higher (winter: 20.92±3.92, summer: 15±2 and post-monsoon: 8.97±3.74 µg/m^3) than the elemental carbon (winter: 10.11±1.98 summer: 9.65±2.97 and post-monsoon: 8.97±3.74 µg/m^3). However, the ratio of OC3/TC is observed higher indicating the formation of secondary organic carbon in the atmosphere. It is also observed that the OC and EC are higher in the winter season than in other seasons. 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 2.60 for winter, summer, and post-monsoon seasons.

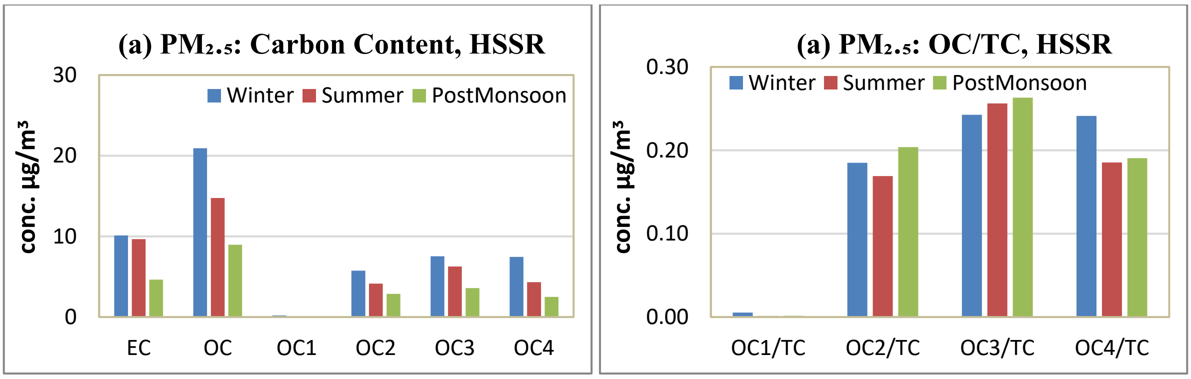


Figure 2.59: EC and OC Content in PM$_{2.5}$ at HSSR

2.4.4.4 PAHs in PM$_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.60 shows the average measured concentration of PAHs at HSSR for winter, summer, and post-monsoon seasons. A statistical summary of PAHs is presented in Table 2.61 for winter, summer, and post-monsoon 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 PAH concentrations in winter were 24±5 ng/m^3, in summer: 22±11 ng/m^3 and in post-monsoon: 15±5 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are (i) B(b)F (5 ng/m^3), B(ghi)P (2 ng/m^3), BaP (2 ng/m^3), DmP (5 ng/m^3) and Chr (2 ng/m^3) for winter season; (ii) B(b)F (2 ng/m^3), DmP (7 ng/m^3), B(ghi)P (2 ng/m^3), AcP (1.42 ng/m^3) and DEP (2.03 ng/m^3) for summer season; and (iii) Ant (2 ng/m^3), B(b)F (2.36 ng/m^3), BaP (2.24 ng/m^3), BbP (1.28 ng/m^3) and DEP (1.14 ng/m^3) for post-monsoon.

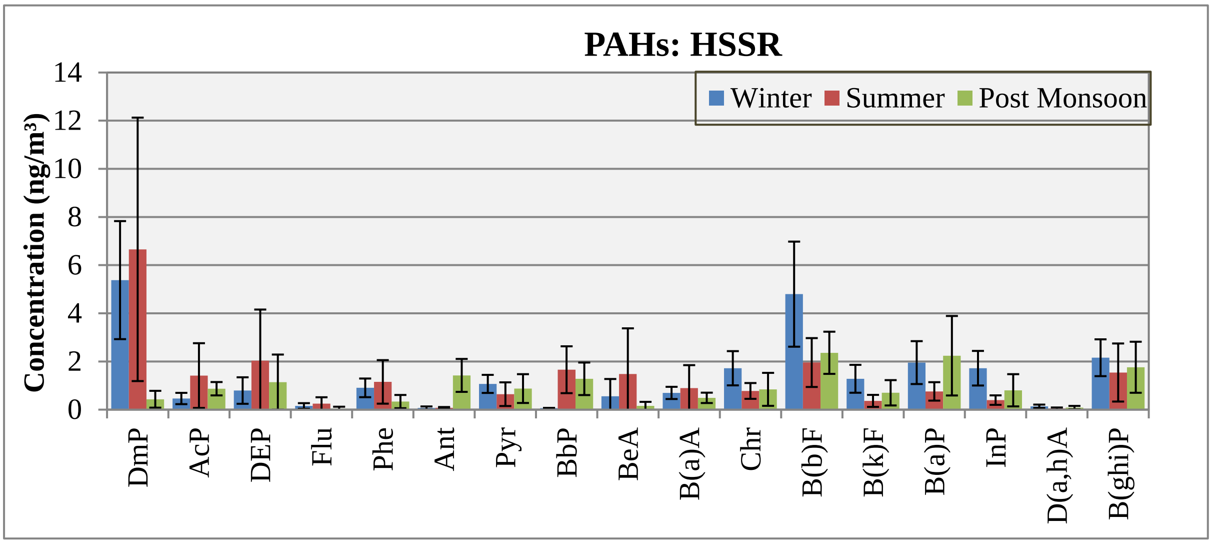


Figure 2.60: PAHs Concentrations in PM$_{2.5}$ at HSSR

2.4.4.5 Molecular Markers in $PM_{2.5}$

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

Figure 2.61 and Table 2.62 show the levels of six molecular markers. The total concentration of markers was 82.80±28.28 ng/m^3 in winter, 84.05±15.90 ng/m^3 in summer and 75.91±7.04 ng/m^3 in post-monsoon. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

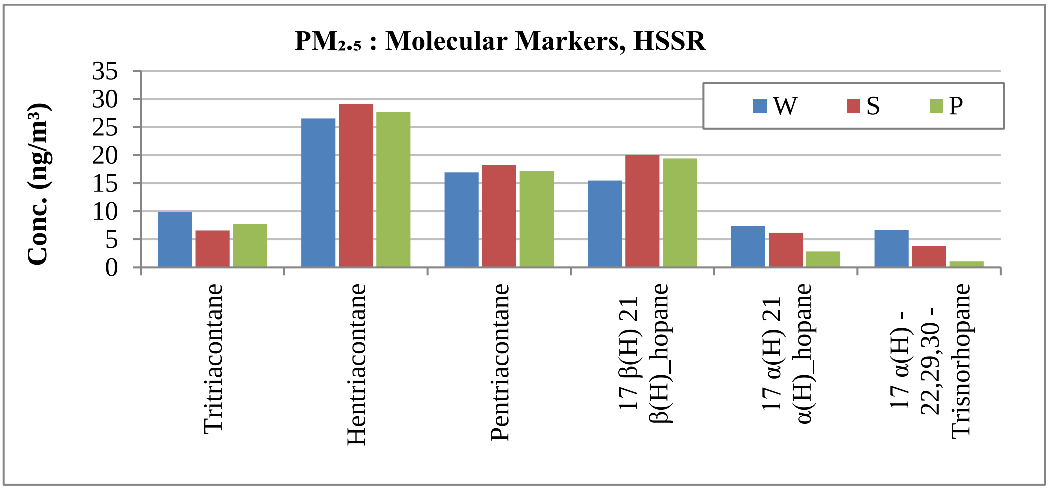


Figure 2.61: Molecular Markers in $PM_{2.5}$ at HSSR

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 winter, summer and post-monsoon seasons at HSSR for PM_{10} (Figure 2.62) and $PM_{2.5}$ (Figure 2.63). 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 2.47 – Table 2.52 for winter, summer and post-monsoon 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 2.53 - Table 2.58 for both season. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and

$PM_{2.5}$. The percentage constituent of the PM is presented in Figure 2.64 (a) and (b) for winter, Figure 2.65(a) and (b) for summer and Figure 2.66 (a) and (b) for post-monsoon seasons.

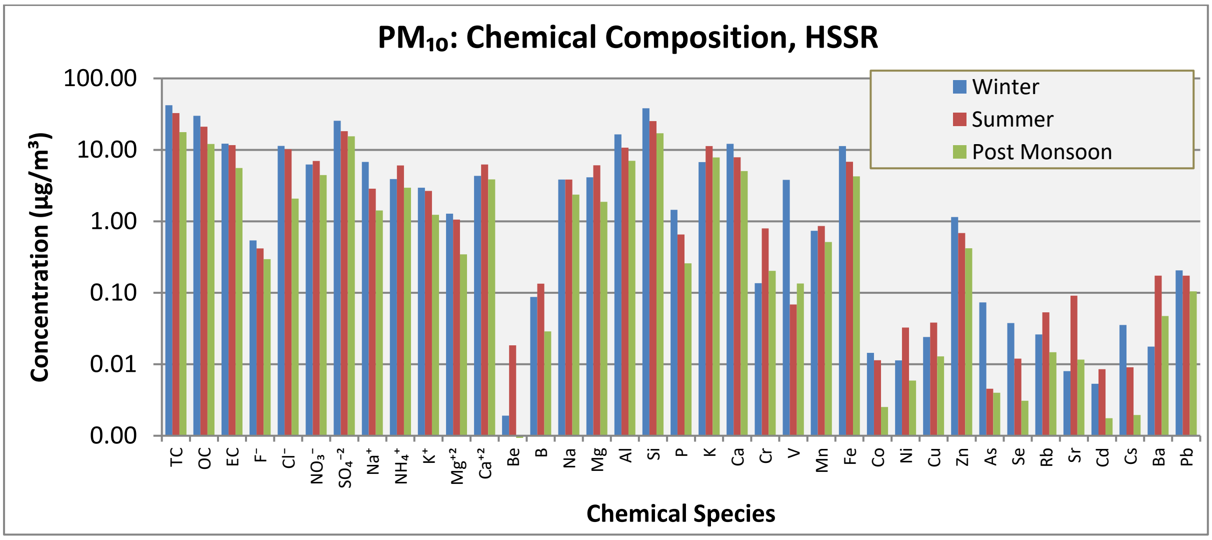


Figure 2.62: Concentrations of species in PM_{10} at HSSR

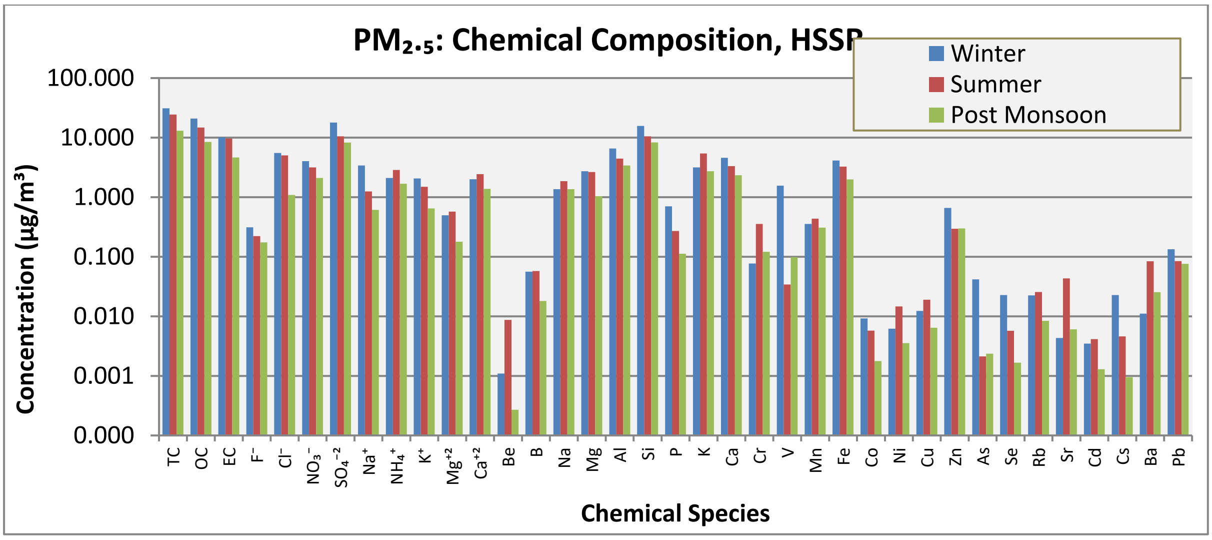


Figure 2.63: Concentrations of species in $PM_{2.5}$ at HSSR

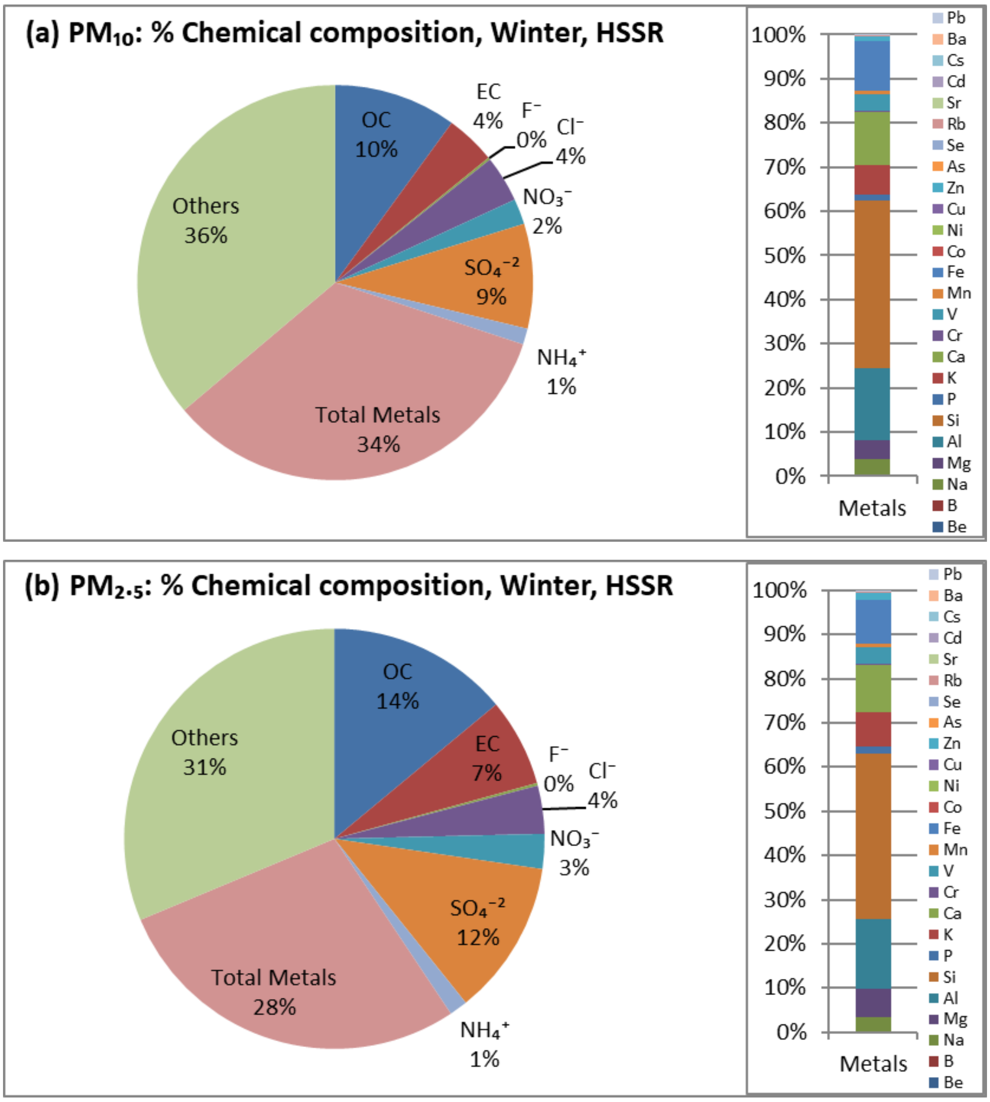
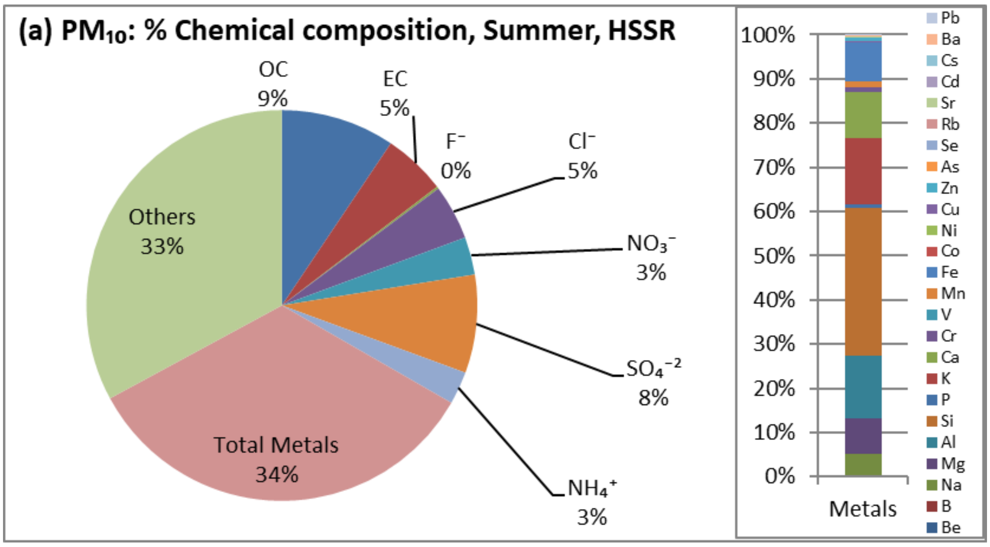


Figure 2.64: Percentage distribution of species in PM at HSSR for Winter Season



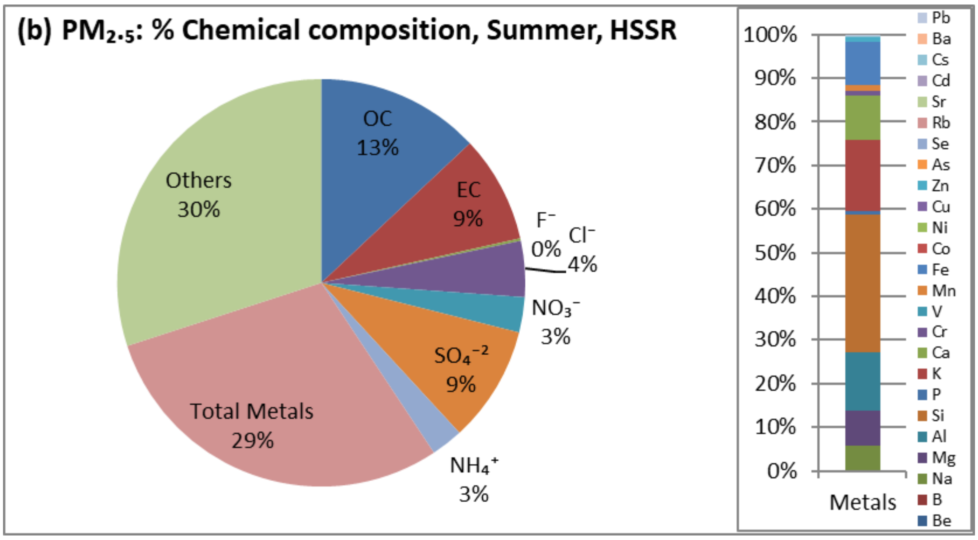


Figure 2.65: Percentage distribution of species in PM at HSSR for Summer Season

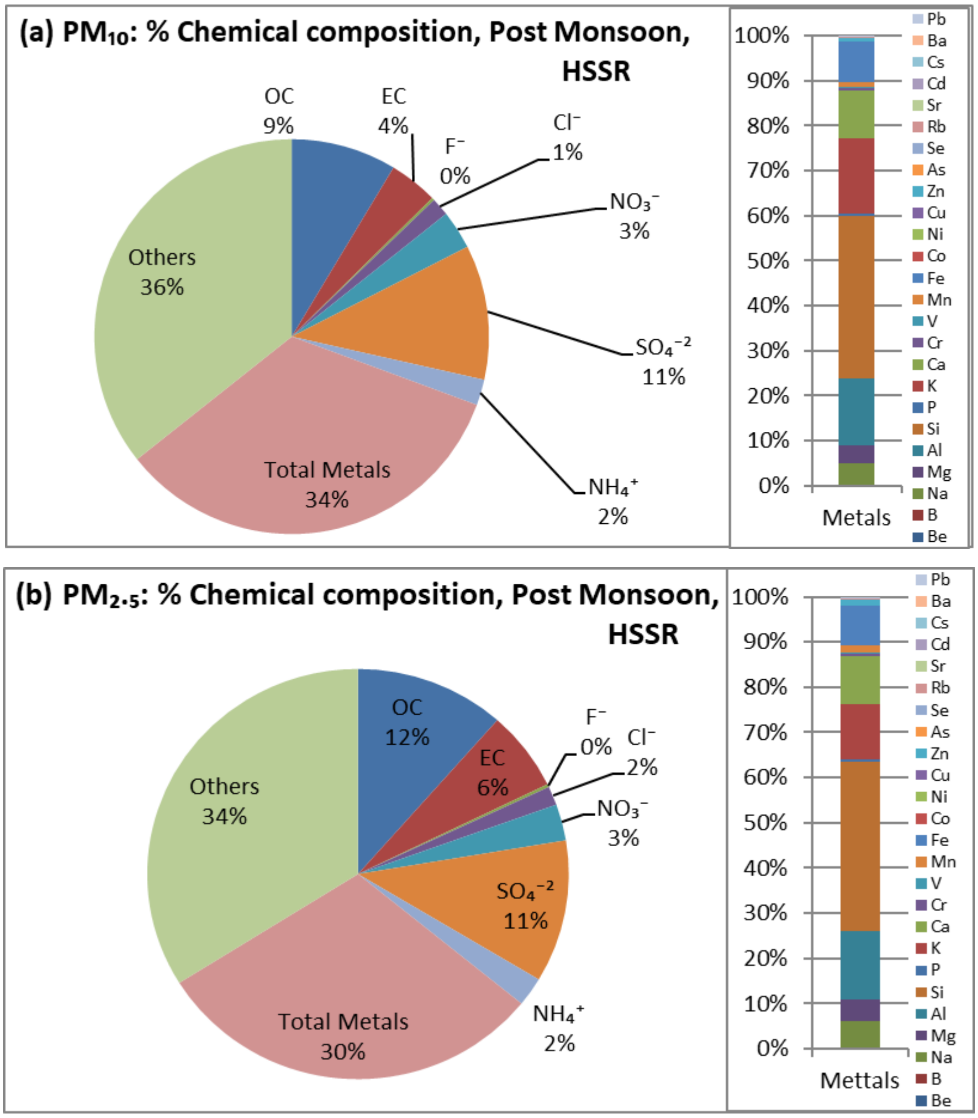


Figure 2.66: Percentage distribution of species in PM at HSSR for Post-monsoon Season

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, summer and post-monsoon seasons (Figure 2.67) at HSSR. 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 major portion of PM is having fine mode during winter (50%), summer (51%) and post-monsoon (53%). The major species contributing to fine mode are TC, OC, EC, NO$_3^-$, SO$_4^{-2}$, Na$^+$, V and As; whereas, the major species contributing to coarse mode are Ca, Mg, Al, Si, P, Ca, Cr, Fe and Cu.

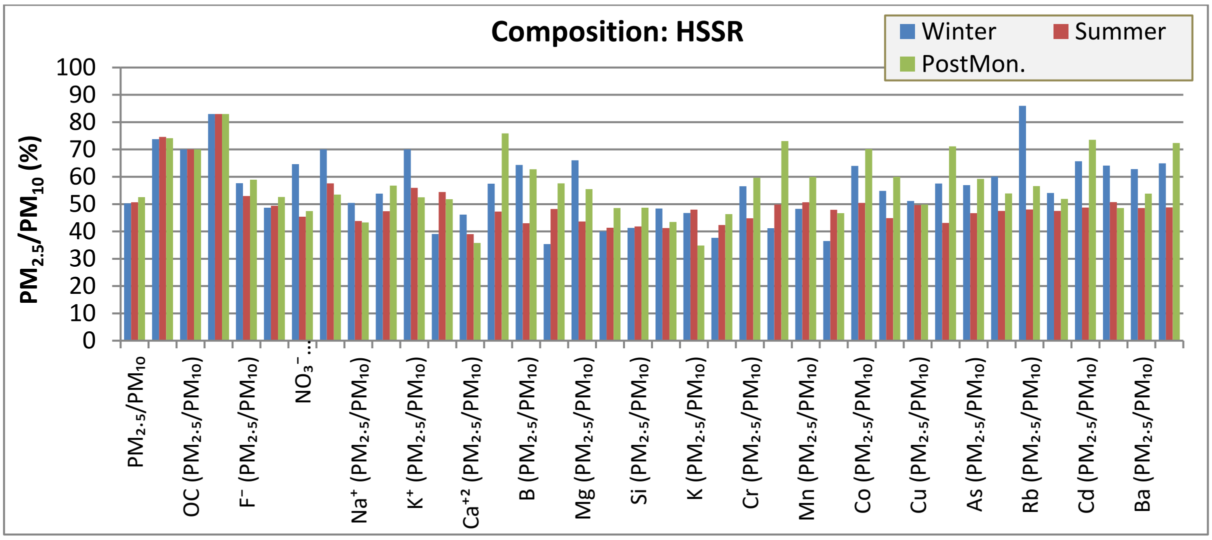


Figure 2.67: Compositional comparison of species in PM$_{2.5}$ Vs PM$_{10}$ at HSSR

Table 2.59: Statistical results of gaseous pollutants (µg/m^3) at HSSR for winter (W), summer (S) and post-monsoon (P) seasons

HSSR(W)	NO$_2$	SO$_2$	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	32.26	11.82	15.80	0.13	0.77	3.32	20.02
SD	6.86	6.28	9.14	0.04	0.44	2.28	10.49
Max	42.24	21.46	33.24	0.18	1.40	7.60	41.98
Min	20.18	2.03	6.97	0.08	0.35	1.52	12.30
CV	0.21	0.53	0.58	0.27	0.57	0.68	0.52
HSSR (S)	NO$_2$	SO$_2$	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	18.56	4.74	4.37	0.89	5.69	10.64	21.59
SD	6.95	3.23	0.29	0.09	0.76	1.68	2.75
Max	29.05	11.49	4.91	1.02	6.47	12.35	24.65
Min	9.36	2.00	4.02	0.77	4.54	8.15	17.62
CV	0.37	0.68	0.07	0.10	0.13	0.16	0.13
HSSR(P)	NO$_2$	SO$_2$	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	18.40	3.49	15.80	0.13	0.77	3.32	20.02
SD	7.24	2.56	9.14	0.04	0.44	2.28	10.49
Max	28.58	10.70	33.24	0.18	1.40	7.60	41.98
Min	5.20	2.00	6.97	0.08	0.35	1.52	12.30
CV	0.39	0.73	0.58	0.27	0.57	0.68	0.52

Table 2.60: Statistical results of carbon contents ($\mu g/m^3$) in $PM_{2.5}$ at HSSR for winter (W), summer (S) and post-monsoon (P) seasons

HSSR(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	149.79	31.03	10.11	20.92	0.20	5.74	7.53	7.45	0.01	0.18	0.24	0.24
SD	28.48	5.78	1.98	3.92	0.45	1.19	1.51	1.55	0.01	0.01	0.01	0.03
Max	212.47	40.95	13.25	27.87	1.74	8.58	10.54	11.08	0.04	0.21	0.27	0.28
Min	98.00	20.07	6.33	13.74	0.00	3.85	4.81	4.63	0.00	0.16	0.22	0.16
CV	0.19	0.19	0.20	0.19	2.29	0.21	0.20	0.21	2.08	0.07	0.06	0.13
HSSR(S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	113.58	24.41	9.65	14.76	0.03	4.15	6.26	4.32	0.00	0.17	0.26	0.19
SD	23.07	4.77	2.97	2.12	0.02	0.92	1.29	0.76	0.00	0.01	0.02	0.06
Max	155.70	31.80	15.22	18.25	0.07	5.67	8.07	5.78	0.00	0.19	0.29	0.28
Min	62.19	15.55	5.46	10.08	0.01	2.54	3.93	3.14	0.00	0.15	0.23	0.12
CV	0.20	0.20	0.31	0.14	0.46	0.22	0.21	0.18	0.36	0.06	0.06	0.30
HSSR(P)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	69.23	13.60	4.63	8.97	0.02	2.87	3.59	2.49	0.00	0.20	0.26	0.19
SD	29.97	5.27	2.27	3.74	0.04	1.65	1.72	0.89	0.00	0.05	0.05	0.04
Max	118.11	20.21	8.61	17.13	0.12	7.36	8.20	3.78	0.01	0.38	0.43	0.24
Min	30.77	4.92	1.76	3.16	0.00	0.89	1.29	0.98	0.00	0.17	0.22	0.08
CV	0.43	0.39	0.49	0.42	1.69	0.57	0.48	0.36	1.56	0.26	0.19	0.21

Table 2.61: Statistical results of PAHs (ng/m^3) in PM$_{2.5}$ at HSSR for winter (W), summer (S) and post-monsoon (P) seasons

HSSR (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	5.38	0.46	0.79	0.15	0.91	0.07	1.07	0.06	0.55	0.69	1.72	4.80	1.28	1.95	1.72	0.14	2.16	23.91
SD	2.45	0.23	0.55	0.12	0.39	0.06	0.38	0.01	0.72	0.25	0.71	2.18	0.58	0.89	0.72	0.07	0.76	5.21
Max	10.47	0.87	1.99	0.34	1.34	0.21	1.57	0.07	2.04	1.06	2.44	8.47	2.24	3.33	2.47	0.23	2.96	30.57
Min	3.36	0.15	0.36	0.00	0.38	0.03	0.72	0.04	0.00	0.37	0.77	2.02	0.57	0.80	0.67	0.05	1.02	16.49
CV	0.46	0.51	0.69	0.75	0.43	0.94	0.35	0.14	1.29	0.36	0.41	0.46	0.45	0.46	0.42	0.50	0.35	0.22
HSSR (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	6.66	1.42	2.03	0.25	1.15	0.08	0.64	1.66	1.48	0.90	0.78	1.96	0.36	0.76	0.40	0.04	1.54	22.09
SD	5.47	1.34	2.13	0.27	0.90	0.03	0.49	0.97	1.89	0.95	0.33	1.01	0.25	0.38	0.20	0.05	1.21	11.22
Max	13.77	5.11	7.05	0.81	2.49	0.13	1.71	3.77	5.79	3.44	1.27	3.34	0.87	1.31	0.69	0.15	4.48	37.64
Min	0.91	0.43	0.17	0.00	0.00	0.04	0.08	0.25	0.11	0.26	0.31	0.33	0.07	0.16	0.09	0.00	0.32	4.22
CV	0.82	0.95	1.05	1.08	0.78	0.41	0.77	0.59	1.28	1.06	0.42	0.52	0.69	0.51	0.50	1.13	0.78	0.51
HSSR (P)	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	0.43	0.87	1.14	0.04	0.34	1.42	0.88	1.28	0.15	0.49	0.84	2.36	0.70	2.24	0.80	0.09	1.76	15.83
SD	0.35	0.28	1.14	0.09	0.28	0.68	0.60	0.68	0.17	0.21	0.68	0.88	0.53	1.65	0.67	0.07	1.06	4.69
Max	1.12	1.28	3.58	0.23	0.95	2.39	1.88	2.29	0.46	0.89	1.95	3.80	1.48	4.54	1.86	0.21	3.39	21.08
Min	0.08	0.55	0.38	0.00	0.15	0.72	0.20	0.44	0.00	0.20	0.26	0.87	0.18	0.56	0.06	0.02	0.53	7.65
CV	0.81	0.32	1.00	2.37	0.82	0.48	0.68	0.53	1.10	0.44	0.81	0.37	0.75	0.74	0.83	0.81	0.60	0.30

Table 2.62: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at HSSR for winter (W), summer (S) and post-monsoon (P) seasons

HSSR(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	9.85	26.53	16.93	15.48	7.38	6.63	82.80
SD	2.79	6.34	4.80	11.36	4.48	0.49	28.28
CV	0.28	0.24	0.28	0.73	0.61	0.07	0.34
HSSR(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	6.59	29.16	18.25	20.01	6.19	3.85	84.05
SD	1.01	4.67	5.05	6.11	1.36	0.67	15.90
CV	0.15	0.16	0.28	0.31	0.22	0.17	0.19
HSSR(PM)	**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	7.77	27.65	17.13	19.42	2.85	1.09	75.91
SD	0.62	3.48	2.67	7.98	0.25	0.43	7.04
CV	0.08	0.13	0.16	0.41	0.09	0.40	0.09

Table 2.63: Statistical results of chemical characterization (μg/m^3) of PM_{10} at HSSR for winter (W) season

HSSR	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	298	29.89	12.19	0.54	11.36	6.23	25.55	6.78	3.90	2.96	1.28	4.33	0.00	0.09	3.85	4.13	16.44	38.19	1.45
SD	55	5.59	2.39	0.16	2.88	2.02	7.90	1.95	1.69	0.92	1.01	1.94	0.00	0.04	2.10	1.53	3.26	7.23	0.96
Max	397	39.81	15.97	0.86	17.03	10.11	39.14	11.19	7.35	5.30	3.82	8.29	0.00	0.16	7.73	7.16	22.25	48.12	3.73
Min	176	19.63	7.63	0.35	6.11	2.82	13.36	3.81	1.27	1.68	0.32	1.65	0.00	0.04	1.79	1.61	9.97	22.95	0.53
CV	0.18	0.19	0.20	0.30	0.25	0.32	0.31	0.29	0.43	0.31	0.79	0.45	0.61	0.40	0.55	0.37	0.20	0.19	0.66
HSSR	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.75	12.16	0.14	3.80	0.74	11.32	0.01	0.01	0.02	1.15	0.07	0.04	0.03	0.01	0.01	0.04	0.02	0.21	63.89
SD	2.99	2.43	0.06	1.61	0.44	2.44	0.00	0.01	0.01	1.03	0.02	0.02	0.00	0.00	0.00	0.01	0.01	0.16	1.73
Max	14.73	16.67	0.25	7.33	1.97	16.23	0.03	0.03	0.04	3.60	0.12	0.06	0.04	0.02	0.02	0.05	0.03	0.68	65.96
Min	3.76	7.46	0.05	1.82	0.31	6.90	0.01	0.01	0.01	0.17	0.04	0.01	0.02	0.00	0.00	0.02	0.01	0.07	59.89
CV	0.44	0.20	0.44	0.42	0.60	0.22	0.34	0.48	0.42	0.89	0.30	0.45	0.15	0.50	0.76	0.28	0.37	0.76	0.03

Table 2.64: Statistical results of chemical characterization (μg/m^3) of $PM_{2.5}$ at HSSR for winter (W) season

HSSR	$PM_{2.5}$	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	149.79	31.03	20.92	10.11	0.31	5.53	4.03	17.89	3.42	2.10	2.07	0.50	2.00	0.00	0.06	1.36	2.73	6.57	15.77
SD	29.48	5.78	3.92	1.98	0.06	1.32	1.33	6.17	1.33	0.70	0.79	0.29	0.79	0.00	0.03	0.65	0.82	1.66	3.74
Max	212.47	40.95	27.87	13.25	0.43	8.37	6.60	32.15	6.77	3.23	4.07	1.01	4.07	0.00	0.13	2.57	3.83	9.67	22.20
Min	97.75	20.07	13.74	6.33	0.21	3.64	2.14	9.45	1.72	0.91	0.70	0.16	1.11	0.00	0.03	0.56	1.39	4.45	10.75
CV	0.20	0.19	0.19	0.20	0.20	0.24	0.33	0.34	0.39	0.34	0.38	0.58	0.39	0.56	0.56	0.48	0.30	0.25	0.24
HSSR	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.16	4.58	0.08	1.56	0.36	4.13	0.01	0.01	0.01	0.66	0.04	0.02	0.02	0.00	0.00	0.02	0.01	0.13	68.77
SD	0.98	1.35	0.04	0.16	0.17	1.30	0.00	0.00	0.01	0.51	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.09	2.21
Max	5.47	7.18	0.18	1.78	0.73	6.71	0.02	0.01	0.03	1.84	0.06	0.04	0.03	0.01	0.02	0.03	0.02	0.35	72.70
Min	1.90	2.68	0.02	1.21	0.14	2.32	0.00	0.00	0.00	0.14	0.02	0.00	0.02	0.00	0.00	0.02	0.01	0.05	64.60
CV	0.31	0.29	0.56	0.10	0.49	0.31	0.39	0.31	0.52	0.77	0.27	0.46	0.10	0.53	1.10	0.10	0.37	0.65	0.03

Table 2.65: Statistical results chemical characterization (μg/m^3) of PM_{10} at HSSR for summer (S) season

HSSR	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	224	21.09	11.62	0.42	10.21	6.98	18.22	2.86	6.06	2.67	1.06	6.25	0.02	0.13	3.85	6.07	10.74	25.24	0.66
SD	67	3.03	3.58	0.36	4.19	3.83	5.61	1.13	2.18	0.79	0.70	1.98	0.00	0.06	1.46	3.81	3.69	8.68	0.47
Max	353	26.07	18.34	1.62	15.85	15.18	29.46	4.87	10.00	3.92	2.54	9.88	0.03	0.26	6.36	15.19	20.00	46.54	1.96
Min	122	14.41	6.58	0.06	4.33	2.19	9.34	1.43	3.20	1.69	0.24	2.85	0.01	0.06	1.94	2.30	5.47	13.97	0.23
CV	0.30	0.14	0.31	0.87	0.41	0.55	0.31	0.39	0.36	0.29	0.66	0.32	0.22	0.41	0.38	0.63	0.34	0.34	0.71
HSSR	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	11.32	7.87	0.80	0.07	0.86	6.82	0.01	0.03	0.04	0.68	0.00	0.01	0.05	0.09	0.01	0.01	0.17	0.17	67.41
SD	5.88	2.92	0.40	0.02	0.44	2.63	0.00	0.02	0.03	0.46	0.00	0.01	0.02	0.05	0.00	0.00	0.08	0.15	3.06
Max	23.47	15.01	1.61	0.11	1.79	13.47	0.02	0.06	0.10	1.72	0.01	0.02	0.11	0.20	0.01	0.01	0.32	0.60	70.89
Min	4.08	3.50	0.21	0.04	0.37	2.76	0.01	0.01	0.01	0.14	0.00	0.01	0.02	0.03	0.00	0.01	0.07	0.04	59.80
CV	0.52	0.37	0.51	0.34	0.51	0.39	0.32	0.56	0.70	0.67	0.84	0.43	0.46	0.57	0.34	0.23	0.44	0.86	0.05

Table 2.66: Statistical results of chemical characterization (μg/m^3) of $PM_{2.5}$ at HSSR for summer (S) season

HSSR	$PM_{2.5}$	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	114	14.76	9.65	0.22	5.04	3.17	10.50	1.25	2.87	1.49	0.57	2.44	0.01	0.06	1.85	2.65	4.44	10.55	0.27
SD	23	2.12	2.97	0.17	1.41	1.74	3.04	0.41	0.93	0.35	0.44	0.80	0.00	0.02	0.59	1.44	0.87	2.67	0.15
Max	156	18.25	15.22	0.68	7.32	6.92	16.87	1.94	4.75	1.97	1.62	4.03	0.01	0.11	2.52	6.69	5.69	16.24	0.62
Min	62	10.08	5.46	0.05	2.48	0.82	6.38	0.66	1.65	0.59	0.12	0.97	0.00	0.02	0.96	1.03	2.29	5.06	0.09
CV	0.20	0.14	0.31	0.76	0.28	0.55	0.29	0.33	0.32	0.24	0.77	0.33	0.22	0.43	0.32	0.55	0.20	0.25	0.56
HSSR	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.43	3.33	0.36	0.03	0.44	3.27	0.01	0.01	0.02	0.29	0.00	0.01	0.03	0.04	0.00	0.00	0.08	0.08	69.97
SD	3.42	0.98	0.21	0.01	0.29	1.25	0.00	0.01	0.01	0.18	0.00	0.00	0.02	0.03	0.00	0.00	0.04	0.08	2.67
Max	15.75	5.36	0.96	0.06	1.20	6.89	0.01	0.03	0.04	0.69	0.01	0.01	0.08	0.14	0.01	0.01	0.17	0.34	74.91
Min	2.18	1.35	0.13	0.01	0.17	1.62	0.00	0.00	0.00	0.07	0.00	0.00	0.01	0.02	0.00	0.00	0.03	0.02	66.24
CV	0.63	0.29	0.60	0.43	0.66	0.38	0.48	0.56	0.62	0.63	0.78	0.40	0.61	0.69	0.50	0.38	0.50	0.94	0.04

Table 2.67: Statistical results chemical characterization (μg/m^3) of PM_{10} at HSSR for Post-monsoon (P) season

HSSR	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	140	12.10	5.58	0.30	2.08	4.44	15.46	1.42	2.96	1.23	0.35	3.87	0.00	0.03	2.36	1.87	7.01	17.07	0.26
SD	62	4.21	2.74	0.20	1.02	2.34	11.88	0.68	1.45	0.93	0.13	2.24	0.00	0.02	1.55	1.02	2.86	6.76	0.10
Max	256	17.92	10.37	0.95	4.48	8.64	37.36	3.12	6.70	3.00	0.55	8.57	0.00	0.06	5.24	3.78	12.48	29.99	0.42
Min	60	4.51	2.12	0.14	0.69	0.98	3.53	0.41	1.51	0.14	0.11	0.93	0.00	0.00	0.58	0.36	3.40	7.57	0.12
CV	0.44	0.35	0.49	0.67	0.49	0.53	0.77	0.48	0.49	0.76	0.38	0.58	0.96	0.71	0.66	0.55	0.41	0.40	0.40
HSSR	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	7.84	5.05	0.20	0.14	0.51	4.26	0.00	0.01	0.01	0.42	0.00	0.00	0.01	0.01	0.00	0.00	0.05	0.10	63.75
SD	5.29	2.19	0.15	0.02	0.41	1.91	0.00	0.00	0.01	0.38	0.00	0.00	0.01	0.01	0.00	0.00	0.04	0.06	2.48
Max	15.71	9.08	0.48	0.16	1.33	7.66	0.00	0.01	0.03	1.24	0.01	0.01	0.03	0.02	0.00	0.01	0.16	0.24	67.25
Min	1.32	2.23	0.00	0.10	0.00	1.60	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	58.90
CV	0.67	0.43	0.76	0.14	0.80	0.45	0.46	0.63	0.58	0.91	0.69	0.55	0.58	0.64	0.53	1.49	0.91	0.56	0.04

Table 2.68: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at HSSR for Post-monsoon (P) season

HSSR	$PM_{2.5}$	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	69	8.47	4.63	0.17	1.09	2.11	8.27	0.61	1.68	0.65	0.18	1.38	0.00	0.02	1.36	1.04	3.41	8.31	0.11
SD	30	2.95	2.27	0.12	0.67	1.37	6.20	0.34	0.90	0.45	0.07	0.68	0.00	0.01	1.22	0.72	2.07	4.72	0.03
Max	118	12.54	8.61	0.58	2.70	5.59	21.21	1.27	3.78	1.43	0.30	2.87	0.00	0.05	4.10	2.43	8.77	20.45	0.18
Min	31	3.16	1.76	0.09	0.53	0.61	1.82	0.24	0.66	0.11	0.07	0.56	0.00	0.00	0.29	0.18	1.48	3.69	0.07
CV	0.43	0.35	0.49	0.70	0.62	0.65	0.75	0.56	0.53	0.70	0.37	0.49	1.31	0.75	0.90	0.69	0.61	0.57	0.30
HSSR	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.73	2.34	0.12	0.10	0.31	1.99	0.00	0.00	0.01	0.30	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.08	66.50
SD	1.56	1.43	0.10	0.02	0.29	1.34	0.00	0.00	0.00	0.29	0.00	0.00	0.01	0.00	0.00	0.00	0.02	0.05	2.66
Max	6.60	5.98	0.31	0.15	0.96	5.34	0.00	0.01	0.02	1.13	0.01	0.00	0.02	0.01	0.00	0.01	0.09	0.22	70.71
Min	1.02	0.98	0.00	0.06	0.00	0.56	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	59.84
CV	0.57	0.61	0.80	0.25	0.95	0.67	0.70	0.73	0.68	0.97	0.79	0.65	0.81	0.64	0.62	1.29	0.93	0.72	0.04

Table 2.69: Correlation Matrix for PM_{10} and its composition at HSSR for winter season

HSSR (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	0.88	0.88	0.82	0.66	0.44	0.59	0.58	0.28	0.43	0.73	0.05	0.49	0.95
TC		1.00	0.99	0.96	0.42	0.20	0.51	0.50	0.26	0.33	0.61	-0.04	0.40	0.77
OC			1.00	0.91	0.43	0.20	0.53	0.47	0.25	0.32	0.62	-0.02	0.38	0.77
EC				1.00	0.38	0.17	0.42	0.54	0.25	0.32	0.55	-0.09	0.42	0.71
NO_3^-					0.30	-0.13	1.00	0.66	0.10	0.69	0.40	0.32	0.27	0.42
SO_4^{-2}					0.66	0.22		1.00	0.14	0.83	0.72	0.42	0.70	0.39
NH_4^+					0.46	-0.08			0.33	1.00	0.61	0.51	0.52	0.24
Metals					0.61	0.54			0.21		0.66	-0.05	0.37	1.00

Table 2.70: Correlation matrix for $PM_{2.5}$ and its composition at HSSR for winter season

HSSR (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	0.73	0.74	0.67	0.51	0.04	0.59	0.70	0.71	0.76	0.72	0.42	0.69	0.95
TC		1.00	0.99	0.96	0.40	-0.12	0.39	0.45	0.55	0.32	0.48	0.16	0.40	0.53
OC			1.00	0.91	0.47	-0.06	0.43	0.41	0.57	0.30	0.54	0.20	0.43	0.55
EC				1.00	0.22	-0.24	0.27	0.50	0.48	0.33	0.35	0.06	0.31	0.46
NO_3^-					0.22	0.05	1.00	0.56	0.57	0.54	0.49	0.64	0.53	0.52
SO_4^{-2}					0.09	-0.30		1.00	0.58	0.84	0.55	0.44	0.40	0.57
NH_4^+					0.20	0.03			0.59	1.00	0.64	0.68	0.52	0.74
Metals					0.54	0.21			0.60		0.70	0.44	0.73	1.00

Table 2.71: Correlation matrix for PM_{10} and its composition at HSSR for summer season

HSSR (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	0.62	0.78	0.41	0.23	0.87	0.73	0.71	0.83	0.71	0.87	0.68	0.70	0.99
TC		1.00	0.92	0.95	0.39	0.76	0.82	0.59	0.36	0.22	0.69	0.63	0.47	0.55
OC			1.00	0.75	0.37	0.83	0.80	0.60	0.60	0.51	0.83	0.66	0.60	0.72
EC				1.00	0.37	0.61	0.74	0.52	0.12	-0.05	0.49	0.53	0.30	0.34
NO_3^-					0.53	0.81	1.00	0.59	0.52	0.38	0.81	0.78	0.59	0.68
SO_4^{-2}					0.21	0.80		1.00	0.46	0.24	0.68	0.76	0.62	0.69
NH_4^+					0.03	0.56			0.88	1.00	0.68	0.45	0.68	0.71
Metals					0.23	0.82			0.82		0.83	0.63	0.70	1.00

Table 2.72: Correlation matrix for $PM_{2.5}$ and its composition at HSSR for summer season

HSSR (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	0.75	0.87	0.58	0.20	0.51	0.74	0.58	0.54	0.13	0.60	0.43	0.58	0.97
TC		1.00	0.91	0.96	0.30	0.69	0.84	0.33	0.26	-0.07	0.57	0.59	0.48	0.62
OC			1.00	0.75	0.21	0.69	0.73	0.33	0.50	0.16	0.60	0.63	0.48	0.77
EC				1.00	0.33	0.61	0.82	0.30	0.05	-0.23	0.49	0.50	0.43	0.45
NO_3^-					0.46	0.47	1.00	0.22	0.16	-0.21	0.39	0.52	0.34	0.68
SO_4^{-2}					-0.05	0.09		1.00	0.19	-0.22	0.61	0.15	0.58	0.57
NH_4^+					-0.28	0.21			0.52	1.00	0.01	0.03	0.24	0.13
Metals					0.19	0.36			0.51		0.48	0.36	0.51	1.00

Table 2.73: Correlation matrix for PM_{10} and its composition at HSSR for Post-monsoon season

HSSR (P)	PM_{10}	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	0.84	0.97	0.75	0.62	0.53	0.91	0.80	0.70	0.90	0.54	0.89	1.00
TC		1.00	0.98	0.94	0.62	0.49	0.60	0.78	0.77	0.53	0.80	0.45	0.78	0.91
OC			1.00	0.84	0.53	0.38	0.62	0.71	0.71	0.44	0.72	0.40	0.71	0.81
EC				1.00	0.71	0.60	0.51	0.80	0.80	0.62	0.84	0.48	0.81	0.97
NO_3^-					0.14	0.35	1.00	0.28	0.42	0.02	0.37	0.46	0.58	0.54
SO_4^{-2}					0.76	0.56		1.00	0.70	0.77	0.90	0.46	0.86	0.88
NH_4^+					0.83	0.45			0.65	1.00	0.61	0.29	0.69	0.69
Metals					0.74	0.62			0.79		0.88	0.56	0.87	1.00

Table 2.74: Correlation matrix for $PM_{2.5}$ and its composition at HSSR for Post-monsoon season

HSSR (P)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.91	0.83	0.92	0.40	0.16	0.30	0.94	0.82	0.51	0.86	0.59	0.88	0.92
TC		1.00	0.97	0.95	0.41	0.11	0.50	0.78	0.76	0.35	0.78	0.49	0.86	0.84
OC			1.00	0.84	0.30	0.00	0.50	0.68	0.65	0.25	0.71	0.39	0.75	0.73
EC				1.00	0.52	0.25	0.45	0.85	0.84	0.44	0.81	0.57	0.92	0.91
NO_3^-					0.06	-0.08	1.00	0.04	0.21	0.04	0.17	0.26	0.29	0.24
SO_4^{-2}					0.57	0.33		1.00	0.83	0.65	0.87	0.56	0.88	0.95
NH_4^+					0.62	0.24			0.39	1.00	0.47	0.45	0.57	0.65
Metals					0.72	0.44			0.86		0.84	0.56	0.95	1.00

2.4.5 HSS Baghera (HSSB)

The sampling period was January 24, 2021 - February 07, 2021, for winter, May 01 – 10, 2021 for summer and September 27, 2021 - October 11, 2021, for post-monsoon.

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

A time series of 24-hour average concentrations of PM_{10} and $PM_{2.5}$ at HSSB is shown for winter (Figure 2.68), summer (Figure 2.69) and post-monsoon (Figure 2.70). Average levels at this site were: $PM_{2.5}$: 116±35 (winter), 42±11 µg/m^3 (summer) and 46±22 µg/m^3 (post-monsoon) and PM_{10}: 181±56 (winter), 65±16 µg/m^3 (summer) and 78±38 µg/m^3 (post-monsoon). In winter, the $PM_{2.5}$ levels were about 2.0 times higher than the NAAQS (60 µg/m^3) and PM_{10} levels were 1.8 times higher than the NAAQS (100 µg/m^3). In summer and post-monsoon, the $PM_{2.5}$ and PM_{10} levels were within the NAAQS limits.

A statistical summary of PM concentrations is presented in Table 2.79 - Table 2.84 for winter, summer and post-monsoon season.

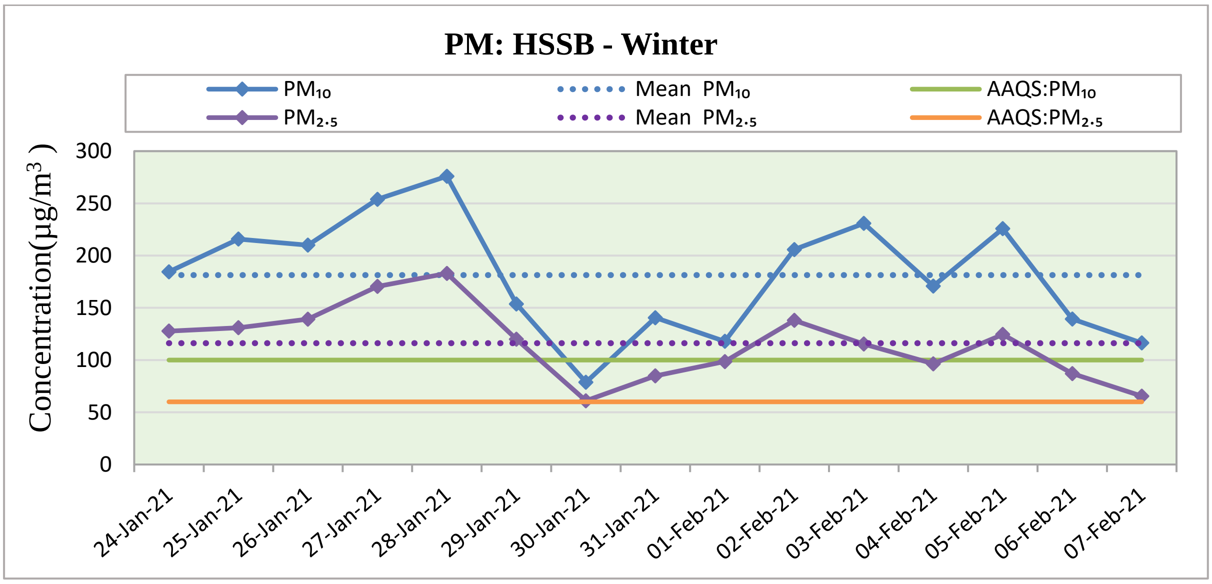


Figure 2.68: PM Concentrations at HSSB for Winter Season

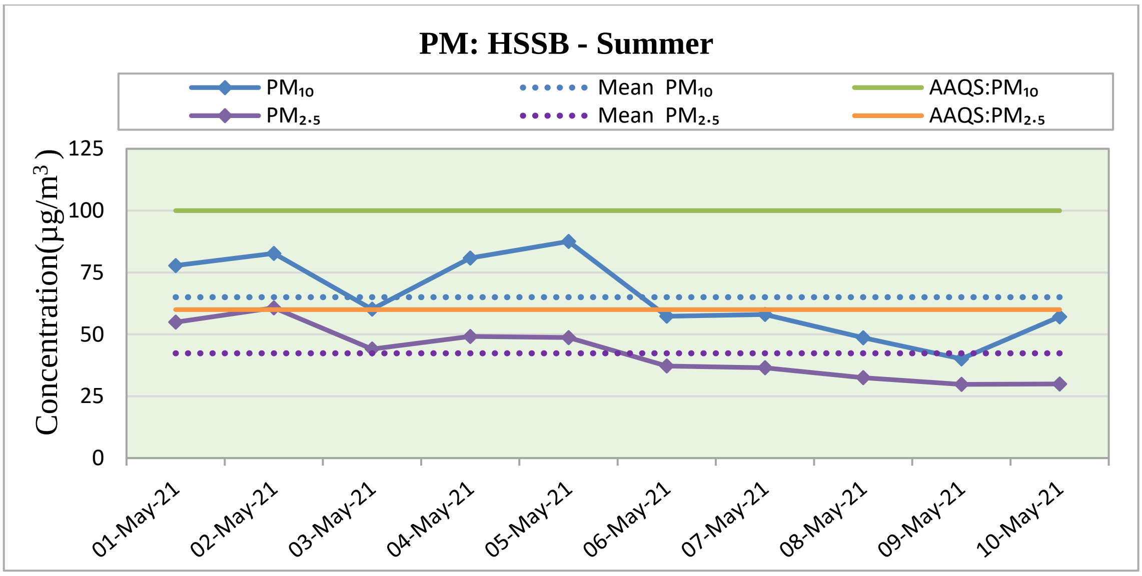


Figure 2.69: PM Concentrations at HSSB for Summer Season

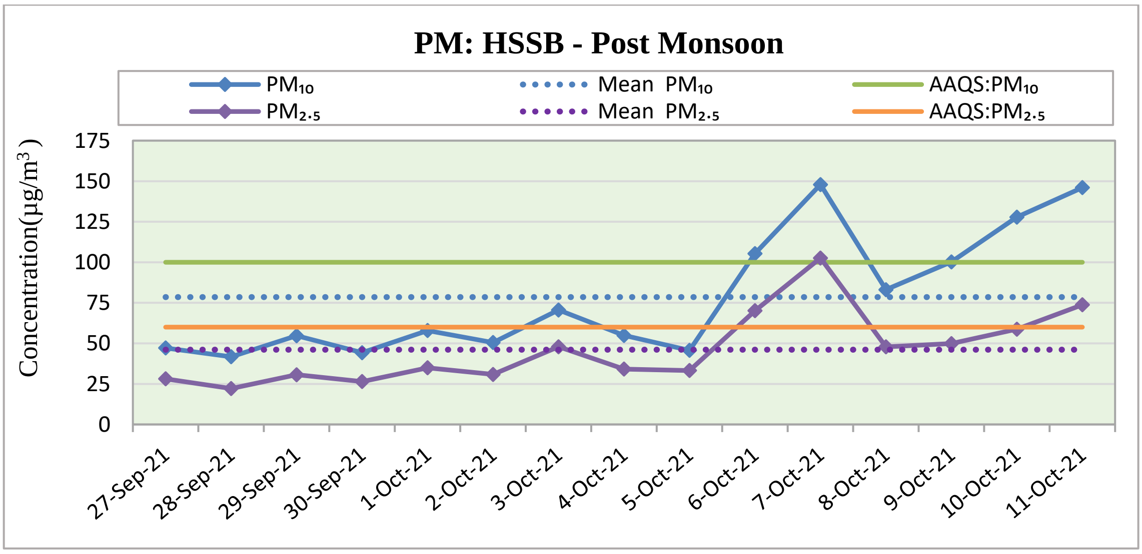


Figure 2.70: PM Concentrations at HSSB for Post-monsoon Season

2.4.5.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter, summer and post-monsoon seasons (Figure 2.71 to Figure 2.73). It was observed that SO_2 concentrations were low and met the air quality standard. NO_2 levels are also under the national standard with an average of 15 days at 25±8 µg/m^3 in winter, 11±2 µg/m^3 in summer season and 12±3 µg/m^3 in post-monsoon season (Table 2.75). The summer concentration of NO_2 dropped dramatically similarly to $PM_{2.5}$ levels. Although, NO_2 is certainly a matter of concern these values can largely be attributed to vehicular pollution and industrial coal combustion.

Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams, local open burning etc.

The Mean concentrations of BTX are presented in Figure 2.74 and the statistical summary is in Table 2.75. The total BTX level is observed 10±7 μg/m^3 (Benzene: 7.72 and Toluene: .13 μg/m^3) in winter, 22±1 μg/m^3 (Benzene: 4.47; Toluene: 1 and o-xylene: 11 μg/m^3) in summer and 14±1 μg/m^3 (Benzene: 2.4; Toluene: 0.5; p-xylene: 4.37 and o-xylene: 6.6 μg/m^3) in post-monsoon seasons. The maximum BTX concentration was observed at 25 μg/m^3 in winter, 24 μg/m^3 in summer and 16 μg/m^3 in post-monsoon seasons. The BTX levels were higher during winter than in the summer.

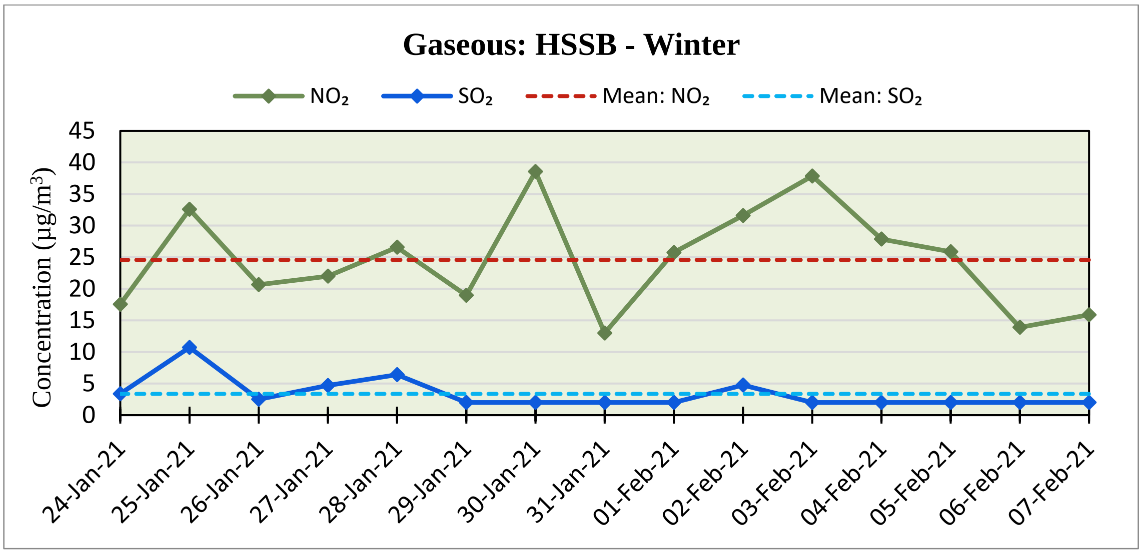


Figure 2.71: SO_2 and NO_2 Concentrations at HSSB for Winter Season

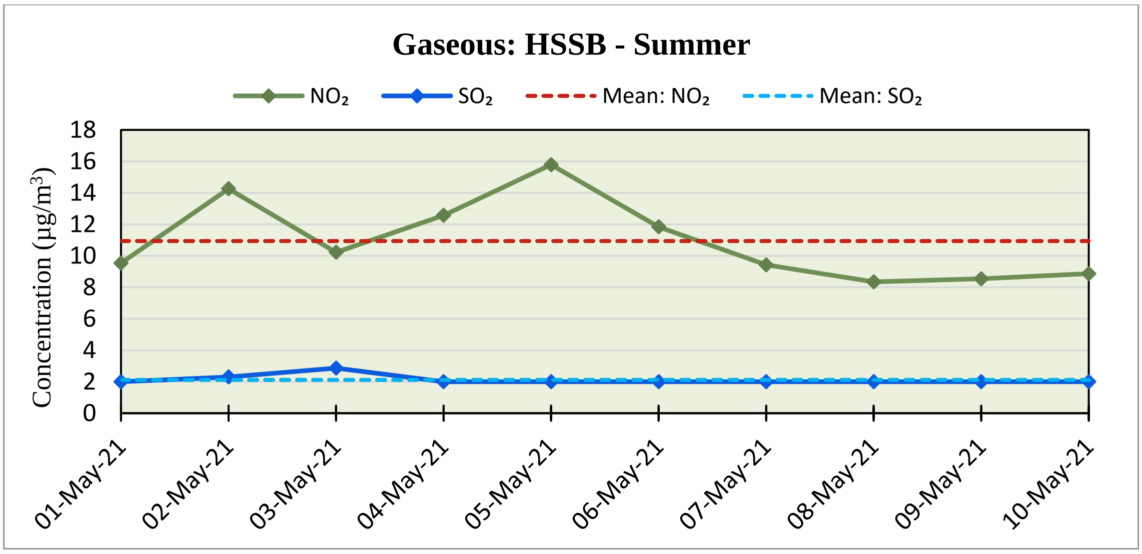


Figure 2.72: SO_2 and NO_2 Concentrations at HSSB for Summer Season

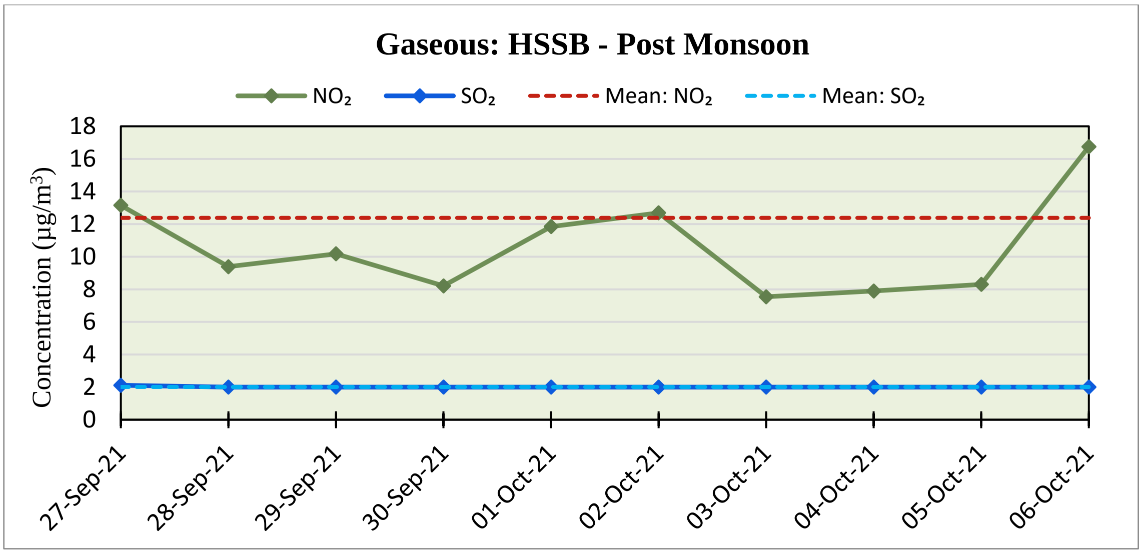


Figure 2.73: SO_2 and NO_2 Concentrations at HSSB for Post Monsson Season

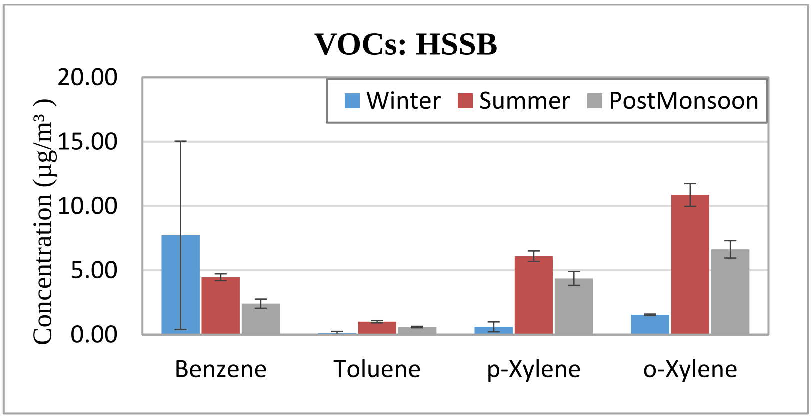


Figure 2.74: VOCs concentration at HSSB

2.4.5.3 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 2.75 (a) and (b) for winter, summer, and post-monsoon seasons. Organic carbon is observed significantly higher (winter: 16.41±4.09, summer: 6.45±1.55 and post-monsoon: 6.18±4.23 µg/m^3) than the elemental carbon (winter: 8.06±1.69 summer: 3.32±0.99 and post-monsoon: 2.91±1.65 µg/m^3). However, the ratio of OC3/TC is observed higher that indicating the formation of secondary organic carbon in the atmosphere. It is also observed that the OC and EC are higher in the winter 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 2.76 for winter, summer, and post-monsoon seasons.

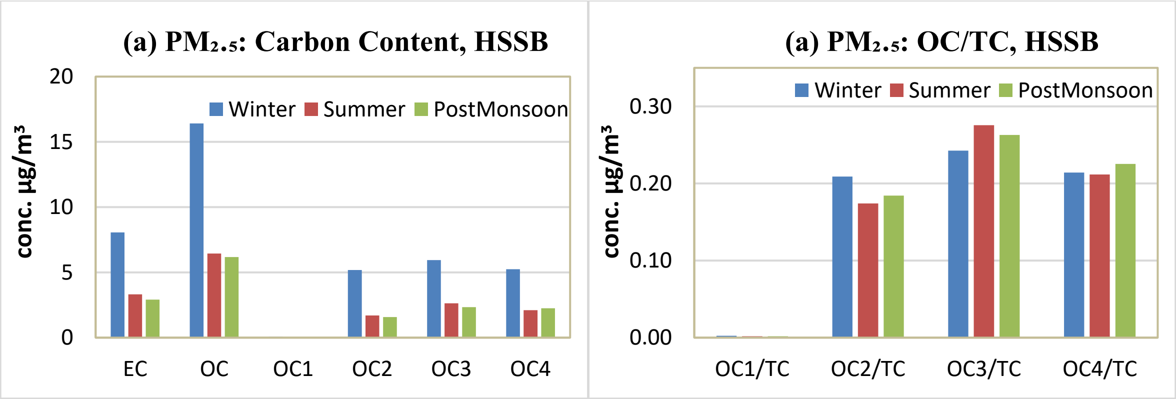


Figure 2.75: EC and OC Content in $PM_{2.5}$ at HSSB

2.4.5.4 PAHs in $PM_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.76 shows the average measured concentration of PAHs at KRNK for winter, summer and post-monsoon seasons. A statistical summary of PAHs is presented in Table 2.77 for winter, summer and post-monsoon 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 PAH concentrations in winter were 13±4 ng/m^3, in summer: 7±3 ng/m^3 and in post-monsoon: 15±5 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are B(b)F (3 ng/m^3), B(ghi)P (1.4 ng/m^3), BaP (1.1 ng/m^3) and DmP (3.41 ng/m^3) for winter season and B(b)F (1.16 ng/m^3), Phe (1.18 ng/m^3) for summer season. For post-monsoon BbP (1.31 ng/m^3), Ant (1.26 ng/m^3), AcP (1.64 ng/m^3), B(b)F (2.25 ng/m^3) and BaP (2.11 ng/m^3)

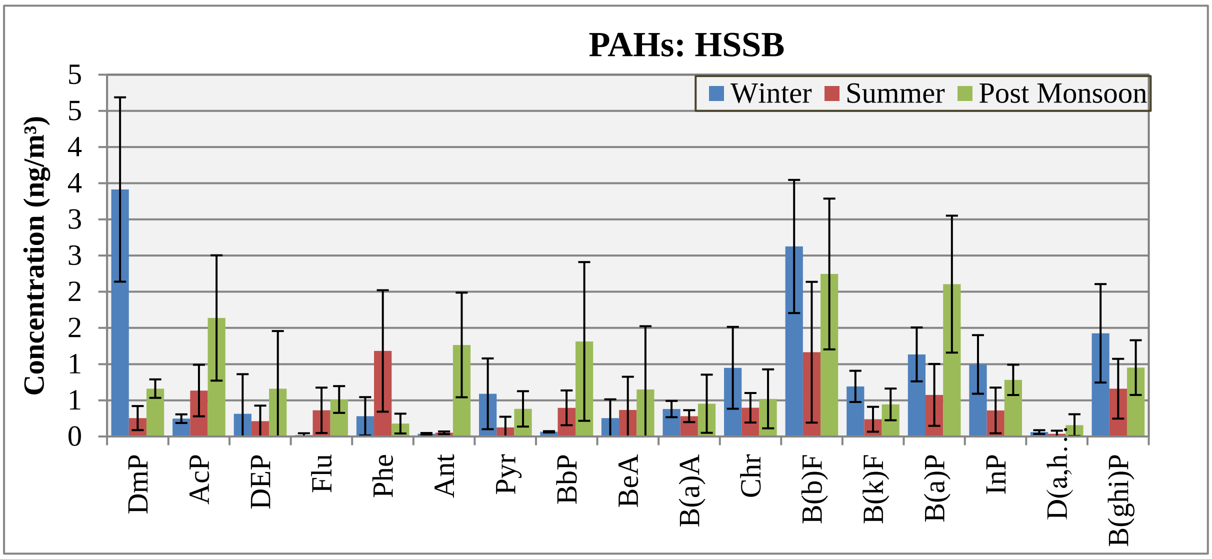


Figure 2.76: PAHs Concentrations in $PM_{2.5}$ at HSSB

2.4.5.5 Molecular Markers in $PM_{2.5}$

Total six molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, 17 β(H) 21 β(H)_hopane, n-Hentriacontane, n-Tritriacontane and n-Pentatriacontane. 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 2.77 and Table 2.78 show the levels of six molecular markers. The total concentration of markers was 100±16.77 ng/m^3 in winter, 41.75±6.05 ng/m^3 in summer and 87.06±23.46 ng/m^3 in post-monsoon. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

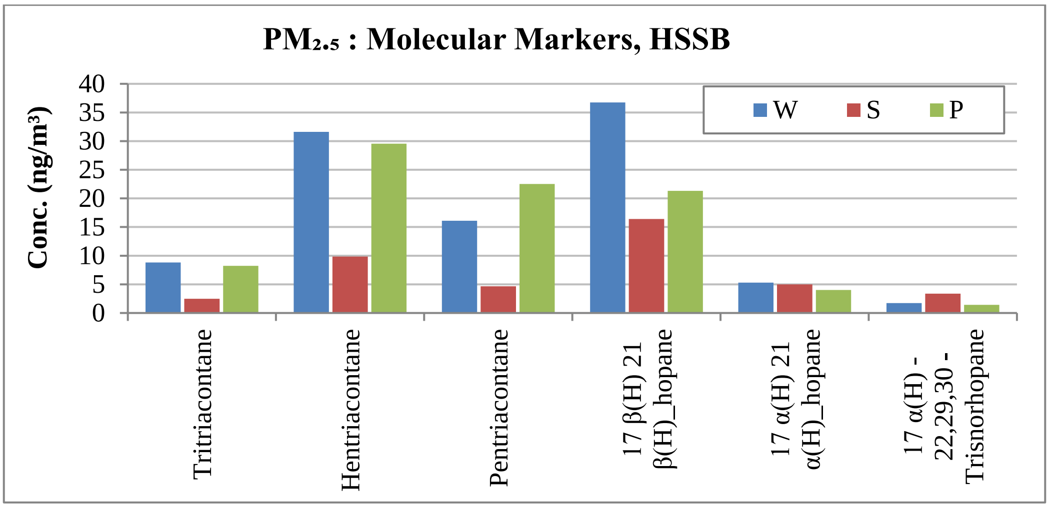


Figure 2.77: Molecular Markers in $PM_{2.5}$ at HSSB

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

Graphical presentations of chemical species are shown for winter, summer and post-monsoon season at HSSB for PM_{10} (Figure 2.78) and $PM_{2.5}$ (Figure 2.79). 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 2.79 - Table 2.84 for winter, summer and post-monsoon seasons.

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 2.85 - Table 2.90 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 2.80(a) and (b) for winter, Figure 2.81(a) and (b) for summer and Figure 2.82 (a) and (b) for post-monsoon season.

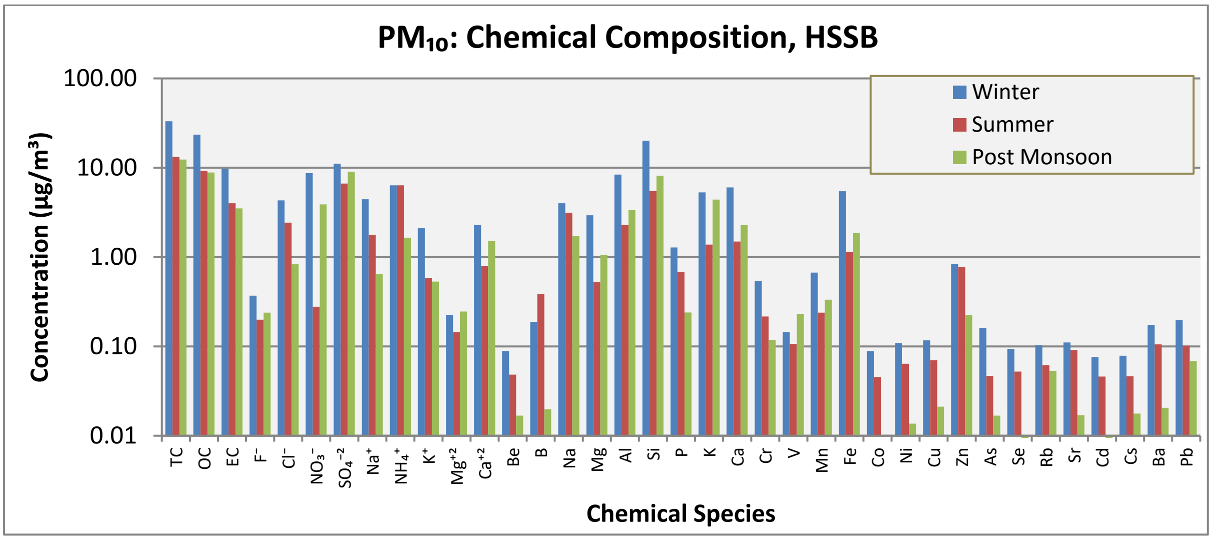


Figure 2.78: Concentrations of species in PM_{10} at HSSB

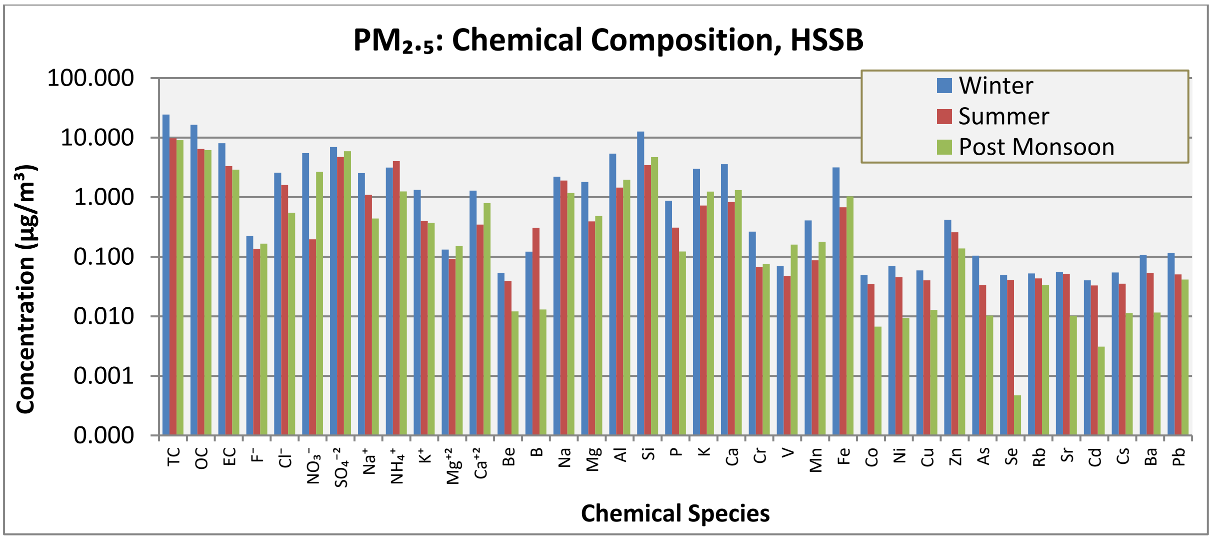


Figure 2.79: Concentrations of species in $PM_{2.5}$ at HSSB

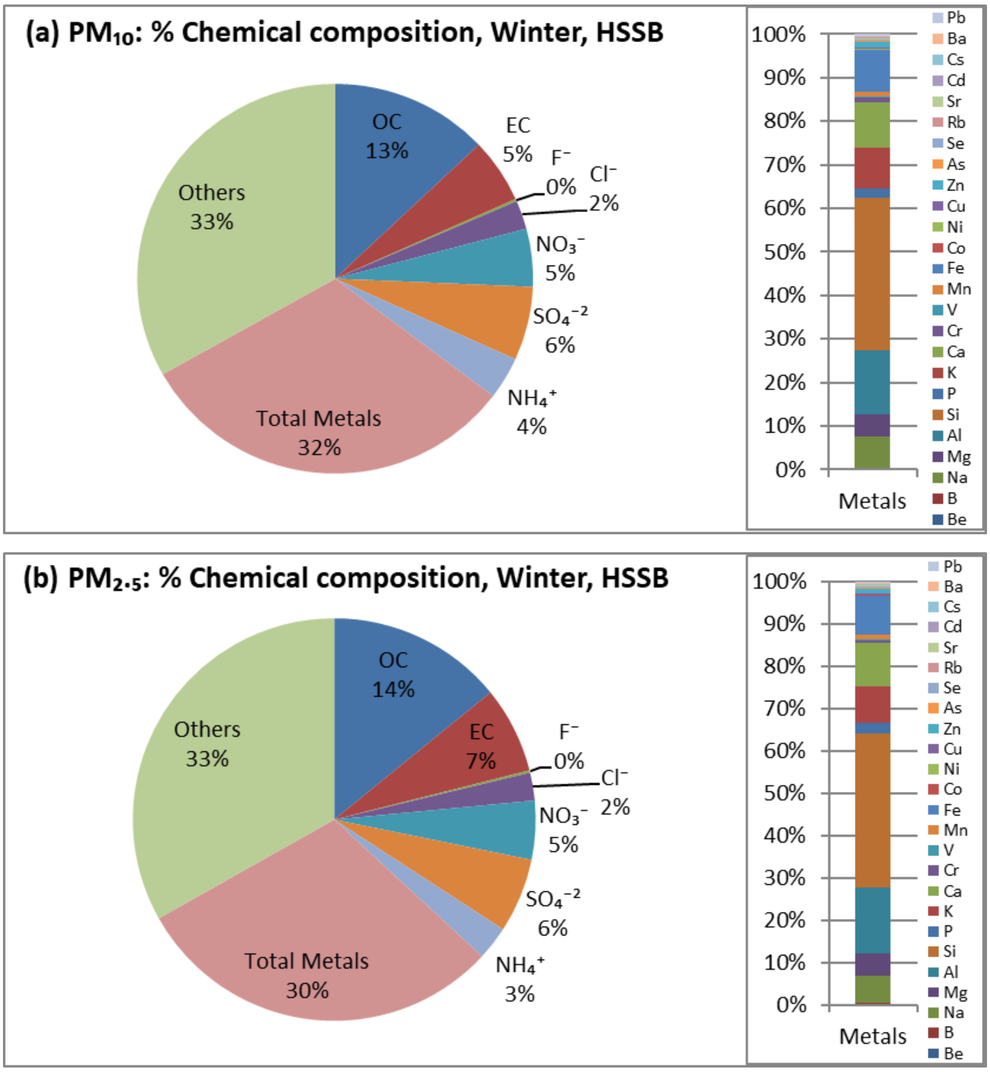
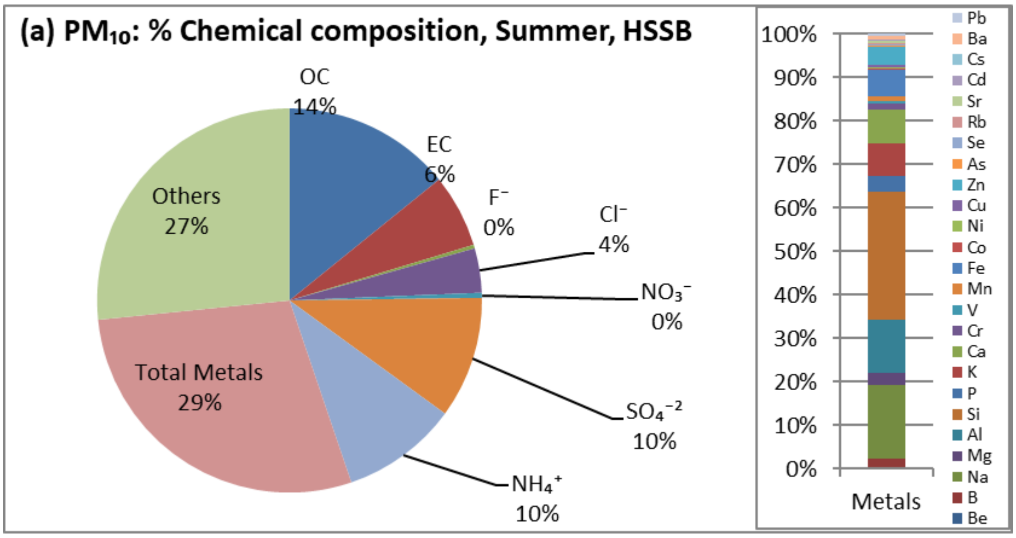


Figure 2.80: Percentage distribution of species in PM at HSSB for Winter Season



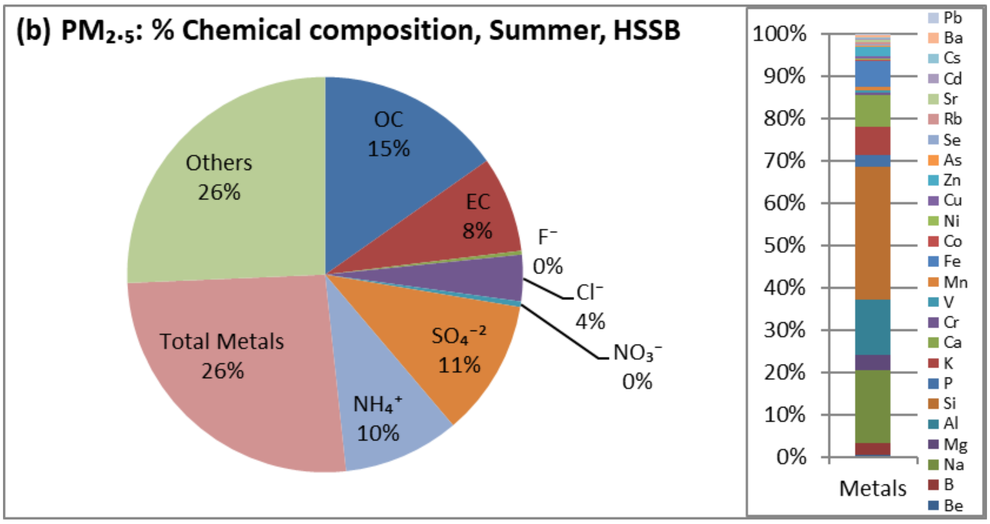


Figure 2.81: Percentage distribution of species in PM at HSSB for Summer Season

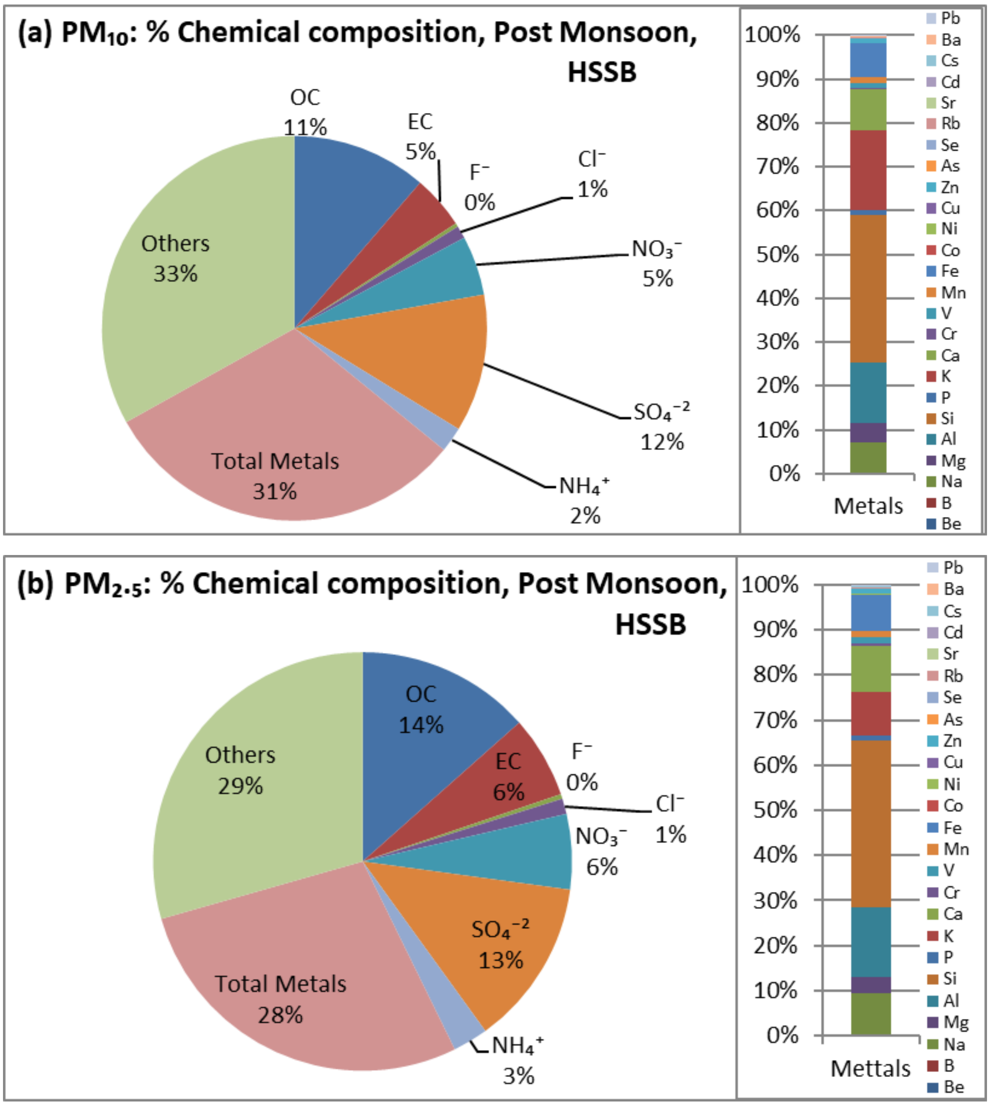


Figure 2.82: Percentage distribution of species in PM at HSSB for Post-monsoon Season

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

A graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown for winter, summer and post-monsoon season (Figure 2.83) at HSSB. 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 is having fine mode during winter (64 %), summer (65%) and post-monsoon (59%). The major species contributing to fine mode are TC, OC, EC, SO_4^{-2}, Na^+, NH_4^+, K^+, B, K, V, Cu, Zn, Cd and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Mg, Al, Si, P, Ca, Cr, Ni and Fe are contributing significantly in fine mode.

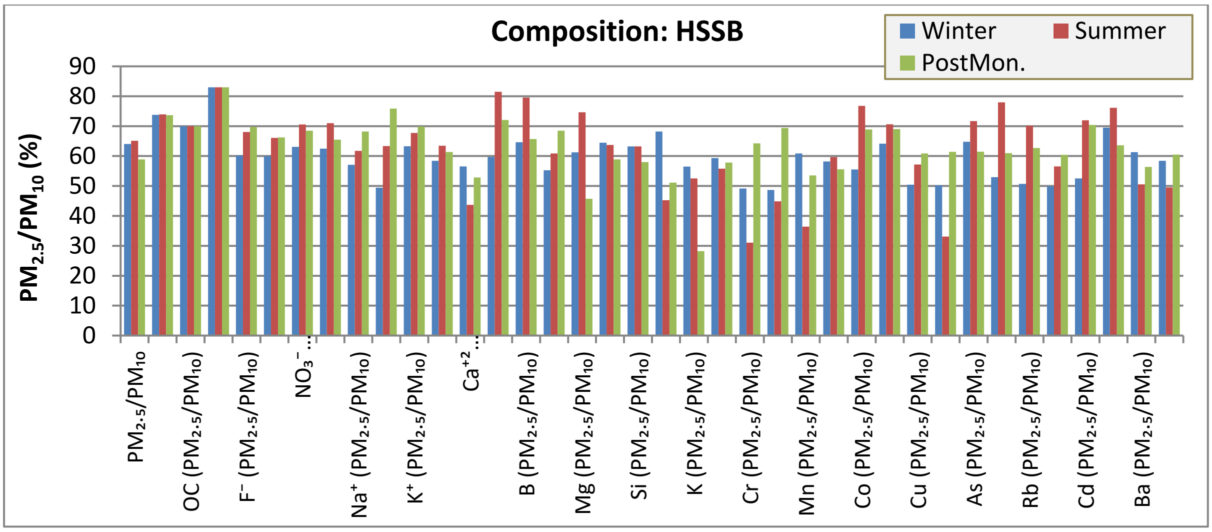


Figure 2.83: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at HSSB

Table 2.75: Statistical results of gaseous pollutants (µg/m^3) at HSSB for winter (W), summer (S) and post-monsoon (P) seasons

HSSB (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.57	3.36	7.72	0.13	0.61	1.54	10.00
SD	7.87	2.37	7.32	0.13	0.39	0.06	7.29
Max	38.55	10.72	22.84	0.39	1.40	1.67	24.85
Min	13.00	2.00	0.00	0.00	0.35	1.52	2.23
CV	0.32	0.71	0.95	1.03	0.64	0.04	0.73
HSSB (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	10.94	2.12	4.47	1.01	6.10	10.86	22.44
SD	2.44	0.27	0.26	0.09	0.41	0.88	1.04
Max	15.79	2.87	4.79	1.11	6.42	12.11	23.73
Min	8.35	2.00	4.16	0.87	5.22	9.76	20.78
CV	0.22	0.13	0.06	0.09	0.07	0.08	0.05
HSSB (P)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	12.38	2.01	2.41	0.59	4.37	6.63	14.00
SD	3.60	0.03	0.36	0.06	0.54	0.67	1.36
Max	18.57	2.11	2.95	0.67	5.03	7.33	15.55
Min	7.54	2.00	2.09	0.53	3.56	5.51	12.00
CV	0.29	0.01	0.15	0.09	0.12	0.10	0.10

Table 2.76: Statistical results of carbon contents (μg/m^3) in $PM_{2.5}$ at HSSB for winter (W), summer (S) and post-monsoon (P) seasons

HSSB(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	116.17	24.47	8.06	16.41	0.06	5.18	5.94	5.24	0.00	0.21	0.24	0.21
SD	33.66	5.37	1.69	4.09	0.04	1.62	1.53	1.21	0.00	0.02	0.03	0.02
Max	182.98	34.06	11.78	24.49	0.12	9.00	9.21	7.76	0.00	0.28	0.28	0.24
Min	61.00	16.45	4.96	11.49	0.00	3.50	4.32	3.44	0.00	0.18	0.20	0.18
CV	0.29	0.22	0.21	0.25	0.60	0.31	0.26	0.23	0.53	0.12	0.11	0.08
HSSB(S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	42.35	9.77	3.32	6.45	0.02	1.71	2.63	2.10	0.00	0.17	0.28	0.21
SD	10.83	2.51	0.99	1.55	0.02	0.45	0.47	0.69	0.00	0.01	0.04	0.02
Max	60.73	13.68	4.78	8.90	0.06	2.27	3.40	3.20	0.01	0.19	0.36	0.23
Min	29.78	5.81	1.81	4.00	0.00	0.81	2.07	1.12	0.00	0.14	0.23	0.18
CV	0.26	0.26	0.30	0.24	1.13	0.26	0.18	0.33	1.28	0.08	0.14	0.09
HSSB(P)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	46.10	9.09	2.91	6.18	0.02	1.57	2.34	2.25	0.00	0.18	0.26	0.23
SD	22.21	5.83	1.65	4.23	0.03	0.74	1.34	2.26	0.00	0.02	0.03	0.05
Max	102.62	26.31	7.08	19.23	0.10	3.32	5.96	9.90	0.01	0.22	0.29	0.38
Min	22.15	4.56	1.31	3.20	0.00	0.94	1.05	0.89	0.00	0.13	0.20	0.19
CV	0.48	0.64	0.57	0.69	1.48	0.47	0.57	1.00	1.47	0.13	0.10	0.22

Table 2.77: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at HSSB for winter (W), summer (S) and post-monsoon (P) seasons

HSSB (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	3.41	0.25	0.31	0.02	0.28	0.04	0.59	0.06	0.25	0.38	0.95	2.63	0.69	1.13	1.00	0.06	1.43	13.48
SD	1.27	0.06	0.55	0.03	0.26	0.01	0.49	0.01	0.26	0.11	0.57	0.92	0.22	0.37	0.40	0.03	0.68	4.25
Max	5.53	0.35	1.53	0.07	0.82	0.05	1.68	0.07	0.69	0.58	2.20	4.29	1.14	1.80	1.60	0.10	2.77	21.96
Min	1.86	0.16	0.02	0.00	0.08	0.02	0.26	0.04	0.00	0.28	0.55	1.78	0.55	0.72	0.63	0.04	0.86	9.96
CV	0.37	0.24	1.74	1.42	0.95	0.29	0.83	0.14	1.02	0.30	0.60	0.35	0.31	0.33	0.41	0.43	0.48	0.32
HSSB (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	0.25	0.63	0.21	0.36	1.18	0.05	0.13	0.40	0.37	0.28	0.40	1.16	0.24	0.57	0.36	0.04	0.66	7.29
SD	0.17	0.36	0.21	0.31	0.84	0.02	0.15	0.24	0.46	0.08	0.20	0.97	0.17	0.43	0.32	0.04	0.41	3.77
Max	0.43	1.10	0.52	0.81	2.34	0.07	0.35	0.71	1.12	0.38	0.64	2.48	0.49	1.14	0.71	0.11	1.15	10.47
Min	0.00	0.17	0.00	0.00	0.00	0.02	0.00	0.10	0.00	0.17	0.13	0.17	0.07	0.11	0.00	0.00	0.20	1.15
CV	0.65	0.56	1.01	0.87	0.71	0.35	1.17	0.61	1.26	0.29	0.51	0.84	0.72	0.74	0.88	1.13	0.63	0.52
HSSB (P)	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	0.66	1.64	0.66	0.51	0.18	1.26	0.38	1.31	0.65	0.45	0.52	2.25	0.44	2.11	0.78	0.16	0.95	14.92
SD	0.13	0.87	0.80	0.19	0.14	0.72	0.24	1.10	0.88	0.40	0.41	1.04	0.22	0.95	0.21	0.15	0.38	4.74
Max	0.85	3.12	2.41	0.85	0.35	2.28	0.78	3.55	2.52	1.34	1.15	3.54	0.70	3.15	0.90	0.47	1.35	20.51
Min	0.49	1.04	0.12	0.32	0.00	0.34	0.13	0.34	0.00	0.15	0.15	0.94	0.18	0.83	0.31	0.03	0.55	9.06
CV	0.19	0.53	1.20	0.36	0.77	0.57	0.64	0.84	1.35	0.89	0.78	0.46	0.49	0.45	0.27	0.96	0.40	0.32

Table 2.78: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at HSSB for winter (W), summer (S) and post-monsoon (P) seasons

HSSB(W)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21β(H)_hopane**	**17 α(H) 21α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	8.81	31.61	16.10	36.75	5.31	1.72	100.30
SD	1.65	0.73	1.51	10.89	1.98	0.47	16.77
CV	0.19	0.02	0.09	0.30	0.37	0.27	0.17
HSSB(S)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21β(H)_hopane**	**17 α(H) 21α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	2.47	9.85	4.66	16.42	4.99	3.36	41.75
SD	0.54	1.87	0.86	10.02	0.77	1.46	6.05
CV	0.22	0.19	0.19	0.61	0.15	0.43	0.14
HSSB(P)	**Tritriacontane**	**Hentriacontane**	**Pentriacontane**	**17 β(H) 21β(H)_hopane**	**17 α(H) 21α(H)_hopane**	**17 α(H) - 22,29,30 - Trisnorhopane**	**Total**
Mean	8.22	29.56	22.52	21.33	4.02	1.42	87.06
SD	1.23	3.92	6.87	12.74	0.80	0.54	23.46
CV	0.15	0.13	0.30	0.60	0.20	0.38	0.27

Table 2.79: Statistical results of chemical characterization (µg/m^3) of PM_{10} at HSSB for winter (W) season

HSSB	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	181	23.4	9.7	0.4	4.3	8.7	11.1	4.4	6.4	2.1	0.2	2.3	9E-2	0.19	4.00	2.94	8.39	20.04	1.28
SD	56	5.8	2.0	0.1	2.6	4.0	5.8	3.6	3.0	0.6	0.1	0.7	6E-2	0.14	2.65	1.32	3.11	7.50	1.28
Max	276	35.0	14.2	0.6	10.3	16.4	23.0	13.1	11.7	3.1	0.5	3.5	2E-1	0.49	8.94	5.68	12.82	31.03	3.32
Min	79	16.4	6.0	0.3	1.4	3.7	2.1	1.1	2.6	0.9	0.0	1.4	4E-2	0.05	0.58	0.87	2.94	7.41	0.32
CV	0.31	0.25	0.21	0.25	0.59	0.46	0.53	0.81	0.47	0.31	0.53	0.31	0.63	0.74	0.66	0.45	0.37	0.37	1.00
HSSB	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.30	6.03	0.54	0.14	0.67	5.44	0.09	0.11	0.12	0.83	0.16	0.09	0.10	0.11	0.08	0.08	0.17	0.20	67.33
SD	2.32	2.35	0.36	0.16	0.36	2.08	0.07	0.08	0.10	0.57	0.24	0.08	0.08	0.07	0.06	0.06	0.09	0.11	2.90
Max	9.26	9.81	1.58	0.67	1.23	9.06	0.28	0.29	0.35	2.15	1.00	0.31	0.33	0.33	0.28	0.27	0.45	0.45	73.58
Min	1.99	2.14	0.16	0.04	0.26	1.85	0.04	0.04	0.04	0.27	0.04	0.03	0.04	0.04	0.03	0.03	0.06	0.07	62.50
CV	0.44	0.39	0.67	1.10	0.54	0.38	0.74	0.74	0.84	0.68	1.50	0.84	0.75	0.67	0.80	0.80	0.52	0.57	0.04

Table 2.80: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at HSSB for winter (W) season

HSSB	$PM_{2.5}$	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	116	16.4	8.1	0.2	2.6	5.5	6.9	2.5	3.1	1.3	0.1	1.3	5E-2	0.12	2.21	1.80	5.41	12.67	0.87
SD	35	4.1	1.7	0.1	1.5	2.8	4.2	1.6	1.3	0.6	0.1	0.2	2E-2	0.10	1.49	0.80	2.14	5.15	0.82
Max	183	24.5	11.8	0.4	5.1	12.3	14.8	5.9	6.0	2.3	0.2	1.6	1E-1	0.28	5.10	3.37	9.33	22.82	2.58
Min	61	11.5	5.0	0.2	0.9	2.5	1.1	0.8	1.4	0.6	0.0	0.9	3E-2	0.03	0.40	0.43	2.20	5.13	0.21
CV	0.30	0.25	0.21	0.30	0.56	0.51	0.60	0.64	0.43	0.43	0.50	0.15	0.35	0.80	0.67	0.44	0.40	0.41	0.94
HSSB	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.99	3.58	0.26	0.07	0.41	3.17	0.05	0.07	0.06	0.42	0.10	0.05	0.05	0.06	0.04	0.05	0.11	0.12	67.19
SD	1.70	1.40	0.18	0.07	0.25	1.22	0.03	0.06	0.04	0.36	0.20	0.04	0.04	0.03	0.03	0.06	0.07	0.08	3.27
Max	6.95	6.28	0.74	0.29	0.84	5.09	0.14	0.22	0.16	1.31	0.82	0.17	0.18	0.13	0.12	0.24	0.28	0.36	75.81
Min	1.08	1.61	0.05	0.02	0.12	1.43	0.02	0.02	0.02	0.08	0.02	0.02	0.02	0.02	0.01	0.01	0.04	0.03	62.51
CV	0.57	0.39	0.69	0.98	0.61	0.39	0.68	0.88	0.75	0.86	1.91	0.74	0.75	0.49	0.69	1.08	0.63	0.72	0.05

Table 2.81: Statistical results chemical characterization (µg/m^3) of PM_{10} at HSSB for summer (S) season

HSSB	$PM_{2.5}$	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	65	9.2	4.0	0.2	2.4	0.3	6.7	1.8	6.4	0.6	0.1	0.8	5E-2	0.39	3.13	0.53	2.28	5.47	0.68
SD	16	2.2	1.2	0.1	0.9	0.2	2.9	0.6	1.6	0.2	0.1	0.2	5E-3	0.05	1.57	0.17	0.79	2.08	0.29
Max	88	12.7	5.8	0.3	4.3	0.6	11.5	2.9	9.4	0.9	0.2	1.1	5E-2	0.51	5.60	0.84	3.59	8.59	1.25
Min	40	5.7	2.2	0.1	1.4	0.0	2.9	0.9	4.0	0.3	0.1	0.4	4E-2	0.32	1.41	0.27	1.22	2.97	0.40
CV	0.25	0.24	0.30	0.28	0.36	0.70	0.43	0.35	0.25	0.31	0.37	0.24	0.10	0.14	0.50	0.33	0.35	0.38	0.43
HSSB	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.38	1.49	0.22	0.11	0.24	1.14	0.05	0.06	0.07	0.78	0.05	0.05	0.06	0.09	0.05	0.05	0.11	0.10	73.82
SD	0.76	0.54	0.16	0.05	0.12	0.44	0.00	0.02	0.03	0.70	0.01	0.01	0.02	0.04	0.00	0.00	0.05	0.05	2.68
Max	2.97	2.25	0.47	0.18	0.41	1.90	0.05	0.09	0.11	1.93	0.06	0.06	0.09	0.18	0.05	0.05	0.18	0.19	77.66
Min	0.51	0.87	0.04	0.04	0.06	0.65	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	69.87
CV	0.55	0.36	0.76	0.44	0.50	0.39	0.10	0.29	0.36	0.90	0.16	0.11	0.25	0.46	0.10	0.10	0.48	0.51	0.04

Table 2.82: Statistical results of chemical characterization ($\mu g/m^3$) of $PM_{2.5}$ at HSSB for summer (S) season

HSSB	$PM_{2.5}$	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	42	6.4	3.3	0.1	1.6	0.2	4.7	1.1	4.0	0.4	0.1	0.3	4E-2	0.31	1.91	0.39	1.45	3.46	0.31
SD	11	1.6	1.0	0.0	0.7	0.2	2.3	0.5	0.5	0.2	0.0	0.1	1E-2	0.03	0.99	0.11	0.54	1.26	0.11
Max	61	8.9	4.8	0.2	2.9	0.5	8.6	2.0	4.6	0.8	0.2	0.5	5E-2	0.35	3.95	0.51	2.26	5.15	0.44
Min	30	4.0	1.8	0.1	0.9	0.0	1.6	0.5	3.2	0.2	0.0	0.2	2E-2	0.27	0.84	0.17	0.88	1.98	0.10
CV	0.26	0.24	0.30	0.26	0.42	0.83	0.50	0.43	0.11	0.45	0.40	0.30	0.25	0.09	0.52	0.28	0.37	0.36	0.34

HSSB	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.72	0.83	0.07	0.05	0.09	0.68	0.03	0.05	0.04	0.26	0.03	0.04	0.04	0.05	0.03	0.04	0.05	0.05	0.03
SD	0.31	0.35	0.03	0.01	0.03	0.32	0.01	0.01	0.01	0.15	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01
Max	1.26	1.35	0.12	0.06	0.16	1.12	0.05	0.07	0.05	0.46	0.06	0.06	0.06	0.07	0.05	0.05	0.07	0.07	0.04
Min	0.33	0.35	0.02	0.02	0.05	0.31	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.02	0.02	0.03	0.02
CV	0.42	0.42	0.49	0.26	0.39	0.46	0.22	0.31	0.23	0.57	0.32	0.27	0.27	0.31	0.35	0.30	0.36	0.34	0.31

Table 2.83: Statistical results chemical characterization ($\mu g/m^3$) of PM_{10} at HSSB for post-monsoon (P) season

HSSB	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	78	8.8	3.5	0.2	0.8	3.9	9.0	0.6	1.6	0.5	0.2	1.5	2E-2	0.02	1.71	1.05	3.35	8.13	0.24
SD	38	6.0	2.0	0.0	0.2	2.5	4.1	0.2	1.6	0.3	0.1	0.7	1E-2	0.01	0.52	0.86	1.41	3.25	0.06
Max	149	27.5	8.5	0.3	1.4	8.0	16.1	1.0	6.4	1.1	0.5	3.4	3E-2	0.04	2.85	3.03	5.94	14.23	0.31
Min	42	4.6	1.6	0.2	0.5	1.1	3.5	0.4	0.4	0.2	0.1	0.9	3E-3	0.00	0.92	0.37	1.63	4.30	0.14
CV	0.48	0.69	0.57	0.18	0.29	0.65	0.45	0.24	0.99	0.55	0.46	0.47	0.60	0.50	0.30	0.81	0.42	0.40	0.25

HSSB	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.40	2.27	0.12	0.23	0.33	1.85	0.01	0.01	0.02	0.22	0.02	0.00	0.05	0.02	0.00	0.02	0.02	0.07	67.34
SD	5.05	0.98	0.08	0.08	0.22	0.89	0.01	0.01	0.02	0.16	0.02	0.00	0.09	0.01	0.01	0.02	0.01	0.06	2.68
Max	13.16	4.13	0.28	0.34	0.91	3.46	0.02	0.03	0.10	0.63	0.06	0.00	0.39	0.03	0.03	0.10	0.04	0.23	71.90
Min	0.42	1.11	0.05	0.10	0.13	0.81	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	62.68
CV	1.15	0.43	0.64	0.33	0.66	0.48	0.62	0.49	1.10	0.72	1.36	0.79	1.76	0.44	1.38	1.25	0.44	0.82	0.04

Table 2.84: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at HSSB for post-monsoon (P) season

HSSB	$PM_{2.5}$	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	46	6.2	2.9	0.2	0.5	2.7	5.9	0.4	1.2	0.4	0.2	0.8	1E-2	0.01	1.17	0.48	1.97	4.72	0.12
SD	22	4.2	1.7	0.0	0.2	2.1	3.1	0.1	1.4	0.2	0.1	0.4	8E-3	0.01	0.58	0.43	0.85	2.08	0.03
Max	106	19.2	7.1	0.2	0.8	6.8	11.9	0.8	5.3	0.8	0.4	1.6	2E-2	0.03	2.57	1.64	4.03	9.82	0.17
Min	22	3.2	1.3	0.1	0.3	0.8	1.6	0.2	0.2	0.1	0.1	0.3	1E-3	0.00	0.50	0.20	0.92	2.39	0.09
CV	0.49	0.69	0.57	0.20	0.30	0.77	0.52	0.31	1.11	0.59	0.54	0.44	0.66	0.61	0.50	0.90	0.43	0.44	0.21
HSSB	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.24	1.32	0.08	0.16	0.18	1.03	0.01	0.01	0.01	0.14	0.01	0.00	0.03	0.01	0.00	0.01	0.01	0.04	70.54
SD	1.28	0.62	0.05	0.07	0.12	0.57	0.00	0.00	0.01	0.11	0.01	0.00	0.06	0.00	0.00	0.01	0.01	0.04	2.39
Max	4.55	2.85	0.17	0.29	0.52	2.35	0.01	0.01	0.06	0.41	0.04	0.00	0.24	0.02	0.02	0.05	0.02	0.16	73.86
Min	0.21	0.64	0.02	0.06	0.07	0.52	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	66.05
CV	1.03	0.48	0.72	0.45	0.69	0.55	0.66	0.48	1.04	0.81	1.38	0.82	1.71	0.42	1.34	1.01	0.49	0.94	0.03

Table 2.85: Correlation matrix for PM_{10} and its composition at HSSB for winter season

SSB (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	0.83	0.72	0.94	0.48	0.41	0.33	0.70	0.59	0.64	0.82	0.86	0.56	0.98
TC		1.00	0.98	0.81	0.76	0.41	0.17	0.33	0.50	0.45	0.80	0.66	0.62	0.76
OC			1.00	0.67	0.84	0.43	0.08	0.17	0.49	0.35	0.73	0.56	0.61	0.64
EC				1.00	0.35	0.25	0.39	0.70	0.41	0.63	0.79	0.77	0.51	0.91
NO_3^-					-0.05	0.40	1.00	0.40	0.17	0.09	0.19	0.31	-0.29	0.22
SO_4^{-2}					-0.05	0.37		1.00	0.54	0.50	0.51	0.64	0.26	0.65
NH_4^+					0.26	0.08			0.17	1.00	0.63	0.70	0.66	0.69
Metals					0.42	0.29			0.51		0.78	0.85	0.58	1.00

Table 2.86: Correlation matrix for $PM_{2.5}$ and its composition at HSSB for winter season

HSSB (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	0.66	0.50	0.89	-0.03	0.30	0.27	0.69	0.53	0.77	0.90	0.69	0.10	0.97
TC		1.00	0.97	0.82	0.02	0.23	0.04	0.11	0.30	0.29	0.55	0.46	0.19	0.53
OC			1.00	0.67	0.03	0.24	-0.07	-0.08	0.25	0.16	0.42	0.37	0.20	0.37
EC				1.00	-0.01	0.15	0.31	0.55	0.33	0.55	0.74	0.55	0.12	0.80
NO_3^-					0.10	0.36	1.00	0.40	0.28	0.25	0.24	0.47	-0.19	0.17
SO_4^{-2}					-0.15	0.39		1.00	0.63	0.50	0.58	0.47	-0.16	0.69
NH_4^+					0.16	0.29			0.36	1.00	0.84	0.53	0.24	0.80
Metals					0.01	0.20			0.47		0.90	0.64	0.13	1.00

Table 2.87: Correlation matrix for PM_{10} and its composition at HSSB for summer season

HSSB (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	0.93	0.92	0.92	0.01	0.32	0.23	0.81	0.48	0.45	0.63	0.13	0.48	0.98
TC		1.00	0.99	0.98	-0.12	0.19	0.23	0.76	0.27	0.45	0.43	0.05	0.35	0.87
OC			1.00	0.96	-0.09	0.14	0.25	0.70	0.21	0.52	0.42	0.05	0.34	0.86
EC				1.00	-0.19	0.28	0.17	0.84	0.38	0.30	0.44	0.05	0.36	0.86
NO_3^-					0.24	-0.15	1.00	0.20	0.12	0.30	0.31	-0.07	0.08	0.23
SO_4^{-2}					-0.33	0.62		1.00	0.63	-0.09	0.66	0.19	0.45	0.74
NH_4^+					0.55	-0.42			-0.06	1.00	0.28	0.08	0.27	0.50
Metals					0.08	0.27			0.56		0.62	0.04	0.41	1.00

Table 2.88: Correlation matrix for $PM_{2.5}$ and its composition at HSSB for summer season

HSSB (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	0.84	0.78	0.90	-0.42	0.30	0.12	0.94	0.53	-0.20	0.61	0.17	0.45	0.96
TC		1.00	0.99	0.98	-0.33	-0.11	0.19	0.65	0.18	0.03	0.34	0.10	0.36	0.74
OC			1.00	0.96	-0.28	-0.18	0.23	0.57	0.13	0.07	0.31	0.07	0.32	0.69
EC				1.00	-0.40	0.01	0.13	0.76	0.26	-0.02	0.39	0.14	0.40	0.81
NO_3^-					0.19	-0.44	1.00	0.06	0.05	0.45	-0.22	0.12	-0.27	0.08
SO_4^{-2}					-0.50	0.44		1.00	0.63	-0.30	0.59	0.13	0.51	0.90
NH_4^+					0.70	-0.56			-0.10	1.00	-0.36	0.28	-0.06	-0.26
Metals					-0.29	0.26			0.70		0.77	0.19	0.55	1.00

Table 2.89: Correlation matrix for PM_{10} and its composition at HSSB for post-monsoon season

HSSB (P)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.89	0.86	0.94	0.22	0.13	0.64	0.81	0.56	0.41	0.91	0.92	0.77	0.96
TC		1.00	1.00	0.97	0.06	0.17	0.63	0.68	0.64	0.65	0.83	0.83	0.52	0.73
OC			1.00	0.95	0.05	0.19	0.62	0.64	0.65	0.67	0.80	0.80	0.49	0.69
EC				1.00	0.09	0.10	0.63	0.78	0.58	0.58	0.90	0.88	0.60	0.83
NO_3^-					0.38	0.69	1.00	0.24	0.72	0.24	0.63	0.61	0.54	0.54
SO_4^{-2}					-0.08	-0.25		1.00	0.24	0.38	0.73	0.69	0.49	0.80
NH_4^+					-0.04	-0.15			0.15	1.00	0.34	0.34	0.02	0.19
Metals					0.29	0.07			0.46		0.87	0.88	0.84	1.00

Table 2.90: Correlation matrix for $PM_{2.5}$ and its composition at HSSB for post-monsoon season

HSSB (P)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.96	0.95	0.97	0.16	0.47	0.76	0.80	0.88	0.68	0.90	0.91	0.46	0.96
TC		1.00	1.00	0.98	0.08	0.48	0.79	0.77	0.88	0.62	0.89	0.89	0.40	0.87
OC			1.00	0.95	0.09	0.50	0.78	0.74	0.87	0.65	0.86	0.87	0.37	0.85
EC				1.00	0.05	0.41	0.79	0.80	0.88	0.55	0.91	0.90	0.48	0.90
NO_3^-					0.29	0.47	1.00	0.35	0.65	0.33	0.71	0.77	0.71	0.76
SO_4^{-2}					-0.33	0.14		1.00	0.78	0.54	0.76	0.69	0.16	0.71
NH_4^+					0.26	0.25			0.59	1.00	0.50	0.61	-0.07	0.58
Metals					0.27	0.47			0.82		0.83	0.91	0.57	1.00

2.4.6 Ayushman Health Centre Morid (AHCM)

Seven-day sampling was done in each season for this site in Bhilai. This site was considered as an additional site in the expected downwind from the SAIL. The sampling period was February 01- 07, 2021 for winter, April 29, 2021 - May 05, 2021, for summer and October 17 – 23, 2021 for post-monsoon.

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

Time series of 24-hour average concentrations of PM_{10} and $PM_{2.5}$ at AHCM is shown for winter (Figure 2.84), summer (Figure 2.85) and post-monsoon (Figure 2.86). Average levels at this site were: $PM_{2.5}$: 108±22 (winter), 53±6 µg/m^3 (summer) and 51±21 µg/m^3 (post-monsoon) and PM_{10}: 222±76 (winter), 84±13 µg/m^3 (summer) and 101±52 µg/m^3 (post-monsoon). In winter, the $PM_{2.5}$ levels were 1.81 times higher than the national air quality standard (NAAQS: 60 µg/m^3) and PM_{10} levels were 2.22 times higher than the NAAQS (100 µg/m^3). In summer, the $PM_{2.5}$ and PM_{10} levels were under NAAQS. In post-monsoon, the mean $PM_{2.5}$ levels were within the limit of standards and PM_{10} levels were slightly higher (1.01 times) than the NAAQS.

A statistical summary of PM concentrations is presented in Table 2.95 - Table 2.100 for winter, summer and post-monsoon season.

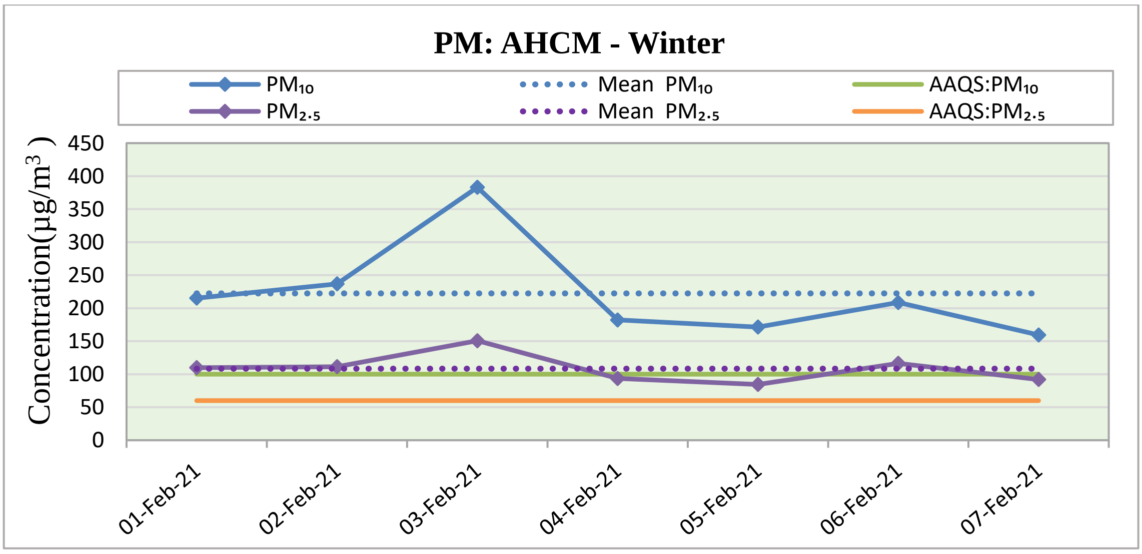


Figure 2.84: PM Concentrations at AHCM for Winter Season

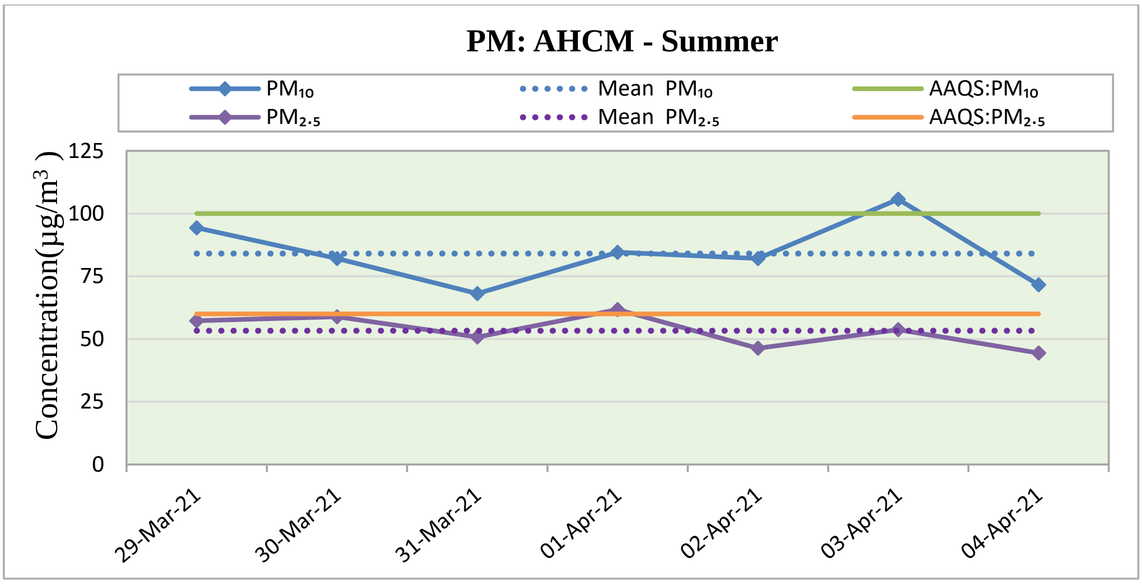


Figure 2.85: PM Concentrations at AHCM for Summer Season

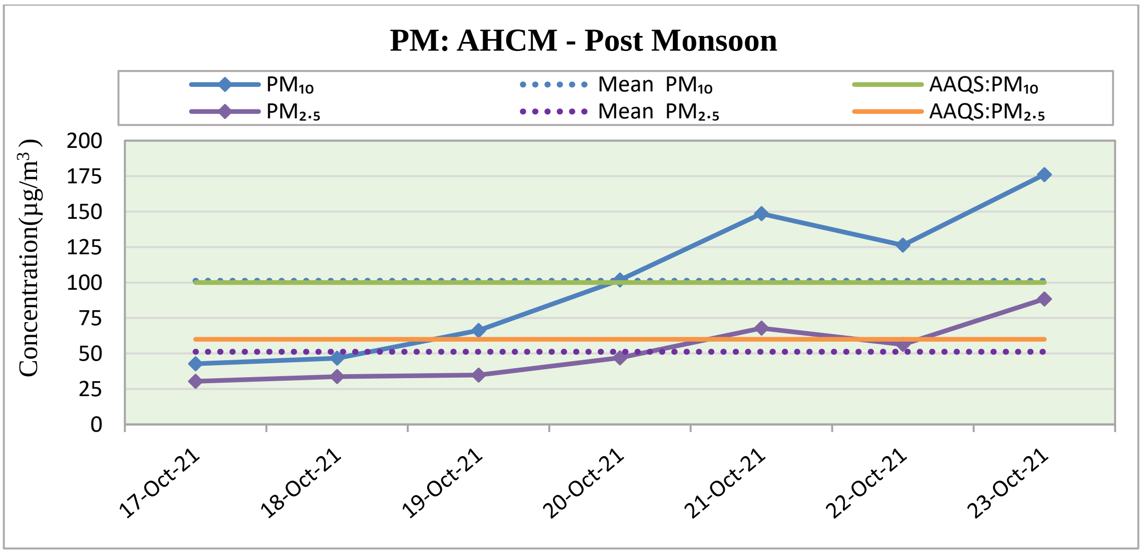


Figure 2.86: PM Concentrations at AHCM for Post-monsoon Season

2.4.6.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter, summer, and post-monsoon seasons (Figure 2.87 to Figure 2.89). It was observed that SO_2 concentrations were low and met the air quality standard in winter, summer and post-monsoon seasons, however, SO_2 levels are significantly high at 15.83 µg/m^3 in the winter season compared to other seasons. NO_2 levels are also under the national standard with an average of 15 days at 27±5.4 µg/m^3 in winter and 12±3 µg/m^3 in summer and 10.65±5.6 µg/m^3 in pos monsoon season (Table 2.91). The summer concentration of NO_2 dropped dramatically similar to $PM_{2.5}$ levels. However, NO_2 is certainly a matter of concern and 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, local open burning etc. VOC sampling was not done at AHCM.

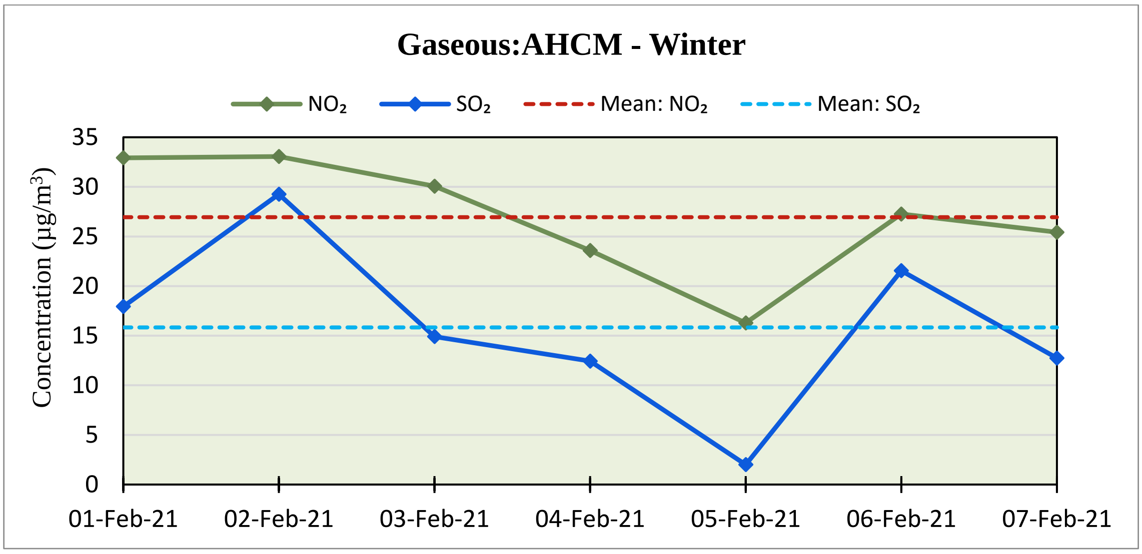


Figure 2.87: SO_2 and NO_2 Concentrations at AHCM for Winter Season

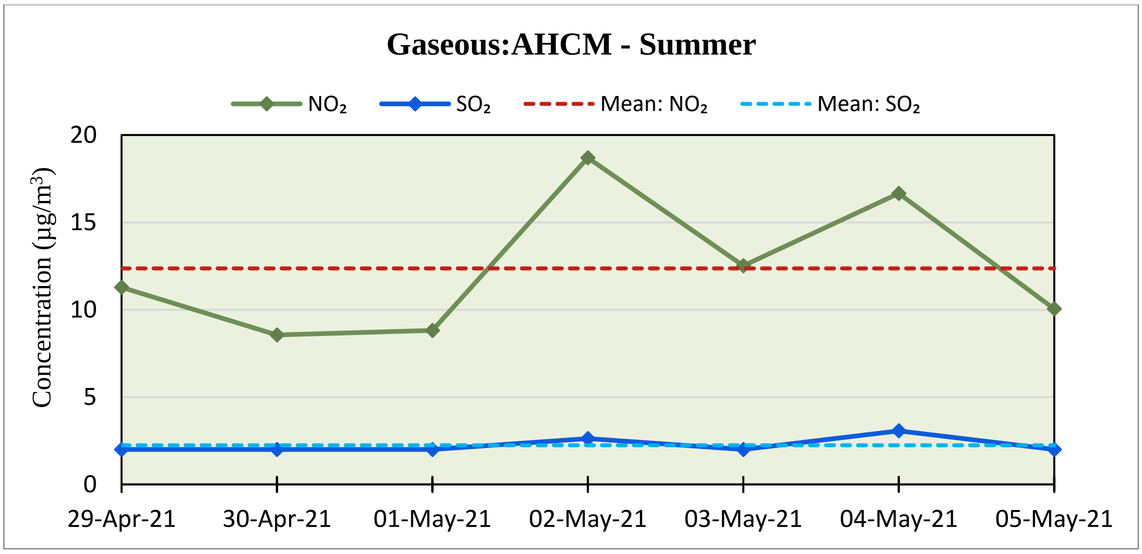


Figure 2.88: SO_2 and NO_2 Concentrations at AHCM for Summer Season

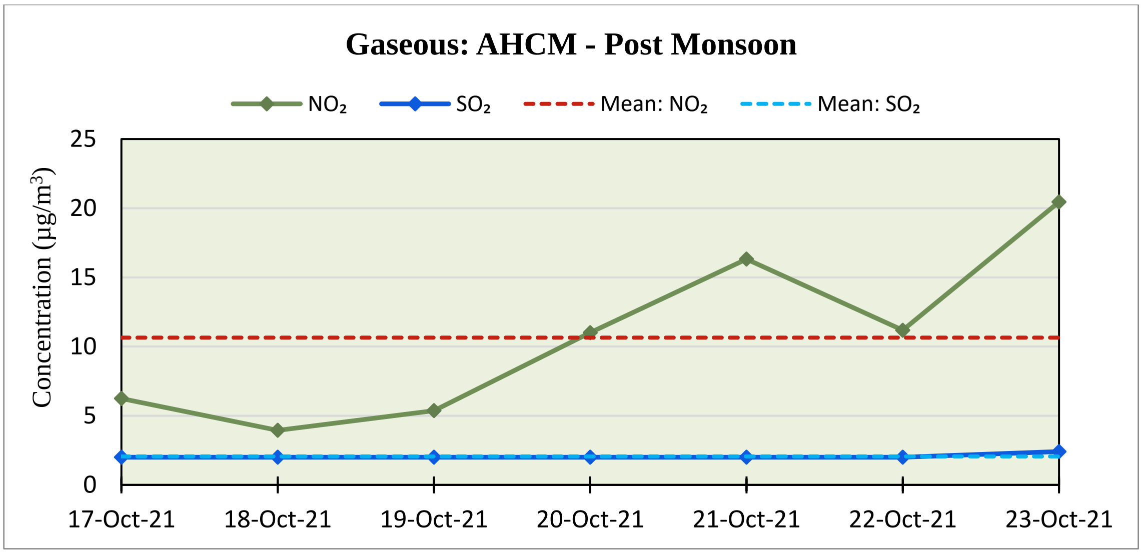


Figure 2.89: SO_2 and NO_2 Concentrations at AHCM for Post-monsoon Season

2.4.6.3 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 2.90 (a) and (b) for winter, summer, and post-monsoon seasons. Organic carbon is observed significantly higher (winter: 17.37±3.25, summer: 6.75±1.12 and post-monsoon: 7.62±3.14 µg/m^3) than the elemental carbon (winter: 7.64±1.80 summer: 3.37±0.59 and post-monsoon: 3.95±2.37 µg/m^3). However, the ratio of OC3/TC is observed higher indicating the formation of secondary organic carbon in the atmosphere. It is also observed that the OC and EC are higher in the winter 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 2.92 for winter, summer and post-monsoon seasons.

