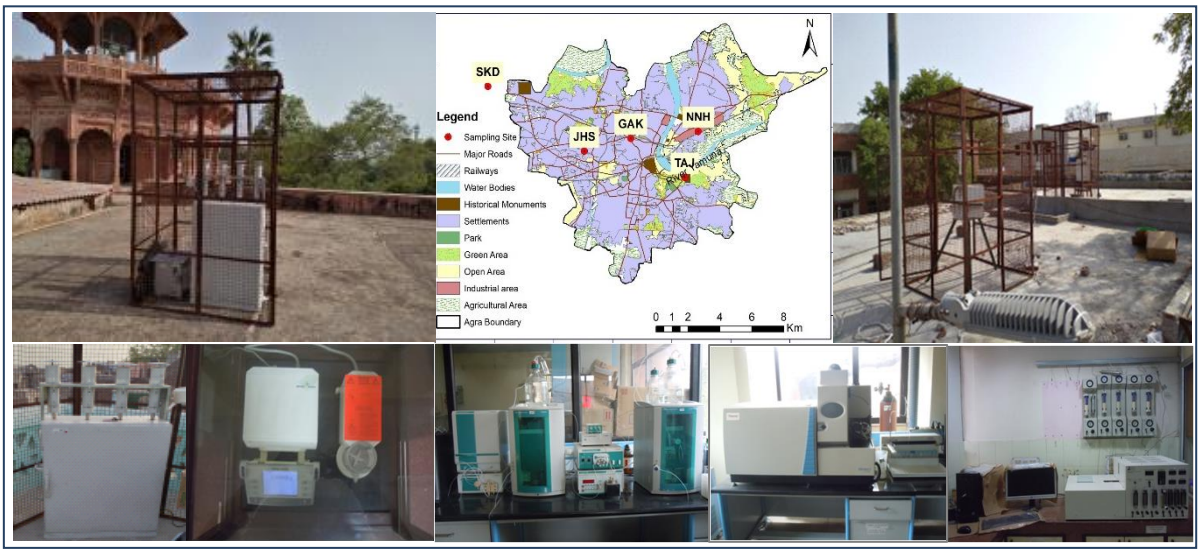
Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in the City of Agra

(Final Report)

Submitted to

Uttar Pradesh Pollution Control Board, Lucknow



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Executive Summary

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

To address the air pollution issues of the City of Agra, the Uttar Pradesh Pollution Control Board (UPPCB), Lucknow has sponsored the study "Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Agra City" to the Indian Institute of Technology Kanpur (IITK). The main objectives of the study are preparation of emission inventory, air quality monitoring in two seasons, chemical composition of PM_{10} and $PM_{2.5}$, apportionment of sources to ambient air quality, trend analysis in historical air quality data and development of pollution control plan for the city. The project has the following specific objectives:

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

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

Air Quality: Measurements

A total of five air quality sampling sites were categorized based on the predominant land-use pattern (Table 1) to cover varying land-uses prevailing in the city. PM_{10} (particulate matter of size less than or equal to 10 µm diameter), $PM_{2.5}$ (particulate matter of size less than or equal

to 2.5 µm diameter), SO_2, NO_2, VOCs (volatile organic compounds), OC (organic carbon), EC (elemental carbon), ions, elements and PAHs (polyaromatic hydrocarbons) were considered for sampling and analysis. The air quality sampling was conducted for two seasons: winter (2018-19) and summer (2019).

Table 1: Description of Sampling Sites of Agra

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	Ghatia Azam Khan Gate	GAK	Commercial	Vehicles, road dust, garbage burning, restaurants, DG sets
2.	Nunhai Industrial Area	NNH	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning
3.	Jaipur House	JHS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
4.	Sikandra	SKD	Residential cum commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
5.	Taj Mahal	TAJ	Sensitive Zone	Vehicles, road dust, garbage/MSW burning

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

- Particulate pollution is the main concern in the city where PM_{10} levels are 2.0 – 4.2 times higher than the national air quality standards in the winter season and 1.5 – 2.0 times in the summer season. $PM_{2.5}$ levels are 2.5 – 5.0 times higher than the national standard in the winter season. In the summer, $PM_{2.5}$ levels marginally exceed (4 – 12%) the national standards.

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

PM_{10} (winter and summer)

The overall average concentration of PM_{10} was 334±84 µg/m^3 in winter and 183±21 µg/m^3 in summer against the acceptable level of 100 µg/m^3. The highest levels were observed at GAK (423±100 µg/m^3) and lowest at JHS (201±48 µg/m^3) in winter. In summer, the highest levels were at JHS and the lowest at TAJ.

In winter, crustal component (Si + Al + Fe + Ca) accounts for about 12% (much less compared to 26% in summer). This suggests soil and road dust have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.25 (of the fraction of crustal component), which suggests the crustal source contributes consistently even in winter, though much less than in summer.

In summer, the crustal component (Si + Al + Fe + Ca) accounts for about 26% of total PM_{10}. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.07 (of the fraction of crustal component), which suggests the sources are consistent and uniform all around the city, forming a layer that envelops the city. GAK and SKD have the highest crustal fraction (around 28% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Agra 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 other important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for about 27% of total PM_{10} and combustion-related total carbon (TC = EC + OC) accounts for about 23%; both fractions of secondary particles and combustion-related carbons have increased in winter and account for 50% of PM_{10}.

In summer, the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$) account for 12% of total PM_{10} and combustion-related total carbon (EC+OC) accounts for about 13%.

The Cl^- content in PM_{10} in winter is consistent and varies between 6 – 10%, an indicator of the burning of municipal and plastic solid waste (MSW); poly vinyl chloride (PVC) is a significant part of MSW. The highest Cl^- content is observed at NNH at 38 µg/m^3 compared to the overall city level of 25 µg/m^3. The Cl^- content in PM_{10} in summer is

consistent at 2.8 – 4.4%. The high level at NNH signifies some local burning of waste either in industrial processes or as means of disposal of solid waste.

The zinc (Zn) levels are highly variable, with city average of 1.85 µg/m^3 in winter and 0.34 µg/m^3 in summer. The maximum levels were at NNH (5.18 µg/m^3) in winter and GAK (0.60 µg/m^3) in summer. The high levels of Zn signify the industrial emissions and tyre wear and burning in the city.

$PM_{2.5}$ (winter and summer)

The overall average concentration of $PM_{2.5}$ is 238±58 µg/m^3 in winter and 67±5 µg/m^3 in summer and against the acceptable level of 60 µg/m^3. The highest levels are observed at GAK (304±77 µg/m^3) and lowest at JHS (153±47 µg/m^3) in winter. In summer, the highest levels were at NNH and the lowest at TAJ.

The crustal component (Si + Al + Fe + Ca) accounts for about 9% in winter and 12% in summer in total $PM_{2.5}$. The CV is about 0.21 in summer, which suggests the source is consistent all around the city though relatively small in winter.

In winter, the important components are the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 31% of total $PM_{2.5}$ and combustion-related total carbon (EC+OC) accounts for 24%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 55%. The highest TC level was observed at GAK (about 90 µg/m^3) and secondary particles at NNH (about 92 µg/m^3).

In summer, the secondary particles account for 23% and combustion-related total carbon (EC+OC) accounts for 27%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 50%. The highest TC was at JHS and secondary particles at NNH.

The Cl^- content in $PM_{2.5}$ was consistent in the winter and summer seasons and varied between 5 – 12%, which is an indicator of the burning of MSW. This is relatively lower in summer than in winter.

Potassium levels

In general, potassium levels are high and variable for PM_{10} (3.0 to 10.2 µg/m^3) both in winter and summer. In $PM_{2.5}$ potassium levels in winter vary between 3.1 to 5.1 µg/m^3. In general, the potassium levels are 2.0 µg/m^3 in urban areas. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.40) show day-to-day variation both in summer and winter.

NO_2 levels

NO_2 levels in winter are higher than those in summer at all sites and the levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 levels were at NNH, 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 (less than 6.0 µg/m^3) in the city were well within the air quality standard.

General inferences

in winter, $PM_{2.5}$ and EC levels are significantly higher at all sites. PM_{10}, OC and NO_2 are high at most sites (except JHS). Levels of $PM_{2.5}$ and EC are statistically higher (at all locations) in winter than in summer. In general, air pollution levels in ambient air (barring traffic intersections) are uniform across the city, suggesting the entire city is stressed under high pollution; in a relative sense, GAK is most polluted, followed by NNH and TAJ. JHS is the least polluted area.

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

Total PAH levels (17 compounds; particulate phase) in winter are high (relatively to levels generally seen in urban areas) at 207 ng/m^3 and B(a)P at 1.73 ng/m^3 (annual standard is 1.0 ng/m^3); the comparison with the annual standard is not advisable due to different averaging times. However, PAH levels in summer drop significantly to about

19 ng/m^3. The highest PAH levels were observed at GAK (winter 344 ng/m^3 and in summer 25 ng/m^3).

The total BTX levels are slightly higher in summer (10.5± 3.5 µg/m^3) than in winter (9.0± 7.6 µg/m^3). The emission rate is expected to be high in summer due to higher temperature, but not much difference in the concentration is due to better dispersion and large ventilation coefficient in summer. The benzene generally meets the annual national standard (5 µg/m^3) in winter (except at GAK) and in summer (except at SKD).

In a broad sense, the air quality is worse in winter than in summer as air contains a much larger contribution of combustion products in winter than in summer.

Emission Inventory

Emission inventory (EI) is a necessity for planning air pollution control activities. The overall baseline EI for Agra City is developed for the base year 2019. The pollutant-wise contribution is shown in Figures 1 to 5. The spatial distribution of pollutant emissions from all sources is presented in Figure 6.

The total PM_{10} emission load in the city is estimated to be 36 t/d. The top four contributors to PM_{10} emissions are road dust (82%), vehicles (5%), hotels (4%) and domestic fuel (3%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to obtain the desired air quality.

$PM_{2.5}$ emission load in the city is estimated to be 14 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (68%), vehicles (12%), domestic fuel burning (7%) and hotels (5%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

NO_x emissions load in the city is estimated to be 19 t/d. Nearly 86% of emissions are attributed to vehicles followed by industries (4%) and domestic (3%). Vehicular emissions occur at ground level, probably making it the most important sources. Apart from being a pollutant, NOx is an important component in the formation of secondary particles (nitrates) and ozone. NOx from vehicles and industry are potential sources for controlling NOx emissions.

SO_2 emission load in the city is estimated to be 1 t/d. Vehicular emission accounts for 33% of the total emission. Domestic fuel burning contributes 22% followed by hotels and restaurants (21%) and industries (17%).

The estimated CO emission is about 38 t/d. Nearly 59% emission of CO is from vehicles, followed by hotels (20%), domestic fuel (13%) and MSW burning (7%).

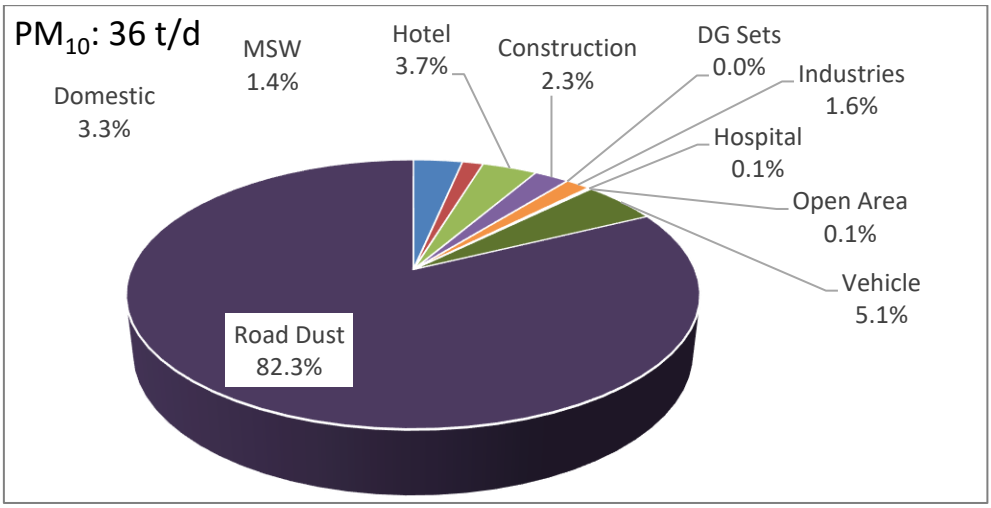

Figure 1: PM_{10} Emission Load of Different Sources in Agra

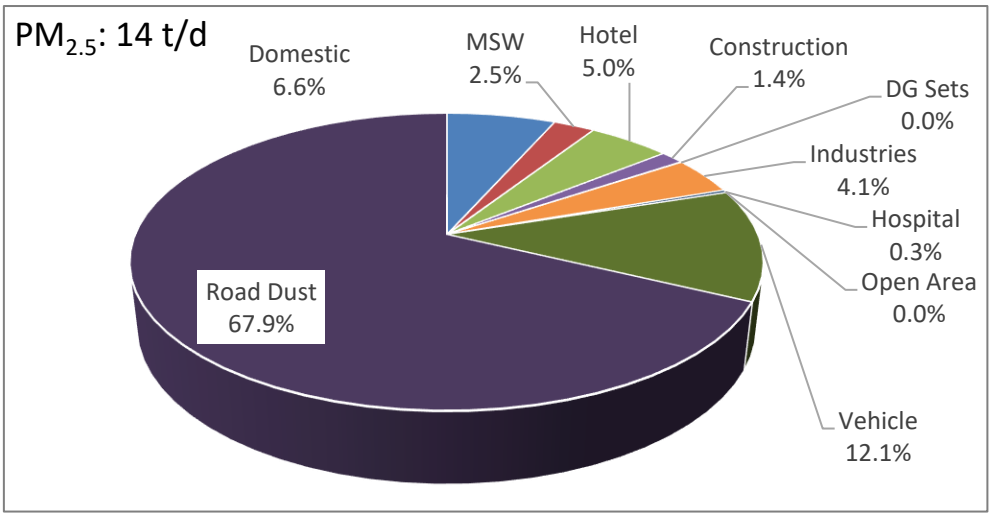

Figure 2: $PM_{2.5}$ Emission Load of Different Sources in Agra

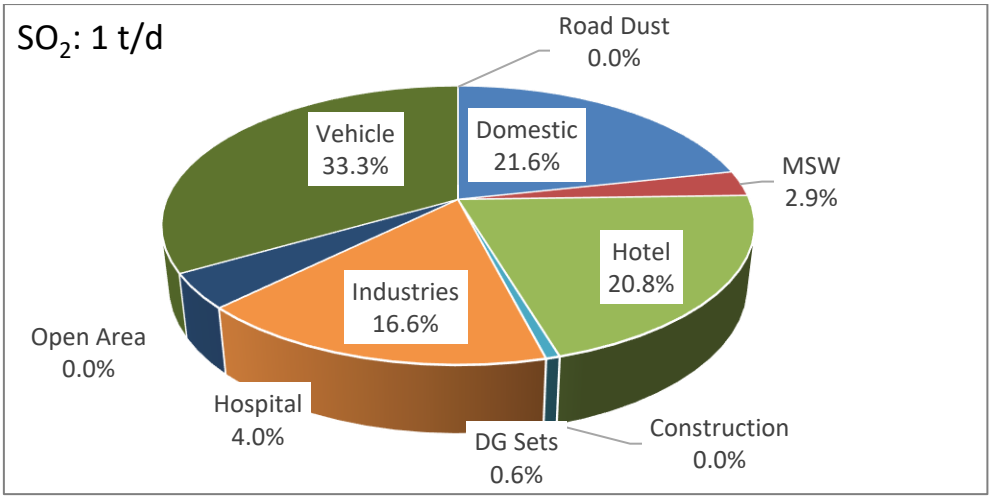

Figure 3: SO_2 Emission Load of Different Sources in Agra

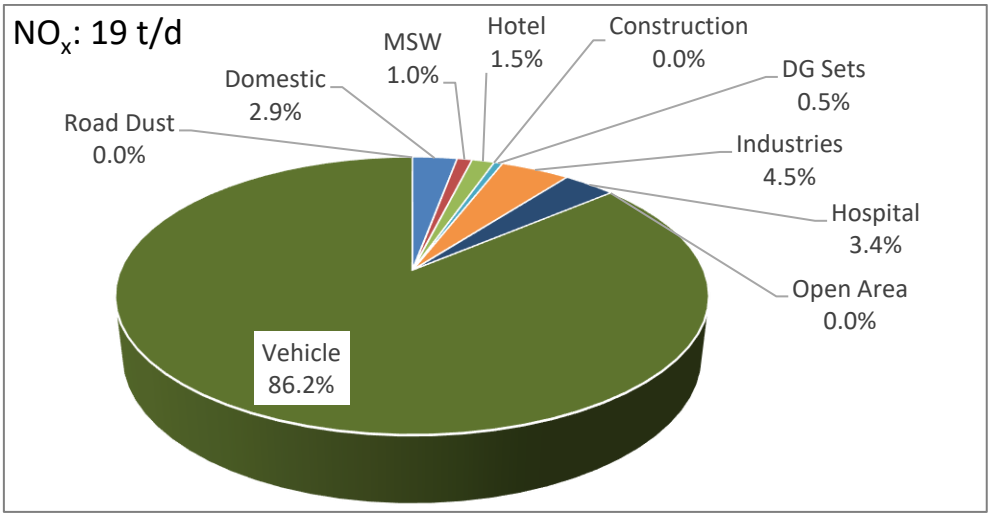

Figure 4: NOx Emission Load of Different Sources in Agra

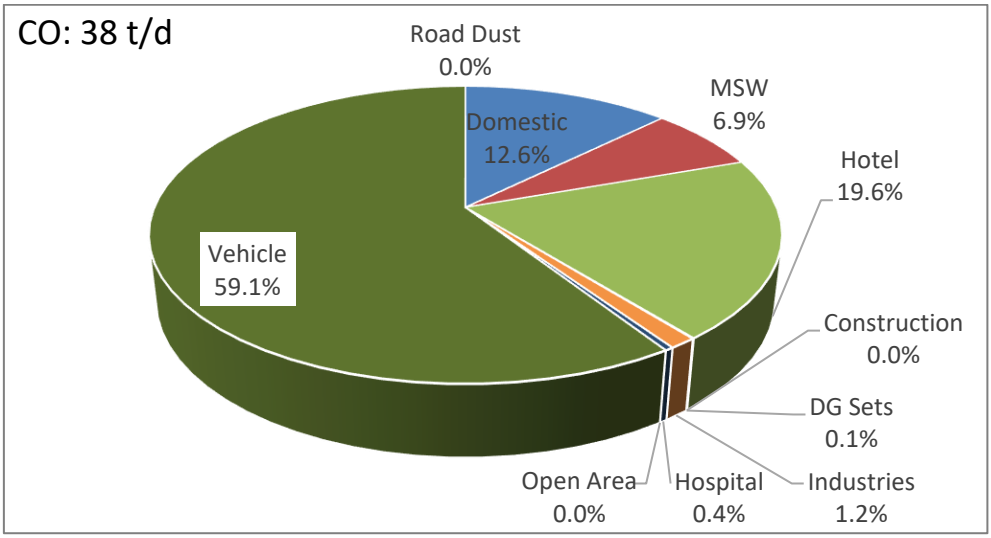

Figure 5: CO Emission Load Contribution of Different Sources in Agra

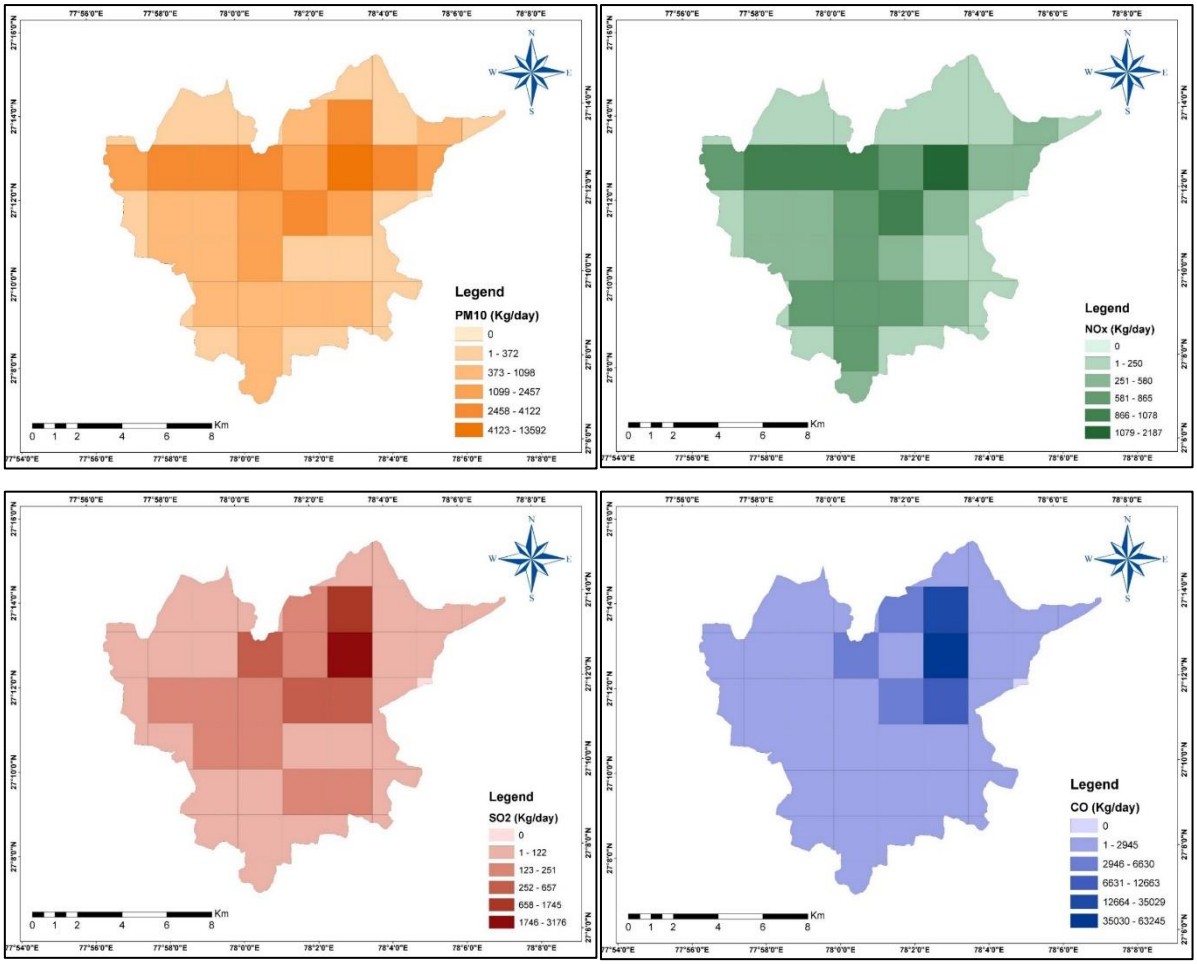

Figure 6: Spatial Distribution of PM_{10}, NO_x, SO_2 and CO Emissions in Agra City

Air Quality Modeling for Source Apportionment: Receptor Modeling

Based on the PMF5.0 (positive matrix factorization model; USEPA 5.0 version) modeling results (Figure 7) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for the preparation of action plan. The important inferences are:

- The sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter.
    - In winter, % contribution of PM_{10} – $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: vehicles (20 – 23%; include all vehicles powered by gasoline, diesel, CNG, DGs and LPG uses), secondary inorganic aerosol (SIA) (19 – 19%), soil and road dust (18 – 14%), coal and fly ash (15 – 16%; includes ash from burning of residual oil), MSW burning (12 - 14%), biomass burning (6 – 8%), industrial (7

– 6%; also includes the contribution from trye wear and burning) and construction material (3 – 1%). It is noteworthy, in winter, major sources for PM_{10} and $PM_{2.5}$ are generally the same.

- In summer, % contribution of PM_{10} - $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: soil and road dust (41 – 35%), coal and fly ash (31 - 23%; includes burning of residual oil), vehicles (8 – 14%; include all vehicles powered by gasoline, diesel, CNG, DGs and LPG uses), biomass burning (7 - 10%), MSW burning (4 – 7%), SIA (4 - 6%), industrial (2 – 3%) and construction material (3 – 3%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

- The most consistent sources for PM_{10} and $PM_{2.5}$ in both seasons are soil and road dust (including construction material), SIA, vehicles that includes a small contribution (less than 0.1%) of DG sets, coal and fly ash and industry. The other sources on average may contribute more (or less), but their contributions are variable from one day to another.
- The consistent presence of biomass and MSW burning (in $PM_{2.5}$) at all sites envelops the entire region.
- In summer, soil and road dust, coal and fly ash and construction activities contribute 75% to PM_{10} and 60% to $PM_{2.5}$. It is observed that in summer, the atmosphere looks brownish indicating presence of large amounts of dust. In winter, the contributions of coal and fly ash, soil and road dust and construction material reduce significantly both in PM_{10} and $PM_{2.5}$ (by 36 and 31%) when winds are low and prevalent atmospheric conditions are calm.
- Coal and fly ash (includes residual oil) are the second most contributor to PM_{10} and $PM_{2.5}$ in summer. High and consistent contributions suggest the combustion of coal in different sectors, i.e., hotel and restaurants, industries, and brick kilns within the 50 km radius of the city.
- The contribution of the biomass burning in summer is at 10% (for $PM_{2.5}$) and 7% (for PM_{10}) and in winter at 8% (for PM_{10}) and 6% (for $PM_{2.5}$). The presence of sizeable biomass is consistent in winter and summer, indicates that local sources present in Agra and nearby areas.

- The contribution of MSW burning is higher in the winter than in the summer. In winter, contribution of MSW burning is very high at GAK in PM_{10} – $PM_{2.5}$ (24 – 25%) followed by SKD (13 – 12%) and NNH (10 – 13%). In summer, contribution of MSW burning varied 2 - 6% in PM_{10} and 6 - 8% in $PM_{2.5.}$ Nagpure et al. (2015) have reported number MSW burning incidents (39 − 202 /km^2/day) and estimated that 223 tons/day of MSW was burnt (~24% of 923 tons/day of generated MSW).
- The Industrial contribution (including the contribution of tyre wear and burning) is high in winter months (7 − 6%) in PM_{10} − $PM_{2.5}$. The maximum contribution was in winter at NNH; $PM_{2.5}$ (18%) and PM_{10} (20%)

Directions for PM control

- Soil and road dust

  In summer, this source contributes about 41% to PM_{10}. The silt load on most of the roads is very high and silt can become airborne with the movement of vehicles. The estimated PM_{10} emission from road dust is about 30 tons per day. Similarly, soil from the open fields gets airborne in summer. The potential control options can be sweeping and watering of roads, better construction and maintenance, growing plants, grass etc., to prevent re-suspension of dust.

- Coal and fly ash

  In summer, coal and fly ash contribute about 31% to PM_{10} and 23% to $PM_{2.5}$. It is a fugitive non-point source. Fly ash emissions from hotels, restaurants, tandoors, brick kilns (within 50 km radius) and some unauthorized use of coal cause emissions and require better housekeeping, fly ash collection, disposal and adoption of improved zigzag technologies in brick kilns. It is important to note that a significant part of fly ash may include construction-related emissions as the cement has up to 35% of fly ash. The construction work of smart city and metro is another potential source of fly ash. It is learnt that there are about 40 registered coal depots in the city. A rough estimate of sale of coal could be 25-30 tonnes per day. A smaller contribution of a large power plant of 665 MW in a 100 km radius is possible in the city depending on meteorology.

- Vehicular pollution

  This source is the third-largest source and most consistently contributing source to PM_{10} and $PM_{2.5}$ in winter and summer. Various control options include the implementation of BS-VI, introduction of electric and hybrid vehicles, traffic planning and restriction of movement of vehicles, retro-fitment in diesel exhaust, improvement in public transport etc. These options are further discussed in Chapter 6.

- 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. All biomass burning in Agra should be banned and strictly implemented.

- MSW burning

  One of the reasons for the burning of MSW/plastic waste is the lack of infrastructure for timely collection of MSW and people conveniently burn or it may smolder slowly for a long time. In this regard, infrastructure for collection and disposal of MSW has to improve and the burning of MSW should be completely banned.

- Secondary particles

  What are the sources of secondary particles, the major contributors to Agra's PM? 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, refineries and brick kilns. However, the 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 a significant mass of $PM_{2.5}$ (about 34%) and any particulate control strategy should also include control of primary precursor gases.

- Industrial sources

  The industrial unit in the NNH must comply with the norms notified by the government. There might be some unauthorized industries in the surroundings of

JHS and TAJ that must be enforced to close such units. At SKD and JHS, a significant contribution might be from trye wear and burning as there were many open tyre burning incidents seen in the Transport Nagar during the monitoring period situated between these sites. The burning of tyres must stop and be collected at the authorized centers for proper disposal.

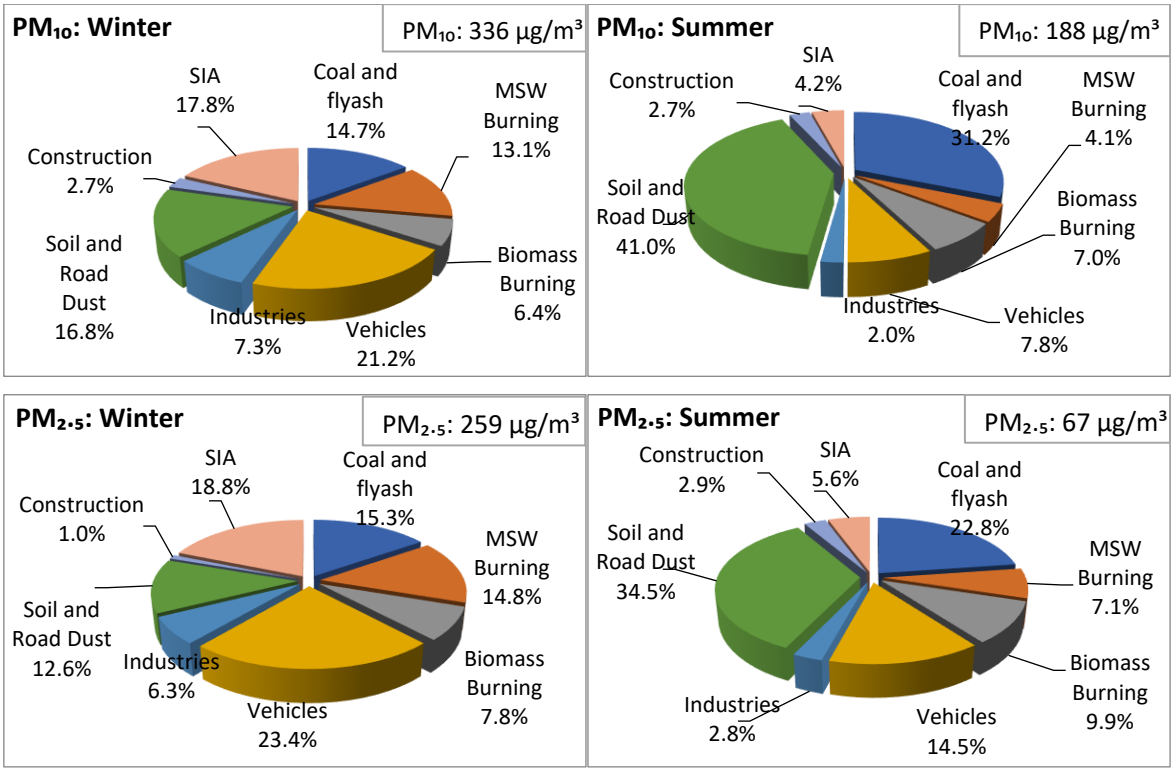

Figure 7: City level source contribution to ambient air PM_{10} and $PM_{2.5}$ levels

Dispersion Air Quality Modeling

The WRF (Weather Research and Forecasting) model for meteorology parameters was validated against the measured data from continuous air quality monitoring station, Agra. The model performed satisfactorily with a statistically significant correlation coefficient ($r > 0.15$; n = 8750) for predicting wind speeds in February, March, April, and June. In general, the wind speeds were overestimated by a factor of 1.2. Furthermore, the time-series plot of observed hourly ambient temperature levels with modeled levels showed a good agreement ($r = 0.86$; n=2900) for all months of 2018. It was concluded that the WRF model provided realistic meteorology and the WRF outputs were used in air quality modeling.

The $PM_{2.5}$ modeled and observed levels over one year showed a good linear association (r = 0.64 n= 350). It is noteworthy that the model under-predicts the concentration by a factor of

more than 2.0. The probable reasons for underestimation by the model are (i) over prediction of wind speed by the WRF model, (ii) inventory may be incomplete and some source may be missing, and (iii) there is a substantial contribution of sources present outside the Agra City. Since the linear association in the model-computed and observed levels is very good, the model could be used for decision-making and useful insights.

The deficit in the model and measured (referred to as unidentified) $PM_{2.5}$ levels were highest during the January-February and November-December months. Also, it is worth noting that there was a sudden spike in these unidentified concentrations of $PM_{2.5}$ during the first week of November. This episodic spike in the unidentified $PM_{2.5}$ concentrations with an average value was 119 $\mu g/m^3$ in the city can be attributed to the influx from the surrounding regions outside the city.

For better insight, Agra city was divided into five regions (Figure 8). Regions 2 (north) and 3 (north-east) showed the highest $PM_{2.5}$ levels. Regions 2 and 3 are densely populated, and region 2 also has a major industrial area. The highest 24-hour average $PM_{2.5}$ concentrations were computed for the winter and summer months of the year 2018. It was observed that region 3 had the 24-hour peak $PM_{2.5}$ concentration at 298 ± 62 $\mu g/m^3$ followed by region 2 with 175 ± 63 $\mu g/m^3$, and region 1 with 140 ± 44 $\mu g/m^3$. Region 5 (south-east) had the least 24-hour average $PM_{2.5}$ at 76 ± 24 $\mu g/m^3$. The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winter (November to February) while the lowest during the summer (May to June).

The highest contributing source was road dust in all the regions followed by vehicular sources in regions 1, 4 and 5. Industrial sources were the second-highest contributors in regions 2 and 3. Domestic sources were the third-highest contributors in regions 1 and 4, where the residential population is concentrated, and industry in region 5.

Overall city-level contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic (7%), and hotels and restaurants (3%).

From the annual average plots, it is seen that $PM_{2.5}$ envelops a large area that gets elongated along the prevailing wind direction (N-E) within the Agra City (Figure 9). The annual standard for $PM_{2.5}$ concentration (40 $\mu g/m^3$) is exceeded in the area surrounding the National Highway 19 (NH-19).

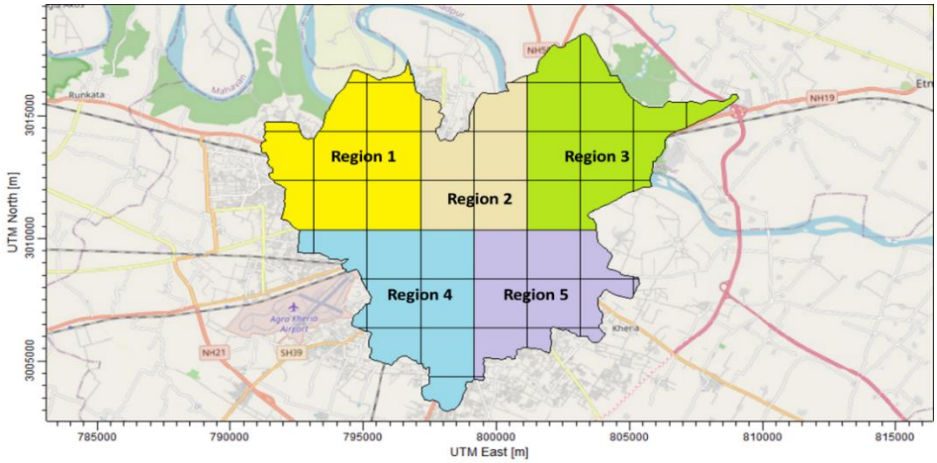

Figure 8: Demarcation of Five Regions for Impact Assessment

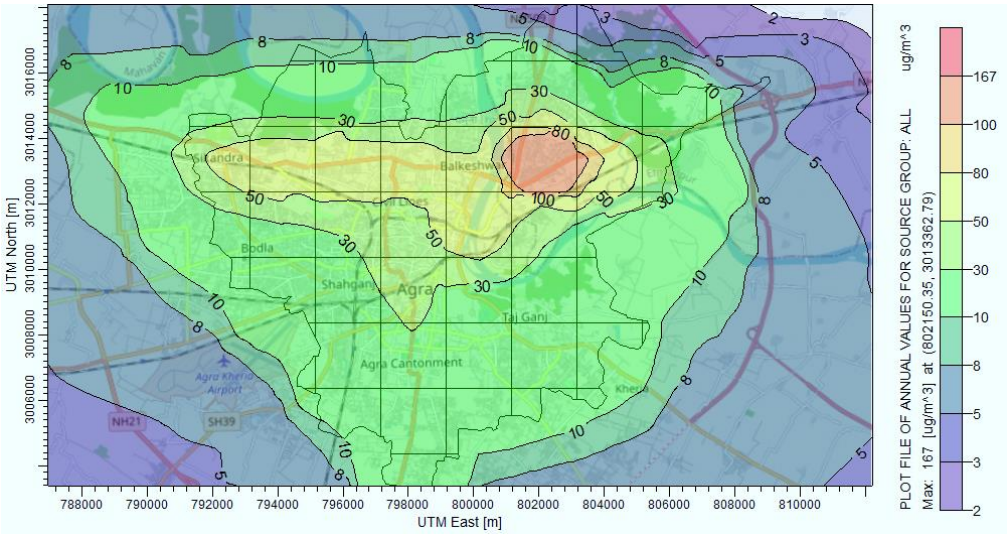

Figure 9: Annual Average $PM_{2.5}$ Levels from All Sources in the City

Control Options and Actions

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

Table 2: Control Options and Action Plan for City of Agra

Source	Control Action	Responsible authorities/agencies	Time Frame
Hotels/ Restaurants	Restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances.	Agra Municipal Corporation	1 year
	Link Commercial license to clean fuel	Agra Municipal Corporation, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 years
	Ash/residue from the tandoor and other activities should not be disposed near the roadside.	Agra Municipal Corporations	1 year
Domestic Sector	LPG to all. Slums are using wood as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	By 2030, city may plan to shift to electric cooking or PNG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped.	Agra Municipal Corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Agra Municipal Corporation, UPPCB	
	Desilting and cleaning of municipal drains	Agra Municipal Corporation	
	Waste burning in Industrial area should be stopped.	UPSIDC, UPPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Agra Municipal Corporation	
	Sensitize people and media through workshops and literature distribution.	Agra Municipal Corporation, UPPCB and NGO	
Construction and Demolition	Wet suppression	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, Urban Development Department, PWD	Immediate

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

Source	Control Action	Responsible authorities/agencies	Time Frame
Road Dust	The silt load in Agra varies from 7.4 to 55.1 g/m^2. The silt load on each road should be reduced under 3 gm/m^2. Regular vacuum sweeping should be done on the road having silt load above 3 gm/$m^{2.}$	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	Immediate
	Convert unpaved roads to paved roads. Maintain pothole free roads.	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake greening of open areas, community places, schools and housing societies.	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, State Forest Department, PWD	
	vacuum assisted sweeping carried out four times in a month, this will reduce road dust emission by 71%	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	
Vehicles	Diesel vehicle entering the city should be equipped with DPF which will bring a reduction of 40% in emissions (This option must be explored once Bharat stage VI fuel is available.)	State Transportation Department	3 years
	Industries must be encouraged to use Bharat stage VI vehicles for transportation of raw and finished products	Industrial Associations	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel driven vehicles.	Transport Department	2 years

Source	Control Action	Responsible authorities/agencies	Time Frame
	Introduction of cleaner fuels (CNG/ LPG) for vehicles.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Agra.	Transport Department, Traffic Police, Agra, NHAI, Toll agencies	Immediate
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. Buses should be CNG or Electric.	Transport Department, Agra City Transport Services Pvt. Ltd	1 year
	Make a time-bound plan for dipper penetration of electric vehicles (EVs), parallelly effort must be made for charging infrastructure including facilities for swiping the batteries. As a first step, two and three-wheeler should be considered for EVs.	The state of Uttar Pradesh and Agra administration	1 year
	Depot spaces should be rationalized to ensure more efficient utilization. Multi-modal, multi-use bus depots to be developed to provide high-class bus services and terminal experience to passengers. Should include well-equipped maintenance workshops. Charging stations shall be set-up.	Transport Department, Agra City Transport Services Pvt. Ltd	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Agra Development Authority, Agra Municipal Corporation, Agra City Transport Services Pvt. Ltd	1 year
	Ensure integration of existing metro system with bus services.	Agra Metro Rail Corporation, Agra Development Authority, Agra Municipal Corporation, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year

Source	Control Action	Responsible authorities/agencies	Time Frame
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year
	IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year
	Movement of materials (raw and product) should be allowed between 10 PM to 5 AM.	Transport Department, Agra Development Authority, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	UPPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and UPPCB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, UPSIDC, Industries Department, UPPCB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, UPSIDC, UPPCB	Immediate
	Follow best practices to minimize fugitive emission within the industry premises, all leakages within the industry should be controlled	Industrial Associations, UPSIDC, UPPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, UPSIDC, UPPCB	
	Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, UPPCB	2 years
	Diesel Generator Sets		

Source	Control Action	Responsible authorities/agencies	Time Frame
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, JVVNL	2 years
	The standby power from DG sets should also be on clean fuel. All industrial DG sets which have gas connections should shift to gas-based generators. The battery-backed UPS/inverters should be considered for other commercial places and hospitals. Renewable energy-based generation should be encouraged.	Industrial Associations, Agra Municipal Corporations, Agra	2 years
Decongestion of Roads at high traffic areas	Strict action on roadside encroachment.	Agra Development Authority, Agra Municipal Corporations, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	6 months
	Disciplined Public transport (designate one lane stop).	Agra City Transport Services Pvt. Ltd., Traffic Police, Agra	
	Removal of free parking zone	Agra Development Authority, Agra Municipal Corporation, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	
	Examine existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI, Traffic Police, Agra	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI, Traffic Police, Agra	
	Mechanized multi storey parking at bus stands, railway stations and big commercial areas.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, NHAI, Traffic Police, Agra	

Source	Control Action	Responsible authorities/agencies	Time Frame
	Identify traffic bottleneck intersections and develop smooth traffic plan. For example, Lohamandi, Rakabganj, Kotwali, Tajganj, Hari-parwat are the main bottlenecks for traffic.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, Traffic Police, Agra	
	Parking policy in congestion area (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, NHAI, Traffic Police, Agra	
	Bijli Ghar and Idgah Bus Stand causes extreme congestion and increased emissions and should be decongested at priority. It is recommended that the city should relocate these bus stations to outskirts of the city (Bijli Ghar may be shifted to trans Yamuna and Idgah may be shifted to near to Patholi Village, Jaipur Road).	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, Traffic Police, Agra	
	An outer road from Keetham connects to Gwalior Road. This road may be connected to Agra ring road (connecting Yamuna Expressway and Agra-Lucknow express way); this will restrict the movement (within Agra city) of those vehicles destined to Jaipur or Gwalior. The ring road should further extend to the Agra-Jaipur highway.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI	2-3 years
	There should be a bypass for heavy vehicles and major godowns should be shifted away from the city at outside areas to prevent the movement of heavy vehicles in the city.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI	2-3 years
Mantola and other major Drains	The major drains of city (Mantola Drain, Taj East Drain/ Kolhai Nala, Water Works Drain, Naraich Nala, Bhairo Nala, Nagla Budhi Nala, Anurag Nagar Nala, Peelakhar	Municipal Corporation and Agra Development Authority	2-3 years

Source	Control Action	Responsible authorities/agencies	Time Frame
	Nala) should be covered, diverted fully to wastewater treatment plant of tertiary level and then only discharge in river Yamuna or perhaps recycled. This will remove the problem NH_3, H_2S and smell in the city and Taj Mahal area		
Crematoriums	Electric, or gas-based crematorium should be installed	Municipal Corporation and Agra Development Authority	1-2 years
*The above steps should not only be implemented in Agra municipal limits rather these should be extended to up to at least 25 km beyond the boundary. This will need support from the central government.			

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Acknowledgments

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1 Introduction

1.1 Background

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

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

Since the enactment of the Air Act 1981, air pollution control programs have focused on point and area source emissions, and many areas have benefited from these control programs. Nonetheless, most cities in the country still face continuing particulate non-attainment problems from particles of unknown origin (or those not considered for pollution control) despite the high level of control applied to many point sources. It is in the latter case that an improved understanding of source-receptor linkages is especially needed if cost-effective emission reductions are to be achieved. Determining the sources of airborne particulate matter is a difficult problem because of the complexity of the urban source mix. The problem is often compounded by the predominance of non-ducted and widely distributed area (fugitive) sources and the lack of understanding of the sources of secondary aerosol, their formation and transport.

The advent of receptor modeling and recent developments in the areas of trace element analysis now permit a much more detailed analysis of ambient aerosol samples. By providing detailed information on the sources of the total, fine and inhalable particles, receptor models can play a major role in developing strategies for controlling airborne particulate matter.

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

To address the air pollution issues of the City of Agra, the Uttar Pradesh Pollution Control Board (UPPCB), Lucknow has sponsored the study "Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Agra City" to the Indian Institute of Technology Kanpur (IITK). The main objectives of the study are preparation of emission inventory, air quality monitoring in two seasons, chemical composition of PM_{10} and $PM_{2.5}$, apportionment sources to ambient air quality, trend analysis in historical air quality data.

1.2 General Description of City

1.2.1 Geography and Demography

Agra is a city in the State of Uttar Pradesh situated between the latitude 27.216º - 27.231º N and longitude 77.939º - 78.122º E on the right bank of river Yamuna. Agra is the fourth-most populous city in Uttar Pradesh and 24th in India. Agra has a large number of tourists (0.7 million in 2018-19 (Lok Sabha, 2019) visiting the city because of its various tourist attraction, the most famous of which is the Taj Mahal, a UNESCO World Heritage Sites. In Agra, key business activities are tourism, trade and commerce and local handicraft industries. The manufacturing and fabrication industries sectors in Agra are categorized as leather and footwear, iron foundries, handicrafts, garments, zari and zardosi work, sweets, automobiles, and cold storage.

The population of Agra city is 1,585,704 (as per the 2011 census) and has shown a consistent increase in the past 50 years (Census-India, 2012). The city is governed by Municipal Corporation, which has 100 wards.

1.2.2 Climate

The climate of Agra features a semi-arid climate that borders on a humid subtropical climate. The city features mild winters, hot and dry summers and a monsoon season. Agra has a reputation for being one of the hottest and the coldest towns in India. In summers, the city witnesses a sudden surge in temperature and at times, mercury goes beyond the 46 °C marks in addition to a very high level of humidity. During summer, the daytime temperature hovers around 46-50 °C. Nights are relatively cooler and the temperature lowers to a comfortable 30 °C.

1.2.3 Emission Source Activities

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

1.3 Need for the Study

1.3.1 Air Pollution Levels: Earlier Studies

$PM_{2.5}$ and PM_{10} concentrations varied seasonally with atmospheric processes and the anthropogenic activities in Agra. A few studies on source apportionment of PM levels have been reported in Agra (Kulshrestha et al., 2009; Singh and Sharma, 2012). These studies have employed trace element markers and principal component analysis at a few locations. Kumar and Shukla (Kumar and Shukla, 2017) from long-term (2002 to 2013) measurements at Taj Mahal have reported levels of TSP (total suspended particulate size 100 μm or less; 275 – 376 $\mu g/m^3$), PM_{10} (particulate matter of size 10 μm or less; 133 - 178 $\mu g/m^3$), NO_2 (17 - 23 $\mu g/m^3$)

and SO_2 (4 – 9 μg/m^3) and Bergin et al. (Bergin et al., 2015) have reported $PM_{2.5}$ (particulate matter of size 2.5 μm or less; 60±39 μg/m^3) during the year 2011-2012.

Although Agra 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.

1.4 Objectives and Scope of Work

Objectively the project aims to achieve the following:

- Development of GIS-based gridded (2 km × 2 km resolution) emission inventory for air pollutants (particulate matter equal and less than 10μm diameter (PM_{10}), particulate matter equal and less than 2.5μm diameter ($PM_{2.5}$), sulphur dioxide (SO_2), carbon monoxide (CO), and oxides of nitrogen (NOx) for the base year, 2019.
- 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.
- Compilation and interpretation of ambient air quality data for PM_{10}, $PM_{2.5}$, SO_2, NO_2 and other pollutants being monitored. The time-series analyses will identify trends such as: (i) significant downward, (ii) significant upward, (iii) firstly decreasing and then increasing, (iv) firstly increasing then decreasing (iv) no trend.
- Monitoring of air pollutants PM_{10}, $PM_{2.5}$, SO_2, NO_2, Benzene, Toluene, and Xylene. Analyze collected PM_{10} and $PM_{2.5}$ mass for elemental composition, ions, elemental carbon, organic carbon, PAHs (Di methyl Phthalate (DmP), Acenaphthylene (AcP), Di ethyl Phthalate (DEP), Fluorene (Flu), Phenanthrene (Phe), Anthracene (Ant), Pyrene (Pyr), Butyl benzyl phthalate (BbP), Bis(2-ethylhexyl) adipate (BeA), Benzo(a)anthracene (B(a)A), Chrysene (Chr), Benzo(b)fluoranthene (B(b)F), Benzo(k)fluoranthene (B(k)F), Benzo(a)pyrene (B(a)P), Indeno(1,2,3-cd)pyrene (InP), Dibenzo(a,h)anthracene (D(a,h)A) and Benzo(ghi)perylene (B(ghi)P)).
- Reconstruction of chemical species of PM and assessment for primary and secondary sources of air pollutants.
- Application of receptor model to establish source receptor linkages of PM_{10}, and $PM_{2.5}$ using state-of the-art modeling to arrive at source apportionments at various sampling

sites.

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

1.5 Approach to the Study

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

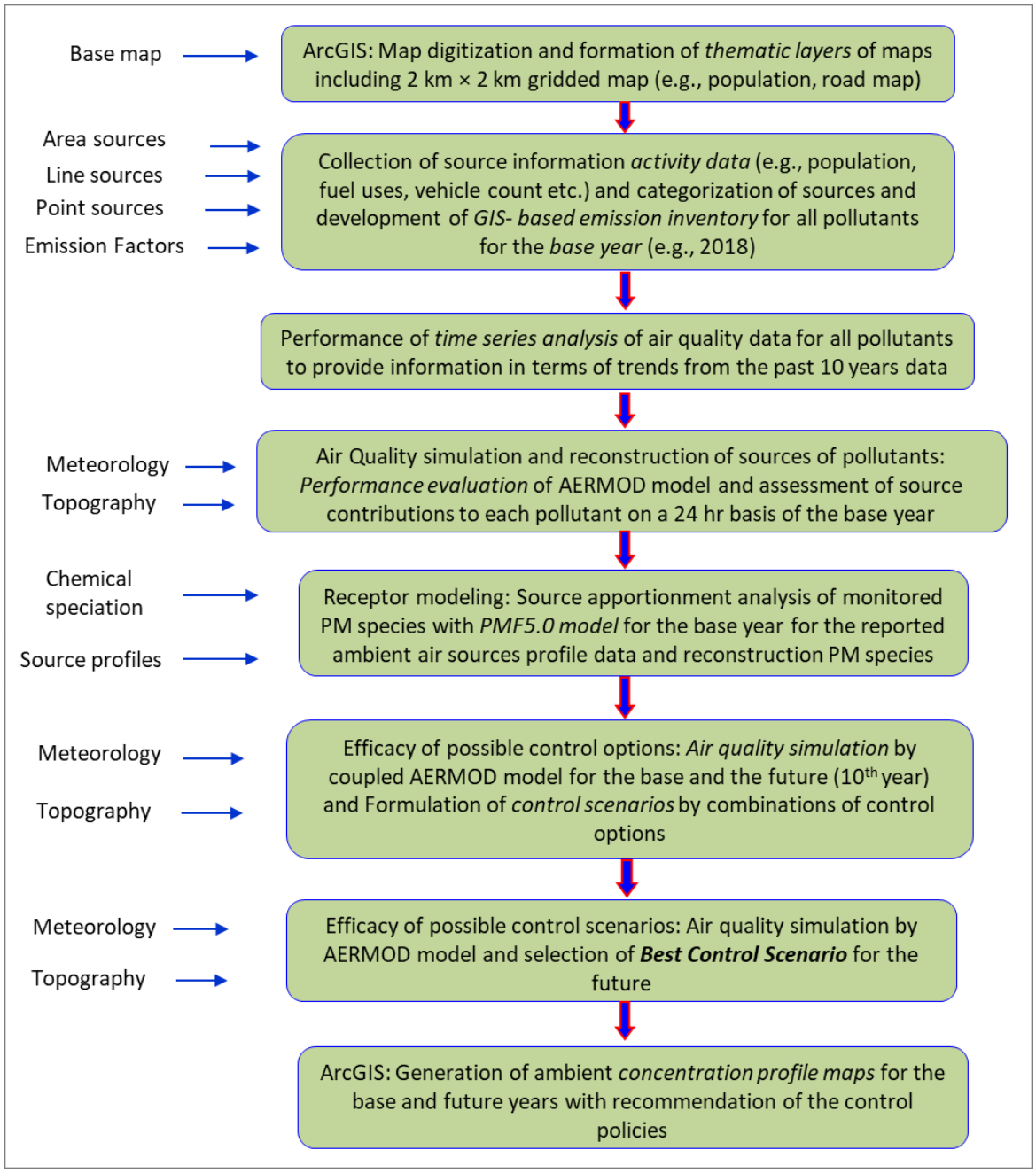


Figure 1.1: Approach to the Study and Major Tasks

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

It was considered appropriate that five sites in a city like Agra 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, mostly public buildings could be better choices as sampling sites. Sites were finalized in consultation with the officials of UPPCB, Agra.

1.5.2 Identification and Grouping of Sources for Emission Inventory

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

1.5.3 Emission Source Profiles

PMF model does not require emission source profiles. Instead, it generates the local profiles based on the matrix database. First, however, a database is developed to find source-specific fingerprint chemical species for assigning the source to the factor generated from the PMF model.

Since for $PM_{2.5}$, Indian or Agra 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). 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); care has been exercised in adopting the profiles for their applicability in the local environment of Agra city. For the sake of uniformity, source profiles for non-vehicular sources for PM_{10} and $PM_{2.5}$ were adopted from USEPA (2006).

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 CMB8.2 (USEPA, 2004) and PMF 5.0 (USEPA, 2014). This model should be able to provide the contribution of each source in the particulate in ambient air. The modeling results should be helpful in identifying major sources for pollution control. It was important to note that along

with source contribution, the model could also provide the associated uncertainties in estimated source contributions.

1.5.5 Application of Dispersion modeling

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

1.6 Report Structure

The overall framework of the study is presented in Figure 1.3. The report is divided into six chapters. The brief descriptions of the chapters are given below.

Chapter 1

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

Chapter 2

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

Chapter 3

This chapter describes the methodology of developing an emission inventory of pollutants at different grids of the city. The chapter also presents and compares the grid-wise results of emission inventory outputs for various pollutants. The contributions of various sources towards

air pollution loads (pollutant-wise) are presented. The QA/QC approaches for emission inventory are also explained in this chapter.

Chapter 4

This chapter presents the methodology used for PMF5.0 modeling for source apportionment study for PM_{10} and $PM_{2.5}$ in the summer and winter. The contribution of various sources at receptor sites and the overall scenario of sources that influences the air quality in the city is presented.

Chapter 5

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

Chapter 6

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

This chapter discusses alternatives for controlling the prominent sources in the city from the management point of view and explains the benefits to be achieved in the future.

2 Air Quality: Measurements, Data Analyses and Inferences

2.1 Introduction

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

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

2.2 Methodology

2.2.1 Site selection and details

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

Table 2.1: Description of Sampling Sites of Agra

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	Ghatia-Azam Khan Gate	GAK	Commercial	Vehicles, road dust, garbage burning, restaurants, DG Sets
2.	Nunhai Industrial Area	NNH	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning
3.	Jaipur House	JHS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
4.	Sikandra	SKD	Residential cum commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
5.	Taj Mahal	TAJ	Sensitive Zone	vehicles, road dust, garbage/MSW burning

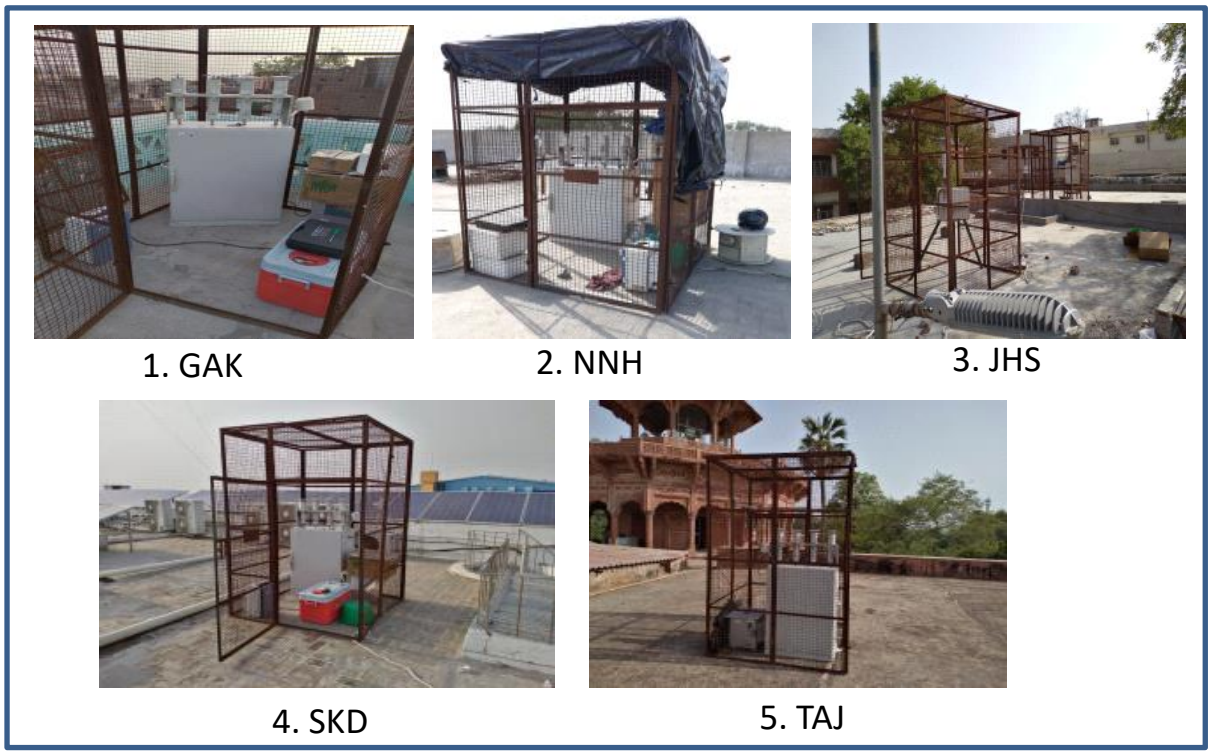


Figure 2.1: Photographs of Sampling Sites showing the physical features

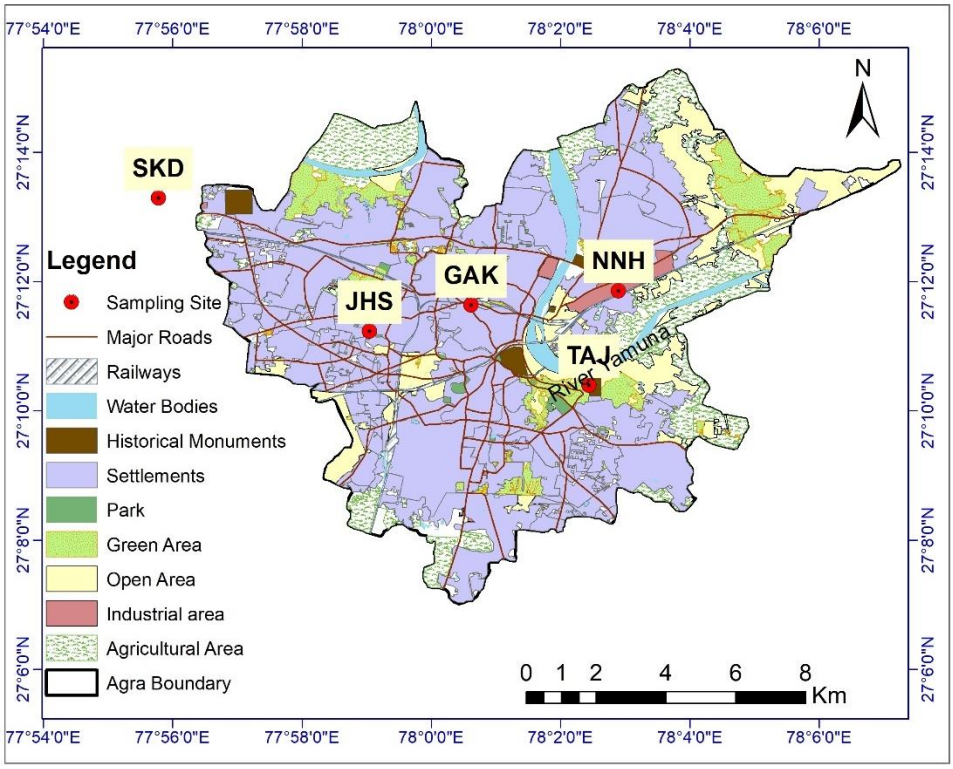


Figure 2.2: Land-use Pattern and Locations of Sampling Sites

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

Table 2.2: Details of Samplers/Analyzers and Methods

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

Table 2.3: Target Chemical components for Characterization of PM

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

2.2.2 Instruments and Accessories

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

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.

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

In addition to conventional pollutants and parameters, this study has analyzed the fraction of organic carbon (OC) and elemental carbon (EC) by thermal optical transmittance (DRI Model

2001A Themal/Optical Carbon Analyzer; Figure 2.3(c)). The explanation of fractions of EC and OC is given in below:

- OC1: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from ambient (~25 °C) to 140 °C.
- OC2: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 140 to 280 °C.
- OC3: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 280 to 480 °C.
- OC4: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 480 to 580 °C.
- EC1: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere at 580 °C.
- EC2: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere from 580 to 740 °C.
- EC3: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere from 740 to 840 °C.
- OP: The carbon evolved from the time that the carrier gas flow is changed from He to 98% He/2% O2 at 580 °C to the time that the laser-measured filter reflectance (OPR) or transmittance (OPT) reaches its initial value. A negative sign is assigned if the laser split occurs before the introduction of O_2.
- OC: OC1 + OC2 + OC3 + OC4 +OP
- EC: EC1 +EC2 + EC3
- Total Carbon (TC): OC1 + OC2 + OC3 + OC4 + EC1 +EC2 + EC3; All carbon evolved from the filter punch between ambient and 840°C under He and 98% He /2% O_2 atmospheres.

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

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

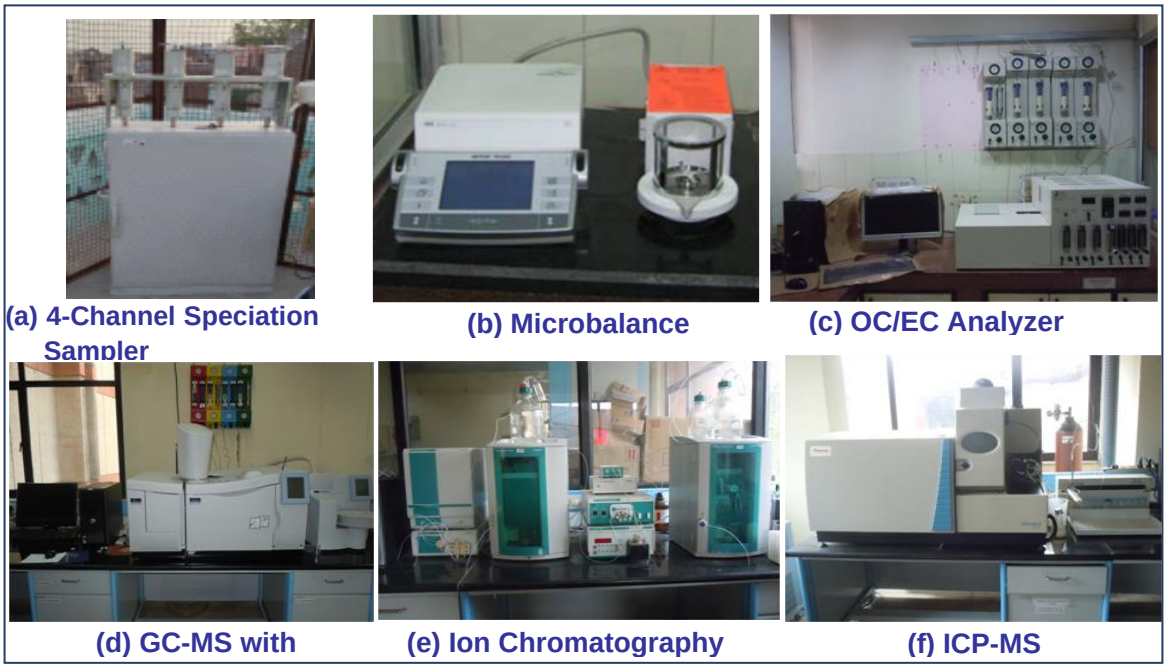


Figure 2.3: Instruments for Sampling and Characterization

2.3 Quality Assurance and Quality Control (QA/QC)

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

For SO_2, and NO_2, analyses were done regularly just after the sampling following the standard operating procedures (SOPs) in the laboratory which was set up at Agra. 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 includes a description of methods, standards to be used, laboratory and field blanks, internal and external standards, development of the database, screening of data, record-keeping including backups, traceability of calculations and standards.

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

Sampling periods: The ambient air sampling has been completed for 20 days at each site for winter (December 05, 2018 - February 18, 2019) and summer (April 08, 2019 - June 30, 2019). The analysis of SO_2 and NO_2 are carried out daily on a regular basis, while gravimetric analysis for particulate matters is done after the completion of the sampling at IIT Kanpur. All efforts were made for the 100% achievement of the sampling and analysis. The overall sampling was achieved over 95% of the time. Efforts were made to sample on extra days to cover the missing days of sampling. The details of sampling days for all pollutants at all monitoring sites are presented in Tables 2.4 to 2.13 for the winter and summer seasons, respectively.

Table 2.4: Sampling days of various pollutants in winter (2018-19) at GAK

GAK, Winter																					
	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec
PM10																					
PM2.5																					
OC																					
EC																					
VOC																					
	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec									
NO2																					
SO2																					

Table 2.5: Sampling days of various pollutants in winter (2018-19) at NNH

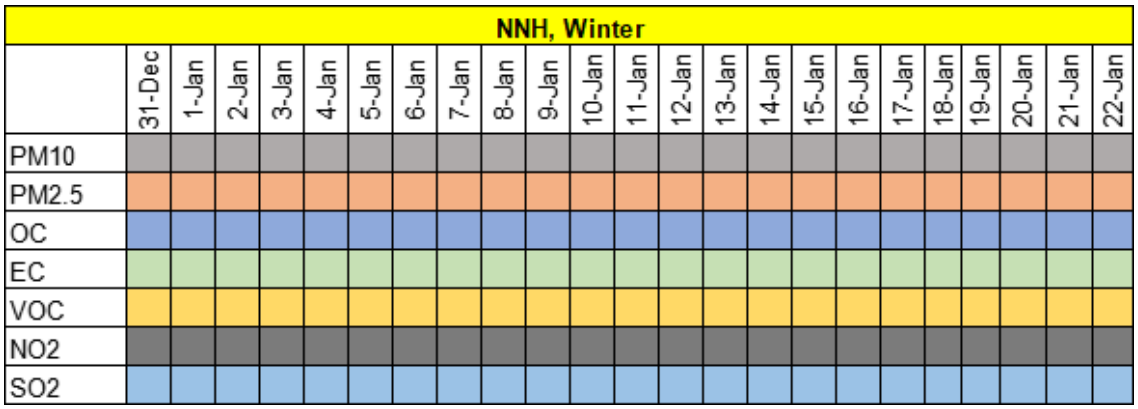


Table 2.6: Sampling days of various pollutants in winter (2018-19) at JHS

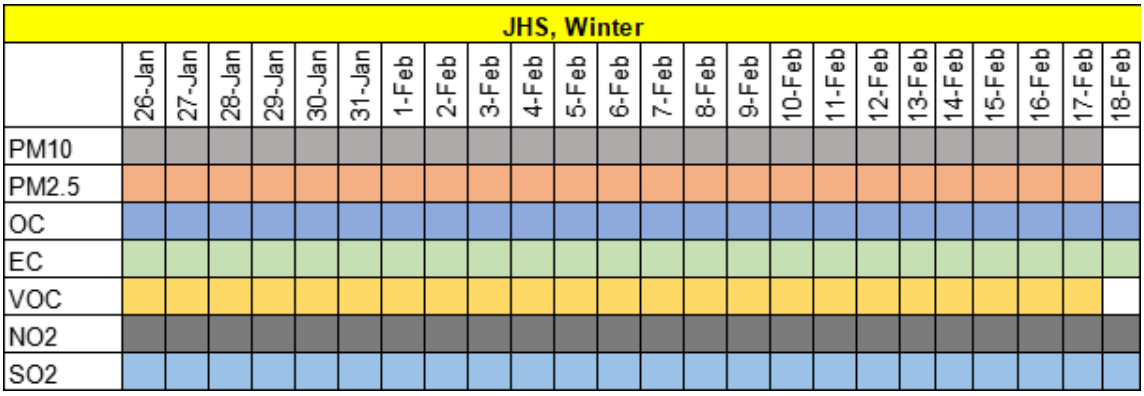


Table 2.7: Sampling days of various pollutants in winter (2018-19) at SKD

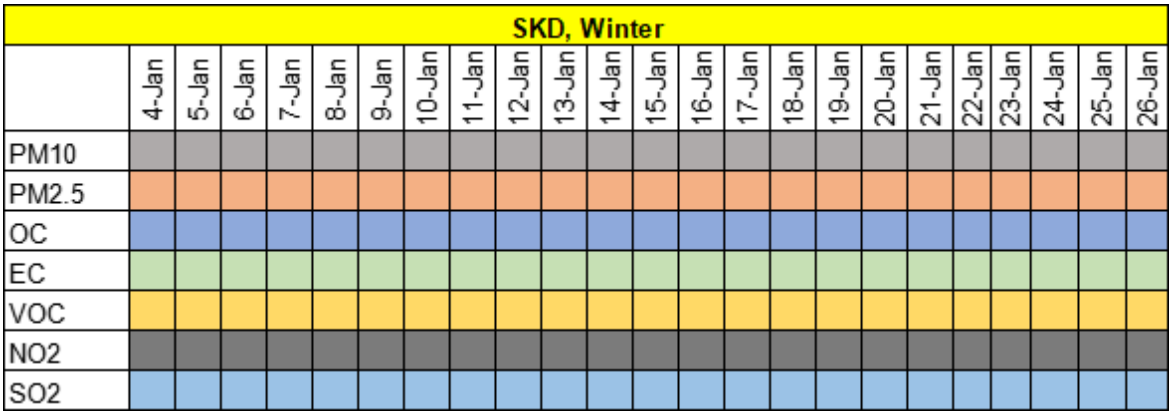


Table 2.8: Sampling days of various pollutants in winter (2018-19) at TAJ

TAJ, Winter																								
	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	
PM10																								
PM2.5																								
OC																								
EC																								
VOC																								
	1-Dec	2-Dec	3-Dec	4-Dec	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	
NO2																								
SO2																								
	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec																
NO2																								
SO2																								

Table 2.9: Sampling days of various pollutants in summer (2019) at GAK

GAK, Summer																					
	8-May	9-May	10-May	11-May	12-May	13-May	14-May	15-May	16-May	17-May	18-May	19-May	20-May	21-May	22-May	23-May	24-May	25-May	26-May	27-May	28-May
PM10																					
PM2.5																					
OC																					
EC																					
VOC																					
NO2																					
SO2																					

Table 2.10: Sampling days of various pollutants in summer (2019) at NNH

NNH, Summer																					
	14-May	15-May	16-May	17-May	18-May	19-May	20-May	21-May	22-May	23-May	24-May	25-May	26-May	27-May	28-May	29-May	30-May	31-May	1-Jun	2-Jun	3-Jun
PM10																					
PM2.5																					
OC																					
EC																					
VOC																					
NO2																					
SO2																					

Table 2.11: Sampling days of various pollutants in summer (2019) at JHS

JHS, Summer	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May	9-May	10-May
PM10																					
PM2.5																					
OC																					
EC																					
VOC																					
NO2																					
SO2																					

Table 2.12: Sampling days of various pollutants in summer (2019) at SKD

SKD, Summer	8-Apr	9-Apr	10-Apr	11-Apr	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	1-May	2-May	3-May
PM10																										
PM2.5																										
OC																										
EC																										
VOC																										
NO2																										
SO2																										

Table 2.13: Sampling days of various pollutants in summer (2019) at TAJ

TAJ, Summer	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun	20-Jun	21-Jun	22-Jun	23-Jun
PM10																							
PM2.5																							
OC																							
EC																							
VOC																							
NO2																							
SO2																							

	24-Jun	25-Jun	26-Jun	27-Jun	28-Jun	29-Jun	30-Jun
NO2							
SO2							

2.4 Ambient Air Quality - Results

2.4.1 Ghatia-Azam Khan Gate (GAK)

The sampling period was December 06 – 31, 2018 for winter and May 8 – 28, 2019 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ at GAK are shown for winter (Figure 2.4) and summer (Figure 2.5). Average levels at this site were: $PM_{2.5}$: 304±77 (winter) and 64±19 µg/m^3 (summer) and PM_{10}: 423±100 (winter) and 179±93 µg/m^3 (summer). In winter, the $PM_{2.5}$ levels were about five times higher than the national air quality standard (NAQS: 60 µg/m^3) and PM_{10} levels were four times higher than the NAQS (100 µg/m^3). In summer, the $PM_{2.5}$ levels generally meet the standards, while PM_{10} is 1.8 times higher than the NAQS.

A statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of PM concentrations is presented in Tables 2.17 – 2.20 for the winter and summer season. In summer, $PM_{2.5}$ levels drop significantly compared to PM_{10} levels that continued to be high in spite of improvement in meteorology and better dispersion. The particle airborne from the soil during dust storms in the dry months of summer can contribute significantly to a coarse fraction (i.e., $PM_{2.5\text{-}10}$).

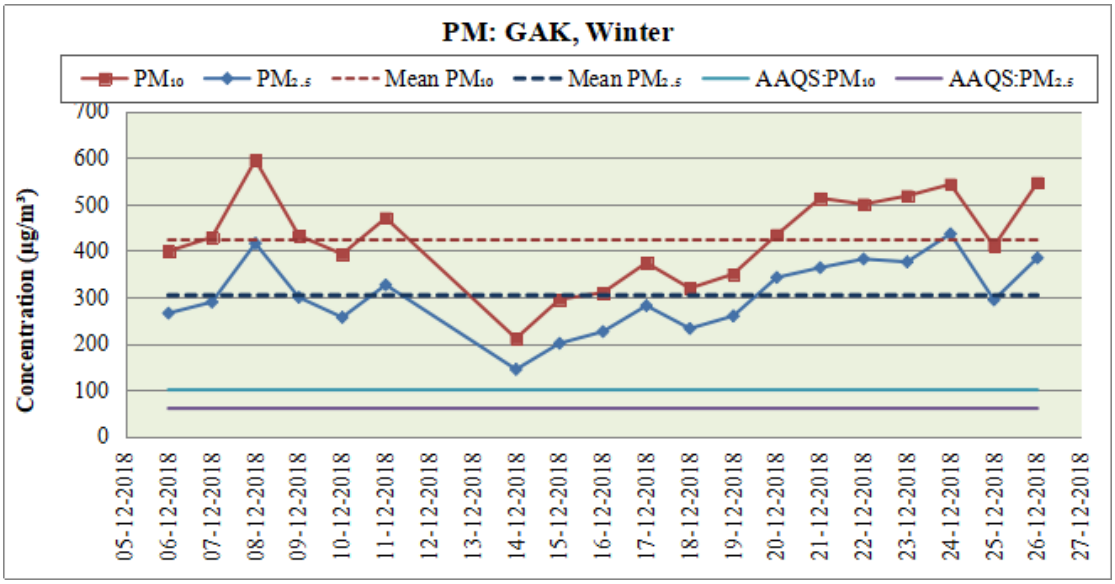


Figure 2.4: PM Concentrations at GAK for Winter Season

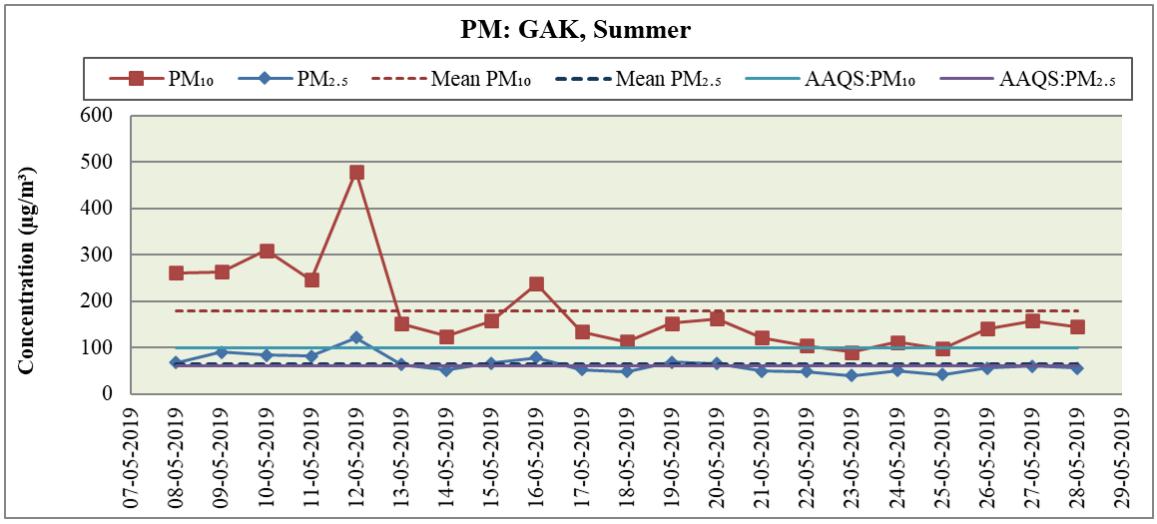


Figure 2.5: PM Concentrations at GAK for Summer Season

2.4.1.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.6) and summer (Figure 2.7) seasons. It was observed that SO_2 concentrations were low (mostly < 5.0 µg/m^3) and meet the air quality standard. NO_2 levels also meet the national standard (80 µg/m^3) with an average of 20 days at 40.8±18.4 µg/m^3 in winter and 20.6±5.4 µg/m^3 in summer season (Table 2.14). The summer concentration of NO_2 dropped dramatically, as does the $PM_{2.5}$ levels. Although NO_2 levels are meeting the standard, it is a matter of concern as NO_2 is largely attributed to vehicular pollution, which is on the rise. Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams or local open burning etc.

The Mean concentrations of benzene, toluene, p-xylene and o-xylene (BTX) are presented in Figure 2.8 and the statistical summary in Table 2.14. The total BTX level is observed 15.1±10.8 µg/m^3 (Benzene: 5.4 and Toluene: 6.4 µg/m^3) in winter and 7.3±0.8 µg/m^3 (Benzene: 2.3 and Toluene: 2.9 µg/m^3) in summer seasons. The BTX levels were higher during summer than in the winter.

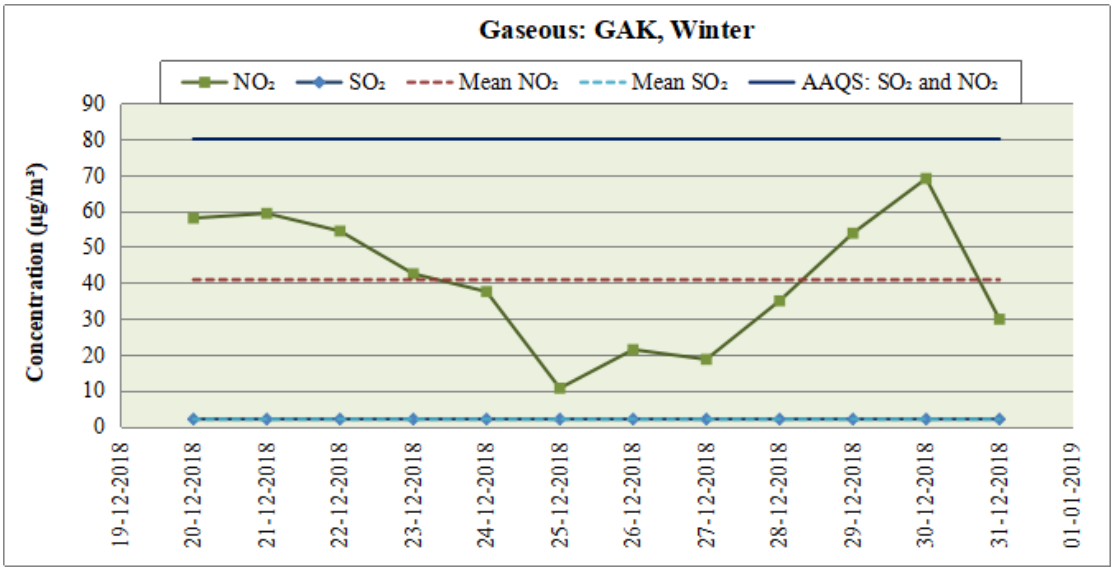


Figure 2.6: SO_2 and NO_2 Concentrations at GAK for Winter Season

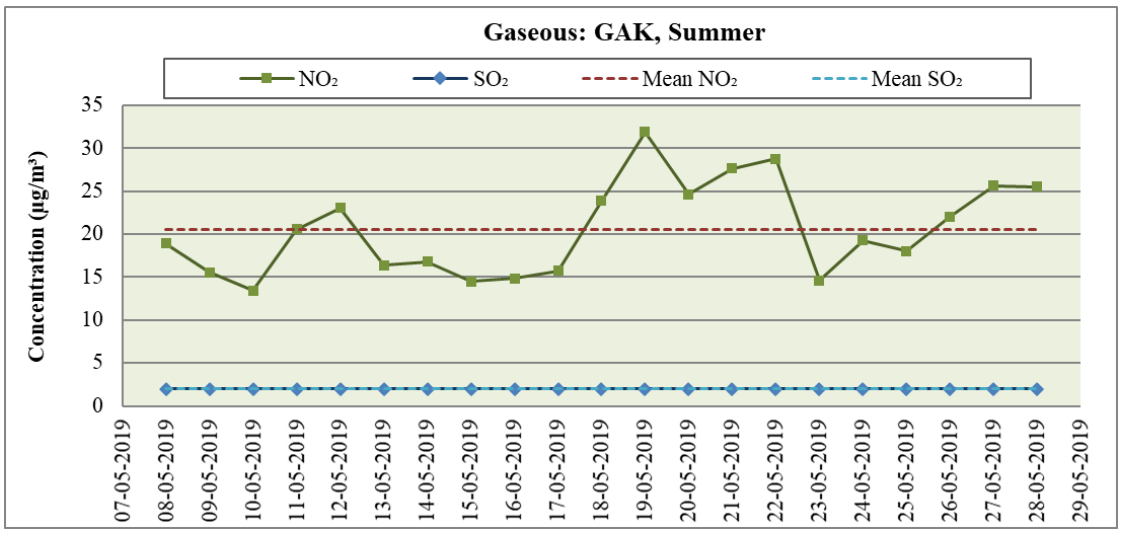


Figure 2.7: SO_2 and NO_2 Concentrations at GAK for Summer Season

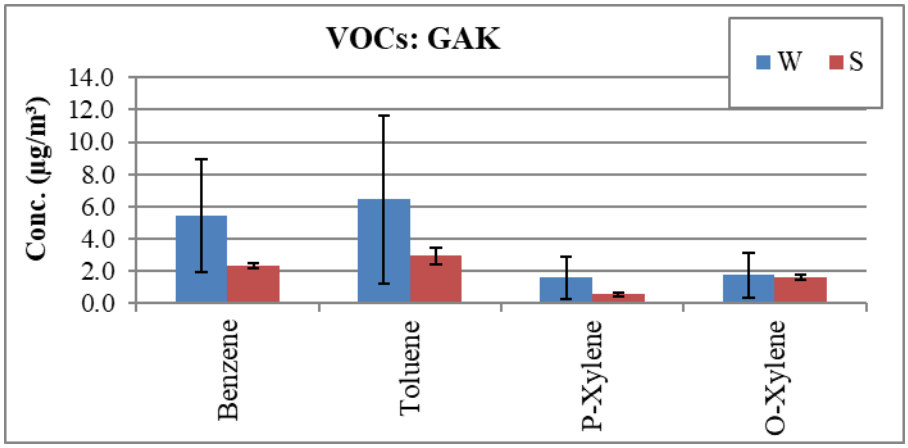


Figure 2.8: VOCs concentration at GAK

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and the ratio of OC fraction to TC are shown in Figure 2.9 (a) and (b) for winter and summer seasons. Organic carbon is observed slightly higher (winter: 48.8±20.5 and summer: 10.6±1.7 µg/m^3) than the elemental carbon (winter: 41.9±16.7 and summer: 6.0±1.9 µg/m^3). It is also observed that the OC and EC are higher in the winter than in the summer. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.15 for winter and summer. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at GAK.

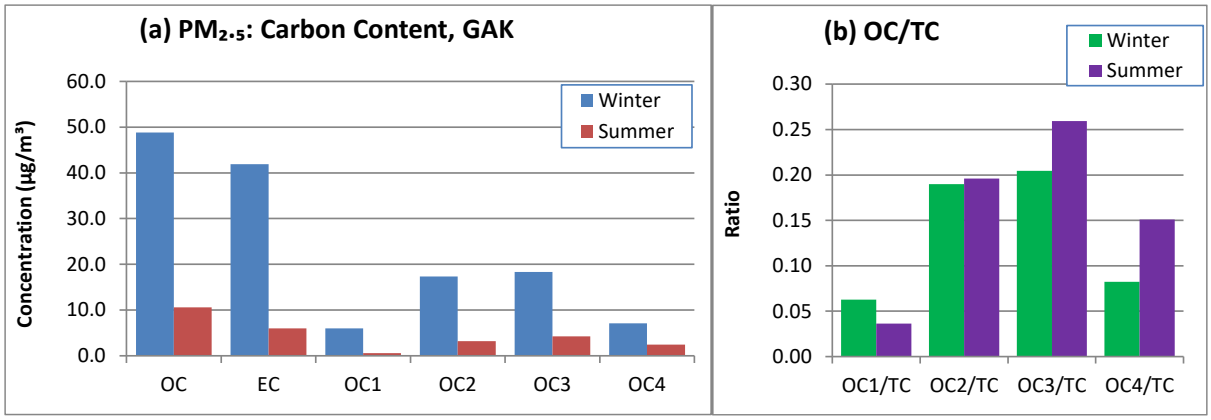


Figure 2.9: EC and OC Content in $PM_{2.5}$ at GAK

TC typically present in an urban environment (i.e., 20–45% of $PM_{2.5}$) (Dinoi et al., 2017), and the results match as TC in $PM_{2.5}$ in winter is about 33% in winter and 25% in summer. It also suggests fresh nearby combustion and burning. It is reported that burning of plastic core wires are extensively done to recover metal in the area.

2.4.1.4 PAHs in $PM_{2.5}$

The concentrations of PAHs (from solid phase only) with some specific markers were analyzed. Figure 2.10 shows the average measured concentration of PAHs at GAK for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.16 for winter and summer seasons. The PAHs compounds analyzed were: (i) Di methyl Phthalate (DmP), (ii) Acenaphthylene (AcP), (iii) Di ethyl Phthalate (DEP), (iv) Fluorene (Flu), (v) Phenanthrene (Phe), (vi) Anthracene (Ant), (vii) Pyrene (Pyr), (viii) Butyl benzyl phthalate (BbP), (ix) Bis(2-ethylhexyl) adipate (BeA), (x) Benzo(a)anthracene (B(a)A), (xi) Chrysene (Chr), (xii) Benzo(b)fluoranthene (B(b)F), (xiii) Benzo(k)fluoranthene (B(k)F), (xiv) Benzo(a)pyrene

(B(a)P), (xv) Indeno(1,2,3-cd)pyrene (InP), (xvi) Dibenzo(a,h)anthracene (D(a,h)A) and (xvii) Benzo(ghi)perylene (B(ghi)P). It is observed that Total PAHs concentrations are much higher in winter season (344±132 ng/m^3) compared to summer season (25±19 ng/m^3). Major PAHs (mostly higher molecular weight compounds) are InP (95 ng/m^3), B(ghi)P (69 ng/m^3), B(b)F (37 ng/m^3), Chr (35 ng/m^3) and B(k)F (28 ng/m^3) for winter season and Phe (4.8 ng/m^3), Ant (3.3 ng/m^3), Flu (3.0 ng/m^3), BeA (2.3 ng/m^3) and DmP (1.4 ng/m^3) for summer season.

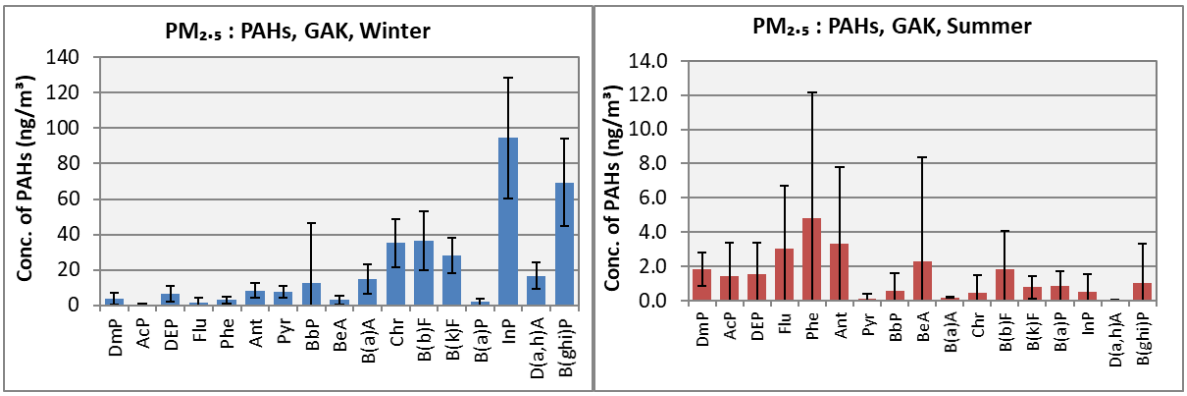


Figure 2.10: PAHs Concentrations in $PM_{2.5}$ at GAK

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

Graphical presentations of chemical species are shown for the winter and summer seasons for PM_{10} (Figure 2.11) and $PM_{2.5}$ (Figure 2.12). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content (EC and OC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb)] along with mass percentage (% R) recovered from PM are presented in Tables 2.17 – 2.20 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Tables 2.21 – 2.24 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 2.13 (a) and (b) for the winter season and Figure 2.14 (a) and (b) for the summer season.

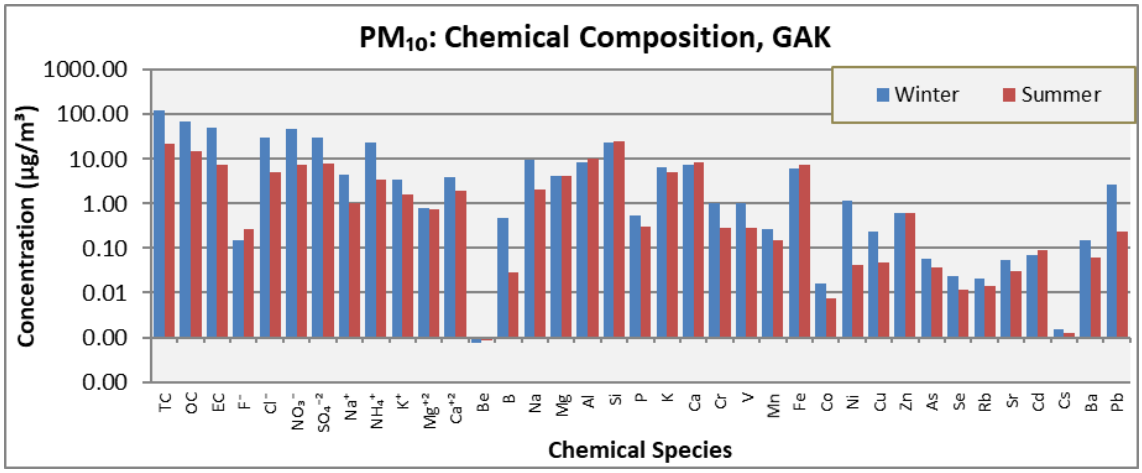


Figure 2.11: Concentrations of species in PM_{10} at GAK

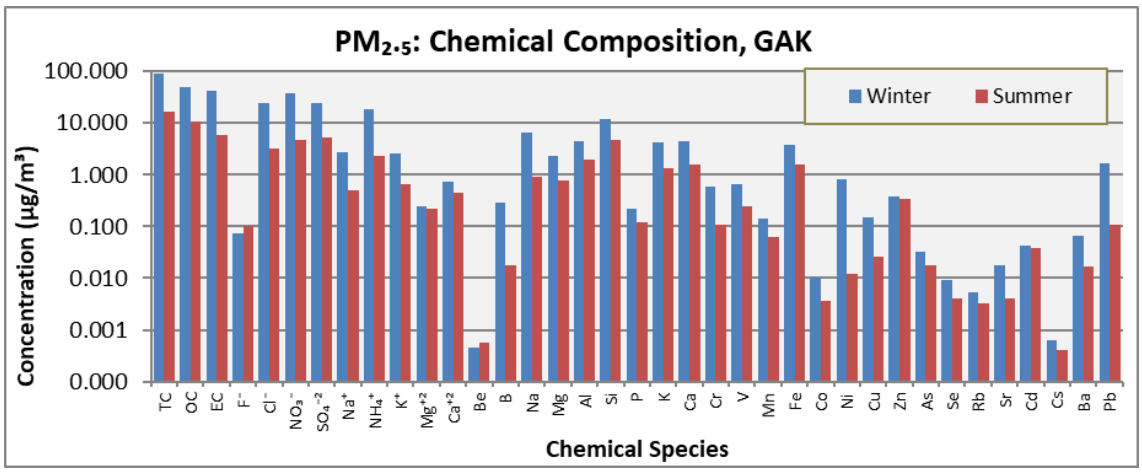
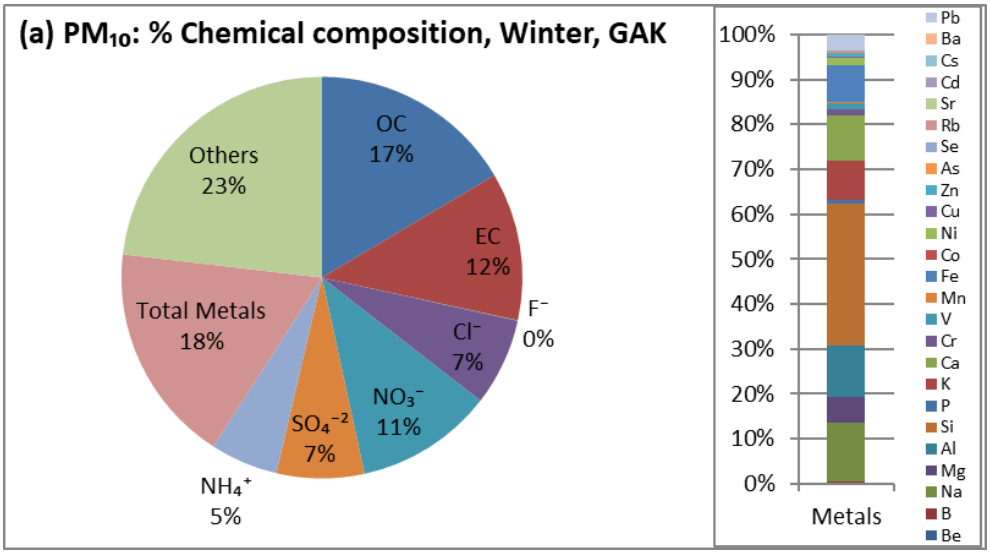


Figure 2.12: Concentrations of species in $PM_{2.5}$ at GAK



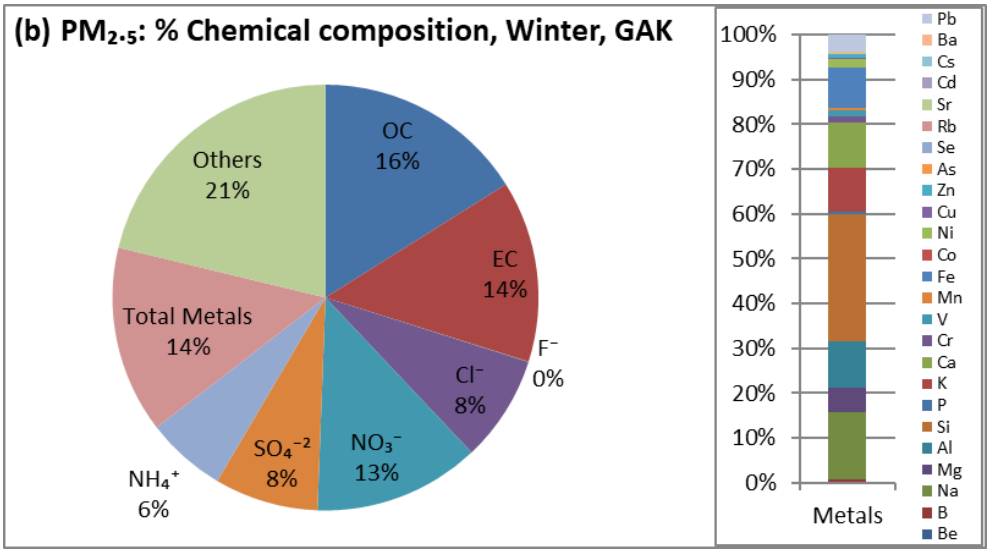
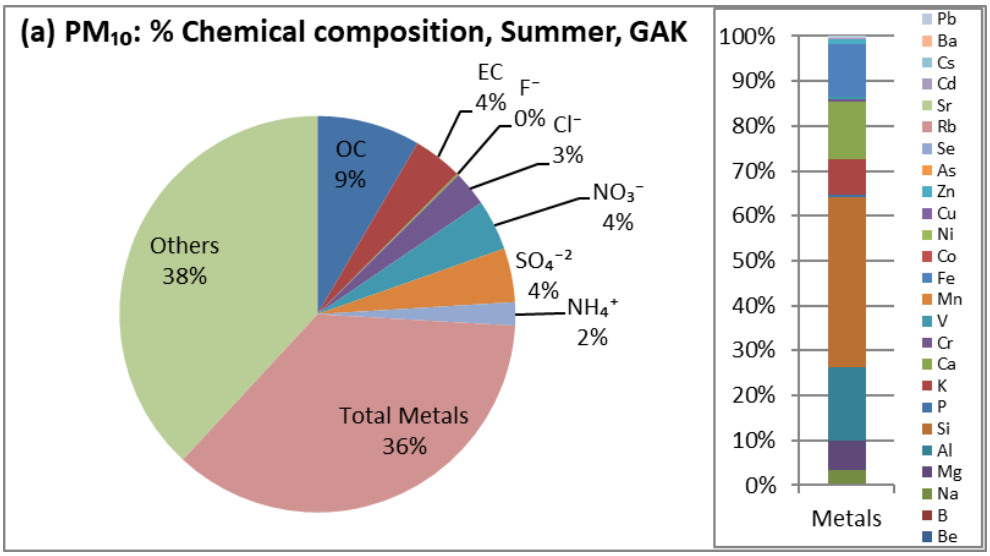


Figure 2.13: Percentage distribution of species in PM at GAK for Winter Season



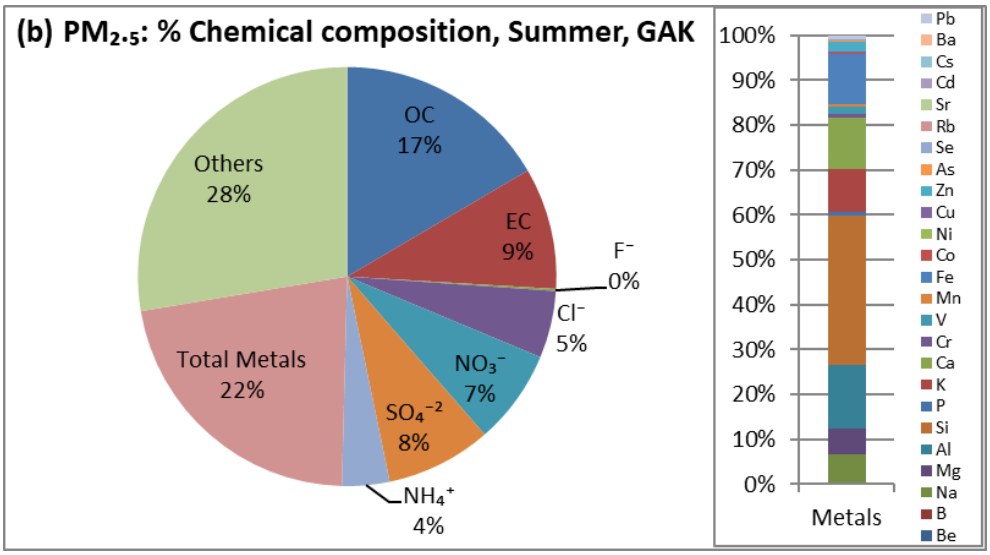


Figure 2.14: Percentage distribution of species in PM at GAK for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and PM_{10} concentrations. The graphical presentation is a better option for understanding the compositional variation. A compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.15) at GAK.