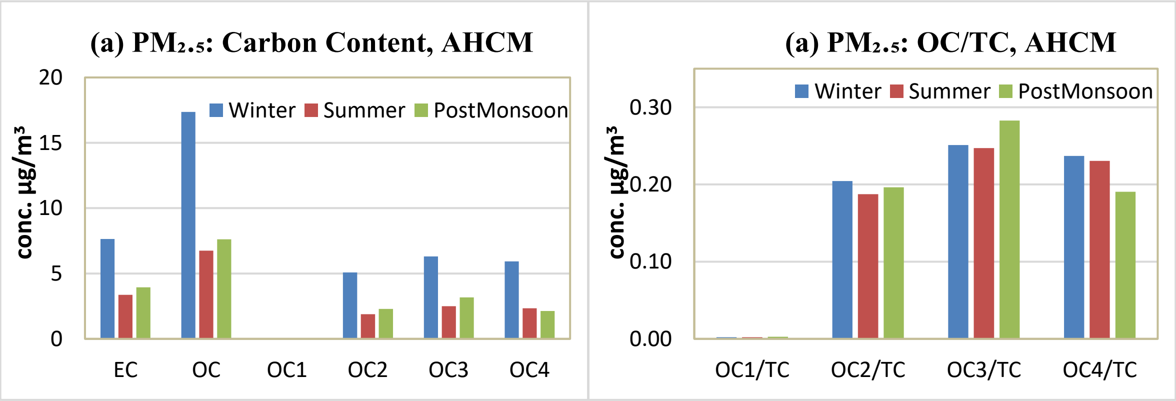


Figure 2.90: EC and OC Content in $PM_{2.5}$ at AHCM

2.4.6.4 PAHs in $PM_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.91 shows the average measured concentration of PAHs at KRNK for winter, summer, and post-monsoon seasons. A statistical summary of PAHs is presented in Table 2.93 for winter, summer, and post-monsoon 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 PAH concentrations in winter were 21±4 ng/m^3, in summer: 21±7 ng/m^3 and in post-monsoon: 20±2 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are (i) B(b)F (4 ng/m^3), B(ghi)P (2 ng/m^3), BaP (2 ng/m^3), DmP (5 ng/m^3) and Chr (1.7 ng/m^3) for winter season; (ii) B(b)F (2.6 ng/m^3), BaP (1.63 ng/m^3), B(ghi)P (1.45 ng/m^3), AcP (1.62 ng/m^3), Flu (1.46 ng/m^3), Phe (3.50 ng/m^3) and DmP (2.99 ng/m^3) for summer season; and (iii) Flu (1.29 ng/m^3), Phe (3.22 ng/m^3), Ant (2.29 ng/m^3), AcP (3.14 ng/m^3), B(b)F (2.56 ng/m^3) and BaP (1.62 ng/m^3) for post-monsoon.

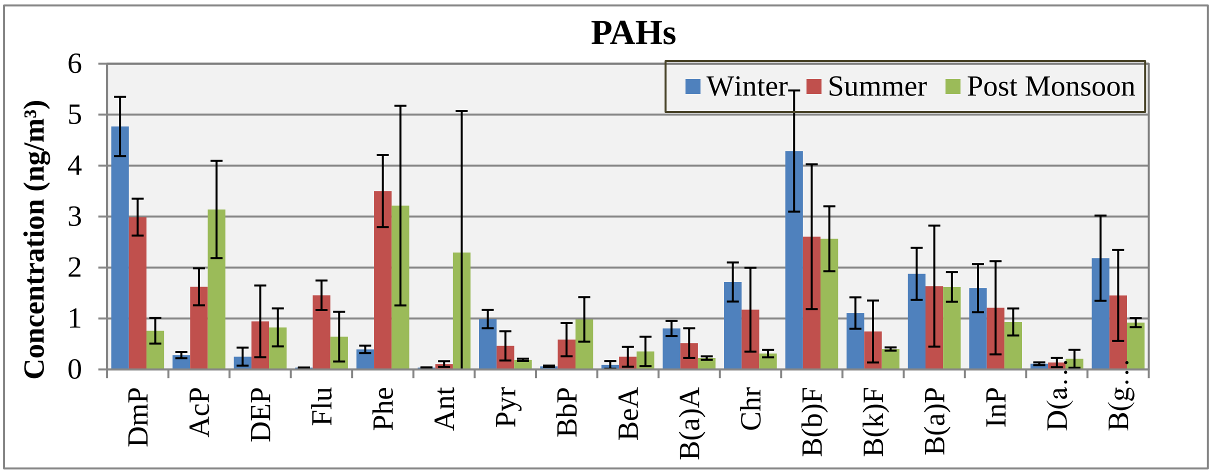


Figure 2.91: PAHs Concentrations in $PM_{2.5}$ at AHCM

2.4.6.5 Molecular Markers in $PM_{2.5}$

Total six molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, 17 β(H) 21 β(H)_hopane, n-Hentriacontane, n-Tritriacontane and n-Pentatriacontane. 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 2.92 and Table 2.94 show the levels of six molecular markers. The total concentration of markers was 72.37 ng/m^3 in winter, 40.77 ng/m^3 in summer and 34.47 ng/m^3 in post-monsoon. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

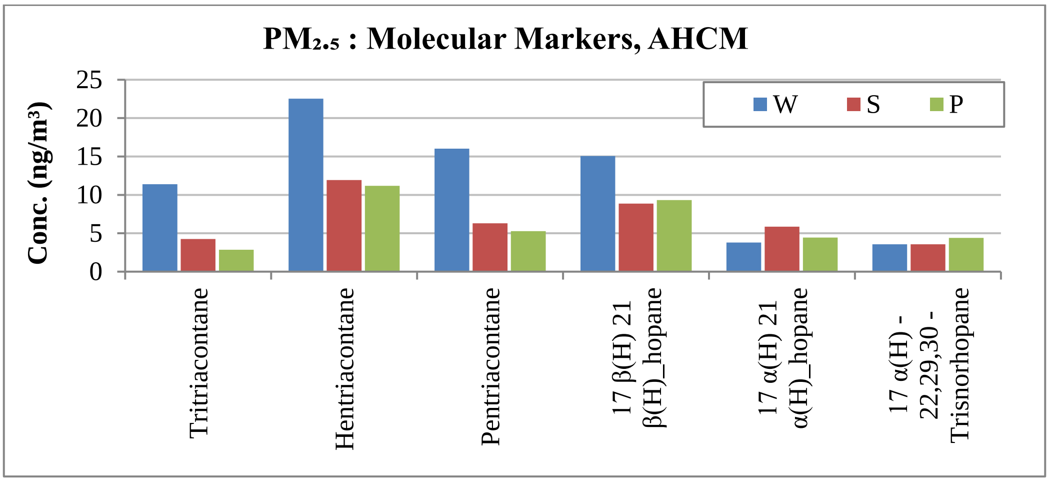


Figure 2.92: Molecular Markers in $PM_{2.5}$ at AHCM

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

Graphical presentations of chemical species are shown for winter, summer and post-monsoon seasons at HSSB for PM_{10} (Figure 2.93) and $PM_{2.5}$ (Figure 2.94). 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 2.95 - Table 2.100 for winter, summer and post-monsoon 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 2.101 - Table 2.106 for both season. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM is presented in Figure 2.95(a) and (b) for winter Figure 2.96 (a) and (b) for summer and Figure 2.97 (a) and (b) for the post-monsoon season.

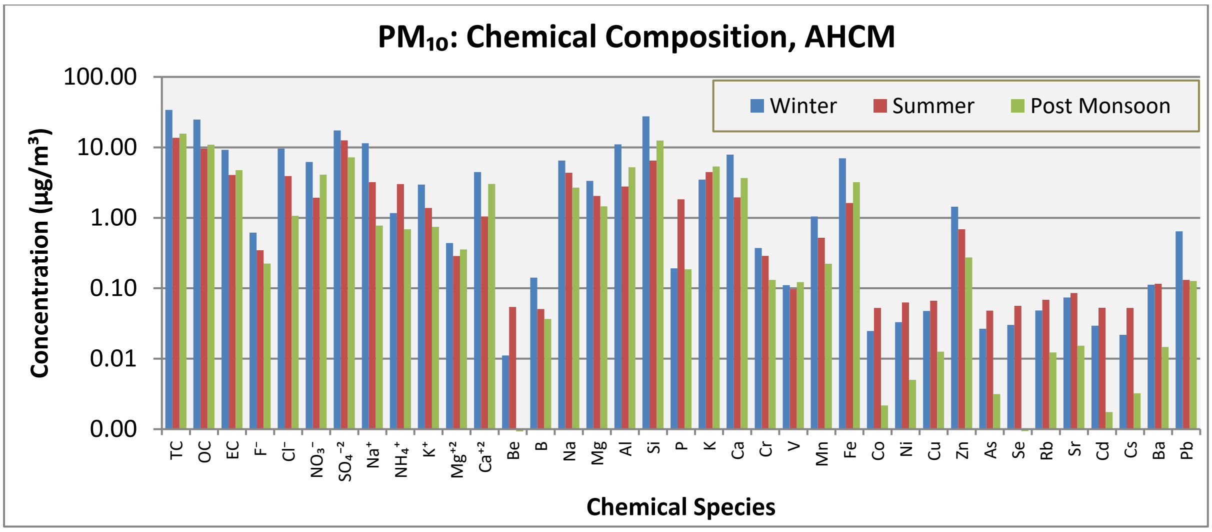


Figure 2.93: Concentrations of species in PM_{10} at AHCM

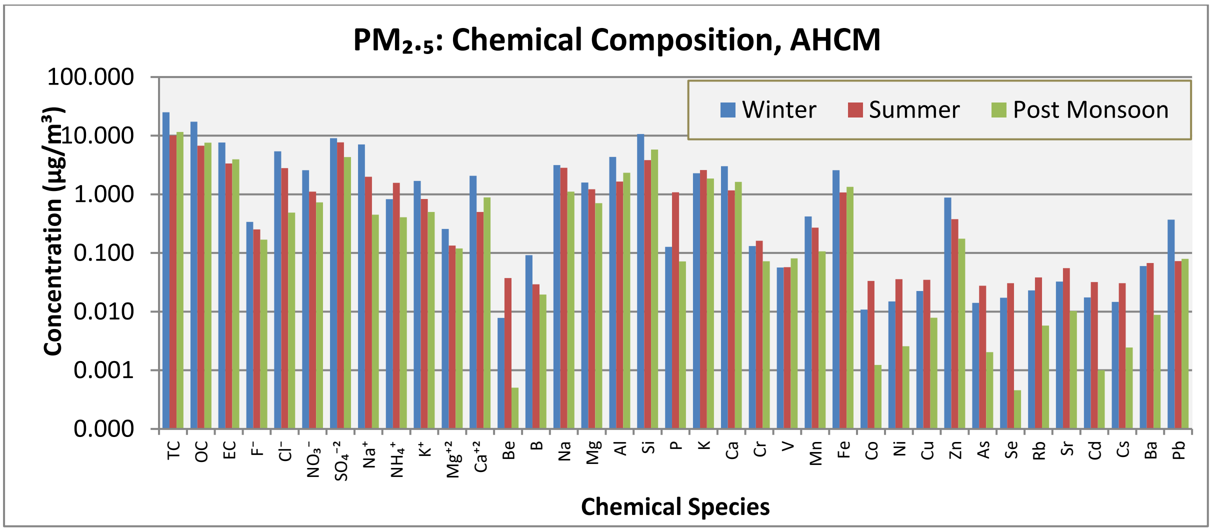
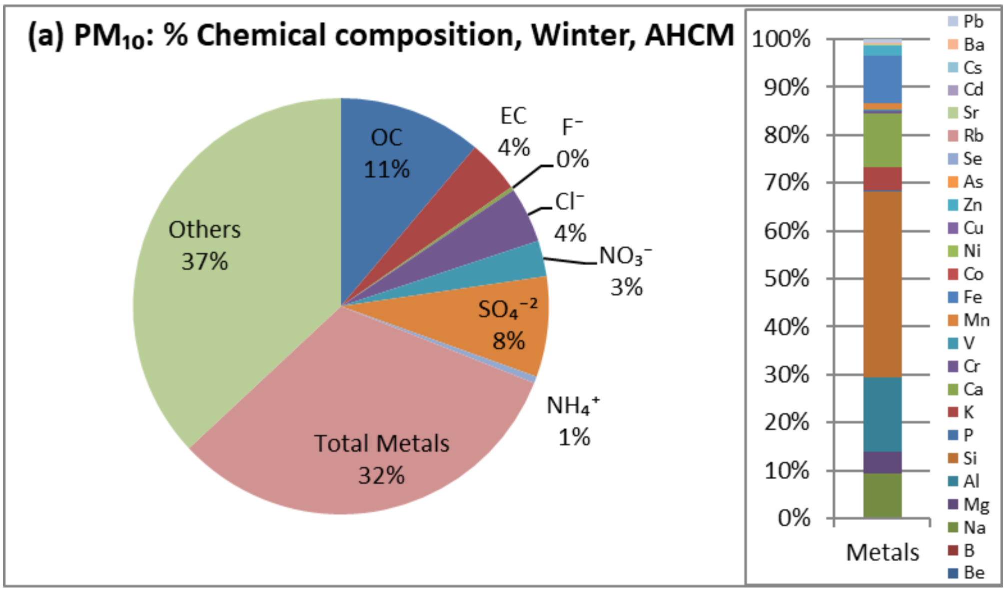


Figure 2.94: Concentrations of species in $PM_{2.5}$ at AHCM



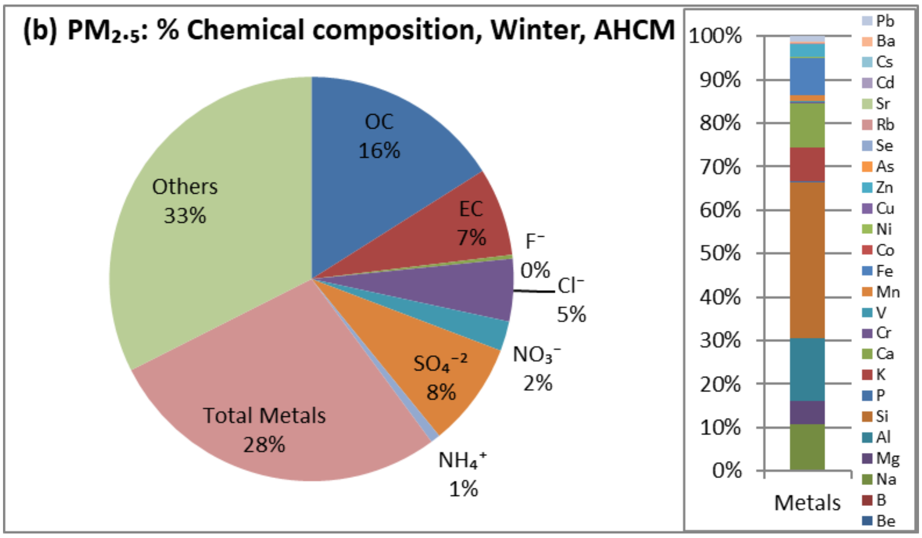


Figure 2.95: Percentage distribution of species in PM at AHCM for Winter Season

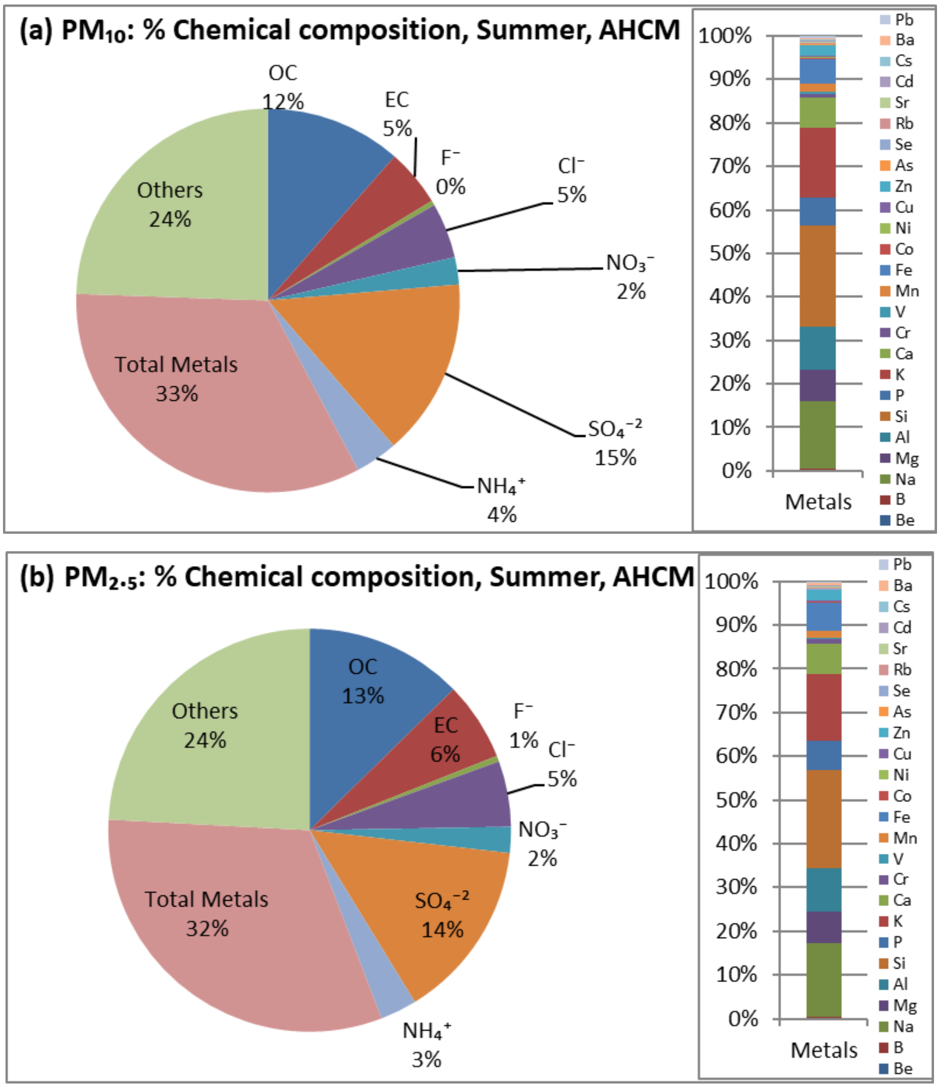


Figure 2.96: Percentage distribution of species in PM at AHCM for Summer Season

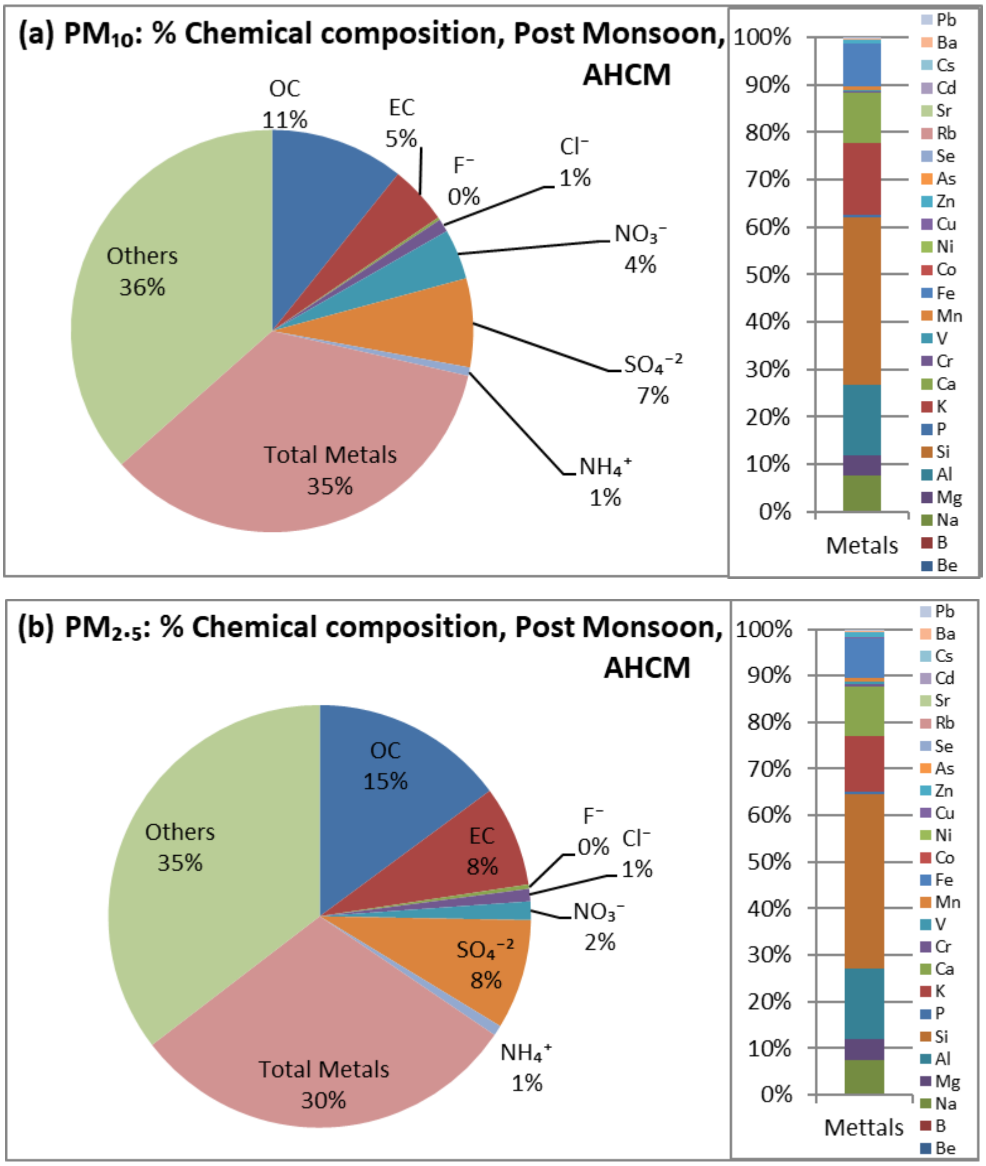


Figure 2.97: Percentage distribution of species in PM at AHCM for Post-monsoon Season

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

A graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown for winter, summer and post-monsoon seasons (Figure 2.98) at AHCM. 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 is having fine mode during winter (49 %), summer (63%) and post-monsoon (51%). The major species contributing to fine mode are TC, OC, EC, SO_4^{-2}, Na^+, NH_4^+, K^+, B, K, V, Cu, Zn, Cd and Pb;

whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Mg, Al, Si, P, Ca, Cr, Ni and Fe are contributing significantly in fine mode.

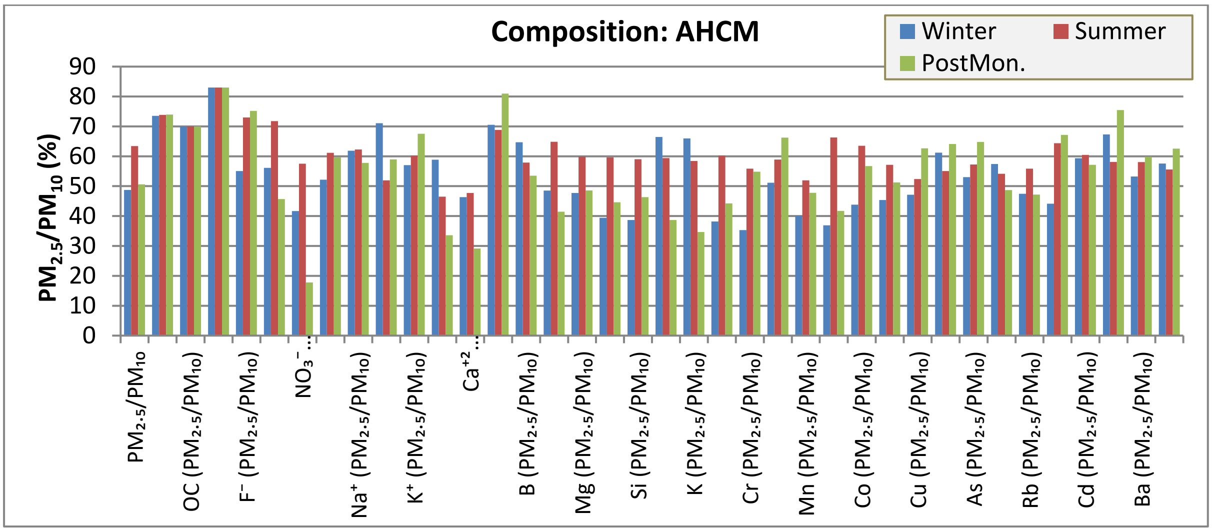


Figure 2.98: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at AHCM

Table 2.91: Statistical results of gaseous pollutants (µg/m^3) at AHCM for winter, summer, and post-monsoon (P) seasons

AHCM (W)	NO_2	SO_2
Mean	26.94	15.83
SD	5.48	7.84
Max	33.06	29.26
Min	16.29	2.00
CV	0.20	0.50
AHCM (S)	NO_2	SO_2
Mean	12.37	2.24
SD	3.63	0.40
Max	18.70	3.06
Min	8.56	2.00
CV	0.29	0.18
AHCM (P)	NO_2	SO_2
Mean	10.65	2.06
SD	5.62	0.14
Max	20.45	2.41
Min	3.94	2.00
CV	0.53	0.07

Table 2.92: Statistical results of carbon contents (μg/m^3) in $PM_{2.5}$ at AHCM for winter (W), summer (S) and post-monsoon (P) seasons

AHCM(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	108.35	25.01	7.64	17.37	0.05	5.08	6.30	5.93	0.00	0.20	0.25	0.24
SD	20.47	4.31	1.80	3.25	0.05	0.73	1.47	1.31	0.00	0.02	0.03	0.03
Max	150.75	33.51	11.04	24.35	0.13	6.35	9.43	8.53	0.01	0.24	0.28	0.28
Min	84.00	20.66	6.25	14.42	0.00	3.98	5.03	4.87	0.00	0.18	0.21	0.21
CV	0.19	0.17	0.24	0.19	0.84	0.14	0.23	0.22	0.93	0.10	0.10	0.12
AHCM(S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	53.30	10.12	3.37	6.75	0.02	1.89	2.50	2.34	0.00	0.19	0.25	0.23
SD	6.48	1.62	0.59	1.12	0.01	0.28	0.42	0.46	0.00	0.01	0.01	0.02
Max	61.74	12.73	4.03	8.70	0.03	2.43	3.25	2.99	0.00	0.20	0.27	0.25
Min	44.41	8.00	2.69	5.30	0.00	1.62	2.00	1.66	0.00	0.17	0.23	0.20
CV	0.12	0.16	0.18	0.17	0.49	0.15	0.17	0.20	0.51	0.06	0.05	0.08
AHCM(P)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	51.22	11.57	3.95	7.62	0.03	2.30	3.17	2.13	0.00	0.20	0.28	0.19
SD	21.27	5.29	2.37	3.14	0.04	1.11	1.22	0.85	0.00	0.02	0.03	0.03
Max	88.41	18.86	8.38	10.70	0.09	3.63	4.43	3.33	0.01	0.23	0.32	0.22
Min	30.41	5.22	1.59	3.63	0.00	1.00	1.66	0.97	0.00	0.17	0.23	0.14
CV	0.42	0.46	0.60	0.41	1.10	0.48	0.39	0.40	1.16	0.10	0.10	0.16

Table 2.93: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at AHCM for winter (W), summer (S) and post-monsoon (P)

AHCM (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	4.77	0.28	0.25	0.03	0.39	0.04	0.99	0.06	0.09	0.80	1.72	4.29	1.11	1.88	1.60	0.11	2.18	20.58
SD	0.58	0.06	0.18	0.00	0.07	0.00	0.18	0.01	0.08	0.15	0.38	1.19	0.31	0.51	0.47	0.03	0.84	4.12
Max	4.77	0.28	0.25	0.03	0.39	0.04	0.99	0.06	0.09	0.80	1.72	4.29	1.11	1.88	1.60	0.11	2.18	20.58
Min	4.77	0.28	0.25	0.03	0.39	0.04	0.99	0.06	0.09	0.80	1.72	4.29	1.11	1.88	1.60	0.11	2.18	20.58
CV	2.68	0.22	0.71	0.11	0.19	0.12	0.18	0.23	0.86	0.18	0.22	0.28	0.28	0.27	0.30	0.25	0.38	0.20
AHCM (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	2.99	1.62	0.94	1.46	3.50	0.11	0.46	0.59	0.25	0.52	1.17	2.61	0.74	1.63	1.21	0.14	1.45	21.38
SD	0.36	0.36	0.70	0.29	0.71	0.06	0.29	0.33	0.19	0.29	0.82	1.42	0.61	1.19	0.91	0.09	0.89	7.46
Max	3.29	1.88	1.75	1.66	3.94	0.14	0.74	0.95	0.43	0.84	2.07	3.51	1.39	2.84	2.12	0.21	2.34	29.62
Min	2.59	1.21	0.47	1.12	2.68	0.04	0.16	0.33	0.04	0.27	0.45	0.97	0.19	0.47	0.29	0.04	0.56	15.08
CV	0.12	0.22	0.75	0.20	0.20	0.53	0.62	0.56	0.79	0.56	0.70	0.55	0.82	0.73	0.76	0.67	0.61	0.35
AHCM (P)	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	0.76	3.14	0.83	0.64	3.22	2.29	0.19	0.98	0.35	0.22	0.31	2.56	0.40	1.62	0.93	0.21	0.92	19.57
SD	0.25	0.96	0.37	0.49	1.96	2.78	0.02	0.44	0.29	0.03	0.07	0.64	0.03	0.29	0.26	0.18	0.09	2.49
Max	0.93	3.85	1.25	1.10	5.34	5.50	0.21	1.44	0.67	0.26	0.37	3.03	0.44	1.89	1.17	0.41	1.01	21.05
Min	0.47	2.05	0.59	0.13	1.49	0.53	0.16	0.57	0.12	0.20	0.23	1.84	0.37	1.31	0.65	0.08	0.83	16.70
CV	0.33	0.30	0.45	0.76	0.61	1.21	0.12	0.45	0.82	0.16	0.23	0.25	0.08	0.18	0.28	0.84	0.10	0.13

Table 2.94: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at AHCM for winter (W), summer (S) and post-monsoon (P)

AHCM (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	11.38	22.53	16.02	15.07	3.80	3.56	72.37
AHCM (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	4.25	11.93	6.30	8.86	5.86	3.56	40.77
AHCM (P)	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	2.85	11.18	5.27	9.33	4.45	4.39	37.47

Table 2.95: Statistical results of chemical characterization (µg/m^3) of PM_{10} at AHCM for winter (W) season

AHCM	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	222	24.81	9.21	0.62	9.64	6.19	17.38	11.45	1.17	2.96	0.44	4.47	0.01	0.14	6.49	3.34	11.01	27.61	0.19
SD	76	4.65	2.17	0.15	3.25	3.38	6.71	4.76	0.99	1.42	0.20	2.20	0.00	0.04	2.21	2.30	4.09	11.41	0.05
Max	383	34.79	13.30	0.87	15.95	11.95	28.82	16.96	3.24	6.00	0.65	8.72	0.02	0.19	9.86	8.35	19.18	51.59	0.27
Min	159	20.60	7.52	0.47	6.09	2.57	12.23	4.66	0.34	1.93	0.07	2.59	0.01	0.10	2.83	1.63	7.67	18.67	0.14
CV	0.34	0.19	0.24	0.24	0.34	0.55	0.39	0.42	0.85	0.48	0.45	0.49	0.33	0.27	0.34	0.69	0.37	0.41	0.27
AHCM	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.48	7.91	0.37	0.11	1.05	6.98	0.02	0.03	0.05	1.44	0.03	0.03	0.05	0.07	0.03	0.02	0.11	0.64	63.28
SD	1.43	3.39	0.10	0.04	0.73	3.07	0.02	0.02	0.03	0.95	0.01	0.01	0.02	0.04	0.03	0.01	0.06	0.68	2.35
Max	6.05	14.95	0.59	0.17	2.14	13.43	0.05	0.06	0.09	2.70	0.04	0.05	0.08	0.15	0.09	0.04	0.20	1.73	67.98
Min	1.96	5.51	0.29	0.06	0.26	4.77	0.01	0.02	0.02	0.12	0.02	0.02	0.03	0.04	0.01	0.02	0.06	0.07	61.11
CV	0.41	0.43	0.28	0.40	0.70	0.44	0.61	0.52	0.56	0.66	0.40	0.42	0.42	0.57	0.92	0.33	0.50	1.06	0.04

Table 2.96: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at AHCM for winter (W) season

AHCM	$PM_{2.5}$	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	108	17.37	7.64	0.34	5.41	2.58	9.06	7.09	0.83	1.69	0.26	2.07	0.01	0.09	3.15	1.59	4.34	10.68	0.13
SD	22	3.25	1.80	0.05	1.48	1.20	3.66	2.54	0.68	0.75	0.10	0.58	0.00	0.02	1.17	1.23	1.08	2.78	0.05
Max	151	24.35	11.04	0.42	8.28	4.77	16.52	10.56	2.16	3.15	0.36	3.18	0.01	0.13	5.22	4.21	5.83	15.39	0.18
Min	84	14.42	6.25	0.28	3.60	1.11	5.98	3.71	0.30	0.97	0.06	1.42	0.01	0.07	1.80	0.51	2.66	6.70	0.03
CV	0.20	0.19	0.24	0.16	0.27	0.46	0.40	0.36	0.82	0.44	0.39	0.28	0.14	0.25	0.37	0.77	0.25	0.26	0.42
AHCM	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.30	3.02	0.13	0.06	0.42	2.58	0.01	0.01	0.02	0.88	0.01	0.02	0.02	0.03	0.02	0.01	0.06	0.37	67.55
SD	1.35	0.87	0.03	0.01	0.25	0.75	0.00	0.00	0.00	0.55	0.00	0.00	0.00	0.01	0.01	0.00	0.06	0.30	1.43
Max	5.13	4.29	0.18	0.07	0.80	3.64	0.01	0.02	0.03	1.70	0.02	0.03	0.03	0.04	0.04	0.02	0.19	0.79	69.84
Min	1.05	1.93	0.09	0.05	0.11	1.70	0.01	0.01	0.01	0.10	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.05	65.34
CV	0.59	0.29	0.25	0.12	0.60	0.29	0.13	0.18	0.21	0.62	0.27	0.28	0.19	0.24	0.53	0.13	0.95	0.80	0.02

Table 2.97: Statistical results chemical characterization (µg/m^3) of PM_{10} at AHCM for summer (S) season

AHCM	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	84	9.6	4.1	0.3	3.9	1.9	12.6	3.2	3.0	1.4	0.3	1.0	0.05	0.05	4.38	2.04	2.78	6.48	1.83
SD	13	1.6	0.7	0.0	1.1	0.5	2.1	0.7	1.1	0.3	0.2	0.2	0.01	0.02	0.86	0.48	0.78	1.72	0.34
Max	106	12.4	4.9	0.4	5.8	2.7	15.8	4.4	4.6	1.7	0.7	1.6	0.07	0.08	5.77	2.89	4.37	9.90	2.49
Min	68	7.6	3.2	0.3	2.5	1.3	8.9	2.7	1.3	0.9	0.2	0.9	0.04	0.02	3.53	1.37	2.11	4.59	1.40
CV	0.15	0.17	0.18	0.08	0.27	0.26	0.17	0.22	0.35	0.22	0.60	0.24	0.15	0.41	0.20	0.24	0.28	0.27	0.19
AHCM	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.46	1.94	0.29	0.10	0.52	1.62	0.05	0.06	0.07	0.69	0.05	0.06	0.07	0.09	0.05	0.05	0.12	0.13	75.91
SD	1.02	0.53	0.07	0.02	0.27	0.53	0.01	0.01	0.01	0.33	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.04	3.51
Max	6.40	2.84	0.40	0.13	0.96	2.62	0.07	0.08	0.09	1.26	0.07	0.07	0.09	0.12	0.07	0.07	0.17	0.19	81.99
Min	3.50	1.31	0.19	0.08	0.19	1.05	0.04	0.05	0.05	0.22	0.03	0.05	0.06	0.07	0.04	0.04	0.09	0.08	70.50
CV	0.23	0.27	0.24	0.18	0.52	0.33	0.13	0.16	0.20	0.49	0.24	0.10	0.14	0.23	0.14	0.14	0.24	0.29	0.05

Table 2.98: Statistical results of chemical characterization (µg/m^3) of PM$_{2.5}$ at AHCM for summer (S) season

AHCM	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	53	6.7	3.4	0.3	2.8	1.1	7.7	2.0	1.6	0.8	0.13	0.50	0.04	0.03	2.84	1.22	1.66	3.83	1.09
SD	6	1.1	0.6	0.0	1.0	0.3	2.1	0.4	0.4	0.2	0.05	0.19	0.01	0.01	0.84	0.54	0.27	1.08	0.11
Max	62	8.7	4.0	0.3	4.4	1.4	10.5	2.7	1.9	1.0	0.22	0.83	0.06	0.04	4.58	2.38	2.07	5.51	1.27
Min	44	5.3	2.7	0.2	1.9	0.8	4.7	1.3	1.0	0.4	0.08	0.31	0.03	0.01	1.93	0.77	1.32	2.31	0.96
CV	0.12	0.17	0.18	0.16	0.35	0.25	0.28	0.22	0.26	0.27	0.34	0.39	0.32	0.31	0.29	0.44	0.16	0.28	0.10
AHCM	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.60	1.17	0.16	0.06	0.27	1.08	0.03	0.04	0.03	0.38	0.03	0.03	0.04	0.06	0.03	0.03	0.07	0.07	75.91
SD	0.52	0.21	0.05	0.02	0.09	0.46	0.01	0.01	0.01	0.16	0.01	0.00	0.01	0.02	0.01	0.01	0.01	0.02	1.93
Max	3.25	1.46	0.24	0.08	0.39	1.74	0.05	0.04	0.04	0.63	0.05	0.04	0.06	0.08	0.05	0.04	0.08	0.12	78.40
Min	1.96	0.89	0.09	0.03	0.15	0.50	0.02	0.03	0.02	0.14	0.02	0.02	0.03	0.03	0.02	0.02	0.04	0.06	73.05
CV	0.20	0.18	0.30	0.31	0.34	0.43	0.36	0.17	0.20	0.43	0.45	0.16	0.25	0.36	0.40	0.32	0.20	0.32	0.03

Table 2.99: Statistical results chemical characterization (µg/m^3) of PM$_{10}$ at AHCM for post-monsoon (P) season

AHCM	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	101	10.9	4.8	0.2	1.1	4.1	7.2	0.8	0.7	0.7	0.36	3.03	0.00	0.04	2.68	1.46	5.21	12.52	0.19
SD	52	4.5	2.9	0.0	0.7	3.0	3.7	0.3	0.6	0.4	0.27	1.82	0.00	0.03	2.53	0.95	2.90	7.01	0.07
Max	176	15.3	10.1	0.3	2.5	8.1	14.7	1.3	1.9	1.2	0.82	6.01	0.00	0.08	7.87	3.07	9.88	24.03	0.27
Min	43	5.2	1.9	0.2	0.3	0.8	3.9	0.4	0.0	0.3	0.11	1.10	0.00	0.01	0.70	0.26	2.23	4.92	0.09
CV	0.51	0.41	0.60	0.20	0.67	0.74	0.51	0.42	0.94	0.49	0.76	0.60	1.71	0.73	0.94	0.65	0.56	0.56	0.38
AHCM	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.37	3.68	0.13	0.12	0.22	3.21	0.00	0.01	0.01	0.27	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.13	63.70
SD	3.84	2.24	0.10	0.02	0.23	2.04	0.00	0.00	0.01	0.26	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.10	2.10
Max	10.63	7.27	0.27	0.17	0.54	6.64	0.00	0.01	0.03	0.82	0.01	0.00	0.03	0.02	0.00	0.01	0.03	0.27	68.13
Min	0.96	1.40	0.00	0.09	0.00	1.24	0.00	0.00	0.01	0.06	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.03	61.91
CV	0.72	0.61	0.73	0.20	1.02	0.64	0.38	0.39	0.71	0.94	0.97	1.25	0.70	0.56	0.49	1.46	0.72	0.78	0.03

Table 2.100: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at AHCM for post-monsoon (P) season

AHCM	$PM_{2.5}$	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	51	7.6	3.9	0.2	0.5	0.7	4.3	0.4	0.4	0.5	0.12	0.88	0.00	0.02	1.11	0.71	2.33	5.80	0.07
SD	21	3.1	2.4	0.0	0.2	0.3	1.7	0.2	0.4	0.3	0.05	0.37	0.00	0.01	0.55	0.44	1.07	2.40	0.02
Max	88	10.7	8.4	0.2	0.7	1.1	7.3	0.7	1.3	1.0	0.22	1.44	0.00	0.04	1.91	1.49	4.39	10.60	0.09
Min	30	3.6	1.6	0.1	0.2	0.3	2.4	0.3	0.0	0.1	0.07	0.42	0.00	0.00	0.47	0.18	1.47	3.66	0.05
CV	0.42	0.41	0.60	0.26	0.39	0.43	0.41	0.36	1.07	0.54	0.44	0.42	1.88	0.72	0.49	0.62	0.46	0.41	0.23
AHCM	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.86	1.63	0.07	0.08	0.11	1.34	0.00	0.00	0.01	0.18	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.08	64.62
SD	0.92	0.86	0.05	0.03	0.11	0.73	0.00	0.00	0.01	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	1.62
Max	3.08	3.35	0.14	0.12	0.27	2.91	0.00	0.00	0.02	0.60	0.01	0.00	0.01	0.02	0.00	0.01	0.02	0.21	66.94
Min	0.73	0.98	0.00	0.04	0.00	0.79	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	62.58
CV	0.50	0.53	0.76	0.33	0.99	0.54	0.40	0.30	0.89	1.10	1.24	1.13	0.45	0.48	0.56	1.55	0.78	0.81	0.03

Table 2.101: Correlation matrix for PM_{10} and its composition at AHCM for winter season

AHCM (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	0.88	0.91	0.43	0.89	0.80	0.89	0.81	0.28	-0.13	0.97	0.18	0.79	0.99
TC		1.00	0.94	0.69	0.57	0.77	0.71	0.84	0.57	0.03	0.80	0.34	0.93	0.81
OC			1.00	0.41	0.64	0.70	0.65	0.69	0.51	-0.28	0.90	0.17	0.89	0.88
EC				1.00	0.19	0.57	0.53	0.82	0.45	0.68	0.25	0.54	0.62	0.32
NO_3^-					0.93	0.83	1.00	0.89	0.17	0.24	0.81	0.29	0.67	0.86
SO_4^{-2}					0.67	0.90		1.00	0.50	0.46	0.67	0.58	0.83	0.71
NH_4^+					-0.09	0.27			0.23	1.00	-0.31	0.56	0.12	-0.25
Metals					0.91	0.71			0.15		0.98	0.05	0.70	1.00

Table 2.102: Correlation matrix for PM$_{2.5}$ and its composition at AHCM for winter season

AHCM (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	0.84	0.78	0.60	0.36	0.51	0.95	0.49	0.25	0.09	0.95	0.33	0.77	0.91
TC		1.00	0.92	0.72	-0.10	0.66	0.78	0.44	0.54	-0.03	0.74	0.24	0.68	0.60
OC			1.00	0.41	-0.02	0.76	0.78	0.10	0.56	-0.37	0.72	0.16	0.66	0.63
EC				1.00	-0.19	0.21	0.46	0.86	0.30	0.58	0.48	0.28	0.43	0.28
NO_3^-					0.48	0.42	1.00	0.33	0.08	-0.02	0.87	0.25	0.63	0.90
SO_4^{-2}					0.00	0.11		1.00	0.21	0.87	0.49	0.51	0.46	0.23
NH_4^+					0.02	-0.23			-0.08	1.00	0.14	0.49	0.13	-0.09
Metals					0.61	0.35			0.02		0.88	0.19	0.65	1.00

Table 2.103: Correlation matrix for PM$_{10}$ and its composition at AHCM for summer season

AHCM (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	0.51	0.72	0.00	0.13	0.22	0.47	0.91	0.27	0.89	-0.52	0.28	0.93
TC		1.00	0.98	0.89	0.36	-0.30	-0.45	0.65	0.41	-0.39	0.59	-0.31	-0.04	0.29
OC			1.00	0.78	0.49	-0.30	-0.52	0.55	0.30	-0.47	0.48	-0.18	-0.14	0.16
EC				1.00	0.00	-0.26	-0.23	0.77	0.60	-0.15	0.74	-0.55	0.21	0.53
NO_3^-					-0.22	0.70	1.00	0.02	0.24	0.19	0.35	-0.20	0.70	0.42
SO_4^{-2}					-0.15	-0.32		1.00	0.25	-0.37	0.76	-0.81	0.27	0.31
NH_4^+					-0.64	0.13			0.54	1.00	0.06	-0.08	0.01	0.54
Metals					-0.24	0.21			0.91		0.80	-0.53	0.34	1.00

Table 2.104: Correlation matrix for PM$_{2.5}$ and its composition at AHCM for summer season

AHCM (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	0.73	0.58	0.89	0.34	-0.12	0.11	0.47	0.62	-0.03	0.51	-0.41	-0.04	0.99
TC		1.00	0.97	0.90	0.20	-0.16	-0.51	-0.04	0.34	-0.24	0.08	-0.24	0.32	0.69
OC			1.00	0.78	0.23	-0.16	-0.66	-0.17	0.18	-0.33	-0.06	-0.10	0.46	0.53
EC				1.00	0.10	-0.13	-0.15	0.21	0.61	-0.04	0.33	-0.48	0.02	0.87
NO$_3^-$					0.15	0.52	1.00	0.25	0.53	0.51	0.13	-0.08	-0.33	0.16
SO$_4^{-2}$					0.01	-0.58		1.00	0.11	0.11	0.93	-0.31	-0.58	0.47
NH$_4^+$					0.18	0.46			0.66	1.00	0.02	0.20	-0.11	-0.09
Metals					0.29	-0.11			0.60		0.51	-0.46	-0.09	1.00

Table 2.105: Correlation matrix for PM$_{10}$ and its composition at AHCM for post-monsoon season

AHCM (P)	PM$_{10}$	TC	OC	EC	F$^-$	Cl$^-$	NO$_3^-$	SO$_4^{-2}$	Na$^+$	NH$_4^+$	K$^+$	Mg^{+2}	Ca^{+2}	Metals
PM$_{2.5}$	1.00	0.99	0.95	0.96	0.81	0.42	0.56	0.84	0.52	-0.57	0.98	0.55	0.98	1.00
TC		1.00	0.98	0.94	0.78	0.40	0.61	0.79	0.62	-0.61	0.98	0.50	0.97	0.99
OC			1.00	0.84	0.74	0.48	0.75	0.64	0.76	-0.66	0.94	0.50	0.91	0.94
EC				1.00	0.77	0.25	0.33	0.94	0.34	-0.47	0.93	0.45	0.97	0.96
NO$_3^-$					0.52	0.72	1.00	0.10	0.83	-0.54	0.63	0.48	0.43	0.55
SO$_4^{-2}$					0.70	0.13		1.00	0.04	-0.40	0.80	0.51	0.86	0.84
NH$_4^+$					-0.61	-0.50			-0.43	1.00	-0.60	-0.75	-0.58	-0.53
Metals					0.81	0.41			0.52		0.98	0.51	0.97	1.00

Table 2.106: Correlation matrix for $PM_{2.5}$ and its composition at AHCM for Post-monsoon season

AHCM (P)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
$PM_{2.5}$	1.00	0.95	0.86	0.98	0.86	0.17	0.77	0.98	0.49	-0.46	0.92	0.30	0.88	0.99
TC		1.00	0.97	0.95	0.87	0.19	0.74	0.96	0.54	-0.64	0.94	0.25	0.90	0.91
OC			1.00	0.84	0.76	0.15	0.69	0.88	0.54	-0.70	0.85	0.26	0.88	0.80
EC				1.00	0.93	0.23	0.73	0.98	0.49	-0.49	0.97	0.22	0.85	0.97
NO_3^-					0.61	0.58	1.00	0.63	0.69	-0.39	0.66	0.28	0.88	0.76
SO_4^{-2}					0.88	0.08		1.00	0.38	-0.50	0.94	0.22	0.81	0.95
NH_4^+					-0.50	-0.39			-0.36	1.00	-0.59	-0.49	-0.67	-0.39
Metals					0.83	0.15			0.49		0.88	0.35	0.86	1.00

2.4.7 Atal Bhawan Gudheli Village (ABGV)

The sampling period was December 18, 2022 - January 01, 2023 (For PM, EC, OC, NO_2, SO_2 and VOC) for a critical period of the winter season at a distance of about 25 km in the upwind direction from the SAIL office.

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

A time series of 24-hour average concentrations of PM_{10} and $PM_{2.5}$ at ABGV is shown for winter (Figure 2.99). Average levels at this site were: $PM_{2.5}$: 146±46 µg/m^3 and PM_{10}: 195±58 µg/m^3. $PM_{2.5}$ levels were about 2.4 times higher than the national air quality standard (NAAQS: 60 µg/m^3) and PM_{10} levels were 1.95 times higher than the NAAQS (100 µg/m^3). The mean levels of PM_{10} and $PM_{2.5}$ at this site were lower than the SAIL and ENPH (industrial sites).

A statistical summary of PM concentrations is presented in Table 2.111 and Table 2.112.

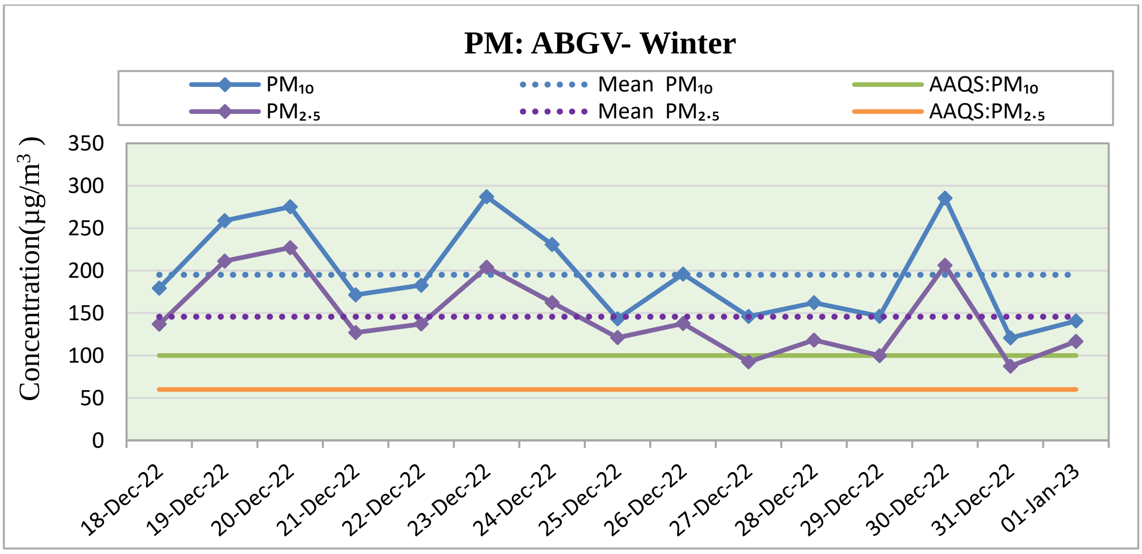


Figure 2.99: PM Concentrations at ABGV for Winter Season

2.4.7.2 Gaseous pollutants

Time series of 24-hour average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.100) season. It was observed that mean SO_2 and NO_2 levels were within the national standard with an average of 15 days at 7.30 µg/m^3 and 20±5.2 µg/m^3 in winter (Table 2.107).

The Mean concentrations of BTX are presented in Figure 2.101 and the statistical summary is in Table 2.107. The total BTX level is observed at 9±7 µg/m^3 (Benzene: 0.79 and p-xylene: 6.29 µg/m^3) in winter. The maximum BTX concentration was observed at 15 µg/m^3 in winter.

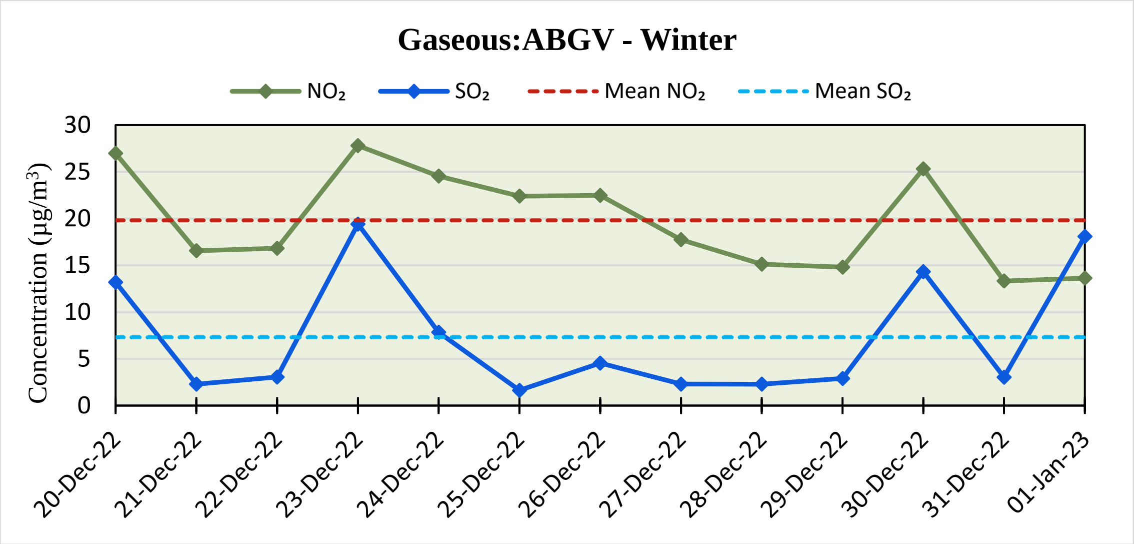


Figure 2.100: SO$_2$ and NO$_2$ Concentrations at ABGV for Winter Season

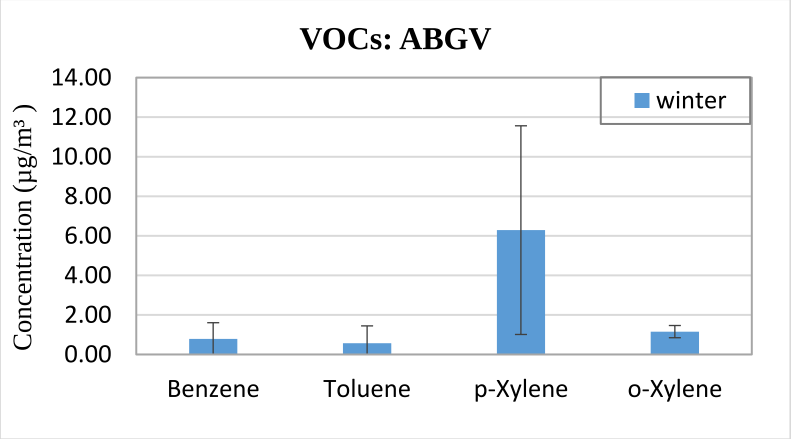


Figure 2.101: VOCs concentration at ABGV

2.4.7.3 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 2.102 (a) and (b) for winter. Organic carbon is observed slightly higher (16.34±4.09 µg/m^3) than the elemental carbon (12.09±3.83 µg/m^3). However, the ratio of OC3/TC is observed higher indicating the formation of secondary organic carbon in the atmosphere. 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 2.108.

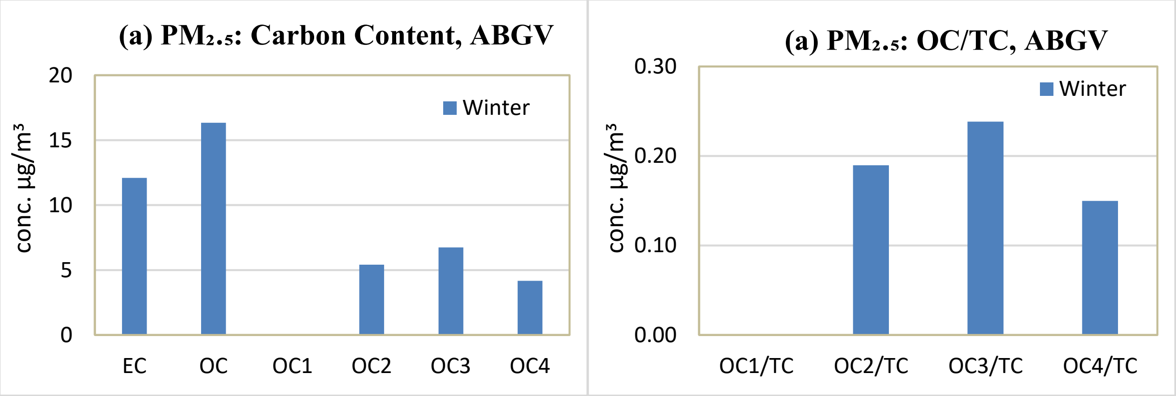


Figure 2.102: EC and OC Content in PM$_{2.5}$ at ABGV

2.4.7.4 PAHs in PM$_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.103 shows the average measured concentration of PAHs at ABGV for winter. A statistical summary of PAHs is presented in Table 2.109 for winter. 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 PAH concentrations in winter were 70±38 ng/m^3. Major PAHs (mostly higher molecular weight compounds) are B(b)F (14 ng/m^3), B(ghi)P (5 ng/m^3), BaP (8 ng/m^3), D(a,h)A (3 ng/m^3), B(a)A (1.2 ng/m^3), Pyr (2 ng/m^3), Phe (6 ng/m^3), AcP(14 ng/m^3), DmP (3 ng/m^3)and Chr (3 ng/m^3).

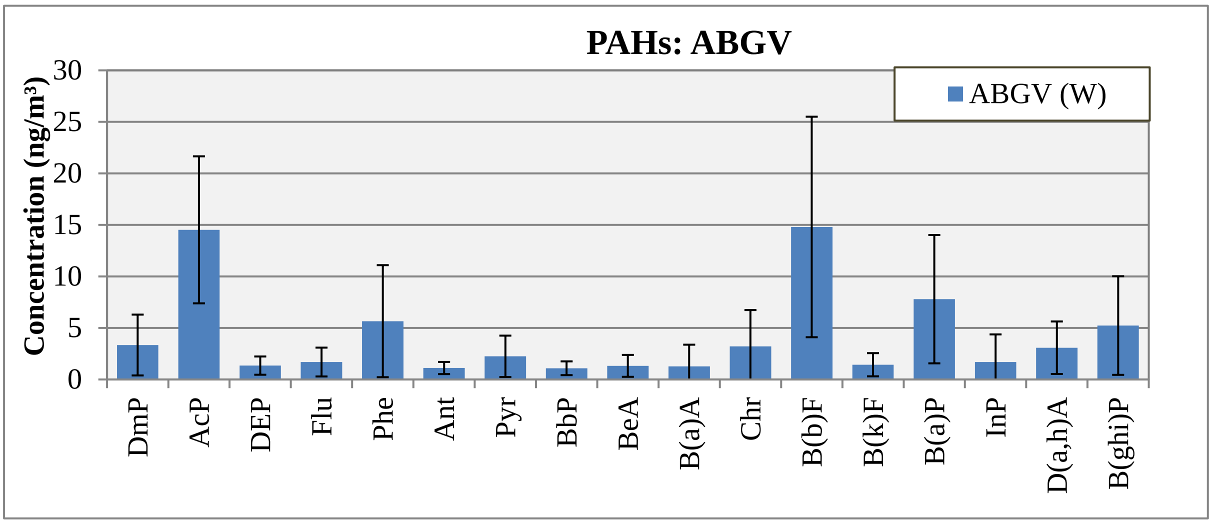


Figure 2.103: PAHs Concentrations in PM$_{2.5}$ at ABGV

2.4.7.5 Molecular Markers in $PM_{2.5}$

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

Figure 2.104 and Table 2.110 show the levels of six molecular markers. The total concentration of markers was 43 ng/m^3. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes the contribution of CGD.

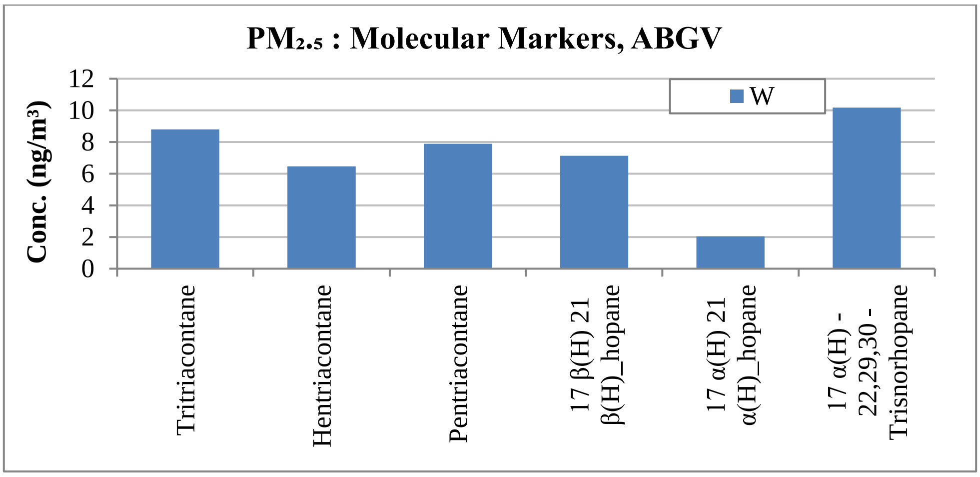


Figure 2.104: Molecular Markers in $PM_{2.5}$ at ABGV

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

Graphical presentations of chemical species are shown for the winter season at ABGV for PM_{10} (Figure 2.105) and $PM_{2.5}$ (Figure 2.106). 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 2.111 and Table 2.112.

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 2.113 and Table 2.114. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM is presented in Figure 2.107(a) and (b) for the winter season.

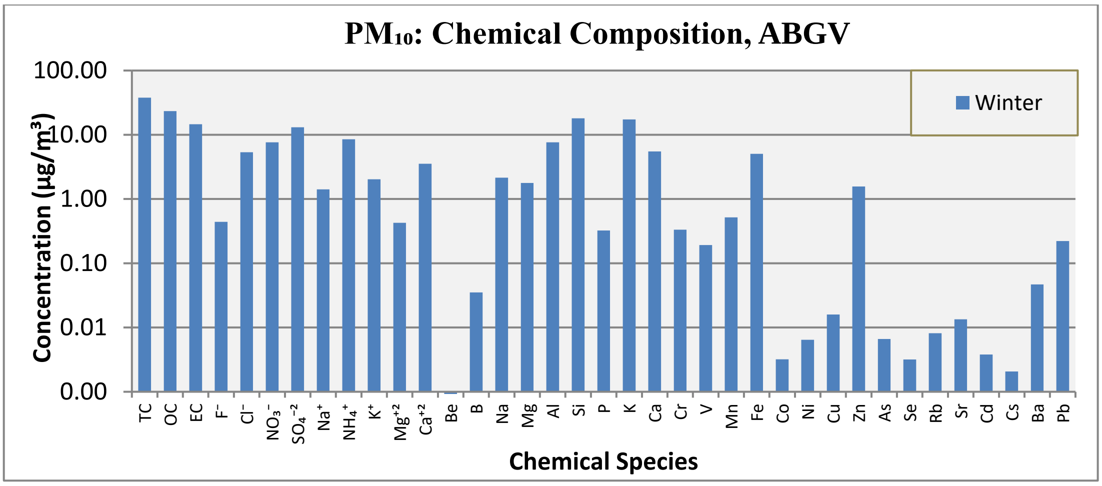


Figure 2.105: Concentrations of species in PM_{10} at ABGV

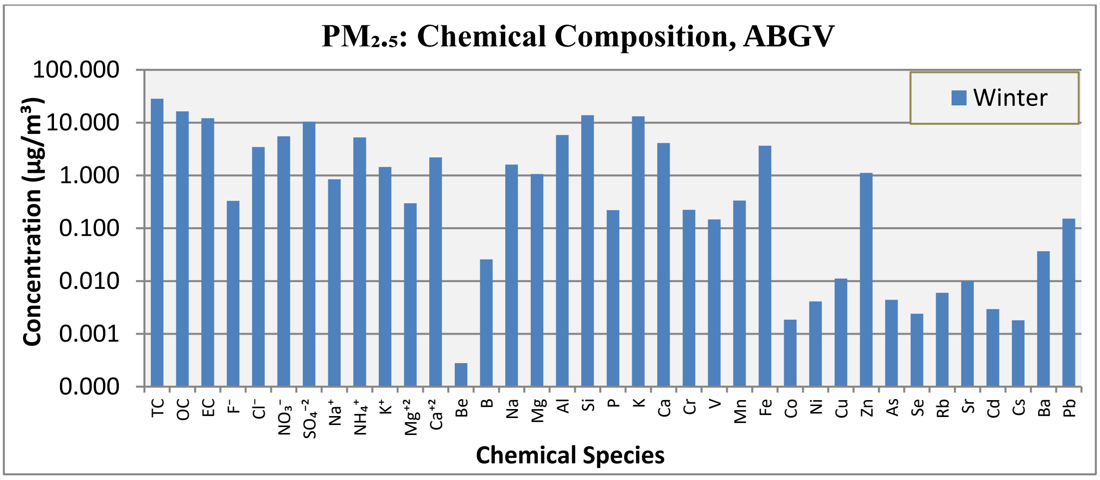
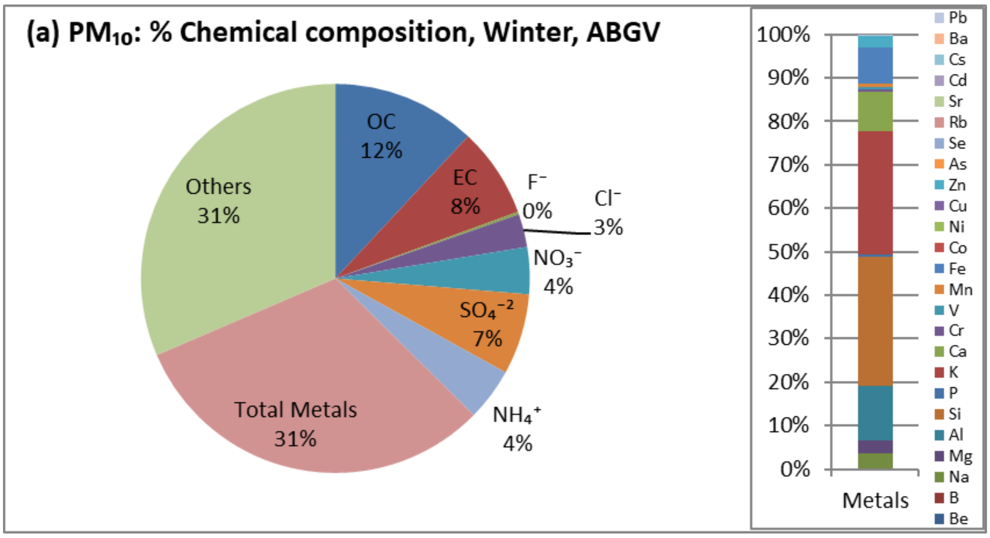


Figure 2.106: Concentrations of species in $PM_{2.5}$ at ABGV



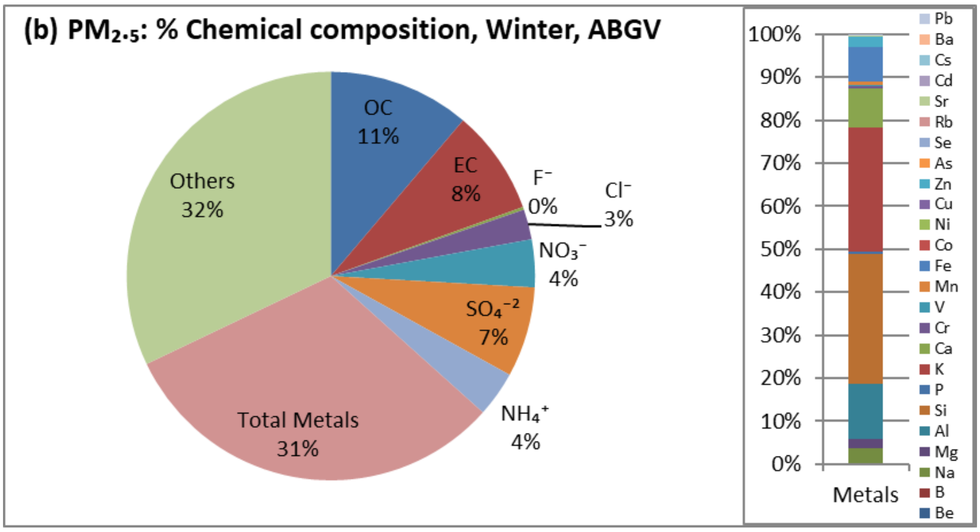


Figure 2.107: Percentage distribution of species in PM at ABGV for Winter Season

2.4.7.7 Comparison of PM$_{10}$ and PM$_{2.5}$ Composition

A graphical compositional comparison of PM$_{2.5}$ Vs PM$_{10}$ for all species is shown for the winter season (Figure 2.108) at ABGV. 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 major portion of PM is having fine mode: 75 %. The major species contributing to fine mode are TC, OC, EC, SO$_4^{-2}$, Na$^+$, NH$_4^+$, K$^+$, B, K, V, Cu, Zn, Cd and Pb; whereas major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Mg, Al, Si, P, Ca, Cr, Ni and Fe are contributing significantly in fine mode.

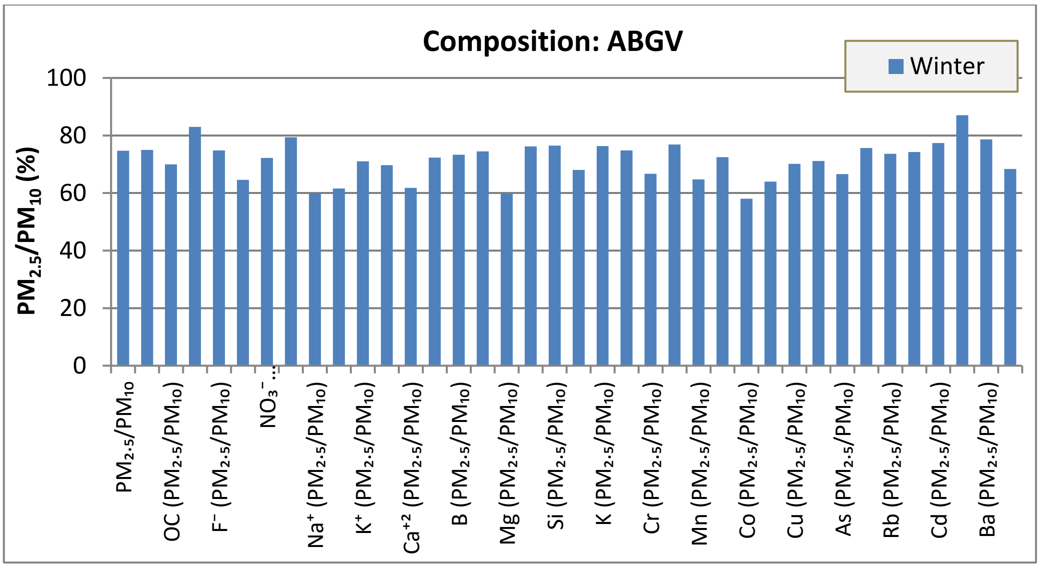


Figure 2.108: Compositional comparison of species in PM$_{2.5}$ Vs PM$_{10}$ at ABGV

Table 2.107: Statistical results of gaseous pollutants (µg/m^3) at ABGV for winter (W) season

ABGV (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	19.81	7.30	0.79	0.57	6.29	1.16	8.80
SD	5.27	6.57	0.82	0.88	5.28	0.31	7.08
Max	27.80	19.42	1.64	1.58	10.66	1.43	15.31
Min	13.32	1.63	0.01	0.00	0.43	0.82	1.26
CV	0.27	0.90	1.04	1.55	0.84	0.27	0.80

Table 2.108: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at ABGV for winter (W) season

ABGV(W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	145.71	28.43	12.09	16.34	0.02	5.41	6.74	4.17	0.00	0.19	0.24	0.15
SD	44.22	7.46	3.83	4.09	0.04	1.55	1.74	1.20	0.00	0.02	0.02	0.03
Max	227.00	0.26	0.32	0.25	0.17	8.88	10.36	7.22	0.01	0.22	0.27	0.24
Min	88.00	44.31	18.70	25.74	0.00	3.57	4.31	3.05	0.00	0.16	0.20	0.10
CV	0.30	20.15	6.62	11.26	1.92	0.29	0.26	0.29	2.05	0.08	0.10	0.23

Table 2.109: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at ABGV for winter (W) seasons

ABGV (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	3.34	14.52	1.34	1.69	5.66	1.11	2.24	1.09	1.32	1.28	3.21	14.80	1.43	7.79	1.69	3.08	5.23	70.81
SD	2.95	7.13	0.89	1.40	5.44	0.59	2.01	0.67	1.06	2.09	3.53	10.70	1.12	6.23	2.69	2.55	4.79	38.64
Max	10.22	28.66	3.10	3.56	16.49	2.21	6.60	2.48	3.47	6.37	11.14	38.81	3.97	22.01	8.22	8.82	16.26	160.46
Min	1.01	6.37	0.27	0.06	0.45	0.47	0.42	0.44	0.22	0.28	0.43	3.67	0.34	1.77	0.17	1.05	1.07	31.66
CV	0.88	0.49	0.66	0.83	0.96	0.53	0.90	0.62	0.81	1.64	1.10	0.72	0.79	0.80	1.59	0.83	0.92	0.55

Table 2.110: Statistical results of molecular markers (ng/m^3) in PM$_{2.5}$ at ABGV for winter (W) seasons

ABGV(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	8.80	6.46	7.89	7.14	2.04	10.18	42.50
SD	2.19	1.76	4.87	1.95	0.97	12.82	20.65
CV	0.25	0.27	0.62	0.27	0.48	1.26	0.49

Table 2.111: Statistical results of chemical characterization (µg/m^3) of PM$_{10}$ at ABGV for winter (W) season

ABGV(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	195	23.3	14.6	0.4	5.4	7.6	13.1	1.4	8.5	2.0	0.4	3.5	4E-4	0.04	2.15	1.78	7.64	18.06	0.32
SD	58	5.8	4.6	0.3	1.9	3.5	3.2	0.6	2.6	0.8	0.3	1.4	2E-4	0.02	0.78	0.55	3.05	7.42	0.08
Max	287	36.8	22.5	1.1	9.8	13.1	18.6	2.5	13.0	3.1	0.8	5.8	7E-4	0.08	3.41	2.61	13.60	32.77	0.45
Min	121	16.1	8.0	0.2	1.7	2.8	7.2	0.6	4.3	0.7	0.0	1.6	4E-5	0.00	0.93	0.91	4.16	10.03	0.23
CV	0.30	0.25	0.32	0.64	0.36	0.46	0.25	0.41	0.31	0.38	0.62	0.39	0.50	0.59	0.36	0.31	0.40	0.41	0.24
ABGV(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	17.30	5.50	0.33	0.19	0.52	5.04	3E-3	6E-3	0.02	1.57	0.01	0.00	8E-3	0.01	4E-3	2E-3	0.05	0.22	69.1
SD	5.34	2.37	0.15	0.04	0.32	2.25	2E-3	4E-3	0.01	1.13	0.00	0.00	6E-3	0.01	3E-3	4E-3	0.03	0.20	2.8
Max	27.18	10.31	0.72	0.28	1.06	9.85	6E-3	2E-2	0.05	3.32	0.01	0.01	2E-2	0.03	1E-2	2E-2	0.11	0.75	76.1
Min	9.22	2.88	0.17	0.15	0.03	2.44	1E-3	2E-3	0.00	0.11	0.00	0.00	1E-3	0.00	3E-4	5E-5	0.01	0.04	64.2
CV	0.31	0.43	0.44	0.19	0.62	0.45	0.50	0.62	0.93	0.72	0.26	0.52	0.73	0.56	0.77	1.88	0.71	0.90	0.04

Table 2.112: Statistical results of chemical characterization (µg/m^3) of PM$_{2.5}$ at ABGV for winter (W) season

ABGV(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	146	16.3	12.1	0.3	3.5	5.5	10.4	0.8	5.2	1.4	0.3	2.2	0.00	0.03	1.60	1.07	5.82	13.81	0.22
SD	46	4.1	3.8	0.3	1.6	3.7	3.2	0.3	2.3	0.7	0.2	1.0	0.00	0.02	0.49	0.50	2.44	5.84	0.08
Max	227	25.7	18.7	0.9	7.6	12.9	17.4	1.4	8.9	3.0	0.7	4.0	0.00	0.06	2.86	1.89	9.66	22.49	0.32
Min	88	11.3	6.6	0.1	1.5	1.9	5.4	0.3	2.3	0.5	0.0	1.1	0.00	0.00	0.85	0.33	2.87	7.06	0.11
CV	0.31	0.25	0.32	0.80	0.47	0.68	0.31	0.37	0.43	0.47	0.68	0.45	0.62	0.67	0.31	0.47	0.42	0.42	0.35
ABGV(W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	13.20	4.12	0.22	0.15	0.34	3.66	0.00	0.00	0.01	1.12	0.00	0.00	0.01	0.01	0.00	0.00	0.04	0.15	68.4
SD	5.62	1.82	0.12	0.03	0.24	1.66	0.00	0.00	0.01	0.92	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.11	2.4
Max	26.68	7.19	0.49	0.20	0.77	6.65	0.00	0.01	0.04	3.07	0.01	0.00	0.01	0.02	0.01	0.02	0.09	0.43	71.5
Min	7.49	2.04	0.08	0.09	0.03	1.82	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	63.9
CV	0.43	0.44	0.54	0.20	0.70	0.45	0.52	0.60	0.93	0.82	0.38	0.54	0.74	0.56	0.67	2.12	0.68	0.73	0.03

Table 2.113: Correlation matrix for PM$_{10}$ and its composition at ABGV for winter season

ABGV (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	0.91	0.81	0.91	0.66	0.56	0.87	0.40	0.21	0.41	0.77	0.65	0.67	0.98
TC		1.00	0.95	0.93	0.66	0.38	0.78	0.15	0.05	0.32	0.70	0.56	0.60	0.84
OC			1.00	0.77	0.66	0.44	0.71	-0.03	0.08	0.27	0.64	0.50	0.63	0.72
EC				1.00	0.58	0.25	0.76	0.37	0.02	0.34	0.69	0.56	0.49	0.88
NO$_3^-$					0.53	0.60	1.00	0.13	0.14	0.14	0.73	0.70	0.73	0.85
SO$_4^{-2}$					0.16	0.12		1.00	0.16	0.46	0.16	0.37	-0.01	0.48
NH$_4^+$					0.40	0.12			0.21	1.00	0.13	0.18	0.00	0.41
Metals					0.61	0.57			0.25		0.78	0.62	0.64	1.00

Table 2.114: Correlation matrix for $PM_{2.5}$ and its composition at ABGV for winter season

ABGV (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	0.90	0.81	0.89	0.52	0.46	0.82	0.35	0.20	0.52	0.61	0.59	0.87	0.99
TC		1.00	0.94	0.94	0.55	0.18	0.61	0.20	-0.02	0.47	0.57	0.34	0.83	0.85
OC			1.00	0.77	0.52	0.19	0.52	-0.02	0.02	0.39	0.59	0.32	0.80	0.75
EC				1.00	0.52	0.15	0.64	0.41	-0.06	0.50	0.48	0.32	0.75	0.86
NO_3^-					0.50	0.58	1.00	0.11	0.01	0.29	0.58	0.83	0.77	0.82
SO_4^{-2}					0.22	0.09		1.00	0.30	0.40	-0.13	0.12	0.12	0.36
NH_4^+					0.44	-0.06			0.16	1.00	0.13	0.34	0.33	0.47
Metals					0.44	0.48			0.24		0.60	0.58	0.81	1.00

2.4.8 Overall Summary and results

The sampling period for winter is December 12, 2020 - February 07, 2021; summer: March 05, 2021 – May 10, 2021, and post-monsoon: September 09, 2021 - October 26, 2021.

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

The seasonal comparison is shown for PM_{10} (Figure 2.109), $PM_{2.5}$ (Figure 2.110) and the ratio of $PM_{2.5}$ to PM_{10} (Figure 2.111) for all sites. The overall summary of experimental results for PM is shown for winter, summer, and post-monsoon seasons (Table 2.115).

Winter

The overall city average of $PM_{2.5}$ in winter was 142 µg/m^3 and PM_{10} was 250 µg/m^3. The $PM_{2.5}$ levels are about 2.4 higher than the NAAQS (60 µg/m^3) and PM_{10} is about 2.5 times higher than the NAAQS (100 µg/m^3). Both $PM_{2.5}$ and PM_{10} levels were highest at SAIL, the industrial site (196 and 344 µg/m^3) followed by levels at HSSR (150 and 298 µg/m^3), a commercial and traffic site. The $PM_{2.5}$ levels were lowest at ABGV (108 µg/m^3) and PM_{10} levels were lowest at HSSB (181 µg/m^3); these levels also exceeded the air quality standards. The highest variability for $PM_{2.5}$ was seen at KRNK (CV: 0.33) followed by ABGV (CV: 0.31) and the least at SAIL (0.17). The highest variation for PM_{10} was seen at AHCM (CV: 0.34) and the least at SAIL (CV: 0.12).

The ratio of $PM_{2.5}$ to PM_{10} is a useful parameter to indicate the relative abundance of fine particulate (i.e., $PM_{2.5}$) and toxicity of particulate matter. The overall city ratio is 0.58 and it was highest at ABGV (0.75), followed by HSSB (0.65) and KRNK (0.60). The relatively high $PM_{2.5}$ at these sites could be attributed to heavy traffic in the area and industrial units.

Summer

The overall city average $PM_{2.5}$ level in summer drops to 91 µg/m^3 but not the PM_{10} levels as the concentration of 175 µg/m^3. The $PM_{2.5}$ level is 1.5 times higher than the standard and PM_{10} is 1.8 times higher than the standard. Both $PM_{2.5}$ and PM_{10} levels were highest at ENPH, the industrial site at 119 and 240 µg/m^3. The PM_{10} and $PM_{2.5}$ levels were lowest at HSSB (65 and 42 µg/m^3); PM_{10} and $PM_{2.5}$ both levels met the air quality standards. The highest variability for $PM_{2.5}$ was seen at HSSB (CV: 0.26) followed by KRNK and SAIL (CV: 0.20). The highest variation for PM_{10} was seen at HSSR (CV: 0.30) and the least at AHCM (CV: 0.15). The overall

$PM_{2.5}$ to PM_{10} city ratio is 0.56 and it was highest at HSSB (0.65). The ratio was similar at other sites.

Post-monsoon

The overall city average of $PM_{2.5}$ level in post-monsoon drops sharply to 50 µg/m^3 and the PM_{10} levels to 93 µg/m^3. The mean $PM_{2.5}$ and PM_{10} levels generally meet the standards in post-monsoon. Both $PM_{2.5}$ and PM_{10} levels were highest at HSSR, the commercial site at 74 and 140 µg/m^3 followed by levels at ENPH (67 and 127 µg/m^3), a traffic site. The PM_{10} and $PM_{2.5}$ levels were lowest at SAIL (28 and 51 µg/m^3). The variability for $PM_{2.5}$ was seen highest at HSSR (CV: 0.53) followed by HSSB (CV: 0.49). The highest variation for PM_{10} was seen at SAIL (CV: 0.60) and the least at HSSR (CV: 0.44). The overall $PM_{2.5}$ to PM_{10} city ratio is 0.55 and it was highest at HSSB (0.60). The ratio was similar at other sites.

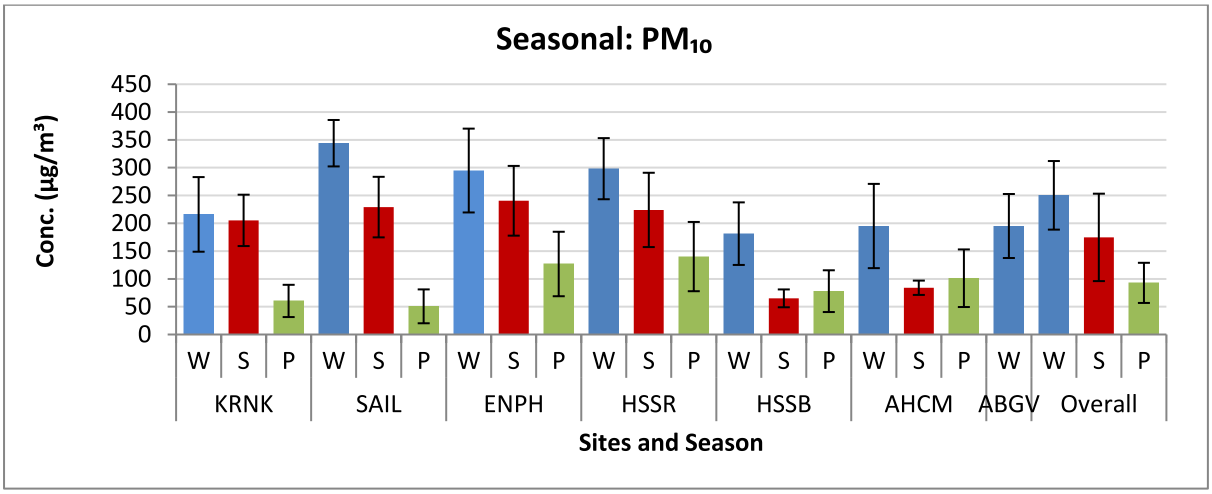


Figure 2.109: Seasonal comparison of PM_{10} levels for all Sites

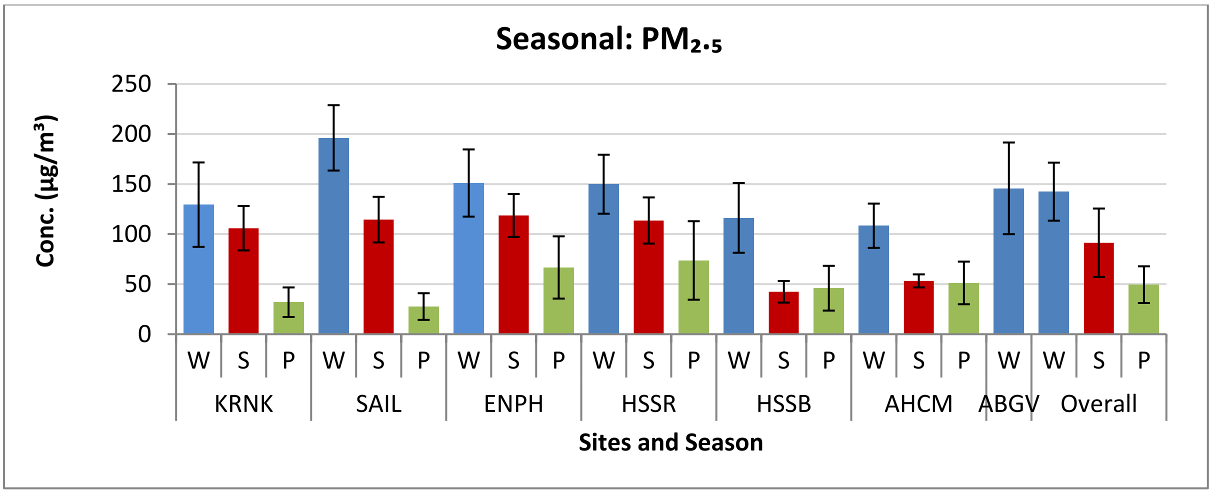


Figure 2.110: Seasonal comparison of $PM_{2.5}$ concentrations for all Sites

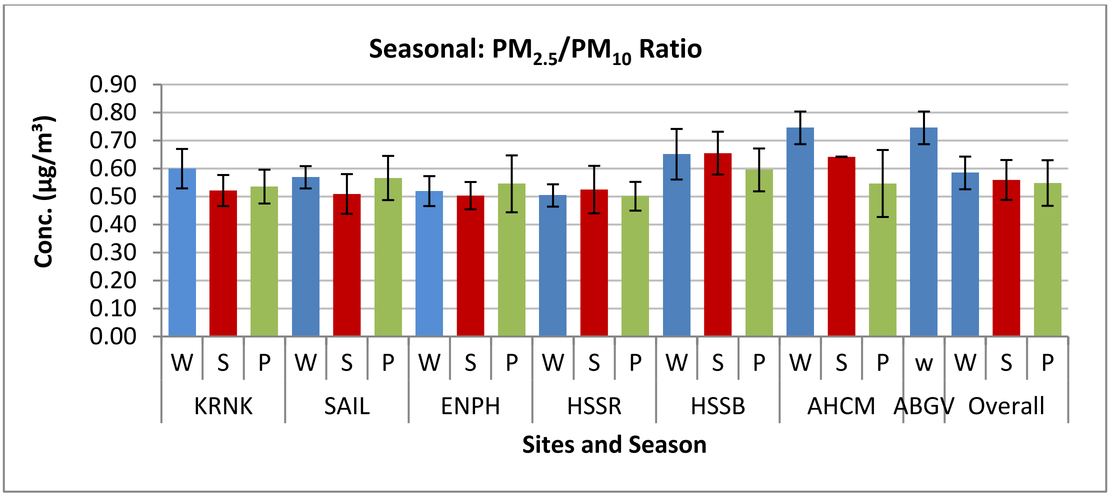


Figure 2.111: Seasonal comparison of $PM_{2.5}$ /PM_{10} ratio

2.4.8.2 Gaseous Pollutants (NO_2 and SO_2)

The seasonal comparison is shown for NO_2 and SO_2 (Figure 2.112). The overall average concentrations with statistical summary are presented in Table 2.116 to Table 2.118 for all sites for winter, summer and post-monsoon seasons.

The SO_2 levels were considerable with an average of 12.27 µg/m^3 in winter but within the air quality standards (80 µg/m^3). Levels were quite low in summer and post-monsoon at all sites (Figure 2.112). 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 all three seasons. The overall city level average NO_2 levels are 28.74 µg/m^3 in winter, 20.68 µg/m^3 in summer and 13.41 µg/m^3 in post-monsoon. The highest NO_2 concentration was observed at SAIL: 41 (winter) and 34 µg/m^3 (summer). NO_2 levels did not exceed 60 µg/m^3 at any site in any season. The substantial value of NO_2 makes it clear that is an emerging pollutant which can largely be attributed to vehicular emissions and industrial coal combustion. It is noteworthy the fact that NO_2 levels are varying at all sites (range: 24 – 41 µg/m^3) in winter. KRNK area is the commercial area having the highest vehicular emission of NO_2. Levels drop in summer and post-monsoon (50% of winter) largely due to high wind speeds, convective conditions, and 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, especially in commercial and industrial areas as it will be difficult to reduce the emission after the fact at a later stage.

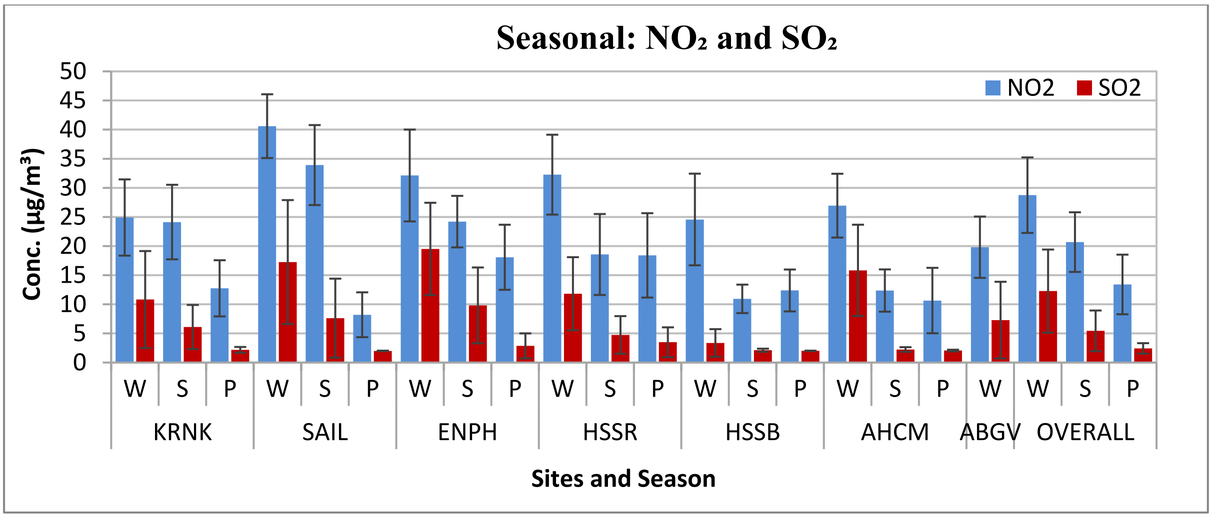


Figure 2.112: Seasonal Comparison of NO_2 and SO_2 levels for all Sites

2.4.8.3 Volatile Organic Compounds (VOCs: BTX)

The seasonal comparison for VOCs (BTX) is shown in Figure 2.113. The overall statistical summary in presented in Table 2.116 - Table 2.118 for all sites for winter, summer, and post-monsoon seasons.

The overall city level average BTX level is 10.2 µg/m^3 in winter, 18.49 µg/m^3 in summer and 15.88 µg/m^3 in post-monsoon. The highest BTX concentration was observed at HSSR (20.0 µg/m^3) in winter, ENPH (23.3 µg/m^3) in summer and KRNK (33.3 µg/m^3) in post-monsoon seasons.

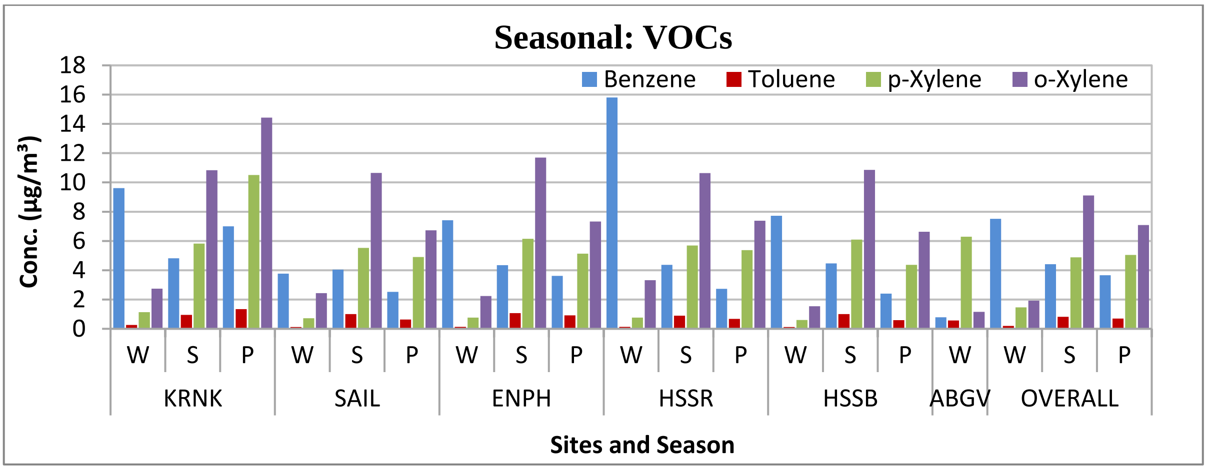


Figure 2.113: Seasonal comparison of VOCs for all Sites

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

The seasonal comparison for OC and EC is presented in Figure 2.114 for PM_{10} and Figure 2.115 for $PM_{2.5}$. The organic carbon is observed higher than the elemental carbon at each site in all the seasons; this is generally true that in the atmosphere volatile and semi-volatile organic compounds continuously undergo nucleation, oxidation, and 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 and post-monsoon seasons probably because of poor dispersion in winter and more combustion sources including biomass and solid waste burning. It is observed that the average TC to $PM_{2.5}$ ratio was maximum at (i) AHCM (23.1%) in winter, (ii) ENPH (24.8%) in summer and (iii) AHCM (22.6%) in post-monsoon; and minimum at (i) ABGV (19.5%) in winter, (ii) AHCM (19.0%) in summer and (iii) SAIL (15.1%) in post-monsoon.

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 2.119 - Table 2.121 for winter, summer and post-monsoon seasons.

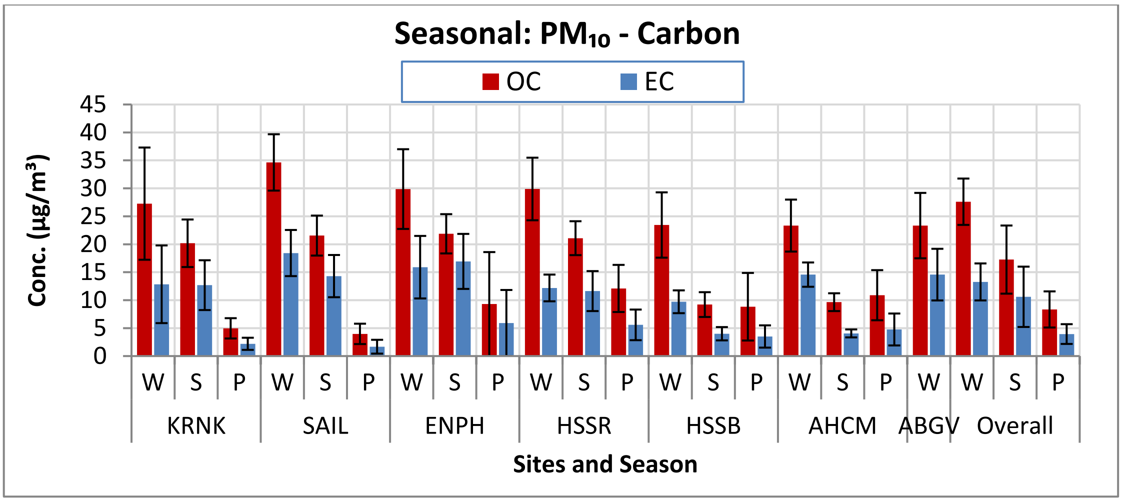


Figure 2.114: Seasonal Comparison of EC and OC in PM_{10} for all Sites

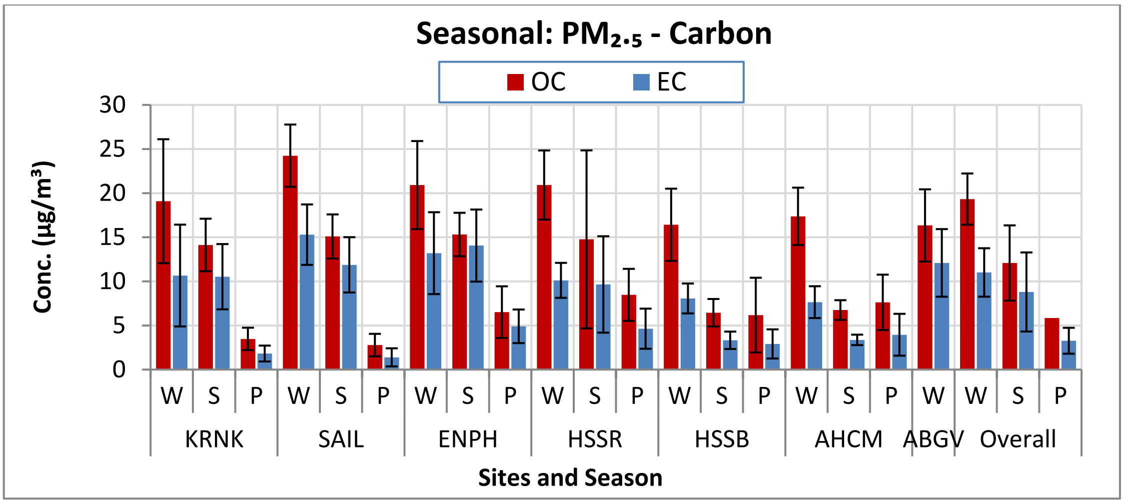


Figure 2.115: Seasonal Comparison of EC and OC in $PM_{2.5}$ for all Sites

2.4.8.5 PAHs in $PM_{2.5}$

The average concentrations of PAHs are shown graphically for winter (Figure 2.116), summer (Figure 2.117) and post-monsoon season (Figure 2.118) for all sites along with the overall average concentration for Bhilai. Average concentrations are shown in Table 2.122 – Table 2.124 with the standard deviation and coefficient of variation (CV) for Bhilai. 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. Seasonal comparison for PAHs is shown in Figure 2.119 which indicates the concentrations are significantly higher in winter (34 ng/m^3) season and summer (27 ng/m^3) compared to post-monsoon (21 ng/m^3)season. Major PAHs are B(b)F, B(ghi)P, BbP, DmP, AcP and Chr. B(a)P although has an annual standard of 1 ng/$m^3$and we cannot compare it with levels of 7 days, however levels of B(a)P (winter mean: 3.23, summer mean: 2.94 and post-monsoon:2.05 ng/m^3) are high and annual standard is most likely to exceed by a fair margin at all 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 (0.39 in winter, 0.38 in summer and 0.35 in post-monsoon) is comparable to the reported values for diesel emissions in all the seasons. It is inferred that the major sources of PAHs are diesel vehicles and industrial DGs.

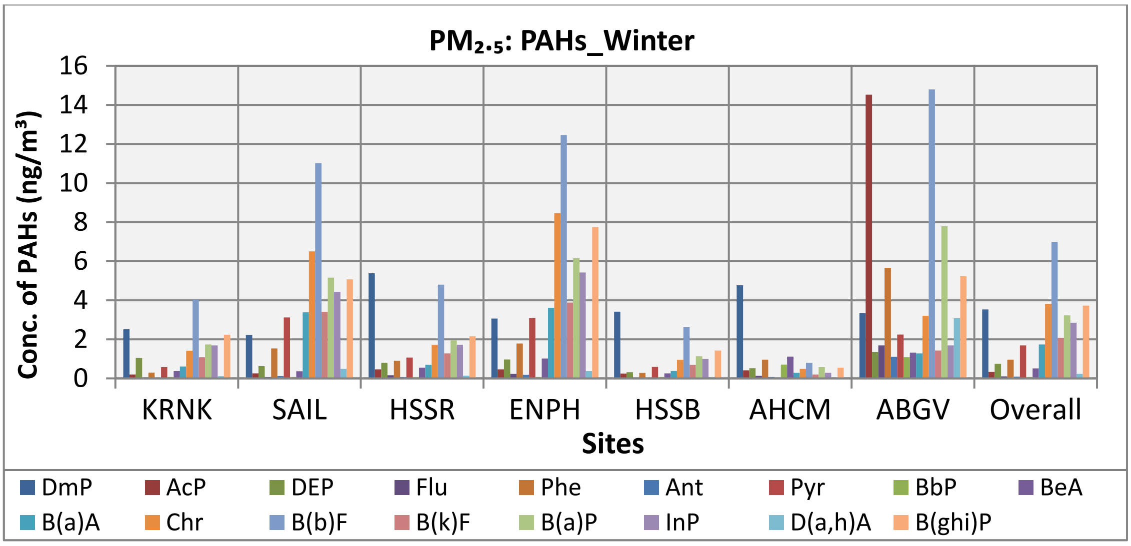


Figure 2.116: Variation in PAHs in $PM_{2.5}$ for winter season

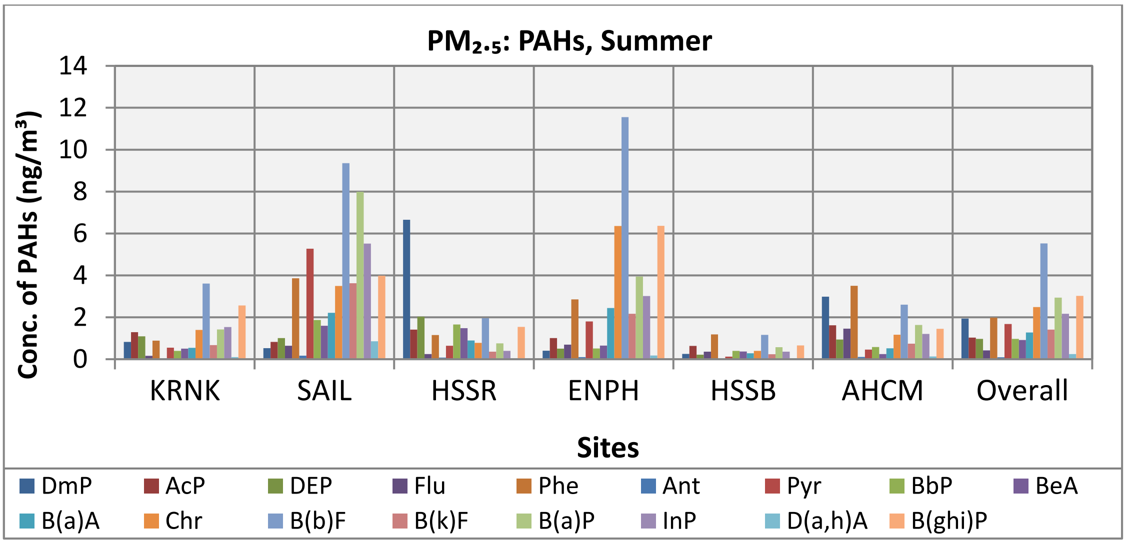


Figure 2.117: Variation in PAHs in $PM_{2.5}$ for summer season

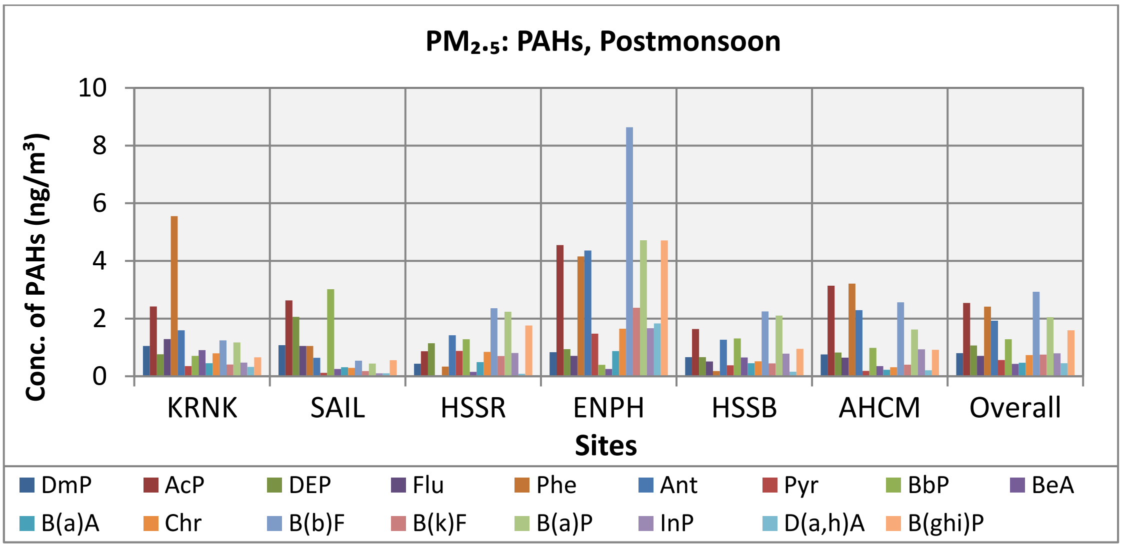


Figure 2.118: Variation in PAHs in $PM_{2.5}$ for post-monsoon

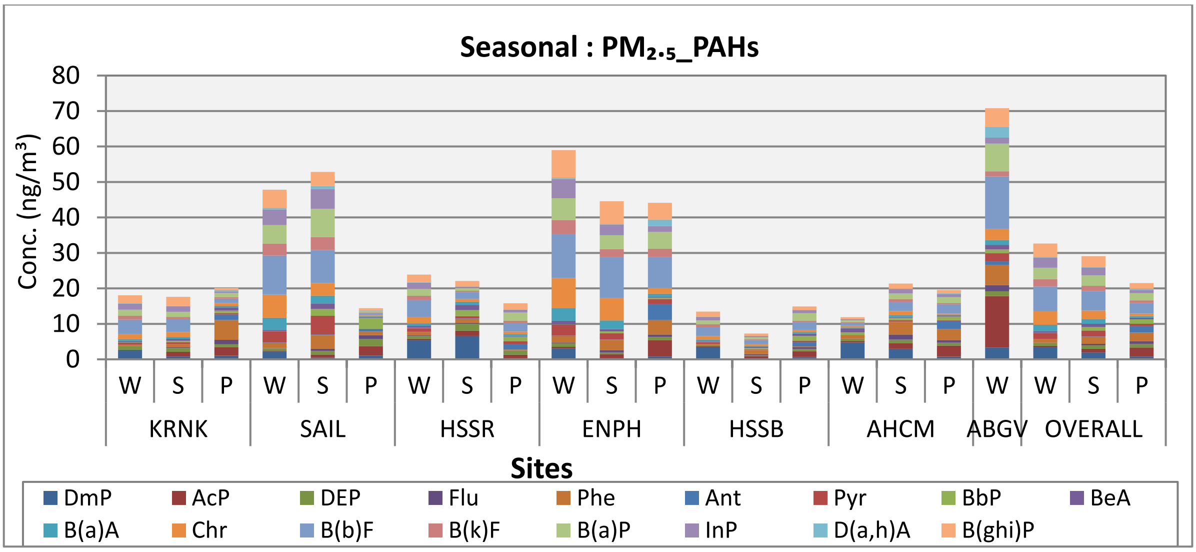


Figure 2.119: Seasonal comparison of in PAHs in $PM_{2.5}$

2.4.8.6 Molecular Markers in $PM_{2.5}$

The average concentrations of molecular markers are shown graphically for winter (Figure 2.120), summer (Figure 2.121) and post-monsoon season (Figure 2.122) for all sites along with the overall average concentration for Bhilai. Average concentrations are shown in Table 2.125- Table 2.127 with the standard deviation and coefficient of variation CV for Bhilai. Seasonal comparison is shown in Figure 2.123 which indicates the concentrations of overall molecular markers are higher in winter (85 ng/m^3) compared to summer (66 ng/m^3) and post-monsoon (64 ng/m^3) season. Hentriacontane and 17 β(H) 21 β(H)_hopane contributed the highest fraction in all the seasons which conclusively establishes the contribution of coal burning, gasoline and diesel combustion in vehicles.

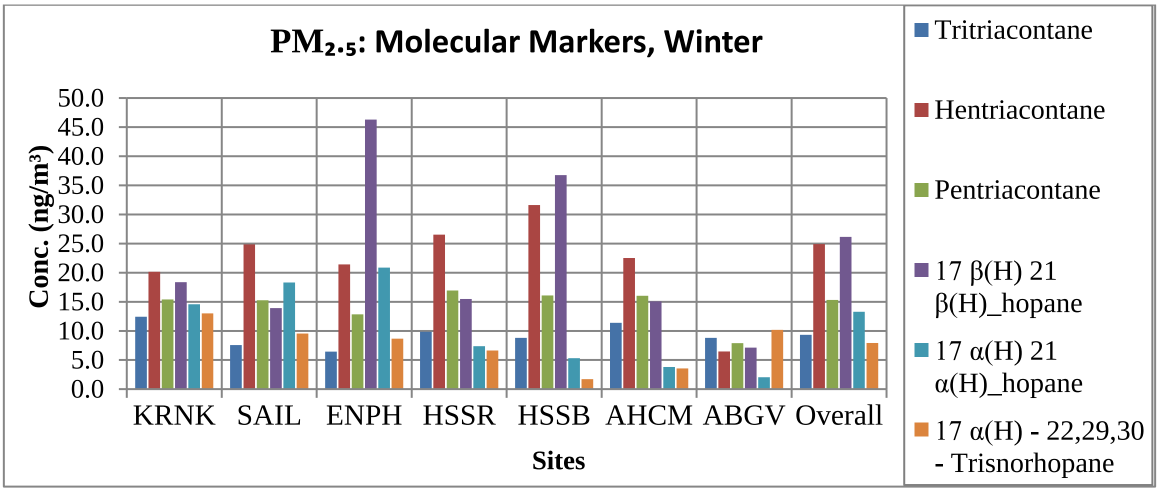


Figure 2.120: Variation in molecular markers in $PM_{2.5}$ for winter season

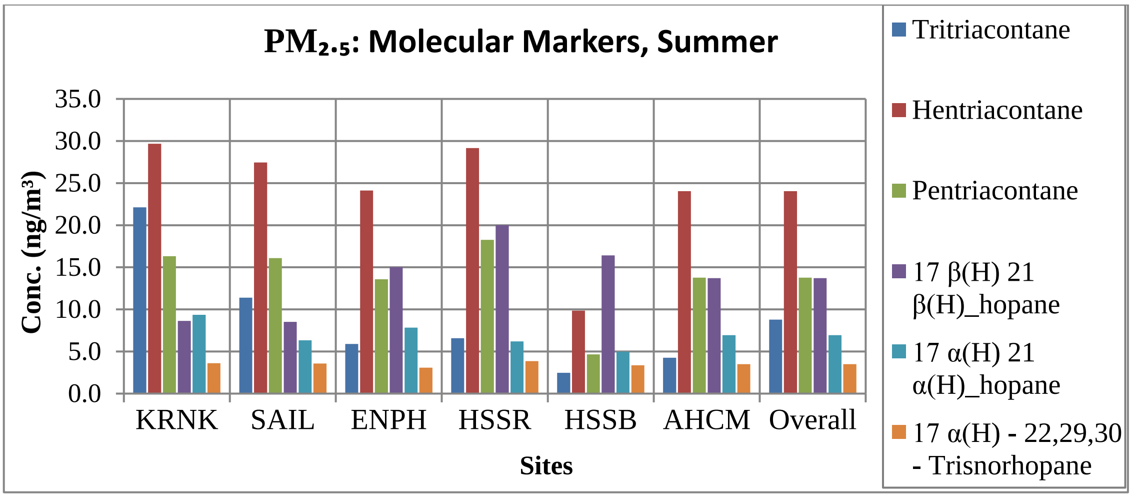


Figure 2.121: Variation in molecular markers in $PM_{2.5}$ for summer season

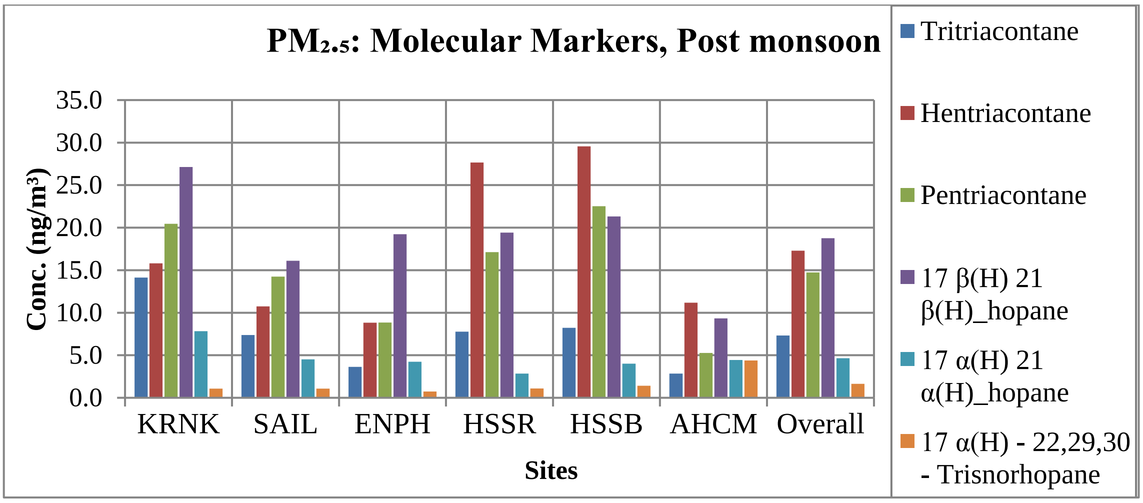


Figure 2.122: Variation in molecular markers in $PM_{2.5}$ for post-monsoon

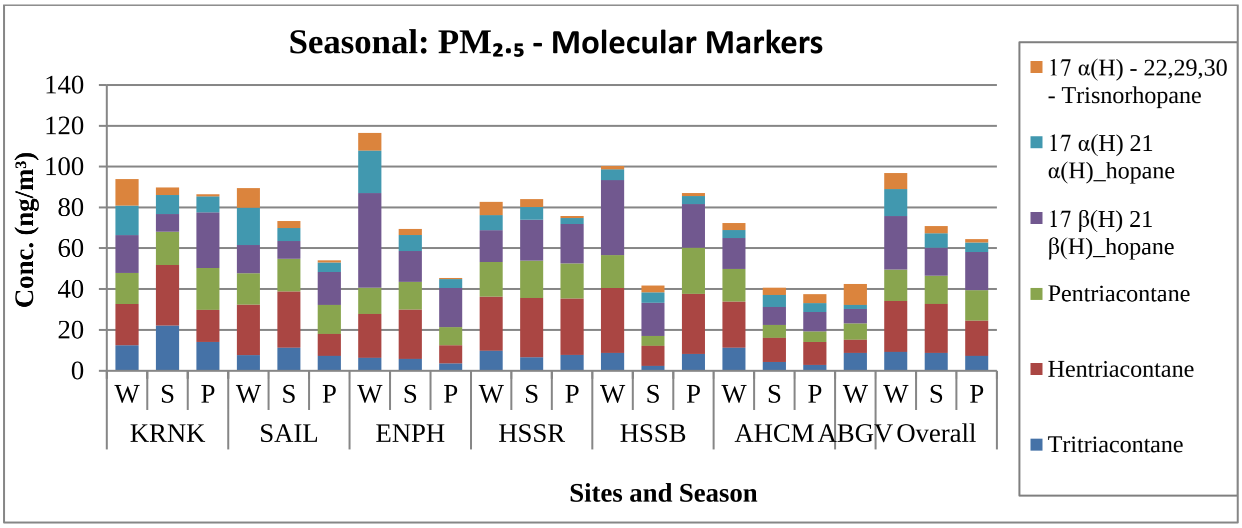
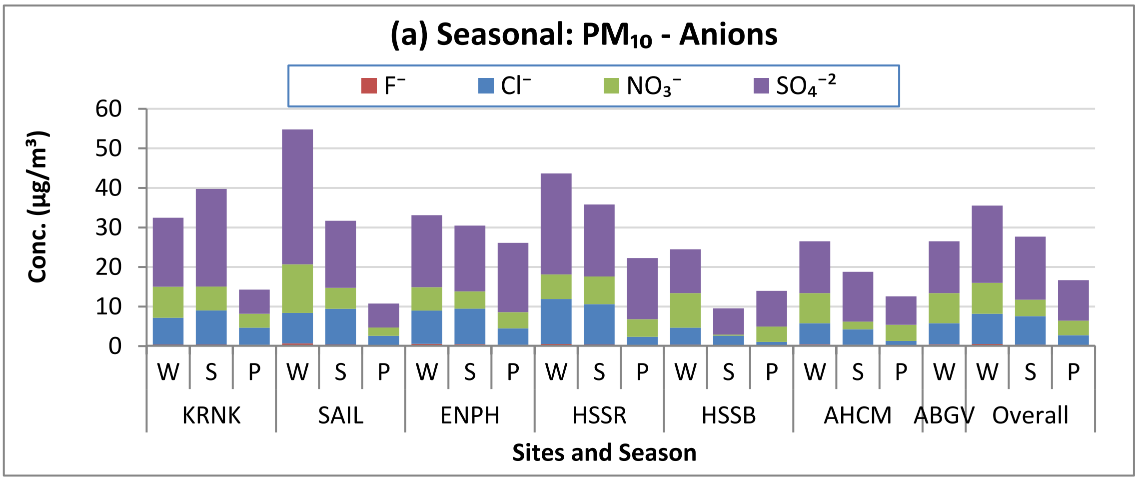
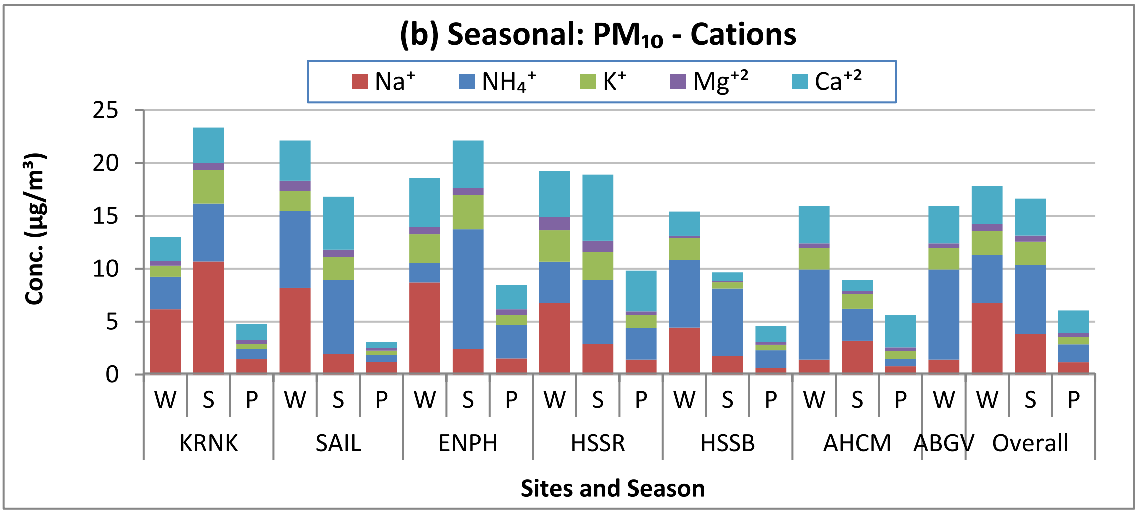


Figure 2.123: Seasonal comparison of molecular markers in $PM_{2.5}$

2.4.8.7 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 2.124 (a), (b) and (c)) and PM$_{2.5}$ (Figure 2.125 (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^+, 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) estimated in composition are presented in the Table 2.128 - Table 2.133 for winter, summer and post-monsoon 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 2.136 - Table 2.140 for winter, summer and post-monsoon seasons.





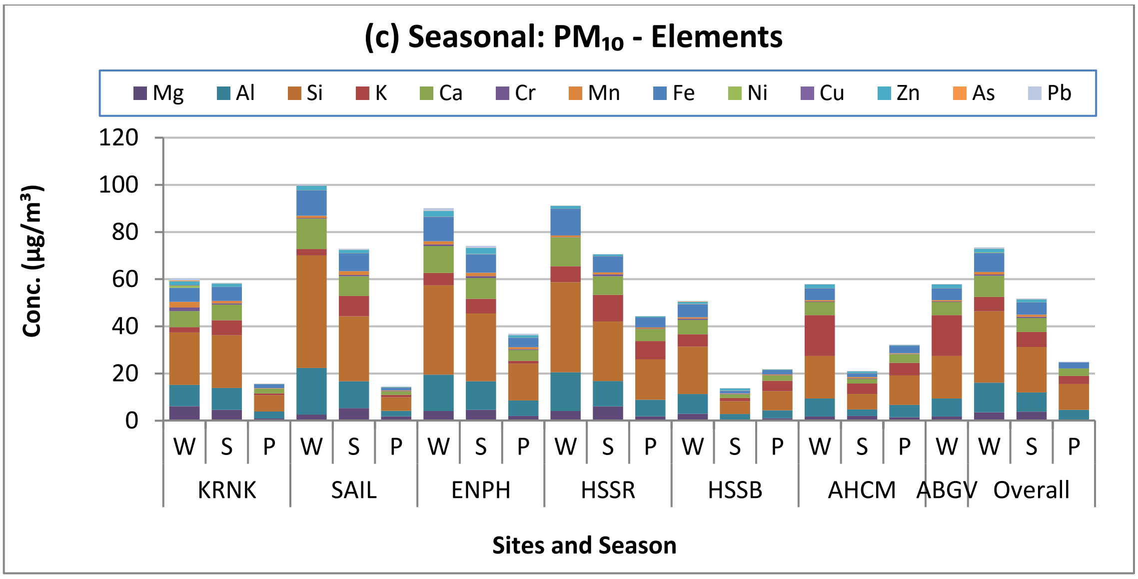
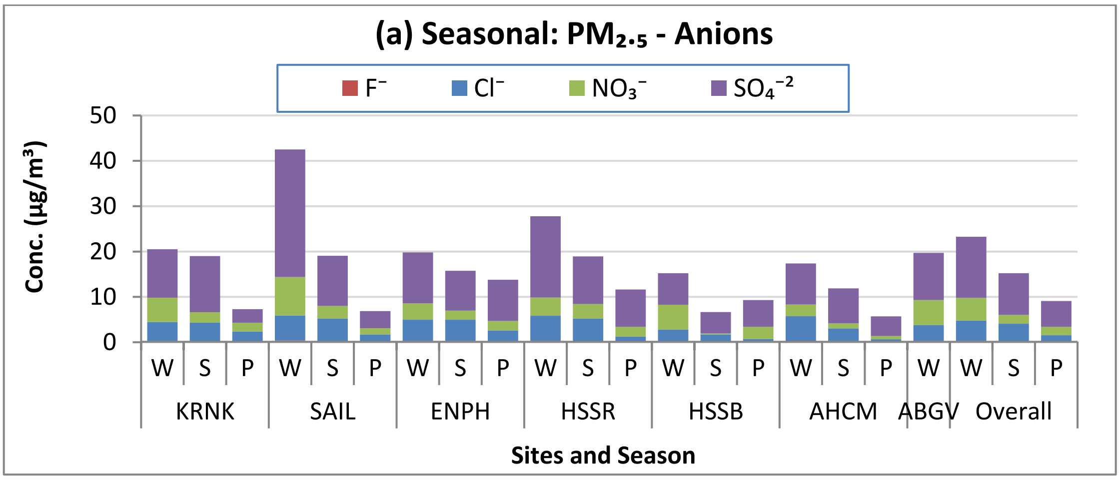
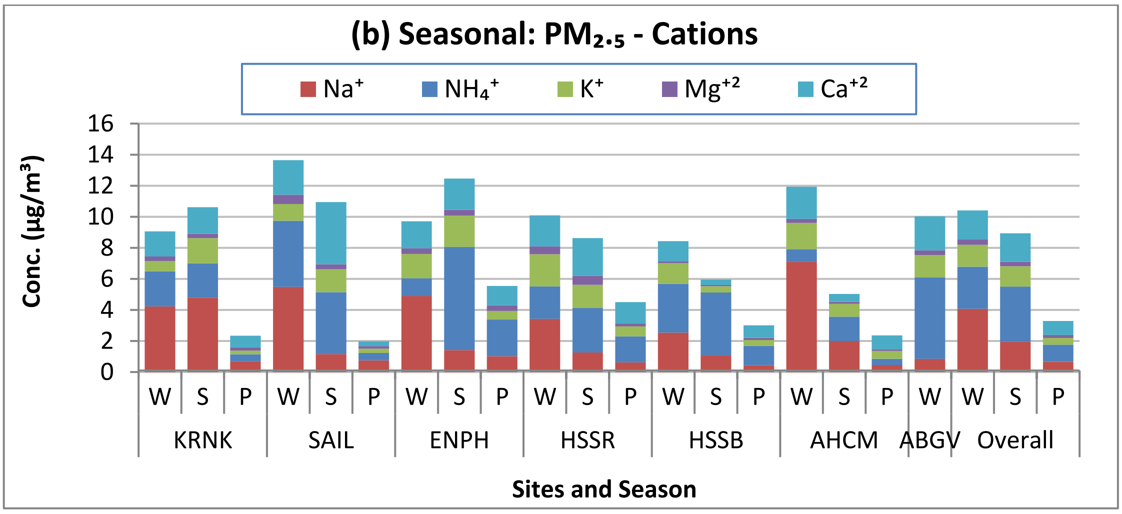


Figure 2.124: Seasonal comparison of ionic and elemental species concentrations in PM_{10} for all sites





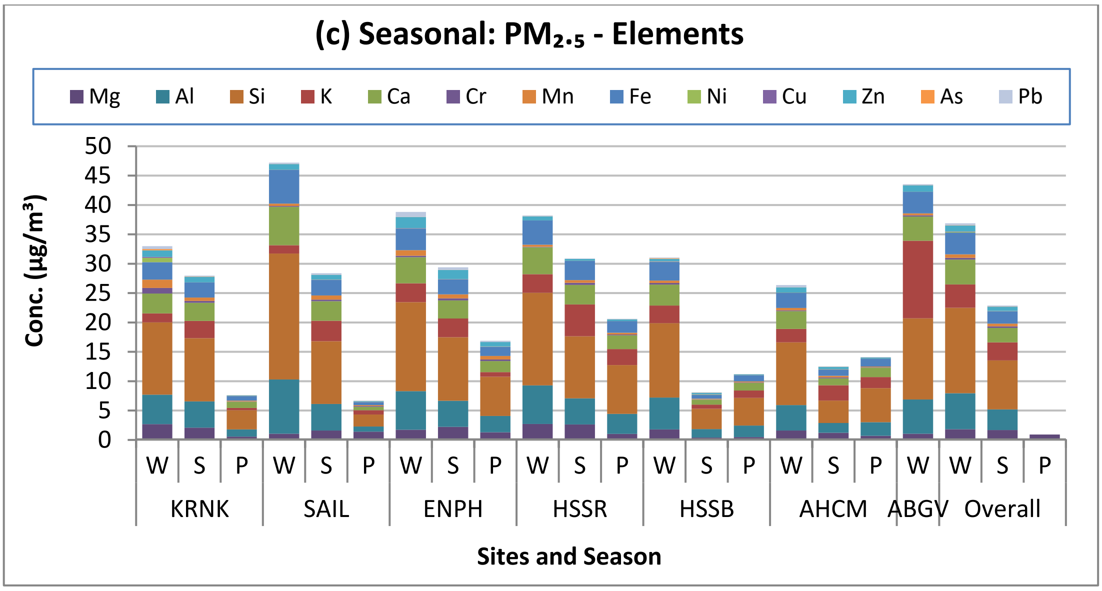


Figure 2.125: Seasonal comparison of ionic and elemental species concentrations in $PM_{2.5}$ for all sites

2.4.8.8 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^+, Ca^{+2}, Mg^{+2}) and elements (Al, Si, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Cd and Pb). A compositional comparison of $PM_{2.5}$ Vs PM_{10} is shown for all major carbon, ions (Figure 2.126) and elements (Figure 2.127) for all sites and both seasons in Bhilai. The overall compositional comparison is also presented in Table 2.134 for all sites.