The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (72%) than summer (36%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Be, B, V, Cu and Zn; whereas, major species contributing in coarse mode are F^-, Mg^{2+}, Ca^{2+}, Mg, Al, Si, P, Ca, Cr, Mn, As, Se, Rb, Sr, Cs and Ba.

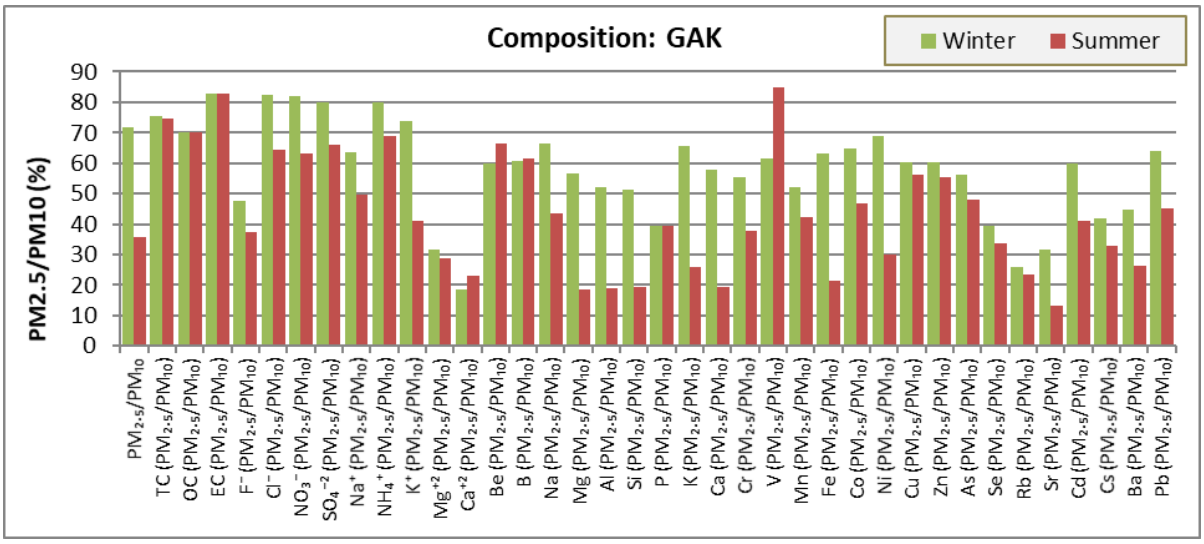


Figure 2.15: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at GAK

Table 2.14: Statistical results of gaseous pollutants (µg/m^3) at GAK for winter (W) and summer (S) seasons

GAK (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	40.82	2.00	5.41	6.42	1.56	1.74	15.13
SD	18.42	0.00	3.49	5.24	1.29	1.41	10.76
Max	68.99	2.00	13.99	19.02	4.95	5.25	41.00
Min	10.61	2.00	1.25	1.10	0.18	0.15	3.28
CV	0.45	0.00	0.64	0.82	0.83	0.81	0.71
GAK (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	20.55	2.00	2.31	2.91	0.53	1.59	7.34
SD	5.39	0.00	0.15	0.50	0.13	0.15	0.84
Max	31.90	2.00	2.79	3.93	0.74	1.96	9.42
Min	13.40	2.00	2.09	2.02	0.33	1.27	5.84
CV	0.26	0.00	0.07	0.17	0.24	0.09	0.11

Table 2.15: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at GAK for Winter (W) and summer (S) seasons

GAK (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	303.7	90.48	48.84	41.88	6.02	17.37	18.33	7.12	0.063	0.190	0.205	0.082
SD	77.3	37.07	20.51	16.72	3.71	7.84	7.16	2.80	0.018	0.015	0.019	0.019
Max	436.3	197.65	111.19	86.45	13.87	41.36	39.67	16.64	0.107	0.215	0.257	0.133
Min	144.0	33.31	18.39	14.93	1.35	6.05	6.57	4.37	0.038	0.162	0.169	0.048
CV	0.25	0.41	0.42	0.40	0.62	0.45	0.39	0.39	0.286	0.080	0.091	0.231
GAK (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	63.9	16.64	10.59	6.00	0.62	3.23	4.27	2.47	0.036	0.196	0.259	0.151
SD	19.2	3.35	1.70	1.89	0.27	0.52	0.84	0.39	0.012	0.016	0.037	0.023
Max	121.3	23.33	14.19	9.13	1.09	4.49	5.99	3.25	0.058	0.227	0.341	0.212
Min	39.4	10.56	7.68	2.88	0.25	2.21	2.73	1.62	0.018	0.176	0.208	0.118
CV	0.30	0.20	0.16	0.31	0.43	0.16	0.20	0.16	0.331	0.083	0.145	0.150

Table 2.16: **Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at GAK for winter (W) and summer (S) seasons**

GAK(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	3.73	0.39	6.32	1.59	2.95	8.38	7.70	12.66	2.91	14.89	35.15	36.52	28.16	1.87	94.60	16.60	69.30	343.74
SD	3.15	0.42	4.52	2.89	1.81	4.16	3.45	33.80	2.65	8.34	13.61	16.52	10.02	2.09	34.04	7.62	24.80	132.73
Max	9.95	1.47	11.13	9.63	6.89	14.24	12.72	108.74	6.78	29.28	61.00	73.62	41.39	6.95	139.15	25.87	100.65	562.89
Min	0.15	0.11	0.00	0.09	0.27	2.64	1.98	0.58	0.22	1.66	11.81	12.85	9.58	0.27	32.08	3.79	24.26	120.44
CV	0.84	1.07	0.71	1.81	0.61	0.50	0.45	2.67	0.91	0.56	0.39	0.45	0.36	1.12	0.36	0.46	0.36	0.39
GAK(S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.84	1.43	1.57	3.02	4.83	3.31	0.12	0.56	2.31	0.19	0.46	1.82	0.79	0.84	0.50	0.03	1.02	24.64
SD	0.96	1.97	1.81	3.67	7.34	4.51	0.31	1.06	6.07	0.04	1.02	2.23	0.65	0.88	1.07	0.05	2.28	18.64
Max	3.44	5.70	4.96	10.03	21.03	12.42	1.03	3.74	20.22	0.32	3.53	6.24	1.77	3.07	3.53	0.14	7.87	69.58
Min	0.66	0.10	0.00	0.00	0.00	0.02	0.00	0.07	0.00	0.16	0.11	0.05	0.05	0.05	0.00	0.00	0.15	9.01
CV	0.52	1.38	1.15	1.22	1.52	1.36	2.54	1.90	2.62	0.23	2.21	1.22	0.82	1.05	2.14	1.91	2.25	0.76

Table 2.17: Statistical results of chemical characterization (µg/m^3) of PM_{10} at GAK for winter (W) season

GAK (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	423	69.8	50.5	0.2	29.8	46.9	29.9	4.3	23.1	3.5	0.8	3.9	8E-4	0.48	9.75	4.19	8.68	23.75	0.55
SD	100	29.3	20.1	0.1	11.9	12.7	10.8	1.8	5.4	1.2	0.6	2.1	2E-4	0.19	4.21	1.57	2.77	5.40	0.16
Max	595	158.8	104.2	0.5	57.7	78.4	50.3	8.9	31.6	6.6	2.6	10.1	1E-3	0.96	16.96	7.46	16.24	32.01	1.01
Min	211	26.3	18.0	0.0	13.1	22.5	14.3	2.6	12.9	1.9	0.2	1.7	5E-4	0.27	4.36	2.66	3.79	12.92	0.33
CV	0.24	0.42	0.40	0.90	0.40	0.27	0.36	0.42	0.23	0.33	0.82	0.54	0.29	0.39	0.43	0.37	0.32	0.23	0.30
GAK (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.53	7.56	1.04	1.04	0.27	6.16	0.02	1.17	0.24	0.63	0.06	0.02	0.02	0.06	0.07	1E-3	0.15	2.64	76.9
SD	1.83	1.63	1.27	0.29	0.19	2.18	0.02	0.81	0.20	0.30	0.07	0.01	0.01	0.02	0.06	4E-4	0.08	2.20	3.1
Max	10.17	11.01	4.55	1.54	0.74	10.36	0.06	2.95	0.85	1.17	0.26	0.06	0.05	0.12	0.25	2E-3	0.44	7.65	82.3
Min	2.93	4.72	0.26	0.53	0.11	2.23	0.00	0.17	0.08	0.11	0.00	0.01	0.00	0.02	0.01	1E-3	0.07	0.45	72.6
CV	0.28	0.22	1.21	0.28	0.71	0.35	1.22	0.70	0.81	0.48	1.19	0.53	0.42	0.34	0.89	0.24	0.54	0.83	0.04
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.18: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at GAK for winter (W) season

GAK (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	304	48.8	41.9	0.1	24.5	38.4	23.9	2.8	18.4	2.6	0.2	0.7	5E-4	0.29	6.47	2.37	4.53	12.21	0.22
SD	77	20.5	16.7	0.1	10.3	11.0	8.8	1.3	4.7	0.7	0.2	0.4	2E-4	0.16	3.19	1.44	1.87	4.81	0.09
Max	436	111.2	86.5	0.3	48.0	68.1	44.9	6.2	26.8	4.3	1.0	1.7	1E-3	0.67	12.95	5.93	8.53	18.91	0.45
Min	144	18.4	14.9	0.0	10.3	20.7	10.4	1.2	10.4	1.3	0.0	0.1	3E-4	0.07	1.65	0.38	2.29	2.43	0.12
CV	0.25	0.42	0.40	1.26	0.42	0.29	0.37	0.48	0.26	0.29	0.88	0.57	0.36	0.56	0.49	0.61	0.41	0.39	0.42
GAK (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.29	4.37	0.58	0.64	0.14	3.89	1E-2	0.81	0.15	0.38	0.03	9E-3	5E-3	2E-2	0.04	6E-4	0.07	1.69	78.8
SD	1.25	1.84	0.81	0.31	0.13	1.87	1E-2	0.60	0.11	0.23	0.05	1E-2	3E-3	1E-2	0.04	2E-4	0.07	1.29	3.9
Max	7.45	7.84	2.72	1.23	0.41	8.05	4E-2	1.95	0.55	1.04	0.19	4E-2	1E-2	5E-2	0.16	9E-4	0.33	4.10	87.8
Min	1.51	1.64	0.04	0.22	0.04	1.42	8E-4	0.12	0.06	0.05	0.00	2E-3	4E-4	3E-4	0.00	2E-4	0.00	0.17	73.5
CV	0.29	0.42	1.41	0.48	0.90	0.48	1.34	0.75	0.75	0.62	1.44	1.10	0.58	0.77	1.00	0.27	1.06	0.76	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.19: Statistical results chemical characterization (µg/m^3) of PM_{10} at GAK for summer (S) season

GAK (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	179	15.1	7.2	0.3	5.1	7.4	7.9	1.0	3.4	1.6	0.8	2.0	9E-4	0.03	2.14	4.20	10.52	24.47	0.30
SD	93	2.4	2.3	0.1	3.0	3.2	2.5	0.3	1.0	0.6	0.6	0.9	3E-4	0.01	1.38	2.95	8.34	17.27	0.18
Max	479	20.3	11.0	0.4	11.3	13.0	12.5	1.6	5.6	3.4	2.1	4.2	2E-3	0.07	6.70	14.02	40.36	81.47	0.74
Min	91	11.0	3.5	0.1	1.8	3.5	4.5	0.4	1.9	0.9	0.2	1.0	7E-4	0.01	0.84	1.64	3.66	8.64	0.07
CV	0.52	0.16	0.31	0.22	0.58	0.43	0.32	0.31	0.28	0.37	0.72	0.46	0.29	0.52	0.65	0.70	0.79	0.71	0.61
GAK (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.09	8.38	0.29	0.29	0.15	7.46	8E-3	0.04	0.05	0.60	0.04	1E-2	1E-2	3E-2	0.09	1E-3	0.06	0.24	63.3
SD	3.19	5.04	0.18	0.04	0.10	4.90	1E-2	0.05	0.02	0.18	0.02	6E-3	1E-2	3E-2	0.14	7E-4	0.03	0.14	3.9
Max	15.13	23.25	0.72	0.38	0.47	22.03	5E-2	0.19	0.13	1.07	0.07	2E-2	5E-2	1E-1	0.60	3E-3	0.14	0.68	71.1
Min	1.99	2.58	0.11	0.22	0.07	1.97	3E-3	0.01	0.03	0.29	0.02	4E-3	3E-3	3E-3	0.01	6E-4	0.03	0.08	57.1
CV	0.63	0.60	0.64	0.15	0.68	0.66	1.43	1.10	0.49	0.31	0.46	0.48	0.88	0.85	1.57	0.59	0.49	0.60	63.3
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.20: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at GAK for summer (S) season

GAK (S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	64	10.6	6.0	0.1	3.3	4.7	5.2	0.5	2.3	0.7	0.2	0.5	6E-4	0.02	0.93	0.78	1.98	4.69	0.12
SD	19	1.7	1.9	0.1	1.6	1.8	1.7	0.2	0.7	0.4	0.2	0.3	6E-5	0.01	0.52	0.44	1.23	2.77	0.10
Max	121	14.2	9.1	0.2	6.7	9.2	9.2	0.8	4.0	1.9	0.7	1.0	7E-4	0.05	2.40	1.89	5.80	12.69	0.49
Min	39	7.7	2.9	0.0	1.5	2.1	2.8	0.2	1.5	0.2	0.1	0.1	4E-4	0.00	0.33	0.34	0.56	1.56	0.04
CV	0.30	0.16	0.31	0.60	0.49	0.39	0.33	0.32	0.29	0.63	0.69	0.60	0.11	0.52	0.56	0.56	0.62	0.59	0.85
GAK (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.32	1.61	0.11	0.24	0.06	1.60	4E-3	1E-2	0.03	0.33	0.02	4E-3	3E-3	4E-3	0.04	4E-4	0.02	0.11	73.3
SD	0.94	0.94	0.06	0.03	0.03	1.11	3E-3	1E-2	0.01	0.12	0.01	2E-3	1E-3	4E-3	0.05	2E-4	0.01	0.06	5.1
Max	3.65	4.42	0.28	0.32	0.12	5.31	1E-2	4E-2	0.05	0.61	0.04	8E-3	6E-3	2E-2	0.26	8E-4	0.05	0.33	81.2
Min	0.37	0.44	0.04	0.18	0.03	0.38	1E-3	2E-3	0.02	0.18	0.01	1E-3	4E-4	4E-4	0.00	3E-4	0.01	0.05	66.5
CV	0.72	0.58	0.58	0.14	0.41	0.69	0.77	0.80	0.38	0.37	0.33	0.55	0.36	1.10	1.45	0.37	0.68	0.58	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

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

GAK (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	0.84	0.81	0.87	0.39	0.57	0.60	0.68	0.19	0.61	0.45	0.32	0.38	0.57
TC		1.00	1.00	0.99	0.12	0.32	0.31	0.38	0.01	0.37	0.40	0.20	0.35	0.19
OC			1.00	0.97	0.11	0.30	0.28	0.37	0.01	0.33	0.40	0.21	0.35	0.17
EC				1.00	0.12	0.35	0.34	0.40	0.01	0.42	0.38	0.19	0.34	0.23
NO_3^-					0.64	0.66	1.00	0.75	0.35	0.48	0.37	0.48	0.33	0.20
SO_4^{-2}					0.80	0.67		1.00	0.33	0.63	0.37	0.51	0.21	0.34
NH_4^+					0.16	0.34			-0.13	1.00	0.12	-0.10	0.15	0.41
Metals					0.14	0.11			0.08		0.27	0.04	0.25	1.00

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

GAK (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	0.87	0.91	0.18	0.48	0.61	0.72	0.20	0.62	0.43	0.12	0.05	0.54
TC		1.00	0.99	0.99	0.08	0.34	0.39	0.52	0.12	0.43	0.52	0.10	-0.02	0.27
OC			1.00	0.97	0.07	0.31	0.35	0.49	0.10	0.38	0.51	0.10	0.00	0.26
EC				1.00	0.09	0.37	0.41	0.53	0.14	0.47	0.51	0.08	-0.07	0.30
NO_3^-					0.56	0.70	1.00	0.83	0.51	0.44	0.32	0.48	0.39	0.16
SO_4^{-2}					0.62	0.72		1.00	0.43	0.57	0.35	0.37	0.32	0.21
NH_4^+					-0.06	0.33			-0.02	1.00	0.13	-0.37	-0.17	0.31
Metals					-0.26	-0.14			-0.17		0.01	-0.16	-0.20	1.00

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

GAK (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	0.46	0.55	0.30	-0.10	0.58	0.56	0.58	0.67	0.58	0.65	0.69	0.69	0.99
TC		1.00	0.94	0.94	0.19	0.15	0.17	0.23	0.55	0.09	0.49	0.16	0.23	0.41
OC			1.00	0.77	0.25	0.23	0.24	0.31	0.59	0.15	0.52	0.36	0.30	0.50
EC				1.00	0.09	0.06	0.08	0.11	0.44	0.00	0.40	-0.07	0.13	0.26
NO_3^-					-0.34	0.92	1.00	0.81	0.15	0.61	0.06	0.28	0.46	0.49
SO_4^{-2}					-0.30	0.71		1.00	0.41	0.42	0.13	0.47	0.47	0.52
NH_4^+					-0.06	0.61			0.05	1.00	0.31	0.45	0.27	0.56
Metals					-0.08	0.52			0.67		0.66	0.70	0.68	1.00

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

GAK (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	0.54	0.65	0.39	0.51	0.52	0.44	0.42	0.20	0.28	0.57	0.76	0.70	0.93
TC		1.00	0.93	0.94	0.49	0.16	0.21	0.28	0.23	-0.08	0.51	0.32	0.36	0.31
OC			1.00	0.77	0.57	0.26	0.28	0.31	0.26	-0.04	0.57	0.53	0.53	0.45
EC				1.00	0.37	0.09	0.14	0.23	0.16	-0.09	0.41	0.11	0.20	0.16
NO_3^-					0.22	0.79	1.00	0.63	-0.10	0.72	0.00	0.33	0.33	0.17
SO_4^{-2}					-0.06	0.50		1.00	-0.01	0.27	-0.04	0.24	0.46	0.17
NH_4^+					0.06	0.67			-0.16	1.00	0.01	0.24	-0.01	0.12
Metals					0.47	0.29			0.20		0.58	0.74	0.63	1.00

2.4.2 Nunhai Industrial Area (NNH)

The sampling period was December 31, 2018 – January 22, 2019 for winter and May 14 – June 03, 2019 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown at NNH for winter (Figure 2.16) and summer (Figure 2.17). Average levels for winter and summer season were 273±86 and 71±30 µg/m^3 (for $PM_{2.5}$) and 367±96 and 182±57 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are about 4.5 times higher than the NAQS and PM_{10} is about 3.7 times higher than the NAQS in winter. The $PM_{2.5}$ levels are about 1.2 times higher and PM_{10} levels are 1.8 times higher than the NAQS in summer. The high levels may be due to industrial emissions. A statistical summary of PM concentrations is presented in Tables 2.28 – 2.31 for the winter and summer seasons. In summer, $PM_{2.5}$ levels drop significantly compared to PM_{10} levels that continued to be high in spite of improvement in meteorology and better dispersion. The particle airborne from the soil during dust storms in the dry months of summer can contribute significantly to a coarse fraction (i.e., $PM_{2.5\text{-}10}$).

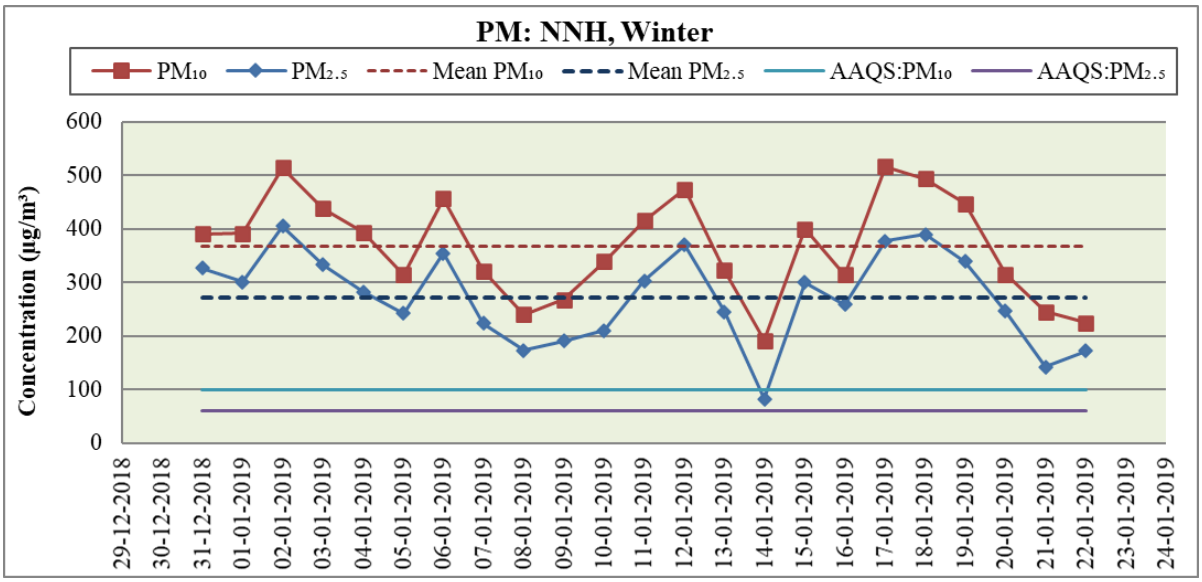


Figure 2.16: PM Concentrations at NNH for Winter Season

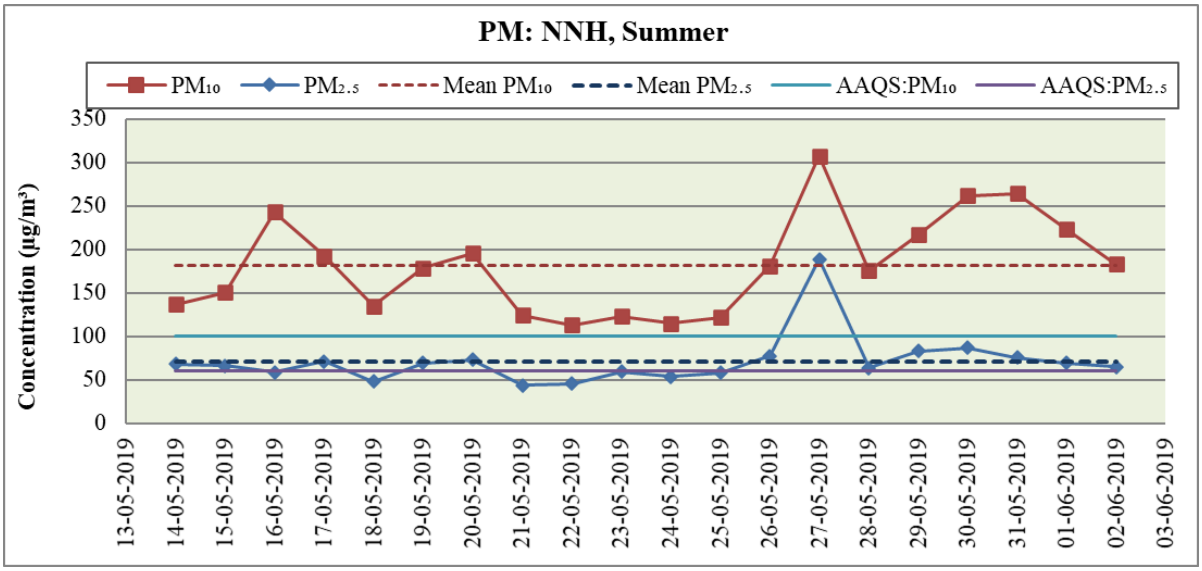


Figure 2.17: PM Concentrations at NNH for Summer Season

2.4.2.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.18) and summer (Figure 2.19) seasons. It was observed that SO_2 concentrations were low (mostly < 5.0 µg/m^3) and meet the air quality standard. NO_2 levels also under the NAQS with an average of 20 days at 42.3±15.3 µg/m^3 in winter and 23.5±6.3 µg/m^3 in summer season (Table 2.25). The summer concentration of SO_2 and NO_2 dropped dramatically similarly $PM_{2.5}$ levels. Although the NO_2 and SO_2 are certainly a matter of concern in the winter season and these values 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 or local open and coal burning etc.

The Mean concentrations of BTX were presented in Figure 2.20 and the statistical summary in Table 2.25. The total BTX level is observed 9.0±8.5 µg/m^3 (Benzene: 4.0 and Toluene: 3.6 µg/m^3) in winter and 7.4±1.3 µg/m^3 (Benzene: 2.6 and Toluene: 2.2 µg/m^3) in summer seasons. The BTX levels were high during winter than in the summer.

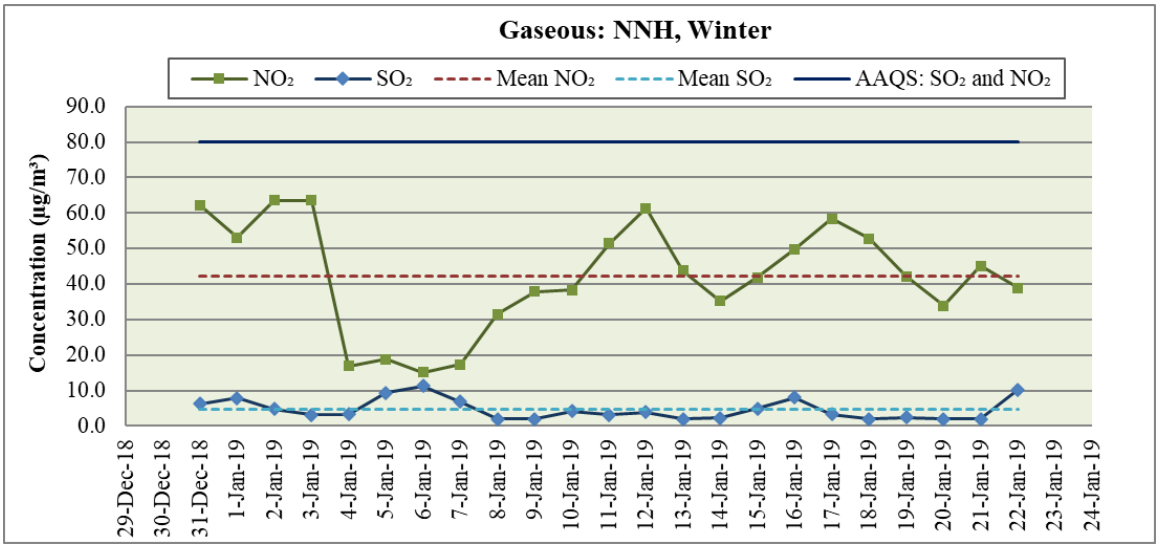


Figure 2.18: SO_2 and NO_2 Concentrations at NNH for Winter Season

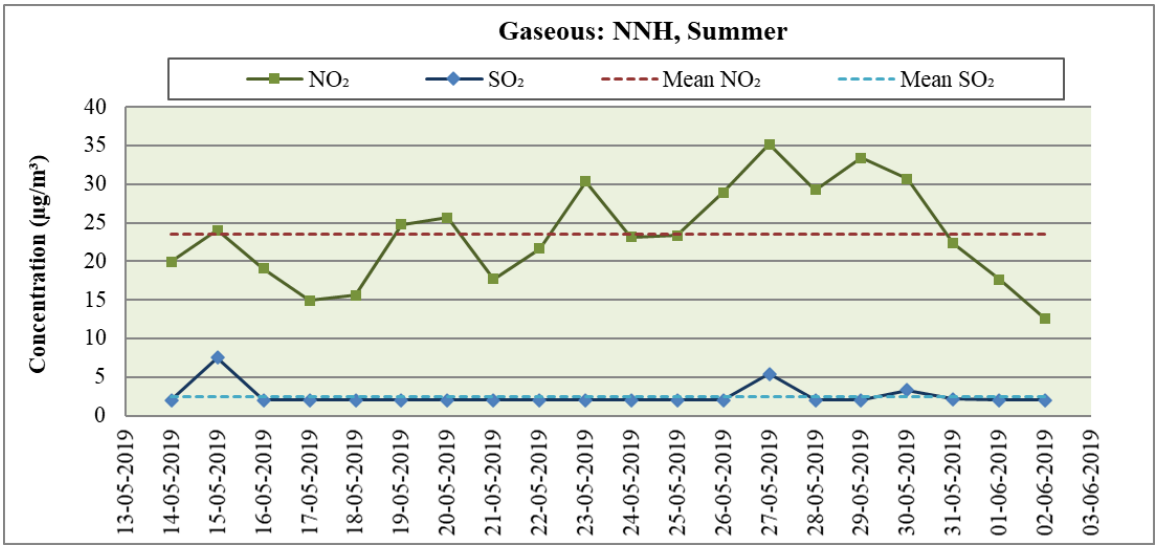


Figure 2.19: SO_2 and NO_2 Concentrations at NNH for Summer Season

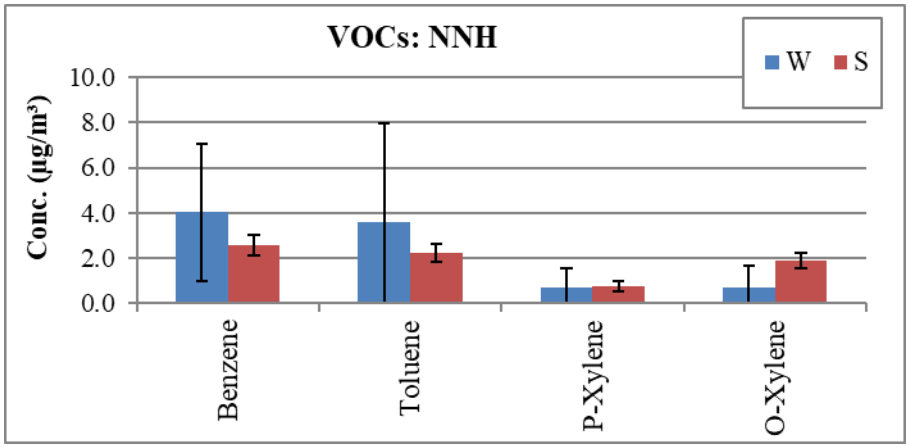


Figure 2.20: VOCs concentration at NNH

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 2.21 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (winter: 37.5±18.6 and summer: 17.7±3.1 µg/m^3) than the elemental carbon (winter: 26.6±13.6 and summer: 6.7±2.3 µg/m^3). It is also observed that the OC and EC are higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.26 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at NNH.

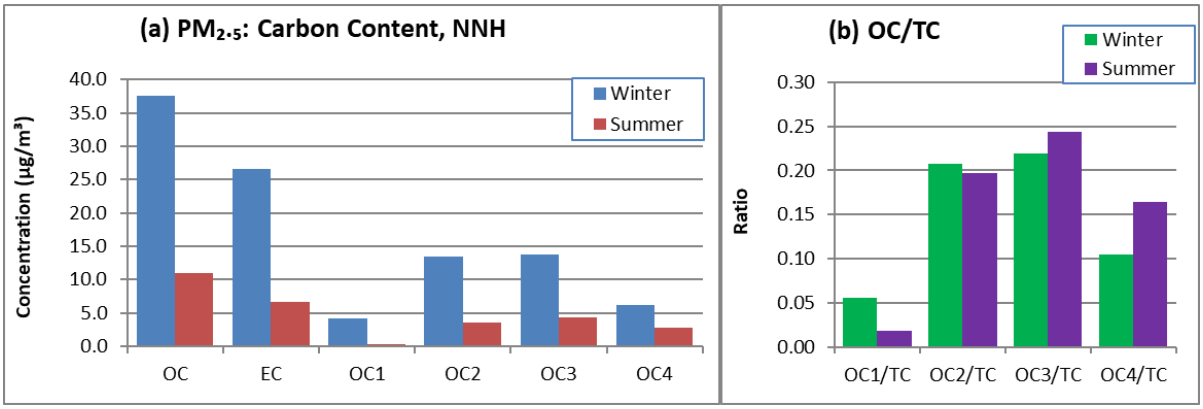


Figure 2.21: EC and OC Content in $PM_{2.5}$ at NNH

2.4.2.4 PAHs in $PM_{2.5}$

Figure 2.22 shows the average measured concentration of PAHs at NNH for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.27 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (226±100 ng/m^3) compared to summer season (15.6±6.7 ng/m^3). Major PAHs are InP (64 ng/m^3), B(ghi)P (47 ng/m^3), Chr (27 ng/m^3), B(b)F (22 ng/m^3) and B(k)F (15 ng/m^3) for winter season and B(ghi)P (2.4 ng/m^3), DmP (2.3 ng/m^3), BeA (1.8 ng/m^3), B(k)F (1.7 ng/m^3), B(b)F (1.5 ng/m^3) and InP (1.3 ng/m^3) for summer season.

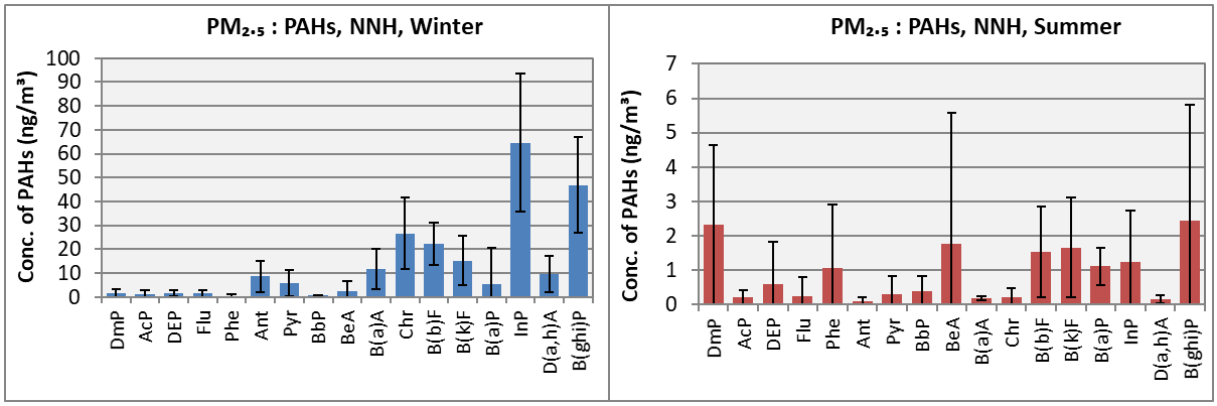


Figure 2.22: PAHs Concentrations in $PM_{2.5}$ at NNH

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

Graphical presentations of chemical species are shown for the winter and summer seasons for PM_{10} (Figure 2.23) and $PM_{2.5}$ (Figure 2.24). 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 Tables 2.28 – 2.31 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Tables 2.32 – 2.35 for both seasons. It is seen that most of the parameters showed a good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituents of the PM are presented in Figure 2.25 (a) and (b) for the winter season and Figure 2.26 (a) and (b) for the summer season.

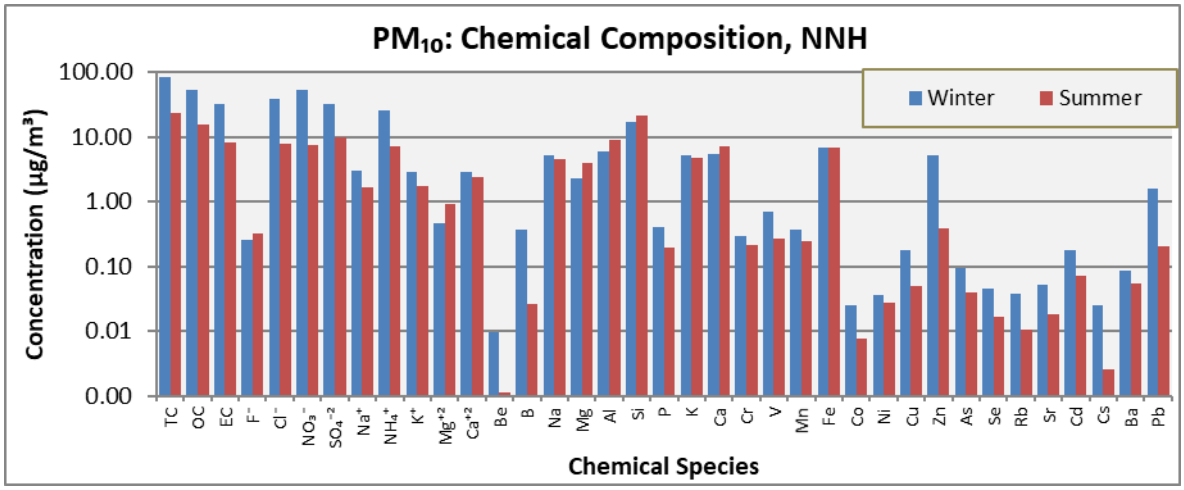


Figure 2.23: Concentrations of species in PM_{10} at NNH

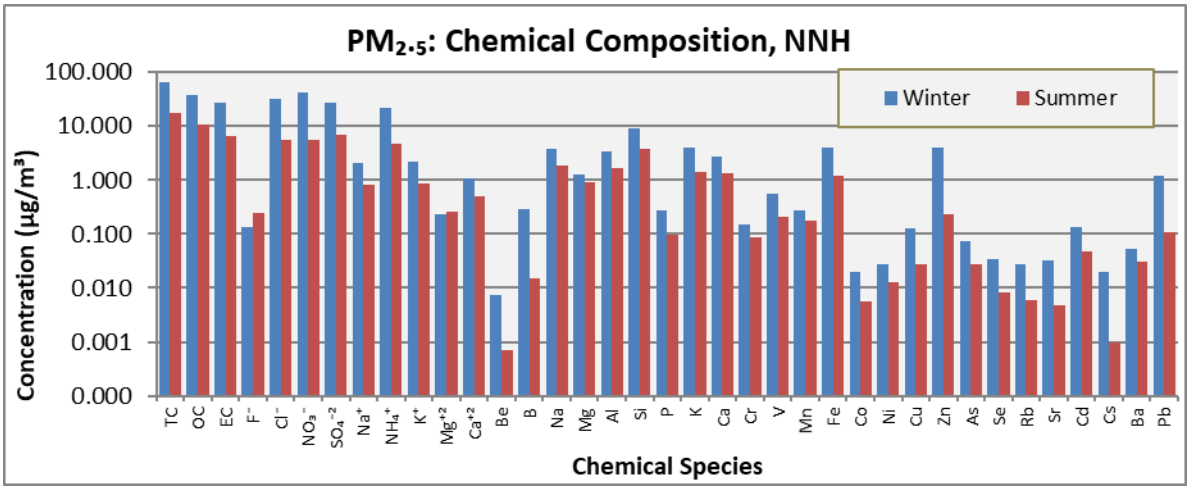
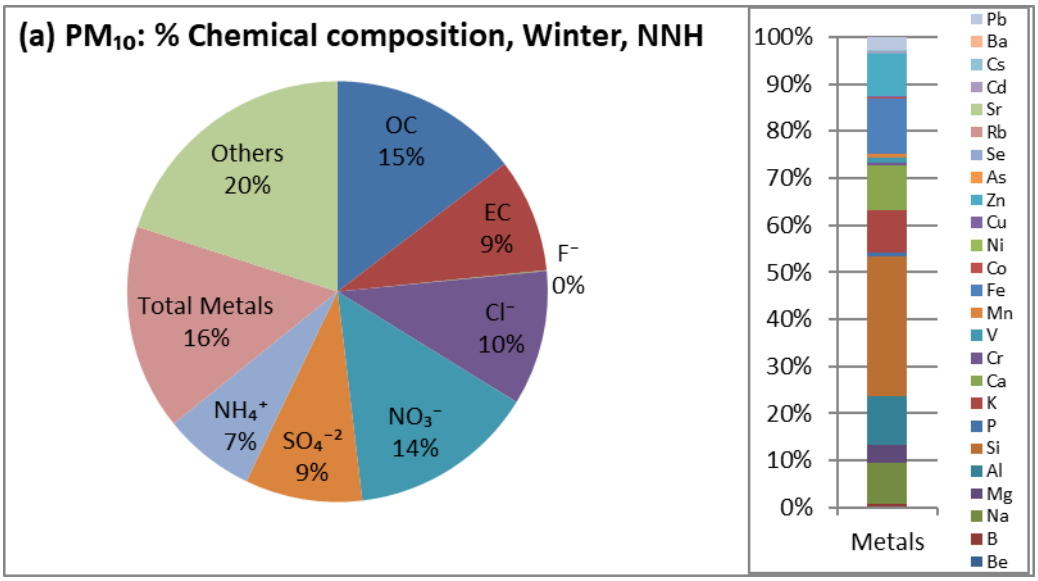


Figure 2.24: Concentrations of species in $PM_{2.5}$ at NNH



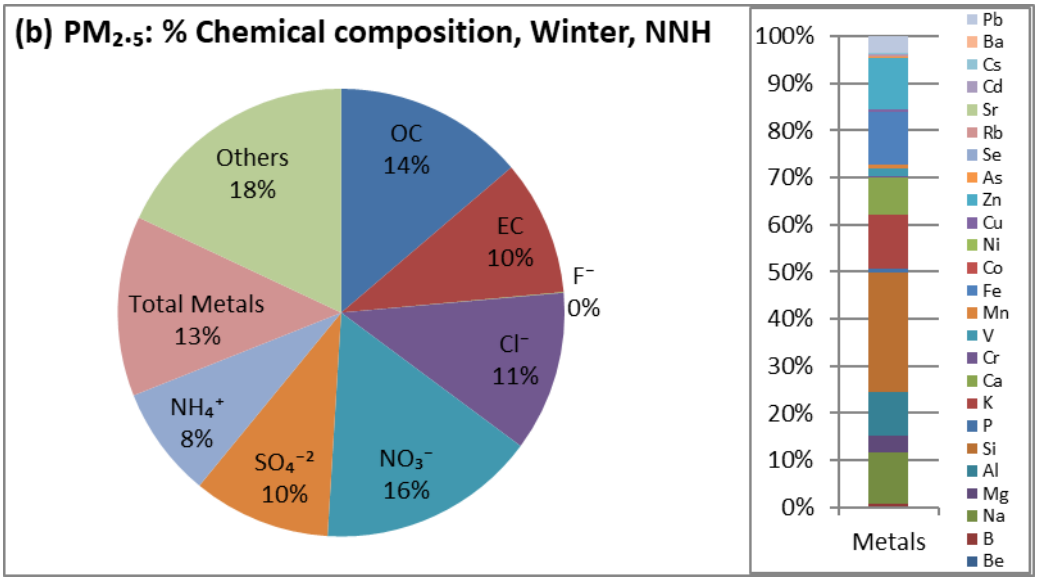


Figure 2.25: Percentage distribution of species in PM at NNH for Winter Season

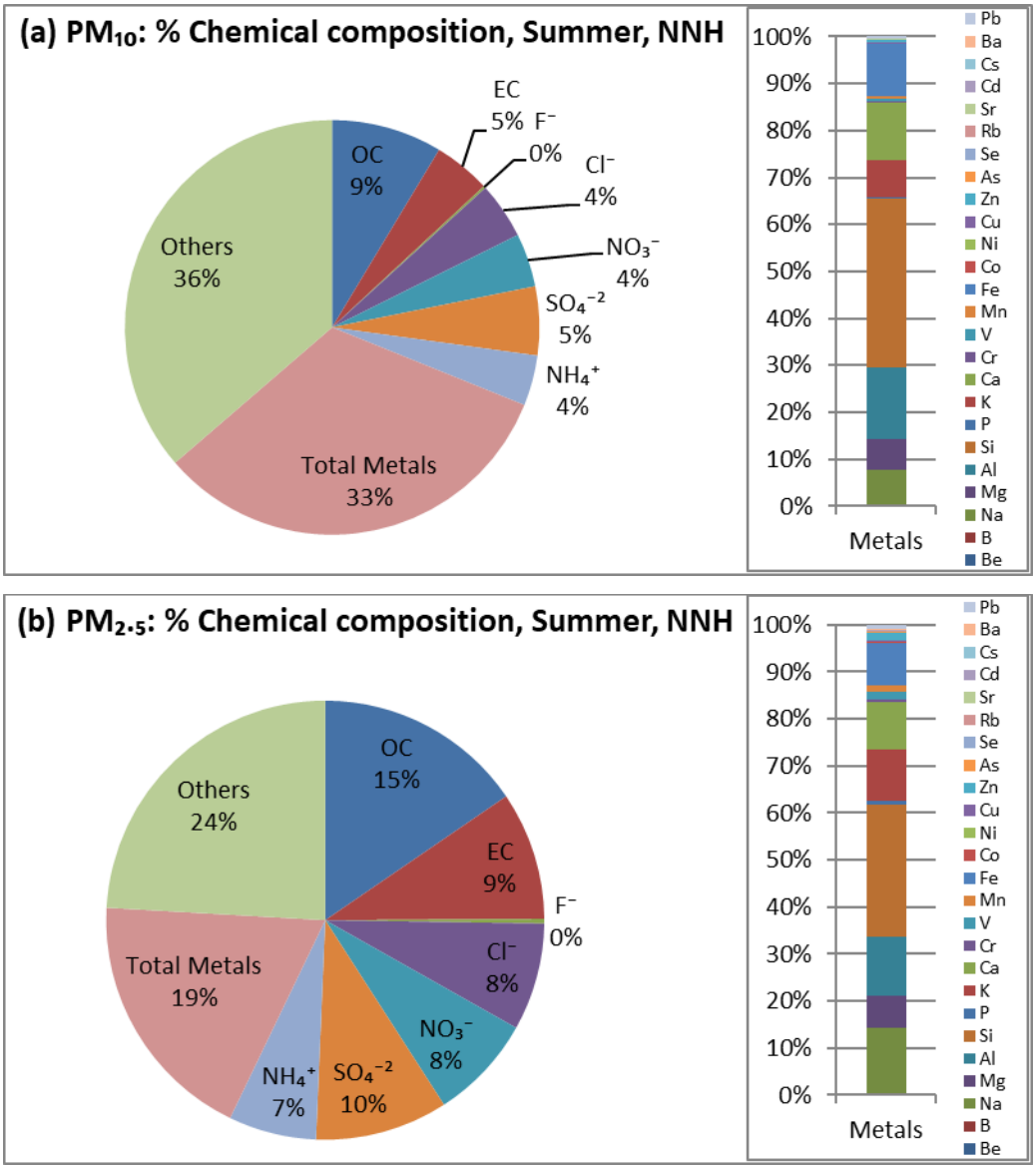


Figure 2.26: Percentage distribution of species in PM at NNH for Summer Season

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

The graphical presentation is the better option for understanding the compositional variation. A compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.27) at NNH. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (74%) than summer (39%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, Be, B, V, Mn, Co, Cu, Zn, As, Rb, Cd, Ba and Pb; whereas major species contributing in coarse mode are Mg^{2+}, Ca^{2+}, Mg, Al, Si, Ca, Cr and Fe.

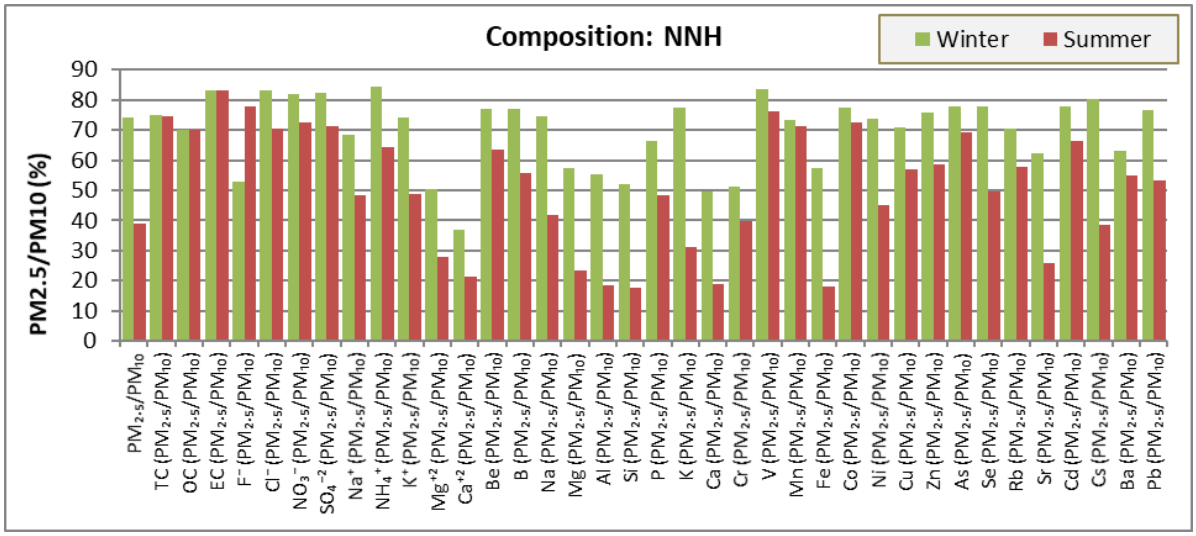


Figure 2.27: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at NNH

Table 2.25: Statistical results of gaseous pollutants (µg/m^3) at NNH for winter (W) and summer (S) seasons

NNH (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	42.28	4.65	4.03	3.60	0.66	0.68	8.96
SD	15.30	2.91	3.04	4.39	0.86	0.96	8.49
Max	63.62	11.20	11.04	19.37	3.14	3.77	35.83
Min	15.10	2.00	1.29	0.27	0.04	0.04	1.93
CV	0.36	0.63	0.76	1.22	1.31	1.40	0.95
NNH (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	23.50	2.52	2.55	2.19	0.74	1.86	7.35
SD	6.34	1.42	0.45	0.39	0.24	0.35	1.29
Max	35.17	7.48	3.05	2.75	1.13	2.29	8.89
Min	12.58	2.00	0.83	0.69	0.28	0.62	2.42
CV	0.27	0.56	0.18	0.18	0.32	0.19	0.18

Table 2.26: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at NNH for winter (W) and summer (S) seasons

NNH (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	272.5	64.11	37.52	26.61	4.11	13.42	13.75	6.25	0.055	0.208	0.220	0.105
SD	85.5	31.99	18.60	13.56	4.07	6.95	6.25	2.63	0.026	0.012	0.019	0.025
Max	405.6	132.75	78.45	57.96	18.99	29.14	27.43	12.20	0.143	0.236	0.251	0.146
Min	82.0	14.94	9.28	5.66	0.50	2.96	3.64	2.18	0.023	0.188	0.160	0.043
CV	0.31	0.50	0.50	0.51	0.99	0.52	0.45	0.42	0.470	0.059	0.087	0.238
NNH (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	71.3	17.74	11.02	6.72	0.36	3.50	4.35	2.81	0.019	0.197	0.244	0.165
SD	30.1	4.93	3.06	2.26	0.28	1.08	1.47	0.50	0.009	0.025	0.032	0.029
Max	189.1	27.04	17.23	10.90	1.25	5.35	7.86	4.21	0.046	0.258	0.302	0.224
Min	43.8	10.42	6.91	3.25	0.11	2.04	2.38	2.13	0.008	0.163	0.200	0.110
CV	0.42	0.28	0.28	0.34	0.77	0.31	0.34	0.18	0.484	0.126	0.130	0.175

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

NNH(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	1.60	1.11	1.55	1.47	0.42	8.58	5.82	0.64	2.40	11.80	26.68	22.18	15.27	5.27	64.49	9.71	46.89	225.86
SD	1.83	1.58	1.39	1.60	0.56	6.51	5.44	0.32	4.22	8.44	14.85	8.90	10.40	15.24	28.88	7.55	20.13	100.36
Max	6.84	5.96	4.62	5.53	1.94	20.32	21.99	1.16	15.55	30.23	52.48	35.03	32.86	53.58	109.84	22.82	77.59	381.87
Min	0.42	0.27	0.04	0.00	0.00	1.03	2.21	0.21	0.25	1.52	5.69	8.15	0.56	0.12	20.46	0.69	16.86	109.02
CV	1.15	1.42	0.90	1.09	1.32	0.76	0.94	0.50	1.76	0.72	0.56	0.40	0.68	2.89	0.45	0.78	0.43	0.44
NNH(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	2.33	0.21	0.59	0.24	1.08	0.12	0.30	0.39	1.78	0.19	0.23	1.54	1.66	1.12	1.26	0.16	2.43	15.61
SD	2.32	0.20	1.23	0.55	1.83	0.10	0.54	0.44	3.79	0.06	0.25	1.33	1.45	0.53	1.49	0.12	3.38	6.73
Max	7.70	0.78	4.04	1.68	5.05	0.32	1.71	1.37	12.06	0.35	0.91	4.06	4.91	2.01	3.86	0.44	9.50	26.91
Min	0.00	0.10	0.00	0.00	0.00	0.02	0.00	0.07	0.00	0.16	0.11	0.08	0.54	0.50	0.01	0.05	0.21	7.12
CV	1.00	0.96	2.10	2.30	1.71	0.89	1.81	1.13	2.12	0.31	1.09	0.87	0.87	0.48	1.18	0.72	1.39	0.43

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

NNH (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	367	53.6	32.1	0.3	38.0	52.5	33.0	3.1	25.9	2.9	0.5	2.9	1E-2	0.38	5.10	2.26	5.98	17.18	0.41
SD	96	26.6	16.3	0.5	17.1	19.1	14.2	2.6	10.4	1.3	0.3	1.6	5E-3	0.17	2.31	0.67	2.13	6.38	0.20
Max	516	112.1	69.8	2.0	73.4	92.7	61.8	13.4	45.3	6.3	1.5	6.8	3E-2	0.81	9.13	3.56	10.43	31.89	0.93
Min	192	13.3	6.8	0.0	12.1	19.2	11.7	0.9	7.0	1.2	0.1	0.8	6E-3	0.16	1.03	1.32	2.83	7.67	0.19
CV	0.26	0.50	0.51	1.79	0.45	0.36	0.43	0.84	0.40	0.43	0.66	0.54	0.47	0.45	0.45	0.30	0.36	0.37	0.47
NNH (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.30	5.56	0.29	0.68	0.37	6.90	0.03	0.04	0.18	5.18	0.09	0.04	0.04	0.05	0.18	0.03	0.08	1.59	79.62
SD	2.41	2.00	0.13	0.22	0.23	2.61	0.01	0.02	0.09	2.47	0.06	0.03	0.02	0.02	0.22	0.01	0.03	1.04	3.83
Max	12.71	10.26	0.56	1.28	1.08	12.81	0.06	0.08	0.40	9.35	0.28	0.10	0.10	0.13	1.07	0.06	0.16	3.81	87.48
Min	2.96	2.75	0.12	0.41	0.06	2.83	0.01	0.01	0.08	1.40	0.03	0.02	0.02	0.03	0.03	0.02	0.04	0.41	67.09
CV	0.45	0.36	0.45	0.32	0.62	0.38	0.44	0.55	0.48	0.48	0.69	0.66	0.52	0.47	1.26	0.43	0.36	0.65	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

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

NNH (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	273	37.5	26.6	0.1	31.6	43.1	27.2	2.1	21.9	2.2	0.2	1.1	8E-3	0.29	3.80	1.29	3.31	8.96	0.27
SD	86	18.6	13.6	0.2	15.0	15.2	11.5	1.0	9.1	1.1	0.2	0.9	3E-3	0.14	1.86	0.56	1.63	4.51	0.18
Max	406	78.5	58.0	0.8	63.4	70.8	48.6	4.7	43.4	4.9	0.8	2.9	2E-2	0.63	7.82	2.80	8.11	20.39	0.72
Min	82	9.3	5.7	0.0	6.5	11.2	8.2	0.6	5.7	0.6	0.1	0.2	5E-3	0.13	0.81	0.53	1.08	3.03	0.08
CV	0.31	0.50	0.51	1.64	0.47	0.35	0.42	0.50	0.42	0.51	0.93	0.83	0.42	0.47	0.49	0.43	0.49	0.50	0.66
NNH (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.11	2.75	0.15	0.57	0.27	3.95	0.02	0.03	0.13	3.93	0.07	0.03	0.03	0.03	0.14	0.02	0.05	1.22	81.9
SD	2.03	1.19	0.10	0.19	0.18	1.94	0.01	0.02	0.06	2.10	0.05	0.02	0.01	0.01	0.19	0.01	0.03	0.88	2.9
Max	9.68	5.16	0.43	1.12	0.91	9.24	0.04	0.07	0.30	7.22	0.20	0.09	0.08	0.07	0.92	0.05	0.12	3.27	87.0
Min	0.87	0.97	0.04	0.38	0.05	1.64	0.01	0.01	0.05	1.07	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.25	76.6
CV	0.49	0.43	0.67	0.33	0.67	0.49	0.48	0.63	0.49	0.53	0.67	0.68	0.55	0.42	1.37	0.42	0.48	0.72	0.04
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.30: Statistical results chemical characterization (µg/m^3) of PM_{10} at NNH for summer (S) season

NNH (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	182	15.7	8.1	0.3	8.0	7.6	9.8	1.7	7.2	1.7	0.9	2.4	1E-3	0.03	4.55	3.92	9.07	21.32	0.20
SD	57	4.4	2.7	0.1	2.5	2.4	1.9	0.7	1.9	0.7	0.5	0.8	1E-4	0.01	2.87	2.06	3.52	8.81	0.07
Max	308	24.6	13.1	0.5	13.3	14.2	13.9	3.5	11.9	4.0	2.2	4.4	1E-3	0.05	14.32	9.85	15.60	35.77	0.34
Min	113	9.9	3.9	0.2	5.4	3.9	7.5	0.6	4.8	0.8	0.3	0.9	9E-4	0.01	1.29	1.61	5.03	10.63	0.09
CV	0.31	0.28	0.34	0.20	0.32	0.32	0.19	0.43	0.27	0.40	0.51	0.34	0.11	0.48	0.63	0.53	0.39	0.41	0.33
NNH (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.66	7.30	0.22	0.27	0.24	6.72	8E-3	0.03	0.05	0.39	0.04	0.02	1E-2	2E-2	0.07	3E-3	0.05	0.20	64.5
SD	1.91	2.77	0.07	0.03	0.23	2.57	2E-3	0.01	0.02	0.13	0.02	0.01	6E-3	1E-2	0.09	4E-4	0.01	0.11	3.6
Max	8.78	12.41	0.34	0.31	1.02	11.57	1E-2	0.06	0.09	0.70	0.07	0.03	2E-2	4E-2	0.32	3E-3	0.08	0.41	71.4
Min	2.14	3.57	0.12	0.21	0.09	3.36	6E-3	0.01	0.02	0.18	0.01	0.01	2E-3	5E-3	0.01	2E-3	0.03	0.06	57.7
CV	0.41	0.38	0.30	0.10	0.93	0.38	0.22	0.39	0.36	0.33	0.42	0.42	0.57	0.56	1.26	0.16	0.27	0.53	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

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

NNH (S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	71	11.0	6.7	0.2	5.6	5.5	7.0	0.8	4.6	0.9	0.3	0.5	7E-4	0.01	1.91	0.91	1.66	3.78	0.10
SD	30	3.1	2.3	0.0	2.0	1.9	1.6	0.3	1.4	0.4	0.2	0.2	9E-5	0.01	2.05	1.42	1.48	3.28	0.03
Max	189	17.2	10.9	0.3	10.1	10.4	11.4	1.5	8.3	1.8	1.2	1.0	9E-4	0.04	10.20	6.88	7.79	17.31	0.14
Min	44	6.9	3.2	0.2	3.1	2.6	5.3	0.3	3.0	0.4	0.1	0.2	6E-4	0.01	0.75	0.31	0.77	1.64	0.04
CV	0.42	0.28	0.34	0.11	0.35	0.34	0.23	0.41	0.29	0.41	0.89	0.42	0.12	0.56	1.08	1.55	0.90	0.87	0.30
NNH (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.45	1.36	0.09	0.21	0.17	1.22	6E-3	0.01	0.03	0.23	0.03	8E-3	6E-3	5E-3	0.05	1E-3	0.03	0.11	77.0
SD	0.98	1.39	0.02	0.03	0.21	1.18	1E-3	0.01	0.01	0.08	0.01	5E-3	4E-3	2E-3	0.06	4E-4	0.01	0.06	4.0
Max	5.10	7.16	0.12	0.26	0.90	5.93	1E-2	0.03	0.05	0.36	0.06	2E-2	1E-2	7E-3	0.20	2E-3	0.05	0.22	82.9
Min	0.74	0.62	0.06	0.14	0.03	0.53	5E-3	0.00	0.00	0.09	0.01	3E-3	6E-4	2E-3	0.01	5E-4	0.01	0.03	66.4
CV	0.68	1.02	0.22	0.15	1.18	0.96	0.18	0.42	0.35	0.33	0.49	0.56	0.62	0.32	1.26	0.37	0.46	0.60	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

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

NNH (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	0.65	0.64	0.65	0.07	0.83	0.70	0.67	0.12	0.77	0.58	-0.16	0.43	0.41
TC		1.00	1.00	0.99	-0.14	0.47	0.21	0.05	-0.03	0.21	0.38	0.04	0.20	-0.22
OC			1.00	0.98	-0.13	0.47	0.19	0.04	-0.03	0.20	0.37	0.01	0.20	-0.21
EC				1.00	-0.16	0.47	0.24	0.06	-0.03	0.23	0.40	0.08	0.19	-0.23
NO_3^-					0.13	0.44	1.00	0.87	0.10	0.79	0.37	0.10	0.18	0.15
SO_4^{-2}					0.16	0.44		1.00	0.25	0.80	0.50	-0.13	0.21	0.37
NH_4^+					-0.11	0.78			0.14	1.00	0.47	-0.12	0.20	0.30
Metals					0.33	0.40			0.17		0.22	-0.34	0.42	1.00

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

NNH (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	0.70	0.69	0.71	0.13	0.80	0.77	0.69	0.16	0.74	0.63	-0.10	0.41	0.64
TC		1.00	1.00	0.99	-0.09	0.48	0.33	0.11	0.00	0.19	0.47	0.03	0.16	0.08
OC			1.00	0.98	-0.07	0.48	0.31	0.09	-0.01	0.17	0.45	0.01	0.15	0.08
EC				1.00	-0.12	0.48	0.36	0.13	0.00	0.22	0.49	0.07	0.18	0.08
NO_3^-					0.19	0.48	1.00	0.87	0.09	0.76	0.47	0.10	0.26	0.44
SO_4^{-2}					0.17	0.46		1.00	0.06	0.82	0.56	-0.12	0.26	0.54
NH_4^+					-0.02	0.79			-0.01	1.00	0.52	-0.22	0.18	0.47
Metals					0.38	0.51			0.46		0.32	-0.17	0.62	1.00

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

NNH (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Metals
PM_{10}	1.00	0.52	0.46	0.52	0.26	0.59	0.67	0.52	0.60	0.26	0.79	0.68	0.35	0.97
TC		1.00	0.96	0.89	0.02	0.52	0.56	0.12	0.17	0.13	0.43	0.13	0.29	0.33
OC			1.00	0.71	0.01	0.45	0.45	0.04	0.10	0.05	0.36	0.03	0.22	0.28
EC				1.00	0.02	0.54	0.63	0.22	0.23	0.23	0.47	0.28	0.36	0.35
NO_3^-					0.14	0.78	1.00	0.58	0.55	0.61	0.73	0.47	0.21	0.54
SO_4^{-2}					0.05	0.41		1.00	0.66	0.47	0.49	0.55	0.37	0.48
NH_4^+					0.16	0.68			0.33	1.00	0.36	0.18	0.22	0.15
Metals					0.28	0.44			0.61		0.77	0.73	0.29	1.00

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

NNH (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	0.51	0.50	0.45	0.13	0.71	0.79	0.74	0.48	0.71	0.49	0.87	0.56	0.95
TC		1.00	0.95	0.90	0.20	0.51	0.56	0.24	0.15	0.27	0.16	0.21	0.47	0.27
OC			1.00	0.71	0.25	0.43	0.45	0.16	0.07	0.14	0.18	0.17	0.44	0.28
EC				1.00	0.09	0.52	0.62	0.30	0.23	0.41	0.10	0.23	0.42	0.21
NO_3^-					0.14	0.81	1.00	0.62	0.26	0.83	0.19	0.59	0.42	0.63
SO_4^{-2}					-0.20	0.49		1.00	0.61	0.65	0.45	0.68	0.31	0.69
NH_4^+					0.12	0.82			0.30	1.00	0.05	0.59	0.13	0.61
Metals					0.08	0.54			0.55		0.57	0.93	0.56	1.00

2.4.3 Jaipur House (JHS)

The sampling period was January 26 – February 18, 2019 for winter and April 20 – May 10, 2019 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.28) and summer (Figure 2.29). Average levels for winter and summer season were 153±47 and 65±12 µg/m^3 (for $PM_{2.5}$) and 201±48 and 202±42 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are about 2.5 times higher than the NAQS and PM_{10} is two times higher than the NAQS in winter. The $PM_{2.5}$ levels generally meet the standards, while PM_{10} is two times higher than the national standard in summer. A statistical summary of PM concentrations is presented in Tables 2.39 – 2.42 for the winter and summer seasons. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards, but PM_{10} levels were stable at the same level as in winter and continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from the soil surface during dust storms in the dry months of summer can contribute significantly to a coarse fraction.

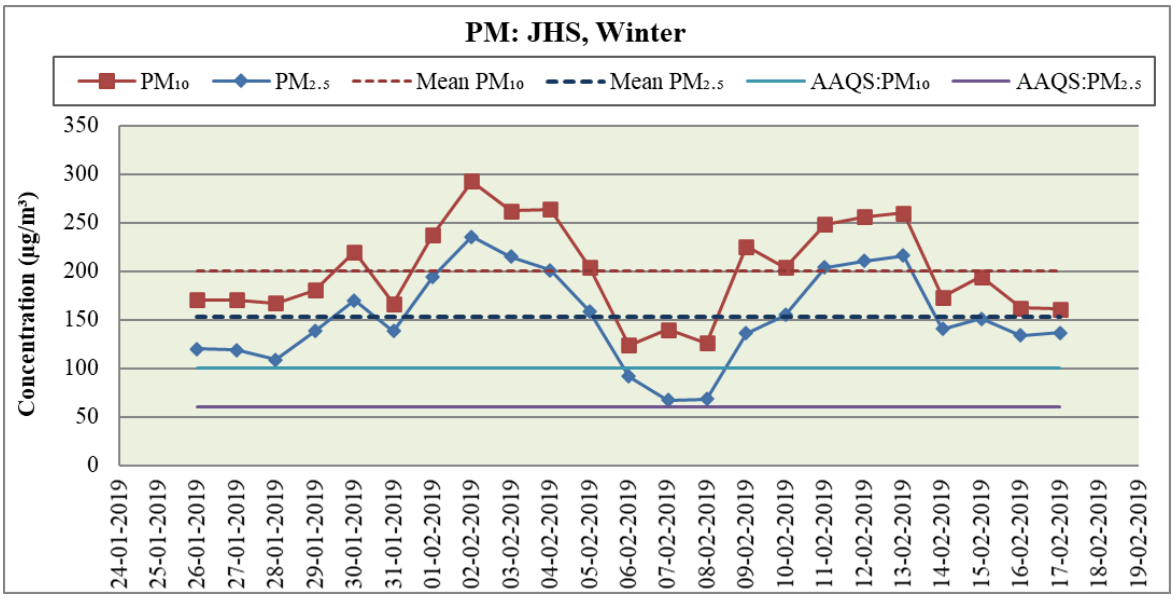


Figure 2.28: PM Concentrations at JHS for Winter Season

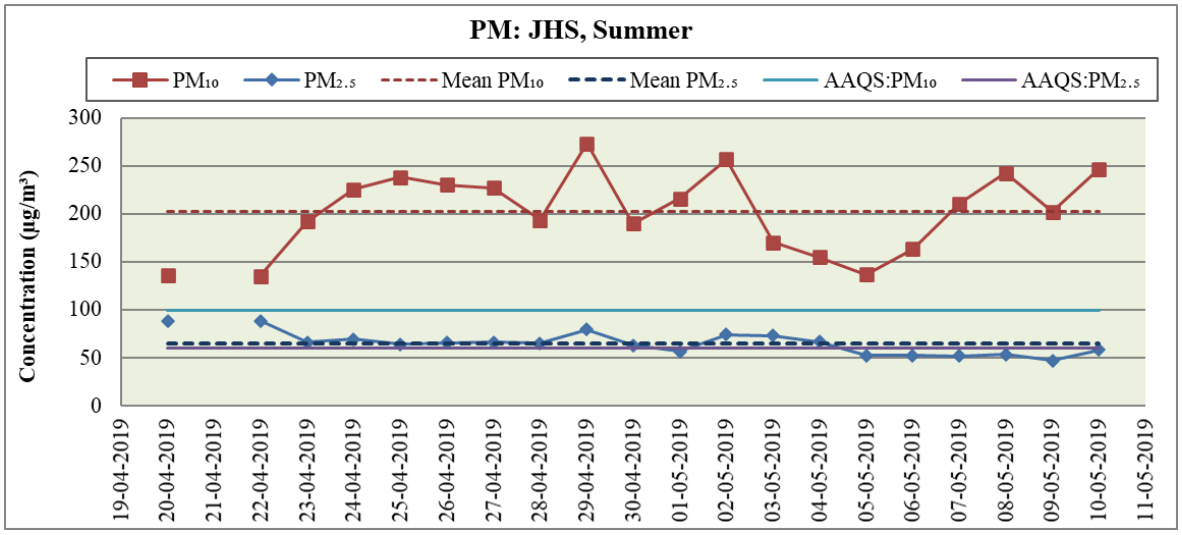


Figure 2.29: PM Concentrations at JHS for Summer Season

2.4.3.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.30) and summer (Figure 2.31) seasons. It was observed that SO_2 concentrations were low (mostly < 5.0 µg/m^3) and meet the air quality standard. NO_2 levels also under the national standard with an average of 20 days at 24.9±11.1 µg/m^3 in winter and 20.6±6.7 µg/m^3 in summer season (Table 2.36). The summer concentration of NO_2 dropped slightly with no significant change. Although, the 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 or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.32 and the statistical summary in Table 2.38. The total BTX level is observed 6.3±5.2 µg/m^3 (Benzene: 2.5 and Toluene: 2.9 µg/m^3) in winter and 10.9±3.9 µg/m^3 (Benzene: 3.9 and Toluene: 5.1 µg/m^3) in summer seasons. The BTX levels were high during summer than the winter.

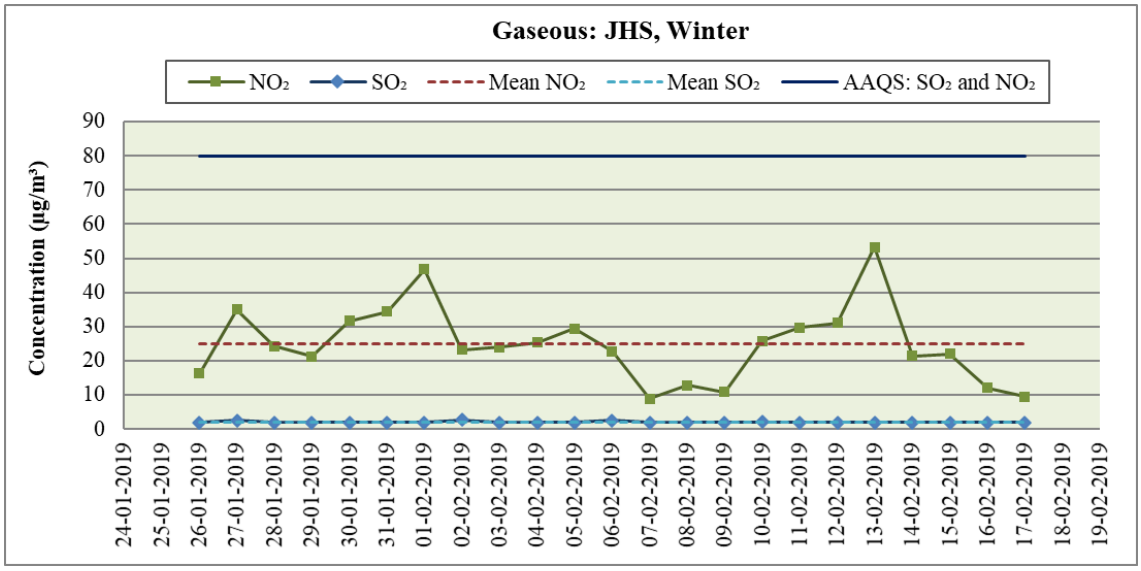


Figure 2.30: SO_2 and NO_2 Concentrations at JHS for Winter Season

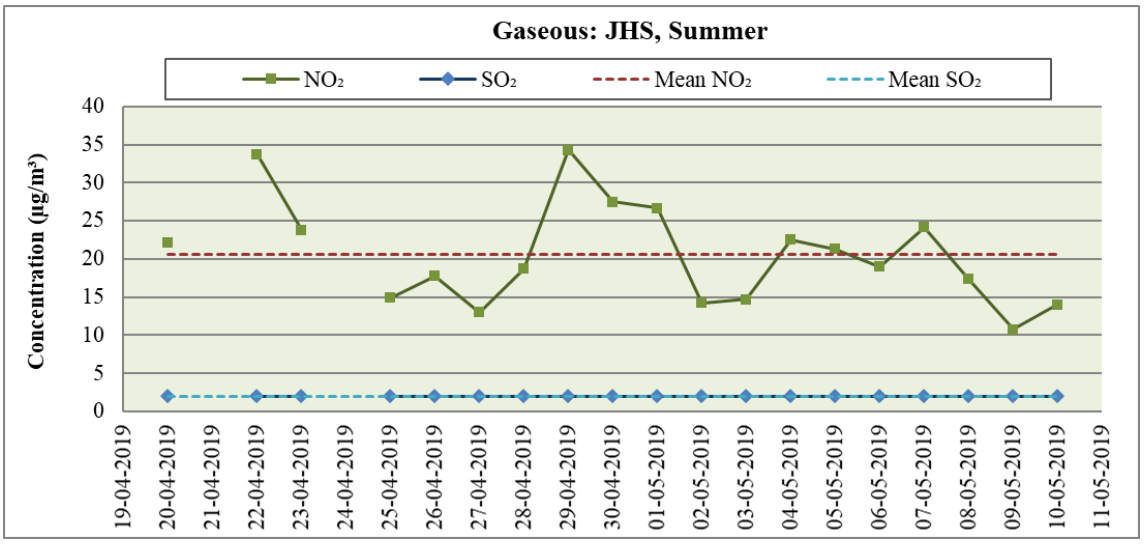


Figure 2.31: SO_2 and NO_2 Concentrations at JHS for Summer Season

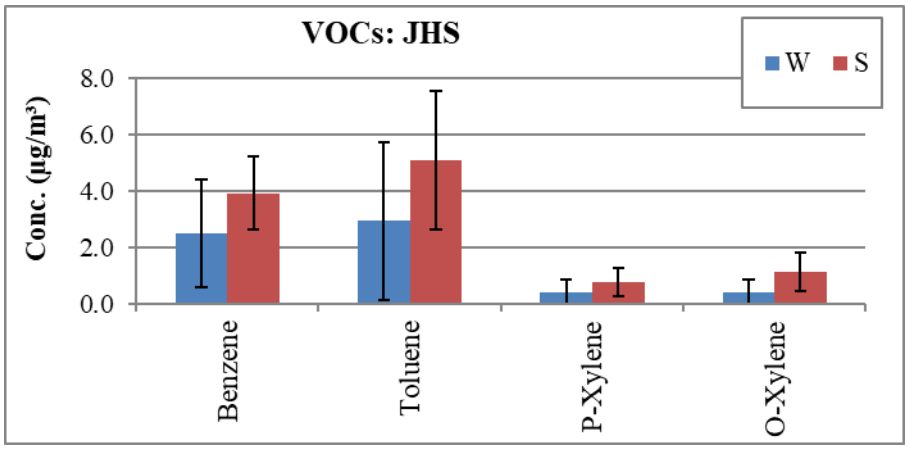


Figure 2.32: VOCs concentration at JHS

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 2.33 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (winter: 14.7±5.0 and summer: 12.5±3.7 µg/m^3) than the elemental carbon (winter: 9.5±4.0 and summer: 7.4±2.3 µg/m^3). It is also observed that the OC and EC are higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.37 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at JHS.

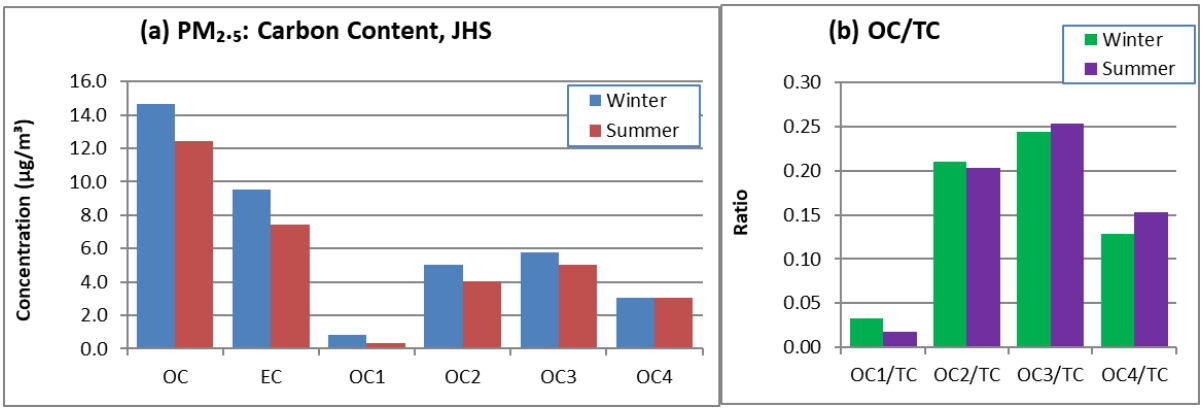


Figure 2.33: EC and OC Content in $PM_{2.5}$ at JHS

2.4.3.4 PAHs in $PM_{2.5}$

Figure 2.34 shows the average measured concentration of PAHs at JHS for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.38 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (62±24 ng/m^3) compared to summer season (14.5±10.9 ng/m^3). Major PAHs are InP (14.9 ng/m^3), B(ghi)P (11.3 ng/m^3), B(b)F (6.3 ng/m^3), DmP (6.1 ng/m^3) and Chr (4.6 ng/m^3) for winter season and B(b)F (3.7 ng/m^3), B(a)P (2.4 ng/m^3), B(k)F (1.59 ng/m^3), Phe (1.56 ng/m^3) and BeA (1.27 ng/m^3) for summer season.

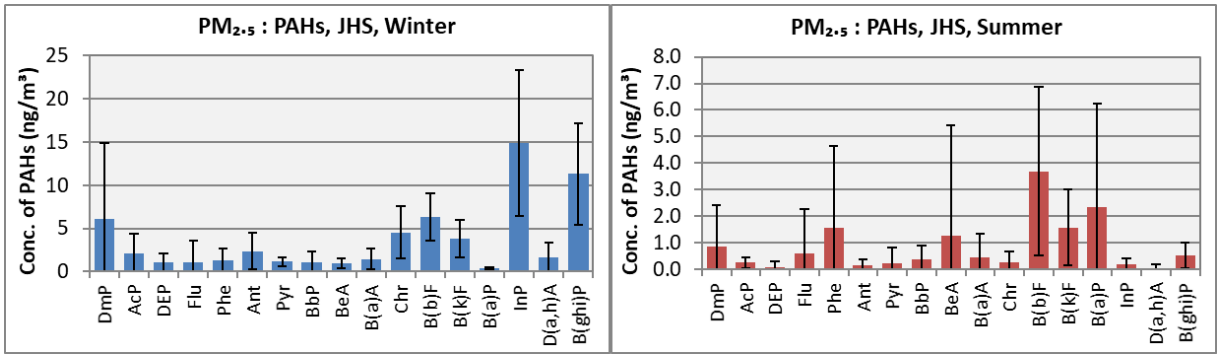


Figure 2.34: PAHs Concentrations in $PM_{2.5}$ at JHS

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

Graphical presentations of chemical species are shown for the winter and summer seasons for PM_{10} (Figure 2.35) and $PM_{2.5}$ (Figure 2.36). 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 Tables 2.39 – 2.42 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Tables 2.43 – 2.46 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 2.37 (a) and (b) for the winter season and Figure 2.38 (a) and (b) for the summer season.

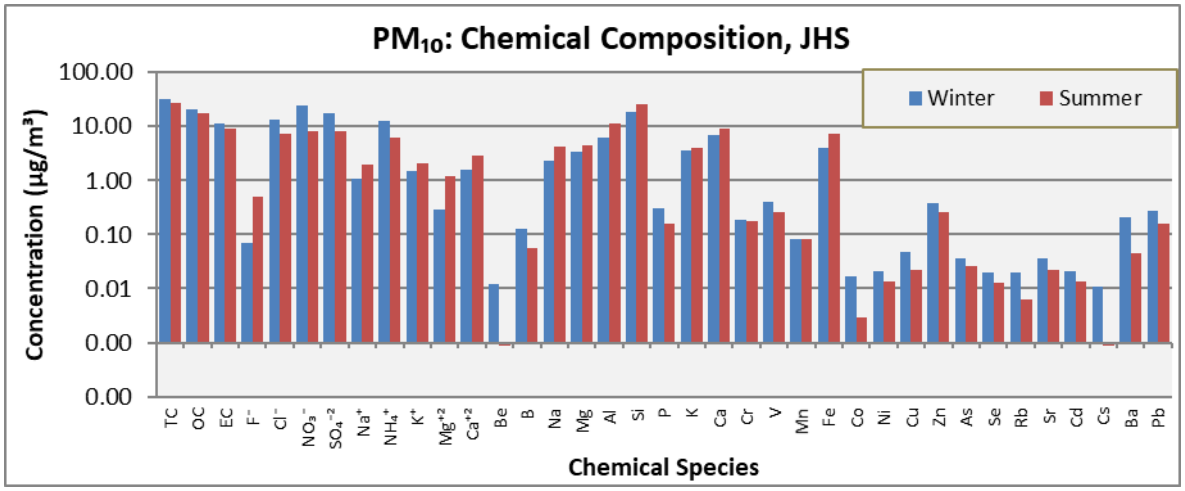


Figure 2.35: Concentrations of species in PM_{10} at JHS

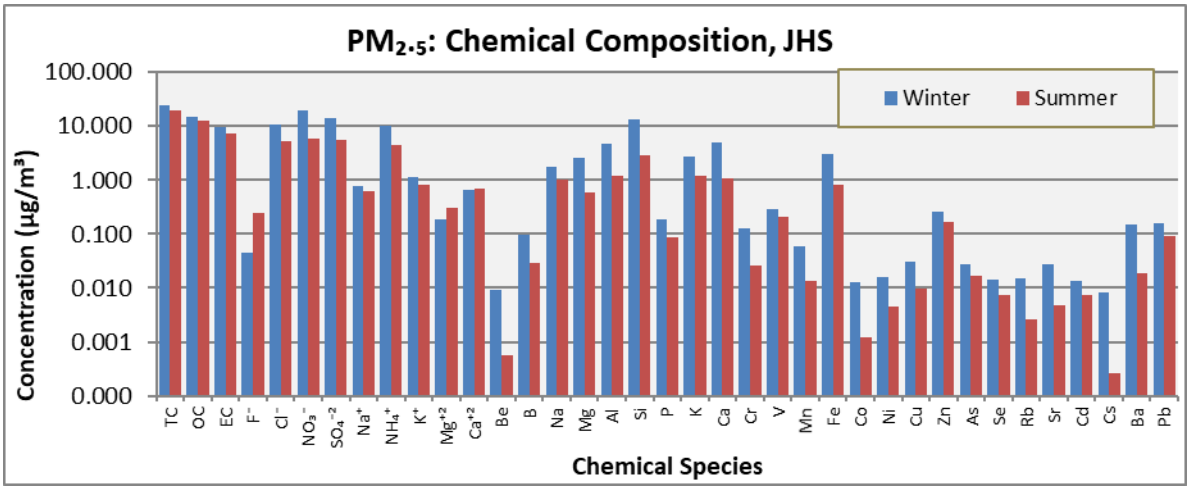
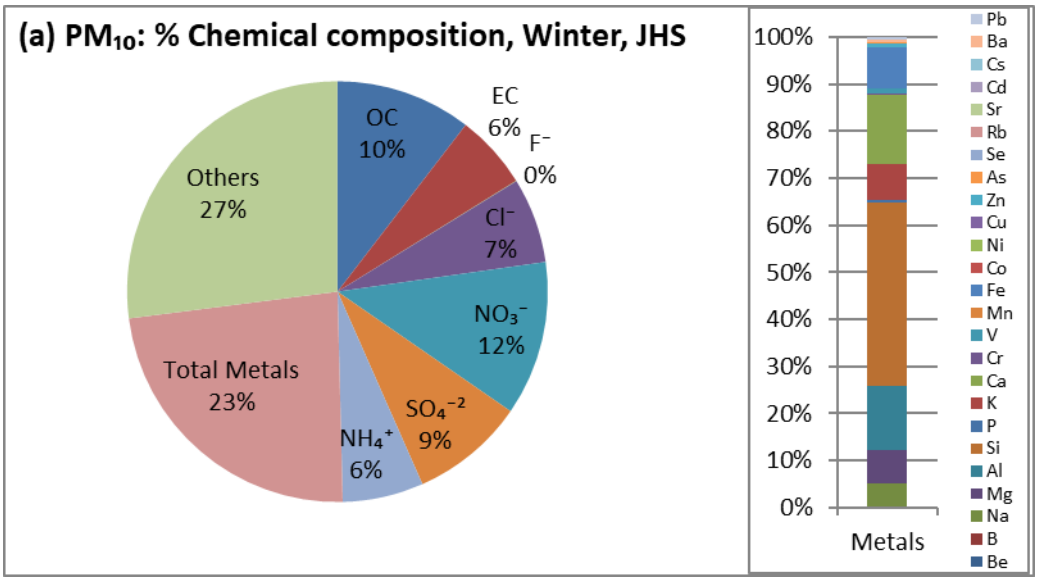


Figure 2.36: Concentrations of species in $PM_{2.5}$ at JHS



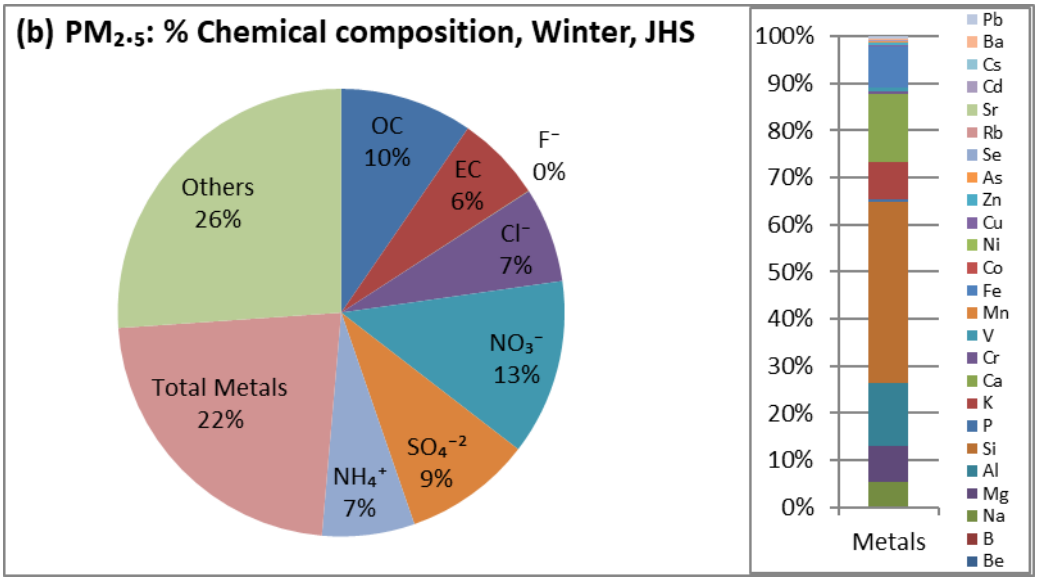


Figure 2.37: Percentage distribution of species in PM at JHS for Winter Season

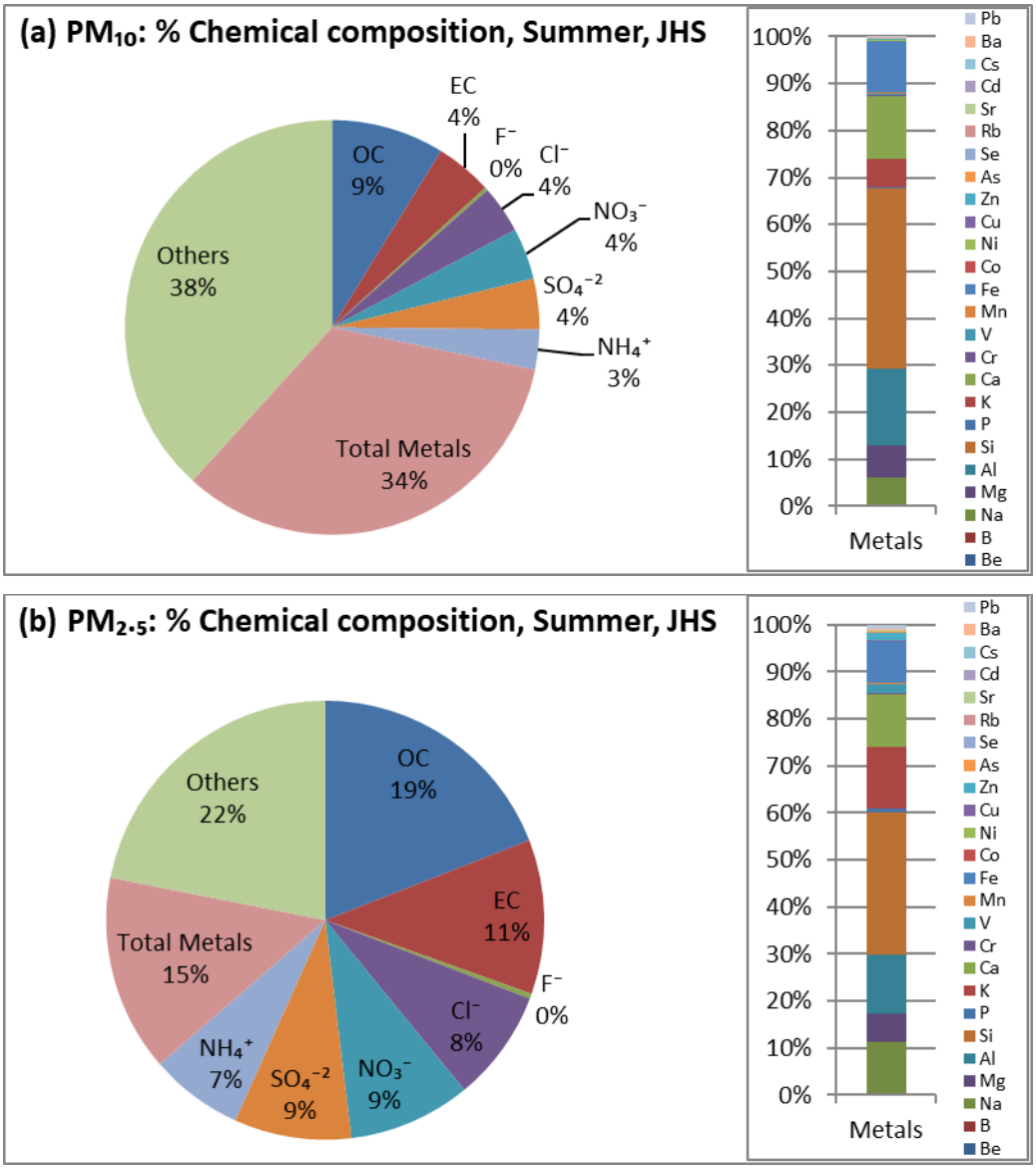


Figure 2.38: Percentage distribution of species in PM at JHS for Summer Season

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

The graphical compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.39) at JHS. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that a significant portion of PM has fine mode during winter (76%) than summer (35%). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, Be, B, P, V, Zn, As, Se, Cd and Pb; whereas, major species contributing in coarse mode are Mg^{+2}, Ca^{2+}, Mg, Al, Si, Ca, Cr, Mn and Fe.

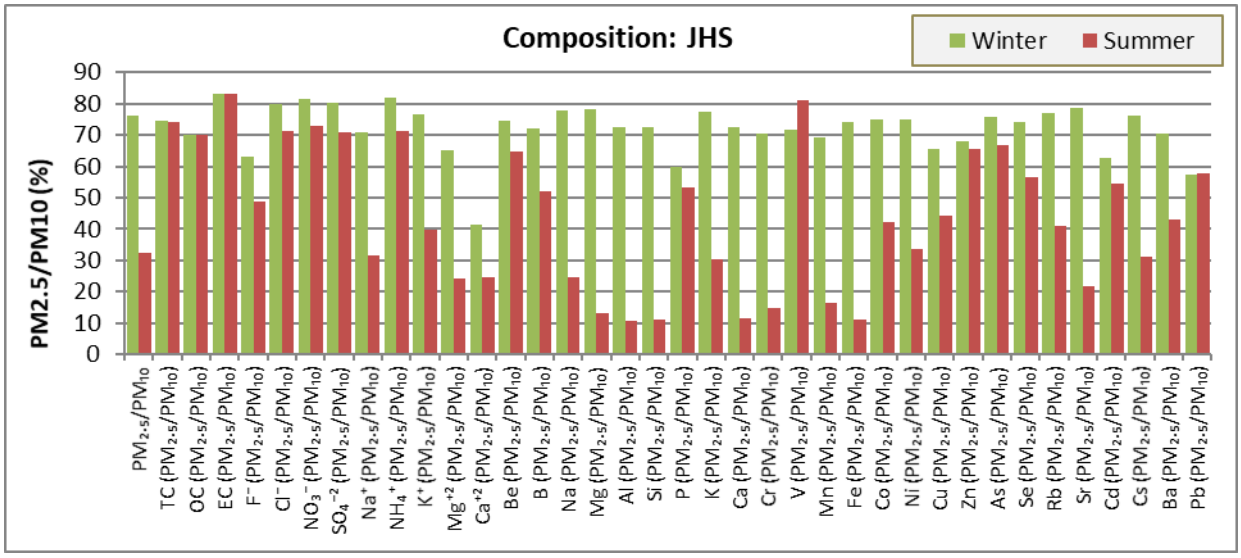


Figure 2.39: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at JHS

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

JHS (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.89	2.08	2.49	2.93	0.42	0.40	6.25
SD	11.13	0.20	1.92	2.79	0.43	0.45	5.24
Max	53.28	2.69	5.78	8.55	1.47	1.60	15.83
Min	8.95	2.00	0.33	0.19	0.02	0.02	0.56
CV	0.45	0.10	0.77	0.95	1.04	1.10	0.84
JHS (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	20.57	2.00	3.90	5.09	0.75	1.13	10.88
SD	6.69	0.00	1.30	2.48	0.50	0.69	3.87
Max	34.32	2.00	6.65	10.39	2.64	2.70	20.00
Min	10.77	2.00	2.03	2.19	0.25	0.35	5.09
CV	0.33	0.00	0.33	0.49	0.66	0.60	0.36

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

JHS (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	152.7	24.19	14.66	9.53	0.86	5.00	5.75	3.05	0.033	0.210	0.244	0.129
SD	47.2	8.91	5.00	4.02	0.53	1.68	1.92	1.04	0.009	0.016	0.035	0.020
Max	235.5	47.56	28.89	18.69	2.45	9.41	11.07	5.96	0.051	0.254	0.359	0.159
Min	67.2	4.90	3.70	1.21	0.15	1.25	1.59	0.71	0.015	0.181	0.205	0.090
CV	0.31	0.37	0.34	0.42	0.61	0.34	0.33	0.34	0.264	0.076	0.144	0.152
JHS (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	65.3	19.86	12.45	7.42	0.37	4.06	5.00	3.03	0.018	0.203	0.253	0.153
SD	11.6	5.46	3.69	2.29	0.19	1.23	1.52	1.00	0.006	0.014	0.039	0.022
Max	89.0	29.96	19.19	11.93	0.90	6.61	8.32	5.82	0.038	0.228	0.351	0.213
Min	47.1	10.91	6.99	3.35	0.14	2.01	2.49	1.67	0.008	0.180	0.206	0.112
CV	0.18	0.27	0.30	0.31	0.51	0.30	0.30	0.33	0.348	0.067	0.154	0.147

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

JHS (W)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	6.05	2.10	1.06	1.10	1.29	2.36	1.18	1.10	1.02	1.46	4.56	6.30	3.78	0.38	14.85	1.63	11.31	61.54
SD	8.88	2.35	1.02	2.45	1.44	2.13	0.52	1.29	0.57	1.21	3.05	2.75	2.16	0.14	8.44	1.76	5.89	23.97
Max	33.77	9.00	3.52	8.78	5.48	8.25	2.31	4.54	2.15	4.55	11.59	12.55	9.12	0.59	34.52	6.32	25.01	114.76
Min	0.36	0.29	0.10	0.00	0.43	0.86	0.17	0.29	0.26	0.19	0.44	1.52	0.62	0.10	0.79	0.00	1.07	22.29
CV	1.47	1.12	0.96	2.22	1.12	0.90	0.44	1.17	0.56	0.82	0.67	0.44	0.57	0.37	0.57	1.08	0.52	0.39
JHS (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	0.86	0.25	0.08	0.59	1.56	0.16	0.23	0.38	1.27	0.46	0.27	3.70	1.59	2.35	0.20	0.05	0.53	14.53
SD	1.56	0.22	0.24	1.68	3.08	0.22	0.59	0.51	4.17	0.87	0.41	3.19	1.41	3.89	0.23	0.13	0.49	10.93
Max	5.14	0.87	0.81	5.60	9.10	0.76	1.98	1.55	13.84	3.10	1.49	10.09	3.61	13.02	0.74	0.44	1.56	33.46
Min	0.00	0.10	0.00	0.00	0.00	0.02	0.00	0.07	0.00	0.16	0.11	0.08	0.19	0.05	0.00	0.00	0.13	2.11
CV	1.83	0.87	3.09	2.87	1.97	1.33	2.54	1.35	3.28	1.89	1.52	0.86	0.89	1.66	1.17	2.82	0.92	0.75

Table 2.39: Statistical results of chemical characterization (µg/m^3) of PM_{10} at JHS for winter (W) season

JHS (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	201	20.9	11.5	0.1	13.1	23.8	17.6	1.1	12.5	1.5	0.3	1.6	1E-2	0.13	2.29	3.34	6.38	18.19	0.31
SD	48	7.1	4.8	0.0	5.4	6.8	5.7	0.5	3.7	0.4	0.2	0.8	8E-3	0.07	0.96	1.11	2.24	6.14	0.26
Max	293	41.3	22.5	0.2	29.4	36.4	32.4	2.1	22.8	2.3	0.8	3.7	3E-2	0.29	4.74	5.64	11.40	31.27	1.34
Min	124	5.3	1.5	0.0	4.4	12.7	10.3	0.4	7.4	0.6	0.1	0.6	2E-3	0.04	0.60	1.09	2.71	7.47	0.03
CV	0.24	0.34	0.42	0.59	0.41	0.29	0.32	0.44	0.30	0.29	0.61	0.49	0.64	0.52	0.42	0.33	0.35	0.34	0.84
JHS (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.53	6.92	0.18	0.41	0.08	4.01	0.02	0.02	0.05	0.38	0.04	0.02	0.02	0.04	0.02	1E-2	0.21	0.27	73.10
SD	1.19	3.14	0.11	0.33	0.04	1.44	0.01	0.01	0.02	0.18	0.02	0.01	0.01	0.02	0.01	5E-3	0.20	0.28	3.36
Max	5.45	13.22	0.51	1.67	0.21	8.32	0.04	0.05	0.09	0.90	0.09	0.07	0.07	0.10	0.05	2E-2	0.58	1.42	78.82
Min	1.54	2.21	0.04	0.09	0.02	1.95	0.00	0.00	0.01	0.17	0.02	0.00	0.01	0.01	0.00	3E-3	0.03	0.05	66.57
CV	0.34	0.45	0.61	0.81	0.53	0.36	0.56	0.65	0.49	0.48	0.49	0.74	0.69	0.64	0.71	0.44	0.95	1.03	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.40: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at JHS for winter (W) season

JHS (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	153	14.7	9.5	0.0	10.5	19.4	14.1	0.8	10.2	1.1	0.2	0.7	9E-3	0.09	1.78	2.60	4.62	13.17	0.19
SD	47	5.0	4.0	0.0	4.5	7.0	5.5	0.5	3.6	0.4	0.1	0.3	6E-3	0.05	0.66	0.94	2.07	5.36	0.09
Max	236	28.9	18.7	0.1	23.4	31.9	28.0	1.9	18.7	1.9	0.6	1.8	2E-2	0.22	2.87	4.62	9.19	24.88	0.40
Min	67	3.7	1.2	0.0	3.4	7.4	6.3	0.1	4.1	0.5	0.0	0.3	7E-4	0.03	0.50	0.88	1.13	3.17	0.03
CV	0.31	0.34	0.42	0.40	0.43	0.36	0.39	0.60	0.35	0.33	0.71	0.49	0.66	0.55	0.37	0.36	0.45	0.41	0.48
JHS (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.74	5.00	0.13	0.30	0.06	2.98	1E-2	0.02	0.03	0.26	0.03	1E-2	0.02	0.03	1E-2	8E-3	0.15	0.16	74.21
SD	1.06	2.67	0.07	0.16	0.03	1.25	8E-3	0.01	0.01	0.12	0.01	9E-3	0.01	0.02	9E-3	4E-3	0.14	0.08	3.26
Max	4.57	11.10	0.25	0.70	0.12	6.86	3E-2	0.04	0.05	0.62	0.07	4E-2	0.05	0.09	3E-2	1E-2	0.48	0.35	78.40
Min	0.71	1.52	0.03	0.08	0.02	1.29	4E-4	0.00	0.00	0.13	0.01	3E-3	0.01	0.01	4E-4	2E-3	0.02	0.03	67.18
CV	0.39	0.53	0.52	0.54	0.52	0.42	0.62	0.65	0.49	0.48	0.50	0.60	0.68	0.71	0.68	0.46	0.93	0.50	0.04
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.41: Statistical results chemical characterization (µg/m^3) of PM_{10} at JHS for summer (S) season

JHS (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	202	17.8	8.9	0.5	7.5	8.1	8.0	2.0	6.3	2.0	1.2	2.8	9E-4	0.06	4.16	4.54	11.13	25.98	0.16
SD	42	5.3	2.8	0.9	1.8	1.7	2.4	0.7	1.7	0.7	0.5	0.8	1E-4	0.03	1.67	1.95	4.08	9.37	0.08
Max	273	27.4	14.4	4.3	10.6	11.2	12.7	3.8	9.3	3.3	2.2	4.5	1E-3	0.11	8.07	8.23	15.89	36.56	0.44
Min	136	10.0	4.0	0.3	4.1	5.6	3.9	1.2	3.7	1.0	0.4	1.6	7E-4	0.01	2.09	1.41	3.43	8.40	0.06
CV	0.21	0.30	0.31	1.73	0.23	0.20	0.30	0.34	0.27	0.32	0.37	0.30	0.13	0.51	0.40	0.43	0.37	0.36	0.50
JHS (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.03	9.05	0.18	0.25	0.08	7.48	3E-3	1E-2	0.02	0.26	0.03	0.01	6E-3	0.02	0.01	9E-4	0.04	0.16	62.43
SD	1.26	3.18	0.07	0.01	0.03	2.69	6E-4	7E-3	0.01	0.10	0.02	0.01	3E-3	0.01	0.01	2E-4	0.01	0.11	4.25
Max	6.45	13.62	0.32	0.27	0.14	12.28	4E-3	4E-2	0.04	0.45	0.06	0.03	1E-2	0.05	0.04	1E-3	0.06	0.43	73.42
Min	1.89	2.98	0.03	0.22	0.02	2.40	2E-3	7E-3	0.01	0.11	0.01	0.00	2E-3	0.00	0.00	3E-4	0.02	0.03	58.53
CV	0.31	0.35	0.38	0.05	0.34	0.36	0.20	0.53	0.41	0.38	0.71	0.51	0.48	0.51	0.85	0.29	0.22	0.71	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.42: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at JHS for summer (S) season

JHS(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	65	12.5	7.4	0.2	5.4	5.9	5.6	0.6	4.5	0.8	0.3	0.7	6E-4	0.03	1.03	0.59	1.18	2.86	0.09
SD	12	3.7	2.3	0.0	1.3	1.3	1.9	0.3	1.3	0.3	0.2	0.3	5E-5	0.02	0.45	0.23	0.38	0.89	0.03
Max	89	19.2	11.9	0.3	8.7	8.4	9.9	1.3	7.1	1.5	0.7	1.5	7E-4	0.08	1.93	1.10	1.93	4.51	0.11
Min	47	7.0	3.3	0.2	2.6	3.5	2.5	0.4	2.4	0.3	0.1	0.4	5E-4	0.01	0.52	0.29	0.67	1.66	0.03
CV	0.18	0.30	0.31	0.15	0.25	0.22	0.34	0.43	0.30	0.33	0.50	0.37	0.10	0.70	0.44	0.39	0.32	0.31	0.29
JHS(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.23	1.06	0.03	0.21	0.01	0.83	1E-3	5E-3	1E-2	0.17	0.02	7E-3	3E-3	5E-3	8E-3	3E-4	0.02	0.09	78.48
SD	0.44	0.39	0.01	0.03	0.01	0.23	3E-4	2E-3	5E-3	0.09	0.01	7E-3	1E-3	4E-3	7E-3	7E-5	0.01	0.07	3.65
Max	1.94	2.21	0.05	0.23	0.03	1.24	2E-3	9E-3	2E-2	0.33	0.06	2E-2	6E-3	1E-2	3E-2	4E-4	0.04	0.27	85.40
Min	0.69	0.52	0.00	0.13	0.00	0.45	8E-4	1E-3	1E-3	0.05	0.00	5E-4	7E-4	3E-4	2E-3	2E-4	0.01	0.01	71.47
CV	0.36	0.37	0.51	0.13	0.48	0.28	0.26	0.40	0.56	0.52	0.83	0.93	0.57	0.72	0.87	0.26	0.47	0.78	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.43: Correlation matrix for PM_{10} and its composition at JHS for winter season

JHS (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	0.73	0.69	0.77	0.44	0.56	0.65	0.66	0.39	0.88	0.62	0.13	-0.12	0.84
TC		1.00	0.99	0.98	0.22	0.49	0.39	0.53	0.00	0.63	0.49	0.06	-0.02	0.35
OC			1.00	0.95	0.22	0.46	0.35	0.51	-0.01	0.59	0.45	0.05	-0.02	0.30
EC				1.00	0.23	0.51	0.43	0.54	0.02	0.68	0.53	0.08	-0.01	0.41
NO_3^-					0.22	0.33	1.00	0.66	0.43	0.80	0.73	0.26	0.00	0.42
SO_4^{-2}					0.18	0.07		1.00	0.34	0.80	0.41	-0.02	-0.39	0.39
NH_4^+					0.34	0.48			0.39	1.00	0.62	0.23	-0.18	0.63
Metals					0.36	0.33			0.40		0.39	-0.03	-0.19	1.00

Table 2.44: Correlation matrix for $PM_{2.5}$ and its composition at JHS for winter season

JHS (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	0.68	0.64	0.72	0.25	0.65	0.79	0.78	0.54	0.93	0.63	0.16	-0.12	0.92
TC		1.00	0.99	0.98	0.35	0.55	0.40	0.52	0.05	0.63	0.46	0.02	-0.05	0.44
OC			1.00	0.95	0.36	0.51	0.35	0.49	0.04	0.57	0.45	0.01	-0.05	0.39
EC				1.00	0.34	0.58	0.44	0.54	0.05	0.68	0.47	0.03	-0.05	0.48
NO_3^-					0.14	0.50	1.00	0.75	0.47	0.89	0.65	0.21	-0.17	0.65
SO_4^{-2}					0.24	0.28		1.00	0.49	0.85	0.42	0.05	-0.22	0.64
NH_4^+					0.17	0.61			0.46	1.00	0.57	0.23	-0.19	0.79
Metals					0.13	0.49			0.56		0.52	0.10	-0.11	1.00

Table 2.45: Correlation matrix for PM_{10} and its composition at JHS for summer season

JHS (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	-0.14	-0.18	-0.04	0.26	-0.13	-0.07	0.03	0.56	-0.10	0.38	0.64	0.60	0.97
TC		1.00	0.96	0.84	0.33	-0.35	-0.24	-0.08	-0.15	0.00	0.27	-0.09	-0.20	-0.34
OC			1.00	0.66	0.43	-0.41	-0.31	-0.20	-0.16	-0.16	0.27	-0.04	-0.19	-0.34
EC				1.00	0.07	-0.15	-0.03	0.16	-0.10	0.31	0.22	-0.15	-0.18	-0.25
NO_3^-					-0.35	0.75	1.00	0.65	0.16	0.66	-0.23	-0.03	-0.23	-0.13
SO_4^{-2}					-0.39	0.76		1.00	0.04	0.71	-0.29	0.02	-0.15	-0.07
NH_4^+					-0.34	0.59			-0.10	1.00	-0.02	-0.15	-0.19	-0.21
Metals					0.22	-0.16			0.55		0.34	0.61	0.63	1.00

Table 2.46: Correlation matrix for $PM_{2.5}$ and its composition JHS for summer season

JHS (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	0.54	0.47	0.54	0.08	0.28	0.56	0.66	0.23	0.65	-0.36	0.75	0.65	0.61
TC		1.00	0.95	0.87	0.06	-0.31	-0.17	0.03	-0.16	-0.05	-0.06	0.25	0.00	-0.19
OC			1.00	0.66	0.10	-0.36	-0.22	-0.09	-0.16	-0.19	0.12	0.19	-0.03	-0.20
EC				1.00	-0.02	-0.16	-0.05	0.23	-0.12	0.16	-0.32	0.28	0.04	-0.14
NO_3^-					-0.29	0.72	1.00	0.64	0.51	0.62	-0.28	0.58	0.66	0.60
SO_4^{-2}					0.21	0.75		1.00	0.24	0.64	-0.49	0.41	0.65	0.44
NH_4^+					0.07	0.34			0.42	1.00	-0.43	0.69	0.74	0.67
Metals					-0.09	0.33			0.50		-0.18	0.69	0.70	1.00

2.4.4 Sikandra (SKD)

The sampling period was January 01 – 26, 2019 for winter and April 08 – May 03, 2019 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.40) and summer (Figure 2.41). Average levels for winter and summer season were 212±69 and 65±12 µg/m^3 (for $PM_{2.5}$) and 312±162 and 201±60 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are about 3.5 times higher than the NAQS and PM_{10} about 3.1 times higher than the NAQS in winter. The $PM_{2.5}$ levels marginally exceed the standards, while PM_{10} is two times higher than the national standard. A statistical summary of PM concentrations is presented in Tables 2.50 – 2.53 for the winter and summer seasons. In summer, $PM_{2.5}$ levels drop significantly and about to meet the national standards. PM_{10} levels also decreased but continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from the soil surface during dust storms in the dry months of summer can contribute significantly to a coarse fraction.

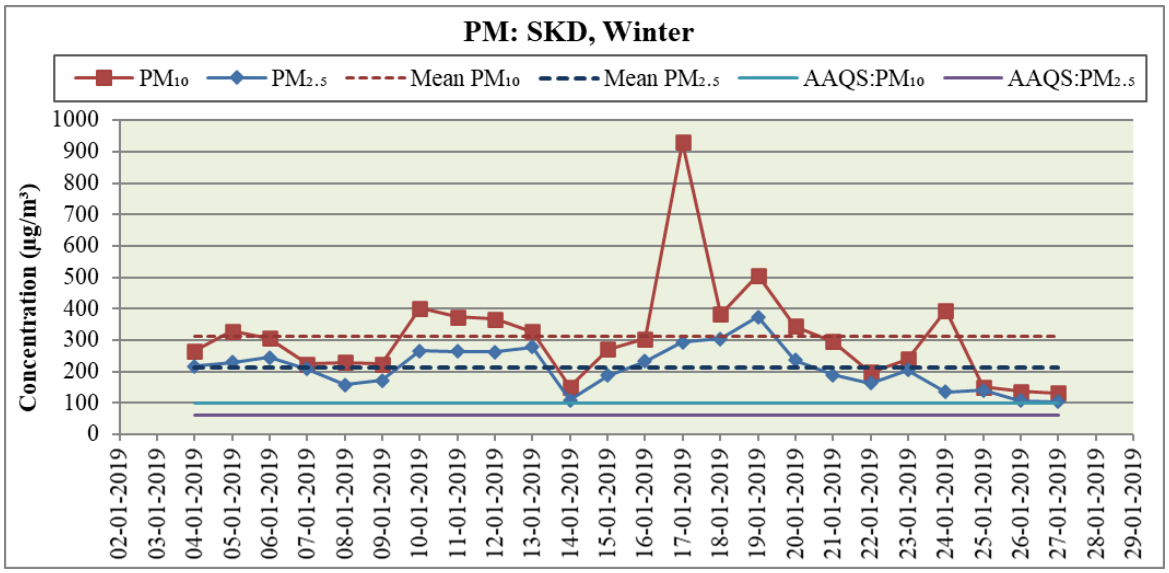


Figure 2.40: PM Concentrations at SKD for Winter Season

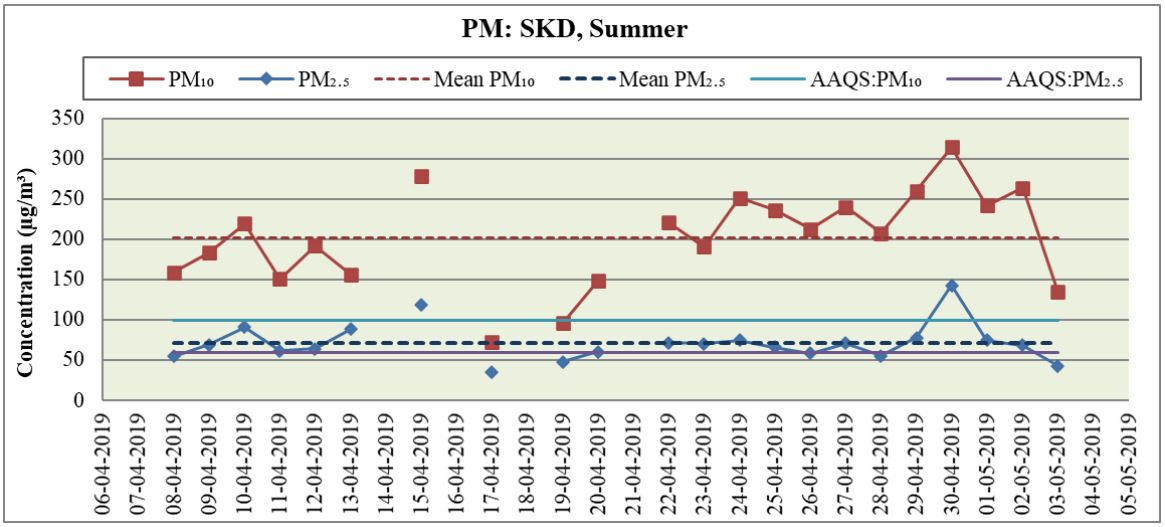


Figure 2.41: PM Concentrations at SKD for Summer Season

2.4.4.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.42) and summer (Figure 2.43) seasons. It was observed that SO_2 concentrations were low (mostly < 5.0 µg/m^3) and meet the air quality standard. NO_2 levels also under the national standard with an average of 20 days at 30.0±13.4 µg/m^3 in winter and 17.7±12.1 µg/m^3 in summer season (Table 2.47). The summer concentration of NO_2 dropped significantly. Although the NO_2 is certainly a matter of concern, these values can largely be attributed to vehicular pollution and DG sets. Variation in NO_2 is due to variability in meteorology and the presence of occasional local sources like DG sets, traffic jams or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.44 and the statistical summary in Table 2.47. The total BTX level is observed 9.9±10.0 µg/m^3 (Benzene: 3.9 and Toluene: 5.4 µg/m^3) in winter and 20.4±9.3 µg/m^3 (Benzene: 5.9 and Toluene: 13.2 µg/m^3) in summer seasons. The BTX levels were high during summer than in the winter.

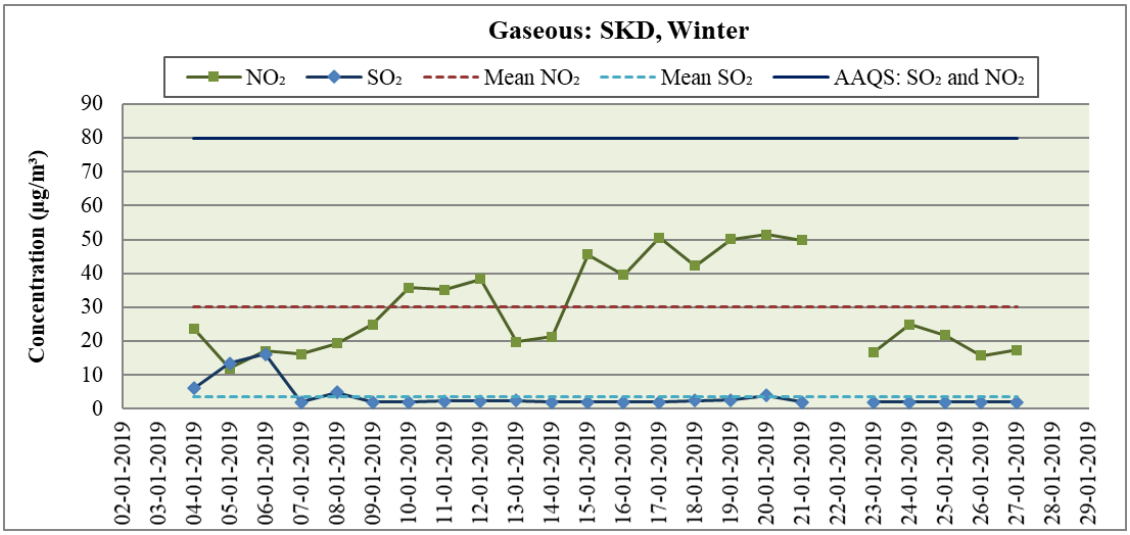


Figure 2.42: SO_2 and NO_2 Concentrations at SKD for Winter Season

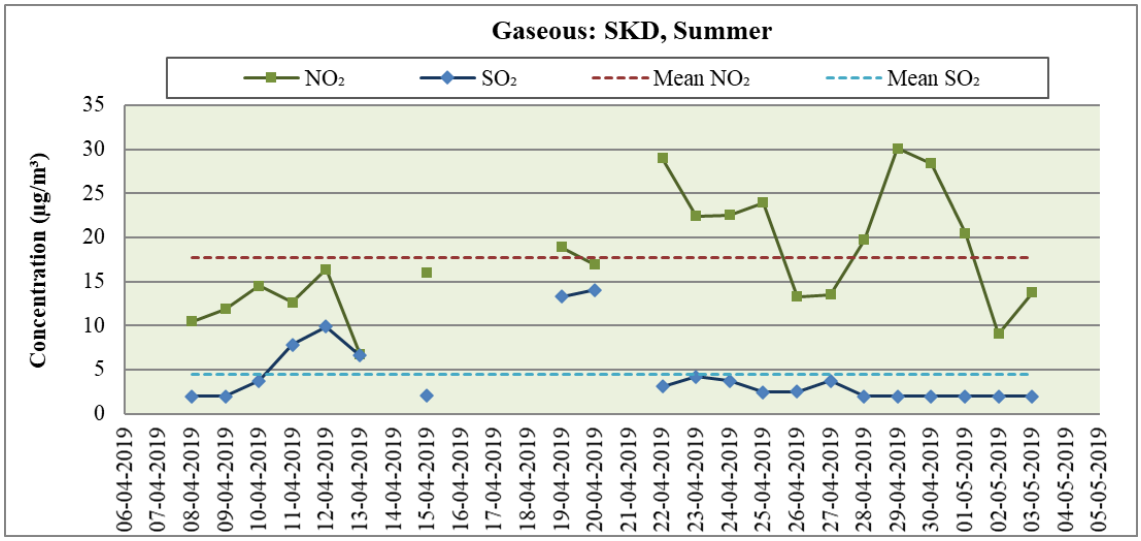


Figure 2.43: SO_2 and NO_2 Concentrations at SKD for Summer Season

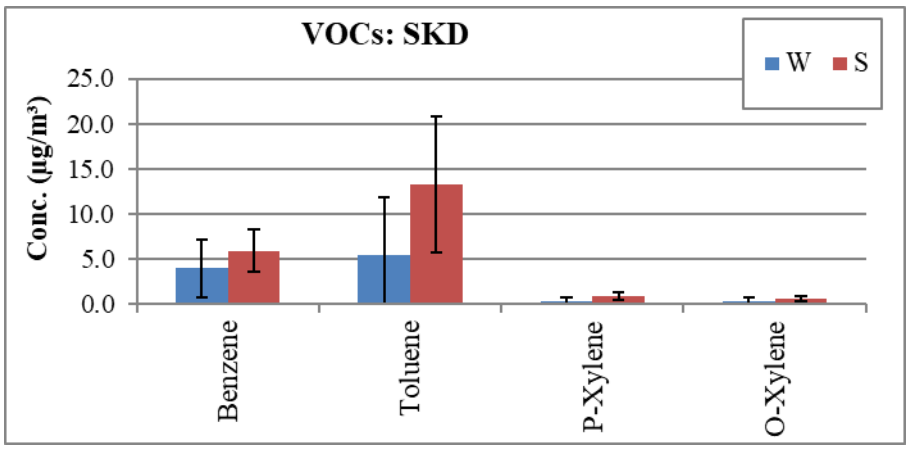


Figure 2.44: VOCs concentration at SKD

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 2.45 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (winter: 30.7±15.4 and summer: 13.3±7.5 µg/m^3) than the elemental carbon (winter: 24.1±12.3 and summer: 8.1±2.8 µg/m^3). It is also observed that the OC and EC are higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.48 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at SKD.

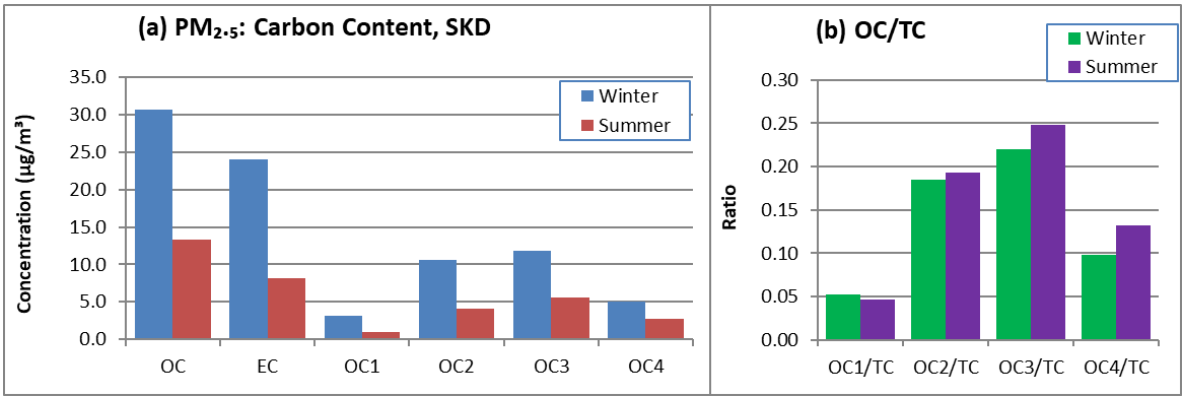


Figure 2.45: EC and OC Content in $PM_{2.5}$ at SKD

2.4.4.4 PAHs in $PM_{2.5}$

Figure 2.46 shows the average measured concentration of PAHs at SKD for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.49 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (169±76 ng/m^3) compared to summer season (24±20 ng/m^3). Major PAHs are InP (42.7 ng/m^3), B(ghi)P (30.3 ng/m^3), Chr (18.1 ng/m^3), B(b)F (17.0 ng/m^3) and Ant (13.9 ng/m^3) for winter season and B(b)F (3.27 ng/m^3), InP (2.69 ng/m^3), B(ghi)P (2.66 ng/m^3), B(k)F (2.57 ng/m^3) and Chr (2.56 ng/m^3) for summer season.

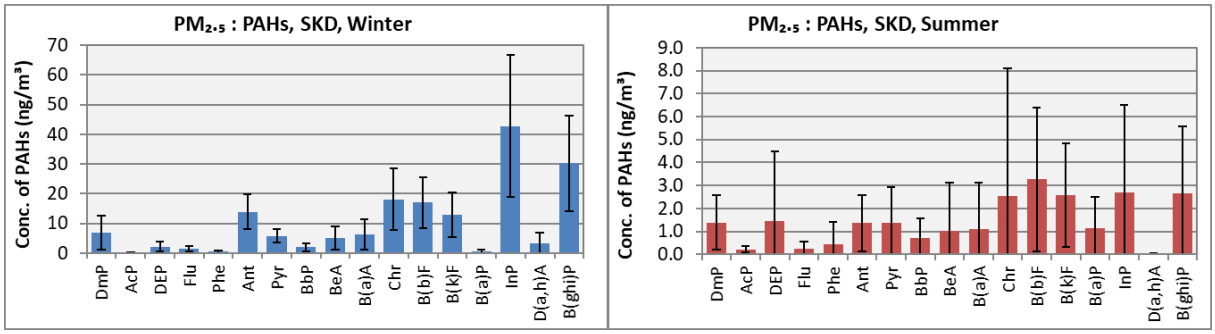


Figure 2.46: PAHs Concentrations in $PM_{2.5}$ at SKD

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

Graphical presentations of chemical species are shown for the winter and summer season at SKD for PM_{10} (Figure 2.47) and $PM_{2.5}$ (Figure 2.48). 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 Tables 2.50 – 2.53 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Tables 2.54 – 2.57 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 2.49 (a) and (b) for the winter season and Figure 2.50 (a) and (b) for the summer season.

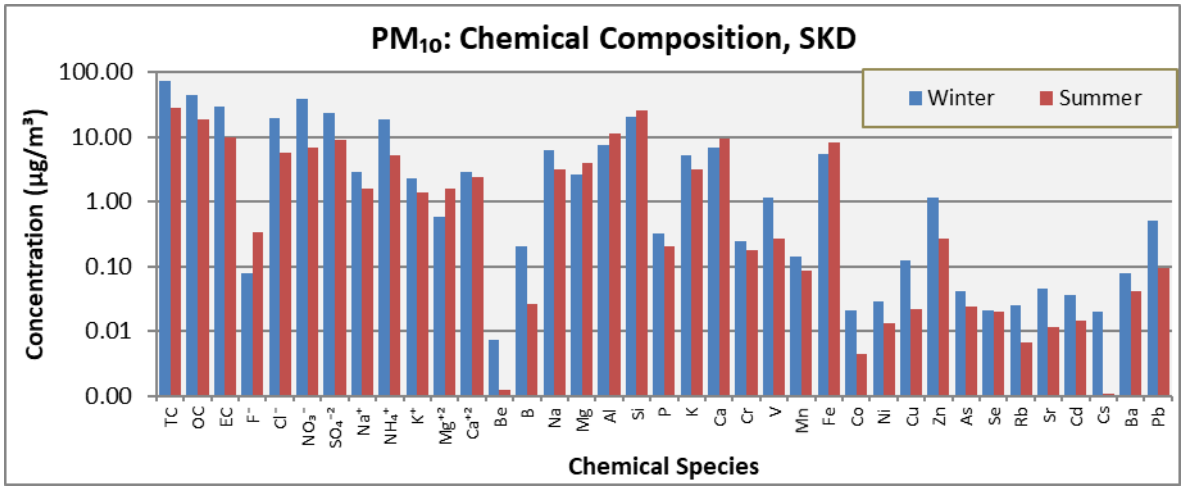


Figure 2.47: Concentrations of species in PM_{10} at SKD

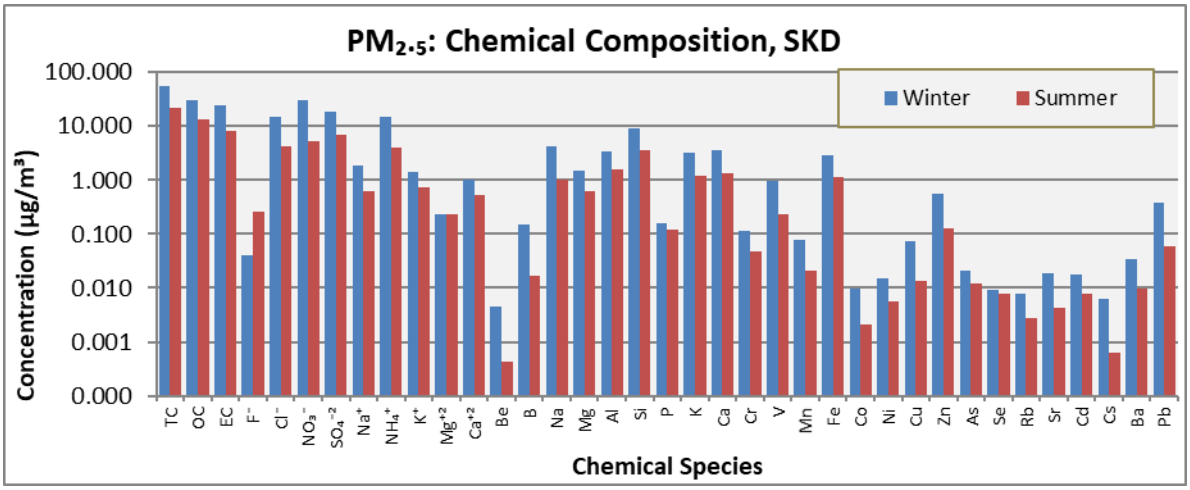


Figure 2.48: Concentrations of species in $PM_{2.5}$ at SKD

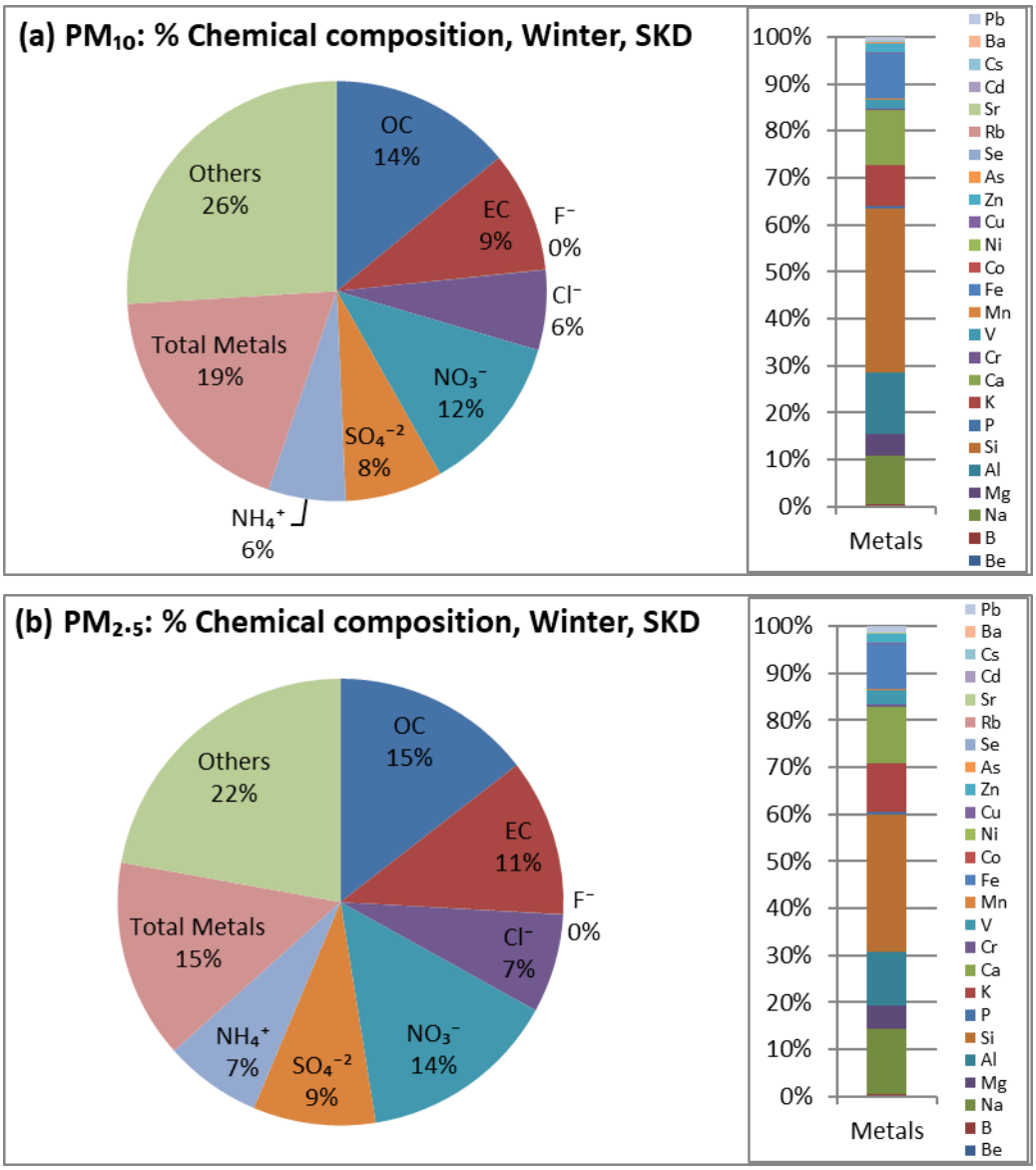


Figure 2.49: Percentage distribution of species in PM at SKD for Winter Season

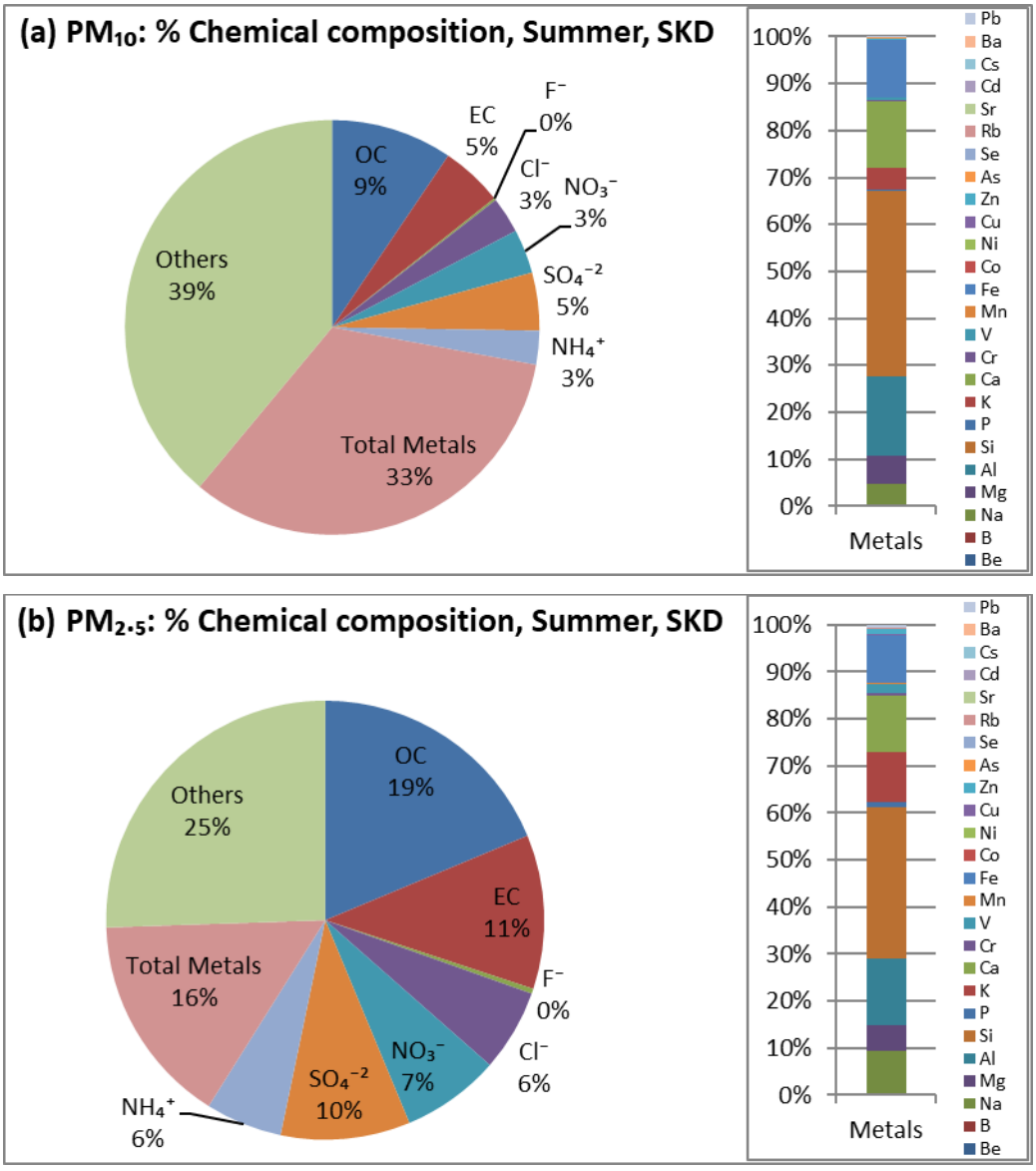


Figure 2.50: Percentage distribution of species in PM at SKD for Summer Season

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

The graphical compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.51) at SKD. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (68%) than summer (35%). The major species contributing to fine mode are TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, K^+, B, V, Cu and Pb; whereas major species contributing in coarse mode are Ca^{+2}, Mg^{+2}, Al, Si, Ca, Cr, Mn, Fe, Co, Se, Rb, Sr and Ba.

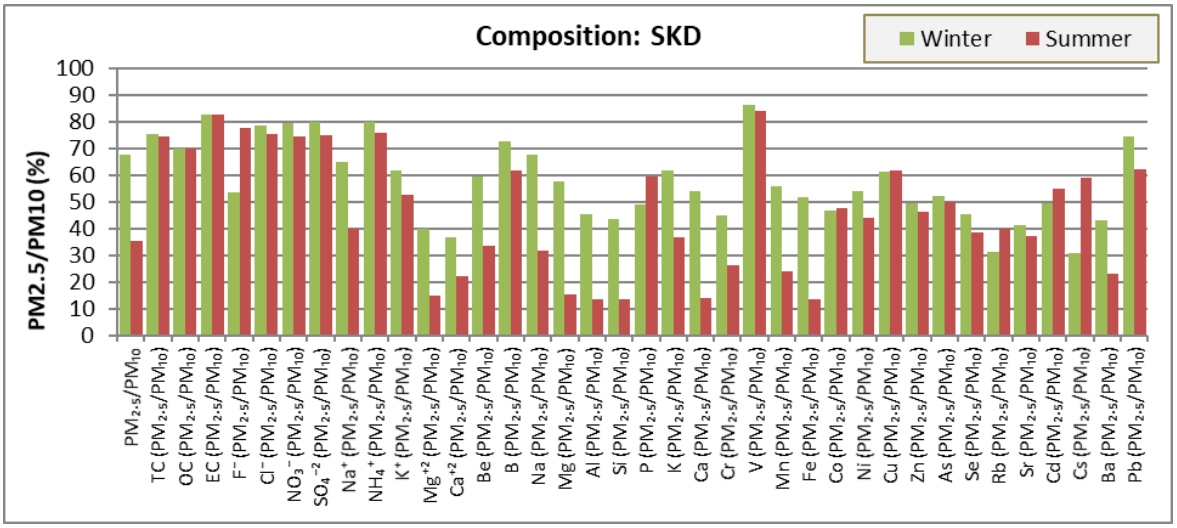


Figure 2.51: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at SKD

Table 2.47: Statistical results of gaseous pollutants (µg/m^3) at SKD for winter (W) and summer (S) seasons

SKD (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	29.99	3.59	3.91	5.38	0.30	0.25	9.85
SD	13.43	3.71	3.17	6.45	0.42	0.37	10.05
Max	51.51	16.18	12.59	22.38	1.81	1.56	38.34
Min	11.94	2.00	0.58	0.39	0.03	0.02	1.22
CV	0.45	1.03	0.81	1.20	1.41	1.45	1.02
SKD (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	17.67	4.44	5.86	13.24	0.76	0.53	20.40
SD	6.60	3.75	2.30	7.59	0.43	0.29	9.32
Max	30.14	14.04	10.37	27.70	1.73	1.23	37.47
Min	6.71	2.00	2.54	1.90	0.28	0.11	5.42
CV	0.37	0.84	0.39	0.57	0.57	0.56	0.46

Table 2.48: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at SKD for winter (W) and summer (S) seasons

SKD (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	211.6	55.03	30.70	24.06	3.15	10.65	11.87	5.02	0.052	0.185	0.220	0.098
SD	68.9	26.92	15.42	12.25	2.31	6.02	5.52	1.95	0.014	0.047	0.026	0.024
Max	374.5	117.99	64.82	53.26	9.22	23.72	24.48	9.45	0.087	0.225	0.291	0.143
Min	104.4	20.71	8.75	8.14	0.74	0.00	4.48	2.35	0.034	0.000	0.176	0.061
CV	0.33	0.49	0.50	0.51	0.73	0.57	0.47	0.39	0.266	0.251	0.116	0.245
SKD (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	71.3	21.43	13.34	8.09	1.01	4.03	5.56	2.74	0.047	0.193	0.248	0.132
SD	23.8	6.96	5.28	2.65	0.41	1.11	3.74	0.70	0.012	0.043	0.060	0.024
Max	143.0	42.81	33.07	13.57	2.10	6.40	21.41	4.65	0.084	0.366	0.500	0.190
Min	34.8	11.79	7.53	2.80	0.41	2.13	2.87	1.66	0.027	0.135	0.190	0.092
CV	0.33	0.32	0.40	0.33	0.41	0.27	0.67	0.25	0.250	0.222	0.241	0.186

Table 2.49: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at SKD for winter (W) and summer (S) seasons

SKD (W)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	6.93	0.23	2.18	1.36	0.48	13.87	5.82	1.96	4.99	6.29	18.09	17.00	12.81	0.46	42.68	3.32	30.25	168.74
SD	5.74	0.11	1.69	0.86	0.52	5.90	2.27	1.41	3.84	5.09	10.30	8.56	7.55	0.60	23.88	3.69	16.03	75.61
Max	21.53	0.43	6.39	2.66	1.55	24.45	9.00	5.24	13.67	15.47	34.62	32.81	26.45	2.20	81.25	11.68	58.22	310.76
Min	0.32	0.11	0.00	0.00	0.00	5.90	1.83	0.74	1.13	0.72	3.45	4.09	2.61	0.05	6.59	0.07	5.51	57.52
CV	0.83	0.46	0.77	0.63	1.09	0.43	0.39	0.72	0.77	0.81	0.57	0.50	0.59	1.29	0.56	1.11	0.53	0.45
SKD (S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.38	0.21	1.45	0.23	0.43	1.36	1.35	0.70	1.04	1.12	2.56	3.27	2.57	1.15	2.69	0.01	2.66	24.16
SD	1.19	0.14	3.03	0.33	0.99	1.22	1.55	0.85	2.08	2.02	5.56	3.13	2.25	1.35	3.80	0.03	2.90	20.31
Max	3.10	0.47	10.81	0.89	3.45	3.55	4.46	2.51	5.77	6.90	16.59	9.17	7.69	5.20	9.89	0.08	7.30	67.73
Min	0.08	0.10	0.00	0.00	0.00	0.02	0.00	0.09	0.00	0.17	0.11	0.10	0.43	0.30	0.00	0.00	0.22	3.48
CV	0.86	0.66	2.09	1.44	2.31	0.90	1.15	1.22	2.00	1.81	2.17	0.96	0.88	1.18	1.41	1.94	1.09	0.84

Table 2.50: Statistical results of chemical characterization (µg/m^3) of PM_{10} at SKD for winter (W) season

SKD (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	312	43.9	29.0	0.1	19.2	38.2	23.5	2.8	18.6	2.3	0.6	2.8	7E-3	0.21	6.21	2.66	7.64	20.32	0.33
SD	162	22.0	14.8	0.1	8.9	17.2	11.3	1.6	8.2	1.0	0.4	2.2	4E-3	0.10	2.71	1.75	8.27	22.49	0.29
Max	929	92.6	64.2	0.3	48.6	93.6	60.8	5.8	46.0	4.8	1.8	9.1	2E-2	0.43	11.85	7.10	42.15	112.98	1.45
Min	132	12.5	9.8	0.0	7.1	17.7	8.1	1.1	5.8	1.0	0.1	0.5	4E-3	0.05	2.14	0.66	1.74	4.37	0.10
CV	0.52	0.50	0.51	0.93	0.46	0.45	0.48	0.56	0.44	0.44	0.74	0.78	0.50	0.46	0.44	0.66	1.08	1.11	0.89
SKD (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.21	6.74	0.25	1.15	0.14	5.55	0.02	0.03	0.12	1.14	0.04	0.02	0.03	0.04	0.04	0.02	0.08	0.50	75.37
SD	5.16	5.79	0.18	0.55	0.10	5.42	0.01	0.02	0.16	1.12	0.03	0.01	0.01	0.02	0.02	0.01	0.05	0.45	4.82
Max	28.06	31.17	0.70	2.97	0.47	28.52	0.04	0.08	0.79	4.24	0.14	0.05	0.05	0.08	0.12	0.04	0.20	1.86	81.68
Min	2.09	1.98	0.06	0.40	0.05	1.66	0.01	0.01	0.03	0.07	0.02	0.00	0.00	0.02	0.01	0.00	0.03	0.08	61.14
CV	0.99	0.86	0.74	0.48	0.68	0.98	0.34	0.53	1.26	0.98	0.70	0.49	0.49	0.36	0.65	0.41	0.62	0.88	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.51: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at SKD for winter (W) season

SKD (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	212	30.7	24.1	0.0	15.2	30.5	18.8	1.8	14.9	1.5	0.2	1.0	4E-3	0.15	4.21	1.54	3.49	8.90	0.16
SD	69	15.4	12.2	0.0	5.7	11.5	7.8	0.8	5.8	0.6	0.2	0.5	3E-3	0.06	1.79	0.99	1.41	4.03	0.10
Max	375	64.8	53.3	0.1	29.1	56.5	36.2	4.3	28.2	2.8	0.9	2.2	2E-2	0.28	8.97	4.85	7.87	22.27	0.43
Min	104	8.7	8.1	0.0	6.2	13.9	6.7	0.9	4.9	0.4	0.1	0.4	2E-3	0.03	1.75	0.55	1.32	3.49	0.05
CV	0.33	0.50	0.51	0.98	0.37	0.38	0.41	0.44	0.39	0.41	0.85	0.49	0.63	0.41	0.42	0.65	0.40	0.45	0.61
SKD (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.21	3.66	0.11	0.99	0.08	2.88	1E-2	0.02	0.08	0.57	0.02	0.01	8E-3	0.02	0.02	6E-3	0.03	0.38	77.85
SD	1.51	1.65	0.07	0.46	0.04	1.53	6E-3	0.01	0.08	0.67	0.01	0.01	4E-3	0.01	0.01	4E-3	0.02	0.32	2.65
Max	7.48	9.29	0.33	2.42	0.19	7.05	3E-2	0.03	0.41	3.28	0.06	0.03	2E-2	0.04	0.05	1E-2	0.07	1.45	81.79
Min	1.30	1.53	0.03	0.35	0.03	0.80	2E-3	0.01	0.01	0.06	0.00	0.00	3E-3	0.00	0.00	8E-4	0.01	0.06	72.63
CV	0.47	0.45	0.61	0.46	0.55	0.53	0.60	0.47	1.12	1.18	0.68	0.59	0.48	0.54	0.68	0.67	0.61	0.85	0.03
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.52: Statistical results chemical characterization (µg/m^3) of PM_{10} at SKD for summer (S) season

SKD (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	201	19.1	9.7	0.3	5.7	6.9	9.1	1.6	5.3	1.4	1.6	2.4	1E-3	0.03	3.20	3.93	11.28	26.32	0.20
SD	60	7.5	3.2	0.1	2.1	2.3	2.8	0.7	1.9	0.4	0.6	1.0	2E-3	0.02	1.89	1.67	4.17	9.50	0.08
Max	314	47.2	16.3	0.8	12.8	12.3	15.3	3.1	11.0	2.2	2.6	4.0	1E-2	0.09	8.00	6.69	17.86	41.11	0.39
Min	73	10.8	3.4	0.3	2.5	2.5	2.5	0.7	1.4	0.3	0.4	0.4	4E-4	0.01	1.00	0.73	2.87	6.84	0.14
CV	0.30	0.40	0.33	0.33	0.38	0.33	0.31	0.43	0.36	0.27	0.41	0.40	1.65	0.59	0.59	0.43	0.37	0.36	0.39
SKD (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.18	9.47	0.18	0.27	0.09	8.07	4E-3	0.01	0.02	0.27	0.02	0.02	7E-3	1E-2	1E-2	1E-3	0.04	0.09	61.61
SD	0.82	3.41	0.07	0.02	0.03	3.02	3E-3	0.01	0.01	0.24	0.02	0.01	2E-3	6E-3	8E-3	3E-4	0.01	0.04	2.87
Max	4.14	14.30	0.31	0.34	0.14	13.11	1E-2	0.05	0.06	1.30	0.07	0.05	1E-2	3E-2	4E-2	2E-3	0.07	0.18	66.98
Min	0.58	2.50	0.01	0.24	0.01	1.57	1E-3	0.00	0.00	0.11	0.00	0.00	3E-3	4E-3	7E-3	6E-4	0.02	0.03	57.49
CV	0.26	0.36	0.40	0.09	0.40	0.37	0.65	0.88	0.67	0.90	0.67	0.76	0.30	0.49	0.54	0.26	0.35	0.48	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.53: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at SKD for summer (S) season

SKD (S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	71	13.3	8.1	0.3	4.3	5.2	6.8	0.6	4.0	0.7	0.2	0.5	4E-4	0.02	1.02	0.61	1.56	3.56	0.12
SD	24	5.3	2.6	0.0	1.6	1.7	2.2	0.2	1.4	0.2	0.1	0.3	2E-4	0.01	0.35	0.35	0.80	1.77	0.06
Max	143	33.1	13.6	0.5	9.2	9.4	12.4	1.1	7.9	1.4	0.5	1.5	1E-3	0.03	2.03	1.77	4.46	9.86	0.33
Min	35	7.5	2.8	0.2	1.8	1.7	1.8	0.3	1.2	0.1	0.1	0.2	3E-4	0.01	0.54	0.28	0.64	1.41	0.06
CV	0.33	0.40	0.33	0.19	0.38	0.33	0.32	0.29	0.35	0.34	0.42	0.53	0.50	0.39	0.34	0.58	0.51	0.50	0.46
SKD (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.18	1.35	0.05	0.23	0.02	1.11	2E-3	6E-3	0.01	0.13	1E-2	8E-3	3E-3	4E-3	8E-3	6E-4	9E-3	0.06	75.05
SD	0.52	0.72	0.04	0.03	0.02	0.69	2E-3	7E-3	0.01	0.06	1E-2	6E-3	1E-3	3E-3	5E-3	3E-4	7E-3	0.03	2.61
Max	2.36	3.99	0.17	0.32	0.08	3.70	6E-3	4E-2	0.04	0.28	4E-2	2E-2	5E-3	2E-2	2E-2	1E-3	3E-2	0.13	80.05
Min	0.14	0.45	0.00	0.18	0.00	0.32	4E-4	1E-3	0.00	0.06	2E-3	6E-4	1E-3	7E-5	2E-3	3E-4	2E-3	0.02	69.90
CV	0.44	0.53	0.86	0.12	0.82	0.62	0.91	1.25	0.64	0.45	0.88	0.78	0.39	0.75	0.64	0.40	0.71	0.59	0.03
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.54: Correlation Matrix for PM_{10} and its composition at SKD for winter season

SKD (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	0.52	0.50	0.54	0.65	0.91	0.78	0.74	0.35	0.81	0.84	0.40	0.58	0.94
TC		1.00	0.99	0.98	0.47	0.62	0.19	0.15	0.42	0.29	0.63	0.65	0.67	0.25
OC			1.00	0.94	0.45	0.59	0.15	0.09	0.45	0.24	0.57	0.71	0.63	0.23
EC				1.00	0.47	0.64	0.24	0.23	0.36	0.36	0.70	0.54	0.70	0.27
NO_3^-					0.25	0.65	1.00	0.89	0.20	0.88	0.68	0.22	0.35	0.72
SO_4^{-2}					0.32	0.67		1.00	0.13	0.90	0.73	-0.05	0.38	0.70
NH_4^+					0.43	0.75			0.26	1.00	0.72	0.12	0.34	0.73
Metals					0.63	0.80			0.26		0.70	0.24	0.44	1.00

Table 2.55: Correlation matrix for $PM_{2.5}$ and its composition at SKD for winter season

SKD (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	0.82	0.78	0.85	0.48	0.84	0.61	0.61	0.23	0.68	0.69	0.01	0.39	0.83
TC		1.00	0.99	0.98	0.46	0.73	0.17	0.11	0.05	0.26	0.55	0.12	0.25	0.54
OC			1.00	0.94	0.42	0.70	0.14	0.05	0.06	0.21	0.49	0.18	0.26	0.49
EC				1.00	0.48	0.75	0.24	0.20	0.05	0.34	0.61	0.05	0.26	0.59
NO_3^-					0.11	0.44	1.00	0.86	0.44	0.82	0.49	0.03	0.19	0.43
SO_4^{-2}					0.18	0.46		1.00	0.39	0.87	0.48	-0.19	0.29	0.52
NH_4^+					0.25	0.61			0.40	1.00	0.55	-0.08	0.17	0.47
Metals					0.49	0.58			0.11		0.61	-0.02	0.46	1.00

Table 2.56: Correlation matrix for PM_{10} and its composition at SKD for summer season

SKD (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	0.67	0.58	0.63	-0.37	0.52	0.54	0.62	0.48	0.71	0.63	0.66	0.51	0.95
TC		1.00	0.96	0.72	0.00	0.44	0.37	0.44	0.16	0.48	0.58	0.27	0.24	0.43
OC			1.00	0.49	0.16	0.38	0.23	0.27	0.17	0.43	0.50	0.27	0.20	0.35
EC				1.00	-0.38	0.42	0.56	0.69	0.06	0.42	0.54	0.15	0.24	0.45
NO_3^-					-0.39	0.76	1.00	0.84	0.14	0.78	0.45	0.24	0.02	0.43
SO_4^{-2}					-0.47	0.59		1.00	0.14	0.71	0.56	0.31	0.13	0.50
NH_4^+					-0.39	0.81			0.40	1.00	0.62	0.49	0.28	0.62
Metals					-0.40	0.39			0.55		0.52	0.71	0.57	1.00

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

SKD (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	0.77	0.67	-0.23	0.76	0.72	0.74	0.71	0.83	0.63	0.72	0.52	0.94
TC		1.00	0.94	0.75	-0.16	0.47	0.41	0.48	0.63	0.51	0.55	0.66	0.58	0.66
OC			1.00	0.49	0.05	0.40	0.25	0.26	0.67	0.46	0.45	0.69	0.74	0.63
EC				1.00	-0.53	0.45	0.58	0.73	0.33	0.43	0.54	0.37	0.04	0.47
NO_3^-					-0.38	0.75	1.00	0.84	0.32	0.76	0.47	0.30	-0.01	0.66
SO_4^{-2}					-0.46	0.61		1.00	0.43	0.67	0.62	0.40	-0.05	0.67
NH_4^+					-0.28	0.78			0.60	1.00	0.61	0.63	0.31	0.82
Metals					-0.14	0.72			0.72		0.53	0.72	0.57	1.00

2.4.5 Taj Mahal (TAJ)

The sampling period was December 05 – 27, 2018 for winter and June 01 – 30, 2019 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.52) and summer (Figure 2.53). Average levels for winter and summer season were 250±53 and 61±22 µg/m^3 (for $PM_{2.5}$) and 334±84 and 184±21 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are 4.2 times higher than the NAQS and PM_{10} is 3.3 times higher than the NAQS in winter. The $PM_{2.5}$ levels generally meet the standards, while PM_{10} is 1.8 times higher than the national standard in summer. A statistical summary of PM concentrations is presented in Table 2.61 – 2.64 for the winter and summer seasons. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards. PM_{10} levels also were dropped significantly but continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from the soil surface during dust storms in the dry months of summer can contribute significantly to a coarse fraction.

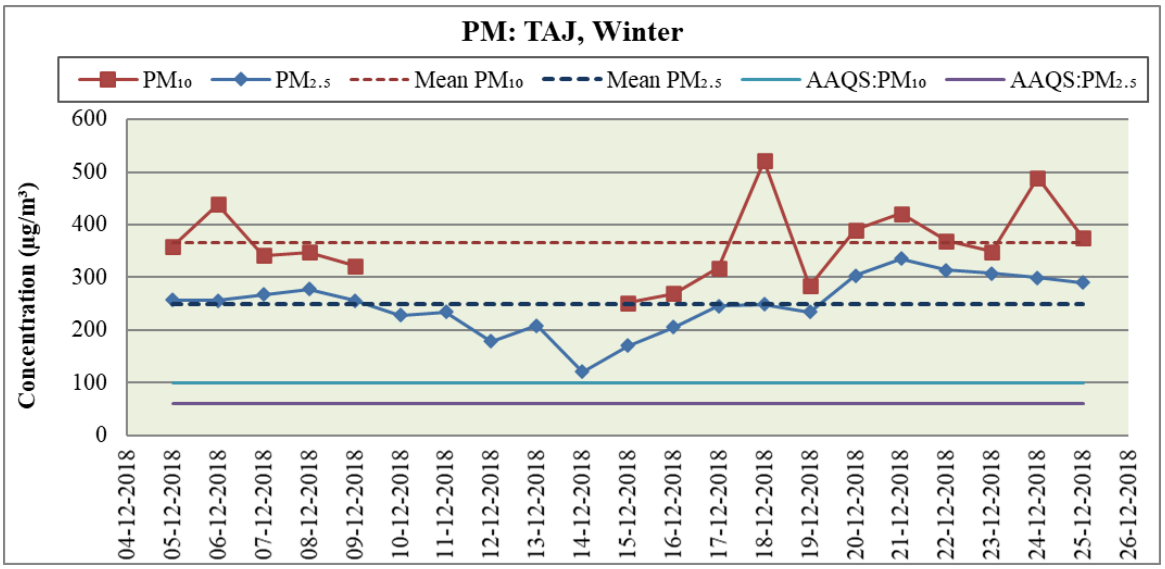


Figure 2.52: PM Concentrations at TAJ for Winter Season

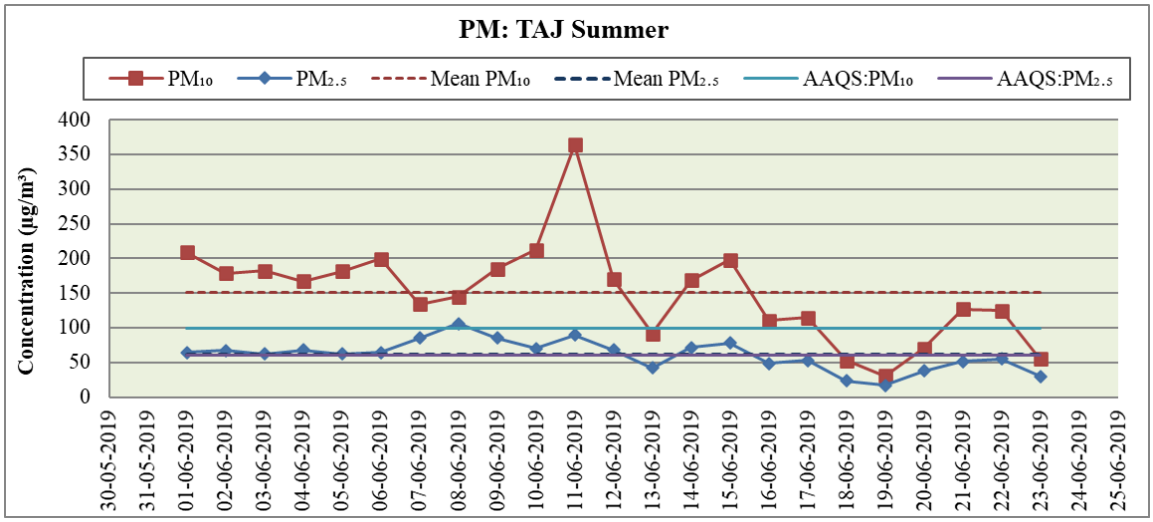


Figure 2.53: PM Concentrations at TAJ for Summer Season

2.4.5.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.54) and summer (Figure 2.55) seasons. It was observed that SO_2 concentrations were low (mostly < 6.0 µg/m^3) and meet the air quality standard. NO_2 levels also under the national standard with an average of 20 days at 27±12 µg/m^3 in winter and 13±8 µg/m^3 in summer season (Table 2.58). The summer concentration of NO_2 dropped significantly. Although, the 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 or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.56 and the statistical summary in Table 2.58. The total BTX level is observed 4.9±3.6 µg/m^3 (Benzene: 2.6 and Toluene: 1.6 µg/m^3) in winter and 6.6±2.3 µg/m^3 (Benzene: 2.6 and Toluene: 2.2 µg/m^3) in summer seasons. The BTX levels were high during summer than in the winter.

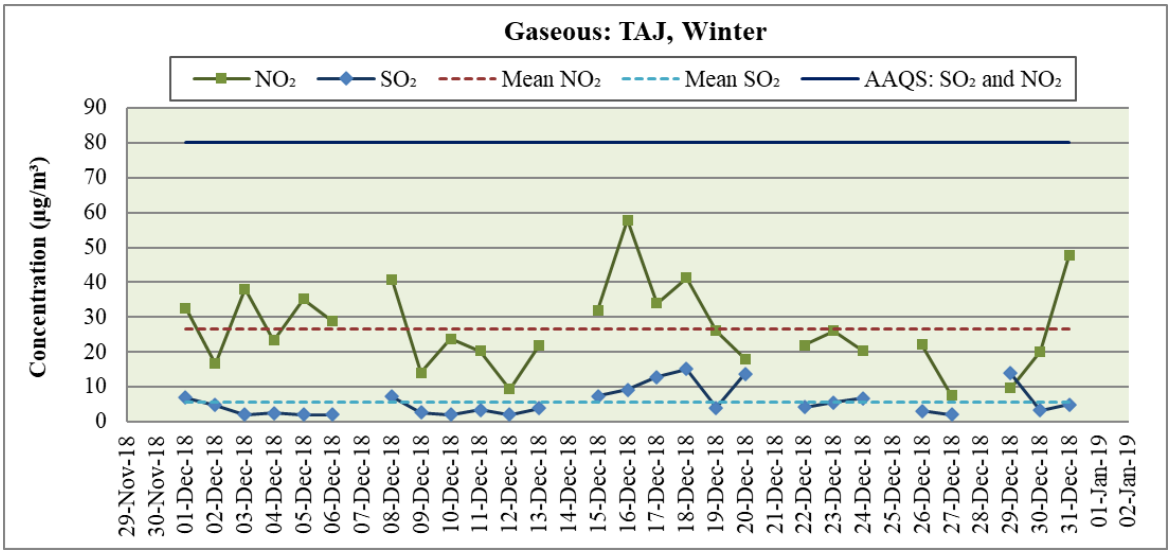


Figure 2.54: SO_2 and NO_2 Concentrations at TAJ for Winter Season

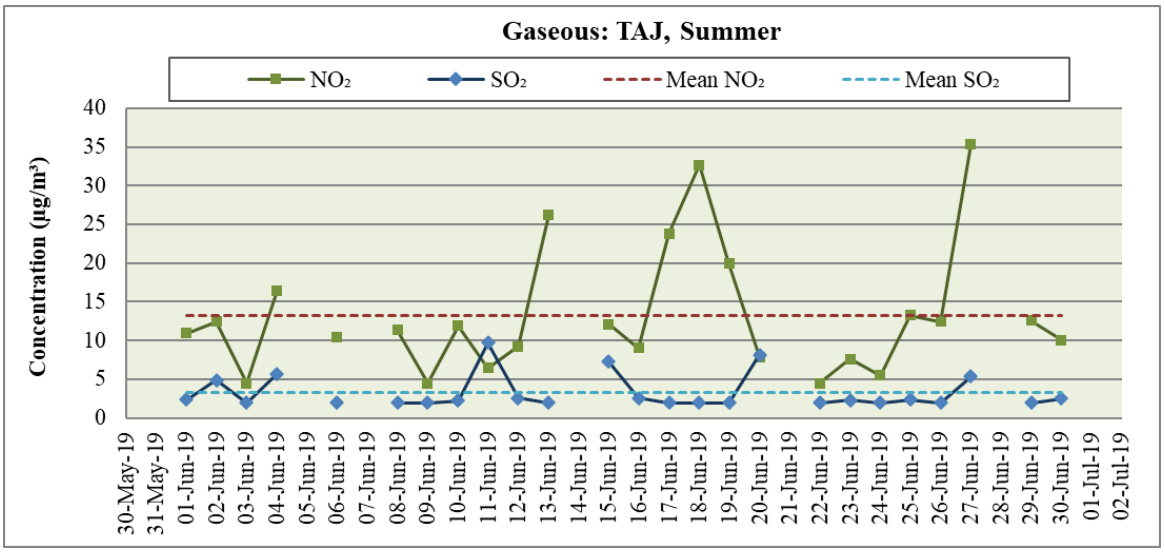


Figure 2.55: SO_2 and NO_2 Concentrations at TAJ for Summer Season

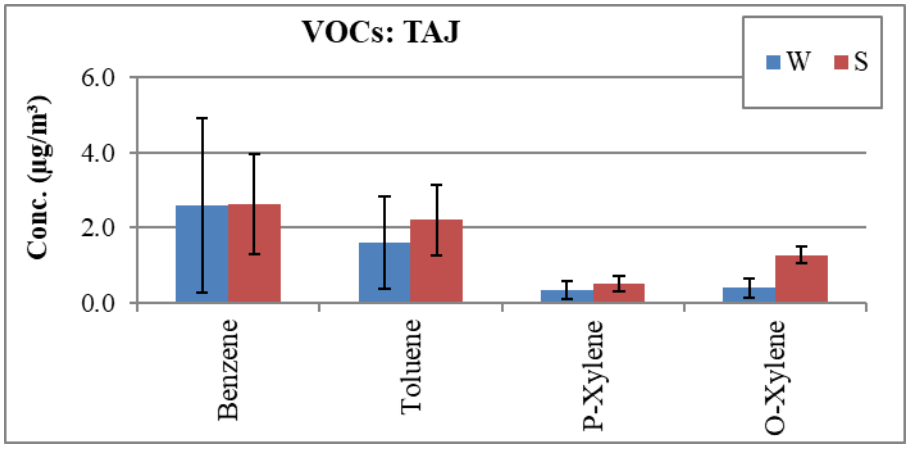


Figure 2.56: VOCs concentration at TAJ

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 2.57 (a) and (b) for winter and summer seasons. Organic carbon is observed slightly higher (winter: 37.3±11.6 and summer: 7.9±2.4 µg/m^3) than the elemental carbon (winter: 28.0±9.9 and summer: 5.2±2.3 µg/m^3). It is also observed that the OC and EC are higher in the winter season than in the summer season. A statistical summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Table 2.59 for winter and summer seasons. The ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in the atmosphere at TAJ.

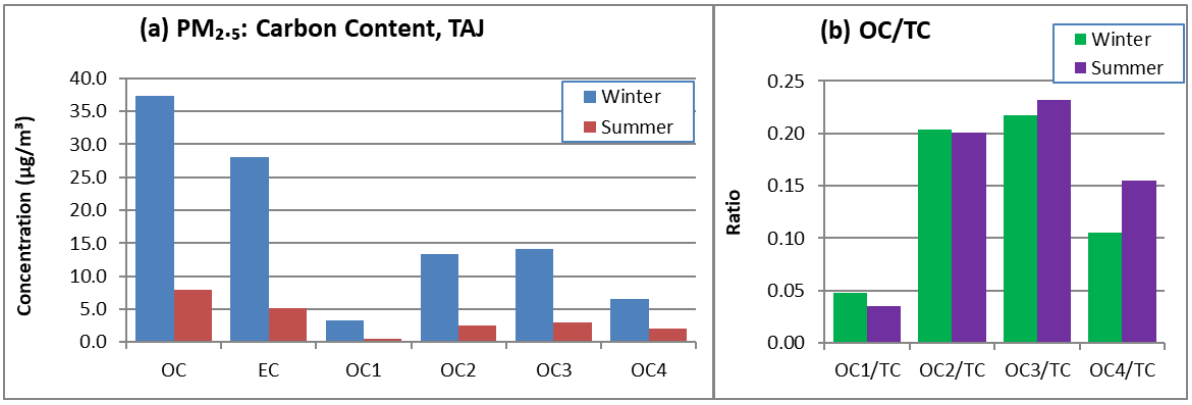


Figure 2.57: EC and OC Content in $PM_{2.5}$ at TAJ

2.4.5.4 PAHs in $PM_{2.5}$

Figure 2.58 shows the average measured concentration of PAHs at TAJ for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.60 for winter and summer seasons. The PAHs compounds analyzed were: (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (233±108 ng/m^3) compared to summer season (15.2±11.1 ng/m^3). Major PAHs are InP (56.2 ng/m^3), B(ghi)P (40.3 ng/m^3), B(b)F (22.9 ng/m^3), Chr (22.7 ng/m^3), B(k)F (18.3 ng/m^3) and BeA (16.8 ng/m^3) for winter season and B(b)F (1.86 ng/m^3), Ant (1.54 ng/m^3), B(ghi)P (1.53 ng/m^3), InP (1.38 ng/m^3) and BeA (1.38 ng/m^3) for summer season.

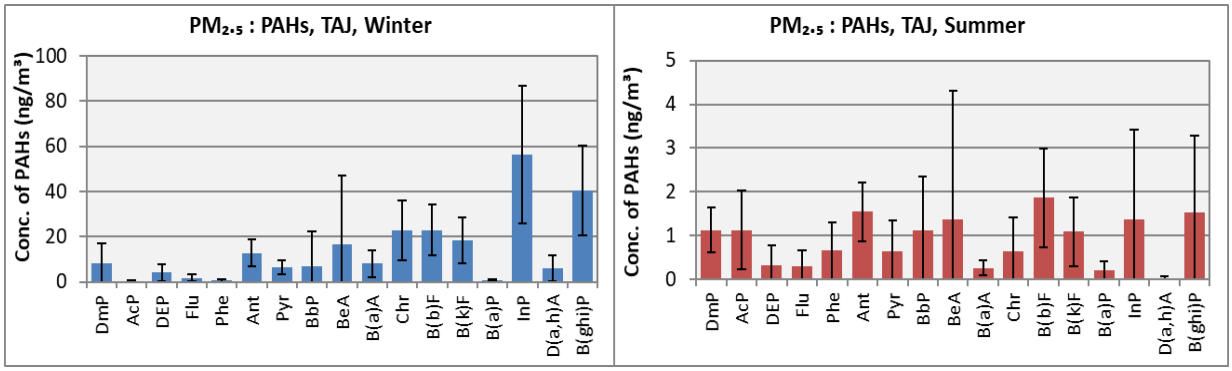


Figure 2.58: PAHs Concentrations in $PM_{2.5}$ at TAJ

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

Graphical presentations of chemical species are shown for the winter and summer seasons at TAJ for PM_{10} (Figure 2.59) and $PM_{2.5}$ (Figure 2.60). 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 Tables 2.61 – 2.64 for winter and summer season.

The correlation between different parameters (i.e., PM, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements)) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Tables 2.65 – 2.68 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 2.61 (a) and (b) for the winter season and Figure 2.62 (a) and (b) for the summer season.

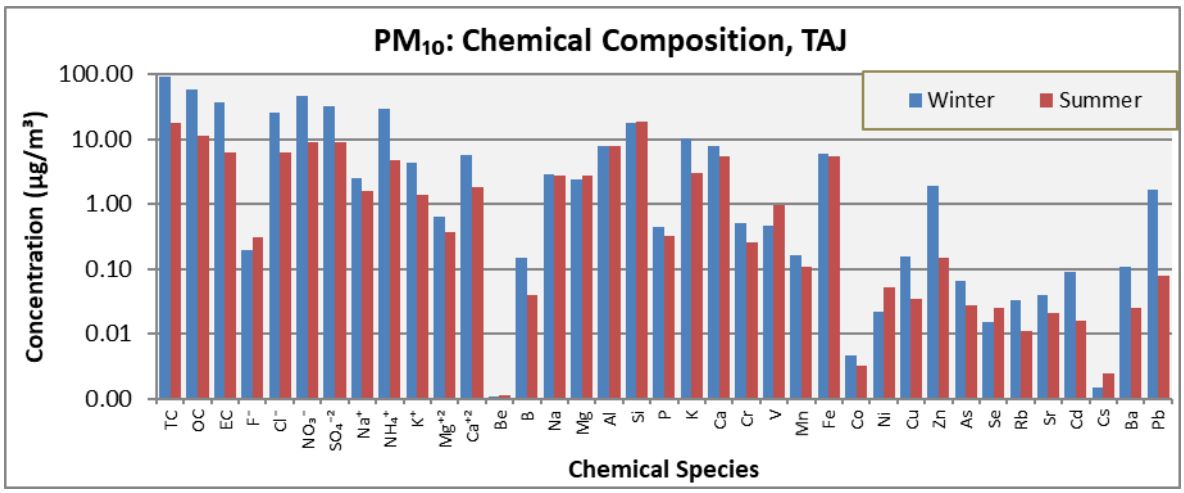


Figure 2.59: Concentrations of species in PM_{10} at TAJ

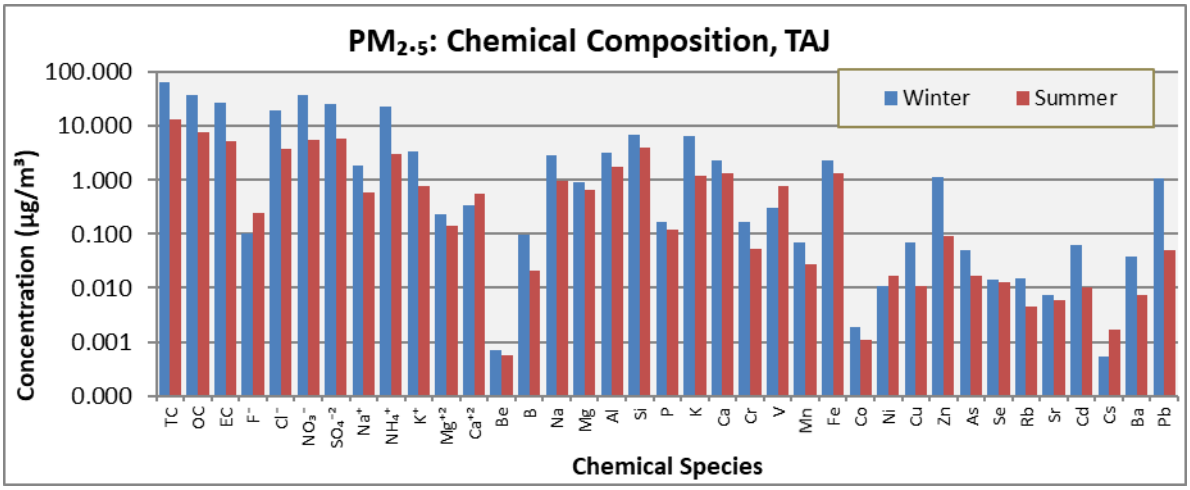


Figure 2.60: Concentrations of species in $PM_{2.5}$ at TAJ

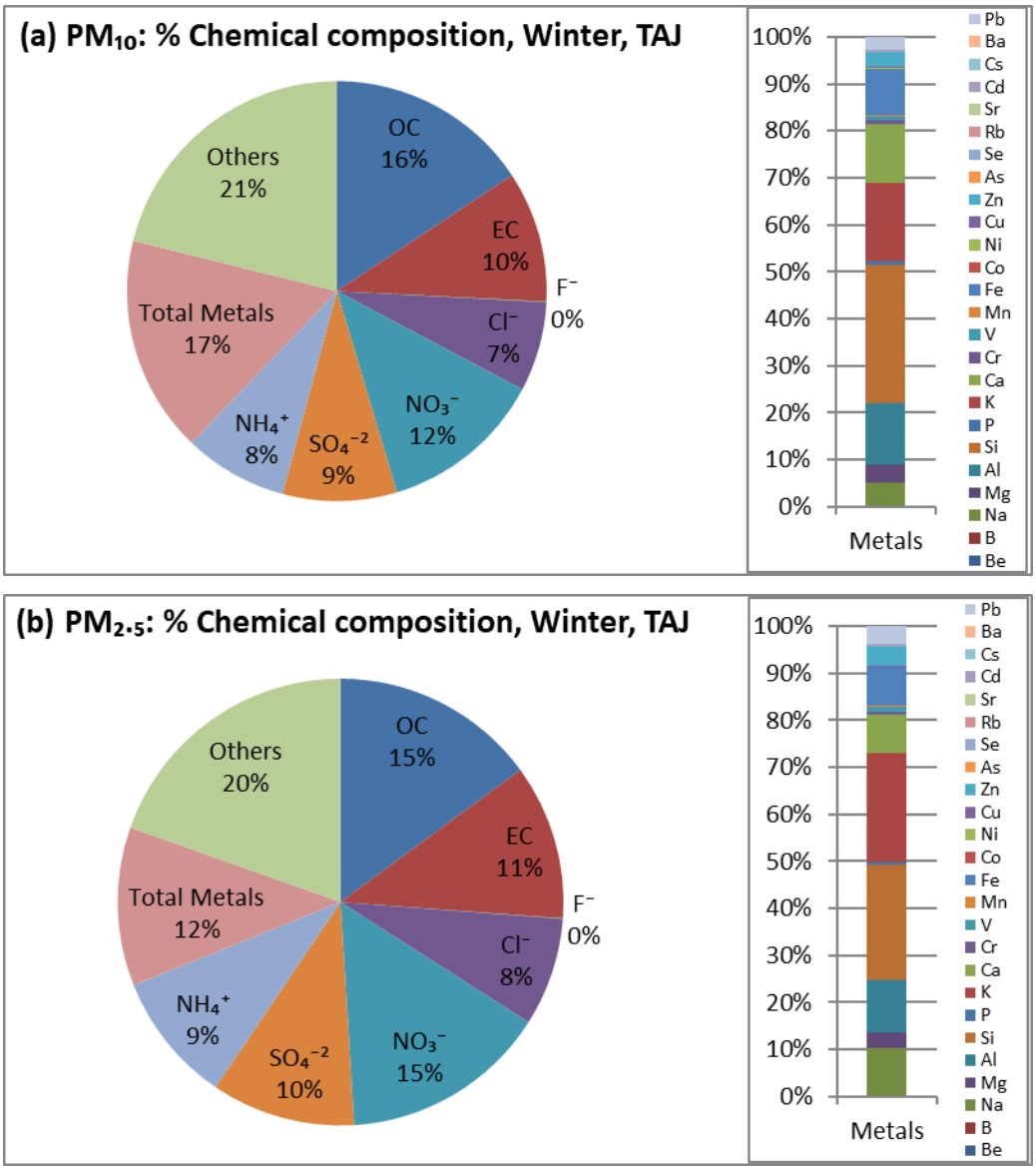


Figure 2.61: Percentage distribution of species in PM at TAJ for Winter Season

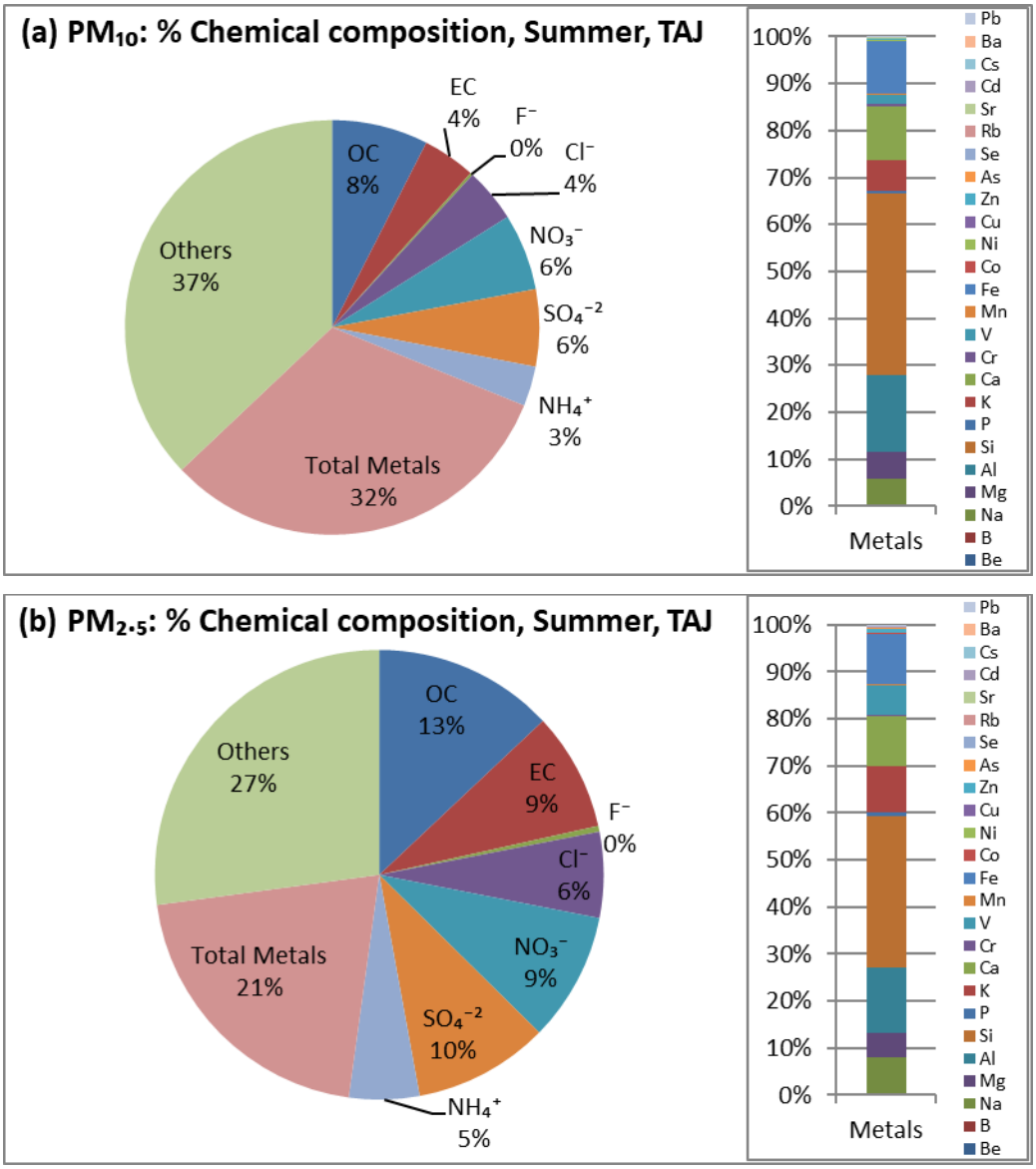


Figure 2.62: Percentage distribution of species in PM at TAJ for Summer Season

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

The graphical compositional comparison of $PM_{2.5}$ vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.63) at TAJ. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM has fine mode during winter (68%) than summer (40%). The major species contributing to fine mode are TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, K^+, Be, B, V, Zn, As, Se, Cd and Pb; whereas, major species contributing in coarse mode are Mg^{2+}, Ca^{2+}, Mg, Al, Si, P, Ca, Cr, Mn, Fe, Co, Ni, Cu, Rb and Sr.

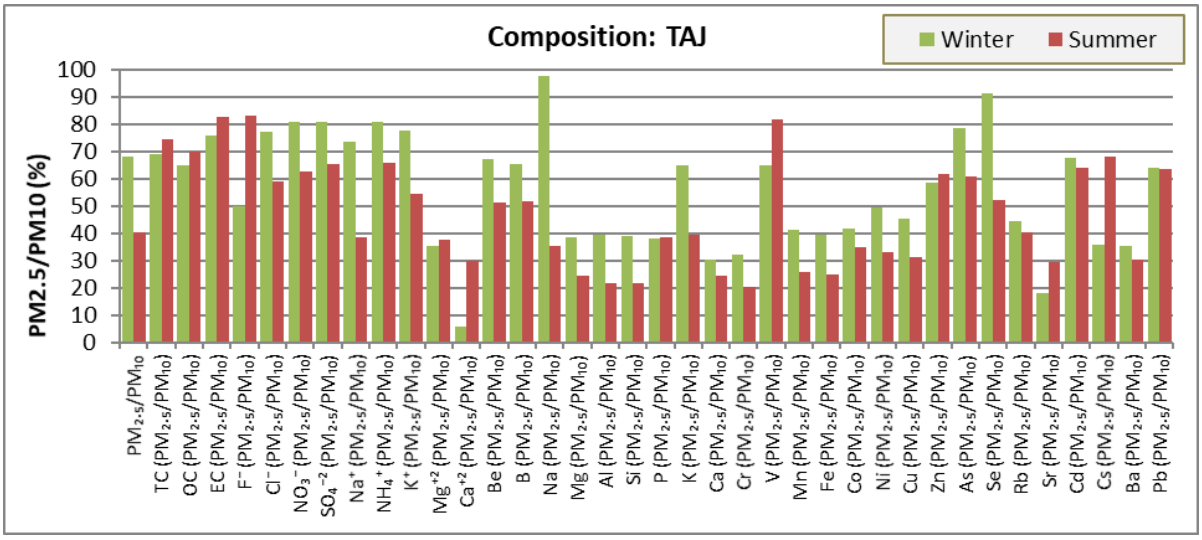


Figure 2.63: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at TAJ

Table 2.58: Statistical results of gaseous pollutants (µg/m^3) at TAJ for winter (W) and summer (S) seasons

TAJ (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	26.51	5.69	2.57	1.61	0.34	0.40	4.92
SD	12.08	4.11	2.32	1.22	0.23	0.25	3.58
Max	57.88	15.12	10.80	4.41	0.94	1.03	13.97
Min	7.51	1.99	0.66	0.17	0.01	0.00	1.49
CV	0.46	0.72	0.90	0.76	0.68	0.64	0.73
TAJ (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	13.26	3.29	2.63	2.21	0.50	1.27	6.60
SD	8.33	2.23	1.32	0.93	0.20	0.22	2.25
Max	35.38	9.74	7.89	4.63	1.00	1.72	14.98
Min	4.50	2.00	1.95	1.71	0.23	0.78	5.22
CV	0.63	0.68	0.50	0.42	0.40	0.17	0.34

Table 2.59: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at TAJ for winter (W) and summer (S) seasons

TAJ (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	249.5	65.28	37.26	28.01	3.31	13.32	14.06	6.58	0.048	0.204	0.218	0.105
SD	52.6	21.40	11.64	9.91	2.13	4.48	4.18	1.39	0.014	0.010	0.013	0.019
Max	335.6	116.80	64.12	52.68	10.27	23.47	22.29	9.15	0.088	0.236	0.242	0.142
Min	121.4	26.98	16.82	10.16	1.12	5.67	6.21	3.82	0.034	0.185	0.191	0.069
CV	0.21	0.33	0.31	0.35	0.64	0.34	0.30	0.21	0.286	0.048	0.060	0.176
TAJ (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	61.0	13.12	7.94	5.19	0.46	2.53	2.94	2.01	0.035	0.201	0.232	0.155
SD	21.6	4.79	2.38	2.47	0.29	0.68	0.89	0.71	0.020	0.028	0.036	0.012
Max	106.2	21.51	12.46	9.53	1.11	3.59	4.76	3.57	0.090	0.255	0.332	0.173
Min	17.3	5.51	3.97	1.49	0.00	1.31	1.55	0.88	0.000	0.154	0.191	0.131
CV	0.35	0.37	0.30	0.48	0.63	0.27	0.30	0.35	0.561	0.142	0.154	0.075

Table 2.60: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at TAJ for winter (W) and summer (S) seasons

TAJ(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	8.29	0.28	4.07	1.83	0.58	12.79	6.40	6.94	16.79	8.12	22.73	22.86	18.33	0.64	56.23	6.00	40.25	233.13
SD	8.62	0.25	3.70	1.41	0.76	6.08	3.21	15.47	30.36	5.92	13.19	11.26	10.13	0.38	30.50	5.56	19.79	107.88
Max	25.07	0.96	11.48	5.28	2.69	24.43	14.02	52.90	106.27	21.99	53.55	45.74	41.92	1.36	121.32	16.34	78.11	433.17
Min	1.53	0.13	0.22	0.47	0.00	1.12	3.44	0.22	1.05	2.98	10.21	12.00	9.80	0.20	26.59	0.75	19.90	112.06
CV	1.04	0.90	0.91	0.77	1.31	0.48	0.50	2.23	1.81	0.73	0.58	0.49	0.55	0.59	0.54	0.93	0.49	0.46
TAJ(S)	DmP	AcP	DEP	Flu	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.12	1.13	0.31	0.30	0.65	1.54	0.64	1.11	1.38	0.26	0.64	1.86	1.09	0.20	1.38	0.02	1.53	15.17
SD	0.52	0.91	0.45	0.35	0.66	0.67	0.70	1.24	2.92	0.16	0.76	1.13	0.79	0.21	2.04	0.04	1.76	11.10
Max	2.49	3.02	1.60	0.98	2.38	2.57	2.58	4.40	10.40	0.72	2.72	3.99	2.68	0.68	5.91	0.15	5.48	44.94
Min	0.66	0.15	0.00	0.00	0.00	0.49	0.09	0.10	0.00	0.16	0.11	0.59	0.31	0.05	0.00	0.00	0.13	4.23
CV	0.46	0.80	1.45	1.15	1.01	0.44	1.09	1.11	2.12	0.62	1.19	0.61	0.73	1.05	1.48	2.34	1.15	0.73

Table 2.61: Statistical results of chemical characterization (µg/m^3) of PM_{10} at TAJ for winter (W) season

TAJ (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	366	57.4	36.8	0.2	25.2	46.2	32.2	2.5	29.1	4.4	0.6	5.8	1E-3	0.15	2.94	2.40	7.98	18.01	0.45
SD	74	16.4	11.6	0.1	7.3	12.3	11.0	1.8	6.1	0.9	0.4	1.7	4E-4	0.05	1.07	1.03	3.33	7.07	0.19
Max	521	91.6	63.5	0.4	37.1	69.6	51.7	6.7	40.2	6.7	1.3	9.8	2E-3	0.27	6.34	5.80	19.01	40.08	1.12
Min	252	34.5	19.7	0.1	13.9	23.0	14.8	0.7	19.2	3.2	0.3	2.9	7E-4	0.07	1.97	1.63	5.10	11.64	0.30
CV	0.20	0.29	0.32	0.56	0.29	0.27	0.34	0.71	0.21	0.21	0.60	0.30	0.39	0.32	0.36	0.43	0.42	0.39	0.43
TAJ (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	10.20	7.70	0.50	0.47	0.16	6.02	0.00	0.02	0.16	1.92	0.06	2E-2	0.03	0.04	0.09	1E-3	0.11	1.66	78.98
SD	3.79	3.19	0.52	0.32	0.07	2.69	0.00	0.01	0.17	1.25	0.06	1E-2	0.01	0.02	0.04	6E-4	0.05	0.98	4.34
Max	23.46	15.39	2.40	1.56	0.40	15.39	0.01	0.05	0.79	6.35	0.20	4E-2	0.08	0.09	0.17	3E-3	0.27	4.40	85.92
Min	6.91	3.83	0.27	0.23	0.09	4.00	0.00	0.01	0.07	0.96	0.01	6E-3	0.02	0.02	0.04	1E-3	0.06	0.61	69.67
CV	0.37	0.41	1.02	0.68	0.42	0.45	0.43	0.43	1.09	0.65	0.96	0.85	0.38	0.43	0.43	0.38	0.45	0.59	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.62: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at TAJ for winter (W) season

TAJ (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	250	37.3	28.0	0.1	19.5	37.4	26.1	1.8	23.6	3.4	0.2	0.3	7E-4	0.10	2.88	0.92	3.17	7.05	0.17
SD	53	11.6	9.9	0.1	6.5	10.0	9.2	1.2	5.3	0.9	0.1	0.2	2E-4	0.04	2.25	0.44	1.22	2.95	0.07
Max	336	64.1	52.7	0.3	32.8	54.6	48.7	4.7	34.6	5.7	0.3	0.9	1E-3	0.17	9.15	1.81	5.50	12.01	0.29
Min	121	16.8	10.2	0.0	8.6	18.0	13.2	0.5	15.0	1.8	0.1	0.1	4E-4	0.03	0.76	0.25	0.57	1.13	0.04
CV	0.21	0.31	0.35	0.83	0.33	0.27	0.35	0.65	0.22	0.26	0.28	0.47	0.28	0.39	0.78	0.48	0.39	0.42	0.39
TAJ (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.62	2.35	0.16	0.30	0.07	2.37	2E-3	0.01	0.07	1.13	0.05	0.01	1E-2	7E-3	0.06	5E-4	0.04	1.07	80.60
SD	2.21	0.98	0.09	0.12	0.03	0.91	7E-4	0.01	0.04	0.45	0.06	0.01	6E-3	8E-3	0.03	3E-4	0.02	0.65	3.94
Max	11.63	4.15	0.42	0.58	0.12	3.81	3E-3	0.03	0.15	2.33	0.20	0.06	3E-2	3E-2	0.12	1E-3	0.09	2.43	87.69
Min	2.50	0.29	0.03	0.04	0.00	0.38	9E-4	0.00	0.02	0.45	0.01	0.00	6E-3	2E-4	0.02	8E-5	0.01	0.17	74.56
CV	0.33	0.42	0.55	0.38	0.44	0.38	0.35	0.46	0.49	0.40	1.18	1.03	0.43	1.06	0.48	0.52	0.50	0.60	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.63: Statistical results chemical characterization (µg/m^3) of PM_{10} at TAJ for summer (S) season

TAJ (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	151	11.3	6.2	0.3	6.4	9.0	9.1	1.6	4.7	1.4	0.4	1.9	1E-3	0.04	2.78	2.71	7.93	18.48	0.32
SD	71	3.4	3.0	0.0	3.3	5.3	3.6	0.8	2.0	0.6	0.2	1.1	4E-4	0.02	1.31	1.87	4.95	10.97	0.15
Max	364	17.8	11.5	0.4	17.6	23.6	15.1	3.7	8.4	2.4	0.8	4.9	2E-3	0.08	7.06	9.51	24.99	53.37	0.56
Min	31	5.7	1.8	0.2	1.5	2.6	2.3	0.5	1.6	0.4	0.1	0.4	7E-4	0.02	0.65	0.22	0.60	1.52	0.08
CV	0.47	0.30	0.48	0.16	0.52	0.59	0.40	0.53	0.43	0.44	0.58	0.57	0.35	0.40	0.47	0.69	0.62	0.59	0.47
TAJ (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.08	5.49	0.26	0.96	0.11	5.41	3E-3	0.05	0.03	0.15	0.03	0.02	1E-2	2E-2	0.02	2E-3	0.02	0.08	64.08
SD	1.75	3.30	0.25	0.83	0.09	3.33	2E-3	0.05	0.02	0.12	0.02	0.01	6E-3	1E-2	0.01	8E-4	0.02	0.07	3.65
Max	8.31	15.24	1.21	2.76	0.49	14.77	9E-3	0.21	0.09	0.45	0.07	0.03	3E-2	5E-2	0.03	5E-3	0.09	0.26	73.35
Min	0.44	0.76	0.01	0.19	0.00	0.66	5E-4	0.01	0.01	0.02	0.01	0.01	3E-3	4E-3	0.01	2E-3	0.00	0.00	58.73
CV	0.57	0.60	0.97	0.86	0.90	0.61	0.70	1.05	0.57	0.80	0.57	0.25	0.53	0.49	0.50	0.33	0.80	0.85	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.64: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at TAJ for summer (S) season

TAJ(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Mg^{+2}	Ca^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	61	7.9	5.2	0.3	3.8	5.7	5.9	0.6	3.1	0.8	0.1	0.6	6E-4	2E-2	0.99	0.67	1.75	4.05	0.12
SD	22	2.4	2.5	0.0	1.7	2.9	2.3	0.3	1.4	0.3	0.1	0.2	7E-5	1E-2	0.44	0.39	1.03	2.19	0.07
Max	106	12.5	9.5	0.3	7.9	13.3	9.6	1.2	5.6	1.7	0.5	1.0	8E-4	5E-2	1.83	1.49	4.30	8.91	0.28
Min	17	4.0	1.5	0.2	0.9	1.6	1.5	0.2	0.8	0.2	0.0	0.2	5E-4	5E-3	0.19	0.10	0.29	0.71	0.02
CV	0.35	0.30	0.48	0.09	0.44	0.51	0.39	0.46	0.45	0.45	0.64	0.41	0.12	0.54	0.45	0.59	0.59	0.54	0.56
TAJ(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.22	1.34	0.05	0.79	0.03	1.35	1E-3	2E-2	1E-2	0.09	0.02	1E-2	4E-3	6E-3	1E-2	2E-3	8E-3	0.05	73.70
SD	0.57	0.74	0.05	0.73	0.02	0.90	7E-4	2E-2	5E-3	0.09	0.01	6E-3	2E-3	2E-3	6E-3	2E-4	5E-3	0.05	4.31
Max	2.28	3.04	0.21	2.62	0.10	4.26	4E-3	8E-2	2E-2	0.31	0.06	2E-2	7E-3	1E-2	2E-2	2E-3	2E-2	0.20	80.04
Min	0.21	0.25	0.00	0.17	0.00	0.18	4E-4	3E-3	3E-3	0.00	0.00	4E-3	2E-3	2E-3	3E-3	1E-3	1E-3	0.00	65.53
CV	0.46	0.55	0.97	0.93	0.83	0.67	0.67	1.23	0.48	0.96	0.88	0.49	0.36	0.39	0.59	0.13	0.66	0.96	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.65: Correlation matrix for PM_{10} and its composition at TAJ for winter season

TAJ (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	0.60	0.60	0.57	0.08	0.54	0.62	0.40	0.09	0.63	0.37	0.04	0.10	0.77
TC		1.00	0.99	0.99	-0.04	0.49	0.27	0.35	0.21	0.28	0.54	-0.06	0.02	-0.02
OC			1.00	0.97	0.02	0.51	0.24	0.31	0.17	0.25	0.57	-0.05	-0.02	0.00
EC				1.00	-0.11	0.45	0.31	0.41	0.27	0.31	0.49	-0.07	0.06	-0.05
NO_3^-					-0.23	0.22	1.00	0.38	0.32	0.70	-0.13	0.17	-0.22	0.50
SO_4^{-2}					-0.58	-0.19		1.00	0.59	0.74	0.32	-0.12	0.39	0.10
NH_4^+					-0.37	-0.04			0.34	1.00	0.24	0.08	0.14	0.44
Metals					0.29	0.36			-0.14		-0.04	0.13	0.05	1.00

Table 2.66: Correlation matrix for $PM_{2.5}$ and its composition at TAJ for winter season

TAJ (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	0.83	0.81	0.84	0.31	0.62	0.57	0.63	-0.66	0.76	0.59	0.25	-0.13	0.51
TC		1.00	0.99	0.99	0.41	0.65	0.34	0.34	-0.55	0.52	0.52	0.11	-0.24	0.19
OC			1.00	0.97	0.44	0.65	0.30	0.30	-0.55	0.48	0.55	0.07	-0.23	0.20
EC				1.00	0.37	0.63	0.38	0.40	-0.55	0.55	0.49	0.16	-0.26	0.18
NO_3^-					0.00	0.31	1.00	0.48	-0.33	0.72	0.12	0.47	0.03	0.05
SO_4^{-2}					-0.22	0.03		1.00	-0.12	0.80	0.40	0.19	-0.15	0.26
NH_4^+					0.00	0.22			-0.40	1.00	0.40	0.23	-0.04	0.24
Metals					0.12	0.08			-0.27		0.54	-0.16	-0.14	1.00

Table 2.67: Correlation matrix for PM_{10} and its composition at TAJ for summer season

TAJ (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	0.67	0.66	0.68	0.67	0.82	0.70	0.79	0.59	0.62	0.78	0.62	0.90	0.99
TC		1.00	0.99	0.99	0.36	0.33	0.55	0.56	0.28	0.37	0.86	0.47	0.58	0.59
OC			1.00	0.95	0.36	0.30	0.54	0.51	0.22	0.29	0.82	0.45	0.58	0.58
EC				1.00	0.35	0.37	0.55	0.60	0.34	0.44	0.88	0.48	0.58	0.58
NO_3^-					0.68	0.45	1.00	0.62	0.39	0.38	0.77	0.73	0.80	0.64
SO_4^{-2}					0.44	0.63		1.00	0.60	0.67	0.78	0.51	0.64	0.72
NH_4^+					0.30	0.67			0.54	1.00	0.55	0.42	0.53	0.55
Metals					0.68	0.84			0.58		0.69	0.56	0.88	1.00

Table 2.68: Correlation matrix for $PM_{2.5}$ and its composition at TAJ for summer season

TAJ (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	0.62	0.58	0.65	0.24	0.65	0.61	0.90	0.48	0.66	0.70	0.35	0.71	0.92
TC		1.00	0.99	0.99	0.00	0.23	0.56	0.53	0.19	0.28	0.64	0.24	0.44	0.32
OC			1.00	0.95	0.04	0.21	0.53	0.47	0.14	0.20	0.56	0.19	0.42	0.28
EC				1.00	-0.03	0.25	0.57	0.57	0.23	0.34	0.70	0.29	0.45	0.36
NO_3^-					0.15	0.26	1.00	0.64	0.37	0.35	0.46	0.44	0.70	0.37
SO_4^{-2}					0.23	0.56		1.00	0.62	0.61	0.65	0.30	0.71	0.80
NH_4^+					0.21	0.47			0.40	1.00	0.63	0.31	0.57	0.60
Metals					0.30	0.63			0.39		0.57	0.23	0.57	1.00

2.4.6 Overall Summary and results

The sampling period for winter is December 06, 2018 to February 18, 2019 and April 08, 2019 to June 30, 2019 for the summer season

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

The seasonal comparison is shown for PM_{10} (Figure 2.64), $PM_{2.5}$ (Figure 2.65) and the ratio of $PM_{2.5}$ to PM_{10} (Figure 2.66) for all sites. The overall summary of experimental results for PM is shown for the winter and summer seasons (Table 2.69).