It is observed that a significant portion of PM has more fine-mode particles (>50%) in all seasons. The major species contributing to fine mode are EC, OC, SO_4^{-2}, NH_4^+, K^+, Co, Ni, Zn, As, Cu and Pb; whereas, the major species contributing to coarse mode are Ca, Al, Si, and Fe.

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}.

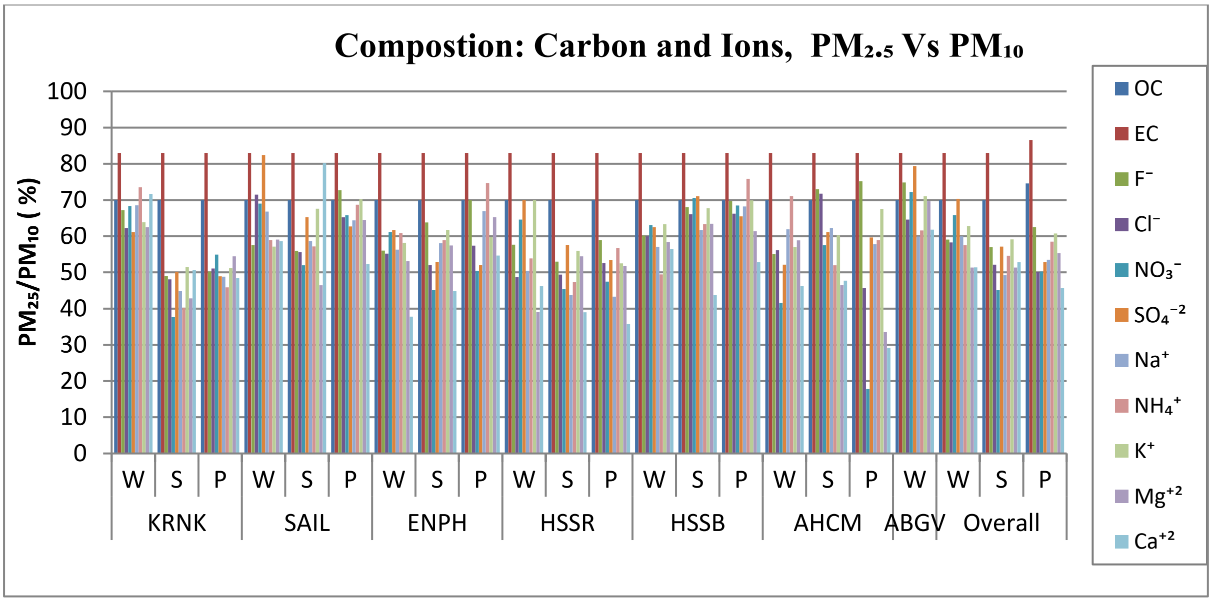


Figure 2.126: Compositional comparison of carbon and ions species in $PM_{2.5}$ Vs PM_{10}

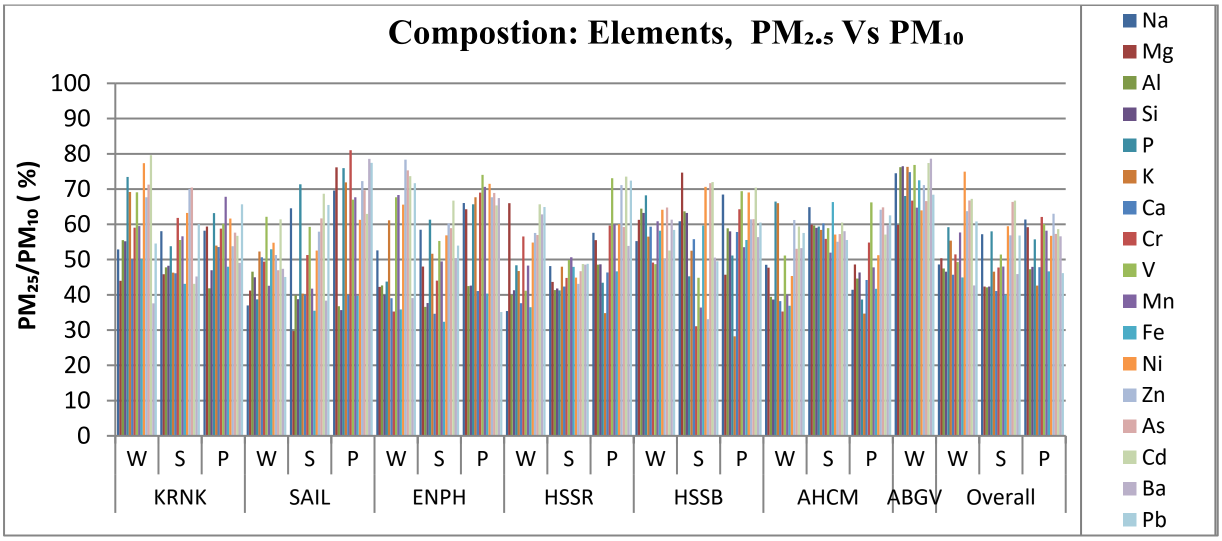


Figure 2.127: Compositional comparison of elemental species in $PM_{2.5}$ Vs PM_{10}

Table 2.115: 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	Post-Monsoon	Winter	Summer	Post-Monsoon	Winter	Summer	Post-Monsoon
KRNK	216±67 (0.31)	205±46 (0.23)	60±29 (0.48)	129±42 (0.33)	106±22 (0.21)	32±15 (0.46)	0.60±0.07 (0.12)	0.06±0.11 (0.54)	0.54±0.06 (0.11)
SAIL	344±42 (0.12)	229±54 (0.24)	51±30 (0.60)	196±33 (0.17)	114±23 (0.20)	28±13 (0.48)	0.57±0.04 (0.07)	0.07±0.14 (0.57)	0.57±0.08 (0.14)
ENPH	295±75 (0.26)	240±63 (0.26)	127±58 (0.46)	151±34 (0.22)	119±21 (0.18)	67±31 (0.47)	0.52±0.05 (0.10)	0.05±0.10 (0.55)	0.55±0.10 (0.19)
HSSR	298±55 (0.18)	224±67 (0.30)	140±62 (0.44)	150±29 (0.20)	114±23 (0.20)	74±39 (0.53)	0.50±0.04 (0.08)	0.08±0.16 (0.50)	0.50±0.05 (0.10)
HSSB	181±56 (0.31)	65±16 (0.25)	78±38 (0.48)	116±35 (0.30)	42±11 (0.26)	46±22 (0.49)	0.65±0.09 (0.14)	0.08±0.12 (0.60)	0.60±0.08 (0.13)
AHCM	222±76 (0.34)	84±13 (0.15)	101±52 (0.51)	108±22 (0.20)	53±6 (0.12)	51±21 (0.42)	0.50±0.06 (0.11)	0.09±0.14 (0.55)	0.55±0.12 (0.22)
ABGV	195±58 (0.30)			146±46 (0.31)			0.75±0.06 (0.08)		
Overall	**250±62 (0.25)**	**175±79 (0.45)**	**93±36 (0.39)**	**142±29 (0.20)**	**91±34 (0.38)**	**50±18 (0.37)**	**0.58±0.09 (0.15)**	**0.07±0.12 (0.55)**	**0.55±0.03 (0.06)**

Table 2.116: 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)
KRNK	24.90	10.82	9.61	0.27	1.13	2.74	13.75
SAIL	40.59	17.26	3.77	0.12	0.72	2.43	7.04
ENPH	32.12	19.51	7.41	0.13	0.76	2.24	10.54
HSSR	32.26	11.82	15.80	0.13	0.77	3.32	20.02
HSSB	24.57	3.36	7.72	0.13	0.61	1.54	10.00
AHCM	26.94	15.83	ND				
ABGV	19.81	7.30	0.79	0.57	6.29	1.16	8.80
Overall	28.74	12.27	7.52	0.19	1.47	1.92	10.02
SD	6.48	7.14	4.78	0.22	1.09	0.99	5.91
CV	0.48	1.48	2.48	3.48	4.48	5.48	6.48

Table 2.117: 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)
KRNK	24.13	6.10	4.82	0.95	5.82	10.84	22.43
SAIL	33.91	7.62	4.04	1.00	5.53	10.65	21.21
ENPH	24.20	9.82	4.34	1.07	6.15	11.70	23.26
HSSR	18.56	4.74	4.37	0.89	5.69	10.64	21.59
HSSB	10.94	2.12	4.47	1.01	6.10	10.86	22.44
AHCM	3.63	0.40	ND				
Overall	20.68	5.44	4.41	0.82	4.88	9.11	18.49
SD	5.12	3.50	0.50	0.08	0.74	1.23	2.33
CV	0.25	0.64	0.11	0.10	0.15	0.13	0.13

Table 2.118: Overall summary of average concentration (µg/m^3) of gaseous pollutants (SO_2, NO_2 and VOCs) for post-monsoon season

Post-monsoon	NO_2	SO_2	Benzene	Toluene	P-Xylene	O-Xylene	Total (BTX)
KRNK	12.75	2.19	7.00	1.34	10.51	14.43	33.28
SAIL	8.21	2.00	2.53	0.64	4.91	6.73	14.80
ENPH	18.08	2.87	3.62	0.92	5.13	7.33	17.00
HSSR	18.40	3.49	2.73	0.68	5.38	7.39	16.18
HSSB	12.38	2.01	2.41	0.59	4.37	6.63	14.00
AHCM	10.65	2.06	ND				
Overall	13.41	2.43	3.66	0.69	5.05	7.09	15.88
SD	5.12	0.89	1.56	0.27	1.11	1.51	3.81
CV	0.38	0.37	0.43	0.39	0.22	0.21	0.24

Table 2.119: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for winter Season

WINTER	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
KRNK	129.42	29.74	10.66	19.08	0.36	5.70	7.25	5.76	0.01	0.19	0.24	0.21
SAIL	196.12	39.54	15.29	24.24	0.08	6.93	8.47	8.76	0.00	0.18	0.21	0.22
ENPH	151.01	34.10	13.20	20.91	0.45	6.14	7.45	6.86	0.01	0.18	0.22	0.21
HSSR	149.79	31.03	10.11	20.92	0.20	5.74	7.53	7.45	0.01	0.18	0.24	0.24
HSSB	116.17	24.47	8.06	16.41	0.06	5.18	5.94	5.24	0.00	0.21	0.24	0.21
AHCM	108.35	25.01	7.64	17.37	0.05	5.08	6.30	5.93	0.00	0.20	0.25	0.24
ABGV	145.71	28.43	12.09	16.34	0.02	5.41	6.74	4.17	0.00	0.19	0.24	0.15
Overall	142.37	30.33	11.01	19.32	0.18	5.74	7.10	6.31	0.00	0.19	0.24	0.21
SD	28.99	5.26	2.75	2.90	0.17	0.64	0.85	1.52	0.00	0.01	0.01	0.03
CV	0.20	0.17	0.25	0.15	0.97	0.11	0.12	0.24	0.80	0.06	0.06	0.14

Table 2.120: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for summer season

SUMMER	PM2.5	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
KRNK	106.35	24.65	10.53	14.12	0.06	4.21	5.94	3.92	0.00	0.17	0.24	0.17
SAIL	114.46	26.96	11.87	15.09	0.14	4.30	5.82	4.82	0.00	0.16	0.22	0.19
ENPH	118.60	29.36	14.05	15.31	0.06	4.66	6.34	4.25	0.00	0.16	0.22	0.15
HSSR	113.58	24.41	9.65	14.76	0.03	4.15	6.26	4.32	0.00	0.17	0.26	0.19
HSSB	42.35	9.77	3.32	6.45	0.02	1.71	2.63	2.10	0.00	0.17	0.28	0.21
AHCM	53.30	10.12	3.37	6.75	0.02	1.89	2.50	2.34	0.00	0.19	0.25	0.23
Overall	91.44	20.88	8.80	12.08	0.05	3.49	4.92	3.63	0.00	0.17	0.24	0.19
SD	34.19	8.66	4.48	4.26	0.04	1.32	1.83	1.13	0.00	0.01	0.02	0.03
CV	0.37	0.41	0.51	0.35	0.83	0.38	0.37	0.31	0.49	0.06	0.10	0.15

Table 2.121: Overall summary of average concentration of carbon content in PM$_{2.5}$ for all sites for Post-monsoon season

Post-monsoon	**PM2.5**	**TC**	**EC**	**OC**	**OC1**	**OC2**	**OC3**	**OC4**	**OC1/TC**	**OC2/TC**	**OC3/TC**	**OC4/TC**
KRNK	31.95	5.30	1.82	3.48	0.01	0.99	1.50	0.98	0.00	0.19	0.29	0.18
SAIL	27.62	4.17	1.39	2.78	0.02	0.83	1.18	0.75	0.00	0.21	0.30	0.18
ENPH	66.56	11.42	4.91	6.51	0.03	1.99	2.42	2.07	0.00	0.17	0.21	0.18
HSSR	69.23	13.60	4.63	8.97	0.02	2.87	3.59	2.49	0.00	0.20	0.26	0.19
HSSB	46.10	9.09	2.91	6.18	0.02	1.57	2.34	2.25	0.00	0.18	0.26	0.23
AHCM	51.22	11.57	3.95	7.62	0.03	2.30	3.17	2.13	0.00	0.20	0.28	0.19
Overall	48.78	9.19	3.27	5.92	0.02	1.76	2.36	1.78	0.00	0.19	0.27	0.19
SD	17.20	3.75	1.47	2.39	0.01	0.78	0.93	0.72	0.00	0.01	0.03	0.02
CV	0.35	0.41	0.45	0.40	0.42	0.45	0.39	0.41	0.51	0.06	0.12	0.09

Table 2.122: 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
KRNK	2.52	0.20	1.04	0.04	0.30	0.04	0.58	0.07	0.37	0.61	1.42	4.03	1.08	1.74	1.68	0.11	2.23	18.05
SAIL	2.22	0.26	0.62	0.06	1.53	0.12	3.12	0.07	0.36	3.38	6.50	11.02	3.41	5.16	4.43	0.48	5.07	47.82
HSSR	5.38	0.46	0.79	0.15	0.91	0.07	1.07	0.06	0.55	0.69	1.72	4.80	1.28	1.95	1.72	0.14	2.16	23.91
ENPH	3.06	0.46	0.97	0.23	1.79	0.18	3.09	0.07	1.01	3.61	8.45	12.46	3.88	6.15	5.43	0.37	7.75	58.98
HSSB	3.41	0.25	0.31	0.02	0.28	0.04	0.59	0.06	0.25	0.38	0.95	2.63	0.69	1.13	1.00	0.06	1.43	13.48
AHCM	4.77	0.41	0.52	0.13	0.96	0.07	0.02	0.71	1.12	0.29	0.49	0.79	0.20	0.57	0.29	0.02	0.55	7.32
ABGV	3.34	14.52	1.34	1.69	5.66	1.11	2.24	1.09	1.32	1.28	3.21	14.80	1.43	7.79	1.69	3.08	5.23	70.81
Overall	3.53	2.37	0.80	0.33	1.63	0.23	1.53	0.30	0.71	1.46	3.25	7.22	1.71	3.50	2.32	0.61	3.49	34.34
SD	1.54	1.15	0.51	0.27	1.03	0.12	0.83	0.12	0.55	1.03	2.28	4.02	0.88	2.05	1.36	0.46	1.90	14.39
CV	0.44	0.49	0.64	0.80	0.63	0.51	0.54	0.38	0.77	0.70	0.70	0.56	0.52	0.58	0.59	0.76	0.54	0.42

Table 2.123: 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
KRNK	0.82	1.29	1.10	0.16	0.89	0.05	0.55	0.40	0.51	0.54	1.40	3.61	0.67	1.42	1.54	0.10	2.57	17.61
SAIL	0.53	0.83	1.01	0.64	3.86	0.17	5.28	1.87	1.60	2.21	3.50	9.36	3.63	7.99	5.52	0.86	3.99	52.83
HSSR	6.66	1.42	2.03	0.25	1.15	0.08	0.64	1.66	1.48	0.90	0.78	1.96	0.36	0.76	0.40	0.04	1.54	22.09
ENPH	0.41	1.01	0.50	0.70	2.86	0.10	1.81	0.52	0.65	2.44	6.36	11.55	2.17	3.95	3.02	0.18	6.37	44.58
HSSB	0.25	0.63	0.21	0.36	1.18	0.05	0.13	0.40	0.37	0.28	0.40	1.16	0.24	0.57	0.36	0.04	0.66	7.29
AHCM	2.99	1.62	0.94	1.46	3.50	0.11	0.46	0.59	0.25	0.52	1.17	2.61	0.74	1.63	1.21	0.14	1.45	21.38
Overall	1.94	1.04	0.97	0.42	1.99	0.09	1.68	0.97	0.92	1.27	2.49	5.53	1.41	2.94	2.17	0.24	3.02	28.88
SD	1.19	0.67	0.94	0.26	0.75	0.04	0.99	0.63	0.97	1.07	1.87	2.79	1.07	2.03	1.75	0.25	1.48	13.64
CV	0.61	0.65	0.97	0.61	0.38	0.42	0.59	0.66	1.05	0.84	0.75	0.50	0.75	0.69	0.81	1.02	0.49	0.47

Table 2.124: Overall summary of average concentration (ng/m^3) of PAHs in PM$_{2.5}$ for all sites for summer season

Post-monsoon	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
KRNK	1.05	2.42	0.76	1.29	5.55	1.59	0.35	0.71	0.91	0.45	0.79	1.24	0.41	1.17	0.47	0.32	0.66	20.15
SAIL	1.08	2.63	2.06	1.05	1.05	0.64	0.12	3.02	0.25	0.31	0.29	0.54	0.18	0.44	0.10	0.10	0.56	14.42
HSSR	0.43	0.87	1.14	0.04	0.34	1.42	0.88	1.28	0.15	0.49	0.84	2.36	0.70	2.24	0.80	0.09	1.76	15.83
ENPH	0.83	4.55	0.94	0.71	4.16	4.36	1.48	0.40	0.25	0.87	1.65	8.64	2.38	4.71	1.67	1.83	4.71	44.13
HSSB	0.66	1.64	0.66	0.51	0.18	1.26	0.38	1.31	0.65	0.45	0.52	2.25	0.44	2.11	0.78	0.16	0.95	14.92
AHCM	0.76	3.14	0.83	0.64	3.22	2.29	0.19	0.98	0.35	0.22	0.31	2.56	0.40	1.62	0.93	0.21	0.92	19.57
Overall	0.80	2.54	1.07	0.71	2.41	1.93	0.56	1.28	0.43	0.47	0.73	2.93	0.75	2.05	0.79	0.45	1.59	21.50
SD	0.29	0.85	0.71	0.45	1.09	1.37	0.43	0.72	0.56	0.24	0.61	1.62	0.43	1.10	0.69	0.45	0.85	6.18
CV	0.36	0.33	0.67	0.63	0.45	0.71	0.76	0.56	1.30	0.51	0.83	0.55	0.57	0.54	0.87	1.01	0.54	0.29

Table 2.125: 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
KRNK	12.42	20.17	15.39	18.36	14.59	13.00	93.93
SAIL	7.57	24.85	15.27	13.91	18.31	9.55	89.46
ENPH	6.43	21.43	12.84	46.29	20.88	8.66	116.53
HSSR	9.85	26.53	16.93	15.48	7.38	6.63	82.80
HSSB	8.81	31.61	16.10	36.75	5.31	1.72	100.30
AHCM	11.38	22.53	16.02	15.07	3.80	3.56	72.37
ABGV	8.80	6.46	7.89	7.14	2.04	10.18	42.50
Overall	9.32	21.94	14.35	21.86	10.33	7.61	85.41
SD	2.09	8.09	4.97	10.59	8.07	4.48	29.49
CV	0.22	0.37	0.35	0.48	0.78	0.59	0.35

Table 2.126: 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
KRNK	22.13	29.67	16.31	8.64	9.36	3.62	89.73
SAIL	11.39	27.45	16.09	8.53	6.33	3.58	73.37
ENPH	5.89	24.13	13.58	15.02	7.84	3.08	69.54
HSSR	6.59	29.16	18.25	20.01	6.19	3.85	84.05
HSSB	2.47	9.85	4.66	16.42	4.99	3.36	41.75
AHCM	4.25	22.03	12.53	12.91	6.76	3.51	66.54
Overall	8.79	22.03	12.53	12.91	6.76	3.51	66.54
SD	7.19	6.21	4.11	5.59	1.90	1.17	18.79
CV	0.82	0.28	0.33	0.43	0.28	0.33	0.28

Table 2.127: Overall summary of average concentration (ng/m^3) of molecular markers in PM$_{2.5}$ for summer season

Post-monsoon	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
KRNK	14.13	15.80	20.45	27.13	7.83	1.08	86.43
SAIL	7.37	10.75	14.24	16.11	4.52	1.07	54.07
ENPH	3.63	8.83	8.85	19.24	4.24	0.74	45.52
HSSR	7.77	27.65	17.13	19.42	2.85	1.09	75.91
HSSB	8.22	29.56	22.52	21.33	4.02	1.42	87.06
AHCM	2.85	11.18	5.27	9.33	4.45	4.39	37.47
Overall	7.33	17.30	14.74	18.76	4.65	1.63	64.41
SD	4.02	9.07	6.69	5.88	1.67	1.37	21.54
CV	0.55	0.52	0.45	0.31	0.36	0.84	0.33

Table 2.128: 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
KRNK	216	27.3	12.8	0.40	6.76	7.86	17.43	6.16	3.08	1.04	0.46	2.26	3E-2	1.35	4.64	6.12	9.02	22.31	1.02
SAIL	344	34.6	18.4	0.69	7.69	12.29	34.14	8.20	7.24	1.89	1.01	3.79	1E-2	0.18	3.39	2.59	19.78	47.70	0.21
ENPH	295	29.9	15.9	0.59	8.39	5.91	18.22	8.71	1.87	2.69	0.69	4.61	1E-2	0.28	10.94	4.10	15.40	37.89	0.40
HSSR	298	29.9	12.2	0.54	11.36	6.23	25.55	6.78	3.90	2.96	1.28	4.33	2E-3	0.09	3.85	4.13	16.44	38.19	1.45
HSSB	181	23.4	9.7	0.37	4.31	8.70	11.10	4.44	6.37	2.10	0.23	2.28	9E-2	0.19	4.00	2.94	8.39	20.04	1.28
AHCM	222	24.8	9.2	0.62	9.64	6.19	17.38	11.45	1.17	2.96	0.44	4.47	1E-2	0.14	6.49	3.34	11.01	27.61	0.19
ABGV	195	23.3	14.6	0.44	5.36	7.62	13.10	1.41	8.52	2.03	0.43	3.55	4E-4	0.04	2.15	1.78	7.64	18.06	0.32
Overall	250	27.6	13.3	0.52	7.64	7.83	19.56	6.73	4.59	2.24	0.65	3.61	2E-2	0.32	5.06	3.57	12.53	30.26	0.70
SD	62	4.1	3.3	0.12	2.43	2.22	7.88	3.22	2.81	0.69	0.37	0.99	3E-2	0.46	2.90	1.40	4.68	11.17	0.54
CV	0.25	0.15	0.25	0.23	0.32	0.28	0.40	0.48	0.61	0.31	0.58	0.27	1.38	1.42	0.57	0.39	0.37	0.37	0.77
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
KRNK	2.22	6.74	1.60	1.41	2.37	5.96	0.086	0.929	0.23	1.66	0.302	0.102	0.155	0.232	0.089	0.077	0.66	0.90	68.08
SAIL	2.70	12.89	0.30	0.05	0.94	10.87	0.019	0.020	0.04	1.85	0.029	0.024	0.034	0.053	0.018	0.022	0.13	0.48	63.75
ENPH	5.25	11.40	0.68	0.13	1.40	10.29	0.021	0.044	0.10	2.38	0.029	0.031	0.052	0.087	0.020	0.020	0.24	1.17	62.36
HSSR	6.75	12.16	0.14	3.80	0.74	11.32	0.014	0.011	0.02	1.15	0.073	0.038	0.026	0.008	0.005	0.035	0.02	0.21	63.89
HSSB	5.30	6.03	0.54	0.14	0.67	5.44	0.089	0.109	0.12	0.83	0.161	0.094	0.104	0.111	0.076	0.079	0.17	0.20	67.33
AHCM	3.48	7.91	0.37	0.11	1.05	6.98	0.025	0.033	0.05	1.44	0.027	0.030	0.048	0.074	0.029	0.022	0.11	0.64	63.28
ABGV	17.30	5.50	0.33	0.19	0.52	5.04	0.003	0.006	0.02	1.57	0.007	0.003	0.008	0.013	0.004	0.002	0.05	0.22	69.11
Overall	6.14	8.95	0.57	0.83	1.10	7.99	0.037	0.165	0.08	1.56	0.090	0.046	0.061	0.082	0.035	0.037	0.20	0.55	65.40
SD	5.18	3.12	0.49	1.39	0.63	2.74	0.035	0.339	0.07	0.50	0.107	0.037	0.051	0.076	0.034	0.030	0.22	0.38	2.69
CV	0.84	0.35	0.87	1.67	0.57	0.34	0.96	2.06	0.92	0.32	1.19	0.81	0.84	0.92	0.99	0.81	1.10	0.70	0.04

Table 2.129: 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
KRNK	129	19.1	10.7	0.27	4.21	5.37	10.66	4.22	2.26	0.67	0.29	1.62	2E-2	0.82	2.45	2.69	5.01	12.31	0.75
SAIL	196	24.2	15.3	0.40	5.49	8.48	28.15	5.48	4.26	1.08	0.60	2.22	7E-3	0.10	1.26	1.07	9.21	21.46	0.08
ENPH	151	20.9	13.2	0.33	4.63	3.61	11.25	4.90	1.14	1.57	0.37	1.74	8E-3	0.17	5.75	1.73	6.57	15.14	0.17
HSSR	150	20.9	10.1	0.31	5.53	4.03	17.89	3.42	2.10	2.07	0.50	2.00	1E-3	0.06	1.36	2.73	6.57	15.77	0.70
HSSB	116	16.4	8.1	0.22	2.59	5.49	6.93	2.53	3.15	1.33	0.13	1.29	5E-2	0.12	2.21	1.80	5.41	12.67	0.87
AHCM	108	17.4	7.6	0.34	5.41	2.58	9.06	7.09	0.83	1.69	0.26	2.07	8E-3	0.09	3.15	1.59	4.34	10.68	0.13
ABGV	146	16.3	12.1	0.33	3.46	5.50	10.41	0.85	5.25	1.44	0.30	2.19	3E-4	0.03	1.60	1.07	5.82	13.81	0.22
Overall	142	19.3	11.0	0.31	4.47	5.01	13.48	4.07	2.71	1.41	0.35	1.88	1E-2	0.20	2.54	1.81	6.13	14.55	0.42
SD	29	2.9	2.7	0.06	1.13	1.89	7.30	2.04	1.61	0.45	0.16	0.34	2E-2	0.28	1.57	0.68	1.58	3.50	0.34
CV	0.20	0.15	0.25	0.18	0.25	0.38	0.54	0.50	0.60	0.32	0.45	0.18	1.32	1.41	0.62	0.38	0.26	0.24	0.81
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
KRNK	1.54	3.38	0.95	0.97	1.41	2.99	0.065	0.72	0.17	1.12	0.22	0.074	0.111	0.14	0.07	0.058	0.25	0.49	71.17
SAIL	1.41	6.53	0.15	0.03	0.40	5.75	0.010	0.01	0.02	0.95	0.01	0.013	0.020	0.03	0.01	0.014	0.06	0.22	68.72
ENPH	3.21	4.45	0.24	0.09	0.95	3.69	0.013	0.03	0.06	1.87	0.02	0.022	0.032	0.05	0.01	0.015	0.09	0.84	66.49
HSSR	3.16	4.58	0.08	1.56	0.36	4.13	0.009	0.01	0.01	0.66	0.04	0.023	0.022	0.00	0.00	0.023	0.01	0.13	68.77
HSSB	2.99	3.58	0.26	0.07	0.41	3.17	0.049	0.07	0.06	0.42	0.10	0.050	0.053	0.06	0.04	0.055	0.11	0.12	67.19
AHCM	2.30	3.02	0.13	0.06	0.42	2.58	0.011	0.01	0.02	0.88	0.01	0.017	0.023	0.03	0.02	0.015	0.06	0.37	67.55
ABGV	13.20	4.12	0.22	0.15	0.34	3.66	0.002	0.00	0.01	1.12	0.00	0.002	0.006	0.01	0.00	0.002	0.04	0.15	68.41
Overall	3.97	4.24	0.29	0.42	0.61	3.71	0.023	0.12	0.05	1.00	0.06	0.029	0.038	0.05	0.02	0.026	0.09	0.33	68.33
SD	4.14	1.16	0.30	0.61	0.41	1.04	0.024	0.26	0.06	0.46	0.08	0.025	0.035	0.05	0.02	0.022	0.08	0.26	1.51
CV	1.04	0.27	1.03	1.45	0.67	0.28	1.06	2.17	1.13	0.46	1.29	0.86	0.92	1.02	1.07	0.84	0.88	0.80	0.02

Table 2.130: 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
KRNK	205	20.2	12.7	0.42	8.60	6.04	24.69	10.68	5.48	3.16	0.66	3.37	1E-2	0.08	0.91	4.57	9.33	22.32	0.99
SAIL	229	21.6	14.3	0.43	9.00	5.29	16.95	1.96	6.99	2.18	0.68	5.00	2E-2	0.11	2.49	5.36	11.40	27.50	1.30
ENPH	240	21.9	16.9	0.49	8.98	4.39	16.61	2.43	11.29	3.27	0.65	4.48	4E-3	0.12	3.41	4.62	12.13	28.72	1.94
HSSR	224	21.1	11.6	0.42	10.21	6.98	18.22	2.86	6.06	2.67	1.06	6.25	2E-2	0.13	3.85	6.07	10.74	25.24	0.66
HSSB	65	9.2	4.0	0.20	2.43	0.28	6.66	1.78	6.35	0.59	0.14	0.79	5E-2	0.39	3.13	0.53	2.28	5.47	0.68
AHCM	84	9.6	4.1	0.35	3.91	1.93	12.58	3.20	3.02	1.38	0.29	1.05	5E-2	0.05	4.38	2.04	2.78	6.48	1.83
Overall	175	17.3	10.6	0.38	7.19	4.15	15.95	3.82	6.53	2.21	0.58	3.49	3E-2	0.15	3.03	3.87	8.11	19.29	1.23
SD	79	6.1	5.4	0.10	3.19	2.56	6.01	3.40	2.71	1.05	0.32	2.20	2E-2	0.12	1.22	2.13	4.42	10.54	0.56
CV	0.45	0.35	0.51	0.26	0.44	0.62	0.38	0.89	0.41	0.48	0.56	0.63	0.78	0.82	0.40	0.55	0.55	0.55	0.45
Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
KRNK	6.34	6.71	0.50	0.03	1.03	5.93	0.008	0.018	0.048	1.359	0.065	0.038	0.036	0.075	0.005	0.002	0.13	0.24	68.04
SAIL	8.65	8.35	0.54	0.06	1.64	7.57	0.011	0.026	0.065	1.351	0.008	0.017	0.045	0.077	0.016	0.008	0.18	0.43	66.87
ENPH	6.20	8.84	0.83	0.05	1.37	7.92	0.028	0.049	0.050	2.525	0.052	0.037	0.061	0.107	0.044	0.029	0.11	0.81	67.39
HSSR	11.32	7.87	0.80	0.07	0.86	6.82	0.011	0.033	0.038	0.684	0.005	0.012	0.053	0.091	0.009	0.009	0.17	0.17	67.41
HSSB	1.38	1.49	0.22	0.11	0.24	1.14	0.045	0.064	0.070	0.778	0.047	0.052	0.062	0.091	0.046	0.046	0.11	0.10	73.82
AHCM	4.46	1.94	0.29	0.10	0.52	1.62	0.052	0.063	0.066	0.687	0.048	0.056	0.069	0.086	0.053	0.053	0.12	0.13	75.91
Overall	6.39	5.87	0.53	0.07	0.94	5.17	0.026	0.042	0.056	1.231	0.037	0.035	0.054	0.088	0.029	0.025	0.14	0.31	69.91
SD	3.41	3.29	0.25	0.03	0.52	3.02	0.019	0.019	0.013	0.708	0.025	0.018	0.012	0.012	0.021	0.021	0.03	0.27	3.91
CV	0.53	0.56	0.48	0.40	0.55	0.58	0.73	0.46	0.23	0.58	0.67	0.51	0.22	0.13	0.73	0.87	0.25	0.86	0.06

Table 2.131: 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
KRNK	106	14.1	10.5	0.21	4.13	2.28	12.39	4.79	2.21	1.63	0.28	1.70	1E-2	0.05	0.53	2.10	4.46	10.77	0.53
SAIL	114	15.1	11.9	0.24	5.00	2.75	11.07	1.15	4.00	1.47	0.32	4.01	1E-2	0.06	1.61	1.59	4.54	10.66	0.93
ENPH	119	15.3	14.1	0.31	4.67	1.98	8.79	1.41	6.65	2.02	0.37	2.01	2E-3	0.08	1.99	2.22	4.44	10.82	1.19
HSSR	114	14.8	9.6	0.22	5.04	3.17	10.50	1.25	2.87	1.49	0.57	2.44	9E-3	0.06	1.85	2.65	4.44	10.55	0.27
HSSB	42	6.4	3.3	0.14	1.60	0.20	4.73	1.10	4.03	0.40	0.09	0.35	4E-2	0.31	1.91	0.39	1.45	3.46	0.31
AHCM	53	6.7	3.4	0.25	2.81	1.11	7.69	2.00	1.57	0.83	0.13	0.50	4E-2	0.03	2.84	1.22	1.66	3.83	1.09
Overall	91	12.1	8.8	0.23	3.88	1.91	9.20	1.95	3.55	1.31	0.29	1.83	2E-2	0.10	1.79	1.70	3.50	8.35	0.72
SD	34	4.3	4.5	0.06	1.39	1.10	2.75	1.43	1.80	0.59	0.17	1.35	2E-2	0.10	0.75	0.81	1.51	3.65	0.40
CV	0.37	0.35	0.51	0.25	0.36	0.57	0.30	0.73	0.51	0.45	0.59	0.74	0.85	1.05	0.42	0.48	0.43	0.44	0.56

Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
KRNK	2.93	3.09	0.31	0.02	0.58	2.56	0.00	0.01	0.02	0.95	0.05	0.03	0.02	0.05	0.00	0.00	0.06	0.14	71.08
SAIL	3.49	3.34	0.28	0.04	0.68	2.69	0.00	0.01	0.03	0.78	0.01	0.01	0.02	0.03	0.01	0.01	0.07	0.28	71.10
ENPH	3.20	3.06	0.37	0.03	0.68	2.56	0.02	0.03	0.03	1.52	0.03	0.03	0.03	0.05	0.03	0.02	0.06	0.44	71.76
HSSR	5.43	3.33	0.36	0.03	0.44	3.27	0.01	0.01	0.02	0.29	0.00	0.01	0.03	0.04	0.00	0.00	0.08	0.08	69.97
HSSB	0.72	0.83	0.07	0.05	0.09	0.68	0.03	0.05	0.04	0.26	0.03	0.04	0.04	0.05	0.03	0.04	0.05	0.05	0.03
AHCM	2.60	1.17	0.16	0.06	0.27	1.08	0.03	0.04	0.03	0.38	0.03	0.03	0.04	0.06	0.03	0.03	0.07	0.07	75.91
Overall	3.06	2.47	0.26	0.04	0.46	2.14	0.02	0.02	0.03	0.70	0.02	0.02	0.03	0.05	0.02	0.02	0.06	0.18	59.98
SD	1.52	1.15	0.12	0.01	0.24	1.02	0.01	0.01	0.01	0.49	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.15	29.44
CV	0.50	0.46	0.46	0.38	0.53	0.48	0.83	0.56	0.26	0.70	0.71	0.55	0.28	0.20	0.77	0.91	0.18	0.85	0.49

Table 2.132: Overall summary of average concentration of chemical species in PM$_{10}$ for all sites for post-monsoon season

Post-monsoon	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
KRNK	60	7.16	4.97	2.19	0.34	4.31	3.53	6.11	1.43	0.97	0.46	0.38	1.56	0.02	0.46	2.01	0.96	2.93	6.97
SAIL	51	5.64	3.97	1.67	0.25	2.34	2.12	6.04	1.17	0.68	0.40	0.25	0.59	0.04	0.03	2.44	1.86	2.36	5.74
ENPH	127	15.21	9.30	5.91	0.35	4.14	4.08	17.52	1.52	3.16	0.93	0.55	2.28	0.02	0.04	3.07	2.04	6.54	15.63
HSSR	140	17.68	12.10	5.58	0.30	2.08	4.44	15.46	1.42	2.96	1.23	0.35	3.87	0.00	0.03	2.36	1.87	7.01	17.07
HSSB	78	12.33	8.83	3.50	0.24	0.83	3.89	9.02	0.64	1.65	0.53	0.25	1.51	0.02	0.02	1.71	1.05	3.35	8.13
AHCM	101	15.65	10.89	4.76	0.22	1.07	4.09	7.22	0.78	0.69	0.74	0.36	3.03	0.00	0.04	2.68	1.46	5.21	12.52
Overall	93	12.28	8.34	3.94	0.28	2.46	3.69	10.23	1.16	1.68	0.72	0.36	2.14	0.02	0.10	2.38	1.54	4.56	11.01
SD	36	4.89	3.23	1.77	0.05	1.48	0.83	5.01	0.37	1.12	0.32	0.11	1.18	0.02	0.17	0.48	0.46	1.97	4.75
CV	0.39	0.40	0.39	0.45	0.19	0.60	0.22	0.49	0.32	0.67	0.45	0.31	0.55	0.87	1.71	0.20	0.30	0.43	0.43

Post-monsoon	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
KRNK	0.70	1.96	0.12	0.42	0.18	1.59	0.01	0.02	0.03	0.14	0.00	0.00	0.03	0.02	0.00	0.01	0.03	0.04	69.78
SAIL	1.02	1.46	0.16	0.68	0.23	1.20	0.03	0.03	0.04	0.21	0.01	0.00	0.05	0.03	0.00	0.02	0.06	0.06	70.46
ENPH	1.18	4.55	0.39	0.46	0.87	3.91	0.02	0.03	0.05	1.09	0.00	0.00	0.04	0.04	0.01	0.02	0.11	0.58	67.85
HSSR	7.84	5.05	0.20	0.14	0.51	4.26	0.00	0.01	0.01	0.42	0.00	0.00	0.01	0.01	0.00	0.00	0.05	0.10	63.75
HSSB	4.40	2.27	0.12	0.23	0.33	1.85	0.01	0.01	0.02	0.22	0.02	0.00	0.05	0.02	0.00	0.02	0.02	0.07	67.34
AHCM	5.37	3.68	0.13	0.12	0.22	3.21	0.00	0.01	0.01	0.27	0.00	0.00	0.01	0.02	0.00	0.00	0.01	0.13	63.70
Overall	3.42	3.16	0.19	0.34	0.39	2.67	0.01	0.02	0.03	0.39	0.01	0.00	0.03	0.02	0.00	0.01	0.05	0.16	67.15
SD	2.91	1.47	0.11	0.22	0.26	1.29	0.01	0.01	0.01	0.35	0.01	0.00	0.02	0.01	0.00	0.01	0.03	0.21	2.89
CV	0.85	0.47	0.56	0.64	0.66	0.48	0.76	0.68	0.53	0.90	0.72	0.56	0.51	0.48	0.64	0.67	0.75	1.27	0.04

Table 2.133: Overall summary of average concentration of chemical species in PM$_{2.5}$ for all sites for post-monsoon season

Post-monsoon	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
KRNK	32	5.30	3.48	1.82	0.17	2.20	1.94	2.99	0.70	0.45	0.23	0.21	0.76	0.01	0.25	1.17	0.57	1.23	3.27
SAIL	28	4.17	2.78	1.39	0.18	1.53	1.40	3.78	0.76	0.47	0.28	0.16	0.31	0.02	0.02	1.70	1.41	0.87	2.05
ENPH	67	11.42	6.51	4.91	0.25	2.37	2.06	9.12	1.02	2.36	0.56	0.36	1.25	0.02	0.03	2.03	1.31	2.78	6.67
HSSR	74	13.10	8.47	4.63	0.17	1.09	2.11	8.27	0.61	1.68	0.65	0.18	1.38	0.00	0.02	1.36	1.04	3.41	8.31
HSSB	46	9.09	6.18	2.91	0.17	0.55	2.67	5.91	0.44	1.25	0.37	0.15	0.80	0.01	0.01	1.17	0.48	1.97	4.72
AHCM	51	11.57	7.62	3.95	0.17	0.49	0.73	4.31	0.45	0.41	0.50	0.12	0.88	0.00	0.02	1.11	0.71	2.33	5.80
Overall	50	9.11	5.84	3.27	0.19	1.37	1.82	5.73	0.66	1.10	0.43	0.20	0.90	0.01	0.06	1.42	0.92	2.10	5.14
SD	18	3.64	2.26	1.47	0.03	0.81	0.67	2.50	0.22	0.81	0.16	0.09	0.38	0.01	0.10	0.37	0.39	0.95	2.28
CV	0.37	0.40	0.39	0.45	0.17	0.59	0.37	0.44	0.33	0.73	0.38	0.44	0.43	0.82	1.63	0.26	0.43	0.45	0.44
Post-monsoon	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
KRNK	0.38	1.05	0.07	0.25	0.12	0.76	0.01	0.01	0.02	0.08	0.00	0.00	0.02	0.01	0.00	0.01	0.01	0.03	71.55
SAIL	0.73	0.58	0.13	0.45	0.16	0.48	0.02	0.02	0.03	0.15	0.01	0.00	0.03	0.02	0.00	0.02	0.04	0.04	74.96
ENPH	0.80	1.87	0.27	0.34	0.61	1.58	0.01	0.02	0.03	0.74	0.00	0.00	0.03	0.03	0.01	0.01	0.07	0.20	71.39
HSSR	2.73	2.34	0.12	0.10	0.31	1.99	0.00	0.00	0.01	0.30	0.00	0.00	0.01	0.01	0.00	0.00	0.03	0.08	66.50
HSSB	1.24	1.32	0.08	0.16	0.18	1.03	0.01	0.01	0.01	0.14	0.01	0.00	0.03	0.01	0.00	0.01	0.01	0.04	70.54
AHCM	1.86	1.63	0.07	0.08	0.11	1.34	0.00	0.00	0.01	0.18	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.08	64.62
Overall	1.29	1.47	0.12	0.23	0.25	1.20	0.01	0.01	0.02	0.26	0.00	0.00	0.02	0.01	0.00	0.01	0.03	0.08	69.93
SD	0.87	0.62	0.08	0.15	0.19	0.55	0.01	0.01	0.01	0.24	0.00	0.00	0.01	0.01	0.00	0.01	0.03	0.06	3.75
CV	0.67	0.42	0.62	0.63	0.77	0.46	0.77	0.72	0.63	0.93	0.72	0.54	0.55	0.59	0.66	0.69	0.85	0.83	0.05

Table 2.134: Ratios of chemical species of PM$_{2.5}$ and PM$_{10}$ for all sites for winter (W), summer (S) and post-monsoon (P) seasons

Sites	KRNK			SAIL			ENPH			HSSR		
Season	W	S	P	W	S	P	W	S	P	W	S	P
PM$_{10}$	216	205	60	344	229	51	295	240	127	298	224	140
PM$_{2.5}$	129	106	32	196	114	28	151	119	67	150	114	74
PM$_{2.5}$/PM$_{10}$	60	52	53	57	50	55	51	49	53	50	51	53
TC (PM$_{2.5}$/PM$_{10}$)	74	75	74	75	75	74	75	76	75	74	75	74
OC (PM$_{2.5}$/PM$_{10}$)	70	70	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	83	83
F^- (PM$_{2.5}$/PM$_{10}$)	67	49	50	58	56	73	56	64	70	58	53	59
Cl^- (PM$_{2.5}$/PM$_{10}$)	62	48	51	71	56	65	55	52	57	49	49	53
NO_3^-(PM$_{2.5}$/PM$_{10}$)	68	38	55	69	52	66	61	45	50	65	45	47
SO_4^{-2}(PM$_{2.5}$/PM$_{10}$)	61	50	49	82	65	63	62	53	52	70	58	53
Na^+ (PM$_{2.5}$/PM$_{10}$)	69	45	49	67	59	64	56	58	67	50	44	43
NH_4^+ (PM$_{2.5}$/PM$_{10}$)	73	40	46	59	57	69	61	59	75	54	47	57
K^+ (PM$_{2.5}$/PM$_{10}$)	64	52	51	57	68	70	58	62	60	70	56	52
Mg^{+2} (PM$_{2.5}$/PM$_{10}$)	62	43	54	59	46	65	53	57	65	39	54	52
Ca^{+2} (PM$_{2.5}$/PM$_{10}$)	72	51	48	59	80	52	38	45	55	46	39	36
Be (PM$_{2.5}$/PM$_{10}$)	64	75	64	57	82	59	79	45	71	58	47	76
B (PM$_{2.5}$/PM$_{10}$)	61	64	56	54	58	70	63	65	70	64	43	63
Na (PM$_{2.5}$/PM$_{10}$)	53	58	58	37	65	70	53	58	66	35	48	58
Mg (PM$_{2.5}$/PM$_{10}$)	44	46	59	41	30	76	42	48	64	66	44	56
Al (PM$_{2.5}$/PM$_{10}$)	56	48	42	47	40	37	43	37	42	40	41	49
Si (PM$_{2.5}$/PM$_{10}$)	55	48	47	45	39	36	40	38	43	41	42	49
P (PM$_{2.5}$/PM$_{10}$)	73	54	63	39	71	76	44	61	66	48	41	43
K (PM$_{2.5}$/PM$_{10}$)	69	46	54	52	40	72	61	52	68	47	48	35
Ca (PM$_{2.5}$/PM$_{10}$)	50	46	54	51	40	40	39	35	41	38	42	46
Cr (PM$_{2.5}$/PM$_{10}$)	59	62	59	49	51	81	35	44	69	57	45	60
V (PM$_{2.5}$/PM$_{10}$)	69	56	60	62	59	67	68	55	74	41	50	73
Mn (PM$_{2.5}$/PM$_{10}$)	59	57	68	43	42	68	68	49	71	48	51	60
Fe (PM$_{2.5}$/PM$_{10}$)	50	43	48	53	35	40	36	32	40	36	48	47
Co (PM$_{2.5}$/PM$_{10}$)	76	60	59	53	38	65	63	74	64	64	50	70
Ni (PM$_{2.5}$/PM$_{10}$)	77	63	62	55	53	61	66	57	71	55	45	60
Cu (PM$_{2.5}$/PM$_{10}$)	77	49	54	53	50	70	61	57	72	51	50	50
Zn (PM$_{2.5}$/PM$_{10}$)	68	70	54	51	58	72	78	60	68	58	43	71
As (PM$_{2.5}$/PM$_{10}$)	71	70	58	47	62	70	75	59	69	57	47	59
Se (PM$_{2.5}$/PM$_{10}$)	72	68	62	54	67	70	69	73	73	60	48	54
Rb (PM$_{2.5}$/PM$_{10}$)	71	67	62	58	48	60	62	54	67	86	48	57
Sr (PM$_{2.5}$/PM$_{10}$)	61	63	58	51	38	70	52	49	73	54	47	52
Cd (PM$_{2.5}$/PM$_{10}$)	80	43	57	61	69	63	74	67	65	66	49	74
Cs (PM$_{2.5}$/PM$_{10}$)	76	44	61	61	78	68	76	58	69	64	51	49
Ba (PM$_{2.5}$/PM$_{10}$)	38	45	49	47	38	79	39	50	67	63	49	54
Pb (PM$_{2.5}$/PM$_{10}$)	55	60	66	45	66	77	72	54	35	65	49	72

Sites	**HSSB**			**AHCM**			**ABGV**	**OVERALL**		
Season	**W**	**S**	**P**	**W**	**S**	**P**	**W**	**W**	**S**	**P**
PM_{10}	181	65	78	195	84	101	195	250	175	93
$PM_{2.5}$	116	42	46	108	53	51	146	142	91	50
$PM_{2.5}/PM_{10}$	64	65	59	49	63	51	75	56	51	54
TC ($PM_{2.5}/PM_{10}$)	74	74	74	74	74	74	75	74	75	78
OC ($PM_{2.5}/PM_{10}$)	70	70	70	70	70	70	70	70	70	75
EC ($PM_{2.5}/PM_{10}$)	83	83	83	83	83	83	83	83	83	87
F^- ($PM_{2.5}/PM_{10}$)	60	68	70	55	73	75	75	59	57	63
Cl^- ($PM_{2.5}/PM_{10}$)	60	66	66	56	72	46	65	58	52	50
NO_3^- ($PM_{2.5}/PM_{10}$)	63	71	68	42	58	18	72	66	45	50
SO_4^{-2} ($PM_{2.5}/PM_{10}$)	62	71	65	52	61	60	79	70	57	53
Na^+ ($PM_{2.5}/PM_{10}$)	57	62	68	62	62	58	60	60	49	54
NH_4^+ ($PM_{2.5}/PM_{10}$)	49	63	76	71	52	59	62	58	55	58
K^+ ($PM_{2.5}/PM_{10}$)	63	68	70	57	60	68	71	63	59	61
Mg^{+2} ($PM_{2.5}/PM_{10}$)	58	63	61	59	46	34	70	51	51	55
Ca^{+2} ($PM_{2.5}/PM_{10}$)	57	44	53	46	48	29	62	51	53	46
Be ($PM_{2.5}/PM_{10}$)	60	82	72	71	69	81	72	62	73	55
B ($PM_{2.5}/PM_{10}$)	65	80	66	65	58	54	73	61	67	51
Na ($PM_{2.5}/PM_{10}$)	55	61	68	49	65	41	74	49	57	61
Mg ($PM_{2.5}/PM_{10}$)	61	75	46	48	60	49	60	50	42	59
Al ($PM_{2.5}/PM_{10}$)	64	64	59	39	60	45	76	47	42	47
Si ($PM_{2.5}/PM_{10}$)	63	63	58	39	59	46	77	47	42	48
P ($PM_{2.5}/PM_{10}$)	68	45	51	66	59	39	68	59	58	56
K ($PM_{2.5}/PM_{10}$)	57	53	28	66	58	35	76	55	47	43
Ca ($PM_{2.5}/PM_{10}$)	59	56	58	38	60	44	75	46	41	48
Cr ($PM_{2.5}/PM_{10}$)	49	31	64	35	56	55	67	51	48	62
V ($PM_{2.5}/PM_{10}$)	49	45	69	51	59	66	77	49	51	60
Mn ($PM_{2.5}/PM_{10}$)	61	36	54	40	52	48	65	58	48	58
Fe ($PM_{2.5}/PM_{10}$)	58	60	56	37	66	42	73	45	40	47
Co ($PM_{2.5}/PM_{10}$)	56	77	69	44	64	57	58	64	68	55
Ni ($PM_{2.5}/PM_{10}$)	64	71	69	45	57	51	64	75	59	57
Cu ($PM_{2.5}/PM_{10}$)	50	57	61	47	52	63	70	65	53	58
Zn ($PM_{2.5}/PM_{10}$)	50	33	61	61	55	64	71	64	57	63
As ($PM_{2.5}/PM_{10}$)	65	72	61	53	57	65	67	67	66	57
Se ($PM_{2.5}/PM_{10}$)	53	78	61	57	54	49	76	63	71	57
Rb ($PM_{2.5}/PM_{10}$)	51	70	63	47	56	47	74	64	57	55
Sr ($PM_{2.5}/PM_{10}$)	50	57	60	44	64	67	74	56	51	62
Cd ($PM_{2.5}/PM_{10}$)	53	72	70	59	60	57	77	67	67	59
Cs ($PM_{2.5}/PM_{10}$)	69	76	64	67	58	75	87	71	68	57
Ba ($PM_{2.5}/PM_{10}$)	61	51	56	53	58	60	79	43	46	57
Pb ($PM_{2.5}/PM_{10}$)	58	50	60	58	56	63	68	61	57	46

Table 2.135: Mean 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}
KRNK	216	44.0	0.204	28.4	0.131	40.1	0.186
SAIL	344	91.2	0.265	53.7	0.156	53.1	0.154
ENPH	295	75.0	0.254	26.0	0.088	45.8	0.155
HSSR	298	78.1	0.262	35.7	0.120	42.1	0.141
HSSB	181	39.9	0.220	26.2	0.144	33.2	0.183
AHCM	222	53.5	0.241	24.7	0.111	34.0	0.153
ABGV	195	36.2	0.186	29.2	0.150	37.9	0.194
Overall	250	59.7	0.23	31.98	0.13	40.87	0.17
SD	62	21.6	0.03	10.22	0.02	6.95	0.02
CV	0.25	0.36	0.13	0.32	0.19	0.17	0.12

Table 2.136: 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/ $PM_{2.5}$
KRNK	129	23.69	0.183	18.30	0.141	29.7	0.230
SAIL	196	42.96	0.219	40.89	0.209	39.5	0.202
ENPH	151	29.85	0.198	16.00	0.106	34.1	0.226
HSSR	150	31.05	0.207	24.02	0.160	31.0	0.207
HSSB	116	24.82	0.214	15.57	0.134	24.5	0.211
AHCM	108	20.62	0.190	12.47	0.115	25.0	0.231
ABGV	146	27.41	0.188	21.16	0.145	28.4	0.195
Overall	142	28.6	0.20	21.20	0.14	30.33	0.21
SD	29	7.3	0.01	9.48	0.03	5.26	0.01
CV	0.20	0.25	0.07	0.45	0.23	0.17	0.07

Table 2.137: 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}
KRNK	205	44.3	0.216	36.2	0.176	32.9	0.160
SAIL	229	54.8	0.239	29.2	0.128	35.9	0.157
ENPH	240	57.6	0.240	32.3	0.134	38.8	0.161
HSSR	224	50.7	0.226	31.3	0.140	32.7	0.146
HSSB	65	10.4	0.160	13.3	0.204	13.2	0.203
AHCM	84	12.8	0.153	17.5	0.209	13.7	0.163
Overall	175	38.4	0.21	26.64	0.17	27.86	0.17
SD	73	19.2	0.03	8.85	0.03	10.09	0.02
CV	0.42	0.50	0.16	0.33	0.20	0.36	0.13

Table 2.138: Statistical summary of major components: $PM_{2.5}$, summer ($\mu g/m^3$)

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/ $PM_{2.5}$
KRNK	106	20.9	0.197	16.9	0.159	24.7	0.233
SAIL	114	21.2	0.185	17.8	0.156	27.0	0.236
ENPH	119	20.9	0.176	17.4	0.147	29.4	0.248
HSSR	114	21.6	0.190	16.5	0.146	24.4	0.215
HSSB	42	6.4	0.152	9.0	0.211	9.8	0.231
AHCM	53	7.7	0.145	10.4	0.195	10.1	0.190
Overall	99	18.2	0.18	15.52	0.16	23.03	0.23
SD	34	7.3	0.02	3.92	0.03	8.66	0.02
CV	0.35	0.40	0.12	0.25	0.17	0.38	0.09

Table 2.139: Statistical summary of major components: PM_{10}, post-monsoon ($\mu g/m^3$)

Post-Monsoon	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}
KRNK	60	13.5	0.223	10.6	0.176	7.2	0.119
SAIL	51	10.8	0.212	8.8	0.175	5.6	0.111
ENPH	127	30.6	0.242	24.8	0.195	15.2	0.120
HSSR	140	33.4	0.238	22.9	0.163	17.7	0.126
HSSB	78	15.6	0.200	14.6	0.187	12.3	0.158
AHCM	101	24.6	0.243	12.0	0.119	15.6	0.155
Overall	93	21.4	0.23	15.61	0.17	12.28	0.13
SD	40	10.4	0.02	7.17	0.01	5.14	0.02
CV	0.43	0.49	0.08	0.46	0.07	0.42	0.14

Table 2.140: Statistical summary of major components: $PM_{2.5}$, post-monsoon ($\mu g/m^3$)

Post-Monsoon	$PM_{2.5}$	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/ $PM_{2.5}$
KRNK	32	6.3	0.198	5.4	0.168	5.3	0.166
SAIL	28	4.0	0.144	5.6	0.205	4.2	0.151
ENPH	67	12.9	0.193	13.5	0.203	11.4	0.171
HSSR	74	16.0	0.218	12.1	0.164	13.1	0.178
HSSB	46	9.0	0.197	9.8	0.214	9.1	0.198
AHCM	51	11.1	0.217	5.4	0.106	11.6	0.226
Overall	50	9.9	0.19	8.65	0.18	9.11	0.18
SD	18	4.4	0.03	3.66	0.04	3.64	0.03
CV	0.37	0.44	0.14	0.42	0.23	0.40	0.15

2.4.9 Statistical Summary

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

2.4.9.1 Box Plot Distribution

Statistical box plots are shown in Figure 2.128 – Figure 2.133 for all sites for $PM_{2.5}$, PM_{10}, NO_2, SO_2, EC and OC for winter (W), summer (S) and post-monsoon (P) seasons. These figures show the min, max, mean, median, 25% quartile, 75% quartile and outliers of the data distribution. The outlier values could possibly due to the local activities (i.e., DG sets emission, biomass burning, traffic congestion, etc.) near the monitoring stations. The SAIL, ENPH and KRNK sites show the largest variability and high pollution level whereas residential areas show low variability in all pollutants. It is to be noted that variability is much higher in winter compared to summer and post-monsoon.

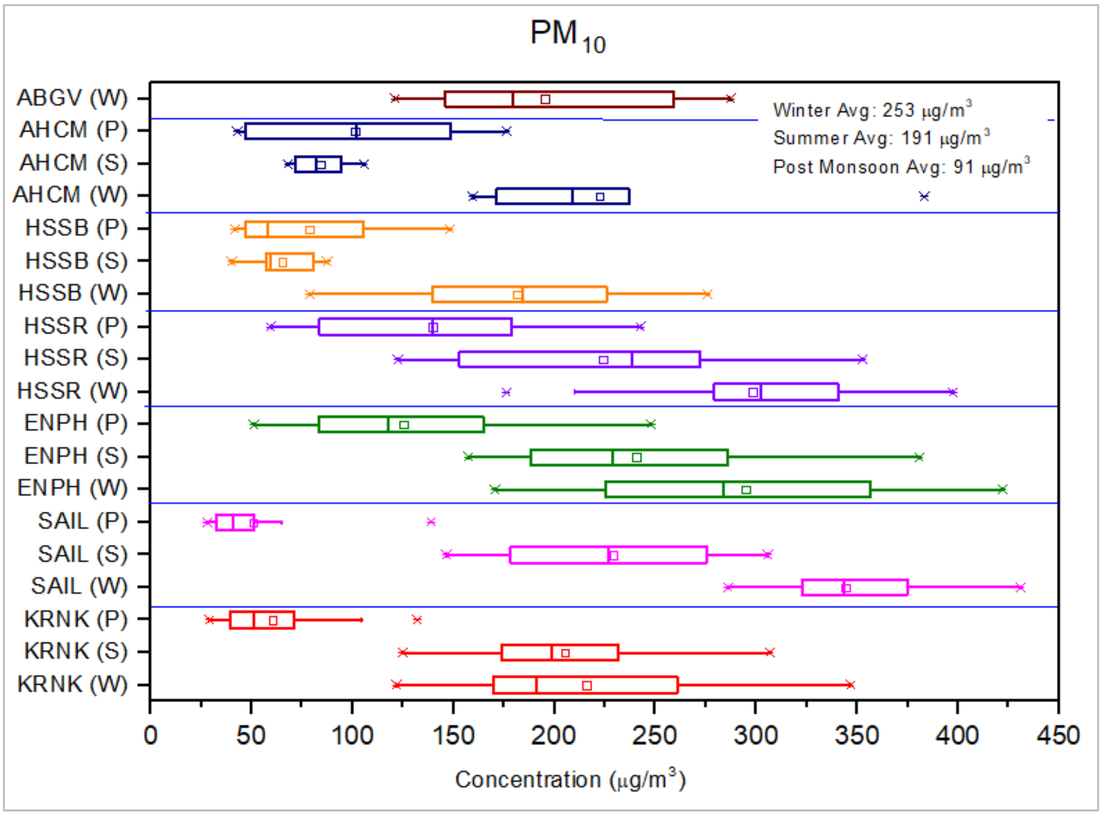


Figure 2.128: Box plot distribution for PM_{10} (winter, summer and post-monsoon)

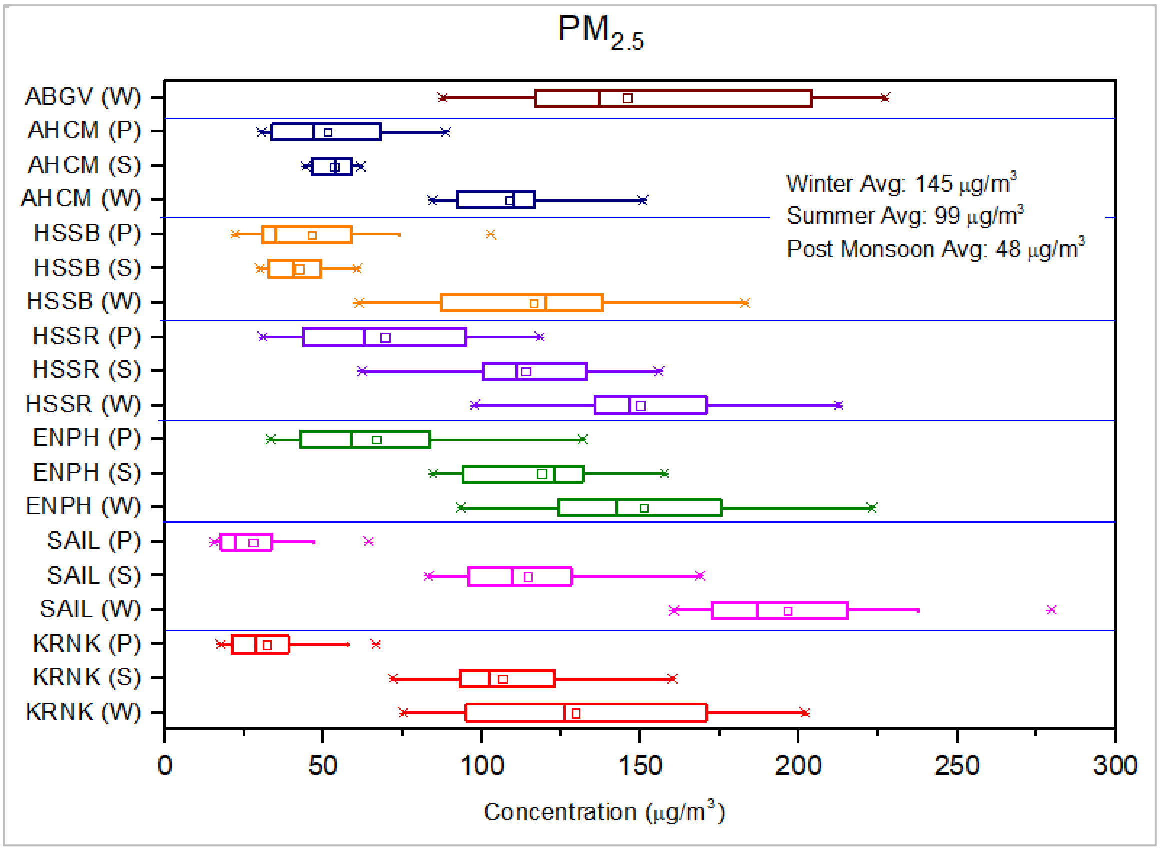


Figure 2.129: Box plot distribution for $PM_{2.5}$ (winter, summer, and post-monsoon)

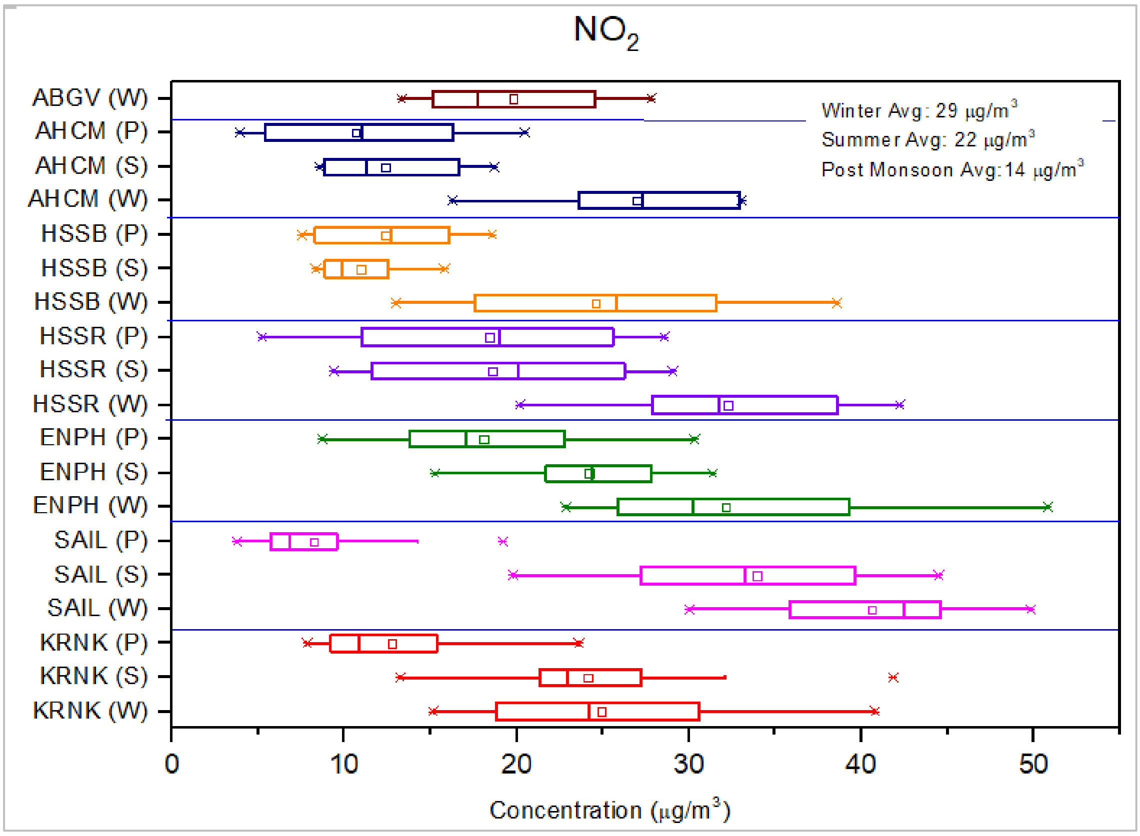


Figure 2.130: Box plot distribution for NO_2 (winter, summer and post-monsoon)

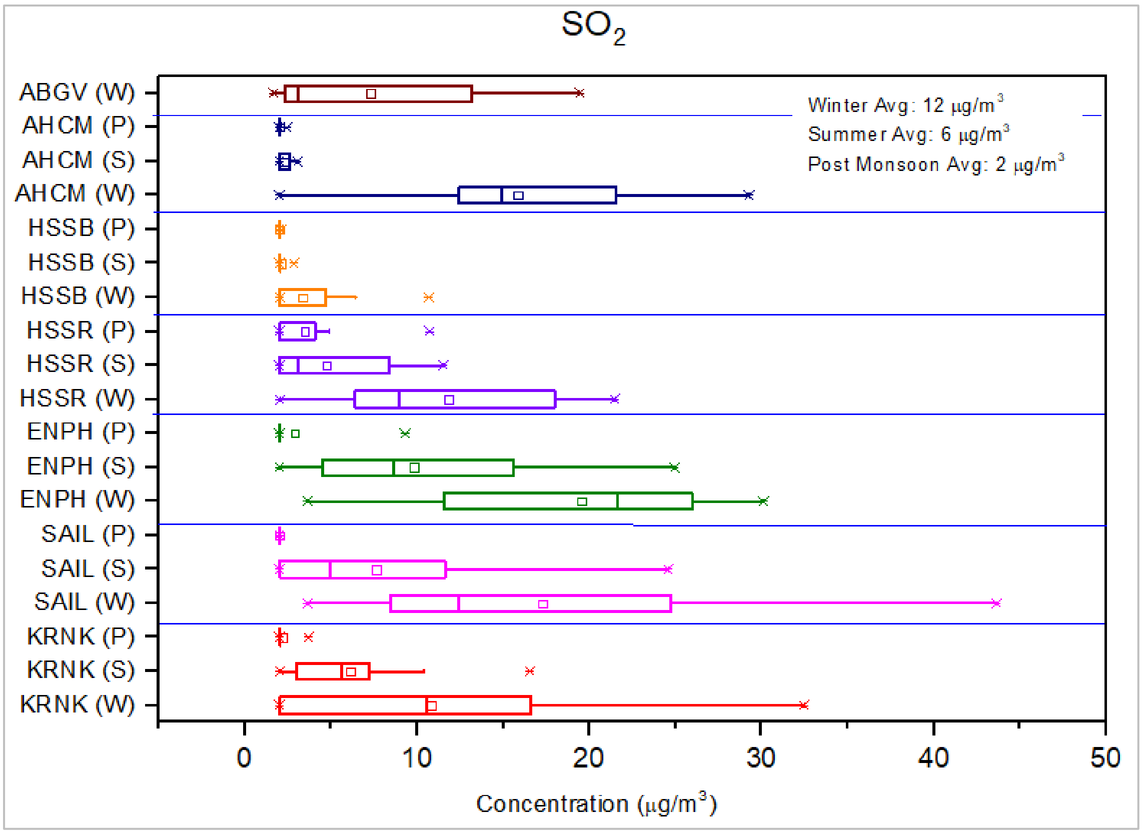


Figure 2.131: Box plot distribution for SO_2 (winter, summer and post-monsoon)

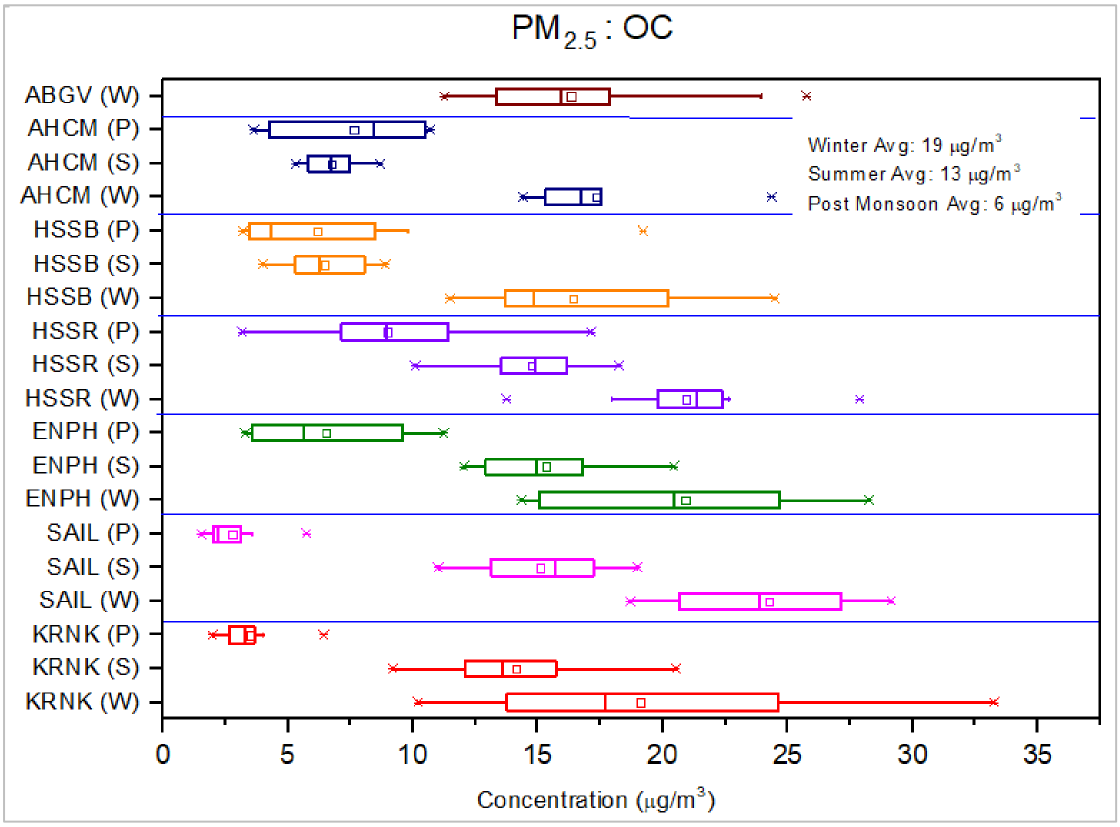


Figure 2.132: Box plot distribution for OC (winter, summer and post-monsoon)

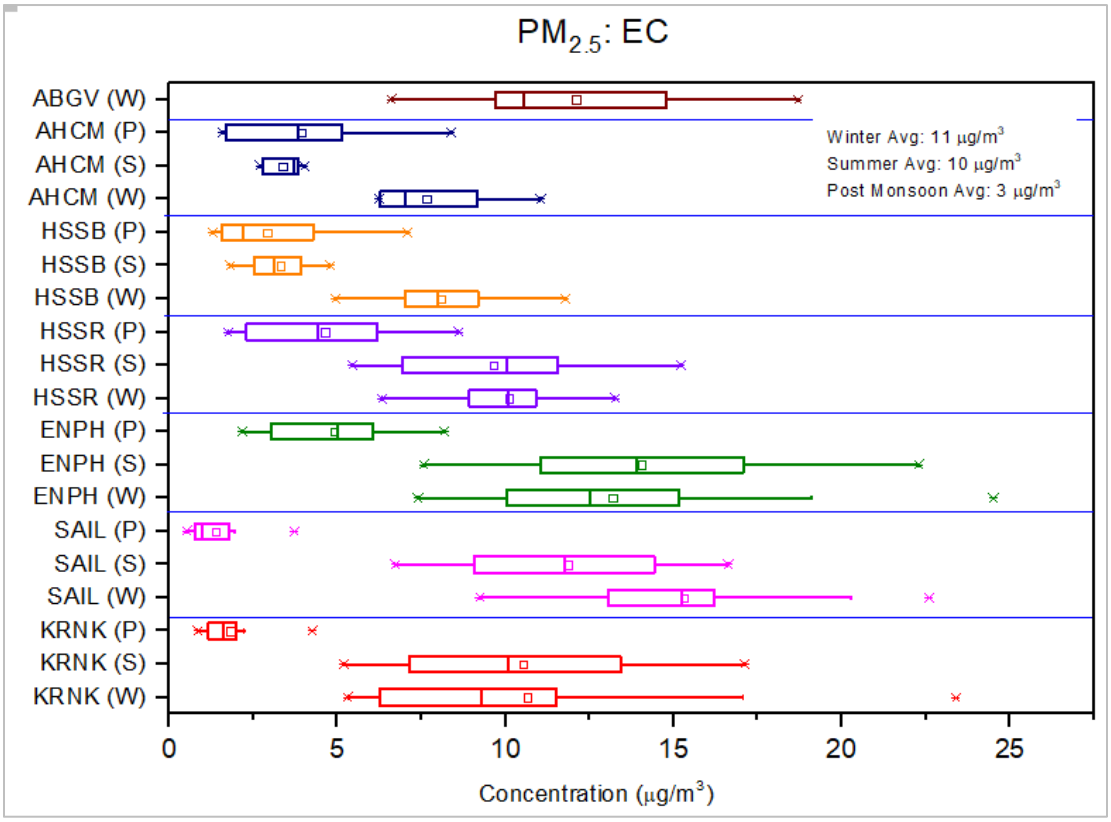


Figure 2.133: Box plot distribution for EC (winter, summer, and post-monsoon)

2.4.9.2 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 and post-monsoon levels for PM_{10}, $PM_{2.5}$, NO_2, SO_2 and carbon content (EC and OC) and also summer levels are higher than post-monsoon. It is observed from Table 2.141 that OC levels are higher at all sites, PM_{10}, $PM_{2.5}$ and NO_2 is higher at all sites except at KRNK (no significance difference). SO_2 is higher at SAIL, ENPH, HSSR and AHCM in winter than summer. It is observed from Table 2.142 that all pollutants are higher (except SO_2 at HSSB) in winter compared to post-monsoon. It is observed from Table 2.143 that PM levels are higher at all sites except at AHCM and HSSB for PM_{10} and at HSSB for $PM_{2.5}$ in summer compared to post-monsoon. The information on seasonal composition of PM can assist in identifying the various sources contributing to ambient pollution level.

Table 2.141: Statistical Comparison Winter Vs Summer

Parameter ➔ Site▼	PM$_{10}$	PM$_{2.5}$	OC	EC	NO$_2$	SO$_2$
KRNK	⇔	⇔	⇧	⇩	⇔	⇔
SAIL	⇧	⇧	⇧	⇧	⇧	⇧
ENPH	⇧	⇧	⇧	⇩	⇧	⇧
HSSR	⇧	⇧	⇧	⇧	⇧	⇧
HSSB	⇧	⇧	⇧	⇧	⇧	⇔
AHCM	⇧	⇧	⇧	⇧	⇧	⇧
⇔ No significant difference		⇧ (Levels higher in winter)		⇩ (Levels lower in winter)		
* No pollutant showed lower concentration in winter						

Table 2.142: Statistical Comparison Winter Vs Post-monsoon

Parameter ➔ Site▼	PM$_{10}$	PM$_{2.5}$	OC	EC	NO$_2$	SO$_2$
KRNK	⇧	⇧	⇧	⇧	⇧	⇧
SAIL	⇧	⇧	⇩	⇧	⇧	⇧
ENPH	⇧	⇧	⇧	⇧	⇧	⇧
HSSR	⇧	⇧	⇧	⇧	⇧	⇧
HSSB	⇧	⇧	⇧	⇧	⇧	⇔
AHCM	⇧	⇧	⇧	⇧	⇧	⇧
⇔ No significant difference		⇧ (Levels higher in winter)		⇩ (Levels lower in winter)		
* No pollutant showed lower concentration in winter						

Table 2.143: Statistical Comparison Summer Vs Post-monsoon

Parameter ➔ Site▼	PM$_{10}$	PM$_{2.5}$	OC	EC	NO$_2$	SO$_2$
KRNK	⇧	⇧	⇧	⇧	⇧	⇧
SAIL	⇧	⇧	⇧	⇧	⇧	⇧
ENPH	⇧	⇧	⇧	⇧	⇧	⇧
HSSR	⇧	⇧	⇧	⇧	⇔	⇔
HSSB	⇩	⇩	⇧	⇧	⇩	⇔
AHCM	⇩	⇧	⇩	⇩	⇧	⇔
⇔ 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 winter, summer and post-monsoon months and critical analyses of air quality data, the following inferences and insights are drawn for developing causal relationship between emission and impact through receptor modeling (Chapter 4). The season-wise, site-specific average concentration of PM_{10}, $PM_{2.5}$ and their compositions have been referred to bring the important inferences to the fore.

- Particulate pollution is the main concern in the city where PM_{10} levels are 1.8– 2.5 times higher than the national air quality standards (NAAQS) in summer and winter months and $PM_{2.5}$ levels are 1.5 – 2.4 times higher than the NAAQS in winter and summer months. PM_{10} and $PM_{2.5}$ levels were within the limit of the NAAQS in post-monsoon.

- 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 three seasons.

Winter - PM_{10}

The overall average concentration of PM_{10} in winter season is 250±62 $\mu g/m^3$ against the acceptable level of 100 $\mu g/m^3$. Highest levels were observed at SAIL (344±40 $\mu g/m^3$) and lowest at HSSB (181±54 $\mu g/m^3$).

The crustal component (Si + Al + Fe + Ca) accounts for about 23%. This suggests soil and road dust was significantly high in PM_{10} in winter. The coefficient of variation (CV) is about 0.36 (of fraction of crustal component) which suggests the crustal source contributes consistently to winter. Though much less compared to the summer season.

The other important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for about 13% of total PM_{10} and combustion related total carbon (TC = EC + OC) accounts for about 16% in winter.

The Cl^- content in PM_{10} in winter is consistent with an average of 3 percent, which is an indicator of burning of plastic solid waste; recall poly vinyl chloride (PVC) is a major part of solid waste. The highest Cl^- content is observed at HSSR at 11.36 $\mu g/m^3$

compared to overall city level of 7.64 µg/m^3. The high level at HSSR signifies some local burning of waste as a means of disposal of solid waste.

Winter - PM$_{2.5}$

The overall average concentration of PM$_{2.5}$ in winter is 142±29 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at SAIL 196±32 µg/m^3 and lowest at HSSR 108±20 µg/m^3. The crustal component (20% in winter, 18% in summer and 20% in post-monsoon) is almost similar in all the three seasons.

The other important components are the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 15% of total PM$_{2.5}$ and combustion related total carbon (EC+OC) accounts for 21%; both secondary particles and combustion related carbon are consistent contributors to PM$_{2.5}$ at about 36%. Highest level of TC was observed at SAIL (39 µg/m^3).

The Cl^- content in PM$_{2.5}$ winter is consistent with an average of 4.47% which is an indicator of burning of solid waste.

Summer - PM$_{10}$

The overall average concentration of PM$_{10}$ in summer season was 175±78 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 22 percent of total PM$_{10}$ in summer. This suggests airborne soil and road dust are the major sources of PM$_{10}$ pollution in summer. The coefficient of variation (CV) is about 0.50, which suggests the sources are inconsistent all around the city forming a layer which envelopes the city. The areas of SAIL and ENPH have the highest crustal fraction (around 23% of total PM$_{10}$). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Bhilai and are more prominent in summer when soil and dust are dry and high-speed winds make the particles airborne. It was observed that in summer the atmosphere looks light brownish which can be attributed to the presence of large amounts of soil dust particles in the atmosphere.

The second significant component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 15 percent of total PM$_{10}$ and combustion related total carbon

(EC+OC) accounts for about 16 percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^-, SO_4^{-2}, and NH_4^+.

The Cl^- content in PM_{10} in summer is consistent at 4 percent, which is an indicator of burning of municipal solid waste and has a relatively similar contribution in summer and winter.

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer is 91±34 µg/m^3 against the acceptable level of 60 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 20% of total $PM_{2.5}$. This suggests airborne soil and road dust is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.40, which suggests the source is consistent all around the city.

The second important component is combustion related total carbon (EC+OC), which account for 25% of total $PM_{2.5}$ and secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$) accounts for 17%; both fractions of secondary particles and combustion related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles, and combustion contribute consistently to $PM_{2.5}$ in summer.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 4%, which is an indicator of burning of municipal solid waste and has a similar contribution to $PM_{2.5}$ and PM_{10}.

Post-monsoon - PM_{10}

The overall average concentration of PM_{10} in post-monsoon season was 93±40 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 23 percent of total PM_{10} in post-monsoon. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in post-monsoon. The coefficient of variation (CV) is about 0.49, which suggests the sources are inconsistent all around the city forming a layer which envelopes the city. The areas of HSSR and ENPH have the highest crustal fraction (around 24% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around Bhilai.

The second significant component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 17 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about 13 percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^-, SO_4^{-2}, and NH_4^+.

The Cl^- content in PM_{10} in post-monsoon is consistent at 3 percent, which is an indicator of burning of municipal solid waste and has a relatively equal contribution in summer and winter.

Post-monsoon - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in post-monsoon season is 50 µg/m^3 (except at ENPH and HSSR where level is 67 µg/m^3 and 74 µg/m^3) within the acceptable level of 60 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 16% of total $PM_{2.5}$. This suggests airborne soil and road dust is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.32, which suggests the source is consistent all around the city.

The second important component is combustion related total carbon (EC+OC), which account for 18% of total $PM_{2.5}$ and secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$) accounts for 17%; fractions of combustion related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles and combustion contribute consistently to $PM_{2.5}$ in post-monsoon.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 3 percent, which is an indicator of burning of solid waste and has a similar contribution to $PM_{2.5}$ and PM_{10}. This is similar in all the three seasons.

Potassium levels

In general potassium levels are high and variable for PM_{10} (3.4 to 6.4 µg/m^3) and $PM_{2.5}$ (1.3 to 4.0 µg/m^3) in winter, summer and post-monsoon. In general potassium level should be less than 2 µg/m^3 which achieved in post-monsoon in $PM_{2.5}$. Potassium is an indicator of biomass burning (includes agricultural residue, plant leaves, wood, dung cake) and high levels and variability show significant biomass burning and it is consistent in all three seasons.

NO_2 levels

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

General inferences

Levels of OC (at all locations), PM_{10}, $PM_{2.5}$ and NO_2 (all sites except at KRNK) are statistically higher in winter than in summer season. Levels of all pollutants at all locations (except SO_2 at HSSB) are statistically higher in winter than post-monsoon. In general air pollution levels in ambient air (barring traffic intersections) are uniform across the city suggesting entire city is stressed under high pollution; in a relative sense, SAIL is most polluted followed by HSSR and ENPH. HSSB is the least polluted area.

It is to be noted that OC3/TC ratio is above 0.20 and highest among ratio of fraction of OC to TC. It suggests a significant component of secondary organic aerosol is formed in atmosphere due to condensation and nucleation of volatile to semi volatile organic compounds, which suggests emissions within and outside of Bhilai.

Total PAH levels (17 compounds; particulate phase) in winter is very high at 34 ng/m^3 the comparison with annual standard is not advisable due to different averaging times. However, PAH levels in summer and post-monsoon drop to about 28 ng/m^3 and 21 ng/m^3.

The concentrations of molecular markers in $PM_{2.5}$ (total of 6 compounds) are also higher in winter (96 ng/m^3) than in summer (71 ng/m^3) and post-monsoon (64 ng/m^3) indicating presence of common sources of emissions from coal, gasoline, and domestic fuel.

The total BTX levels are lesser in winter (9 µg/m^3) than in summer (18 µg/m^3) and post-monsoon (15 µg/m^3). The emission rate in summer is higher due to higher temperature. The average benzene level exceeded the annual national standard (5 µg/m^3) in winter.

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

3 Emission Inventory

3.1 Introduction

Emission inventory (EI) is a basic necessity for planning air pollution control activities, and it provides a reliable estimate of total emissions of different pollutants and their spatial and temporal distribution and identification and characterization of primary 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 the study area for the year 2022 is presented.

3.2 Methodology

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

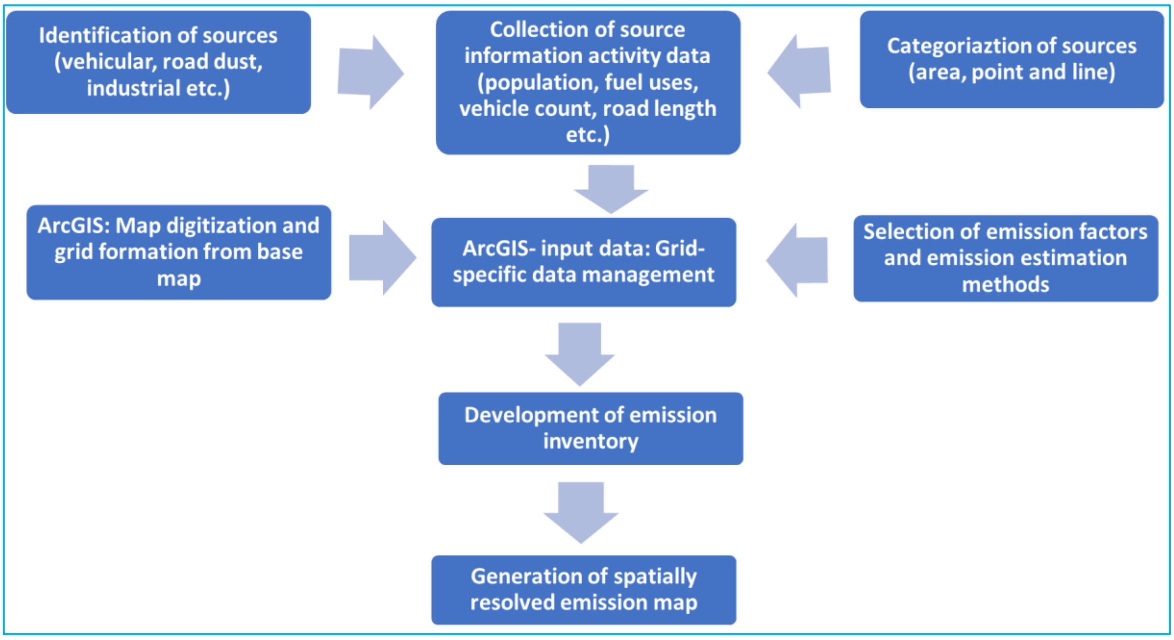


Figure 3.1: Stepwise Methodology Adopted for the Study

3.2.1 Digital Data Generation and Land-use Map

The land-use map of the study area is prepared in terms of agriculture, vegetation, industrial, water bodies, road network, settlements, and open areas. (Figure 3.2-Figure 3.10).

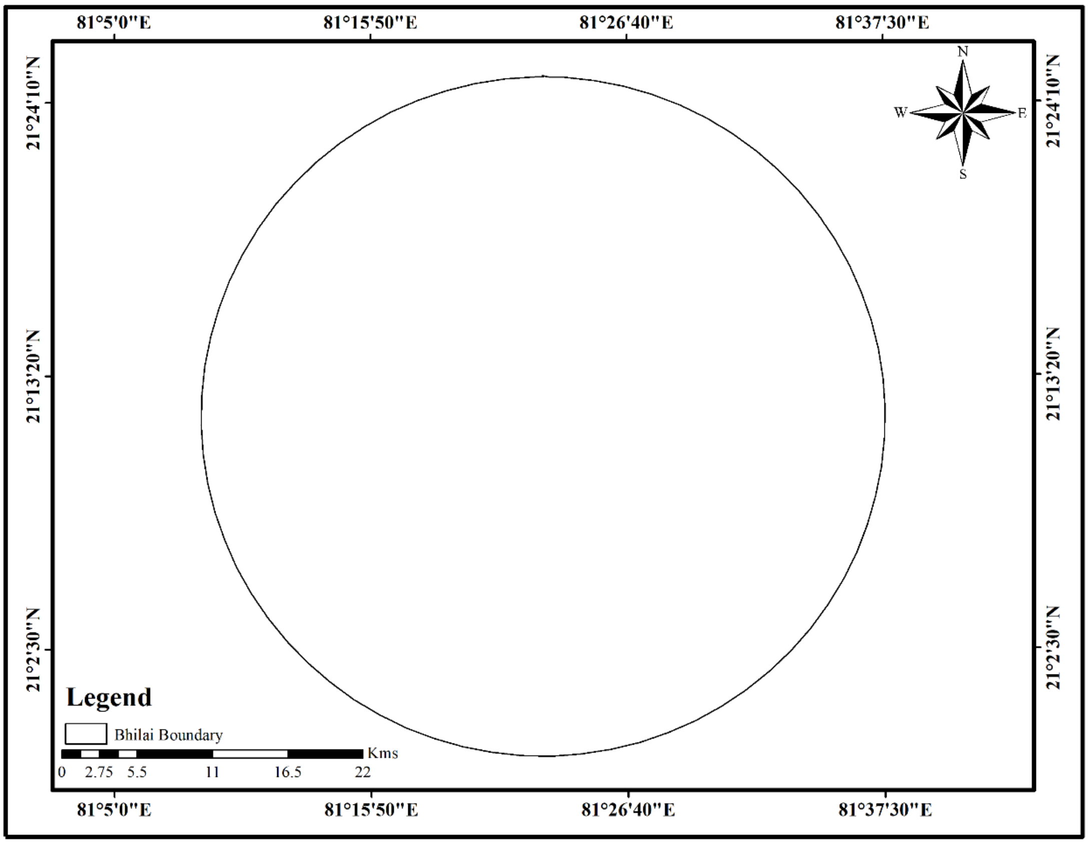


Figure 3.2: Study area boundary epicenter at SAIL

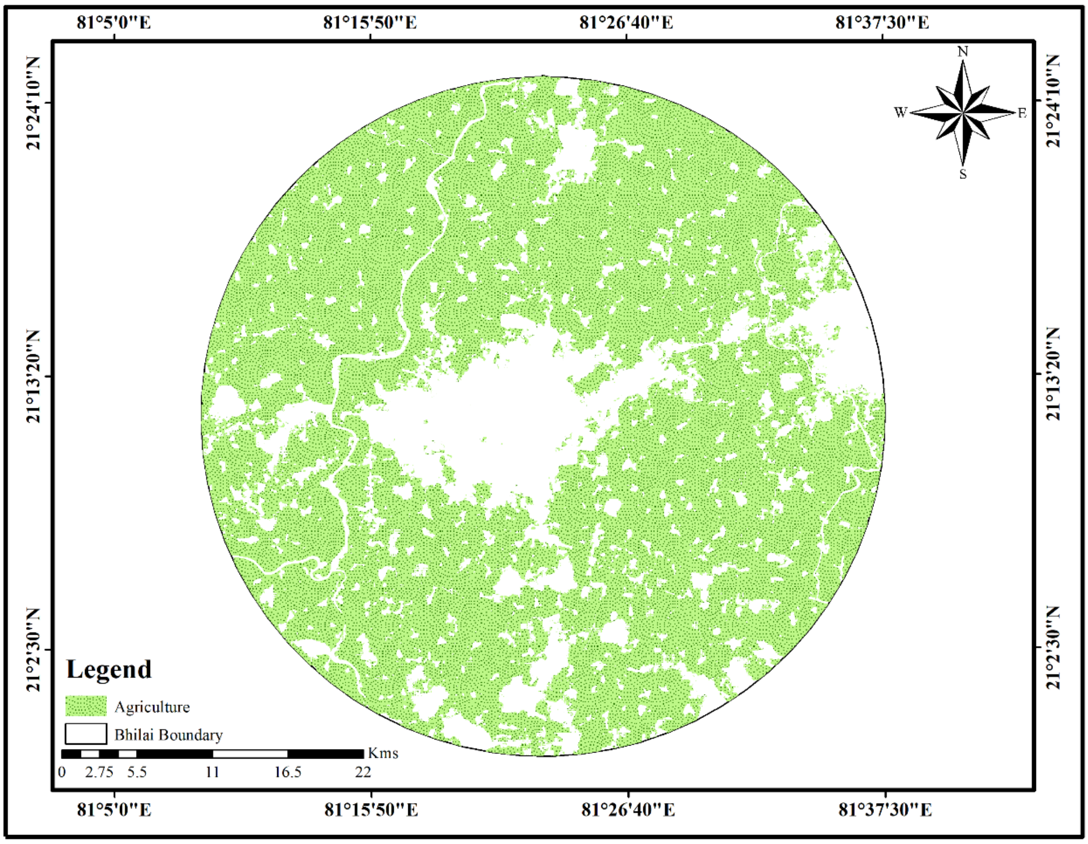


Figure 3.3: Agricultural Area Map

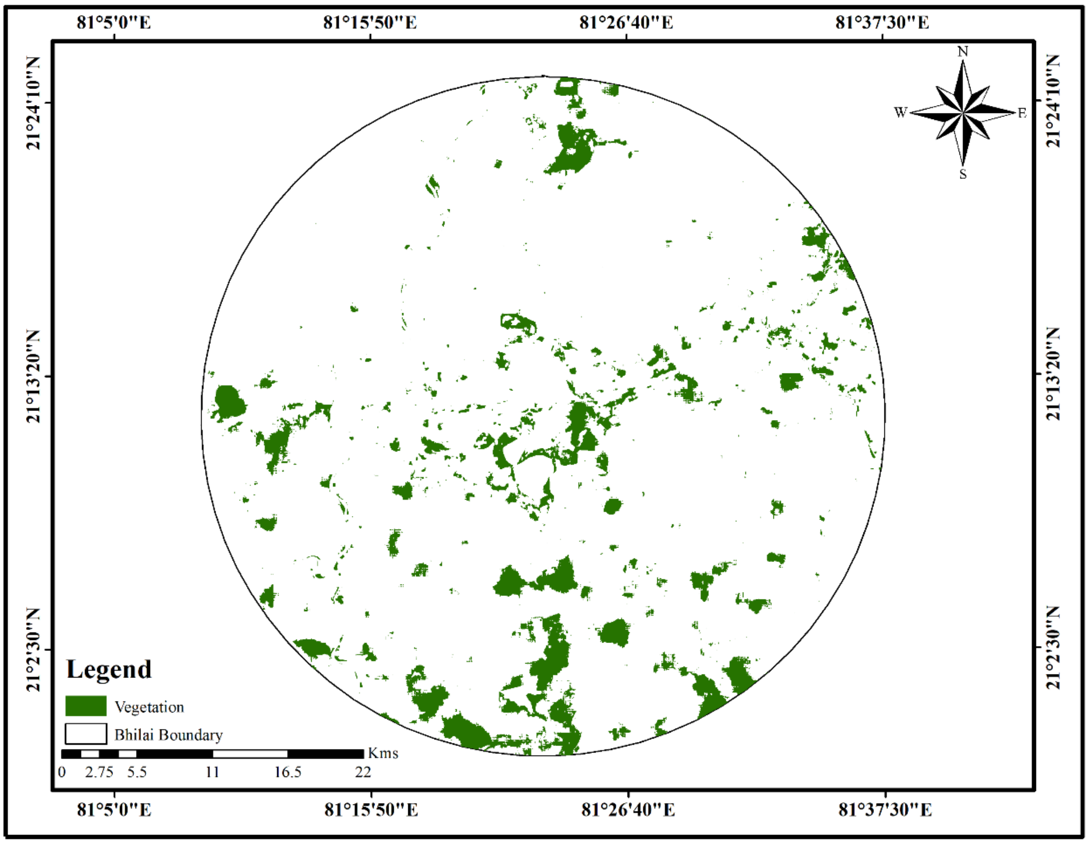


Figure 3.4: Vegetation Map

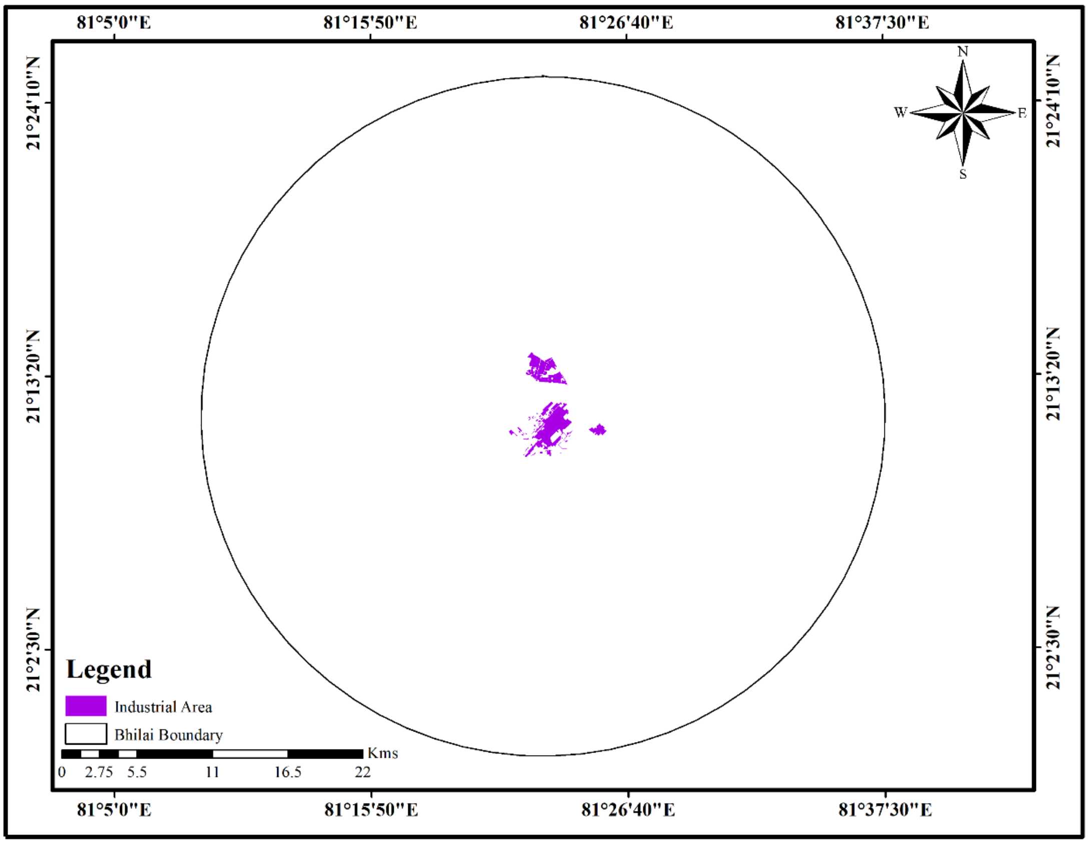


Figure 3.5: Industrial Area Map

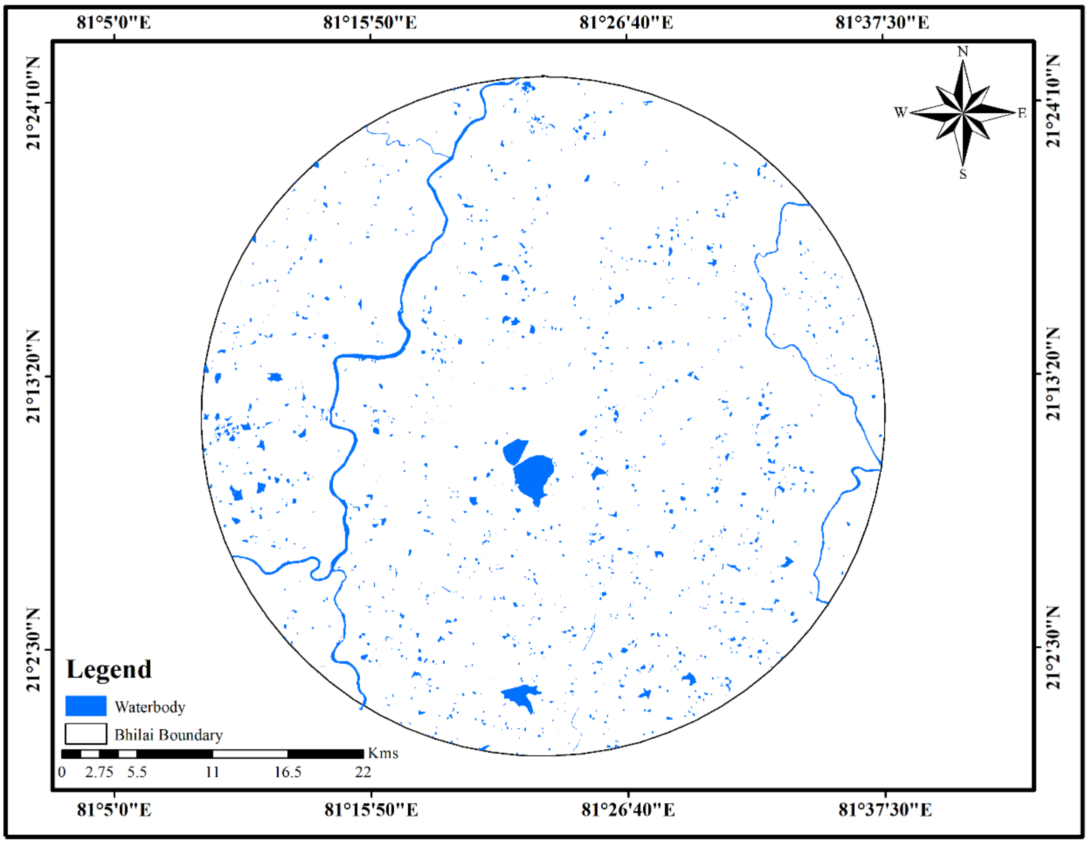


Figure 3.6: Waterbodies Area Map

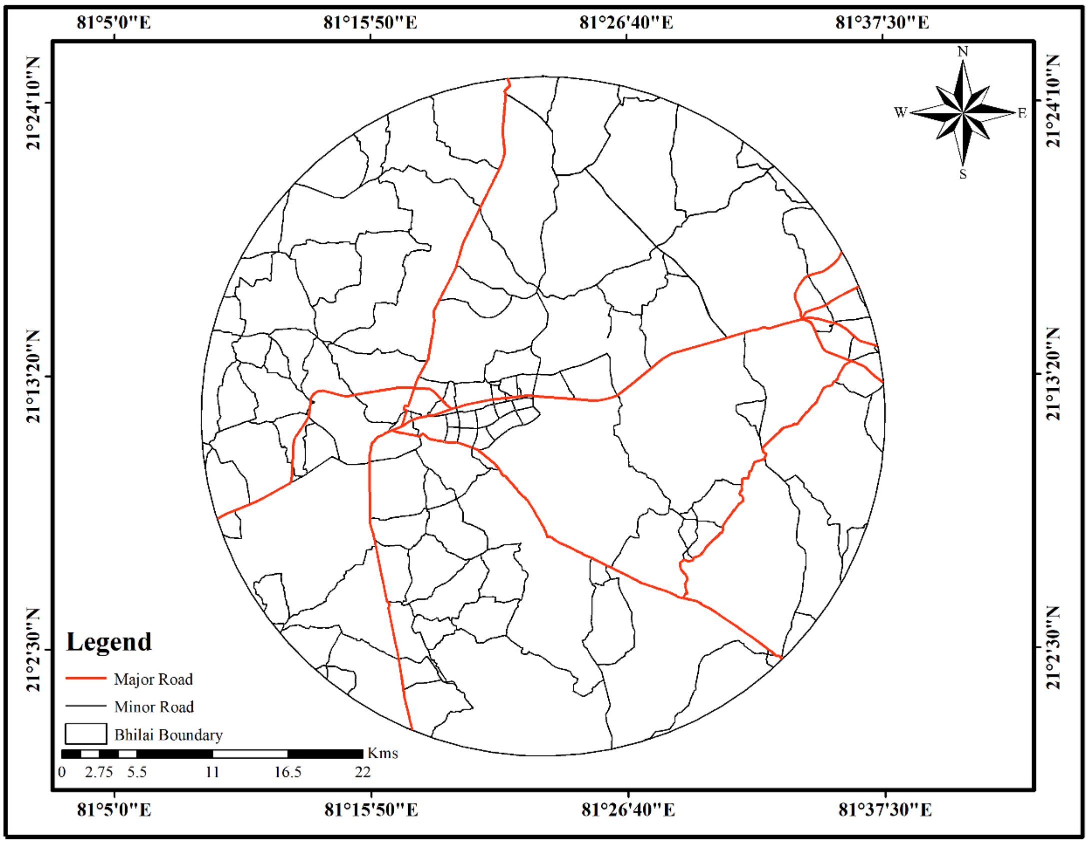


Figure 3.7: Road Network Map

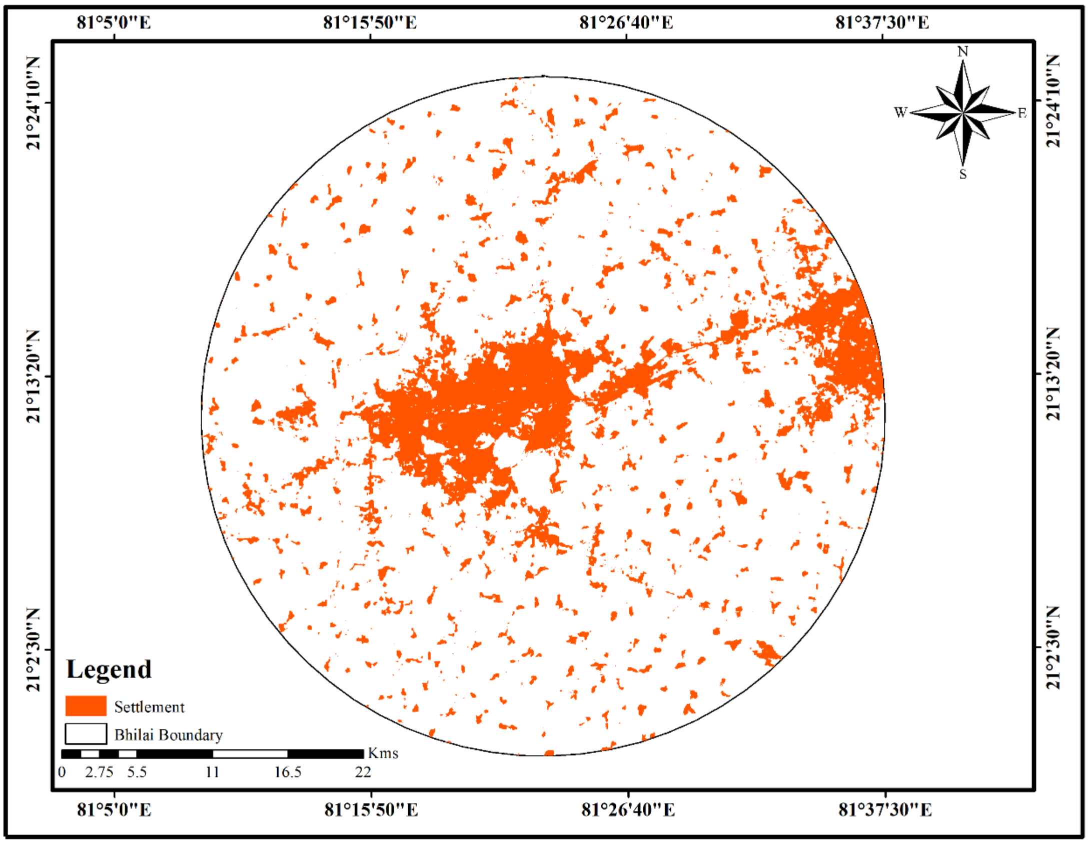


Figure 3.8: Settlement Area Map

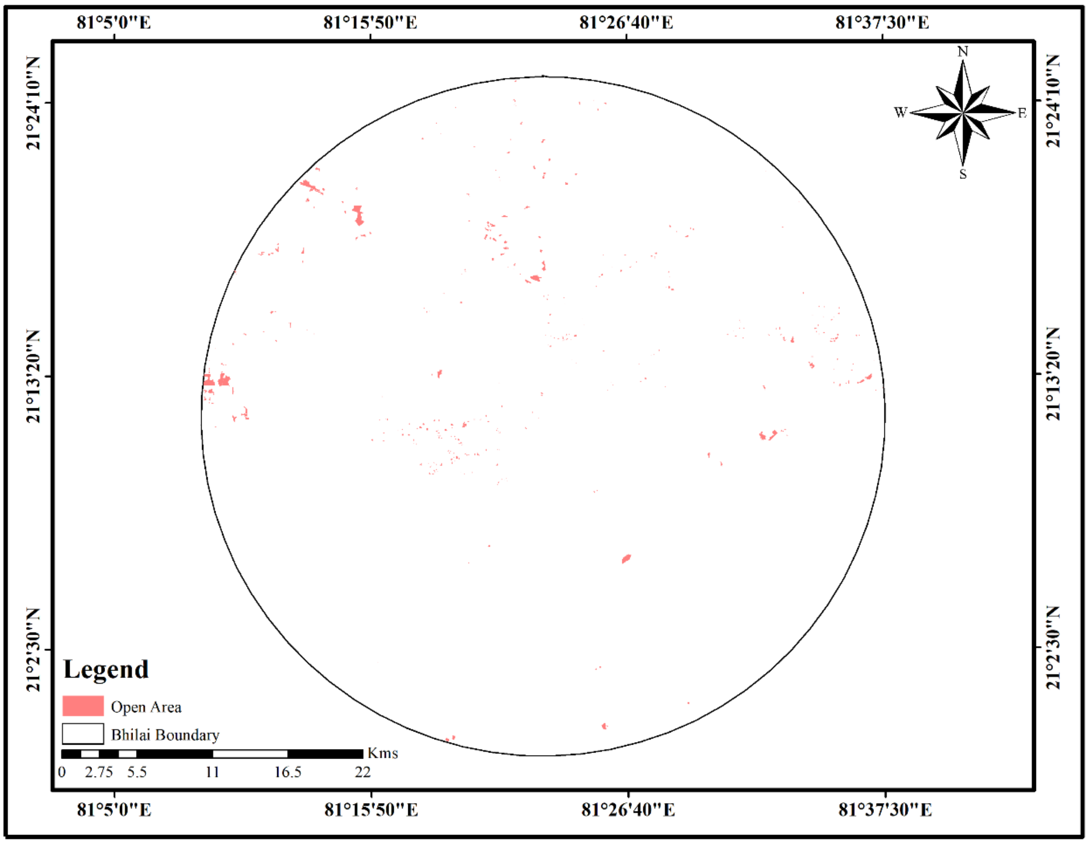


Figure 3.9: Open Area Map

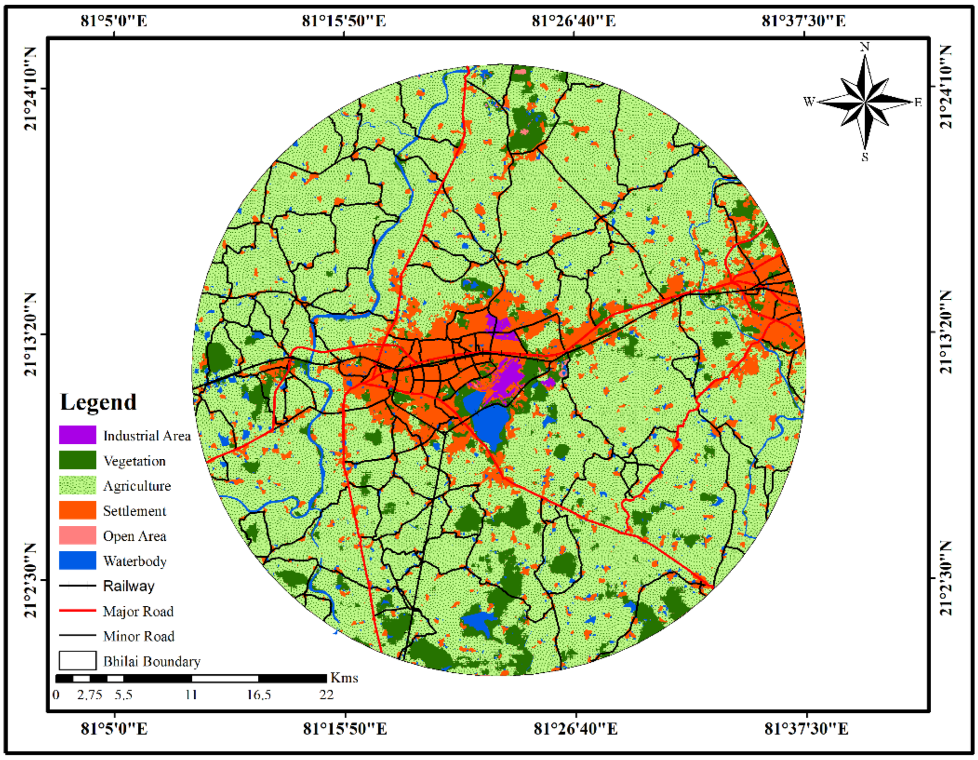


Figure 3.10: Land use Map of Bhilai city

At the time of the development of the emission inventory, a suitable coding system was adopted to avoid the confusion and misrepresentation of results and interpretation. The emissions have been calculated for Bhilai city. The grid map of Bhilai with grid identity numbers is shown in Figure 3.11. The study area was divided into grids of 2 x 2 km^2.

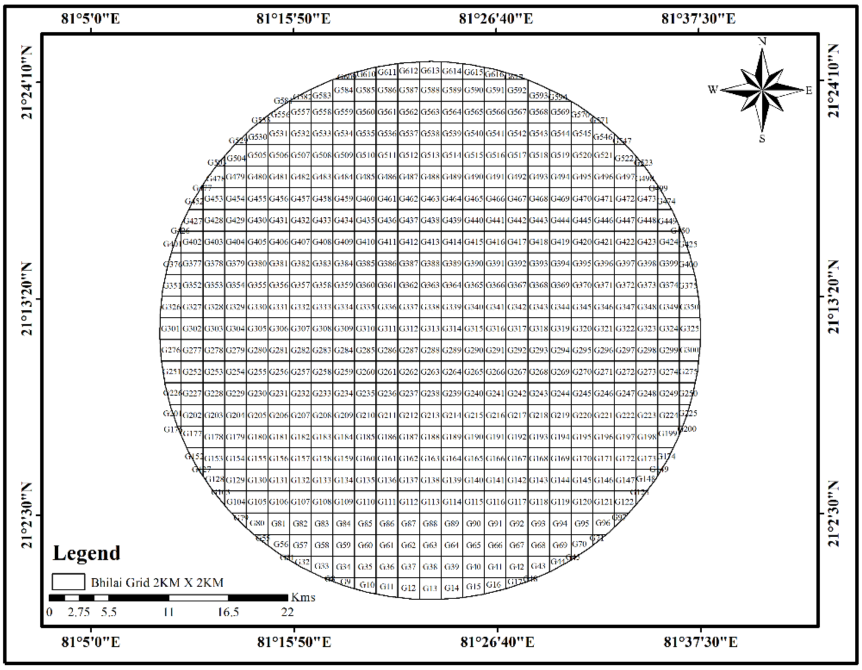


Figure 3.11: Grid Map of Bhilai city showing Grid Identity Numbers

3.2.2 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 3.12.

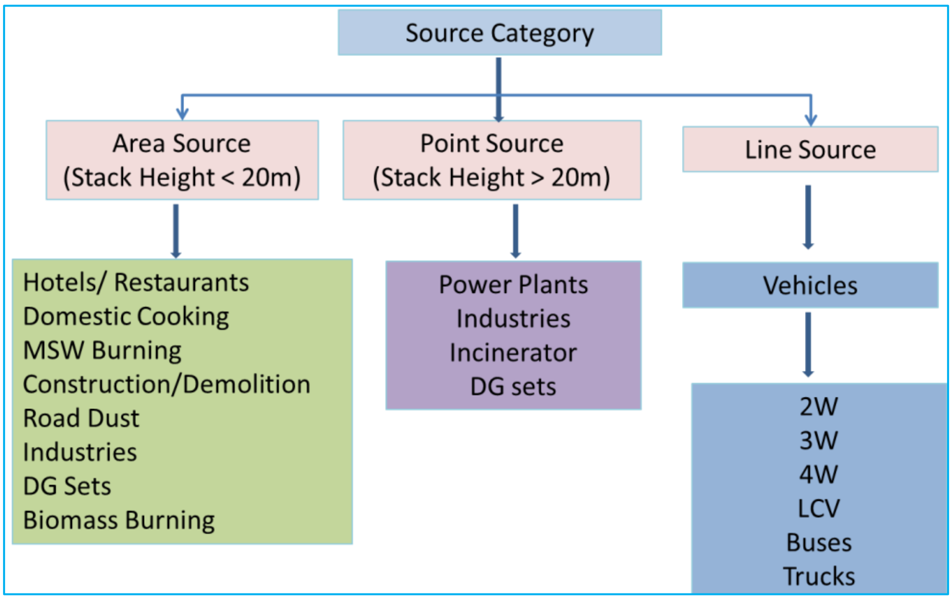


Figure 3.12: Source Category and type of sources

3.2.3 Data Collection

The IITK team collected the primary and secondary activity data. Domestic surveys, vehicular traffic count, parking lane surveys, road dust, etc., were physically done in the study area for primary data generation. The main sources of secondary data collection are from CSPCB, the Census of India, and CPCB website, the 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.

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 travelled, or duration of the activity (e.g., grams of particulate emitted per kilogram of coal burnt). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages 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 general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100) \tag{4.1}$$

Where:

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

3.2.5 Domestic Sector

The interior boundaries in the map (Figure 3.2) show the administrative boundaries of 94 wards and 8 Tehsil in Bhilai city. The projected population of Bhilai city for the year 2023 is approximately 30 Lakhs. The emission from the domestic sector for the city is calculated. The population-wise fuel consumption pattern shows LPG (liquid petroleum gas) at 84% (CEEW, 2019), wood at 8%, coal at 5%, kerosene at 2%, dung (1%), and crop residue (1%). During the field survey, it was observed that most economically weaker/ slum areas use wood and dung as fuel for cooking, although they have been given LPG cylinders.

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, NO_x, and CO). The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

After obtaining the area of wards, the emission density (e.g., PM_{10} per sq. km) for each ward was calculated for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NO_x, and CO). The emission density in terms of kg/d/m^2 in each ward was calculated based on the population and area of the ward.

Emission Density (kg/d/ m^2) = Emission of Ward (kg/d) / Ward Area (m^2) ……. Eq. 2

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

$$Grid\ Emissions = \sum_{i=1}^{N} (area\ of\ fraction\ ward\ i\ in\ grid \times emission\ density\ of\ ward, i) \quad \ldots\ldots\text{. Eq. 3}$$

Where N= no. of wards in the grid

i = i^{th} ward in the grid

The emissions from the domestic sector in Bhilai city are given in Figure 13. The emission contributions in this sector from different fuel types and different pollutants is shown in Figure 3.14 – Figure 3.18. The spatial distribution of different pollutants is shown in Figure 3.19 – Figure 3.23.