Winter

The overall city average of $PM_{2.5}$ in winter was 238±58 µg/m^3 and PM_{10} was 334±84 µg/m^3. The $PM_{2.5}$ levels are about 4.0 times higher than the national air quality standard (60 µg/m^3) and PM_{10} about 3.3 times higher than the standard (100 µg/m^3). Both $PM_{2.5}$ and PM_{10} levels were highest at GAK, the commercial site at 304 and 423 µg/m^3, followed by levels at NNH (273 and 367 µg/m^3), an industrial site. The highest variability was seen at SKD (CV: 0.33) for $PM_{2.5}$ followed by NNH and JHS (CV: 0.31). The levels were quite steady at GAK (CV: 0.25), and TAJ (CV: 0.21). The highest variation for PM_{10} was seen at SKD (CV: 0.52) and least at TAJ (CV: 0.20).

The ratio of $PM_{2.5}$ to PM_{10} is a useful parameter to indicate the relative abundance of fine particles (i.e., $PM_{2.5}$) and toxicity of particulate matter. The overall city ratio is 0.73 and it was highest at JHS (0.75), followed by TAJ (0.74) and NNH (0.73). The relatively high $PM_{2.5}$ at these sites could be attributed to heavy traffic in the area and industrial units in NNH.

Summer

The overall city average of $PM_{2.5}$ levels in summer dropped sharply to 67 µg/m^3 also PM_{10} dropped to 184 µg/m^3 compared to winter. The $PM_{2.5}$ levels generally meet the standards, while PM_{10} is 1.8 times higher than the standard. $PM_{2.5}$ level was highest in NNH (industrial area) and PM_{10} levels were highest at JHS (residential and traffic area), 71 and 204 µg/m^3, respectively.

The PM_{10} and $PM_{2.5}$ levels were lowest at TAJ (61 and 151 µg/m^3); PM_{10} levels exceed the air quality standards. The highest variability was seen at NNH (CV: 0.42) for $PM_{2.5}$ followed by TAJ (CV: 0.35) and SKD (CV: 0.33). The highest variation for PM_{10} was seen at GAK (CV:

0.52) and least at JHS (CV: 0.22). The overall $PM_{2.5}$ to PM_{10} city ratio is 0.38 and it was highest at TAJ (0.44). The ratio was similar at other sites.

It is a positive finding that $PM_{2.5}$ levels in summer are expected to almost comply with national standards of 60 µg/m^3.

The time-series data also reveal that within winter, levels of PM_{10} and $PM_{2.5}$ may show increasing or decreasing patterns. It is seen that levels are highest and increase during the last week of December and the first week of January (Figures 2.4 and 2.52). In the later part of January, more so in February, the levels drop rapidly (Figure 2.40). Typical calm conditions tend to cease in late January and February and wind speed begins to rise, resulting in better dilution and dispersion of the pollutants.

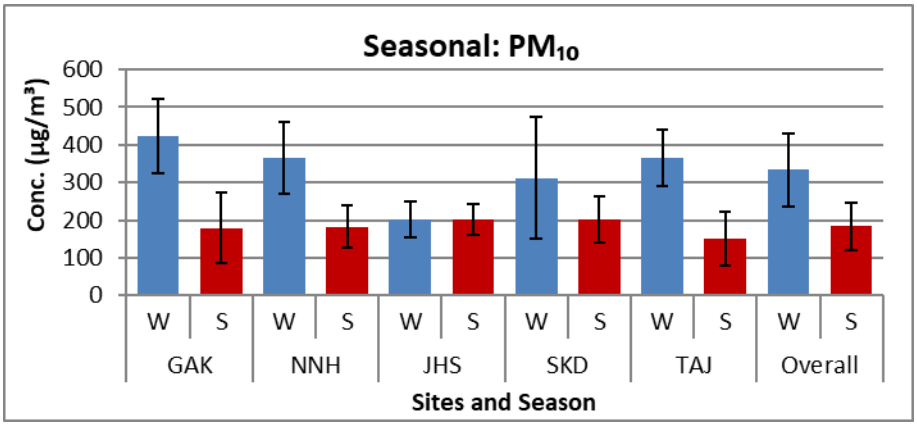


Figure 2.64: Seasonal comparison of PM_{10} levels for all Sites

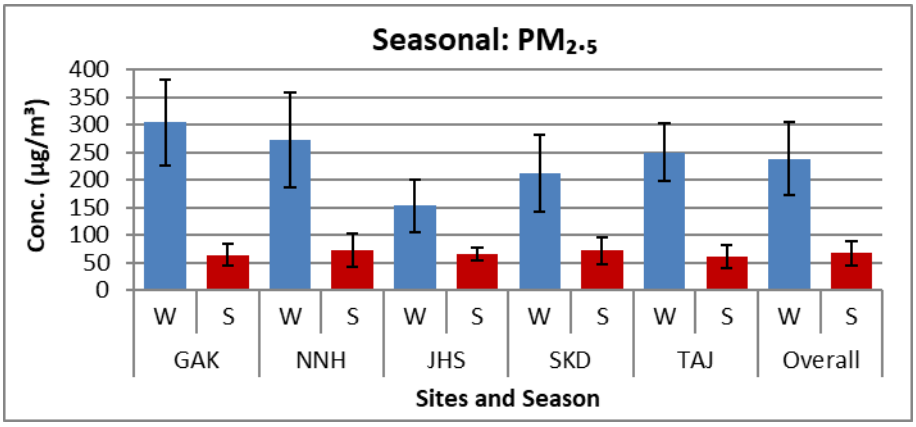


Figure 2.65: Seasonal comparison of $PM_{2.5}$ concentrations for all Sites

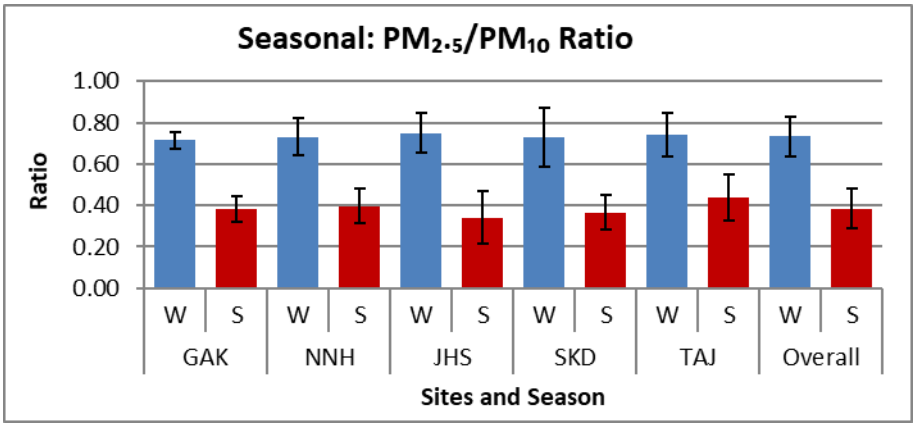


Figure 2.66: Seasonal comparison of $PM_{2.5}$ /PM_{10} ratio

2.4.6.2 Gaseous Pollutants (NO_2 and SO_2)

The seasonal comparison is shown for NO_2 and SO_2 (Figure 2.67). The overall average concentrations with statistical summary are presented in Tables 2.70 and 2.71 for all sites for winter and summer seasons.

The SO_2 levels were quite low (mostly < 5.0 µg/m^3) and were always within the air quality standards (80 µg/m^3) with some peaks at SKD at 16 µg/m^3 in winter and 14 µg/m^3 in summer; levels were mostly below 5.0 µg/m^3 in summer at all sites (Figures 2.67). The SO_2 levels being very low have not been further discussed.

It was observed that NO_2 levels were complying with the air quality standards (80 µg/m^3) during both seasons. The overall city-level average NO_2 levels are 32.9 µg/m^3 in winter and 19.1 µg/m^3 in summer. The highest NO_2 concentration was observed at NNH during both seasons: 42.3 (winter) and 23.5 µg/m^3 (summer). At GAK and NNH, on certain days in winter NO_2 levels may exceed 60 µg/m^3 and reach close to the standard. It is clear that NO_2 is an emerging pollutant that can largely be attributed to vehicular emissions. GAK (commercial area) and NNH (industrial area) are having higher vehicular emissions of NO_2. Levels sharply drop in summer (less than 50% of winter level) largely due to high wind speeds, convective conditions, large mixing height resulting in better dilution and dispersion of the NO_2.

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

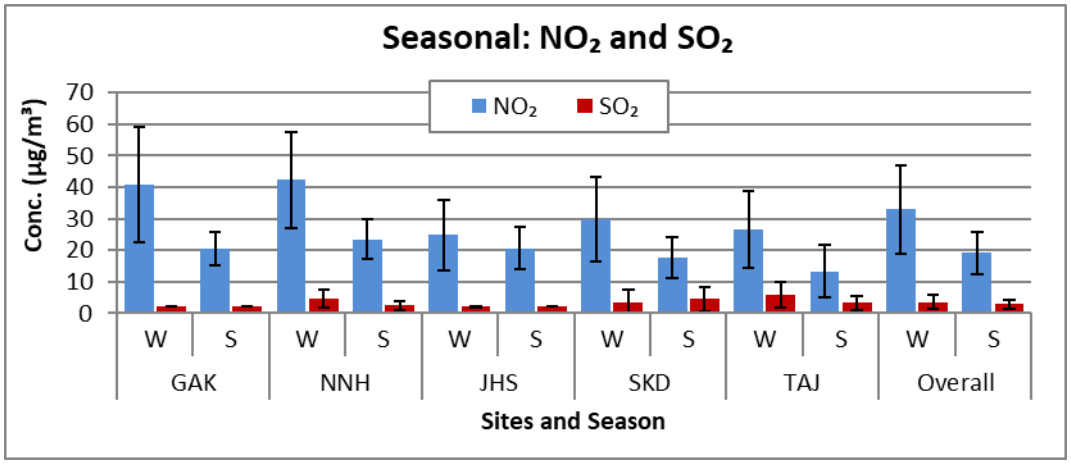


Figure 2.67: Seasonal Comparison of NO_2 and SO_2 levels for all Sites

2.4.6.3 Volatile Organic Compounds (VOCs: BTX)

The seasonal comparison for VOCs (BTX) is shown in Figure 2.68. The overall statistical summary is presented in Tables 2.70 – 2.71 for all sites for the winter and summer seasons.

The overall city-level average of BTX levels is 9.0±7.6 µg/m^3 in winter and 10.5±3.5 µg/m^3 in summer. The highest BTX concentration was observed at GAK (15.1 µg/m^3) in winter and SKD (20.4 µg/m^3) in summer seasons.

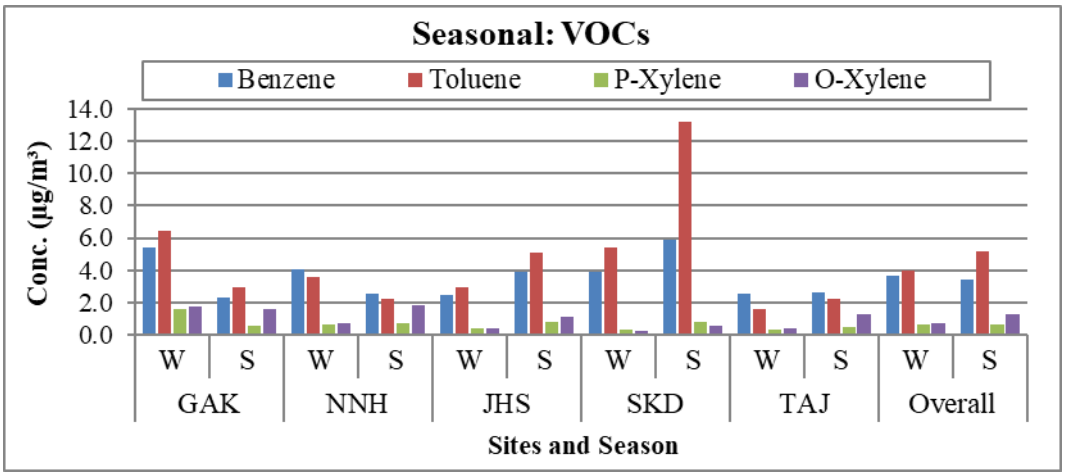


Figure 2.68: Seasonal comparison of VOCs for all Sites

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

The seasonal comparison for OC and EC is presented in Figure 2.69 for PM_{10} and Figure 2.70 for $PM_{2.5}$. The $PM_{2.5}$ contained a high fraction of TC (OC+EC), 24% in winter and 27% in summer seasons. The OC is observed higher than the EC at each site during winter and summer; this is generally true that in the atmosphere volatile and semi-volatile organic compounds

continuously undergo nucleation, oxidation, condensation and convert into organic particles, whereas EC remains unchanged, as a result the ratio of OC to EC further increases. However, the ratio of OC3/TC is observed higher than other OCs; this indicates the formation of secondary organic carbon particles in the atmosphere is an important process. It is also observed that the OC and EC are higher in the winter season than in the summer season, probably because of poor dispersion in winter and more combustion sources, including biomass and municipal solid waste (MSW) burning. It is observed that the average TC to $PM_{2.5}$ ratio were maximum (30%) at GAK followed by TAJ and minimum (16%) at JHS in winter (Table 2.82) and maximum (30%) at JHS and minimum (22%) at TAJ in summer (Table 2.84).

The overall summary of carbon content (TC, EC, OC; OC1, OC2, OC3 and OC4 with fractions OC1/TC, OC2/TC, OC3/TC and OC4/TC) is presented in Tables 2.72 - 2.73 for winter and summer seasons.

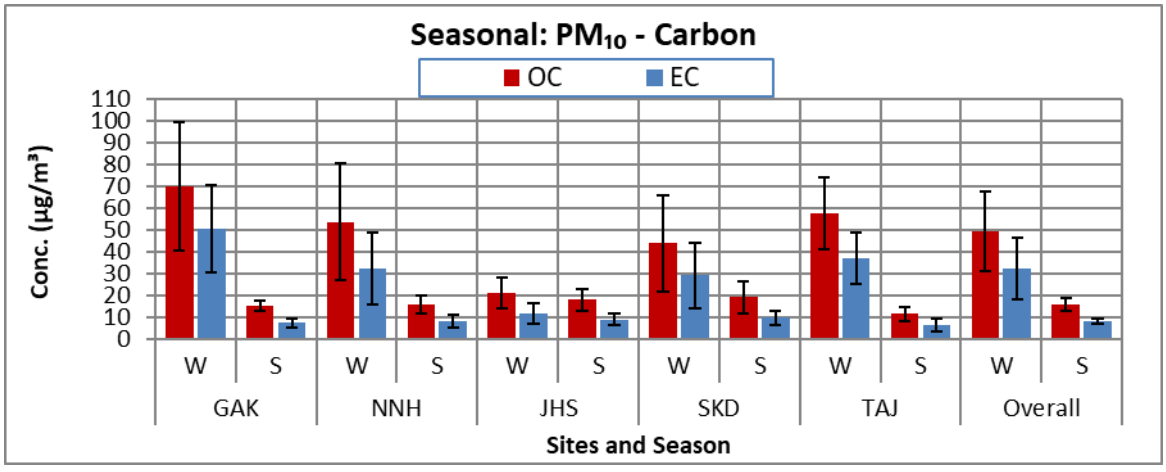


Figure 2.69: Seasonal Comparison of EC and OC in PM_{10} for all Sites

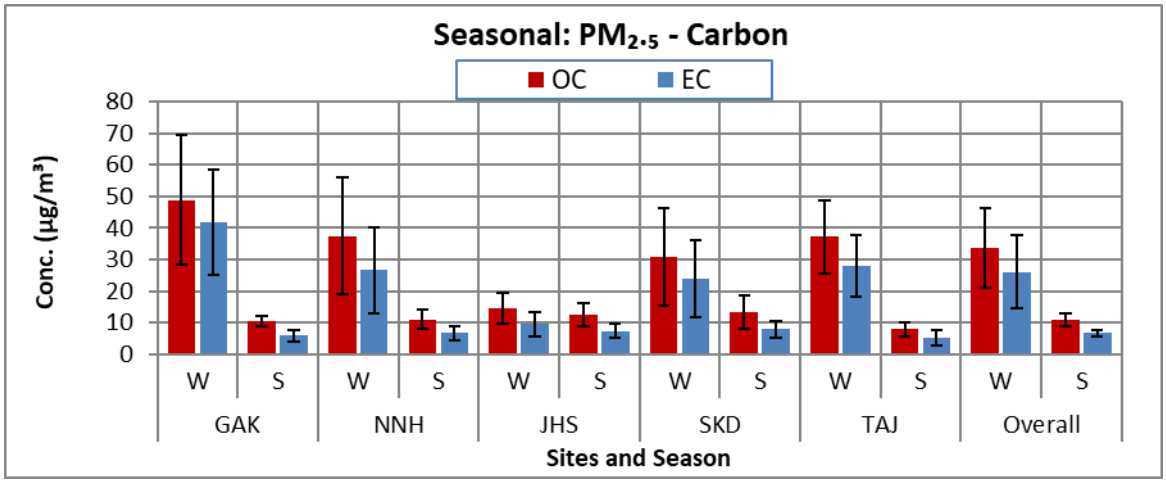


Figure 2.70: Seasonal Comparison of EC and OC in $PM_{2.5}$ for all Sites

2.4.6.5 PAHs in $PM_{2.5}$

The average concentrations of PAHs are shown graphically for the winter season (Figure 2.71) and summer season (Figure 2.72) for all sites along with the overall average concentration for Agra. Average concentrations are shown in Tables 2.74 – 2.75 with the standard deviation and coefficient of variation CV for Agra City. The PAHs compounds analyzed are (i) DmP, (ii) AcP, (iii) DEP, (iv) Flu, (v) Phe, (vi) Ant, (vii) Pyr, (viii) BbP, (ix) BeA, (x) B(a)A, (xi) Chr, (xii) B(b)F, (xiii) B(k)F, (xiv) B(a)P, (xv) InP, (xvi) D(a,h)A and (xvii) B(ghi)P. Seasonal comparisons for PAHs are shown in Figure 2.73, indicating that the concentrations are significantly higher in the winter season than in the summer season. Major PAHs are InP, B(ghi)P, B(b)F, B(k)F and Chr. The overall average total PAHs were much higher in winter (206±88 ng/m^3) than in summer (18±14 ng/m^3). B(a)P, although has the annual standard of 1 ng/m^3 and we cannot compare it with levels of 20 days, however levels of B(a)P (winter mean: 1.7 and summer mean: 1.1 ng/m^3) were slightly high and annual standard is most likely to meet by a fair margin at most sites except NNH in the winter season and at JHS in the summer season. 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 (0.58 in winter and 0.42 in summer) is comparable to the reported values for coal combustion in the winter season and diesel emissions in the summer season. It is inferred that the major sources of PAHs are diesel vehicles and coal combustion.

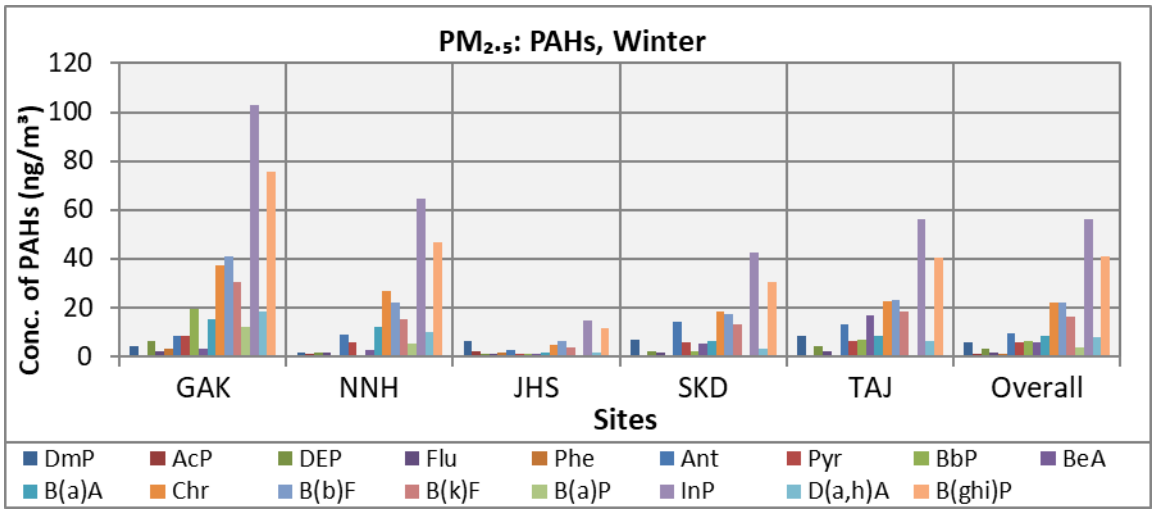


Figure 2.71: Variation in PAHs in $PM_{2.5}$ for winter season

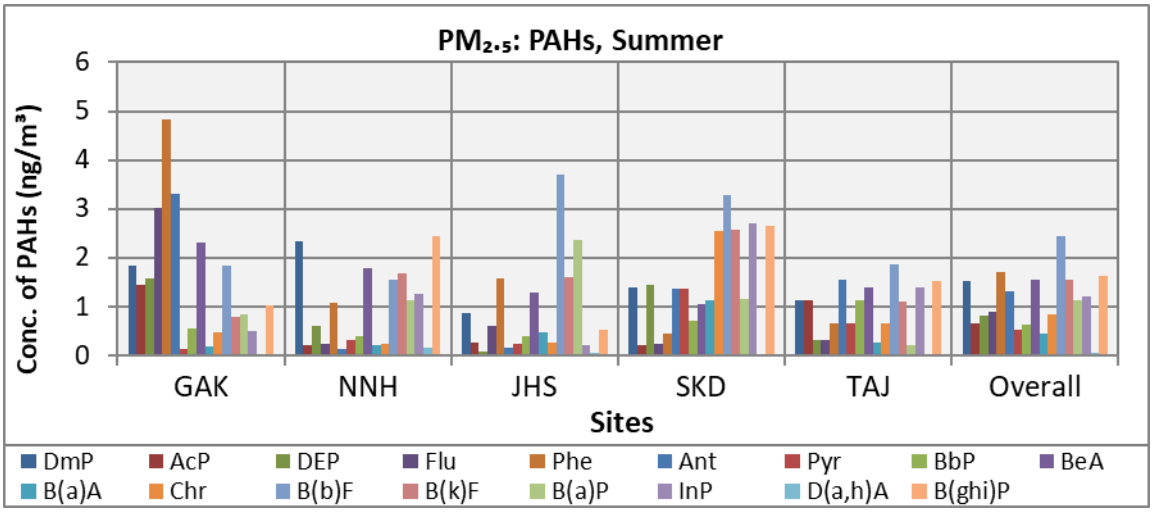


Figure 2.72: Variation in PAHs in $PM_{2.5}$ for summer season

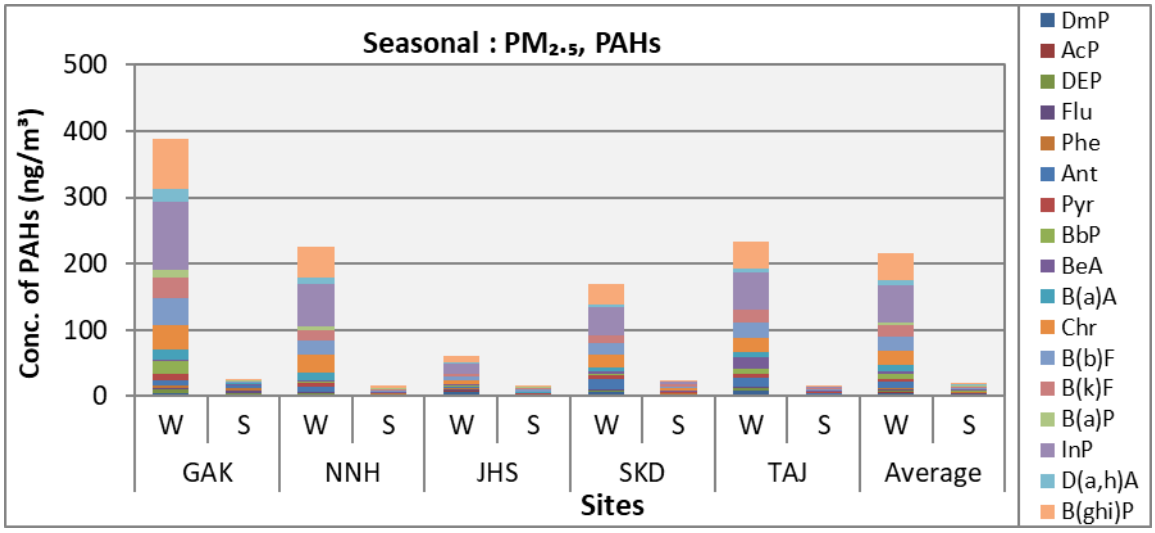


Figure 2.73: Seasonal comparison of PAHs in $PM_{2.5}$

2.4.6.6 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 2.74 (a), (b) and (c)) and $PM_{2.5}$ (Figure 2.75 (a), (b) and (c)). Overall summary of average concentrations for all sites along with overall average, standard deviation (SD) and coefficient of variation (CV) for PM (PM_{10} and $PM_{2.5}$), its composition [carbon content (EC and OC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb)] along with mass percentage (%R) estimated in composition are presented in Tables 2.76 – 2.79 for winter and summer seasons.

The statistical summary of the major components (i.e., crustal elements – Si, Ai, Fe, Ca; Secondary ions - NO_3^-, SO_4^{-2}, NH_4^+; TC) in PM_{10} and $PM_{2.5}$ are presented in Tables 2.81 – 2.84 for winter and summer seasons.

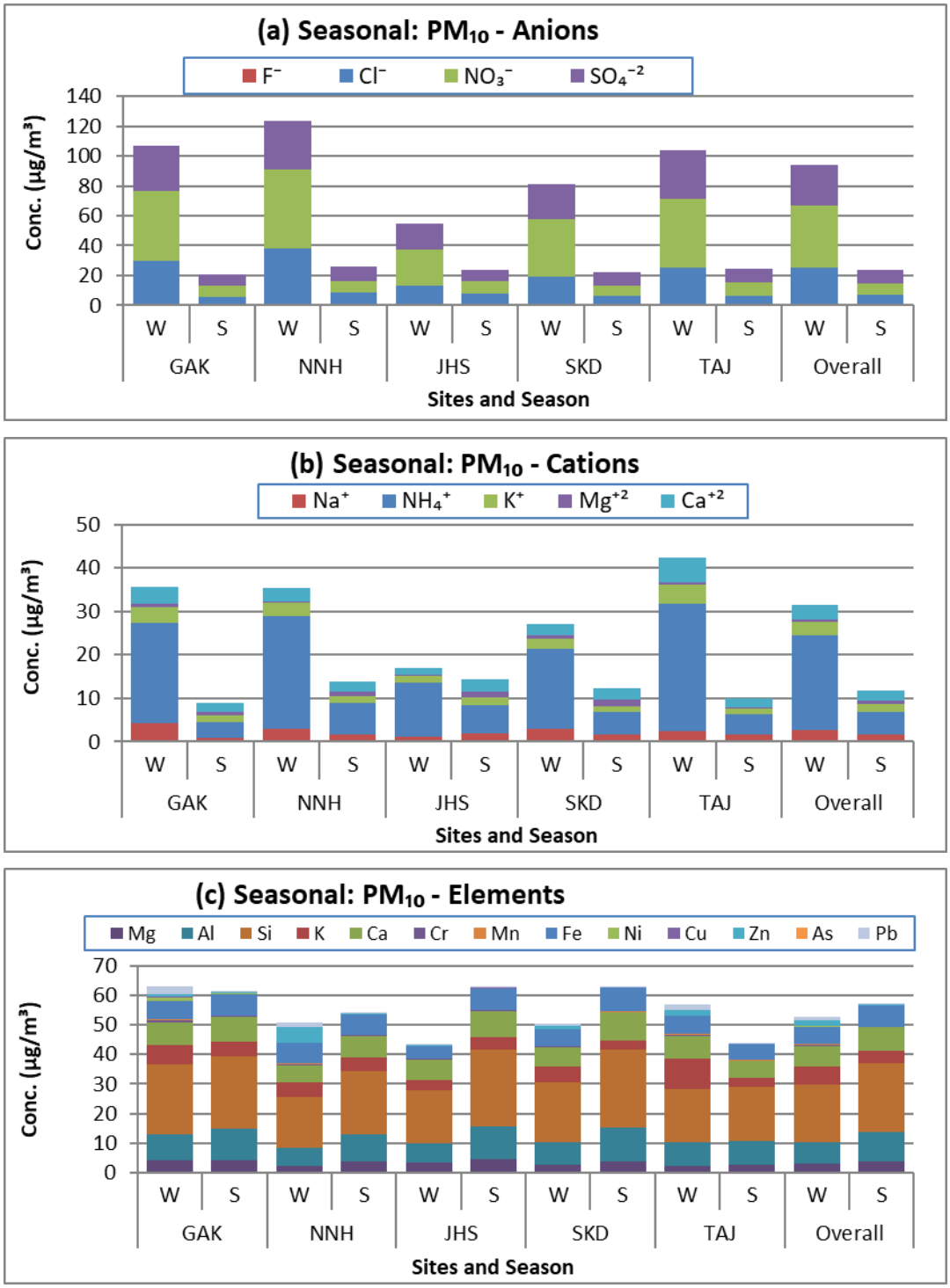


Figure 2.74: Seasonal comparison of ionic and elemental species concentrations in PM_{10} for all sites

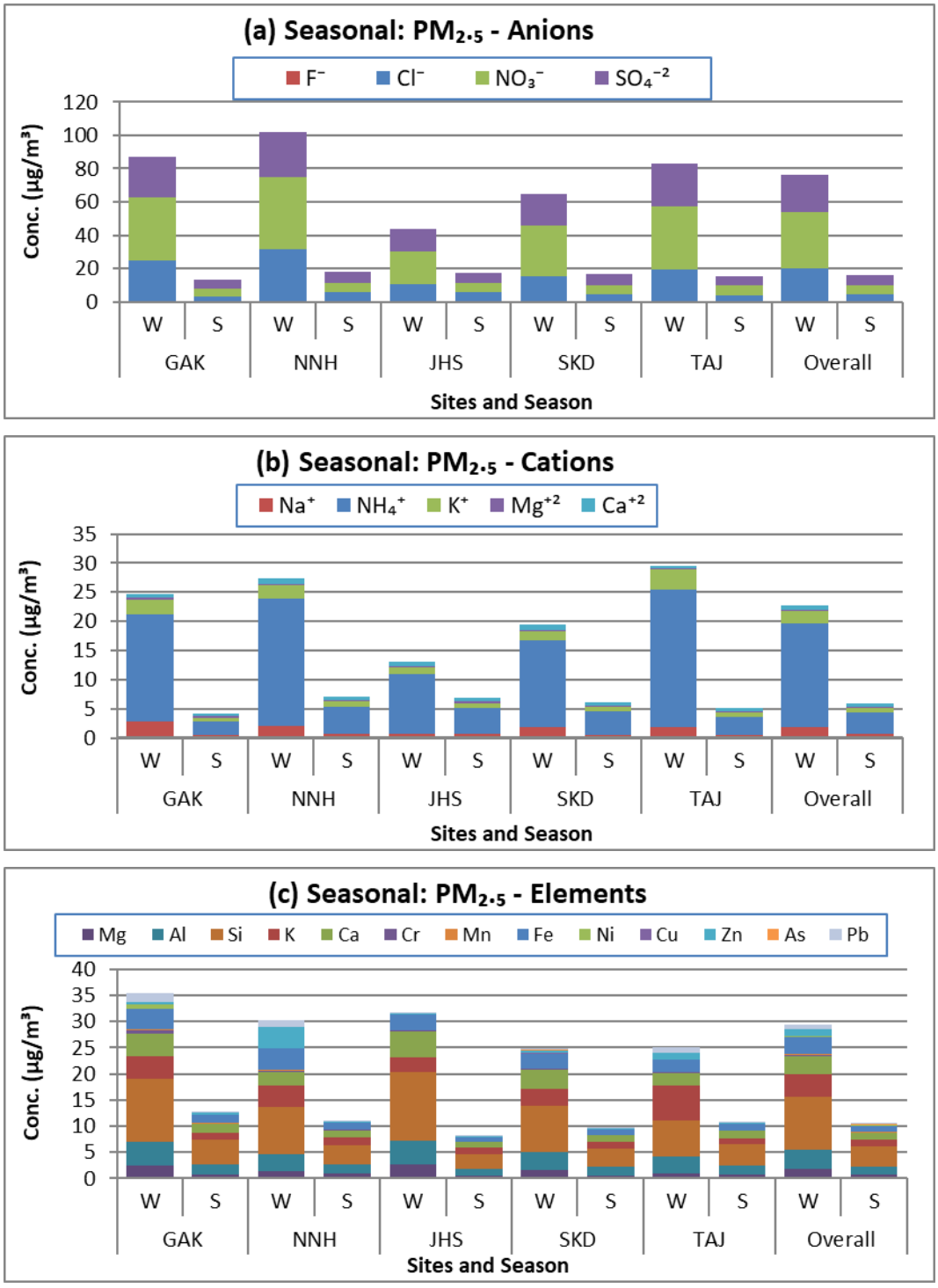


Figure 2.75: Seasonal comparison of ionic and elemental species concentrations in $PM_{2.5}$ for all sites

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

The graphical presentation is the better option for understanding the compositional variation. The major chemical species considered for overall compositional comparisons are carbon (OC and EC), ions (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Mg^{+2}, Ca^{+2}) and elements (Na, Mg, Al, Si,

P, K, Ca, Cr, V, Mn, Fe, Ni, Zn, As, Cd, Ba and Pb). Compositional comparison of $PM_{2.5}$ vs PM_{10} is shown for all major carbon, ions (Figure 2.84) and elements (Figure 2.85) for all sites and both seasons in Agra. The overall compositional comparison is also presented in Table 2.80 for all sites.

It is observed that a significant portion of PM has more fine-mode particles during winter (71%) than in summer (36%). The major species contributing to fine mode are EC, OC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, V, Zn, As, Cd and Pb; whereas, major species contributing in coarse mode are Mg^{+2}, Ca^{+2}, Ca, Al, Si, Cr, P, Fe and Ba (Figures 2.76 and 2.77).

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}.

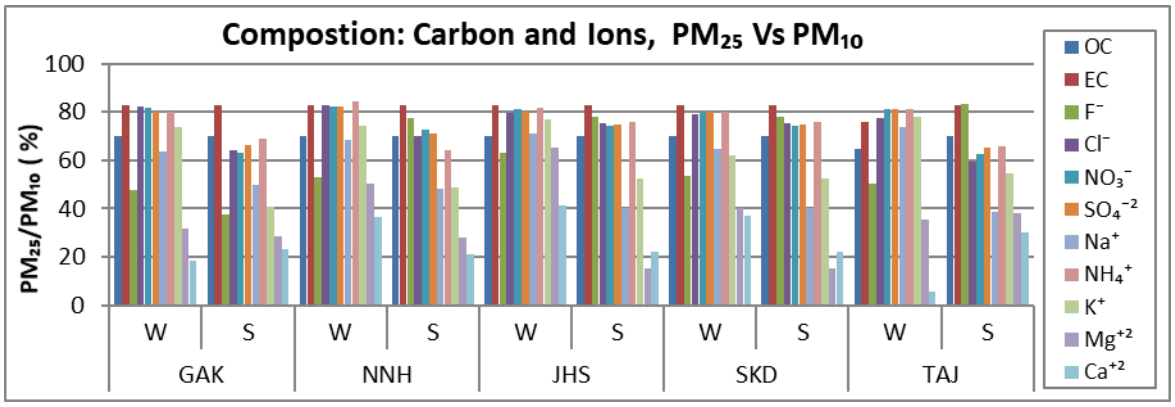


Figure 2.76: Compositional comparison of carbon and ions species in $PM_{2.5}$ Vs PM_{10}

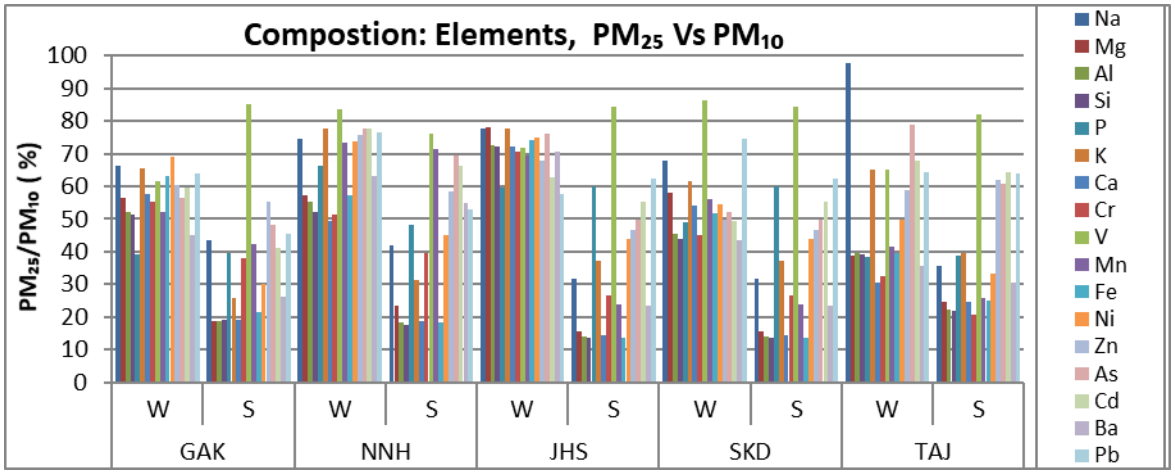


Figure 2.77: Compositional comparison of elemental species in $PM_{2.5}$ Vs PM_{10}

Table 2.69: Overall summary of experimental results of PM (mean±SD µg/m^3)

PM	PM_{10}		$PM_{2.5}$		$PM_{2.5}/PM_{10}$	
Sites	Winter	Summer	Winter	Summer	Winter	Summer
GAK	423±100 (0.24)	179±93 (0.52)	304±77 (0.25)	64±19 (0.30)	0.72±0.04 (0.06)	0.38±0.06 (0.16)
NNH	367±96 (0.26)	182±57 (0.31)	273±86 (0.31)	71±30 (0.42)	0.73±0.09 (0.12)	0.40±0.08 (0.21)
JHS	201±48 (0.24)	202±42 (0.21)	153±47 (0.31)	65±12 (0.18)	0.75±0.10 (0.13)	0.34±0.12 (0.36)
SKD	312±162 (0.52)	201±60 (0.30)	212±69 (0.33)	71±24 (0.33)	0.73±0.15 (0.20)	0.36±0.08 (0.23)
TAJ	366±74 (0.20)	151±71 (0.47)	250±53 (0.21)	61±22 (0.35)	0.74±0.11 (0.14)	0.44±0.11 (0.25)
Overall	334±84 (0.25)	183±21 (0.11)	238±58 (0.25)	67±5 (0.07)	0.73±0.01 (0.02)	0.38±0.04 (0.09)
Values show in parenthesis are the coefficient of variation (CV)						

Table 2.70: 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)
GAK	40.82	2.00	5.41	6.42	1.56	1.74	15.13
NNH	42.28	4.65	4.03	3.60	0.66	0.68	8.96
JHS	24.89	2.08	2.49	2.93	0.42	0.40	6.25
SKD	29.99	3.59	3.91	5.38	0.30	0.25	9.85
TAJ	26.51	5.69	2.57	1.61	0.34	0.40	4.92
Overall	32.90	3.60	3.68	3.99	0.66	0.69	9.02
SD	14.07	2.18	2.79	4.02	0.65	0.69	7.62
CV	0.43	0.61	0.76	1.01	0.99	0.99	0.85

Table 2.71: 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)
GAK	20.55	2.00	2.31	2.91	0.53	1.59	7.34
NNH	23.50	2.52	2.55	2.19	0.74	1.86	7.35
JHS	20.57	2.00	3.90	5.09	0.75	1.13	10.88
SKD	17.67	4.44	5.86	13.24	0.76	0.53	20.40
TAJ	13.26	3.29	2.63	2.21	0.50	1.27	6.60
Overall	19.11	2.85	3.45	5.13	0.66	1.28	10.51
SD	6.67	1.48	1.10	2.38	0.30	0.34	3.52
CV	0.35	0.52	0.32	0.46	0.45	0.27	0.33

Table 2.72: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for winter Season

Winter	$PM_{2.5}$	TC	OC	EC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
GAK	303.7	90.5	48.8	41.9	6.02	17.37	18.33	7.12	0.063	0.190	0.205	0.082
NNH	272.5	64.1	37.5	26.6	4.11	13.42	13.75	6.25	0.055	0.208	0.220	0.105
JHS	152.7	24.2	14.7	9.5	0.86	5.00	5.75	3.05	0.033	0.210	0.244	0.129
SKD	211.6	55.0	30.7	24.1	3.15	10.65	11.87	5.02	0.052	0.185	0.220	0.098
TAJ	249.5	65.3	37.3	28.0	3.31	13.32	14.06	6.58	0.048	0.204	0.218	0.105
Overall	238	59.8	33.8	26.0	3.49	11.95	12.75	5.60	0.050	0.200	0.221	0.104
SD	52	21.4	11.2	10.3	1.66	4.08	4.09	1.45	0.010	0.010	0.013	0.015
CV	0.22	0.36	0.33	0.40	0.48	0.34	0.32	0.26	0.194	0.050	0.058	0.144

Table 2.73: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for summer season

Summer	$PM_{2.5}$	TC	OC	EC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
GAK	63.9	16.6	10.6	6.0	0.62	3.23	4.27	2.47	0.036	0.196	0.259	0.151
NNH	71.3	17.7	11.0	6.7	0.36	3.50	4.35	2.81	0.019	0.197	0.244	0.165
JHS	65.3	19.9	12.5	7.4	0.37	4.06	5.00	3.03	0.018	0.203	0.253	0.153
SKD	71.3	21.4	13.3	8.1	1.01	4.03	5.56	2.74	0.047	0.193	0.248	0.132
TAJ	61.0	13.1	7.9	5.2	0.46	2.53	2.94	2.01	0.035	0.201	0.232	0.155
Overall	66.6	17.8	11.1	6.7	0.56	3.47	4.43	2.61	0.031	0.198	0.247	0.151
SD	4.1	2.9	1.8	1.0	0.24	0.57	0.88	0.35	0.011	0.004	0.009	0.011
CV	0.06	0.16	0.17	0.15	0.43	0.16	0.20	0.13	0.355	0.018	0.037	0.071

Table 2.74: 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
GAK	3.73	0.39	6.32	1.59	2.95	8.38	7.70	12.66	2.91	14.89	35.15	36.52	28.16	1.87	94.60	16.60	69.30	343.74
NNH	1.60	1.11	1.55	1.47	0.42	8.58	5.82	0.64	2.40	11.80	26.68	22.18	15.27	5.27	64.49	9.71	46.89	225.86
JHS	6.05	2.10	1.06	1.10	1.29	2.36	1.18	1.10	1.02	1.46	4.56	6.30	3.78	0.38	14.85	1.63	11.31	61.54
SKD	6.93	0.23	2.18	1.36	0.48	13.87	5.82	1.96	4.99	6.29	18.09	17.00	12.81	0.46	42.68	3.32	30.25	168.74
TAJ	8.29	0.28	4.07	1.83	0.58	12.79	6.40	6.94	16.79	8.12	22.73	22.86	18.33	0.64	56.23	6.00	40.25	233.13
Overall	5.32	0.82	3.04	1.47	1.14	9.20	5.38	4.66	5.62	8.51	21.44	20.97	15.67	1.73	54.57	7.45	39.60	206.60
SD	5.64	0.94	2.46	1.84	1.02	4.96	2.98	10.46	8.33	5.80	11.00	9.60	8.05	3.69	25.15	5.24	17.33	88.11
CV	1.06	1.14	0.81	1.25	0.89	0.54	0.55	2.24	1.48	0.68	0.51	0.46	0.51	2.14	0.46	0.70	0.44	0.43

Table 2.75: 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
GAK	1.84	1.43	1.57	3.02	4.83	3.31	0.12	0.56	2.31	0.19	0.46	1.82	0.79	0.84	0.50	0.03	1.02	24.64
NNH	2.33	0.21	0.59	0.24	1.08	0.12	0.30	0.39	1.78	0.19	0.23	1.54	1.66	1.12	1.26	0.16	2.43	15.61
JHS	0.86	0.25	0.08	0.59	1.56	0.16	0.23	0.38	1.27	0.46	0.27	3.70	1.59	2.35	0.20	0.05	0.53	14.53
SKD	1.38	0.21	1.45	0.23	0.43	1.36	1.35	0.70	1.04	1.12	2.56	3.27	2.57	1.15	2.69	0.01	2.66	24.16
TAJ	1.12	1.13	0.31	0.30	0.65	1.54	0.64	1.11	1.38	0.26	0.64	1.86	1.09	0.20	1.38	0.02	1.53	15.17
Overall	1.51	0.65	0.80	0.88	1.71	1.30	0.53	0.63	1.56	0.44	0.83	2.44	1.54	1.13	1.20	0.05	1.63	18.82
SD	1.31	0.69	1.35	1.32	2.78	1.34	0.74	0.82	3.81	0.63	1.60	2.20	1.31	1.37	1.73	0.07	2.16	13.54
CV	0.87	1.07	1.69	1.50	1.63	1.04	1.40	1.31	2.44	1.42	1.92	0.90	0.85	1.22	1.43	1.39	1.33	0.72

Table 2.76: 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
GAK	423	69.8	50.5	0.16	29.82	46.90	29.91	4.33	23.07	3.52	0.78	3.87	8E-4	0.48	9.75	4.19	8.68	23.75	0.55
NNH	367	53.6	32.1	0.25	37.99	52.51	33.05	3.06	25.93	2.91	0.47	2.95	1E-2	0.38	5.10	2.26	5.98	17.18	0.41
JHS	201	20.9	11.5	0.07	13.13	23.83	17.59	1.10	12.48	1.48	0.30	1.60	1E-2	0.13	2.29	3.34	6.38	18.19	0.31
SKD	312	43.9	29.0	0.08	19.23	38.23	23.50	2.84	18.60	2.34	0.59	2.83	7E-3	0.21	6.21	2.66	7.64	20.32	0.33
TAJ	366	57.4	36.8	0.20	25.23	46.17	32.17	2.51	29.15	4.40	0.64	5.79	1E-3	0.15	2.94	2.40	7.98	18.01	0.45
Overall	334	49.1	32.0	0.15	25.08	41.53	27.24	2.77	21.85	2.93	0.55	3.41	6E-3	0.27	5.26	2.97	7.33	19.49	0.41
SD	84	18.3	14.1	0.08	9.57	11.13	6.56	1.16	6.51	1.11	0.18	1.56	5E-3	0.15	2.97	0.80	1.13	2.65	0.10
CV	0.25	0.37	0.44	0.52	0.38	0.27	0.24	0.42	0.30	0.38	0.33	0.46	0.82	0.57	0.56	0.27	0.15	0.14	0.24
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
GAK	6.53	7.56	1.04	1.04	0.27	6.16	0.016	1.168	0.24	0.63	0.057	0.024	0.020	0.056	0.070	0.001	0.15	2.64	76.91
NNH	5.30	5.56	0.29	0.68	0.37	6.90	0.025	0.037	0.18	5.18	0.094	0.044	0.038	0.052	0.177	0.025	0.08	1.59	79.62
JHS	3.53	6.92	0.18	0.41	0.08	4.01	0.017	0.021	0.05	0.38	0.036	0.020	0.020	0.036	0.021	0.011	0.21	0.27	73.10
SKD	5.21	6.74	0.25	1.15	0.14	5.55	0.021	0.028	0.12	1.14	0.040	0.021	0.025	0.045	0.036	0.020	0.08	0.50	75.37
TAJ	10.20	7.70	0.50	0.47	0.16	6.02	0.005	0.022	0.16	1.92	0.065	0.015	0.033	0.040	0.090	0.001	0.11	1.66	78.98
Overall	6.15	6.90	0.45	0.75	0.21	5.73	0.017	0.255	0.15	1.85	0.059	0.025	0.027	0.046	0.079	0.012	0.13	1.33	76.80
SD	2.50	0.85	0.35	0.33	0.11	1.07	0.008	0.510	0.07	1.95	0.023	0.011	0.008	0.008	0.061	0.011	0.05	0.96	2.67
CV	0.41	0.12	0.77	0.44	0.55	0.19	0.46	2.00	0.48	1.06	0.39	0.46	0.30	0.18	0.78	0.91	0.43	0.72	0.03

Table 2.77: 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
GAK	304	48.8	41.9	0.07	24.52	38.38	23.93	2.76	18.44	2.59	0.25	0.72	5E-4	0.29	6.47	2.37	4.53	12.21	0.22
NNH	273	37.5	26.6	0.13	31.55	43.10	27.17	2.10	21.88	2.16	0.24	1.08	8E-3	0.29	3.80	1.29	3.31	8.96	0.27
JHS	153	14.7	9.5	0.04	10.49	19.40	14.11	0.78	10.22	1.14	0.19	0.66	9E-3	0.09	1.78	2.60	4.62	13.17	0.19
SKD	212	30.7	24.1	0.04	15.16	30.51	18.81	1.85	14.93	1.45	0.24	1.04	4E-3	0.15	4.21	1.54	3.49	8.90	0.16
TAJ	250	37.3	28.0	0.10	19.54	37.42	26.05	1.85	23.61	3.42	0.23	0.34	7E-4	0.10	2.88	0.92	3.17	7.05	0.17
Overall	238	33.8	26.0	0.08	20.25	33.76	22.01	1.87	17.82	2.15	0.23	0.77	4E-3	0.18	3.83	1.75	3.82	10.06	0.20
SD	58	12.5	11.5	0.04	8.18	9.20	5.46	0.71	5.40	0.91	0.02	0.31	4E-3	0.10	1.75	0.72	0.70	2.54	0.05
CV	0.25	0.37	0.44	0.49	0.40	0.27	0.25	0.38	0.30	0.42	0.09	0.40	0.87	0.54	0.46	0.41	0.18	0.25	0.23
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
GAK	4.29	4.37	0.58	0.64	0.14	3.89	0.010	0.81	0.15	0.38	0.03	0.009	0.005	0.02	0.04	0.001	0.07	1.69	78.81
NNH	4.11	2.75	0.15	0.57	0.27	3.95	0.020	0.03	0.13	3.93	0.07	0.035	0.027	0.03	0.14	0.020	0.05	1.22	81.91
JHS	2.74	5.00	0.13	0.30	0.06	2.98	0.013	0.02	0.03	0.26	0.03	0.015	0.015	0.03	0.01	0.008	0.15	0.16	74.21
SKD	3.21	3.66	0.11	0.99	0.08	2.88	0.010	0.02	0.08	0.57	0.02	0.009	0.008	0.02	0.02	0.006	0.03	0.38	77.85
TAJ	6.62	2.35	0.16	0.30	0.07	2.37	0.002	0.01	0.07	1.13	0.05	0.014	0.015	0.01	0.06	0.001	0.04	1.07	80.60
Overall	4.19	3.63	0.23	0.56	0.12	3.21	0.011	0.18	0.09	1.25	0.04	0.016	0.014	0.02	0.05	0.007	0.07	0.90	78.67
SD	1.50	1.10	0.20	0.29	0.09	0.68	0.006	0.35	0.05	1.53	0.02	0.010	0.008	0.01	0.05	0.008	0.05	0.63	2.95
CV	0.36	0.30	0.87	0.51	0.71	0.21	0.58	2.02	0.52	1.23	0.51	0.64	0.60	0.47	0.93	1.12	0.67	0.70	0.04

Table 2.78: 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
GAK	179	15.1	7.2	0.27	5.15	7.41	7.88	1.02	3.40	1.65	0.77	2.00	9E-4	0.03	2.14	4.20	10.52	24.47	0.30
NNH	182	15.7	8.1	0.32	8.02	7.59	9.78	1.70	7.17	1.75	0.93	2.42	1E-3	0.03	4.55	3.92	9.07	21.32	0.20
JHS	202	17.8	8.9	0.51	7.53	8.08	7.99	2.01	6.30	2.03	1.24	2.83	9E-4	0.06	4.16	4.54	11.13	25.98	0.16
SKD	201	19.1	9.7	0.34	5.70	6.93	9.09	1.56	5.32	1.38	1.57	2.41	1E-3	0.03	3.20	3.93	11.28	26.32	0.20
TAJ	151	11.3	6.2	0.30	6.36	9.03	9.09	1.57	4.68	1.39	0.37	1.86	1E-3	0.04	2.78	2.71	7.93	18.48	0.32
Overall	183	15.8	8.1	0.35	6.55	7.81	8.77	1.57	5.38	1.64	0.97	2.31	1E-3	0.04	3.37	3.86	9.98	23.31	0.24
SD	21	3.0	1.4	0.09	1.21	0.80	0.81	0.36	1.45	0.27	0.46	0.39	2E-4	0.01	0.99	0.69	1.44	3.35	0.07
CV	0.11	0.19	0.17	0.27	0.18	0.10	0.09	0.23	0.27	0.16	0.47	0.17	0.17	0.36	0.29	0.18	0.14	0.14	0.29
Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
GAK	5.09	8.38	0.29	0.29	0.15	7.46	0.008	0.041	0.047	0.602	0.037	0.012	0.014	0.030	0.092	0.001	0.06	0.24	63.28
NNH	4.66	7.30	0.22	0.27	0.24	6.72	0.008	0.028	0.049	0.390	0.039	0.017	0.010	0.018	0.070	0.003	0.05	0.20	64.53
JHS	4.03	9.05	0.18	0.25	0.08	7.48	0.003	0.014	0.022	0.262	0.026	0.013	0.006	0.023	0.014	0.001	0.04	0.16	62.43
SKD	3.18	9.47	0.18	0.27	0.09	8.07	0.004	0.013	0.022	0.272	0.024	0.020	0.007	0.011	0.014	0.001	0.04	0.09	61.61
TAJ	3.08	5.49	0.26	0.96	0.11	5.41	0.003	0.051	0.034	0.151	0.027	0.025	0.011	0.020	0.016	0.002	0.02	0.08	64.08
Overall	4.01	7.94	0.23	0.41	0.13	7.03	0.005	0.029	0.035	0.335	0.031	0.017	0.010	0.021	0.041	0.002	0.05	0.15	63.18
SD	0.88	1.60	0.05	0.31	0.07	1.02	0.002	0.017	0.013	0.171	0.007	0.005	0.003	0.007	0.037	0.001	0.01	0.07	1.19
CV	0.22	0.20	0.22	0.76	0.50	0.15	0.46	0.58	0.38	0.51	0.23	0.31	0.34	0.34	0.90	0.50	0.32	0.44	0.02

Table 2.79: 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
GAK	64	10.6	6.0	0.10	3.31	4.67	5.21	0.51	2.34	0.67	0.22	0.46	6E-4	0.02	0.93	0.78	1.98	4.69	0.12
NNH	71	11.0	6.7	0.25	5.64	5.51	6.97	0.82	4.62	0.85	0.26	0.51	7E-4	0.01	1.91	0.91	1.66	3.78	0.10
JHS	65	12.5	7.4	0.25	5.37	5.91	5.65	0.64	4.49	0.81	0.30	0.70	6E-4	0.03	1.03	0.59	1.18	2.86	0.09
SKD	71	13.3	8.1	0.26	4.30	5.17	6.81	0.62	4.03	0.72	0.24	0.54	4E-4	0.02	1.02	0.61	1.56	3.56	0.12
TAJ	61	7.9	5.2	0.25	3.76	5.66	5.94	0.61	3.09	0.76	0.14	0.56	6E-4	0.02	0.99	0.67	1.75	4.05	0.12
Overall	67	11.1	6.7	0.22	4.48	5.38	6.12	0.64	3.72	0.76	0.23	0.55	6E-4	0.02	1.17	0.71	1.63	3.79	0.11
SD	5	2.1	1.1	0.07	1.01	0.48	0.76	0.11	0.97	0.07	0.06	0.09	1E-4	0.01	0.41	0.13	0.30	0.67	0.02
CV	0.07	0.19	0.17	0.31	0.22	0.09	0.12	0.18	0.26	0.09	0.26	0.16	0.17	0.29	0.35	0.19	0.18	0.18	0.15
Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
GAK	1.32	1.61	0.11	0.24	0.06	1.60	0.004	0.012	0.026	0.33	0.02	0.004	0.003	0.004	0.038	0.000	0.017	0.107	73.28
NNH	1.45	1.36	0.09	0.21	0.17	1.22	0.006	0.012	0.028	0.23	0.03	0.008	0.006	0.005	0.047	0.001	0.030	0.107	77.02
JHS	1.23	1.06	0.03	0.21	0.01	0.83	0.001	0.005	0.010	0.17	0.02	0.007	0.003	0.005	0.008	0.000	0.019	0.091	78.48
SKD	1.18	1.35	0.05	0.23	0.02	1.11	0.002	0.006	0.014	0.13	0.01	0.008	0.003	0.004	0.008	0.001	0.009	0.058	75.05
TAJ	1.22	1.34	0.05	0.79	0.03	1.35	0.001	0.017	0.011	0.09	0.02	0.013	0.004	0.006	0.010	0.002	0.008	0.050	73.70
Overall	1.28	1.34	0.06	0.33	0.06	1.22	0.003	0.010	0.018	0.19	0.02	0.008	0.004	0.005	0.022	0.001	0.017	0.083	75.50
SD	0.11	0.20	0.03	0.25	0.07	0.29	0.002	0.005	0.009	0.09	0.01	0.003	0.001	0.001	0.019	0.001	0.009	0.027	2.21
CV	0.08	0.15	0.51	0.76	1.12	0.23	0.69	0.50	0.50	0.49	0.30	0.40	0.37	0.16	0.85	0.72	0.54	0.33	0.03

Table 2.80: Ratios of chemical species of $PM_{2.5}$ and PM_{10} for all sites for winter (W) and summer (S) seasons

Sites	GAK		NNH		JHS		SKD		TAJ		Overall	
Season	W	S	W	S	W	S	W	S	W	S	W	S
PM_{10}	423	179	367	182	201	202	312	201	366	151	334	183
$PM_{2.5}$	304	64	273	71	153	65	212	71	250	61	238	67
$PM_{2.5}/PM_{10}$	72	36	74	39	76	35	68	35	68	40	71	36
OC ($PM_{2.5}/PM_{10}$)	70	70	70	70	70	70	70	70	65	70	69	70
EC ($PM_{2.5}/PM_{10}$)	83	83	83	83	83	83	83	83	76	83	81	83
F^- ($PM_{2.5}/PM_{10}$)	48	37	53	78	63	78	53	78	50	83	52	64
Cl^- ($PM_{2.5}/PM_{10}$)	82	64	83	70	80	75	79	75	77	59	81	68
NO_3^- ($PM_{2.5}/PM_{10}$)	82	63	82	73	81	75	80	75	81	63	81	69
SO_4^{-2} ($PM_{2.5}/PM_{10}$)	80	66	82	71	80	75	80	75	81	65	81	70
Na^+ ($PM_{2.5}/PM_{10}$)	64	50	68	48	71	40	65	40	74	39	67	41
NH_4^+ ($PM_{2.5}/PM_{10}$)	80	69	84	64	82	76	80	76	81	66	82	69
K^+ ($PM_{2.5}/PM_{10}$)	74	41	74	49	77	53	62	53	78	55	73	47
Mg^{+2} ($PM_{2.5}/PM_{10}$)	32	29	51	28	65	15	40	15	36	38	41	24
Ca^{+2} ($PM_{2.5}/PM_{10}$)	19	23	37	21	41	22	37	22	6	30	23	24
Be ($PM_{2.5}/PM_{10}$)	60	66	77	63	75	34	60	34	67	52	71	54
B ($PM_{2.5}/PM_{10}$)	61	62	77	56	72	62	73	62	66	52	69	56
Na ($PM_{2.5}/PM_{10}$)	66	44	75	42	78	32	68	32	98	36	73	35
Mg ($PM_{2.5}/PM_{10}$)	57	19	57	23	78	15	58	15	39	25	59	18
Al ($PM_{2.5}/PM_{10}$)	52	19	55	18	72	14	46	14	40	22	52	16
Si ($PM_{2.5}/PM_{10}$)	51	19	52	18	72	14	44	14	39	22	52	16
P ($PM_{2.5}/PM_{10}$)	39	39	66	48	60	60	49	60	38	39	49	46
K ($PM_{2.5}/PM_{10}$)	66	26	78	31	78	37	62	37	65	40	68	32
Ca ($PM_{2.5}/PM_{10}$)	58	19	50	19	72	14	54	14	30	24	53	17
Cr ($PM_{2.5}/PM_{10}$)	55	38	51	40	70	27	45	27	33	21	50	29
V ($PM_{2.5}/PM_{10}$)	62	85	83	76	72	84	86	84	65	82	75	82
Mn ($PM_{2.5}/PM_{10}$)	52	42	73	71	69	24	56	24	42	26	60	45
Fe ($PM_{2.5}/PM_{10}$)	63	21	57	18	74	14	52	14	39	25	56	17
Co ($PM_{2.5}/PM_{10}$)	65	47	77	72	75	48	47	48	42	35	65	53
Ni ($PM_{2.5}/PM_{10}$)	69	30	74	45	75	44	54	44	50	33	69	36
Cu ($PM_{2.5}/PM_{10}$)	60	56	71	57	65	62	61	62	45	31	60	51
Zn ($PM_{2.5}/PM_{10}$)	60	55	76	58	68	47	50	47	59	62	68	57
As ($PM_{2.5}/PM_{10}$)	56	48	78	69	76	50	52	50	79	61	70	59
Se ($PM_{2.5}/PM_{10}$)	39	34	78	50	74	39	46	39	92	52	66	47
Rb ($PM_{2.5}/PM_{10}$)	26	23	71	58	77	40	31	40	45	41	51	39
Sr ($PM_{2.5}/PM_{10}$)	32	13	62	26	79	37	41	37	18	29	46	23
Cd ($PM_{2.5}/PM_{10}$)	60	41	78	66	63	55	50	55	68	64	69	53
Cs ($PM_{2.5}/PM_{10}$)	42	33	80	38	76	59	31	59	36	68	61	48
Ba ($PM_{2.5}/PM_{10}$)	45	26	63	55	71	23	43	23	35	31	54	36
Pb ($PM_{2.5}/PM_{10}$)	64	45	77	53	58	62	74	62	64	64	68	54

Table 2.81: 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}
GAK	423	46.2	0.109	99.9	0.236	120.2	0.284
NNH	367	35.6	0.097	111.5	0.304	85.7	0.234
JHS	201	35.5	0.177	53.9	0.269	32.4	0.162
SKD	312	40.3	0.129	80.3	0.257	72.8	0.233
TAJ	366	39.7	0.109	107.5	0.294	94.3	0.258
Overall	334	39.4	0.124	90.6	0.272	81.1	0.234
SD	84	4.4	0.032	23.8	0.028	32.3	0.046
CV	0.252	0.111	0.255	0.262	0.101	0.398	0.195

Table 2.82: 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/$PM_{2.5}$
GAK	304	25.00	0.082	80.75	0.266	90.5	0.298
NNH	273	18.97	0.070	92.15	0.338	64.1	0.235
JHS	153	25.77	0.169	43.73	0.286	24.2	0.158
SKD	212	18.92	0.089	64.25	0.304	55.0	0.260
TAJ	250	14.94	0.060	87.09	0.349	65.3	0.262
Overall	238	20.72	0.094	73.59	0.309	59.8	0.243
SD	58	4.57	0.043	19.73	0.035	23.9	0.052
CV	0.25	0.22	0.46	0.27	0.11	0.40	0.21

Table 2.83: 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}
GAK	179	50.8	0.284	18.7	0.104	22.3	0.125
NNH	182	44.4	0.244	24.5	0.135	23.8	0.131
JHS	202	53.6	0.265	22.4	0.111	26.7	0.132
SKD	201	55.1	0.274	21.3	0.106	28.8	0.143
TAJ	151	37.3	0.247	22.8	0.151	17.6	0.116
Overall	183	48.3	0.263	22.0	0.121	23.9	0.129
SD	21	7.4	0.017	2.2	0.021	4.3	0.010
CV	0.114	0.153	0.065	0.098	0.170	0.181	0.076

Table 2.84: Statistical summary of major components: $PM_{2.5}$, summer (µg/m^3)

Summer	$PM_{2.5}$	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/$PM_{2.5}$	Sec Ions (NO_3^- + SO_4^{-2} + NH_4^+)	Ratio Sec Ions/$PM_{2.5}$	TC	Ratio TC/$PM_{2.5}$
GAK	64	9.9	0.155	12.2	0.191	16.6	0.260
NNH	71	8.0	0.113	17.1	0.240	17.7	0.249
JHS	65	5.9	0.091	16.0	0.246	19.9	0.304
SKD	71	7.6	0.106	16.0	0.225	21.4	0.301
TAJ	61	8.5	0.139	14.7	0.241	13.1	0.215
Overall	67	8.0	0.121	15.2	0.228	17.8	0.266
SD	5	1.4	0.026	1.9	0.022	3.2	0.037
CV	0.069	0.180	0.214	0.123	0.098	0.179	0.140

2.4.7 Statistical Summary

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

2.4.7.1 Box Plot Distribution

Statistical box plots are shown in Figures 2.78 to 2.83 for all sites for $PM_{2.5}$, PM_{10}, NO_2 and SO_2, EC and OC for winter (W) and summer (S) season. These figures show the mean, median, 25% quartile, 75% quartile and outliers of the data distribution. The outlier values could be possibly due to the local activities (i.e., DG sets emission, biomass burning, traffic congestion etc.) near the monitoring stations. The GAK, NNH and SKD sites show the largest variability and high pollution level, whereas residential areas show low variability in PM_{10}. The same trend and pattern are applicable for $PM_{2.5}$ and NO_2, OC, EC. It is to be noted that variability is much higher in winter than in summer.

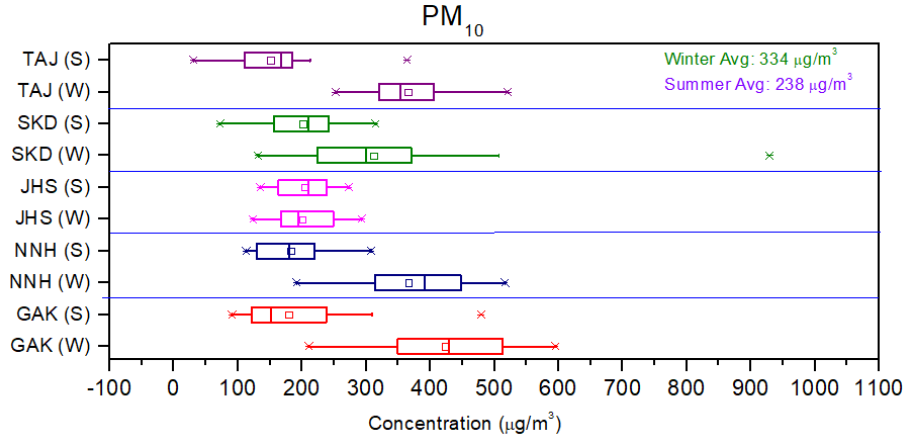


Figure 2.78: Box plot distribution for PM_{10} (winter and summer)

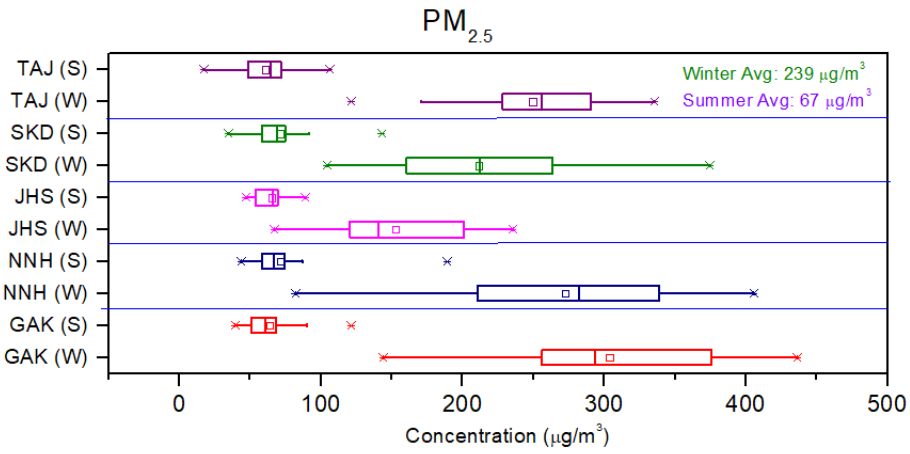


Figure 2.79: Box plot distribution for $PM_{2.5}$ (winter and summer)

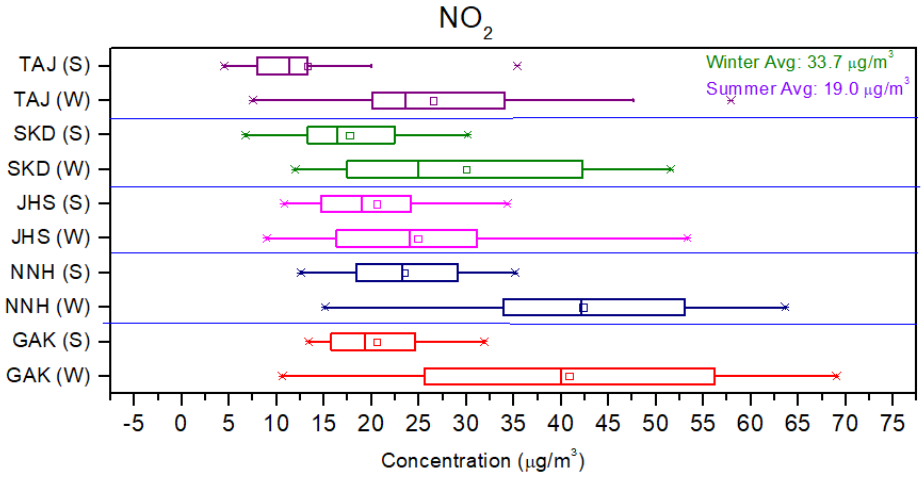


Figure 2.80: Box plot distribution for NO_2 (winter and summer)

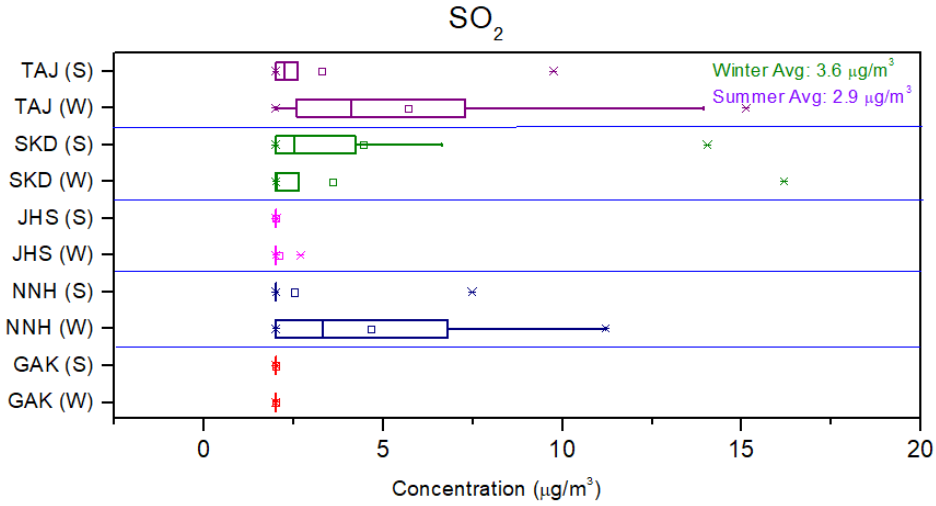


Figure 2.81: Box plot distribution for SO_2 (winter and summer)

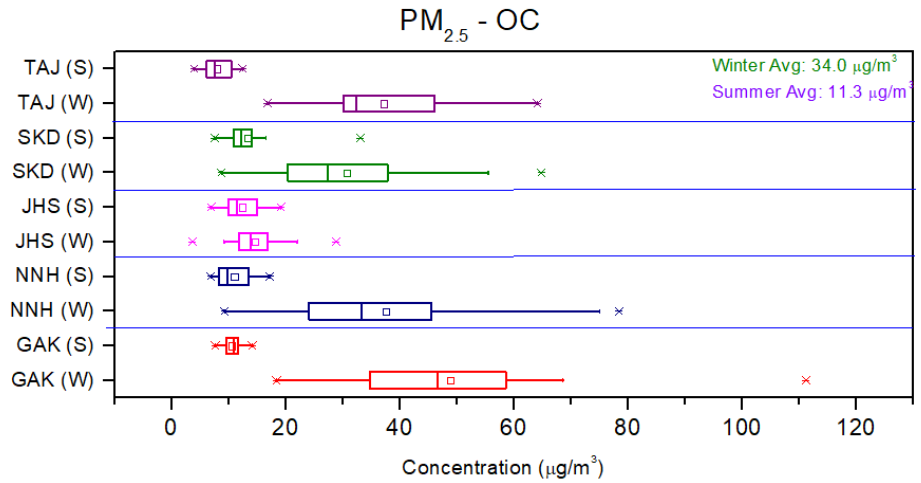


Figure 2.82: Box plot distribution for OC (winter and summer)

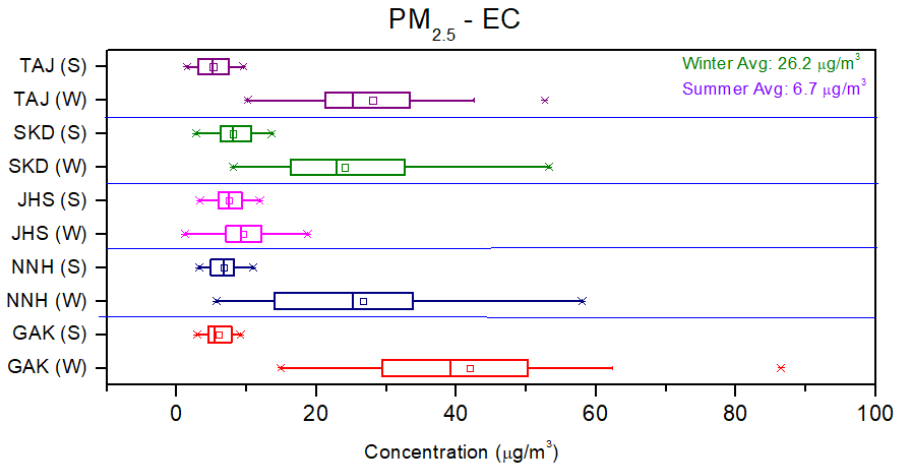


Figure 2.83: Box plot distribution for EC (winter and summer)

2.4.7.2 Statistics of t-Test for Seasonal Comparison

Student t-test statistics are performed at 5% level of significance to estimate if winter levels are higher (or lower) than summer levels for PM_{10}, $PM_{2.5}$, NO_2, SO_2 and carbon content (EC and OC). It is observed from Table 2.85 that in winter, $PM_{2.5}$ and EC levels are significantly higher at all sites, PM_{10}, OC and NO_2 levels are higher at all sites except JHS and SO_2 levels are higher at NNH and TAJ. There is no significant difference in PM_{10}, OC and NO_2 levels at JHS and SO_2 levels at GAK, JHS and SKD in summer and winter.

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

Table 2.85: Statistical Comparison Winter vs Summer

Parameter / Site	PM_{10}	$PM_{2.5}$	OC	EC	NO_2	SO_2
GAK	↑	↑	↑	↑	↑	↔
NNH	↑	↑	↑	↑	↑	↑
JHS	↔	↑	↔	↑	↔	↔
SKD	↑	↑	↑	↑	↑	↔
TAJ	↑	↑	↑	↑	↑	↑

↔ No significant difference; ↑ (Levels higher in winter); ↓ (Levels lower in winter)

* No pollutant showed lower concentration in winter

2.5 Interpretations and Inferences

Based on the extensive air quality measurements in the summer and winter months and critical analyses of air quality data, the following inferences and insights are drawn for developing a causal relationship between emission and impact through receptor modeling (Chapters 4). The season-wise, site-specific average air concentration of PM_{10}, $PM_{2.5}$ and their compositions and gaseous pollutants (Tables 2.69 – 2.79 and 2.81 – 2.85) have been referred to bring the important inferences to the fore.

- Particulate pollution is the main concern in the city where PM_{10} levels are 2.0 – 4.2 times higher than the national air quality standards in the winter season and 1.5 – 2.0 times in the summer season. $PM_{2.5}$ levels are 2.5 – 5.0 times higher than the national standard in the winter season. In the summer, $PM_{2.5}$ levels marginally exceed (4 – 12 %) the national standards.

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

PM_{10} (winter and summer)

The overall average concentration of PM_{10} was 334±84 µg/m^3 in winter and 183±21 µg/m^3 in summer against the acceptable level of 100 µg/m^3. The highest levels were observed at GAK (423±100 µg/m^3) and lowest at JHS (201±48 µg/m^3) in winter. In summer, the highest levels were at JHS and the lowest at TAJ.

In winter, crustal component (Si + Al + Fe + Ca) accounts for about 12% (much less compared to 26% in summer). This suggests soil and road dust have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.25 (of the fraction of crustal component), which suggests the crustal source contributes consistently even in winter, though much less than in summer.

In summer, the crustal component (Si + Al + Fe + Ca) accounts for about 26% of total PM_{10}. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.07 (of the fraction of crustal component), which suggests the sources are consistent and uniform all around the city, forming a layer that envelops the city. GAK and SKD have the highest crustal fraction

(around 28% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Agra 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 other important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for about 27% of total PM_{10} and combustion-related total carbon (TC = EC + OC) accounts for about 23%; both fractions of secondary particles and combustion-related carbons have increased in winter and account for 50% of PM_{10}.

In summer, the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$) account for 12% of total PM_{10} and combustion-related total carbon (EC+OC) accounts for about 13%.

The Cl^- content in PM_{10} in winter is consistent and varies between 6 – 10%, an indicator of the burning of municipal and plastic solid waste (MSW); poly vinyl chloride (PVC) is a significant part of MSW. The highest Cl^- content is observed at NNH at 38 µg/m^3 compared to the overall city level of 25 µg/m^3. The Cl^- content in PM_{10} in summer is consistent at 2.8 – 4.4%. The high level at NNH signifies some local burning of waste either in industrial processes or as means of disposal of solid waste.

The zinc (Zn) levels are highly variable, with city average of 1.85 µg/m^3 in winter and 0.34 µg/m^3 in summer. The maximum levels were at NNH (5.18 µg/m^3) in winter and GAK (0.60 µg/m^3) in summer. The high levels of Zn signify the industrial emissions and tyre wear and burning in the city.

$PM_{2.5}$

The overall average concentration of $PM_{2.5}$ is 238±58 µg/m^3 in winter and 67±5 µg/m^3 in summer and against the acceptable level of 60 µg/m^3. The highest levels are observed at GAK (304±77 µg/m^3) and lowest at JHS (153±47 µg/m^3) in winter. In summer, the highest levels were at NNH and the lowest at TAJ.

The crustal component (Si + Al + Fe + Ca) accounts for about 9% in winter and 12% in summer in total $PM_{2.5}$. The CV is about 0.21 in summer, which suggests the source is consistent all around the city though relatively small in winter.

In winter, the important components are the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 31% of total $PM_{2.5}$ and combustion-related total carbon (EC+OC) accounts for 24%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 55%. The highest TC level was observed at GAK (about 90 µg/m^3) and secondary particles at NNH (about 92 µg/m^3).

In summer, the secondary particles account for 23% and combustion-related total carbon (EC+OC) accounts for 27%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 50%. The highest TC was at JHS and secondary particles at NNH.

The Cl^- content in $PM_{2.5}$ was consistent in the winter and summer seasons and varied between 5 – 12%, which is an indicator of the burning of MSW. This is relatively lower in summer than in winter.

Potassium levels

In general, potassium levels are high and variable for PM_{10} (3.0 to 10.2 µg/m^3) both in winter and summer. In $PM_{2.5}$ potassium levels in winter vary between 3.1 to 5.1 µg/m^3. In general, the potassium levels are than 2.0 µg/m^3 in urban areas. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.40) show day-to-day variation both in summer and winter.

NO_2 levels

NO_2 levels in winter are higher than those in summer at all sites and the levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 levels were at NNH, 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 (less than 6.0 µg/m^3) in the city were well within the air quality standard.

General inferences

in winter, $PM_{2.5}$ and EC levels are significantly higher at all sites. PM_{10}, OC and NO_2 are high at most sites (except JHS). Levels of $PM_{2.5}$ and EC are statistically higher (at all locations) in winter than in summer. In general, air pollution levels in ambient air (barring traffic intersections) are uniform across the city, suggesting the entire city is stressed

under high pollution; in a relative sense, GAK is most polluted, followed by NNH and TAJ. JHS is the least polluted area.

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

Total PAH levels (17 compounds; particulate phase) in winter is high (relatively to levels generally seen in urban areas) at 207 ng/m^3 and B(a)P at 1.73 ng/m^3 (annual standard is one ng/m^3); the comparison with the annual standard is not advisable due to different averaging times. However, PAH levels in summer drop significantly to about 19 ng/m^3. The highest PAH levels were observed at GAK (winter 344 ng/m^3 and in summer 25 ng/m^3).

The total BTX levels are slightly higher in summer (10.5± 3.5 µg/m^3) than in winter (9.0± 7.6 µg/m^3). The emission rate is expected to be high in summer due to higher temperature, but not much difference in the concentration is due to better dispersion and large ventilation coefficient in summer. The benzene generally meets the annual national standard (5 µg/m^3) in winter (except at GAK) and in summer (except at SKD).

In a broad sense, the air quality is worse in winter than in summer as air contains a much larger contribution of combustion products in winter than in summer.

In a broad sense, fractions of secondary particles of both PM_{10} and $PM_{2.5}$ in two seasons were consistent and needed to be controlled for better air quality in Agra. Combustion sources, vehicles, coal, biomass burning and MSW burning are other consistent sources in winter and require a strategy to control these sources. In summer, air quality cannot be improved unless we find effective control solutions for soil and road dust, fly ash re-suspension. The possible effective mixture of control options is discussed in Chapter 6.

3 Emission Inventory

3.1 Introduction

Emission inventory (EI) is a basic necessity for planning air pollution control activities. EI provides a reliable estimate of total emissions of different pollutants, their spatial and temporal distribution, and identification and characterization of main sources. This information on EI is an essential input to air quality models for developing strategies and policies. In this chapter, the emission inventory of the study area for the year 2019 is presented.

3.2 Methodology

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

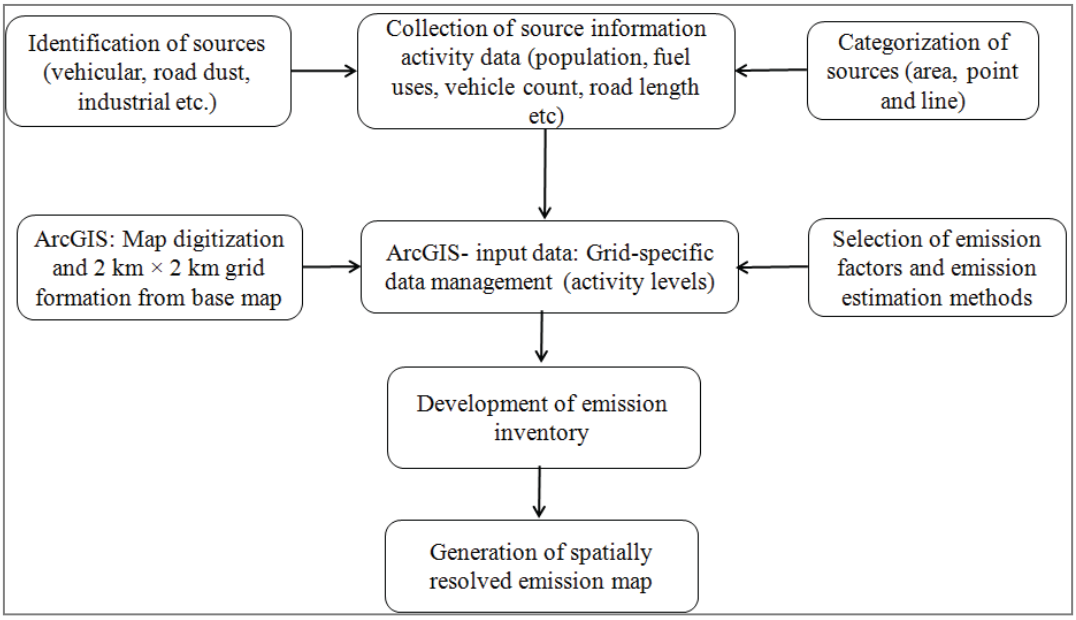


Figure 3.1: Stepwise Methodology adopted for the Study

3.2.1 Data Collection

The primary and secondary data were collected by the IITK team. For example, construction and demolition data were collected by field survey and validated by satellite imagery. Road dust sampling at 16 locations was conducted. A physical survey of industrial areas was also done. The main sources of secondary data collection are from UPPCB, Census of India, CPCB website, AAI (Airport Authority of India), Indian Railways, Agra Development Authority,

Public Works Department, Transport Department, and Toll Plazas. 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.

3.2.2 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, agriculture, road network, water bodies, etc. (Figure 3.2 to Figure 3.12).

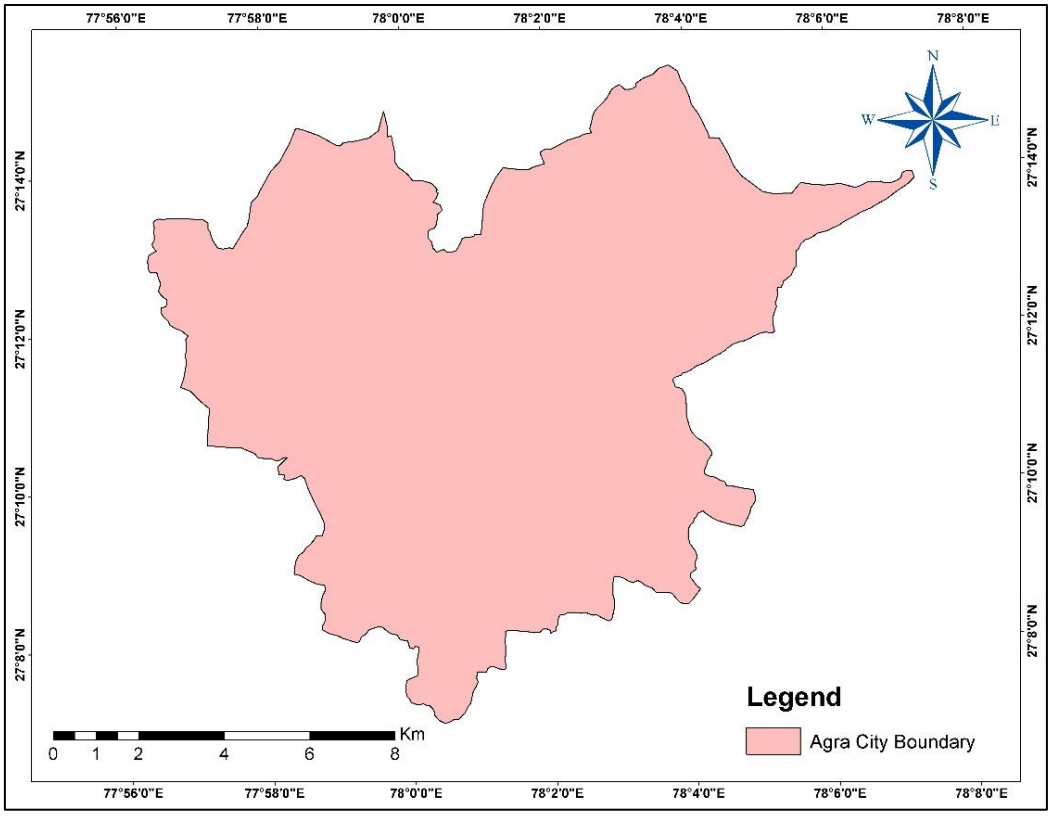


Figure 3.2: Agra City Boundary

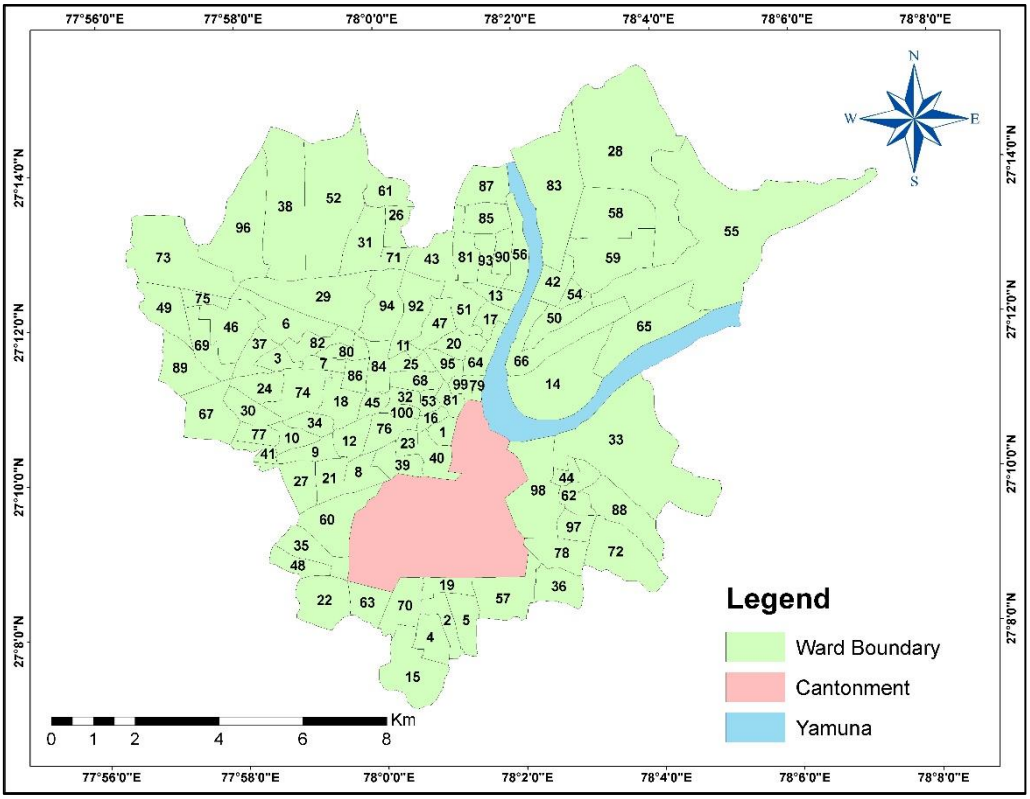


Figure 3.3: Ward Map

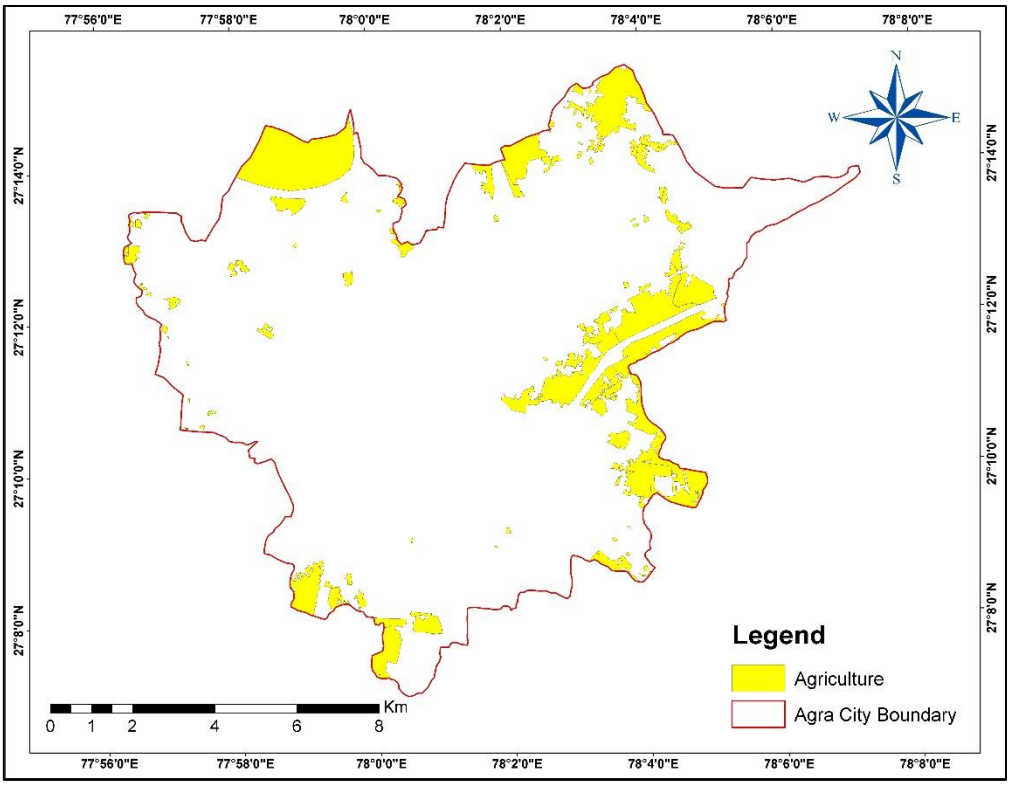


Figure 3.4: Agricultural Area Map

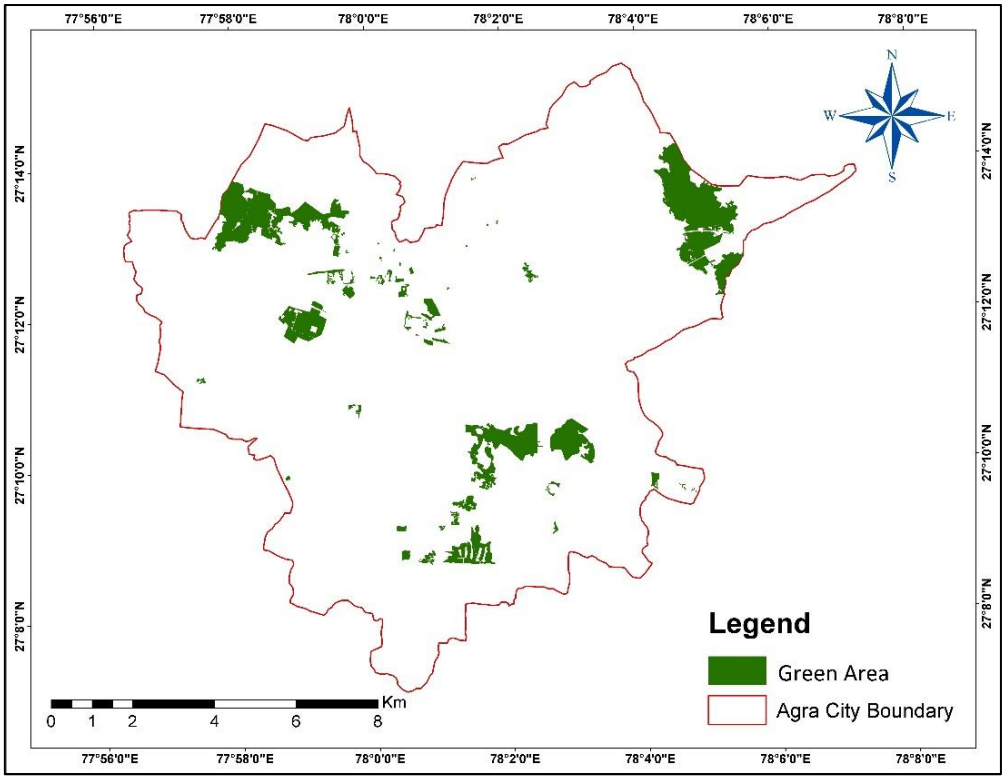


Figure 3.5: Green Area Map

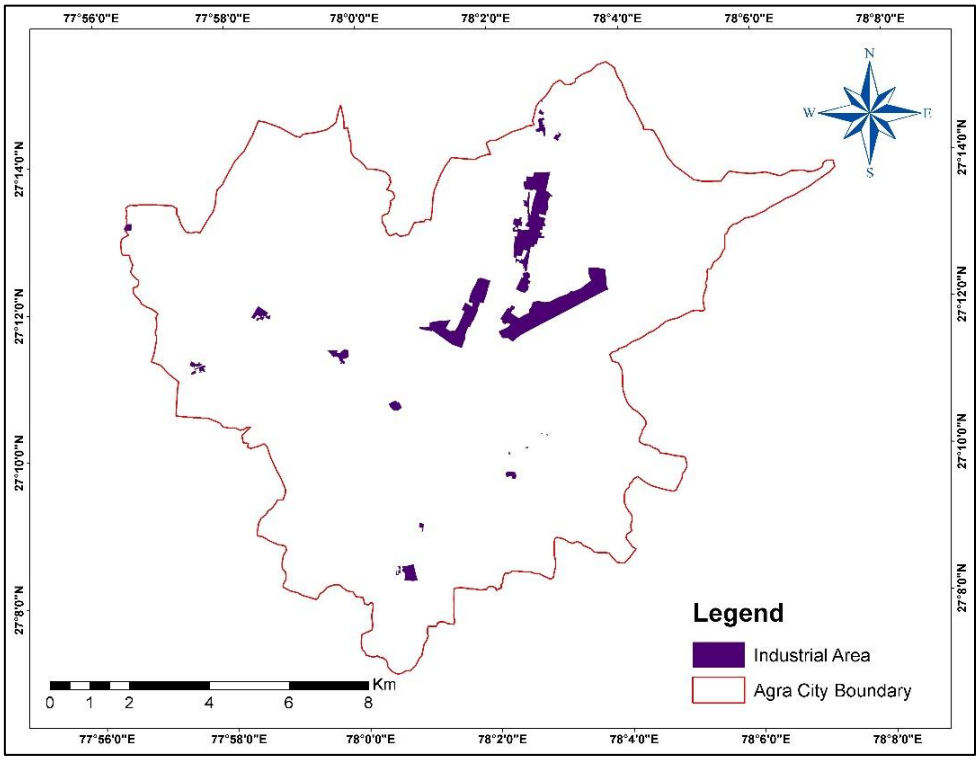


Figure 3.6: Industrial Area Map

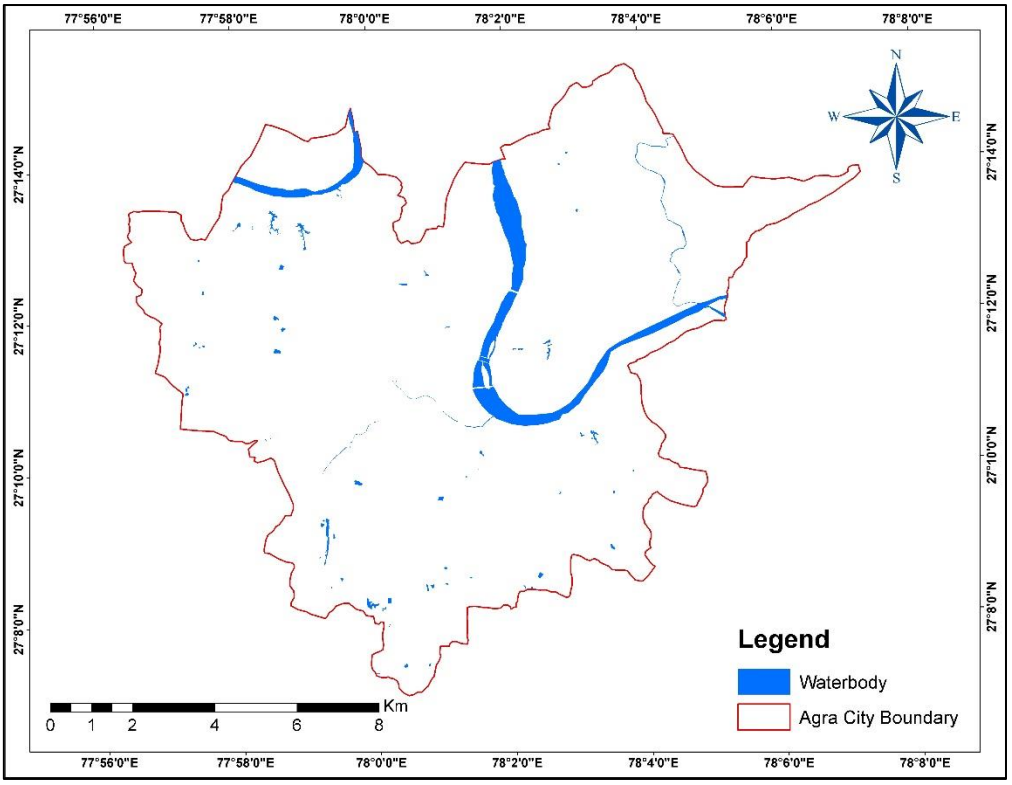


Figure 3.7: Waterbodies Area Map

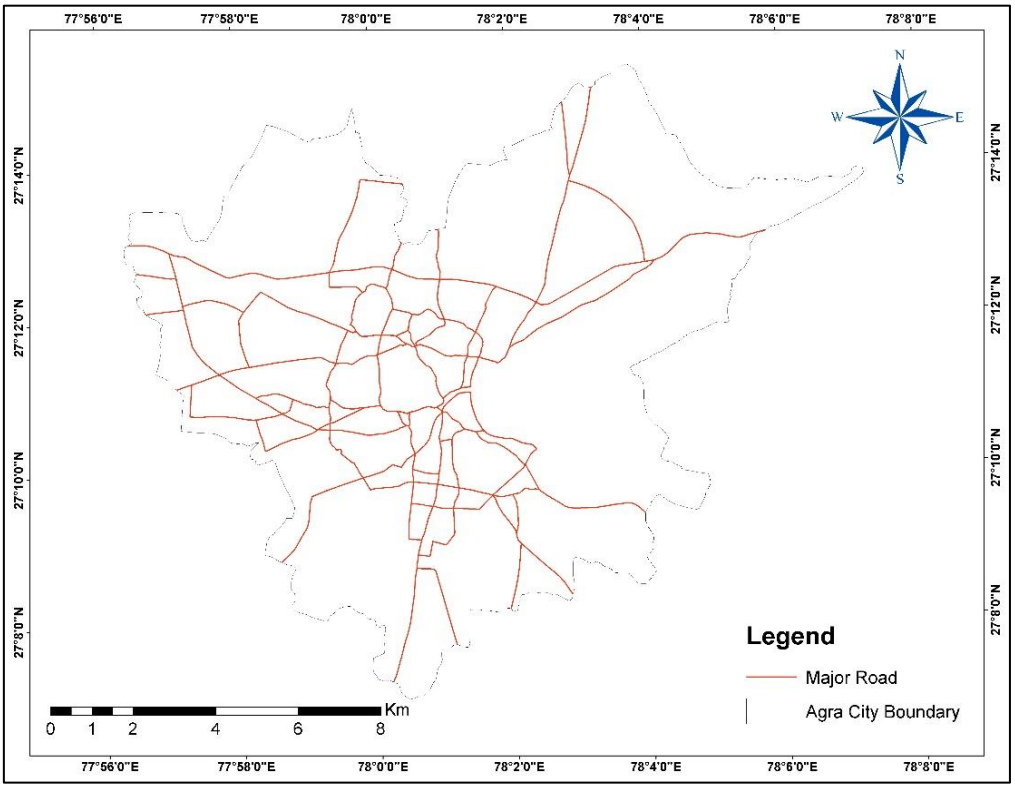


Figure 3.8: Major Road Network Map

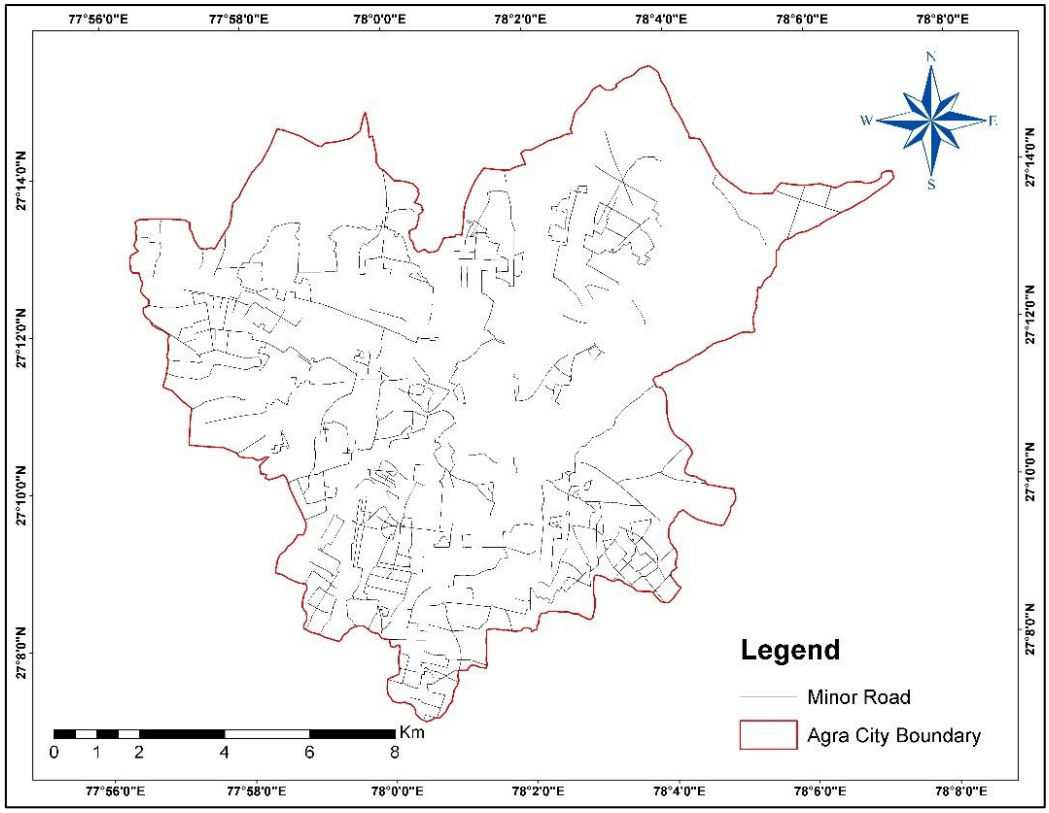


Figure 3.9: Minor Road Network Map

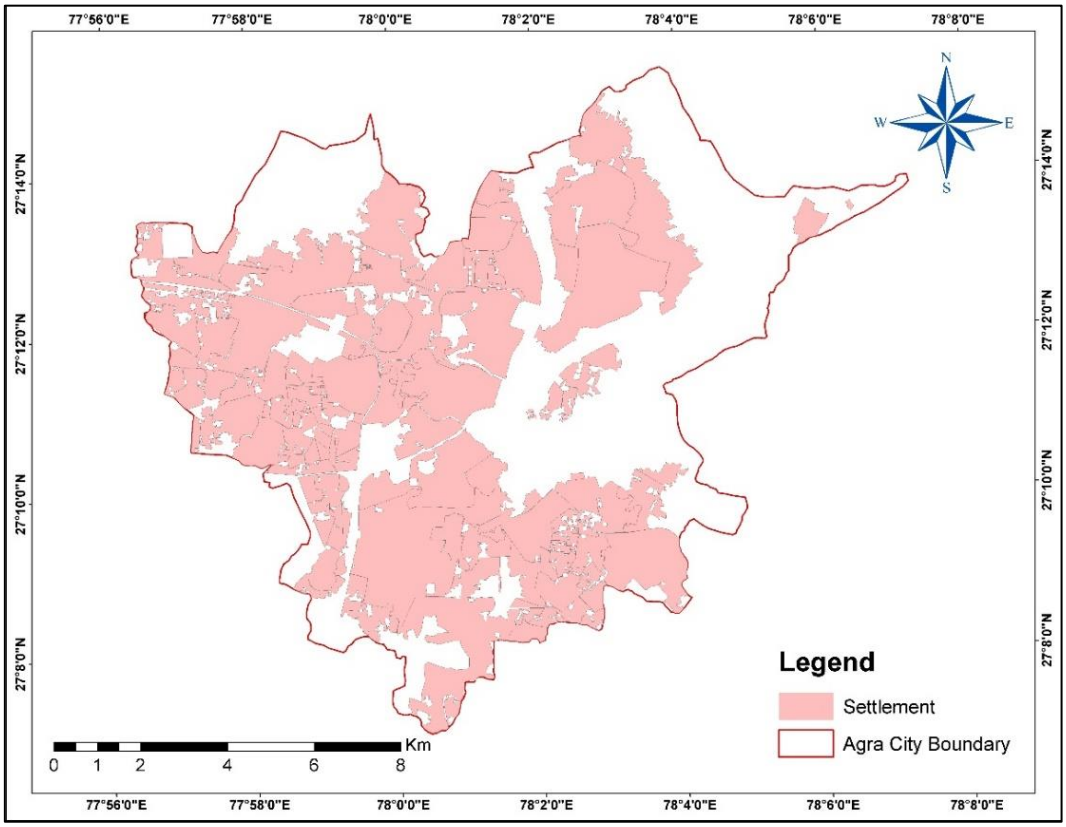


Figure 3.10: Settlement Area Map

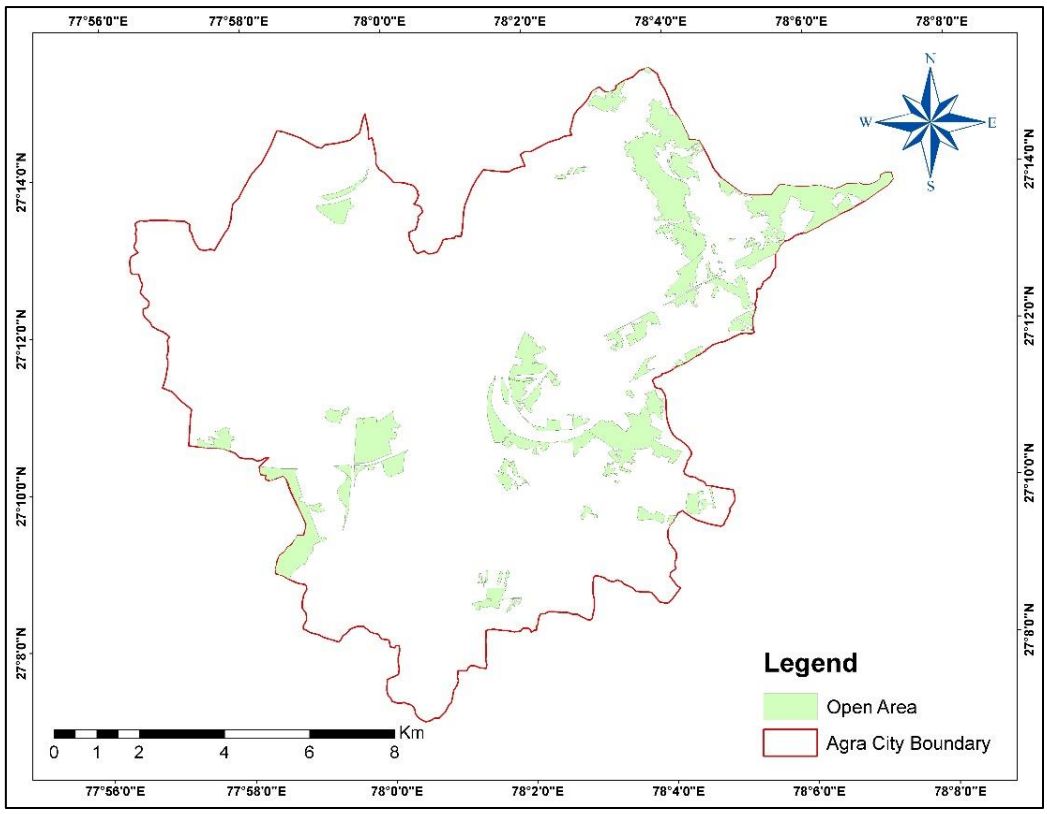


Figure 3.11: Open Area Map

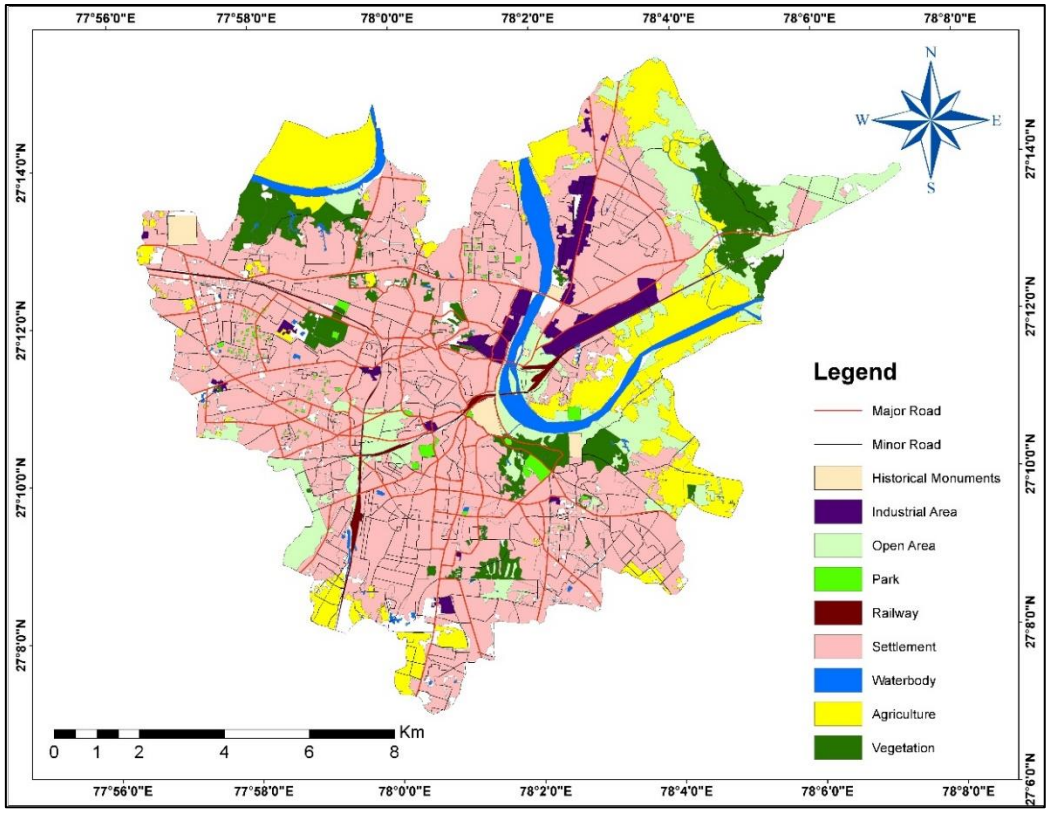


Figure 3.12: Land-use Map of Agra city

At the time of development of the emission inventory, a suitable coding system was adopted to avoid confusion and misrepresentation of results and interpretation. The emissions have been calculated for Agra city. The Grid map of Agra with grid identity numbers is shown in Figure 3.13. The entire study area was divided into grid cells of 2 km x 2 km.

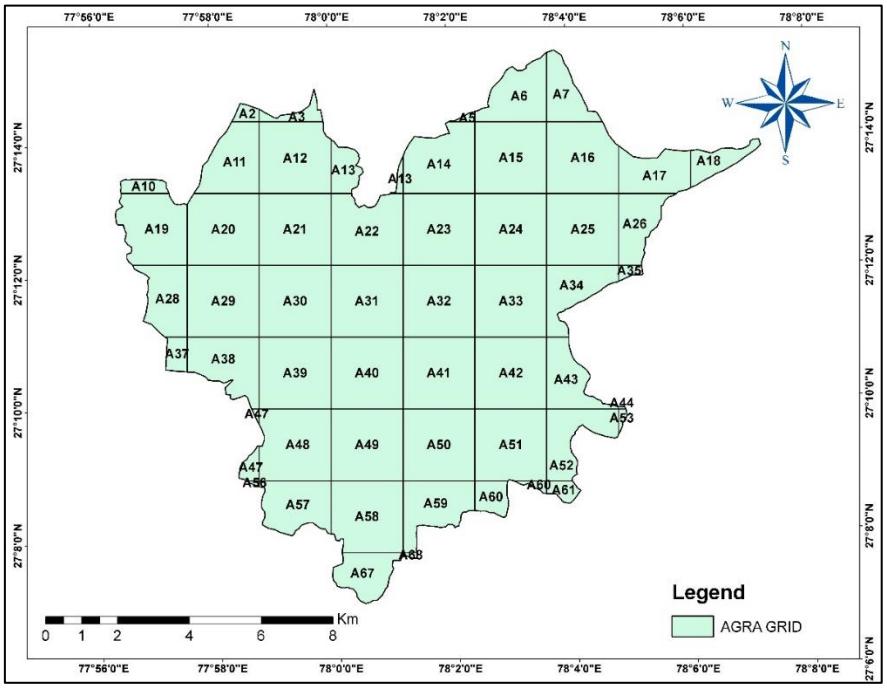


Figure 3.13: Grid Map of Agra showing Grid Identity Numbers

3.2.3 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 (Annexure 1). 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 the 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:

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

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

3.2.4 Domestic Sector

The interior boundaries in the map (Figure 3.14) show the administrative boundaries of wards in Agra City. The Agra city consists of 100 wards as shown in Figure 3.14. There are four zones in the city of Agra (i) Chatta zone having 30 wards (ii) Hari Parvat zone having 21 wards (iii) Loha Mandi zone having 26 wards and (iv) Taj Ganj zone having 23 wards. The fuel consumption pattern shows 85% LPG consumption (CRISIL report), wood (10%), cow dung (3%), coal (1%) and crop residue (1%). The slum area details have been obtained from Agra Nagar Nigam and an on-field survey is conducted by the IITK team. There are approximately 250 areas identifies as slums and below the poverty line. The majority of the slum area are using wood and cow dung as a fuel source for cooking. Although they have been given LPG cylinders, due to their economic conditions, the refilling is not frequent.

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

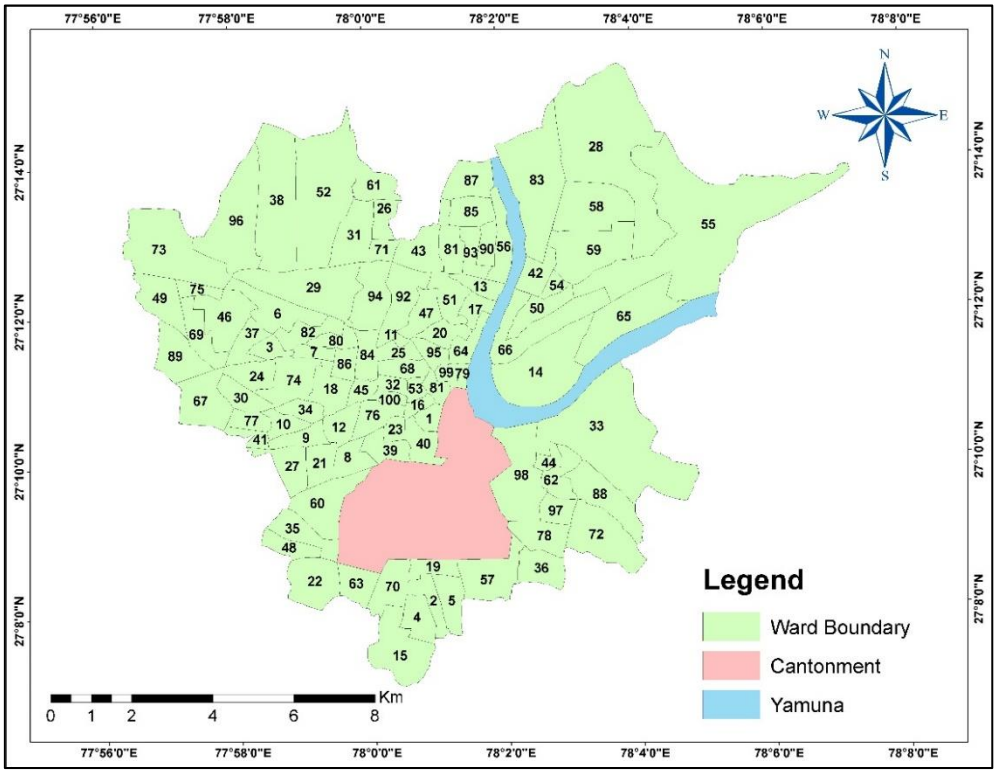


Figure 3.14: Wards in Agra

The overall emission from domestic sources is presented in Figure 3.15. The emission contribution from different fuel types to different pollutants is shown in Figure 3.16 to Figure 3.20. For spatial distribution of different pollutants (Figure 3.21 to Figure 3.25), emission per capita, in each ward and village was calculated, as activity data was available on the basis of per capita.

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

$$\text{Emission Density (kg/day/m}^2\text{)} = \text{Emission of Ward (kg/day)} / \text{Ward Area (m}^2\text{)} \qquad (3.2)$$

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

$$Grid.Emission = \sum_{i=1}^{N} (\text{ area of fraction ward i in grid X emission density of ward, i}) \qquad (3.3)$$

Where N= no. of wards in the grid

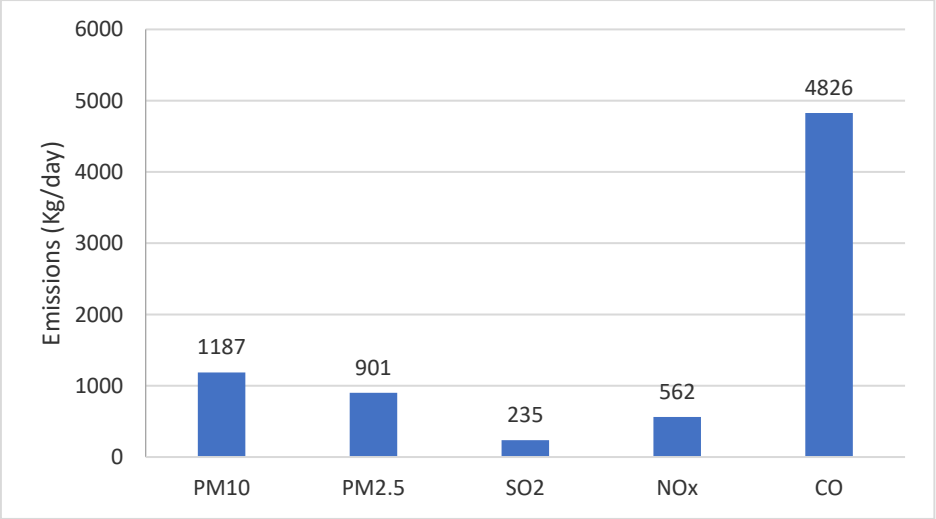


Figure 3.15: Emission Load from Domestic Sector (kg/day)

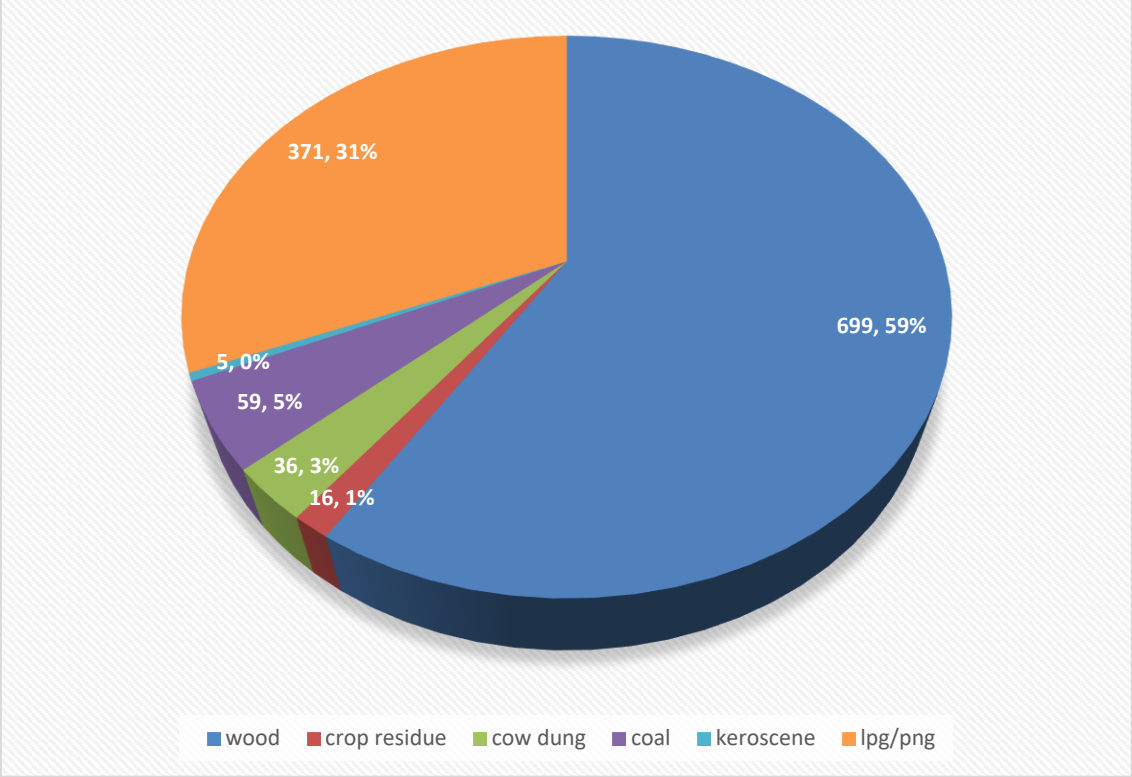


Figure 3.16: PM_{10} Emission load from Domestic Sector (Kg/day, %)

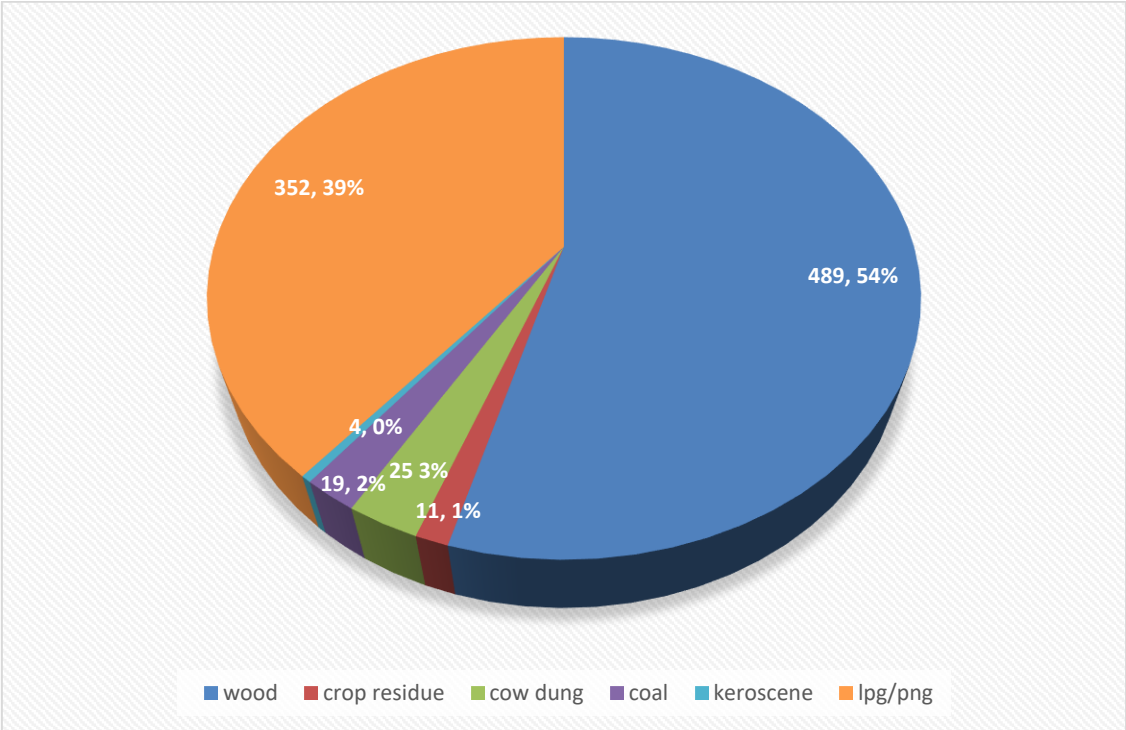


Figure 3.17: $PM_{2.5}$ Emission load from Domestic Sector (Kg/day, %)

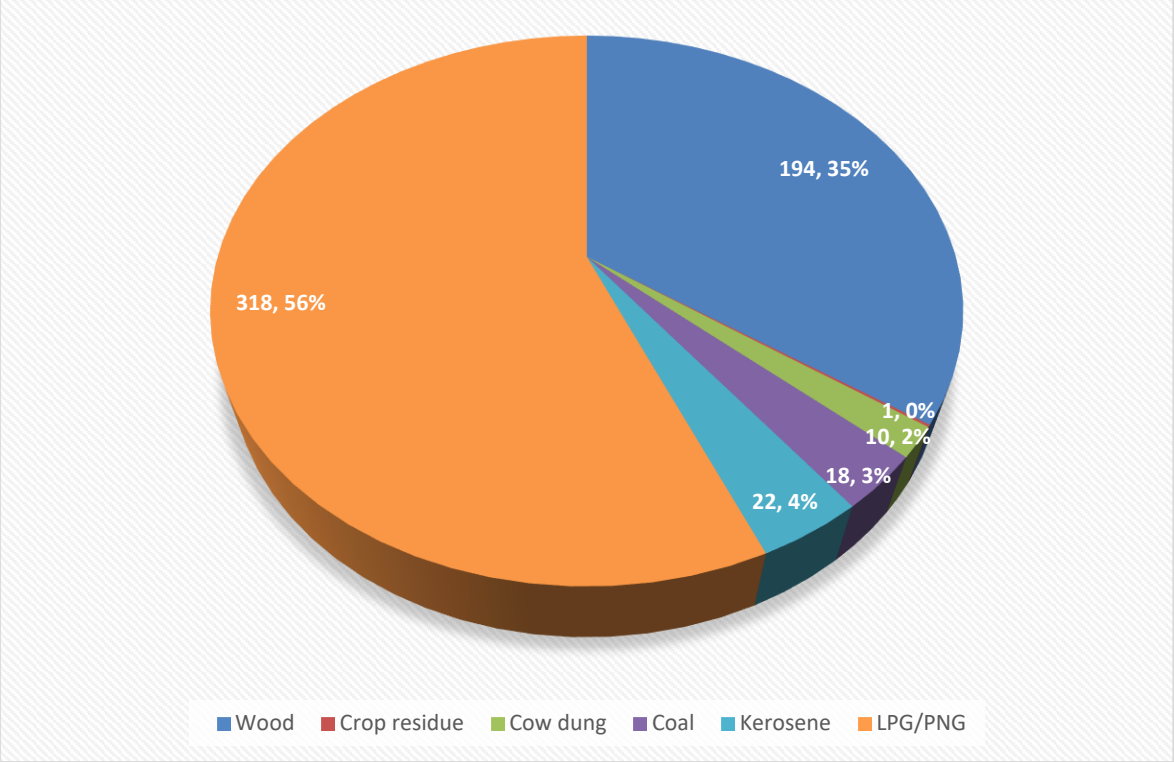


Figure 3.18: NOx Emission load from Domestic Sector (Kg/day, %)

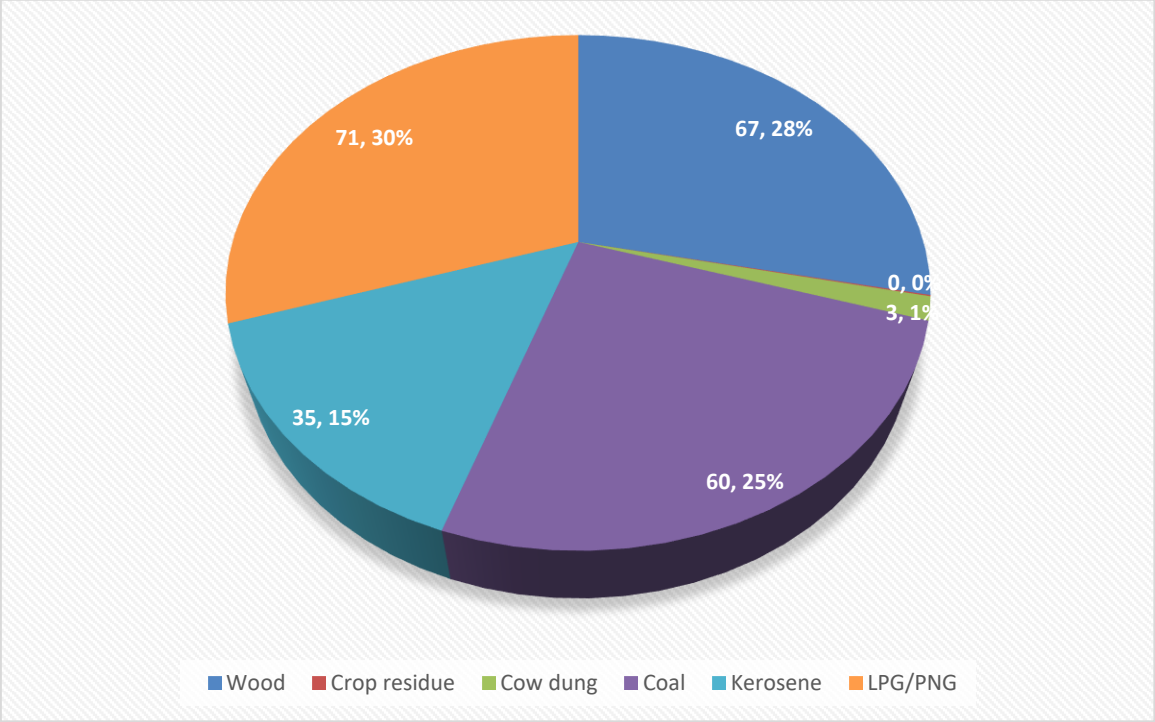


Figure 3.19: SO_2 Emission load from Domestic Sector (Kg/day, %)

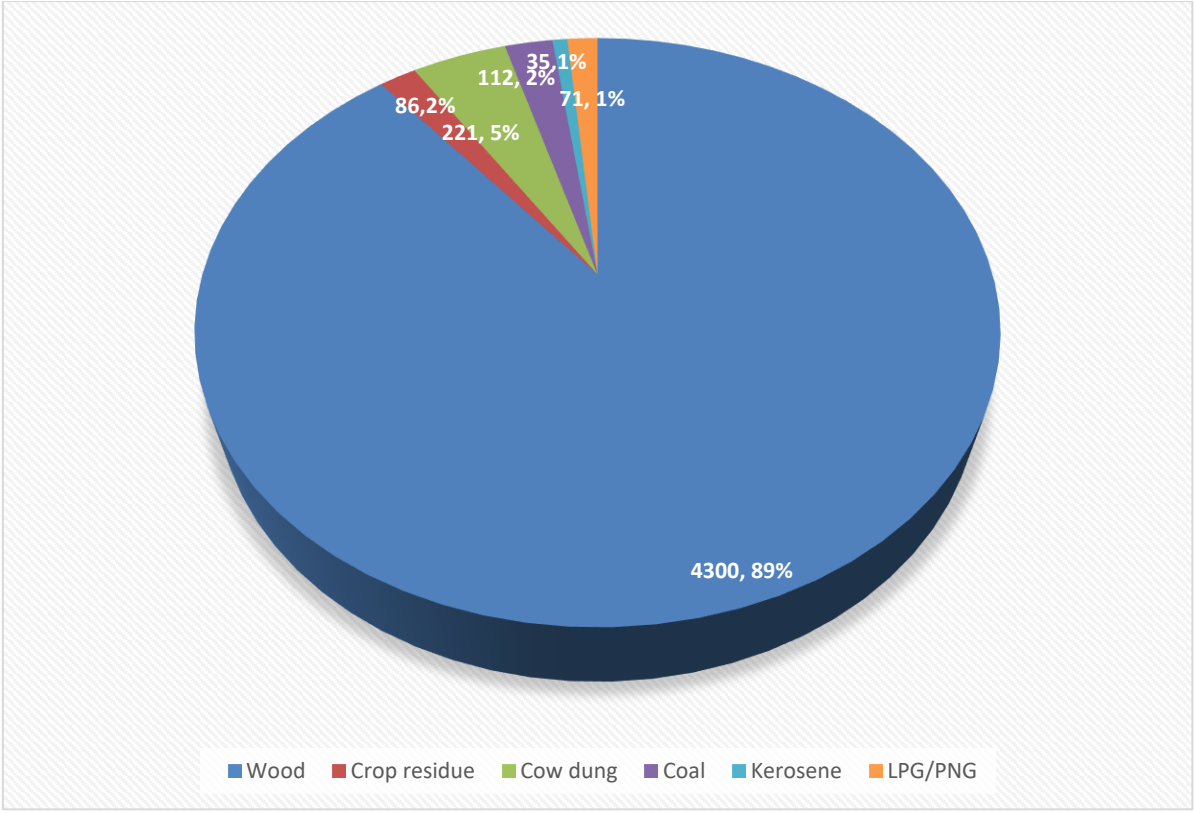


Figure 3.20: CO Emission load from Domestic Sector (Kg/day, %)

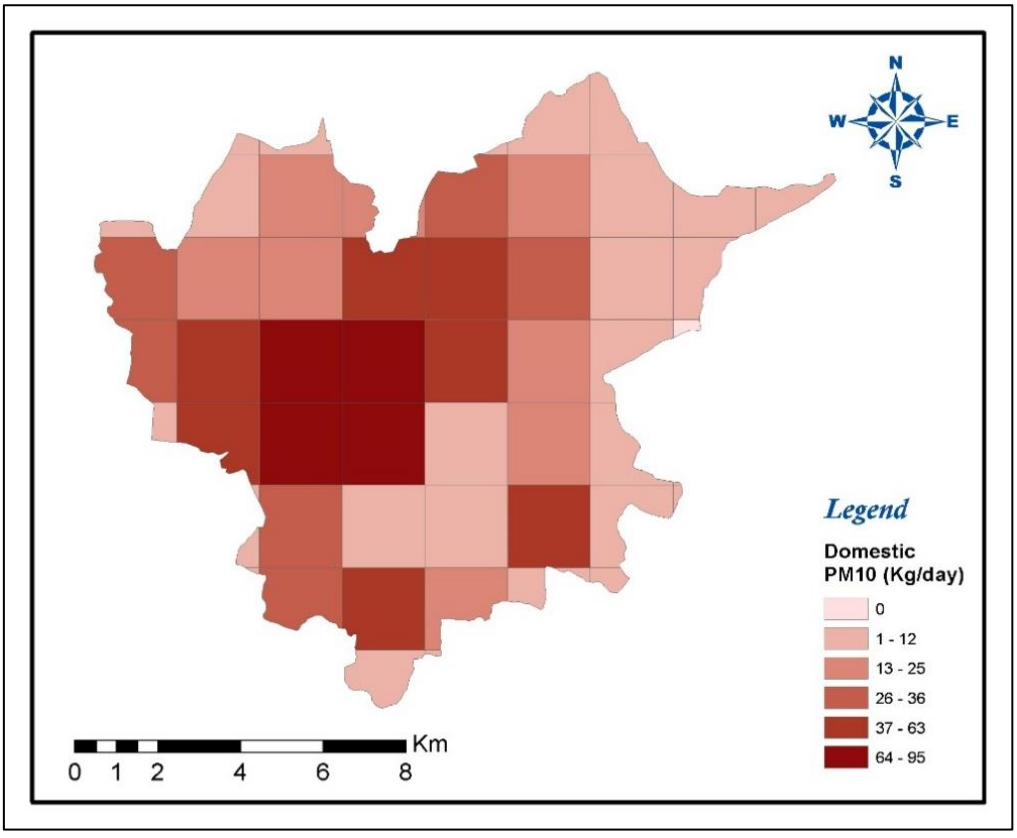


Figure 3.21: Spatial Distribution of PM_{10} Emissions from Domestic Sector

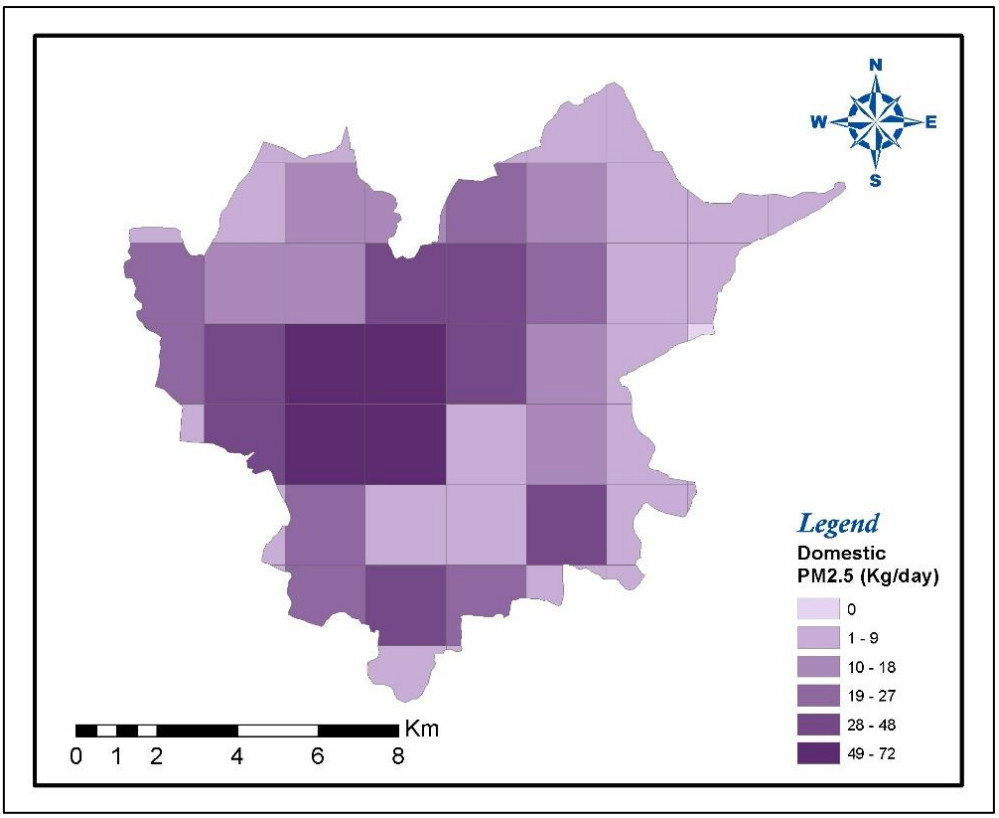


Figure 3.22: Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector

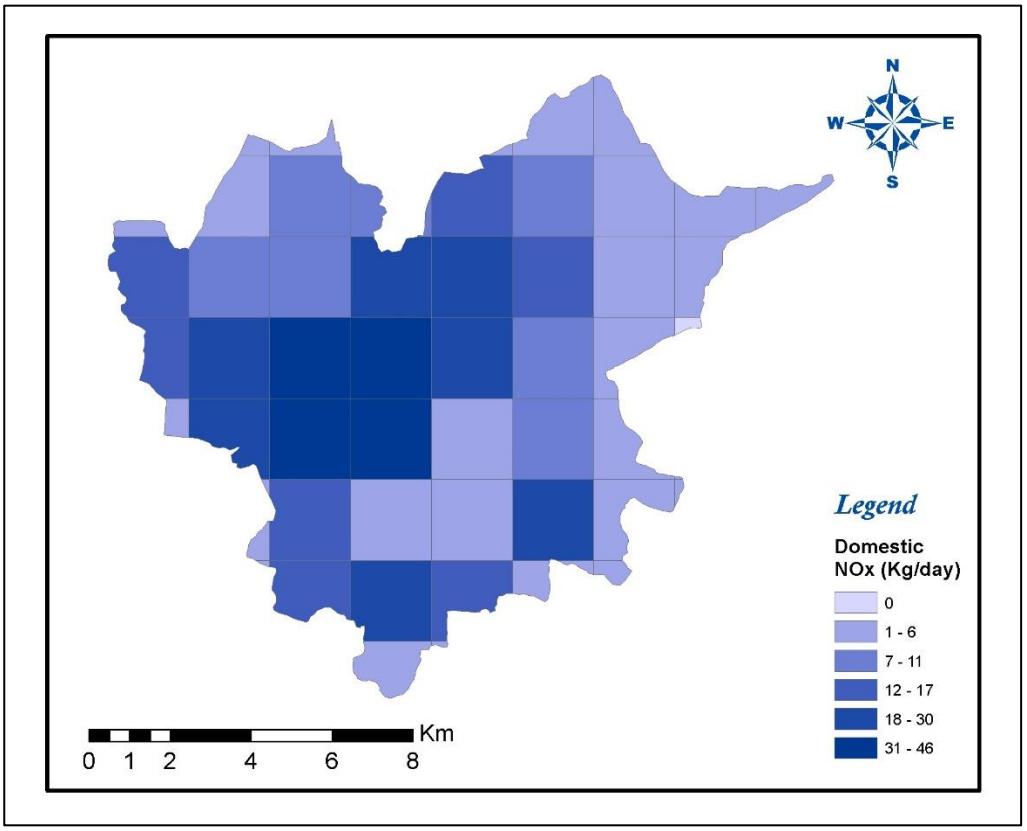


Figure 3.23: Spatial Distribution of NOx Emissions from Domestic Sector

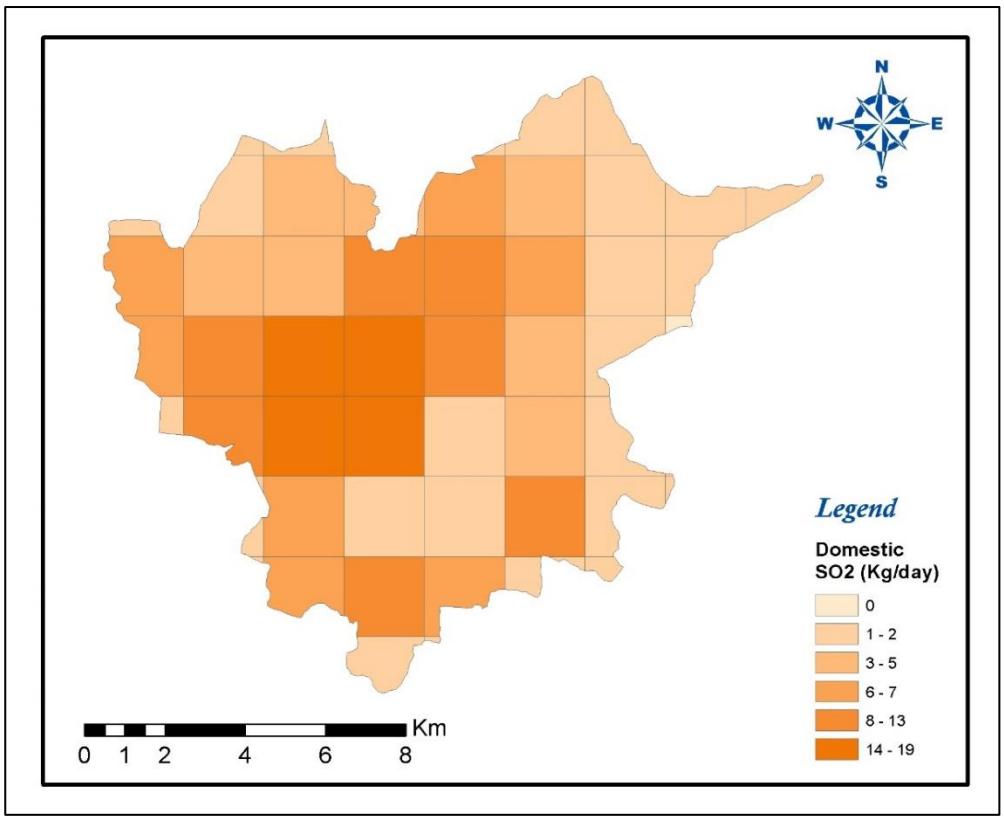


Figure 3.24: Spatial Distribution of SO_2 Emissions from Domestic Sector

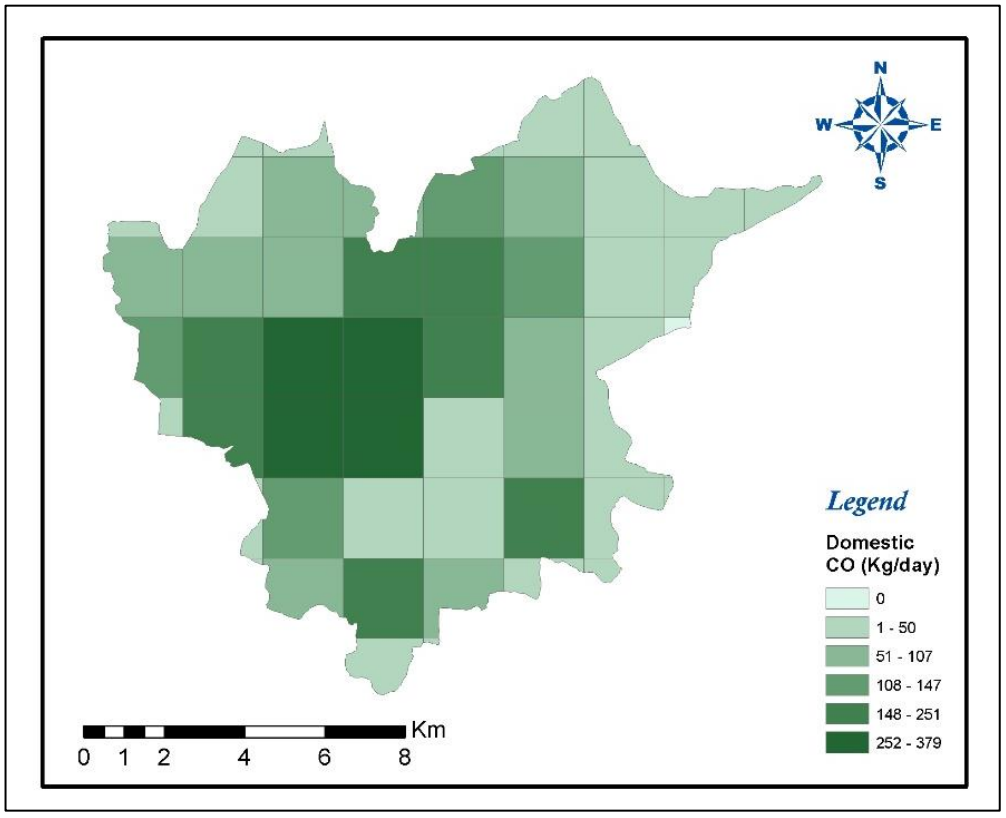


Figure 3.25: Spatial Distribution of CO Emissions from Domestic Sector

3.2.5 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities. The satellite imagery was also used to identify the construction activities. The major construction activities include buildings (including residential housing and apartments) information was obtained from Agra Development Authority, PWD, CPWD, and Nagar Nigam, and a detailed survey was done. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road (Figure 3.26 and Figure 3.27). The flyover construction at ISBT showing the construction material dumped in the middle of the road is shown in Figure 3.28. The areas under construction activities were calculated on the basis of survey data and GIS. The construction and demolition sites are given in Figure 3.29. The emission factors given by AP-42 (USEPA, 2000) were used for estimating the construction and demolition emissions.

Figure 3.26: Construction material and debris near constructuion sites

Figure 3.27: Construction material and debris near constructuion sites

Figure 3.28: ISBT location showing the dumping of construction material

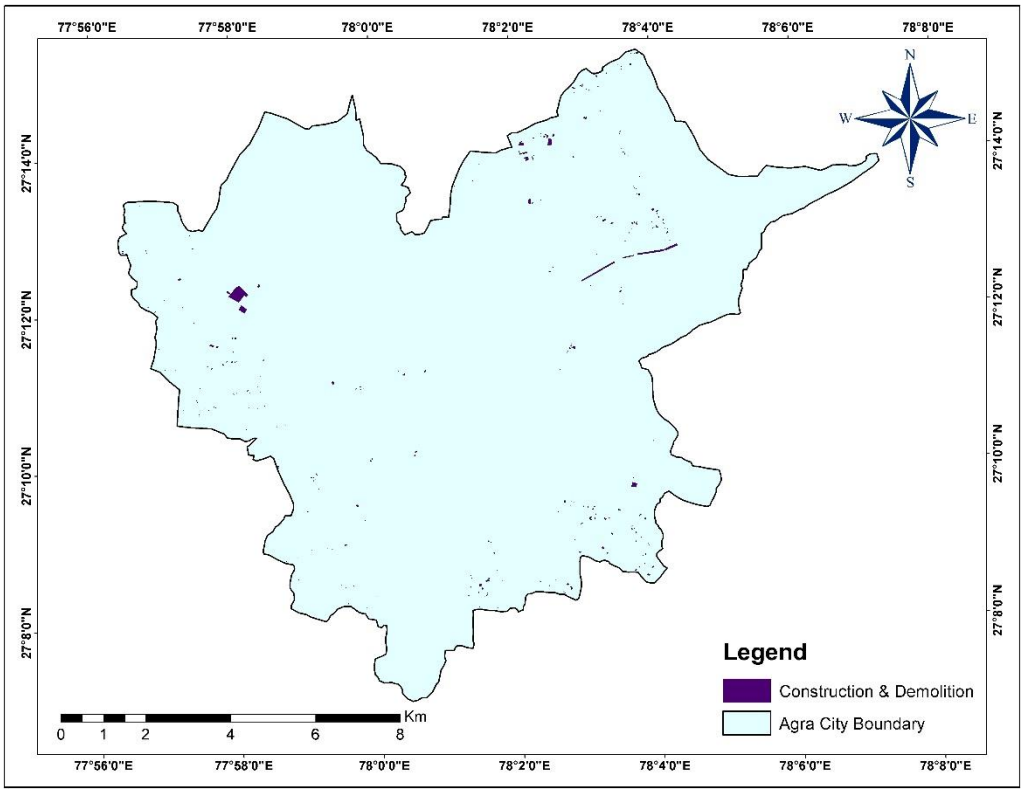


Figure 3.29: Construction/Demolition Sites

Total emissions from construction and demolition activities are presented in Figure 3.30. The spatially resolved map of construction and demolition activities is shown in Figure 3.31 to Figure 3.32.

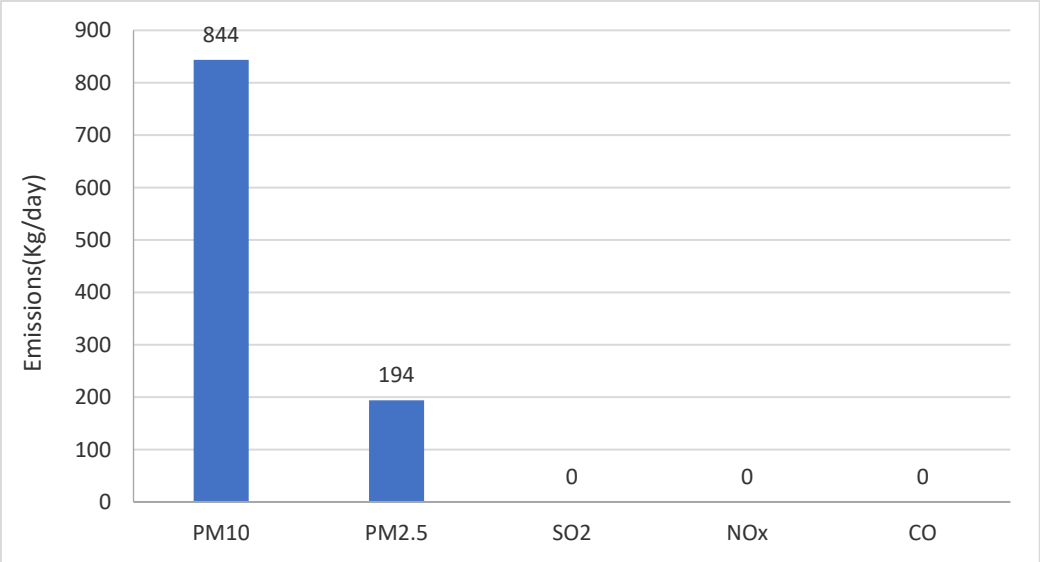


Figure 3.30: Emission Load from Construction and Demolition activities (kg/day)

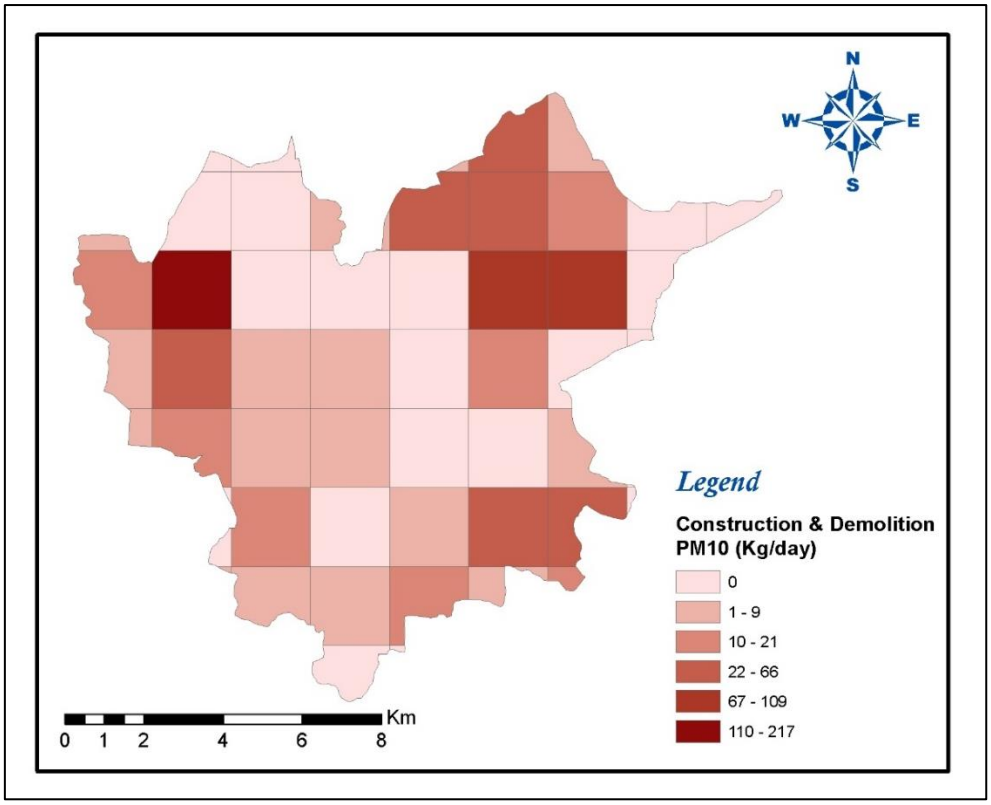


Figure 3.31: Spatial Distribution of PM_{10} Emissions from Construction/Demolition

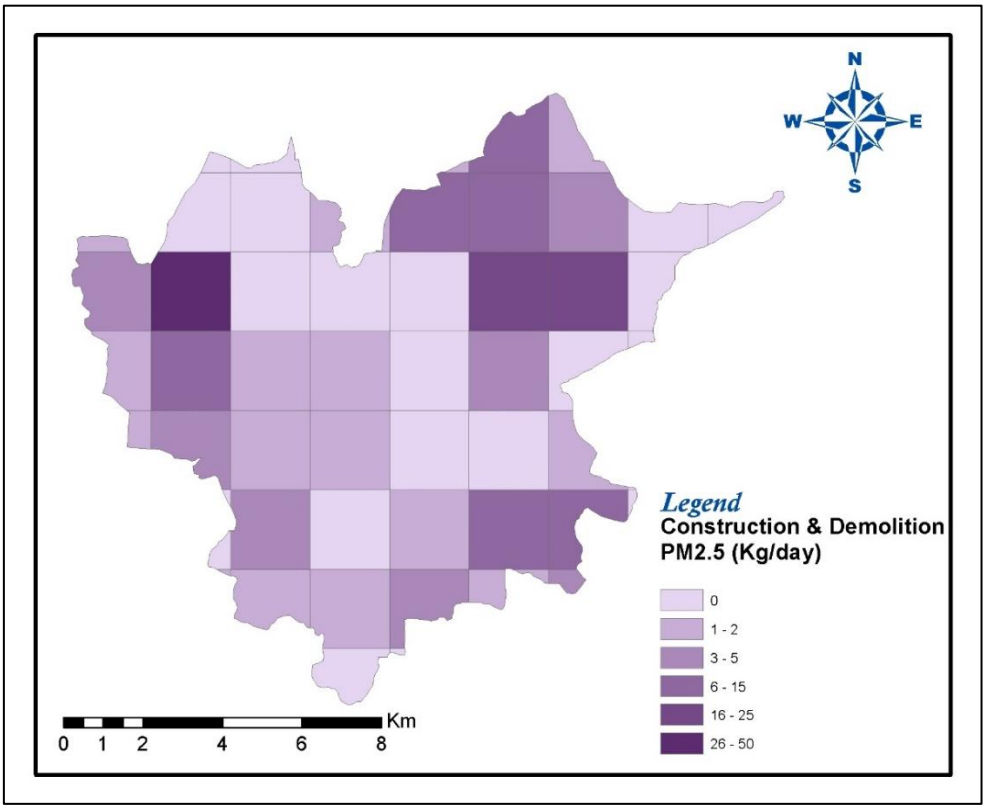


Figure 3.32: Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition

3.2.6 Diesel Generator Sets (DG sets)

The location of the DG set is shown in Figure 3.33. The industries use DG sets as a backup; approximately 80 DG sets are installed in industries (source: consent data). During the industrial survey, it was found out that DG sets operate for 30 minutes per day. Most of the industries use natural gas as fuel to generator sets. The calculation is based on Eq (3.1), where ER, overall efficiency reduction was taken as zero. The CPCB (2011) emission factors were used for emission estimation. The total emissions from DG sets are shown in Figure 3.34, the spatial distribution of emissions from DG Sets is shown in Figure 3.35 to Figure 3.39.

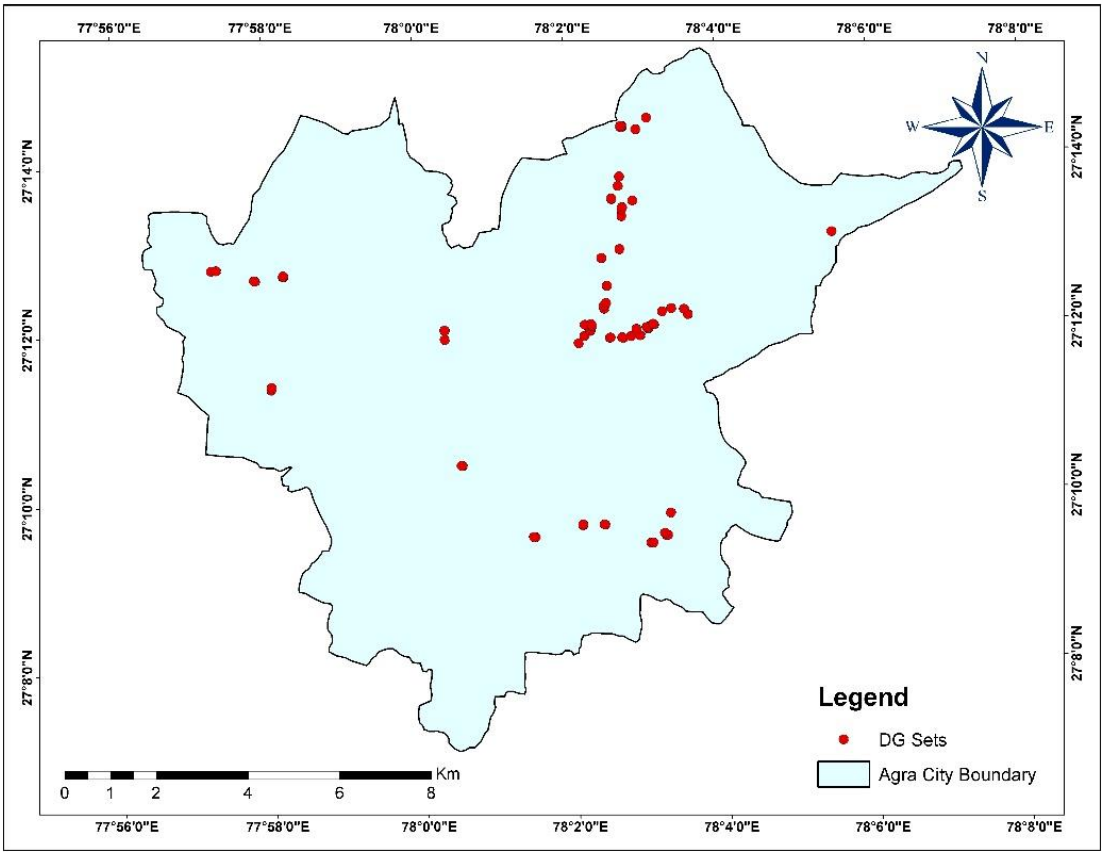


Figure 3.33: Location of Industrial DG Sets

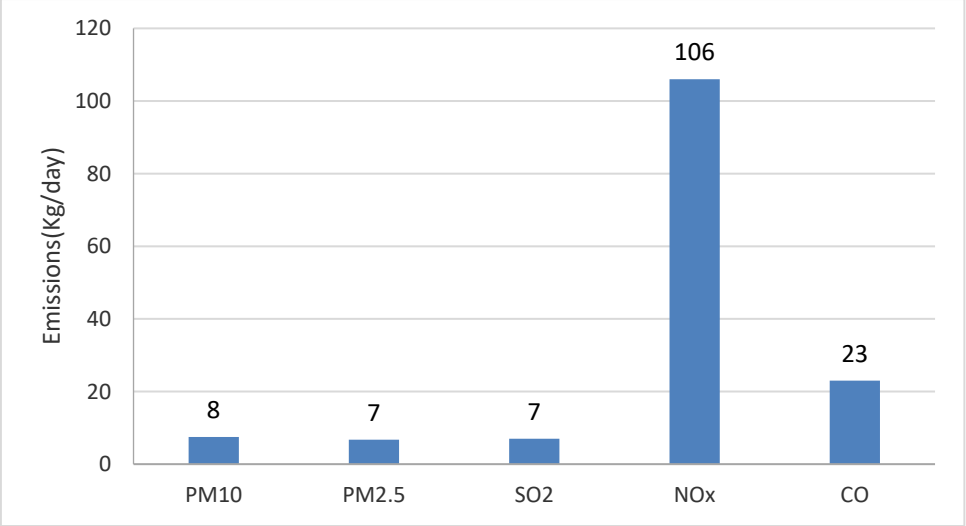


Figure 3.34: Emission Load (kg/day) from DG sets

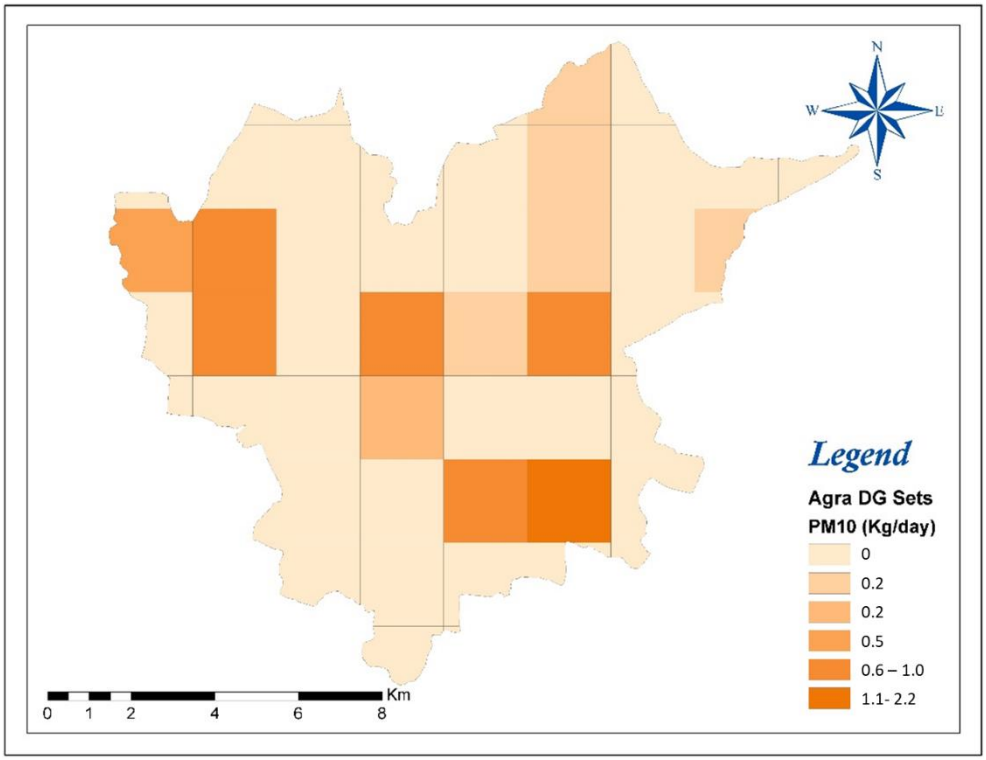


Figure 3.35: Spatial Distribution of PM_{10} Emissions from DG Sets

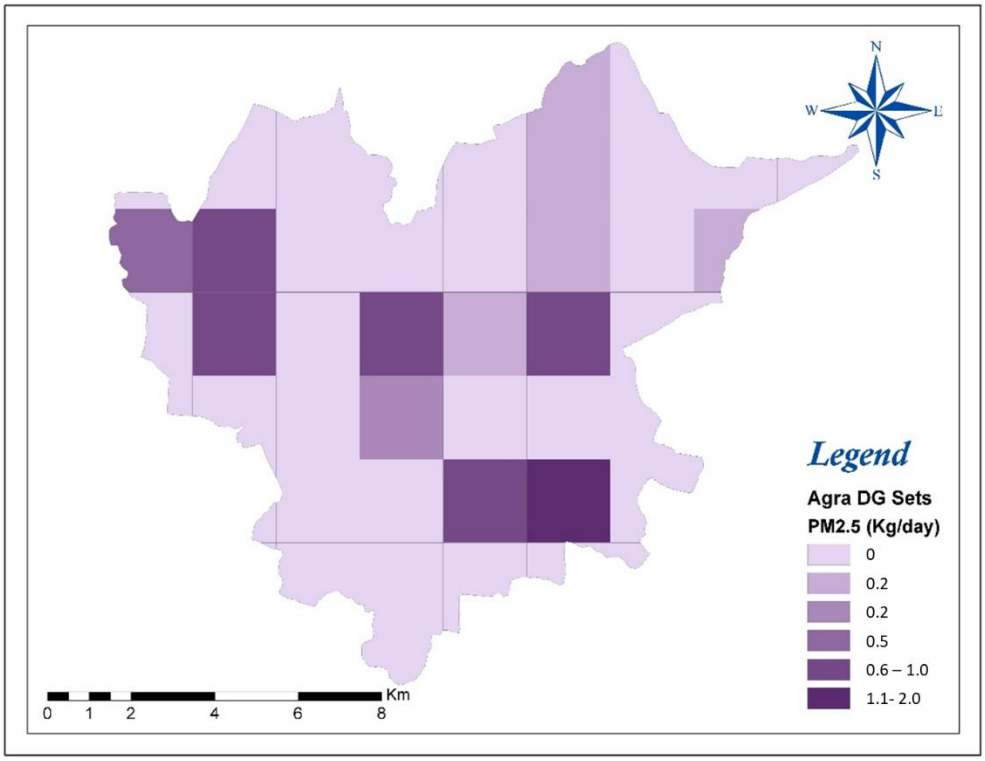


Figure 3.36: Spatial Distribution of $PM_{2.5}$ Emissions from DG Sets

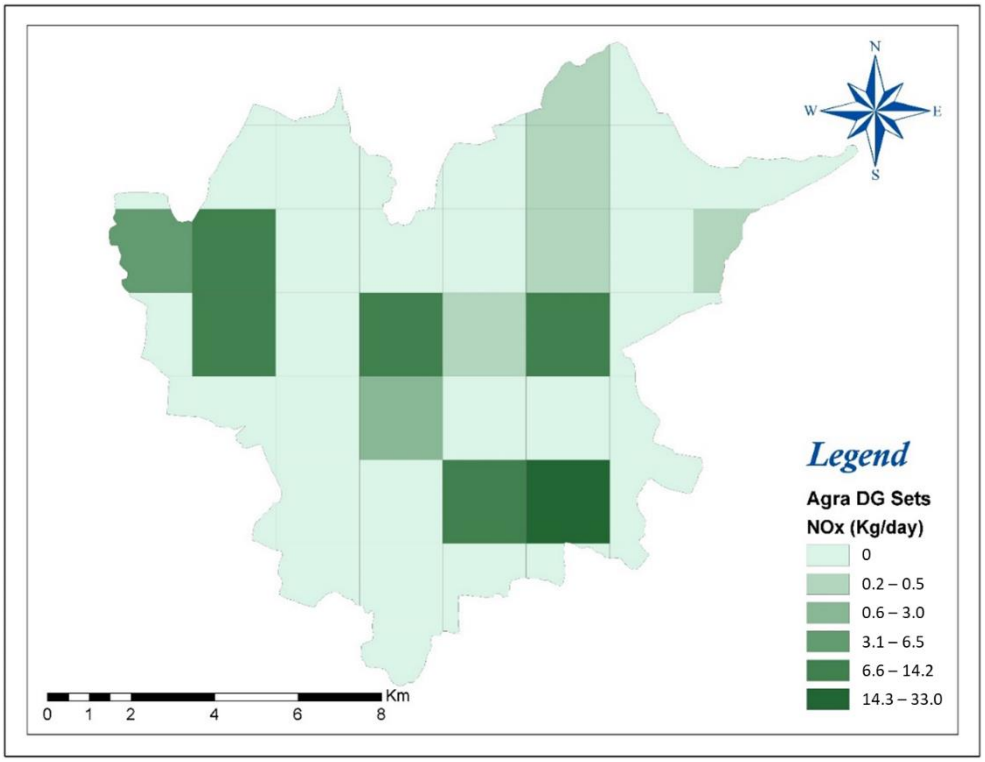


Figure 3.37: Spatial Distribution of NOx Emissions from DG Set

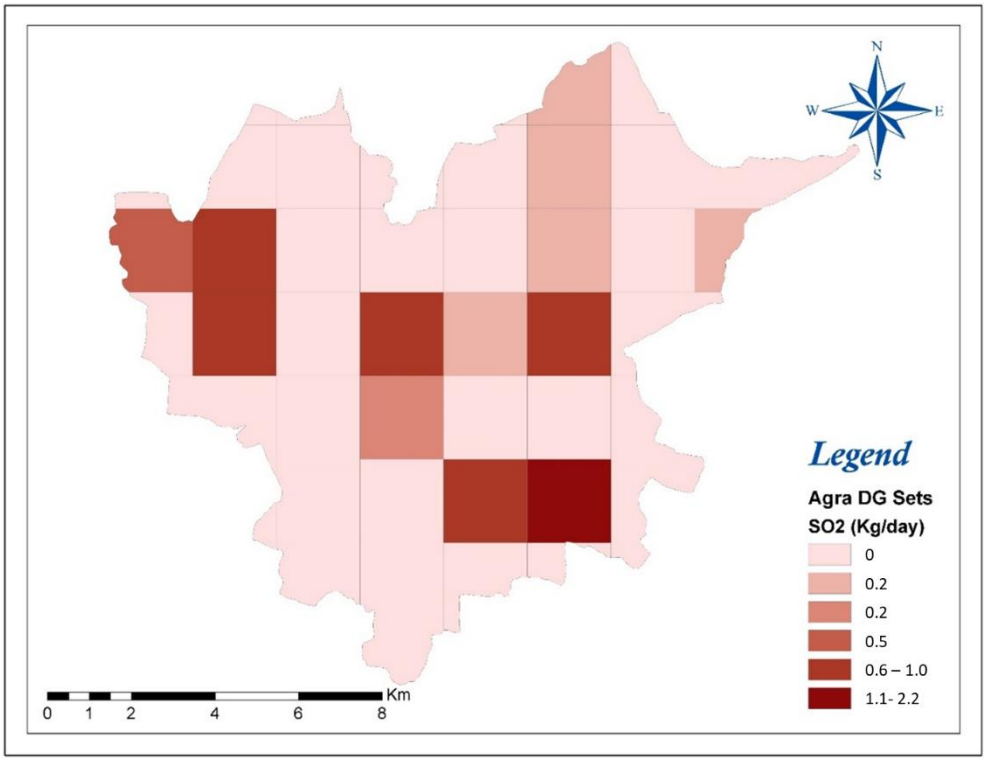


Figure 3.38: Spatial Distribution of SO_2 Emissions from DG Set

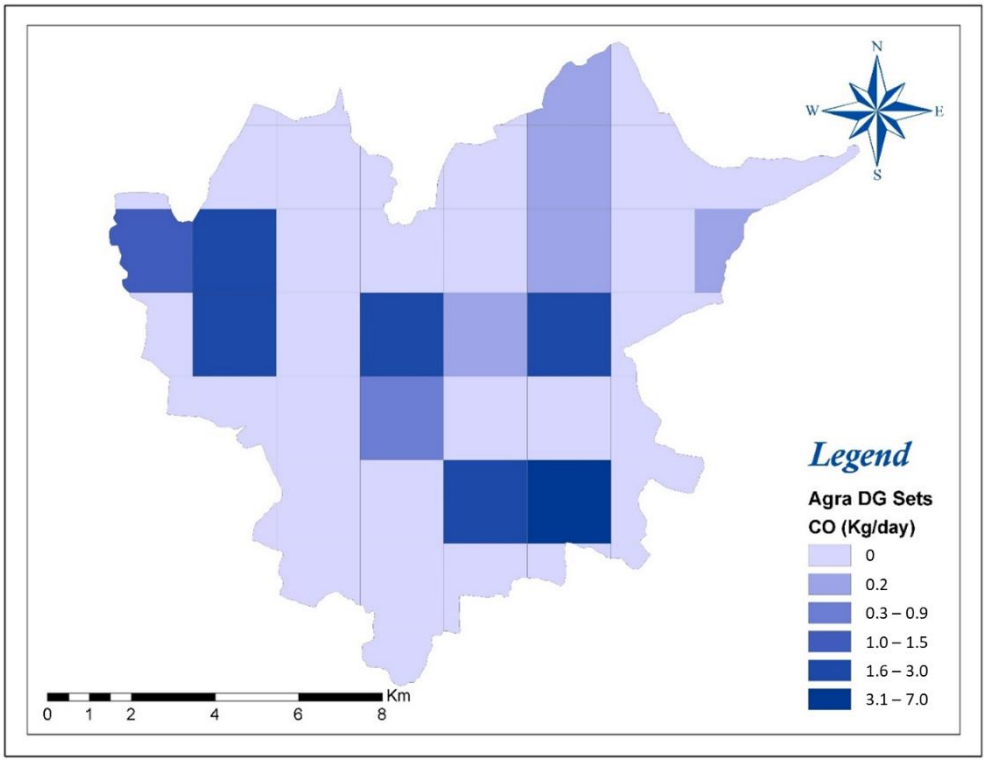


Figure 3.39: Spatial Distribution of CO Emissions from DG Sets

3.2.7 Hotels and restaurants

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

During the field survey, it was observed that hotels, restaurants, etc. use coal as fuel in tandoors. The total number of big hotels and restaurant enterprises was approximately 1300 (Figure 3.40), mainly situated in the Tajganj area, which is near to Taj Mahal. It was observed that coal/wood is being used as fuel in the tandoor; the common fuel other than wood is LPG. The average consumption of wood/coal in each establishment is estimated to be 30 kg per day based on a primary survey. The fuel consumption for each fuel type was estimated for each grid. In most of the cases, it was found that there were no control devices installed at these activities. The emissions of various parameters such as SO_2, NOx, PM_{10}, $PM_{2.5}$, and CO were estimated from each fuel type's activity data and then summed up in each grid cell. The emission factors given by CPCB (2011) were used. The overall emission from this area source (Hotels/Restaurants) is shown in Figure 3.41. The spatial distribution of emissions from hotels/restaurants is shown in Figure 3.42 to Figure 3.46.

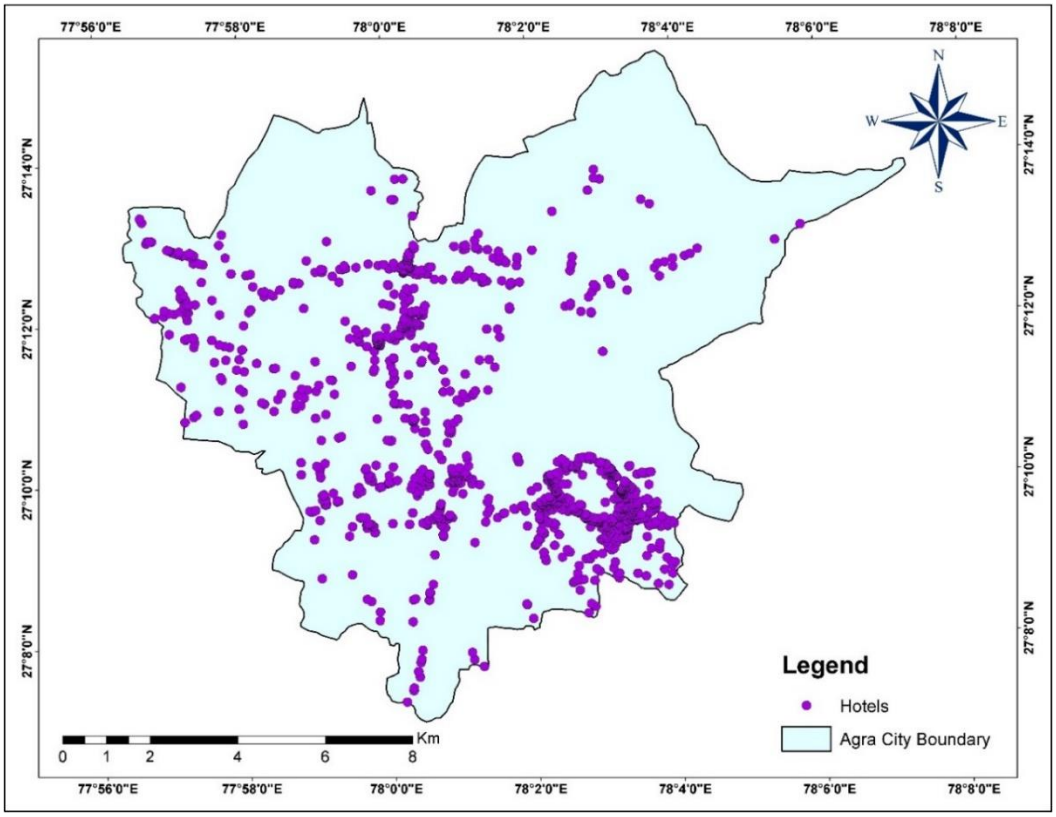


Figure 3.40: Location of Hotels and Restaurants

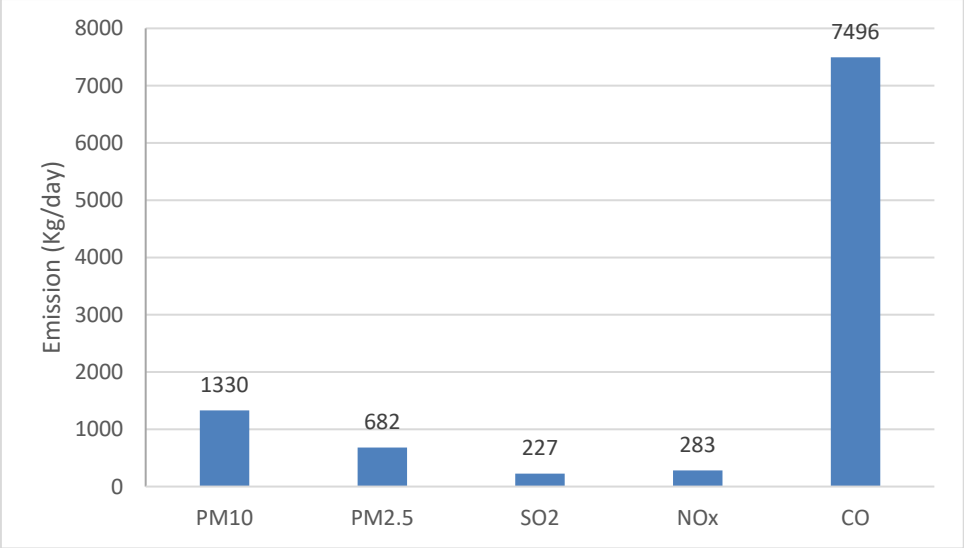


Figure 3.41: Emission Load from Hotels and Restaurants

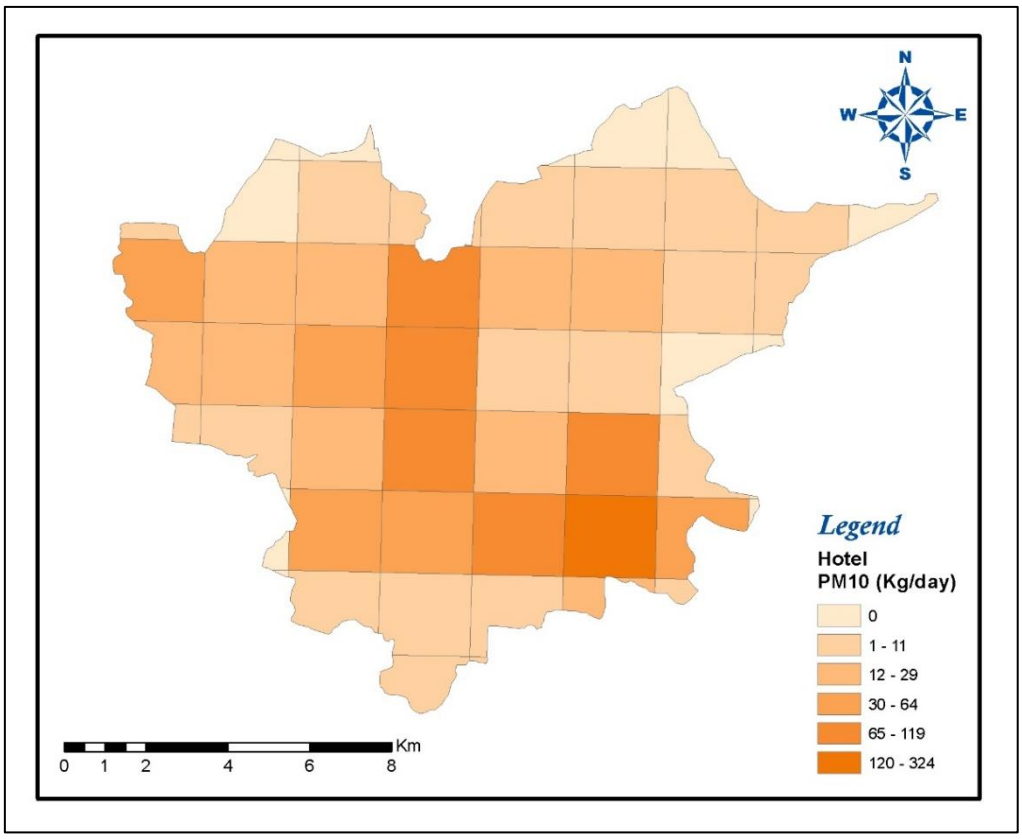


Figure 3.42: Spatial Distribution of PM_{10} Emissions from Hotels and Restaurants

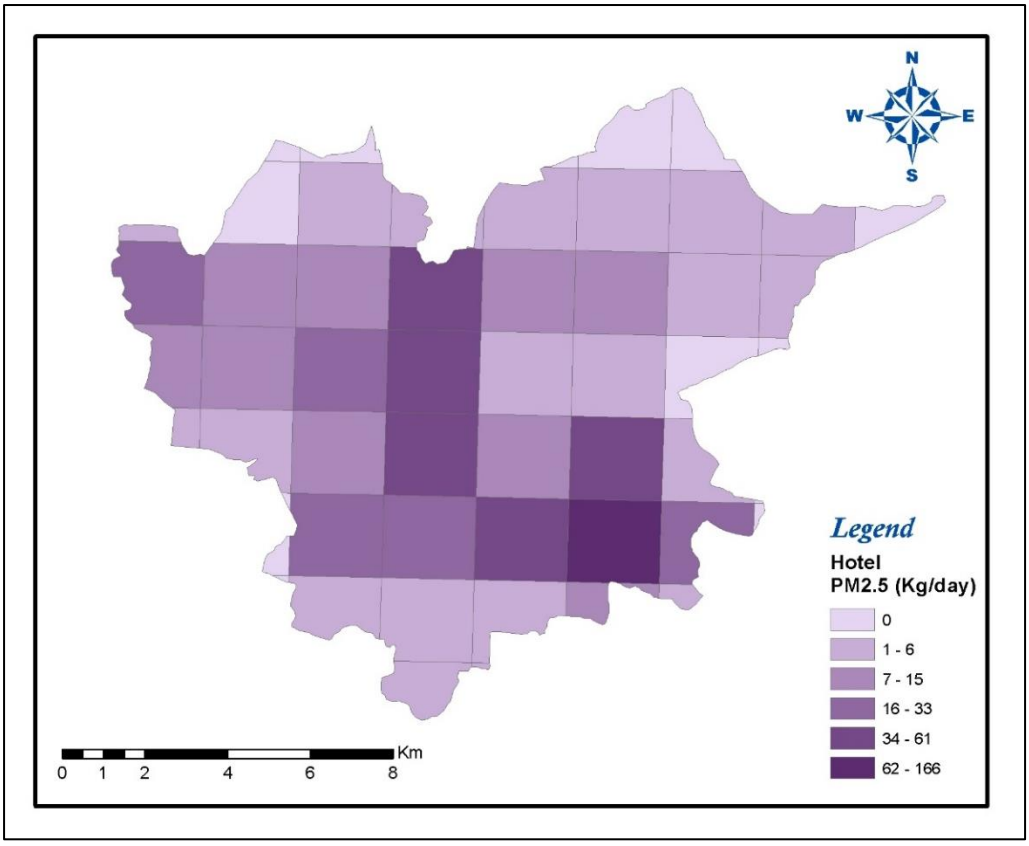


Figure 3.43: Spatial Distribution of $PM_{2.5}$ Emissions from Hotels and Restaurants

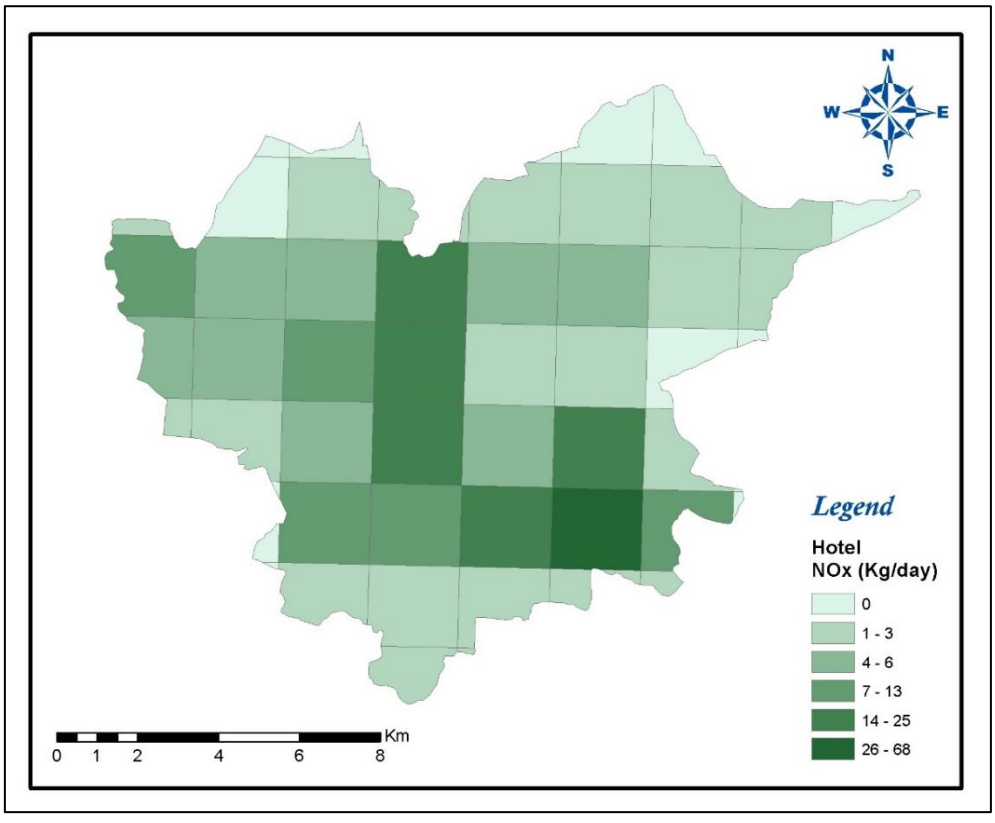


Figure 3.44: Spatial Distribution of NO_X Emissions from Hotels and Restaurant

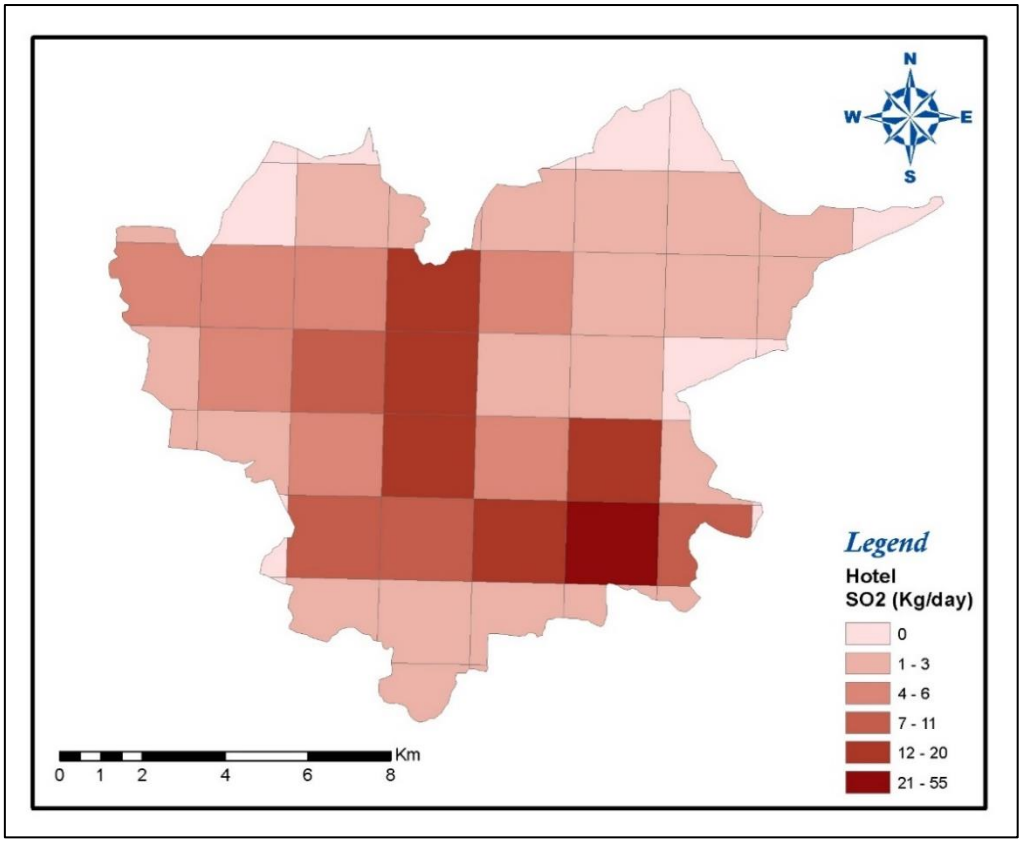


Figure 3.45: Spatial Distribution of SO_2 Emissions from Hotels and Restaurants

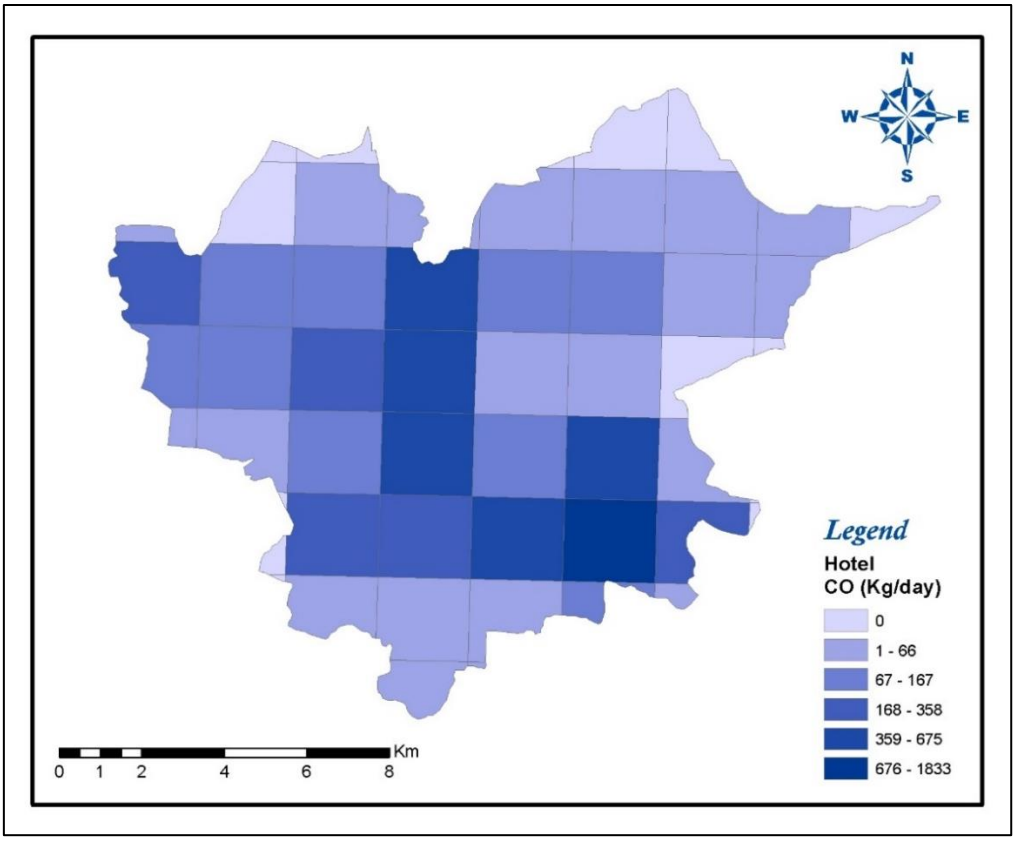


Figure 3.46: Spatial Distribution of CO Emissions from Hotels and Restaurant

3.2.8 Municipal Solid Waste burning

The refuse or municipal solid waste (MSW) burning depends on solid waste generation and the extent of disposal and infrastructure for collection. This emission is expected to be large in the regions of economically weaker strata of the society, which do not have proper infrastructure for the collection and disposal of MSW. The solid waste generation depends on the nature of the locality in that region, i.e., for example, if the area has more commercial activities, high population density, there will be more garbage generation.