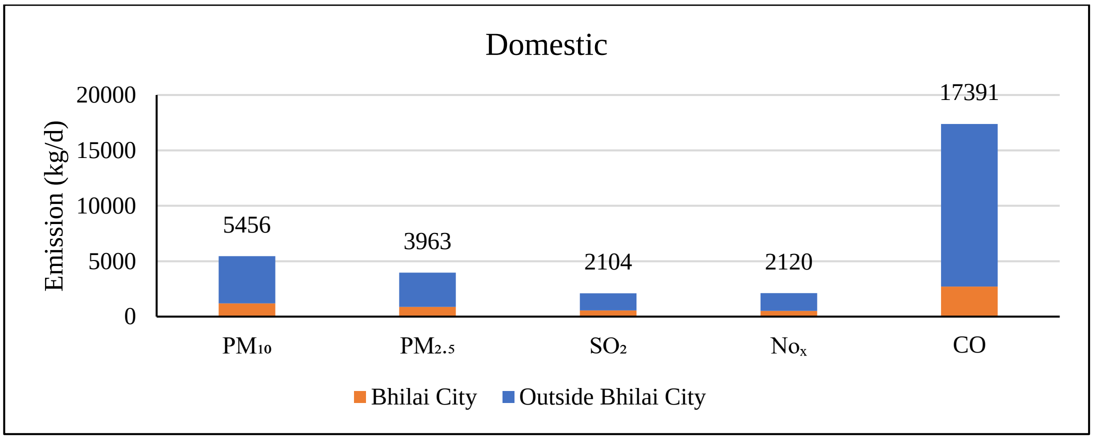


Figure 3.13: Emission load from Domestic Sector (kg/d)

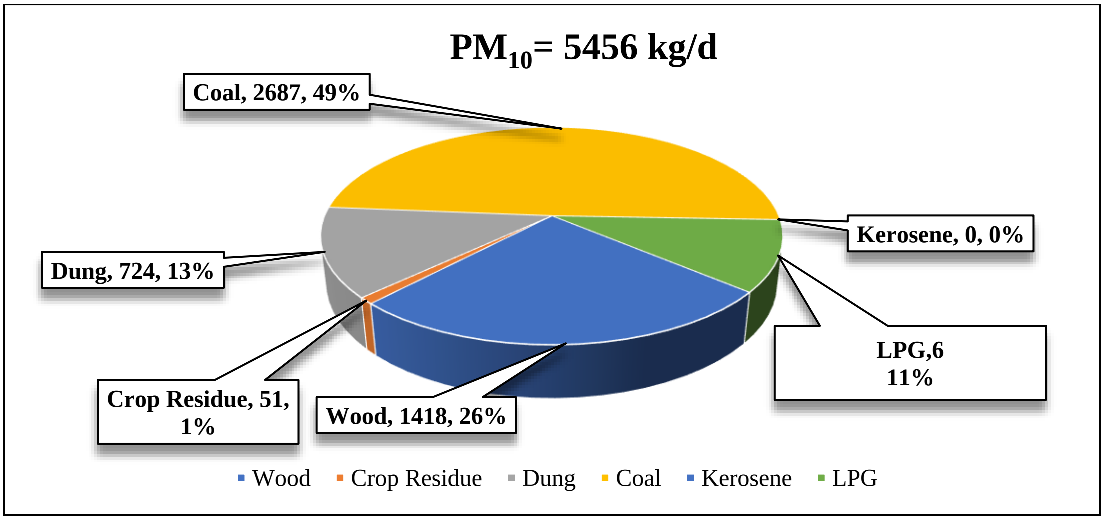


Figure 3.14: PM$_{10}$ Emission load from Domestic Sector (kg/d, %)

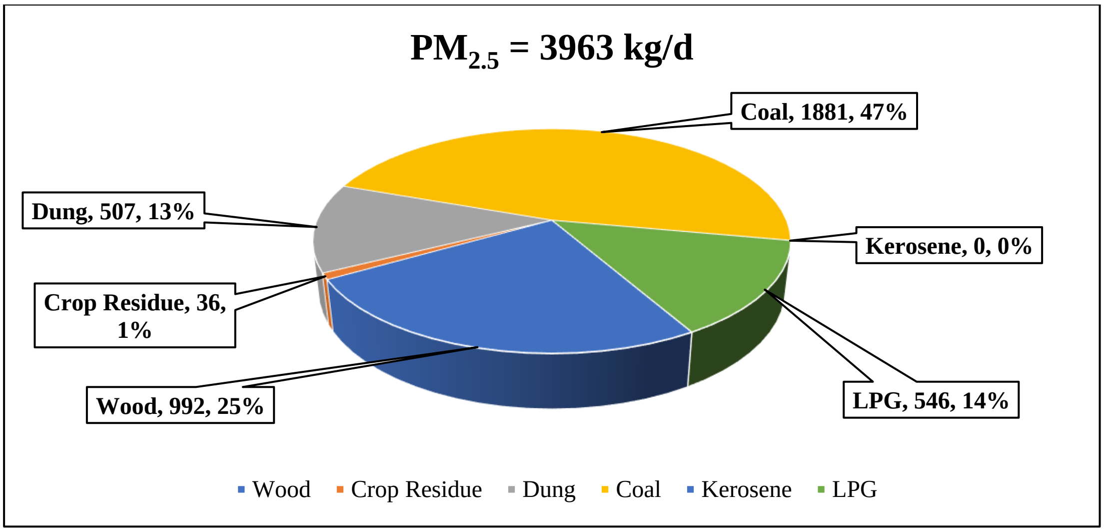


Figure 3.15: $PM_{2.5}$ Emission load from Domestic Sector (kg/d, %)

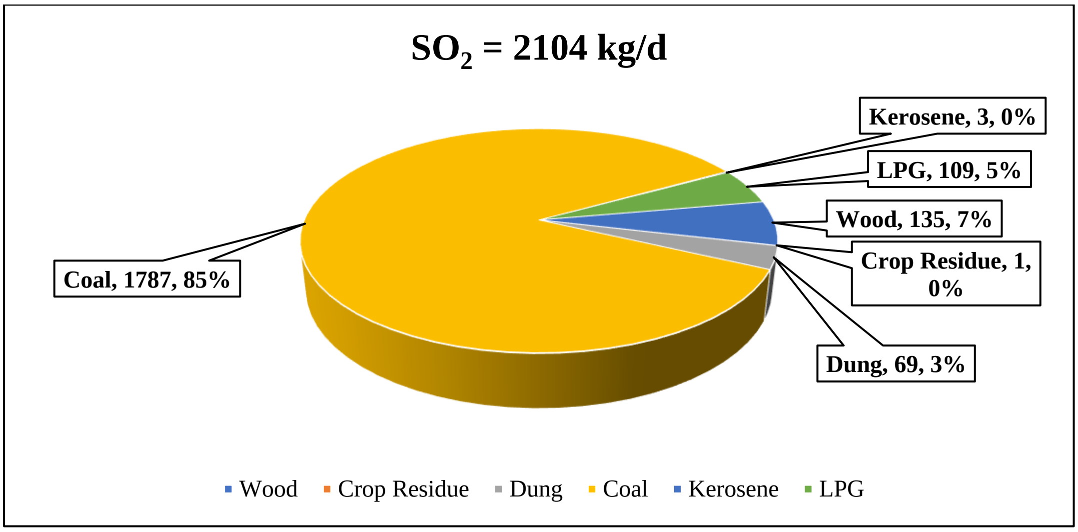


Figure 3.16: SO_2 Emission load from Domestic Sector (kg/d, %)

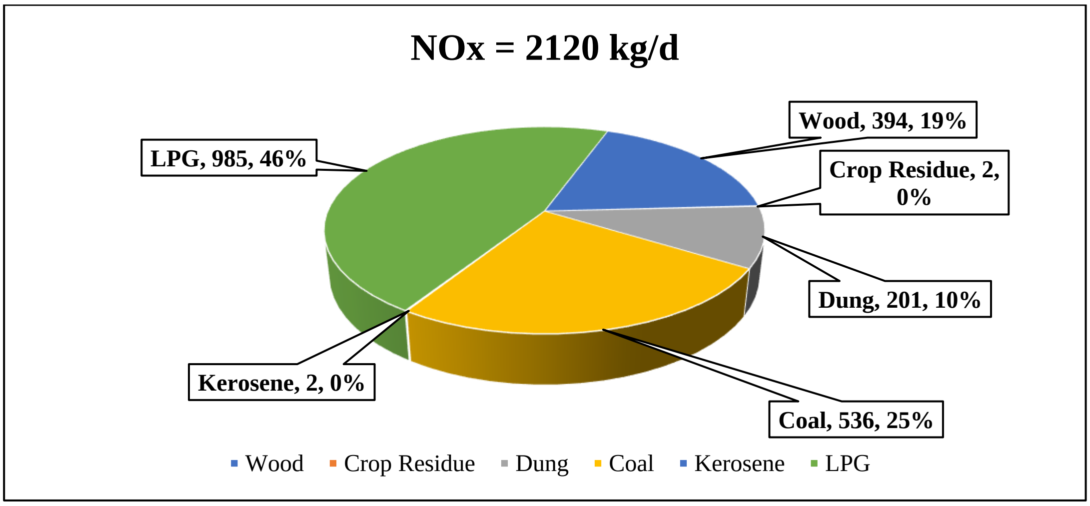


Figure 3.17: NO_x Emission load from Domestic Sector (kg/d, %)

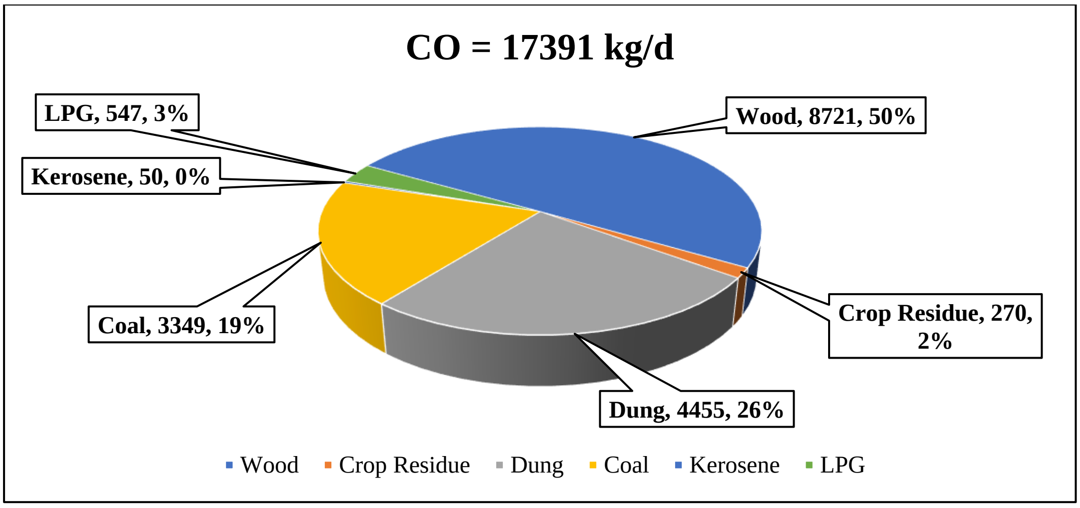


Figure 3.18: CO Emission load from Domestic Sector (kg/d, %)

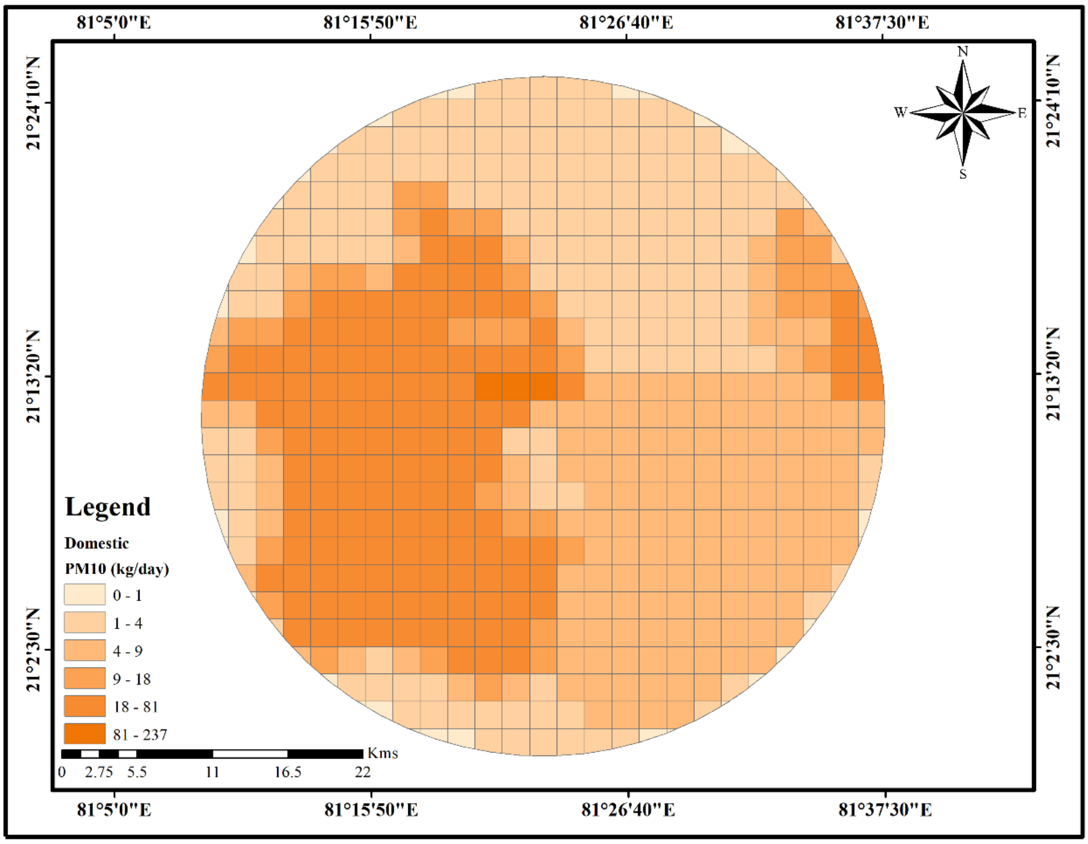


Figure 3.19: Spatial Distribution of PM_{10} Emissions from Domestic Sector

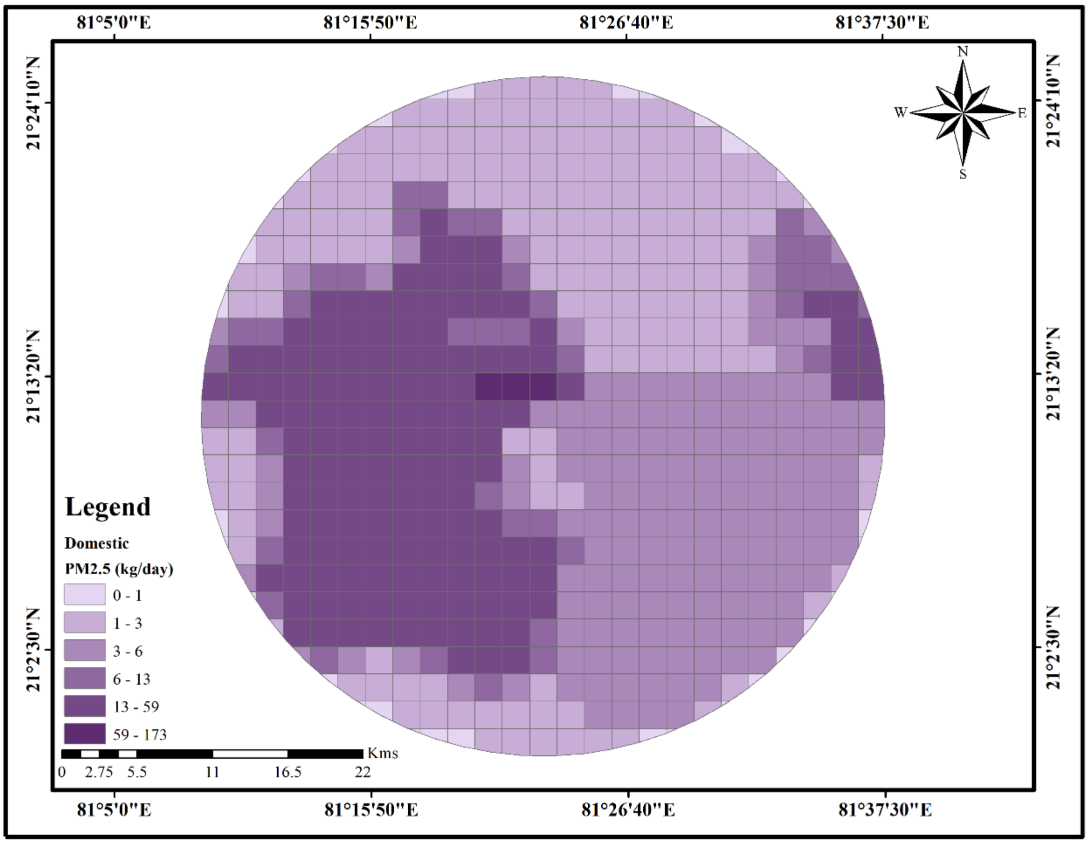


Figure 3.20: Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector

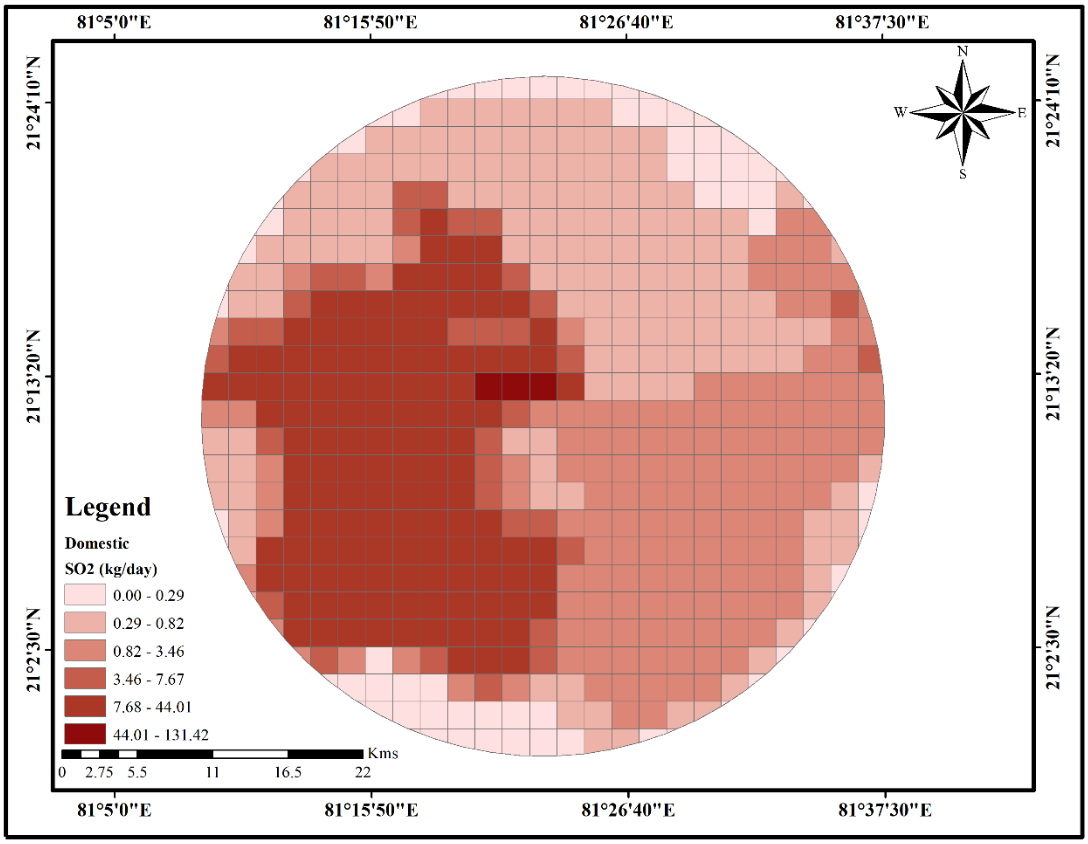


Figure 3.21: Spatial Distribution of SO_2 Emissions from Domestic Sector

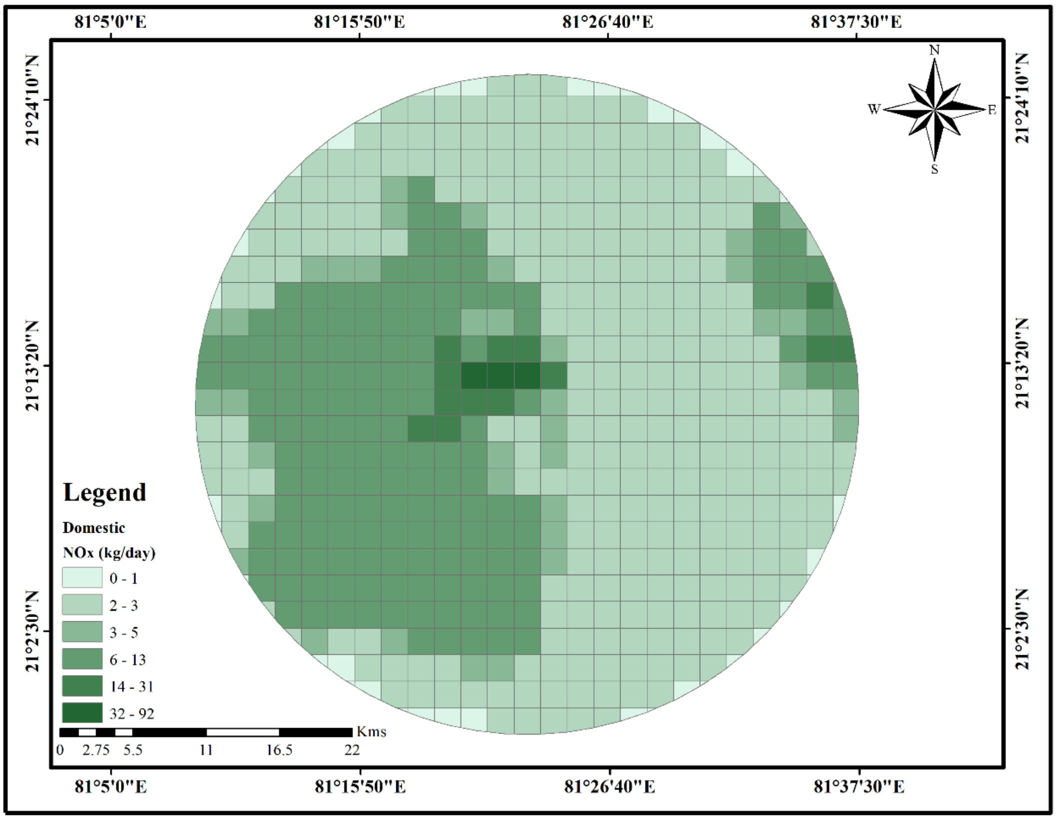


Figure 3.22: Spatial Distribution of NO_x Emissions from Domestic Sector

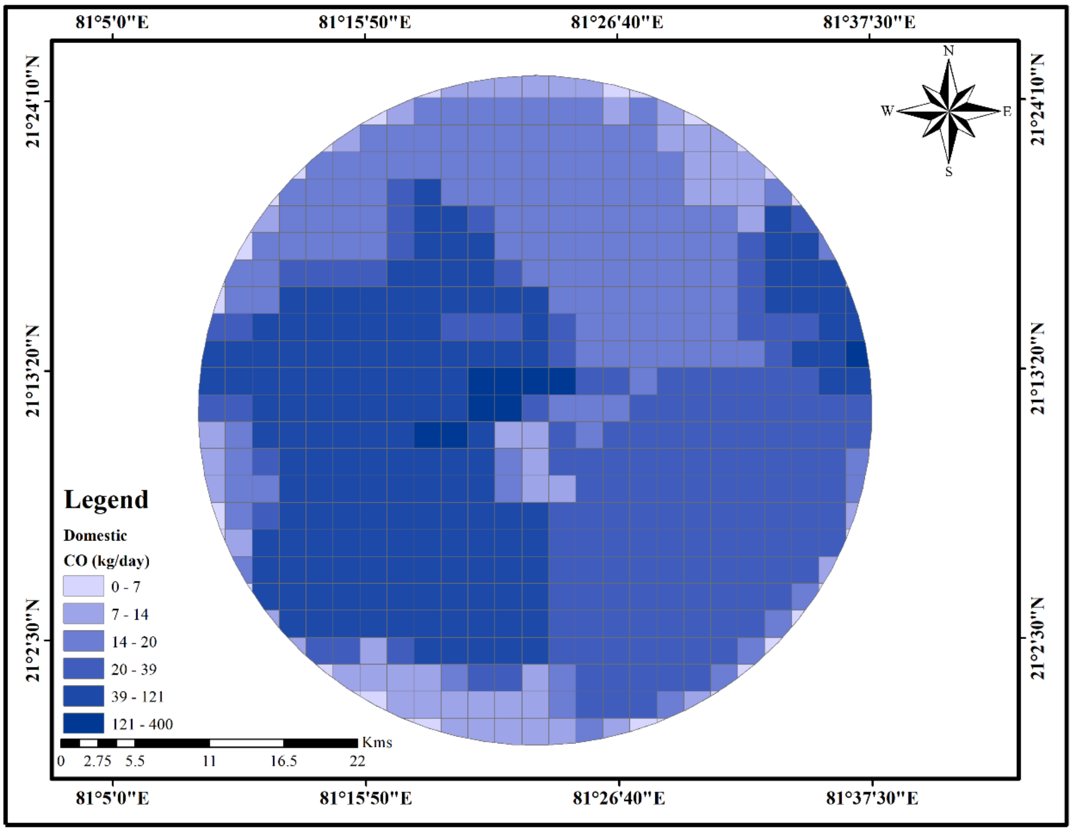


Figure 3.23: Spatial Distribution of CO Emissions from Domestic Sector

3.2.6 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. The major construction activities include large constructions (residential, commercial, roads, and industrial). Information about construction was obtained from PWD, CPWD, and field surveys. The satellite imagery was also used to validate the construction activities. Nearly at all construction sites, the construction material and debris (lying in the open, without cover) are stored outside the construction premises, mainly near the road. The areas under construction activities were calculated based on survey data and GIS-based calculations. The location of construction and demolition sites at Bhilai city is given in Figure 3.24.

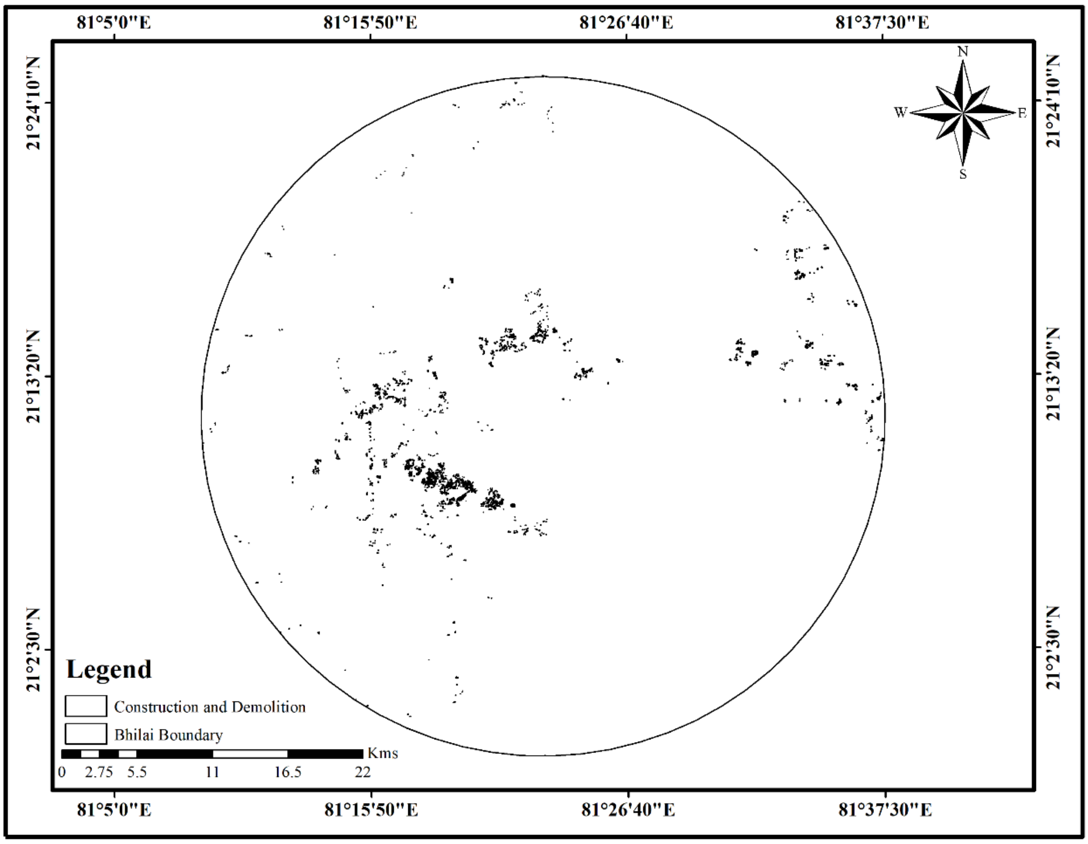


Figure 3.24: Location of Construction and Demolition sites at Bhilai city

The Emission load of PM_{10} and $PM_{2.5}$ from construction and demolition is 2869 kg/d and 660 kg/d (Figure 3.25). The construction sites and debris associated with generating particulate emissions are shown in Figure 3.26. The spatially resolved emission map of construction and demolition activities is shown in Figure 3.27 and Figure 3.28.

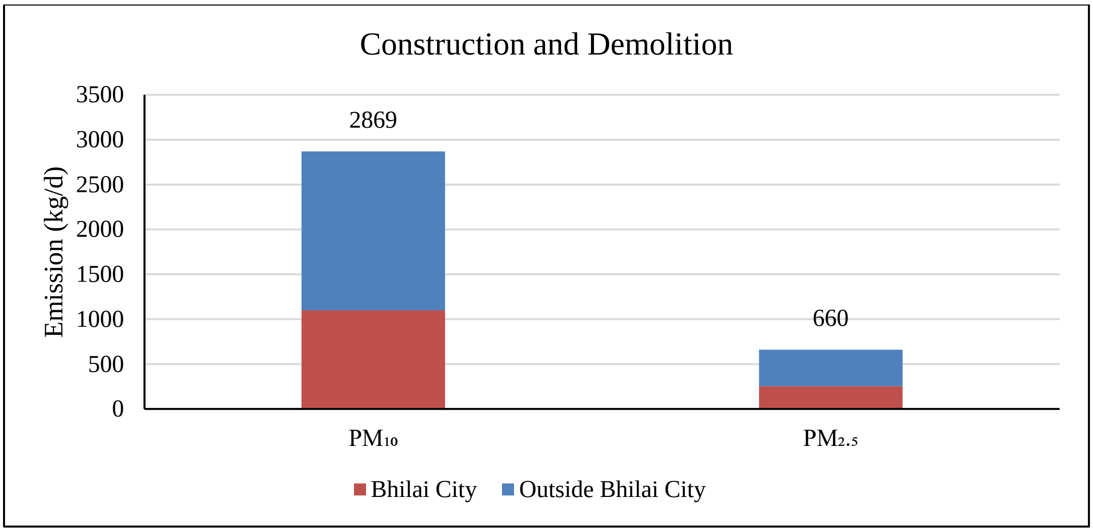


Figure 3.25: Emissions from Construction and Demolition (kg/d)

Figure 3.26: Construction material and debris near construction sites

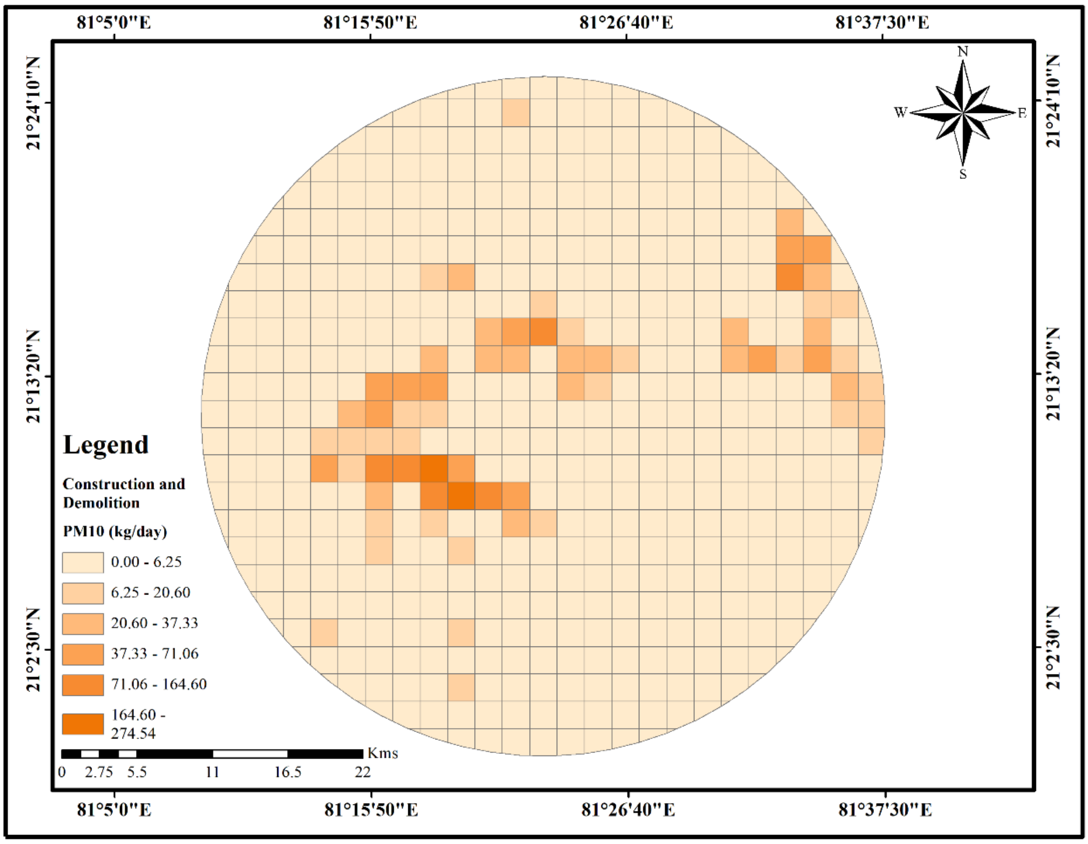


Figure 3.27: Spatial Distribution of PM_{10} Emissions from Construction/Demolition

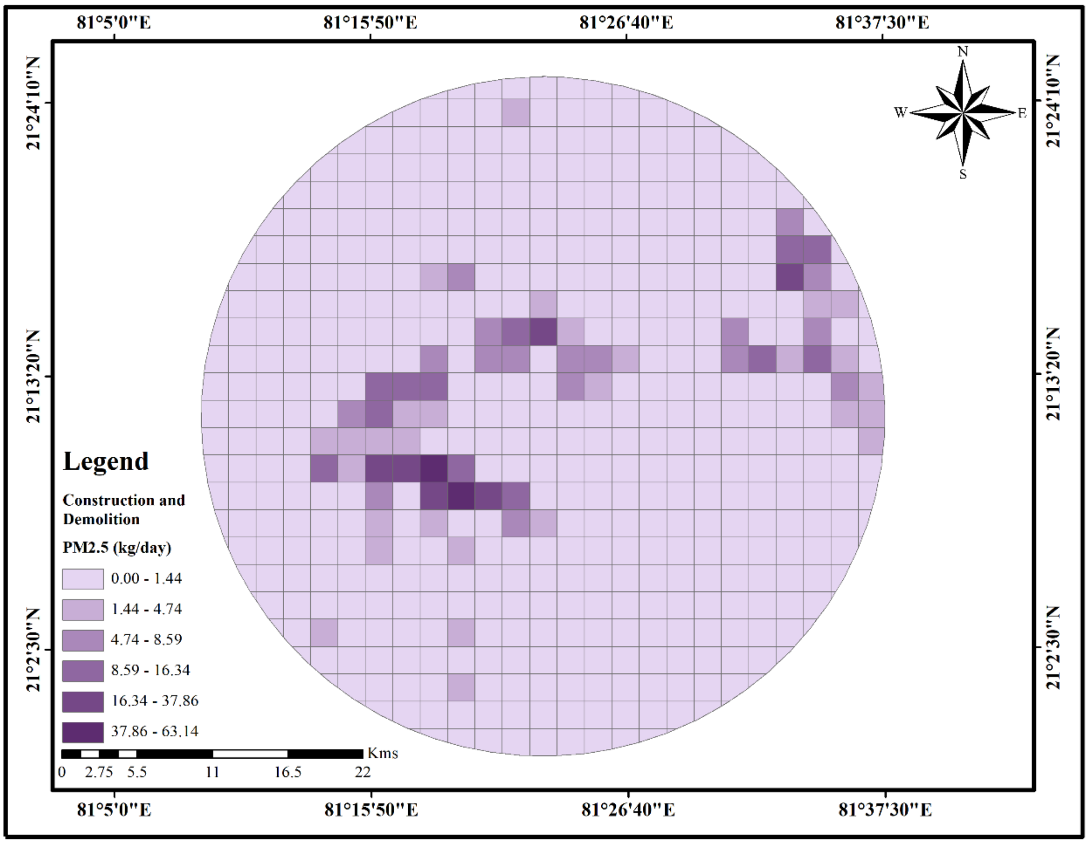


Figure 3.28: Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition

3.2.7 Hotels Establishment

The hotel establishment of included Hotel, Restaurants, Guest House, and Banquet Hall. The IITK team conducted the primary survey to identify the hotels and restaurants with more than a 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 common fuel other than wood is LPG. The total number of Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) are approximately 561 (Figure 3.29) 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. The emissions of various pollutants 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. The overall emission from this area source (Hotels, Restaurants, GHs, and BHs) is shown in Figure 3.30. The spatial distribution of emissions is shown in Figure 3.31-Figure 3.35.

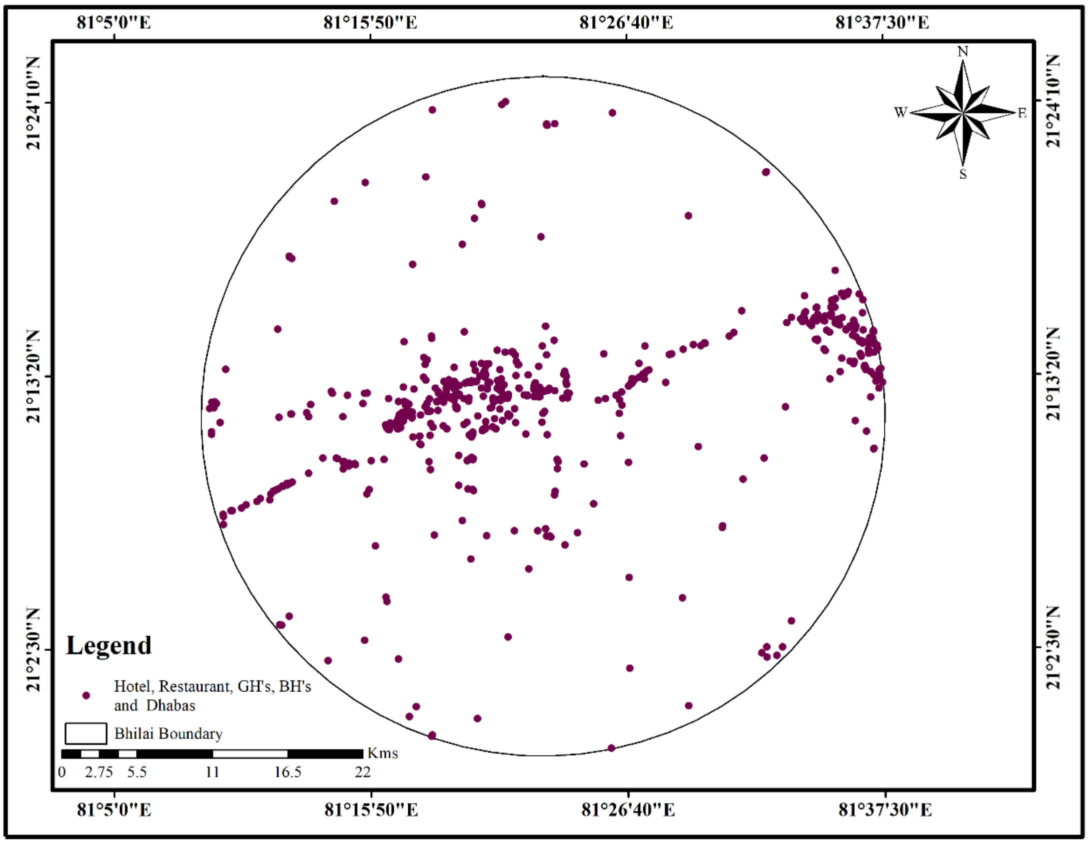


Figure 3.29: Location of Hotel Establishment

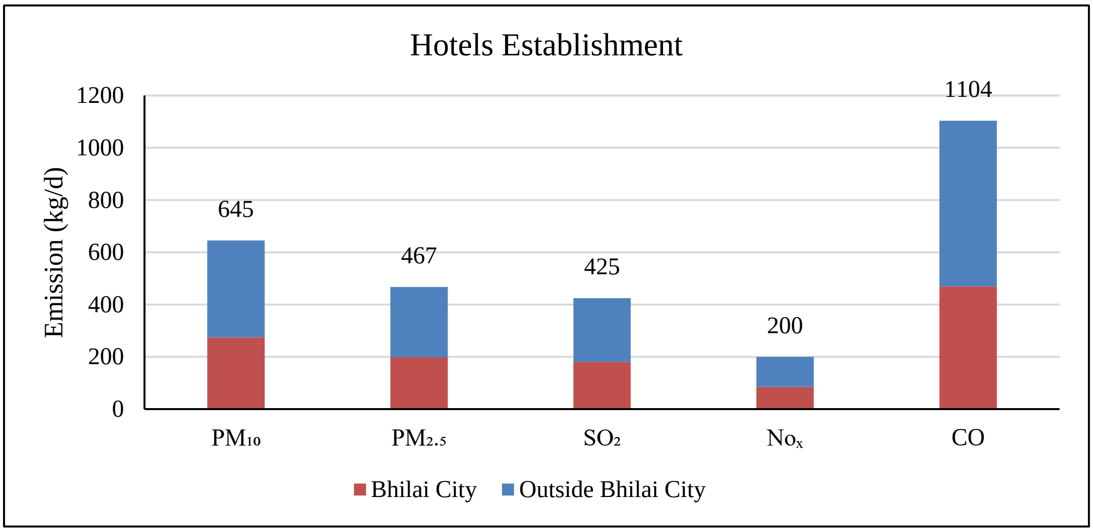


Figure 3.30: Emission Load from Hotels Establishment (kg/d)

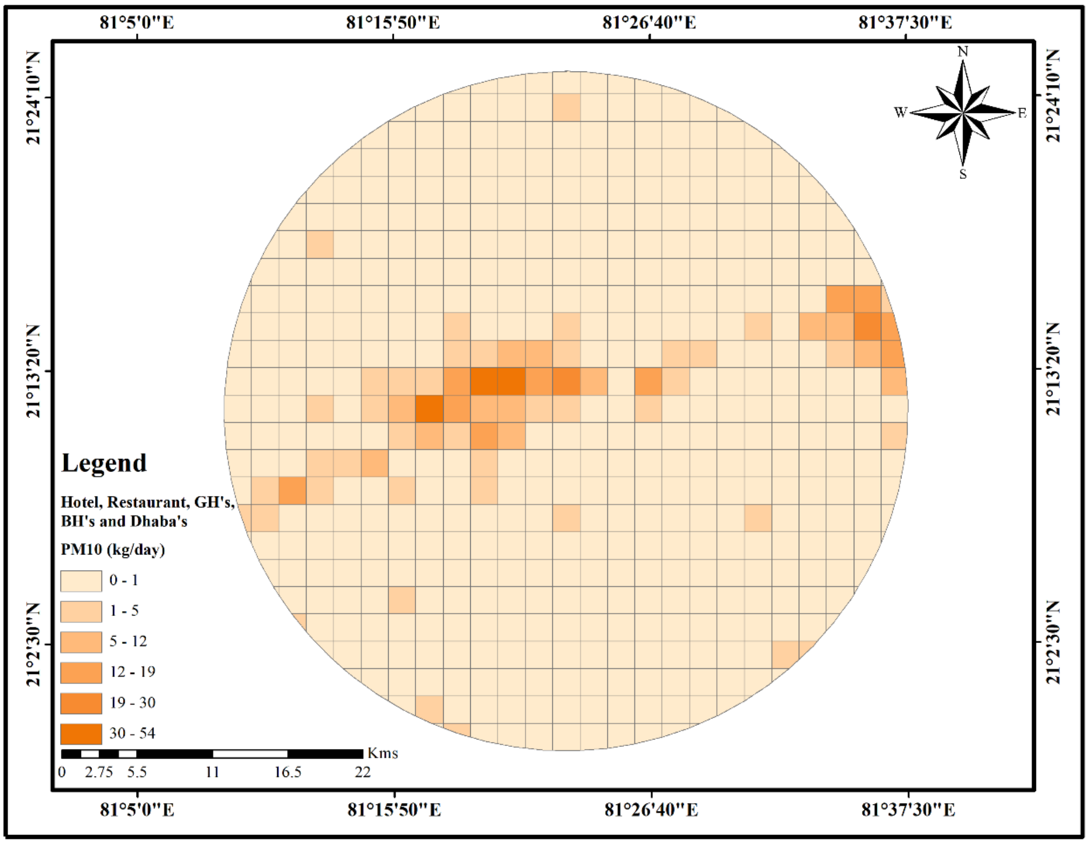


Figure 3.31: Spatial Distribution of PM_{10} Emissions from Hotels Establishment

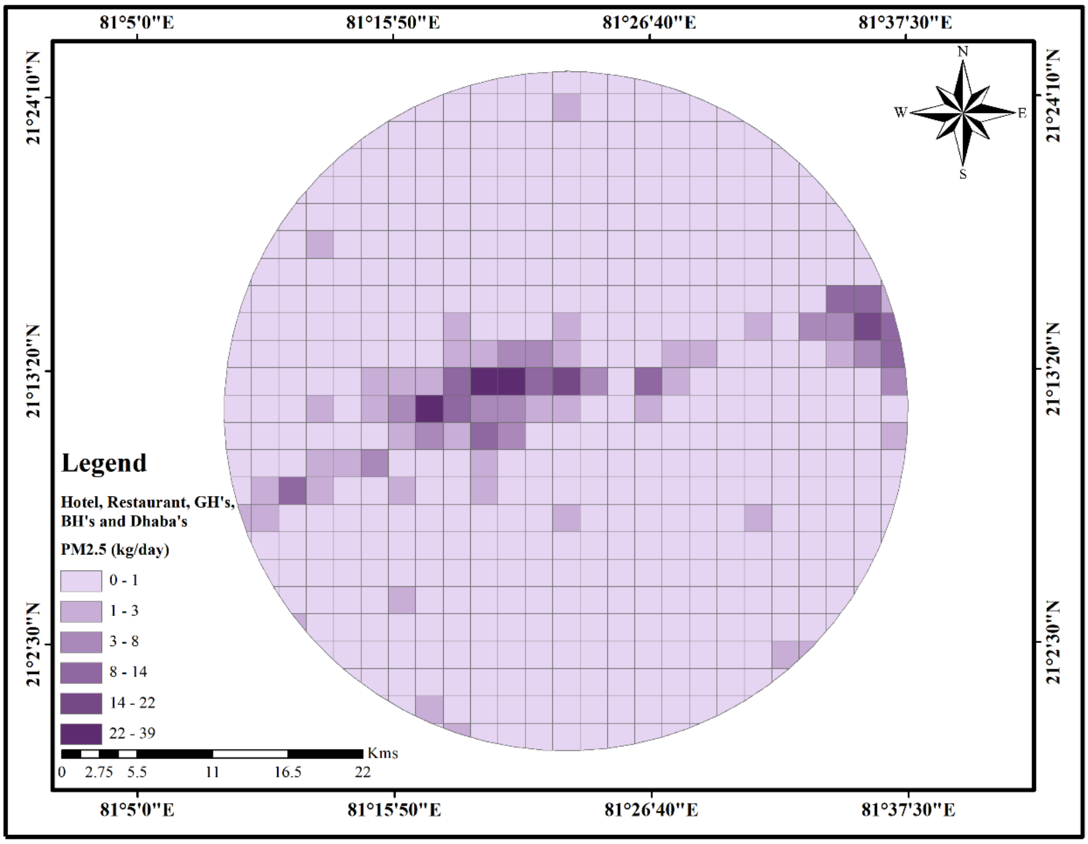


Figure 3.32: Spatial Distribution of $PM_{2.5}$ Emissions from Hotel Establishment

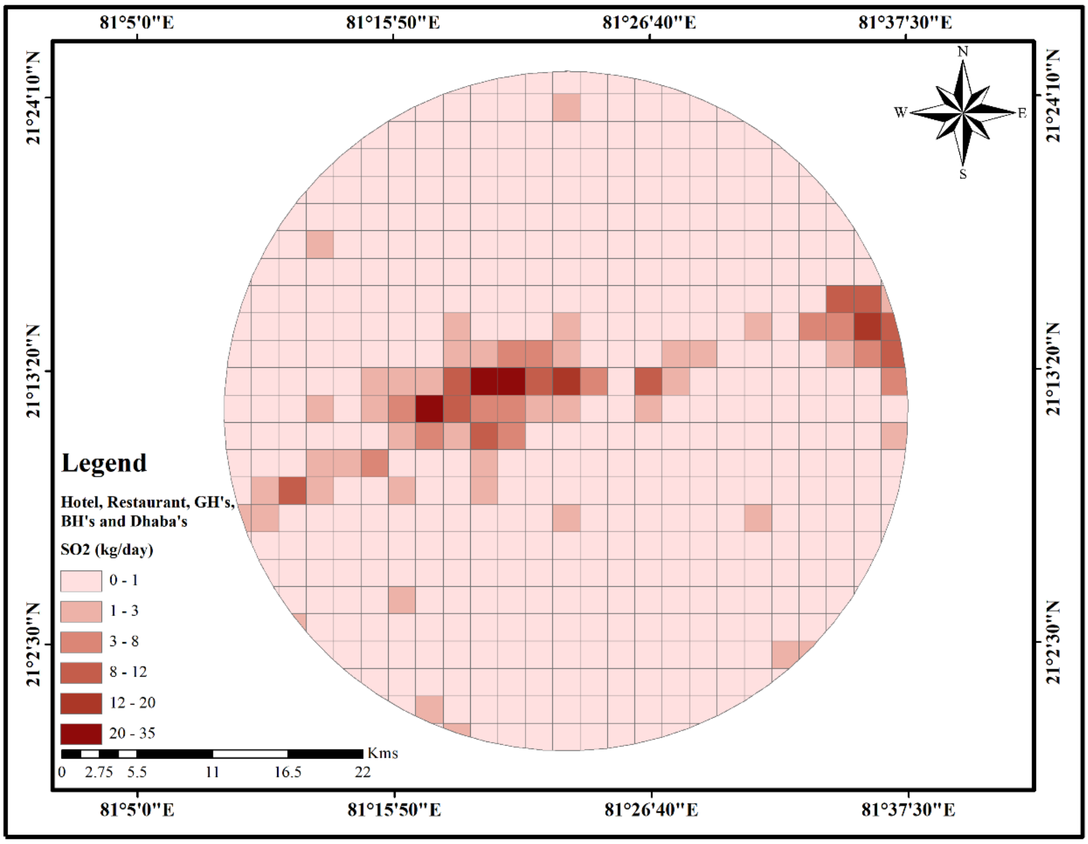


Figure 3.33: Spatial Distribution of SO_2 Emissions from Hotel Establishment

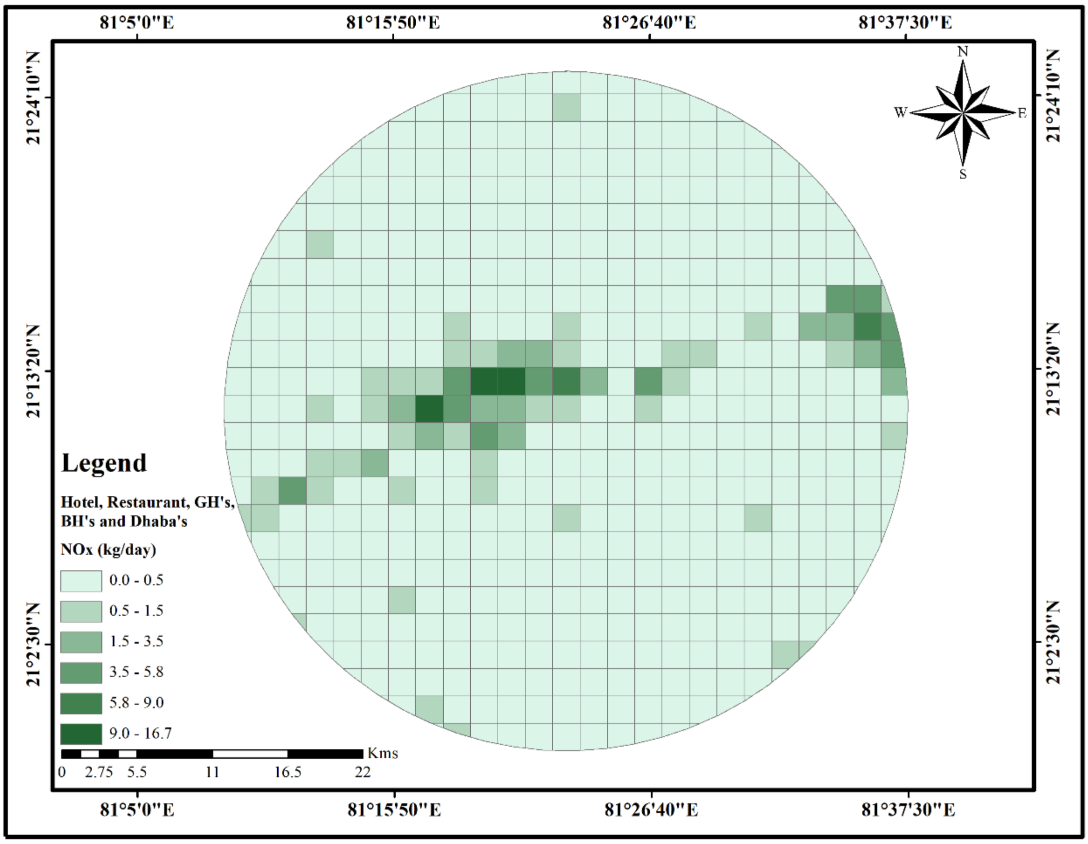


Figure 3.34: Spatial Distribution of NO_x Emissions from Hotel Establishment

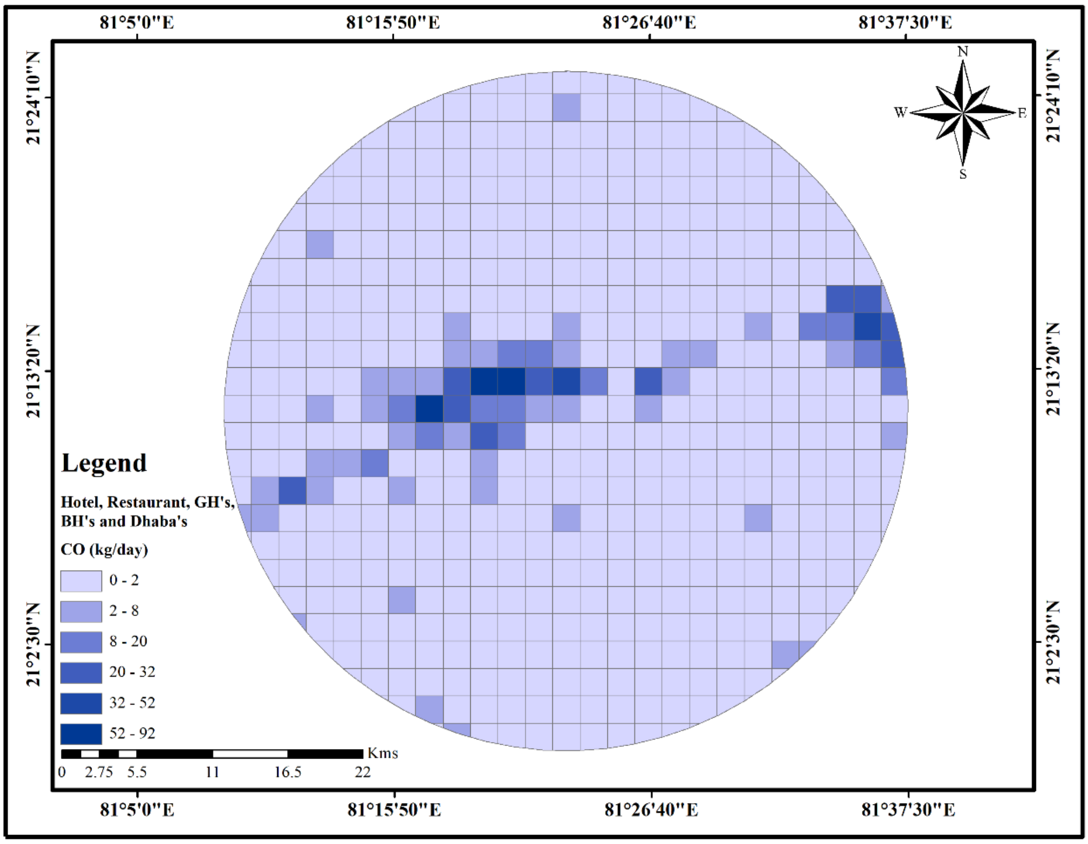


Figure 3.35: Spatial Distribution of CO Emissions from Hotel Establishment

3.2.8 Brick Kiln

Brick kiln is one of the major contributors to air pollution. A detailed survey was conducted by the IITK team and activity data were collected. There are approximately 59 brick kilns in Bhilai (Figure 3.36). These all-brick kilns are situated outside the Bhilai city boundary. These kilns use wood and coal as fuel. The emissions of various pollutants such as SO_2, NOx, PM_{10}, $PM_{2.5}$, and CO were estimated from the activity data from each fuel type and then were summed up in each grid cell. The emission factors given by CPCB (2011) were used. The overall emission from brick kilns is shown in Figure 3.37. The spatial distribution of emission from brick kilns is shown in Figure 3.38 to Figure 3.42.

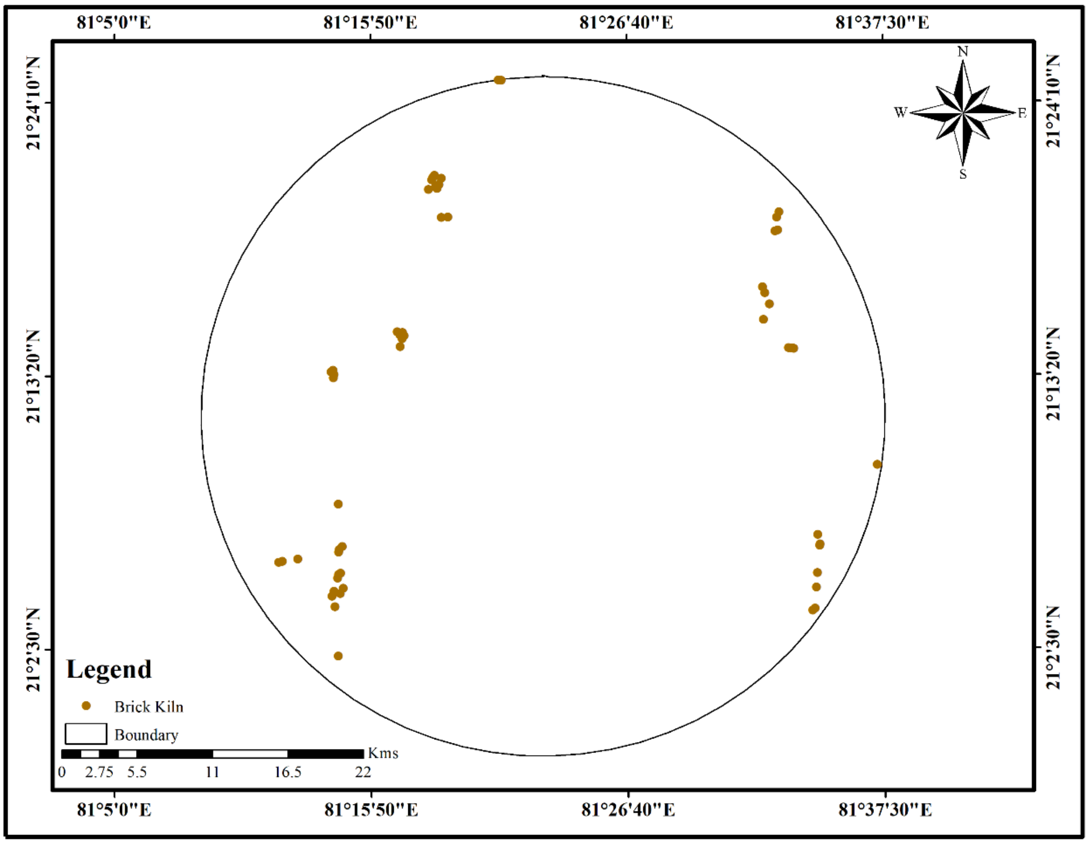


Figure 3.36: Location of Brick Kiln in Bhilai

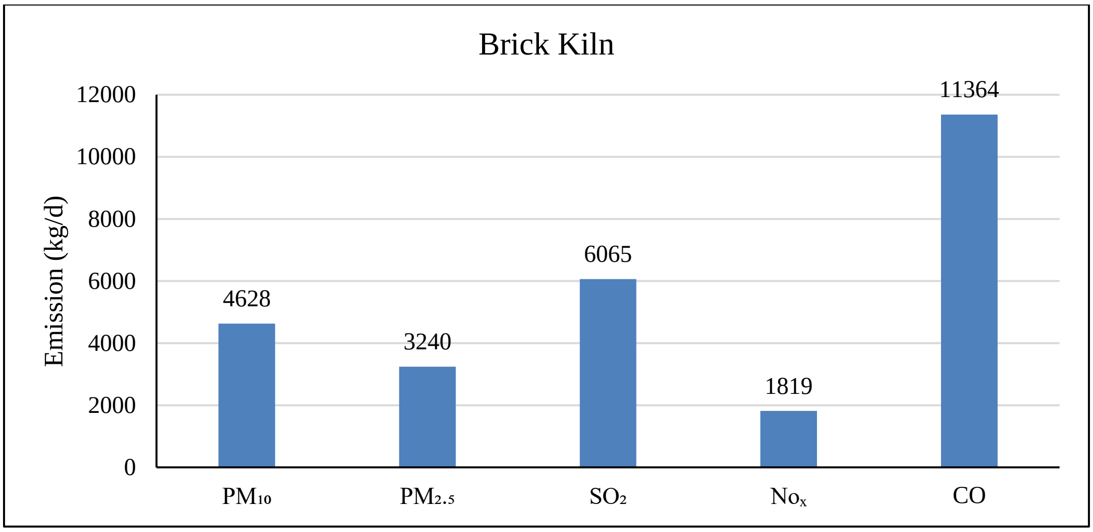


Figure 3.37: Emission Load from Brick Kiln (kg/d)

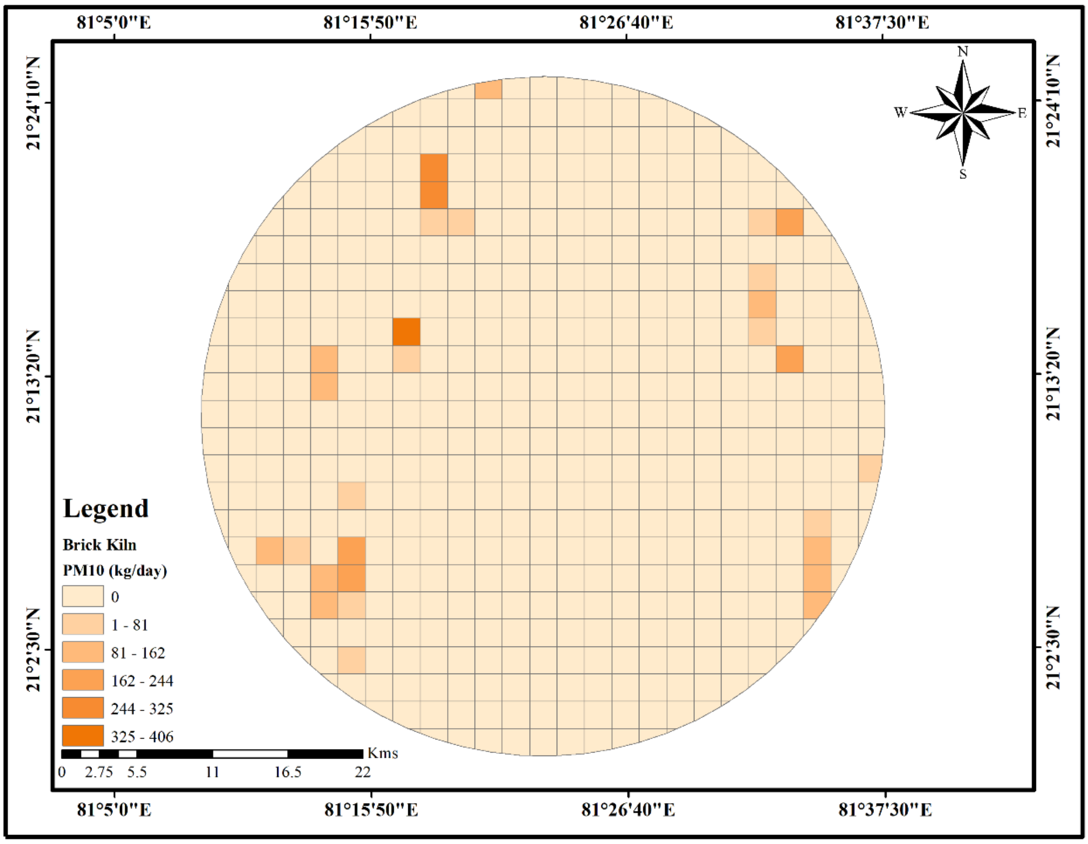


Figure 3.38: Spatial Distribution of PM_{10} Emissions from Brick Kiln

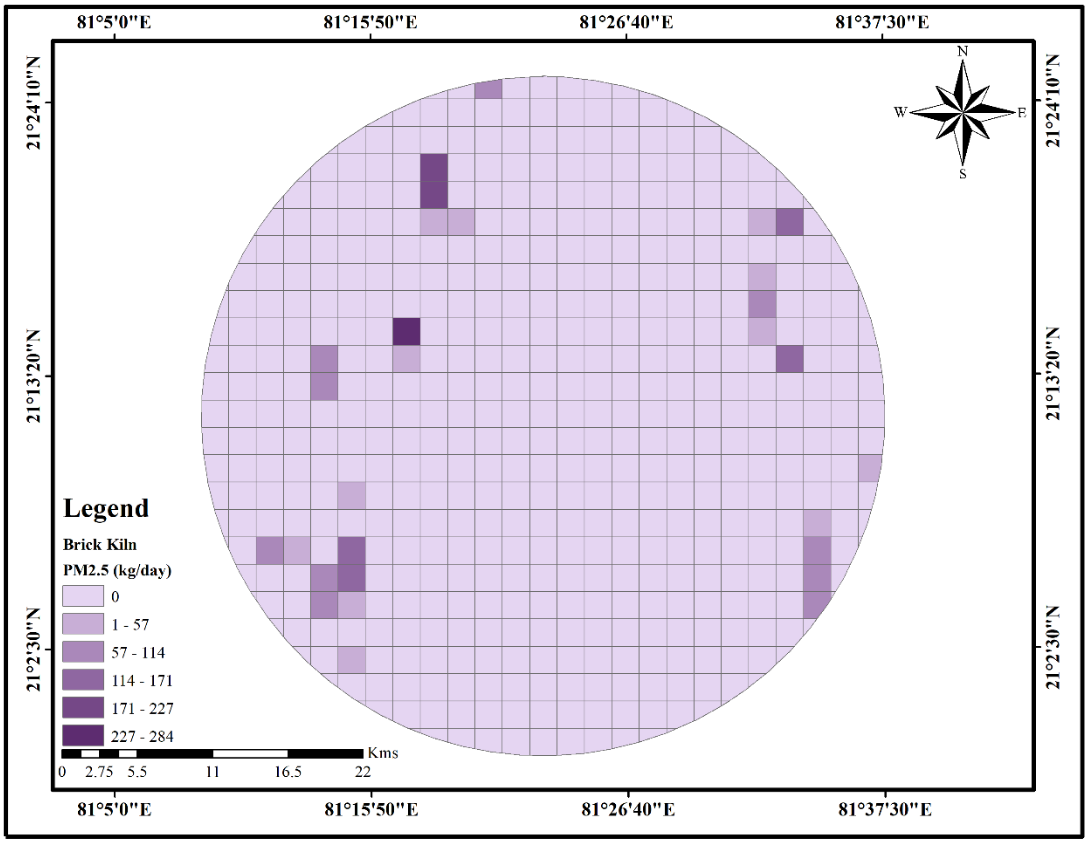


Figure 3.39: Spatial Distribution of $PM_{2.5}$ Emissions from Brick Kiln

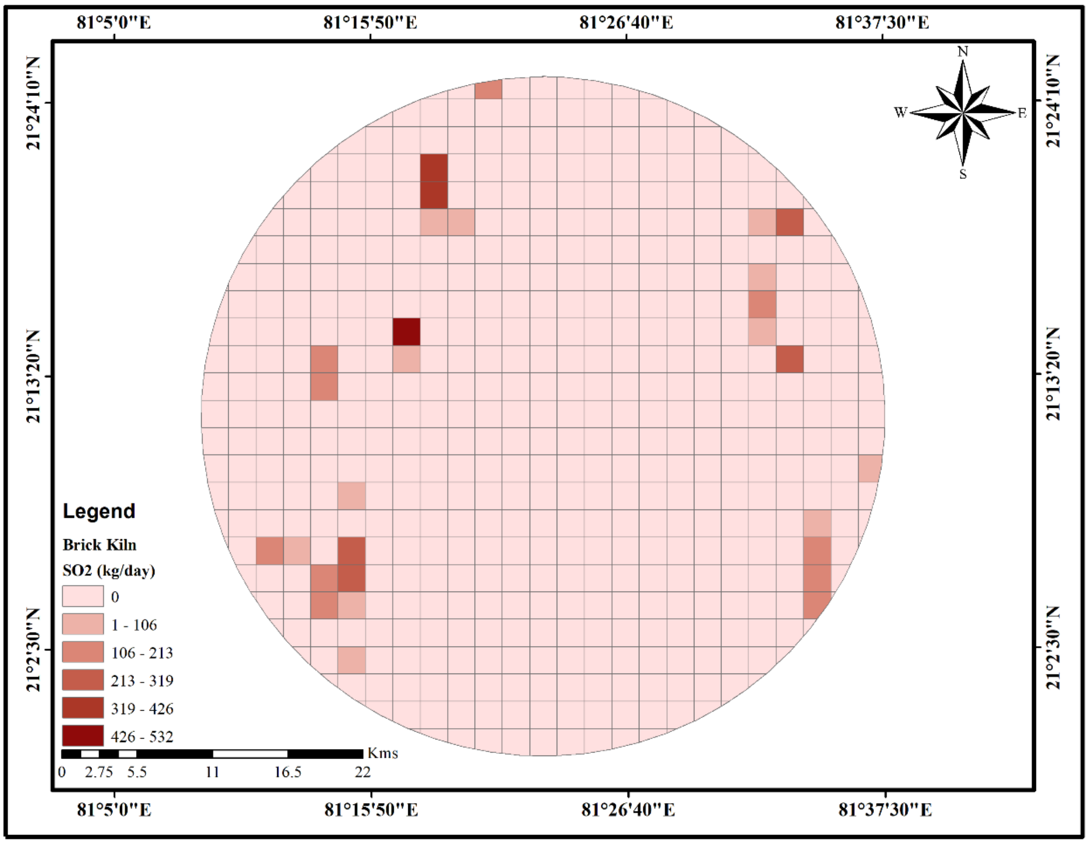


Figure 3.40: Spatial Distribution of SO_2 Emissions from Brick Kiln

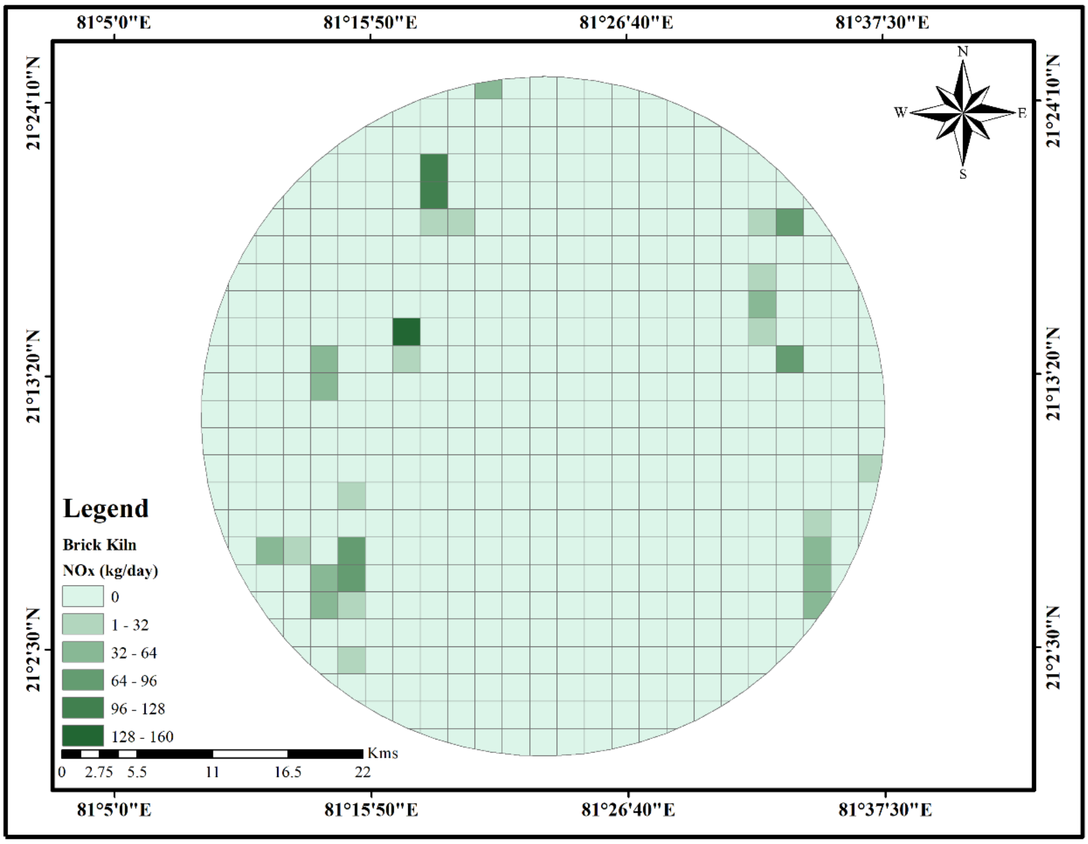


Figure 3.41: Spatial Distribution of NO_x Emissions from Brick Kiln

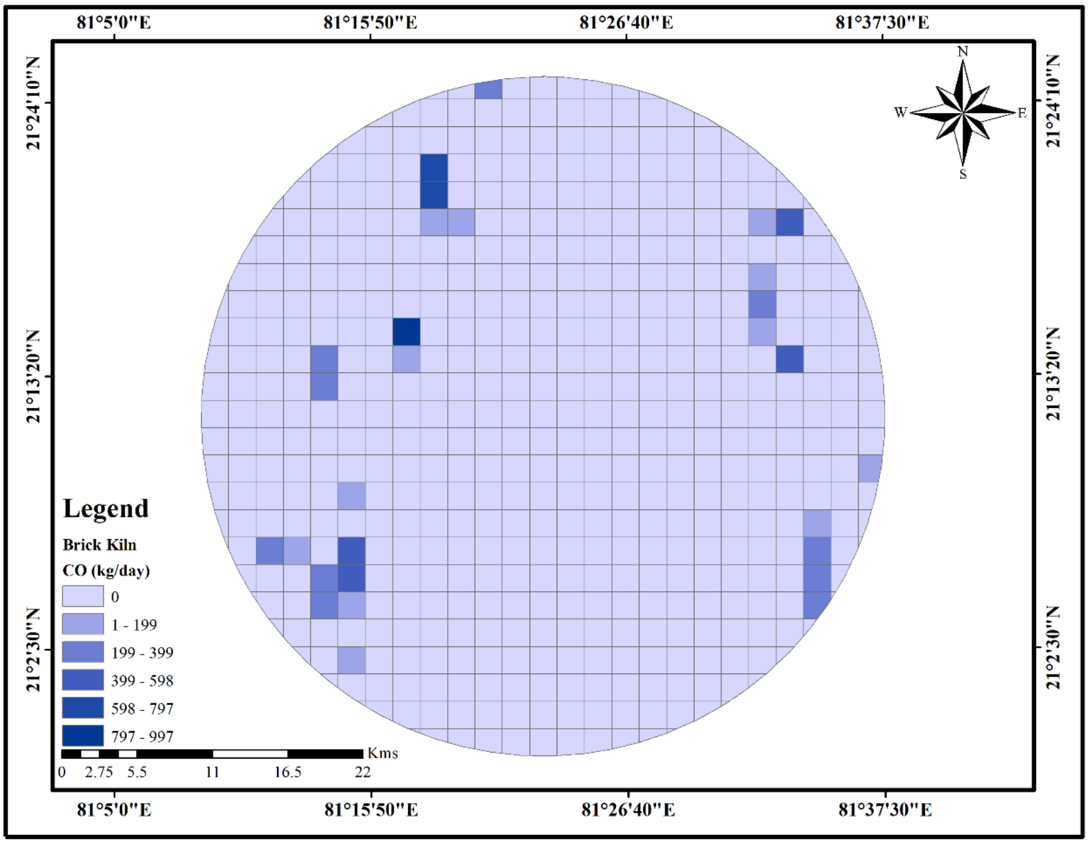


Figure 3.42: Spatial Distribution of CO Emissions from Brick Kiln

3.2.9 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 1087 MT/day and the waste collected is approximately 772 MT/day. The waste collection efficiency is 71% in Bhilai city (NGT report March 2023), and several events of waste burning have been observed during the city survey. The survey was conducted on weekdays and weekends and the frequency of waste burning events is calculated in the low-, middle: and higher-income areas. The waste burning at different locations in Bhilai city is shown in Figure 3.43.

Figure 3.43: Solid Waste Burning in Bhilai City

The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emission from waste burning using the same procedure of emission density in a ward or village. The emissions from solid waste burning are presented in Figure 3.44 and spatial distribution in Figure 3.45-Figure 3.49.

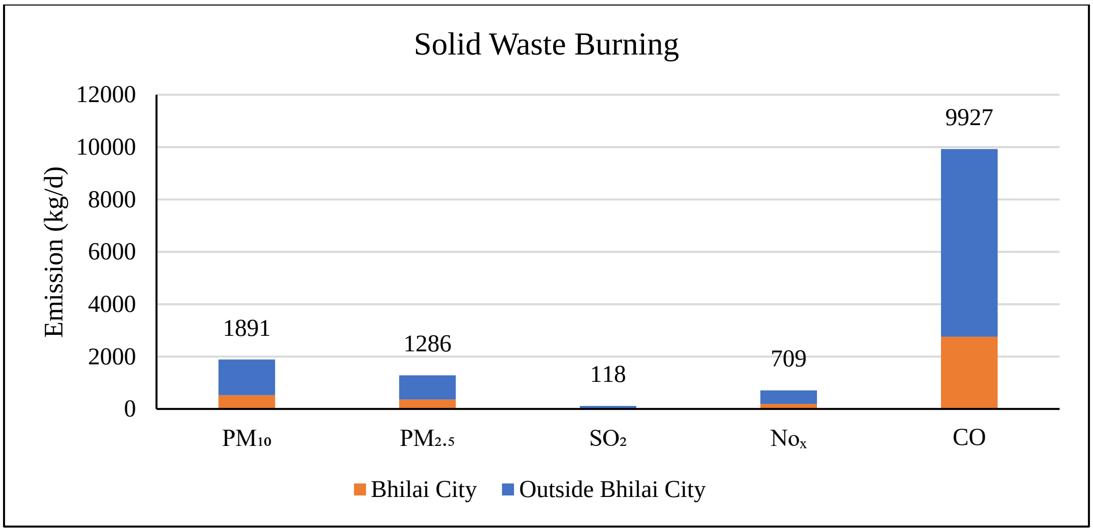


Figure 3.44: Emission Load from Waste Burning (kg/d)

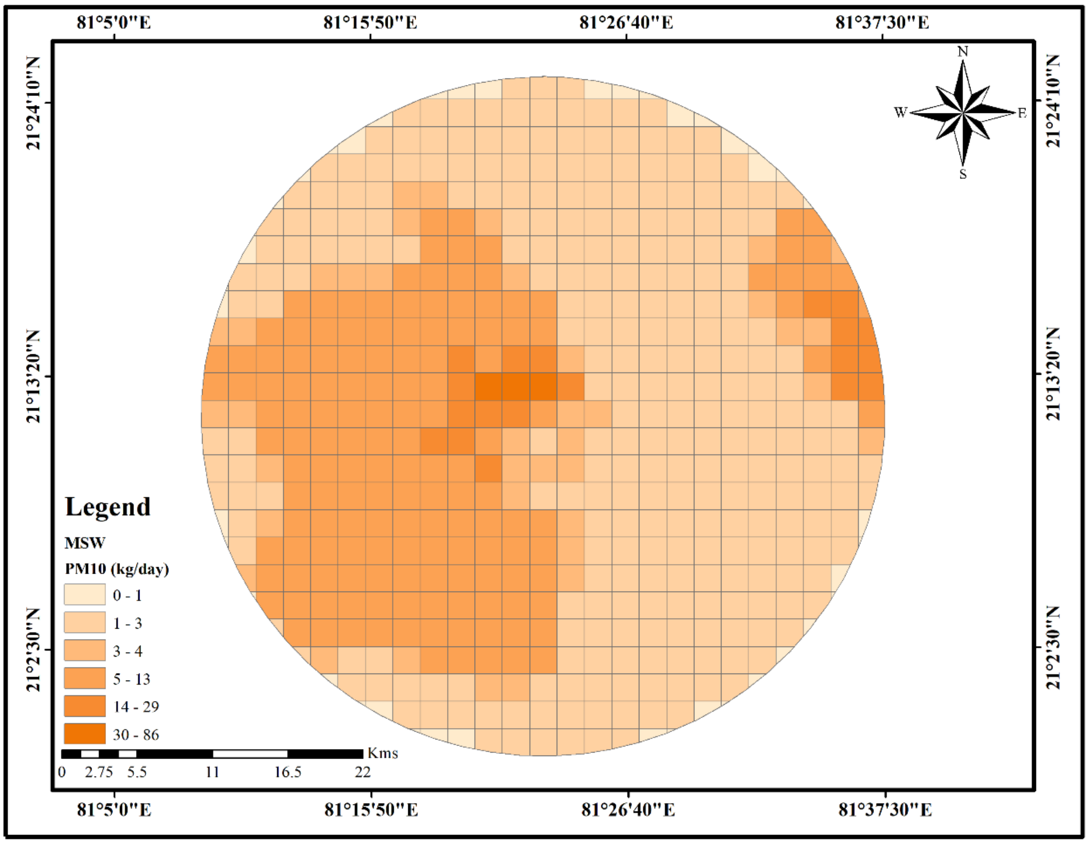


Figure 3.45: Spatial Distribution of PM_{10} Emissions from Solid Waste Burning

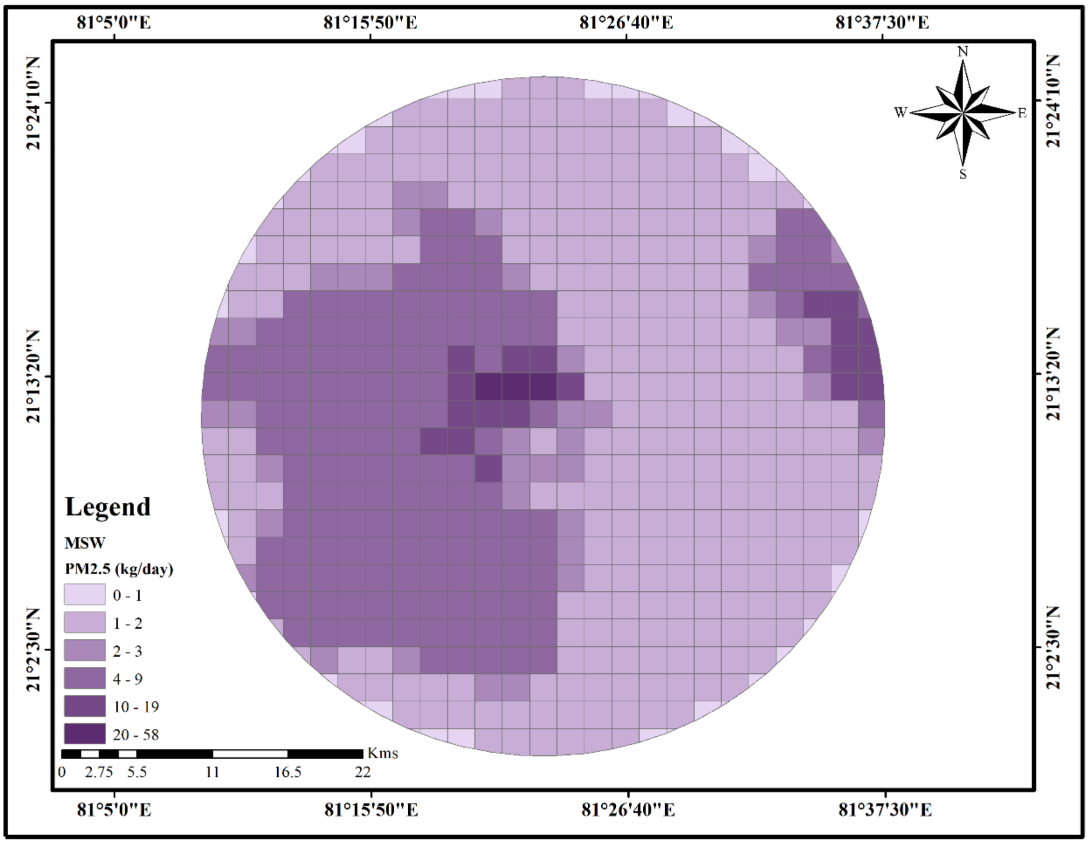


Figure 3.46: Spatial Distribution of $PM_{2.5}$ Emissions from Solid Waste Burning

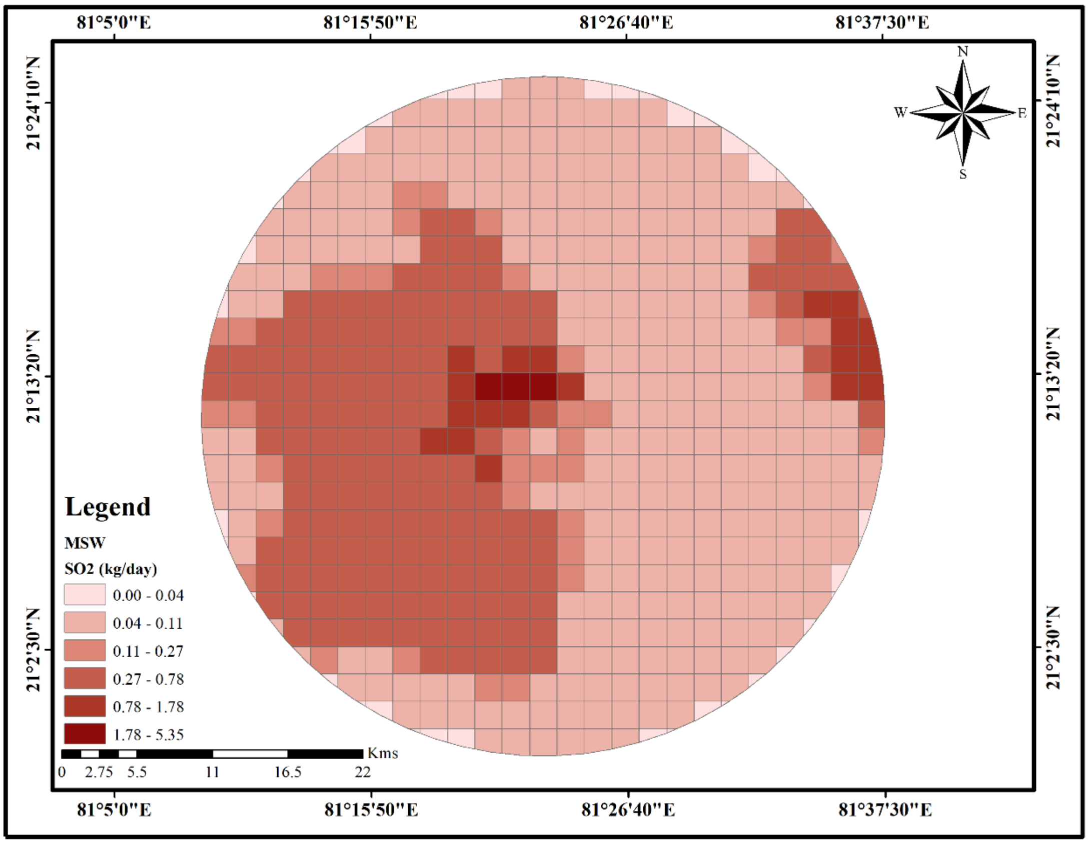


Figure 3.47: Spatial Distribution of SO_2 Emissions from Solid Waste Burning

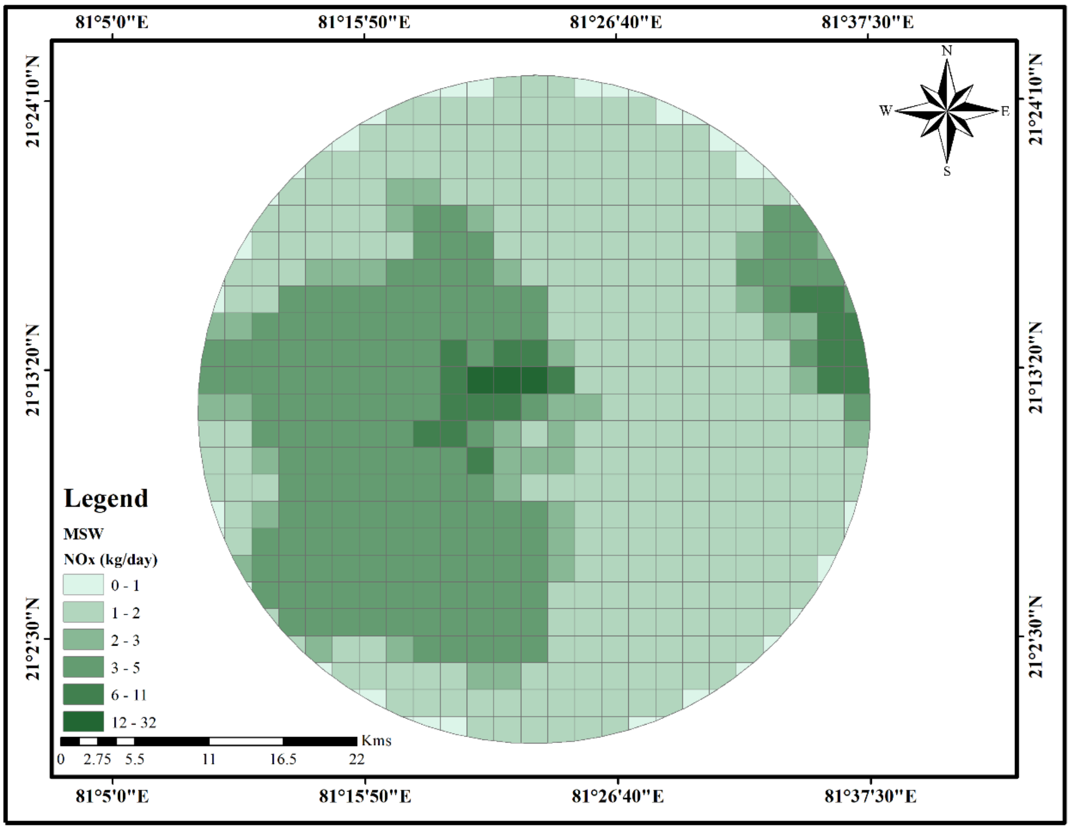


Figure 3.48: Spatial Distribution of NO_x Emissions from Solid Waste Burning

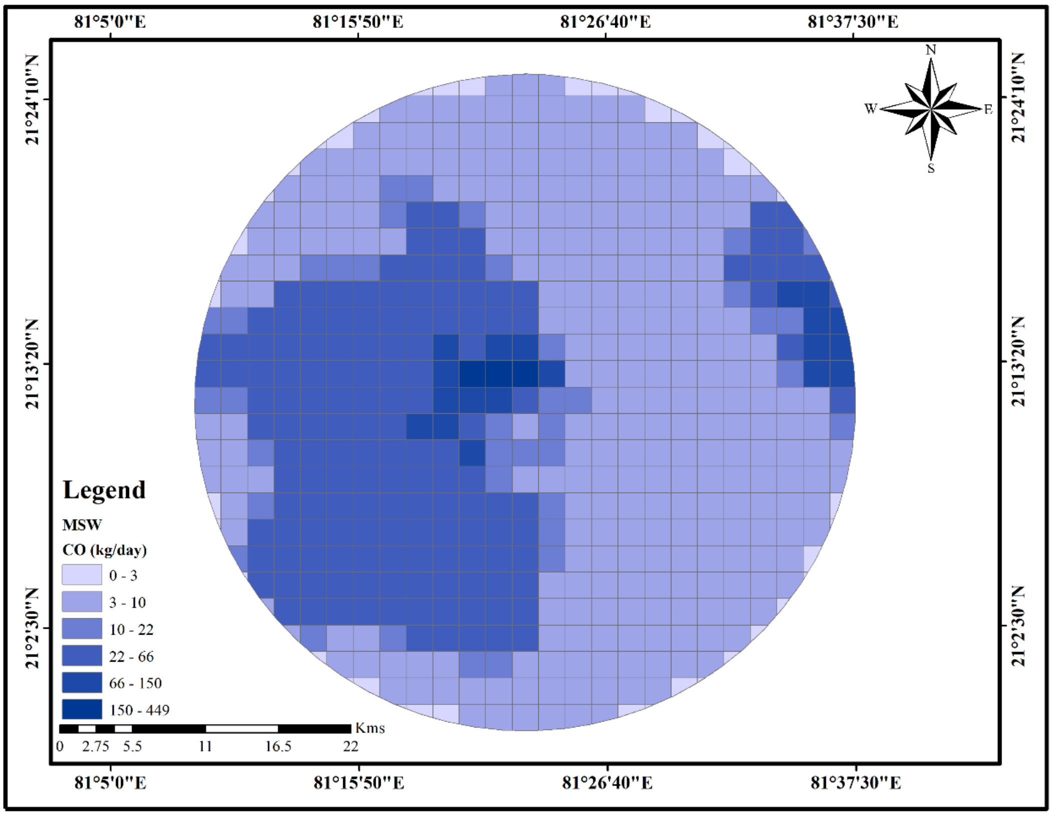


Figure 3.49: Spatial Distribution of CO Emissions from Solid Waste Burning

3.2.10 Hospitals

A detailed survey was undertaken to estimate the emission from hospitals in Bhilai city. There are approximately 170 hospitals in the city (Figure 3.50). The overall emissions from hospitals along with their average DG set capacity of 62.5 KVA and running two hours in a day are presented in Table 3.1. The emission load from hospitals is given in Figure 3.51. The Spatial distribution of emissions from Hospitals is given in Figure 3.52 to Figure 3.56.

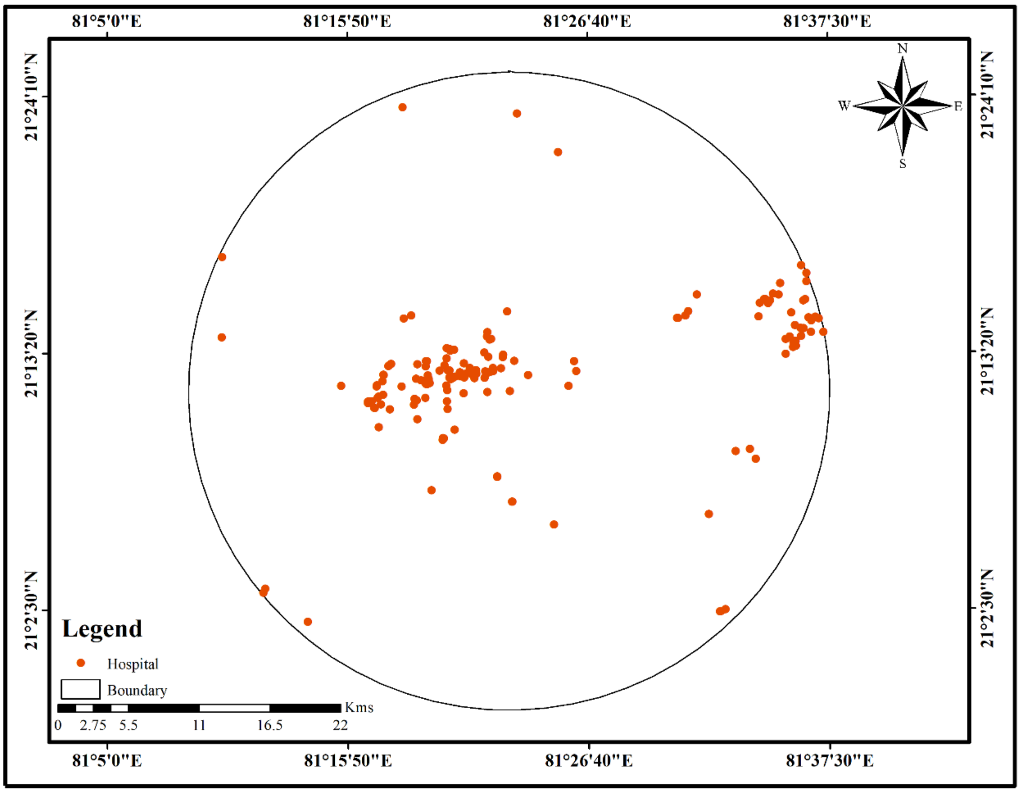


Figure 3.50: Locations of Hospitals in Bhilai city

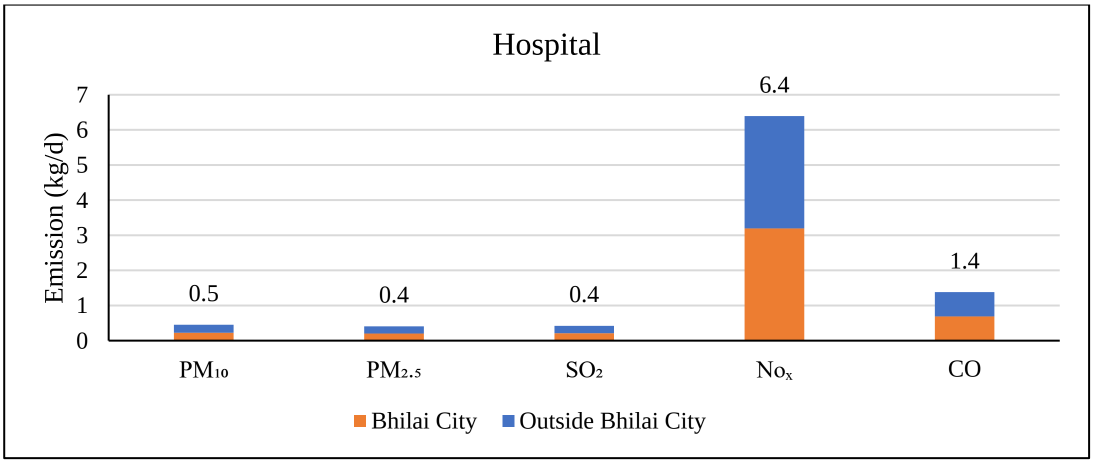


Figure 3.51: Emission Load from Hospitals (kg/d)

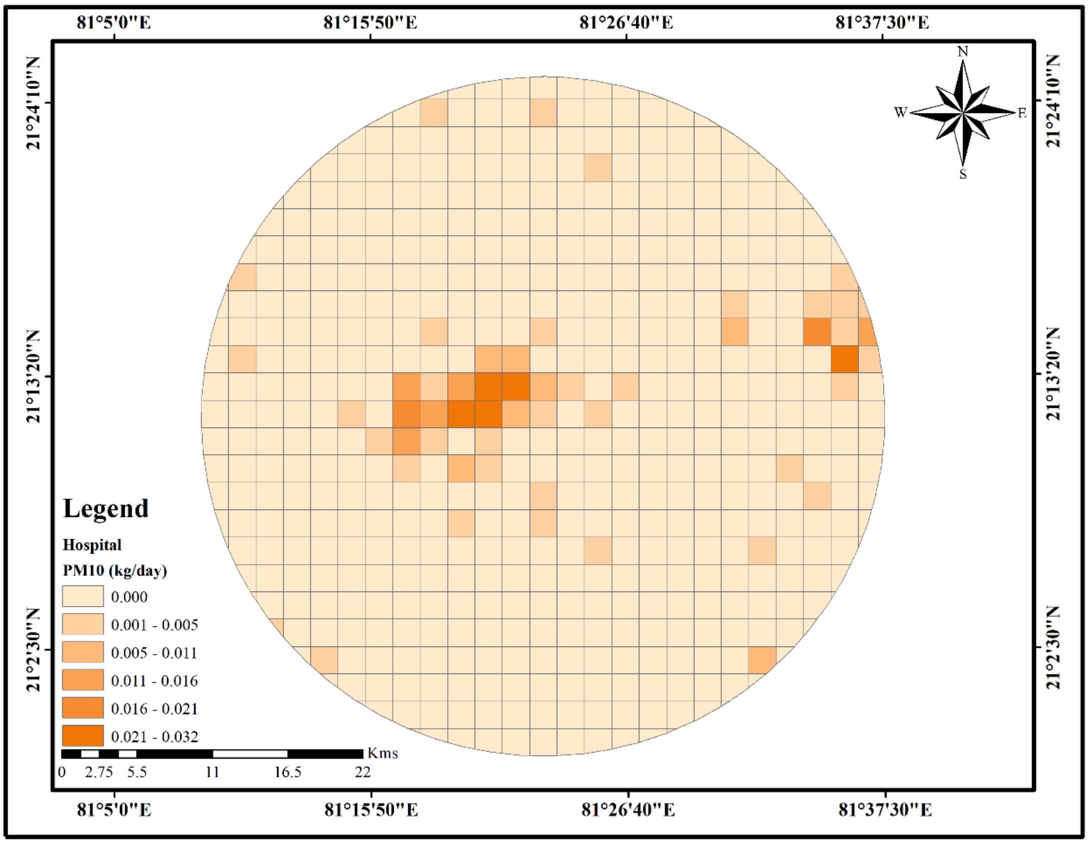


Figure 3.52: Spatial Distribution of PM_{10} Emissions from Hospitals

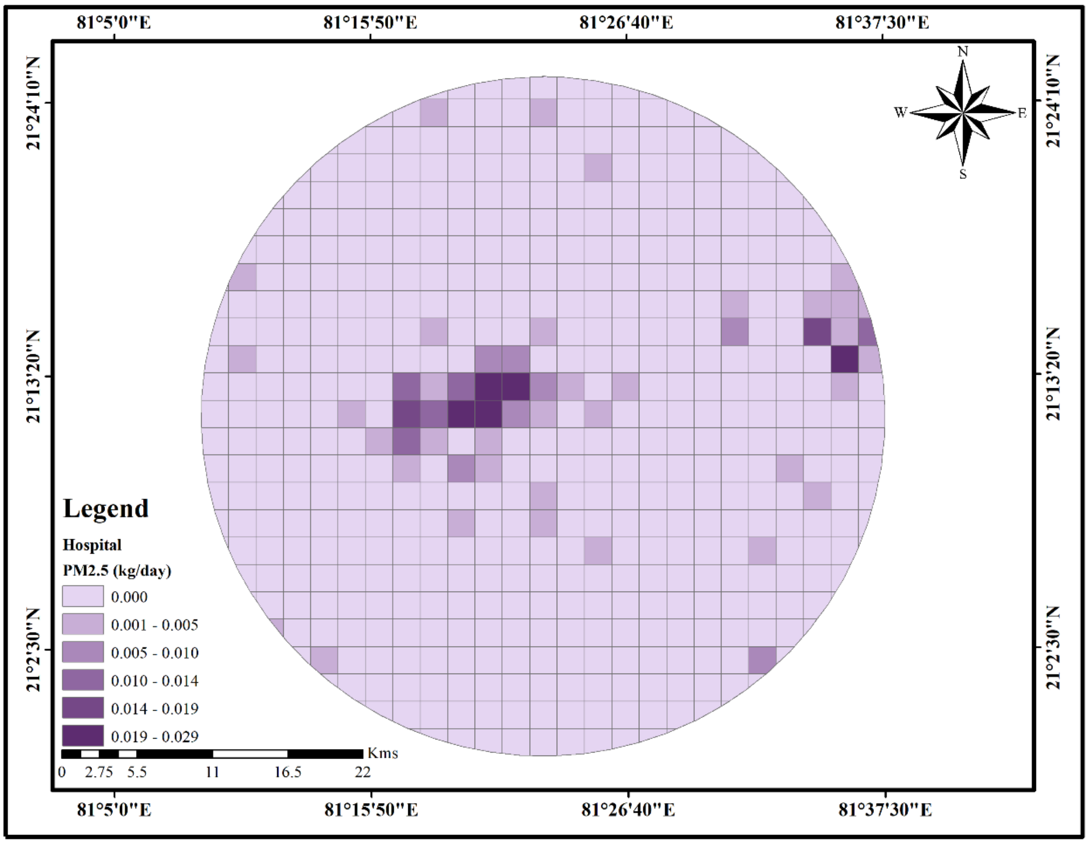


Figure 3.53: Spatial Distribution of $PM_{2.5}$ Emissions from Hospitals

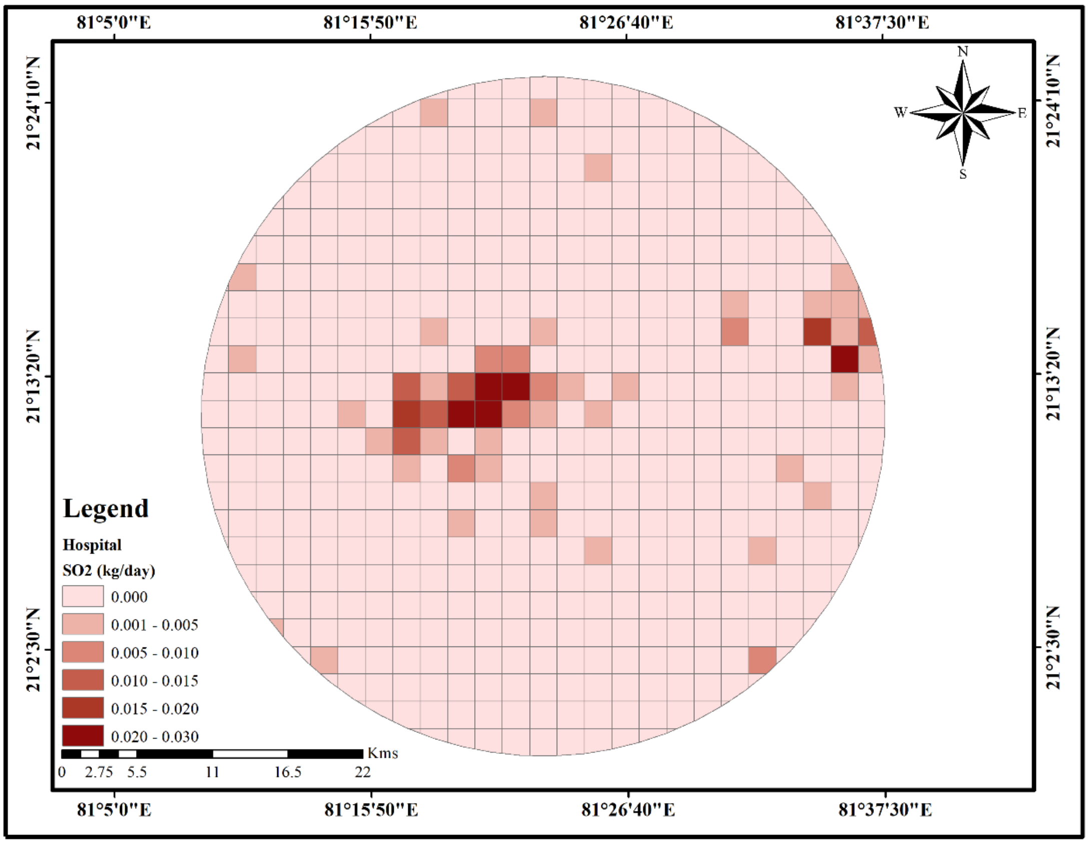


Figure 3.54: Spatial Distribution of SO_2 Emissions from Hospitals

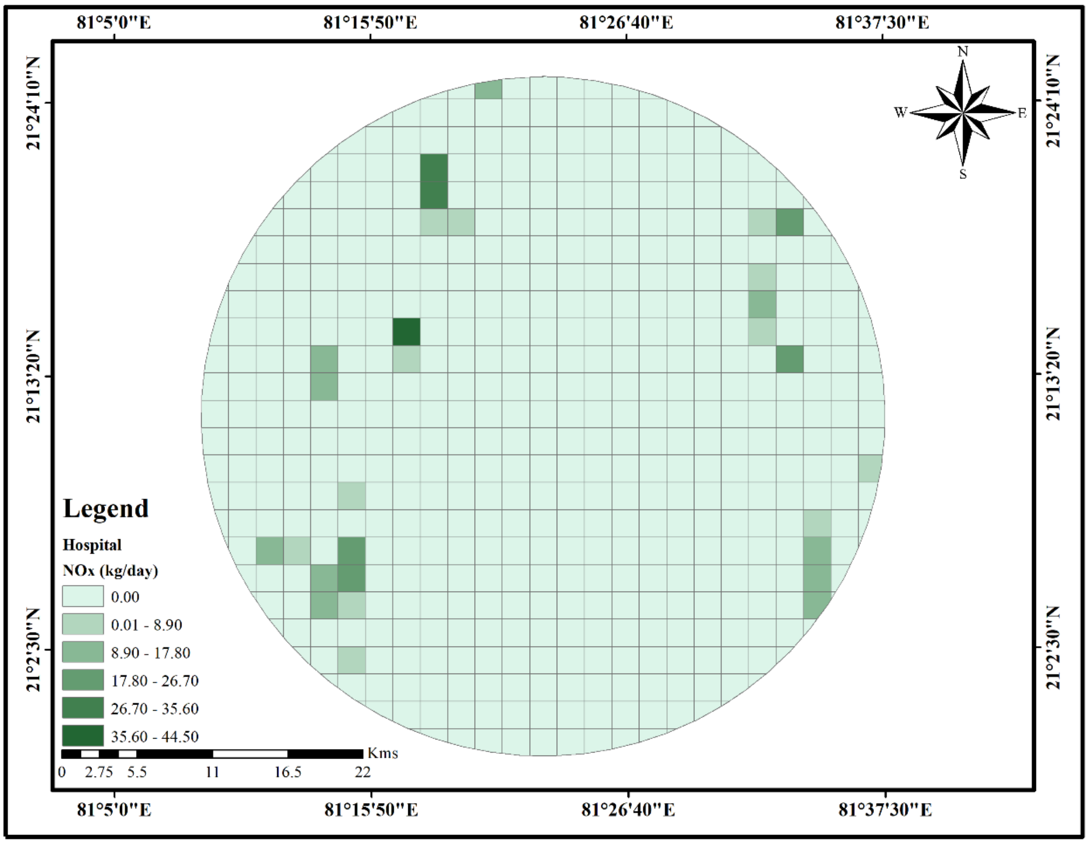


Figure 3.55: Spatial Distribution of NO_x Emissions from Hospitals

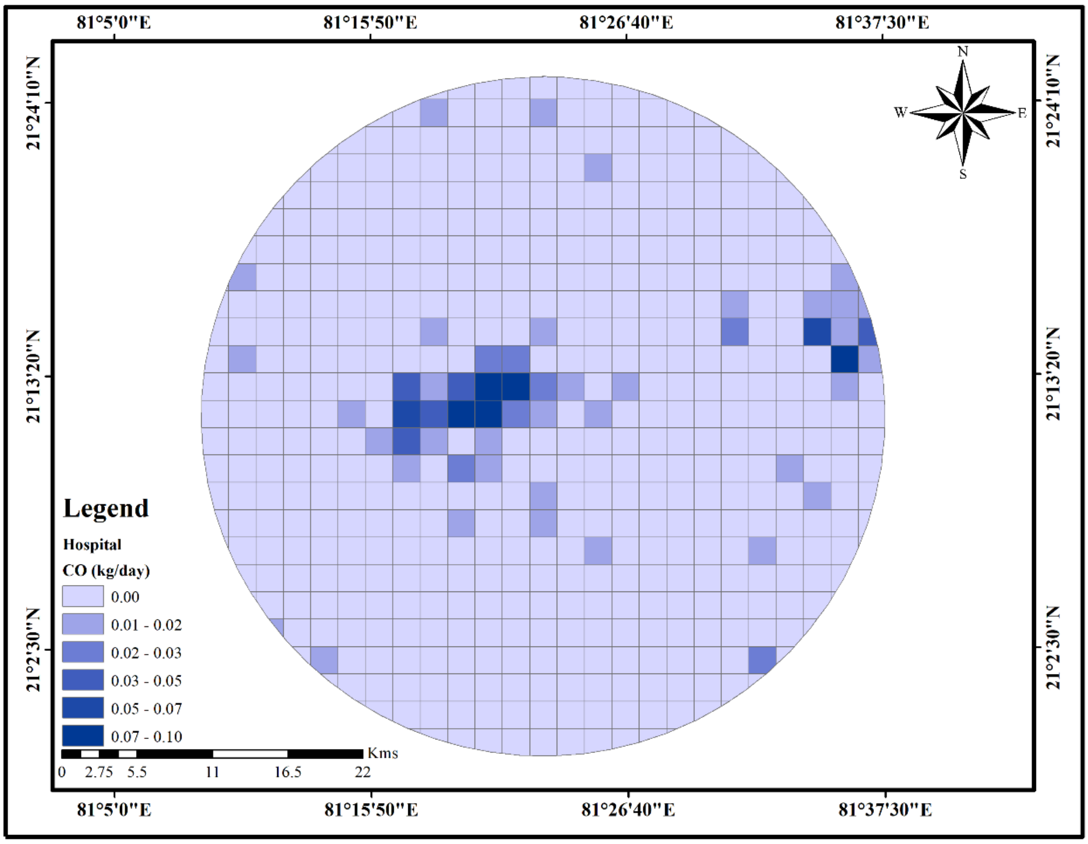


Figure 3.56: Spatial Distribution of CO Emissions from Hospitals

3.2.11 Industries

Out of 98 total industrial units, there are approximately 26 industrial units with boilers and furnaces (Blast, Induction, and Reheating furnaces) that contribute to particulate and gaseous emissions (Table 3.1). The Bhilai Steel Plant (BSP) has 59 different operational units which may cause air pollution out of a total 98 units in the study area. The major operations in BSP are coke oven batteries, basic oxidation furnaces (BOF)/steel melting shop (SMS), sintering, blast furnaces and raw material storage and handling. Major fuels in the study area are coke oven gas (COG), coal, rice husk, furnace oil, and blast furnace gases. The industrial locations are given in Figure 3.57. Information on stacks, fuel, and their consumption was obtained from CECB. AP-42 (USEPA, 2000)/CPCB emission factors were used to calculate the emissions. For further analysis, the industries are categorized based on stack height as an area source (stack height < 15 m) and as a point source (stack height > 15 m). The major emissions were from the large point source industries**.**

Figure 3.58 presents the overall industry emissions (stack height < 15 m) as an area source. There are around 3 industrial units categorized as area sources in Moradabad city. The boiler/baby boilers are majorly falling under this category. The spatial distribution of industries (area source) lying within the boundary is shown in Figure 3.59 to Figure 3.63.

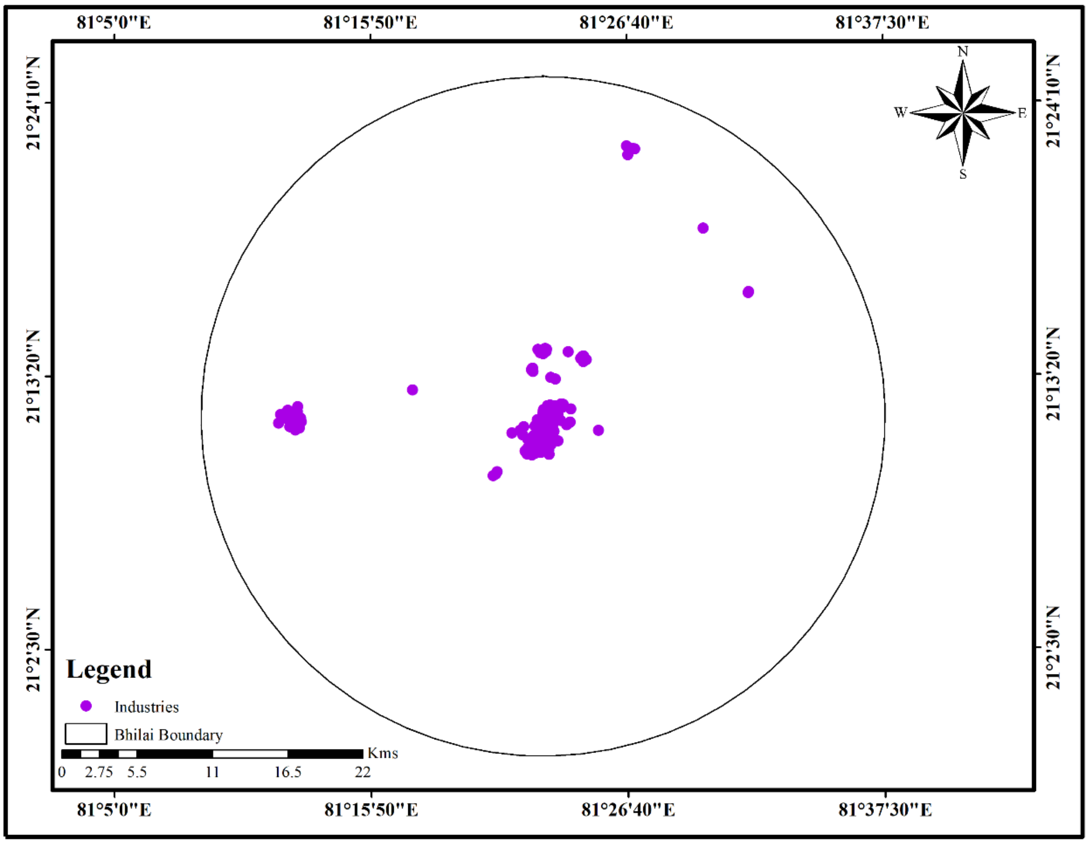


Figure 3.57: Locations of Industries in Bhilai city

Table 3.1: Furnace/Boiler Details in Bhilai (emissions in kg/d)

(Source: CECB Consent Data)

S. No.	Boiler/Furnace Type	Fuel used in Boiler/Furnace	No. of Furnaces/ Boilers/ Units	PM_{10} (kg/day)	$PM_{2.5}$ (kg/day)	SO_2 (kg/day)	NOx (kg/day)	CO (kg/day)
1	Fluidised Bed Combustion System	Dolochar and Coal Fines	1	845	756	1966	2277	52
2	Attached To DRI Plant Through ESP	Coal	1	245	109	2461	2849	65
3	Boiler	Coal, Dolachar, Rice Husk	9	13046	3688	21929	25401	2317
4	Basic Tunnel Kiln (Refractory)	PCM Oil	1	9	8	122	24	2

S. No.	Boiler/Furnace Type	Fuel used in Boiler/Furnace	No. of Furnaces/ Boilers/ Units	PM_{10} (kg/day)	$PM_{2.5}$ (kg/day)	SO_2 (kg/day)	NOx (kg/day)	CO (kg/day)
5	Distillation Unit	Furnace Oil	1	3	2	753	146	13
6	Rotary Kiln Stand By and Commom Stack	Furnace Oil	1	0.27	0.24	76.30	14.85	1.35
7	Ferro Alloys	Electricity	1	38.10	34.29	0.00	0.00	0.00
8	Grinding Section Cement Mills	Coal	1	35	18	950	1100	25
9	Induction Furnace	Electricity	6	548	493	0	0	0
10	Kiln	Coal	3	4630	1208	2732	3164	72
11	Kiln of Pellet Plant	Furnace Oil	1	43	38	610	119	11
12	Kiln Preheater	Coal	1	23	12	12493	14466	329
13	Sodium Bi Chromate	Furnace Oil	1	0.27	0.24	76	14.9	1.35
14	Sponge Iron Kiln	Coal	3	945	405	9076	10509	239
15	Sponge Iron With FBC Power Plant	Coal Char and Dolochar	1	389	173	3914	4532	103
16	Stack Attach With Distillation Unit	Creosote Oil	1	0.17	0.16	40	20	1.8
17	Slag Dryer	Coal	1	1.2	0.6	625	723	16
18	Roller Press Common Stack	Pet Coke	1	15	7	8068	9342	212
19	Rolling Mill	Furnace Oil	3	40.88	36.80	797	155	14.1
20	Reheating Furnace	Coal	1	140	100	181	209	5
Bhilai Steel Plant (BSP)								
21	Power Plant (Boiler)	Coal	2	7503	3335	75427	87336	1984.9
22	Coke Oven Battery	Coke Oven and BF Gas	11	11055	8090	2579	1296	846
23	Sinter Plant	Coke Oven Gas	4	3303	1295	49	20	14
24	Blast Furnace	BF Gas, Coke Oven	8	3439	1682	2363	1381	872
25	Power And Blowing Station	Coke Oven and BF Gas	4	249	243	2933	1474	962
26	SMS Stack	Coke Oven and LD Gas	6	10389	7143	46.2	19	13.2
27	SMS Ladle Furnace	Coke Oven and LD Gas	2	2897	1992	11.5	4.8	3.28
28	SMS 2 Desulphurization Unit	Coke Oven and LD Gas	1	8.09	5.67	5.8	2.4	1.64
29	Merchant Mill	Coke Oven, LD And BF Gas	1	15.07	13.57	130.5	66	43

S. No.	Boiler/Furnace Type	Fuel used in Boiler/Furnace	No. of Furnaces/ Boilers/ Units	PM$_{10}$ (kg/day)	PM$_{2.5}$ (kg/day)	SO$_2$ (kg/day)	NOx (kg/day)	CO (kg/day)
30	BRM Stack	Coke Oven, LD And BF Gas	1	7.40	6.67	64.1	32.6	21.2
31	Wire Rod Mill Stack	Coke Oven, Ld and BF Gas	1	6.98	6.29	60.5	31	20
32	Rail and Structural Mill With URM Stack 1	Coke Oven, LD and BF Gas	2	27.30	24.59	236.4	120	78
33	Quenching and Tempering Facility	Nitrogen (dry)	1	0.00	0.00	0.0	0.00	0.00
34	Tar Plant Stack	Coke Oven	1	1.24	1.18	18.6	8.2	5.51
35	Blooming and Billet Mil Stack	Coke Oven, LD and BF Gas	7	0.00	0.00	0.0	0.00	0.00
36	Forge Shop Stack	Coke Oven and LD Gas	3	0.82	0.77	10.7	4.47	3.04
37	Machine Shop Stack	Coke Oven and LD Gas	1	0.52	0.49	6.8	2.84	1.93
38	Foundry Shop Stack	Coke Oven and LD Gas	3	0.59	0.56	7.7	3.22	2.19
39	Conveyor transfer, Pile formation, Batch drop front end loader	Fugitive emission	0	177	62.7	0.0	0.0	0.0
A	Industries excluding BSP (1 to 20)		**39**	**20995**	**7090**	**66868**	**75066**	**3479**
B	BSP (21 to 39)		**59**	**39080**	**23903**	**83950**	**91802**	**4873**
	Total		**98**	**60075**	**30993**	**150818**	**166868**	**8352**

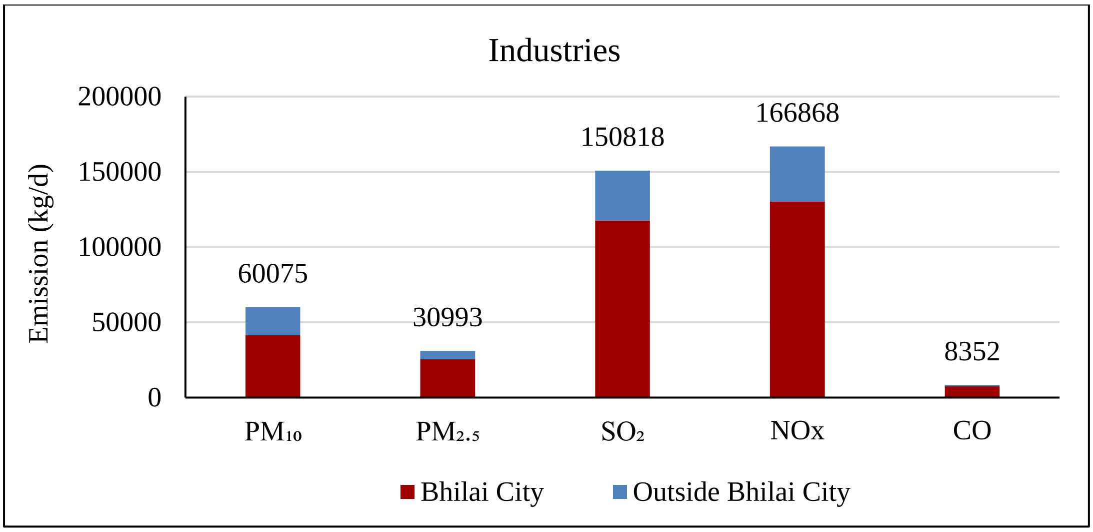


Figure 3.58: Emission Load from Industries (kg/d)

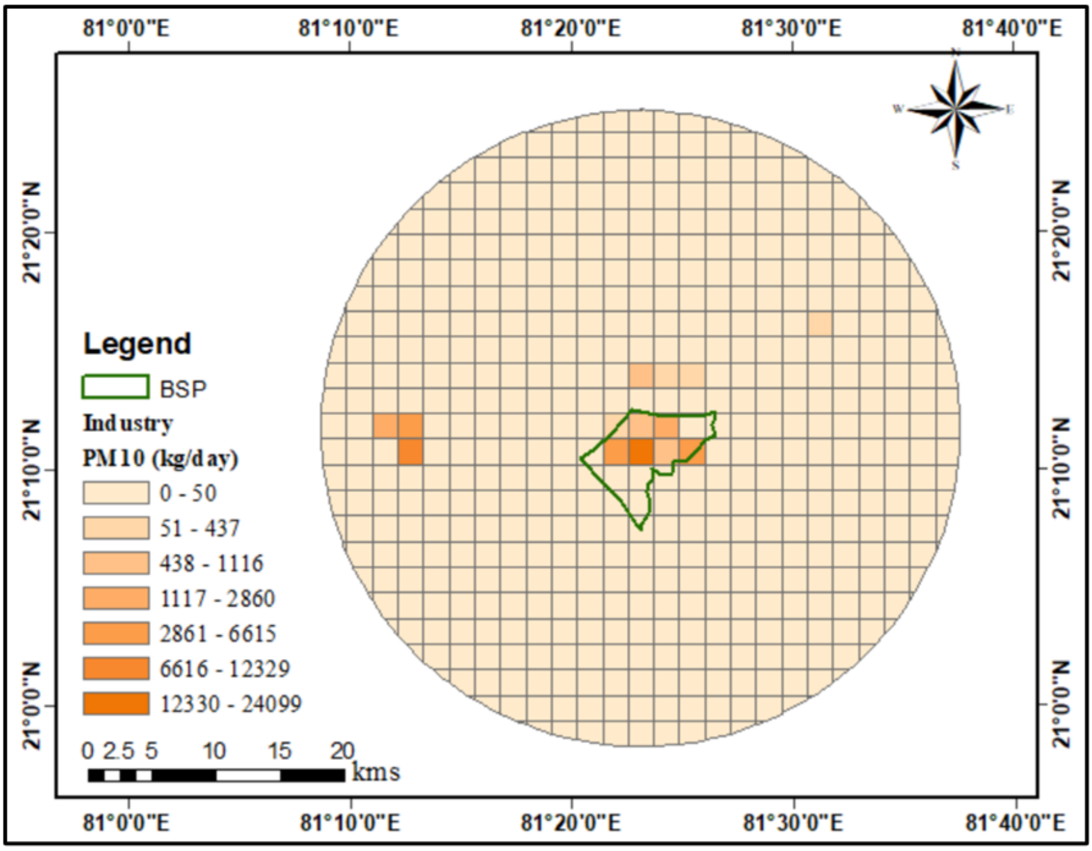


Figure 3.59: Spatial Distribution of PM_{10} Emissions from Industries

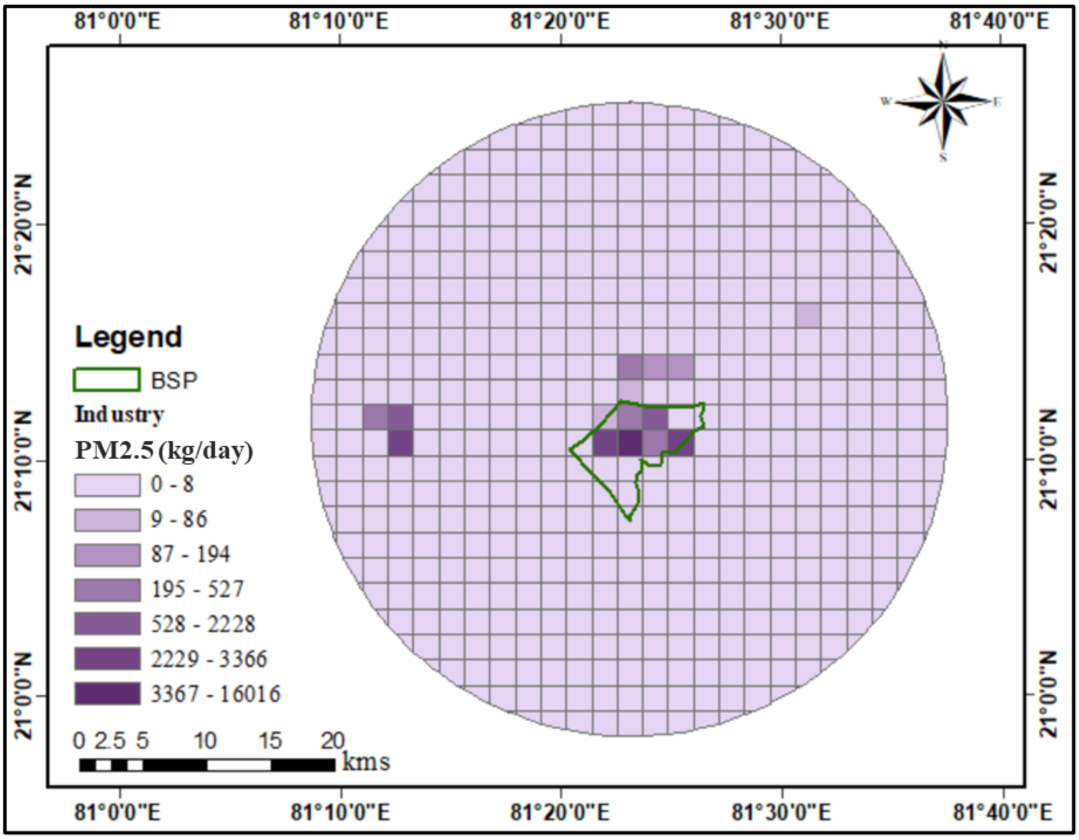


Figure 3.60: Spatial Distribution of $PM_{2.5}$ Emissions from Industries

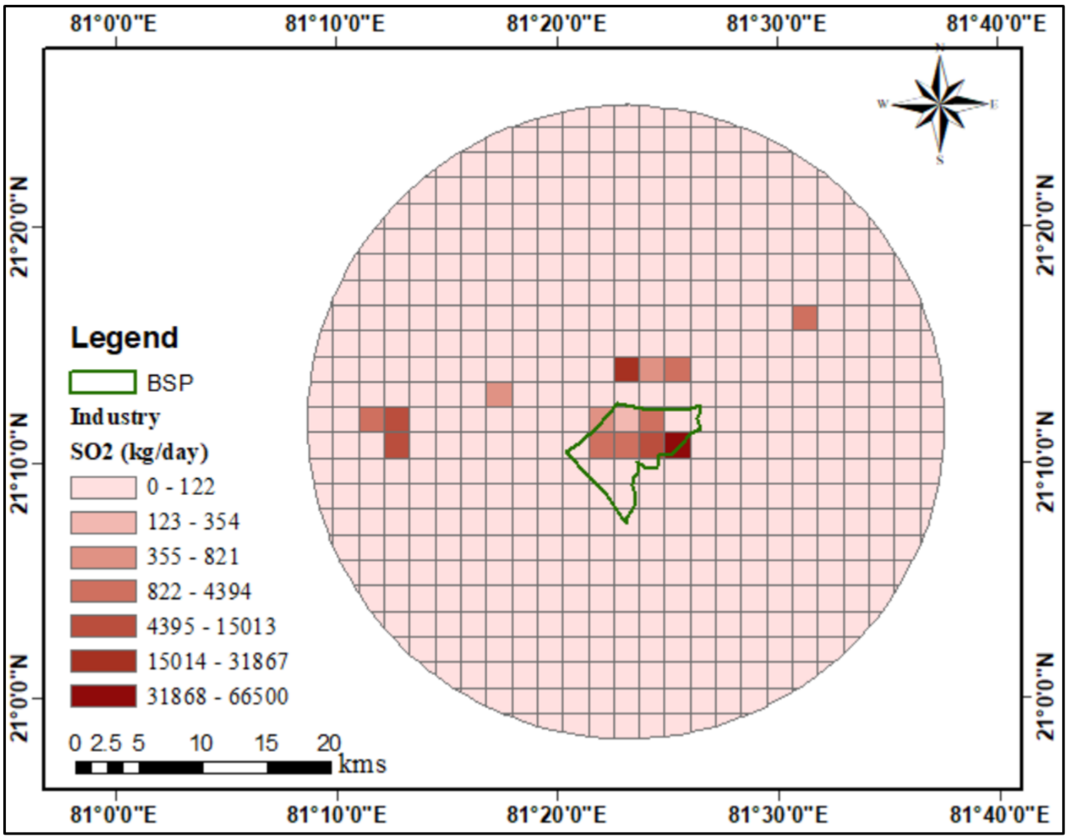


Figure 3.61: Spatial Distribution of SO_2 Emissions from Industries

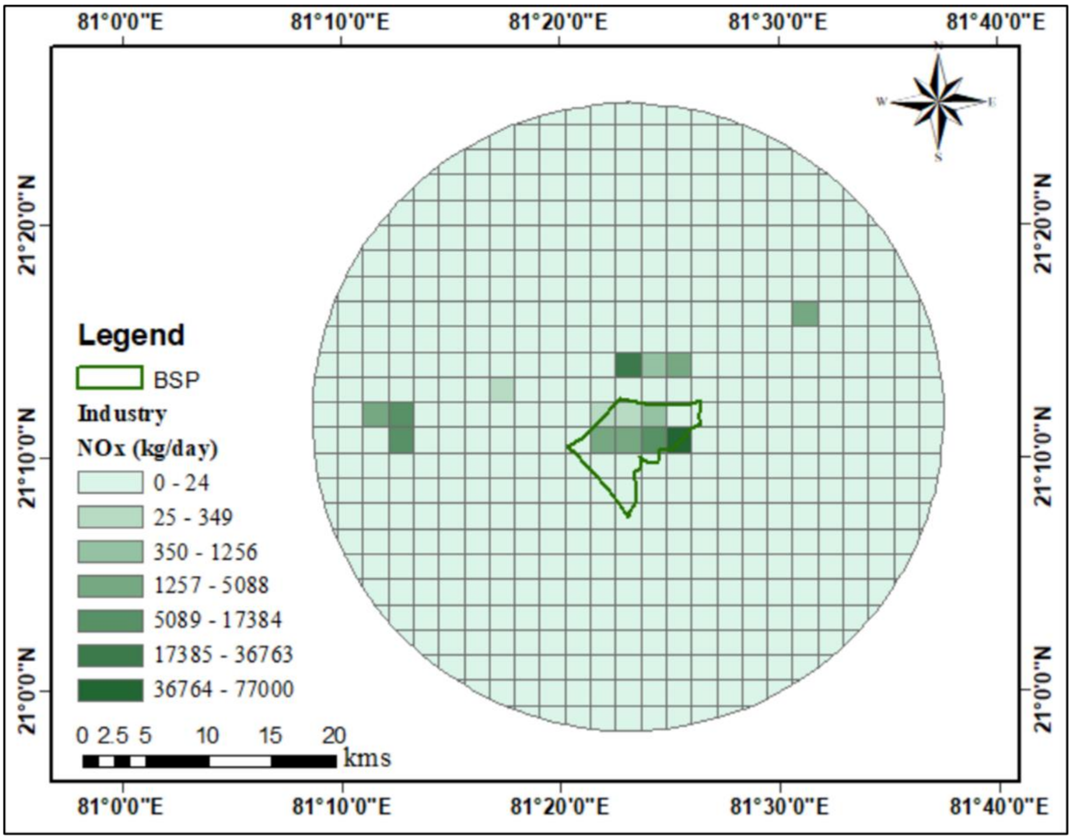


Figure 3.62: Spatial Distribution of NO_x Emissions from Industries

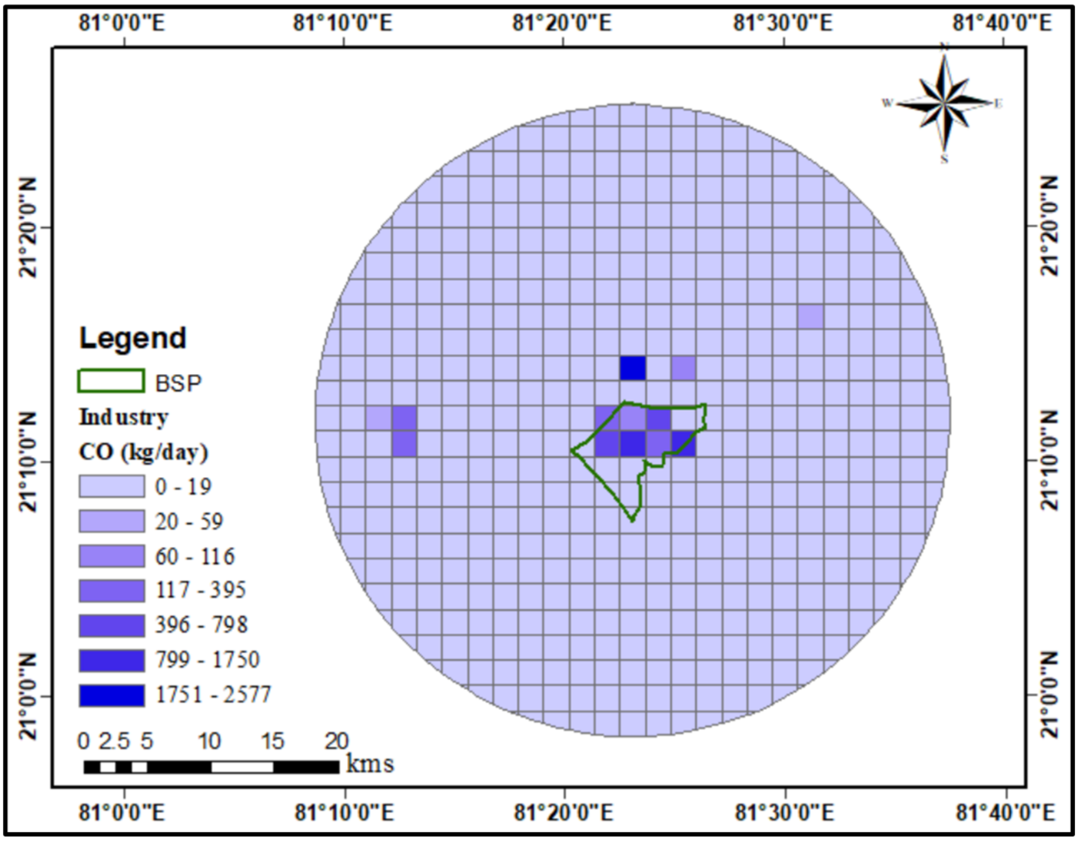


Figure 3.63: Spatial Distribution of CO Emissions from Industries

3.2.12 Parking Lot Survey

To obtain the prevalence of vehicle technology types operating in the city and fuel use, parking lot questionnaire surveys (engine technology and capacity, vehicle age, fuel use, etc.) were done at Twenty locations (Acc Chowk, Atal Chowk, Bharat Mata Chowk, Dhamdha Under Bridge Durg, Gada Chowk, Jail Tiraha, Jalband Road, Jawahar Nehru Park, Maharana Pratap Chowk, Murmunda Chowk, Nadnrani Chowk, Nankatti Minor Patan Road, Pulgaon Chowk, Raipura Chowk, Rajnandgaon Road, Shiv Para, Shivaji Chowk, Smriti nagarm, Tatibandh chowk). ARAI (2011) and CPCB (2011) emission factors were used to calculate vehicle emissions. Figure 3.64 to Figure 3.66 parking lane survey results for 2Ws, 3Ws, and 4Ws in terms of engine size and year of manufacturing. This information is vital in calculating the emission from vehicles on the road. The emission factors vary considerably for engine size, fuel use, and age of the vehicles.