A detailed survey was done according to the land-use pattern of the city. Major commercial areas identified were Sanjay Palace, Shahganj, Subhash Bazaar, Agra Fort, Fatehabad road, Jaipur House, Sikandra Bosla sector 6, 7, and 8. Bhagwan talkies, Belanganj, Baluganj, Sadar Bazaar, Raja Ki Mandi market, St. Johns Crossing, Maithan, Pathwari, Bagh Muzaffar Khan, Wazirpura and Hari Parwat Crossing. Major residential areas (having high density) were Ghatia Azam khan, Mantola, Tajganj, Nai ki Mandi, Loha Mandi, and Idgah. The residential area having moderate population density was Jaipur house colony, Saket Nagar, Janakpuri, Vijay Nagar Colony, Khandari, and Kamla Nagar. Residential Areas having low population density were Sanjay palace, Subhash Park, Sadar bazaar, Laweys colony, and Dayalbagh. Major institutional areas were Dayalbagh, Khandari, and MG Road.

An extensive survey was conducted in these localities for 3 hours in the morning and 3 hours in the evening. The survey observations indicated that there were more MSW burning incidents in the morning compared to the evening, typically starting around 6 am. MSW-burning was not observed in the afternoon and then commenced again in the evening.

The garbage measurements were also taken, which were lying in the area; for example, the area of that collection point is 1.0 m^2, height is 0.3 m, volume of one point=1.0*0.3= 0.3 m^3. The dry density of garbage is taken as 800 kg/m^3. The mass of garbage at that street =800*0.3=240 kg. The number of MSW-burning incidents was recorded in the identified survey area. Also, these incidents were mapped according to the ward population. The methodology estimates that about 2% of the MSW is being burnt in each ward of the city.

The emission factors are given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emission from MSW burning. It is reported that Agra has MSW-burning incidents in the range of 39−202 incidents/km^2/day in the summer (Nagpure et al., 2015). It is estimated that approximately 63 tonnes per day are being burnt as MSW burning (Figure 3.47).

Figure 3.47: MSW Burning in several parts of Agra city

The emission factors are given by CPCB (2011) and AP-42 (USEPA, 2000) were used for estimating the emission from MSW burning using the same procedure of emission density in a ward or village. The emissions from MSW burning are presented in Figure 3.48 and spatial distribution in Figure 3.49 to Figure 3.53.

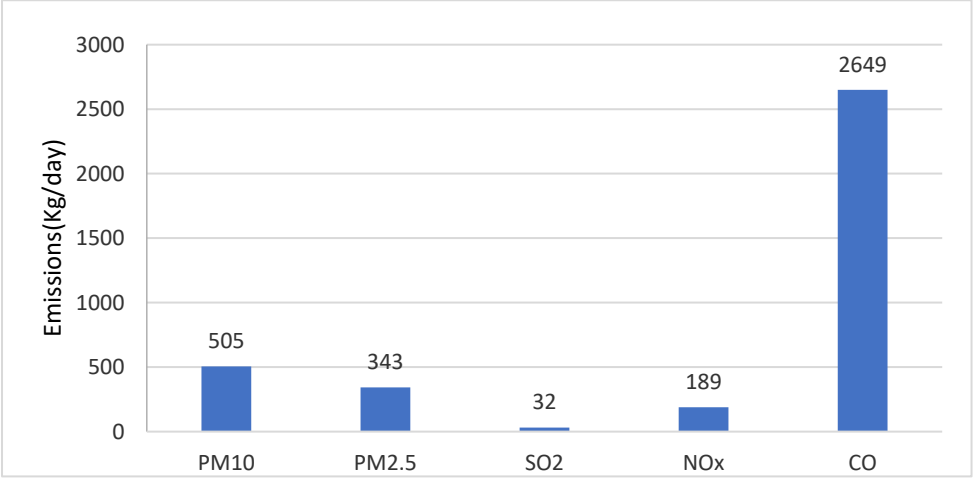


Figure 3.48: Emission Load from MSW Burning

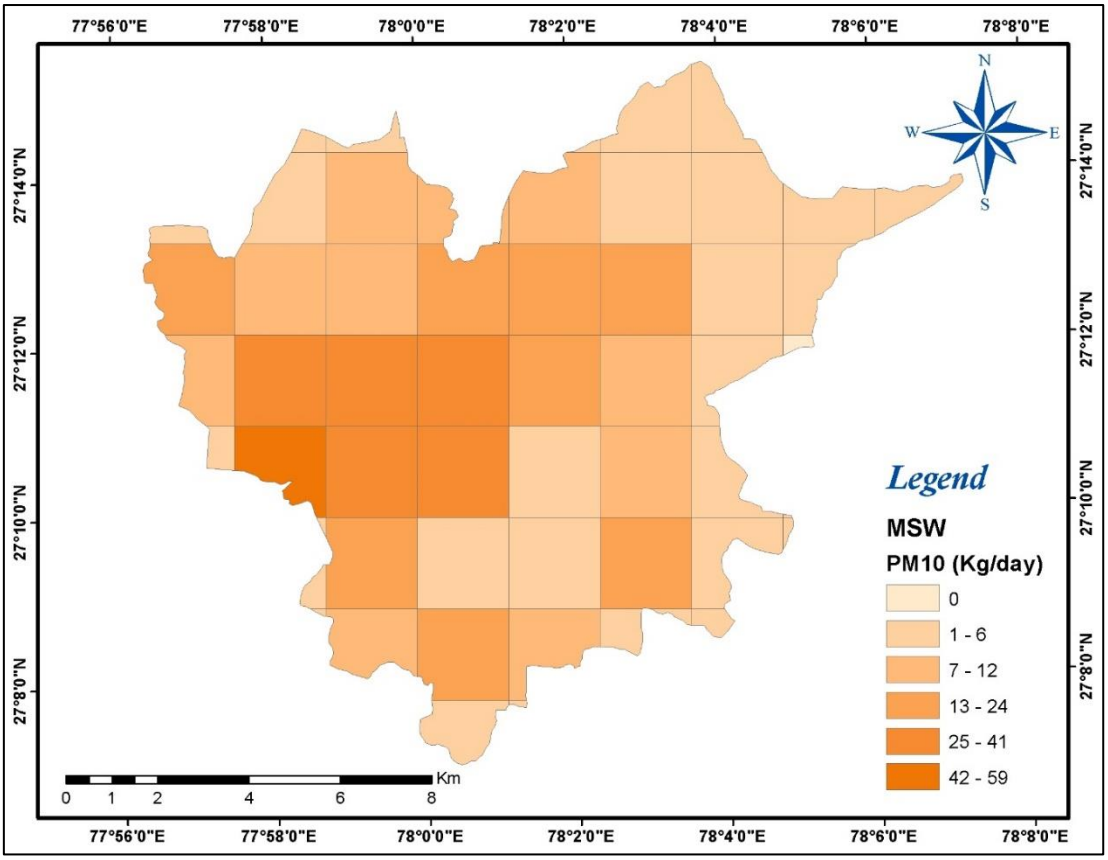


Figure 3.49: Spatial Distribution of PM_{10} Emissions from MSW Burning

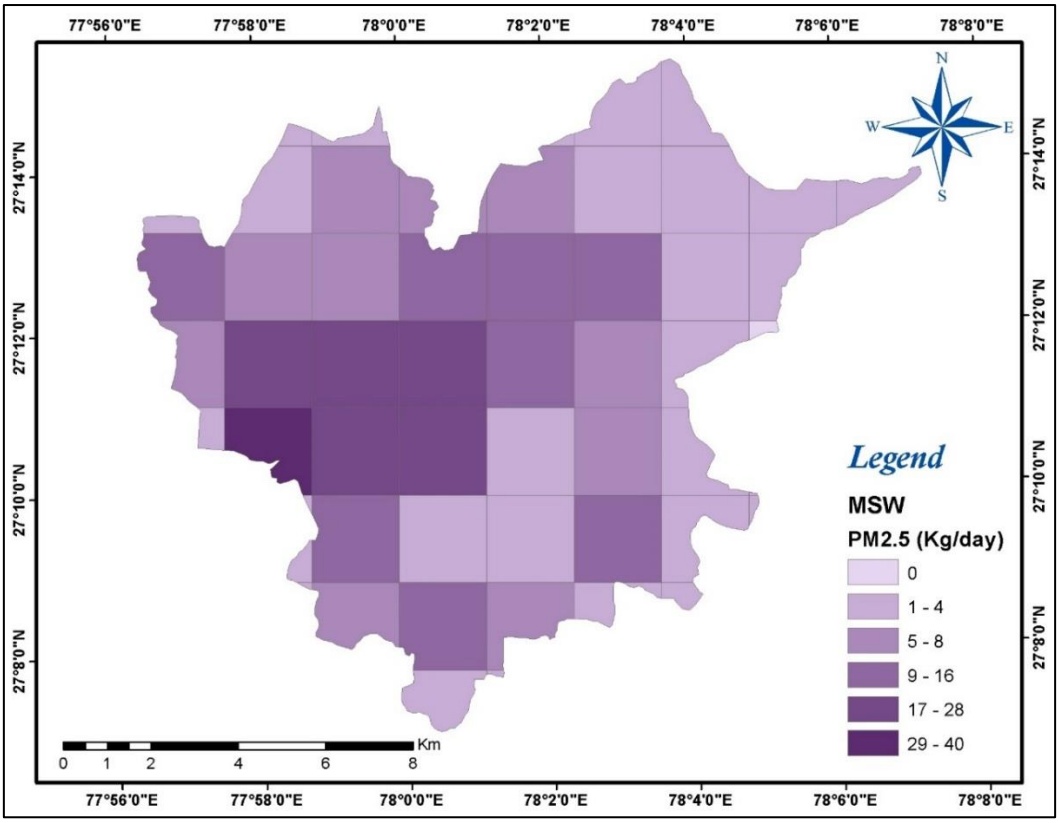


Figure 3.50: Spatial Distribution of $PM_{2.5}$ Emissions from MSW Burning

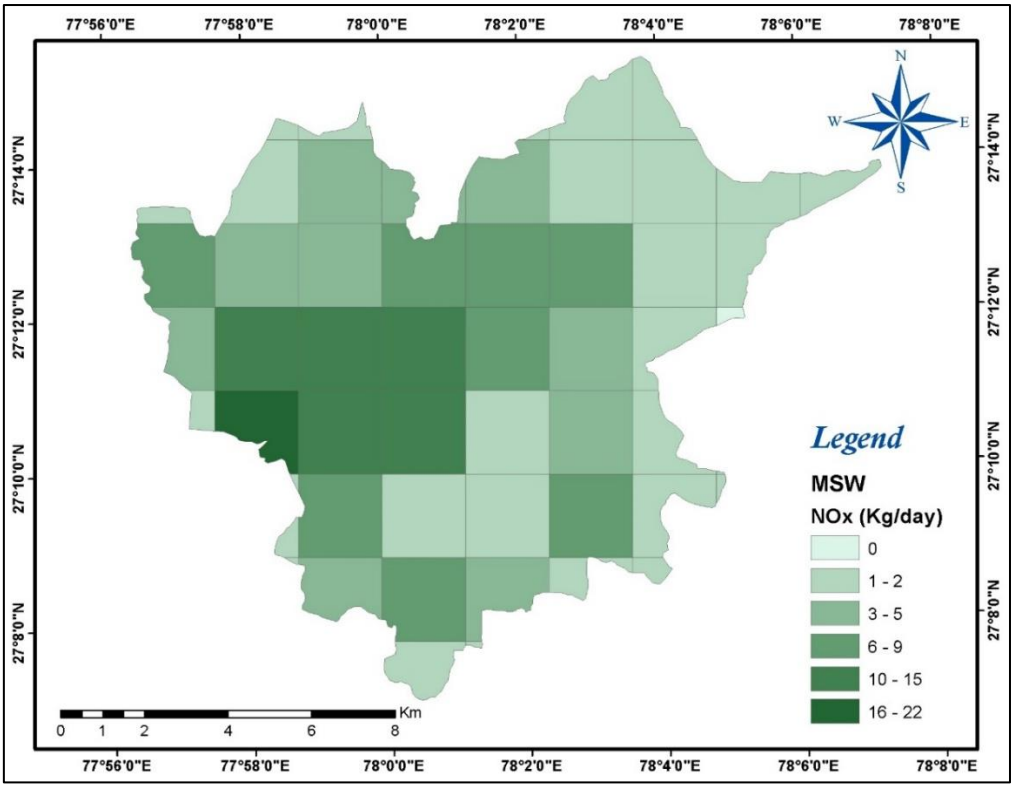


Figure 3.51: Spatial Distribution of NO_X Emissions from MSW Burning

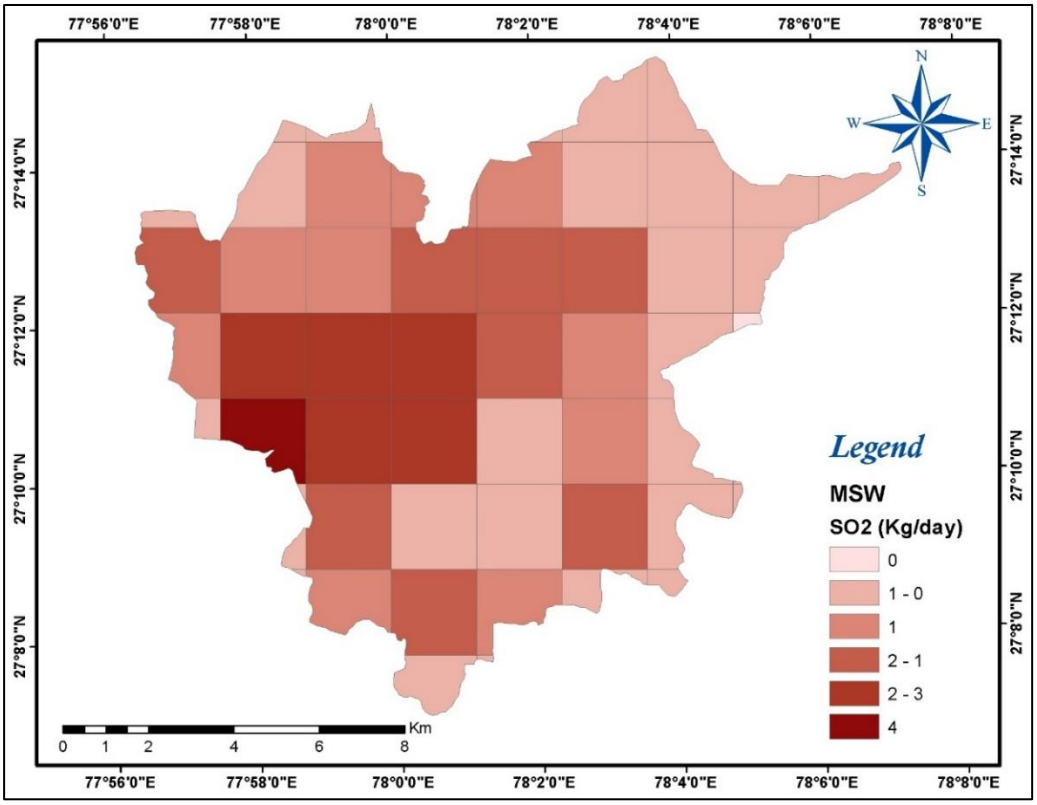


Figure 3.52: Spatial Distribution of SO_2 Emissions from MSW Burning

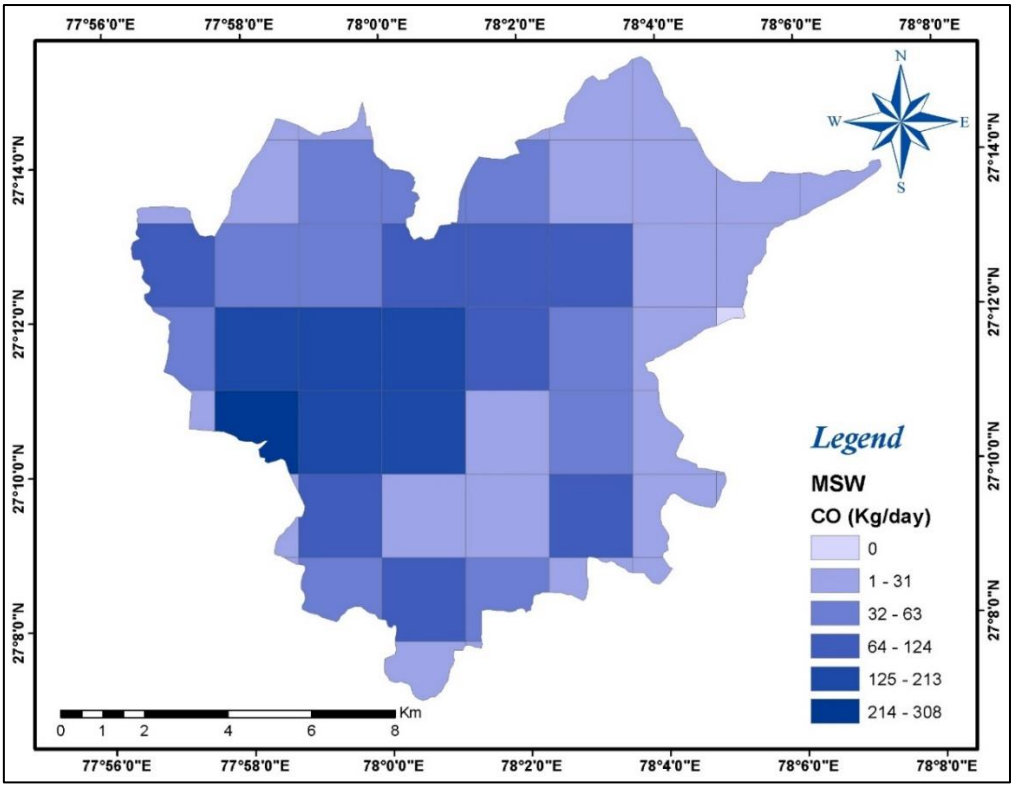


Figure 3.53: Spatial Distribution of CO Emissions from MSW Burning

3.2.9 Open Area

The Emission Load for Open Area in Agra City is given in Figure 3.54. The only contribution is of PM_{10} in open area source. The spatial distribution of PM_{10} is given in Figure 3.55.

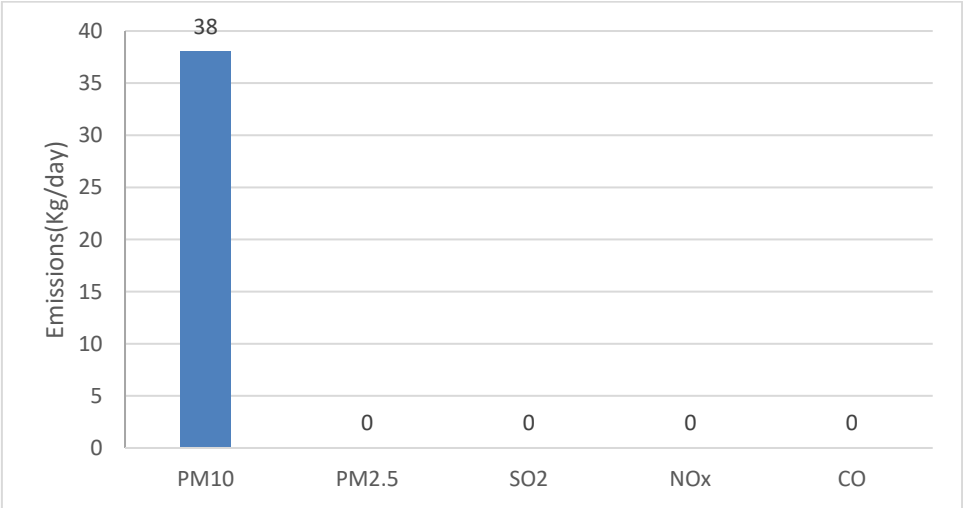


Figure 3.54: Emission Load from Open Area (kg/day)

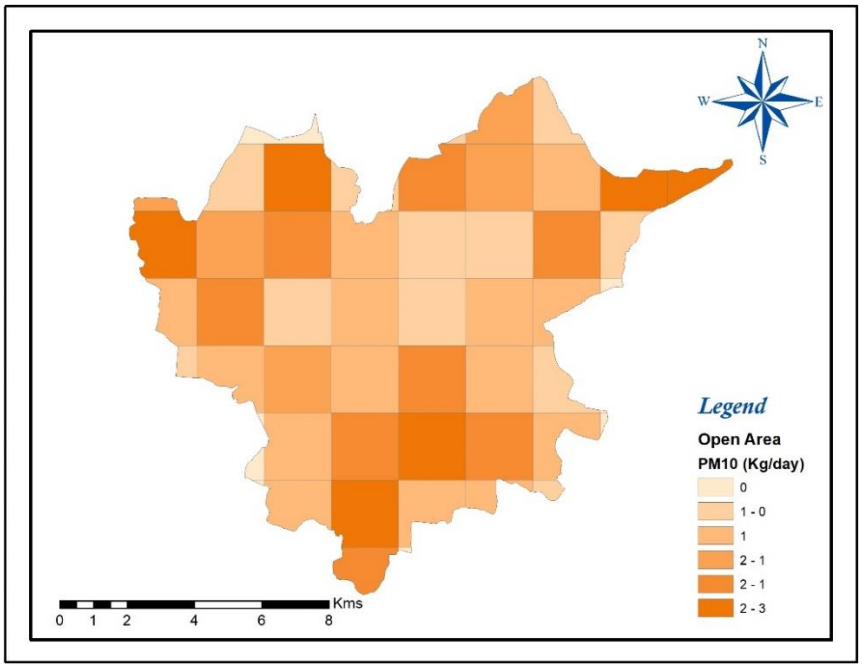


Figure 3.55: Spatial Distribution of PM_{10} Emissions from Open Area

3.2.10 Hospitals

A detailed survey was undertaken to assess Hospital's emissions. The locations of Hospitals in Agra City are given in Figure 3.56. The emission load from hospitals is given in Figure 3.57. Maximum emissions for the hospitals are from NOx. The Spatial distribution of emissions from Hospitals is given in Figure 3.58 to Figure 3.62.

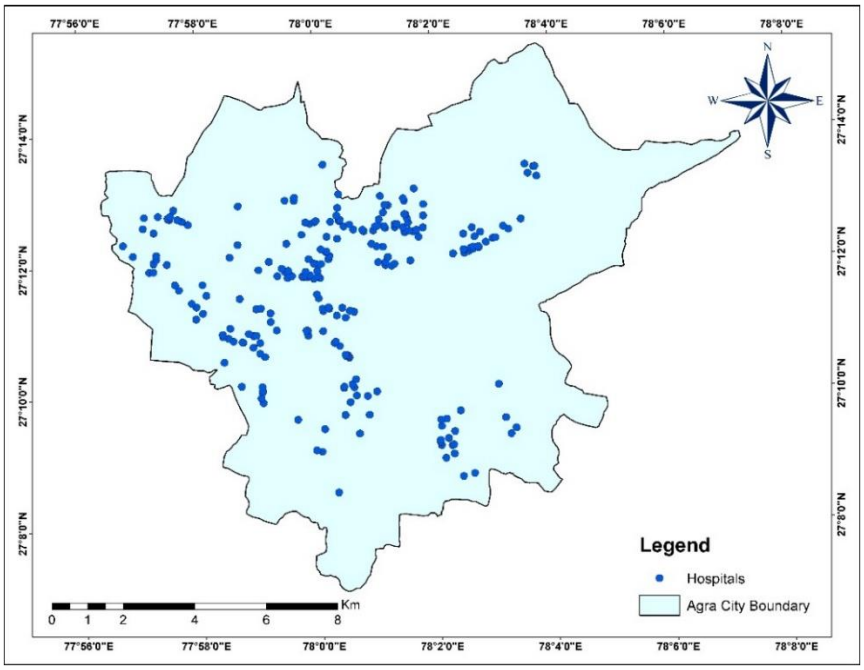


Figure 3.56: Locations of Hospitals in Agra City

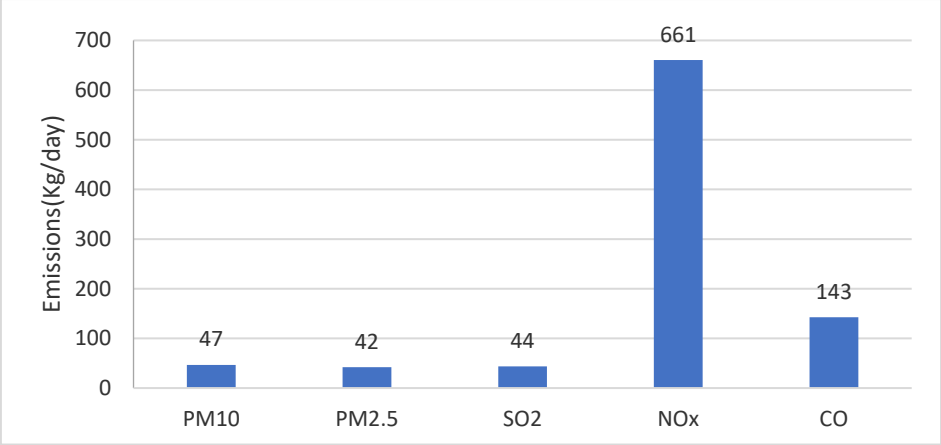


Figure 3.57: Emission Load from Hospitals (kg/day)

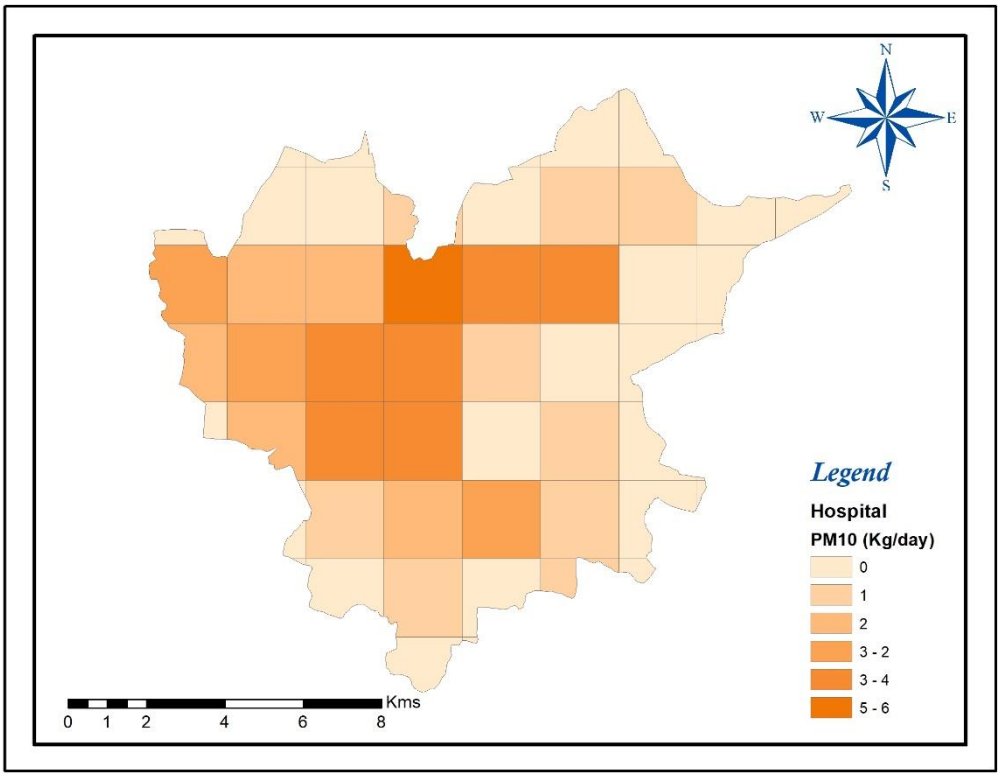


Figure 3.58: Spatial Distribution of PM_{10} Emissions from Hospitals

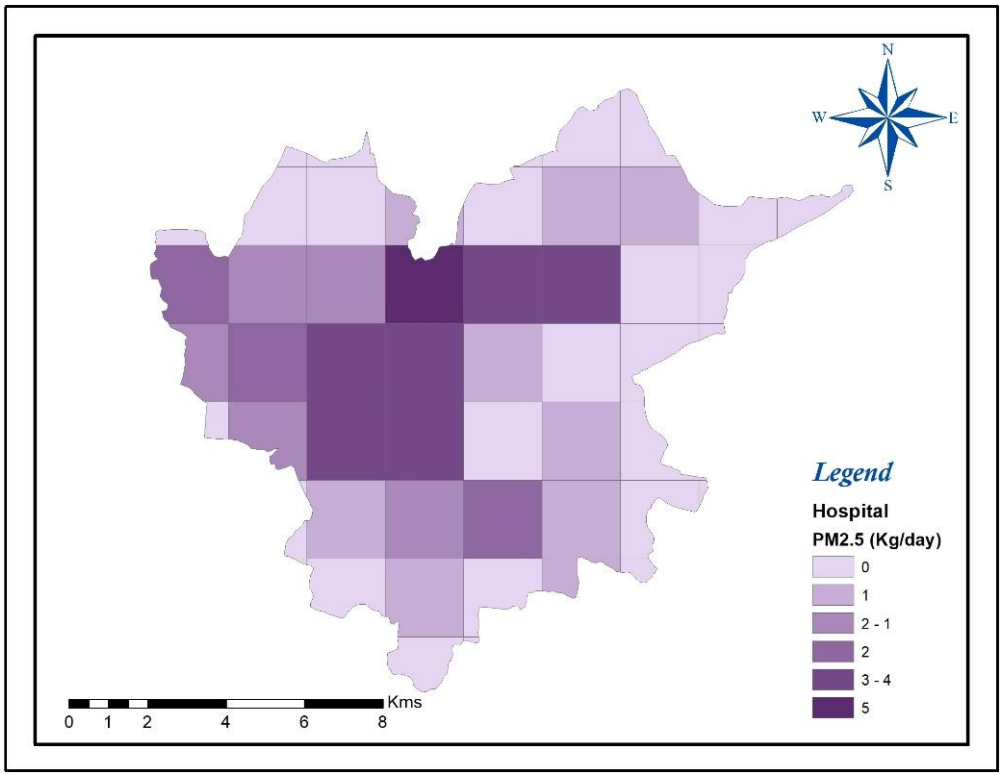


Figure 3.59: Spatial Distribution of $PM_{2.5}$ Emissions from Hospitals

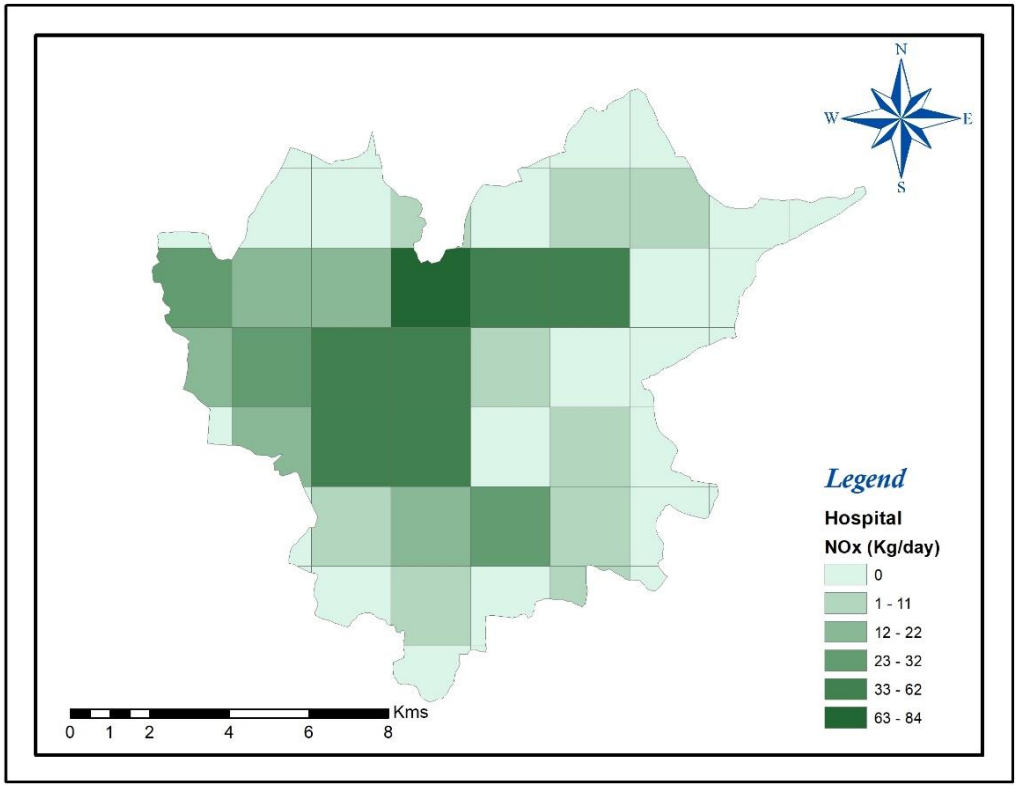


Figure 3.60: Spatial Distribution of NOx Emissions from Hospitals

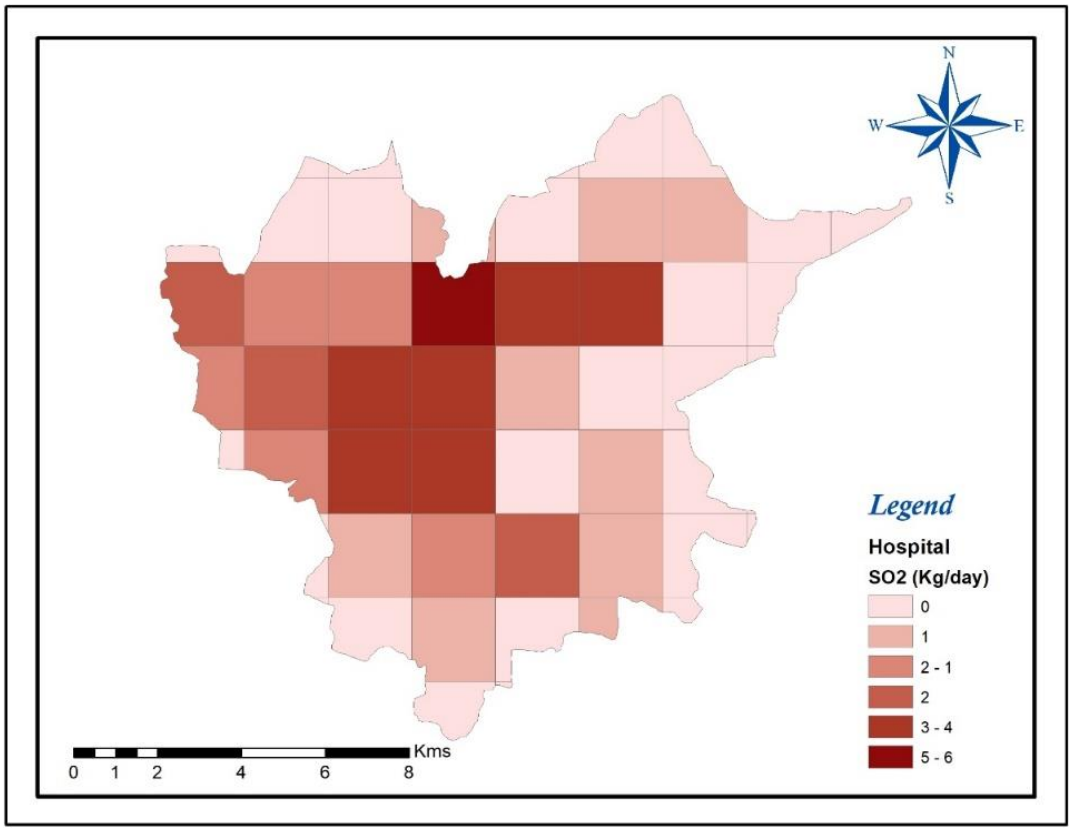


Figure 3.61: Spatial Distribution of SO_2 Emissions from Hospitals

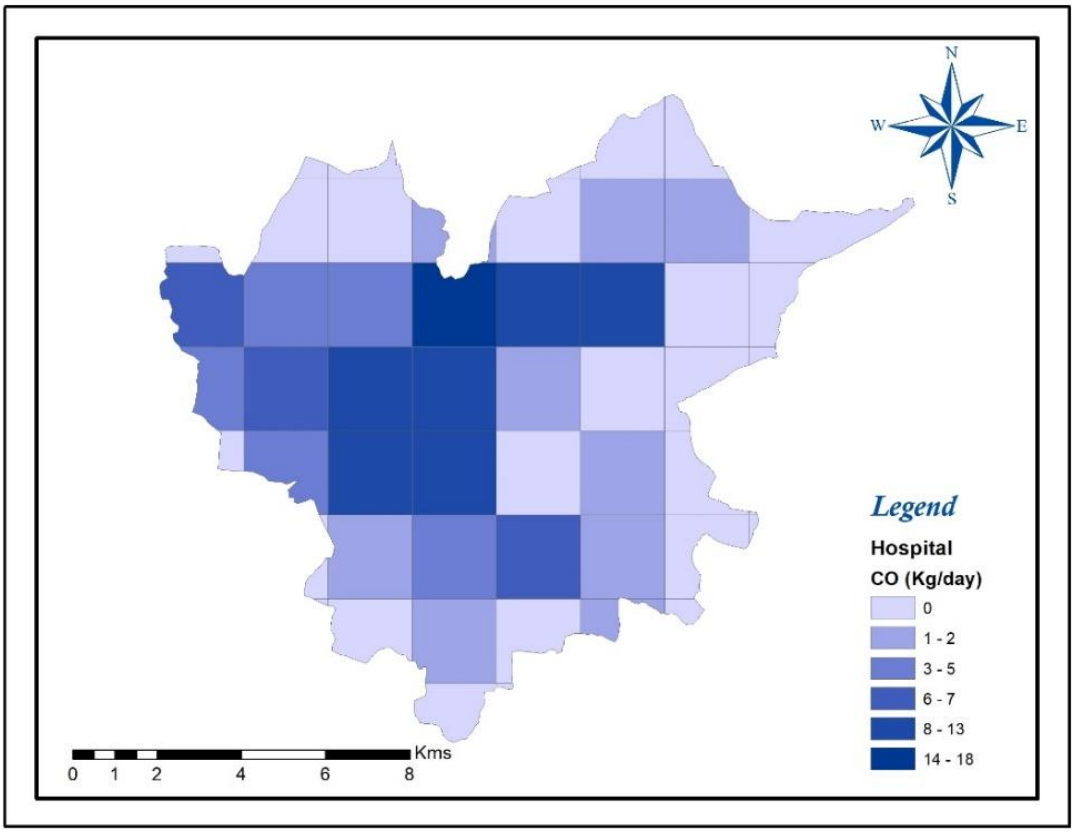


Figure 3.62: Spatial Distribution of CO Emissions from Hospitals

3.2.11 Industries

There are over 100 industrial units in Agra (Figure 3.63). A total of 102 boiler and furnaces exist in these industrial units. There are 48 cupola furnaces (gas-based cokeless) and 36 induction furnaces operating in industries within Agra city. The cupola furnace and induction furnace operate for a limited period i.e., 1.5 to 2 months in the year. The emission from these furnaces has been considered for their operating period and normalized for the year. Cyclones and multi-cyclones were installed as air pollution control devices. The calculation is based on Eq (3.1), where ER, overall efficiency reduction was taken as 50%. The overall emissions estimated from the different types of boilers, furnaces, etc. are presented in Table 3.1. The large contribution is from cupola furnaces as they use graphite beds during the process. Induction furnaces are present but smaller in size and capacity and cause emission due to inefficient suction hood having poor suction capacity. Due to this, the emissions from induction furnaces become fugitive as they are not collected by the suction hood.

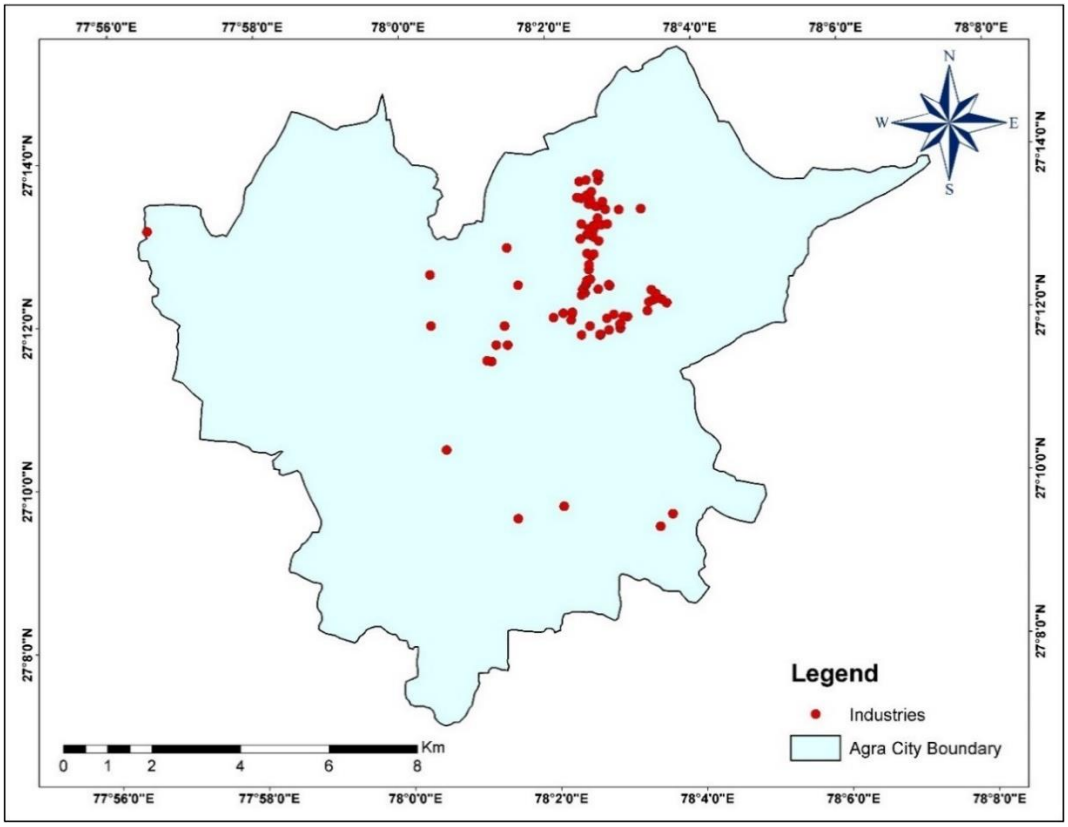


Figure 3.63: Location of Industries

Table 3.1: Furnace/Boiler Details in Agra City (Source: Consent Data, UPPCB)

Boiler/Furnace Type	Fuel used in Boiler/Furnace /DG Sets	No of Furnaces/ Boilers/DG Sets	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
Baby Boiler	Diesel (2)	2	4	3.6	51	18	2
Boiler	Diesel (5), Natural Gas (3)	8	6	5.1	42	40	12
Induction Furnace	Electricity	36	116	104	0	0	0
Annealing Furnace	Natural Gas	1	0.1	0.1	0	1	1
Cupola Furnace	Gas and Coke Bed	48	461	438	88	790	434
Pit furnace	Gas	5	0.13	0.12	0	3	2
Tank furnace	Gas	2	1	0.8	0	18	10
Total		102	102	588	551	181	870

Industries as Area Source

Figure 3.64 presents the overall emissions from industries (stack height < 20 m) as an area source. All cupola and induction furnaces and the majority of boilers fall under this category.

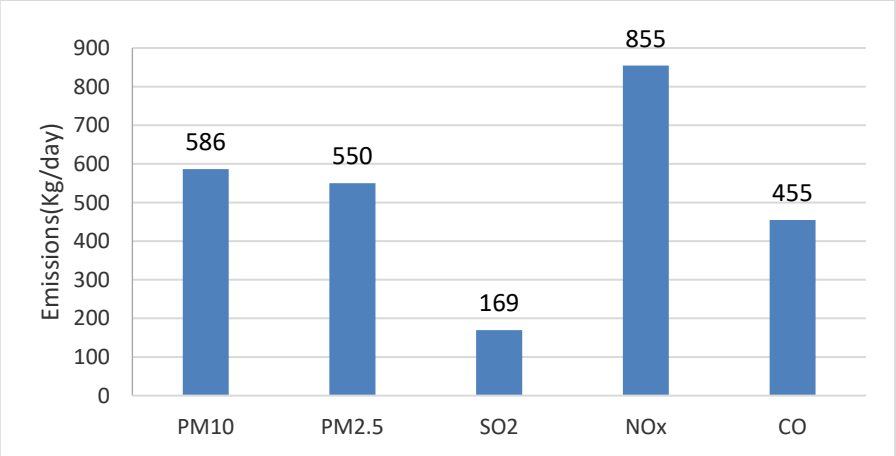


Figure 3.64: Emission Load from Industries as Area Source

Industries as Point Source

The industries having a stack height of more than 20 m have been taken as a point source. Only two industries in Agra are having chimney height equal to or more than 20 meters (Figure 3.65). The information on stacks, fuel, and its consumption was obtained from UPPCB. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. The emission of pollutants from large industries is shown in Figure 3.66.

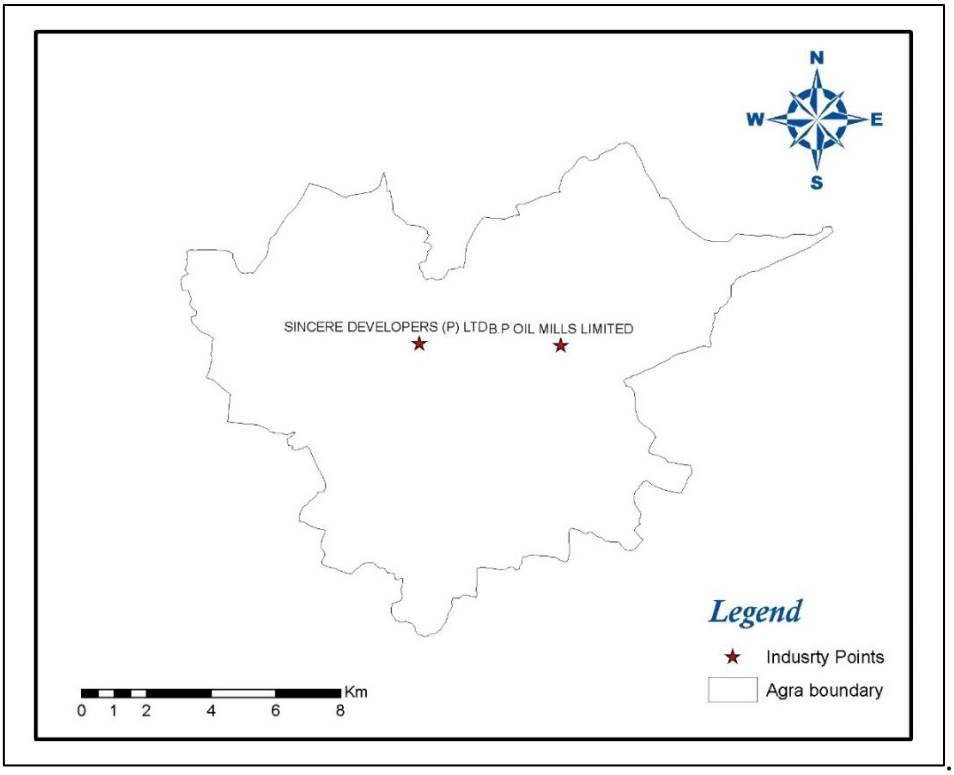


Figure 3.65: Location of Industries as point source

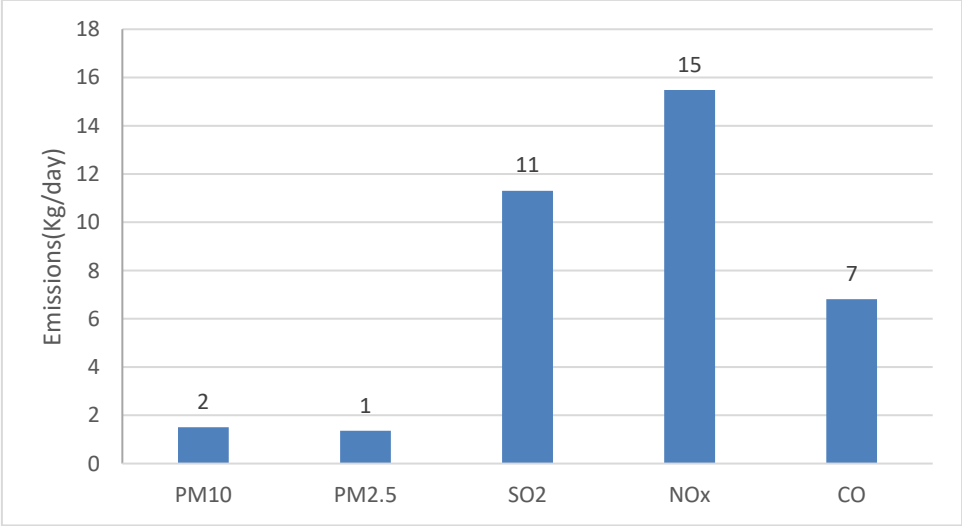


Figure 3.66: Emission Load from Industrial Point Source

The spatial distribution of emissions from industries (point and area source) is presented in Figure 3.67 to Figure 3.71.

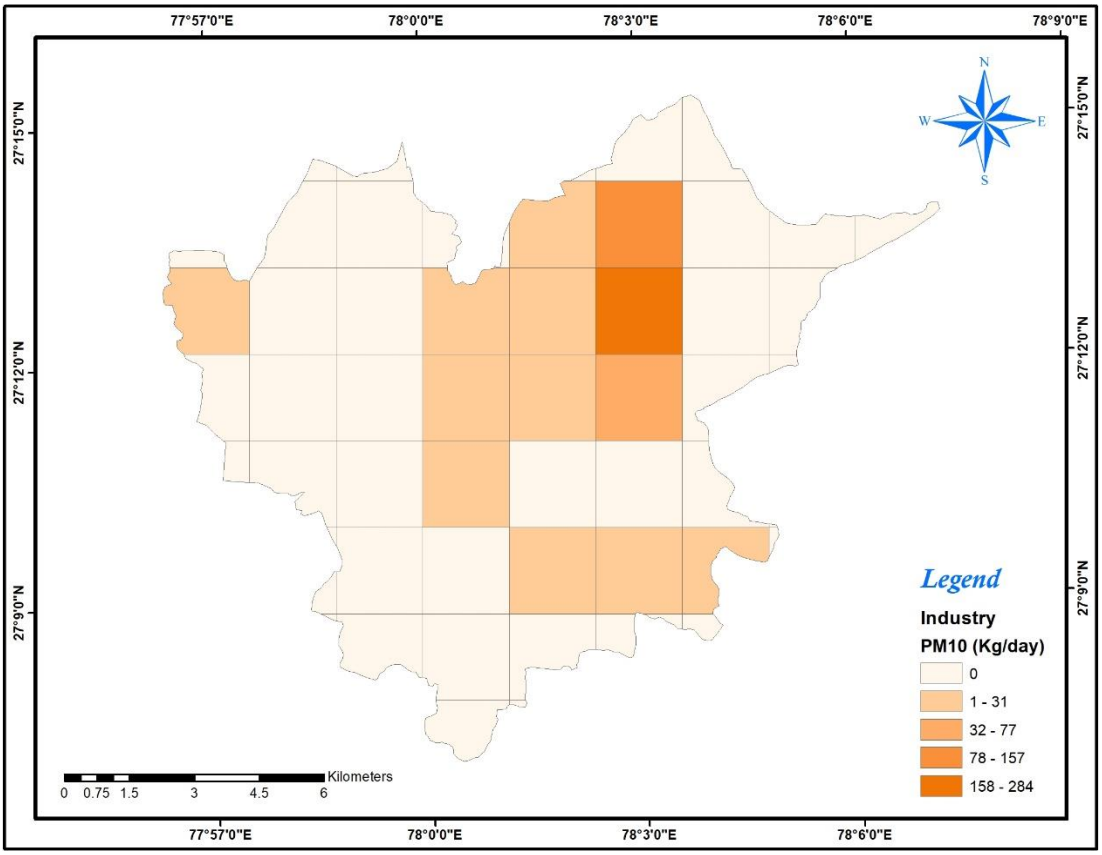


Figure 3.67: Spatial Distribution of PM_{10} Emissions from Industries

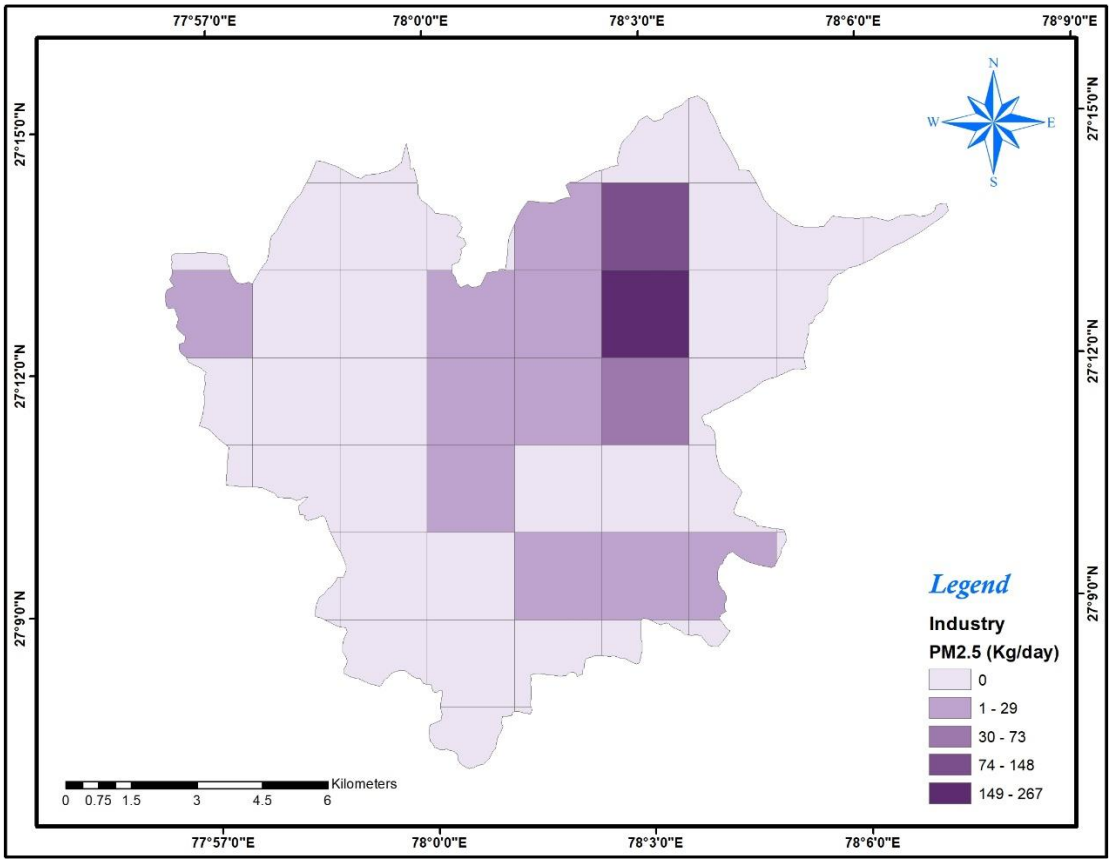


Figure 3.68: Spatial Distribution of $PM_{2.5}$ Emissions from Industries

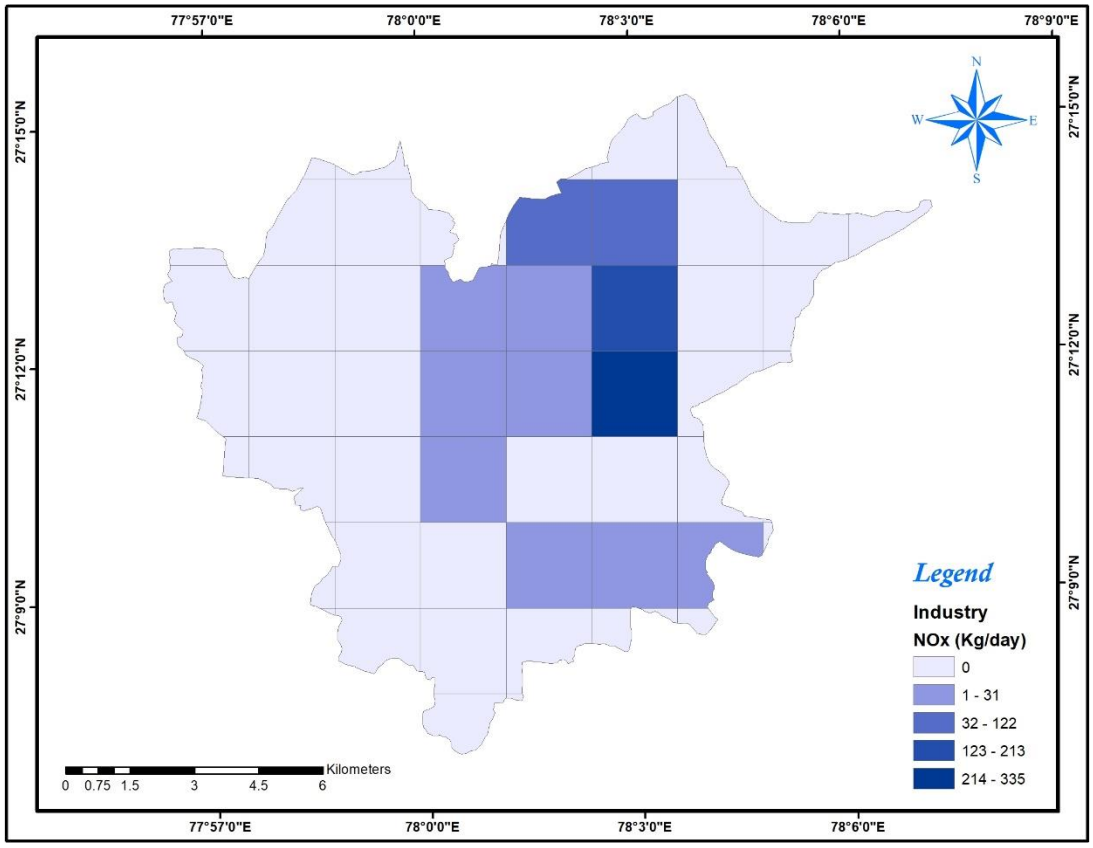


Figure 3.69: Spatial Distribution of NOx Emissions from Industries

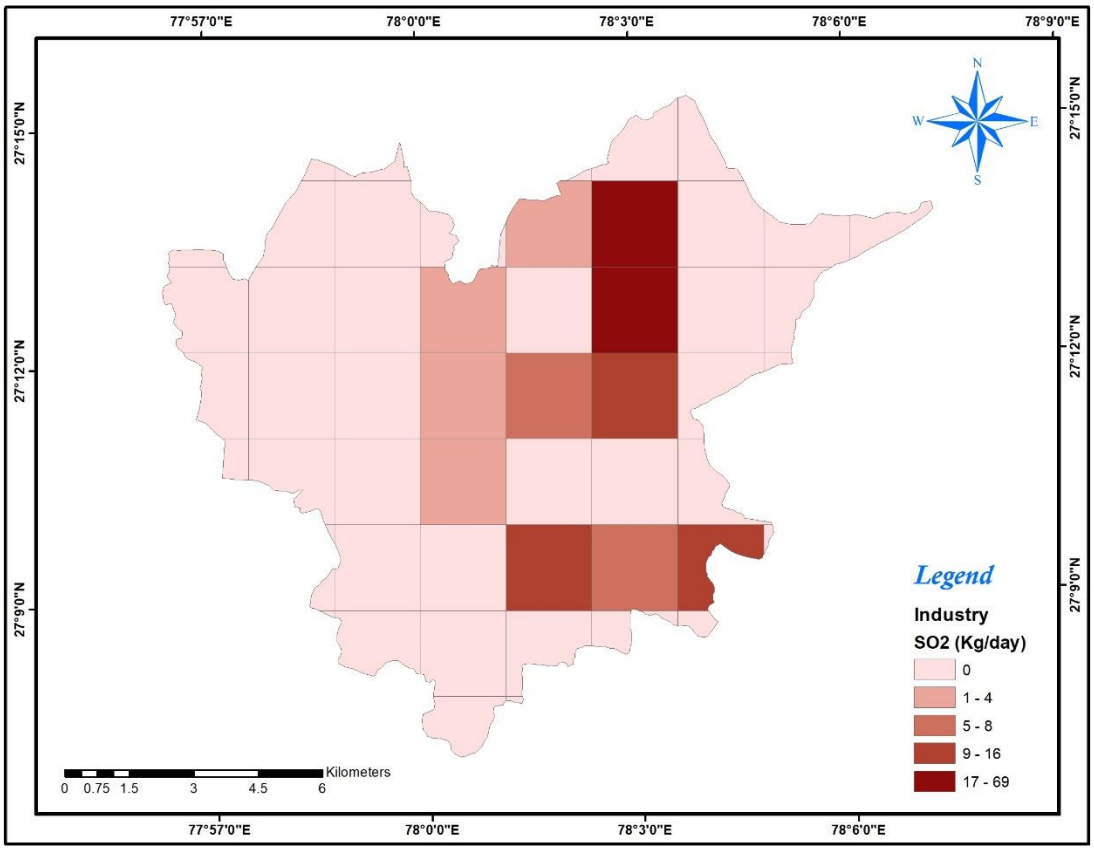


Figure 3.70: Spatial Distribution of SO_2 Emissions from Industries

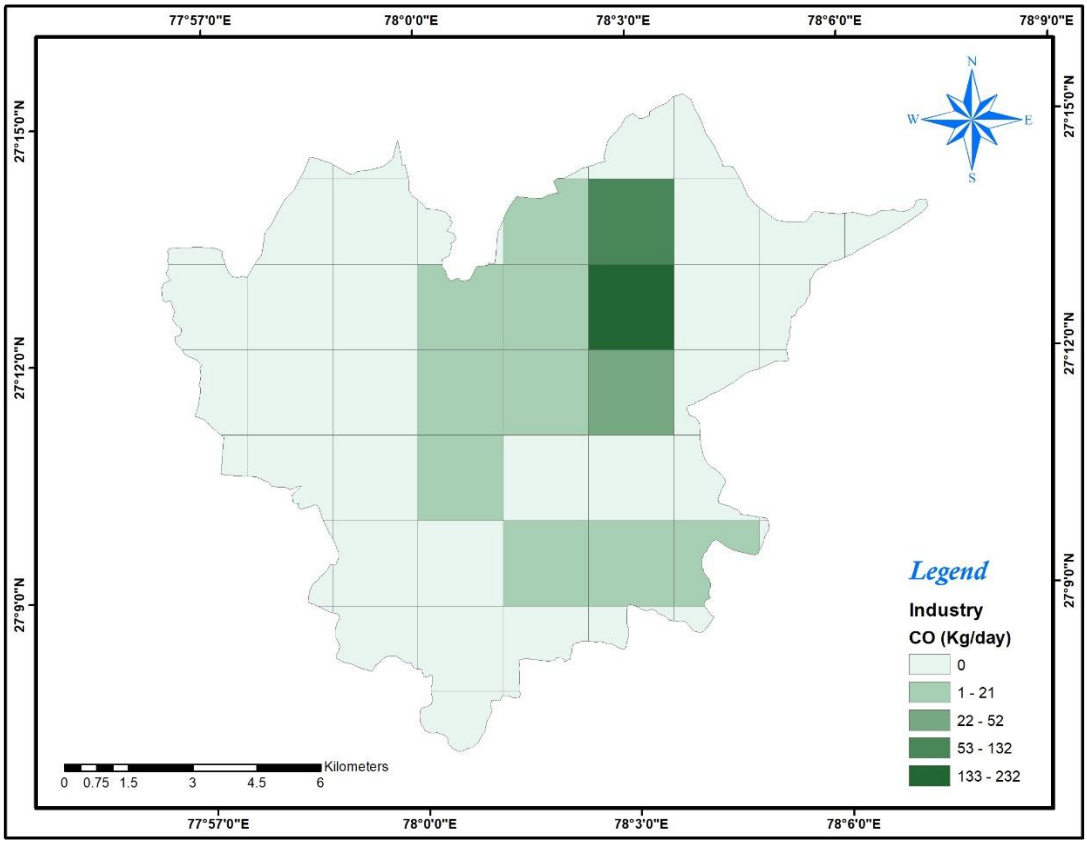


Figure 3.71: Spatial Distribution of CO Emissions from Industries

3.2.12 Vehicular - Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, Buses, and Trucks at 16 locations were obtained by video recording at crossings (Figure 3.72). From these 16 traffic locations, the data were extrapolated for the remaining grid cells. Road lengths in each cell for major and minor roads were calculated from the digitized maps using the ArcGIS tool, ArcMap, and extracted into the grids. The information on traffic flow from traffic counts was translated into the vehicles on the roads in each grid. Wherever it was feasible, either traffic flow was taken directly from the traffic data, and for interior grids, traffic from medium roads going the highways was taken to flow in the interior part of the city. The emissions from each vehicle category for each grid are estimated and summed up.

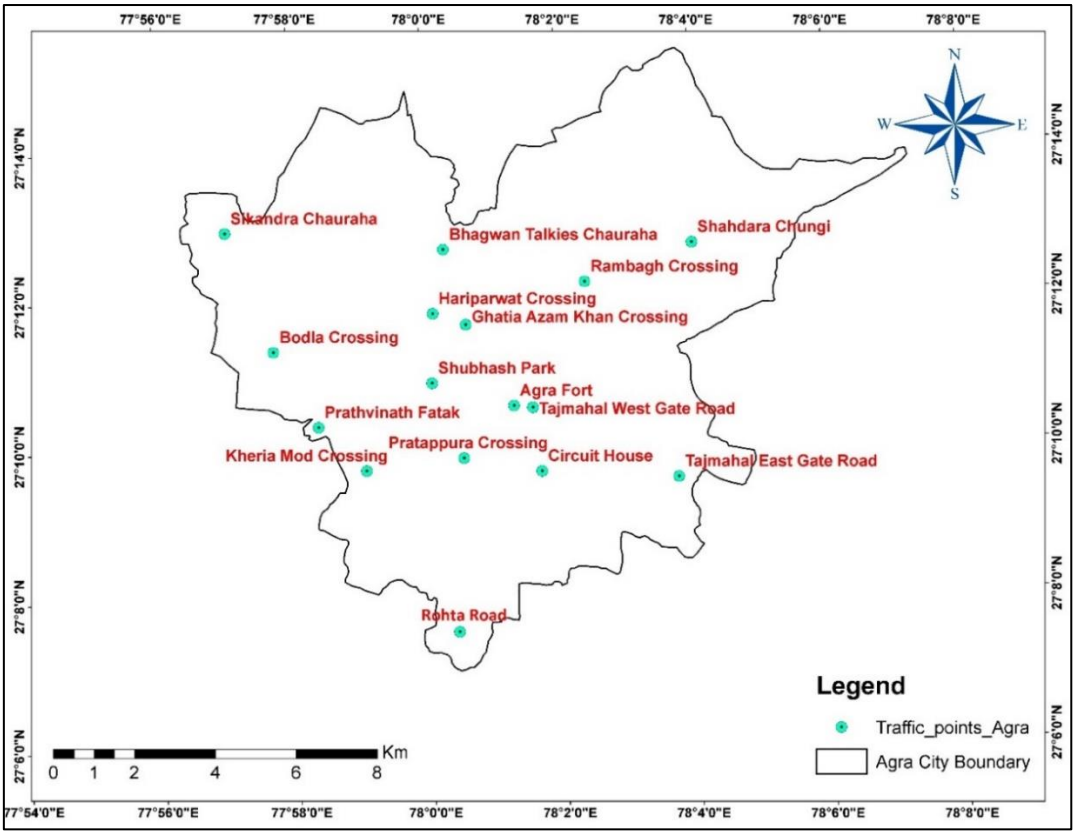


Figure 3.72: Traffic location considered for vehicle emission in the city of Agra.

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

The emission from vehicles is shown in Figure 3.73. The spatial distribution of emissions from vehicles is presented in Figure 3.74 to Figure 3.78.

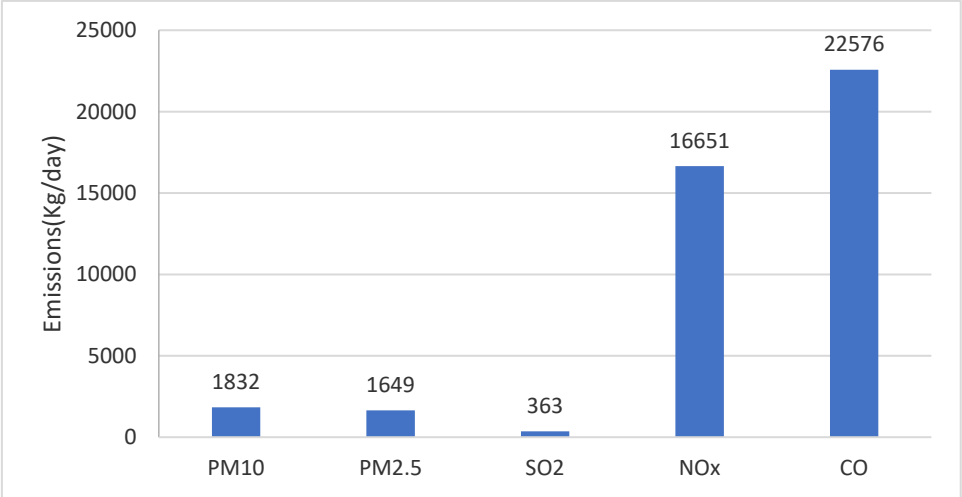


Figure 3.73: Emission Load from Vehicles (kg/day)

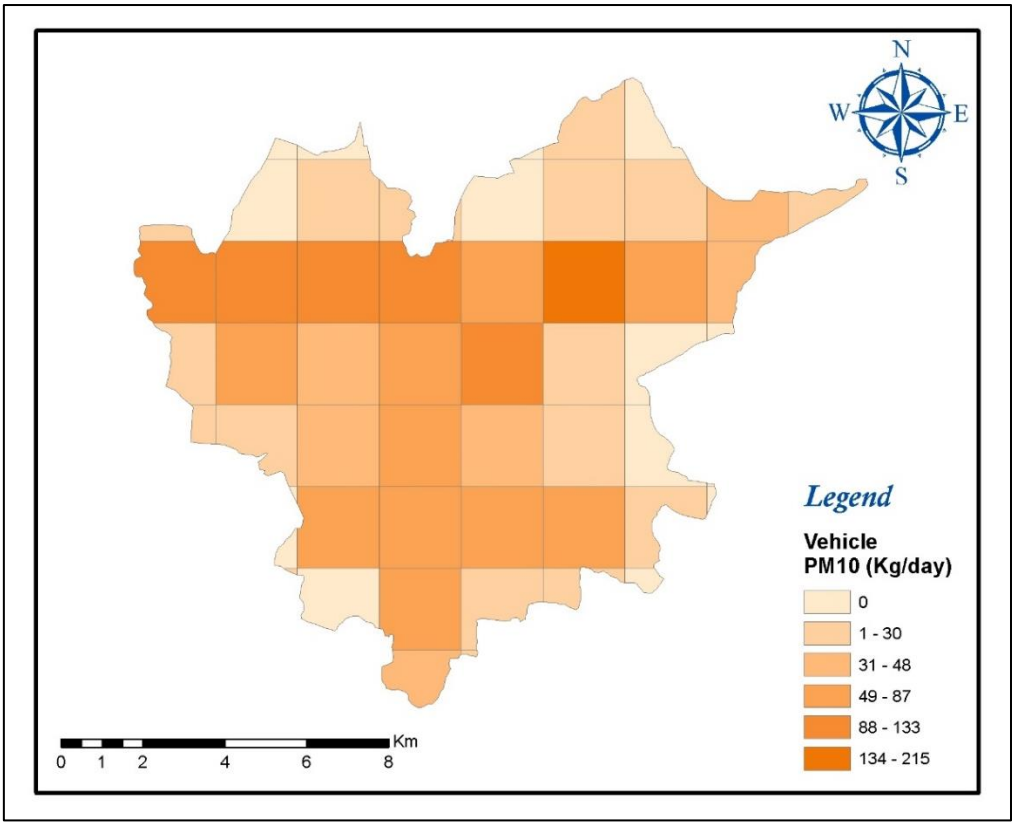


Figure 3.74: Spatial Distribution of PM_{10} Emissions from Vehicles

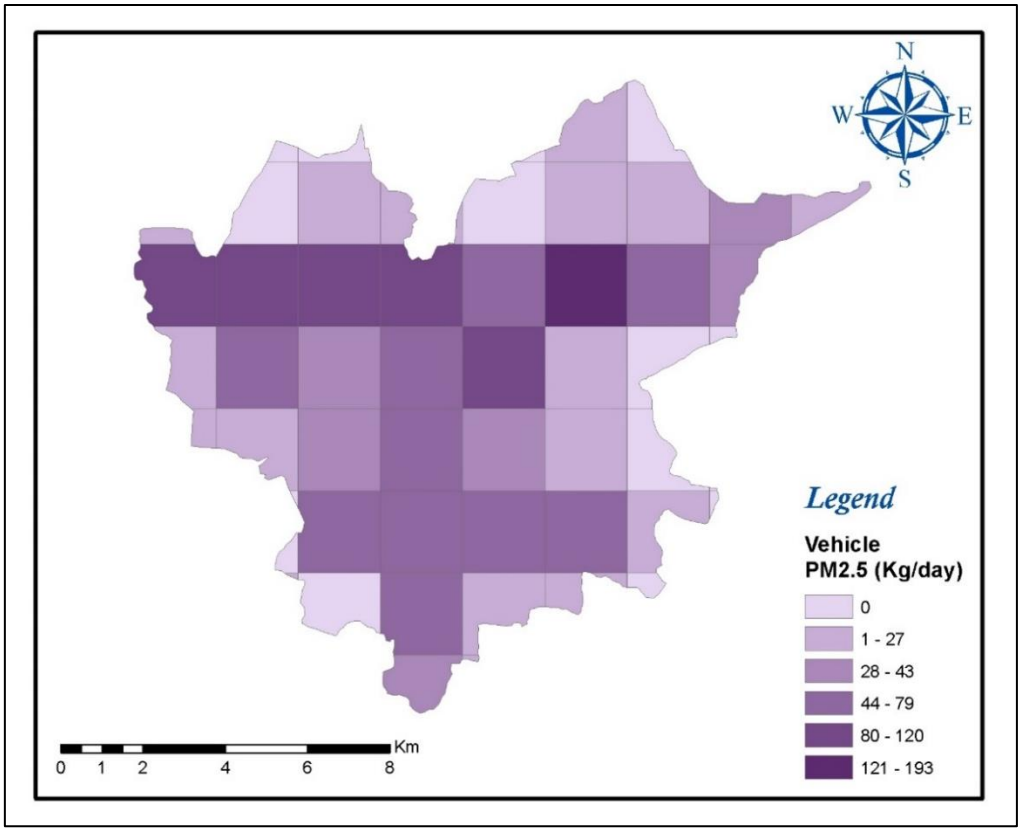


Figure 3.75: Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles

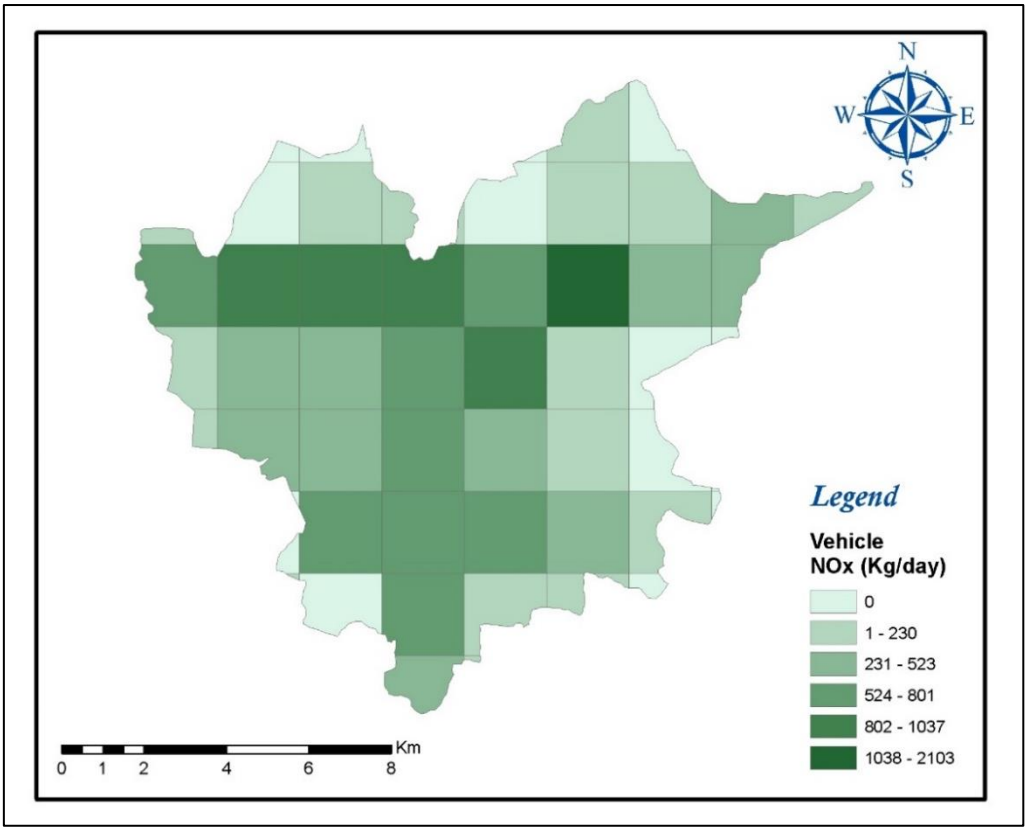


Figure 3.76: Spatial Distribution of NOx Emissions from Vehicles

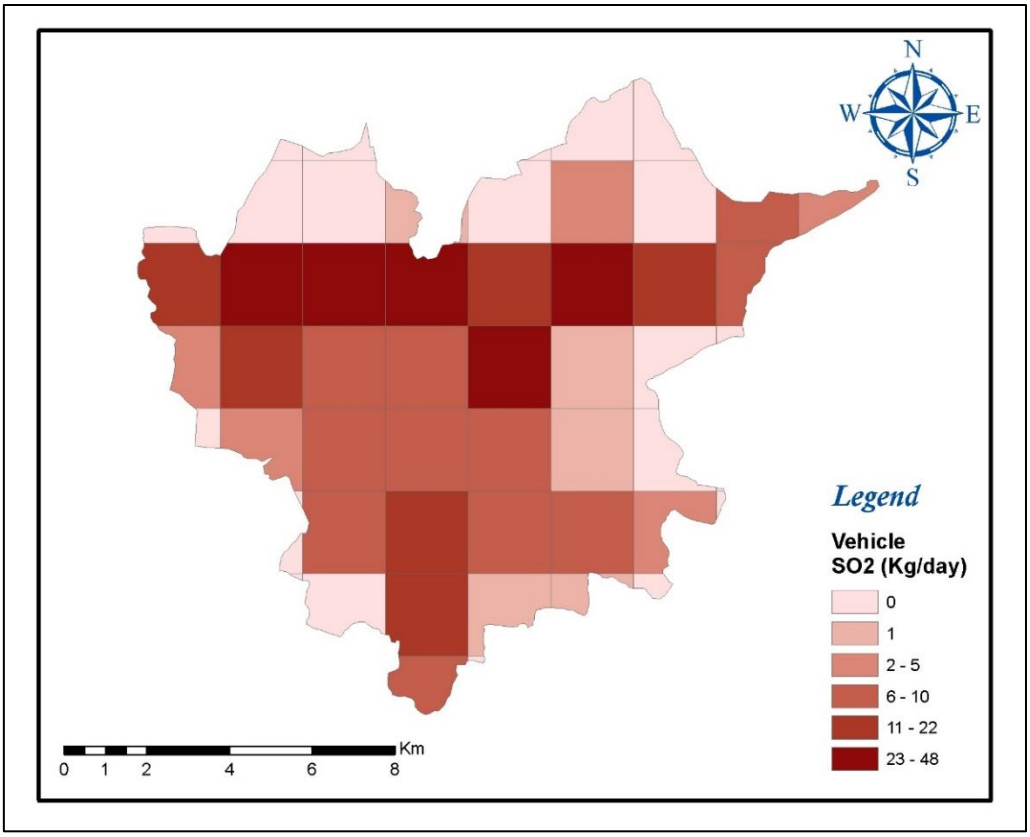


Figure 3.77: Spatial Distribution of SO_2 Emissions from Vehicles

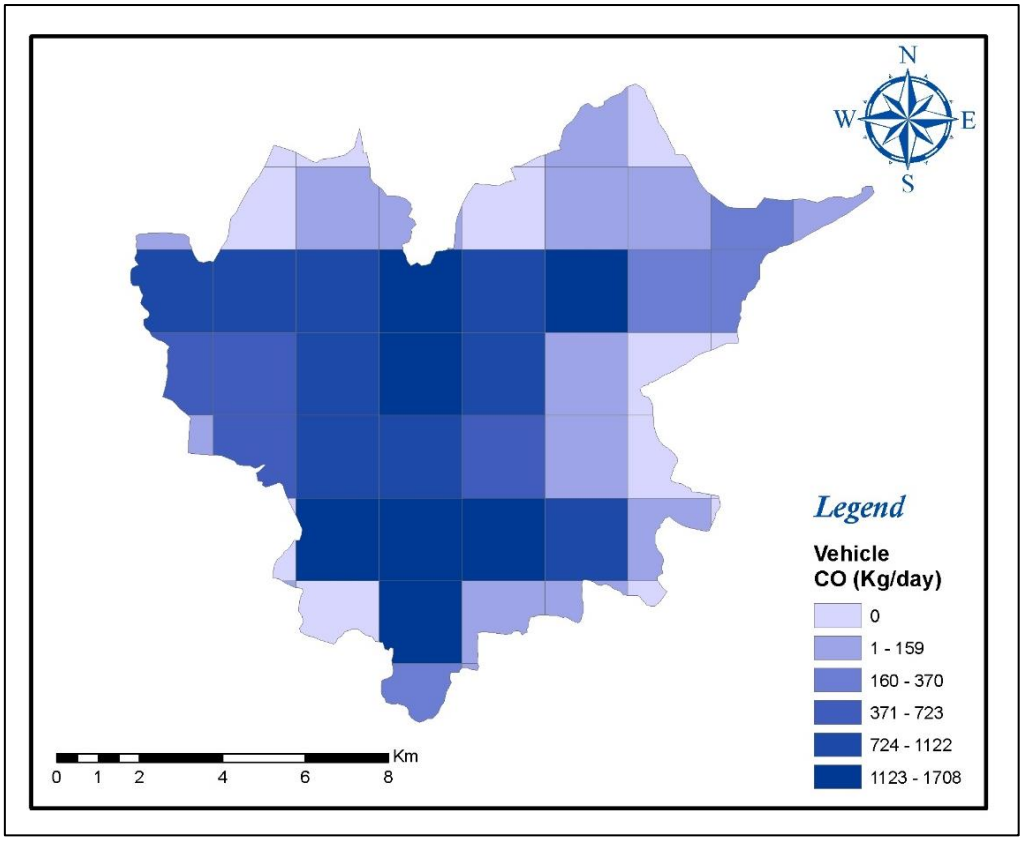


Figure 3.78: Spatial Distribution of CO Emissions from Vehicles

3.2.13 Vehicle Congestion

Agra is a commercial city. A major part of its industrial activity is in the form of small-scale and household industries. These are mainly located in the old Mughal city, particularly Lohamandi, Rakabganj, Kotwali, Tajganj areas. The large-scale units are located in Chatta and Hariparvat areas. The important industries are textile, leather, foundries, diesel engines, generator sets, electrical goods, fans, pipes, C.I, casting, leather goods including shoes, steel rolling, packaging materials, etc. The major handicrafts are marble, leather, carpet, brassware, and artistic dari and jewelry crafts. Commercial activities and high population density need better road infrastructure and smooth traffic movement. The road network within the city is not developed enough to cater to these requirements. Intermediate Public Transport (IPT) is the popular mode of transport due to the lack of a proper public transport system. The road network of the city offers a poor level of service, affecting safety, efficiency, and the economy of traffic operating within the city. The lack of connecting roads with other parts of the city and within the slums poses a grave issue and affects transport connectivity. This is one of the fundamental issues that is generally neglected in city developments and needs thorough planning and execution. The roads in the central part (which is a commercial area) of Agra are narrow (2-4 meters) in width, occupied with on-road parking. The unavailability of proper parking spots

near the market area results in roadside parking, which decreases the road availability for the plying vehicles and hinders the traffic movements (Figure 3.79).

There is a need to improve the U-turns on the major roads of Agra as they create heavy traffic density (congestion) on highways and main roads during peak hours, e.g., Guru ka Tal (Figure 3.79). One of the major problems that contribute to slow traffic movement is encroachments along the road by temporary extension of shops (Figure 3.80).

Figure 3.79: Heavy Traffic Congestion on Highways/Roads

Figure 3.80: Encroachments along the road by temporary extension of shops

The typical Traffic conditions at different locations in Agra City are given in Figure 3.81. Consequently, the major Traffic bottlenecks are mentioned in Table 3.2. The color coding used here is Red, Orange, and Green, indicating the slow traffic to fast traffic movement, respectively. The major issue is the slow traffic movement that refers to the congestion conditions on the road. Hence decongestion plan for the major Traffic Bottleneck intersections of Agra city is recommended. There must be no Parking zone (up to 100m) near the congested intersection listed in Table 3.2. Certain Parking policies in congestion areas (high parking cost, at city centers, only parking is limited for physically challenged people, etc.) must be implemented. The introduction of one-way traffic routes (e.g., Madiakatra, Jeoni Mandi) can play a vital role in the decongestion plan.

Table 3.2: Major Traffic Bottleneck at Agra City

Bhogipura Crossing	Nagar Nigam Intersection
Rakabganj Intersection	Deewani Intersection
Raja mandi Intersection	Sultan Ganj Intersection
Pachkuian Intersection	Jiwani Mandi Intersection
Hariparwat Intersection	Langre Ki chowki Intersection
Professor Colony Intersection	Bijali Ghar Intersection
RBS Crossing	Kinari Bazar Intersection
Lohamandi Intersection	Pipal Mandi Intersection
Madiakatra Intersection	Mantola Intersection
Church Road Khandari Intersection	Rambagh Intersection
Idgah Intersection	NH3 NH11 Bypass road.
Shahganj Crossing	Rui Ki Mandi Crossing

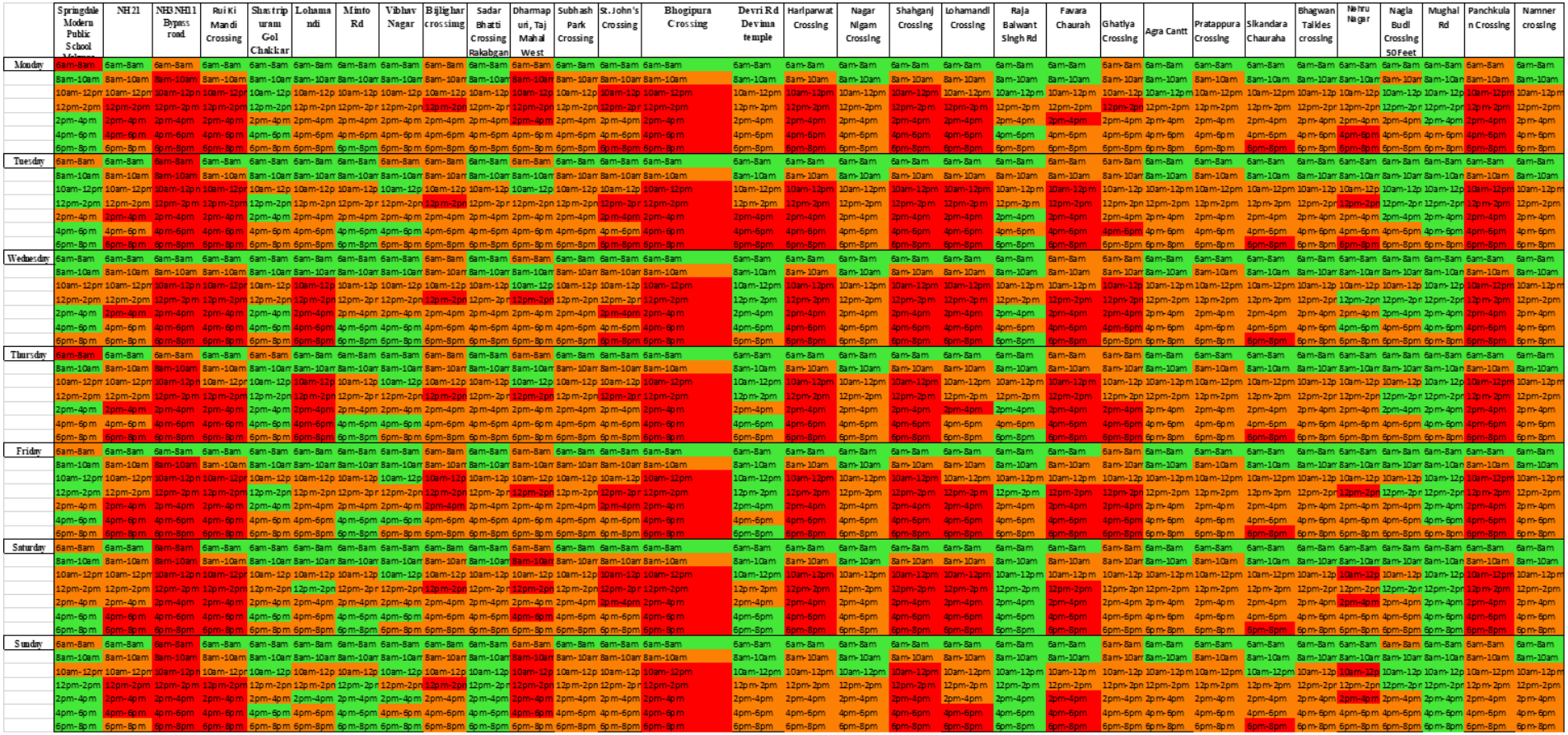


Figure 3.81: Typical Traffic conditions at different locations in Agra City

3.2.14 Parking Lot Survey

To obtain the prevalence of vehicle technology types operating in the city and fuel used, parking lot questionnaire surveys (engine technology and capacity, vehicle age, fuel use, etc.) were done at 15 locations (Sanjay Place, Nagar Nigam Office, Bhagwan Talkies, Dayalbagh, Taj-Mahal, Agra Fort, Shahganj, Raja ki Mandi, Cantt Railway Station, Hari Parwat, Sadar Bazar, Belanganj, Baluganj, Jaipur House, and Bodla Crossing) in the city of Agra. Out of the total of 9258 vehicles surveyed, the breakdown was: 5474 2-Ws; 687 3-Ws; 2427 4-Ws, 101 LCVs, 124 Buses, and 445 Trucks. During the parking lot survey, it was found out that 3Ws, LCVs, and City Buses run on CNG and trucks on diesel and 90% fleet are post-2005. Approximately 25% percent of 4-Ws use diesel and the remaining 75% use gasoline. ARAI (2011) and CPCB (2011) emission factors were used to calculate the emissions. Figure 3.82 and Figure 3.83 present parking lane survey results for 2Ws 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 uses, and age of the vehicles.