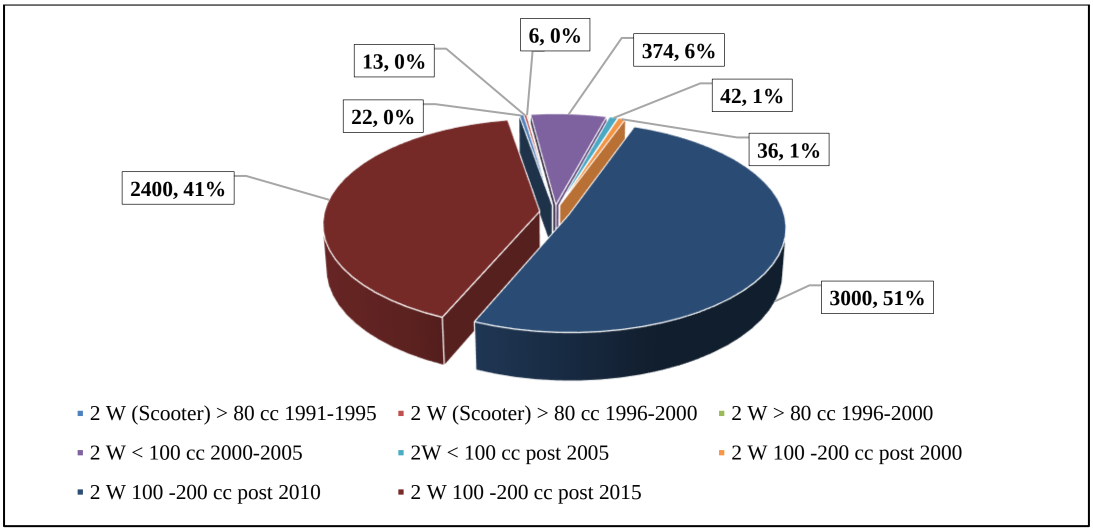


Figure 3.64: Distribution of 2-Ws in the study area (parking lot survey)

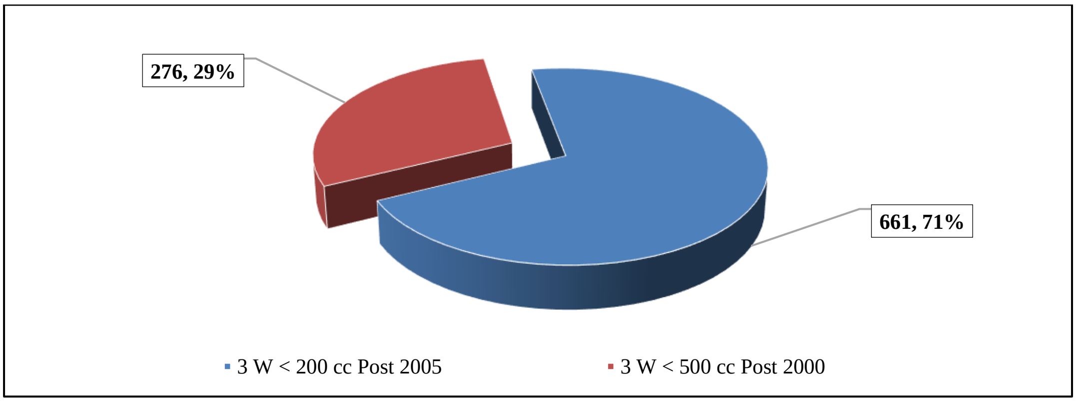


Figure 3.65: Distribution of 3-Ws in the study area (parking lot survey)

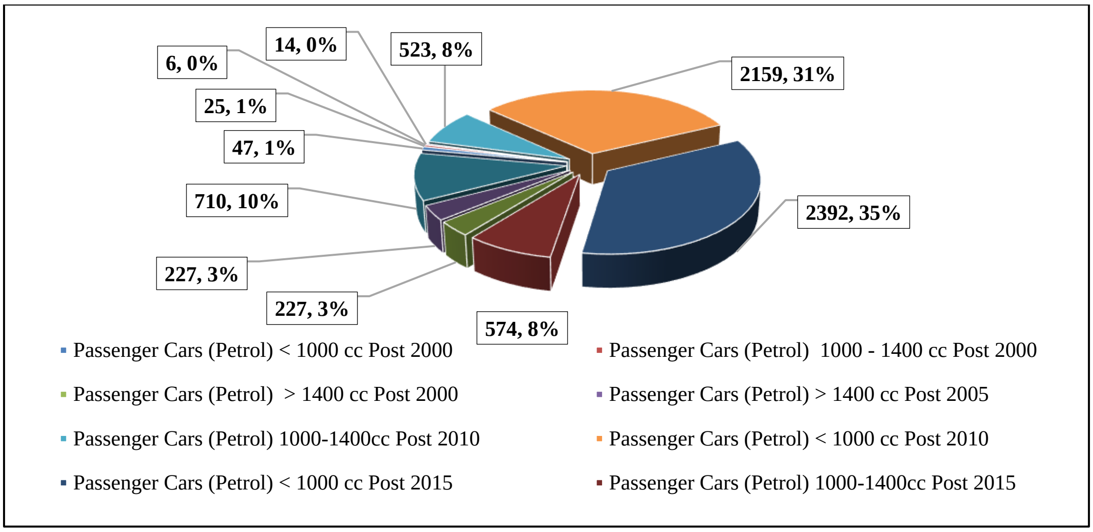


Figure 3.66: Distribution of 4-Ws in the study area (parking lot survey)

3.2.13 Vehicular-Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, buses, and trucks at Twenty locations was obtained by video recording (Figure 3.67). From these Twenty traffic locations (Acc Chowk, Atal Chowk, Bharat Mata Chowk, Dhamdha Under Bridge Durg, Gada Chowk, Jail Tiraha, Jalband Road, Jawahar Nehru Park, Maharana Pratap Chowk, Murmunda Chowk, Nadnrani Chowk, Nankatti Minor Patan Road, Pulgaon Chowk, Raipura Chowk, Rajnandgaon Road, Shiv Para, Shivaji Chowk, Smriti nagarm, Tatibandh chowk), the traffic data were extrapolated for the remaining grids. Road lengths in each grid for major and minor roads were calculated from the digitized maps using the ArcGIS tool, ArcMap, and extracted into the grids. The traffic counts were translated into the vehicles (and their types) on the roads in each grid. Wherever it was feasible, either traffic flow was taken directly from the traffic data. 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.

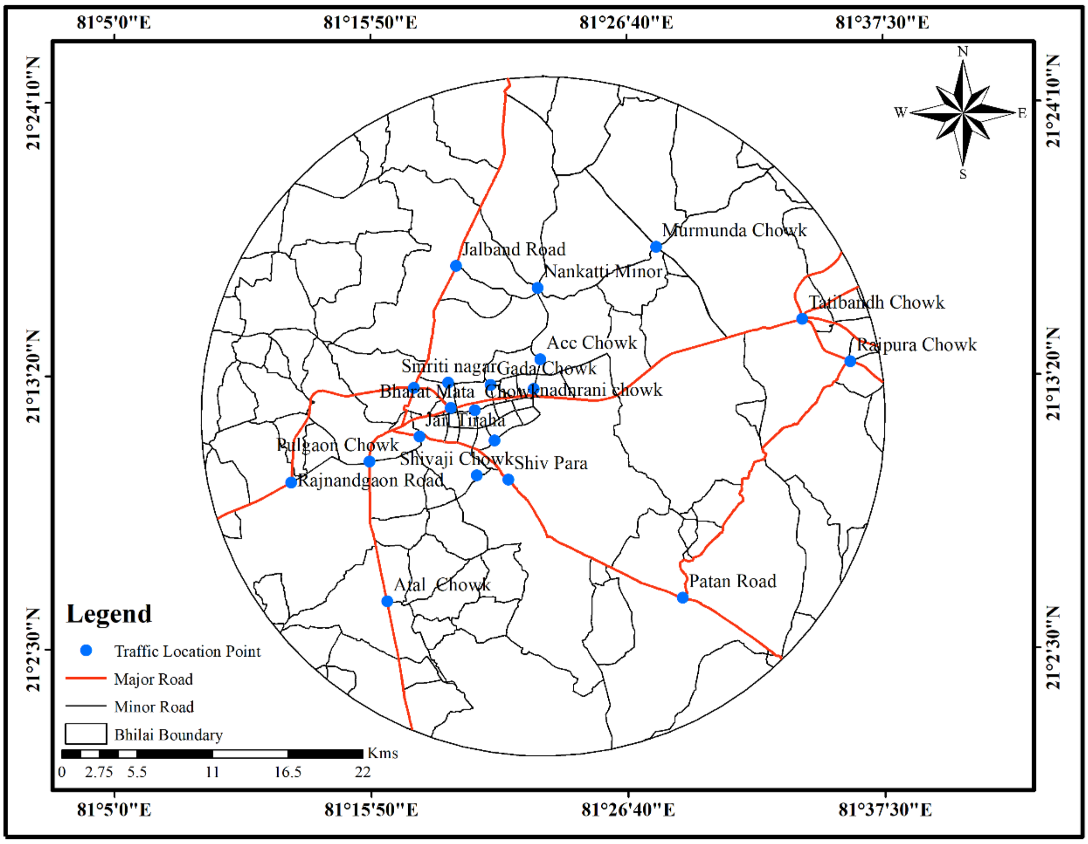


Figure 3.67: Location of Traffic survey points in Bhilai city

The emission from vehicles is shown in Figure 3.68. The emission contribution of each vehicle type in Bhilai is presented in Figure 3.69 to Figure 3.73. The spatial distribution of emissions from vehicles is presented in Figure 3.74- Figure 3.78.

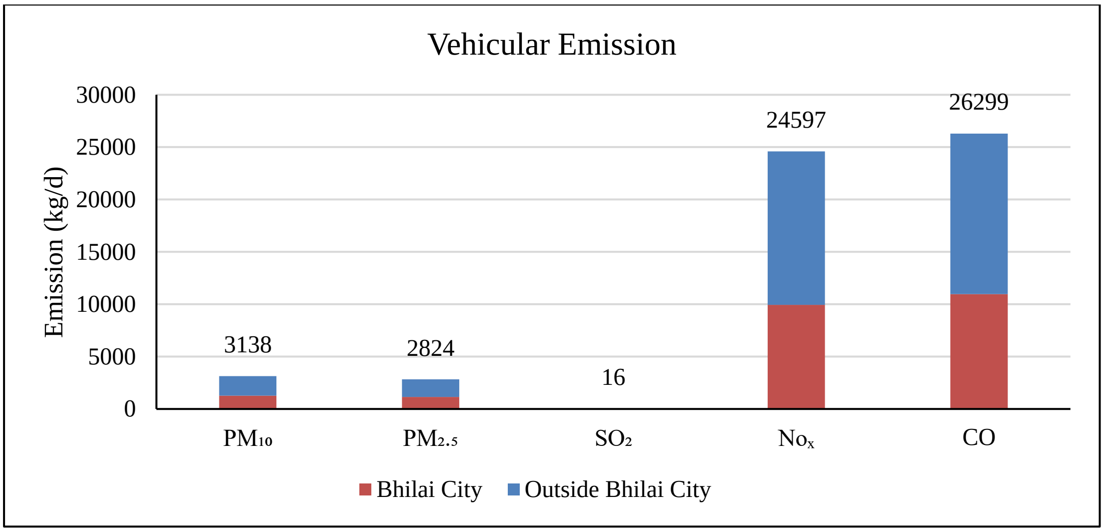


Figure 3.68: Emission Load from Vehicles (kg/d)

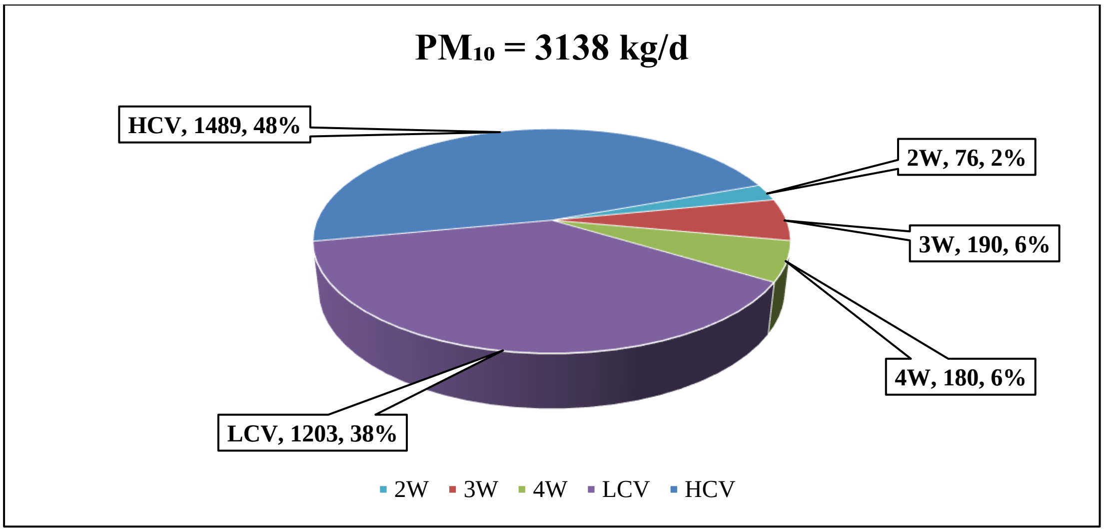


Figure 3.69: PM_{10} Emission Load contribution of each vehicle type (kg/d)

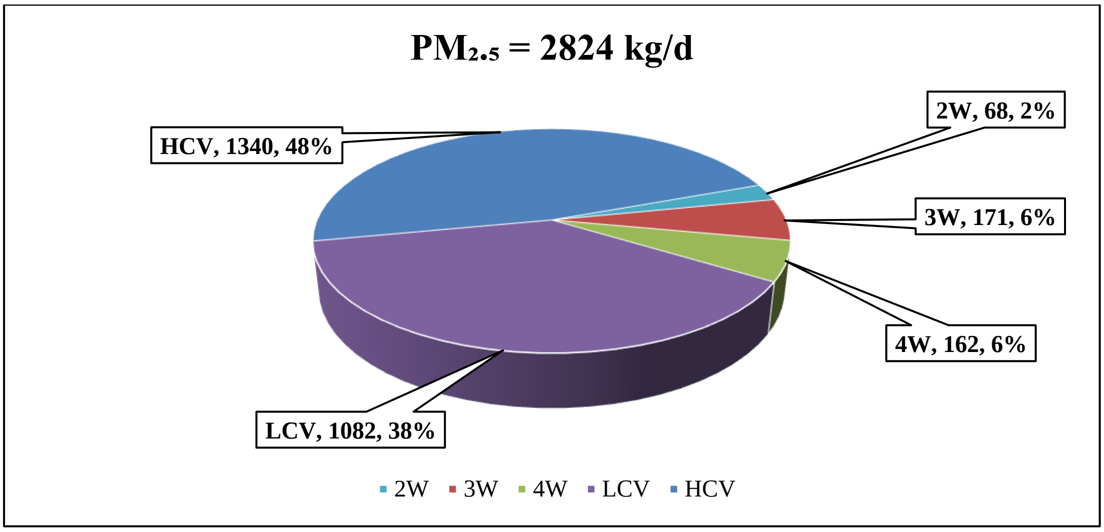


Figure 3.70: $PM_{2.5}$ Emission Load contribution of each vehicle type (kg/d)

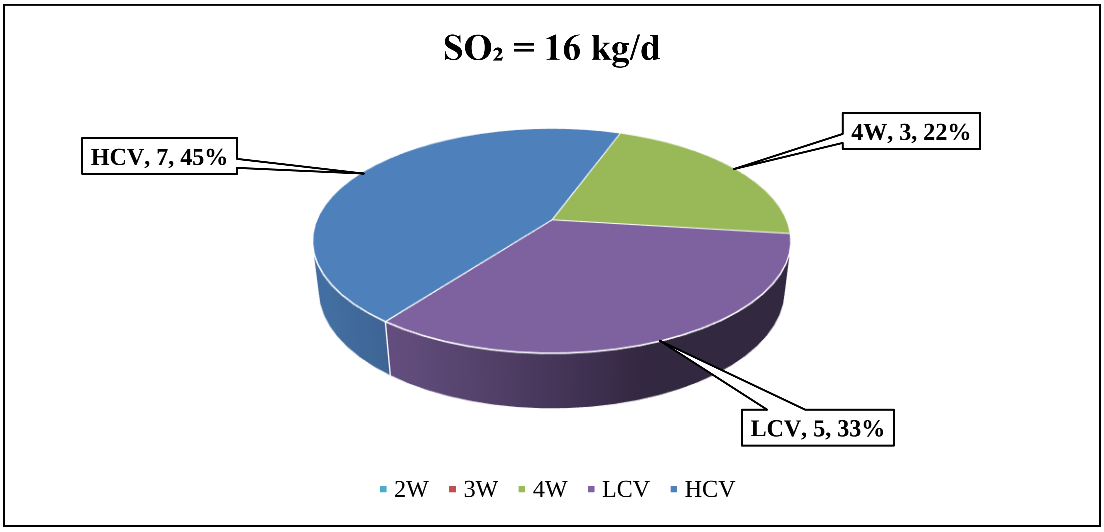


Figure 3.71: SO_2 Emission Load contribution of each vehicle type (kg/d)

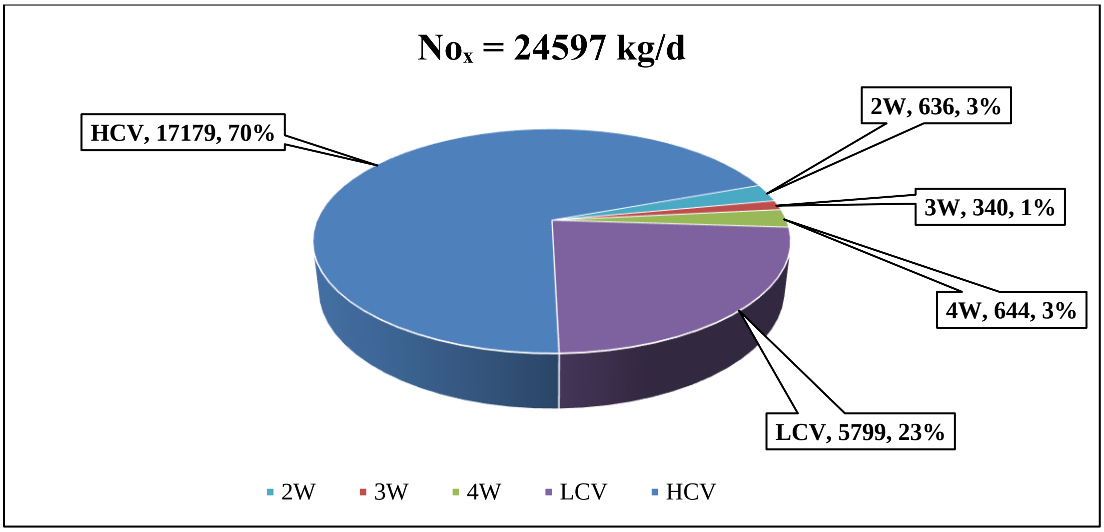


Figure 3.72: NO_x Emission Load contribution of each vehicle type (kg/d)

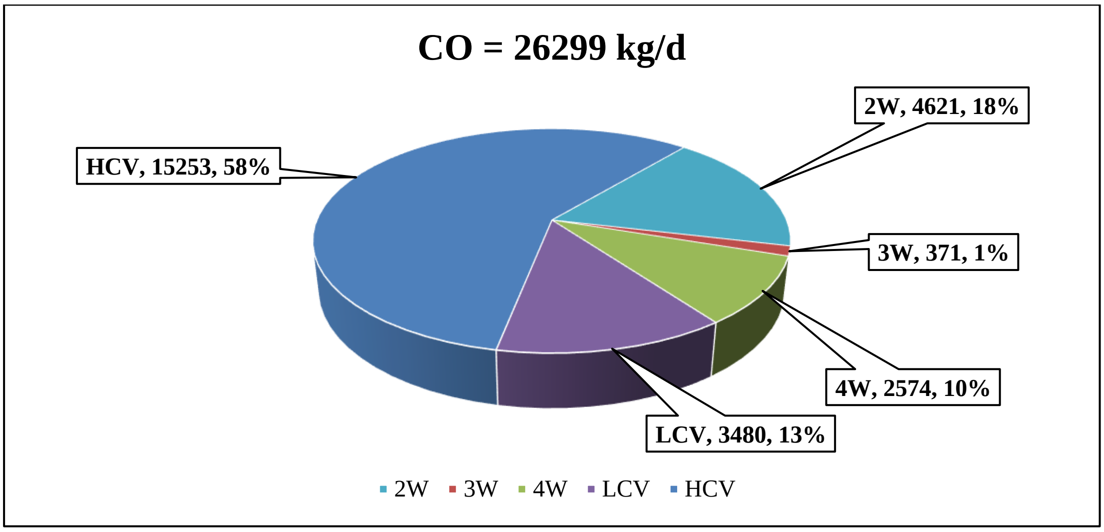


Figure 3.73: CO Emission Load contribution of each vehicle type (kg/d)

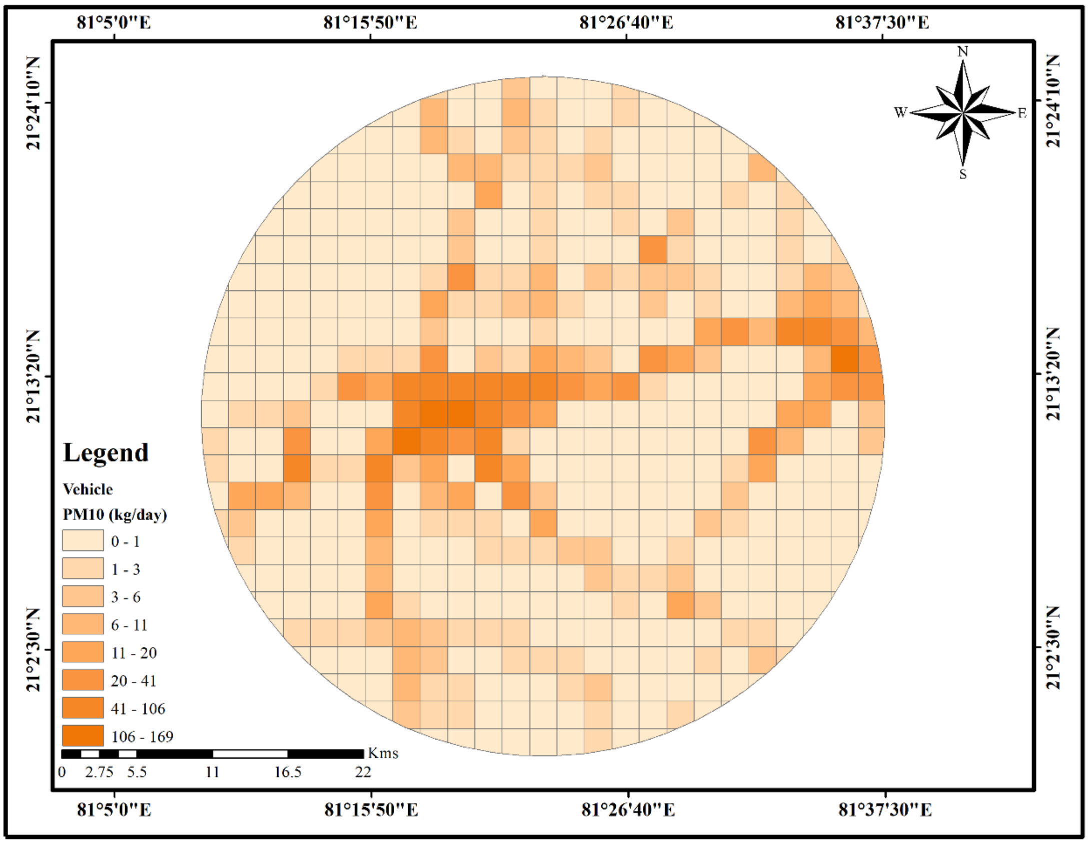


Figure 3.74: Spatial Distribution of PM_{10} Emissions from Vehicles

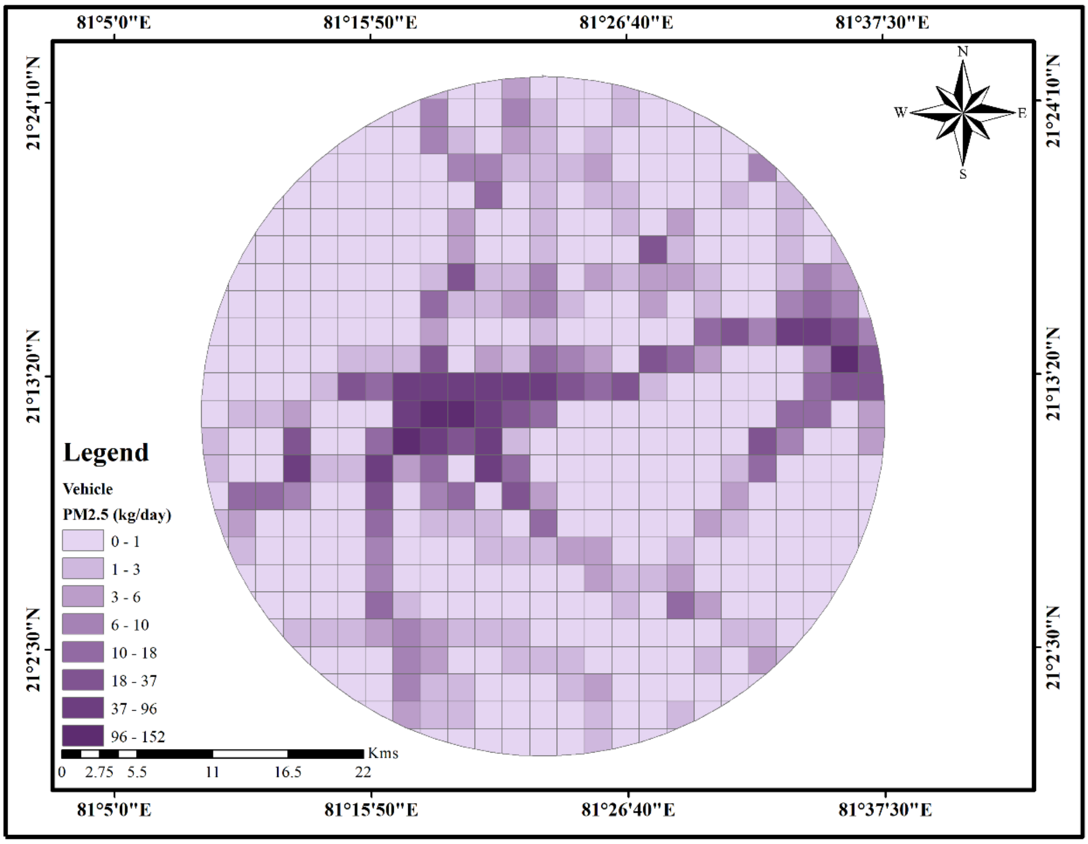


Figure 3.75: Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles

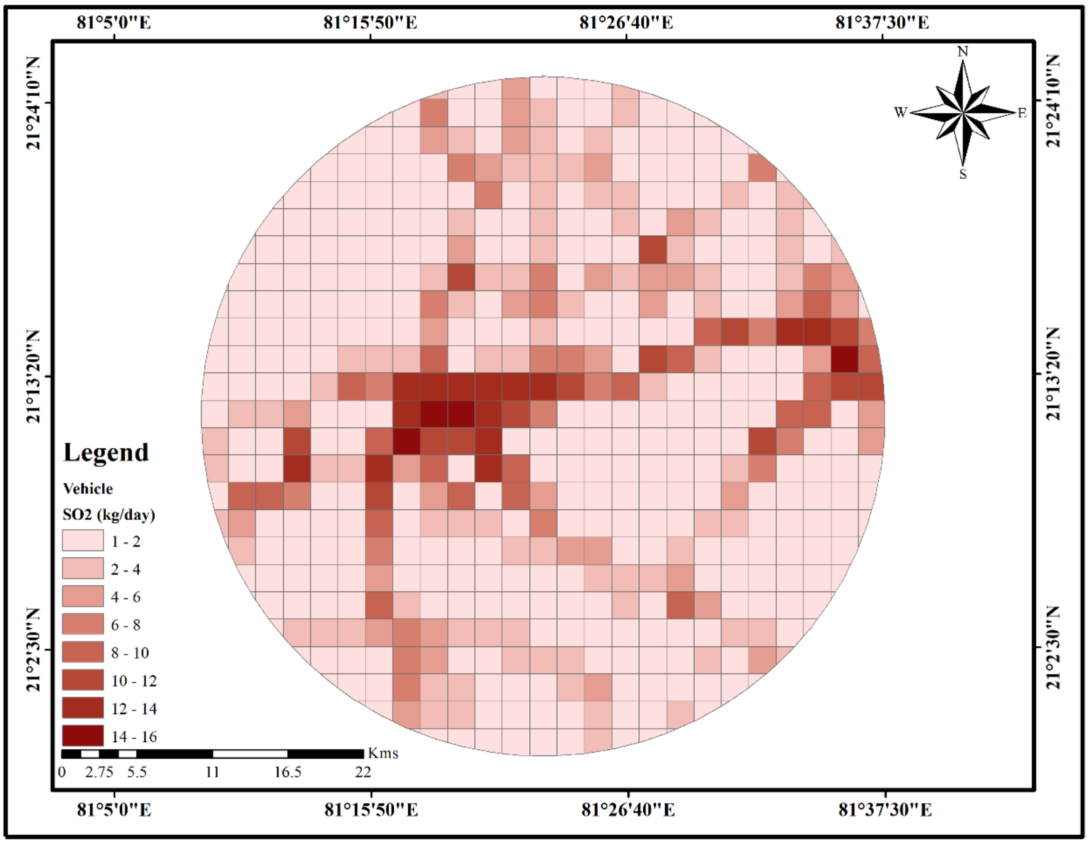


Figure 3.76: Spatial Distribution of SO_2 Emissions from Vehicles

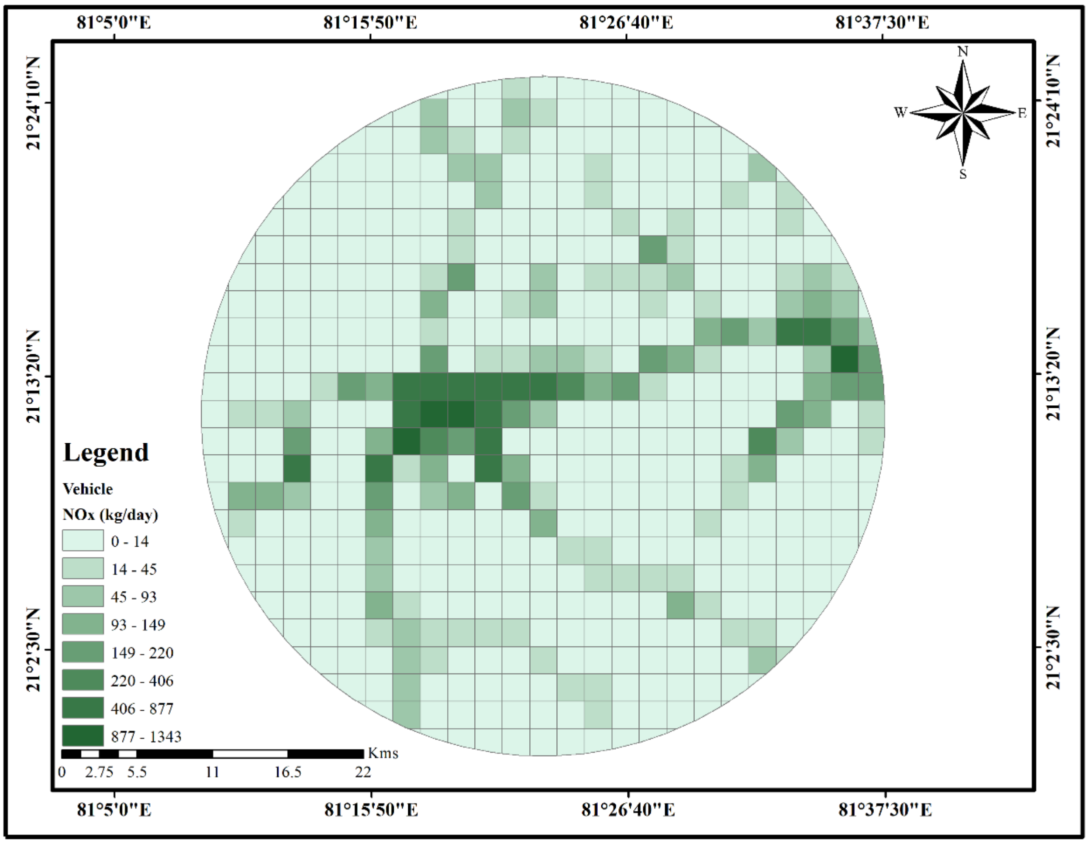


Figure 3.77: Spatial Distribution of NO_x Emissions from Vehicles

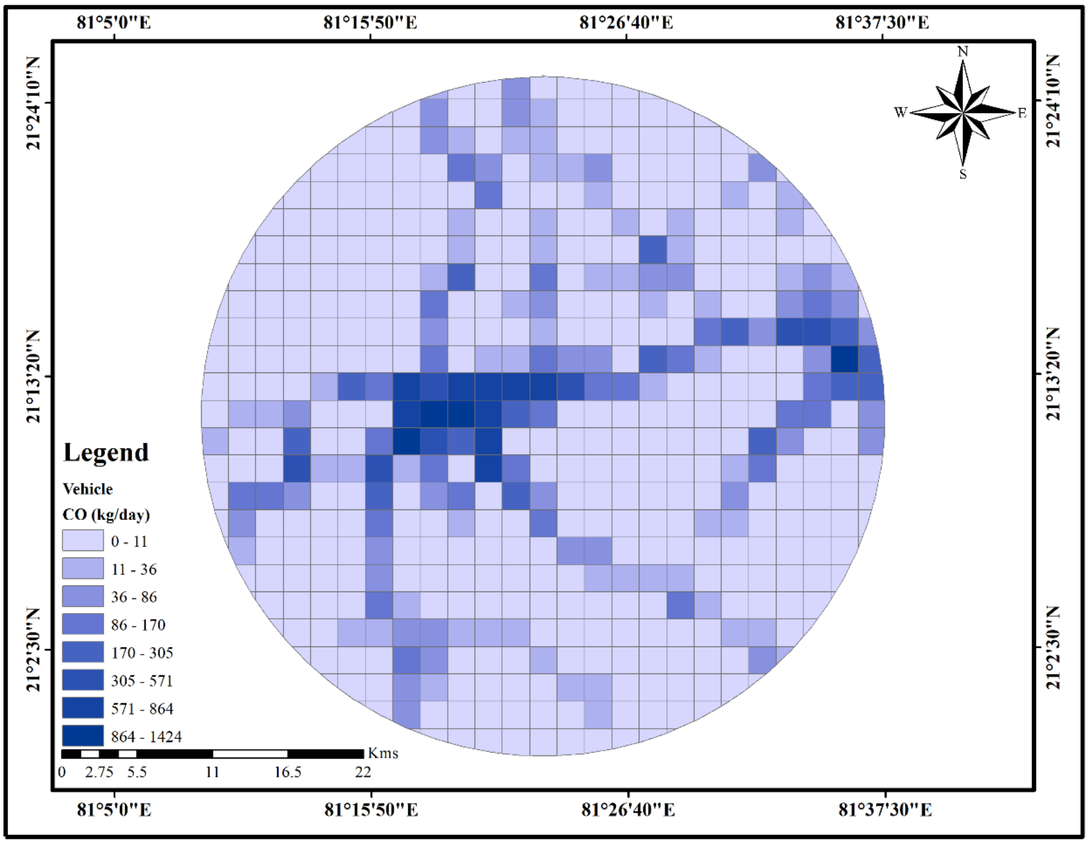


Figure 3.78: Spatial Distribution of CO Emissions from Vehicles

3.2.14 Traffic Congestion

Bhilai is a city in Durg district of the Indian state of Chhattisgarh, in eastern central India. Along with its twin city Durg, the urban agglomeration of Durg-Bhilainagar has a population of more than a million, making it the second-largest urban area in Chhattisgarh after Raipur. Bhilai is a major industrial city as well as an education hub of central India. The Bhilai metropolis contains three municipal corporations: Bhilai Municipal Corporation, Bhilai-Charoda, Municipal Corporation and Risali Municipal Corporation.

The twin city of Durg-Bhilai is well connected with a network of national and state highways. Some major highways passing through the city are National Highway 53 (NH-53), SH-7 till Bemetara and SH-22 till Abhanpur. The proposed Durg–Raipur–Arang Expressway will start from Durg and will pass near the outskirts of Bhilai till Arang, which after completion, will enhance connectivity and commute in the state.

There is a total of 15 railway stations in the twin city including railway stations serving adjacent and minor neighbourhoods within the city.

The typical Traffic conditions at different locations in Bhilai are given in Figure 3.79. The figure depicts the traffic report of Bhilai for two traffic hotspots of the city for the 7 days of the week. The colour coding used here is Red, Orange, and Green, indicating the slow traffic to fast traffic movement. Acc Chowk, Atal Chowk, Tatibandhan, Nankatti Minor, Patan Road, and Maharana Pratap Chowk are some of the major bottleneck points in the city (Table 3.2).

Table 3.2: Major Traffic Bottleneck Points

Acc Chowk	Atal Chowk	Tatibandh chowk
Nankatti Minor	Patan Road	Maharana Pratap Chowk

DAY	**Acc Chowk**	**Atal Chowk**	**Bharat Mata Chowk**	**Gada Chowk**	**Jail Tira**
Sunday	🟩 8am-10am	🟥 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2
	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6
	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8
Monday	🟩 8am-10am	🟧 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12
	🟥 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2
	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4
	🟥 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8
Tuesday	🟧 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟧 10am-12pm	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2
	🟩 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8
Wednesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12
	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2
	🟥 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6
	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8
Thursday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12
	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2
	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4
	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6
	🟥 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8
Friday	🟧 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12
	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm	🟩 12pm-2
	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6
	🟥 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8
Saturday	🟧 8am-10am	🟥 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10
	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2
	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6
	🟥 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8

DAY	Jawahar Nehru Park	Maharana Pratap Chowk	Murmunda Chowk	Nadnrani Chowk	Nankatti Minor
Sunday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12p
	🟩 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2p
	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm
	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Monday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟥 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟥 10am-12p
	🟩 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2p
	🟩 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm
	🟩 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟩 6pm-8pm
Tuesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12p
	🟩 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2p
	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm
	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Wednesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12p
	🟩 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2p
	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm
	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Thursday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12p
	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2p
	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm
	🟩 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟩 6pm-8pm
Friday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟥 10am-12p
	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2p
	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm
	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Saturday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟩 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12p
	🟩 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2p
	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm
	🟩 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm

DAY	Raipura Chowk	Rajnandgaon Road	Shiv Para	Shivaji Chowk	Smriti nagar
Sunday	🟩 8am-10am	🟧 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm
	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm
	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Monday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm
	🟧 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm
	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Tuesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm
	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm
	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Wednesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm
	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm
	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Thursday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
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	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
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Friday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
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	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm
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	🟧 6pm-8pm	🟩 6pm-8pm	🟩 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Saturday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm
	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm
	🟧 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm
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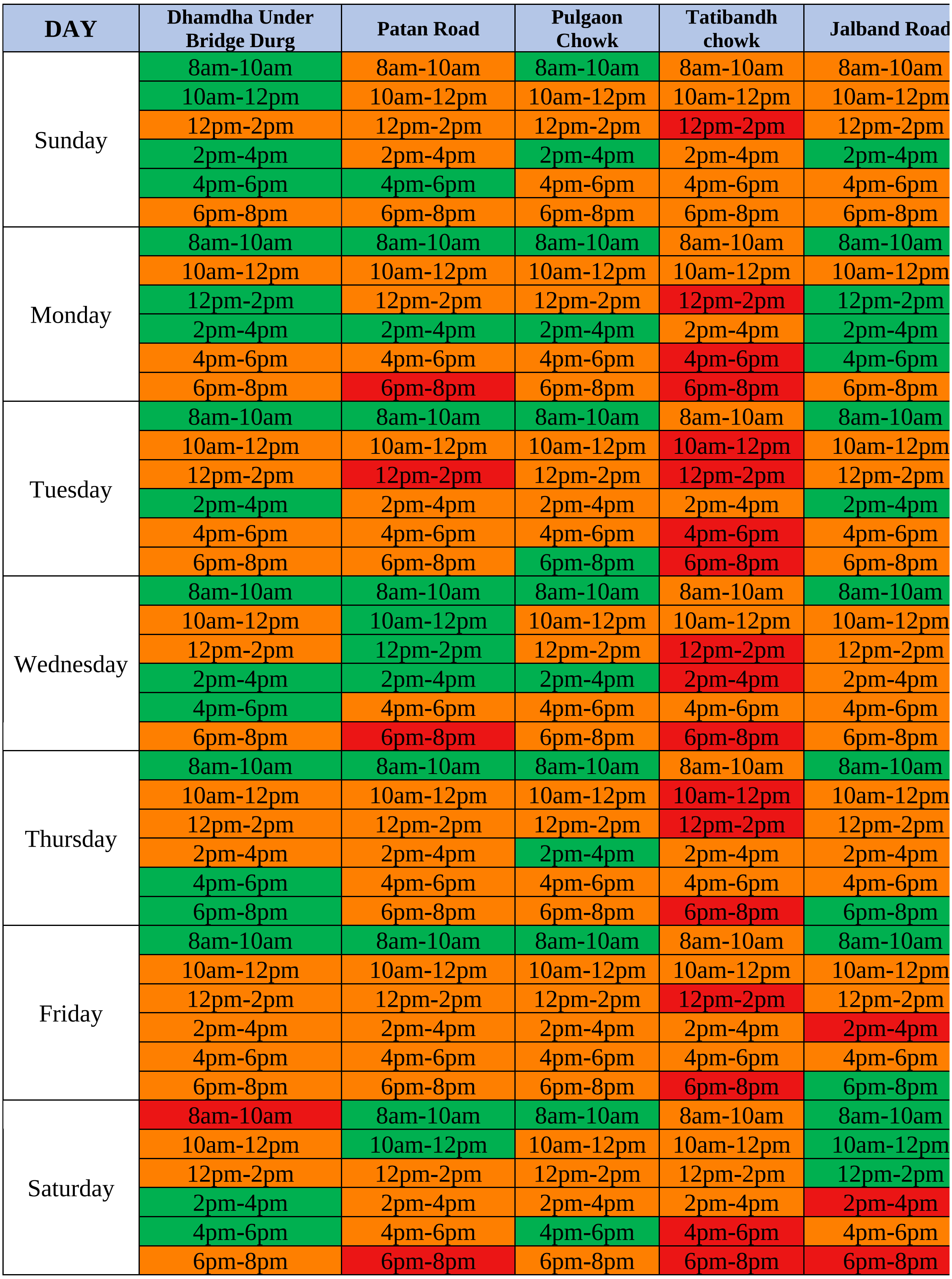


DAY	**Dhamdha Under Bridge Durg**	**Patan Road**	**Pulgaon Chowk**	**Tatibandh chowk**	**Jalband Road**
Sunday	🟩 8am-10am	🟧 8am-10am	🟧 8am-10am	🟧 8am-10am	🟧 8am-10am
	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm
	🟩 4pm-6pm	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm
Monday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟩 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟩 12pm-2pm
	🟩 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟩 4pm-6pm
	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
Tuesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟩 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
Wednesday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟩 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
	🟩 2pm-4pm	🟩 2pm-4pm	🟩 2pm-4pm	🟥 2pm-4pm	🟧 2pm-4pm
	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm
Thursday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟥 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
	🟧 2pm-4pm	🟧 2pm-4pm	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm
	🟩 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟩 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟩 6pm-8pm
Friday	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟧 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟥 12pm-2pm	🟧 12pm-2pm
	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm
	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟧 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟩 6pm-8pm
Saturday	🟥 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am	🟩 8am-10am
	🟧 10am-12pm	🟩 10am-12pm	🟧 10am-12pm	🟧 10am-12pm	🟩 10am-12pm
	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟧 12pm-2pm	🟩 12pm-2pm
	🟩 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟧 2pm-4pm	🟥 2pm-4pm
	🟩 4pm-6pm	🟧 4pm-6pm	🟩 4pm-6pm	🟥 4pm-6pm	🟧 4pm-6pm
	🟧 6pm-8pm	🟥 6pm-8pm	🟧 6pm-8pm	🟥 6pm-8pm	🟥 6pm-8pm

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

Figure 3.79: Typical Traffic conditions at different locations in Bhilai city

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 traveling on the road. Silt loading (sL) refers to the mass of the silt-size 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:

$$E_{ext} = k\,(sL/2)^{0.65}\,(W/3\,)^{1.5}\,(1\text{-}1.2P/N) \qquad \text{……. (Eq.4)}$$

Where;

E = emission from road dust (kg/d)

sL = road surface silt loading (grams per square meter) (g/m^2), and

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

k = constant (a function of particle size) in g VKT^{-1} (vehicle kilometre travel)

P=number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period

N = number of days in the averaging period

The road dust sampling was carried out at Twenty locations (Figure 3.80). The silt loads (sL) sampling as an example, is shown for two locations (Figure 3.81). 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 the emission rate (g VKT^{-1}) was calculated. The emission loads from paved and unpaved roads were calculated using Eq. 4 and shown in Figure 3.82. The spatial distribution of Emissions from Road Dust Re-suspension is presented in Figure 3.83 and Figure 3.84.

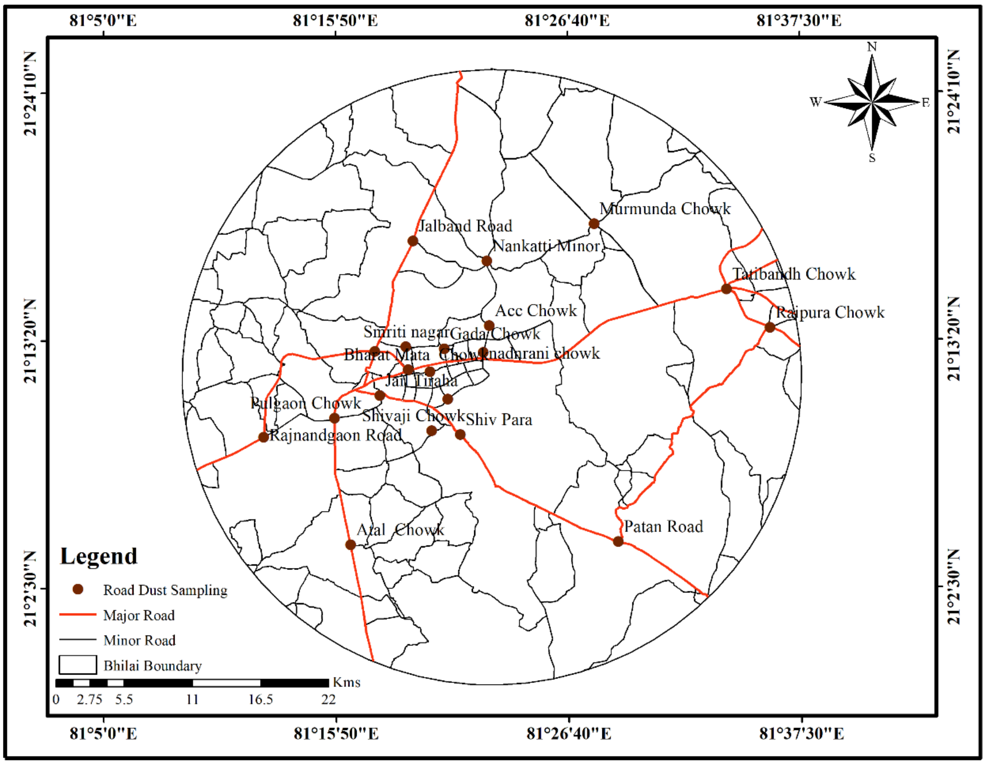


Figure 3.80: Road Dust Sampling Locations

Figure 3.81: Road Dust Sampling in the City of Bhilai

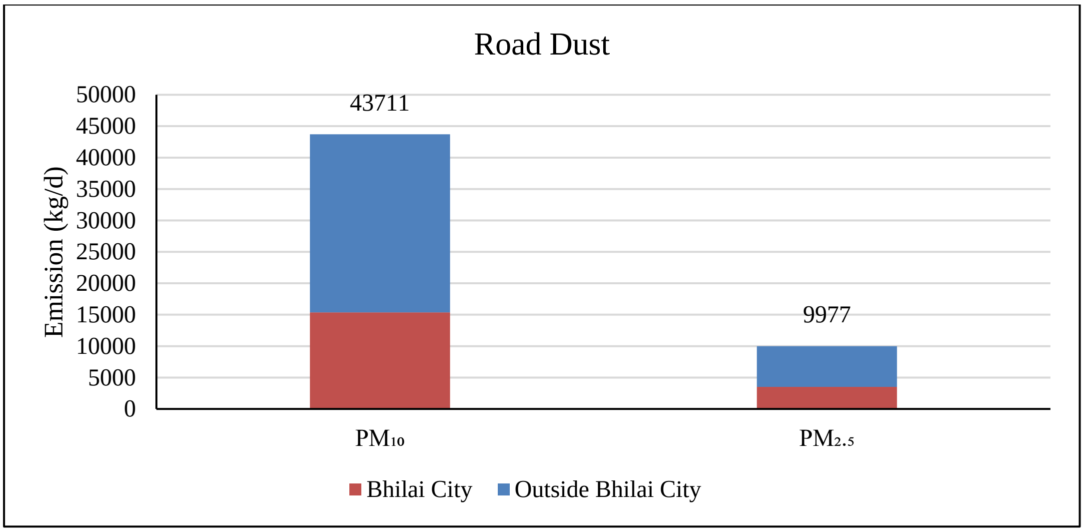


Figure 3.82: Emissions from Road Dust in Bhilai (Kg/d)

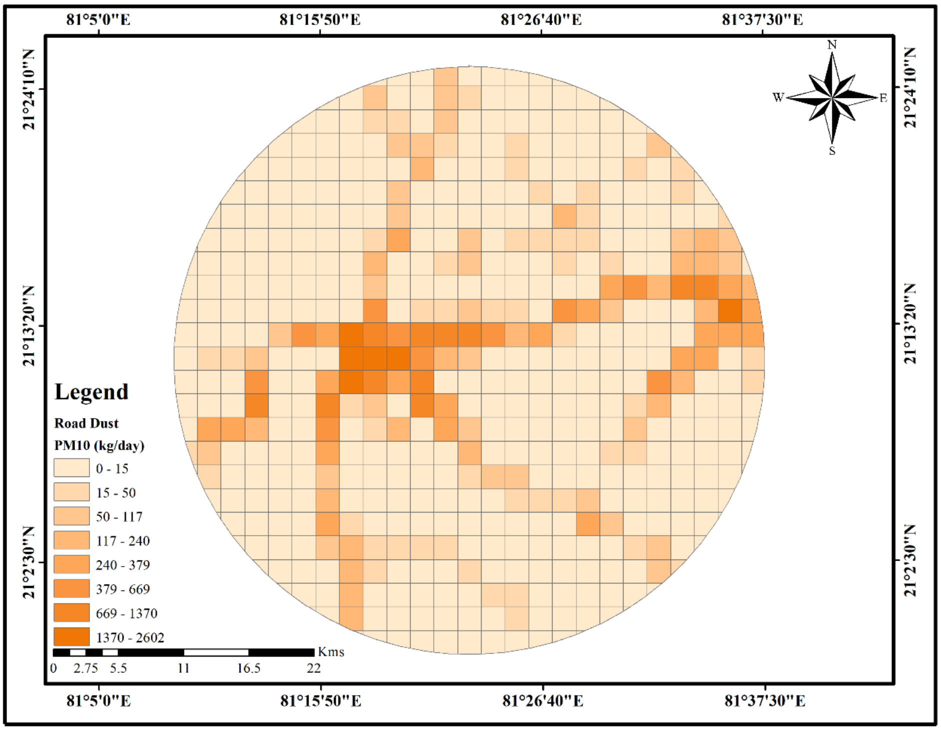


Figure 3.83: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

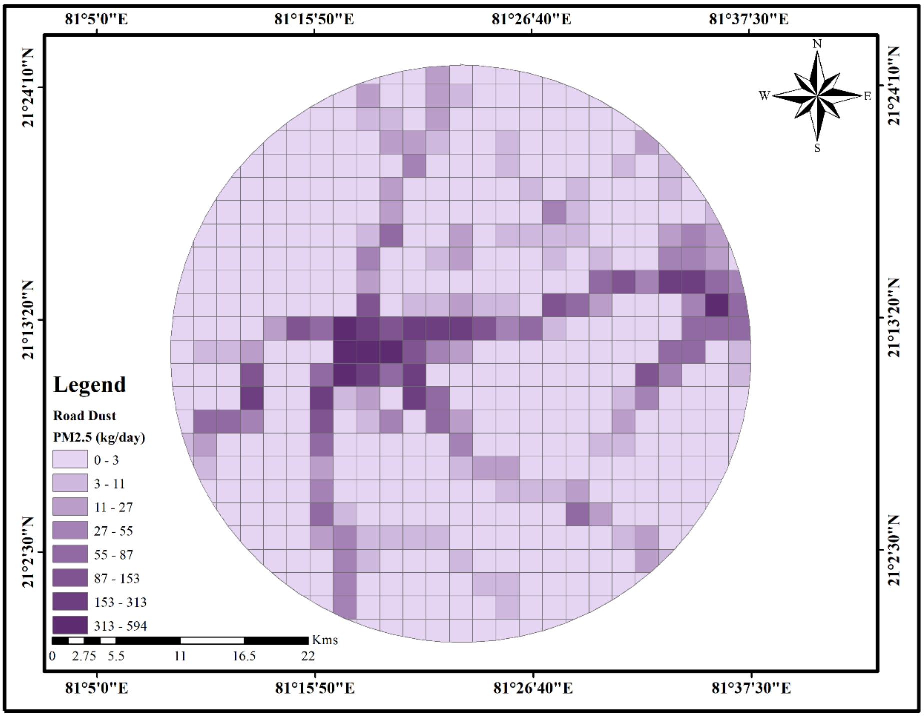


Figure 3.84: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

3.3 Bhilai City-Level Emission Inventory

The overall baseline emission inventory for the entire Bhilai is presented in Table 3.3. The pollutant-wise contribution is shown in Figure 3.95 to Figure 3.99. The spatial distribution of pollutant emissions from all sources is illustrated in Figure 3.100 to Figure 3.104. The pollutant-wise gridded emissions are provided in Annexure 2.

Table 3.3: City-Level Inventory of Bhilai (kg/d)

SOURCES	Bhilai City Level Emission (kg/day)				
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
Construction and Demolition	1098	253			
Hotel, restaurants, BH's and GH's	275	199	181	85	470
Solid waste	526	357	33	197	2760
Road Dust	15378	3510			
Domestic	1190	877	561	521	2714
Industries	41423	25402	117750	130403	7498
Hospitals	0.2	0.2	0.2	3.2	0.7
Vehicles	1272	1144	7	9944	10967
Total	**61162**	**31742**	**118532**	**141153**	**24410**

The total PM_{10} emission load in the city is estimated to be 61 tonnes/d. The top four contributors to PM_{10} emissions are industries (68%), road dust (25%), vehicles (2%), and domestic (2%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources was required to obtain the desired air quality.

$PM_{2.5}$ emission load in the city is estimated to be 32 tonnes/d. The top four contributors to $PM_{2.5}$ emissions are industries (80%), road dust (11%), vehicles (3%) and domestic (3%); 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 119 tonnes/d. Industries (99%), domestic (0.5%), and hotel establishments (0.2%) are the main sources of SO_2 contribution.

NO_x emissions load in the city is estimated to be 141 tonnes/d. The majority of total emissions are attributed to industries (93%), vehicles (7%), and domestic (0.4%).

The estimated CO emission is about 24 tonnes/d. The major contributors to CO emissions are vehicles (45%), industries (31%), domestic (11%), and solid waste (11%).

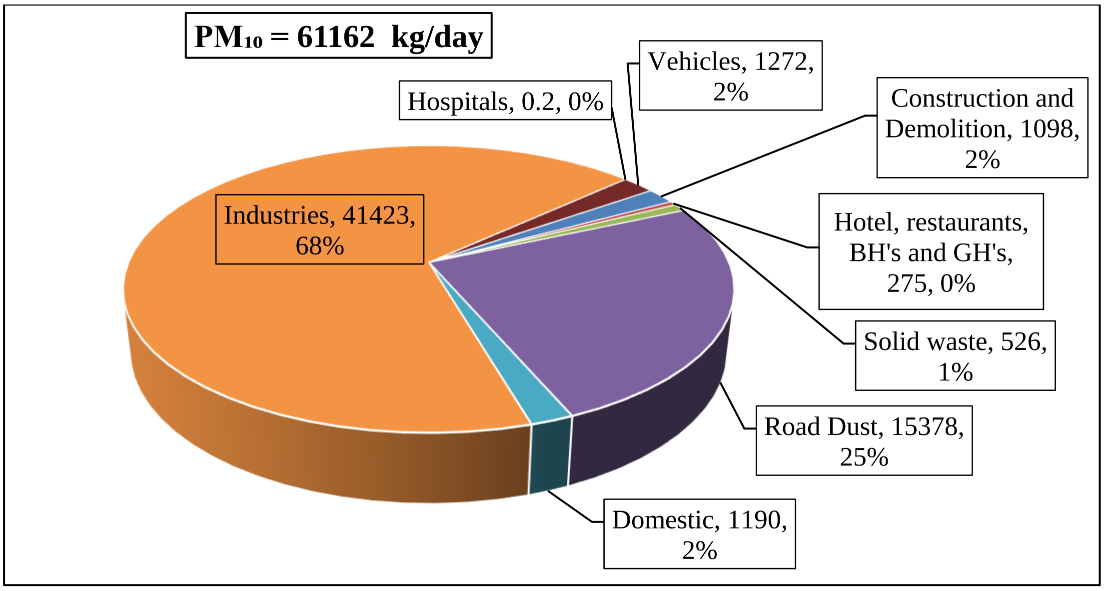


Figure 3.85: PM_{10} Emission Load Contribution of Different Sources

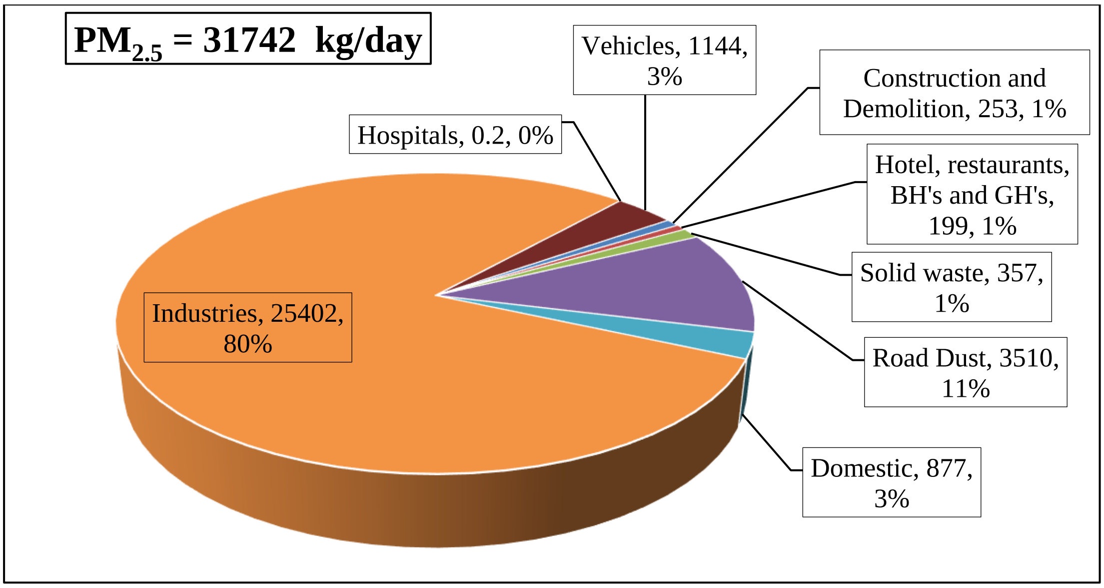


Figure 3.86: $PM_{2.5}$ Emission Load Contribution of Different Sources

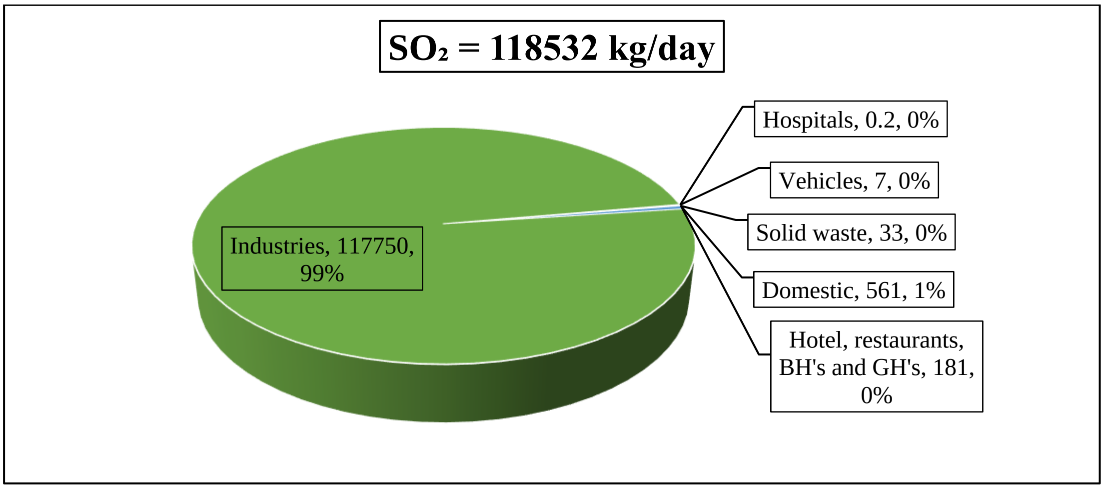


Figure 3.87: SO_2 Emission Load Contribution of Different Sources

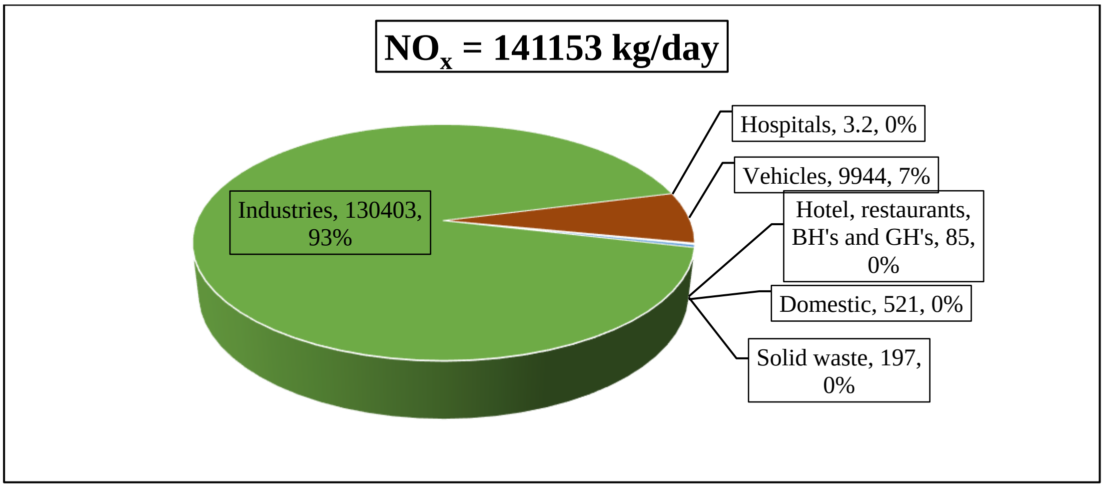


Figure 3.88: NO_x Emission Load Contribution of Different Sources

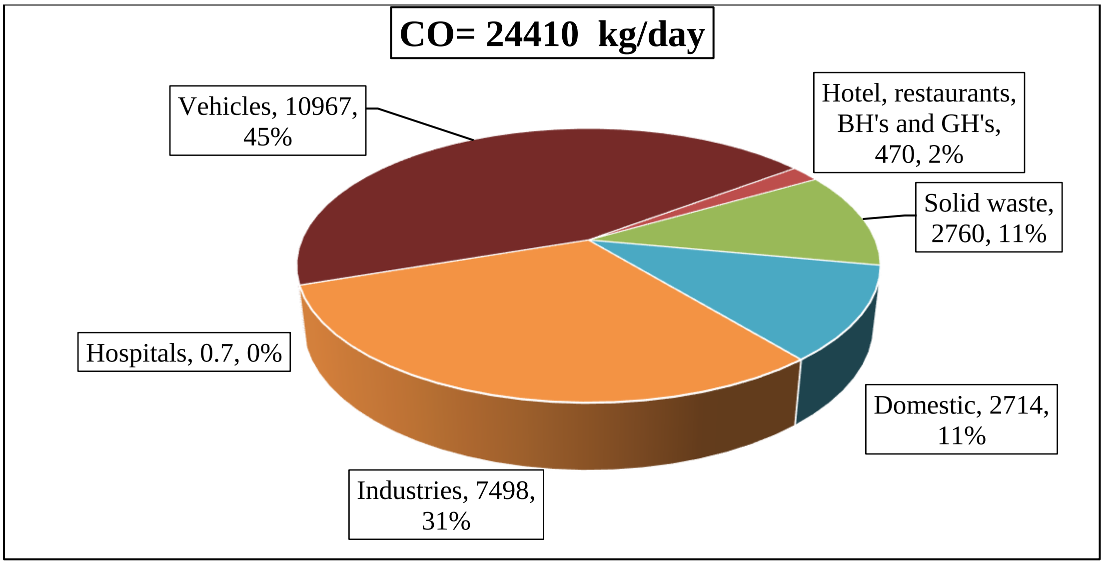


Figure 3.89: CO Emission Load Contribution of Different Sources

3.4 Outside City-Level Emission Inventory

The overall baseline emission inventory for the outside city-level inventory of Bhilai 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 illustrated in Figure 3.100 to Figure 3.104. The pollutant-wise gridded emissions are provided in Annexure 2.

Table 3.4: Outside City-Level Inventory (kg/d)

SOURCES	Outside City Level Emission (kg/day)				
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
Construction and Demolition	1771	407			
Hotel, restaurants, BH's and GH's	371	268	244	115	634
Solid waste	1365	928	85	512	7168
Road Dust	28333	6467			
Domestic	4266	3086	1543	1599	14677
Industries	18652	5591	33068	36465	854
Hospitals	0.2	0.2	0.2	3.2	0.7
Vehicles	1866	1679	10	14653	15331
Brick Kiln	4628	3240	6065	1819	11364
Total	**61252**	**21666**	**41015**	**55166**	**50029**

The total PM_{10} emission load outside city is estimated to be 61 tonnes/d. The top three contributors to PM_{10} emissions are road dust (46%), industries (30%), and brick kilns (8%); 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 was required to obtain the desired air quality.

$PM_{2.5}$ emission load outside city is estimated to be 22 tonnes/d. The top three contributors to $PM_{2.5}$ emissions are road dust (30%), industries (26%), and brick kilns (15%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

SO_2 emission load outside city is estimated to be 41 tonnes/d. Industries (81%), brick kilns (15%), and domestic (4%) are the main sources of SO_2 contribution.

NO_x emissions load outside city is estimated to be 55 tonnes/d. The majority of total emissions are attributed to industries (66%), vehicles (27%), and brick kilns (3%).

The estimated CO emission is about 50 tonnes/d. The major contributors to CO emissions are vehicles (31%), domestic (29%), and brick kilns (23%).

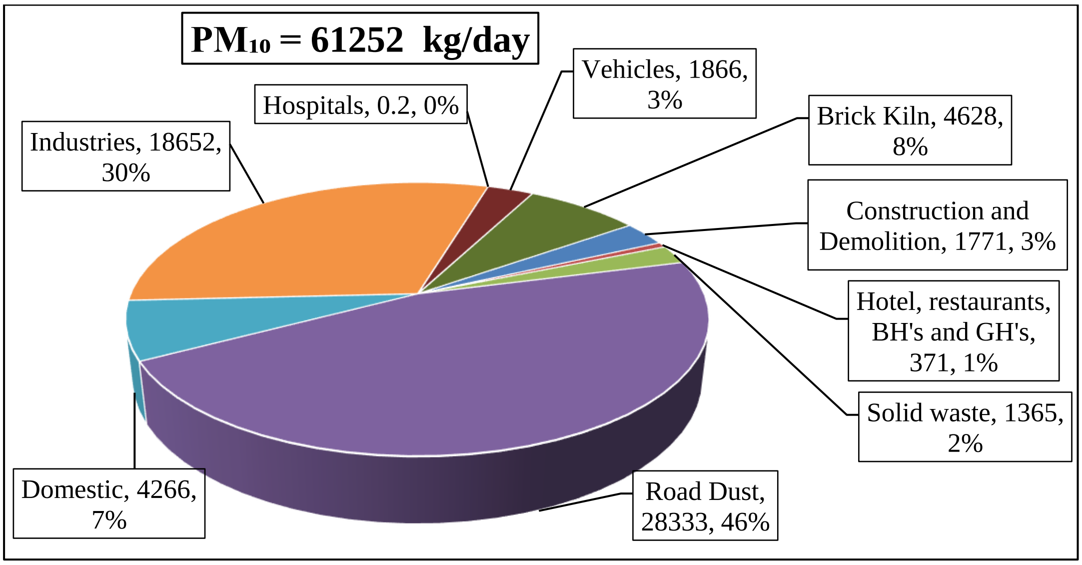


Figure 3.90: PM_{10} Emission Load Contribution of Different Sources

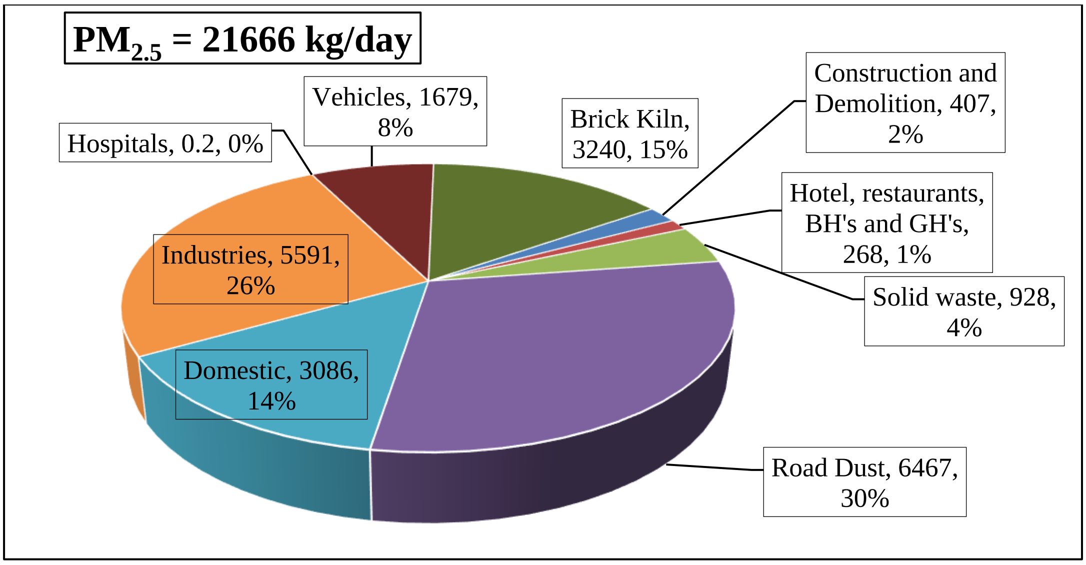


Figure 3.91: $PM_{2.5}$ Emission Load Contribution of Different Sources

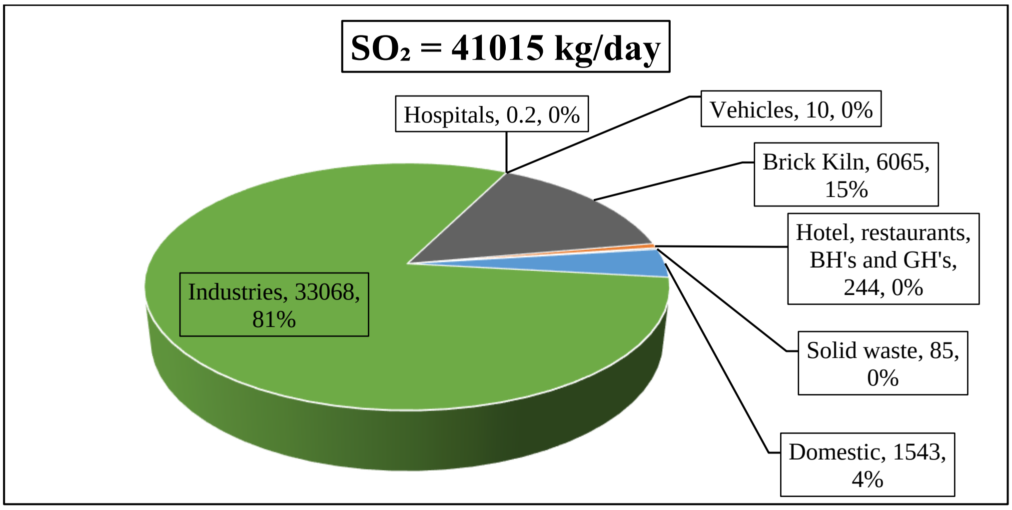


Figure 3.92: SO_2 Emission Load Contribution of Different Sources

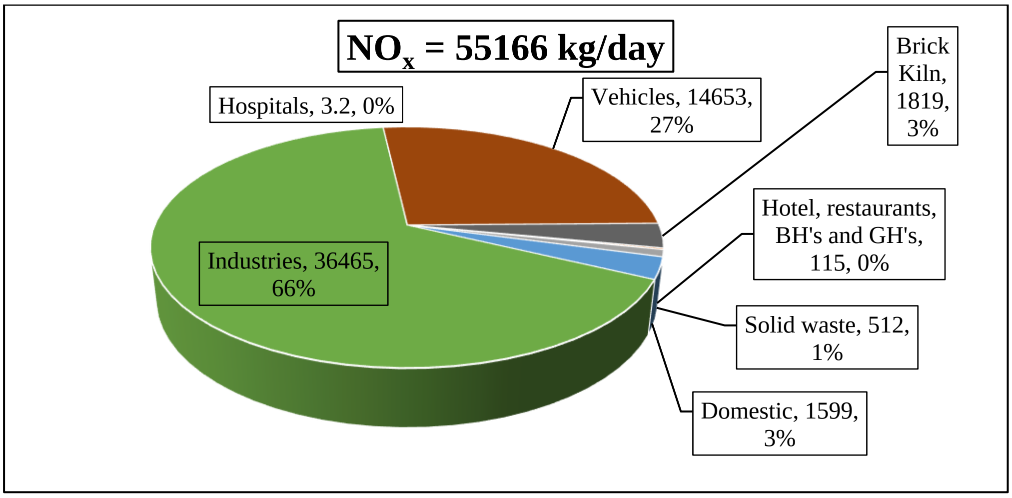


Figure 3.93: NO_x Emission Load Contribution of Different Sources

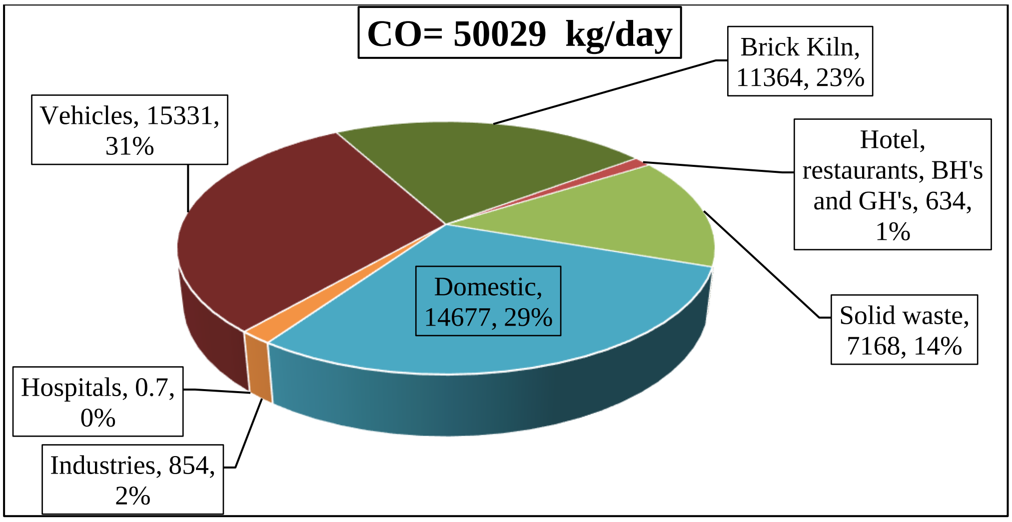


Figure 3.94: CO Emission Load Contribution of Different Sources

3.5 Combined Emission Inventory

The overall baseline emission inventory for the entire Bhilai region (in the radius of 25 km from Bhilai Steel Plant) is presented in Table 3.5. The pollutant-wise contribution is shown in Figure 3.95 to Figure 3.99. The spatial distribution of emissions from different sources is illustrated in Figure 3.100 to Figure 3.104. The pollutant-wise gridded emissions are provided in Annexure 2.

Table 3.5: Combined Emission Inventory of Study Area (kg/d)

SOURCES	Combined Level Emission (kg/day)				
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
Construction and Demolition	2869	660			
Hotel, restaurants, BH's and GH's	645	467	425	200	1104
Solid Waste	1891	1286	118	709	9927
Road Dust	43711	9977			
Domestic	5456	3963	2104	2120	17391
Industries-Others	20995	7090	66868	75066	3479
Industries-BSP	39080	23903	83950	91802	4873
Industrial DG Sets	0.02	0.02	0.02	0.34	0.07
Hospitals	0.50	0.40	0.40	6.4	1.4
Vehicles	3138	2824	16	24597	26299
Brick Kiln	4628	3240	6065	1819	11364
Total	**122414**	**53410**	**159546**	**196320**	**74438**

The total PM_{10} emission load in the study area is estimated to be 122 tonnes/d. The top four contributors to PM_{10} emissions are industries (49%; break-up: Bhilai Steel Plant (BSP), 32% and others 17%), road dust (36%), brick kilns (4%), and domestic (4%); these are based on annual emissions. Seasonal and daily emissions could be variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources is required to obtain the desired air quality.

$PM_{2.5}$ emission load in the study area is estimated to be 53 tonnes/d. The top four contributors to $PM_{2.5}$ emissions are industries (58%; break up: BSP: 45% and others: 13%), road dust (19%), domestic (8%), and bick kilns (6%); these are based on annual emissions. Seasonal and daily emissions could be variable depending on the activities in progress.

SO_2 emission load in the study area is estimated to be 160 tonnes/d. Industries (95%; break-up: BSP: 53% and others: 42%), brick kilns (4%), and domestic (1%) are the main sources.

NO_x emissions load in the study area is estimated to be 196 tonnes/d. The majority of total emissions are attributed to industries (85%; break-up BSP: 47% and others: 38%), vehicles (13%), and domestic (1%).

The estimated CO emission is 74 tonnes/d. The major contributors to CO emissions are vehicles (35%), domestic (23%), and brick kilns (15%).

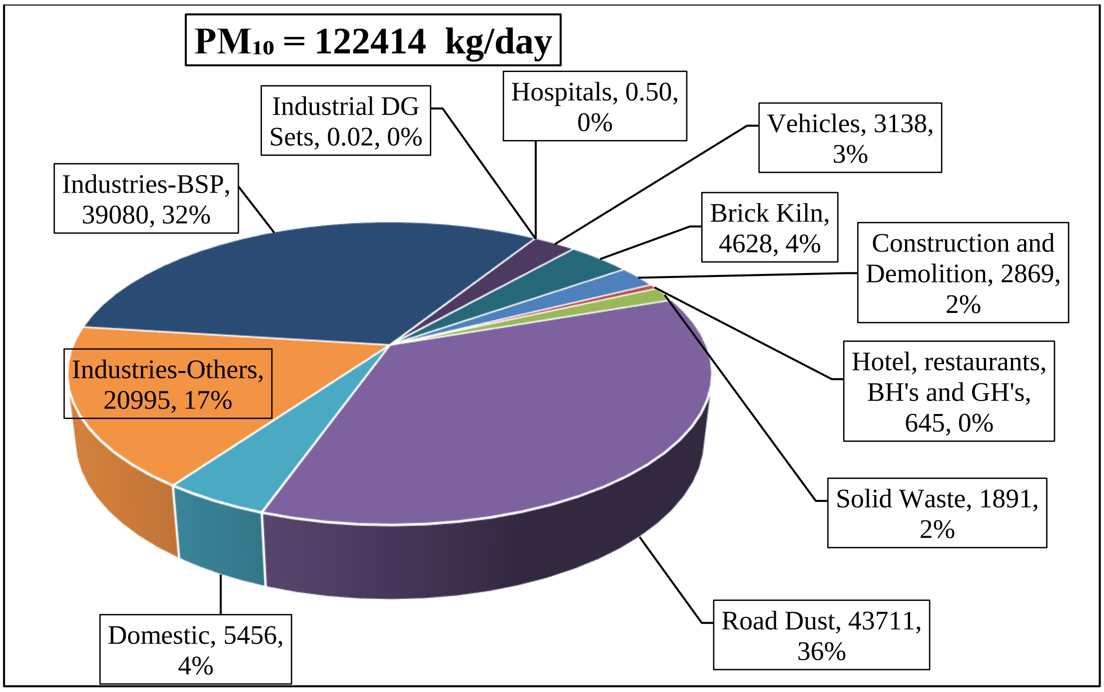


Figure 3.95: PM_{10} Emission Load Contribution of Different Sources

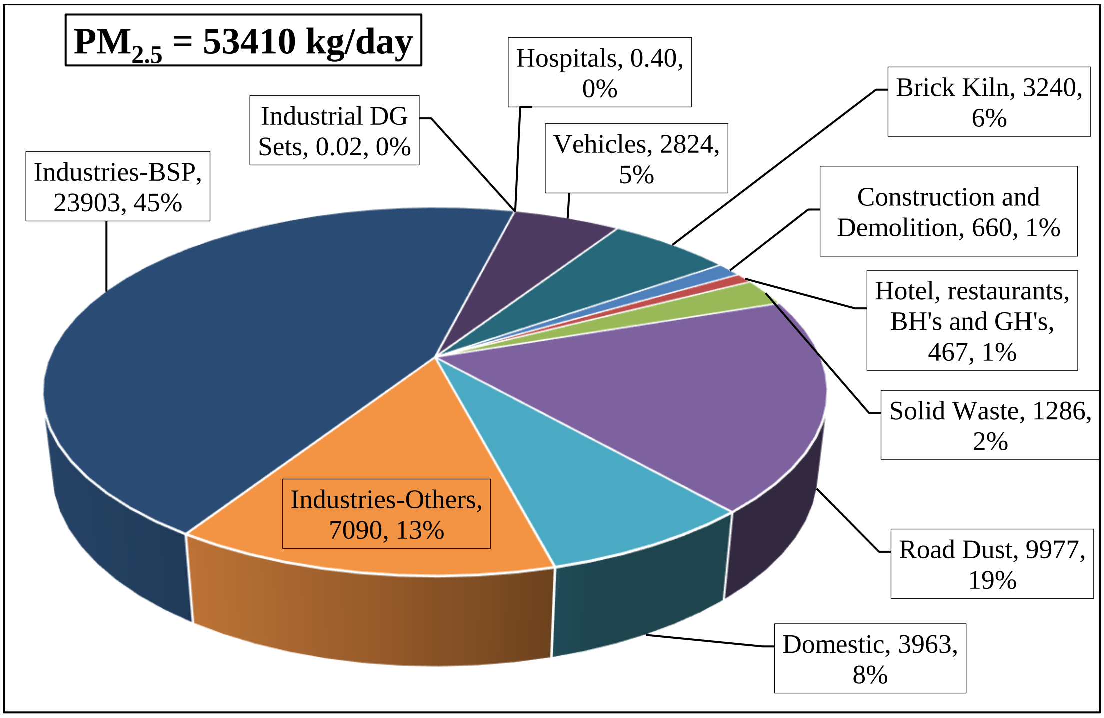


Figure 3.96: $PM_{2.5}$ Emission Load Contribution of Different Sources

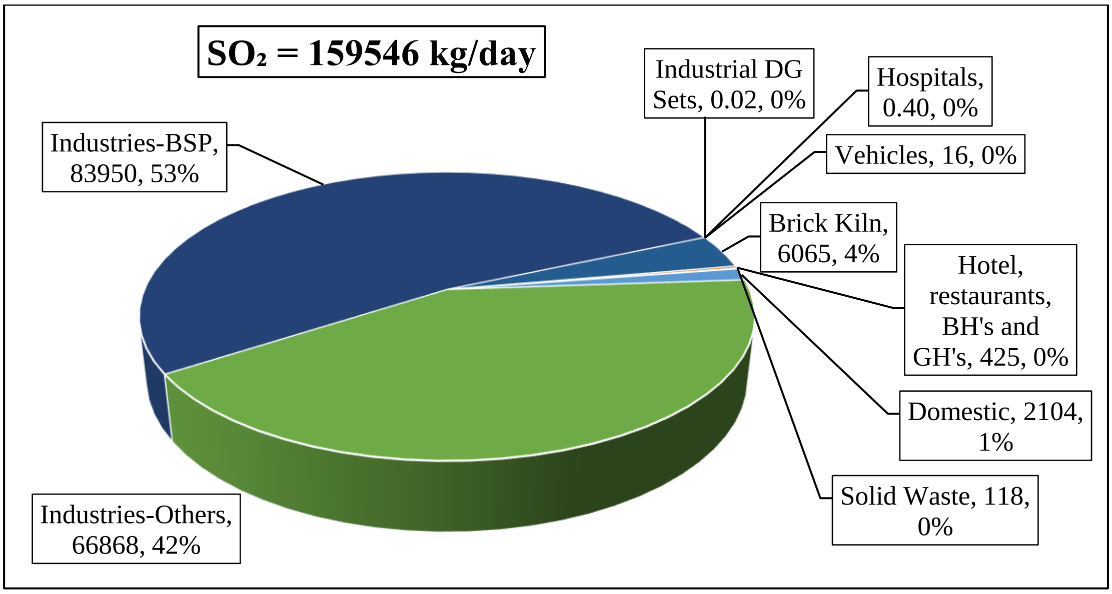


Figure 3.97: SO_2 Emission Load Contribution of Different Sources

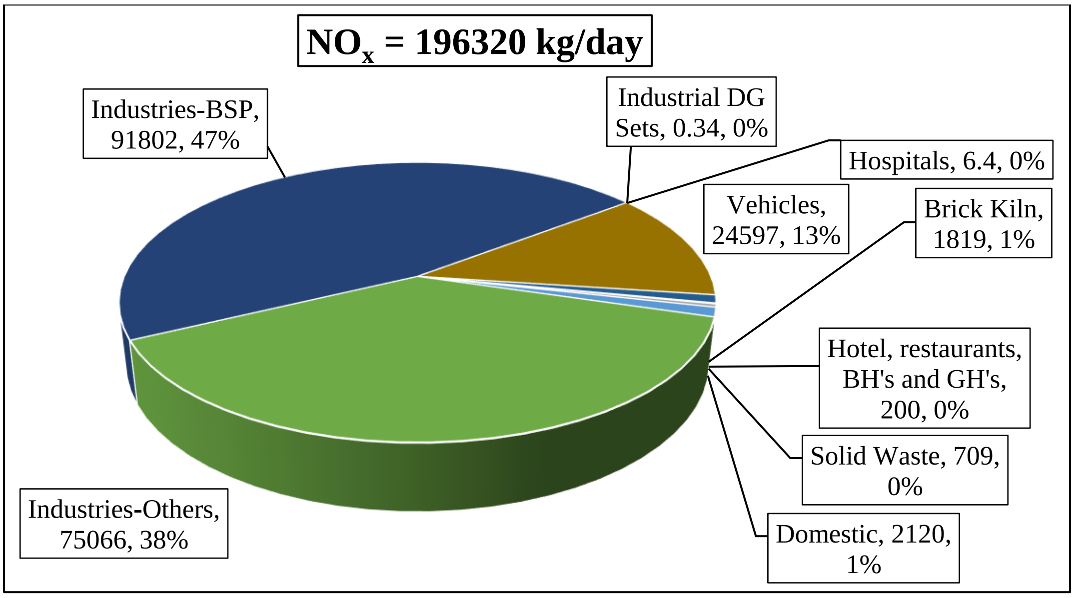


Figure 3.98: NO_x Emission Load Contribution of Different Sources

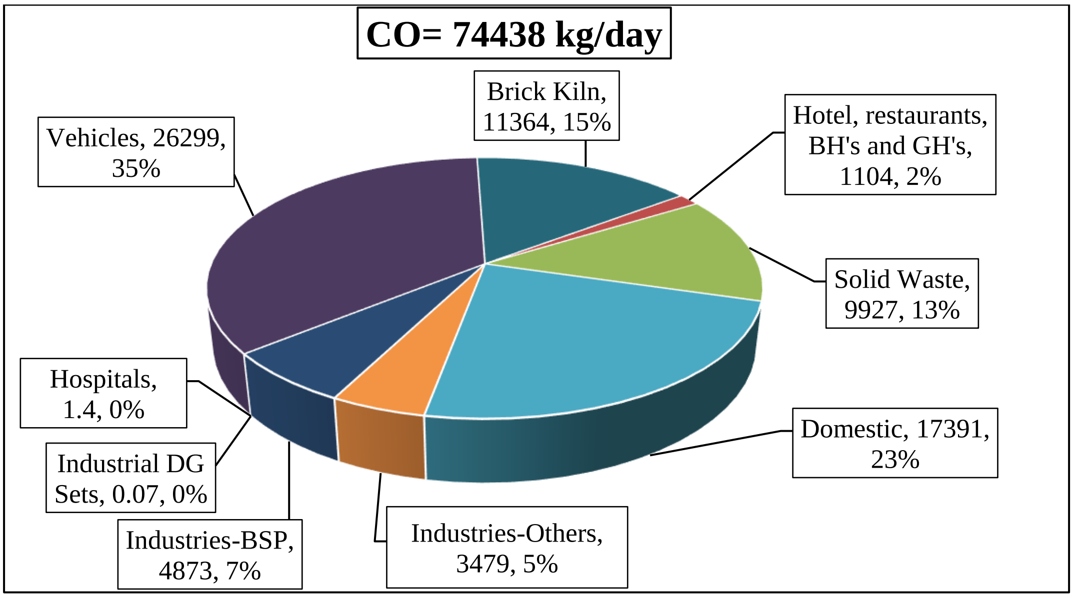


Figure 3.99: CO Emission Load Contribution of Different Sources

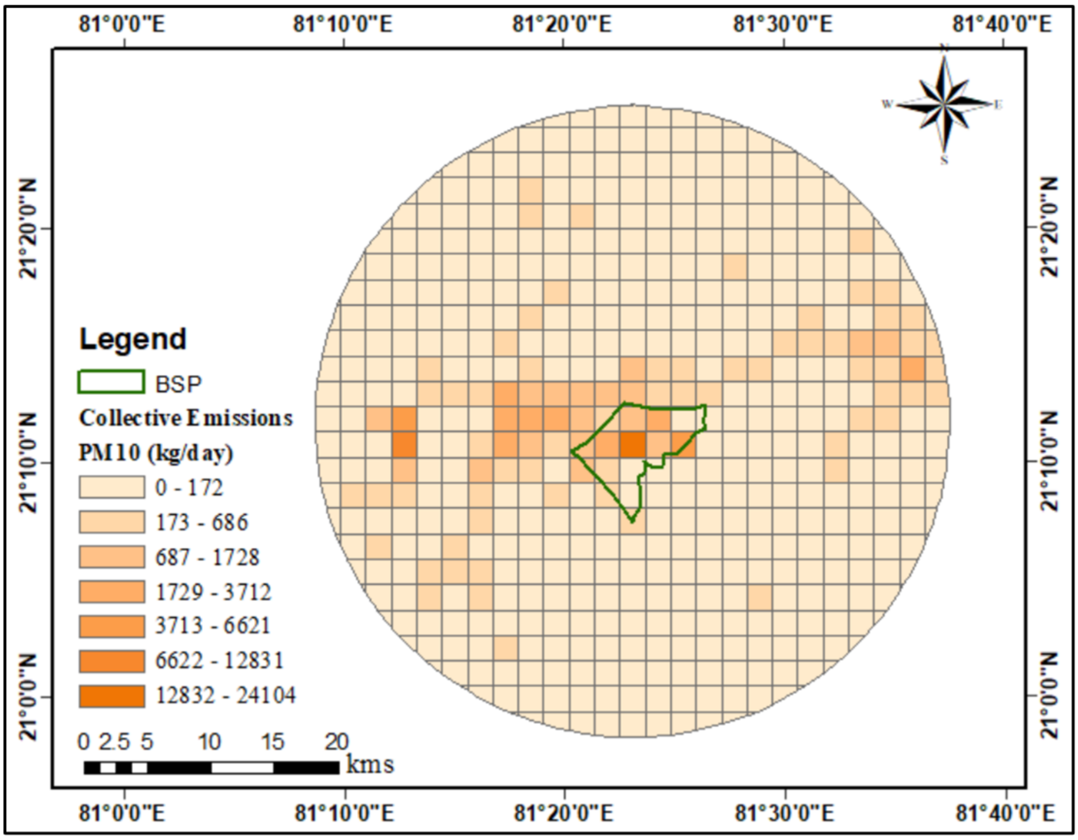


Figure 3.100: Spatial Distribution of PM_{10} Emissions in Bhilai

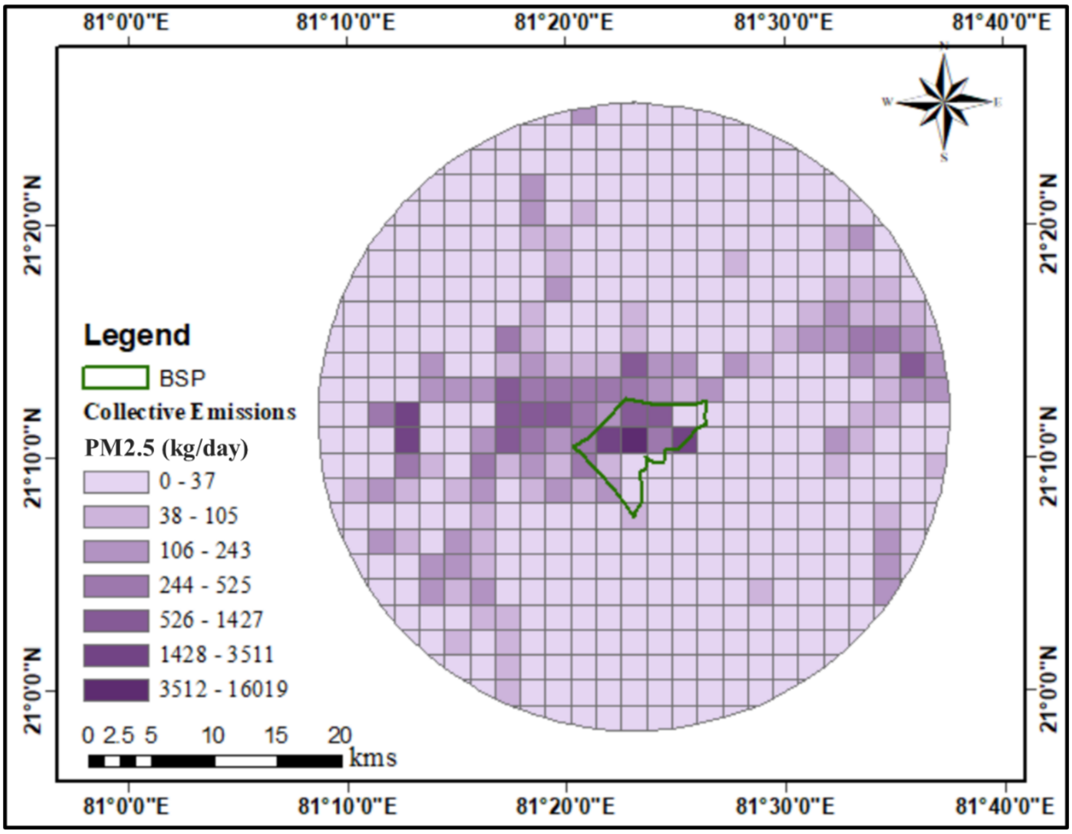


Figure 3.101: Spatial Distribution of $PM_{2.5}$ Emissions in Bhilai

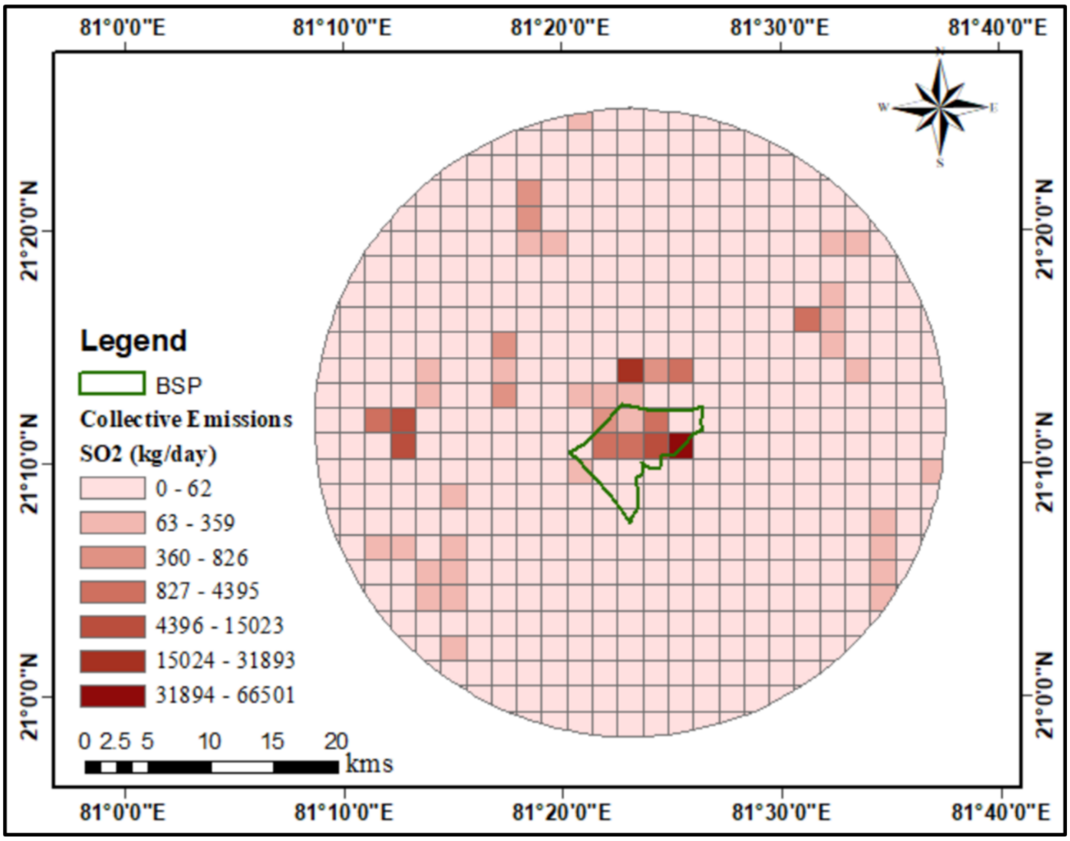


Figure 3.102: Spatial Distribution of SO_2 Emissions in Bhilai

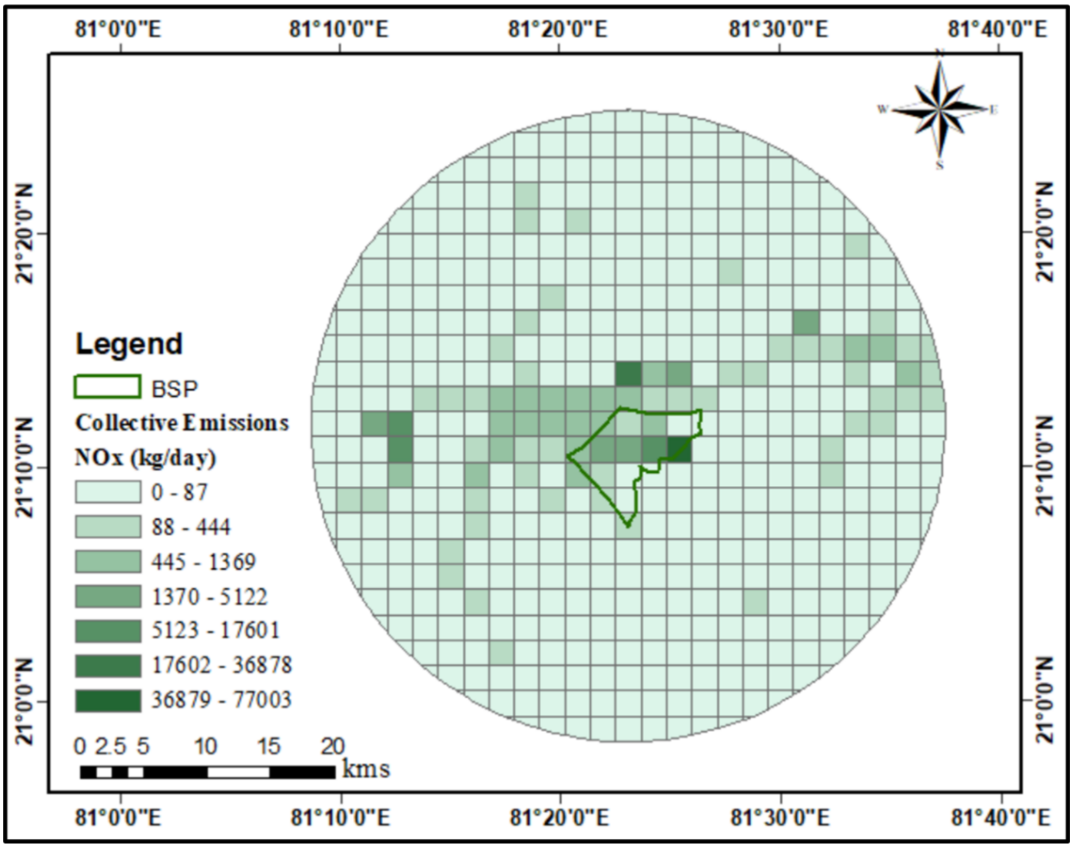


Figure 3.103: Spatial Distribution of NO_x Emissions in Bhilai

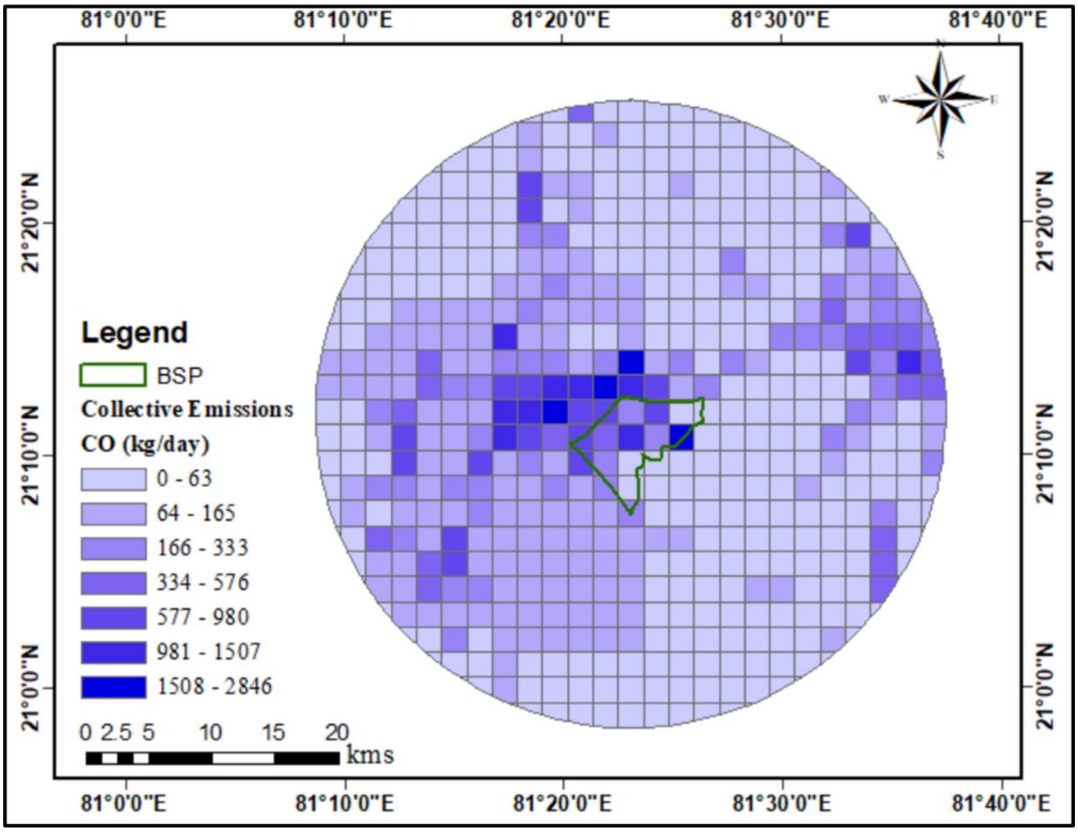


Figure 3.104: Spatial Distribution of CO Emissions in Bhilai

4 Receptor Modelling and Source Apportionment

4.1 Receptor Modeling

In a complicated urban atmosphere, identifying and quantifying 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 adopt the source reductions of environmental pollutants. There are two types of modeling approaches to establishing 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 statistical.

CMB modeling is preferred if source profiles are known. In this Chapter, CMB technique has been attempted to fully understand contribution of each source to ambient air PM_{10} and $PM_{2.5}$ concentrations. Positive matrix factorization (PMF) was used to get the first-hand information about possible sources in the study area. However, 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 for quantitative source composition data (Watson et al., 1994). The CMB method assumes that there is linearity in 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 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 CMB 8.2 is developed by USEPA (2004).

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

Since for $PM_{2.5}$, Indian or city-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 Bhilai 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 three seasons (summer, winter, and post-monsoon) 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 0.60 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 the interpretation of results and to indicate how the sources located upwind of Bhilai could impact air quality in Bhilai.

4.3 CMB Modeling Results and Interpretation

It may be noted that vehicular sources include all vehicles powered by gasoline, diesel and diesel uses in DG sets. 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 co-linearity in source profiles. In addition, LPG from domestic cooking is also the part of vehicular emission due co-linearity in profiles.

Solid waste burning and organic waste burning (residential garbage, paper, plastics, dried leaves etc.) are referred together as “Waste Burning”.

Fly ash, contributing from both industry (using coal and fly ash as combustion fuels) and cement (during construction) is included in the category “coal combustion”.

Biomass burning includes agricultural residue, plant leaves, wood and dung cake. Biomass burning is a regional issue, mostly contributing from outside the city and creating a significant background. It is also observed that biomass burning emissions can also come from industries using boilers which use Dolachar coal. The industrial contribution excludes coal combustion and flyash.

4.3.1 Kripal Nagar, Kohka (KRNK)

4.3.1.1 Winter Season [sampling period: Dec 12 – Dec 26, 2020]

PM_{10} (winter)

The average PM_{10} concentration was 216 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 over 15 days) in terms of concentration and percentage respectively at KRNK. Table 4.1 presents summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was vehicular emissions (61 µg/m^3 ~ 28.0%) followed by coal and flyash (49 µg/m^3 ~ 22.8%). The other major sources are soil and road dust (34 µg/m^3 ~ 15.9%), industrial emission (24 µg/m^3 ~ 11.2%), waste burning (18 µg/m^3 ~ 8.2%), secondary inorganic aerosols (SIA; 13 ~ 6.2%) and construction (4.9 %) and biomass burning (2.9%).

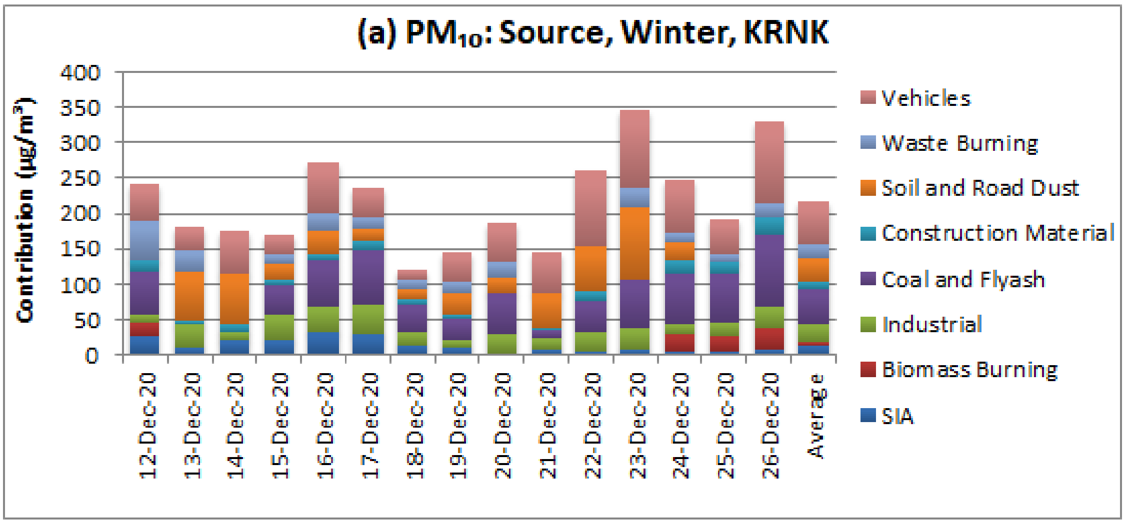
$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 129 µg/m^3 (i.e., about 0.60 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 15 days) in terms of concentration and percentage respectively at KRNK. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emissions (41 µg/m^3 ~ 30.8%) followed by soil and road dust (24 µg/m^3 ~ 18.5%). The other major sources are coal and flyash (20 µg/m^3 ~ 15.6%), industrial emission (18 µg/m^3 ~ 13.9%), SIA (9 µg/m^3 ~ 6.9%), waste burning (6.3 µg/m^3 ~ 4.8%), construction (4.8%) and biomass burning (4.5%). The Industrial emissions exclude coal combustion.

HYSPLIT back trajectories (Figure 4.3) indicate that wind is flowing from North and NE direction. Winds can pick up the pollutants on the way from neighboring districts especially from large sources (e.g., crop residue burning (CRB)) and tall emitting sources but these contributions have not been quantifying.

Inferences

- The vehicular emission has major contribution (28% for PM_{10} and 31% for $PM_{2.5}$) to the PM at KRNK.
- Coal and flyash contribute significantly to PM_{10} and $PM_{2.5}$ (23% for PM_{10} and 16% for $PM_{2.5}$).
- Soil and road dust contribute substantially to PM_{10} and $PM_{2.5}$ (16% for PM_{10} and 18% for $PM_{2.5}$).
- Industrial contribution is significant in PM_{10} and $PM_{2.5}$ (11% for PM_{10} and 14% for $PM_{2.5}$).
- The secondary particles contribute to PM_{10} (6%) and $PM_{2.5}$ (7%). These particles are expected to be sourced 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 waste burning contribution is significant. It is clearly seen that waste burning is one of the major sources that contributes to PM_{10} and $PM_{2.5}$. This emission is expected to be large from regions of economically lower strata of society which do not have proper infrastructure for collection and disposal of solid waste.



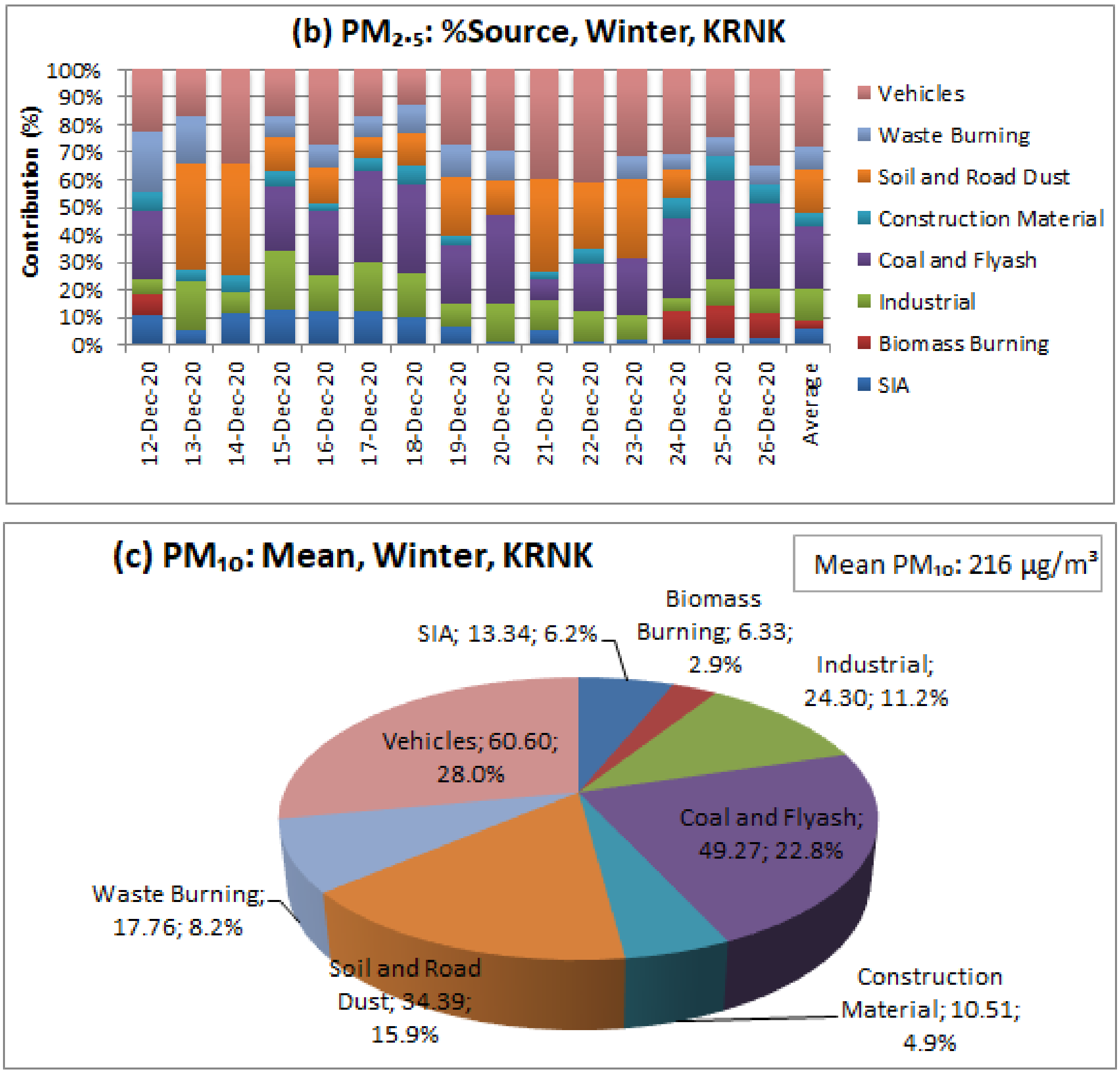
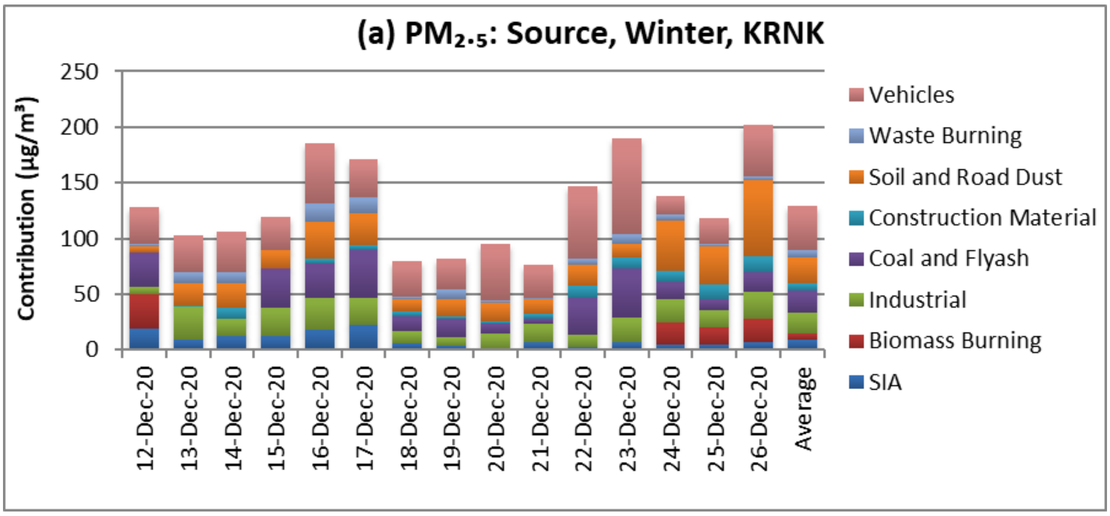


Figure 4.1: CMB modeling for PM$_{10}$ at KRNK for winter season



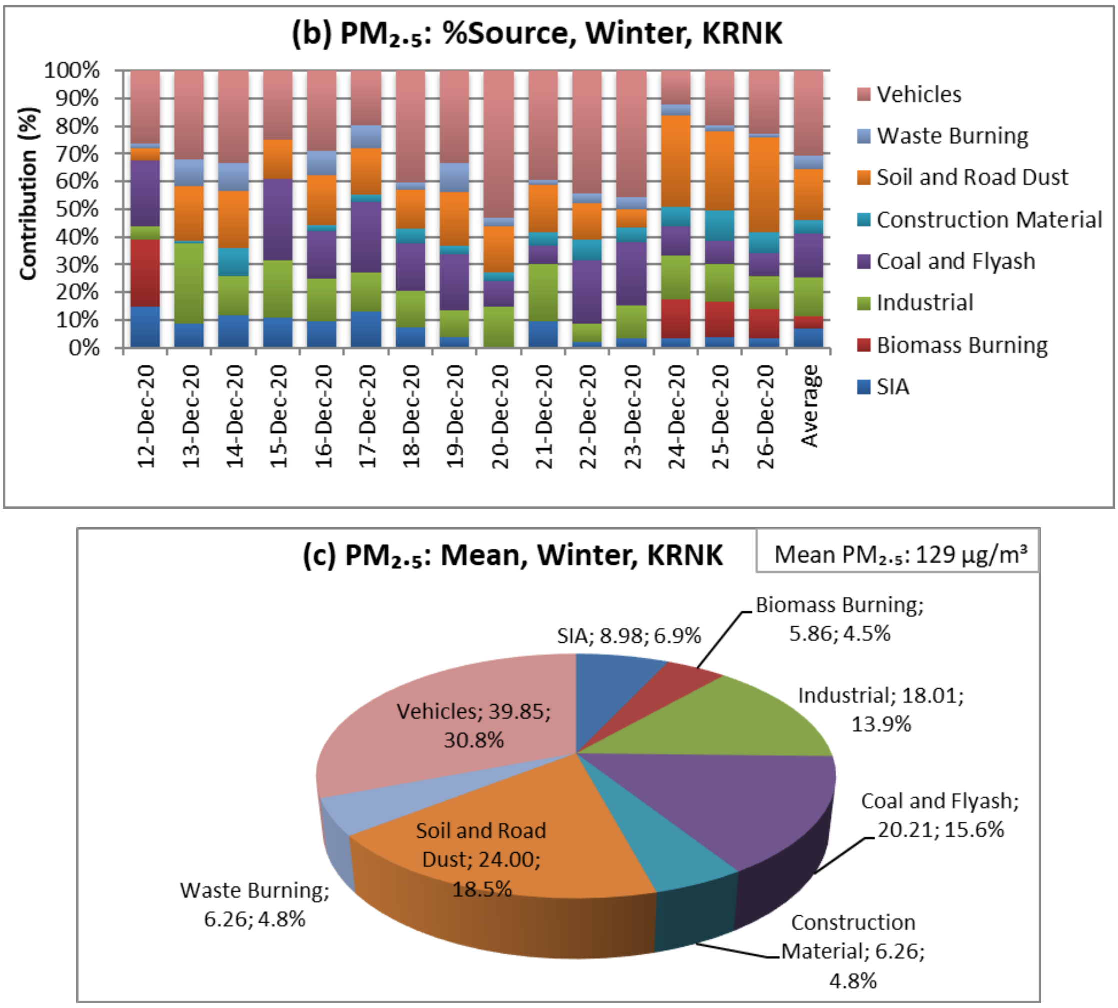


Figure 4.2: CMB modeling for $PM_{2.5}$ at KRNK for winter season

Table 4.1: Statistical summary: KRNK, winter season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	216	218	100.9	0.78	129	134	103.7	0.76
SD	67	68	4.0	0.08	42	43	5.8	0.09
CV	0.31	0.31	0.04	0.10	0.33	0.32	0.06	0.13
Maximum	347	350	108.6	0.92	202	203	116.8	0.88
Minimum	122	118	96.1	0.58	75	74	98.1	0.55

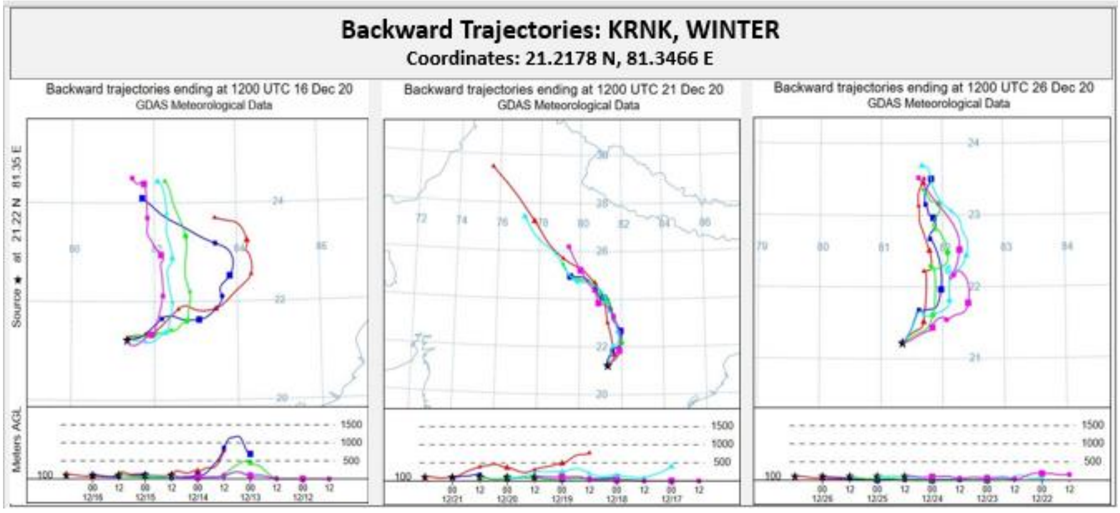


Figure 4.3: Backward trajectories at KRNK for winter season

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

PM_{10} (summer)

The average PM_{10} concentration was 205 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 15 days) in terms of concentration and percentage respectively at KRNK. Table 4.2 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was coal and flyash (54 µg/m^3 ~ 26.5%) followed by soil and road dust (47 µg/m^3 ~ 22.9%) and biomass burning (38 µg/m^3 ~ 18.6%). Other significant sources are SIA (24 µg/m^3 ~ 11.6%), vehicular emission (20 µg/m^3 ~ 9.7%), construction material (6.1%) and waste burning (4.3%) in PM_{10}. Contribution of the industry was estimated to be less than 1 % in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 106 µg/m^3; the $PM_{2.5}$/PM_{10} ratio is about 0.52. 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 15 days) in terms of concentration and percentage respectively at KRNK. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (26 µg/m^3 ~ 24%) followed by biomass burning (23 µg/m^3 ~ 22%). Other major sources are coal and flyash (20 µg/m^3 ~ 14%), vehicular emission (17 µg/m^3 ~ 16%), SIA (8.9%), waste burning (5.4%) and construction material (5.1%). The contribution of the industry was estimated to be less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.6) show that wind is not stable in any direction and wind mass travels over neighbouring districts before entering into Bhilai. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

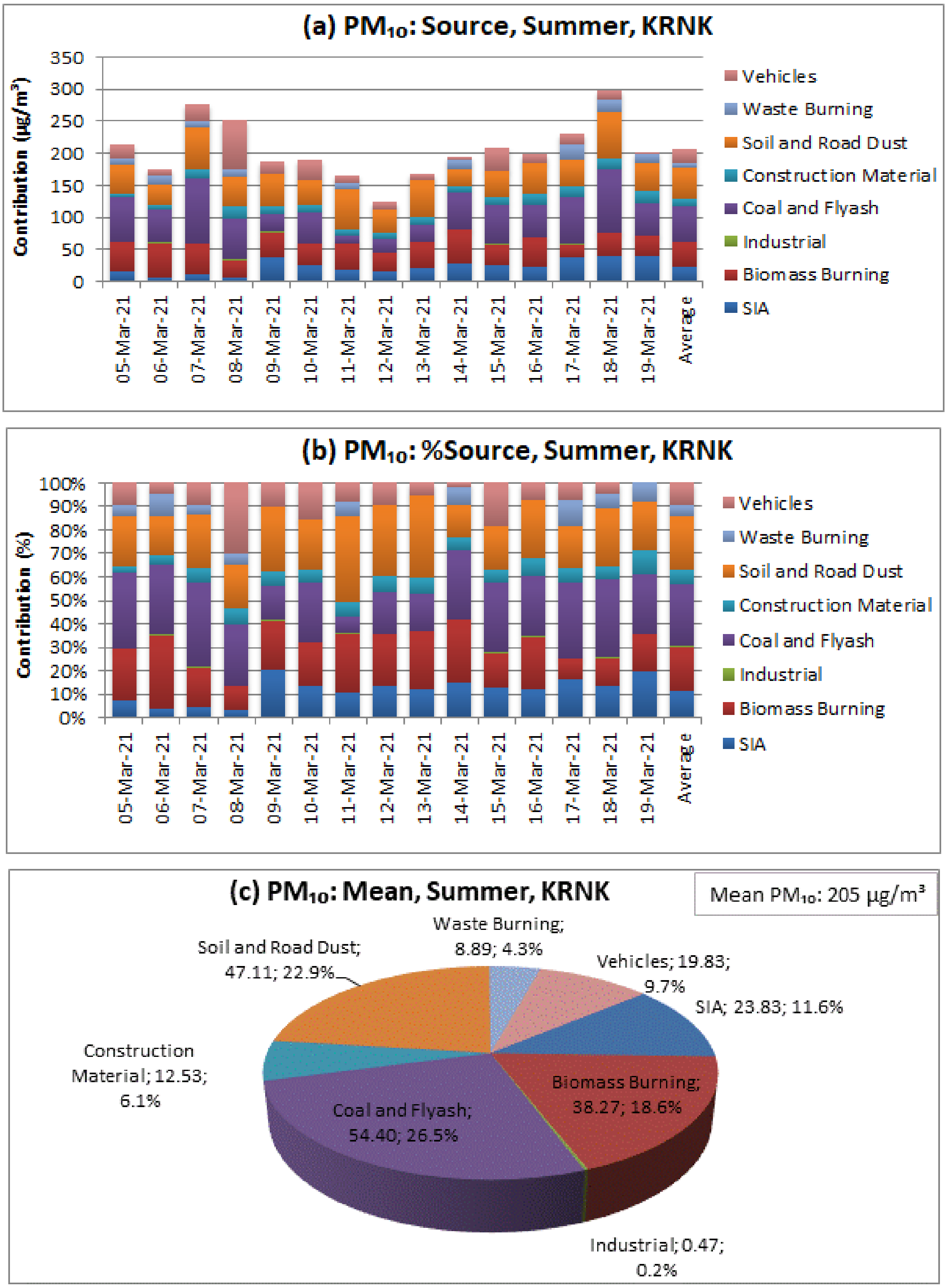


Figure 4.4: CMB modeling for PM$_{10}$ at KRNK for summer season

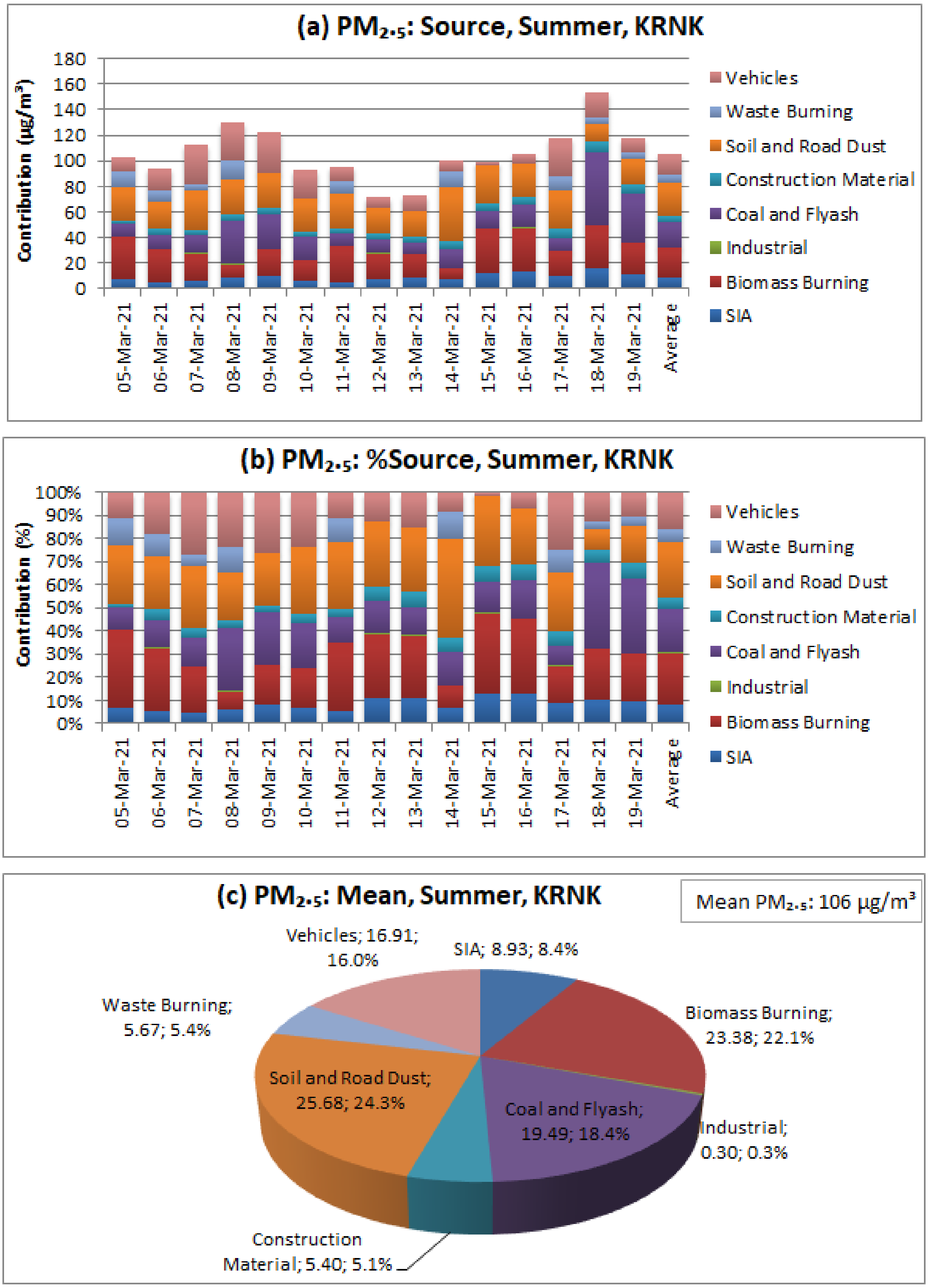


Figure 4.5: CMB modeling for $PM_{2.5}$ at KRNK for summer season

Table 4.2: Statistical summary: KRNK, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	205	205	99.8	0.78	106	110	103.4	0.74
SD	46	47	2.3	0.06	22	26	5.8	0.04
CV	0.23	0.23	0.02	0.08	0.21	0.23	0.06	0.06
Maximum	307	310	102.2	0.90	153	178	116.1	0.81
Minimum	125	126	92.5	0.69	72	71	94.5	0.67

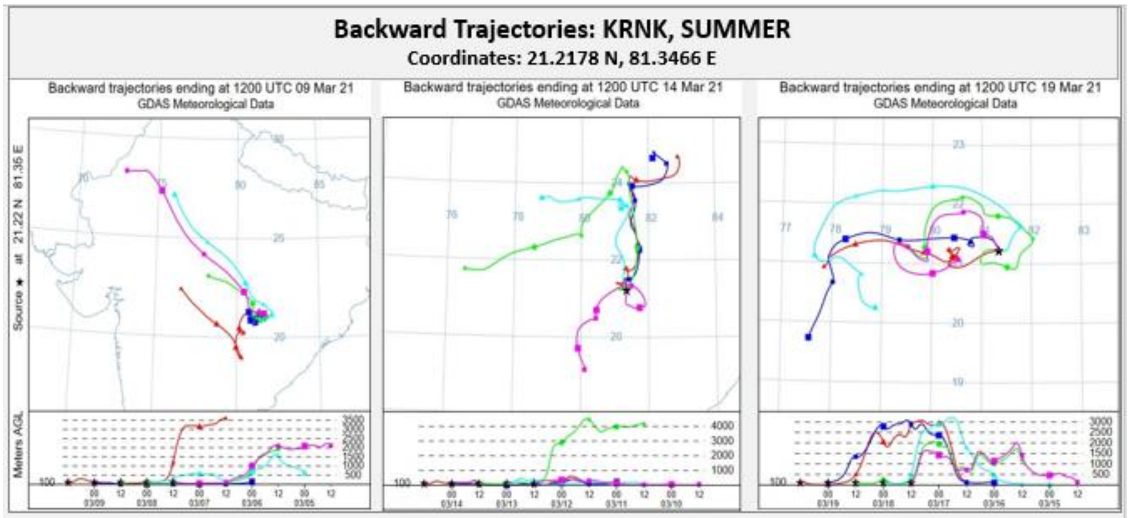


Figure 4.6: Backward trajectories at KRNK for summer season

Inferences

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

4.3.1.3 Post-monsoon Season [sampling period: Sep 09 – 23, 2021]

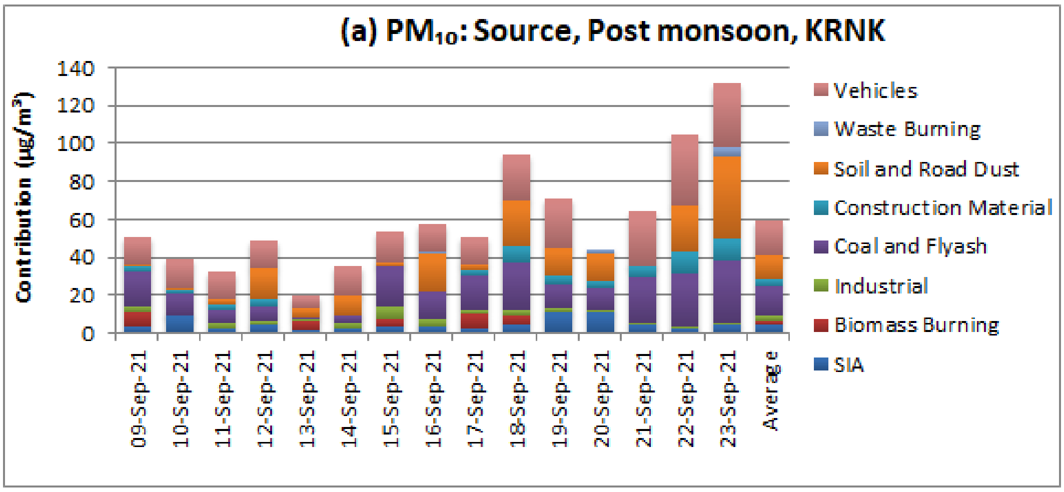
PM_{10} (post-monsoon)

The average PM_{10} concentration was 60 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 15 days) in terms of concentration and percentage respectively at KRNK. Table 4.3 presents a summary of the performance and acceptability of the CMB model. It is observed that the major source contributing to PM_{10} was vehicular emission (18 µg/m^3 ~ 31%) followed by coal and flyash (16 µg/m^3 ~ 27%) and soil and road dust (12 µg/m^3 ~ 20%). Other significant sources are SIA (5 µg/m^3 ~ 8.1%), constructional material (6.7%), industrial (3.7%) and biomass burning (3.2%) in PM_{10}. The contribution of the waste burning was estimated to be less than 1% in PM_{10}.

$PM_{2.5}$ (post-monsoon)

The average $PM_{2.5}$ concentration was 32 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.53. 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 15 days) in terms of concentration and percentage respectively at KRNK. It is observed that the major source contributing to $PM_{2.5}$ vehicular emission (11 µg/m^3 ~ 35%) followed by soil and road dust (9 µg/m^3 ~ 27%). Other major sources are coal and flyash (7 µg/m^3 ~ 18%), SIA (8.9%), construction material (5.4%), industrial (4.0%) and waste burning (1.4%). The contribution of biomass burning was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.9) show that most of the time the wind is from the West and sometimes from the North. These winds pick up pollutants on the way over neighboring districts and states especially from tall emitting sources.



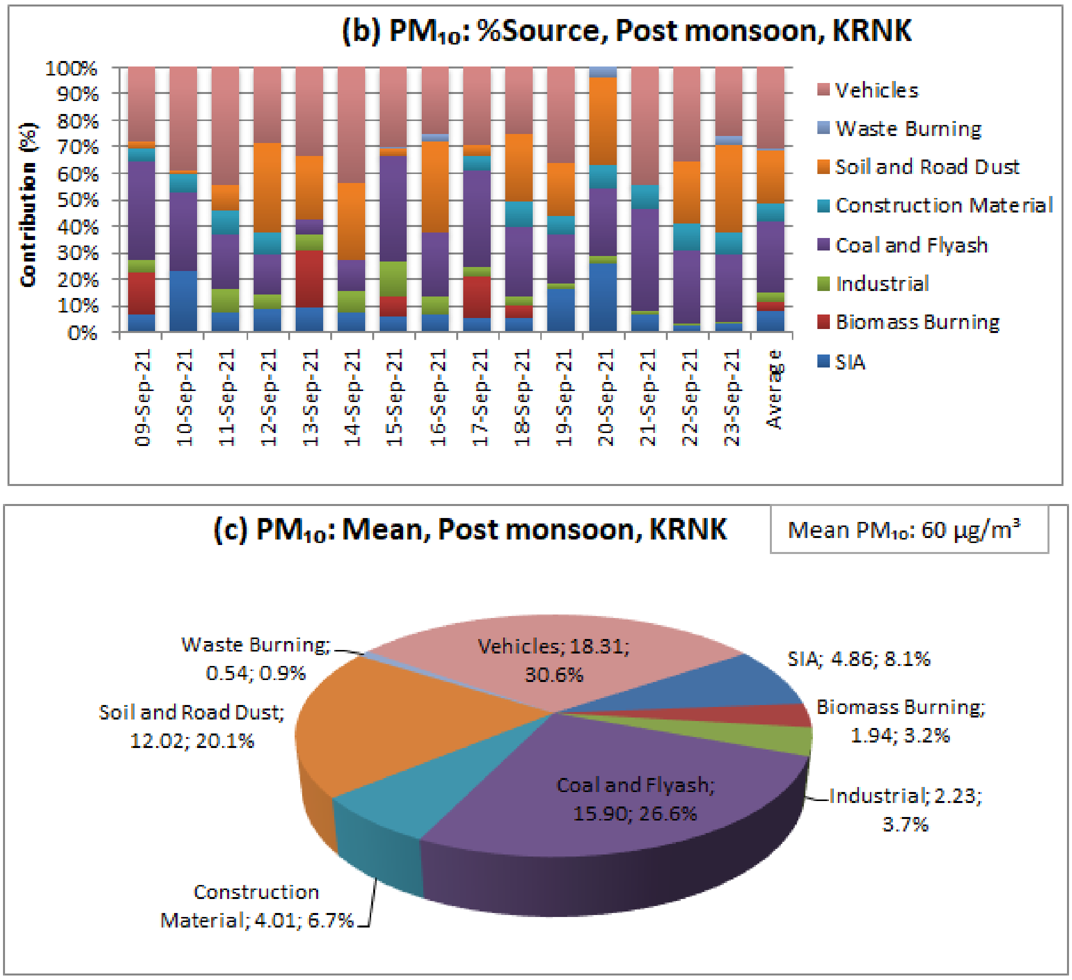
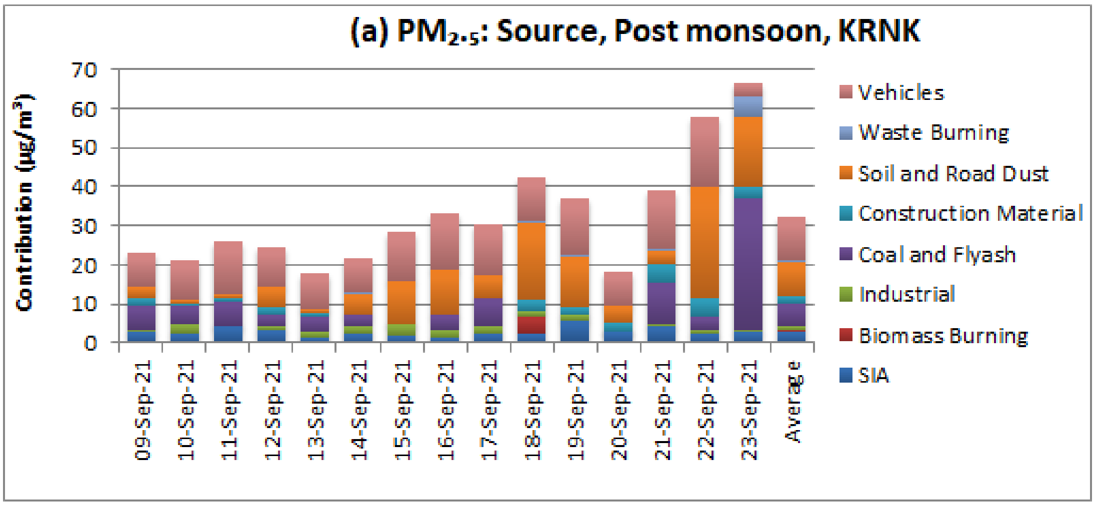


Figure 4.7: CMB modeling for PM_{10} at KRNK for Post-monsoon season



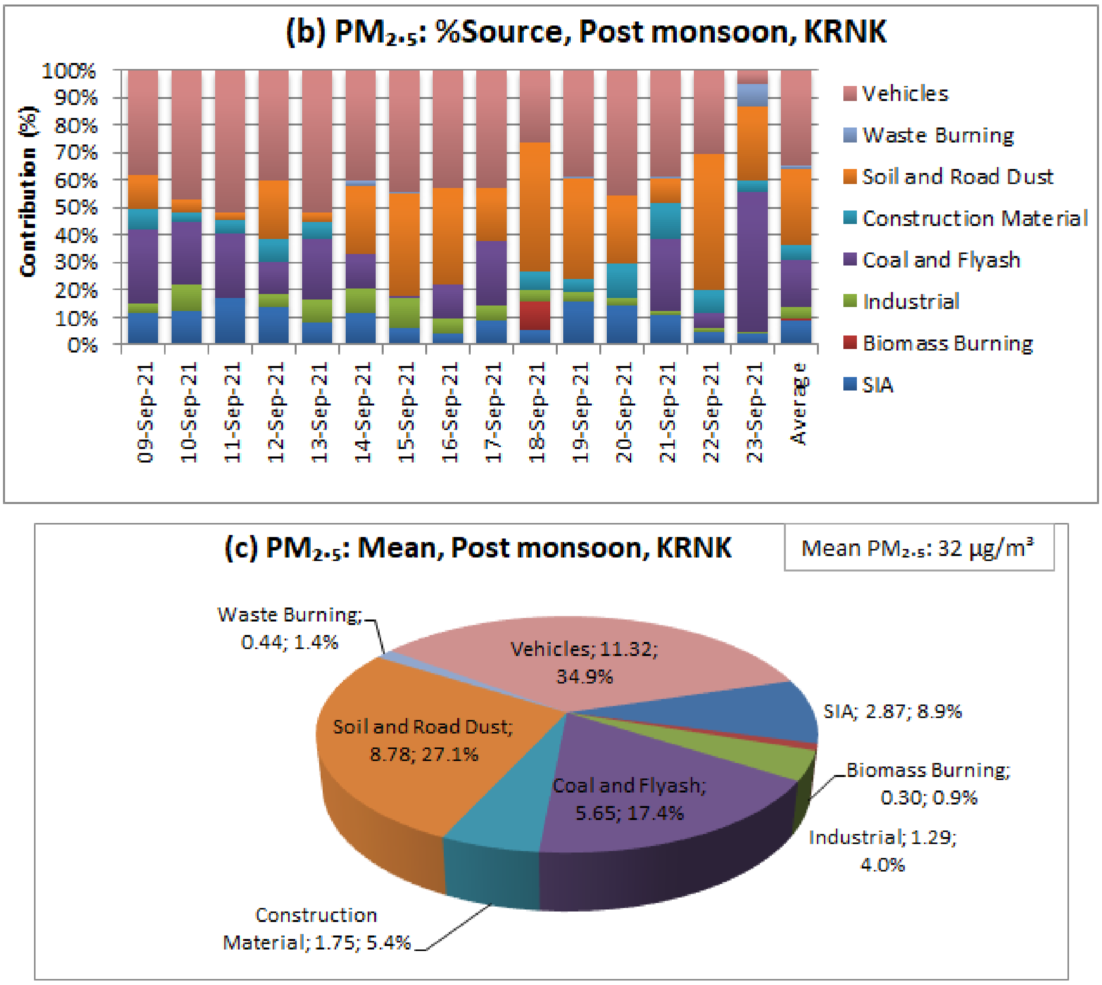


Figure 4.8: CMB modeling for $PM_{2.5}$ at KRNK for Post-monsoon season

Table 4.3: Statistical summary: KRNK, Post-monsoon season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	60	63	104.5	0.8	32	33	103.9	0.75
SD	29	29	5.4	0.1	15	15	7.2	0.09
CV	0.48	0.47	0.05	0.12	0.45	0.44	0.07	0.11
Maximum	132	132	118.4	0.89	66	65	118.2	0.88
Minimum	29	33	98.3	0.54	18	20	86.7	0.59

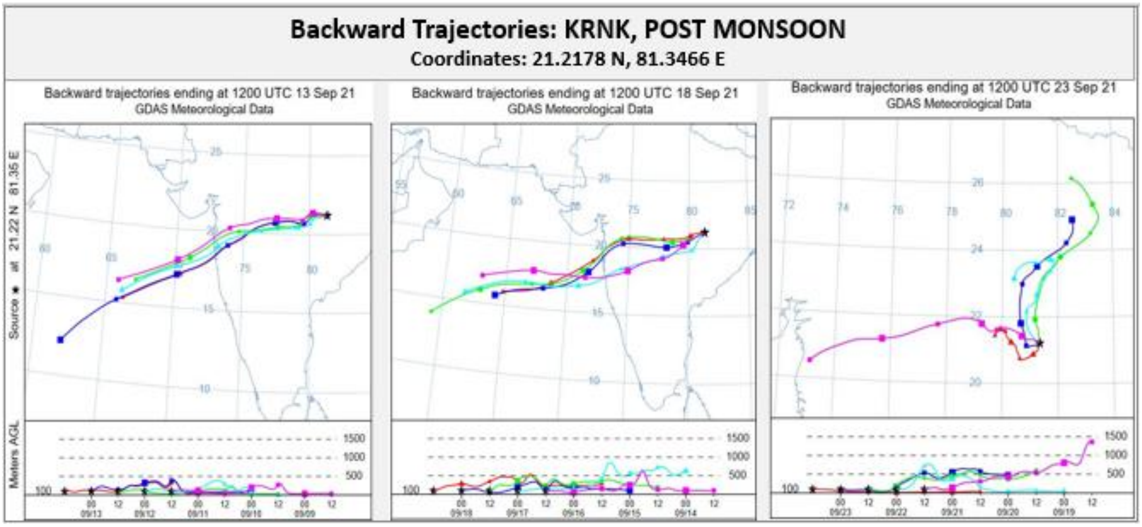


Figure 4.9: Backward trajectories at KRNK for post-monsoon season

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Vehicular emissions become the major PM_{10} and $PM_{2.5}$ sources. The post-monsoon period when meteorological conditions are favorable to reduce baseline pollution levels and good air quality.

4.3.2 SAIL Steel Plant (SAIL)

4.3.2.1 Winter Season [sampling period: Dec 25, 2020 – Jan 08, 2021]

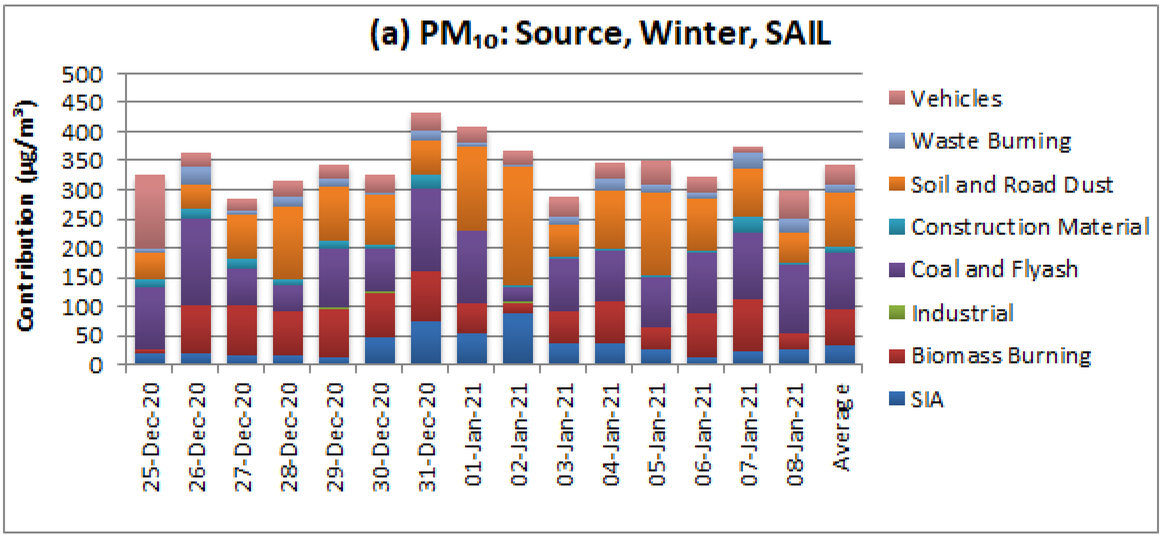
PM_{10} (winter)

The average PM_{10} concentration was 344 µg/m^3. Figure 5.7 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at SAIL. Table 4.4 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was coal and flyash (94 µg/m^3 ~ 27.4%) followed by road and soil dust (93 µg/m^3 ~ 27%). The other major sources are biomass burning (61 µg/m^3 ~ 18%), vehicular emission (34 µg/m^3 ~ 10%), SIA (34 µg/m^3 ~ 10%), waste burning (4%) and construction (3%) and industrial emissions (less than 1%).

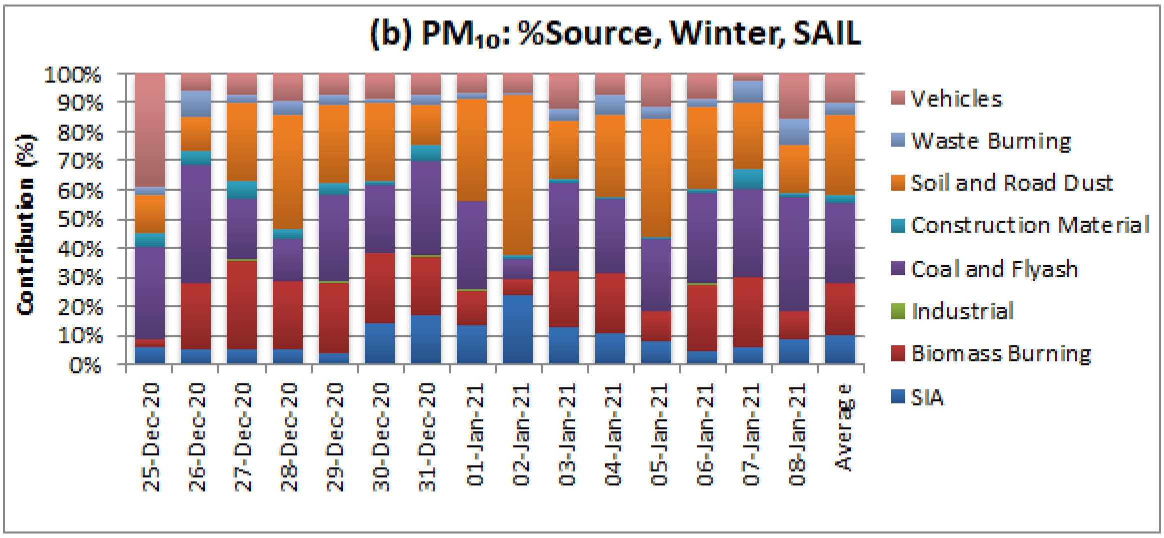
$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 196 µg/m^3. Figure 5.8 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at SAIL. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (45 µg/m^3 ~ 23%) followed by coal and flyash (43 µg/m^3 ~ 22%). Other predominant sources are biomass burning (43 µg/m^3 ~ 22%), vehicular emission (30 µg/m^3 ~ 15%) and SIA (20 µg/m^3 ~ 10%), waste burning (4%) and construction material (3%). Contribution of the industrial emission was estimated to be less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.12) show that most of the time wind is blown from the NE direction. These winds pick up the pollutants on the way especially from large and tall emitting sources over the neighboring districts before entering the city.



(a) PM_{10}: Source, Winter, SAIL



(b) PM_{10}: %Source, Winter, SAIL

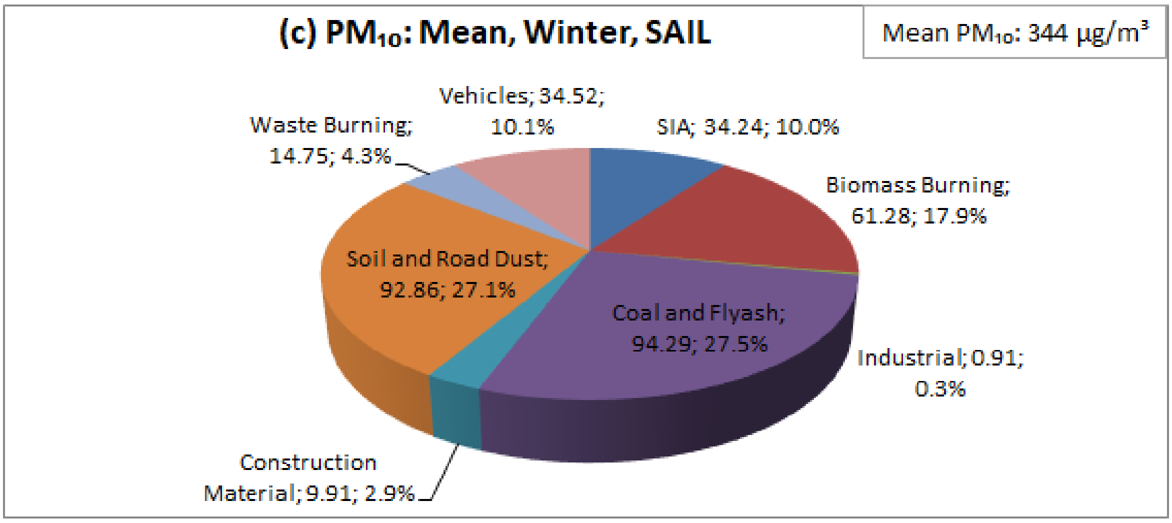
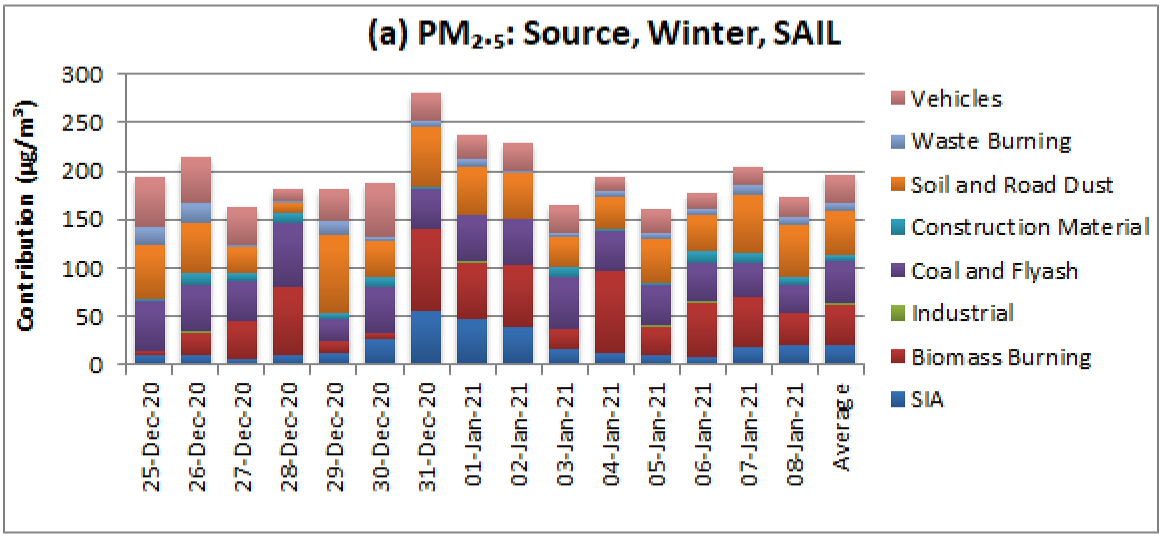
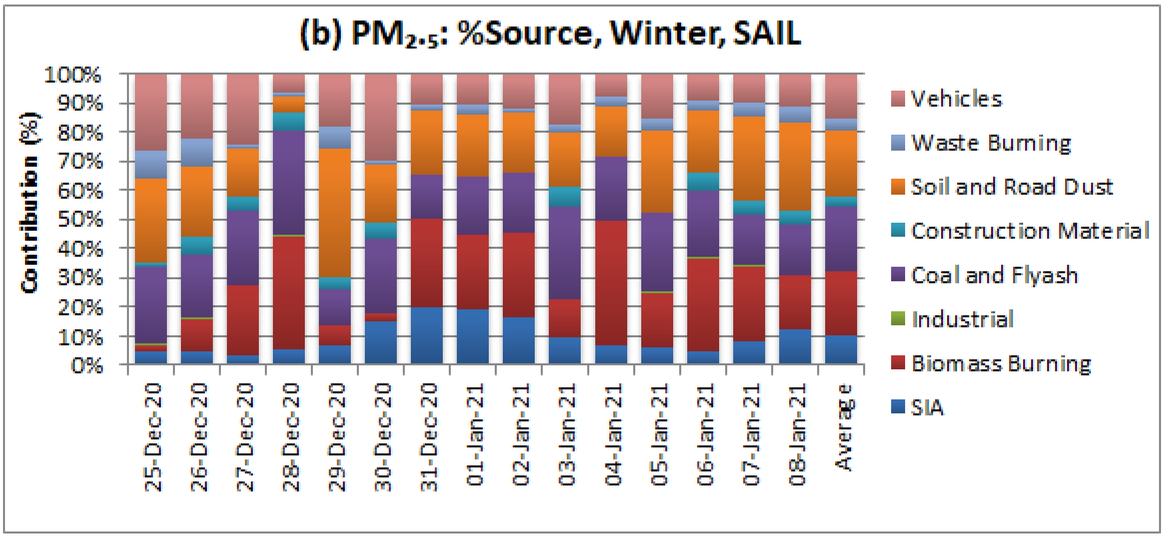


Figure 4.10: CMB modeling for PM$_{10}$ at SAIL for winter season





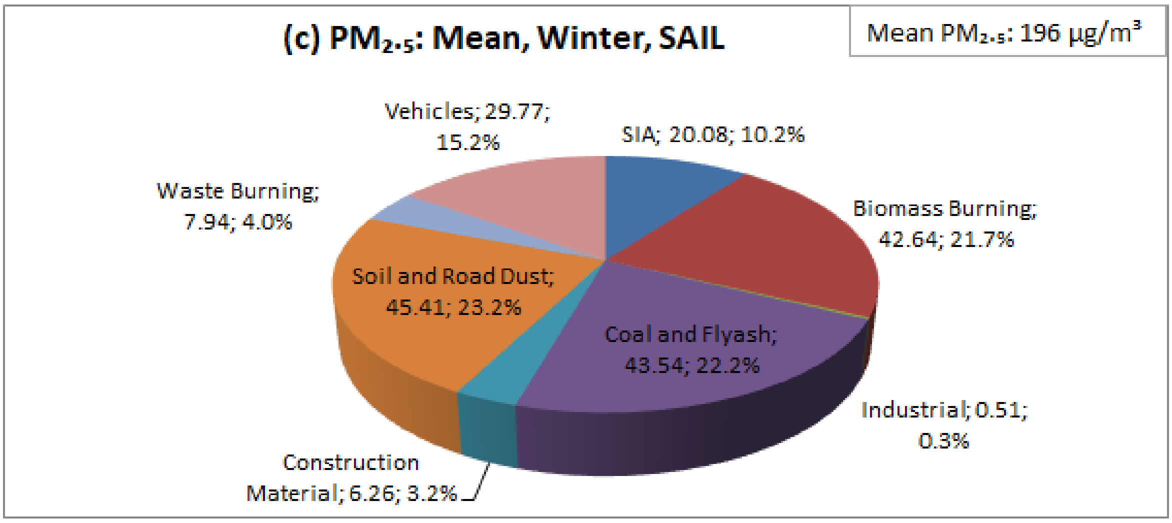


Figure 4.11: CMB modeling for $PM_{2.5}$ at SAIL for winter season

Table 4.4: Statistical summary: SAIL, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	344	348	101.1	0.83	196	203	103.7	0.85
SD	42	46	3.0	0.05	33	32	4.6	0.05
CV	0.12	0.13	0.03	0.06	0.17	0.16	0.04	0.06
Maximum	431	433	108.8	0.90	280	281	114.9	0.92
Minimum	286	282	97.0	0.70	161	165	98.8	0.75

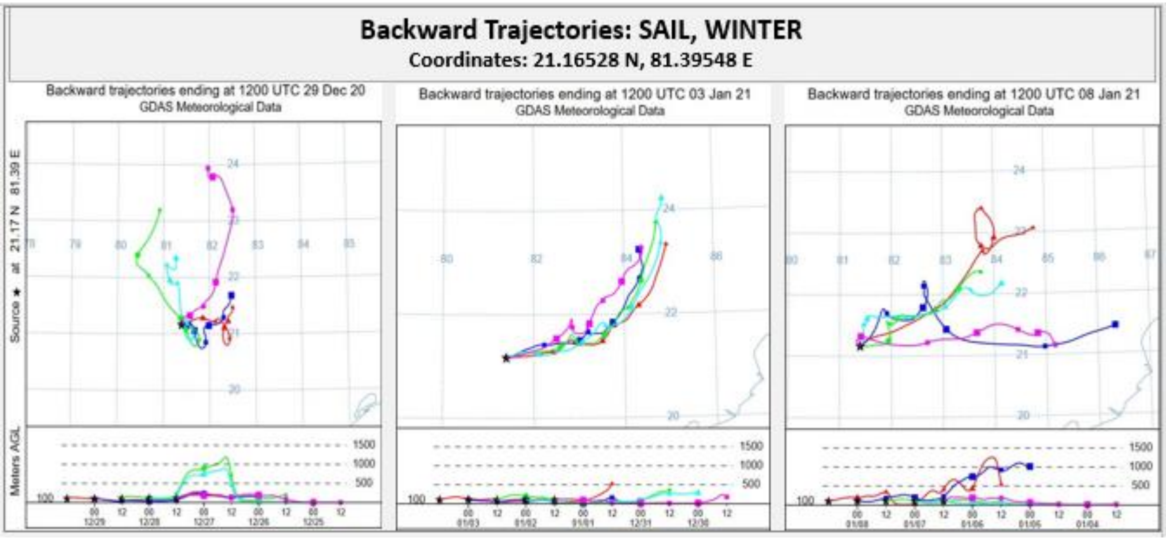


Figure 4.12: Backward trajectories at SAIL for winter season

Inferences

For both PM_{10} and $PM_{2.5}$, coal-flyash and soil-road dust contribute about equally (at about 27% and 23% respectively) and biomass burning at 18% for PM_{10} and 22% for $PM_{2.5}$. The biomass burning is high at SAIL which indicates irregular management of waste generated from industries which succeed in open burning.

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

PM_{10} (summer)

The average PM_{10} concentration was 229 µg/m^3. Figure 5.10 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at SAIL. Table 4.5 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was soil and road dust (67 µg/m^3 ~ 30%) followed by coal and flyash (52 µg/m^3 ~ 23%) and biomass burning (42 µg/m^3 ~ 18%). The other significant sources are SIA (23 µg/m^3 ~ 10%), vehicular emission (8%), waste burning (6%) and construction material (5%). Contribution of the industrial emission were estimated to be less than 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 114 µg/m^3. Figure 5.11 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at SAIL. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (35 µg/m^3 ~ 30%) followed by soil and road dust (22 µg/m^3 ~ 19%). Other significant sources are coal and flyash (20 µg/m^3 ~ 18%), SIA (14 µg/m^3 ~ 12%), vehicular emission (10 µg/m^3 ~ 8%) and construction material (7%). Contribution of the industrial emission was estimated less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.15) show that wind is not stable in any direction and wind mass travels over neighbouring districts before entering Bhilai city. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

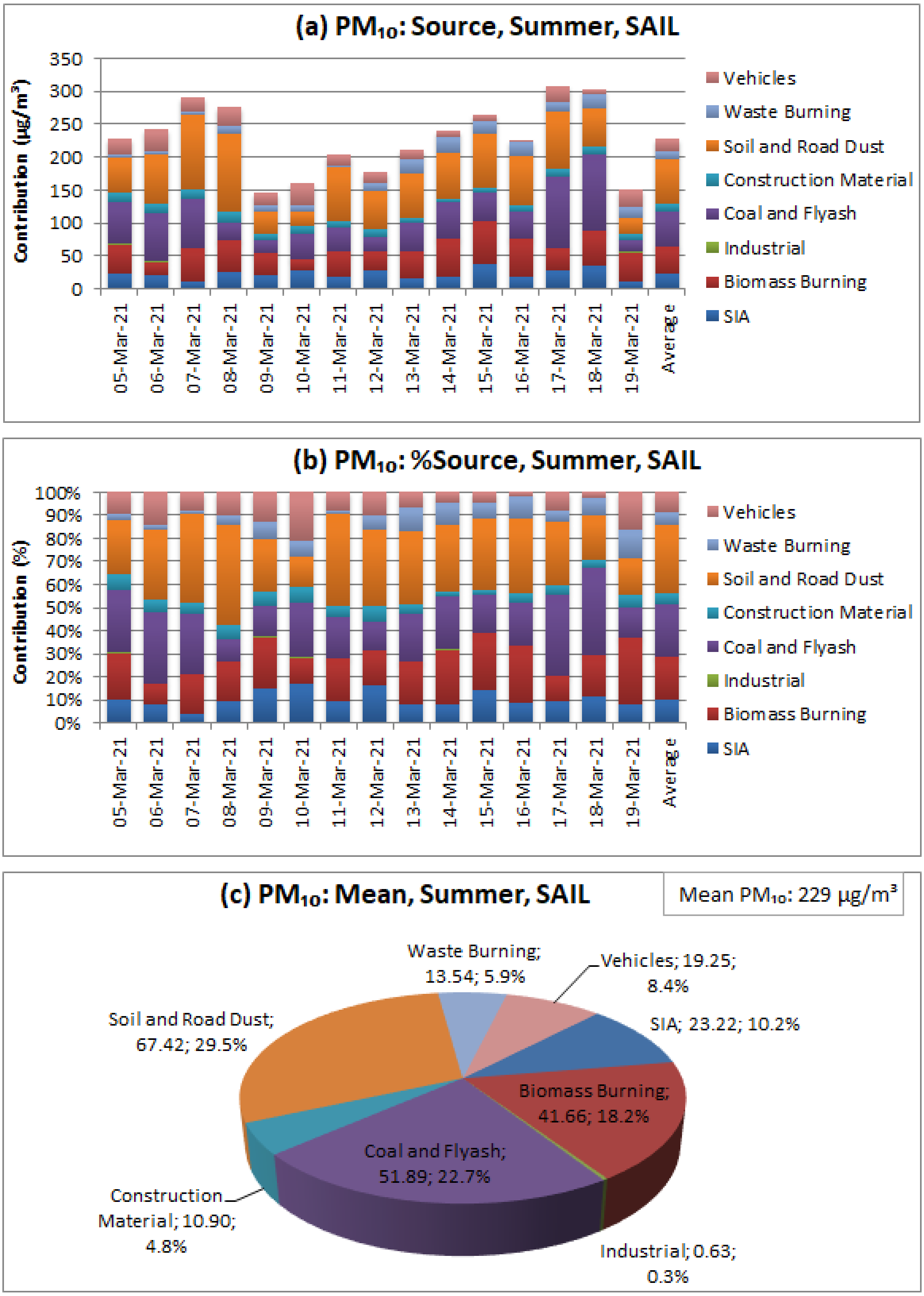


Figure 4.13: CMB modeling for PM$_{10}$ at SAIL for summer season

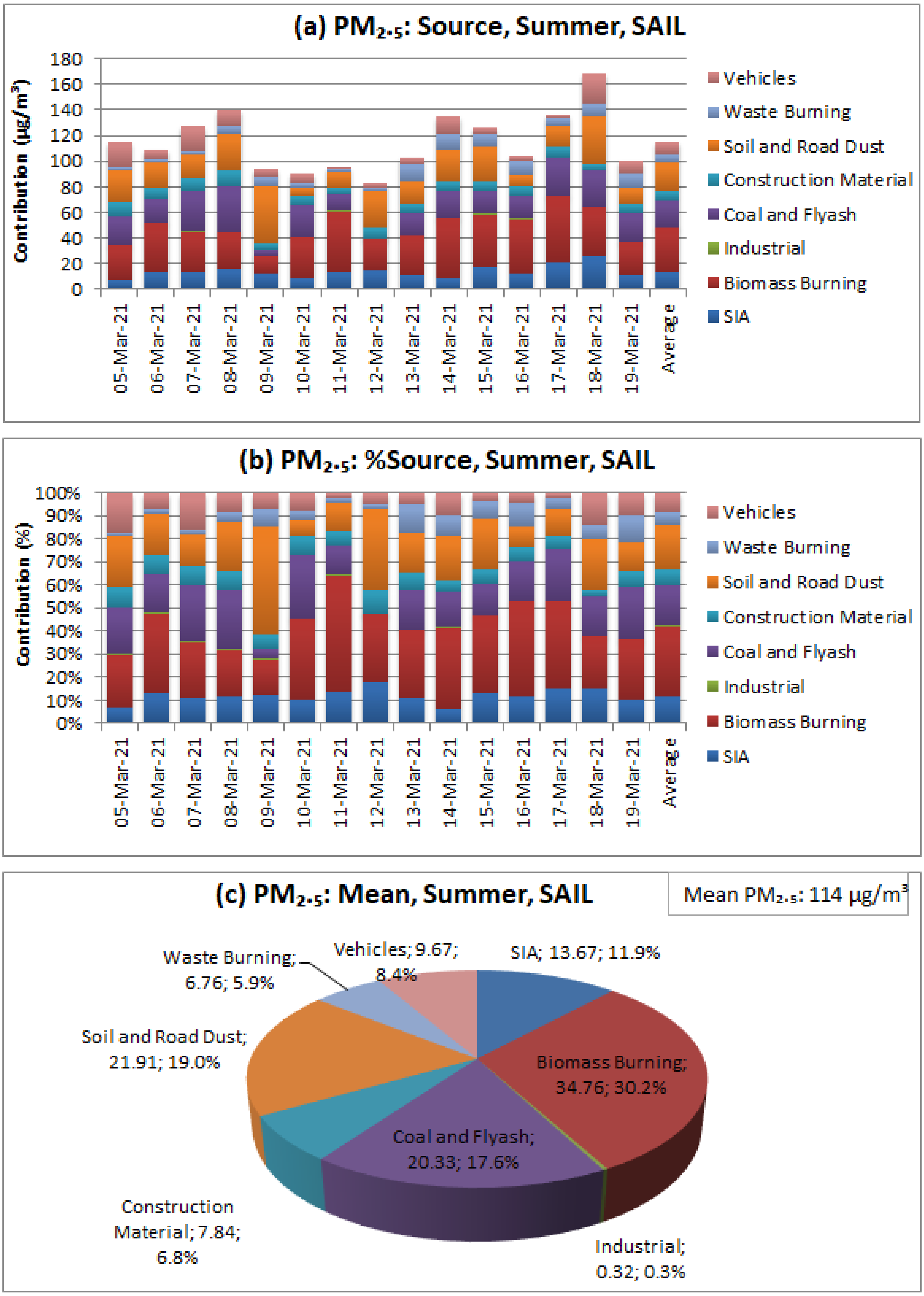


Figure 4.14: CMB modeling for $PM_{2.5}$ at SAIL for summer season

Table 4.5: Statistical summary: SAIL, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	229	234	101.8	0.81	114	121	105.8	0.80
SD	54	59	5.2	0.06	23	25	4.4	0.08
CV	0.24	0.25	0.05	0.07	0.20	0.21	0.04	0.11
Maximum	306	331	109.3	0.93	169	182	115.5	0.94
Minimum	146	151	90.3	0.72	83	87	97.8	0.66

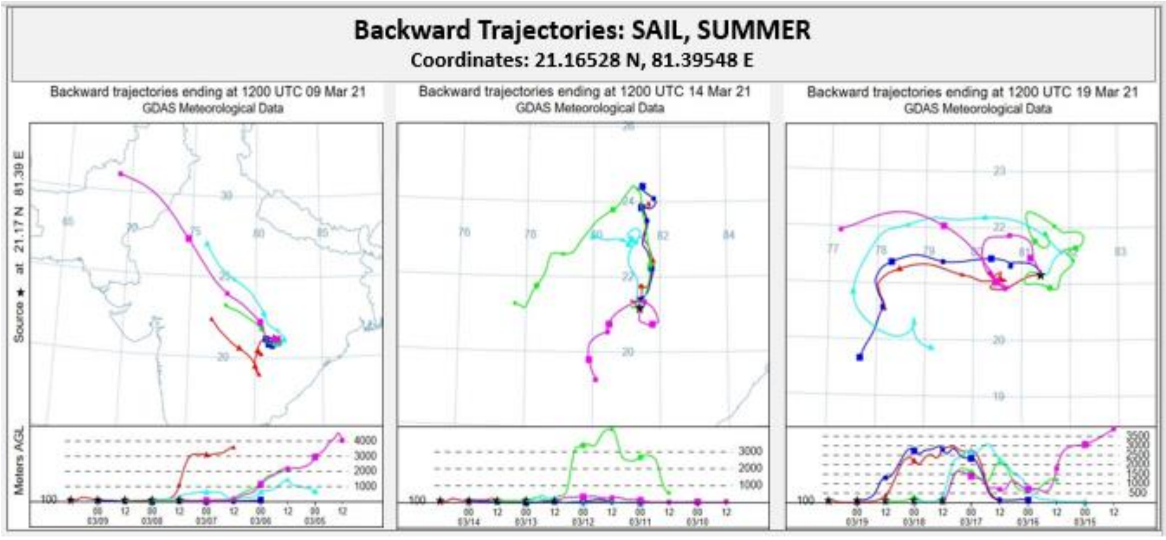


Figure 4.15: Backward trajectories at SAIL for Summer Season

Inference

Coal-flyash and soil-road dust are the major contributors in summer for PM_{10}. Biomass burning is the major contributor to $PM_{2.5}$. The sampling site was at the SAIL office which is the epicenter and industrial area that had the movement of large trucks ferrying raw materials and finished products. The biomass burning is exceptionally high at SAIL which indicates the use of wood-based fuel e.g., (Dolachar coal).

4.3.2.3 Post-monsoon Season [sampling period: Sep 09 – 23, 2021]

PM_{10} (post-monsoon)

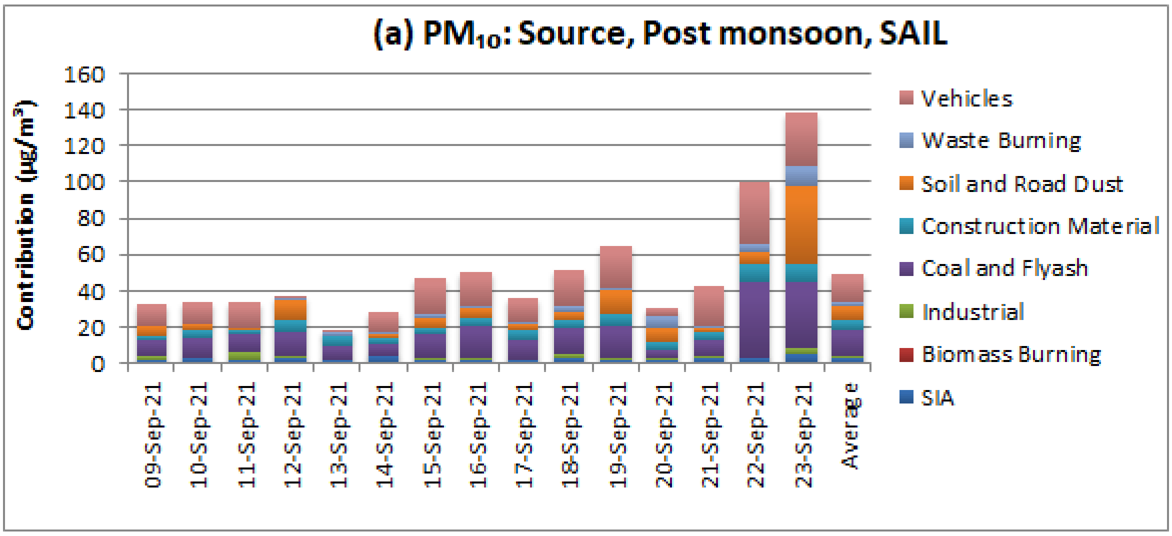
The average PM_{10} concentration was 51 µg/m^3. Figure 5.4 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at SAIL. Table 4.6 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was vehicular emission (16 µg/m^3 ~

31%) followed by coal and fly ash (15 µg/m^3 ~ 29%) and soil and road dust (8 µg/m^3 ~ 15%) in PM$_{10}$. Other significant sources are construction material (5 µg/m^3 ~ 10%), SIA (5%), waste burning (5%) and industrial emission (3%) in PM$_{10}$. No Contribution of the biomass burning was estimated in PM$_{10}$.

PM$_{2.5}$ (post-monsoon)

The average PM$_{2.5}$ concentration was 28 µg/m^3; the PM$_{2.5}$/PM$_{10}$ ratio is about 0.2. Figure 5.5 (a), (b), (c) represents PM$_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at SAIL. It is observed that the major source contributing to PM$_{2.5}$ was vehicular emission (12 µg/m^3 ~ 45%) followed by soil and road dust (15 µg/m^3 ~ 18%). Other major sources are coal and flyash (4 µg/m^3 ~ 15%), construction material (7%), SIA (6%), waste burning and industrial emission (<5%). No Contribution of the biomass burning was estimated in PM$_{2.5}$.

HYSPLIT back trajectories (Figure 4.18) show that most of the time wind is from SW and north; These winds pick up pollutants on the way especially from tall emitting sources.



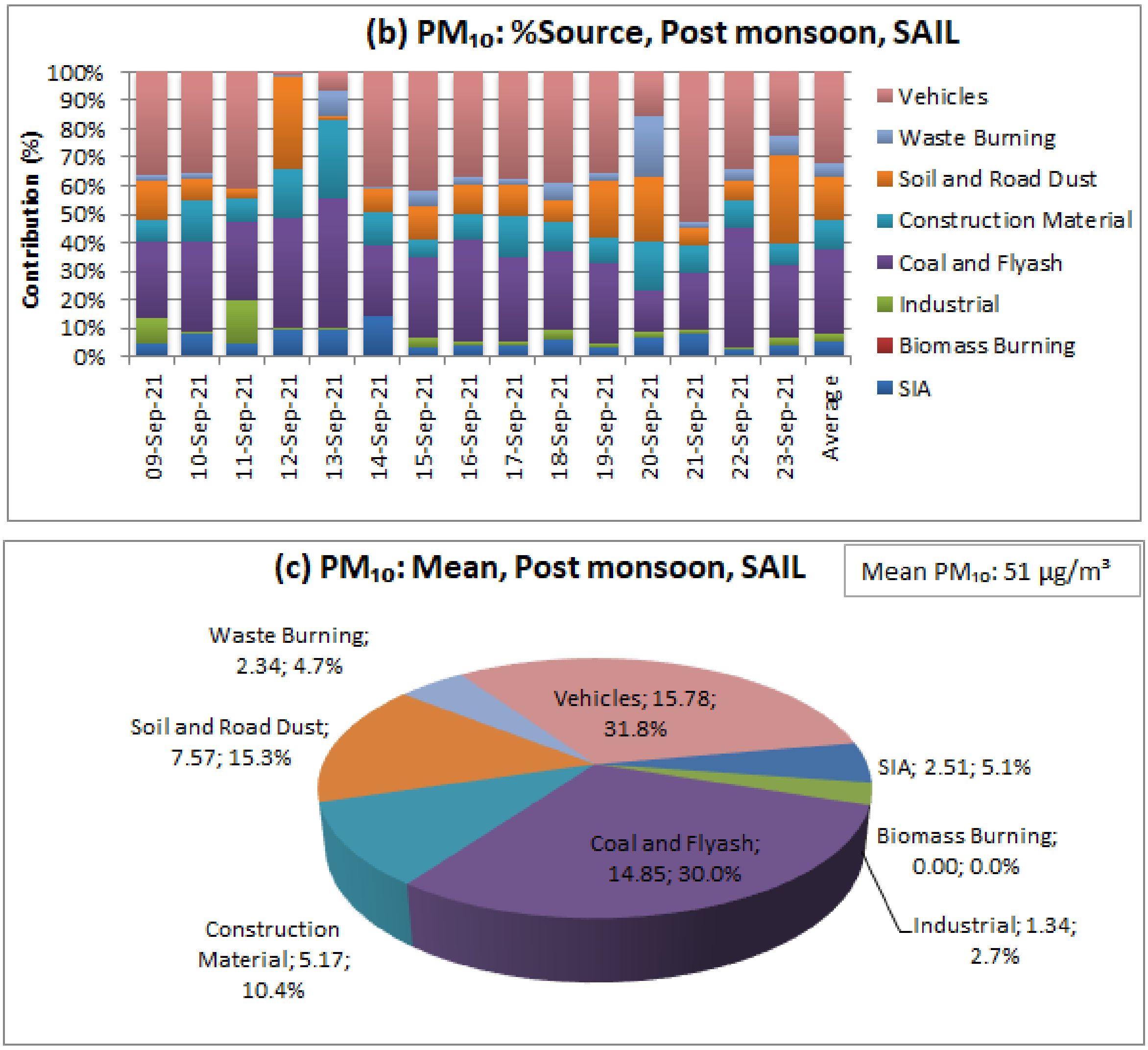
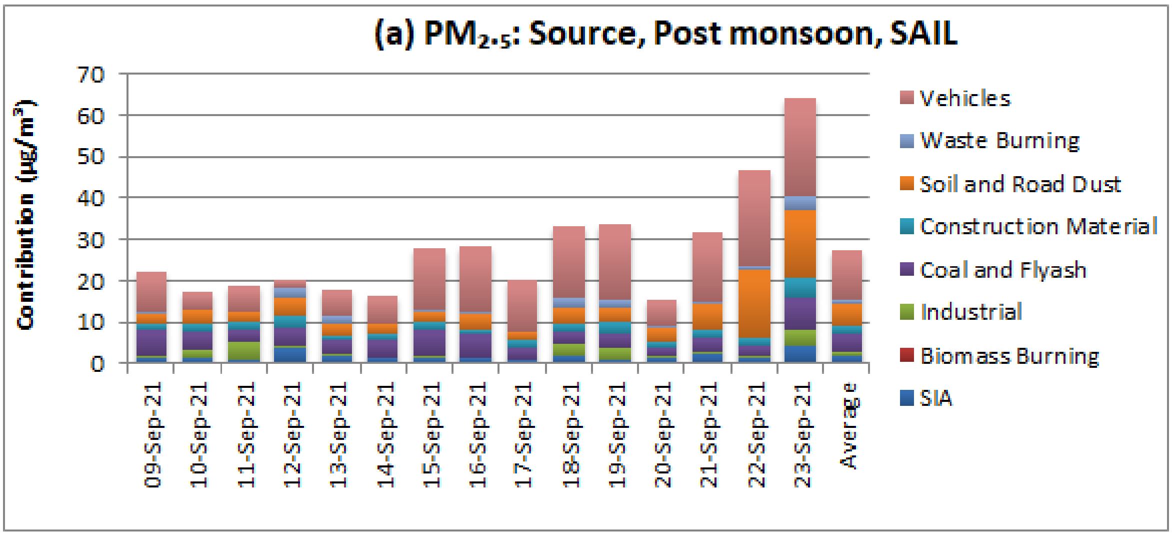


Figure 4.16: CMB modeling for PM$_{10}$ at SAIL for Post-monsoon season



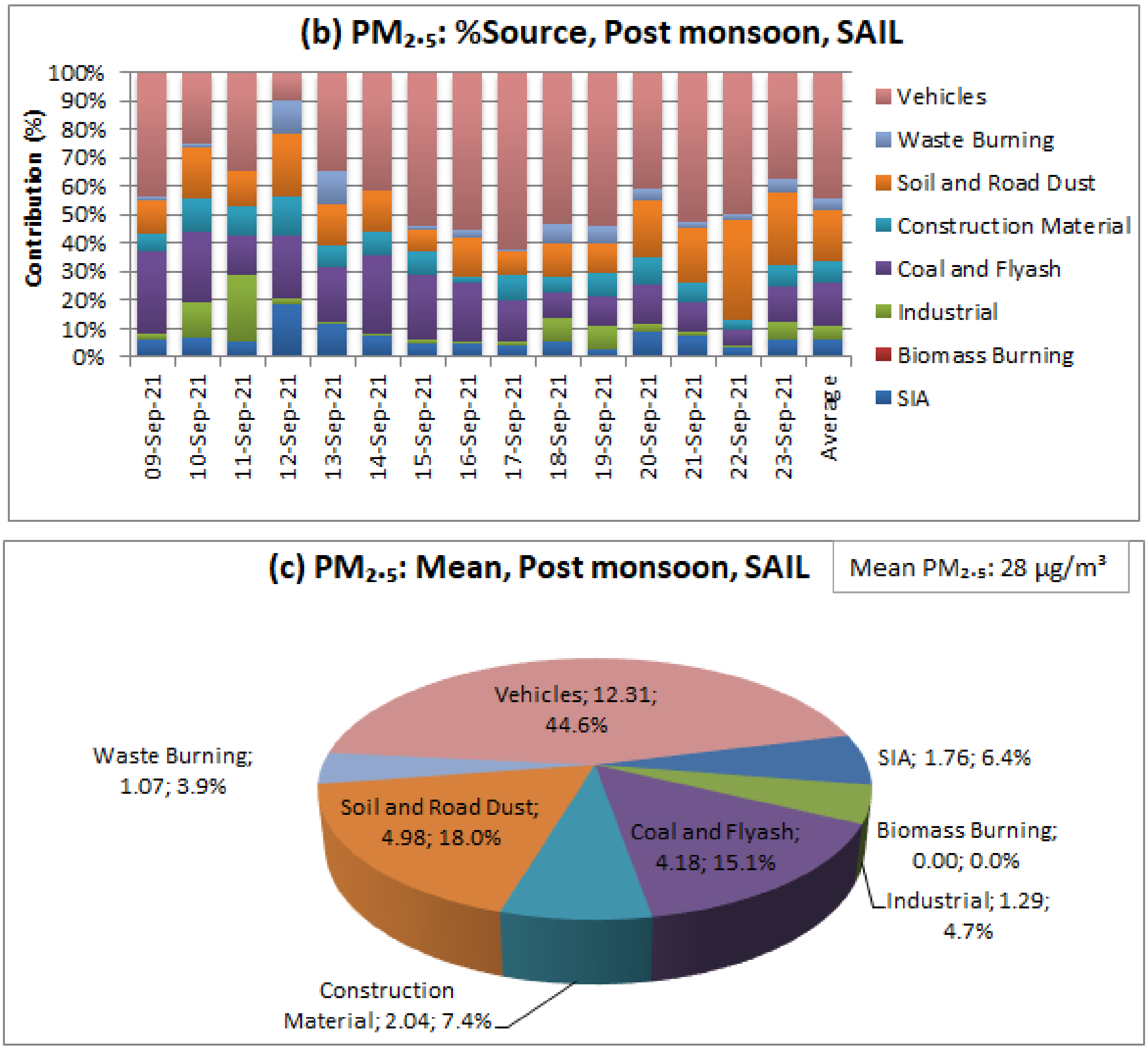


Figure 4.17: CMB modeling for $PM_{2.5}$ at SAIL for Post-monsoon season

Table 4.6: Statistical summary: SAIL, Post-monsoon season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	51	51	100.6	0.76	28	28	100.8	0.69
SD	30	30	2.6	0.07	13	13	7.2	0.09
CV	0.60	0.59	0.03	0.09	0.48	0.48	0.07	0.13
Maximum	139	140	105.5	0.85	64	65	109.7	0.84
Minimum	28	28	95.5	0.61	15	15	79.5	0.53

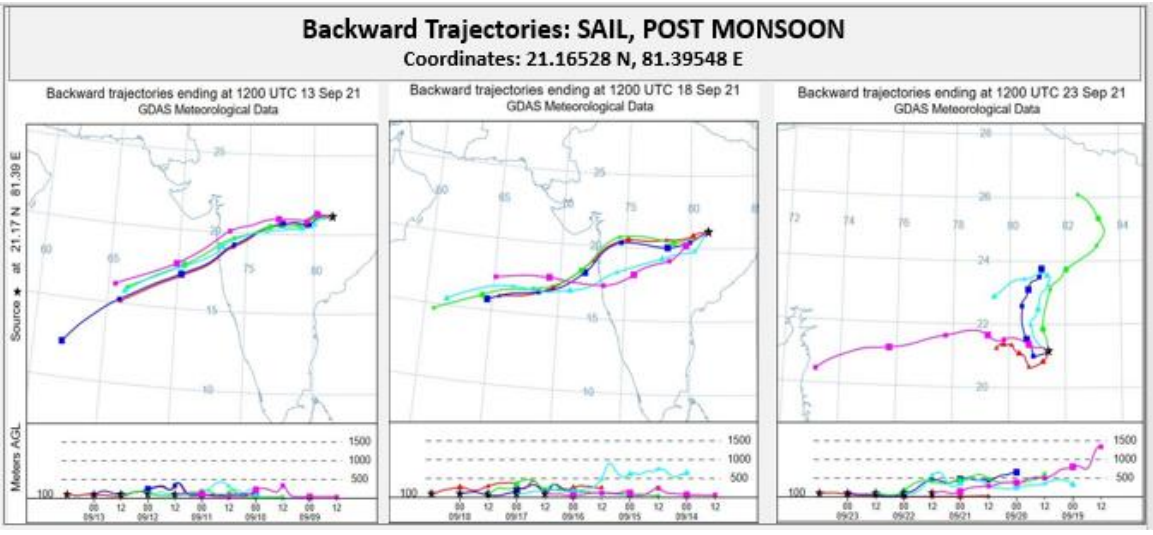


Figure 4.18: Backward trajectories at SAIL for post-monsoon season

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Vehicles, coal and fly ash, and soil and road dust have become the major PM_{10} and $PM_{2.5}$ sources. It was observed that atmosphere in post-monsoon looked blueish indicating cleaner environment which may be due to moderate speeds wind and wet conditions (rainy days) which suppress the dust and other fugitive emissions.

4.3.3 Engineering Park, Hathkhoj (ENPH)

4.3.3.1 Winter Season [sampling period: Jan 11 – 25, 2021]

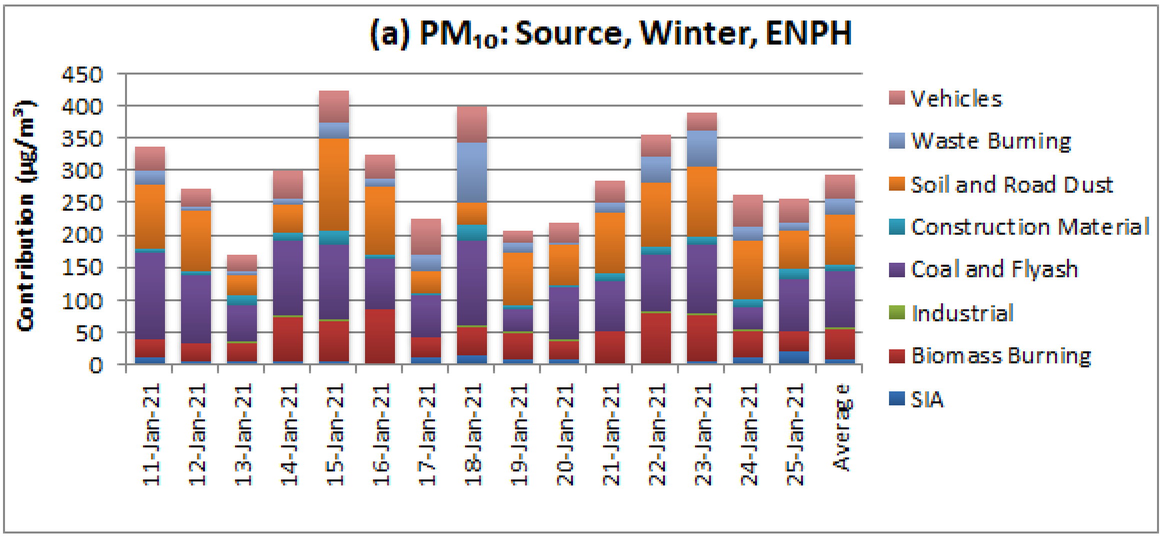
PM_{10} (winter)

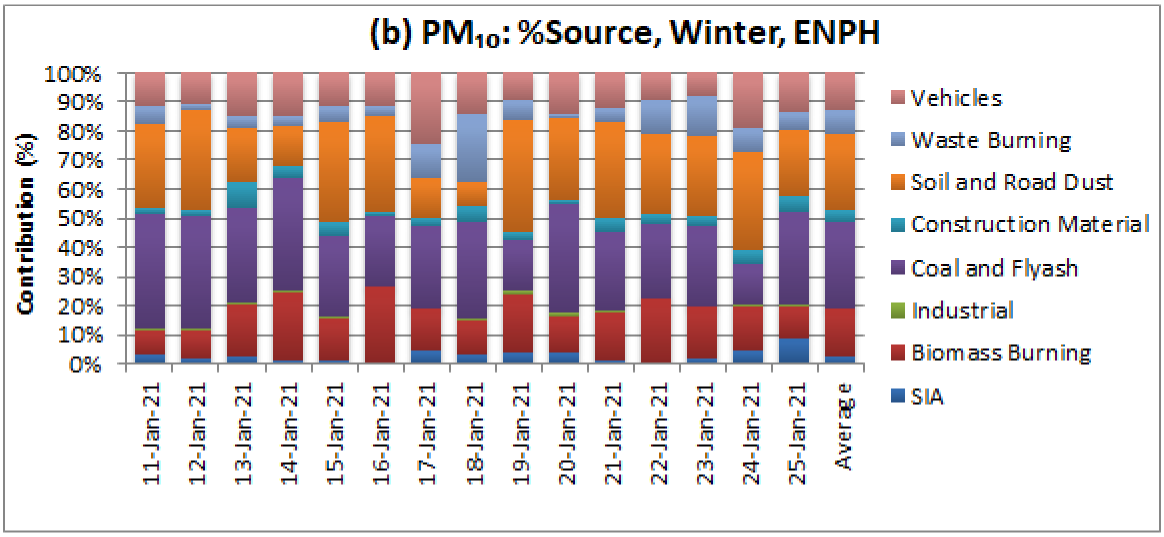
The average PM_{10} concentration was 295 µg/m^3. Figure 4.19 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at ENPH. Table 4.7 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was coal and flyash (87 µg/m^3 ~ 29%) followed by soil and road dust (78 µg/m^3 ~ 26%) and biomass burning (48 µg/m^3 ~ 16%). The other significant contributing sources are vehicular emission (38 µg/m^3 ~ 13%), waste burning (24 µg/m^3 ~ 8%) and construction material (11 µg/m^3 ~ 4%) and SIA (3%). Contribution of the industrial emission was estimated to be less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 151 µg/m^3. 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 15 days) in terms of concentration and percentage respectively at ENPH. It is observed that the major source contributing to $PM_{2.5}$ was coal and flyash (44 µg/m^3 ~ 29%) followed by biomass burning (31 µg/m^3 ~ 20%). Other major sources are vehicular emission (29 µg/m^3 ~ 20%), soil and road dust (22 µg/m^3 ~ 15%), waste burning (15µg/m^3 ~ 10%), SIA (1.4%) and construction material (2%). Contribution of the industrial emission was estimated to be less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.21) show that show that wind is not stable in any direction and wind mass travel over to neighboring districts before entering into Bhilai. These winds pick up the pollutants on the way, especially from large and tall emitting sources.





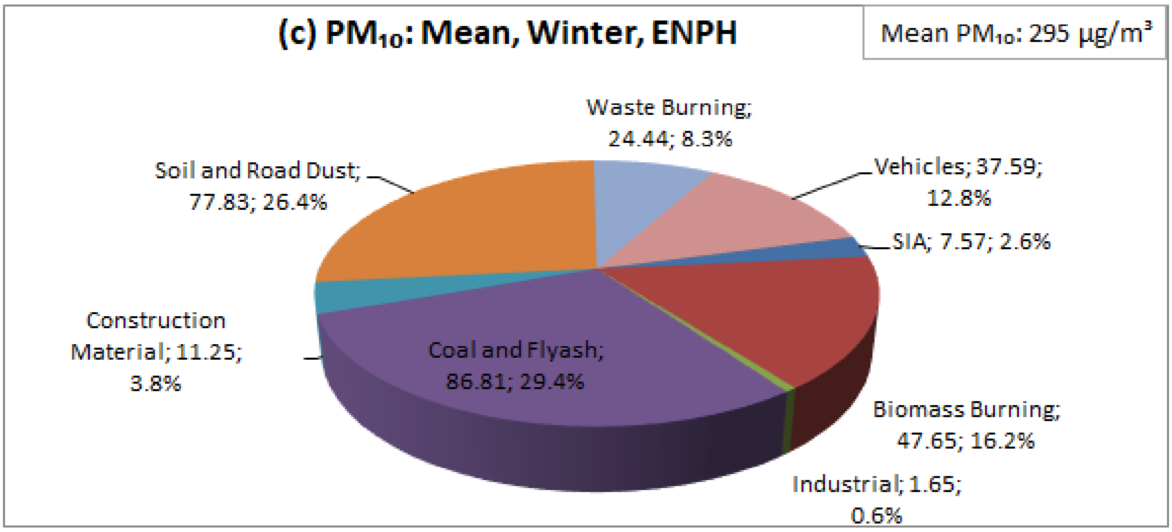
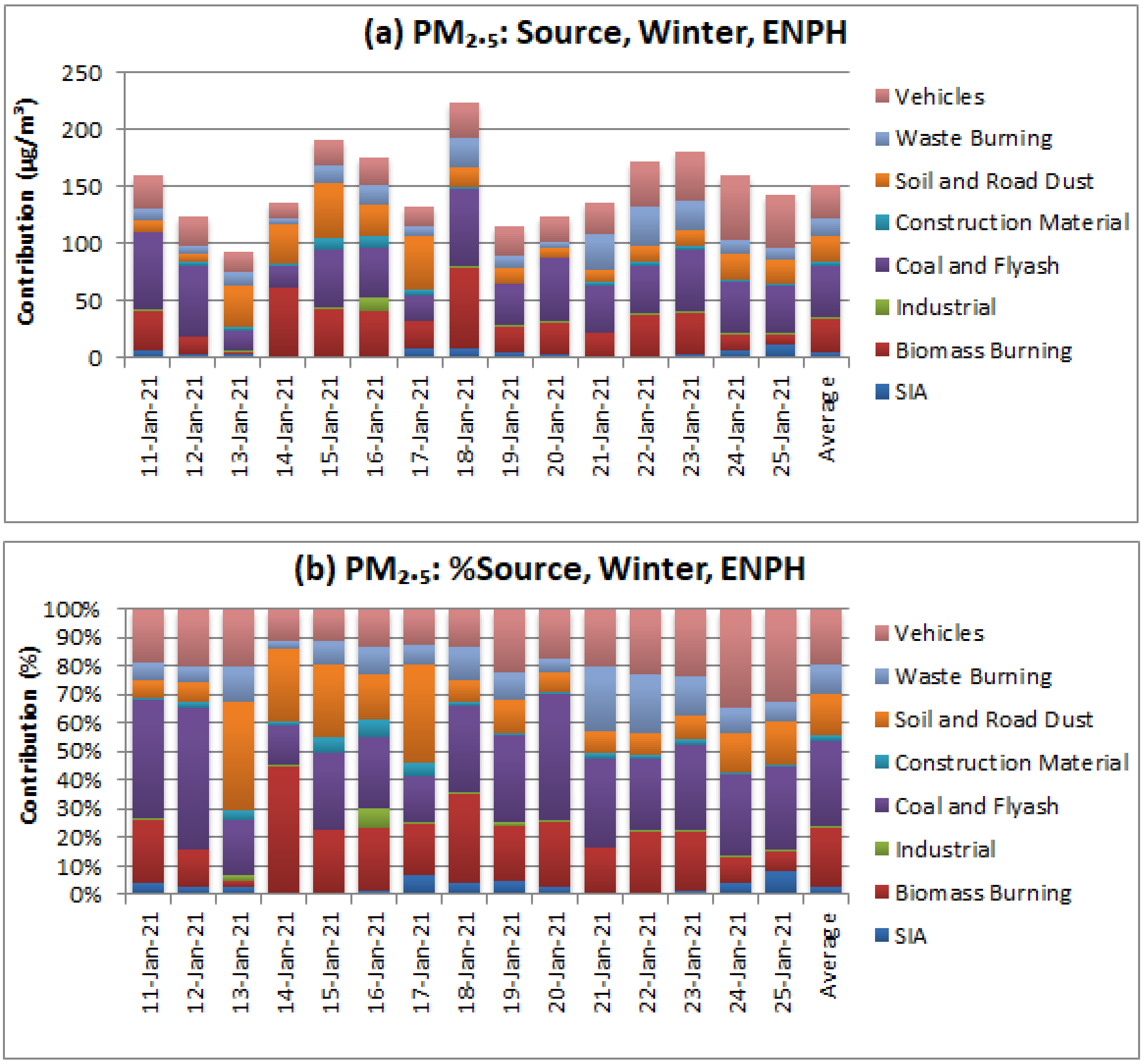


Figure 4.19: CMB modeling for PM_{10} at ENPH winter season



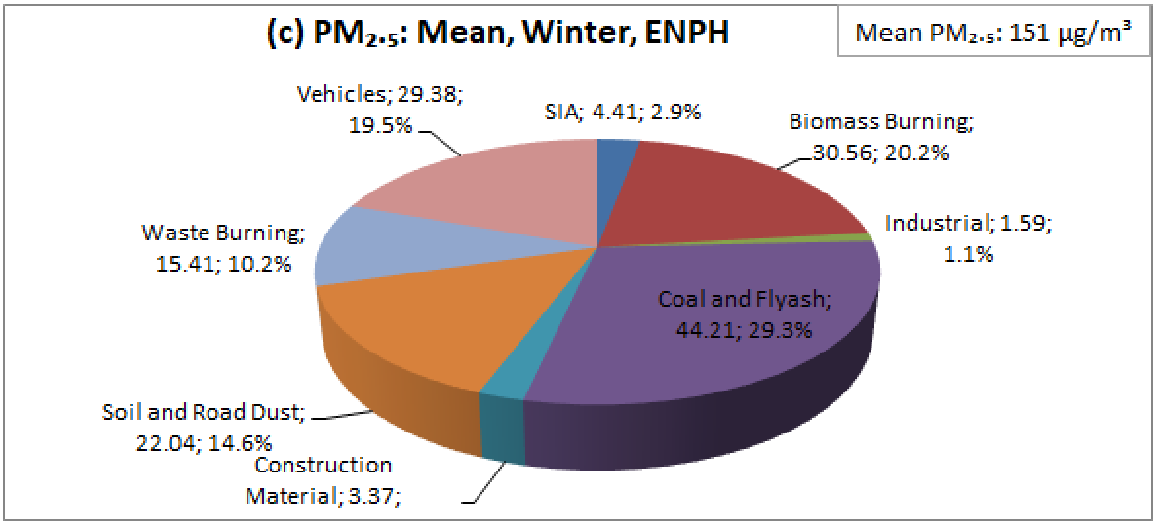


Figure 4.20: CMB modeling for $PM_{2.5}$ at ENPH, winter season

Table 4.7: Statistical summary: ENPH, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	295	302	102.2	0.88	151	164	108.3	0.83
SD	75	79	4.4	0.03	34	39	7.0	0.08
CV	0.26	0.26	0.04	0.03	0.22	0.24	0.07	0.10
Maximum	422	450	113.1	0.93	223	248	119.5	0.94
Minimum	170	170	98.5	0.82	93	97	96.7	0.63

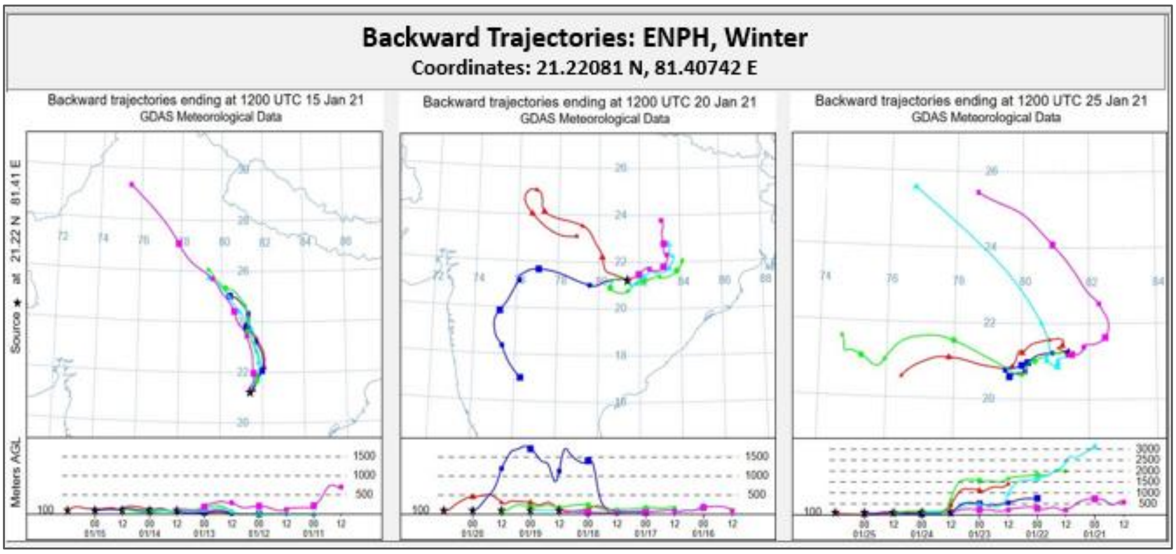


Figure 4.21: Backward trajectories at ENPH for winter season

Inferences

Coal and flyash (29%) and soil and road dust (26%) are the highest contributing sources for PM_{10} followed by biomass burning (16%). For $PM_{2.5}$ coal and flyash (29%) and Biomass burning (20%) are the highest contributing sources. Biomass burning contribution is coming out to be significant at an industrial site indicate the use of wood-based fuel (Dolachar) in the industries.

4.3.3.2 Summer Season [sampling period: Mar 22 – Apr 05, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 240 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 15 days) in terms of concentration and percentage respectively at ENPH. Table 4.8 presents summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was coal and flyash (58 µg/m^3 ~ 24%) followed by soil and road dust (50 µg/m^3 ~ 21%). The other significant sources are biomass burning (31 µg/m^3 ~ 13%), vehicular emission (30 µg/m^3 ~ 12%), SIA (30 µg/m^3 ~ 12%), waste burning (26 µg/m^3 ~ 11%) and construction material (14 µg/m^3 ~ 6%). Contribution of the industrial emission was estimated to be less than 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 119 µg/m^3. 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 15 days) in terms of concentration and percentage respectively at ENPH. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (30 µg/m^3 ~ 25%) followed by coal and flyash (23 µg/m^3 ~ 20%). Other significant sources are SIA (16 µg/m^3 ~ 14%), soil and road dust (16 µg/m^3 ~ 13%), vehicular emission (14 µg/m^3 ~ 11%), waste burning (11 µg/m^3 ~9%) and construction material (7%). Contribution of the industrial emission was estimated to be less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.24) show that most of the time wind is from NW and wind mass travels over neighboring districts before entering Bhilai. These winds pick up the pollutants on the way especially from large sources.

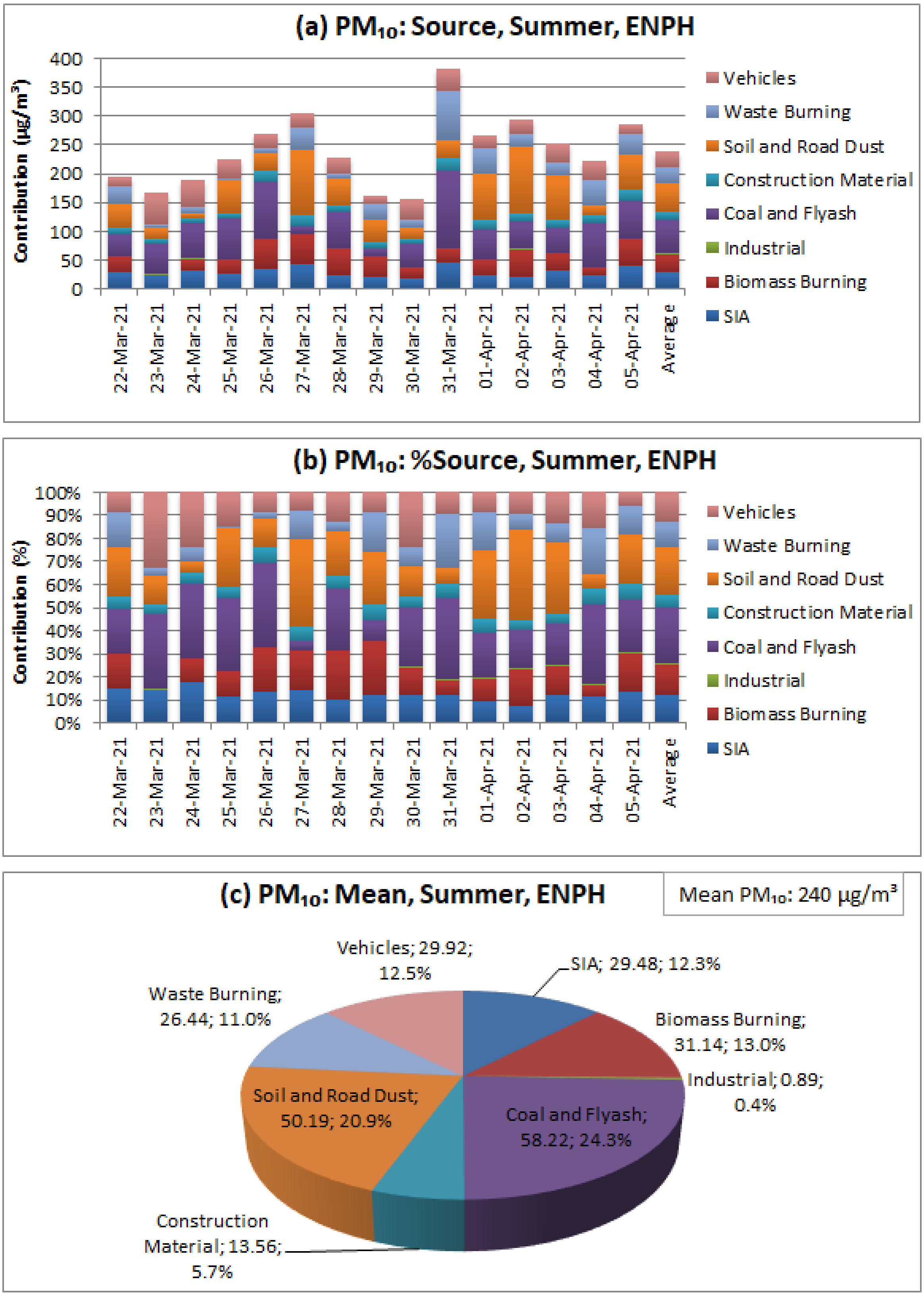


Figure 4.22: CMB modeling for PM$_{10}$ at ENPH for summer season

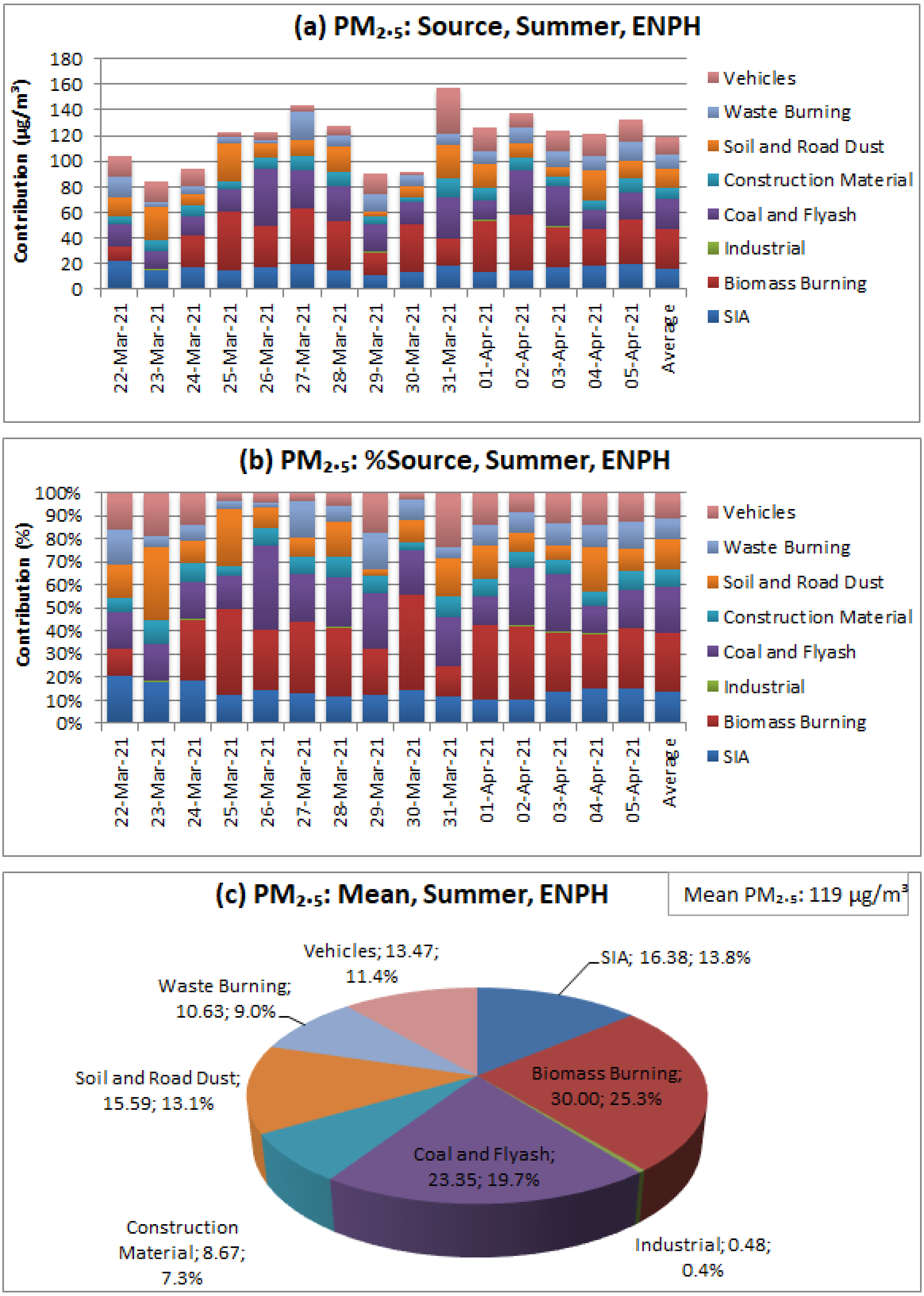


Figure 4.23: CMB modeling for $PM_{2.5}$ at ENPH for summer season

Table 4.8: Statistical summary: ENPH, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	240	249	103.7	0.79	119	125	105.7	0.76
SD	63	64	4.0	0.06	21	22	4.9	0.06
CV	0.26	0.26	0.04	0.08	0.18	0.18	0.05	0.07
Maximum	381	398	113.4	0.89	158	167	113.7	0.86
Minimum	157	165	99.7	0.70	85	86	98.9	0.69

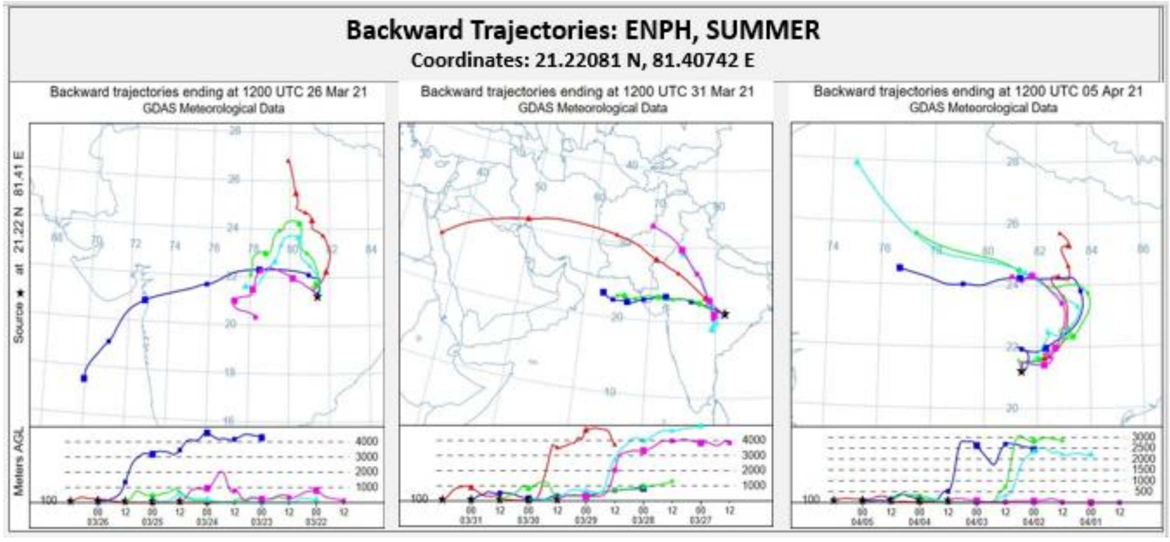


Figure 4.24: Backward trajectories at ENPH for summer season

Inference

Coal and flyash is the highest and second highest contributor for PM_{10} (24%) and $PM_{2.5}$(20%) which can be mainly because of the use of coal and flyash in the industries. Biomass burning (about 25% and 13% for PM_{10} and $PM_{2.5}$ respectively) is contributing very prominent in PM_{10} and $PM_{2.5}$. It could be due to uses of Dolachar in industries.

4.3.3.3 Post-monsoon Season [sampling period: Sep 26 – 10, 2021]

PM_{10} (post-monsoon)

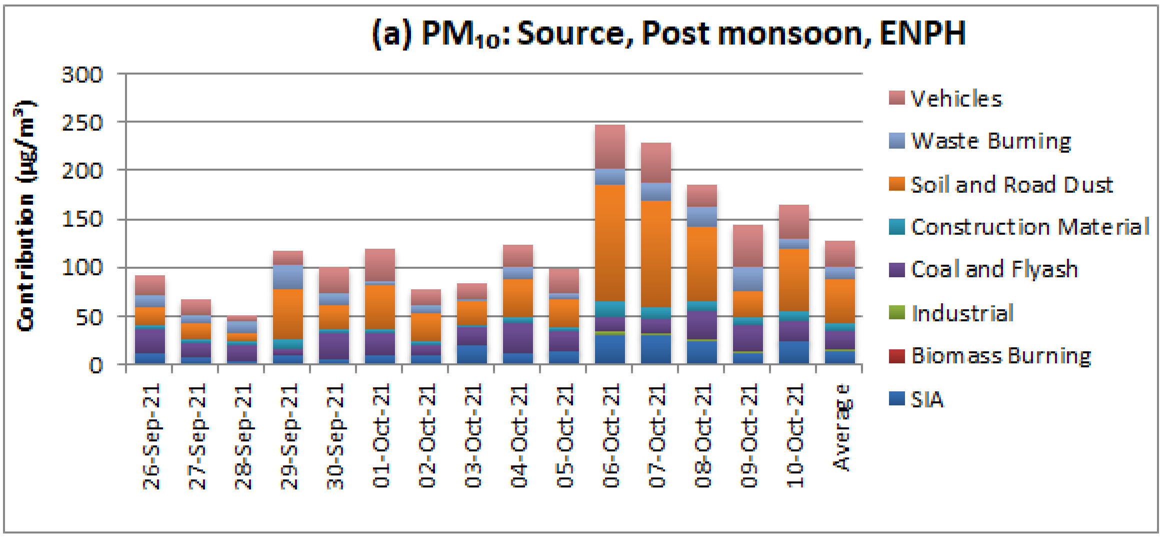
The average PM_{10} concentration was 127 µg/m^3. Figure 4.25 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at ENPH. Table 4.9 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was soil and road dust (45 µg/m^3 ~ 36%) followed by vehicular emission (26 µg/m^3 ~ 21%) and coal and fly ash (20 µg/m^3 ~

16%). Other significant sources are SIA (15 µg/m^3 ~ 12%), waste burning (10%) and construction material (6%). Contribution of the industries was estimated less than 1 % in PM_{10}.

$PM_{2.5}$ (post-monsoon)

The average $PM_{2.5}$ concentration was 67 µg/m^3; the $PM_{2.5}$/PM_{10} ratio is about 0.52. Figure 4.26 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at ENPH. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emission (21.4 µg/m^3 ~ 32%) followed by coal and flyash (16 µg/m^3 ~ 24%). Other major sources are soil and road dust (11 µg/m^3 ~ 17%), SIA (13%), waste Burning (8%), construction material (4%) and industrial emission (<2%). Contribution of the biomass burning is coming negligible in post-monsoon season for $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.27) show that most of the time wind is from SW and NW and wind mass travels over neighboring districts before entering Bhilai. These winds pick up pollutants on the way especially from tall emitting sources.


(a) PM_{10}: Source, Post monsoon, ENPH

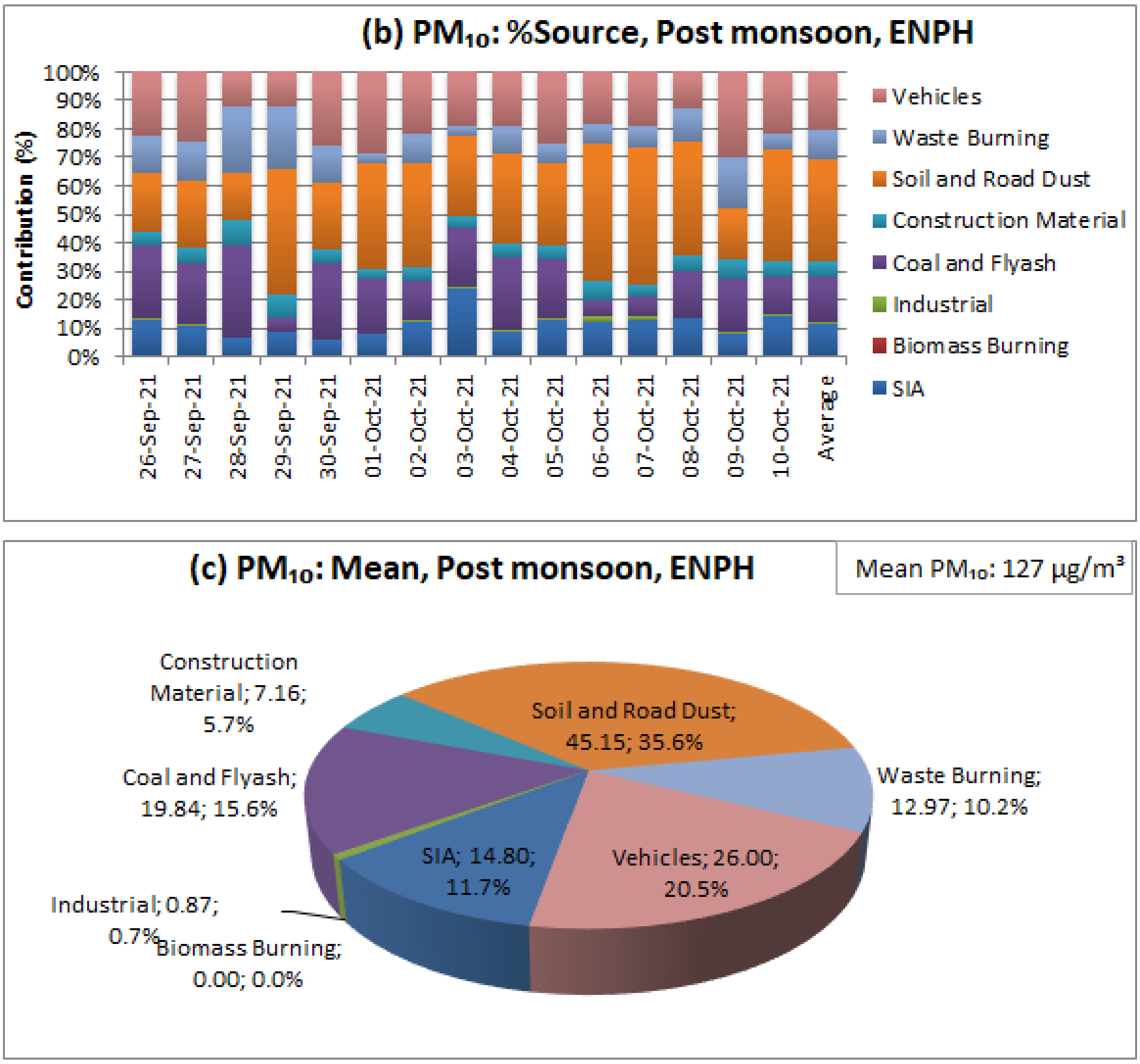
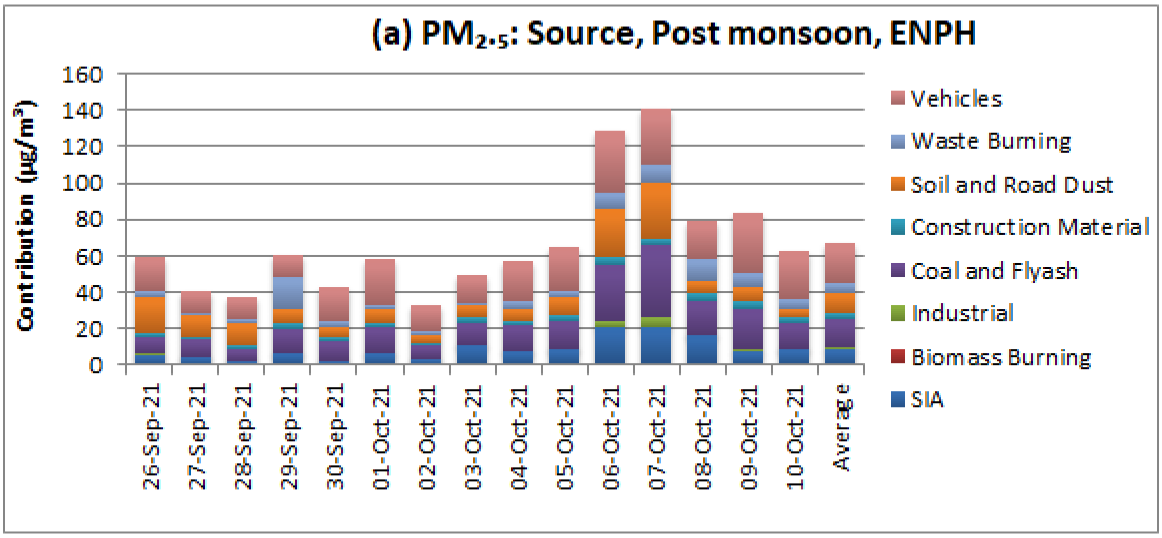


Figure 4.25: CMB modeling for PM$_{10}$ at ENPH for post-monsoon season



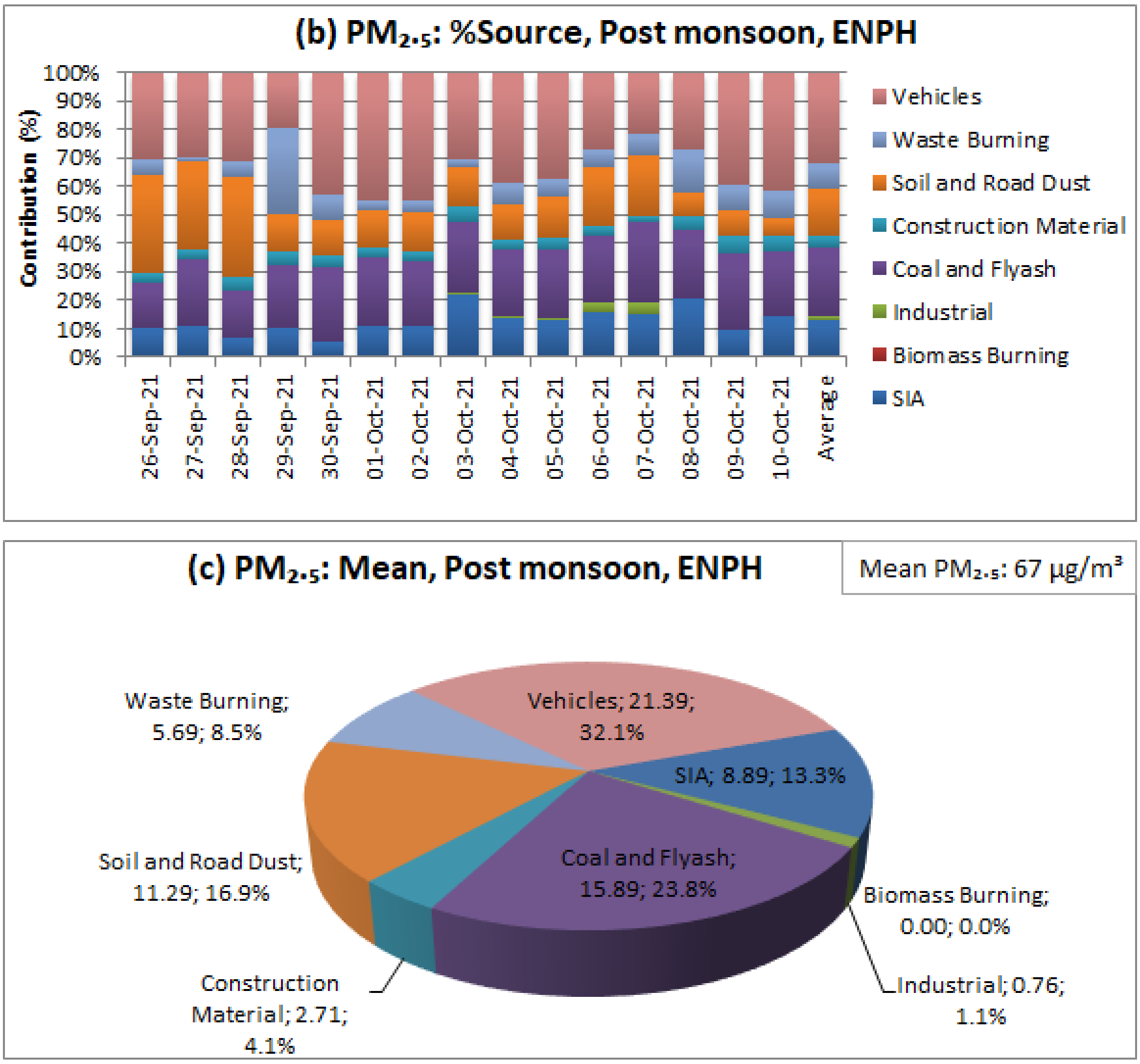


Figure 4.26: CMB modeling for $PM_{2.5}$ at ENPH for post-monsoon season

Table 4.9: Statistical summary: ENPH, post-monsoon season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	127	128	101.3	0.79	67	69	103.9	0.83
SD	58	58	1.6	0.07	31	31	4.4	0.05
CV	0.46	0.45	0.02	0.08	0.47	0.44	0.04	0.06
Maximum	248	250	104.6	0.89	141	141	113.7	0.93
Minimum	51	51	98.9	0.67	33	35	99.4	0.75

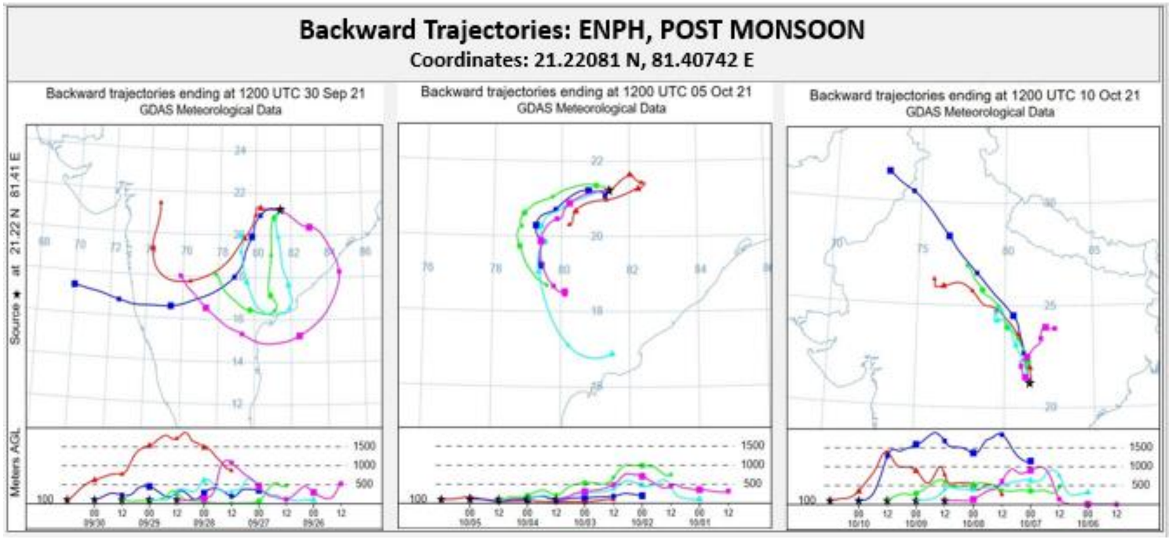


Figure 4.27: Backward trajectories at ENPH for Post monsoon season

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Soil and road dust has become the major contributor to PM_{10}. However, coal and fly ash is major contributor to $PM_{2.5}$. It was observed that the atmosphere in post-monsoon looked white to gray indicating presence of large amounts of dust which may be due to moderate speeds wind and dry conditions which makes the dust airborne.

4.3.4 HSS Risali (HSSR)

4.3.4.1 Winter Season [sampling period: Jan 03 – 17, 2021]

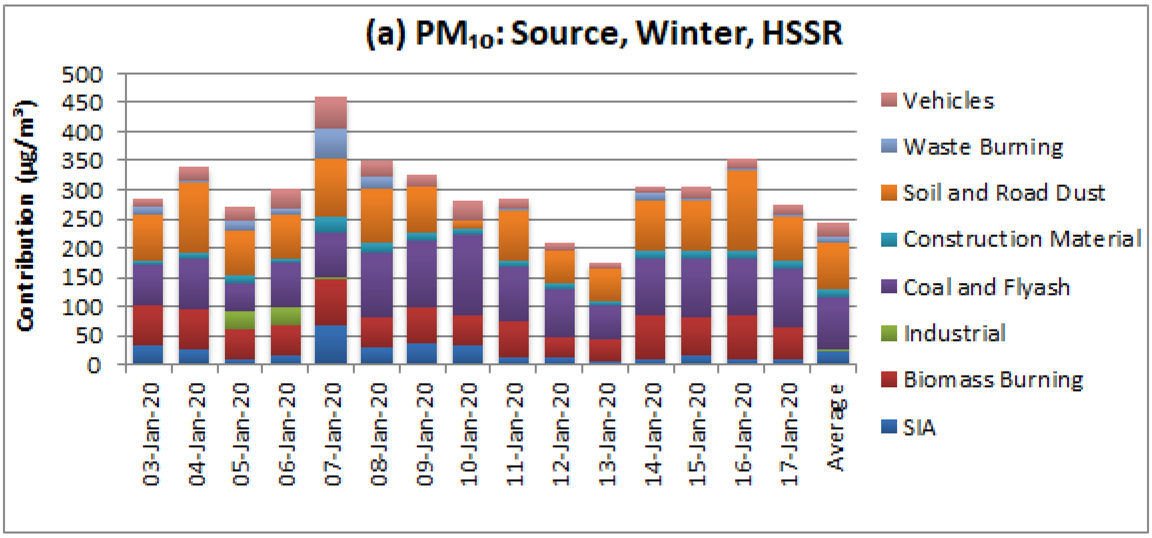
PM_{10} (winter)

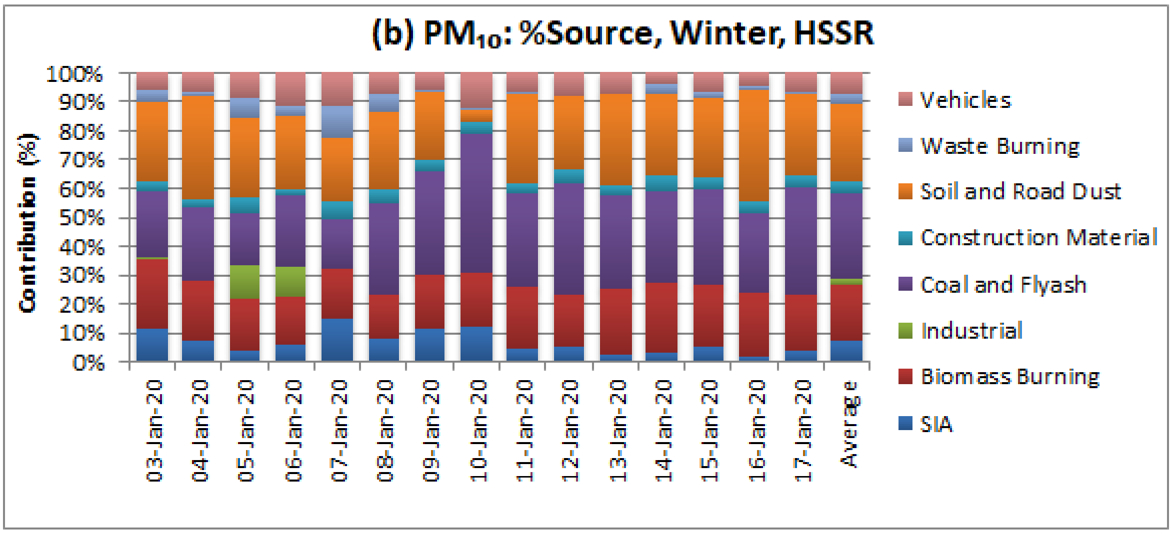
The average PM_{10} concentration was 298 µg/m^3. Figure 4.28 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSR. Table 4.10 presents summary of performance and acceptability of CMB model. It is observed that the major contributing source to PM_{10} was coal and flyash (89 µg/m^3 ~ 30%) followed by soil and road dust (81 µg/m^3 ~ 27%) and biomass burning (60 µg/m^3 ~ 20%). The other significant contributing sources are vehicular emission (23 µg/m^3 ~ 8%), SIA (22 µg/m^3 ~ 7%), construction material (4%) and waste burning (3%). Contribution of the industrial emission was estimated less than 2% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 150 µg/m^3. Figure 4.29 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSR. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (57 µg/m^3 ~ 38%) followed by coal and flyash (41 µg/m^3 ~ 27%). Other significant sources are soil and road dust (18 µg/m^3 ~ 12%), vehicular emission (14 µg/m^3 ~ 9%) and construction (6%) and waste burning (2%). Contribution from industrial emission was estimated to be less than 2%.

HYSPLIT back trajectories (Figure 4.30) show that wind is not stable in any direction and wind mass travel over to neighboring districts before entering Bhilai. These winds pick up the pollutants on the way especially from large and tall emitting sources.


(a) PM_{10}: Source, Winter, HSSR


(b) PM_{10}: %Source, Winter, HSSR

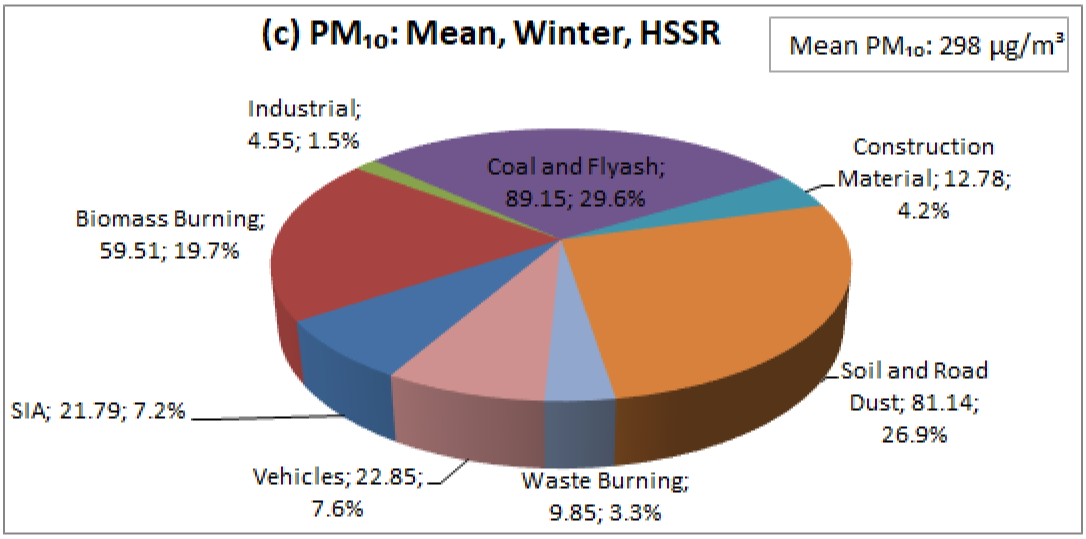
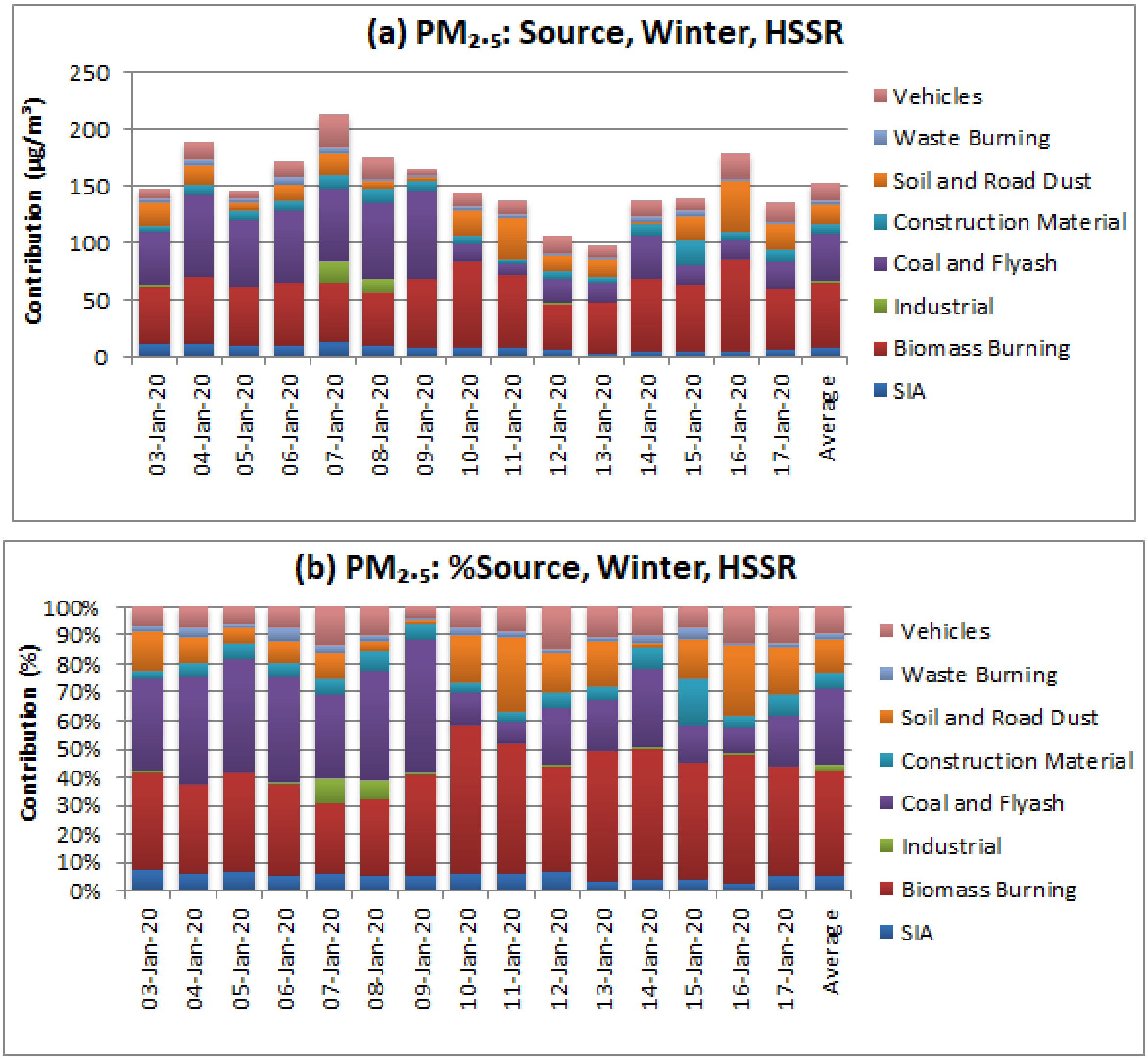


Figure 4.28: CMB modeling for PM_{10} at HSSR for winter season



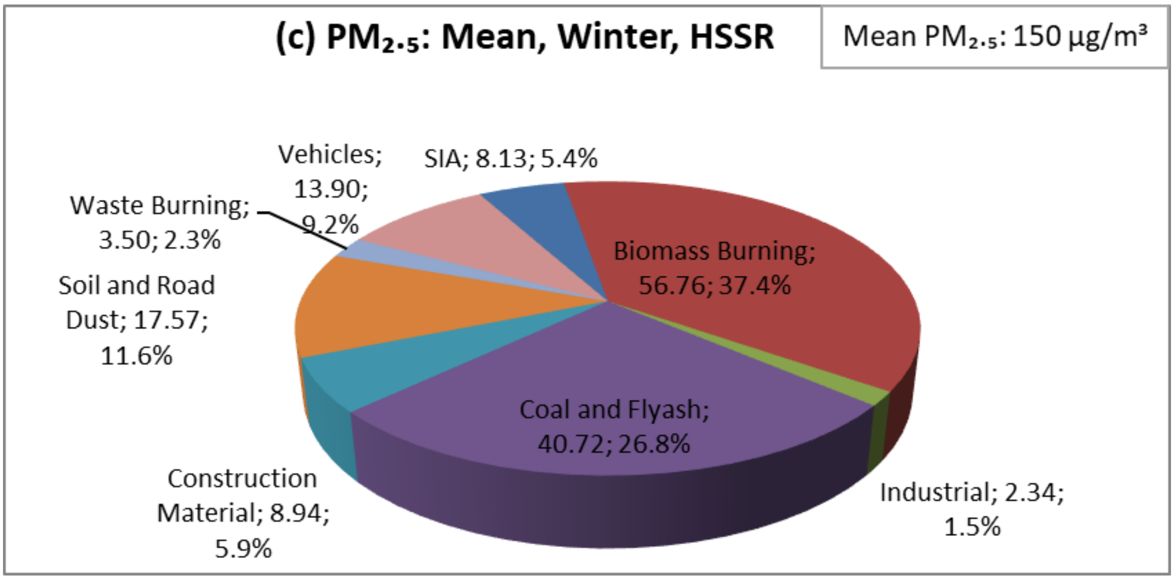


Figure 4.29: CMB modeling for $PM_{2.5}$ at HSSR for winter season

Table 4.10: Statistical summary: HSSR, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	298	315	105.4	0.81	150	161	107.2	0.88
SD	55	61	4.3	0.06	29	34	5.8	0.06
CV	0.18	0.19	0.04	0.07	0.20	0.21	0.05	0.06
Maximum	397	400	113.3	0.88	213	224	118.3	0.93
Minimum	176	189	99.8	0.68	98	106	96.8	0.71

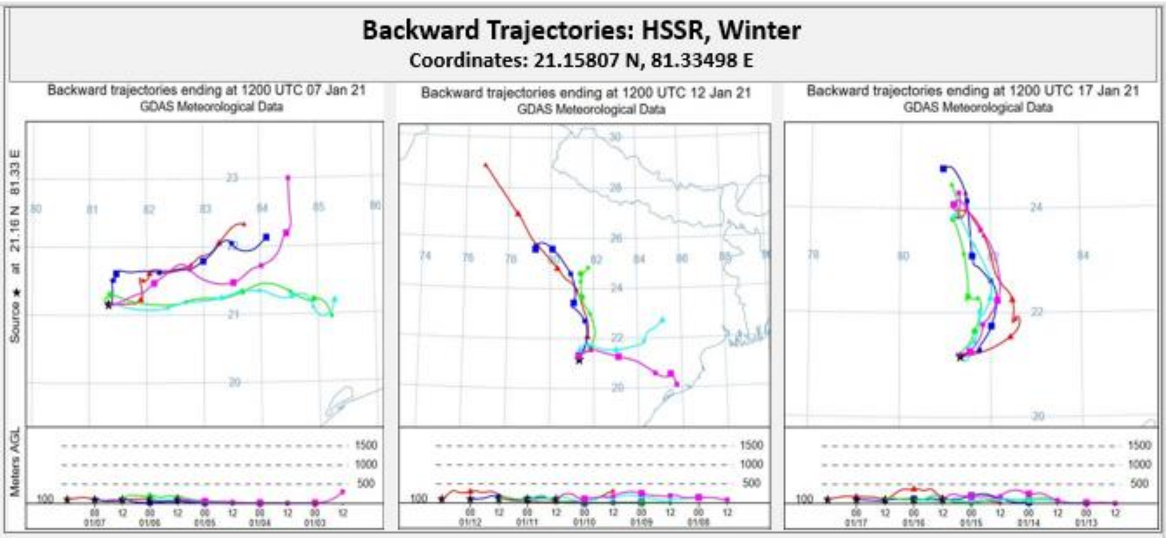


Figure 4.30: Backward trajectories at HSSR for winter season

Inference

It is to be noted that at HSSR, coal and flyash (30%) is the highest contributor for PM_{10} and Biomass burning (38%) for $PM_{2.5}$. Soil and road dust contribution decreased from 27% in PM_{10} to 12% in $PM_{2.5}$.