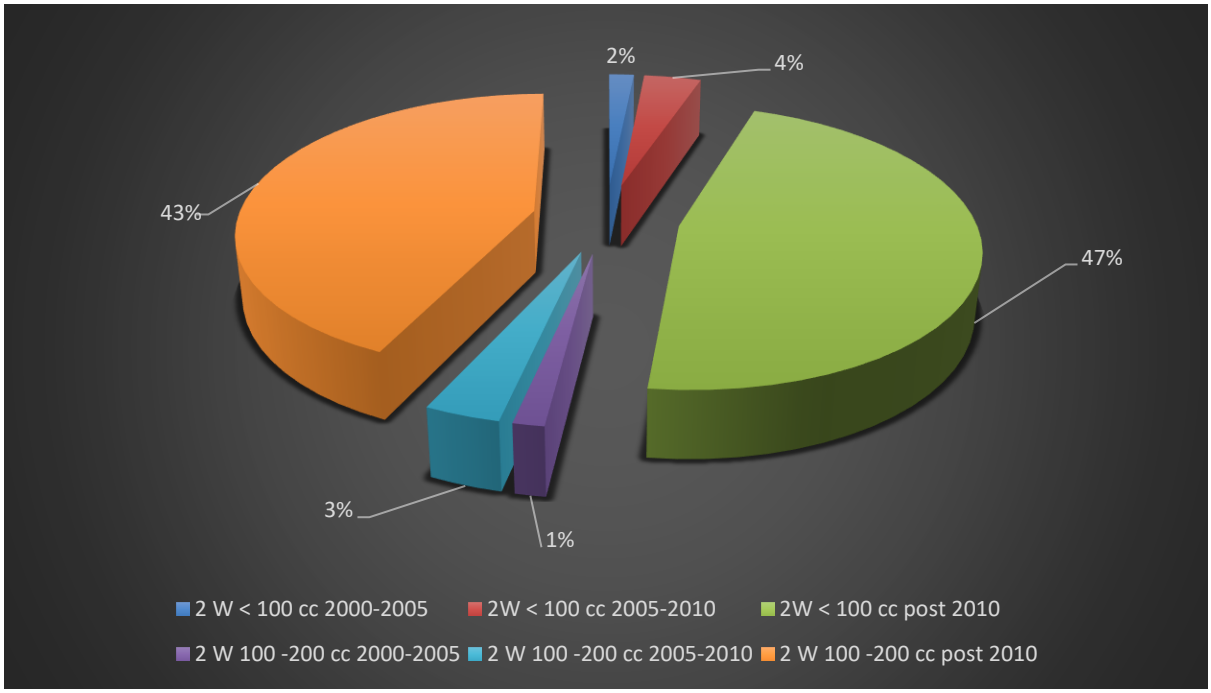


Figure 3.82: Distribution of 2-Ws in the study area (parking lot survey)

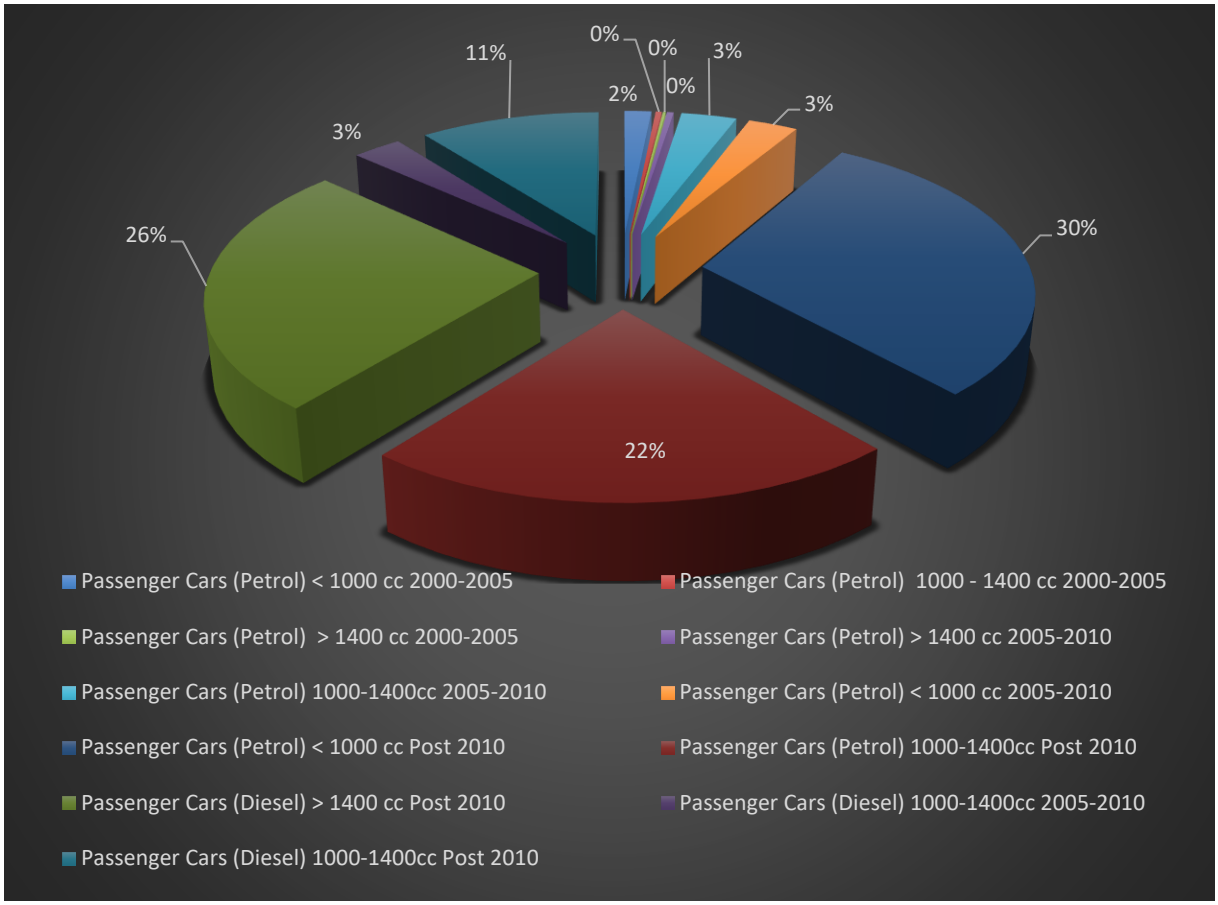


Figure 3.83: Distribution of 4-Ws in the study area (parking lot survey)

The emission contribution of each vehicle type in the city of Agra is presented in Figure 3.84 to Figure 3.88.

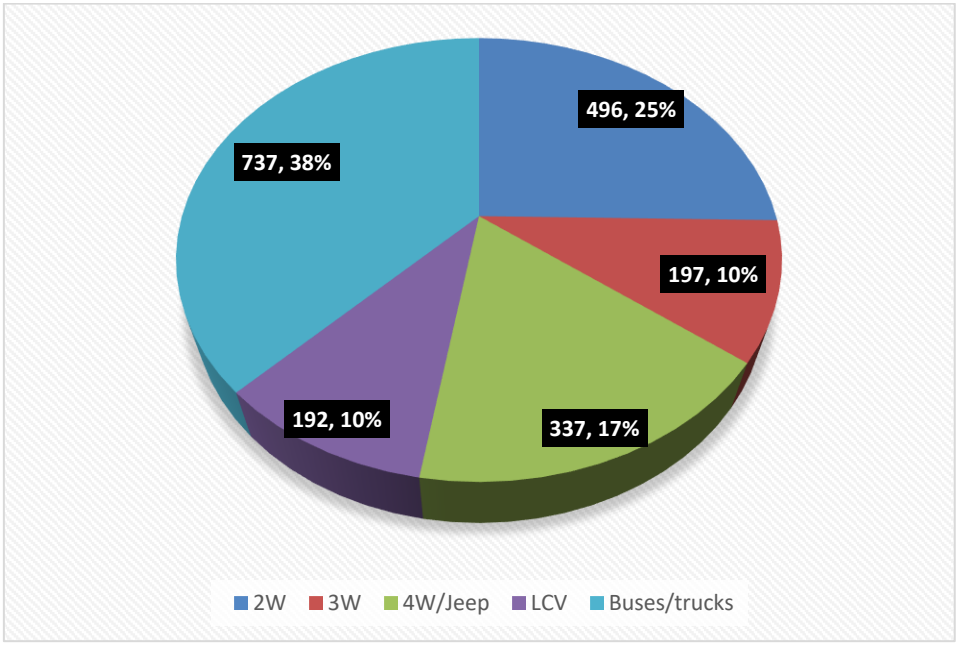


Figure 3.84: PM_{10} Emission Load contribution of each vehicle type (kg/day)

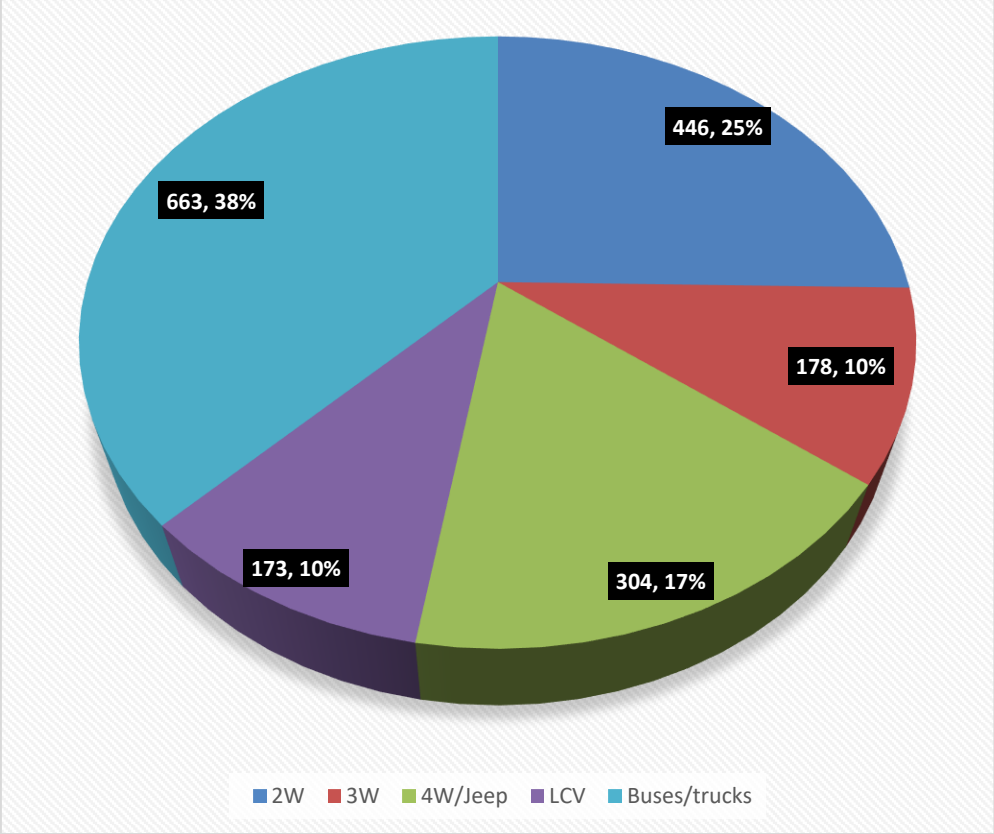


Figure 3.85: $PM_{2.5}$ Emission Load contribution of each vehicle type (kg/day)

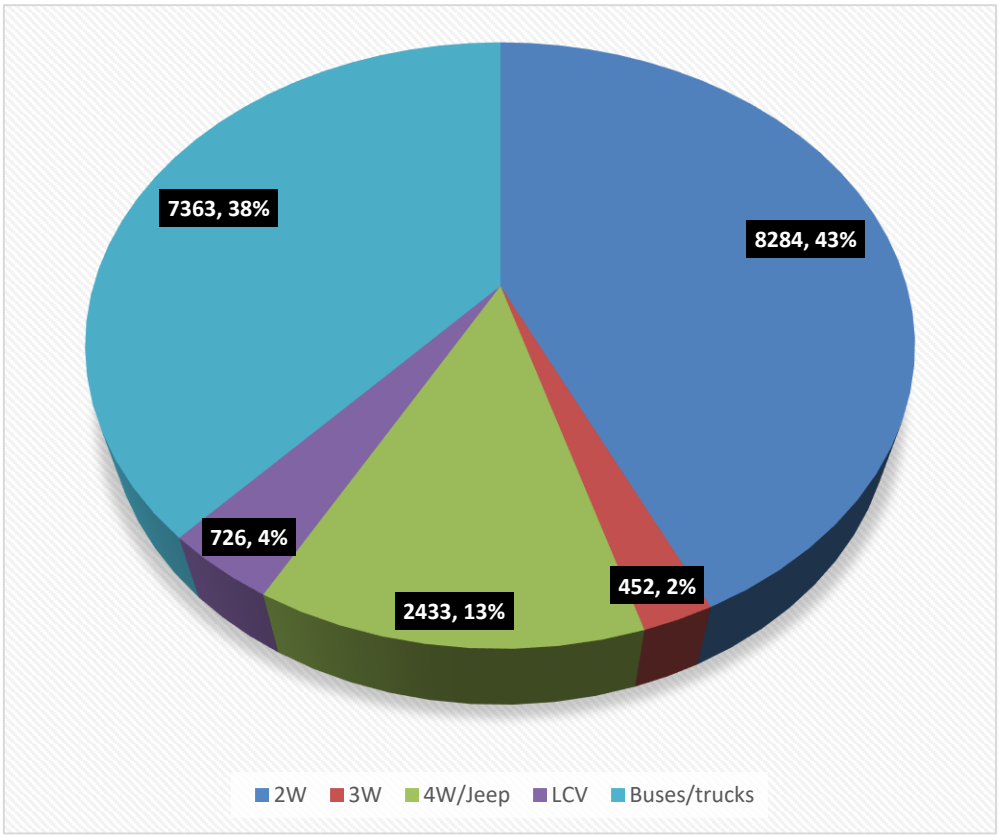


Figure 3.86: NO_x Emission Load contribution of each vehicle type (kg/day)

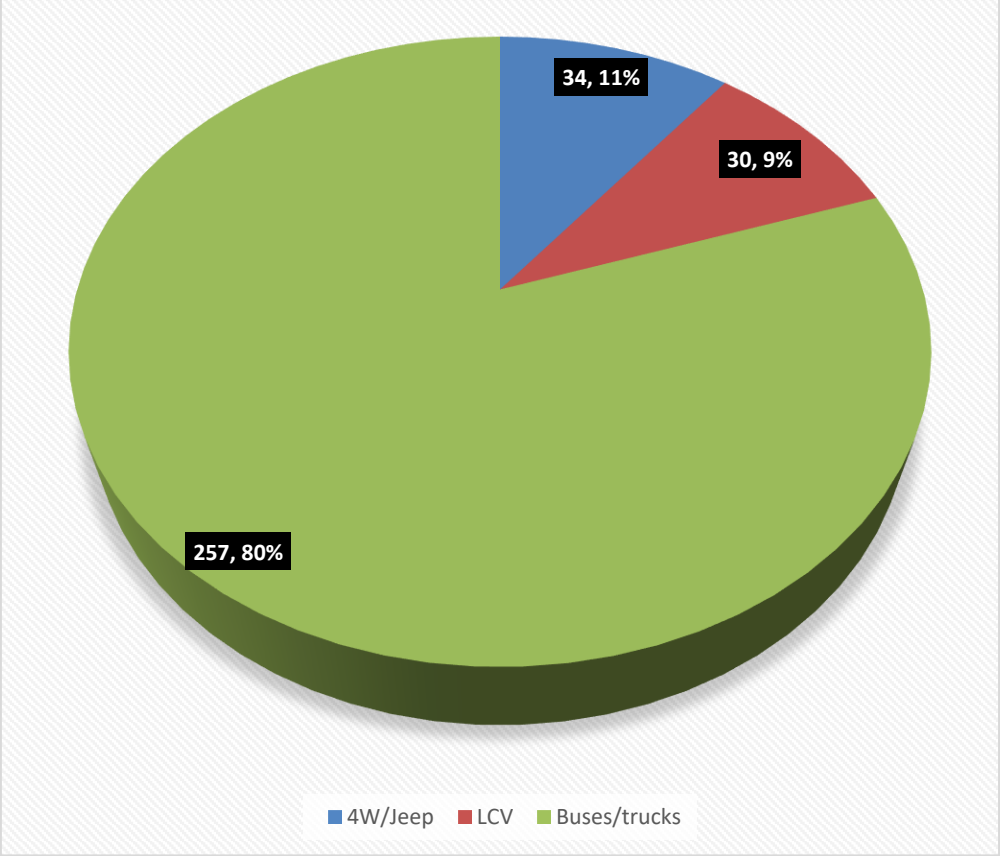


Figure 3.87: SO_2 Emission Load contribution of each vehicle type (kg/day)

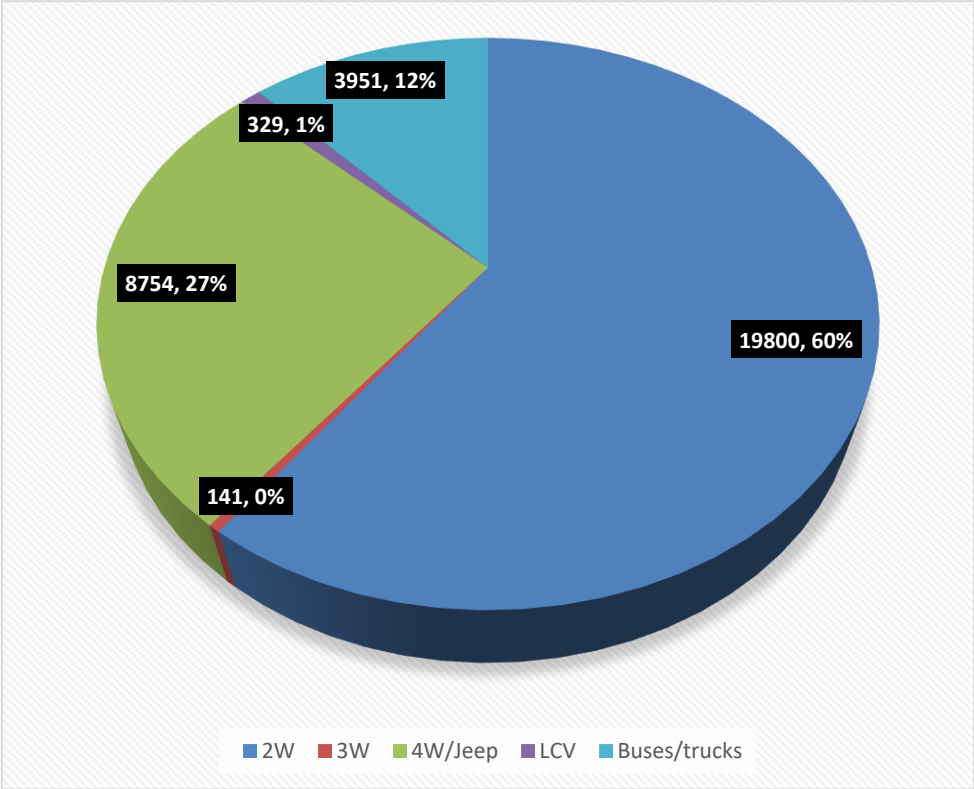


Figure 3.88: CO Emission Load contribution of each vehicle type (kg/day)

3.2.15 Paved and Unpaved Road Dust

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

$$E_{ext} = [\, k\,(sL)^{0.91} \times (W)^{1.02} \,]\,(1 - P/4N) \quad (3.4)$$

Where

E = particulate emission factor (having units matching the units of k),

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

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

E_{ext} = annual or other long-term average emission factor in the same units as k,

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

N = number of days in the averaging period.

k: constant (a function of particle size) in g VKT^{-1} (Vehicle Kilometer Travel).

The road dust sampling locations are given in Figure 3.89. The silt loads (sL) samples from 16 locations were collected (Figure 3.90 and Figure 3.91). Then mean weight of the vehicle fleet (W) was estimated by giving the weightage to the percentage of vehicles of all types with their weight. Then emission rate (g VKT^{-1}) was calculated based on Eq (3.4). VKT for each grid was calculated by considering the tonnage of each road. Then finally, the emission loads from paved and unpaved roads were found out by using Eq (3.4). Silt Road at Different Locations in the City of Agra is given in Table 3.3. The lowest silt load observed at circuit house road (7.4 gm/m^2) and highest at Rohta road (55.1 gm/m^2). There is a need to clean the road on a regular basis. The road dust deposition can be seen in Figure 3.93. It can be seen the roads are broken in patches causing higher road dust emissions (Figure 3.94). There are several locations (transport nagar, pratapura, baluganj, and chipitola) where oil, grease, and oils are thrown on the roads (Figure 3.95). In the winter and monsoon season, it is less due to moisture and dew atmospheric conditions. The variation in silt load is shown in Figure 3.92. The Spatial

Distribution of Emissions from Road Dust Re-suspension is presented in Figure 3.96 to Figure 3.97.

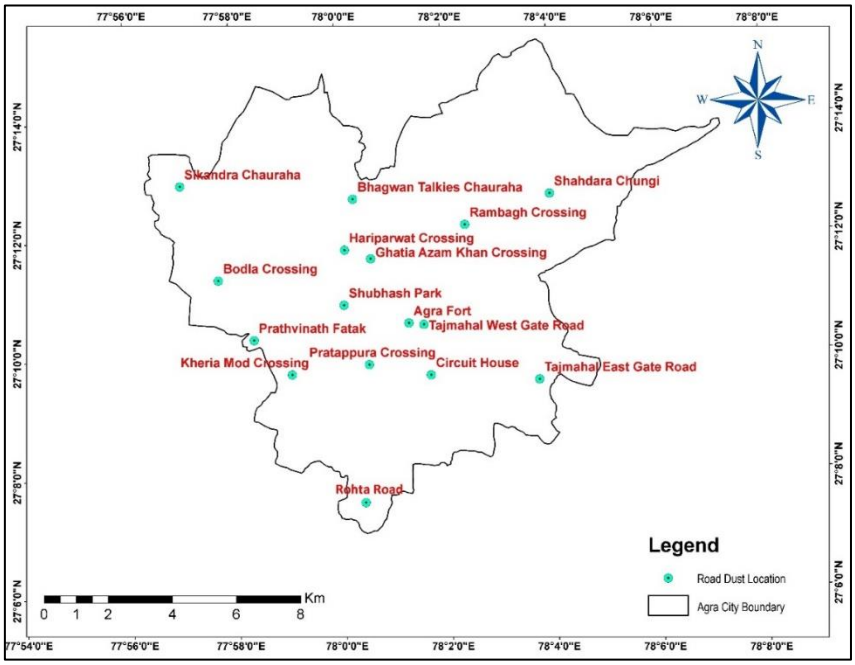


Figure 3.89: Road Dust Sampling Location

Figure 3.90: Road Dust Sampling in the City of Agra

Figure 3.91: Road Dust Sampling in the City of Agra

Table 3.3: Silt Road at Different Locations in the City of Agra

S.No	Location Name	Silt Load (g/m^2)
1	Sikandra	39.2
2	Bhagwan Talkies	30.7
3	Shahdara Chungi	48.5
4	Rambagh	24.5
5	Hariparwat	13.75
6	Ghatia Azam Khan	19.2
7	Bodla Crossing	20.6
8	Subhash Park	8.8
9	Agra Fort	9.3
10	Taj Mahal West Gate	8.4
11	Prathvinath Fatak	45.2
12	Pratapura	11.2
13	Kheria Mod	35.7
14	Circuit House	7.4
15	Tajmahal East Road	11.9
16	Rohta Road	55.1

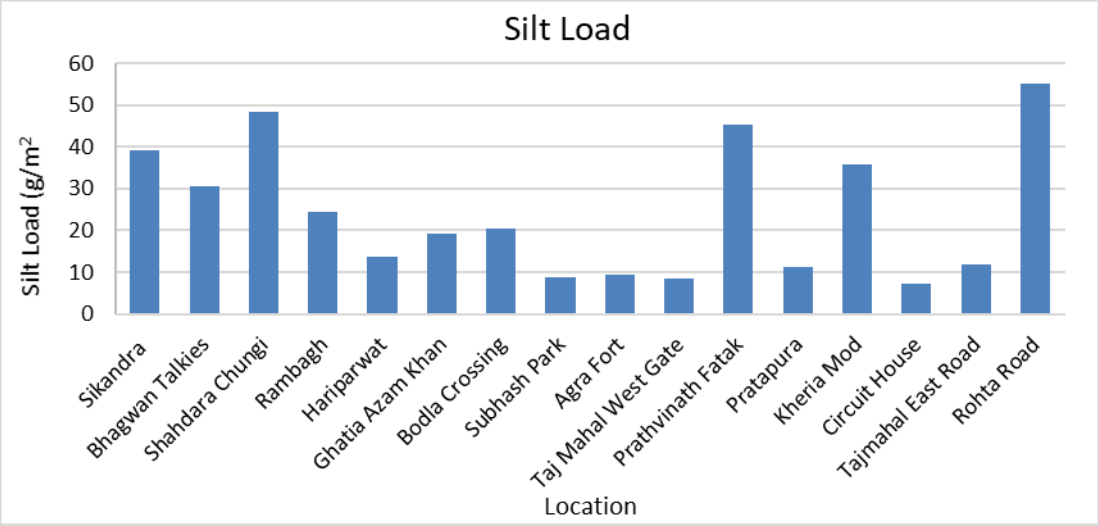


Figure 3.92: Silt Load Variation in the City of Agra

Figure 3.93: Road dust deposition on unpaved road

Figure 3.94: Broken roads causing higher road dust emissions

Figure 3.95: Oil/grease on unpaved roads

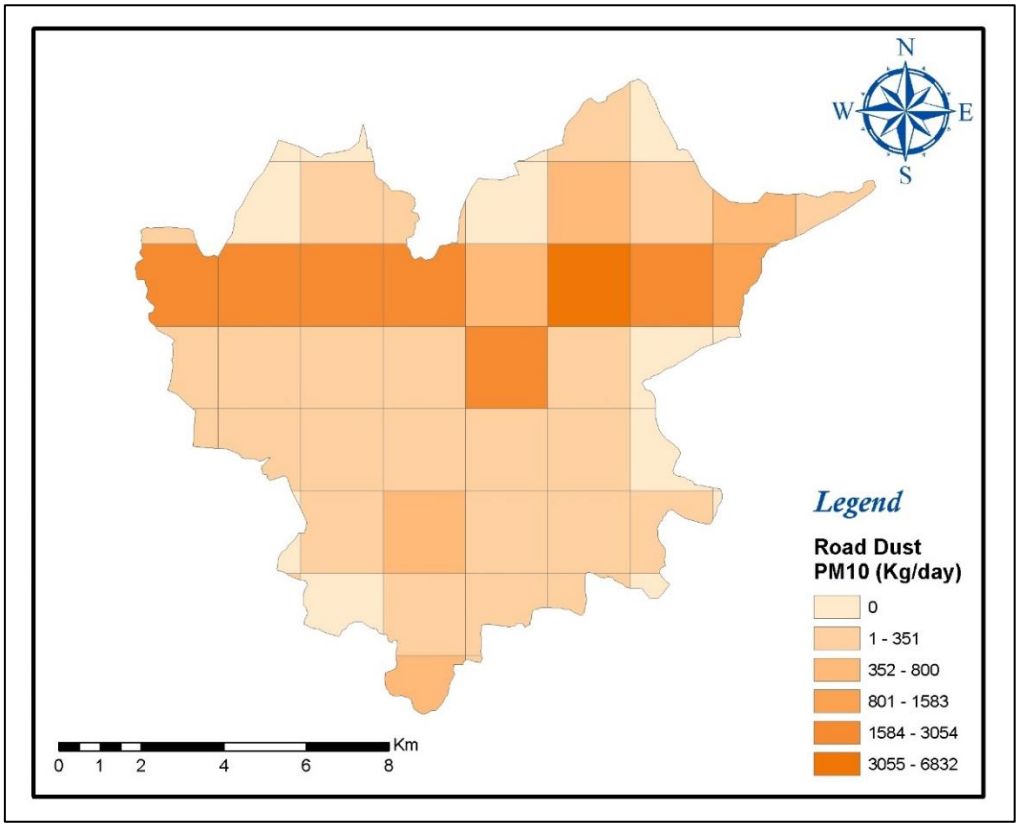


Figure 3.96: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

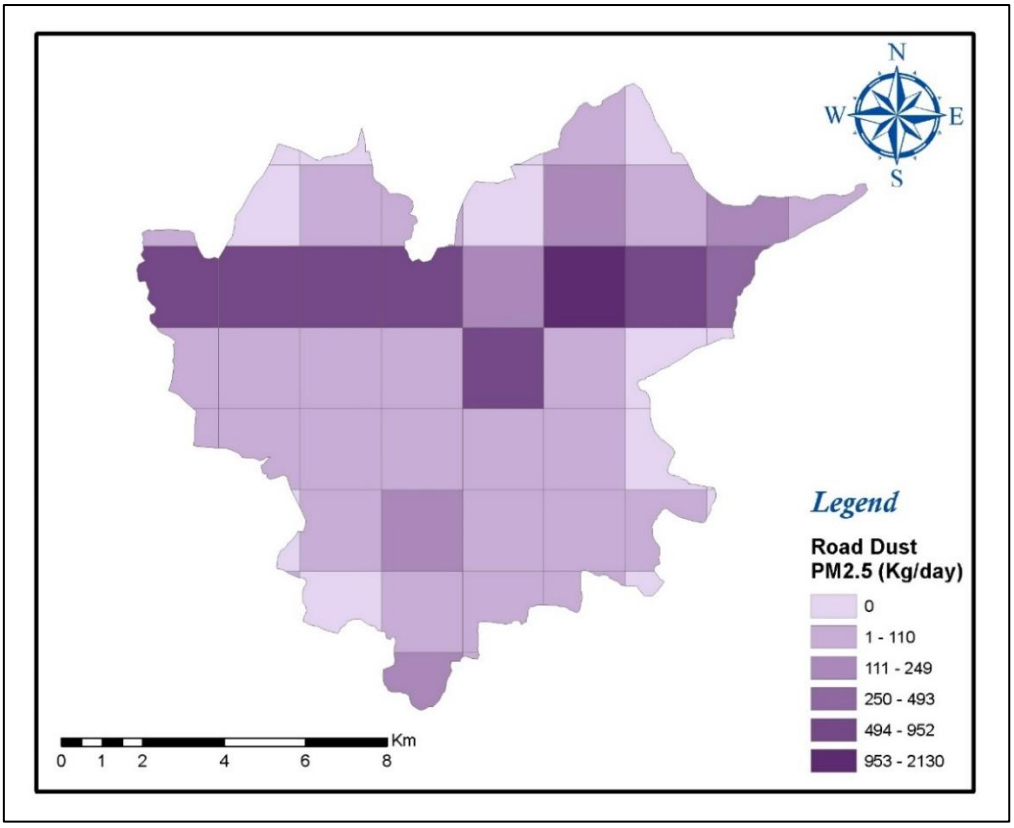


Figure 3.97: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

3.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 3.4. The pollutant-wise contribution is shown in Figure 3.98 to Figure 3.101. The spatial distribution of pollutant Emissions from all sources is presented in Figure 3.102 to Figure 3.107.

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

Sources	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
Domestic	1187	901	235	562	4826
MSW	505	343	32	189	2649
Hotel	1330	682	227	283	7496
Construction	844	194	0	0	0
DG Sets	8	7	7	106	23
Industries	588	551	181	870	461
Hospital	47	42	44	661	143
Open Area	38	0	0	0	0
Vehicle	1832	1649	363	16651	22576
Road Dust	29595	9227	0	0	0
Total	**35973**	**13596**	**1089**	**19322**	**38174**

The total PM_{10} emission load in the city is estimated to be 36 t/d. The top four contributors to PM_{10} emissions are road dust (82%), vehicles (5%), hotels (4%) and domestic fuel (3%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to obtain the desired air quality.

$PM_{2.5}$ emission load in the city is estimated to be 14 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (68%), vehicles (12%), domestic fuel burning (7%) and hotels (5%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

NO_x emissions load in the city is estimated to be 19 t/d. Nearly 86% of emissions are attributed to vehicles followed by industries (4%) and domestic (3%). Vehicular emissions occur at ground level, probably making it the most important sources. Apart from being a pollutant, NOx is an important component in the formation of secondary particles (nitrates) and ozone. NOx from vehicles and industry are potential sources for controlling NOx emissions.

SO_2 emission load in the city is estimated to be 1 t/d. Vehicular emission accounts for 33% of the total emission. Domestic fuel burning contributes 22% followed by hotels and restaurants (21%) and industries (17%).

The estimated CO emission is about 38 t/d. Nearly 59% emission of CO is from vehicles, followed by hotels (20%), domestic fuel (13%) and MSW burning (7%).

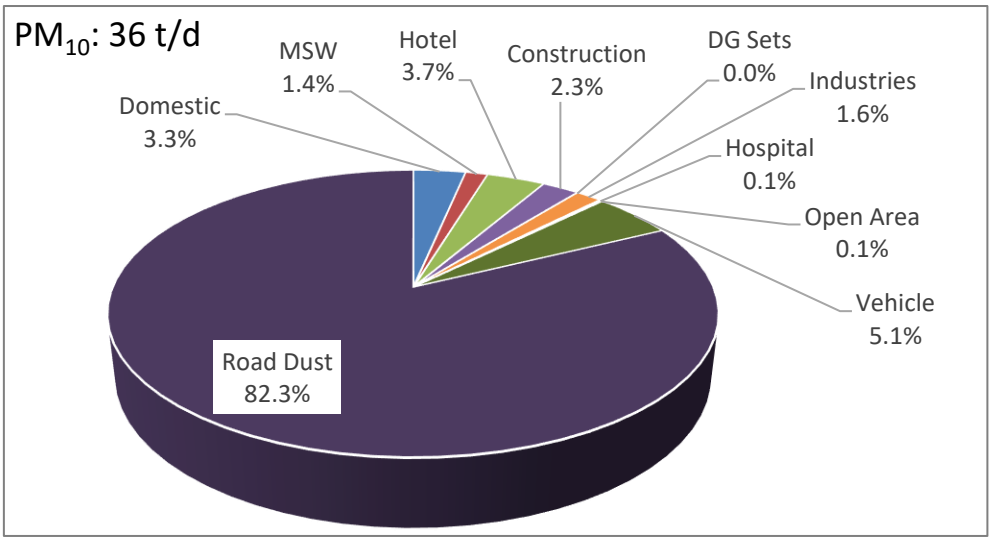


Figure 3.98: PM_{10} Emission Load of Different Sources

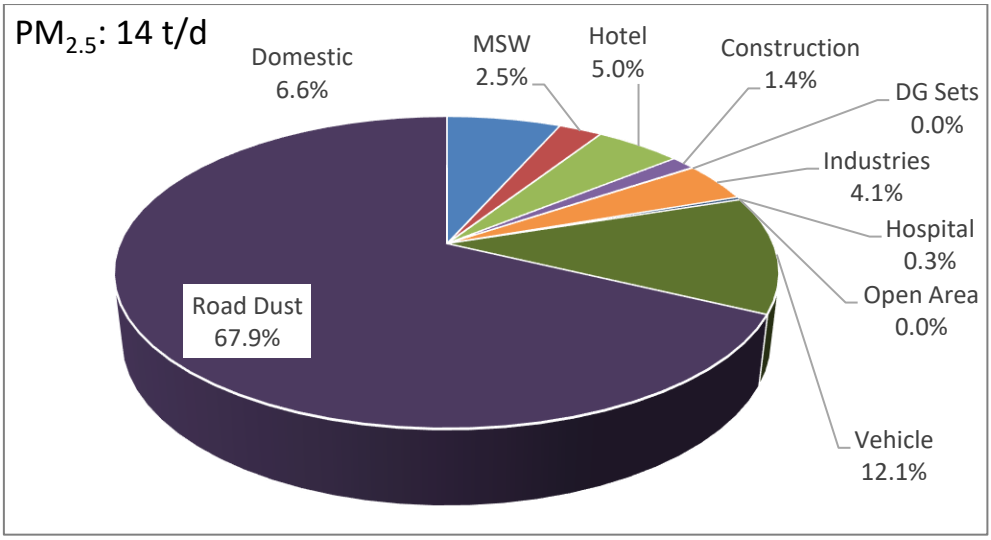


Figure 3.99: $PM_{2.5}$ Emission Load of Different Sources

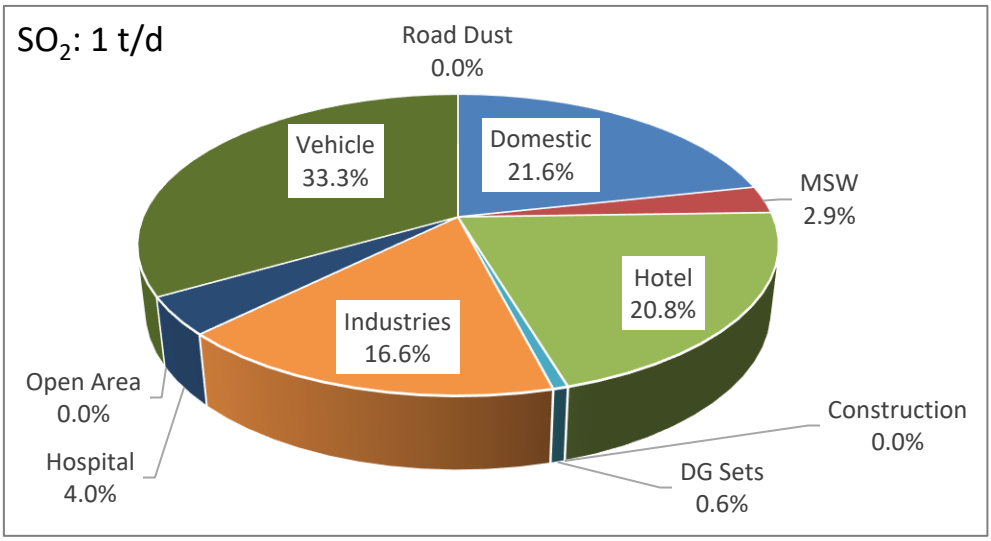


Figure 3.100: SO_2 Emission Load of Different Sources

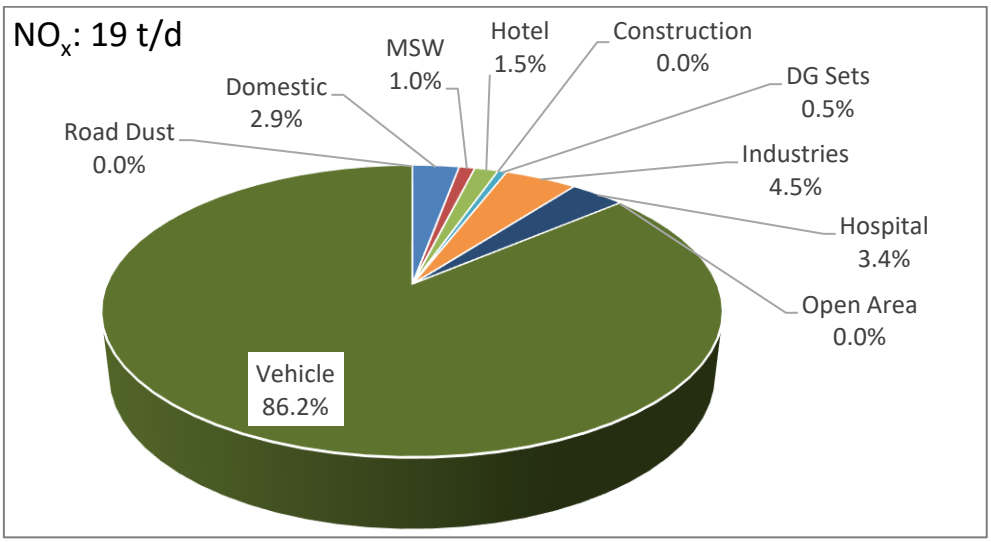


Figure 3.101: NOx Emission Load of Different Sources

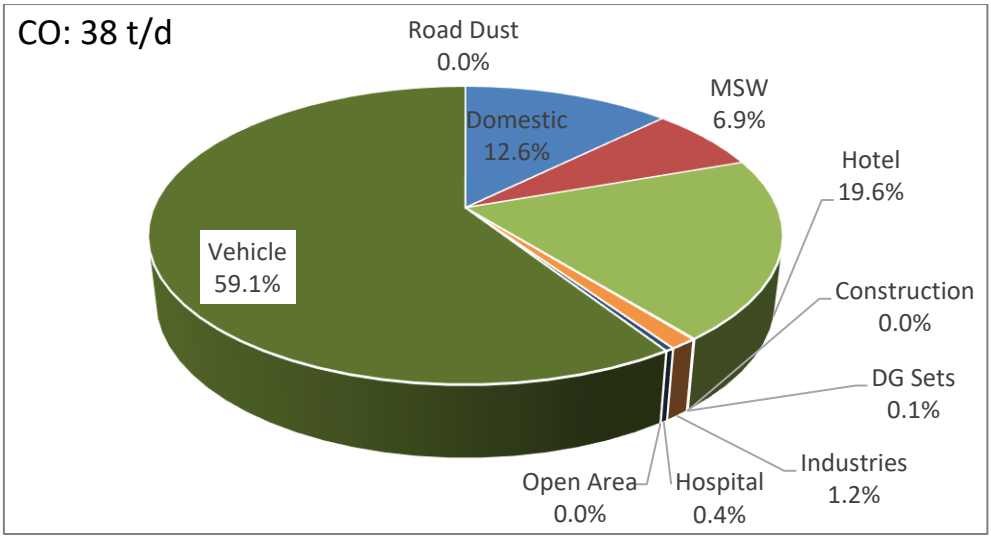


Figure 3.102: CO Emission Load Contribution of Different Sources

Spatial variation of emission quantity suggests that for PM_{10}, $PM_{2.5}$, CO, SO_2, and NOx, the central downtown area, south-west of the city show higher emissions than other parts.

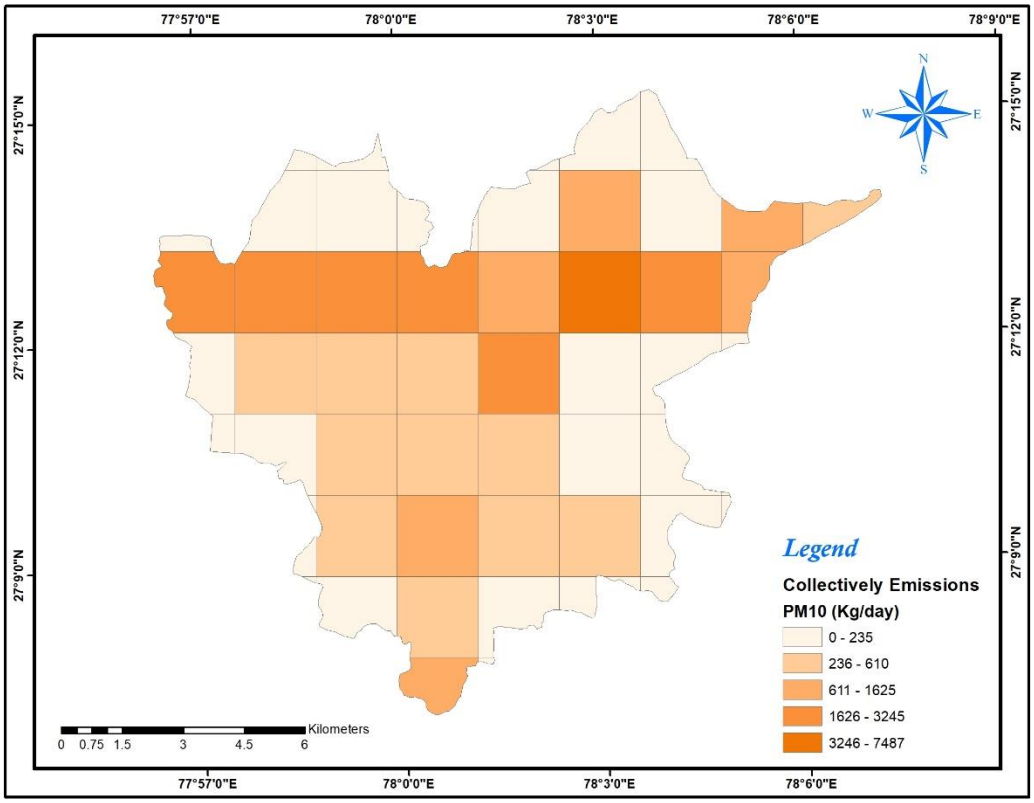


Figure 3.103: Spatial Distribution of PM_{10} Emissions in the City of Agra

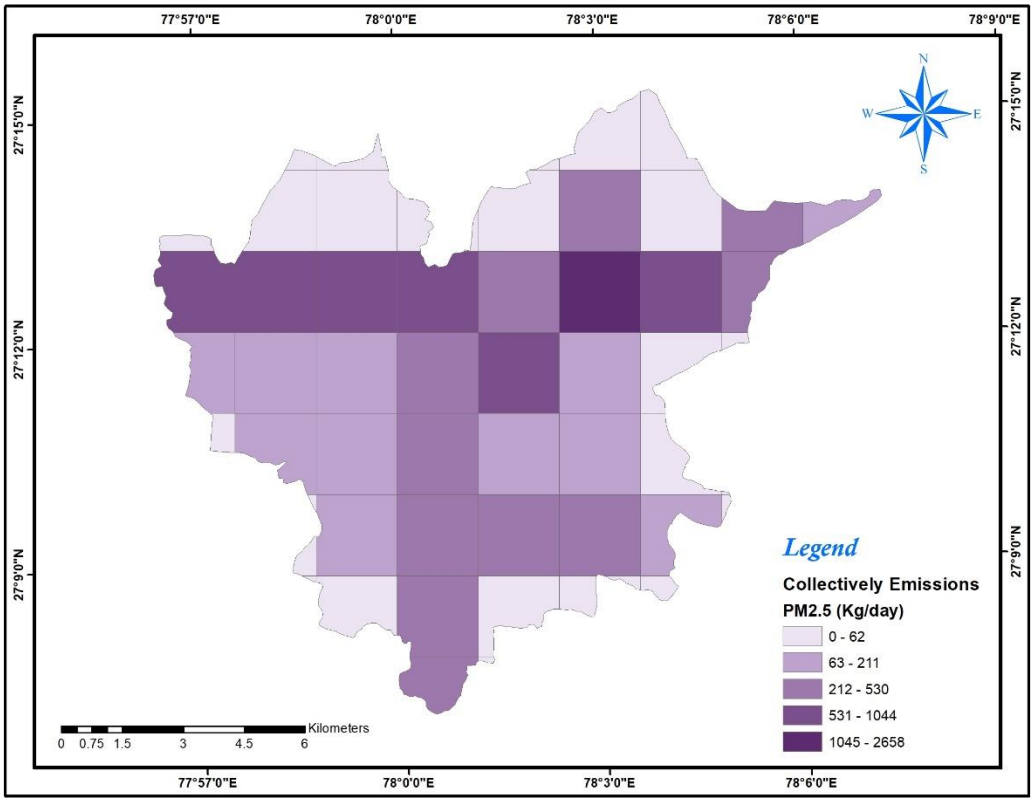


Figure 3.104: Spatial Distribution of $PM_{2.5}$ Emissions in the City of Agra

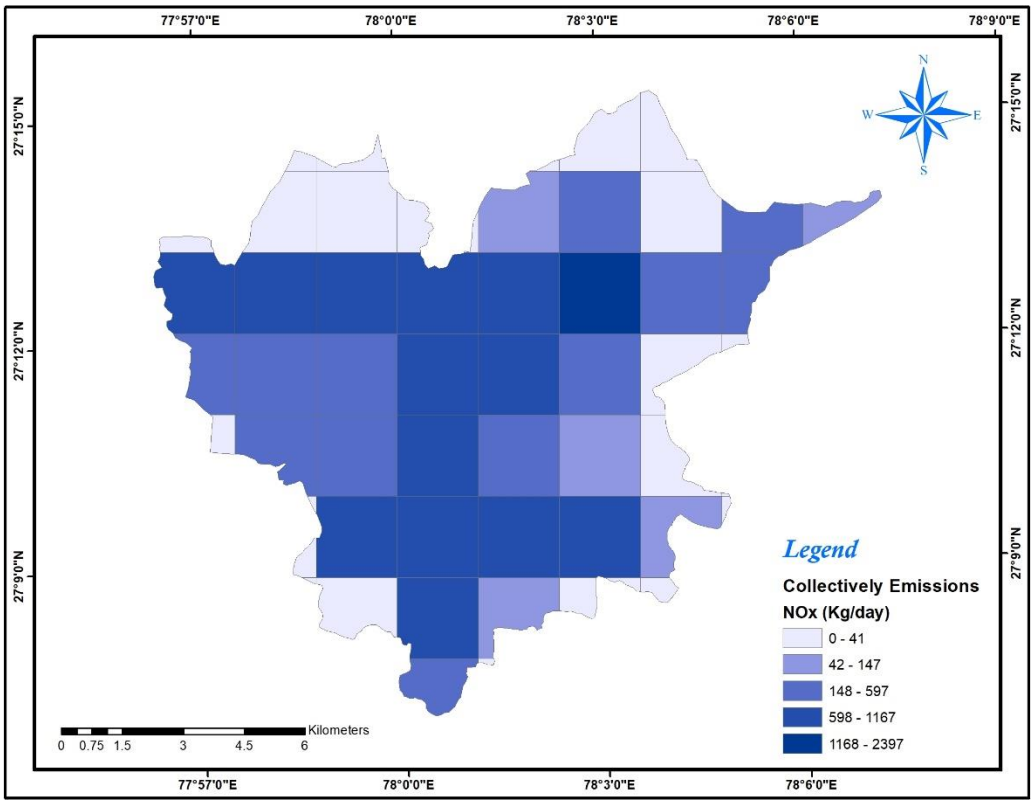


Figure 3.105: Spatial Distribution of NOx Emissions in the City of Agra

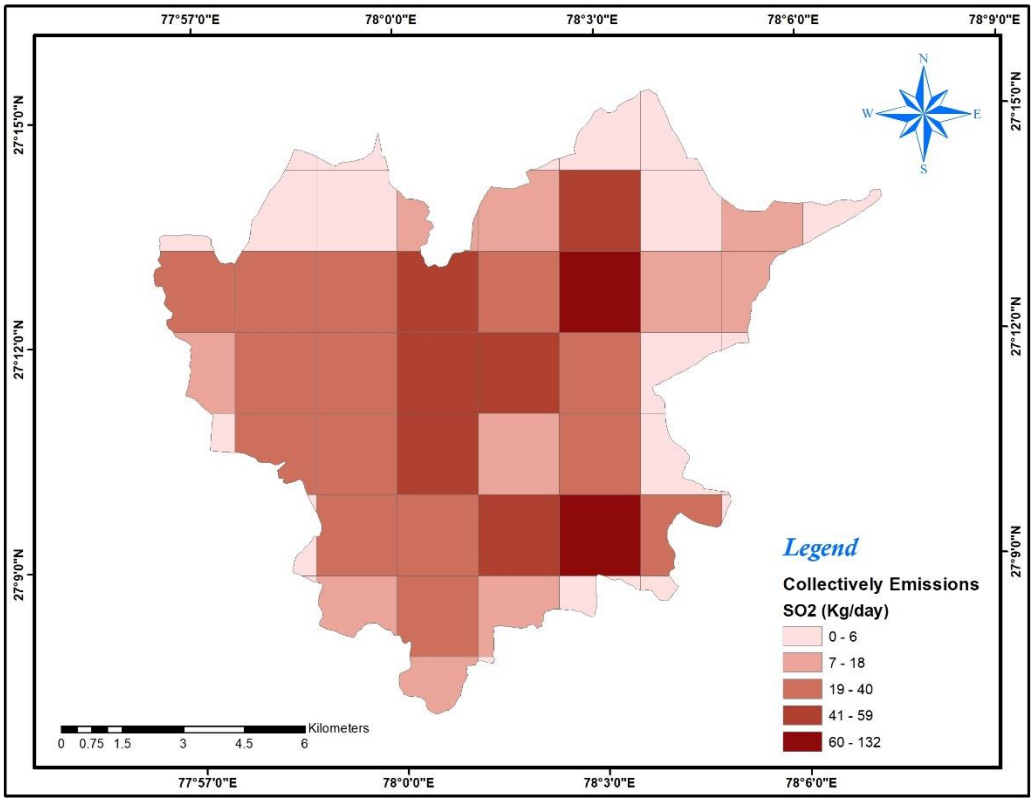


Figure 3.106: Spatial Distribution of SO_2 Emissions in the City of Agra

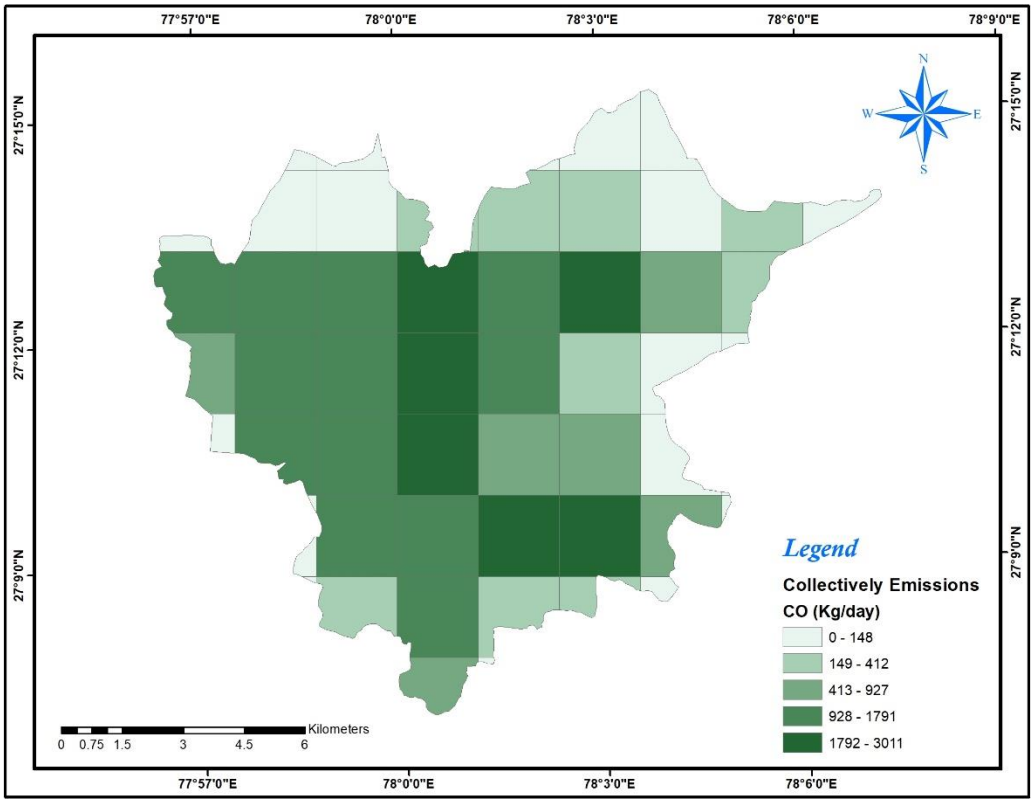


Figure 3.107: Spatial Distribution of CO Emissions in the City of Agra

4 Receptor Modelling and Source Apportionment

4.1 Receptor Modeling

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

1. Dispersion Modeling and
2. Receptor source Modeling.

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

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

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

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

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

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

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

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

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

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

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

If the C_i and F_{ij} at the receptor for all p of the source types suspected of affecting the receptor are known, and p≤n (n = number of the species), a set of n simultaneous equations exist from which the source type contribution S_j may be calculated by least square methods. The software used for apportioning the sources is PMF5.0, developed by USEPA (2004).

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

USEPA's PMF5.0 (USEPA, 2014) is a multivariate factor analysis tool that solves a matrix of speciated data of samples into two matrices: factor contributions (S) and source profiles (F). The resolved source profiles were interpreted to identify the contributing sources at the receptor based on the reported source profiles and emissions inventories. The PMF model derives the source contributions and profiles through minimizing the critical parameter that is called objective function Q (given below) (USEPA, 2014).

$$Q = \sum_{k=1}^{n}\sum_{i=1}^{m}\left[\frac{C_{ik} - \sum_{j=1}^{P} F_{ij}S_{jk}}{u_{ik}}\right]^2$$

Where *m* is the number of chemical species, *n* is the number of samples, and *P* is the number of source factors/profiles.

Ambient PM_{10} and $PM_{2.5}$ observations with chemical composition were used for apportionment of sources for about 200 samples each for PM_{10} and $PM_{2.5}$, collected during 2018-2019 in winter and summer.

The PMF identified contributing sources by minimizing the objective function Q within 10% uncertainty. The results with the lowest Q_{robust} are analyzed in terms of R-square and percent mass (predicted to measured). The results showed the R-square was above 0.98 for both PM_{10} and $PM_{2.5}$ and the percent mass accounted was over 80%.

The apportioned factors are assigned to the sources based on their fingerprint species contributing to the factor collected from the literature. The mean contributions of species in the source profiles for PM_{10} and $PM_{2.5}$ are presented in Figures 4.1 – 4.2. The results of PMF5.0 at each location for each season are described in Section 4.3.

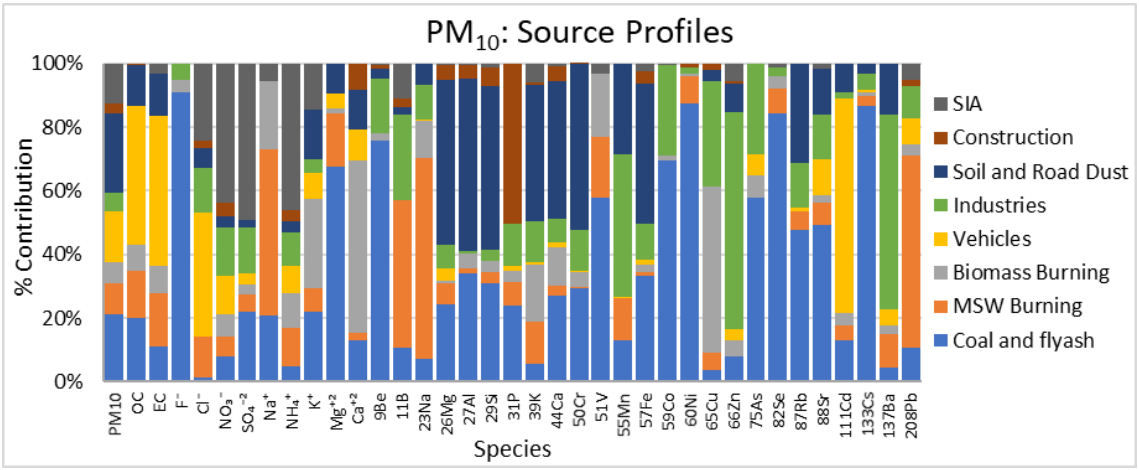


Figure 4.1: PMF-based Source profiles for PM_{10}

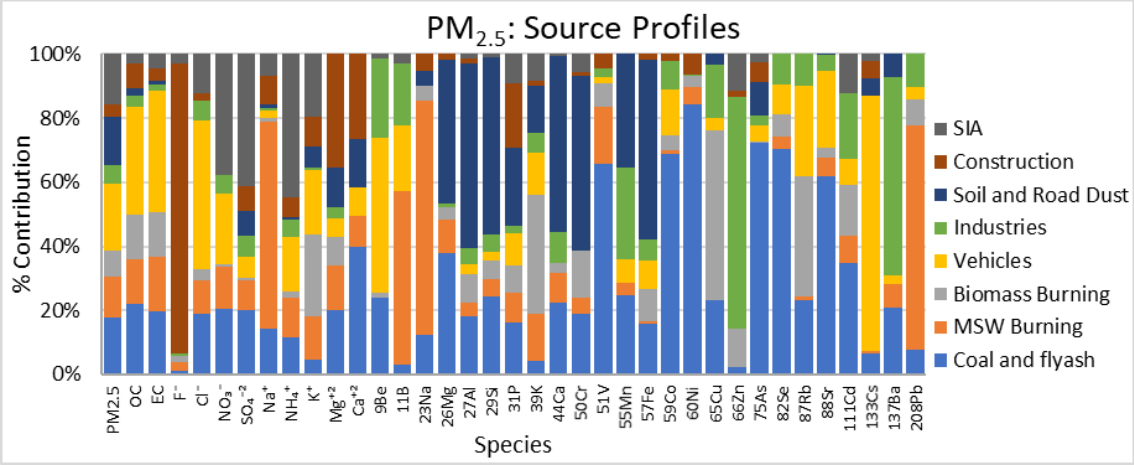


Figure 4.2: PMF-based Source profiles for $PM_{2.5}$

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

4.3 PMF Modeling Results and interpretation

It may be noted that vehicles and diesel generators (DGs) include all vehicles powered by gasoline, diesel, CNG, DGs and LPG uses. The Coal and fly ash source include coal and residual oil combustion and fly ash. The factors of similar nature are considered as a single entity for better clarity.

The statistical summary of performance and acceptability of PMF model for PM_{10} and $PM_{2.5}$ for winter and summer is given in Tables 4.1 to 4.4.

4.3.1 Ghatia-Azam Khan Gate (GAK)

4.3.1.1 Winter Season [sampling period: Dec 06 – 31, 2018]

PM_{10} (winter)

The average PM_{10} concentration was 423 µg/m^3. Figure 4.3 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at GAK. It is observed that the major source contributing to PM_{10} was vehicles (107 µg/m^3 ~ 25%) followed by municipal solid waste (MSW) burning (102 µg/m^3 ~ 24%) and coal and fly ash (61 µg/m^3 ~ 14%). The other significant sources are secondary

inorganic aerosols (SIA; 13%), soil and road dust (13%) and biomass burning (6%). The minor sources are construction material (2%) and industrial emission (2%).

$PM_{2.5}$ (winter)

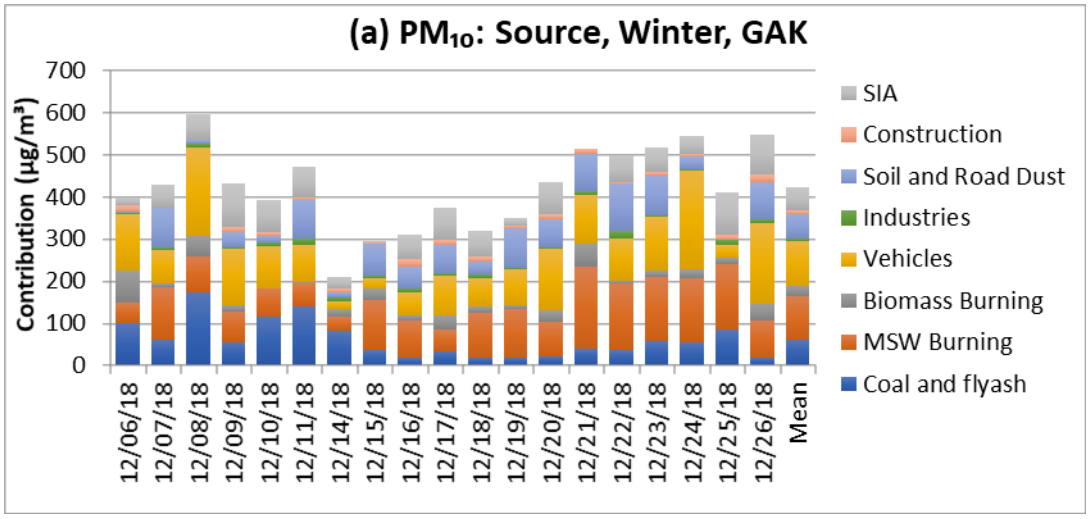
The average $PM_{2.5}$ concentration was 304 µg/m^3 (i.e., about 0.72 of PM_{10}). Figure 4.4 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at GAK. It is observed that the major source contributing to $PM_{2.5}$ was MSW burning (75 µg/m^3 ~ 25%) followed by vehicles (68 µg/m^3 ~ 23%) and coal and fly ash (54 µg/m^3 ~ 18%). Other sources are SIA (13%), soil and road dust (11%), biomass burning (7%), construction material (2%) and industrial emissions (1%).

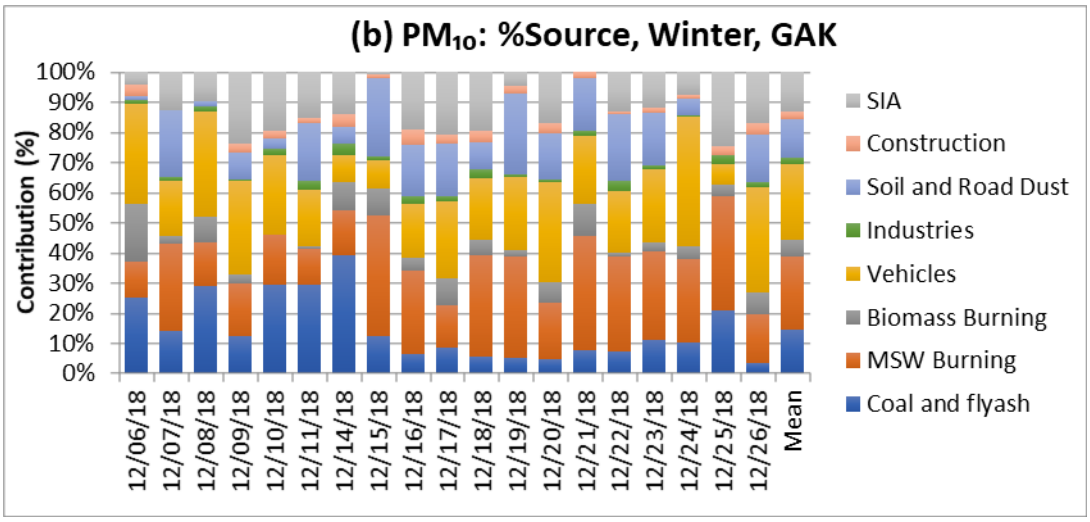
HYSPLIT back trajectories (Figure 4.5) indicate that wind is flowing mostly from the NW direction. Winds can pick up the pollutants on the way, especially from large sources and tall emitting sources, but these contributions have not been quantified.

Inferences

- The MSW burning has a major contribution to PM_{10} (24%) and $PM_{2.5}$ (25%) at GAK. This emission is expected to be large from regions of economically lower strata of society that do not have proper infrastructure for the collection and disposal of solid waste.
- The vehicles contribute significantly to PM_{10} (25%) and $PM_{2.5}$ (23%).
- Coal and fly ash contribution increased to 18% in $PM_{2.5}$ compared to 14% in PM_{10}.
- Soil and road dust (13 – 10%) contribution is higher in PM_{10} (13%) compared to $PM_{2.5}$ (10%). The consistent levels during the winter season may be due to low wind speed (more calm conditions). It can be seen the high fraction of $PM_{2.5}$ in PM_{10} (about 0.72 of PM_{10}).
- The SIA contributes to PM_{10} (13%) and $PM_{2.5}$ (13%). These particles are expected to source from precursor gases (SO_2 and NO_x) emitted from far distances. However, the contribution of NO_x from local sources, especially vehicles and power plants, can also contribute to nitrates. For sulfates, the major contribution can be attributed to large power plants and refineries from long distances.

- Biomass burning also has a significant contribution. This emission is expected from regions of economically lower strata of society where they used wood/dungs for cooking the food and crop residue burning in the nearby areas.





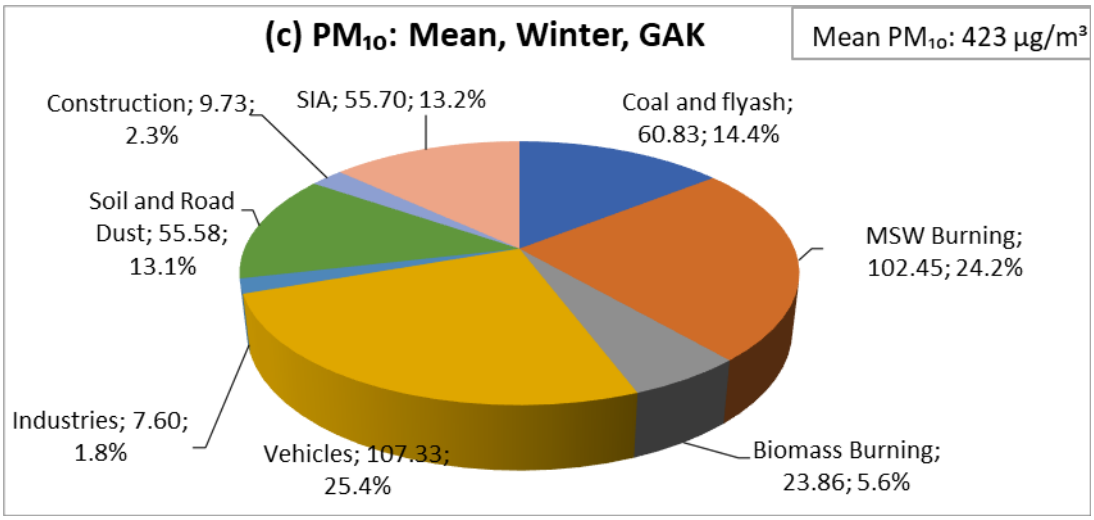


Figure 4.3: PMF modeling for PM_{10} at GAK for winter season

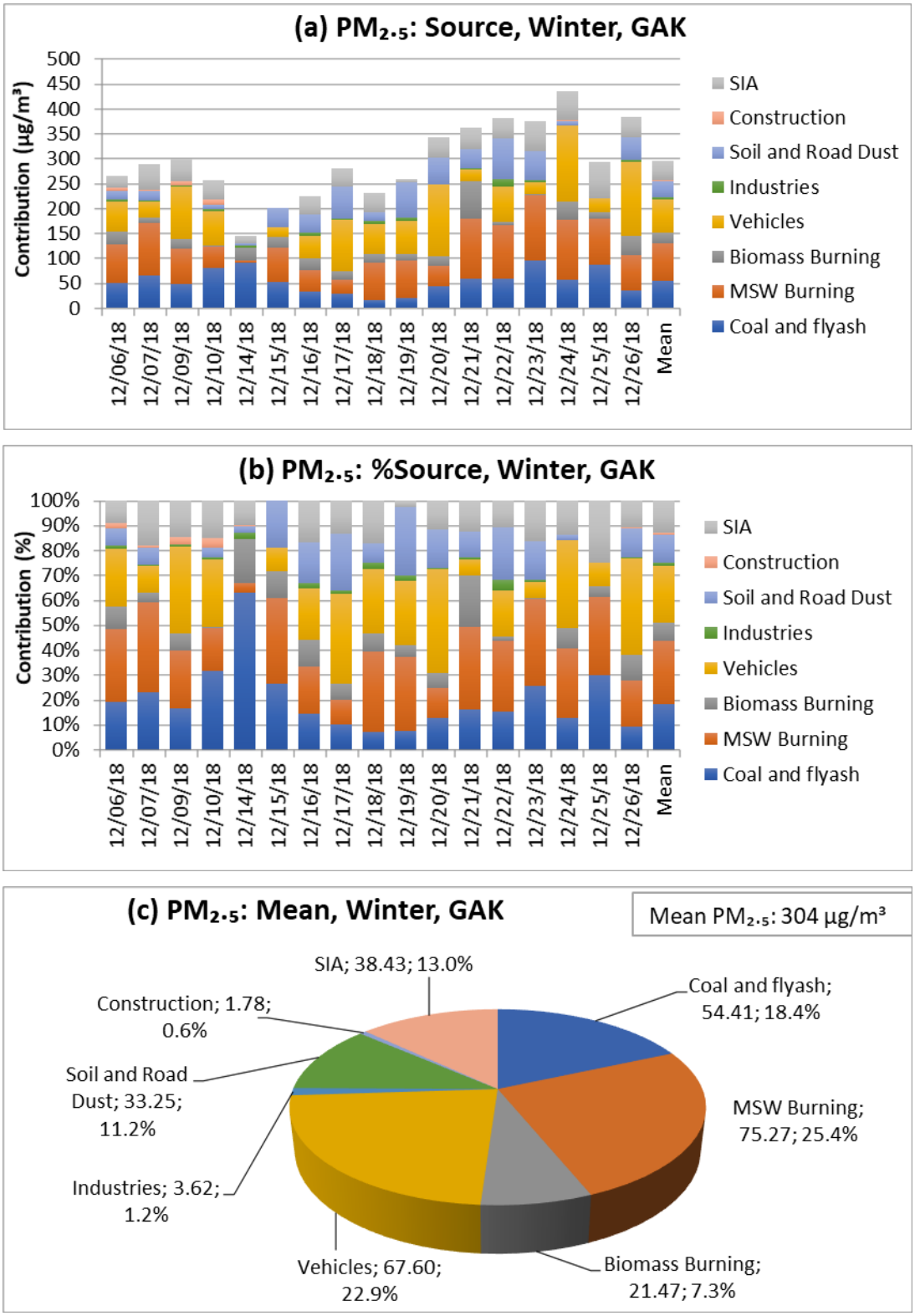


Figure 4.4: PMF modeling for $PM_{2.5}$ at GAK for winter season (MSW burning includes burning of plastic core wires to recover metal)

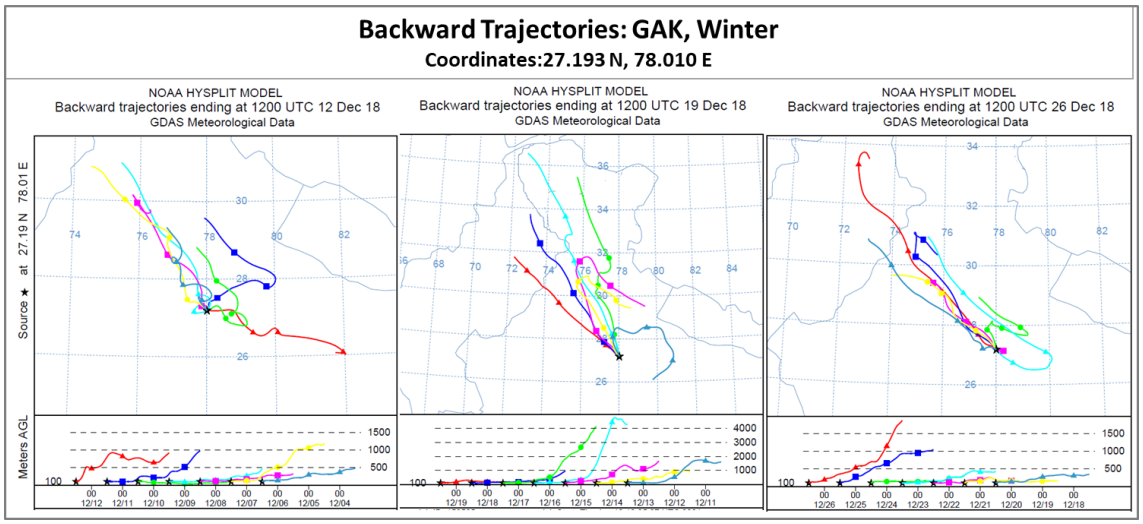


Figure 4.5: Backward trajectories at GAK for winter season

4.3.1.2 Summer Season [sampling period: May 8 – 28, 2019]

PM_{10} (summer)

The average PM_{10} concentration was 179 µg/m^3. Figure 4.6 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at GAK. It is observed that the major PM_{10} source contributing was soil and road dust (97 µg/m^3 ~ 51%) followed by coal and fly ash (49 µg/m^3 ~ 26%) in PM_{10}. Other sources are vehicles (13 µg/m^3 ~ 7%), biomass burning (6%), industrial (4%), construction material (4%), MSW burning (2%) and SIA (1%) in PM_{10}. The contribution of the SIA was least in PM_{10}.

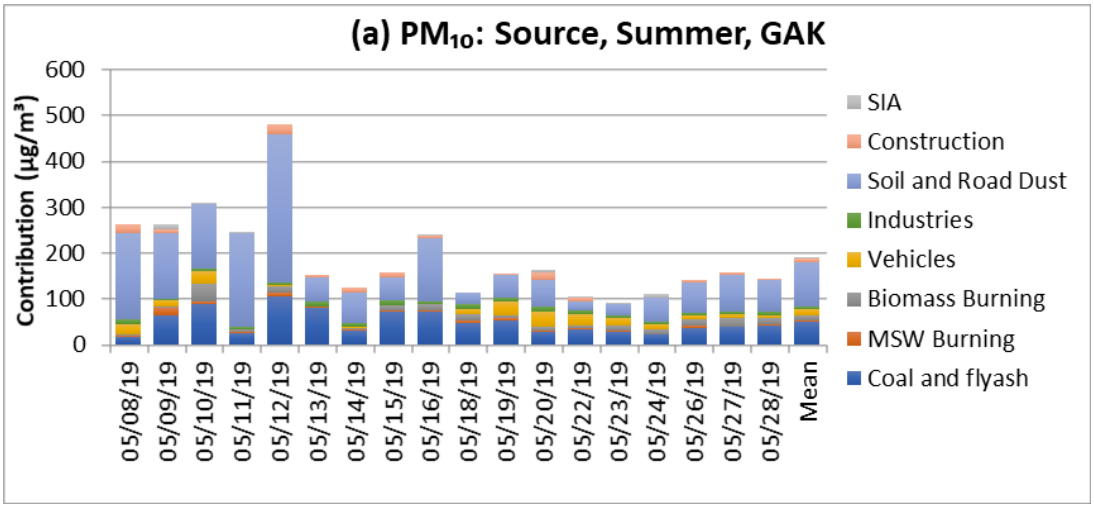
$PM_{2.5}$ (summer)

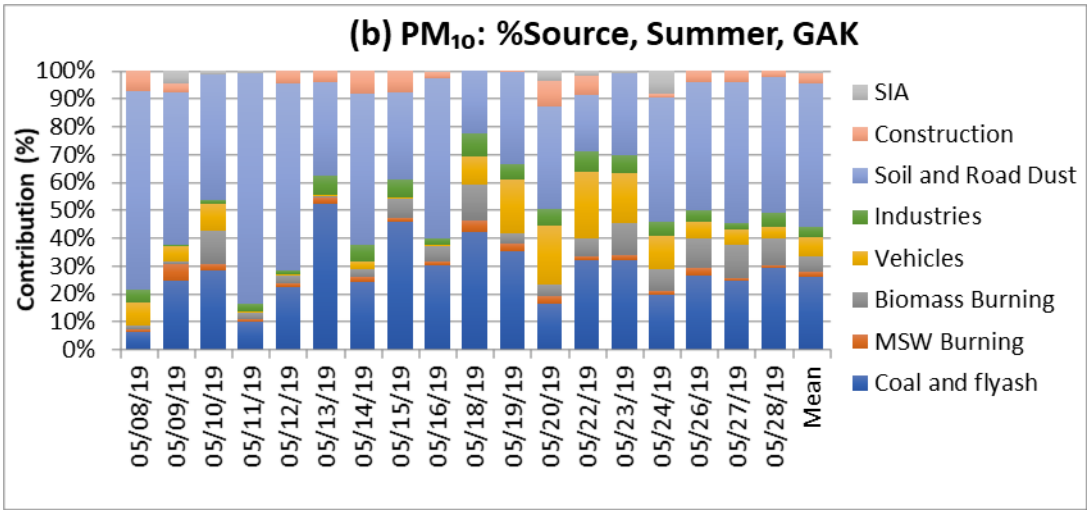
The average $PM_{2.5}$ concentration was 64 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.38. Figure 4.7 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at GAK. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (25 µg/m^3 ~ 38%) followed by coal and fly ash (16 µg/m^3 ~ 26%). Other significant sources are biomass burning (11%), vehicles (9%), industrial (6%), MSW burning (6%) and SIA (3%). The construction material contributes less than 1% to $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.8) show that most of the time wind is from NW and West and wind mass travels over the Thar Desert in Rajasthan and part of Punjab and Haryana before entering Agra. These winds pick up the pollutants on the way, especially from tall emitting sources.

Inferences

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





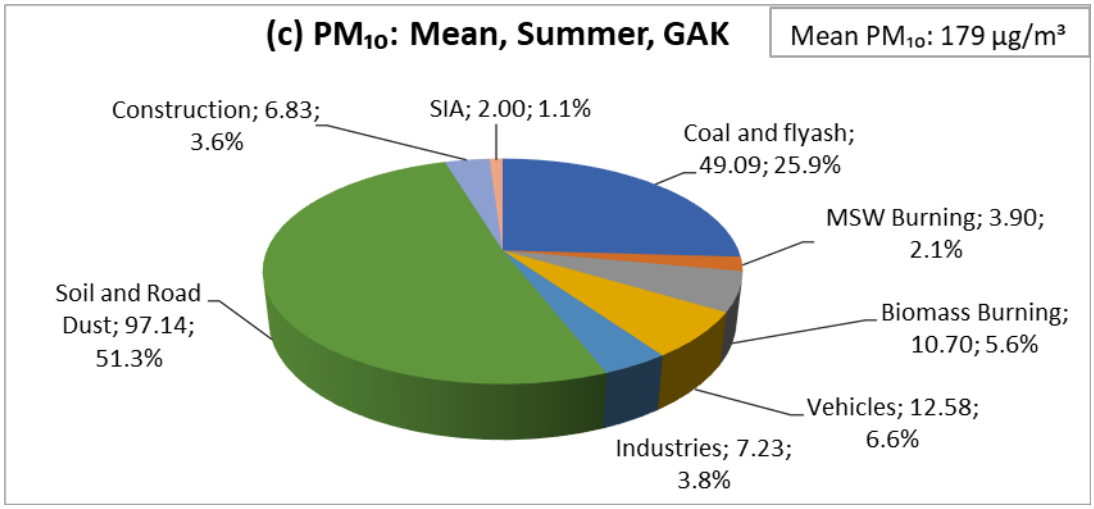
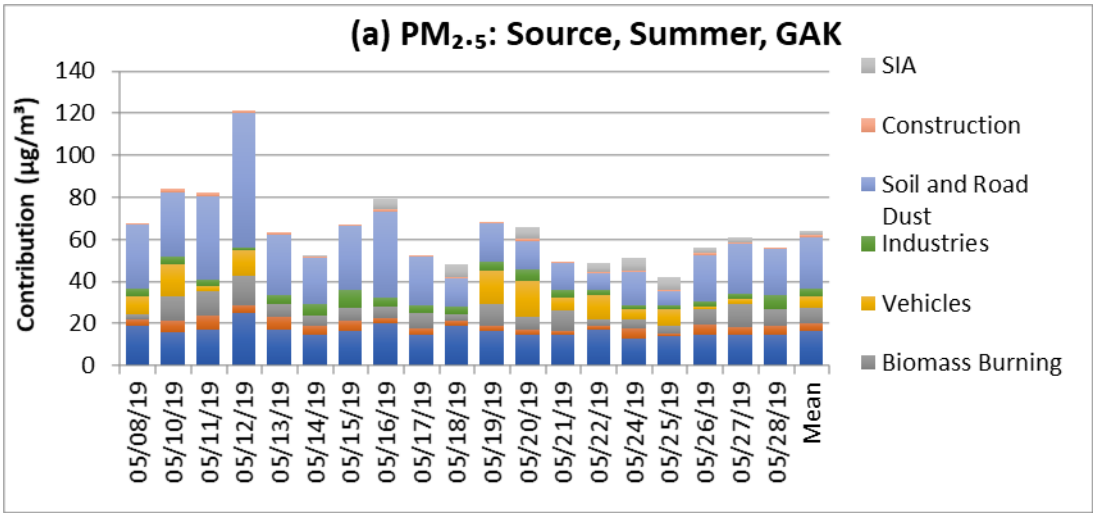
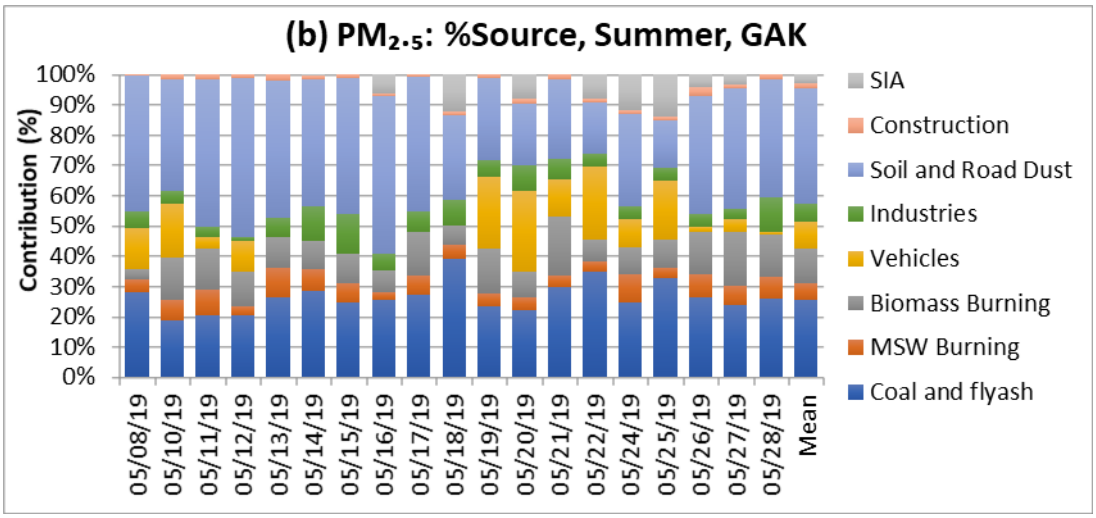


Figure 4.6: PMF modeling for PM_{10} at GAK for summer season





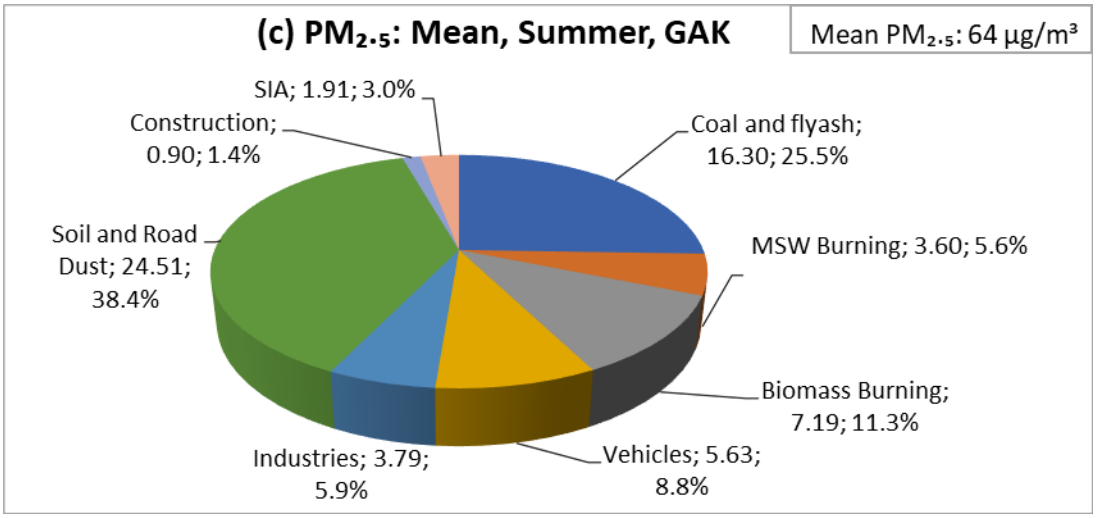


Figure 4.7: PMF modeling for $PM_{2.5}$ at GAK for summer season

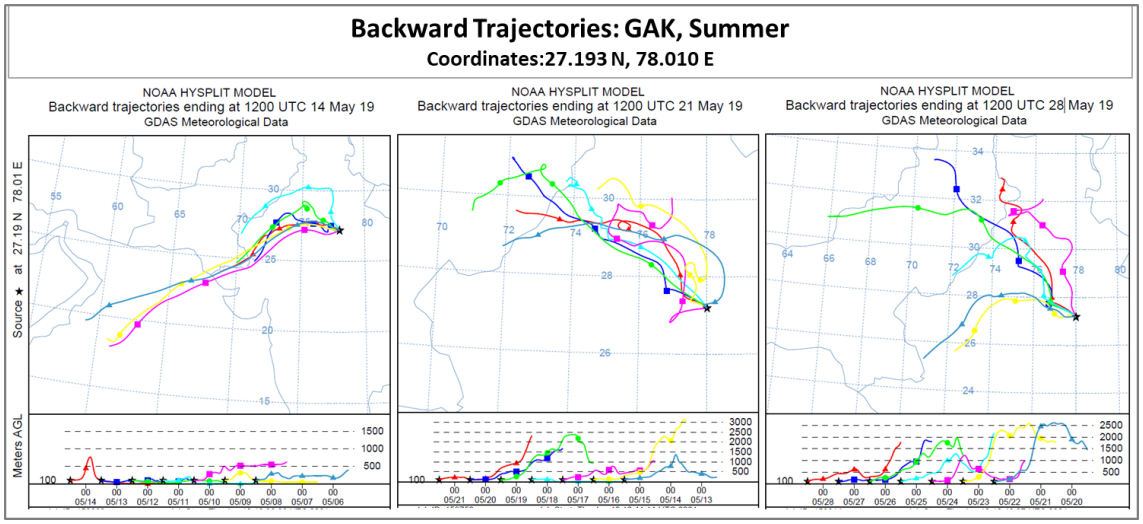


Figure 4.8: Backward trajectories at GAK for summer season

4.3.2 Nunhai Industrial Area (NNH)

4.3.2.1 Winter Season [sampling period: Dec 31, 2018 – Jan 22, 2019]

PM_{10} (winter)

The average PM_{10} concentration was 367 µg/m^3. Figure 4.9 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at NNH. It is observed that the major PM_{10} source contributing was vehicles (84 µg/m^3 ~ 23%) followed by industrial emission (73 µg/m^3 ~ 20%) and coal and fly ash

(66 µg/m^3 ~ 18%) in PM_{10}. The other significant sources are SIA (56 µg/m^3 ~ 15%), soil and road dust (36 µg/m^3 ~ 10%), MSW burning (36 µg/m^3 ~ 10%), biomass burning (4%) and construction material (2%). The contribution of the construction material was the lowest in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 273 µg/m^3 (i.e., about 0.73 of PM_{10}). Figure 4.10 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at NNH. It is observed that the major source contributing to $PM_{2.5}$ was vehicles (77 µg/m^3 ~ 28%) followed by industrial emission (50 µg/m^3 ~ 18%) and SIA (40 µg/m^3 ~ 15%). Other predominant sources are MSW burning (13%), coal and fly ash (13%), soil and road dust (7%) and biomass burning (4%). The contribution of construction material was estimated at about 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.11) show that wind is mostly from NW and wind mass travels over the states of Punjab, Haryana and Delhi before entering Agra. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Vehicles and industrial emissions are the major contributing sources to both PM_{10} and $PM_{2.5}$. MSW burning, SIA, coal and fly ash, soil/road dust and biomass burning are the consistent sources contributing to PM_{10} and $PM_{2.5}$ and slightly changed. The industrial emissions and MSW burning are exceptionally high at NNH, indicating irregular waste generated from industries that succeed for open burning.

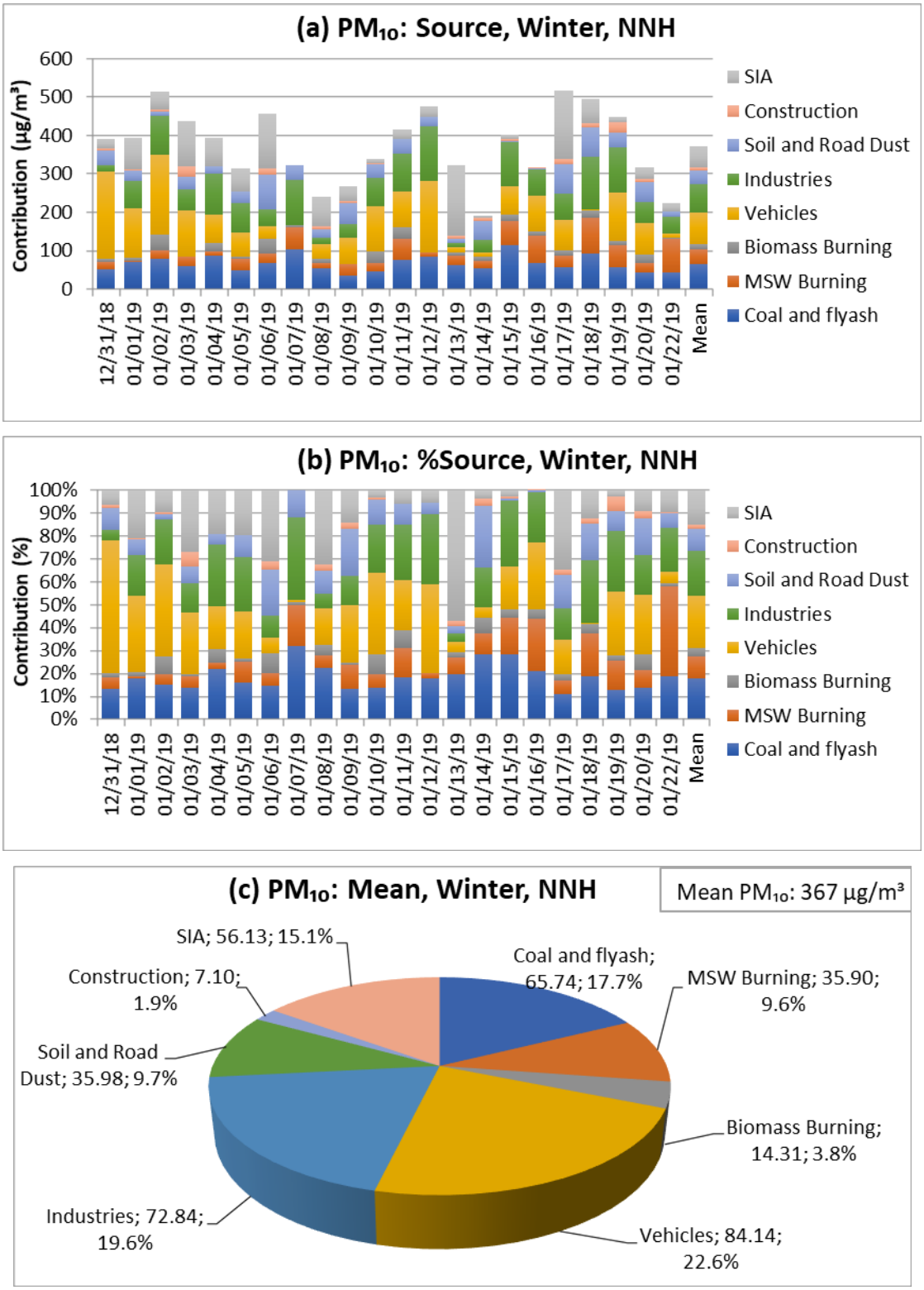


Figure 4.9: PMF modeling for PM_{10} at NNH for winter season

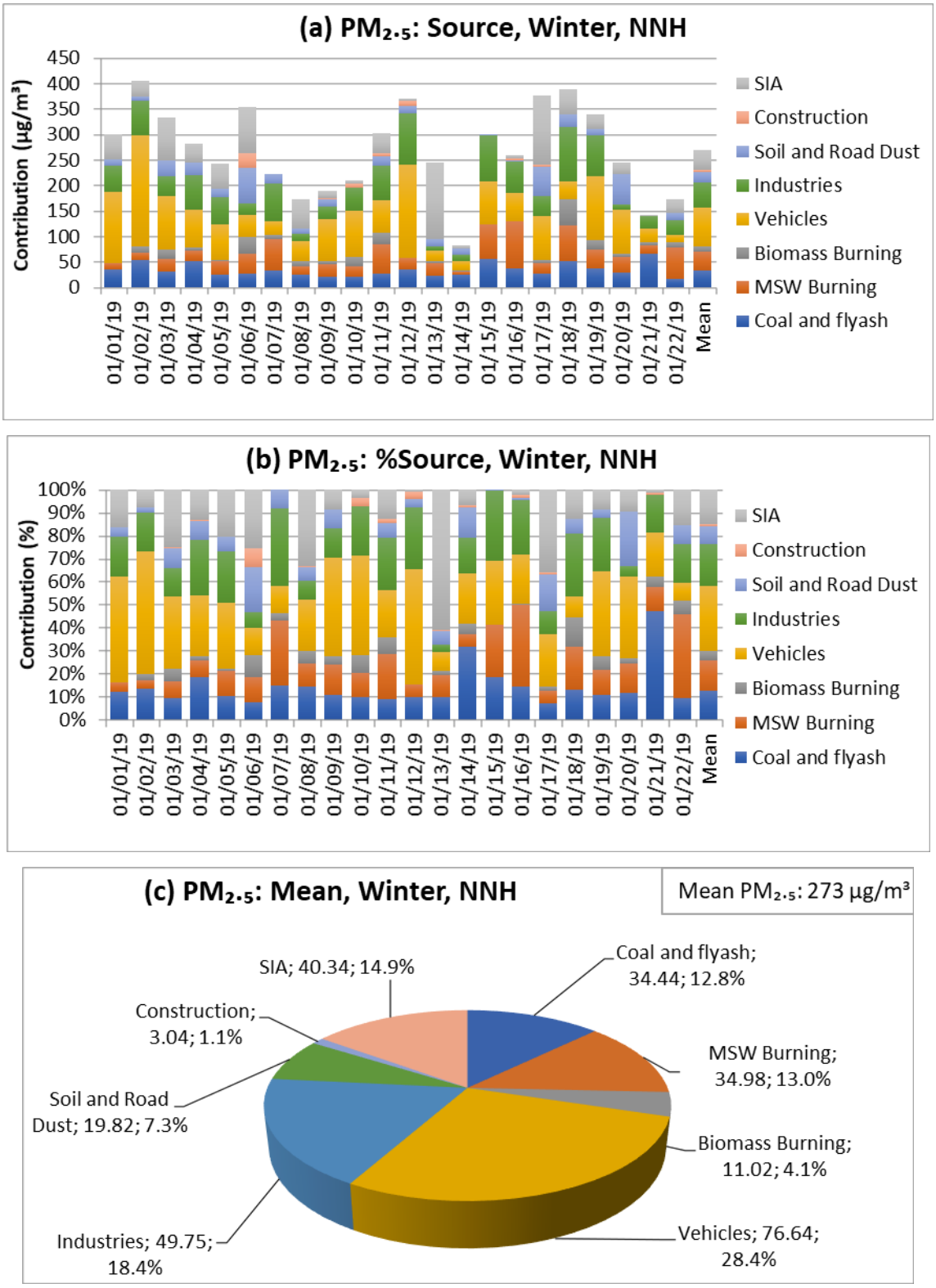


Figure 4.10: PMF modeling for $PM_{2.5}$ at NNH for winter season

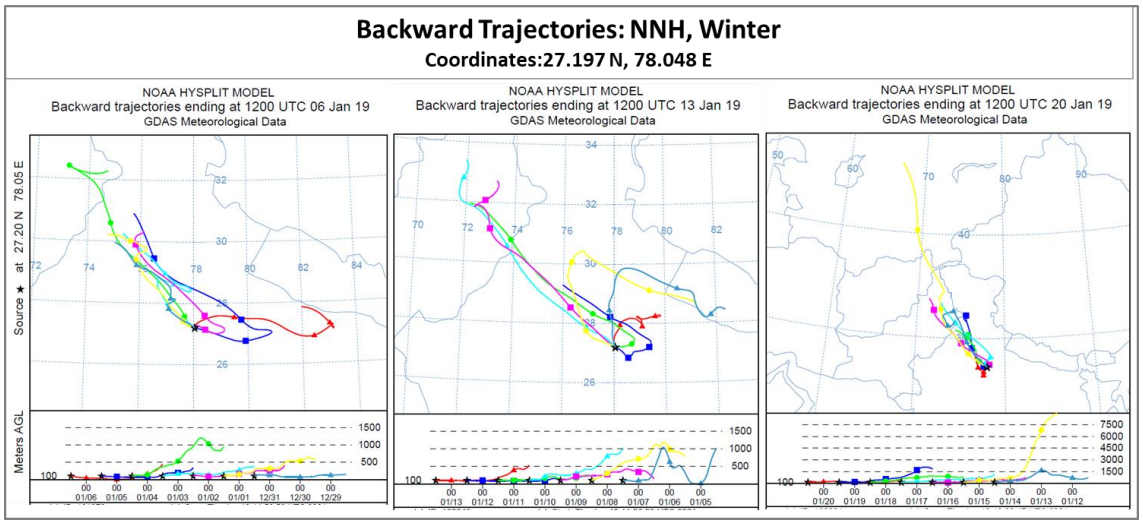


Figure 4.11: Backward trajectories at NNH for winter season

4.3.2.2 Summer Season [sampling period: May 14 – June 03, 2019]

PM_{10} (summer)

The average PM_{10} concentration was 182 µg/m^3. Figure 4.12 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at NNH. It is observed that the major PM_{10} source contributing was soil and road dust (71 µg/m^3 ~ 39%) followed by coal and fly ash (56 µg/m^3 ~ 31%). The other significant sources are vehicles (17 µg/m^3 ~ 9%), biomass burning (8%), SIA (5%), MSW burning (4%) and industrial (3%). (1%). The contribution of construction material is lowest at 1% in PM_{10}.