4.3.4.2 Summer Season [sampling period: Mar 22, 2021- April 05, 2021]

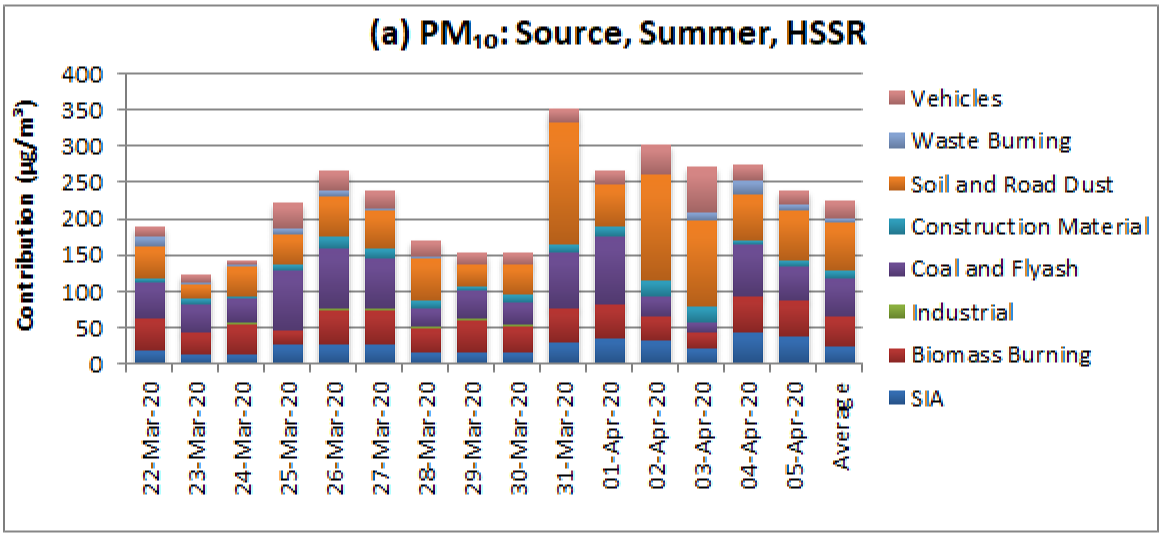
PM_{10} (summer)

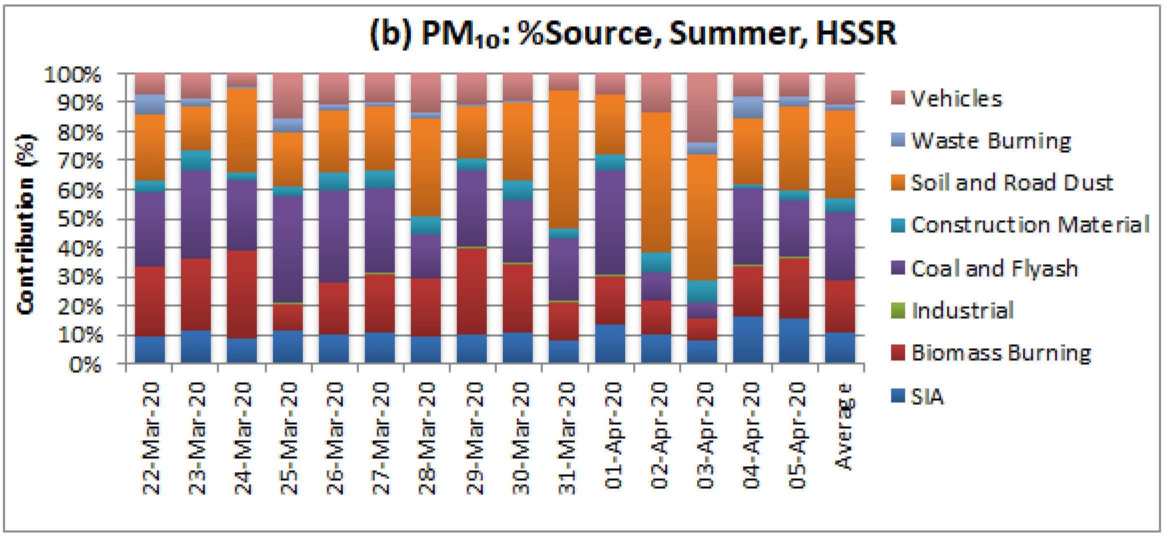
The average PM_{10} concentration was 224 µg/m^3. Figure 4.31(a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSR. Table 4.11 presents summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was soil and road dust (67 µg/m^3 ~ 30%) followed by coal and flyash (52 µg/m^3 ~ 23%). The other significant sources are biomass burning (40 µg/m^3 ~ 18%), SIA (25 µg/m^3 ~ 11%), vehicular emission (24 µg/m^3 ~ 11%) and construction material (5%). Other minor sources are waste burning (2%) and industrial emission (<1%).

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 42 µg/m^3. Figure 4.32 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSR. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (30 µg/m^3 ~ 27%) followed by coal and flyash (24 µg/m^3 ~ 21%). The other significant sources are vehicular emission (21 µg/m^3 ~ 18%), soil and road dust (20 µg/m^3 ~ 18%), SIA (12 µg/m^3 ~ 11%) and construction material (4%). Other minor sources are waste burning (<2%) and industrial emission (<1%).

HYSPLIT back trajectories (Figure 4.33) show that most of the time wind is from NW and wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from large emitting sources.





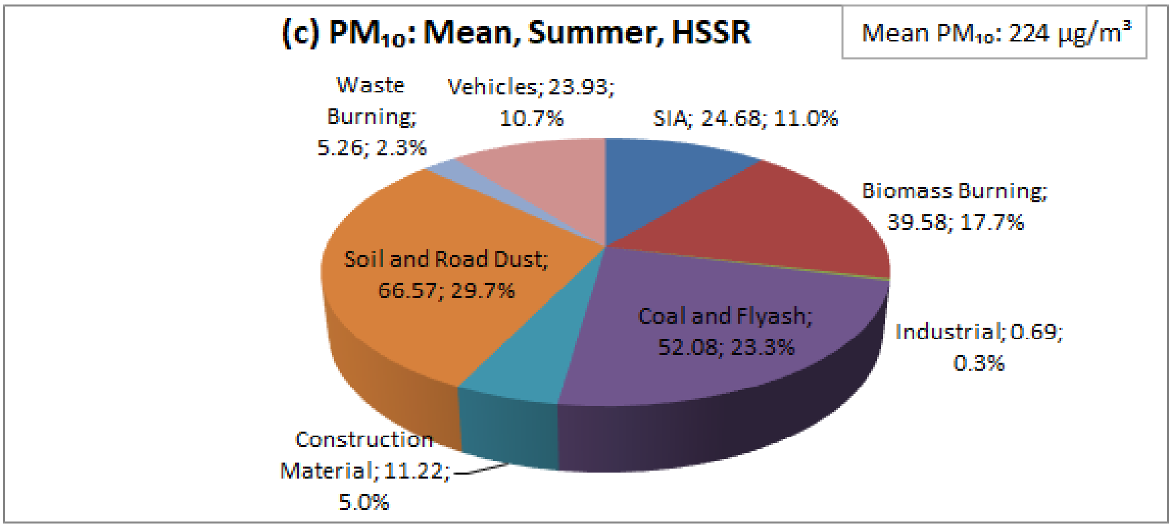


Figure 4.31: CMB modeling for PM$_{10}$ at HSSR for summer season

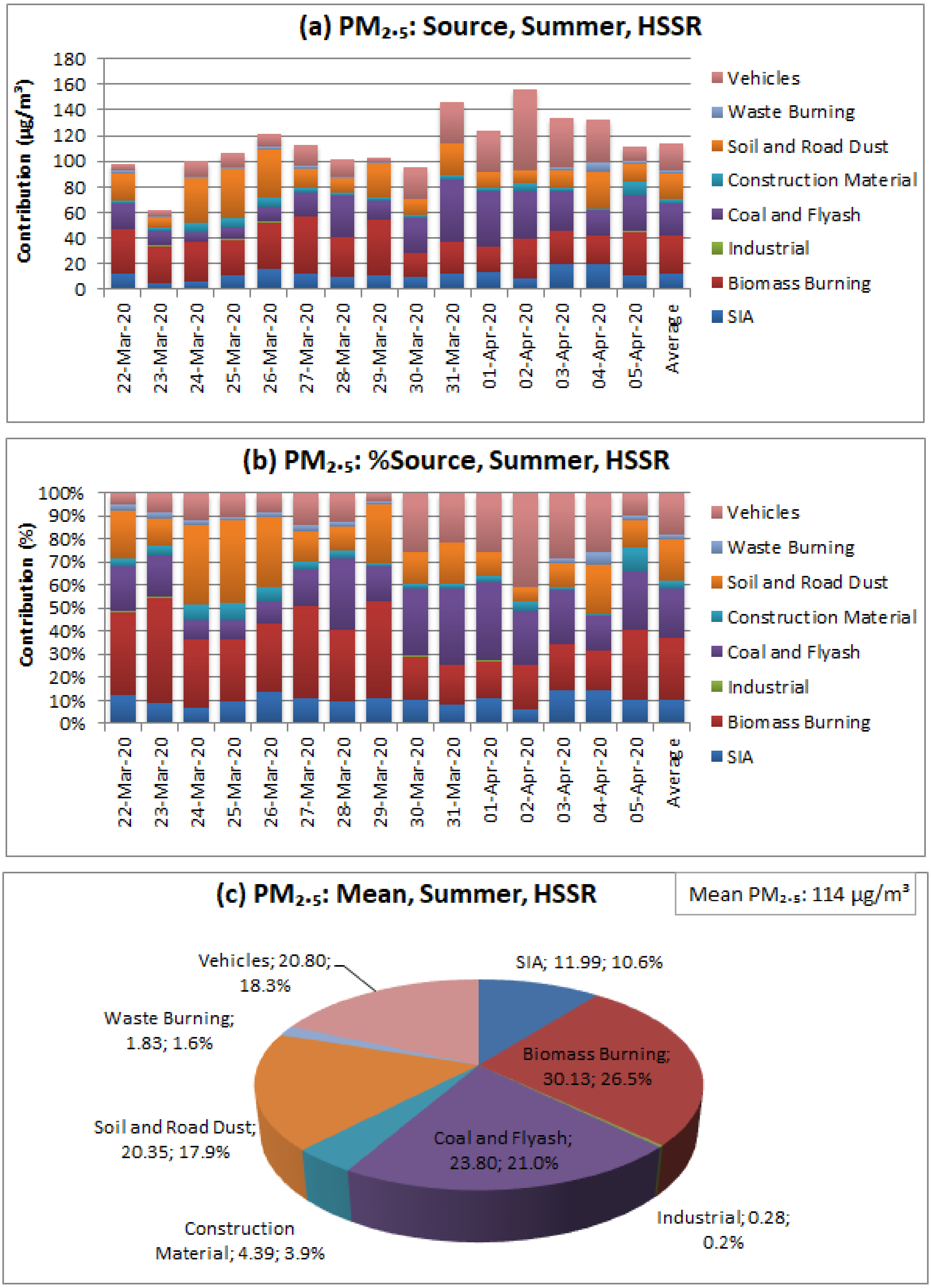


Figure 4.32: CMB modeling for $PM_{2.5}$ at HSSR for summer season

Table 4.11: Statistical summary: HSSR, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	224	227	101.6	0.82	114	121	106.2	0.81
SD	67	65	3.0	0.05	23	25	5.5	0.06
CV	0.30	0.29	0.03	0.07	0.20	0.21	0.05	0.08
Maximum	353	354	109.0	0.90	156	158	119.2	0.93
Minimum	122	123	96.2	0.73	62	69	100.9	0.73

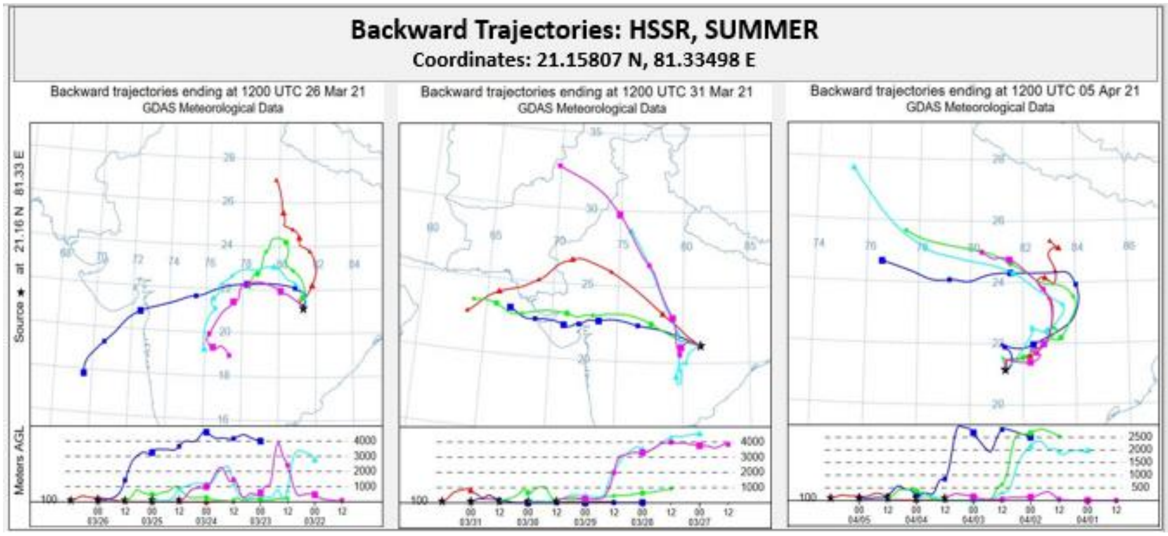


Figure 4.33: Backward trajectories at HSSR for summer season

Inference

soil and road dust is the highest contributor to PM_{10}. Biomass burning and coal and flyash is consistently contributing to both PM_{10} and $PM_{2.5}$. Vehicular emissions are also higher in $PM_{2.5}$.

4.3.4.3 Post-monsoon Season [sampling period: Oct 13 – 26, 2021]

PM_{10} (post-monsoon)

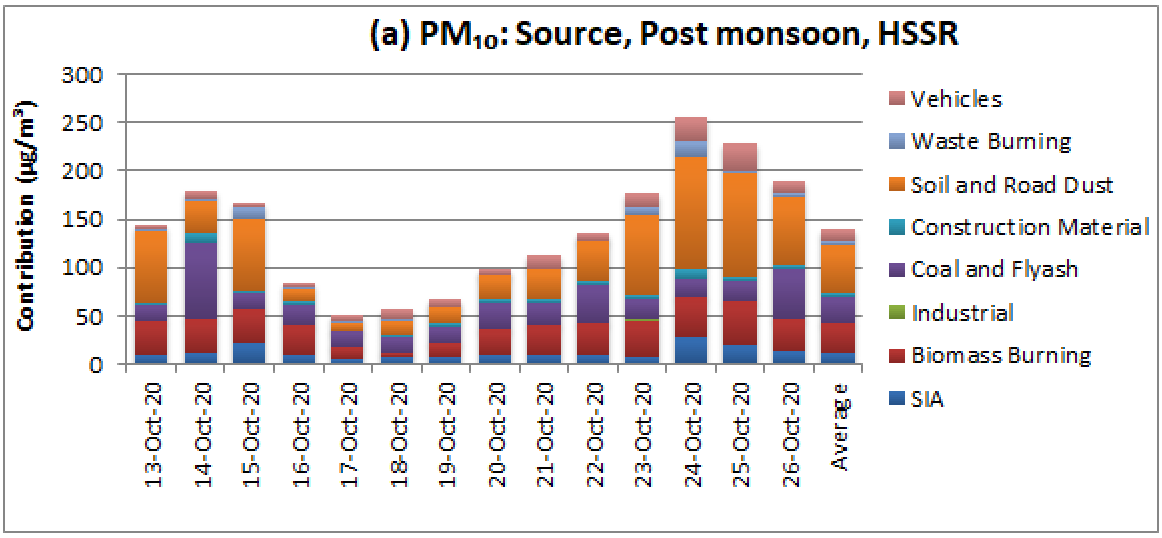
The average PM_{10} concentration was 140 µg/m^3. Figure 4.34(a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSR. Table 4.12 presents summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was soil and road dust (50 µg/m^3 ~ 36%) followed by biomass burning (30 µg/m^3 ~ 22%) and coal and fly ash (27 µg/m^3 ~ 19%). Other significant sources are SIA (12 µg/m^3 ~ 9%), vehicular emission (11 µg/m^3 ~

8%), construction material (3%) and waste burning (2.9%). Contribution of the industrial emission was estimated less than 1 % in PM_{10}.

$PM_{2.5}$ (post-monsoon)

The average $PM_{2.5}$ concentration was 74 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.52. Figure 4.35(a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSR. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (23 µg/m^3 ~ 33%) followed by biomass burning (16 µg/m^3 ~ 22%). Other major sources are coal and flyash (13 µg/m^3 ~ 17%), vehicular emission (13%), SIA (8%), waste burning (5%) and construction material (3%). Contribution of the industrial emission was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.36) show that most of the time wind is from NW and NE. The wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from tall emitting sources.



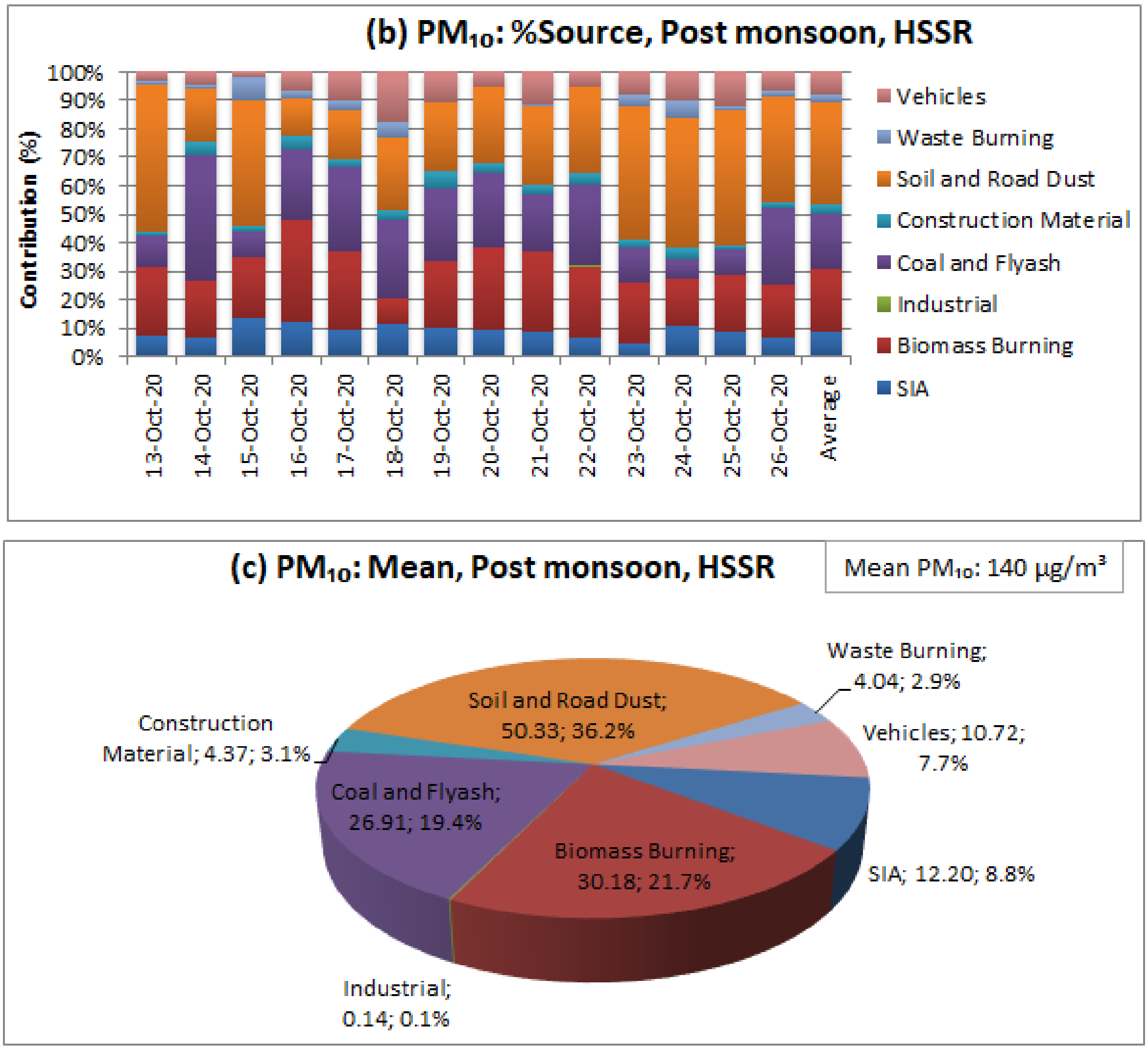
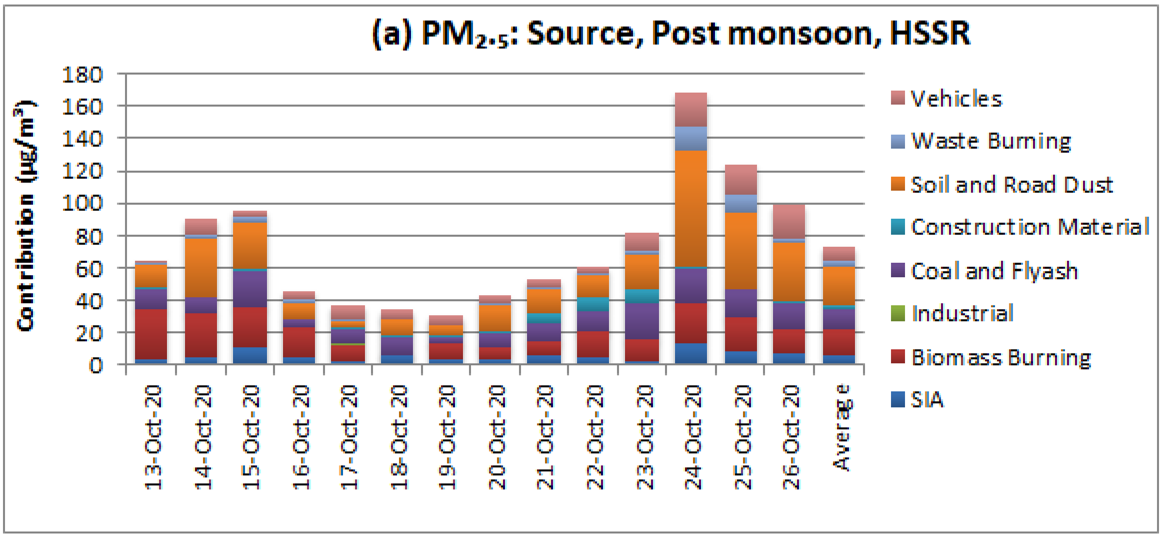


Figure 4.34: CMB modeling for PM$_{10}$ at HSSR for post-monsoon season



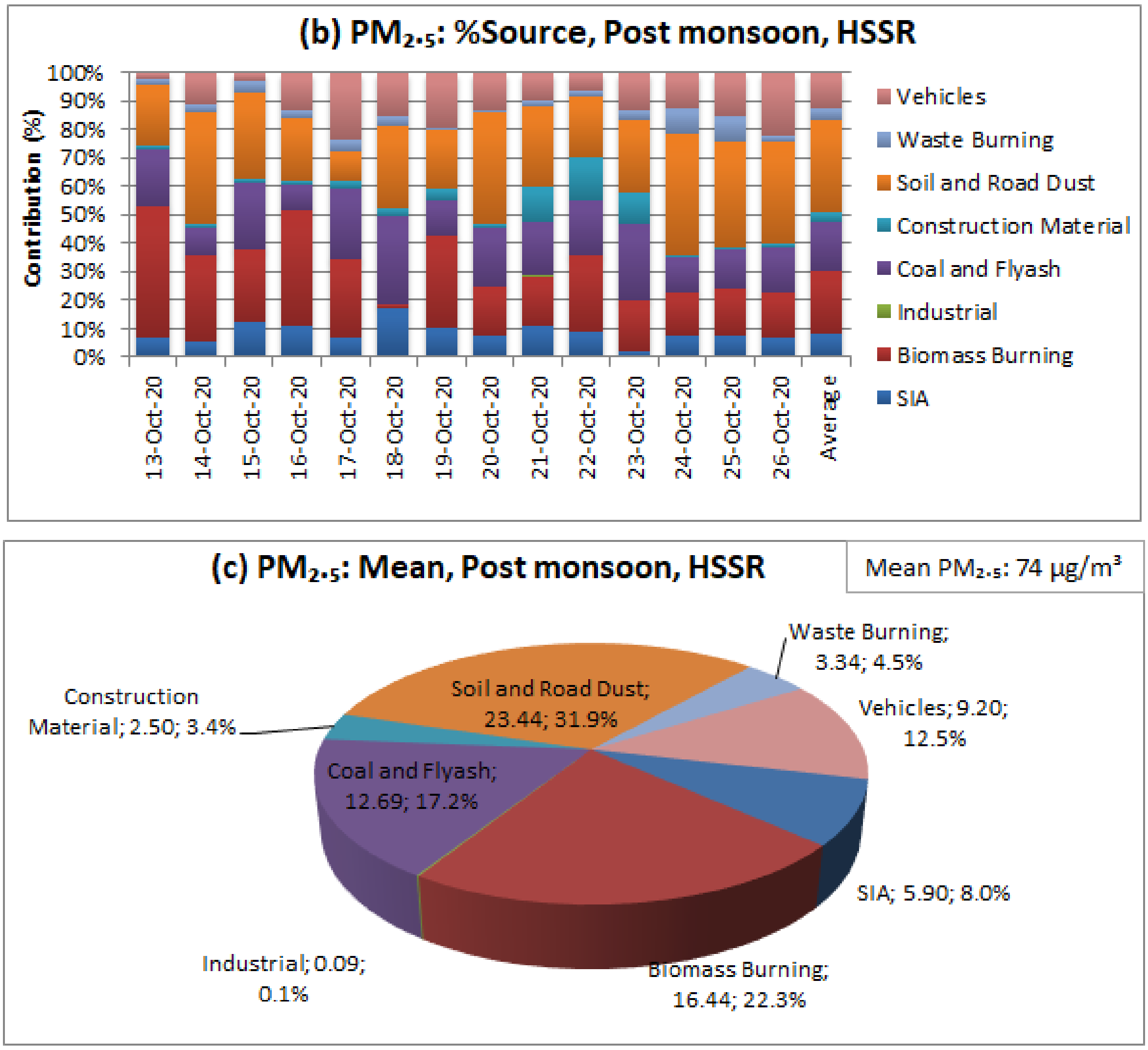


Figure 4.35: CMB modeling for $PM_{2.5}$ at HSSR for post-monsoon season

Table 4.12: Statistical summary: HSSR, post-monsoon season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	140	145	102.6	0.8	74	77	106.0	0.81
SD	62	68	3.3	0.1	39	39	5.8	0.07
CV	0.44	0.47	0.03	0.07	0.53	0.51	0.05	0.09
Maximum	256	279	108.9	0.91	168	175	116.6	0.91
Minimum	60	63	99.4	0.73	31	33	100.2	0.65

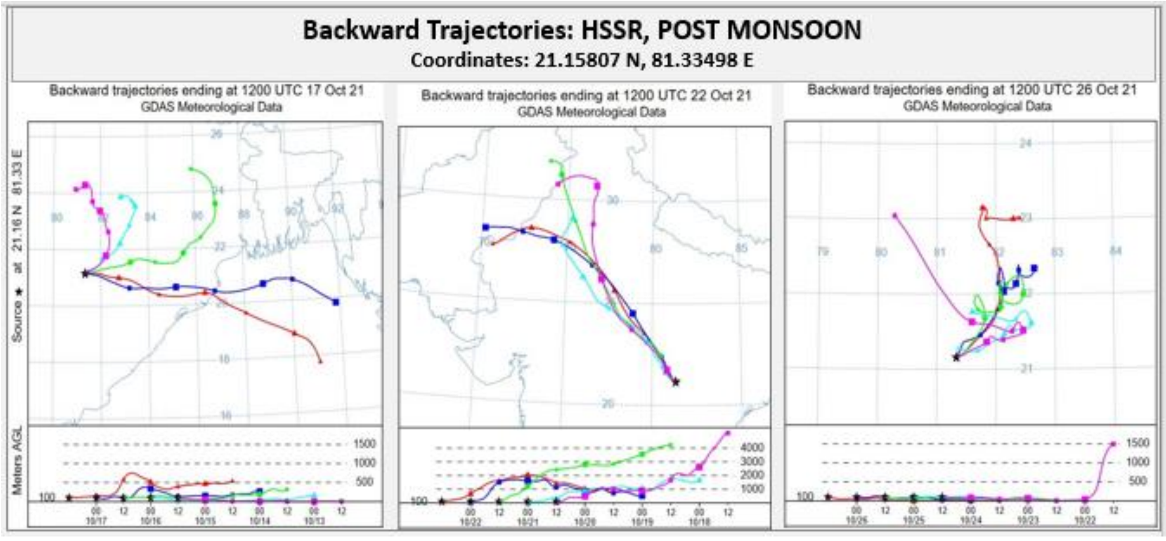


Figure 4.36: Backward trajectories at HSSR for post-monsoon season

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Soil and road dust and biomass burning have become the major PM_{10} and $PM_{2.5}$ sources. Coal and flyash is also higher in both PM_{10} and $PM_{2.5}$. It was observed that the atmosphere in post-monsoon looked blueish to gray indicating presence of moderate amounts of dust which may be due to high speeds wind and dry conditions (low rainfall) which makes the dust airborne.

4.3.5 HSS Baghera (HSSB)

4.3.5.1 Winter Season [sampling period: Jan 24 – Feb 07, 2021

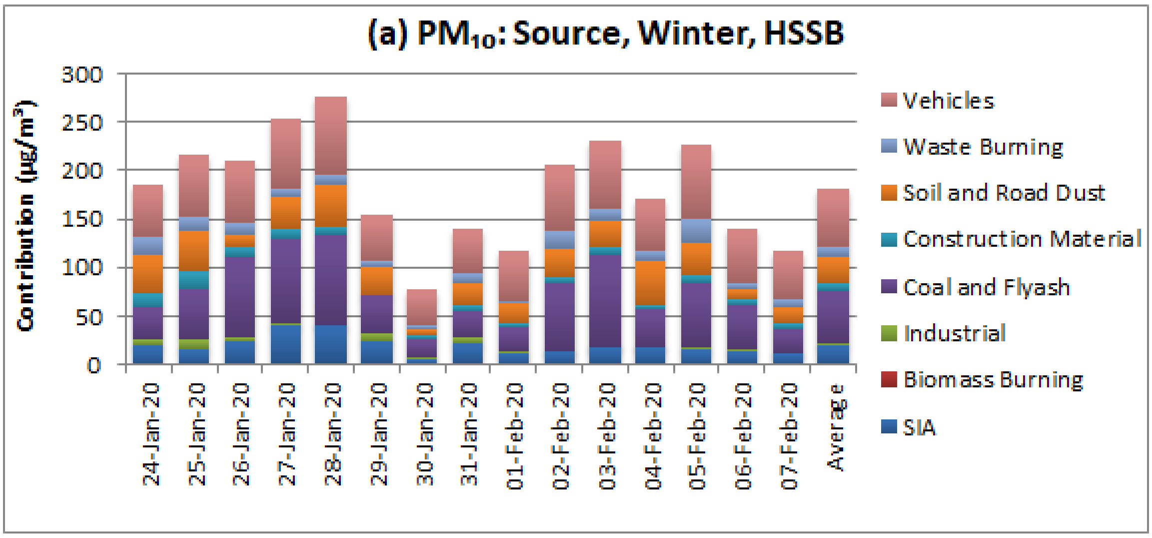
PM_{10} (winter)

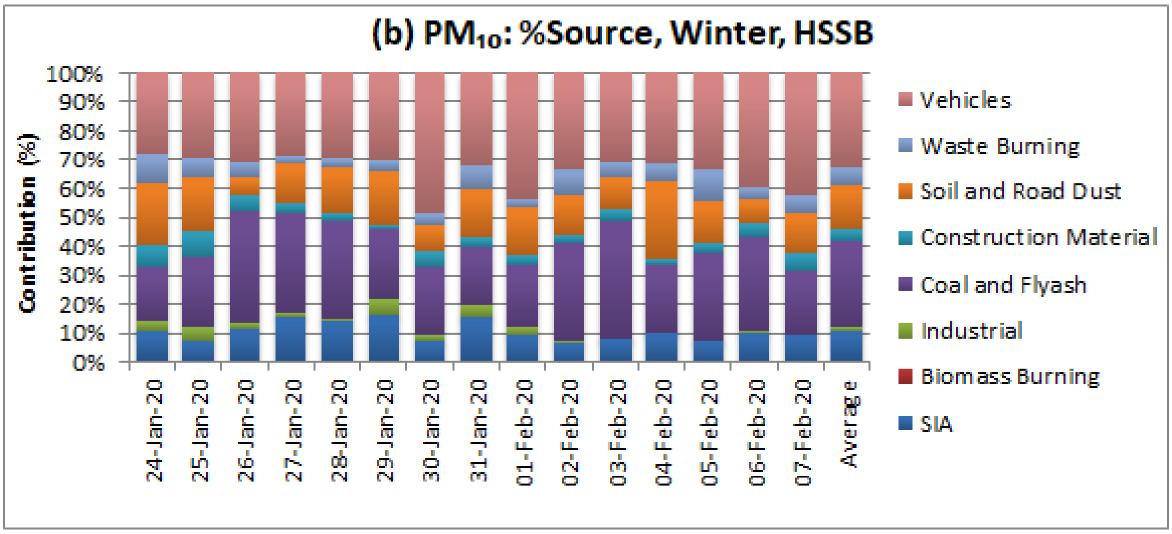
The average PM_{10} concentration was 181 µg/m^3. Figure 4.37(a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSB. Table 4.13 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was vehicular emission (59 µg/m^3 ~ 33%) followed by coal and flyash (53 µg/m^3 ~ 30%) and soil and road dust (27 µg/m^3 ~ 15%). The other significant contributing sources are SIA (20 µg/m^3~ 11%), waste burning (11 µg/m^3 ~ 6%) and construction material (4%). Contribution of the industrial emission was estimated less than 2% in PM_{10}. Biomass burning is estimated negligible.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 116 µg/m^3. Figure 4.38(a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSB. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emission (43 µg/m^3 ~ 37%) followed by coal and flyash (37 µg/m^3 ~ 32%) and soil and road dust (17 µg/m^3 ~ 15%). Other significant sources are SIA (12 µg/m^3 ~ 11%), construction material (5%) and waste burning (3%). The minor source is industrial emission (<2%) and biomass burning is negligible in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.39) show that most of the time wind is from North and sometime from NE. The wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from tall emitting sources.





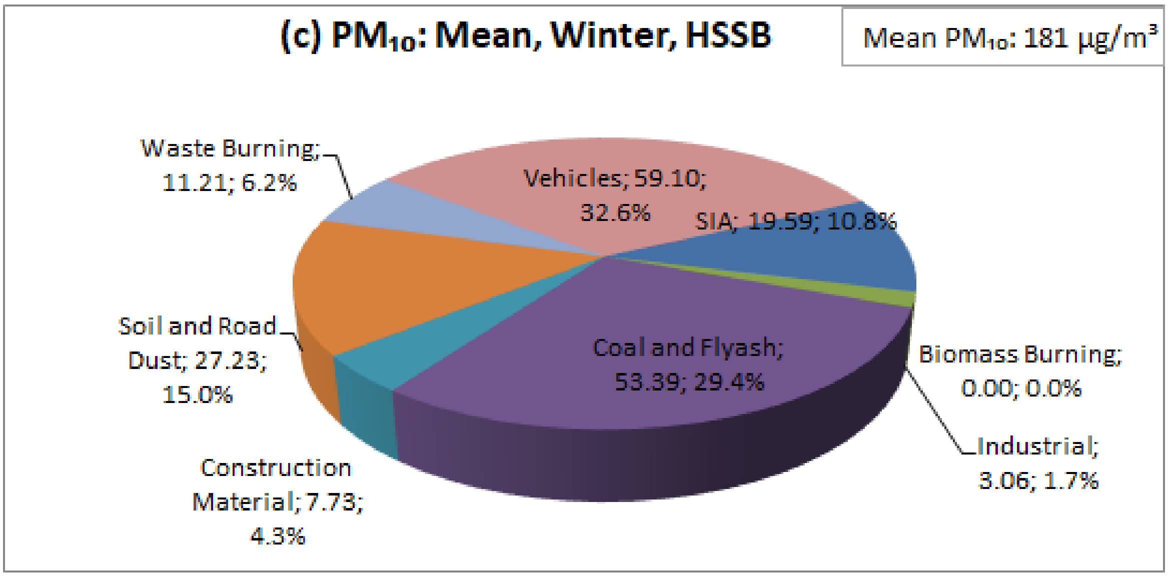
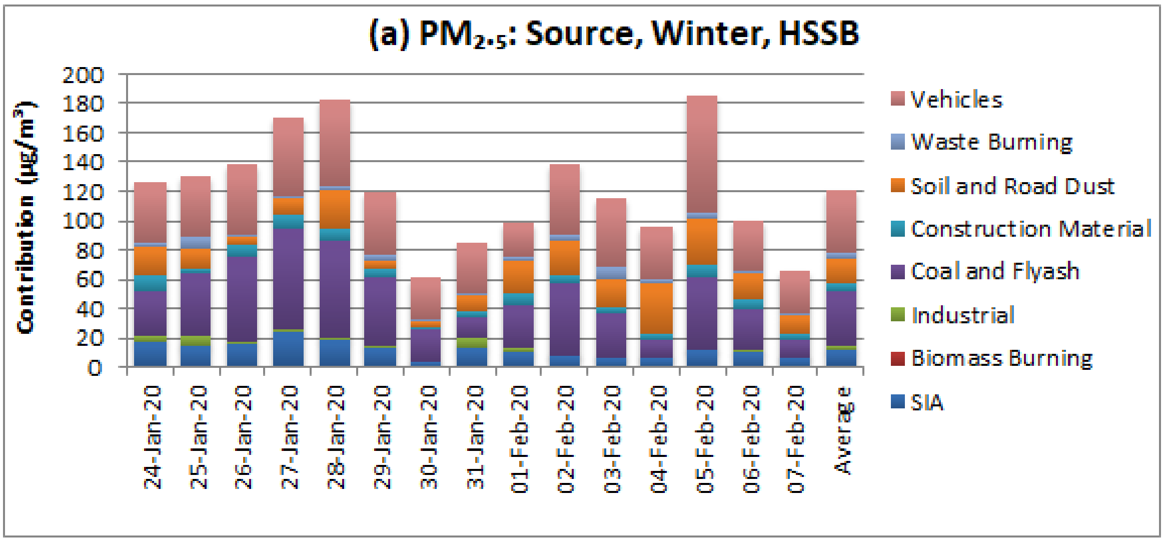
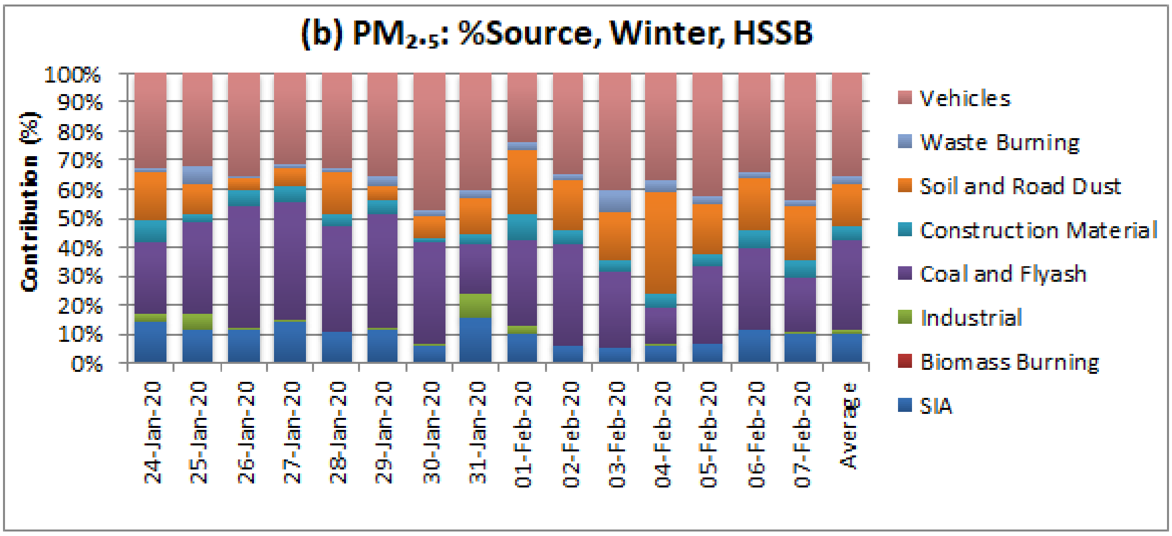


Figure 4.37: CMB modeling for PM$_{10}$ at HSSB for winter season





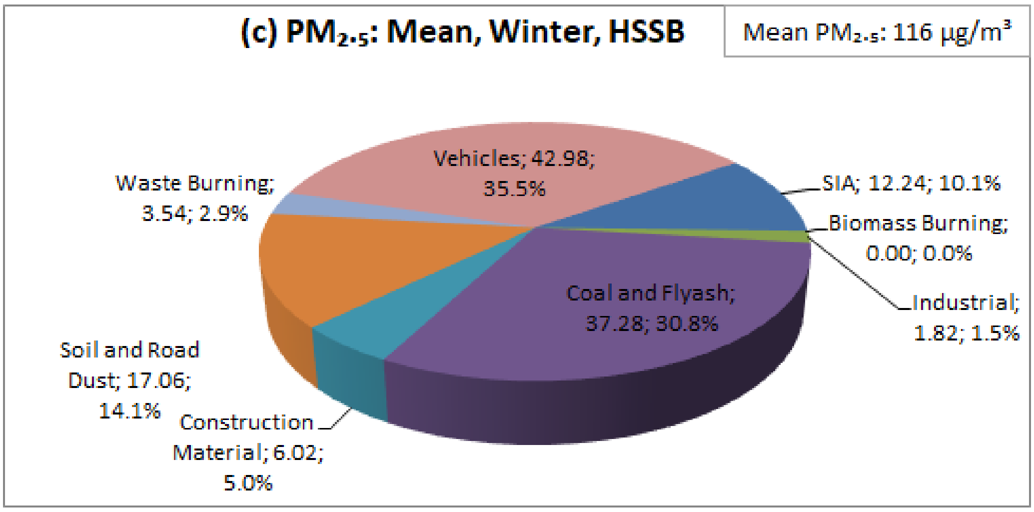


Figure 4.38: CMB modeling for PM$_{2.5}$ at HSSB for winter season

Table 4.13: Statistical summary: HSSB, winter season

	PM$_{10}$				PM$_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	181	188	104.2	0.85	116	120	104.3	0.87
SD	56	57	4.8	0.04	35	34	5.7	0.05
CV	0.31	0.30	0.05	0.05	0.30	0.29	0.05	0.06
Maximum	276	286	113.1	0.92	183	188	119.3	0.95
Minimum	79	85	96.6	0.75	61	65	98.6	0.74

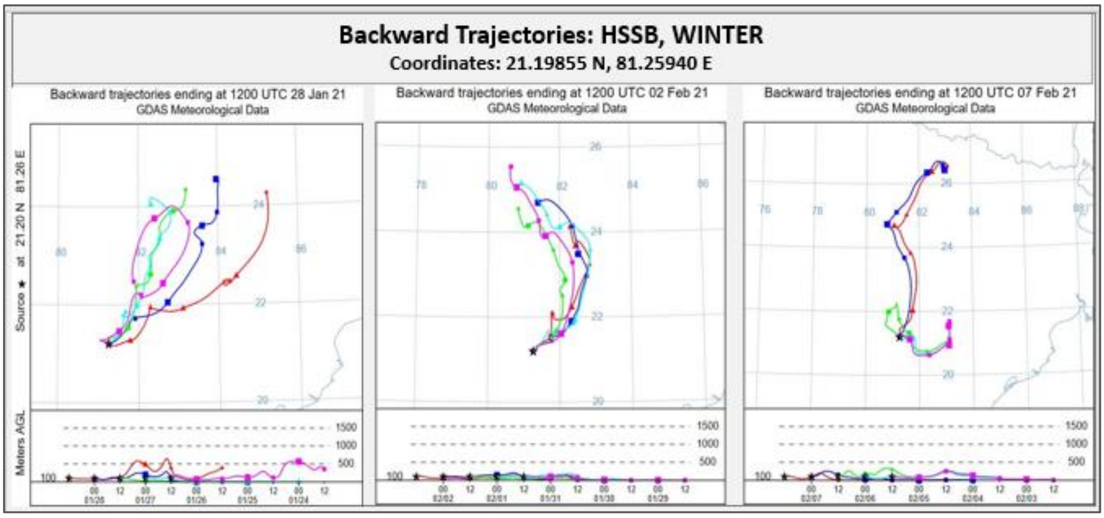


Figure 4.39: Backward trajectories at HSSB for winter season

Inference

Contributions of vehicles, coal and flyash and soil and road dust are consistently high both in PM$_{10}$ and PM$_{2.5}$. SIA also appears to be widespread and consistently contributing to both PM$_{10}$ and PM$_{2.5}$.

4.3.5.2 Summer Season [sampling period: May 01 - 10, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 65 µg/m^3. Figure 4.40(a), (b), (c) shows PM_{10} concentration contribution of sources, percent contribution of sources and summary of sources (average over 10 days) at HSSB. Table 4.14 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was vehicular emission (23 µg/m^3 ~ 35%) followed by coal and flyash (11 µg/m^3 ~ 18%). The other significant contributing sources are soil and road dust (10 µg/m^3 ~ 15%), SIA (9 µg/m^3 ~ 14%), waste burning (7%), construction material (7%) and industrial emission (4%). Biomass burning is estimated negligible.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 42 µg/m^3. Figure 4.41(a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSB. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emission (17 µg/m^3 ~ 41%) followed by SIA (8 µg/m^3 ~ 18%). Other significant sources are coal and flyash (6 µg/m^3 ~ 14.3%), soil and road dust (14.2%), construction material (5%) and industrial emission (4%). The contribution of the waste burning was less than 3%. Biomass burning is negligible in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.42) show that most of the time wind is from SW and SE wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from large emitting sources.

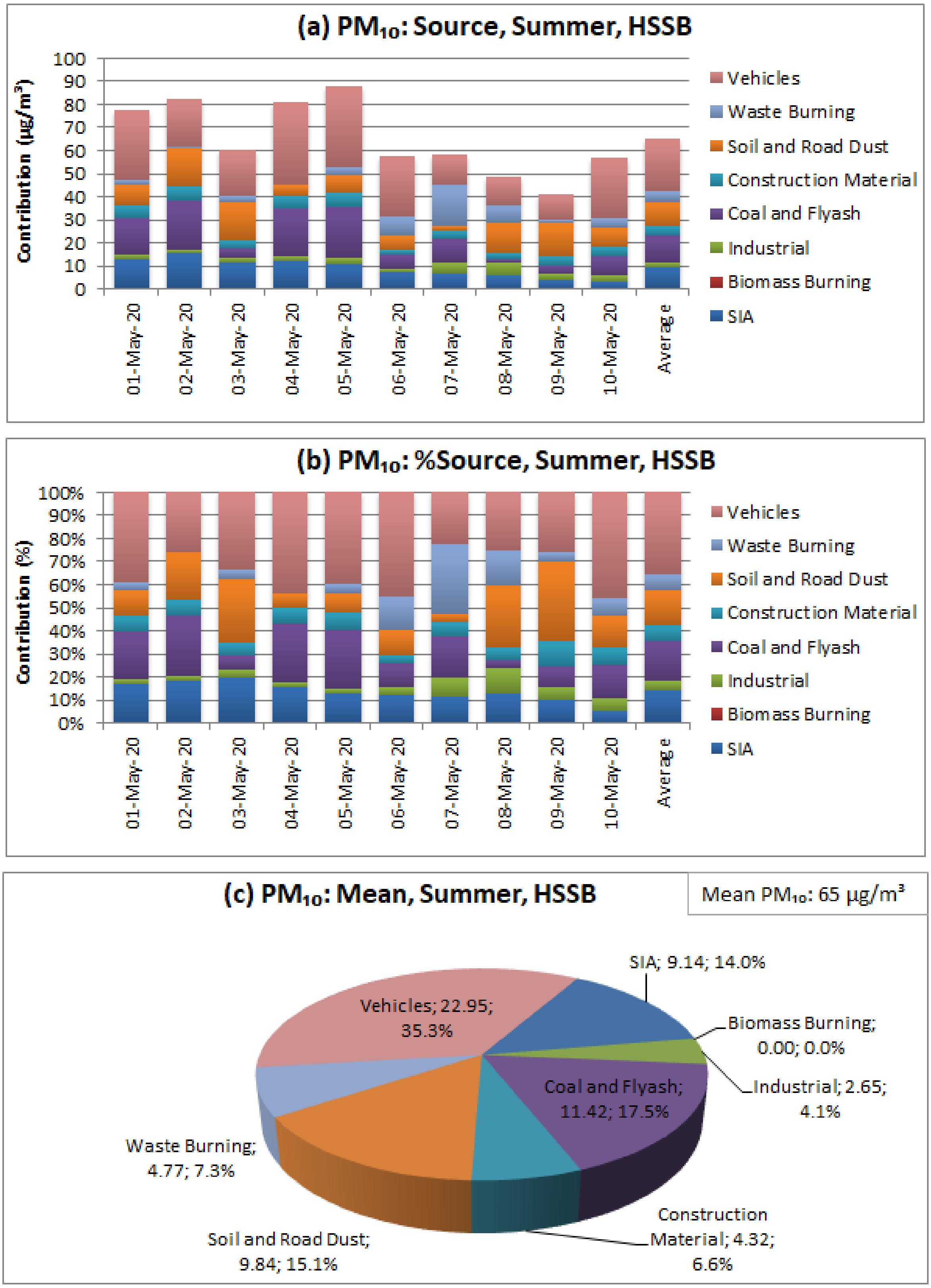


Figure 4.40: CMB modeling for PM_{10} at HSSB for summer season

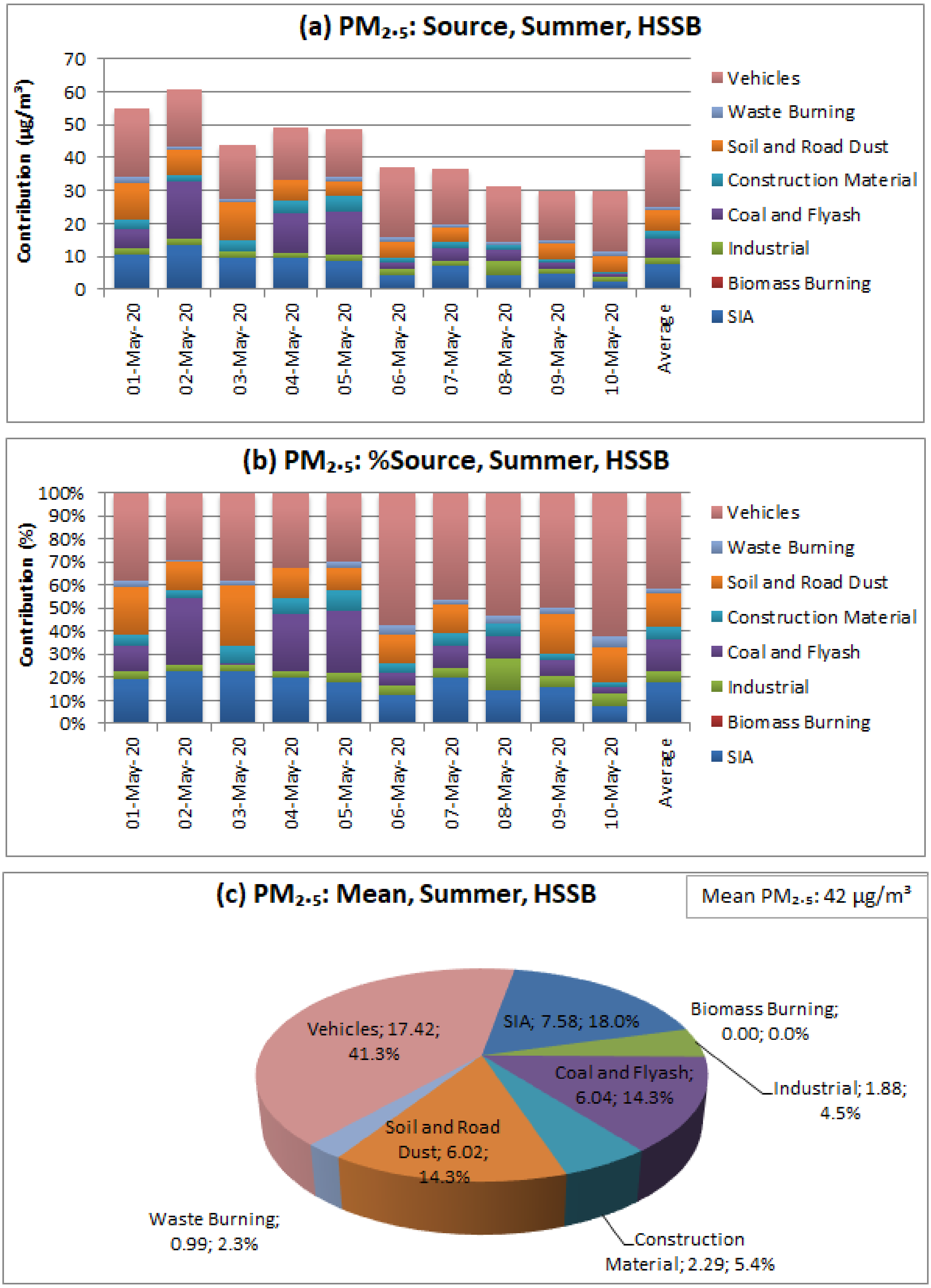


Figure 4.41: CMB modeling for $PM_{2.5}$ at HSSB for summer season

Table 4.14: Statistical summary: HSSB, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	65	68	103.4	0.71	42	42	101.1	0.82
SD	16	17	6.8	0.07	11	9	4.5	0.08
CV	0.25	0.25	0.07	0.11	0.26	0.22	0.04	0.10
Maximum	88	91	115.5	0.80	61	56	106.2	0.89
Minimum	40	41	97.2	0.60	30	30	91.5	0.67

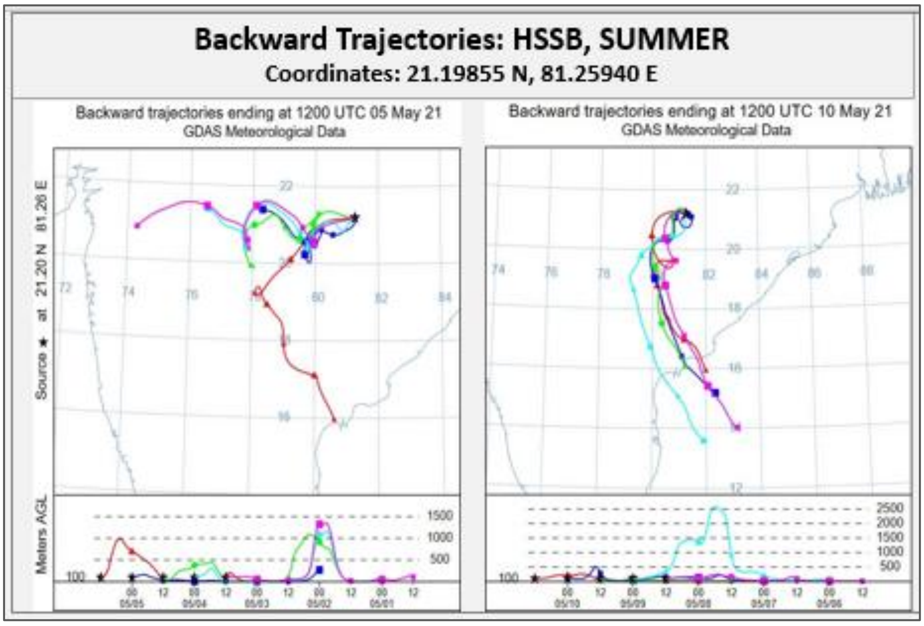


Figure 4.42: Backward trajectories at HSSB for summer season

Inference

Vehicular emission is contributing the highest in both PM_{10} and $PM_{2.5}$. Coal combustion the significant contributor in PM_{10} and Secondary inorganic emissions are coming out higher in $PM_{2.5}$ contributions.

4.3.5.3 Post-monsoon Season [sampling period: Sep 27 – Oct 11, 2021]

PM_{10} (post-monsoon)

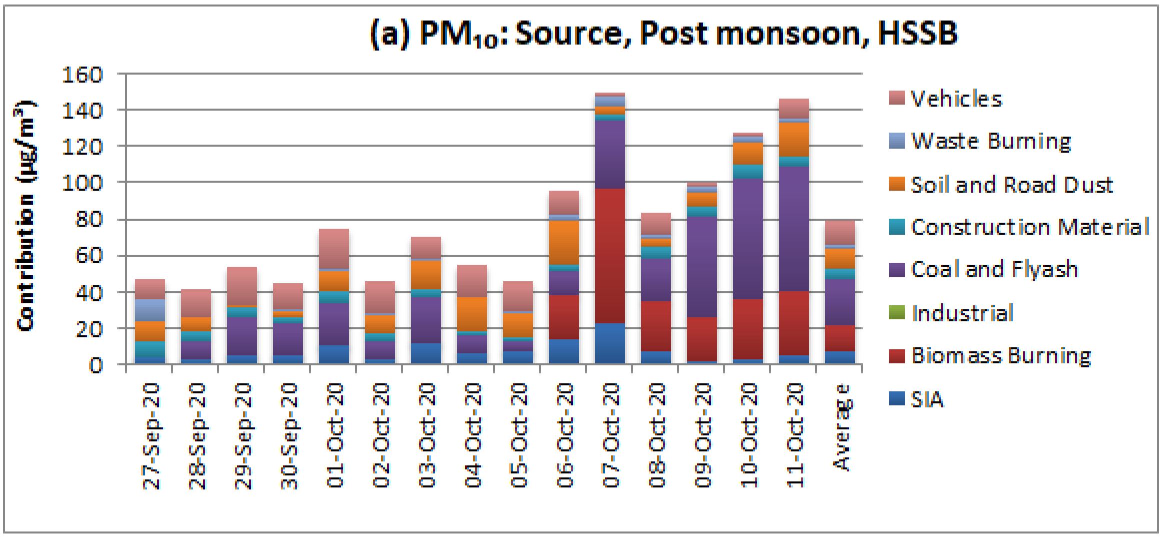
The average PM_{10} concentration was 78 µg/m^3. Figure 4.43(a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSB. Table 4.15 presents summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was coal and flyash (26 µg/m^3 ~ 33%) followed by biomass burning (15 µg/m^3 ~ 19%) and vehicular emission (13 µg/m^3 ~

16%). Other significant sources are soil and road dust (11 µg/m^3 ~ 14%), SIA (7 µg/m^3 ~ 9.4%), construction material (5 µg/m^3 ~ 6%) and waste burning (3%) in PM_{10}. Contribution of the industrial emission (other than coal combustion) was less than 1% in PM_{10}.

$PM_{2.5}$ (post-monsoon)

The average $PM_{2.5}$ concentration was 46 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.58. Figure 4.44(a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at HSSB. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emission (11 µg/m^3 ~ 30%) followed by biomass burning (10 µg/m^3 ~ 23%). Other major sources are coal and flyash (8.5 µg/m^3 ~ 18%), soil and road dust (7 µg/m^3 ~ 16%), SIA (5 µg/m^3 ~ 10%), construction material (5%) and waste burning (3%). Contribution of the industrial emission was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.45) show that most of the time wind is from NW and SW and wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from tall emitting sources.


(a) PM_{10}: Source, Post monsoon, HSSB

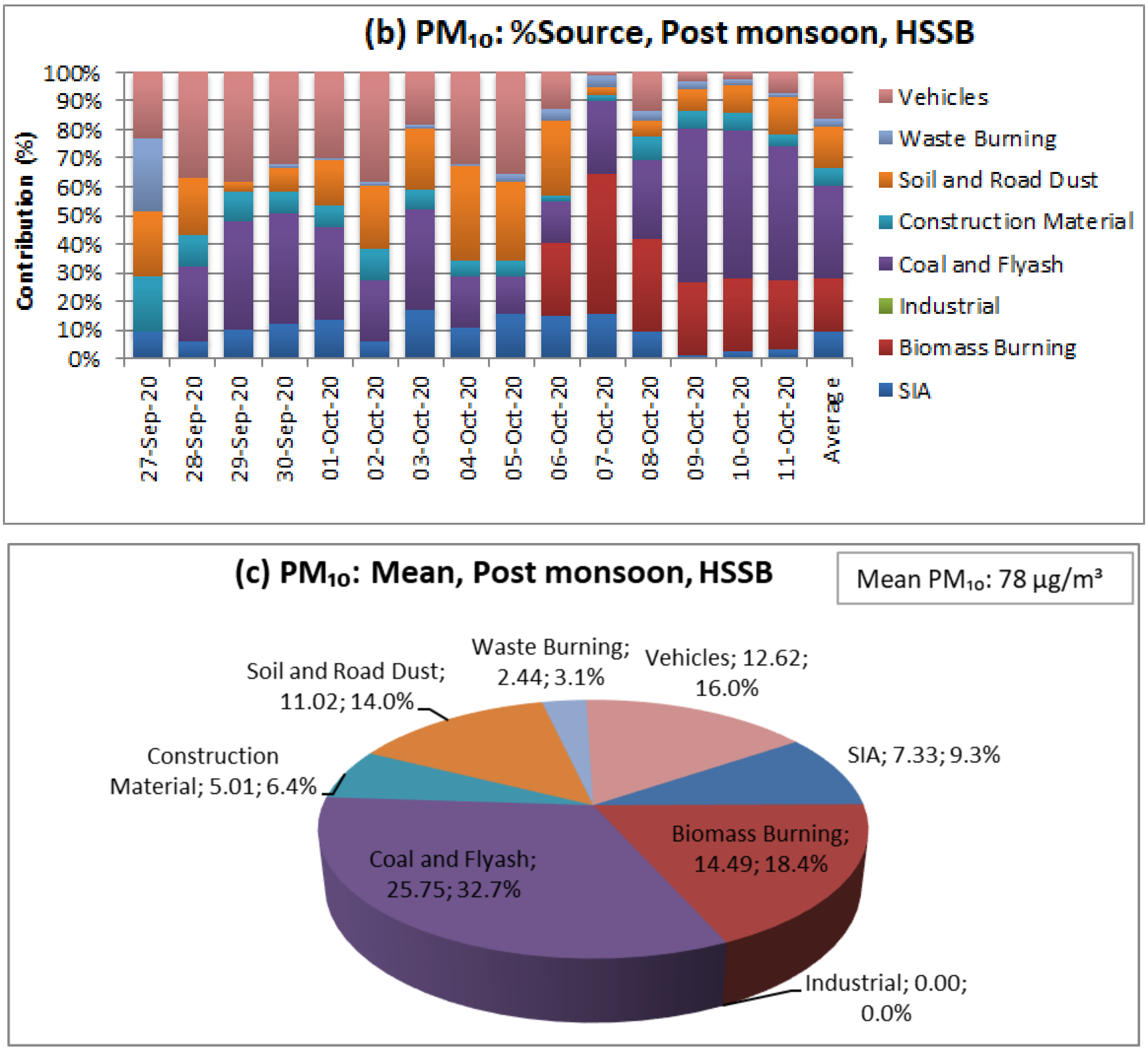
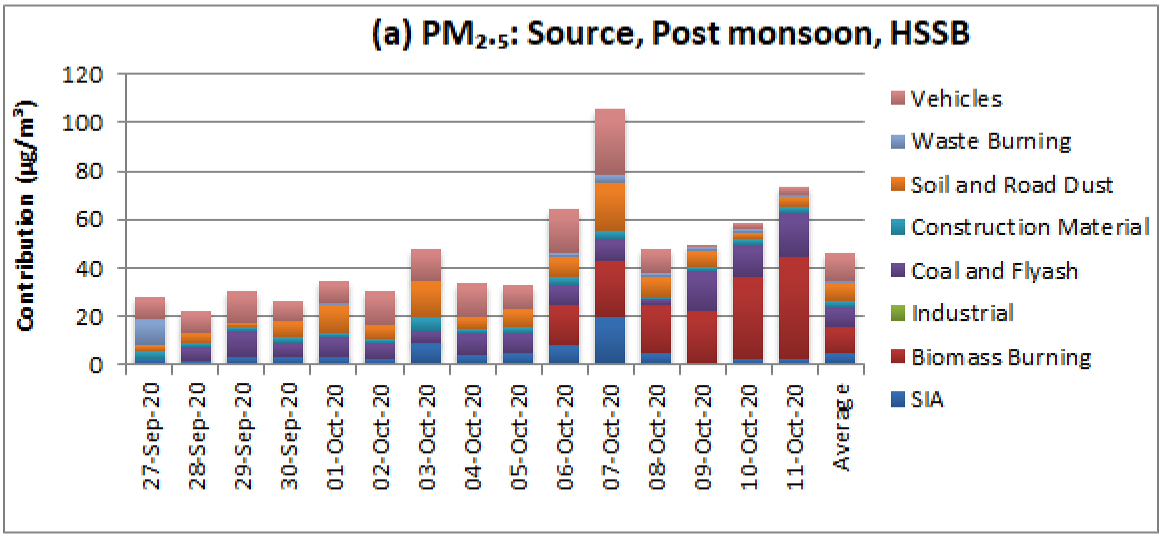


Figure 4.43: CMB modeling for PM_{10} at HSSB for post-monsoon season



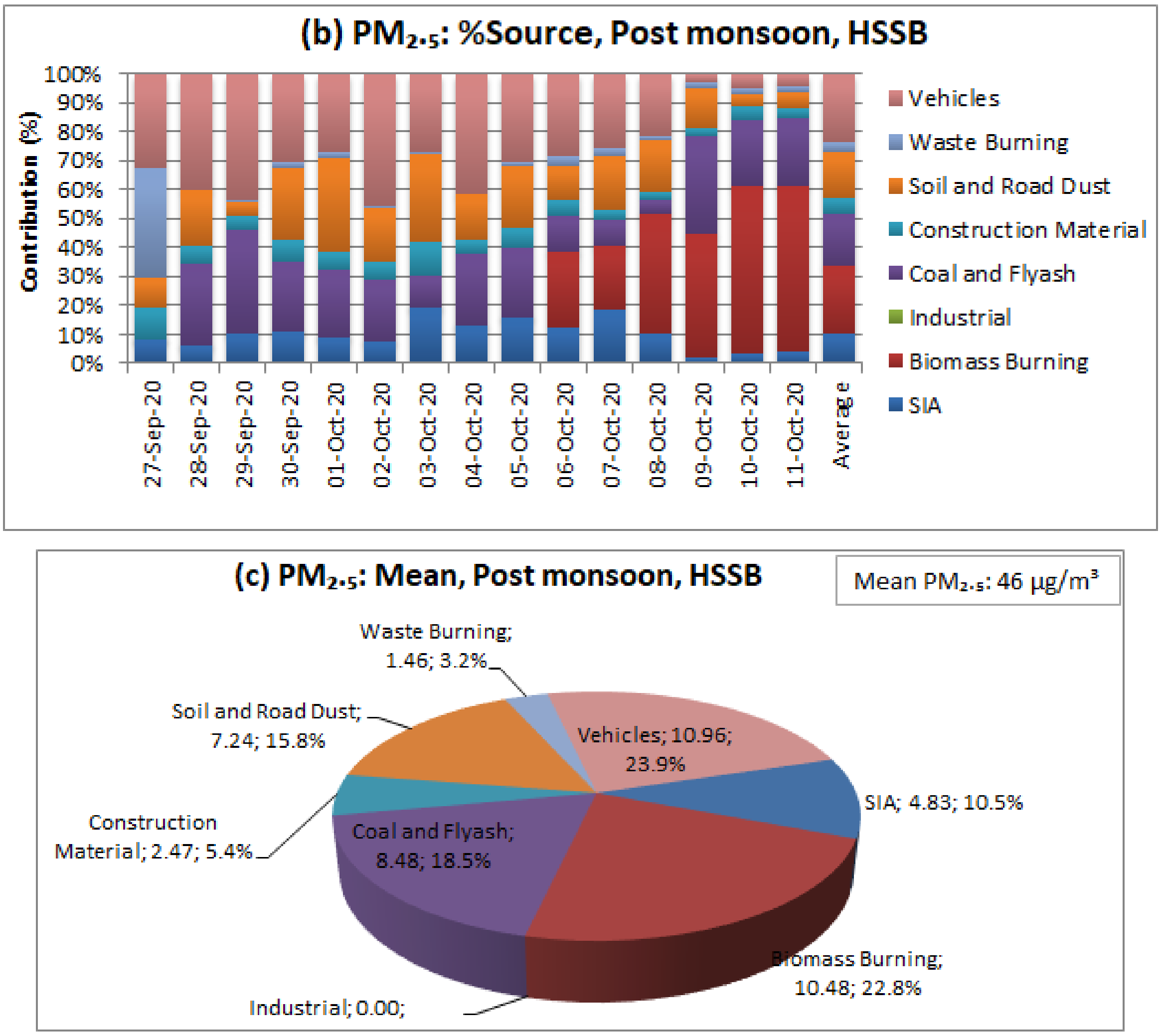


Figure 4.44: CMB modeling for $PM_{2.5}$ at HSSB for post-monsoon season

Table 4.15: Statistical summary: HSSB, post-monsoon season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	78	78	100.9	0.8	46	49	106.7	0.74
SD	38	38	4.9	0.1	22	25	5.7	0.07
CV	0.48	0.48	0.05	0.09	0.49	0.50	0.05	0.09
Maximum	149	160	109.4	0.90	106	111	116.1	0.88
Minimum	42	45	91.0	0.66	22	22	96.0	0.60

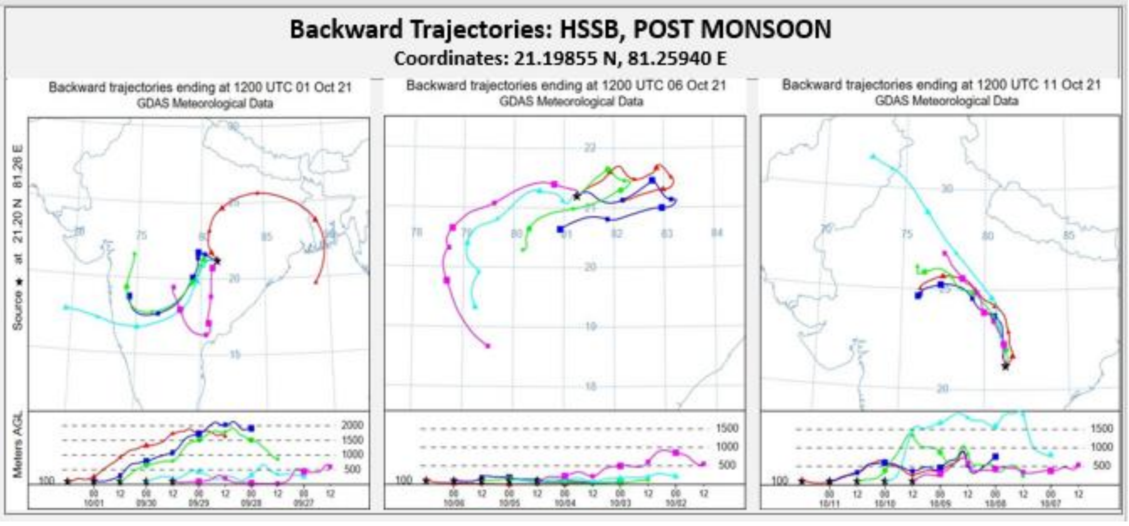


Figure 4.45: Backward trajectories at HSSB for post-monsoon season

Inferences

The major sources contributing to PM_{10} is coal and flyash. Vehicular emission has become the major $PM_{2.5}$ sources. Biomass burning is consistently contributing to both PM_{10} and $PM_{2.5}$. The ambient air quality is better and meets the standards.

4.3.6 Ayushman Health Centre, Morid (AHCM)

4.3.6.1 Winter Season [sampling period: Feb 01 - 07, 2021]

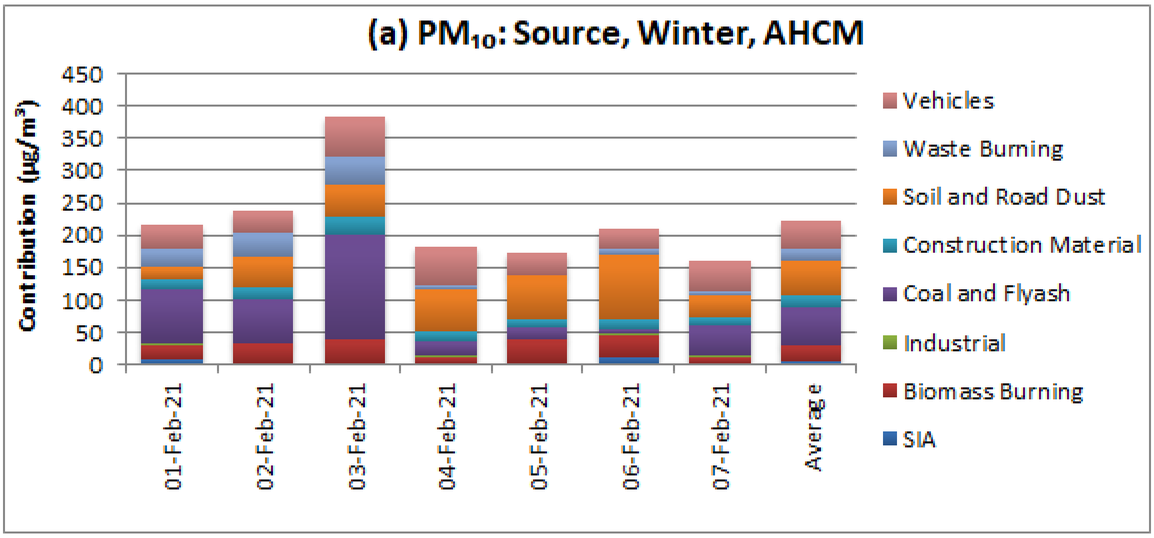
PM_{10} (winter)

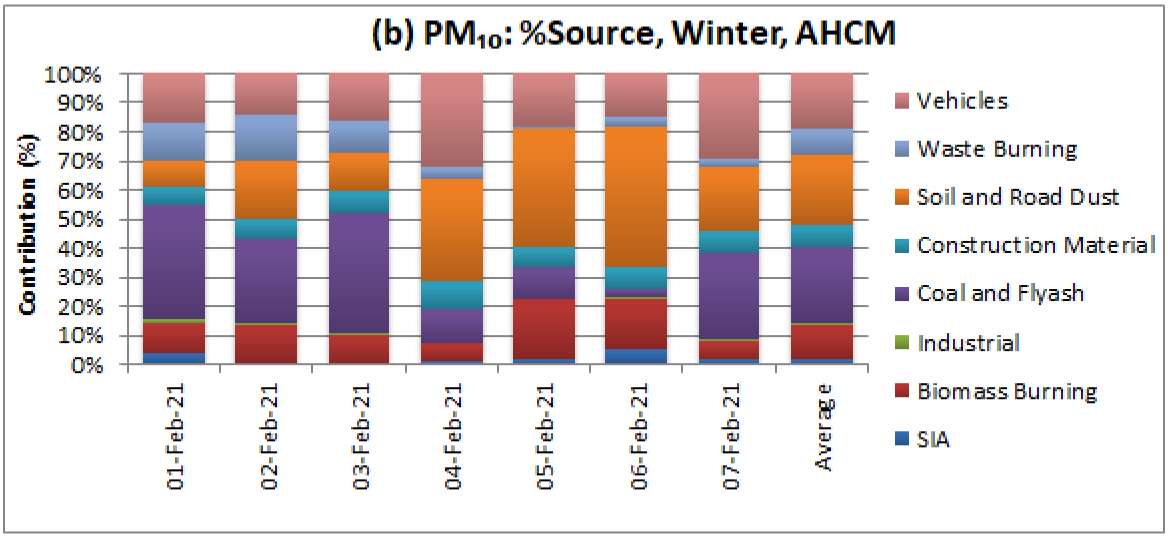
The average PM_{10} concentration was 222 µg/m^3. Figure 4.46(a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at AHCM. Table 4.16 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was coal and flyash (55 µg/m^3 ~ 26%) followed by soil and road dust (58 µg/m^3 ~ 25%) and vehicular emission (43 µg/m^3 ~ 19%). The other significant contributing sources are biomass burning (26 µg/m^3~ 12%), waste burning (19 µg/m^3 ~ 8%), construction material (17 µg/m^3 ~ 8%) and SIA (4 µg/m^3 ~ 2%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 108 µg/m^3. Figure 4.47(a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at AHCM. It is observed that the major source contributing to $PM_{2.5}$ was coal and flyash (30 µg/m^3 ~ 28%) followed by vehicular emission (29 µg/m^3 ~ 27%) and biomass burning (21 µg/m^3 ~ 19%). Other significant sources are soil and road dust (13 µg/m^3 ~ 12%) and waste burning (7 µg/m^3 ~ 7%) and construction (5%). The minor source SIA (2%) and industrial emission was estimated to be less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.48) show that most of the time wind is from North and sometime from SW. The wind mass travels over neighboring districts and states before entering in Bhilai. These winds pick up the pollutants on the way especially from large emitting sources.





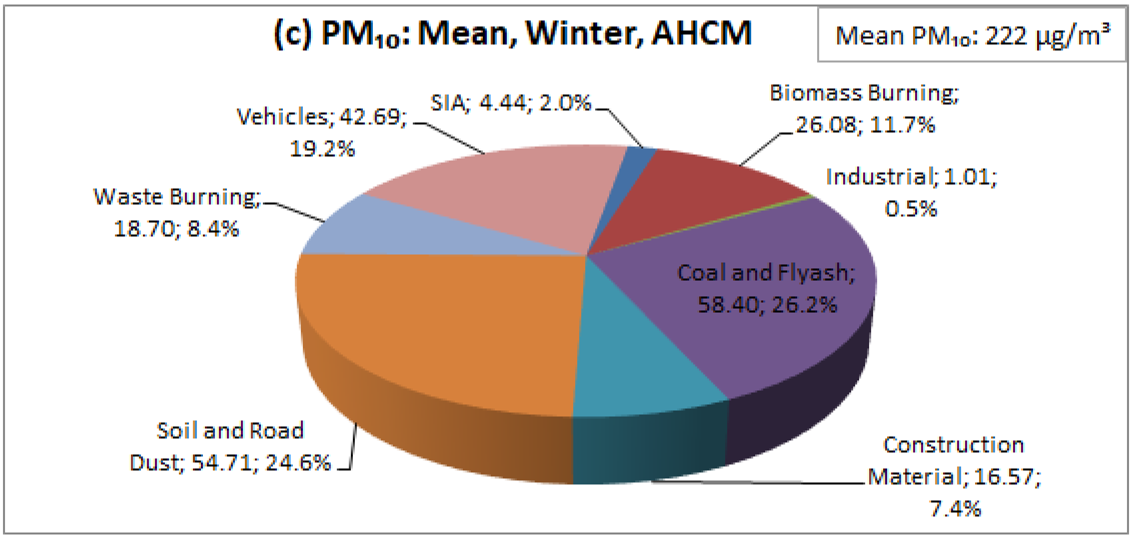
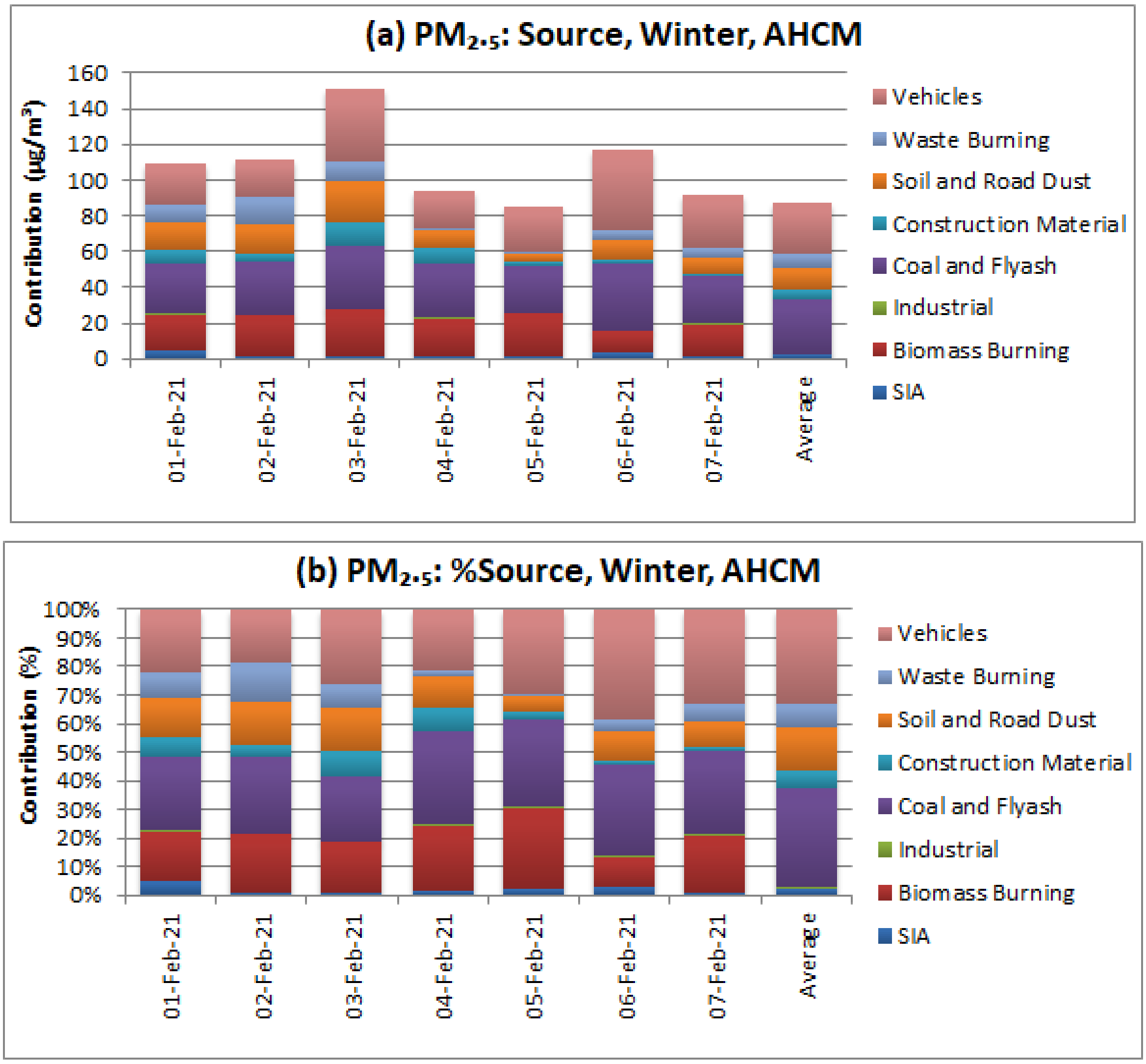


Figure 4.46: CMB modeling for PM_{10} at AHCM for winter season



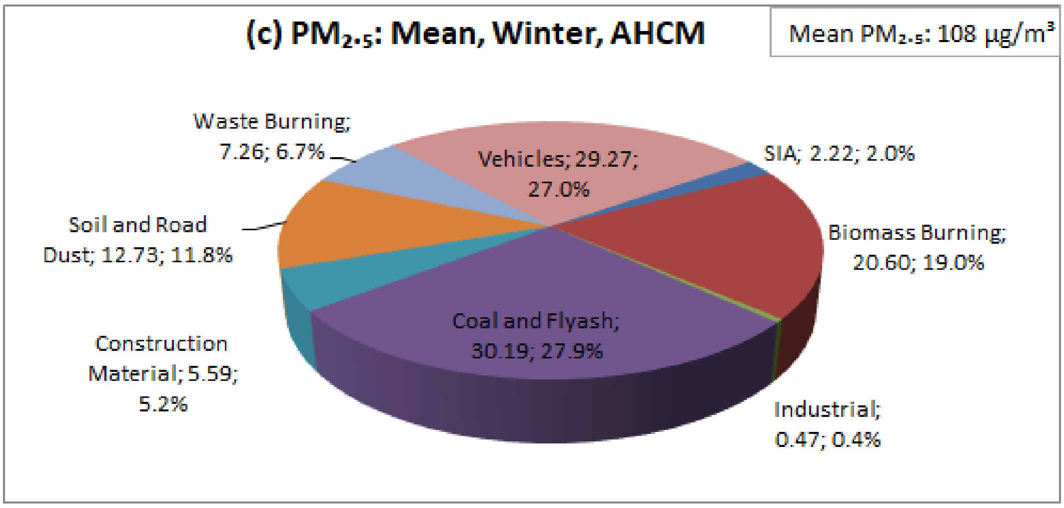


Figure 4.47: CMB modeling for $PM_{2.5}$ at AHCM for winter season

Table 4.16: Statistical summary: AHCM, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	222	227	102.6	0.85	108	118	107.3	0.89
SD	76	74	2.8	0.06	22	33	8.6	0.05
CV	0.34	0.33	0.03	0.07	0.20	0.28	0.08	0.06
Maximum	383	385	107.6	0.94	151	182	120.8	0.95
Minimum	160	167	100.0	0.79	85	85	100.6	0.82

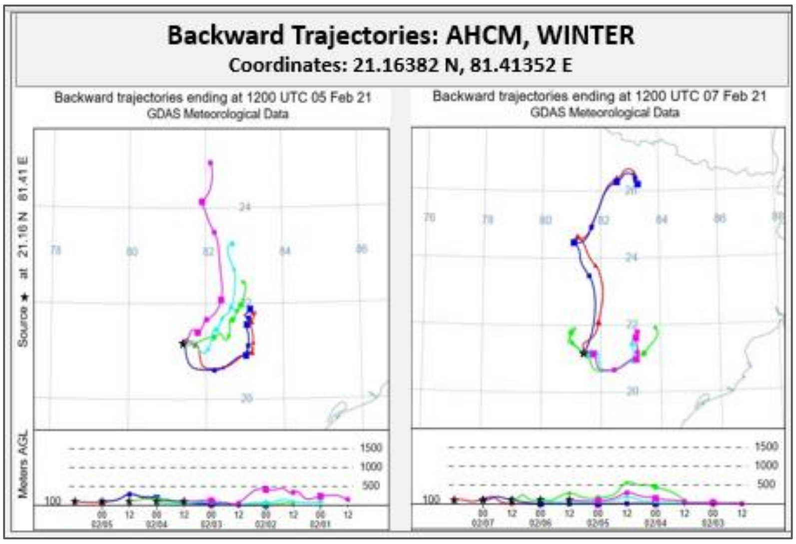


Figure 4.48: Backward trajectories at AHCM for winter season

Inference

Contributions of coal and flyash is consistently high both in PM_{10} and $PM_{2.5}$. Soil and road dust contribution is high in PM_{10}. Vehicular emission is almost equal to the coal combustion contribution in $PM_{2.5}$.

4.3.6.2 Summer Season [sampling period: April 29 – May 05, 2021]

PM_{10} (summer)

The average PM_{10} concentration was 84 µg/m^3. Figure 4.49(a), (b), (c) shows PM_{10} concentration contribution of sources, percent contribution of sources and summary of sources (average over 15 days) at AHCM. Table 4.17 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was vehicular emission (29 µg/m^3 ~ 36%) followed by coal and flyash (15 µg/m^3 ~ 18%). The other significant contributing sources are soil and road dust (14 µg/m^3 ~ 17%), SIA (12 µg/m^3 ~ 14%), waste burning (7 µg/m^3 ~8%) and construction material (7%). The minor Contributing source was industrial emission (<1%) in PM_{10}. Biomass burning contribution was less than 1% at this site in summer.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 53 µg/m^3. Figure 4.50(a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at AHCM. It is observed that the major source contributing to $PM_{2.5}$ was vehicular emission (18 µg/m^3 ~ 30%) followed by coal and flyash (11 µg/m^3 ~ 21%). Other significant sources are soil and road dust (11 µg/m^3 ~ 20%), SIA (7%), SIA (7 µg/m^3 ~ 13%), waste burning (6%) and construction material (6%). Contribution of the industrial emissions and biomass buring were less than 1% $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.51) show that most of the time wind is from West and SW wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from large emitting sources.

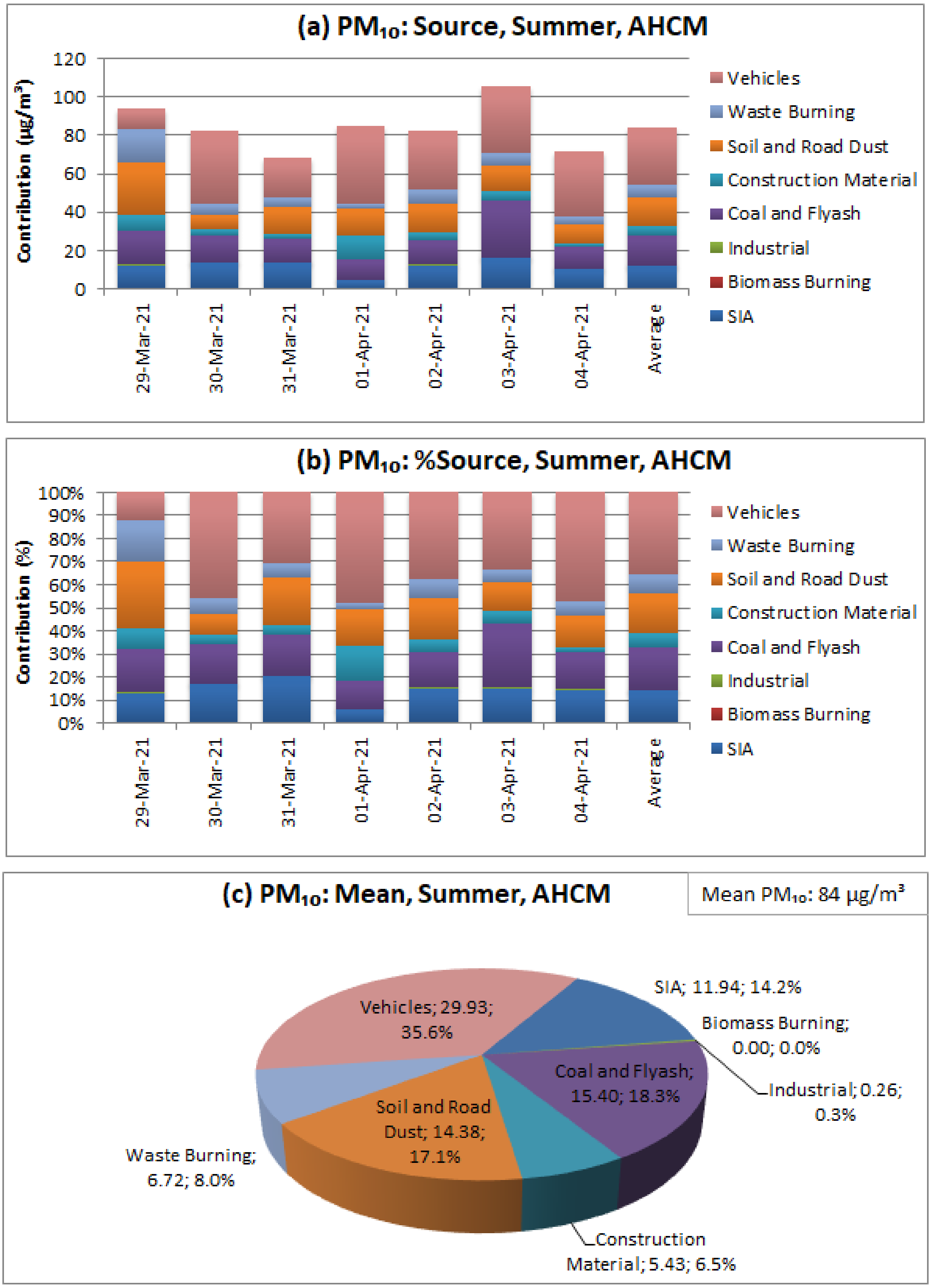


Figure 4.49: CMB modeling for PM$_{10}$ at AHCM for summer season

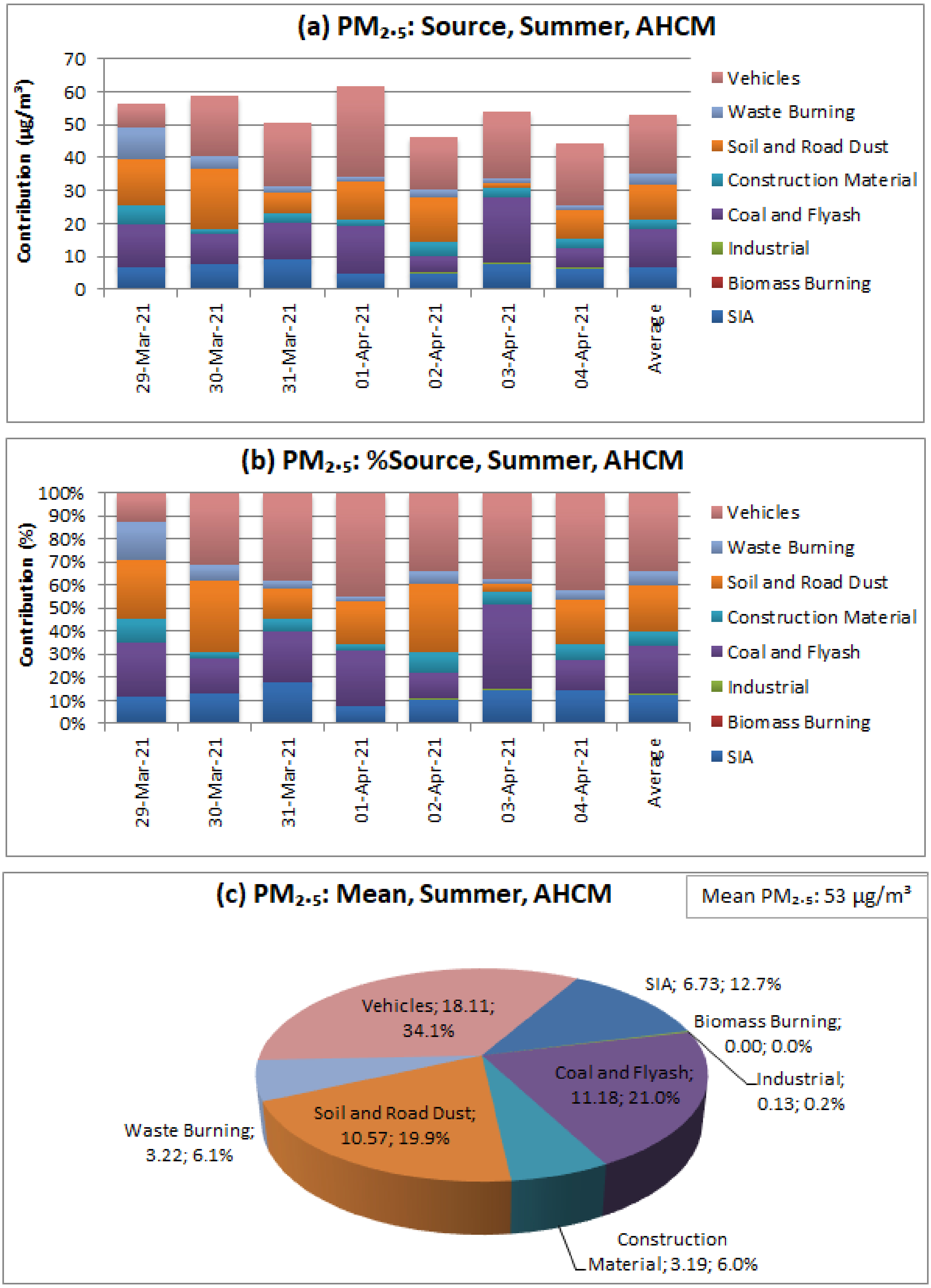


Figure 4.50: CMB modeling for $PM_{2.5}$ at AHCM for summer season

Table 4.17: Statistical summary: AHCM, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	84	85	101.5	0.81	53	54	101.6	0.80
SD	13	13	3.5	0.10	6	8	4.9	0.05
CV	0.15	0.15	0.03	0.12	0.12	0.15	0.05	0.07
Maximum	106	108	109.0	0.89	62	66	112.2	0.84
Minimum	68	72	99.2	0.60	44	44	97.3	0.70

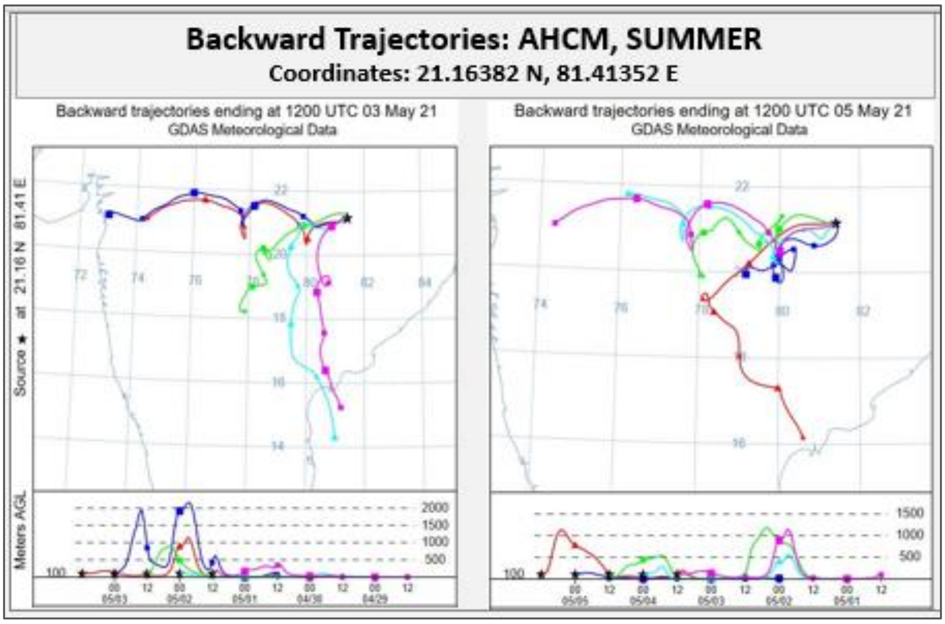


Figure 4.51: Backward trajectories at AHCM for summer season

Inference

In summer, vehicular emission and coal and flyash are coming out to be the major sources for both PM_{10} and $PM_{2.5}$.

4.3.6.3 Post-monsoon Season [sampling period: Oct 17 – 23, 2021]

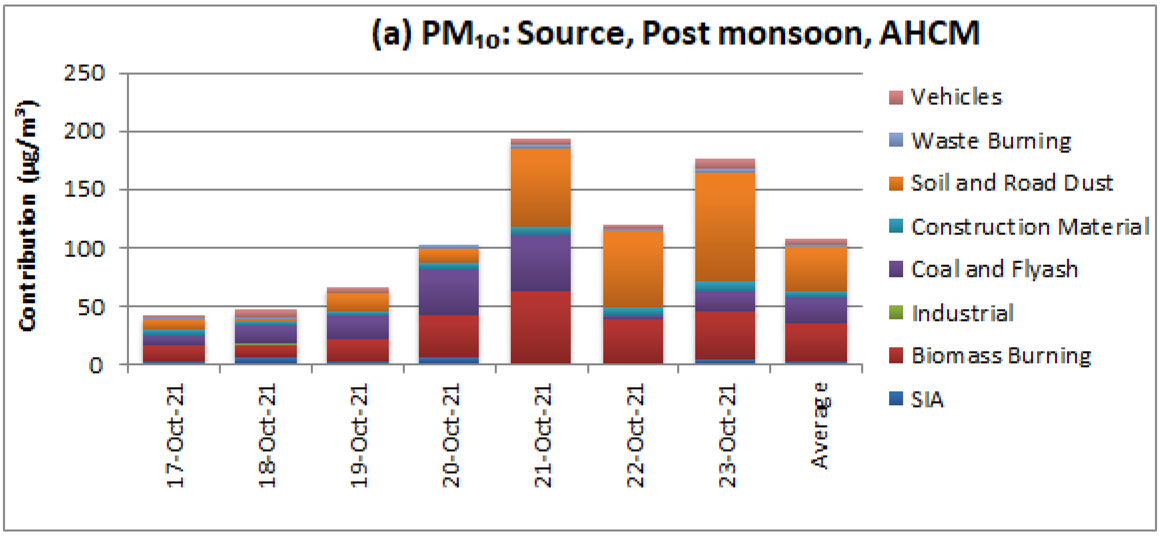
PM_{10} (post-monsoon)

The average PM_{10} concentration was 101 µg/m^3. Figure 4.52 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at AHCM. Table 4.18 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was soil and road dust (38 µg/m^3 ~ 37%) followed by biomass burning (31 µg/m^3 ~ 31%) and coal and fly ash (22 µg/m^3 ~ 22%). Other significant sources are construction material (5 µg/m^3 ~ 5%), vehicular emission (4 µg/m^3 ~ 4%), SIA (3%) and waste burning (2%) in PM_{10}. Contribution of the industrial emission was less than 1 % in PM_{10}.

$PM_{2.5}$ (post-monsoon)

The average $PM_{2.5}$ concentration was 51 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.50. Figure 4.53 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at AHCM. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (19 µg/m^3 ~ 38%) followed by coal and flyash (15 µg/m^3 ~ 29%). Other major sources are soil and road dust (10 µg/m^3 ~ 19%), vehicular emission (2 µg/m^3 ~ 5%), waste burning (4%), SIA (3%) and construction material (3%). Contribution of the industrial emission was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.54) show that most of the time wind is from NW and north and wind mass travels over neighboring districts before entering in Bhilai. These winds pick up the pollutants on the way especially from tall emitting sources.



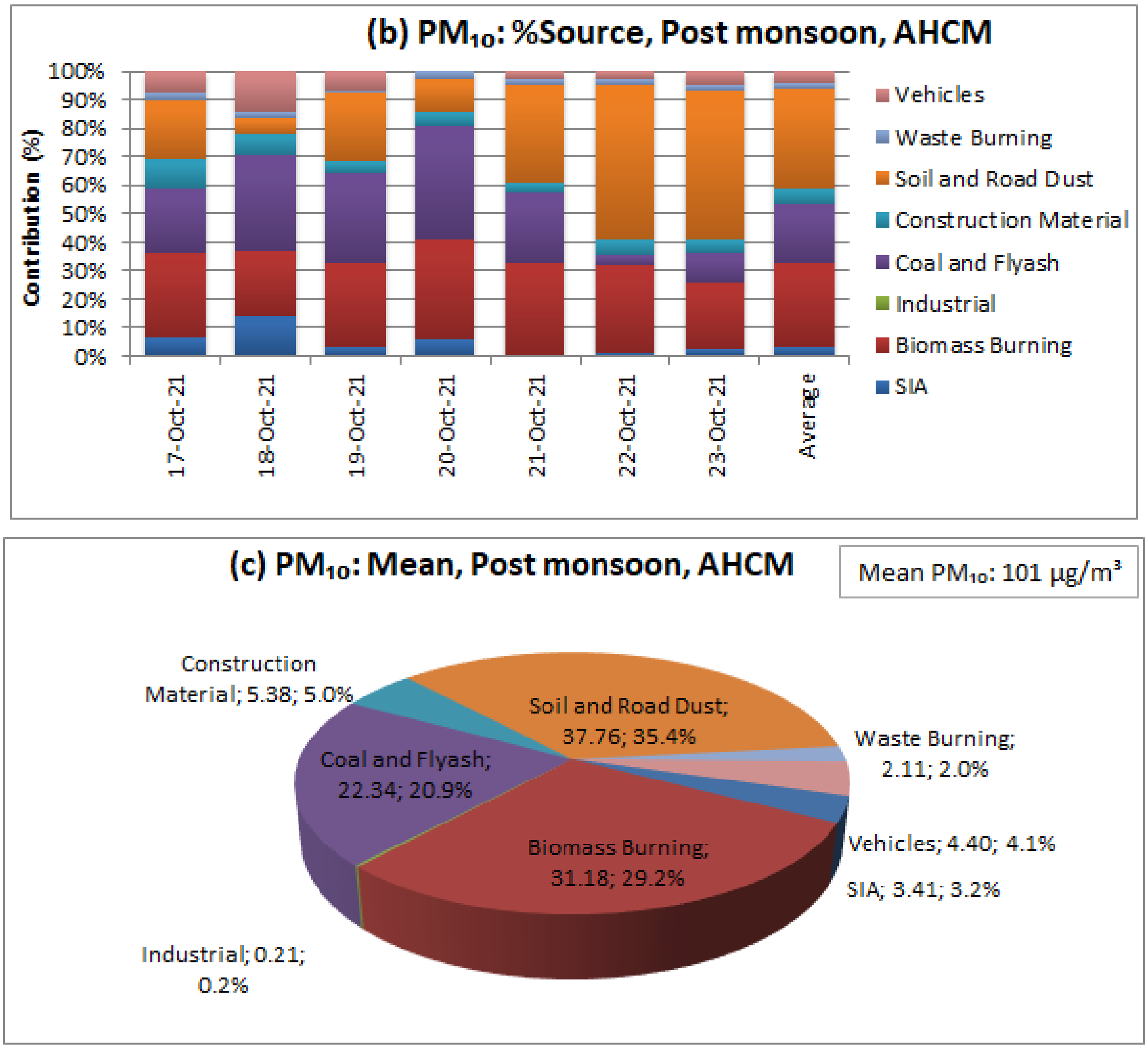
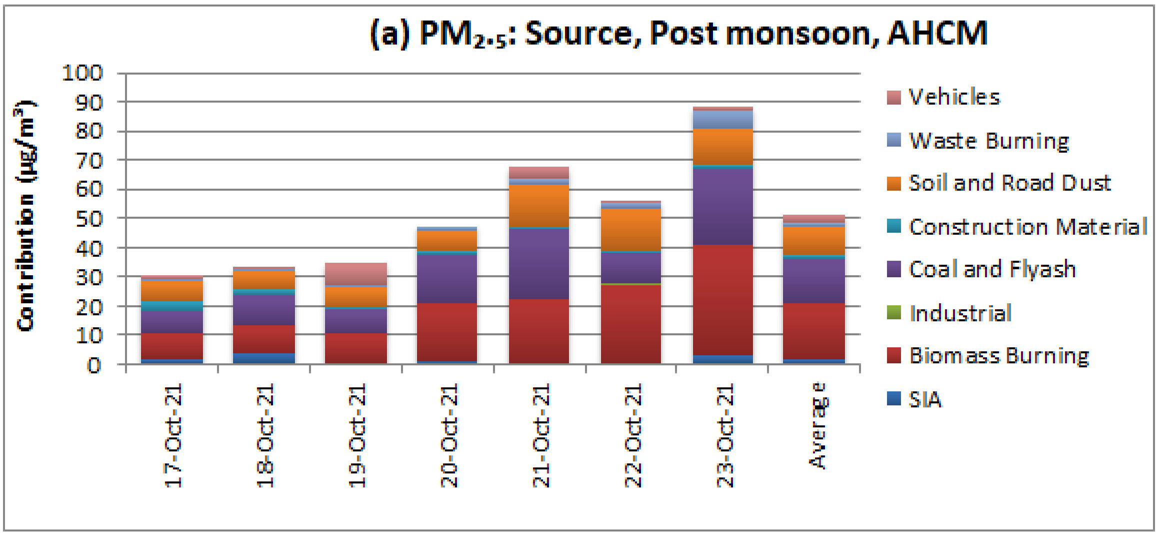


Figure 4.52: CMB modeling for PM_{10} at AHCM for post-monsoon season



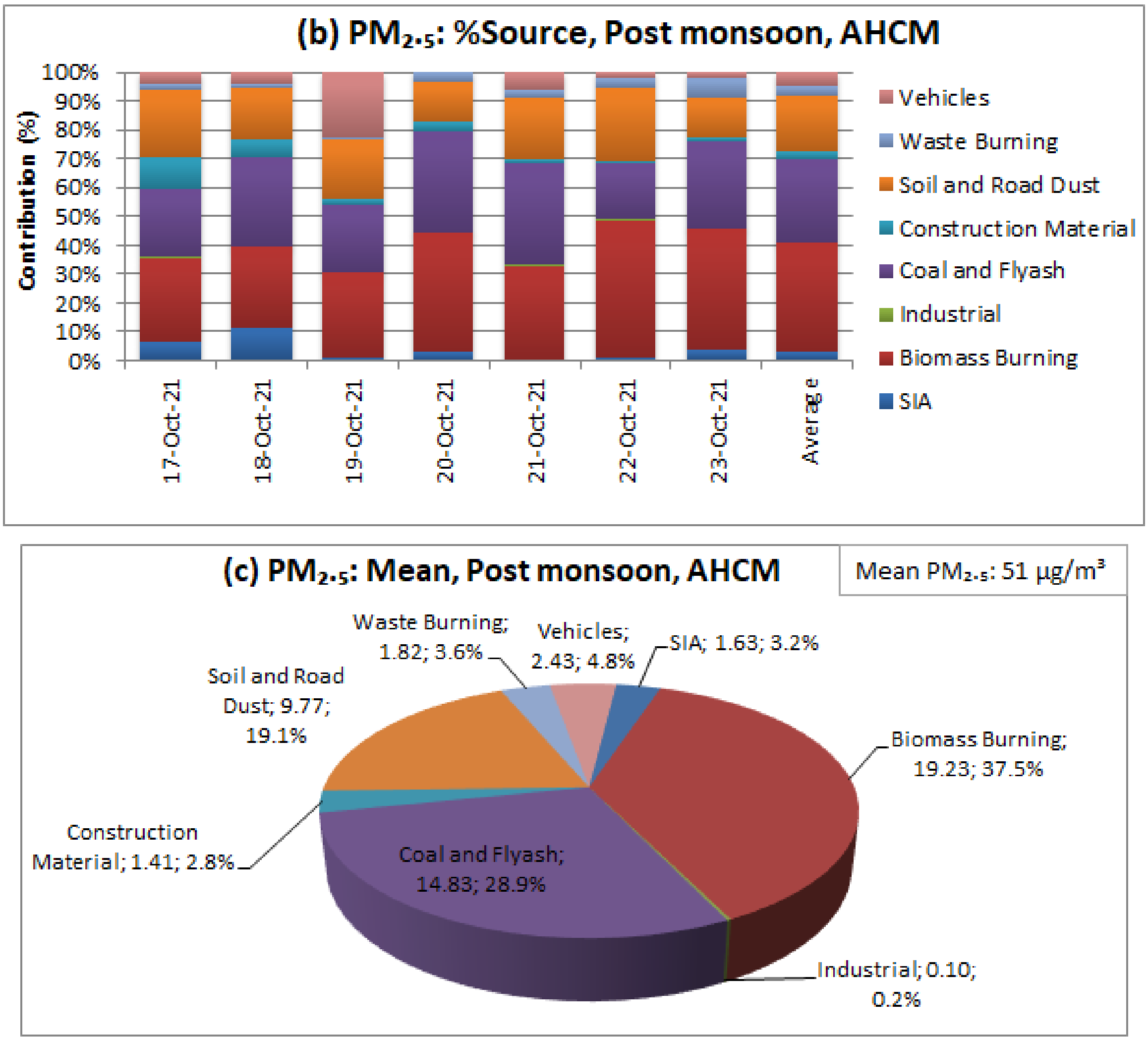


Figure 4.53: CMB modeling for $PM_{2.5}$ at AHCM for post-monsoon season

Table 4.18: Statistical summary: AHCM, post-monsoon season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	101	101	100.1	0.8	51	53	103.5	0.84
SD	52	50	3.9	0.1	21	21	4.3	0.05
CV	0.51	0.50	0.04	0.11	0.42	0.39	0.04	0.05
Maximum	176	176	103.0	0.87	88	89	111.1	0.89
Minimum	43	43	91.9	0.65	30	30	99.4	0.76

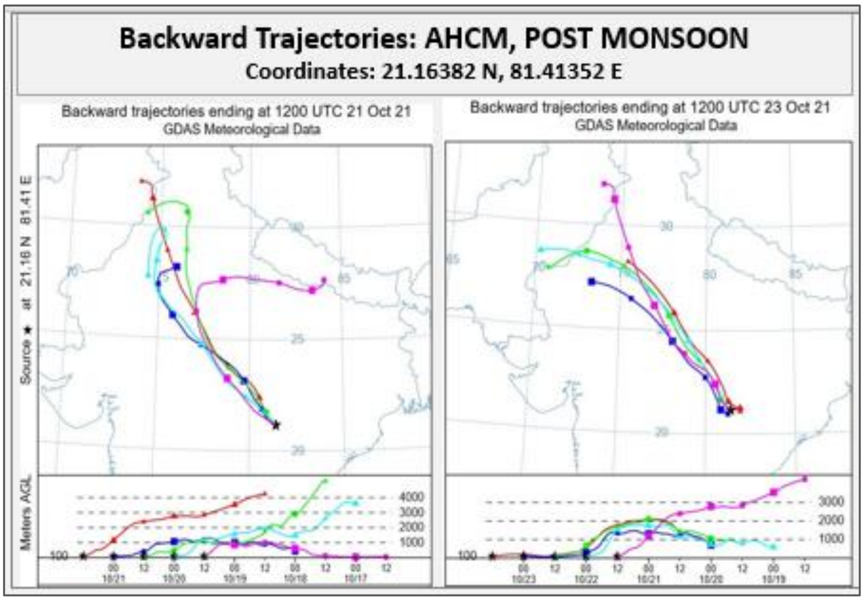


Figure 4.54: Backward trajectories at AHCM for post-monsoon season

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have changed. Soil and road dust and biomass burning have become the major PM_{10} sources. Biomass burning and coal combustion have become the major $PM_{2.5}$ sources. It was observed that the atmosphere in post-monsoon looked blueish indicating clear atmosphere with less amounts of pollutants compared to other seasons which may be due to high speeds wind and wet conditions which suppress the pollutants and stops dust emissions. Biomass burning is the major contributor for both PM_{10} and $PM_{2.5}$ indicating residential wood and agricultural burning.

4.3.7 Atal Bhawan, Gudeli Village (ABGV)

4.3.7.1 Winter Season [sampling period: Dec 18 – Jan 01, 2021]

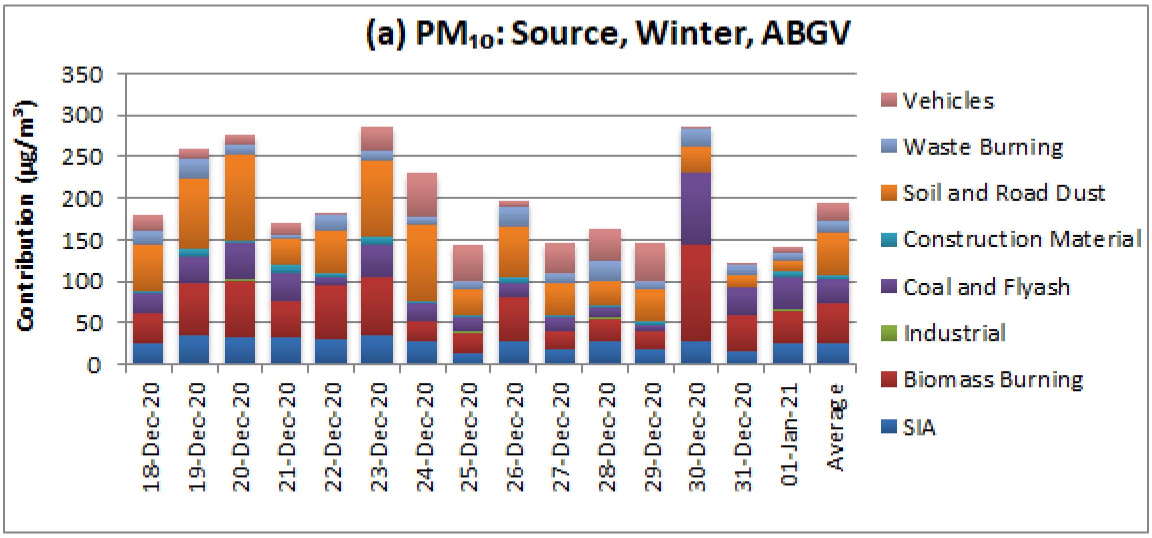
PM_{10} (winter)

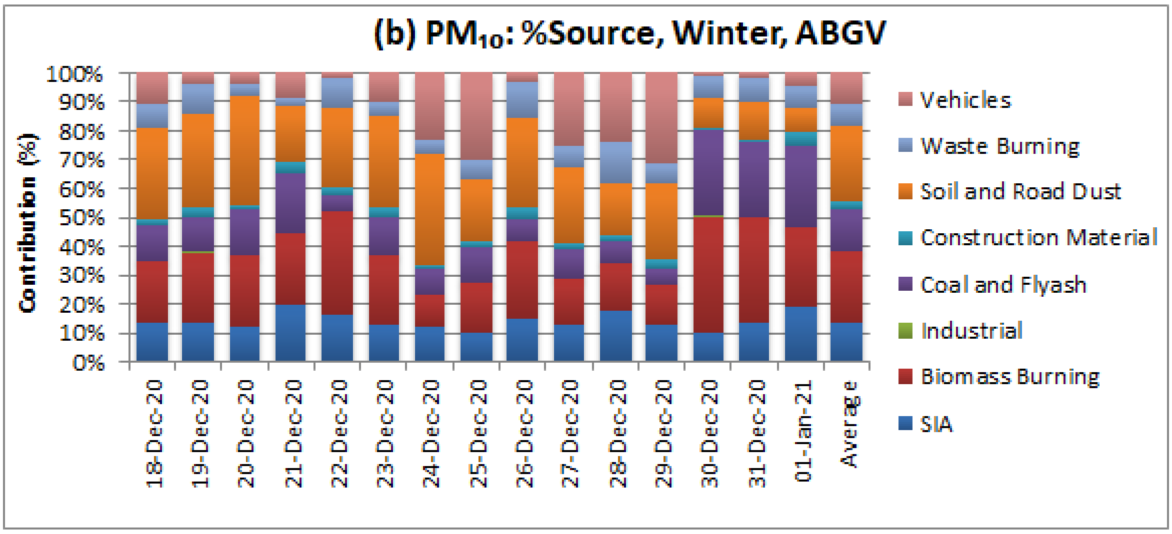
The average PM_{10} concentration was 195 µg/m^3. Figure 4.55 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at ABGV. Table 4.19 presents a summary of performance and acceptability of CMB model. It is observed that the major source contributing to PM_{10} was soil and road dust (51 µg/m^3 ~ 21%) followed by biomass burning (48 µg/m^3 ~ 24%) and coal and flyash (28 µg/m^3 ~ 15%). The other significant contributing sources are SIA (27 µg/m^3~ 14%), vehicular emission (21 µg/m^3 ~ 11%), waste burning (15 µg/m^3 ~ 8%) and construction material (2%). Contribution of the industrial emission was less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 146 µg/m^3. Figure 4.56 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over 15 days) in terms of concentration and percentage respectively at ABGV. It is observed that the major source contributing to $PM_{2.5}$ was biomass burning (42 µg/m^3 ~ 29%) followed by soil and road dust (30 µg/m^3 ~ 20%) and coal and flyash (22.5 µg/m^3 ~ 15%). Other significant sources are vehicular emission (18 µg/m^3 ~ 12.6%) and SIA (17.3 µg/m^3 ~ 12%) and waste burning (12.4 µg/m^3 ~ 8.5%). The minor sources are construction material (2%), industrial emission (<1%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.57) show that most of the time wind is from NW. These winds pick up the pollutants on the way especially from large sources.





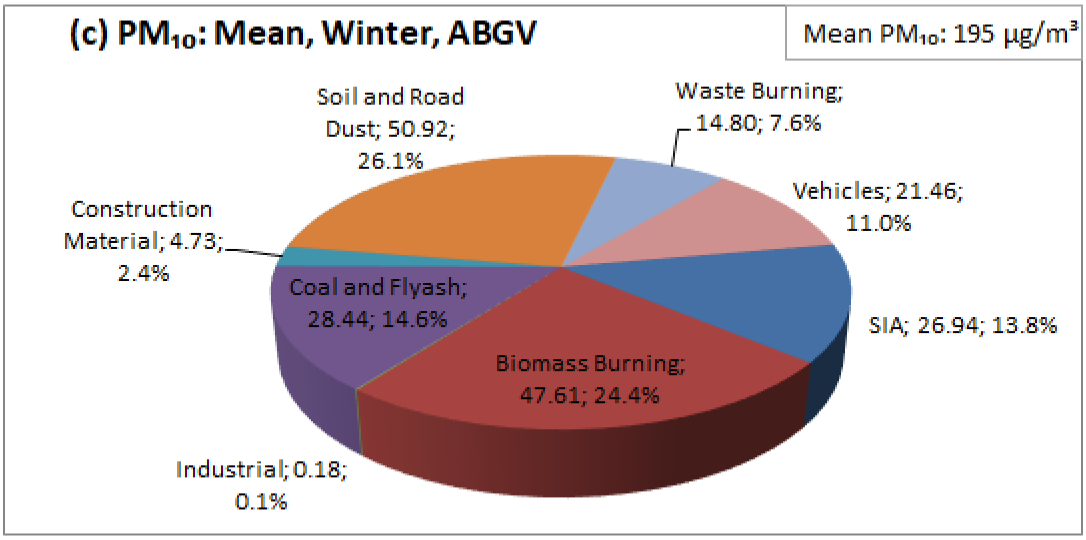
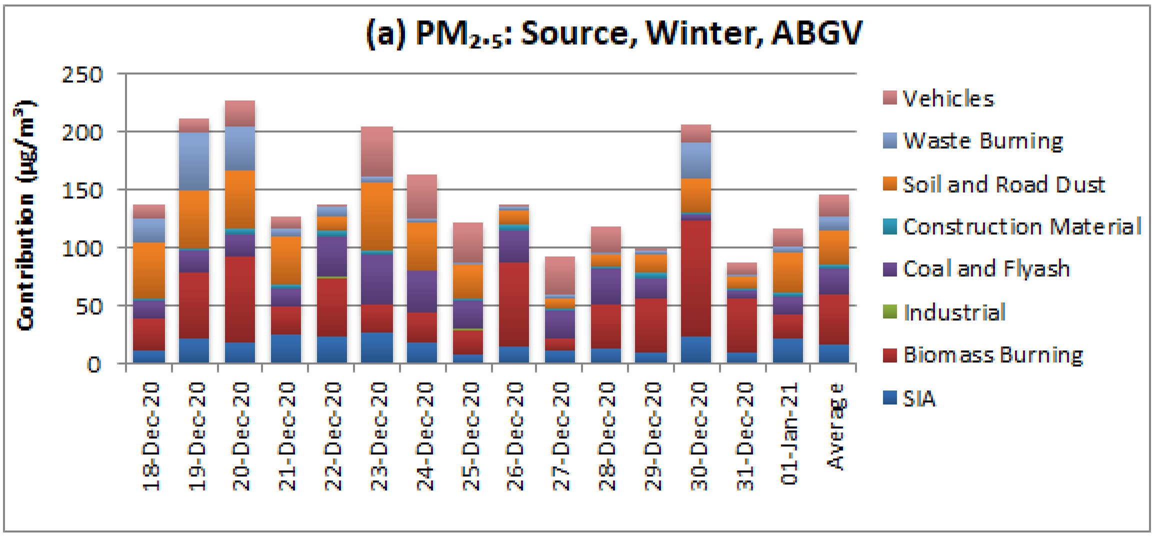


Figure 4.55: CMB modeling for PM_{10} at ABGV for winter season



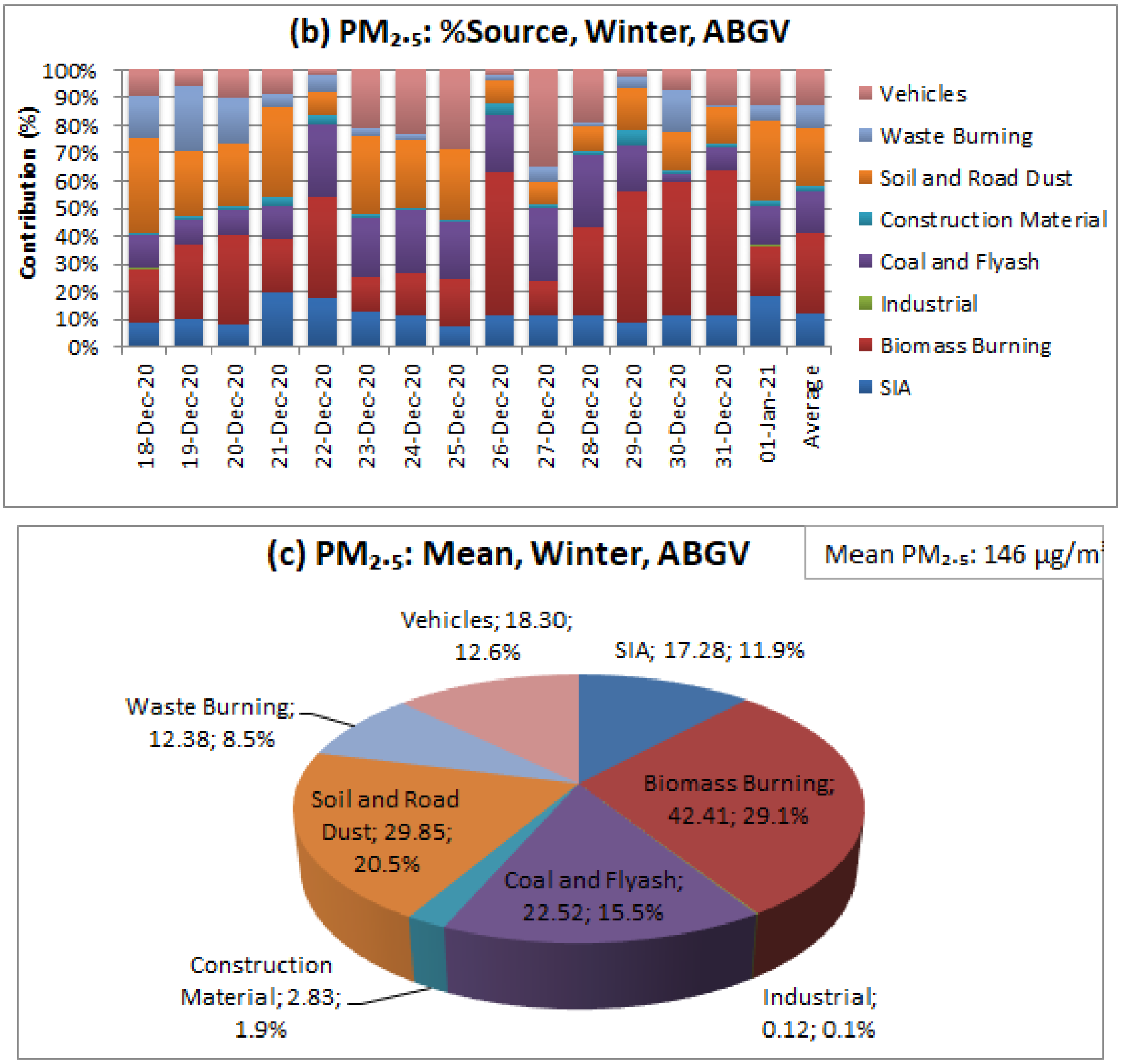


Figure 4.56: CMB modeling for $PM_{2.5}$ at ABGV for winter season

Table 4.19: Statistical summary: ABGV, winter season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	195	201	103.2	0.72	146	156	106.0	0.77
SD	58	59	3.2	0.08	46	54	7.3	0.05
CV	0.30	0.30	0.03	0.11	0.31	0.35	0.07	0.07
Maximum	287	288	110.3	0.88	227	246	115.3	0.85
Minimum	121	121	99.1	0.60	88	86	92.5	0.66

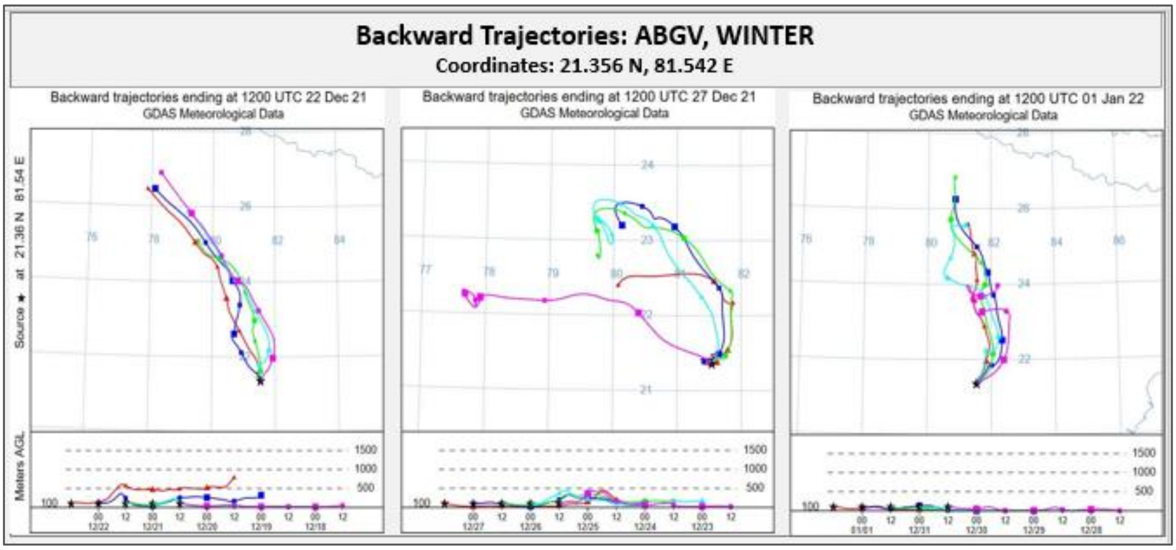


Figure 4.57: Backward trajectories at ABGV for winter season

Inference

Contributions of soil and road dust and biomass burning are consistently high both in PM_{10} and $PM_{2.5}$. coal and flyash also appears to be high consistently contributing to both PM_{10} and $PM_{2.5}$.

4.4 Long range transport and contribution

HYSPLIT back trajectories show that most of the time wind is from NW to NE (winter), nd NW to NE and sometimes South to SW (summer) and West (post-monsoon). Wind mass as it travels over different states and districts before entering in Bhilai may pick up the pollutants on the way especially from large sources and tall emitting sources; however, these contributions have not been quantified. There is no assessment made on emissions upstream of Bhilai and their contribution in Bhilai.

4.5 Overall Summary and Source Apportionment at a Glance

The overall summary of CMB modeling results is shown in Figure 4.58 to Figure 4.60. Table 4.20 – Table 4.25 provide summary with overall statistics. The mail highlights of CMB results are summarized below.

- Ranges of source contributions to PM_{10} are secondary inorganic aerosols (SIA; 0.04 – 26%), biomass burning (0 – 49%), industrial (0 – 22%), coal and flyash (0 – 54%), soil and road dust (0 – 54%), vehicles (0 – 53%), waste burning (0 – 30%) and construction material (0 – 19%).

- Ranges of source contributions to $PM_{2.5}$ are SIA (0.18 – 22%), biomass burning (0 – 54%), industrial (0 – 29%), coal and flyash (0 – 51%), soil and road dust (0 – 49%), vehicles (0 – 64%), waste burning (0 – 30%) and construction material (0 - 16%).
- Contribution of SIA particles (PM_{10}: 17 – 3% and $PM_{2.5}$: 23 – 6%), biomass burning (PM_{10}: 19 – 10% and $PM_{2.5}$: 32 – 30%), vehicles (PM_{10}: 11 – 5% and $PM_{2.5}$: 17 – 14%) and waste burning (PM_{10}: 6 – 4% and $PM_{2.5}$: 8 – 6%) are higher during winter season compared to summer season both in $PM_{2.5}$ and PM_{10}.
- SIA contribution is higher during summer season (PM_{10}: 12.2% and $PM_{2.5}$: 12.5%). compared to winter (PM_{10}: 7.1% and $PM_{2.5}$: 7.1%) and post-monsoon (PM_{10}: 8% and $PM_{2.5}$: 8%).
- Soil and road dust contribution is higher during post-monsoon season (PM_{10}: 26% and $PM_{2.5}$: 23%) compared to winter (PM_{10}: 20% and $PM_{2.5}$: 16%) and summer (PM_{10}: 23% and $PM_{2.5}$: 18%).
- Contribution of coal and flyash is higher during post-monsoon season in PM_{10} (24%) and during winter in $PM_{2.5}$ (24%).
- Waste burning is slightly higher in winter (PM_{10}: 6.6% and $PM_{2.5}$: 5.6%) season but almost equal compared to summer (PM_{10}: 6.4% and $PM_{2.5}$: 5%) and post-monsoon (PM_{10}: 4% and $PM_{2.5}$: 4.3%).
- Vehicular emission contribution is higher $PM_{2.5}$ (about 23%) in all seasons compared to PM_{10} (about 18%).
- Low industrial emission (winter 2.5%; summer 0.9% and post-monsoon 1.5%) is estimated compared to all other sources of air pollution.
- Biomass contribution in PM_{10} is higher in post-monsoon (12%) and for $PM_{2.5}$ in winter (19%).
- Construction material contribution to air pollution is about 5% in all the seasons for both PM_{10} and $PM_{2.5}$.

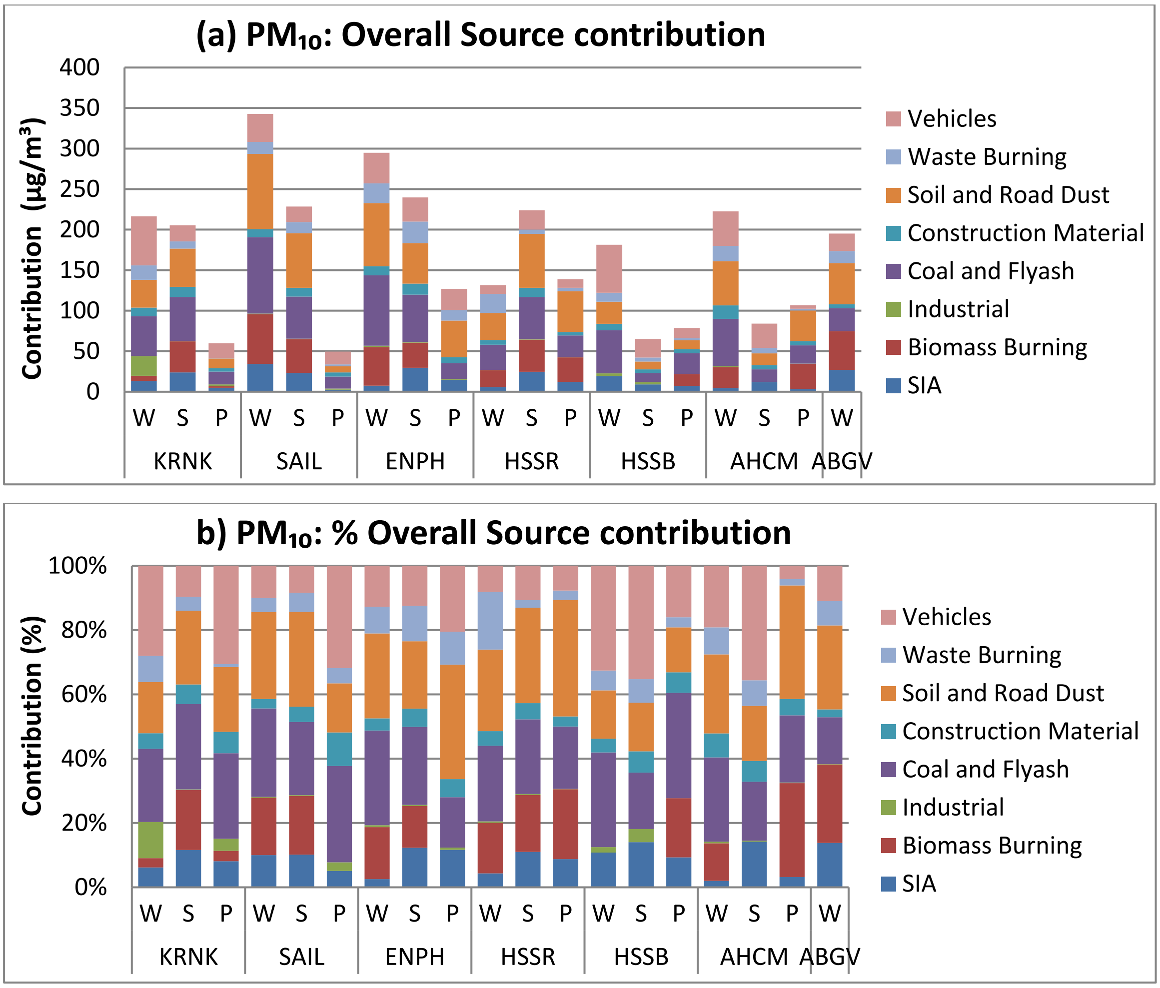
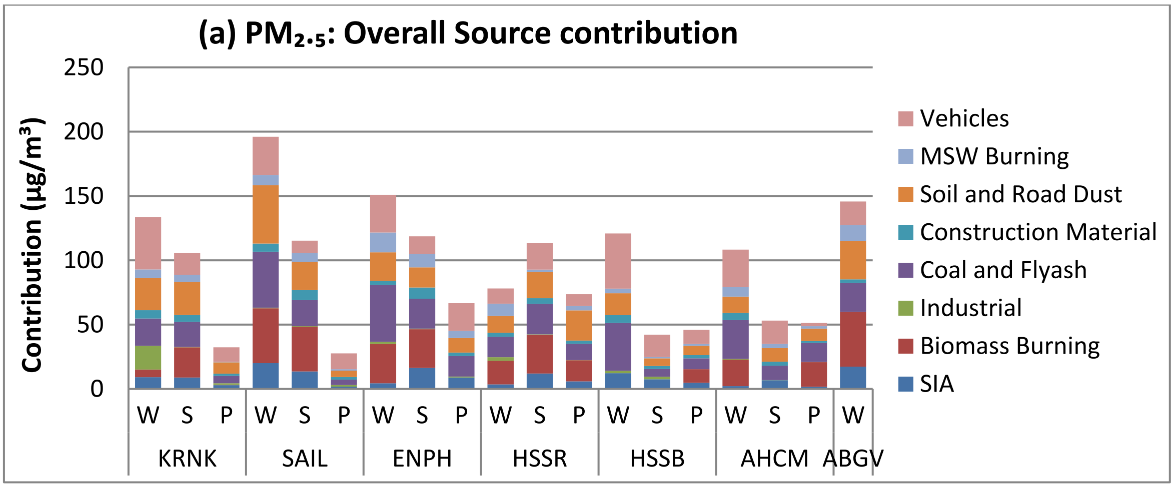


Figure 4.58: Overall results of CMB modeling for PM_{10}



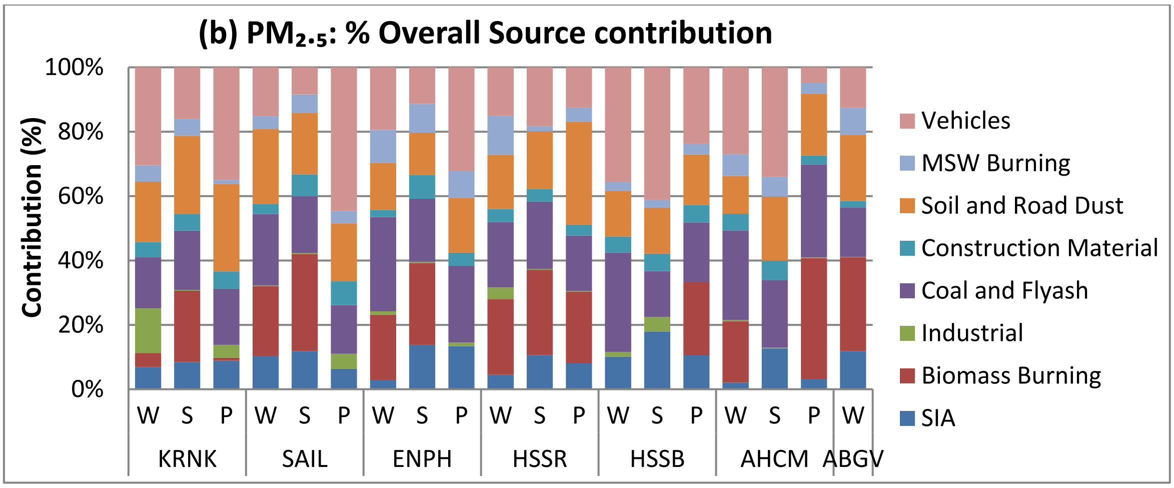


Figure 4.59: Overall results of CMB modeling for $PM_{2.5}$

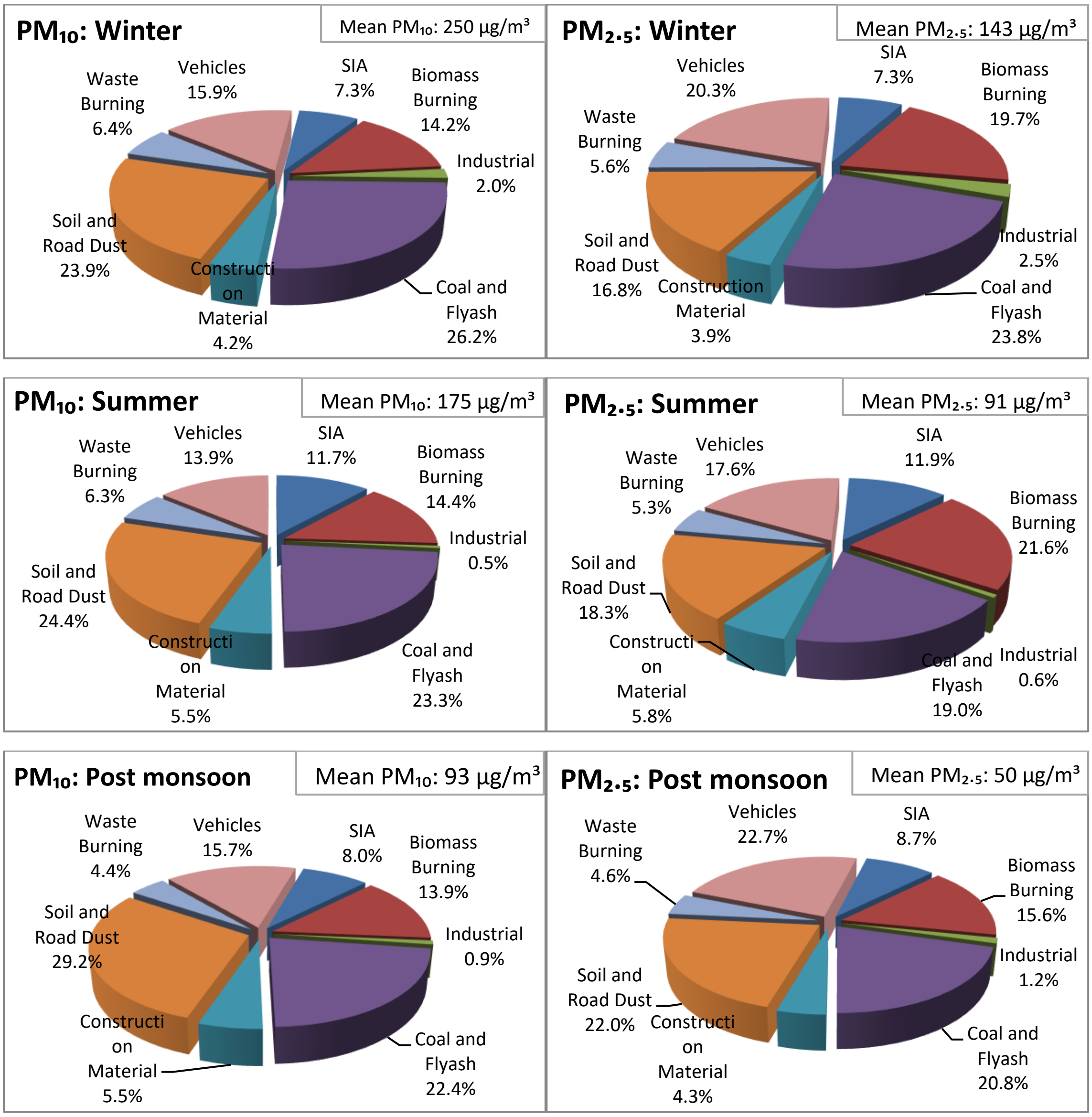


Figure 4.60: City level source contribution to ambient air PM_{10} and $PM_{2.5}$ levels (Industrial contribution excluding coal and flyash)

Table 4.20: Statistical summary of the source apportionment in PM_{10} for winter season

Site location	Parameter	Measured PM_{10}	Calculated PM_{10}	% Mass Calculated	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	Mean	216	218	101	0.8	6.2	2.9	11.2	22.8	4.9	15.9	8.2	28.1
	SD	67	68	4	0.1	4.6	4.4	5.0	11.5	2.6	13.6	6.2	8.7
	CV	0.31	0.31	0.04	0.1	0.7	1.5	0.4	0.5	0.5	0.9	0.7	0.3
	Max	347	350	109	0.9	12.7	11.4	21.7	35.8	8.4	40.7	23.0	41.3
	Min	122	118	96	0.6	0.9	0.0	5.1	0.0	0.0	0.0	0.0	12.5
SAIL	Mean	344	348	101	0.8	10.0	17.8	0.3	27.4	2.9	27.0	4.3	10.0
	SD	42	46	3	0.1	5.6	8.1	0.1	8.9	2.3	11.6	2.5	8.5
	CV	0.12	0.13	0.03	0.1	0.6	0.5	0.2	0.3	0.8	0.4	0.6	0.8
	Max	431	433	109	0.9	23.2	30.7	0.4	40.6	7.4	54.1	8.6	39.0
	Min	286	282	97	0.7	4.0	2.7	0.1	6.7	0.2	12.1	0.7	2.6
ENPH	Mean	295	302	102	0.9	2.6	16.2	0.6	29.4	3.8	26.4	8.3	12.8
	SD	75	79	4	0.0	2.2	5.3	0.3	7.6	2.0	8.9	5.7	4.1
	CV	0.26	0.26	0.04	0.0	0.9	0.3	0.5	0.3	0.5	0.3	0.7	0.3
	Max	422	450	113	0.9	8.6	26.5	1.2	39.1	8.8	38.3	23.5	24.2
	Min	170	170	99	0.8	0.0	8.6	0.3	13.8	1.4	8.6	1.5	7.7
HSSR	Mean	298	315	105	0.8	7.3	20.0	1.5	29.9	4.3	27.2	3.3	7.7
	SD	55	61	4	0.1	4.4	2.7	3.8	7.9	1.2	7.5	3.5	2.7
	CV	0.18	0.19	0.04	0.1	0.6	0.1	2.5	0.3	0.3	0.3	1.1	0.3
	Max	397	400	113	0.9	17.3	24.5	11.4	48.1	7.3	39.0	13.1	13.1
	Min	176	189	100	0.7	2.2	14.9	0.1	17.2	1.7	4.3	0.1	3.7
HSSB	Mean	181	188	104	0.9	10.8	0.0	1.7	29.4	4.3	15.0	6.2	32.6
	SD	56	57	5	0.0	3.3	0.0	1.8	7.3	2.1	5.3	2.7	6.5
	CV	0.31	0.30	0.05	0.0	0.3	--	1.1	0.2	0.5	0.4	0.4	0.2
	Max	276	286	113	0.9	16.1	0.0	5.4	41.1	8.9	26.7	11.6	48.7
	Min	79	85	97	0.8	6.7	0.0	0.1	18.2	1.1	6.5	2.7	28.3

AHCM	Mean	222	227	103	0.9	2.0	11.7	0.5	26.3	7.5	24.6	8.4	19.2
	SD	76	74	3	0.1	1.7	5.5	0.3	15.1	1.0	14.7	6.1	7.4
	CV	0.34	0.33	0.03	0.1	0.9	0.5	0.8	0.6	0.1	0.6	0.7	0.4
	Max	383	385	108	0.9	5.2	20.6	1.2	41.9	9.5	47.8	16.4	32.0
	Min	160	167	100	0.8	0.5	5.9	0.3	3.3	6.5	8.5	0.4	13.9
ABGV	Mean	195	201	103	0.7	13.8	24.4	0.1	14.6	2.4	26.1	7.6	11.0
	SD	58	59	3	0.1	2.8	8.6	0.0	8.1	1.5	9.6	3.2	11.2
	CV	0.30	0.30	0.03	0.1	0.2	0.4	0.5	0.6	0.6	0.4	0.4	1.0
	Max	287	288	110	0.9	19.6	40.2	0.2	30.1	5.2	39.1	14.7	31.2
	Min	121	121	99	0.6	10.2	10.8	0.0	5.4	0.1	8.1	2.9	0.9

Table 4.21: Statistical summary of the source apportionment in PM_{10} for summer season

Site location	Parameter	Measured PM_{10}	Calculated PM_{10}	% Mass Calculated	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	Mean	205	205	100	1	11.6	18.6	0.2	26.5	6.1	23.0	4.3	9.7
	SD	46	47	2	0	5.3	6.3	0.2	8.2	1.8	6.5	3.9	7.5
	CV	0.23	0.23	0.02	0.08	0.5	0.3	0.7	0.3	0.3	0.3	0.9	0.8
	Max	307	310	102	1	20.6	30.7	0.6	36.2	10.4	36.5	10.6	30.2
	Min	125	126	93	1	3.0	8.7	0.0	7.4	2.3	13.8	0.0	0.1
SAIL	Mean	229	234	102	1	10.1	18.2	0.3	22.7	4.8	29.4	5.9	8.4
	SD	54	59	5	0	3.7	5.7	0.1	8.6	1.5	8.5	3.3	5.3
	CV	0.24	0.25	0.05	0.07	0.4	0.3	0.5	0.4	0.3	0.3	0.6	0.6
	Max	306	331	109	1	17.2	28.9	0.6	38.1	6.9	42.9	12.2	20.9
	Min	146	151	90	1	3.7	8.8	0.1	9.2	2.2	13.3	1.4	1.9
ENPH	Mean	240	249	104	1	12.3	13.0	0.4	24.2	5.6	20.9	11.0	12.4
	SD	63	64	4	0	2.5	6.2	0.2	9.8	0.9	10.8	6.7	7.6

	CV	0.26	0.26	0.04	0.08	0.2	0.5	0.5	0.4	0.2	0.5	0.6	0.6
	Max	381	398	113	1	17.3	22.9	0.7	36.4	7.0	39.0	22.9	32.6
	Min	157	165	100	1	7.5	0.0	0.1	4.4	4.4	4.9	0.9	6.2
HSSR	Mean	224	227	102	1	11.0	17.7	0.3	23.2	5.0	29.7	2.3	10.7
	SD	67	65	3	0	2.4	6.7	0.1	9.0	1.8	10.7	2.4	4.8
	CV	0.30	0.29	0.03	0.07	0.2	0.4	0.4	0.4	0.4	0.4	1.0	0.4
	Max	353	354	109	1	16.0	30.1	0.6	36.6	7.8	48.3	7.4	23.7
	Min	122	123	96	1	7.9	7.6	0.1	5.0	1.7	15.0	0.0	4.4
HSSB	Mean	65	68	103	1	14.1	0.0	4.1	17.6	6.6	15.1	7.3	35.3
	SD	16	17	7	0	4.2	0.0	2.9	8.3	2.0	10.5	9.3	9.1
	CV	0.25	0.25	0.07	0.11	0.3	--	0.7	0.5	0.3	0.7	1.3	0.3
	Max	88	91	116	1	19.6	0.0	10.6	25.7	11.3	35.1	30.2	45.7
	Min	40	41	97	1	5.6	0.0	2.1	3.5	3.3	3.4	0.0	22.3
AHCM	Mean	84	85	102	1	14.2	0.0	0.3	18.3	6.5	17.1	8.0	35.6
	SD	13	13	3	0	4.4	0.0	0.1	4.9	4.4	6.6	4.8	12.8
	CV	0.15	0.15	0.03	0.12	0.3	--	0.4	0.3	0.7	0.4	0.6	0.4
	Max	106	108	109	1	20.2	0.0	0.5	27.9	15.2	29.4	17.9	48.0
	Min	68	72	99	1	5.8	0.0	0.1	12.1	2.5	9.2	2.6	11.9

Table 4.22: Statistical summary of the source apportionment in PM_{10} for post-monsoon

Site location	Parameter	Measured PM_{10}	Calculated PM_{10}	% Mass Calculated	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	Mean	60	63	104	1	8.0	3.2	3.7	26.3	6.6	19.9	0.9	30.3
	SD	29	29	5	0	6.9	6.3	3.6	10.3	3.9	13.4	1.4	11.3
	CV	0.48	0.47	0.05	0.12	0.9	2.0	1.0	0.4	0.6	0.7	1.5	0.4
	Max	132	132	118	1	25.9	16.0	13.1	39.6	10.5	35.1	4.0	44.7
	Min	29	33	98	1	2.8	0.0	0.0	3.7	0.0	0.0	0.0	0.0
SAIL	Mean	51	51	101	1	5.0	0.0	2.6	29.3	10.2	14.9	4.6	31.1
	SD	30	30	3	0	3.0	0.0	4.0	6.8	3.7	9.3	5.1	14.4
	CV	0.60	0.59	0.03	0.09	0.6	--	1.5	0.2	0.4	0.6	1.1	0.5
	Max	139	140	106	1	14.0	0.0	15.4	42.2	17.3	31.1	21.5	52.5
	Min	28	28	96	1	2.6	0.0	0.4	14.6	6.3	0.9	0.0	0.8
ENPH	Mean	127	128	101	1	11.7	0.0	0.7	15.6	5.7	35.6	10.2	20.5
	SD	58	58	2	0	4.4	0.0	0.5	8.2	1.6	10.5	6.2	5.7
	CV	0.46	0.45	0.02	0.08	0.4	--	0.7	0.5	0.3	0.3	0.6	0.3
	Max	248	250	105	1	24.0	0.0	1.9	32.7	9.0	48.3	22.9	30.3
	Min	51	51	99	1	5.9	0.0	0.1	4.9	3.4	16.6	2.9	12.0
HSSR	Mean	140	145	103	1	8.7	21.5	0.1	19.2	3.1	35.9	2.9	7.6
	SD	62	68	3	0	2.5	6.4	0.1	10.4	1.4	13.0	2.6	4.0
	CV	0.44	0.47	0.03	0.07	0.3	0.3	0.6	0.5	0.4	0.4	0.9	0.5
	Max	256	279	109	1	13.7	36.2	0.2	44.2	6.0	51.2	8.1	17.0
	Min	60	63	99	1	4.5	8.6	0.0	7.1	1.4	12.9	0.0	2.1
HSSB	Mean	78	78	101	1	9.4	18.6	0.0	33.0	6.4	14.1	3.1	16.2
	SD	38	38	5	0	5.4	16.4	0.0	15.5	4.1	9.4	6.2	14.3
	CV	0.48	0.48	0.05	0.09	0.6	0.9	--	0.5	0.6	0.7	2.0	0.9

	Max	149	160	109	1	17.5	49.0	0.0	54.2	18.7	32.6	25.3	38.7
	Min	42	45	91	1	1.4	0.0	0.0	0.0	2.2	2.9	0.0	1.1
AHCM	Mean	101	101	100	1	3.4	30.8	0.2	22.1	5.3	37.3	2.1	4.4
	SD	52	50	4	0	4.6	6.5	0.1	13.4	2.4	19.5	0.8	4.5
	CV	0.51	0.50	0.04	0.11	1.4	0.2	0.7	0.6	0.5	0.5	0.4	1.0
	Max	176	176	103	1	13.9	41.4	0.4	39.8	10.8	52.5	2.9	14.1
	Min	43	43	92	1	0.8	22.7	0.1	3.3	3.8	5.3	0.6	0.0

Table 4.23: Statistical summary of the source apportionment in $PM_{2.5}$ for winter season

Site location	Parameter	Measured $PM_{2.5}$	Calculated $PM_{2.5}$	% Mass Calculated	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	Mean	136	140	104	1	6.8	4.3	13.6	15.6	4.7	18.4	5.0	29.9
	SD	40	40	6	0	4.1	6.9	5.8	9.0	3.4	8.5	3.7	11.6
	CV	0.3	0.3	0.1	0.1	0.6	1.6	0.4	0.6	0.7	0.5	0.8	0.4
	Max	202	203	117	1	12.9	19.9	28.7	28.3	11.1	33.9	11.3	53.3
	Min	77	77	98	1	0.4	0.0	3.8	0.0	0.0	3.6	0.0	12.1
SAIL	Mean	196	203	104	1	10.2	21.7	0.3	22.2	3.2	23.2	4.0	15.2
	SD	33	32	5	0	5.7	12.3	0.1	6.3	2.6	8.5	2.8	7.2
	CV	0.2	0.2	0.0	0.1	0.6	0.6	0.5	0.3	0.8	0.4	0.7	0.5
	Max	280	281	115	1	20.2	42.6	0.5	36.3	6.6	44.0	10.0	29.6
	Min	161	165	99	1	3.7	2.1	0.1	12.4	0.1	5.4	1.3	6.6
ENPH	Mean	151	164	108	1	2.9	20.2	1.1	29.3	2.2	14.6	10.2	19.5
	SD	34	39	7	0	2.4	10.1	1.6	9.8	1.8	10.3	5.6	7.1
	CV	0.2	0.2	0.1	0.1	0.8	0.5	1.5	0.3	0.8	0.7	0.5	0.4
	Max	223	248	120	1	8.5	44.2	6.6	49.6	5.9	37.4	22.5	34.9

	Min	93	97	97	1	0.2	2.1	0.0	13.4	0.4	6.2	3.2	11.1
HSSR	Mean	150	161	107	1	5.4	37.9	1.6	27.2	6.0	11.7	2.3	9.3
	SD	29	34	6	0	1.3	8.7	2.8	12.5	3.2	8.3	1.2	3.4
	CV	0.2	0.2	0.1	0.1	0.2	0.2	1.8	0.5	0.5	0.7	0.5	0.4
	Max	213	224	118	1	7.5	53.7	9.0	46.8	16.4	29.5	4.9	14.7
	Min	98	106	97	1	3.2	24.5	0.1	7.6	3.1	1.1	0.8	3.6
HSSB	Mean	116	120	104	1	10.5	0.0	1.6	32.1	5.2	14.7	3.0	37.0
	SD	35	34	6	0	3.2	0.0	2.4	9.2	1.9	8.5	1.9	9.0
	CV	0.3	0.3	0.1	0.1	0.3	--	1.5	0.3	0.4	0.6	0.6	0.2
	Max	183	188	119	1	15.4	0.0	8.3	42.0	8.7	35.3	7.6	63.1
	Min	61	65	99	1	5.3	0.0	0.1	12.6	1.9	3.9	1.1	23.8
AHCM	Mean	108	118	107	1	2.0	19.0	0.4	27.9	5.2	11.8	6.7	27.0
	SD	22	33	9	0	1.4	5.6	0.1	3.6	3.1	3.5	4.6	7.2
	CV	0.2	0.3	0.1	0.1	0.7	0.3	0.3	0.1	0.6	0.3	0.7	0.3
	Max	151	182	121	1	4.7	28.4	0.6	32.6	8.8	15.3	14.3	38.7
	Min	85	85	101	1	0.7	10.1	0.3	22.8	1.6	5.7	0.8	18.4
ABGV	Mean	146	156	106	1	11.9	29.1	0.1	15.5	1.9	20.5	8.5	12.6
	SD	46	54	7	0	3.7	14.7	0.0	7.6	1.4	9.3	7.0	10.0
	CV	0.3	0.3	0.1	0.1	0.3	0.5	0.5	0.5	0.7	0.5	0.8	0.8
	Max	227	246	115	1	20.1	52.5	0.2	26.4	5.6	34.4	23.4	34.7
	Min	88	86	93	1	7.1	12.3	0.0	2.6	0.8	8.4	0.4	1.6

Table 4.24: Statistical summary of the source apportionment in $PM_{2.5}$ for summer season

Site location	Parameter	Measured $PM_{2.5}$	Calculated $PM_{2.5}$	% Mass Calculated	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	Mean	106	110	103	1	8.4	22.1	0.3	18.4	5.1	24.2	5.4	16.0
	SD	22	26	6	0	2.7	8.6	0.2	8.5	1.7	7.3	5.1	7.8
	CV	0.2	0.2	0.1	0.1	0.3	0.4	0.6	0.5	0.3	0.3	1.0	0.5
	Max	153	178	116	1	13.2	34.5	0.7	36.7	7.0	42.3	12.3	26.6
	Min	72	71	95	1	4.5	7.7	0.0	8.4	1.6	8.8	0.0	1.7
SAIL	Mean	114	121	106	1	11.9	30.4	0.3	17.8	6.9	19.2	5.9	8.5
	SD	23	25	4	0	2.9	9.2	0.2	7.4	1.8	10.3	3.8	4.8
	CV	0.2	0.2	0.0	0.1	0.2	0.3	0.6	0.4	0.3	0.5	0.6	0.6
	Max	169	182	116	1	17.6	50.1	0.6	27.3	10.4	46.7	12.6	17.4
	Min	83	87	98	1	6.6	15.0	0.1	0.0	2.9	6.7	1.7	2.0
ENPH	Mean	119	125	106	1	13.8	25.3	0.4	19.7	7.3	13.1	9.0	11.4
	SD	21	22	5	0	3.0	10.6	0.2	6.3	1.7	7.4	4.2	6.4
	CV	0.2	0.2	0.0	0.1	0.2	0.4	0.4	0.3	0.2	0.6	0.5	0.6
	Max	158	167	114	1	20.8	41.3	0.8	36.1	10.1	31.6	15.8	23.4
	Min	85	86	99	1	10.3	0.0	0.1	11.6	3.7	3.4	2.3	2.7
HSSR	Mean	114	121	106	1	10.6	26.5	0.2	21.0	3.9	17.9	1.6	18.3
	SD	23	25	6	0	2.6	9.7	0.1	8.7	2.7	9.5	1.5	10.5
	CV	0.2	0.2	0.1	0.1	0.2	0.4	0.4	0.4	0.7	0.5	0.9	0.6
	Max	156	158	119	1	14.6	45.8	0.5	34.2	10.0	35.8	5.3	40.8
	Min	62	69	101	1	5.9	16.2	0.1	8.0	0.3	6.2	0.0	4.0
HSSB	Mean	42	42	101	1	17.9	0.0	4.4	14.3	5.4	14.2	2.3	41.1
	SD	11	9	5	0	4.9	0.0	3.2	10.4	2.2	7.0	1.4	11.7
	CV	0.3	0.2	0.0	0.1	0.3	#DIV/0!	0.7	0.7	0.4	0.5	0.6	0.3

	Max	61	56	106	1	22.4	0.0	13.6	29.0	9.1	26.2	4.7	62.0
	Min	30	30	92	1	7.4	0.0	2.7	0.7	2.3	0.0	0.0	28.9
AHCM	Mean	53	54	102	1	12.6	0.0	0.2	21.0	6.0	19.8	6.1	34.0
	SD	6	8	5	0	3.4	0.0	0.1	8.6	2.7	9.8	4.9	10.6
	CV	0.1	0.2	0.0	0.1	0.3	#DIV/0!	0.6	0.4	0.5	0.5	0.8	0.3
	Max	62	66	112	1	18.0	0.0	0.4	36.8	10.3	30.6	16.5	44.7
	Min	44	44	97	1	7.5	0.0	0.0	11.3	2.7	2.9	2.5	12.4

Table 4.25: Statistical summary of the source apportionment in PM$_{2.5}$ for post-monsoon

Site location	Parameter	Measured PM$_{2.5}$	Calculated PM$_{2.5}$	% Mass Calculated	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	WASTE Burning	Vehicles
KRNK	Mean	32	33	104	1	8.9	0.9	4.0	17.5	5.4	27.3	1.4	35.2
	SD	15	15	7	0	5.0	2.7	3.5	14.4	4.3	14.9	2.1	13.0
	CV	0	0	0	0	0.6	2.8	0.9	0.8	0.8	0.5	1.5	0.4
	Max	66	65	118	1	21.0	10.3	11.1	50.6	12.8	49.4	8.0	63.7
	Min	18	20	87	1	3.9	0.0	0.0	0.0	0.0	3.7	0.0	5.1
SAIL	Mean	28	28	101	1	6.4	0.0	4.7	15.1	7.4	18.0	3.9	44.6
	SD	13	13	7	0	3.9	0.0	6.2	7.1	3.0	7.3	3.9	13.6
	CV	0	0	0	0	0.6	--	1.3	0.5	0.4	0.4	1.0	0.3
	Max	64	65	110	1	18.2	0.0	23.4	28.4	13.7	35.4	12.1	62.1
	Min	15	15	80	1	3.0	0.0	0.2	5.3	2.1	7.9	0.0	10.0
ENPH	Mean	67	69	104	1	13.3	0.0	1.1	23.8	4.1	16.9	8.5	32.1
	SD	31	31	4	0	4.6	0.0	1.2	3.3	1.1	9.4	6.9	8.1
	CV	0	0	0	0	0.3	--	1.1	0.1	0.3	0.6	0.8	0.3
	Max	141	141	114	1	22.0	0.0	4.1	28.2	5.9	35.3	29.9	44.9

	Min	33	35	99	1	5.3	0.0	0.0	15.7	2.4	6.0	1.2	19.8
HSSR	Mean	74	77	106	1	8.0	22.3	0.1	17.2	3.4	31.8	4.5	12.5
	SD	39	39	6	0	3.6	11.7	0.1	6.7	4.9	9.3	2.7	6.3
	CV	1	1	0	0	0.4	0.5	0.6	0.4	1.5	0.3	0.6	0.5
	Max	168	175	117	1	17.3	46.4	0.2	31.2	15.3	42.7	9.5	23.6
	Min	31	33	100	1	2.3	1.3	0.0	8.6	0.6	10.4	0.7	2.5
HSSB	Mean	46	49	107	1	10.5	22.8	0.0	18.5	5.4	15.8	3.2	23.9
	SD	22	25	6	0	5.3	22.7	0.0	10.4	2.8	8.6	9.3	13.8
	CV	0	0	0	0	0.5	1.0	--	0.6	0.5	0.5	2.9	0.6
	Max	106	111	116	1	19.5	57.5	0.0	35.6	11.9	32.6	37.4	45.7
	Min	22	22	96	1	1.9	0.0	0.0	0.0	3.0	4.4	0.0	3.2
AHCM	Mean	51	53	104	1	3.2	37.5	0.2	29.0	2.8	19.1	3.6	4.8
	SD	21	21	4	0	4.1	7.8	0.1	6.2	3.6	4.5	2.0	7.6
	CV	0	0	0	0	1.3	0.2	0.5	0.2	1.3	0.2	0.6	1.6
	Max	88	89	111	1	11.6	47.9	0.3	35.6	10.5	25.7	6.8	22.5
	Min	30	30	99	1	0.3	28.1	0.1	19.2	0.9	14.0	0.5	0.0

Table 4.26: 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	Waste Burning	Vehicles
KRNK	216	13.3	6.3	24.3	49.3	10.5	34.4	17.8	60.6
SAIL	344	34.2	61.3	0.9	94.3	9.9	92.9	14.8	34.5
ENPH	295	7.6	47.6	1.6	86.8	11.3	77.8	24.4	37.6
HSSR	298	21.8	59.5	4.5	89.2	12.8	81.1	9.9	22.9
HSSB	181	19.6	0.0	3.1	53.4	7.7	27.2	11.2	59.1
AHCM	222	4.4	26.1	1.0	58.4	16.6	54.7	18.7	42.7
ABGV	195	26.9	47.6	0.2	28.4	4.7	50.9	14.8	21.5
Overall	250	18.3	35.5	5.1	65.7	10.5	59.9	15.9	39.8
SD	62	10.6	25.0	8.6	24.8	3.7	24.8	4.9	15.7

Table 4.27: Concentration apportionment: winter 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	WASTE Burning	Vehicles
KRNK	136	9.2	5.9	18.5	21.2	6.4	25.0	6.8	40.7
SAIL	196	20.1	42.6	0.5	43.5	6.3	45.4	7.9	29.8
ENPH	151	4.4	30.6	1.6	44.2	3.4	22.0	15.4	29.4
HSSR	150	8.1	56.8	2.3	40.7	8.9	17.6	3.5	13.9
HSSB	116	12.2	0.0	1.8	37.3	6.0	17.1	3.5	43.0
AHCM	108	2.2	20.6	0.5	30.2	5.6	12.7	7.3	29.3
ABGV	146	17.3	42.4	0.1	22.5	2.8	29.8	12.4	18.3
Overall	143	10.5	28.4	3.6	34.2	5.6	24.2	8.1	29.2
SD	29	6.5	20.8	6.6	9.7	2.0	10.9	4.4	10.6

Table 4.28: Percentage apportionment: winter PM_{10}

Site location	PM_{10} ($\mu g/m^3$)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	216	6.2	2.9	11.2	22.8	4.9	15.9	8.2	28.1
SAIL	344	10.0	17.8	0.3	27.4	2.9	27.0	4.3	10.0
ENPH	295	2.6	16.2	0.6	29.4	3.8	26.4	8.3	12.8
HSSR	298	7.3	20.0	1.5	29.9	4.3	27.2	3.3	7.7
HSSB	181	10.8	0.0	1.7	29.4	4.3	15.0	6.2	32.6
AHCM	222	2.0	11.7	0.5	26.3	7.5	24.6	8.4	19.2
ABGV	195	13.8	24.4	0.1	14.6	2.4	26.1	7.6	11.0
Overall	250	7.5	13.3	2.3	25.7	4.3	23.2	6.6	17.3
SD	62	4.3	9.0	4.0	5.5	1.6	5.3	2.1	9.7

Table 4.29: 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	WASTE Burning	Vehicles
KRNK	136	6.8	4.3	13.6	15.6	4.7	18.4	5.0	29.9
SAIL	196	10.2	21.7	0.3	22.2	3.2	23.2	4.0	15.2
ENPH	151	2.9	20.2	1.1	29.3	2.2	14.6	10.2	19.5
HSSR	150	5.4	37.9	1.6	27.2	6.0	11.7	2.3	9.3
HSSB	116	10.5	0.0	1.6	32.1	5.2	14.7	3.0	37.0
AHCM	108	2.0	19.0	0.4	27.9	5.2	11.8	6.7	27.0
ABGV	146	11.9	29.1	0.1	15.5	1.9	20.5	8.5	12.6
Overall	143	7.1	18.9	2.7	24.2	4.1	16.4	5.7	21.5
SD	29	3.9	13.2	4.9	6.6	1.6	4.4	2.9	10.1

Table 4.30: 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	Waste Burning	Vehicles
KRNK	205	23.8	38.3	0.5	54.4	12.5	47.1	8.9	19.8
SAIL	229	23.2	41.7	0.6	51.9	10.9	67.4	13.5	19.2
ENPH	240	29.5	31.1	0.9	58.2	13.6	50.2	26.4	29.9
HSSR	224	24.7	39.6	0.7	52.1	11.2	66.6	5.3	23.9
HSSB	65	9.1	0.0	2.6	11.4	4.3	9.8	4.8	23.0
AHCM	84	11.9	0.0	0.3	15.4	5.4	14.4	6.7	29.9
Overall	175	20.4	25.1	0.9	40.6	9.7	42.6	10.9	24.3
SD	79	8.0	19.8	0.9	21.2	3.8	25.1	8.2	4.7

Table 4.31: 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	Waste Burning	Vehicles
KRNK	106	8.9	23.4	0.3	19.5	5.4	25.7	5.7	16.9
SAIL	114	13.7	34.8	0.3	20.3	7.8	21.9	6.8	9.7
ENPH	119	16.4	30.0	0.5	23.3	8.7	15.6	10.6	13.5
HSSR	114	12.0	30.1	0.3	23.8	4.4	20.3	1.8	20.8
HSSB	42	7.6	0.0	1.9	6.0	2.3	6.0	1.0	17.4
AHCM	53	6.7	0.0	0.1	11.2	3.2	10.6	3.2	18.1
Overall	91	10.9	19.7	0.6	17.4	5.3	16.7	4.9	16.1
SD	34	3.8	15.7	0.7	7.2	2.5	7.4	3.6	3.9

Table 4.32: 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	Waste Burning	Vehicles
KRNK	205	11.6	18.6	0.2	26.5	6.1	23.0	4.3	9.7
SAIL	229	10.1	18.2	0.3	22.7	4.8	29.4	5.9	8.4
ENPH	240	12.3	13.0	0.4	24.2	5.6	20.9	11.0	12.4
HSSR	224	11.0	17.7	0.3	23.2	5.0	29.7	2.3	10.7
HSSB	65	14.1	0.0	4.1	17.6	6.6	15.1	7.3	35.3
AHCM	84	14.2	0.0	0.3	18.3	6.5	17.1	8.0	35.6
Overall	175	12.2	11.2	0.9	22.1	5.8	22.5	6.5	18.7
SD	79	1.6	8.9	1.5	3.5	0.8	6.1	3.0	13.1

Table 4.33: 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	WASTE Burning	Vehicles
KRNK	106	8.4	22.1	0.3	18.4	5.1	24.2	5.4	16.0
SAIL	114	11.9	30.4	0.3	17.8	6.9	19.2	5.9	8.5
ENPH	119	13.8	25.3	0.4	19.7	7.3	13.1	9.0	11.4
HSSR	114	10.6	26.5	0.2	21.0	3.9	17.9	1.6	18.3
HSSB	42	17.9	0.0	4.4	14.3	5.4	14.2	2.3	41.1
AHCM	53	12.6	0.0	0.2	21.0	6.0	19.8	6.1	34.0
Overall	91	12.5	17.4	1.0	18.7	5.8	18.1	5.0	21.5
SD	34	3.2	13.7	1.7	2.5	1.3	4.0	2.7	13.1

Table 4.34: Concentration apportionment: Post-monsoon 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	Waste Burning	Vehicles
KRNK	60	4.9	1.9	2.2	15.9	4.0	12.0	0.5	18.3
SAIL	51	2.5	0.0	1.3	14.8	5.2	7.6	2.3	15.8
ENPH	127	14.8	0.0	0.9	19.8	7.2	45.1	13.0	26.0
HSSR	140	12.2	30.2	0.1	26.9	4.4	50.3	4.0	10.7
HSSB	78	7.3	14.5	0.0	25.8	5.0	11.0	2.4	12.6
AHCM	101	3.4	31.2	0.2	22.3	5.4	37.8	2.1	4.4
Overall	93	7.5	13.0	0.8	20.9	5.2	27.3	4.1	14.6
SD	36	5.0	14.8	0.9	5.0	1.1	19.2	4.5	7.3

Table 4.35: Concentration apportionment: Post-monsoon $PM_{2.5}$ (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	WASTE Burning	Vehicles
KRNK	32	2.9	0.3	1.3	5.6	1.8	8.8	0.4	11.3
SAIL	28	1.8	0.0	1.3	4.2	2.0	5.0	1.1	12.3
ENPH	67	8.9	0.0	0.8	15.9	2.7	11.3	5.7	21.4
HSSR	74	5.9	16.4	0.1	12.7	2.5	23.4	3.3	9.2
HSSB	46	4.8	10.5	0.0	8.5	2.5	7.2	1.5	11.0
AHCM	51	1.6	19.2	0.1	14.8	1.4	9.8	1.8	2.4
Overall	50	4.3	7.7	0.6	10.3	2.1	10.9	2.3	11.3
SD	18	2.8	8.8	0.6	4.9	0.5	6.5	1.9	6.1

Table 4.36: Percentage apportionment: Post-monsoon PM_{10}

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	Waste Burning	Vehicles
KRNK	60	8.0	3.2	3.7	26.3	6.6	19.9	0.9	30.3
SAIL	51	5.0	0.0	2.6	29.3	10.2	14.9	4.6	31.1
ENPH	127	11.7	0.0	0.7	15.6	5.7	35.6	10.2	20.5
HSSR	140	8.7	21.5	0.1	19.2	3.1	35.9	2.9	7.6
HSSB	78	9.4	18.6	0.0	33.0	6.4	14.1	3.1	16.2
AHCM	101	3.4	30.8	0.2	22.1	5.3	37.3	2.1	4.4
Overall	93	7.7	12.4	1.2	24.3	6.2	26.3	4.0	18.4
SD	36	3.0	13.1	1.6	6.5	2.3	11.1	3.3	11.2

Table 4.37: Percentage apportionment: Post-monsoon $PM_{2.5}$

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	WASTE Burning	Vehicles
KRNK	32	8.9	0.9	4.0	17.5	5.4	27.3	1.4	35.2
SAIL	28	6.4	0.0	4.7	15.1	7.4	18.0	3.9	44.6
ENPH	67	13.3	0.0	1.1	23.8	4.1	16.9	8.5	32.1
HSSR	74	8.0	22.3	0.1	17.2	3.4	31.8	4.5	12.5
HSSB	46	10.5	22.8	0.0	18.5	5.4	15.8	3.2	23.9
AHCM	51	3.2	37.5	0.2	29.0	2.8	19.1	3.6	4.8
Overall	50	8.4	13.9	1.7	20.2	4.7	21.5	4.2	25.5
SD	18	3.5	15.9	2.1	5.2	1.7	6.5	2.4	14.9

4.6 Interpretations and Inferences

Based on the CMB modeling results (Figure 4.58 and Figure 4.59) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for preparation of action plan. Tables 4-20 to 4-25, 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, winter and post-monsoon.
    - The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include coal and flyash (26 – 24%), soil and road dust (23 – 16%), SIA particles (8 - 7%), biomass burning (13 – 19%), vehicles (17 - 21%) and waste burning (7 - 6%). It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.
    - The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include coal and flyash (22 – 19%), soil and road dust (23 – 18%), biomass burning (11 – 17%), vehicles (19 – 22%), waste burning (6 – 5%), and SIA particles (12 – 13%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
    - The post-monsoon sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include soil and road dust (26 – 22%), biomass burning (12 – 14%), vehicles (18 – 25%), waste burning (4 – 4%), coal and flyash (24 – 20%) and SIA particles (8 – 8%). It is noteworthy, in post-monsoon also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The four most consistent sources for PM_{10} and $PM_{2.5}$ in all the season are biomass burning, vehicles, coal and flyash and soil and road dust. The other sources on average may contribute more (or less) but their contributions are variable from one day to another.
- Consistent presence of SIA, biomass burning and vehicles in PM_{10} and $PM_{2.5}$ across all sites and in three seasons, suggests these particles encompass entire Bhilai region as a layer.

- Like the above point, in winter, consistent presence of soil and road dust encompass entire Bhilai region as a layer.

- Soil and road dust in summer contribute 23 – 18% and the coal and flyash contribute 22 – 19% to PM_{10} and $PM_{2.5}$. It is observed that in summer the atmosphere looks whitish to grayish indicating presence of large amounts of dust and; re-suspension of dust appears to be the cause of large contribution of these sources.

- The contribution of the biomass burning in winter is quite high at 13% (for PM_{10}) 19% (for $PM_{2.5}$). The presence of sizeable biomass is consistent in PM both winter, summer and post-monsoon indicated to local sources present in Bhilai and nearby areas. There is an immediate need to control or find alternatives to eliminate biomass emissions to observe any significant improvement in air quality in Bhilai.

- SIA particle levels are higher in summer compared to winter and post-monsoon.
- Vehicular emission contribution to PM_{10} (about 18%) and $PM_{2.5}$ (about 23%) is consistently similar in all the three season.

Directions for PM control

- Secondary particles

  These particles are expected to source from precursor 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 and refineries. However, contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. Behera and Sharma (2010) for Kanpur have concluded that secondary inorganic aerosol accounted for significant mass of $PM_{2.5}$ (about 34%) and any particulate control strategy should also include control of primary precursor gases.

- Vehicular pollution

  This source is the third and second largest source and most consistently contributing source to PM_{10} and $PM_{2.5}$ in winters. Various control options include the implementation of Euro 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 5.

- Biomass burning

  Biomass burning should be minimized if not completely stopped. Possibly it could be switched to cleaner fuel for domestic fuel, local bakery and hotels industries and other local thermal energy consuming industries in industries.

- Waste burning

  One of the reasons for burning waste is lack of infrastructure for timely collection of waste and people conveniently burn or it may smolder slowly for a long time. In this regard, infrastructure for collection and disposal of waste must improve and burning of waste should be completely banned.

- Coal and flyash

  In summer coal and flyash contribute about 22% of PM_{10} and unless sources contributing to flyash are controlled, one cannot expect improvement in air quality. It appears these sources are more of fugitive in nature than regular point sources. Flyash emission from hotels, restaurants and tandoors also cause large emissions and requires better housekeeping and flyash disposal.

- Soil and road dust

  In summer this source contributes about 23 % to PM_{10}. The silt load on some of the roads in bhilai is very high and silt can become airborne with the movement of vehicles. The estimated PM_{10} emission from road dust is over 15.378 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 resuspension of dust.

In summer, air quality cannot be improved unless we find effective control solutions for soil and road dust, fly ash re-suspension. The effectiveness of the pollution control options and selection of optimal mix of control options are analyzed in Chapter 5.

5 Control options, Analyses and Prioritization for Actions

5.1 Air Pollution Scenario in the City of Bhilai

The city of Bhilai has several environmental issues and it is a nonattainment city for national air quality standards in respect of PM_{10} and $PM_{2.5}$. There are several prominent sources within and outside Bhilai city contributing to PM_{10} and $PM_{2.5}$ in its ambient air. Chapter 3 presented the emission inventory and Chapter 4 described the apportionment of sources contributing to ambient air pollution. The summary of the source apportionment results is presented below.

- The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include coal and flyash (26 – 24%), soil and road dust (23 – 16%), SIA particles (8 - 7%), biomass burning (13 – 19%), vehicles (17 - 21%) and waste burning (7 - 6%). It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include coal and flyash (22 – 19%), soil and road dust (23 – 18%), biomass burning (11 - 17%), vehicles (19 – 22%), waste burning (6 – 5%), and SIA particles (12 - 13%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The post-monsoon sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include soil and road dust (26 – 22%), biomass burning (12 - 14%), vehicles (18 – 25%), waste burning (4 – 4%), coal and flyash (24 - 20%) and SIA particles (8 - 8%). It is noteworthy, in post-monsoon also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

Although source contributions to winter, summer and post monsoon air pollution are different, the overall action plan should include control of 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.

5.2 Source-wise Overall Control Actions

5.2.1 Hotels, Restaurants and Banquet Halls

The large hotels, restaurants, banquet halls (BH) and bakeries were surveyed. During the field survey, it was observed that hotels, restaurants, etc. use coal as fuel in tandoors. The common fuel other than wood is LPG. The total number of Hotels, Restaurants, Guest Houses (GHs), and Banquet Halls (BHs) are approximately 561; It was observed that in addition to LPG, coal/wood is being used as fuel in the tandoors, barbeques, and BH. The PM emission in the form of flyash contributes to air pollution from these activities.

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 Bhilai metropolis contains three municipal corporations: Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation. The Municipal corporations of Bhilai 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 commitment. A 70% reduction in PM_{10} (reduced city level (RCL): 82.5 kg/d and reduced outside city level (ROCL): 111.3 kg/d) and $PM_{2.5}$ (RCL: 59.7 kg/d and ROCL: 80.4 kg/d) can be achieved by adopting clean fuels like PNG/LPG or electric appliances.

Some of the large hotels and restaurants have DG sets. The DG sets should be under the designated emission norms, meet stack height requirements and use only BS-VI fuel with a diesel particulate filter (DPF). DG sets of 2KVA and smaller (operating at ground level) may be banned and one can use an inverter or solar-based generators.

5.2.2 Solid Waste Burning

In winter, the overall PM_{10} and $PM_{2.5}$ contribution from waste burning is about 6.35%, and stopping this burning is the simplest way to reduce PM_{10} and $PM_{2.5}$ levels. Although the waste burning is banned in the area the contribution coming out in the analyses proves otherwise. Any form of garbage or waste burning should be fully stopped and strictly monitored for its compliance. The muncipal corporations (Bhilai, Bhilai 3 Charoda and Risali), may consider imposing penalties and fines to deter people from burning any residue and further improve the collection and disposal of the waste.

The solid waste generation is around 1087 MT/day and the waste collected is approximately 772 MT/day. The solid waste collection efficiency is 71% in Bhilai city (NGT report, March 2023), and several events of solid waste burning and dumping have been observed during the city survey. (Figure 5.1).

The Municipal corporations, Bhilai should strengthen the infrastructure and prioritize the SW collection mechanism starting systematically in each ward with an emphasis on public awareness to ensure 100% collection of SWS (including access to remote and congested areas) and disposal at the scientific landfill site. Special attention is required for fruits and vegetable markets, commercial areas, industrial areas, mandis, collection of tree leaves, and high-rise residential buildings.

Figure 5.1: Waste dumping and burning in some parts of city

A mechanism should be developed to carry out a mass balance of waste generation, collection, and disposal on a weekly and monthly basis. Major commercial areas identified for this issue were Risali, Junwani, Shanti Nagar, Bhilai-Charoda, Baba Deep Singh Nagar, Nehru Nagar, Sector 9 and Jamul etc.

Desilting and cleaning of municipal drains by Municipal corporations, Bhilai 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.

In Bhilai-Durg region, four solid waste dump sites were identified; Potiyakala, Jamul, Kundara Para & Radhika Nagar. These MSW dump sites are to be managed and maintained scientifically for proper treatment/segregation. The treatment and rightful disposal of fresh waste should not take more than 7 days i.e., as open storage becomes a major source of VOCs.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by CECB, municipal corporation, NGOs and municipal corporators.

A helpline Number (For reporting complaints about air pollution viz., open burning, fugitive emission due to construction activities, etc.) should be created and advertised.

5.2.3 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 in the open, without covers) are being stored outside the construction premises and near the road (Figure 5.2). The Emission load of PM_{10} and $PM_{2.5}$ from construction and demolition is 2869 kg/d and 660 kg/d (combined both inside the city and outside).

Every C&D activity should fully comply with C&D Waste Management Rules, 2016. A few C&D waste recycling facilities must be developed, which is a common practice in large cities. The control measures for emissions should include:

- Wet suppression of building material (except cement)
- wind speed reduction barriers (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: cover the storage and provide the windbreakers.
- Vehicle cleaning and specific fixed wheel washing on leaving the site and moving on haul routes.

- The actual construction area is covered by a fine screen.
- No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road).
- The haul road (from the main road to the construction area) should be brick roads or interlocking blocks that can sustain the weight of loaded trucks and should be regularly cleaned.

The above control measures should be coordinated and supervised by Chhattisgarh Housing Board, Municipal Corporations, Urban Development Departments, PWDs, and CECB.

Figure 5.2: Construction material and debris near construction sites

The suggested control measures will reduce the emission by 50% in PM_{10} (RCL: 549 kg/d and ROCL: 885.5 kg/d) and $PM_{2.5}$ (RCL: 126.5 kg/d and ROCL: 203.5 kg/d). This will also reduce the road dust and fly ash contribution to ambient air concentration.

5.2.4 Domestic sector

The projected population for the year 2025 is estimated as 7,25,552 and the emissions from the domestic sector for the projected population are estimated. An on-field survey was conducted at 94 wards and 8 Tehsil in Bhilai city to obtain the fuel usage pattern. The population-wise fuel consumption pattern shows LPG (liquid petroleum gas) at 84% (CEEW, 2019), wood at 8%, coal at 5%, kerosene (at 2%), dung (1%), and crop residue (1%).

During the field survey, it was observed that most economically weaker/ slum areas use wood and dung as fuel for cooking, although they have been given LPG cylinders.

Overall LPG and PNG should be made available to the remaining of households to make the city 100% LPG and PNG fuels. 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.

This action of LPG and PNG supply is expected to reduce 82% for PM_{10} (RCL emission: 214.2 kg/d and ROCL emission: 767.88 kg/d) and 82% for $PM_{2.5}$ (RCL emission: 157.86 kg/d and ROCL emission: 555.48 kg/d).

5.2.5 Soil and Road Dust

It has been observed that the soil and road dust emissions and their 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, an important factor in PM emissions from the road varied from 8 to 16.6 g/m^2 which is high in certain areas (Figure 5.3). The industrial areas, where heavy-duty vehicle movement is seen, also show high road dust emissions. It is suggested that high traffic density and heavy-duty vehicle roads should be properly maintained, paved from one end to another, have sidewalks through interlocking blocks for pedestrians, and have proper drainage from the road. Shrubs should be planted on-road dividers and dust removed from the edge of the dividers. Out of the total road network, about 60% of surface quality is poor.

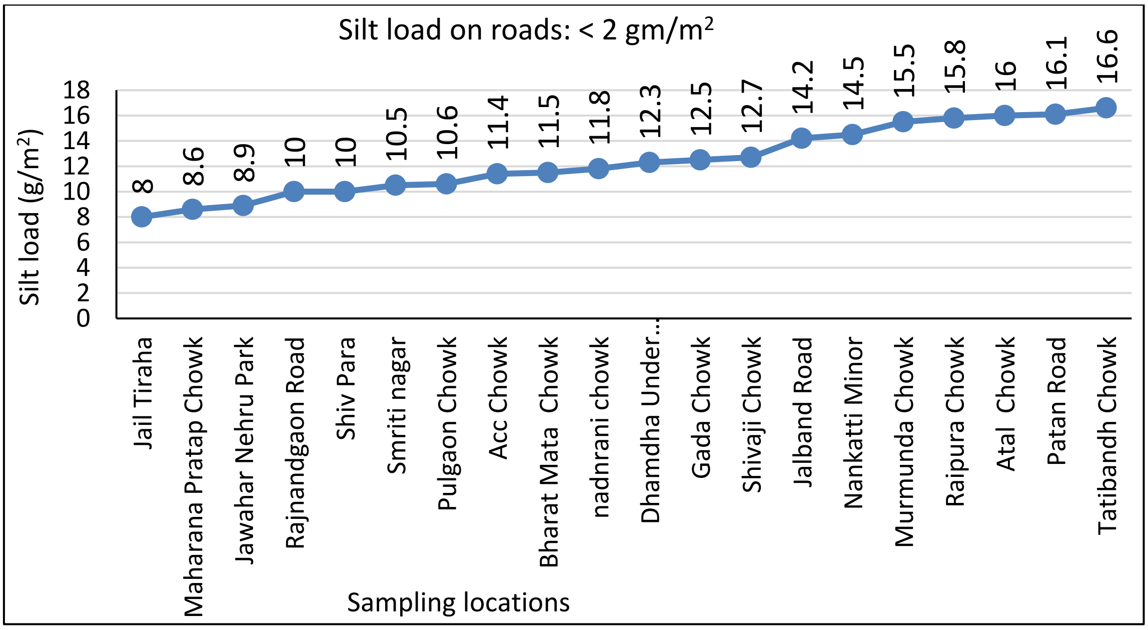


Figure 5.3: Silt load at different locations

The following control measures are suggested to reduce the dust emissions from the major roads:

1. Mechanical sweeping with water wash: The road dust PM_{10} emission estimated is 43.7 tons/day and $PM_{2.5}$ 9.9 tons/day. The emissions depend on the season and moisture on the road. This emission will be maximum in summer and least in monsoon. The 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 effort is likely to reduce emissions by 22729.72 kg/d (RCL: 7381.44 kg/d and ROCL: 13599.84 kg/d) for PM_{10} and by 5188.04 kg/d (RCL: 1648.8 kg/d and ROCL: 3104.16 kg/d) for $PM_{2.5}$.
2. Vacuum-assisted Sweeping: The efficiency of vacuum-assisted sweeping is 90% (Amato et al., 2010) and this should be part of the specification that there are no leakages of collected dust from vacuum trucks. If the sweeping is done twice a month, the road dust emission will be reduced by 42% of PM_{10} (RCL: 8919.24 kg/d and ROCL: 16433.14 kg/d) and $PM_{2.5}$ (RCL: 2053.8 kg/d and ROCL: 3750.86 kg/d). If the frequency of sweeping is increased to four times a month, then the road dust emission will be reduced by 71% of PM_{10} (RCL: 4459.62 kg/d and ROCL: 8216.57 kg/d) and $PM_{2.5}$ (RCL: 1017.9 kg/d and ROCL: 1875.43 kg/d).
3. It is more important that the condition of the roads is properly maintained and paved wall to wall including shoulders. Broken roads are the source of silt accumulation and particle generation.
4. If the silt road is greater than 2 g/m^2, the vacuum-assisted sweeping should be carried out along with water washing by the municipal council.
5. NHAI should ensure that the silt load on highways is less than 2 gm/m^2.
6. The condition of the roads must be maintained properly with no potholes and shoulders paved by interlocking concrete to have a proper sidewalk.
7. Convert all unpaved, partially paved roads to fully paved roads. PWD (Public Works Department) and city administration may take action in this regard.
8. The truck carrying construction material, or any airborne material should be covered.
9. Vacuum sweeping of roads with high silt load locations should be carried out at

least four times a month also carpeting of shoulders, maintenance of the road, dividers, and kerbs should be carried out at regular intervals. This activity should have proper documentation including the quantity of dust collected from the roads.

10. Shrubs and perennial forages, or grass covers should be planted on the medians wherever possible.
11. Soil dust could be part of road dust also. It is recommended that open fields should be kept slightly wet and small shrubs are planted to prevent the drift of dust in summer.

Road dust deposition can be seen on the roads. It can be seen the roads are broken in patches causing higher road dust emissions (Figure 5.4).

Figure 5.4: Broken roads causing higher road dust emissions.

The above control measures should be coordinated and supervised by Chhattisgarh Housing Board, Municipal Corporations of Bhilai, NHAI, PWD, and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

For example, certain roads are having less than 2.0 gm/m^2 of silt load and interlocked concrete shoulders within the city, which can be seen and employed in the entire city. (Figure 5.5).

❑ Construction of Foot Paths

❑ End to End Development of Roads

Figure 5.5: Quality of dust-free Roads, footpaths and dividers with dust control (Courtesy: Greater Hyderabad Municipal Corporation)

5.2.6 Vehicle Emission Control, Congestion and Traffic Management

The vehicle emission contribution is significant for CO, NO$_x$, 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 HSSB has very large vehicle contributions with an overall contribution of 37% and 41% in PM$_{2.5}$ in winter and summer months and SAIL has very large vehicle contributions with an overall contribution of 44% in PM$_{2.5}$ in post monsoon months .

The control measures must focus on advanced technological intervention for diesel vehicles like Diesel Particulate Filters (DPF). The specific 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 (BS-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 material and finished products from the industry.
3. By the end of 2030, a target of 50% of the total registration of vehicles in the city should be electric vehicles (EVs) in the sector of 2Ws, 3Ws and passenger cars. A suitable subsidy or tax break may be considered for individuals opting for EVs. Charging infrastructure should come up quickly at multiple places (As per Ministry of Petroleum guidelines, charging infrastructure for EV- Revised guidelines and standards, Oct 1, 2019, MoP), including charging at public buildings and parking lots and battery swapping facilities should be planned to avoid long charging periods, especially for two-wheelers.

Transition to EV Cars and Emission Reductions

- Period: 2022 to 2032
  - Y-to-Y growth rate: 9%
  - EV sales in the first year: 10% (of total)
  - Increment in sales in EV 20% of the previous year

4. All the diesel-based city public transport (government/private buses) should be phased out completely in the next five years, and city transport should be operated only through metro, e-vehicle, or on CNG. All new public transport should be CNG or electric buses.
5. It is expected that all vehicles on BS-IV and lower must be scrapped by 2031 and on the road, fleet must of BS-VI. The overall emissions from vehicles will be reduced by 93%.
6. 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 authorized service centres in sufficient numbers to cater to the need of their vehicles in the city. The automobile manufacturing company-owned service centres (AMCOSC) should be fully equipped for complete inspection and maintenance of vehicles ensuring vehicles conform to emission norms and fuel economy after servicing. Every vehicle at least once a year should undergo a thorough check-up and compliance with pollution control devices and their proper function from an authorized centre.

7. The current official PUC centres in Bhilai-Durg are about 50 at *Transport Department* but 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.
8. Linking of PUC centres with remote servers and elimination of manual intervention in PUC testing.
9. 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%20AIS170%20%20RSD_DF_Sep_20200930_C.pdf).
10. Restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles.
11. Check the overload vehicles: Use weigh-in-motion bridges/machines (WIM) and Weighbridges 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.
12. Transport department government of Chhattisgarh should plan and install multiple electric charging facilities in its depots (in Bhilai and other destinations) to quickly move towards electric buses.
13. Incentivise and aggressively implement e-mobility including required charging infrastructure. Strategic plan for EV charging infrastructure at each 3 km in urban areas, 25 km on highways (both sides), and 100 km for buses and trucks and swappable battery stations.
14. The 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.
15. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modifications. Ensure integration of the existing metro system with bus service.
16. Information technology (IT) systems in buses, bus stops, and control centres and passenger information systems should be introduced for the reliability of bus services and monitoring.

17. 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 in one place completely blocking the road at the terminus.
18. Other than a few roads, there is a lack of footpath availability and marking of zebra crossing for pedestrian movements and people are forced to walk on the road. Proper footpaths and ease of crossing should be available for pedestrians.
19. 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.
20. 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.
21. Ensure that all heavy-duty vehicles entering in the city must undergo regular emission testing at state-monitored PUC centers to verify the compliance with the latest emission standards.
22. Implement low-emission zones in areas with high pollution levels, such as densely populated areas.

Decongestion of Roads

Bhilai is a city in Durg district of the Indian state of Chhattisgarh, in eastern central India. Along with its twin-city Durg, the urban agglomeration of Durg-Bhilainagar has a population of more than a million, making it the second-largest urban area in Chhattisgarh after Raipur. Bhilai is a major industrial city as well as an education hub of central India.

The twin city of Durg-Bhilai is well connected with a network of national and state highways. Some major highways passing through the city are National Highway 53 (NH-53), SH-7 till Bemetara and SH-22 till Abhanpur. The proposed Durg–Raipur–Arang Expressway will start from Durg and will pass near the outskirts of Bhilai till Arang, which after completion, will enhance connectivity and commute in the state.

There is total 15 railway stations in the twin city that includes railway stations serving adjacent and minor neighbourhoods within the city.

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 industrial and commercial area of SAIL, ENPH and Risali etc., requiring specific attention including installation of DPF.

To increase the average speed and get full advantage of BS-VI, decongestion, removing encroachments from the roads, and stopping unauthorized and improper parking are essential. The off-street parking is inadequate in the city causing jams and permanent congestion because of on-street haphazard parking.

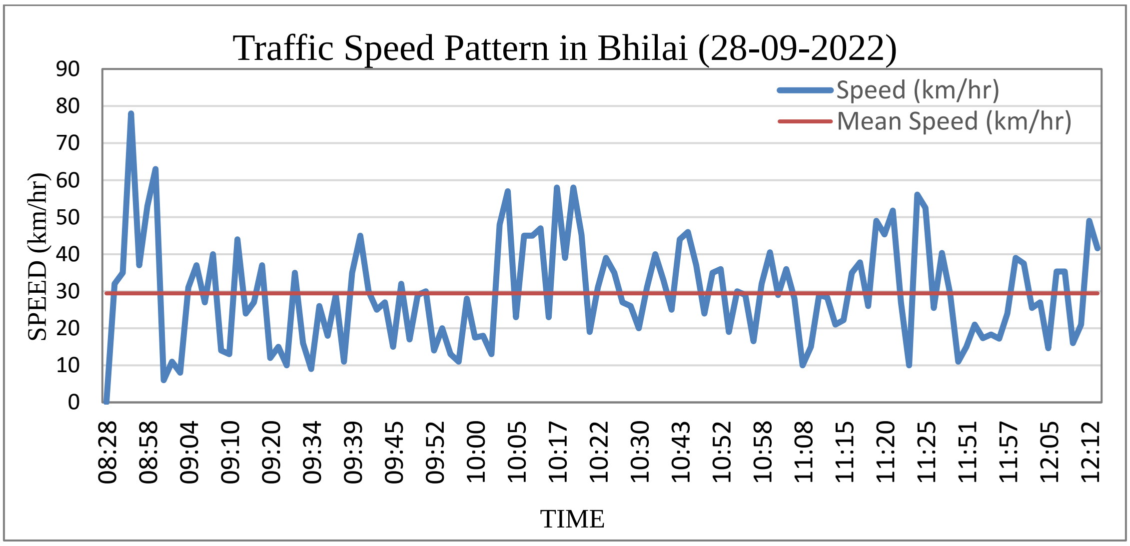


Figure 5.6: Traffic Speed Pattern in Bhilai

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 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%.
- 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.
- Heavy-duty vehicles and buses which are destined for other cities pass through major roads within Bhilai city and create heavy congestion. The important points of congestion are ACC Chowk, Atal Chowk, Bharat Mata Chowk, Dhamdha Under

Bridge Durg, Gada Chowk, Jail Tiraha, Jalband Road, Jawahar Nehru Park, Maharana Pratap Chowk, Murmunda Chowk, Nadnrani Chowk, Nankatti Minor Patan Road, Pulgaon Chowk, Raipura Chowk, Rajnandgaon Road, Shiv Para, Shivaji Chowk, Smriti nagarm, Tatibandh chowk.

During the traffic recording and survey, the following major intersections are identified as traffic bottlenecks (Table 5.1).

Table 5.1: Major Traffic Bottleneck

Acc Chowk	Atal Chowk	Tatibandh chowk
Nankatti Minor	Patan Road	Maharana Pratap Chowk

Parking spaces

Off-street parking is inadequate in the city. There must be no parking zone (up to 50 m including auto, electric, and hand-pulled rickshaw) near the intersections (Figure 5.7) it will help the smooth traffic flow. Certain parking policies in congested areas (high parking costs, at city centres, and parking should be limited for differently abled people.

Vehicles are parked on roads and a few places occupying 50 percent of the thoroughfares virtually causing traffic jams and very slow movement of traffic. The parking problem is very severe at Acc Chowk Atal Chowk, Tatibandh chowk, Nankatti Minor, Patan Road, Maharana Pratap Chowk.

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 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 in width & one-way streets less than 4 m in 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 roadway width less than the highway and for this reason, it is desirable to prohibit parking on them.

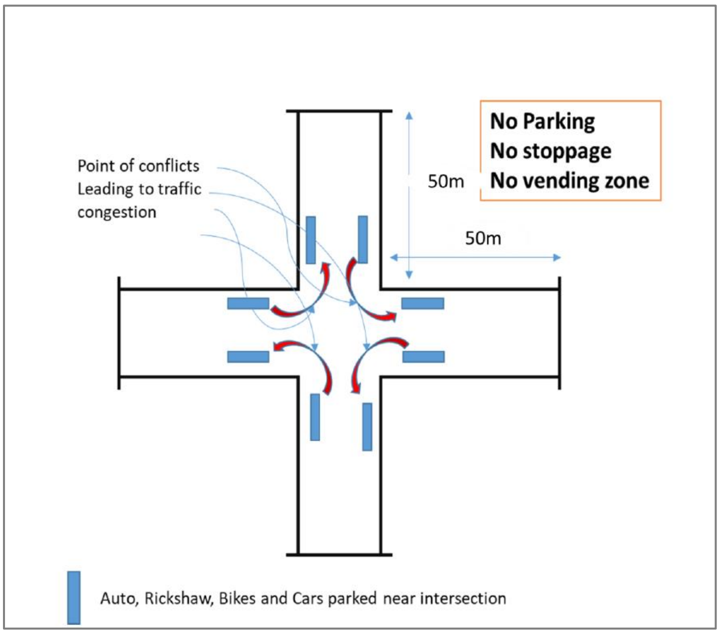


Figure 5.7: Conflicts due to on-street parking near intersections

There are modern technologies to facilitate multilevel car parking systems and the city should consider multilevel car parking systems.

Automated Multilevel Car Parking Systems

Automated car parking Systems are much in vogue - a method of automatic parking and retrieving cars that typically use a system of pallets and lifts and signalling 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 very detailed assessment of the parking required, space availability, and traffic flow. These can be further categorized into fully automatic or semi-automatic systems.

Dependent/Stack System: This allows two passenger cars to be parked one above the other (Figure 5.8). 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.

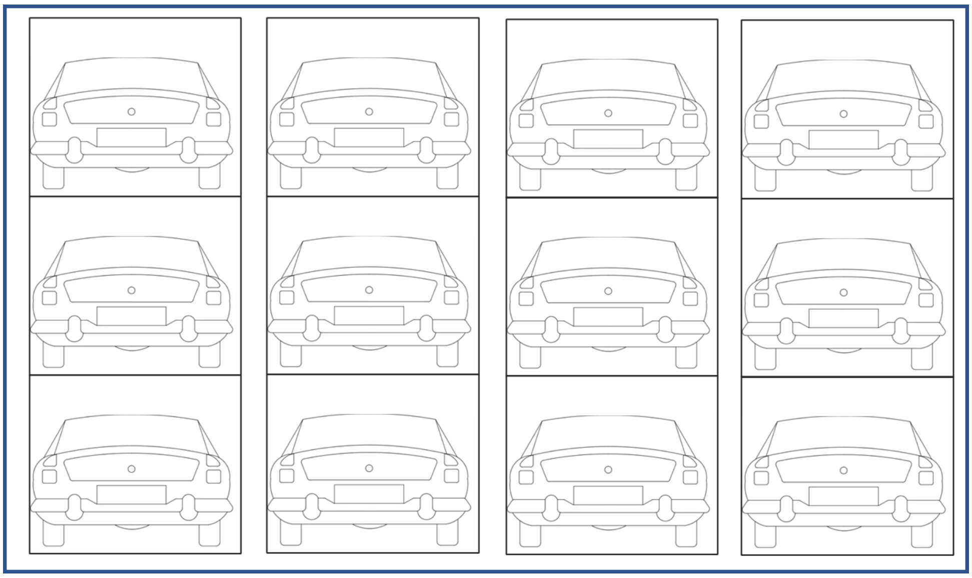


Figure 5.8: Multi-level car parking (example)

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, high parking charges need 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 with defined rules to be enforced. "No parking zone" and no-vending zone signs should be placed at required locations exhibiting parking issues.

Mostly, the parking is done on the walkways, and there is insufficient street space for pedestrians, cyclists, and public transport. In 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.

Promoting Public Transport Travel

Increasing the efficiency of public transport can deliver the 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. 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 lead to congestion at bottlenecks while turning.

5.2.7 Industries

Ambient air samples collected in the industrial area during the winter months show high levels of PM_{10} and $PM_{2.5.}$ Out of 98 total industrial units, there are approximately 26 industrial units with boilers and furnaces (Blast, Induction, Sponge Iron Kiln and Reheating furnaces) that contribute to particulate and gaseous emissions The total PM_{10} emissions are 60 t/d and for $PM_{2.5}$ it is 31 t/d from industries in combined form.

It was seen unauthorized dumping of fly ash and industrial wastes of industries in the industrial areas (Figure 5.9). The dirty flumes were seen in stacks of iron industries that causes high emissions with no air pollution control or ineffective control from the industries (Figure 5.10).

The major operations in BSP are coke oven batteries, basic oxidation furnaces (BOF)/steel melting shop (SMS), sintering, blast furnaces and raw material storage and handling. It is also observed that most industries in study area use coke oven gas (COG), coal, rice husk, furnace oil, and blast furnace gas as fossil fuels, in the industries. Since the residential areas are surrounded by industrial clusters within the city, the industries to be shifted to PNG or LDO or other cleaner fuels in a time-bound manner wherever it possible.

Figure 5.9: Flyash and waste dumping in the industrial area

Figure 5.10: Uncontrolled emissions from industries in Bhilai

A coordinated effort under the supervision of CECB and Industrial Departments (i.e., Industrial Association) is suggested to implement the following control measures:

- The industry to be shifted to PNG or LDO or other cleaner fuel in a time-bound manner wherever possible.
- Most industries use multi-cyclones as air pollution control devices. It is recommended that these cyclones should be replaced by baghouses/ESP for effective control of particulate emissions especially for industries using coal, husk, and other solid fuel.

- 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 emissions within the industry premises; all leakages, transfer points, loading and unloading, and material handling within the industry should be controlled.
- Maintain the inventory of all the raw materials, fuel consumptions, solid waste, hazardous waste and wastewater generation and reclycling/treatment in the industries, and periodic updatations and reporting to CECB.
- Periodic third-party audits need to be conducted to ensure the efficiency of air pollution control systems installed in industries as well as compliance with ambient air quality standards.
- All loose and dust generating fuel/raw materials like coal, ore, rice husk etc. must be kept under covered sheds or kept covered with large tarpaulin sheets within industrial premises, to reduce resuspension of loose materials in air with wind movement.
- Use eco-friendly dust suppressant chemicals on coal and ore stockpiles to form a crust over the piles, minimizing coal dust dispersion.
- Reduce the emissions in Bhilai Steel Plant from the operations in the bake oven, steel melting shop, sinter plant and raw material sotorage and handling.
- 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 SW (solid waste) and burnt in several parts of Bhilai. It is recommended that no industrial waste should be mixed with SW rather disposed of at TSDF (treatment storage and disposal facility) for hazardous waste disposal.
- There are industries with induction furnaces, which is a very polluted 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 the sides and top of the building.

- There are many small boilers in many industrial clusters in Bhilai. Replacement of small boilers with common boilers for steam generation in a cluster of industrial units is an important way forward. There are several advantages of switching from individual small boilers to common boilers. The individual industrial units can avoid a range of costs that include the cost of installing small boilers and associated fuel costs, the cost of air pollution control devices, and operation and maintenance costs, and can also avoid the need for getting environmental clearances for boilers.
- To address the pollution caused by fugitive emissions using induction furnaces a fume gas-capturing device has been developed and is commercially available. A side-based suction (Figure 5.11 to Figure 5.13) is far more effective than top suction, which interferes with the movement of the crane.

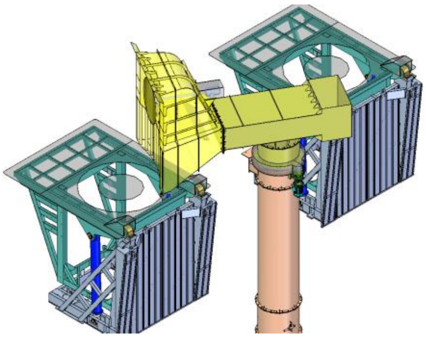


Figure 5.11: Proposed Suction Hood (Pic courtesy: Electrotherm)

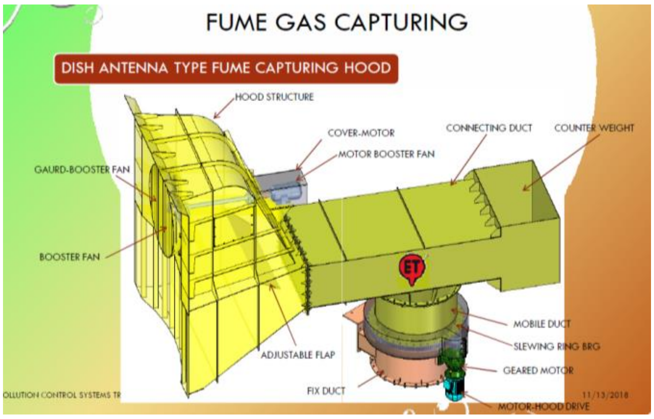


Figure 5.12: Side-based Suction Hood (Pic courtesy: Electrotherm)

Figure 5.13: Working on side-based Suction Hood

- It is recommended that a fume gas-capturing hood followed by a baghouse should be used to control air pollution.

The economics of the side-based suction hood for an induction furnace:

Assume a capacity of 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 crores

Pollution control cost is 10% of turnover. This 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 CECB. 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 all hazardous waste should send to an industrial non-hazardous TSDF for industrial waste. 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 Municipal corporations of Bhilai and CECB.

5.2.8 Diesel Generator Sets

To discourage the use of DG sets, the key focus must (i) strengthening of grid power supply, uninterrupted power supply to the industries in the region and replacing DG sets with gas-based sets, (ii) 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.

While the new installation can be based on PNG-based sets, the existing ones can be replaced in a phased manner. Continuous supply of gas must be ensured. It may be noted that while the capital cost of a diesel generator set is lower than that of the gas-based set, the operational cost of the gas-based set is lower as CNG prices are much lower than the diesel prices.

5.2.9 Secondary Particles: Control of SO_2 and NO_2 from Large point sources

The secondary particles contribute about 7 percent in winter, 12 percent in summer and 8 % in post-monsoon in $PM_{2.5}$. These particles source from precursor gases (SO_2, NO_x, and NH_3), 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 and iron industries. The prevalent wind from the southeast and southwest can bring in the secondary sulfates and nitrates from large industries almost from all sides in Bhilai. However, the contribution of NO_x from local sources, especially vehicles and iron industries can also contribute to nitrates. Behera and Sharma (2010) for Kanpur have concluded that secondary inorganic aerosol accounted for a significant mass of $PM_{2.5}$ (about 34%) and any particulate control strategy should also include control of primary precursor gases. What is even more significant, controlling secondary particles through the control of SO_2 and NOx will benefit the larger area of Bhilai-Durg region.

There are 4 thermal power plants with a total capacity of over 4700 MW in the state of Chhattisgarh. These power plants are expected to contribute to secondary particles. Based on the study done by Quazi (2013), was shown that power plants contribute nearly 80% of sulfates and 50% of nitrates to the receptor concentration. A calculation assuming a 90% reduction in SO_2 from these plants can reduce 72% of sulfates.

SO_2 removal technologies include wet flue gas desulfurization (FGD), dry FGD utilizing a spray dryer absorber, and dry adsorbent (lime and limestone) injection. Most SO_2 removal processes are engineered oxidation systems that transform calcium sulfite (CaSO3) formed by the SO_2 removal process to calcium sulfate ($CaSO_4$: gypsum).

5.3 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 other options for controlling air pollutants.

Table 5.2 summarizes the potential control options that includes technological and management interventions with timeline and identified agencies for taking or implementing the actions for $PM_{2.5}$ and PM_{10}.

5.4 Strengthening of CECB Bhilai Regional Office

The following measures may be taken to strengthen Bhilai Regional Office of CECB

- 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 analysis of metals, ions, and molecular markers.

Table 5.2: A Glance of Overall Control Options and Action Plan (for details see section 5.2)

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
Hotels/ Restaurants/ Banquet Halls	All Restaurants small or large should not use coal and shift to gas-based or electric (for a sitting capacity of more than 15 persons) appliances.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	1 year
	Link Commercial license to clean fuel	Municipal Corporations of Bhilai, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	Ash/residue from the tandoor and other activities should not be disposed of near the roadside. Requires ward-level surveillance.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	1 year
Domestic Sector	LPG to all. Slums and about 16% of the population are still using wood, coal, biomass, and dung cake as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year
	No new building complex or society be allowed without a PNG supply distribution network	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	By 2030, the city may plan to shift to electric cooking (common in Western countries) or PNG at the minimum.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	5 - 7 years
Solid Waste (SW) Burning	Develop the Scientific Treatment, Storage, and Disposal Facilities (TSDFs) at dumping sites.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	2-3 years
	Any type of garbage burning should be strictly stopped. Current waste collection and surveillance are poor.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation., CECB, CGHB.	
	Desilting and cleaning of municipal drains	Bhilai Municipal Corporations	
	Waste burning in Industrial areas should be stopped.	CSIDC, CECB	
	Daily, Monthly mass balance of SW generation and disposal	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation.	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Sensitize people and media through workshops and literature distribution so as not to burn the waste.	Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation., CECB, and NGO	
Construction and Demolition	Wet suppression	Chhattisgarh Housing Board (CGHB), Bhilai Municipal Corporation, Bhilai-Charoda Municipal Corporation and Risali Municipal Corporation., Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction sites)	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to a construction and demolition processing facility.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	Immediate
	Proper handling and storage of raw material: cover the storage and provide the windbreakers.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	The actual construction area should be covered by a fine screen.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	No storage (no matter how small) of construction material near the roadside (up to 10 m from the edge of the road)	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD	
	Sensitize construction workers and contract agencies through workshops.	CGHB, MCB, MCR and Bhilai-Charoda MC, Urban Development Department, PWD, CECB, and NGO	
Road Dust	The silt load in Bhilai varies from 8 to 17 g/m^2. The silt load on each road should be reduced to under 2 gm/m^2. Regular vacuum sweeping should be done on the road having a silt load above 2 gm/m^2.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, PWD, CECB (for silt load compliance)	Immediate
	Convert unpaved roads to paved roads. Maintain pothole-free roads.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, PWD, CECB to carry out surveillance	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, PWD	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Increase green cover and plantation. Undertake the green of open areas, community places, schools, and housing societies.	CGHB, MCB, MCR and Bhilai-Charoda MC, National Highway Authority, State Forest Department, PWD	
	Vacuum-assisted sweeping is carried out four times a month on major roads with road washing.	CGHB, MCB, MCR and Bhilai-Charoda MC, 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 the BS-IV category as well)	State Transportation Department	5 years
	Industries must be encouraged to use BS-VI or BS-IV (with DPF) vehicles for the transportation of raw and finished products.	Industrial Associations and State transport Department	Immediate
	Restriction on plying and phasing out of 10-year-old commercial diesel-driven vehicles.	Transport Department	2 years
	Introduction of cleaner fuels (CNG/ LPG) for all vehicles (other than 2-W).	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Check to overload: Expedited installation of weigh-in-motion bridges and machines at all entry points to Bhilai.	Transport Department, Traffic Police Bhilai, NHAI, Toll agencies	Six-months
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. All new city buses should be electric.	Transport Department, RTOs Bhilai	1 year
	Bus stop and their parking should be rationalized to ensure more efficient utilization. The depots should include well-equipped maintenance workshops. Adequate charging stations.	Transport Department, RTOs Bhilai	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	MCB, MCR and Bhilai-Charoda MC, RTOs Bhilai	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	CGHB, RTOs Bhilai, Traffic Police- Bhilai	1 year
	IT systems in buses, bus stops, control centers, and passenger information systems for the reliability of bus services and monitoring.	CGHB, RTOs Bhilai, Traffic Police- Bhilai	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Movement of materials (raw and products) within the city should be allowed between 10 PM to 5 AM.	Transport Department -Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	1 year
	All the diesel-based city public transport (school and government/private buses) should be phased out completely in the next three years, and city transport should be operated only through metro, e-vehicle or on CNG. All new public transport should be CNG or electric buses.	Transport Department-Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	3 – 10 years
	Incentivise and aggressively implement e-mobility including required charging infrastructure. Strategic plan for EV charging infrastructure at each 3 km in urban areas, 25 km on highways (both sides) and 100 km for buses and trucks and swappable battery stations.	Transport Department-Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	2 years
	Adequate vehicle scrappage infrastructure should be developed in the next three years. Extended Producer Responsibility (EPR) may be considered for vehicle manufacturers, who will have to build required vehicle scrap plants.	Transport Department- Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Ensure that all heavy-duty vehicles entering in the city must undergo regular emission testing at state-monitored PUC centers to verify the compliance with the latest emission standards.	Transport Department-Bhilai, RTOs Bhilai, Traffic Police- Bhilai, CECB	1 year
	Implement low-emission zones in areas with high pollution levels, such as densely populated areas.	Transport Department-Bhilai, RTOs Bhilai, Traffic Police-Bhilai, CECB	2 - 5 years
	Public transport is to be strengthened with metro and/or adequate number of buses, route plan based on commute surveys and mobile-based ticketing and seating systems is developed in all major cities.	Transport Department-Bhilai, CGHB, RTOs Bhilai, Traffic Police- Bhilai	2 – 5 years
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	CECB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal Council and CECB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, CGHB, CSIDC, Industries Department, CECB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, CSIDC, CECB	Immediate

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Following best practices to minimize fugitive emissions within the industry premises, all leakages within the industry should be controlled.	Industrial Associations, CSIDC, CECB	Immediate
	The area and road in front of the industry should be the responsibility of the industry	Industrial Associations, CSIDC, CECB	
	Maintain the inventory of all the raw materials, fuel consumptions, solid waste, hazardous waste and wastewater generation and reclycling/treatment in the industries, and periodic updatations and reporting to CECB	Industrial Associations, CECB	1 year
	Periodic third-party audits need to be conducted to ensure the efficiency of air pollution control systems installed in industries as well as compliance with ambient air quality standards.	Industrial Associations, CECB	1 year
	All loose and dust generating fuel/raw materials like coal, ore, rice husk etc. must be kept under covered sheds or kept covered with large tarpaulin sheets within industrial premises, to reduce resuspension of loose materials in air with wind movement.	Industrial Associations, CECB	1 year

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Use eco-friendly dust suppressant chemicals on coal and ore stockpiles to form a crust over the piles, minimizing coal dust dispersion.	Industrial Associations, CECB	1 year
	Reduce the emissions in Bhilai Steel Plant from the operations in the bake oven, steel melting shop, sinter plant and raw material sotorage and handling.	BSP, CECB	2 year
	Category A Industries (using coal and other dirty fuels)		
	About 26 boilers, heaters and furnaces in Bhilai are running using Coal, Briquettes, Rise Husk, Wood, HSD, Furnace Oil, Waste, Firewood and other dirty solid fuels which should be shifted to natural gas and electricity wherever possible.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, CECB	2 years
	Almost all rotary furnaces having significant emissions are running on coal that needs to be shifted to natural gas and electricity.	Industrial Associations, CECB	2 years
	Cyclones, multi-cyclones should be replaced by baghouses/ESP. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, CECB	2 years

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Category B Industries (Induction Furnace)		
	Fume gas capturing hood followed by baghouse should be used to control air pollution.	Industrial Associations, CECB	2 years
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries.	State Energy Department, HPSEBL	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 in high-traffic areas	Strict action on roadside encroachment. Disciplined movement of tempos to stop only at designated spots. Action on driving in the wrong lane.	CGHB, MCB, MCR and Bhilai-Charoda MC, RTOs Bhilai, Traffic Police- Bhilai	1 year
	Disciplined Public transport (designate one lane stop).	RTOs Bhilai, Traffic Police-Bhilai	
	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.	CGHB, MCB, MCR and Bhilai-Charoda MC., RTOs Bhilai, Traffic Police- Bhilai	
	Examine the existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	CGHB, RTOs Bhilai, NHAI, Traffic Police, Bhilai	

Source	Control Action	Responsible authorities	Time Frame (within a specified time)
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	CGHB, RTOs Bhilai, NHAI, Traffic Police, Bhilai	
	Mechanized multi-story parking at bus stands, and big commercial areas. Remove at least 50 percent of on-street parking in the city.	CGHB, RTOs Bhilai, Greater Bhilai Municipal Corporation, NHAI, Traffic Police, Bhilai	
	Identify traffic bottleneck intersections and develop a smooth traffic plan. For example, ACC Chowk, Atal Chowk, Tatibandh chowk, Nankatti Minor Patan Road and Maharana Pratap Chowk are the main bottlenecks for traffic.	CGHB, RTOs Bhilai, Greater Bhilai Municipal Corporation, Traffic Police, Bhilai	
	Parking policy in congested areas (high parking cost, at city centres, only parking is limited for physically challenged people, etc).	CGHB, RTOs Bhilai, Greater Bhilai Municipal Corporation, NHAI, Traffic Police, Bhilai	
*The above steps should not only be implemented in Bhilai Corporation municipal, Risali Municipal Corporation and Bhilai-Charoda Municipal Corporation limits rather these should be extended up to outer city boundary.			

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Annexure 1

Table showing the Emission Factors (EF) used while estimating the emissions (Source: CPCB 2011).

Source		Units of Emission factor	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO
Domestic	Wood	g/kg	5.04	4.54	0.48	1.4	31
	Crop residue	g/kg	11	9.90	0.12	0.49	58
	Dung	g/kg	5.04	4.54	0.48	1.4	31
	Coal	g/kg	20	18	13.3	3.99	24.92
	Kerosene	g/lit	0.61	0.55	4	2.5	62
	LPG	g/lit and kg/10^6 M^3	2.1	1.89	0.4	1.8	0.25
DG Set		g/kwh	0.0266	0.024	0.0248	0.376	0.0812
WASTE Burning		g/kg	8	5.44	0.5	3	42
Brick Kiln	wood	g/kg	15.3	13.7	0.2	1.4	115.4
	coal	g/kg	10.15	7.10	13.3	3.99	24.92
Industrial	LDO	g/lit	2.37	2.13	18.84S	6.6	0.6
	HSD	g/lit	1.49	1.34	18.84S	6.6	0.6
	Rice Husk	g/kg	11	9.9	0.12	0.49	58
	Wood	g/kg	17.3	15.57	0.2	1.3	126.3
	Natural gas	kg/$(10)^6$ m^3 (SCM)	121.6	109.4	9.6	2240	1344
	Coal	g/kg	10.15	9.14	19S	11	0.25
	Diesel	g/lit	0.0266	0.024	0.0248	0.376	0.0812
Vehicle	2 wheelers	g/vkt	0.035	0.03	0	0.29	2.12
	3 wheelers	g/vkt	0.27	0.24	*	0.5	0.54
	4 wheelers	g/vkt	0.06	0.05	*	0.25	1
	LCV	g/vkt	0.64	0.58	*	3.1	1.86
	Bus	g/vkt	1.24	0.74	*	9.46	8.4
	Truck	g/vkt	1.24	0.74	*	9.46	8.4
Construction		kg/d/m^2	0.0021	0.0005	-	-	-

* Average kilometre run per litre of diesel is taken as: 10 km (for 3W); 15 km (for 4W); 7 km (for LCV and 5 km (for Buses/Trucks). Sulfur content in diesel is taken as =10 ppm (wt/wt).

Annexure 2

Gridded Emissions for Bhilai city are represented below.

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G8	7.07	1.87	0.01	2.48	3.06
G9	5.54	3.13	1.65	2.91	12.39
G10	2.14	1.52	0.20	0.86	11.89
G11	2.83	2.01	0.26	1.13	15.70
G12	3.23	2.30	0.30	1.29	17.94
G13	3.65	2.46	0.31	1.34	18.66
G14	3.22	2.29	0.30	1.29	17.89
G15	15.06	6.64	1.37	10.29	31.70
G16	7.34	3.67	0.62	4.52	21.25
G17	7.41	3.06	0.33	5.88	15.37
G18	0.90	0.35	0.03	0.74	1.66
G31	0.10	0.07	0.01	0.04	0.54
G32	2.52	1.35	0.15	0.64	8.86
G33	151.47	41.25	1.86	51.31	70.12
G34	15.02	5.88	0.32	11.20	29.90
G35	14.37	5.59	0.32	9.40	27.87
G36	4.55	3.26	1.08	1.71	20.80
G37	3.38	2.41	0.31	1.35	18.80
G38	3.38	2.41	0.31	1.35	18.80
G39	4.03	2.87	0.50	1.56	21.44
G40	24.35	9.56	0.94	18.05	45.25
G41	5.72	4.06	0.99	2.11	28.33
G42	5.72	4.06	0.99	2.11	28.33
G43	14.13	6.96	1.68	9.56	36.26
G44	2.61	1.85	0.45	0.96	12.90
G45	0.14	0.10	0.02	0.05	0.69
G55	0.76	0.47	0.05	0.38	3.41
G56	4.55	2.47	0.26	1.86	16.55
G57	3.38	2.41	0.31	1.35	18.80
G58	170.18	46.08	0.36	70.06	89.12
G59	15.38	5.99	0.32	11.53	30.27
G60	36.93	12.40	1.63	11.78	38.40
G61	13.28	9.45	4.41	4.76	47.28
G62	9.95	7.08	3.03	3.61	37.69
G63	3.84	2.73	0.50	1.51	20.11
G64	26.57	10.12	0.90	19.59	46.21
G65	41.29	14.73	1.01	32.31	61.99
G66	5.72	4.06	0.99	2.11	28.33

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G67	5.72	4.06	0.99	2.11	28.33
G68	8.15	4.82	0.99	4.39	30.95
G69	9.64	5.28	1.00	5.80	32.57
G70	4.70	3.34	0.82	1.73	23.26
G71	0.88	0.63	0.15	0.33	4.38
G79	6.20	4.42	2.31	2.18	20.06
G80	23.71	13.97	6.16	11.87	61.85
G81	90.41	62.87	108.64	35.40	232.13
G82	7.95	3.77	0.32	5.21	23.15
G83	211.36	61.28	4.26	92.28	133.69
G84	64.85	28.75	8.34	43.74	114.66
G85	25.35	18.04	9.42	8.91	82.01
G86	26.64	18.96	9.95	9.36	85.72
G87	38.40	22.46	9.96	19.11	96.47
G88	40.50	20.66	7.52	23.68	87.05
G89	15.83	7.06	0.99	10.50	37.49
G90	7.73	4.71	0.99	4.27	31.02
G91	7.79	5.20	1.76	3.43	31.52
G92	5.72	4.06	0.99	2.11	28.33
G93	5.72	4.06	0.99	2.11	28.33
G94	14.07	6.66	1.00	9.97	37.36
G95	6.04	4.16	0.99	2.41	28.67
G96	87.98	28.71	3.28	52.58	86.56
G97	38.50	12.16	1.77	19.56	29.82
G103	12.89	6.74	3.28	7.11	24.22
G104	37.88	21.66	9.44	18.49	92.15
G105	46.54	24.23	9.96	18.00	95.46
G106	44.02	24.63	10.71	23.46	103.10
G107	108.60	40.04	9.60	43.45	118.42
G108	172.03	57.59	9.94	76.57	155.66
G109	70.04	31.92	9.97	46.01	127.04
G110	74.81	31.97	9.97	33.07	111.71
G111	46.19	24.76	9.96	25.34	103.24
G112	51.34	26.81	10.73	29.23	109.23
G113	22.55	16.05	8.20	7.94	74.51
G114	5.83	4.10	0.99	2.23	28.47
G115	6.55	4.33	0.99	3.00	29.44
G116	8.14	4.84	0.99	4.71	31.56
G117	5.72	4.06	0.99	2.11	28.33
G118	5.72	4.06	0.99	2.11	28.33
G119	5.72	4.06	0.99	2.11	28.33
G120	39.33	13.15	1.00	18.51	45.48

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G121	61.53	18.68	1.01	24.06	50.16
G122	8.33	5.24	1.70	4.31	30.81
G123	1.02	0.68	0.16	0.46	4.61
G127	0.89	0.64	0.33	0.31	2.87
G128	23.38	16.26	8.37	8.82	73.21
G129	29.69	20.40	10.72	11.56	89.81
G130	189.99	132.95	222.76	74.13	485.53
G131	107.83	75.80	116.35	41.27	285.09
G132	420.24	121.73	11.58	155.24	235.04
G133	48.53	25.54	9.96	28.20	106.98
G134	36.18	21.67	9.95	15.70	91.70
G135	32.54	20.66	9.95	13.57	89.88
G136	29.88	19.87	9.95	11.36	88.01
G137	27.74	19.31	9.95	10.54	87.19
G138	25.84	18.39	9.61	9.08	83.52
G139	8.60	6.11	2.22	3.11	36.22
G140	8.46	4.95	1.00	5.05	31.99
G141	13.19	6.48	1.00	10.14	38.33
G142	5.72	4.06	0.99	2.11	28.33
G143	297.78	81.08	1.84	116.88	144.13
G144	96.15	27.74	1.02	37.68	63.71
G145	20.47	7.93	1.00	7.91	34.10
G146	5.72	4.06	0.99	2.11	28.33
G147	10.38	5.59	1.00	7.17	34.34
G148	167.87	117.27	213.59	66.42	423.27
G149	0.13	0.09	0.01	0.05	0.71
G152	9.71	6.83	3.38	3.60	32.13
G153	29.96	19.54	9.73	9.91	85.08
G154	26.74	18.99	9.95	9.46	85.84
G155	189.47	132.78	222.76	73.62	484.96
G156	271.46	189.88	329.16	106.31	685.21
G157	211.68	66.35	9.99	73.00	148.60
G158	27.55	19.24	9.95	10.24	86.72
G159	26.98	19.06	9.95	9.67	86.07
G160	28.92	19.52	9.95	9.78	86.20
G161	28.34	19.48	9.95	10.90	87.48
G162	29.85	20.46	10.72	11.92	90.46
G163	26.64	18.96	9.95	9.36	85.72
G164	9.88	7.02	2.77	3.55	39.73
G165	35.50	13.11	1.01	27.76	59.35
G166	47.28	16.02	1.78	24.36	54.52
G167	38.25	12.74	1.00	16.79	43.72

Grid	**PM_{10} Kg/Day**	**$PM_{2.5}$ Kg/Day**	**SO_2 Kg/Day**	**NOx Kg/Day**	**CO Kg/Day**
G168	84.17	24.60	1.01	32.96	59.02
G169	5.72	4.06	0.99	2.11	28.33
G170	5.72	4.06	0.99	2.11	28.33
G171	5.72	4.06	0.99	2.11	28.33
G172	7.85	4.76	0.99	4.43	31.08
G173	169.37	118.14	213.62	67.37	429.96
G174	2.77	1.88	0.24	1.29	14.71
G176	0.61	0.26	0.03	0.41	1.36
G177	23.32	8.64	0.63	15.71	37.41
G178	186.17	130.61	221.54	72.23	476.37
G179	107.83	75.80	116.35	41.27	285.09
G180	26.64	18.96	9.95	9.36	85.72
G181	270.55	189.59	329.16	105.43	684.20
G182	152.96	53.91	10.76	71.29	152.24
G183	29.76	19.95	9.95	12.38	89.16
G184	30.49	19.99	9.95	11.04	87.64
G185	39.76	22.66	10.72	11.00	89.18
G186	34.78	21.44	9.96	16.72	94.14
G187	34.93	21.64	9.96	18.28	96.82
G188	51.64	26.16	10.73	20.47	99.00
G189	111.84	35.98	4.74	49.10	95.66
G190	82.13	24.72	1.02	39.55	68.55
G191	8.48	4.95	1.00	5.08	32.02
G192	5.74	4.07	0.99	2.13	28.35
G193	19.44	8.01	1.00	11.21	38.43
G194	18.68	7.58	1.00	8.45	34.93
G195	5.72	4.06	0.99	2.11	28.33
G196	5.73	4.07	1.00	2.15	28.34
G197	7.55	4.66	0.99	4.10	30.70
G198	170.10	118.39	213.68	68.14	430.48
G199	5.76	3.85	0.48	2.83	30.01
G200	0.15	0.11	0.01	0.06	0.87
G201	36.22	11.75	2.54	13.31	25.90
G202	90.42	27.56	2.21	45.19	72.41
G203	10.30	7.35	3.00	3.94	39.50
G204	26.64	18.96	9.95	9.36	85.72
G205	26.64	18.96	9.95	9.36	85.72
G206	31.60	20.10	9.95	9.36	85.72
G207	308.88	95.36	10.04	142.89	223.85
G208	38.03	22.08	9.95	15.00	92.14
G209	57.25	26.86	9.96	19.06	96.75
G210	47.42	25.47	10.73	23.61	103.58

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G211	37.40	22.21	9.96	18.72	96.43
G212	45.96	21.37	8.40	8.02	71.92
G213	262.34	81.45	11.15	109.30	185.22
G214	12.44	8.86	4.14	4.40	45.55
G215	5.72	4.06	0.99	2.11	28.33
G216	8.20	4.86	0.99	4.71	31.50
G217	6.46	4.29	0.99	2.82	29.14
G218	12.36	6.14	1.00	8.48	35.66
G219	33.02	12.43	1.01	25.63	55.55
G220	35.51	13.14	2.54	15.63	45.50
G221	5.72	4.06	0.99	2.11	28.33
G222	9.13	5.18	1.00	5.82	32.74
G223	87.44	61.08	107.32	34.76	229.24
G224	6.61	4.32	0.52	3.51	33.41
G225	1.97	1.34	0.17	0.89	10.53
G226	3.06	2.19	0.41	1.35	15.32
G227	323.30	87.86	2.26	134.26	161.51
G228	402.40	111.33	9.78	133.15	173.02
G229	244.51	77.07	13.07	86.55	168.61
G230	28.70	19.43	9.95	9.36	85.72
G231	107.83	75.80	116.35	41.27	285.09
G232	488.47	141.48	11.61	189.65	266.92
G233	26.64	18.96	9.95	9.36	85.72
G234	171.83	56.96	9.99	60.98	144.42
G235	451.83	129.58	11.58	143.98	247.84
G236	159.35	46.76	6.52	8.22	74.84
G237	425.14	115.14	1.54	171.94	208.06
G238	91.54	26.35	0.55	41.70	61.28
G239	4.50	3.23	0.65	2.00	22.21
G240	5.72	4.06	0.99	2.11	28.33
G241	5.72	4.06	0.99	2.11	28.33
G242	8.16	4.83	0.99	4.45	31.02
G243	8.77	5.02	1.00	5.04	31.70
G244	6.47	4.31	0.99	2.92	29.29
G245	84.68	25.63	1.02	42.31	70.64
G246	5.72	4.06	0.99	2.11	28.33
G247	9.78	5.39	1.00	6.52	33.57
G248	6.67	4.40	1.00	3.43	30.13
G249	5.64	4.01	0.74	2.11	30.03
G250	3.46	2.46	0.33	1.32	19.46
G251	14.91	6.08	0.55	10.39	29.46
G252	12.55	5.70	0.65	8.32	30.65

Grid	**PM_{10} Kg/Day**	**$PM_{2.5}$ Kg/Day**	**SO_2 Kg/Day**	**NOx Kg/Day**	**CO Kg/Day**
G253	9.08	6.48	2.48	3.53	36.06
G254	1114.06	312.51	11.84	555.42	660.63
G255	111.81	40.72	11.50	21.53	102.71
G256	61.67	32.07	15.34	23.19	112.57
G257	1185.31	333.37	11.11	559.11	658.64
G258	221.06	66.25	9.97	38.24	118.54
G259	367.26	108.57	11.28	113.76	217.58
G260	86.00	39.86	14.26	19.68	135.44
G261	1231.02	351.75	127.98	646.04	791.17
G262	299.94	83.25	1.26	135.74	169.78
G263	5.52	4.03	0.68	2.96	25.98
G264	10.04	7.26	1.99	4.59	44.20
G265	5.72	4.06	0.99	2.11	28.33
G266	8.20	4.84	0.99	4.49	31.07
G267	7.81	4.72	0.99	4.11	30.63
G268	5.72	4.06	0.99	2.11	28.33
G269	5.93	4.13	0.99	2.34	28.60
G270	41.82	14.57	1.77	21.56	50.76
G271	189.52	55.41	1.83	102.00	136.79
G272	7.57	4.72	1.00	4.68	31.83
G273	5.72	4.06	0.99	2.11	28.33
G274	5.72	4.06	0.98	2.11	28.45
G275	86.16	60.37	107.06	33.84	225.37
G276	23.19	9.14	1.39	14.71	38.00
G277	5.60	3.92	0.91	2.48	25.75
G278	25.35	16.38	7.71	10.69	74.12
G279	12830.52	3510.54	15023.22	17601.30	694.57
G280	40.55	22.26	9.95	10.62	87.07
G281	39.80	21.99	9.95	9.42	85.78
G282	442.25	127.86	13.12	152.55	233.12
G283	2185.59	614.75	15.34	1125.09	1260.47
G284	930.49	290.55	21.93	443.72	752.03
G285	507.91	186.79	36.08	263.26	575.97
G286	1059.75	315.94	10.00	682.30	904.13
G287	3712.48	2507.40	2452.57	1911.64	574.25
G288	24103.94	16019.33	3766.36	1885.20	1247.65
G289	897.80	401.74	8928.96	10340.77	275.85
G290	6621.01	2944.31	66501.20	77002.53	1777.24
G291	9.10	5.13	1.00	5.36	32.01
G292	5.72	4.06	0.99	2.11	28.33
G293	5.72	4.06	0.99	2.11	28.33
G294	6.89	4.91	1.76	2.47	30.33

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G295	5.72	4.06	0.99	2.11	28.33
G296	491.64	140.00	1.18	283.42	333.16
G297	150.11	42.83	1.03	68.52	96.42
G298	5.72	4.06	0.99	2.11	28.33
G299	5.72	4.06	0.99	2.11	28.33
G300	66.27	26.11	3.83	51.01	108.59
G301	14.15	9.59	4.46	4.84	45.98
G302	35.53	15.27	3.54	22.91	62.86
G303	1728.09	488.44	2251.45	2623.24	166.98
G304	4996.49	2277.91	8733.18	9054.88	360.52
G305	29.27	20.23	10.72	10.85	88.93
G306	60.29	27.98	11.49	11.75	91.46
G307	86.57	37.09	15.34	15.66	103.74
G308	2053.99	578.70	45.88	871.23	1041.90
G309	2531.09	708.13	20.83	1272.54	1493.30
G310	2641.94	746.10	19.83	1369.17	1634.64
G311	824.14	277.02	21.16	615.95	979.52
G312	297.20	162.05	706.68	567.58	743.52
G313	816.73	567.36	359.37	276.42	297.99
G314	2867.35	1427.25	2209.94	1259.59	831.91
G315	20.04	8.12	1.36	8.41	31.95
G316	11.63	6.94	2.62	6.31	35.69
G317	5.72	4.06	0.99	2.11	28.33
G318	5.72	4.06	0.99	2.11	28.33
G319	5.72	4.06	0.99	2.11	28.33
G320	7.00	4.45	0.99	3.22	29.56
G321	9.51	5.21	1.00	5.39	31.99
G322	348.67	96.57	1.86	158.58	190.39
G323	292.71	80.97	1.08	132.46	161.98
G324	16.92	7.53	1.81	2.83	33.37
G325	68.00	24.40	1.17	45.69	97.99
G326	25.33	17.94	9.40	8.86	80.98
G327	26.66	18.96	9.95	9.38	85.74
G328	26.64	18.96	9.95	9.36	85.72
G329	26.82	19.01	9.95	9.54	85.93
G330	267.67	153.19	223.54	98.34	510.16
G331	466.52	135.46	11.60	191.16	271.01
G332	428.83	121.35	12.32	117.76	194.29
G333	2790.02	724.24	764.53	1034.17	943.67
G334	1157.53	337.14	29.30	522.09	696.73
G335	826.98	304.87	62.49	675.49	1049.40
G336	1329.70	494.42	118.72	845.09	1506.63

Grid	**PM_{10} Kg/Day**	**$PM_{2.5}$ Kg/Day**	**SO_2 Kg/Day**	**NOx Kg/Day**	**CO Kg/Day**
G337	1303.11	525.19	148.80	822.41	1674.07
G338	1151.95	441.09	130.60	712.05	1200.36
G339	686.05	243.39	53.72	355.10	649.11
G340	235.82	66.25	1.78	106.51	138.35
G341	372.12	108.06	9.49	169.91	218.96
G342	60.90	20.26	3.91	21.74	52.59
G343	5.41	3.84	0.88	2.01	27.24
G344	5.72	4.06	0.99	2.11	28.33
G345	5.72	4.06	0.99	2.11	28.33
G346	10.97	5.65	1.00	6.66	33.39
G347	7.28	4.42	0.99	2.11	28.33
G348	310.42	87.08	1.33	142.22	183.38
G349	369.35	117.20	3.48	209.73	366.79
G350	336.88	114.79	9.73	206.63	386.12
G351	25.03	16.21	8.11	7.63	69.83
G352	28.08	19.30	9.95	9.54	85.89
G353	26.66	18.96	9.95	9.39	85.75
G354	26.74	18.99	9.95	9.46	85.84
G355	191.06	133.12	222.76	73.32	484.62
G356	38.40	22.41	9.96	18.35	95.61
G357	37.75	22.23	9.96	18.01	95.22
G358	120.89	79.51	116.36	49.79	294.44
G359	541.85	157.53	15.70	187.65	291.12
G360	60.90	43.68	25.09	23.59	167.89
G361	103.53	49.42	19.73	42.16	161.25
G362	106.72	54.77	19.98	44.44	214.53
G363	1256.33	571.42	31892.74	36877.57	2846.05
G364	394.13	224.79	826.06	763.69	143.86
G365	495.43	213.22	4394.96	5122.21	180.01
G366	20.86	7.33	1.18	1.92	24.61
G367	430.80	118.15	3.61	188.89	220.55
G368	389.49	104.55	3.58	140.02	164.86
G369	77.46	22.57	1.35	27.90	51.42
G370	45.86	13.00	0.57	5.19	28.01
G371	58.94	15.77	0.60	1.80	24.55
G372	259.59	176.95	320.15	97.90	626.44
G373	211.13	65.26	3.93	72.33	169.40
G374	1969.86	571.69	10.80	1102.91	1394.02
G375	355.69	137.26	18.85	213.67	531.16
G376	12.48	8.02	3.74	3.82	36.70
G377	17.62	10.24	4.08	5.11	47.52
G378	25.77	16.84	8.26	8.05	74.63

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G379	26.68	18.97	9.95	9.40	85.76
G380	27.19	19.13	9.95	9.91	86.38
G381	26.82	19.01	9.95	9.54	85.94
G382	26.73	18.99	9.95	9.46	85.83
G383	432.60	303.17	541.97	168.92	1082.56
G384	121.03	45.03	11.52	48.90	128.97
G385	20.43	14.60	7.21	7.79	67.52
G386	39.72	16.17	4.41	6.21	50.96
G387	72.32	23.87	4.62	6.33	52.22
G388	129.63	44.81	11.50	22.48	104.40
G389	13.73	6.16	1.33	2.31	28.67
G390	5.61	3.36	0.41	2.94	24.20
G391	4.07	2.89	0.41	1.56	22.61
G392	8.96	4.37	0.42	5.73	27.18
G393	5.24	3.74	1.18	1.92	24.61
G394	352.83	95.48	1.28	150.49	175.56
G395	466.18	125.28	2.08	190.38	217.97
G396	338.40	125.89	107.04	123.67	315.83
G397	1454.94	383.82	7.23	520.02	551.10
G398	1261.64	340.77	8.22	511.59	568.39
G399	457.20	149.13	18.36	215.09	404.70
G400	236.12	86.12	15.98	91.73	265.73
G401	1.24	0.87	0.12	0.50	6.72
G402	4.64	3.07	0.41	2.13	23.29
G403	4.21	2.99	0.47	1.61	23.01
G404	21.06	14.98	7.59	7.44	70.09
G405	26.81	19.01	9.95	9.54	85.93
G406	26.64	18.96	9.95	9.36	85.72
G407	27.25	19.11	9.95	9.56	85.96
G408	26.76	18.99	9.95	9.48	85.86
G409	261.13	81.84	10.02	116.52	196.71
G410	34.39	21.37	9.96	16.85	94.60
G411	33.89	21.22	9.96	16.37	94.03
G412	62.47	29.79	9.97	40.13	122.16
G413	107.55	40.64	7.93	74.46	151.30
G414	14.58	6.19	0.51	11.25	34.63
G415	11.47	5.12	0.42	8.17	30.23
G416	6.58	3.65	0.41	3.80	25.20
G417	42.61	14.54	0.44	34.42	58.62
G418	4.07	2.89	0.41	1.56	22.61
G419	30.92	10.99	0.43	25.52	50.25
G420	197.80	88.99	1947.92	2256.60	73.87

Grid	PM_{10} Kg/Day	$PM_{2.5}$ Kg/Day	SO_2 Kg/Day	NOx Kg/Day	CO Kg/Day
G421	169.51	118.81	213.55	67.07	435.60
G422	161.30	50.38	2.66	61.14	136.49
G423	295.52	99.72	13.44	133.63	287.98
G424	196.57	76.97	14.38	83.53	274.33
G425	22.73	16.01	3.90	11.76	96.77
G426	0.06	0.04	0.01	0.02	0.34
G427	4.18	2.74	0.37	2.02	20.60
G428	4.59	3.06	0.41	2.08	23.23
G429	6.37	4.52	1.37	2.38	29.00
G430	17.40	12.38	6.04	6.16	59.87
G431	16.21	11.49	5.50	5.82	56.39
G432	10.35	7.36	3.07	3.73	40.16
G433	26.04	18.46	9.62	9.27	83.75
G434	82.06	33.33	9.96	28.88	105.47
G435	413.09	123.92	10.07	197.87	288.35
G436	33.15	20.38	9.25	17.05	90.81
G437	24.89	14.19	5.43	14.71	66.47
G438	90.45	29.26	0.47	81.45	117.44
G439	5.44	3.30	0.41	2.78	24.02
G440	33.29	11.70	0.43	27.64	52.68
G441	23.33	8.70	0.43	18.75	42.43
G442	50.63	16.96	0.44	41.25	66.10
G443	58.16	19.21	0.45	49.84	78.29
G444	13.55	5.75	0.42	10.02	32.36
G445	4.07	2.89	0.41	1.56	22.61
G446	93.22	65.54	108.02	37.74	257.15
G447	204.46	57.65	2.53	30.85	104.84
G448	221.12	69.20	3.50	86.40	190.78
G449	94.73	36.31	4.04	43.10	140.52
G450	0.52	0.33	0.07	0.29	1.90
G452	1.77	1.18	0.16	0.81	8.95
G453	9.61	4.40	0.41	4.18	25.71
G454	7.69	5.47	2.72	2.75	28.74
G455	4.52	3.00	0.41	1.62	22.68
G456	4.37	2.98	0.41	1.86	22.96
G457	4.07	2.89	0.41	1.56	22.61
G458	7.93	5.54	1.94	3.05	33.01
G459	26.64	18.90	9.89	9.46	85.48
G460	108.75	40.74	9.97	44.17	120.94
G461	24.21	17.21	8.90	8.56	78.84
G462	5.33	3.76	0.92	2.04	26.03
G463	15.13	6.27	0.42	11.90	34.88

Grid	PM$_{10}$ Kg/Day	PM$_{2.5}$ Kg/Day	SO$_2$ Kg/Day	NOx Kg/Day	CO Kg/Day
G464	4.07	2.89	0.41	1.56	22.61
G465	4.07	2.89	0.41	1.56	22.61
G466	6.53	3.63	0.41	3.76	25.14
G467	225.65	69.72	0.55	199.33	250.69
G468	22.31	8.39	0.42	17.84	41.38
G469	4.07	2.89	0.41	1.56	22.61
G470	4.07	2.89	0.41	1.56	22.61
G471	9.90	6.40	1.09	3.87	41.62
G472	72.70	26.38	2.59	18.31	94.42
G473	70.21	25.62	2.59	15.99	91.77
G474	35.39	12.13	0.93	13.49	39.75
G477	0.03	0.02	0.00	0.01	0.15
G478	4.15	2.50	0.31	2.16	18.06
G479	4.53	3.01	0.41	1.76	22.85
G480	4.07	2.89	0.41	1.56	22.61
G481	4.12	2.91	0.41	1.61	22.67
G482	4.25	2.95	0.41	1.74	22.82
G483	18.89	12.98	6.20	7.24	62.05
G484	107.83	75.80	116.35	41.27	285.09
G485	160.13	87.55	114.36	63.81	296.24
G486	19.34	11.48	4.60	8.47	54.22
G487	4.72	3.35	0.69	1.78	24.42
G488	17.28	6.93	0.42	13.90	37.26
G489	4.07	2.89	0.41	1.56	22.61
G490	4.07	2.89	0.41	1.56	22.61
G491	23.61	8.78	0.43	19.00	42.72
G492	11.37	5.09	0.42	8.07	30.12
G493	34.07	11.94	0.43	28.34	53.49
G494	12.14	5.32	0.42	8.77	30.89
G495	3.93	2.79	0.40	1.51	21.85
G496	84.59	59.26	106.73	33.23	218.29
G497	307.41	195.18	321.61	125.02	700.34
G498	16.13	10.23	1.86	7.62	61.64
G499	0.06	0.04	0.01	0.03	0.26
G503	0.39	0.28	0.04	0.15	2.17
G504	5.22	3.06	0.36	3.03	21.81
G505	5.33	3.29	0.41	2.84	24.12
G506	5.70	3.41	0.41	3.20	24.55
G507	4.36	2.98	0.41	1.85	22.95
G508	15.47	10.79	5.00	5.86	53.61
G509	346.10	242.26	433.02	135.65	867.19
G510	6.85	4.05	0.71	3.91	27.04

Grid	**PM_{10} Kg/Day**	**$PM_{2.5}$ Kg/Day**	**SO_2 Kg/Day**	**NOx Kg/Day**	**CO Kg/Day**
G511	207.26	57.40	0.47	94.10	118.13
G512	4.07	2.89	0.41	1.56	22.61
G513	13.41	5.75	0.42	10.29	32.97
G514	6.46	3.62	0.41	3.80	25.26
G515	21.37	8.11	0.42	17.00	40.42
G516	12.31	5.38	0.42	8.91	31.09
G517	4.07	2.89	0.41	1.56	22.61
G518	8.68	4.23	0.40	5.74	26.80
G519	3.06	2.18	0.29	1.20	17.11
G520	26.69	9.28	0.29	22.32	41.17
G521	7.43	3.47	0.28	5.12	21.34
G522	32.33	11.55	0.54	26.21	50.74
G523	14.60	4.71	0.12	12.28	17.57
G529	0.55	0.39	0.06	0.21	3.07
G530	3.53	2.50	0.36	1.35	19.59
G531	4.33	2.97	0.41	1.83	22.92
G532	11.34	5.07	0.42	7.26	29.36
G533	7.88	3.97	0.41	3.80	25.26
G534	330.60	230.82	426.03	130.98	822.18
G535	81.47	27.62	0.47	79.73	115.10
G536	95.39	28.18	0.45	51.70	76.72
G537	23.79	8.12	0.42	9.92	31.07
G538	14.93	6.22	0.42	11.72	34.66
G539	17.04	6.86	0.42	13.69	37.00
G540	47.53	16.07	0.44	41.06	68.62
G541	4.07	2.89	0.41	1.56	22.61
G542	4.07	2.89	0.41	1.56	22.61
G543	8.39	3.99	0.35	5.69	24.80
G544	3.00	2.14	0.28	1.18	16.79
G545	9.98	4.24	0.28	7.40	23.97
G546	77.32	24.86	1.05	67.05	92.02
G547	0.37	0.26	0.03	0.14	2.06
G555	0.31	0.22	0.03	0.12	1.69
G556	3.46	2.20	0.29	1.73	16.38
G557	4.54	3.04	0.41	2.04	23.18
G558	4.07	2.89	0.41	1.56	22.61
G559	61.43	21.22	0.45	59.49	91.15
G560	24.11	9.26	0.43	21.45	46.14
G561	4.26	2.93	0.41	1.56	22.61
G562	82.26	23.64	0.43	34.70	56.15
G563	15.98	6.52	0.42	12.46	35.55
G564	4.07	2.89	0.41	1.56	22.61

Grid	**PM_{10} Kg/Day**	**$PM_{2.5}$ Kg/Day**	**SO_2 Kg/Day**	**NOx Kg/Day**	**CO Kg/Day**
G565	14.71	6.12	0.42	11.22	33.87
G566	3.98	2.83	0.40	1.53	22.14
G567	4.07	2.89	0.41	1.56	22.61
G568	8.26	3.88	0.33	5.65	23.96
G569	3.00	2.14	0.28	1.18	16.78
G570	6.06	2.65	0.19	4.40	15.40
G571	0.20	0.14	0.02	0.08	1.14
G581	0.00	0.00	0.00	0.00	0.01
G582	1.39	0.92	0.12	0.65	6.92
G583	3.19	2.26	0.32	1.22	17.72
G584	64.61	22.24	0.46	62.74	94.96
G585	4.98	3.10	0.41	1.56	22.61
G586	7.49	4.25	1.18	1.92	24.61
G587	122.88	35.15	1.22	53.97	79.58
G588	31.85	13.20	3.51	22.84	54.12
G589	4.07	2.89	0.41	1.56	22.61
G590	9.18	4.44	0.42	6.20	28.02
G591	12.19	4.94	0.29	9.49	26.74
G592	9.57	4.34	0.35	6.84	26.11
G593	6.71	3.21	0.29	4.52	20.02
G594	0.84	0.60	0.08	0.33	4.70
G609	12.07	4.12	0.08	11.76	17.38
G610	2.39	1.44	0.19	0.71	10.32
G611	165.07	115.59	213.08	64.85	413.63
G612	94.20	26.64	0.35	42.60	60.89
G613	10.16	4.46	0.35	7.64	26.19
G614	5.45	2.95	0.32	3.35	20.10
G615	2.66	1.89	0.27	1.02	14.80
G616	12.20	4.30	0.15	10.31	19.55
G617	1.99	0.80	0.04	1.56	4.26