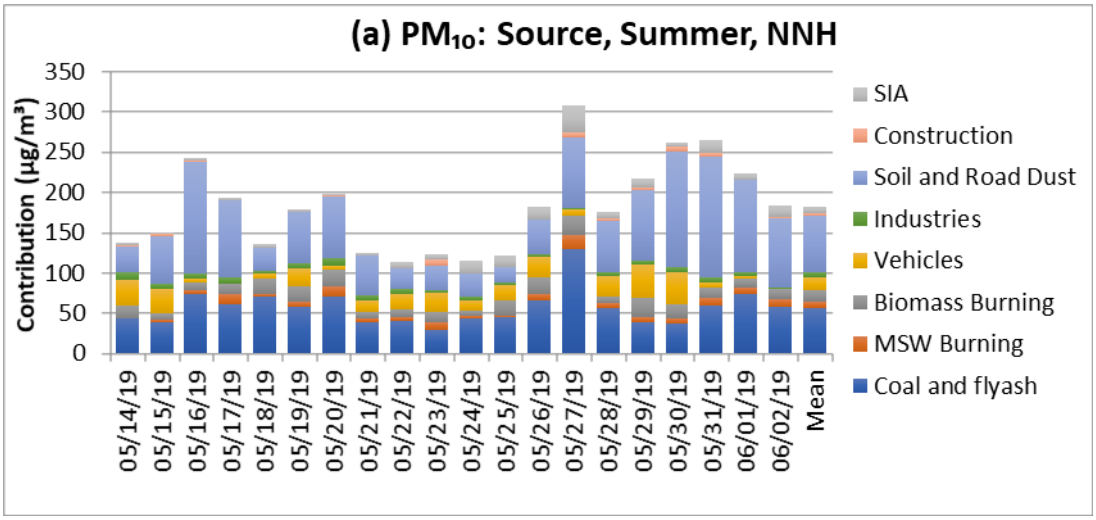
$PM_{2.5}$ (summer)

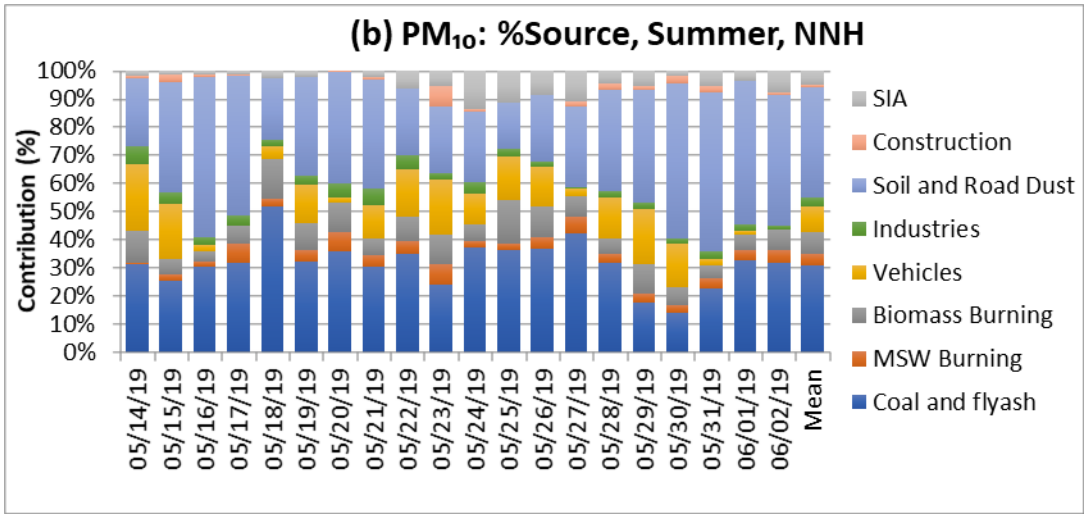
The average $PM_{2.5}$ concentration was 71 µg/m^3 ($PM_{2.5}/PM_{10}$ is 0.40). Figure 4.13 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at NNH. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (22 µg/m^3 ~ 31%) followed by coal and fly ash (14 µg/m^3 ~ 20%), vehicles (13 µg/m^3 ~ 18%). Other significant sources are biomass burning (9 µg/m^3 ~ 13%), MSW burning (8%), SIA (4%) and industrial emissions (4%) and construction material (3%).

HYSPLIT back trajectories (Figure 4.14) show that wind is mostly from NW and W. Wind mass travels over the Thar Desert in Rajasthan and part of states of Punjab and Haryana before entering Agra. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inference

Soil/Road dust and coal/fly ash are the major contributors in summer both for PM_{10} and $PM_{2.5}$; at the same time, vehicles, biomass burning and construction material are prominent both in PM_{10} and $PM_{2.5}$. The sampling site was in the middle of the industrial area, which had large trucks ferrying raw material and finishes products. The MSW burning and industrial emissions also contribute a significant amount at NNH that indicates irregular management of waste generated from industries that succeed in open burning.





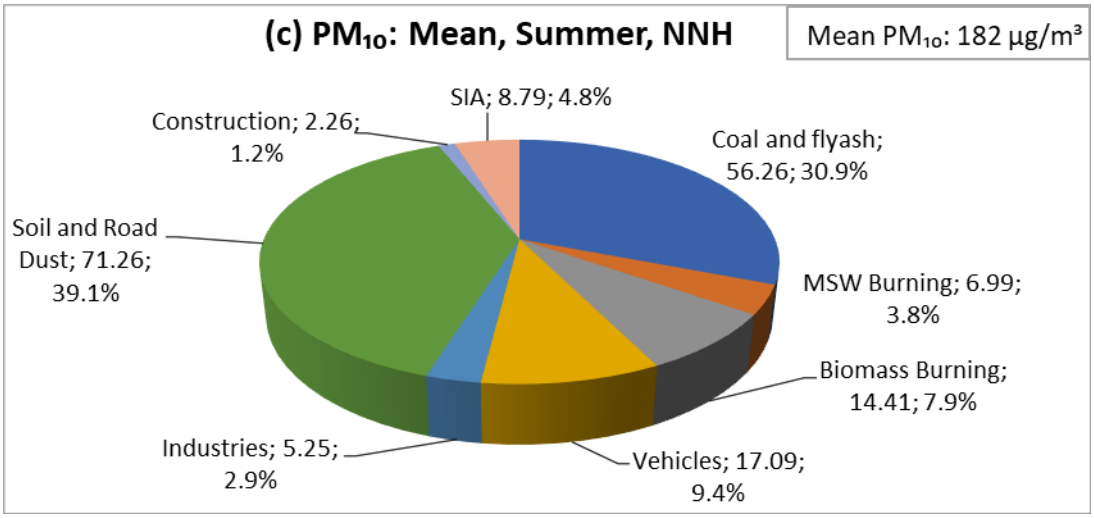
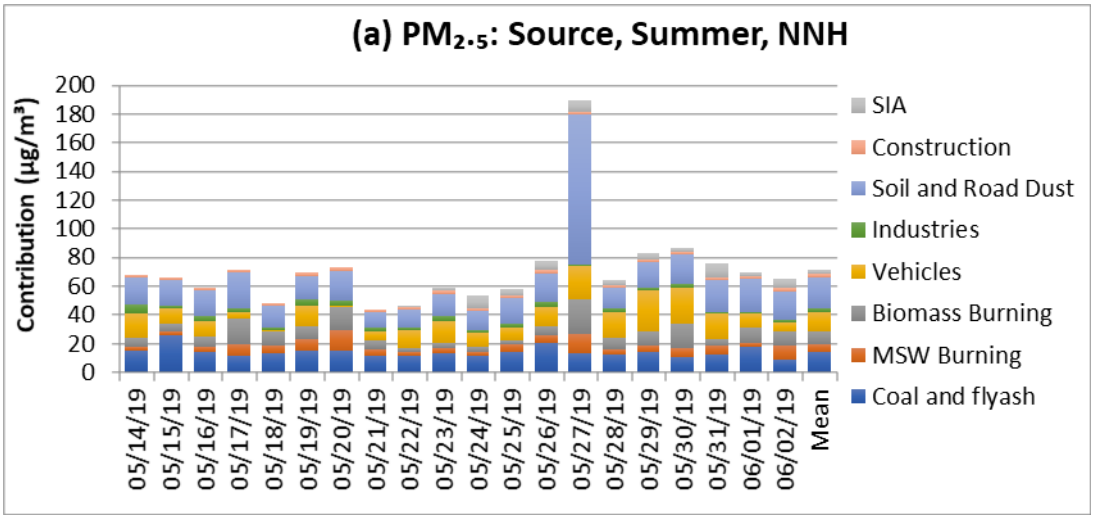
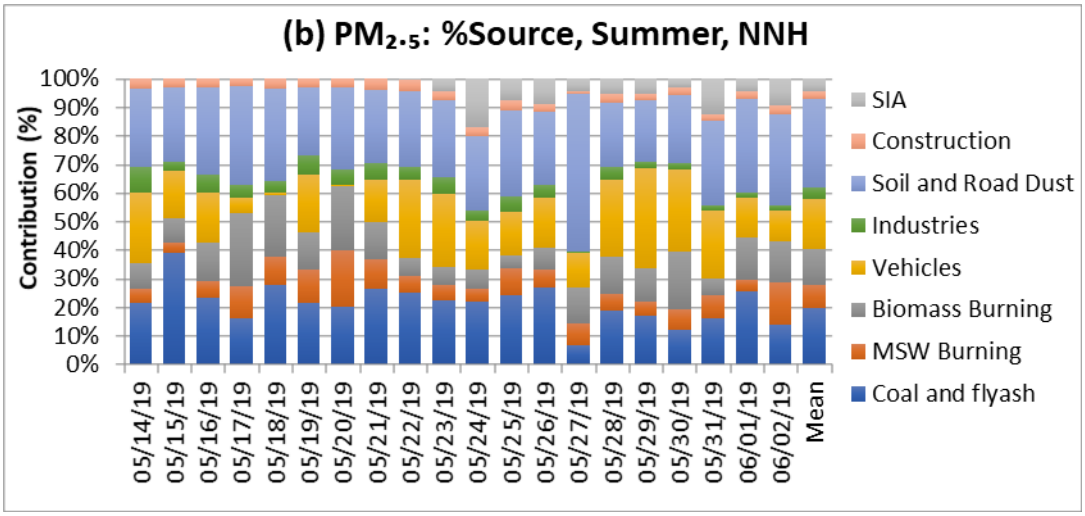


Figure 4.12: PMF modeling for PM_{10} at NNH for summer season





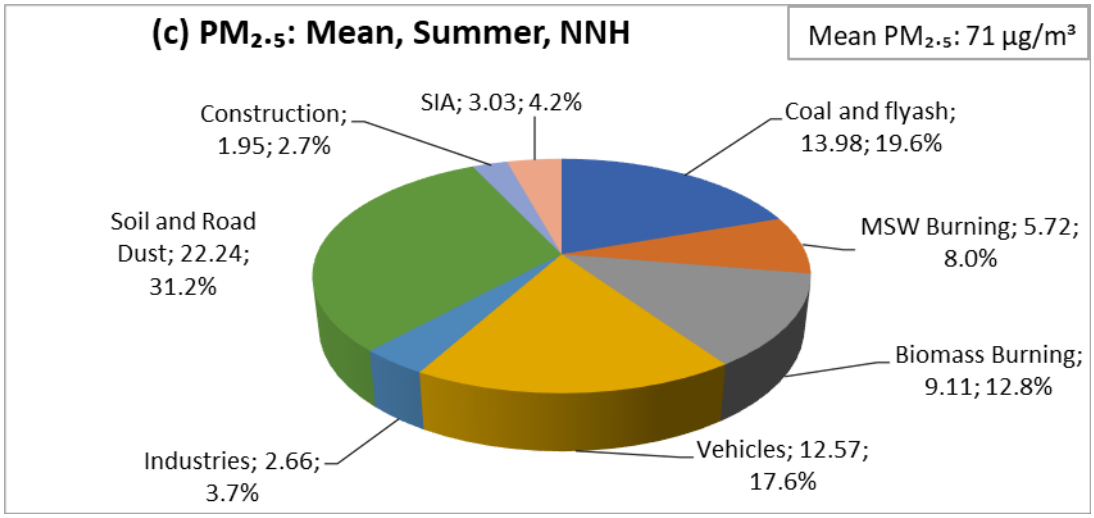


Figure 4.13: PMF modeling for $PM_{2.5}$ at NNH for summer season

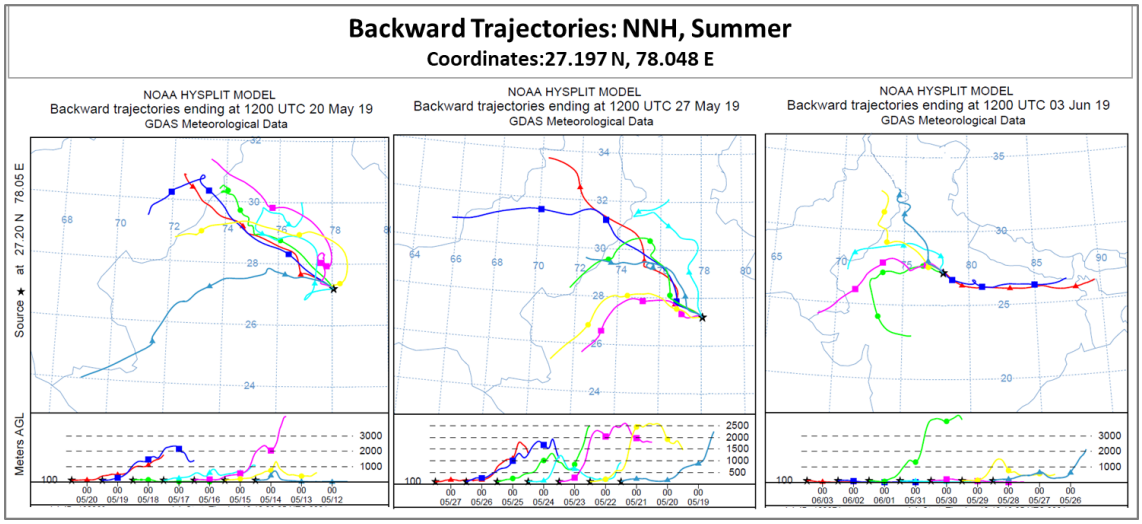


Figure 4.14: Backward trajectories at NNH for Summer Season

4.3.3 Jaipur House (JHS)

4.3.3.1 Winter Season [sampling period: Jan 26 – Feb 18, 2019]

PM_{10} (winter)

The average PM_{10} concentration was 201 µg/m^3. Figure 4.15 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at JHS. It is observed that the major PM_{10} source contributing was soil and road dust (52 µg/m^3 ~ 25%) followed by SIA (50 µg/m^3 ~ 24%) and coal and fly ash (38

μg/m^3 ~ 18%). The other significant contributing sources are vehicles (30 μg/m^3 ~ 14%), MSW burning (6%), industrial emission (5%), construction material (4%) and biomass burning (4%).

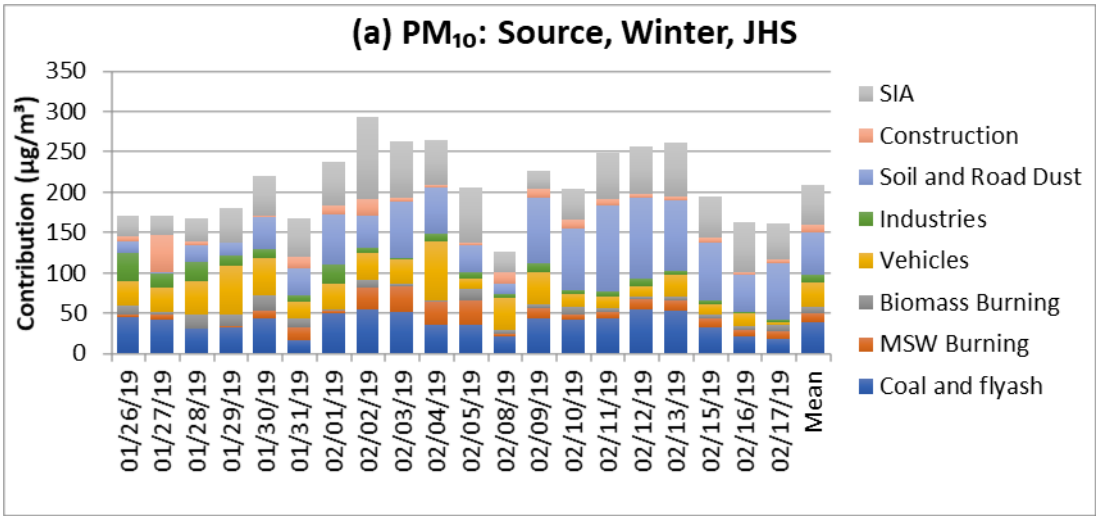
$PM_{2.5}$ (winter)

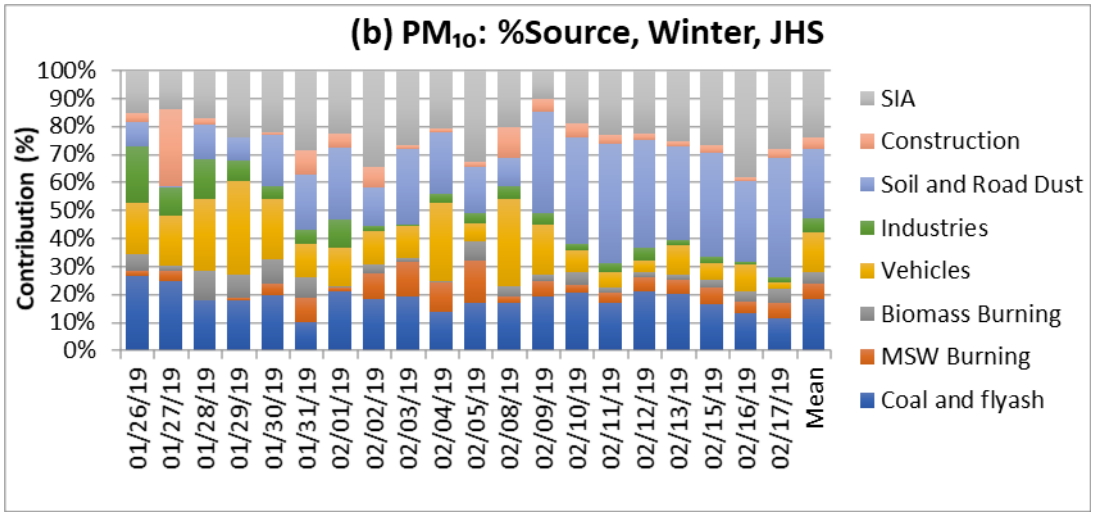
The average $PM_{2.5}$ concentration was 153 μg/m^3 (i.e., about 0.75 of PM_{10}). Figure 4.16 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at JHS. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (43 μg/m^3 ~ 29%) followed by SIA (29 μg/m^3 ~ 19%) and vehicles (27 μg/m^3 ~ 18%). Other major sources are coal and fly ash (26 μg/m^3 ~ 17%), MSW burning (5.6%), industrial emission (5.4%) and biomass burning (5.3%). The contribution of the construction material was lowest at 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.17) show that most of the time wind is mostly from NW and sometimes from SE. The wind mass travels over Punjab, Haryana, Delhi and part of Rajasthan before entering Agra. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Soil and road dust and construction material are combinedly contributed 29% in PM_{10} and 30% in $PM_{2.5}$. Coal and fly ash is also consistent and high both in PM_{10} (18%) and $PM_{2.5}$ (17%). It is a bit surprising that these sources consist of the major portion of PM. In winter, the wind speed is generally low and mostly about to calm conditions. Therefore, fine mode particles retain in the atmosphere. In the area of about 50 km radius, there are several brick kiln units operated and caused emissions.





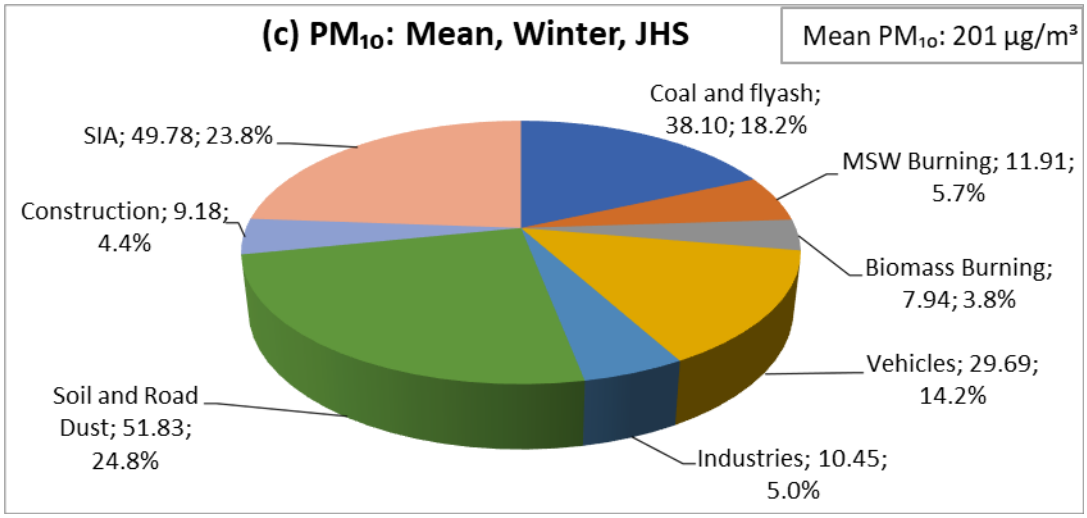


Figure 4.15: PMF modeling for PM_{10} at JHS winter season

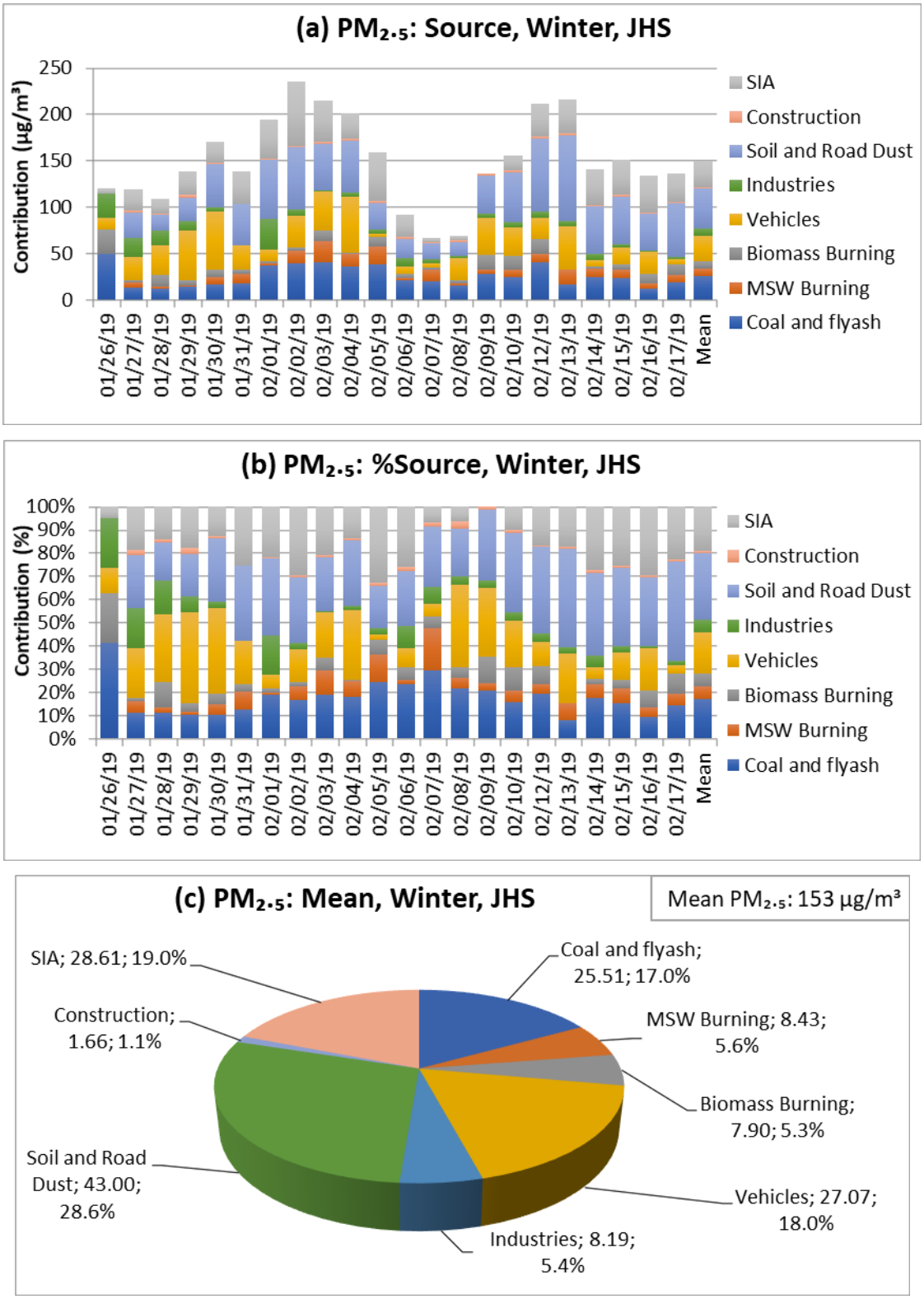


Figure 4.16: PMF modeling for $PM_{2.5}$ at JHS, winter season

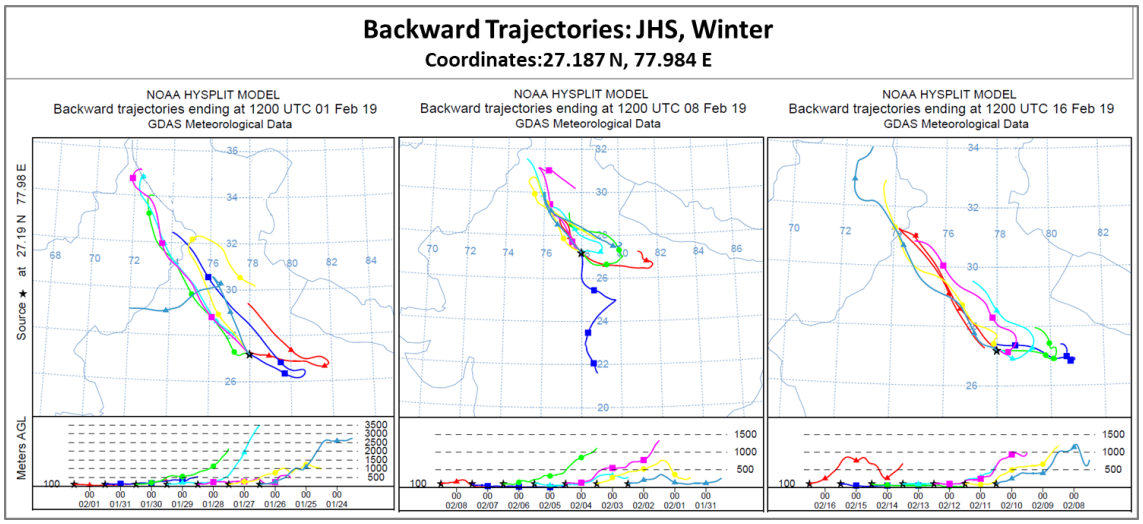


Figure 4.17: Backward trajectories at JHS for winter season

4.3.3.2 Summer Season [sampling period: April 20 - May 10, 2019]

PM_{10} (summer)

The average PM_{10} concentration was 202 µg/m^3. Figure 4.18 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at JHS. It is observed that the major PM_{10} source contributing was soil and road dust (73 µg/m^3 ~ 36%) followed by coal and fly ash (63 µg/m^3 ~ 32%) in PM_{10}. The other significant sources are vehicles (18 µg/m^3 ~ 9%), biomass burning (18 µg/m^3 ~ 9%), MSW burning (6%), SIA (4%) and construction material (2%). The contribution of the industrial emission was lowest at 1.4% in PM_{10}.

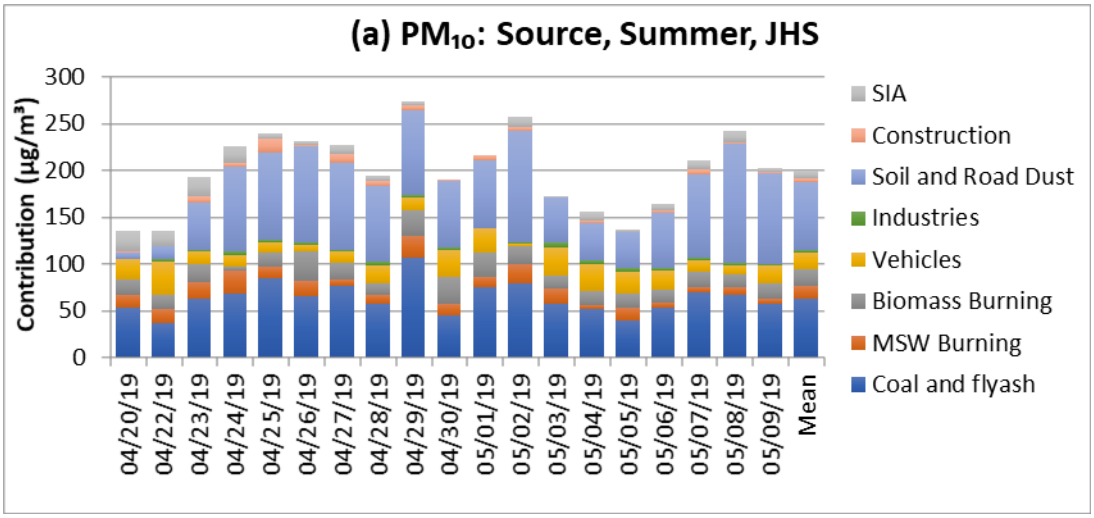
$PM_{2.5}$ (summer)

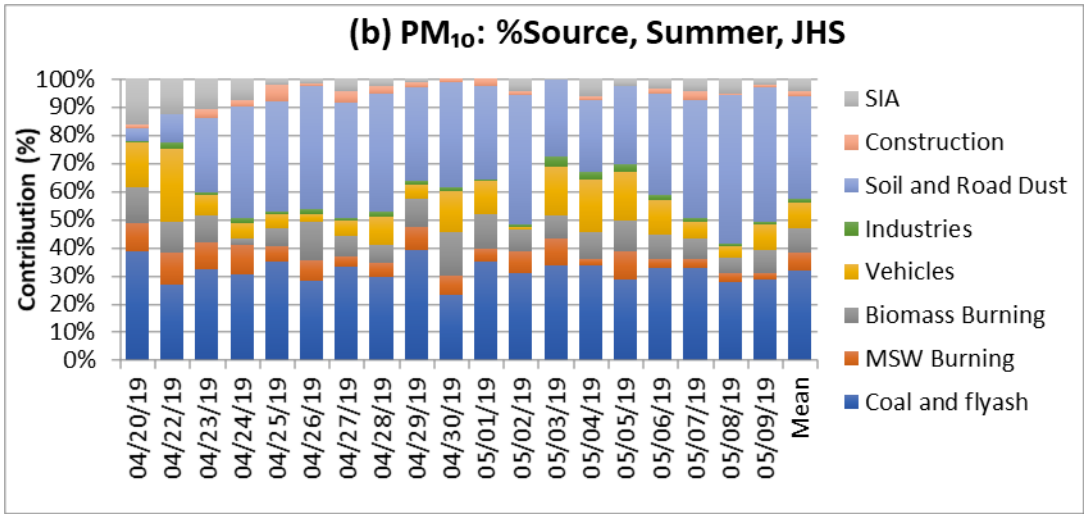
The average $PM_{2.5}$ concentration was 65 µg/m^3 (i.e., about 0.35 of PM_{10}). Figure 4.19 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively, at JHS. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (19 µg/m^3 ~ 29%) followed by vehicles (16 µg/m^3 ~ 24%). Other significant sources are coal and fly ash (12 µg/m^3 ~ 19%), MSW burning (8.5%), biomass burning (6.5%), SIA (6.5%), construction material (3.5%) and industrial (3.2%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.20) show that wind is mainly from NW to SW and sometimes from the east. The wind mass travels over different states and the Thar Desert before entering Agra. These winds pick up the pollutants on the way, especially from large sources.

Inference

Soil and road dust is major contributors in summer both for PM_{10} and $PM_{2.5}$. Coal and fly ash is also the second major contributor to PM_{10} and $PM_{2.5}$. The loose particles are airborne with high-speed wind from the desert, open barren fields, open dumping sites of fly ash, no control at construction sites caused the high contribution to PM.





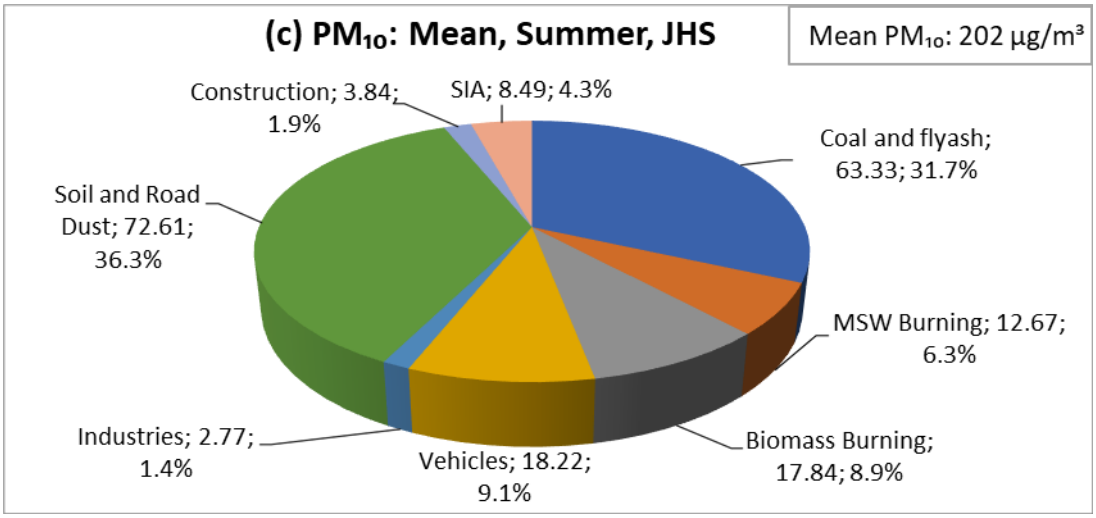
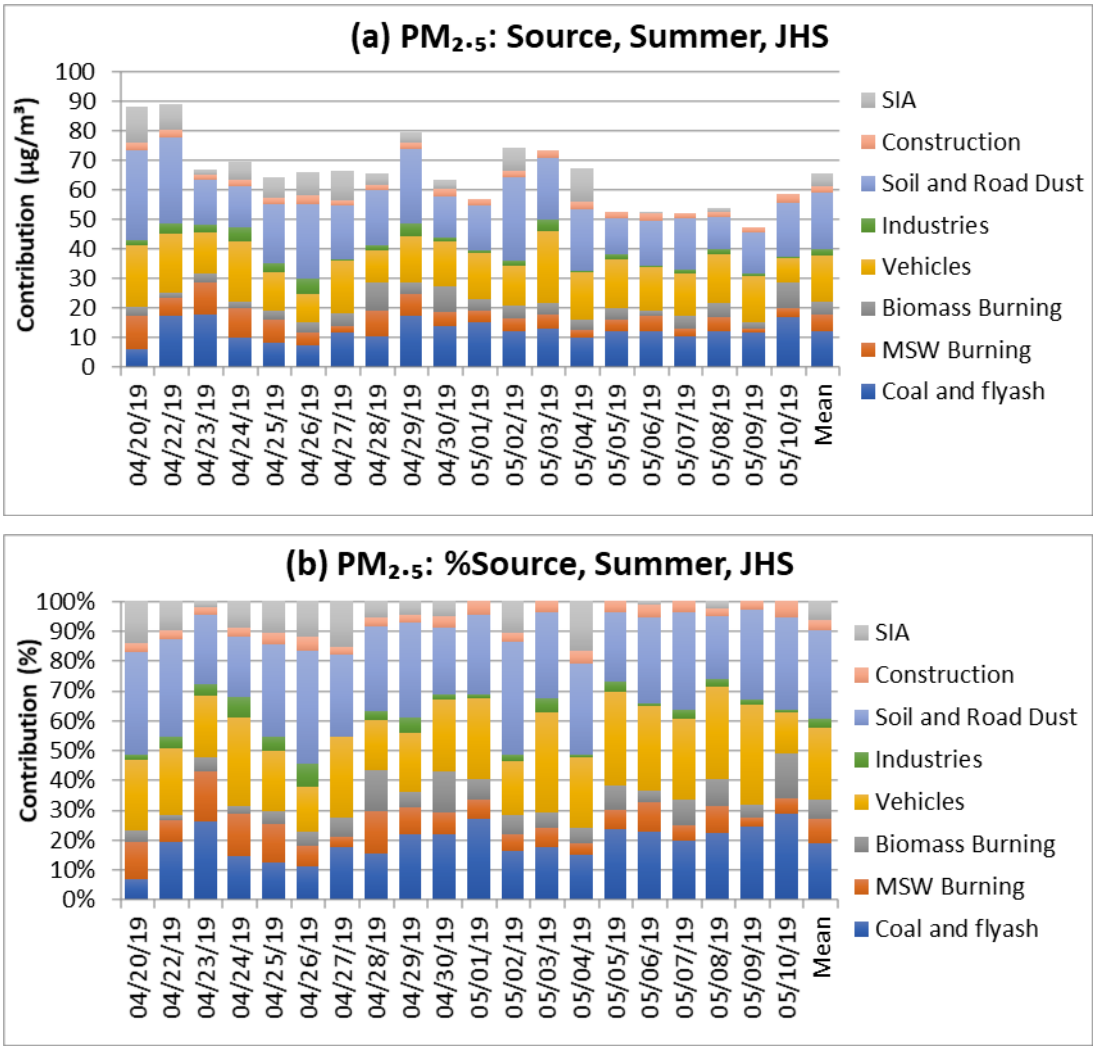


Figure 4.18: PMF modeling for PM_{10} at JHS for summer season



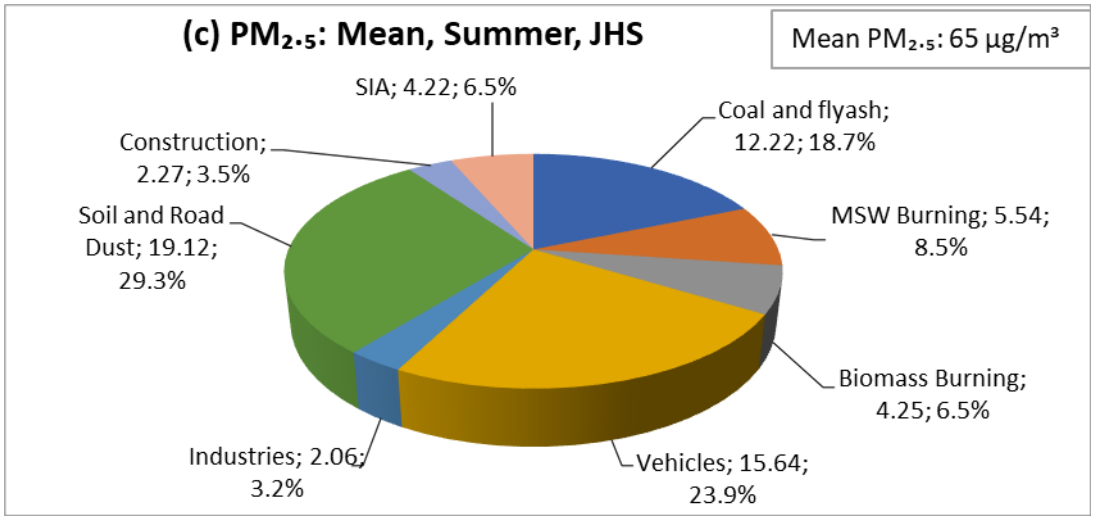


Figure 4.19: PMF modeling for $PM_{2.5}$ at JHS for summer season

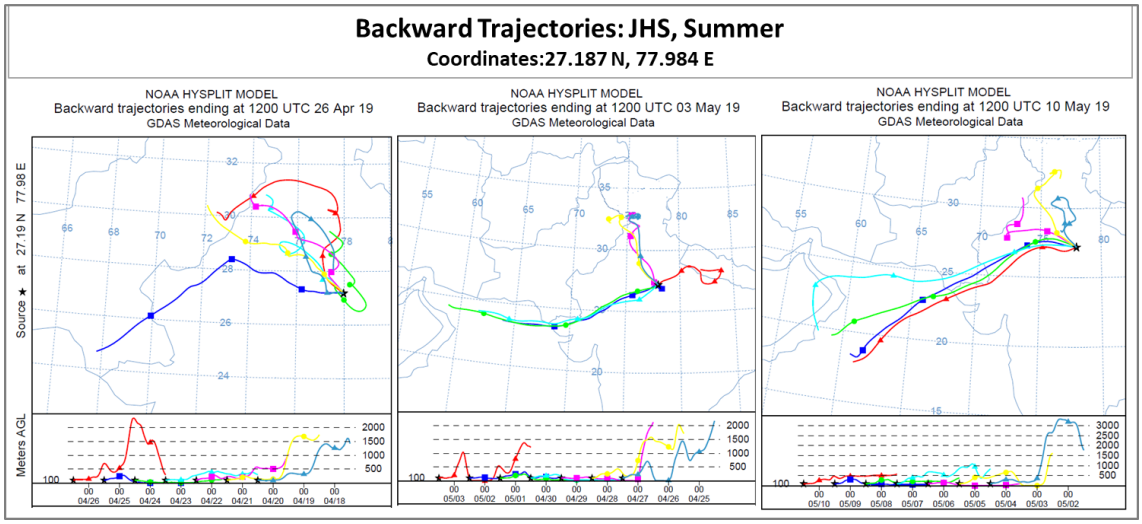


Figure 4.20: Backward trajectories at JHS for summer season

4.3.4 Sikandra (SKD)

4.3.4.1 Winter Season [sampling period: Jan 04 – 26, 2019]

PM_{10} (winter)

The average PM_{10} concentration was 312 µg/m^3. Figure 4.21 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at SKD. It is observed that the major contributing source was SIA (63 µg/m^3 ~ 20%) followed by vehicles (61 µg/m^3 ~ 19%) and coal and fly ash (54.4 µg/m^3 ~ 17.5%).

The other significant contributing sources are soil and road dust (53.5 µg/m^3 ~ 17%), MSW burning (40 µg/m^3 ~ 13%), biomass burning (6%), industrial emission (4%) and construction material (2.5%).

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 212 µg/m^3 (i.e., about 0.73 of PM_{10}). Figure 4.22 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at SKD. It is observed that the major source contributing to $PM_{2.5}$ was coal and fly ash (52 µg/m^3 ~ 24%) followed by SIA (42 µg/m^3 ~ 20%) and vehicles (42 µg/m^3 ~ 20%). Other significant sources are soil and road dust (30 µg/m^3 ~ 14%), MSW burning (26 µg/m^3 ~ 12%), biomass burning (7%) and industrial emission (3%). The contribution of the construction material was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.23) show that wind is not stable in any direction and wind mass travels over to neighboring districts before entering into Agra. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inference

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. It is to be noted that at SKD, SIA particles and vehicles about 20% and MSW burning 12-13% are consistent in $PM_{2.5}$ and PM_{10}. The coal and fly ash is significantly increased to 24% in $PM_{2.5}$ compared to 17% in PM_{10}. The MSW burning contributes a significant amount at SKD that indicates irregular management of waste generated from industries that succeed for open burning. It is noted that industrial contribution is about 3 – 4% both in $PM_{2.5}$ and PM_{10}, which are slightly higher in the residential cum commercial area. It could be due to open burning of waste tyres in the nearby area (i.e., Transport Nagar) as industrial activities in SKD is negligible.

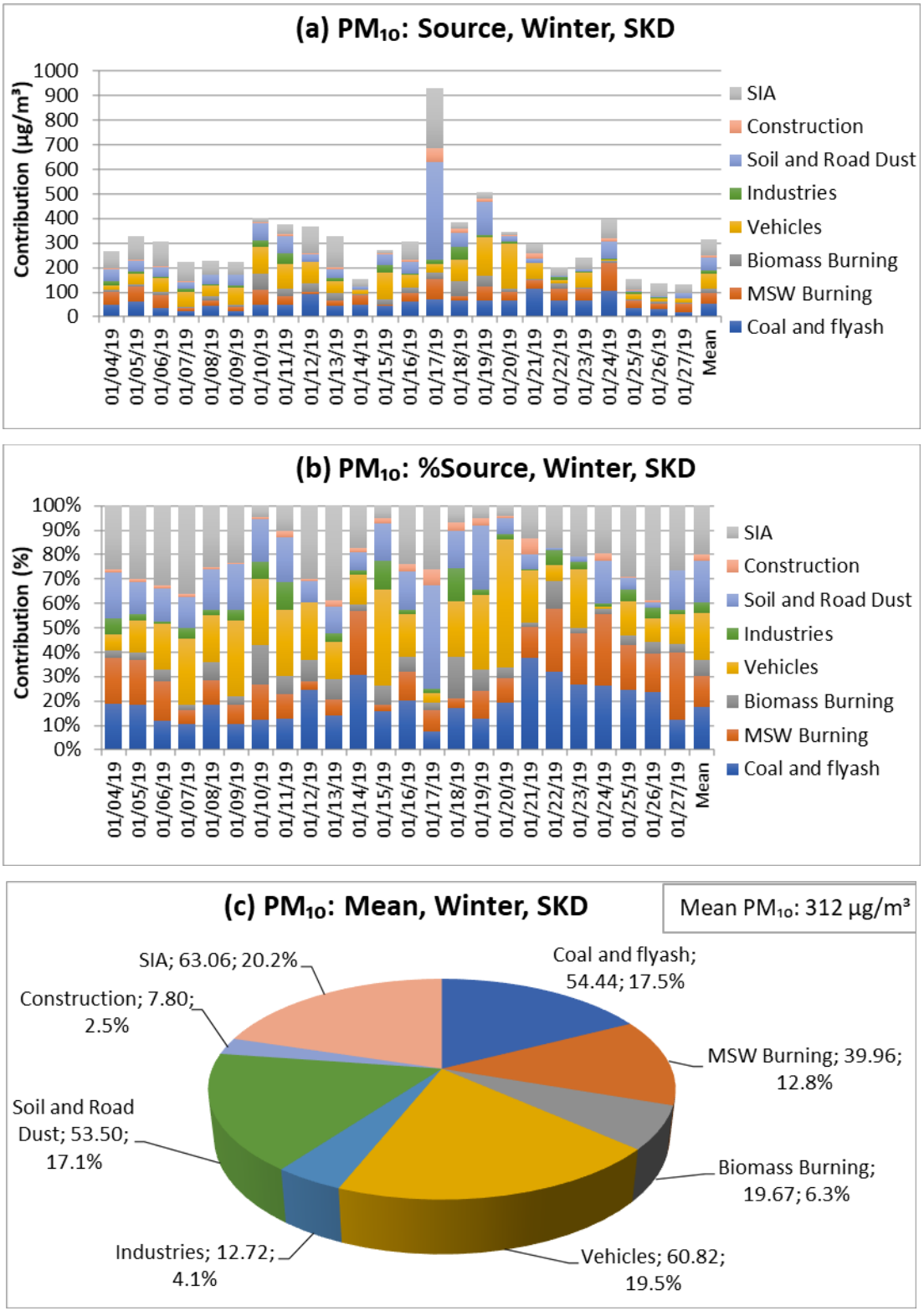


Figure 4.21: PMF modeling for PM_{10} at SKD for winter season

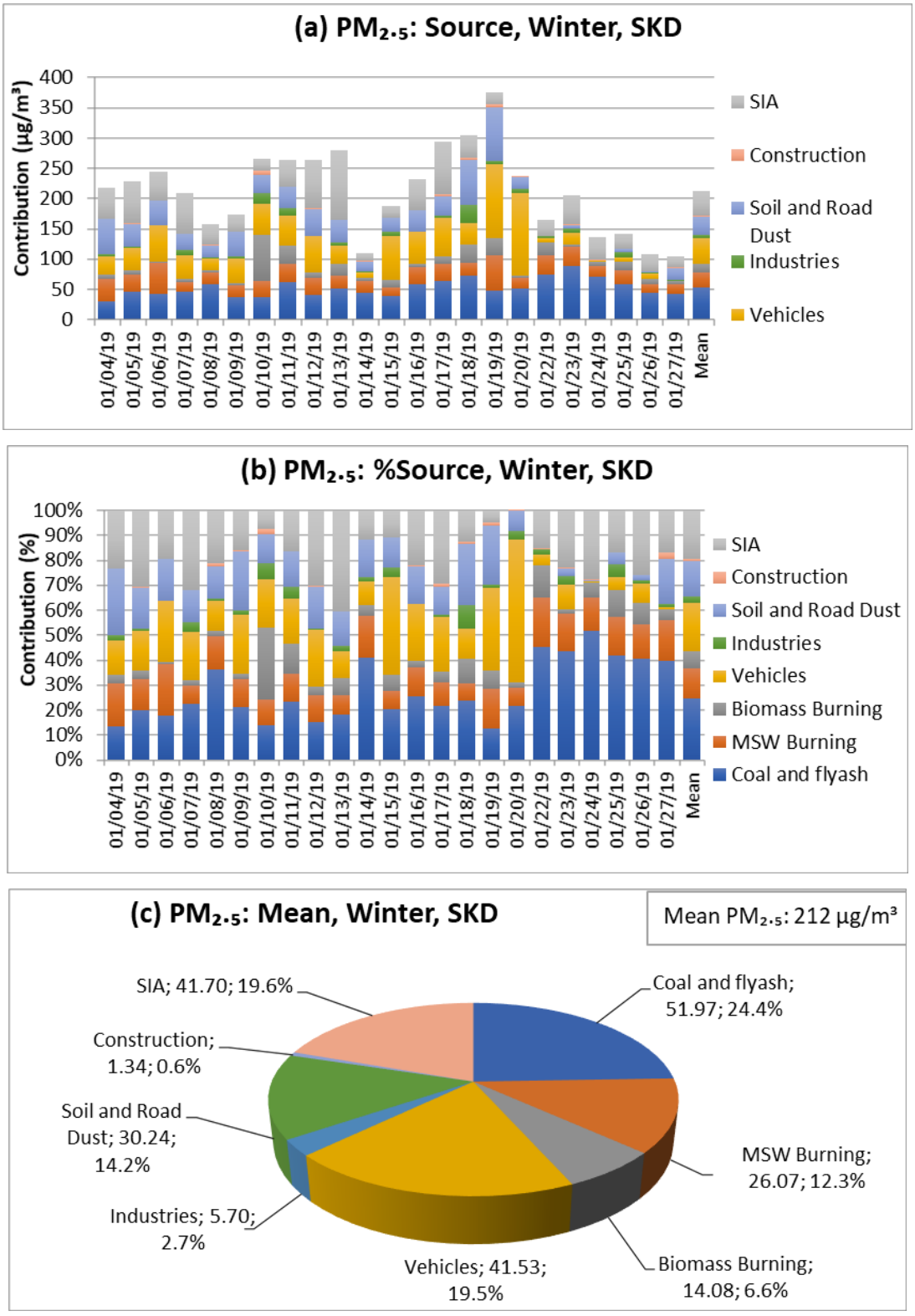


Figure 4.22: PMF modeling for $PM_{2.5}$ at SKD for winter season

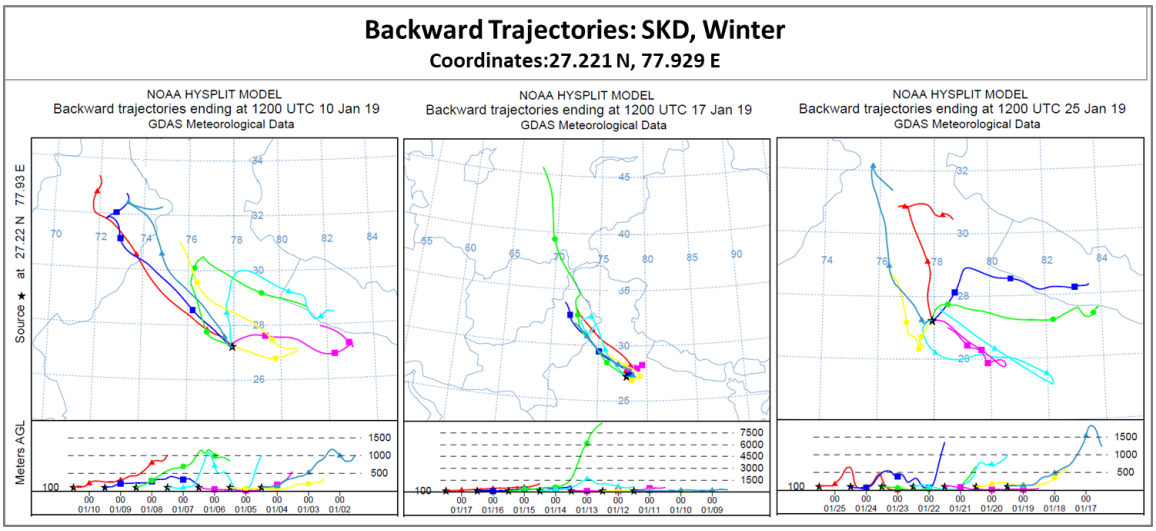


Figure 4.23: Backward trajectories at SKD for winter season

4.3.4.2 Summer Season [sampling period: April 08 – May 03, 2019]

PM_{10} (summer)

The average PM_{10} concentration was 201 µg/m^3. Figure 4.24 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at SKD. It is observed that the major PM_{10} source contributing was coal and fly ash (85 µg/m^3 ~ 42%) followed by soil and road dust (66 µg/m^3 ~ 33%). The other significant sources are vehicles (15 µg/m^3 ~ 8%), biomass burning (7%), SIA (4%), MSW burning (3%) and construction material (3%). The contribution of the industrial emissions was lowest at 1% in PM_{10}.

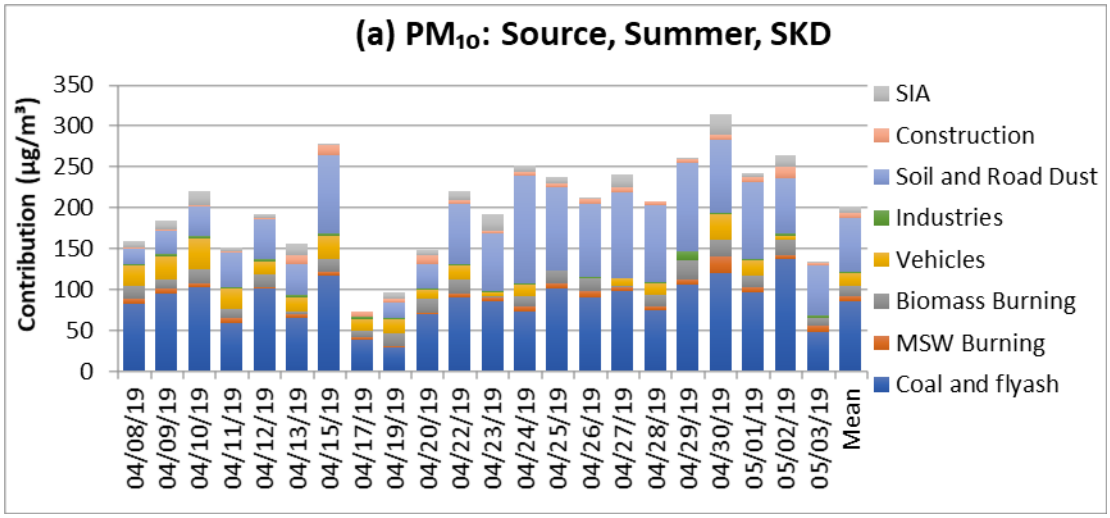
$PM_{2.5}$ (summer)

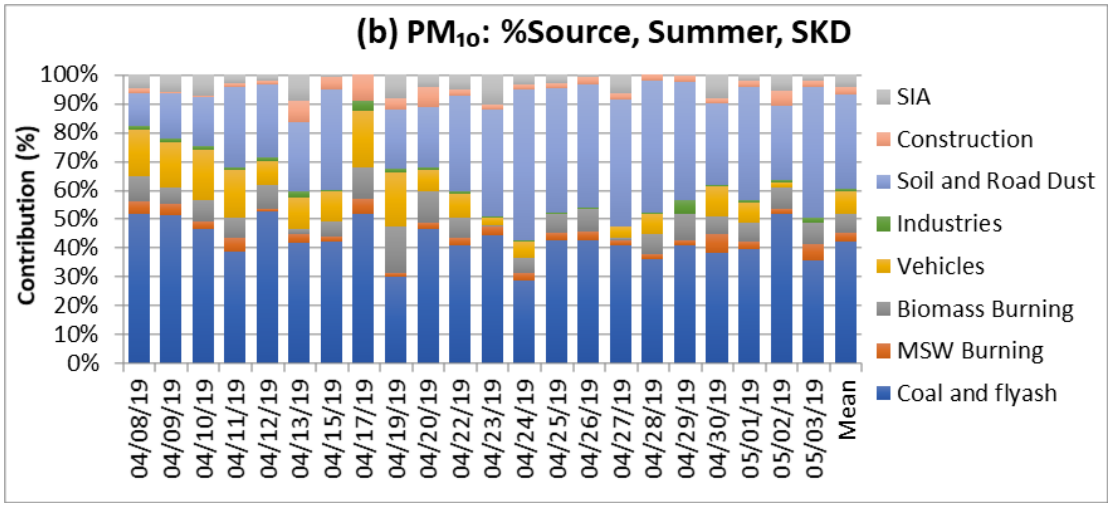
The average $PM_{2.5}$ concentration was 71 µg/m^3 (i.e., about 0.44 of PM_{10}). Figure 4.25 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at SKD. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (26 µg/m^3 ~ 37%) followed by coal and fly ash (15 µg/m^3 ~ 21%). Other significant sources are vehicles (10 µg/m^3 ~ 14%), biomass burning (9%), SIA (8%), MSW burning (6%) and construction material (4%). The contribution of the industrial emissions was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.26) show that wind is not stable in any particular direction and wind mass travel over to neighboring districts before entering into Agra. These winds pick up the pollutants on the way, especially from large and tall emitting sources.

Inference

Soil and road dust is major contributors in summer both for PM_{10} and $PM_{2.5}$. Coal and fly ash is also the second major contributor to PM_{10} and $PM_{2.5}$. The loose particles are airborne with high-speed wind from the desert, open barren fields, open dumping sites of fly ash, no control at construction sites caused the high contribution to PM. The high contribution of coal and fly ash may be emitted from the brick kilns within 50 km radius.





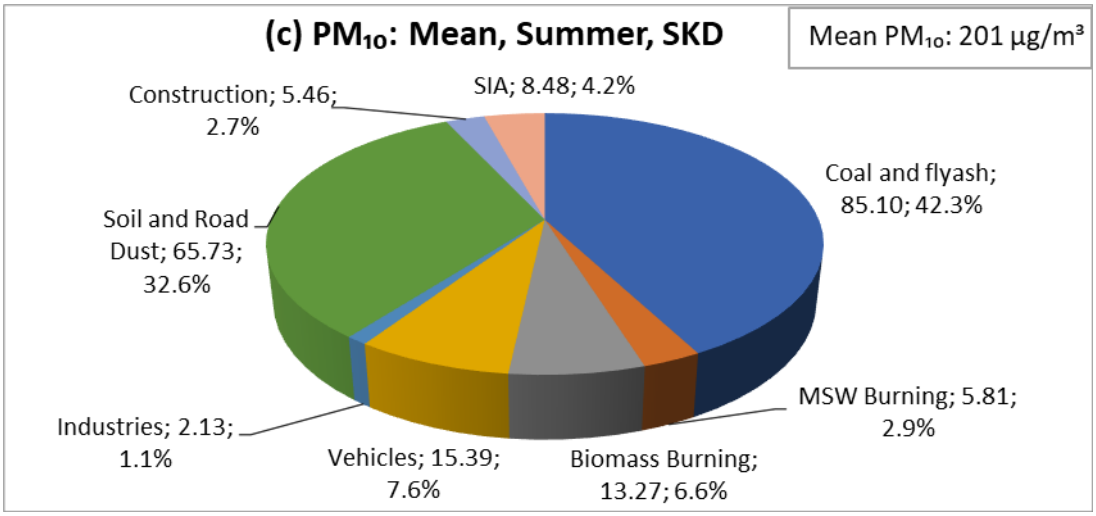
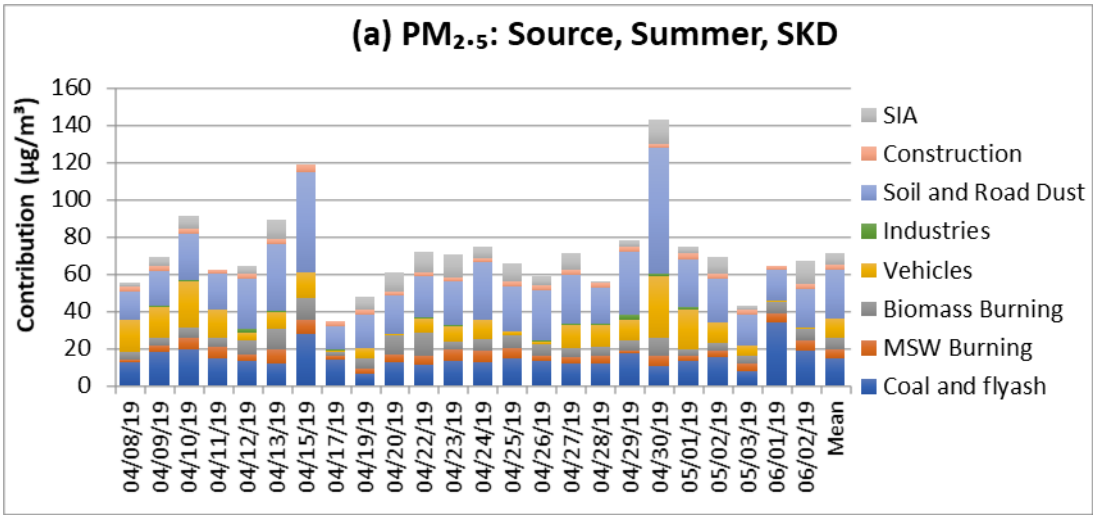
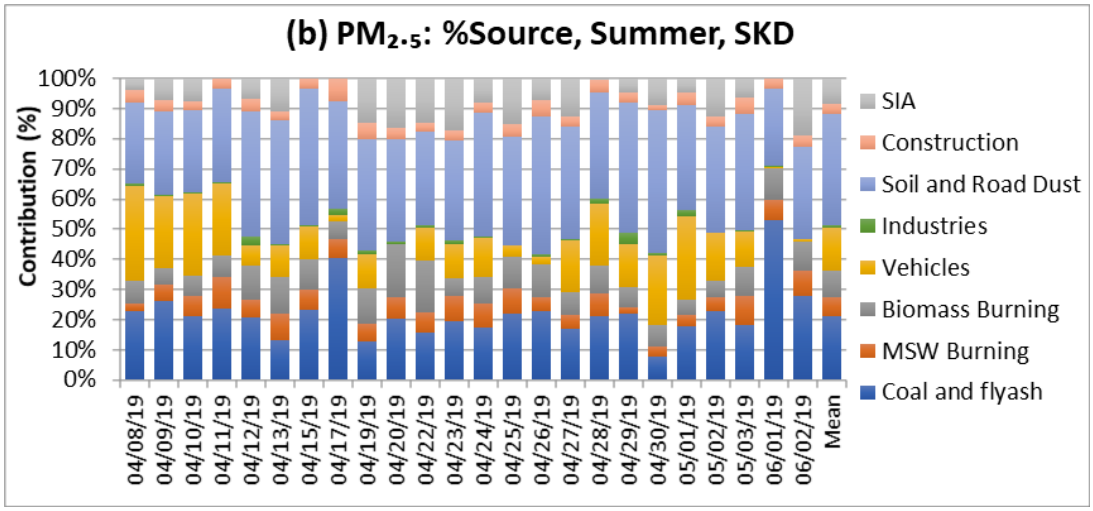


Figure 4.24: PMF modeling for PM_{10} at SKD for summer season





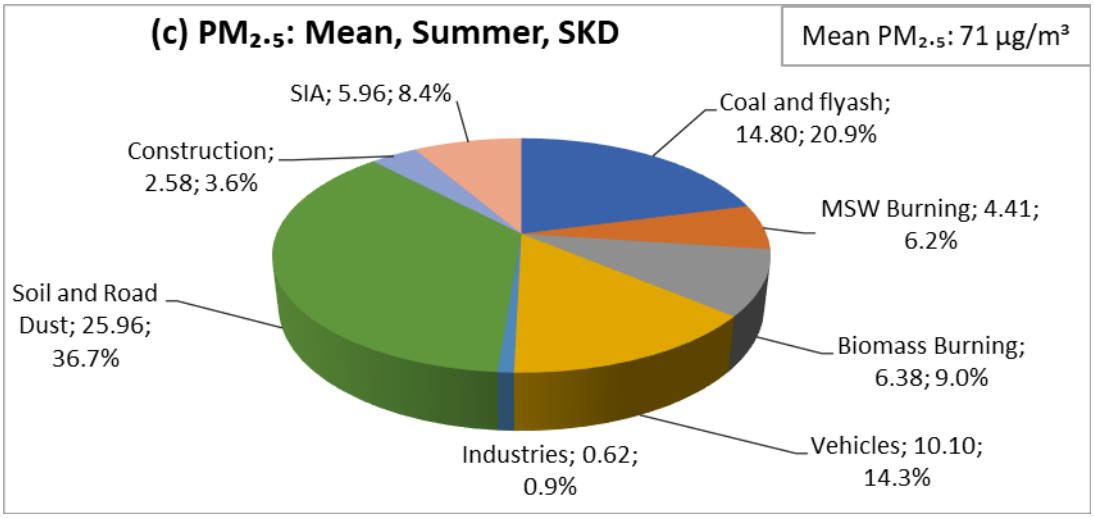


Figure 4.25: PMF modeling for $PM_{2.5}$ at SKD for summer season

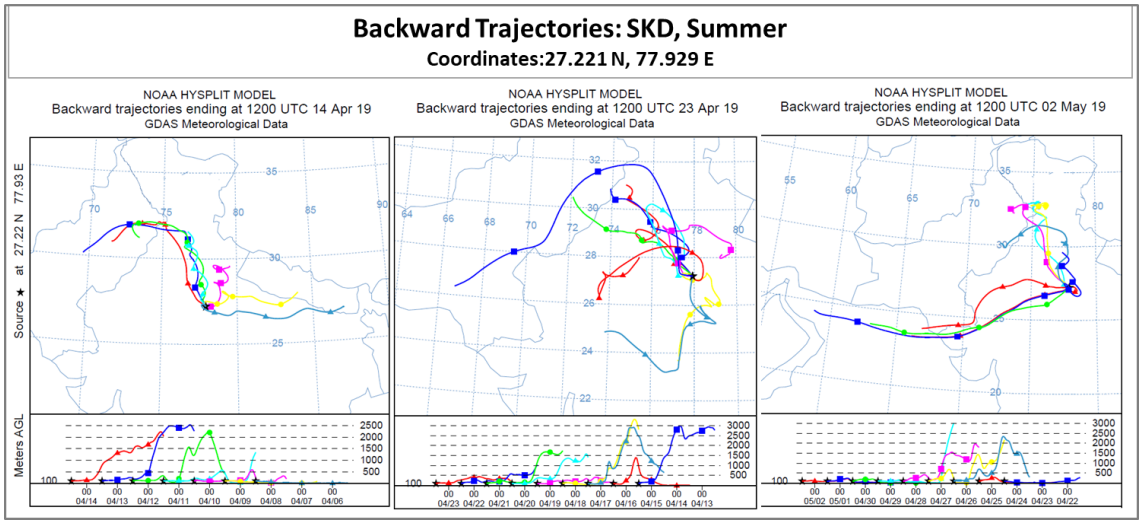


Figure 4.26: Backward trajectories at SKD for summer season

4.3.5 Taj Mahal (TAJ)

4.3.5.1 Winter Season [sampling period: Dec 12 – 27, 2018]

PM_{10} (winter)

The average PM_{10} concentration was 366 µg/m^3. Figure 4.27 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively at TAJ. It is observed that the major PM_{10} source contributing was soil and road dust (85 µg/m^3~ 23%) followed by SIA (75 µg/m^3 ~ 20%) and vehicles (75 µg/m^3 ~ 20%).

The other significant contributing sources are biomass burning (42 µg/m^3 ~ 11%), MSW burning (8%), coal and fly ash (8%), industrial emission (5%) and construction material (3%) in PM_{10}.

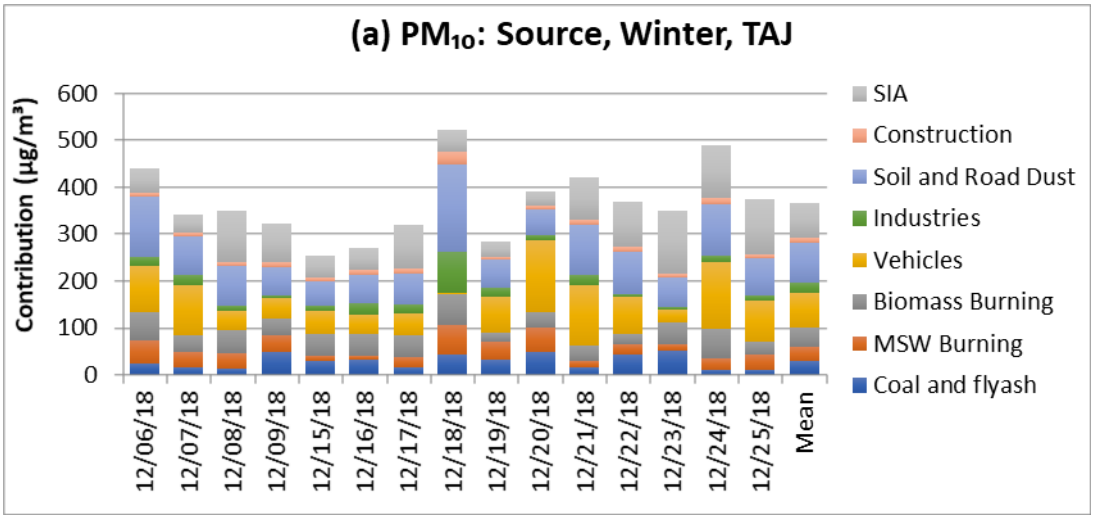
$PM_{2.5}$ (winter)

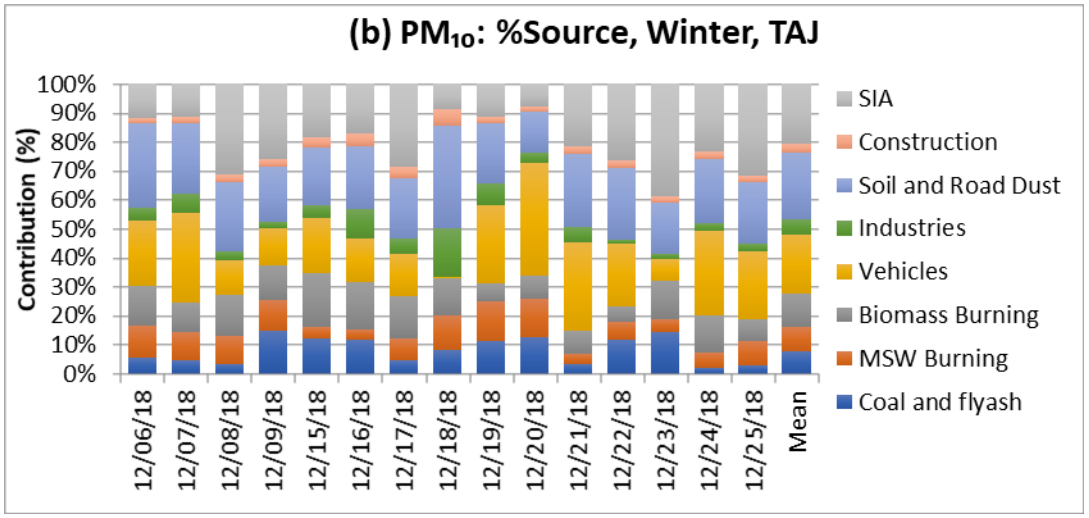
The average $PM_{2.5}$ concentration was 250 µg/m^3 (i.e., about 0.73 of PM_{10}). Figure 4.28 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively at TAJ. It is observed that the major source contributing to $PM_{2.5}$ was SIA (72 µg/m^3 ~ 30%) followed by vehicles (62 µg/m^3 ~ 25%) and biomass burning (37 µg/m^3 ~ 15%). Other significant sources are MSW burning (30 µg/m^3 ~ 12%), soil and road dust (22 µg/m^3 ~ 9%), coal and fly ash (6%), industrial emission (3%). The contribution of construction material was lowest at 1.4% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.29) show that most of the time wind is from NW and sometimes from SW. The wind mass travels over Punjab, Haryana and Rajasthan before entering Agra. These winds pick up the pollutants on the way, especially from large sources.

Inference

SIA (21 – 29%) is the major source followed by vehicular contribution (20 – 25%) for both PM_{10} and $PM_{2.5}$. It is a bit surprising that SIA particles have such a high contributor to $PM_{2.5}$. Contributions of biomass burning and MSW burning are high for both PM_{10} and $PM_{2.5}$. The high contribution of MSW burning indicates irregular management of waste generated and succeeds for open burning.





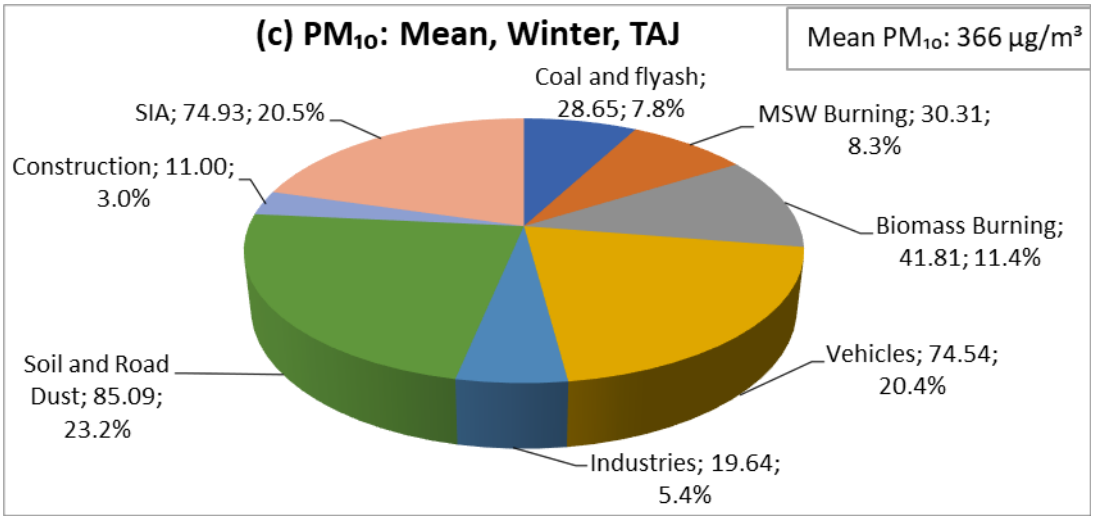
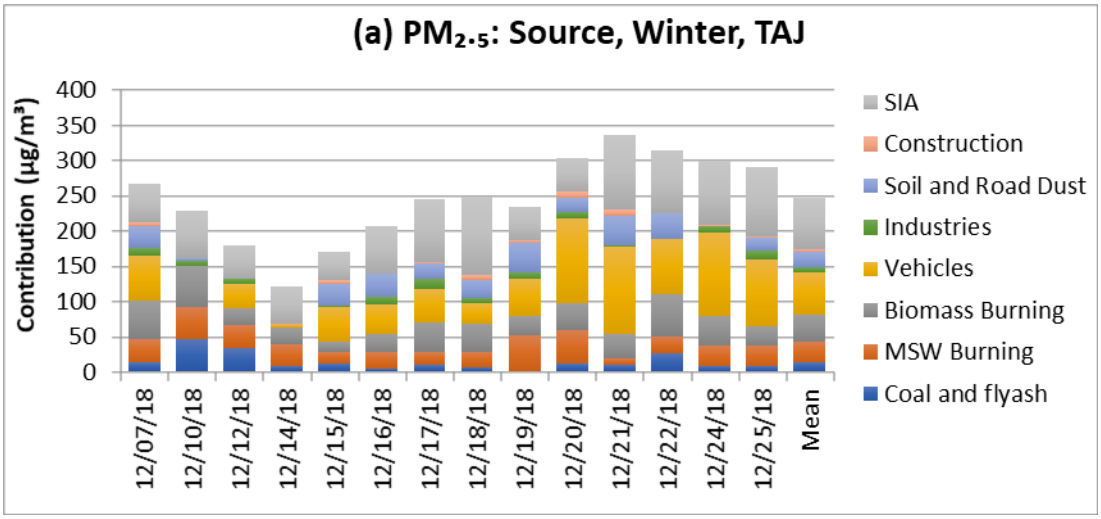


Figure 4.27: PMF modeling for PM_{10} at TAJ for winter season



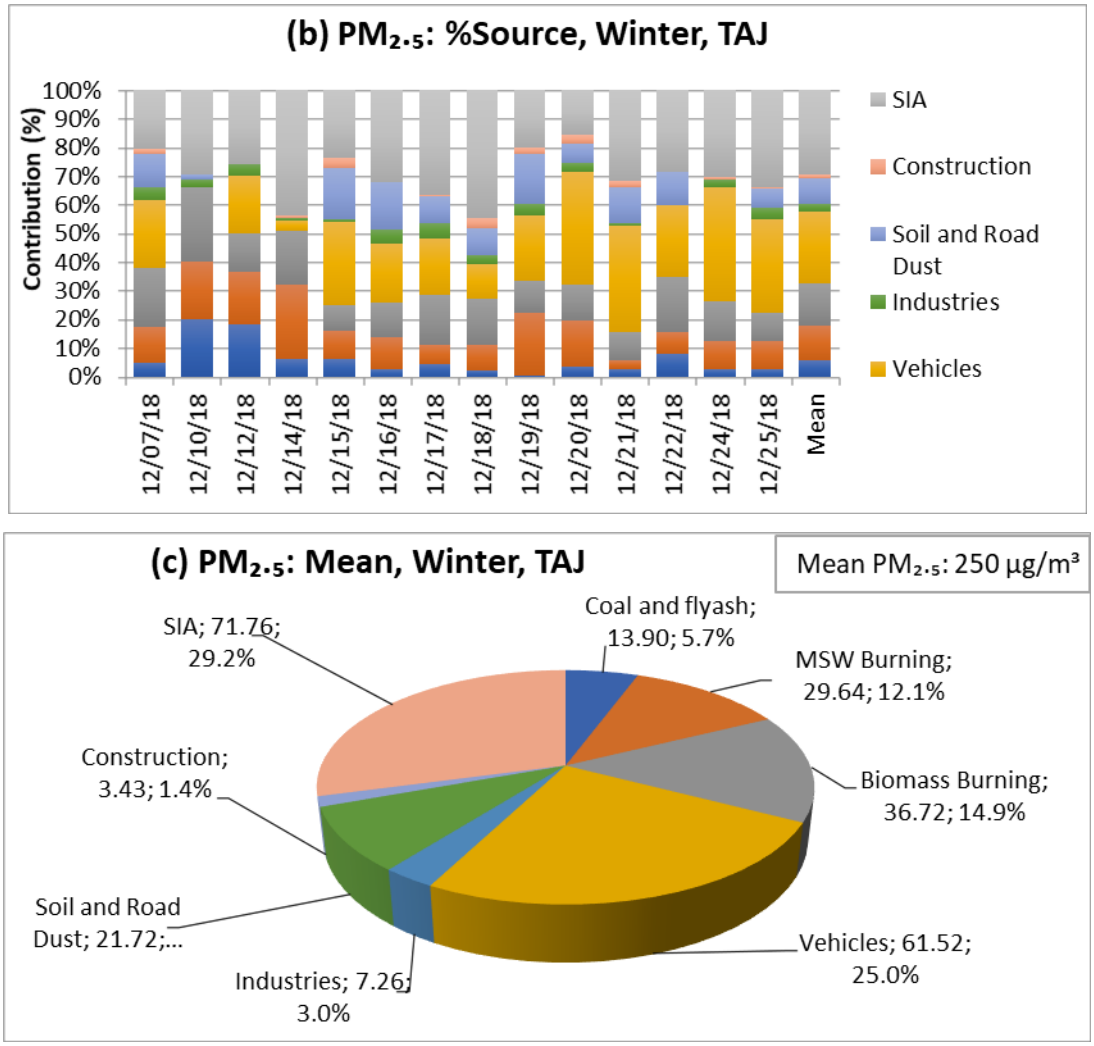


Figure 4.28: PMF modeling for $PM_{2.5}$ at TAJ for winter season

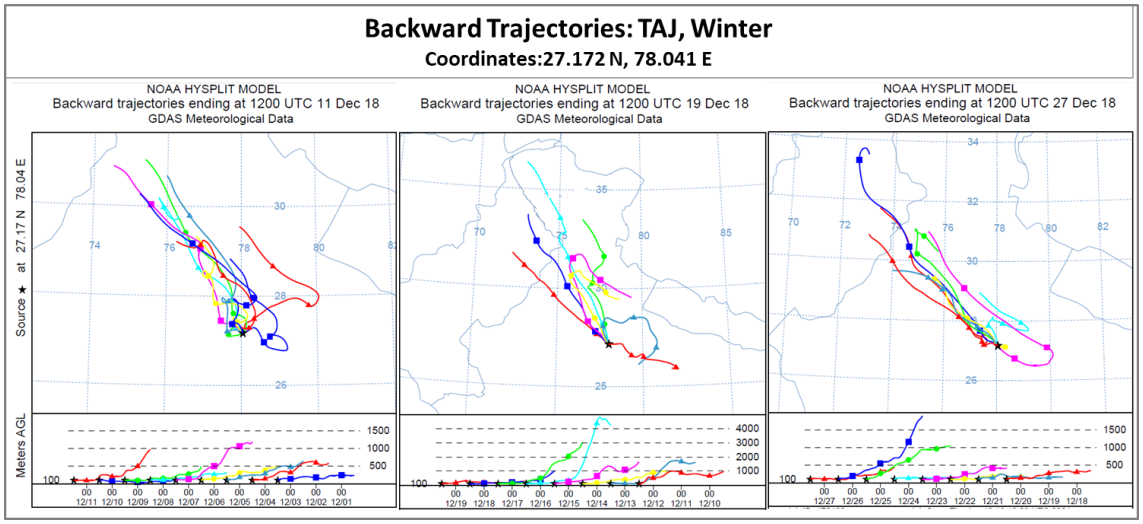


Figure 4.29: Backward trajectories at TAJ for winter season

4.3.5.2 Summer Season [sampling period: June 01 – 30, 2019]

PM_{10} (summer)

The average PM_{10} concentration was 151 µg/m^3. Figure 4.30 (a), (b), (c) shows PM_{10} concentration contribution of sources, percent contribution of sources and summary of sources (average over about 20 days) at TAJ. It is observed that the major PM_{10} source contributing was soil and road dust (85 µg/m^3 ~ 47%) followed by coal and fly ash (39 µg/m^3 ~ 24%). The other significant contributing sources are SIA (11 µg/m^3 ~ 7%), vehicles (6%), biomass burning (6%) and MSW burning (5%) and construction material (4%). The contribution of industrial emission was lowest at 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 61 µg/m^3. Figure 4.31 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage, respectively at TAJ. It is observed that the major source contributing to $PM_{2.5}$ was soil and road dust (24 µg/m^3 ~ 37%) followed by coal and fly ash (19 µg/m^3 ~ 30%). Other significant sources are biomass burning (10%), vehicles (7%), MSW burning (7%), SIA (6%) and construction material (3%). The contribution of the industrial emission was estimated at less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.32) show that wind is mostly from west and east. The wind mass travels over the Thar Desert before entering Agra. These winds pick up the pollutants on the way, especially from large sources.

Inference

Soil and road dust and construction material are combinedly major contributors in summer both for PM_{10} and $PM_{2.5}$. Coal and fly ash is also the second major contributor to PM_{10} and $PM_{2.5}$. The loose particles are airborne with high-speed wind from the desert, open barren fields, open dumping sites of fly ash, no control at construction sites caused the high contribution to PM.

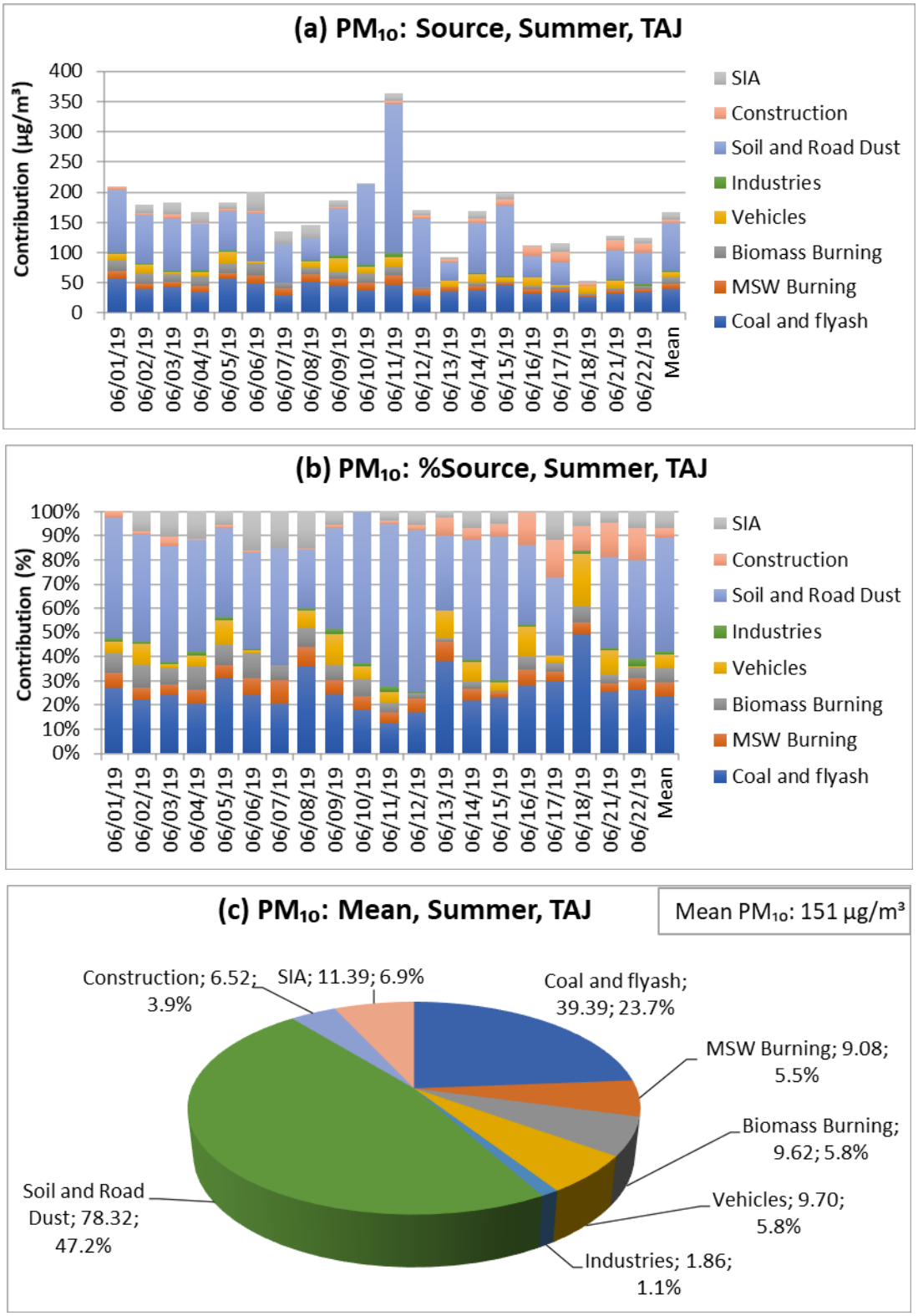
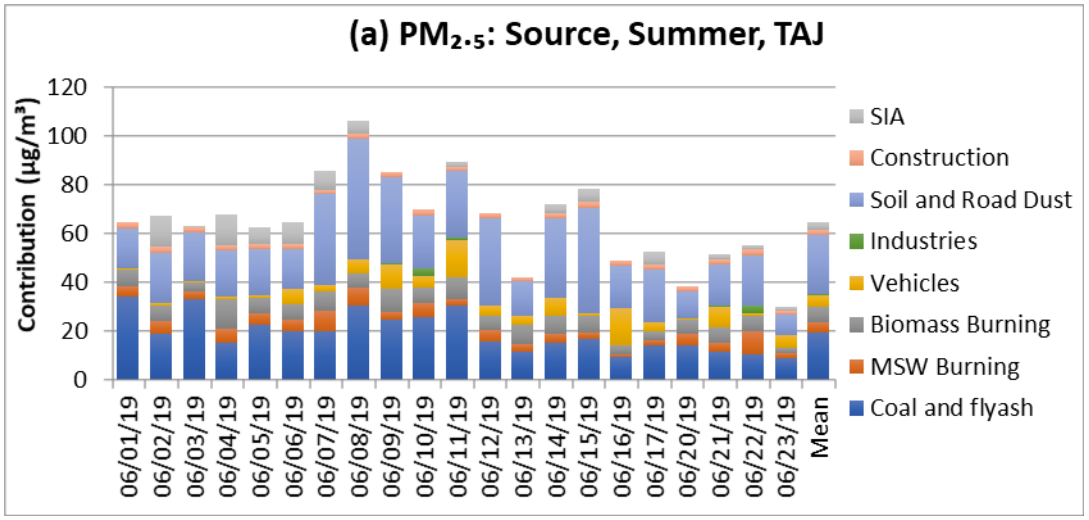
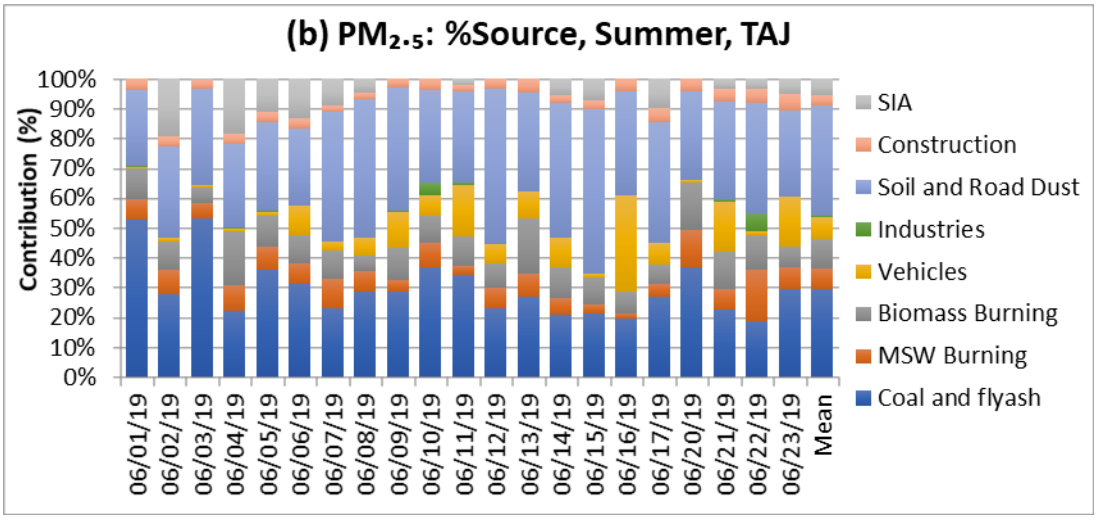


Figure 4.30: PMF modeling for PM_{10} at TAJ for summer season





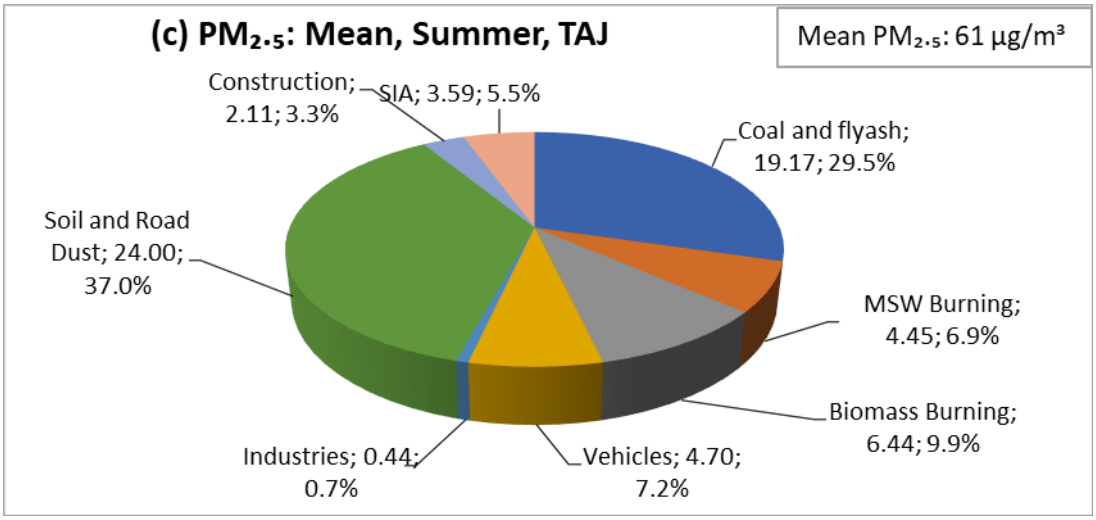


Figure 4.31: PMF modeling for $PM_{2.5}$ at TAJ for summer season

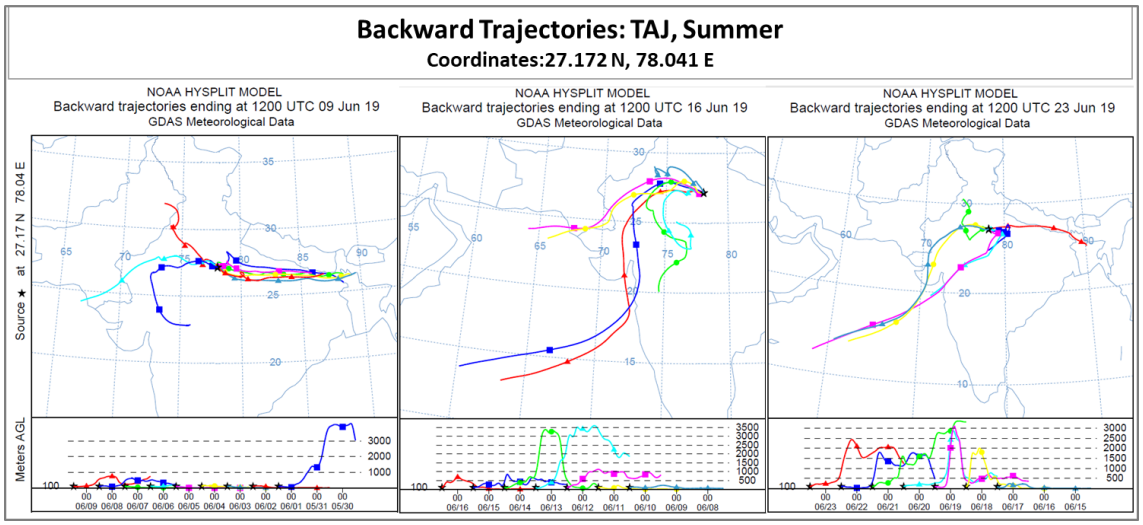


Figure 4.32: Backward trajectories at TAJ for summer season

4.4 Long-range transport and contribution

HYSPLIT back trajectories show that most of the time wind is from NW (winter) and SW (summer) and sometimes from SE. Wind mass as it travels over Thar desert and states of Punjab, Haryana, Delhi before entering Agra may pick up the pollutants on the way, especially from large sources (e.g., desert soil and CRB) and tall emitting sources; however, these contributions have not been quantified. There is no assessment made on emissions upstream of Agra and their contribution in Agra.

4.5 Overall Summary and Source Apportionment at a Glance

The overall summary of PMF modeling results is shown in Figure 4.33 and Figure 4.34. Tables 4.1 - 4.4 provide a summary with overall statistics. The main highlights of PMF results are summarized below.

- Ranges of source contributions to PM_{10} are: soil and road dust (10 – 51%), coal and fly ash (8 – 42%), vehicles (6 – 25%), MSW burning (2 – 24%), biomass burning (4 – 11%), industrial (1 – 20%), construction material (1 – 4%) and secondary inorganic aerosols (SIA; 1 – 24%).
- Ranges of source contributions to $PM_{2.5}$ are: soil and road dust (7 – 38%), coal and fly ash (6 – 30%), vehicles (7 – 28%), MSW burning (6 – 25%), biomass burning (4 – 15%), industrial (1 – 18%), construction material (0.6 – 4%) and SIA (3 – 29%).

- Contribution of vehicles (PM_{10}: 20 – 8% and $PM_{2.5}$: 23 – 14%), SIA (PM_{10}: 19 – 4% and $PM_{2.5}$: 19 – 6%), MSW burning (PM_{10}: 12 – 4% and $PM_{2.5}$: 14 – 7%), industrial (PM_{10}: 7 – 2% and $PM_{2.5}$: 6 – 3%) are higher during winter season compared to summer season both in PM_{10} and $PM_{2.5}$.
- Contribution of soil and road dust (PM_{10}: 41 – 18% and $PM_{2.5}$: 35 – 14%), coal and fly ash (PM_{10}: 31 – 15% and $PM_{2.5}$: 23 – 16%) and biomass burning (PM_{10}: 7 – 6% and $PM_{2.5}$: 10 – 7%) are higher during summer season compared to winter season both in PM_{10} and $PM_{2.5}$.
- The contribution of construction material is higher in PM_{10} (2.8%) compared to $PM_{2.5}$ (1.0%) during the winter season and lower in PM_{10} (2.7%) compared to $PM_{2.5}$ (2.9%) during the summer season.

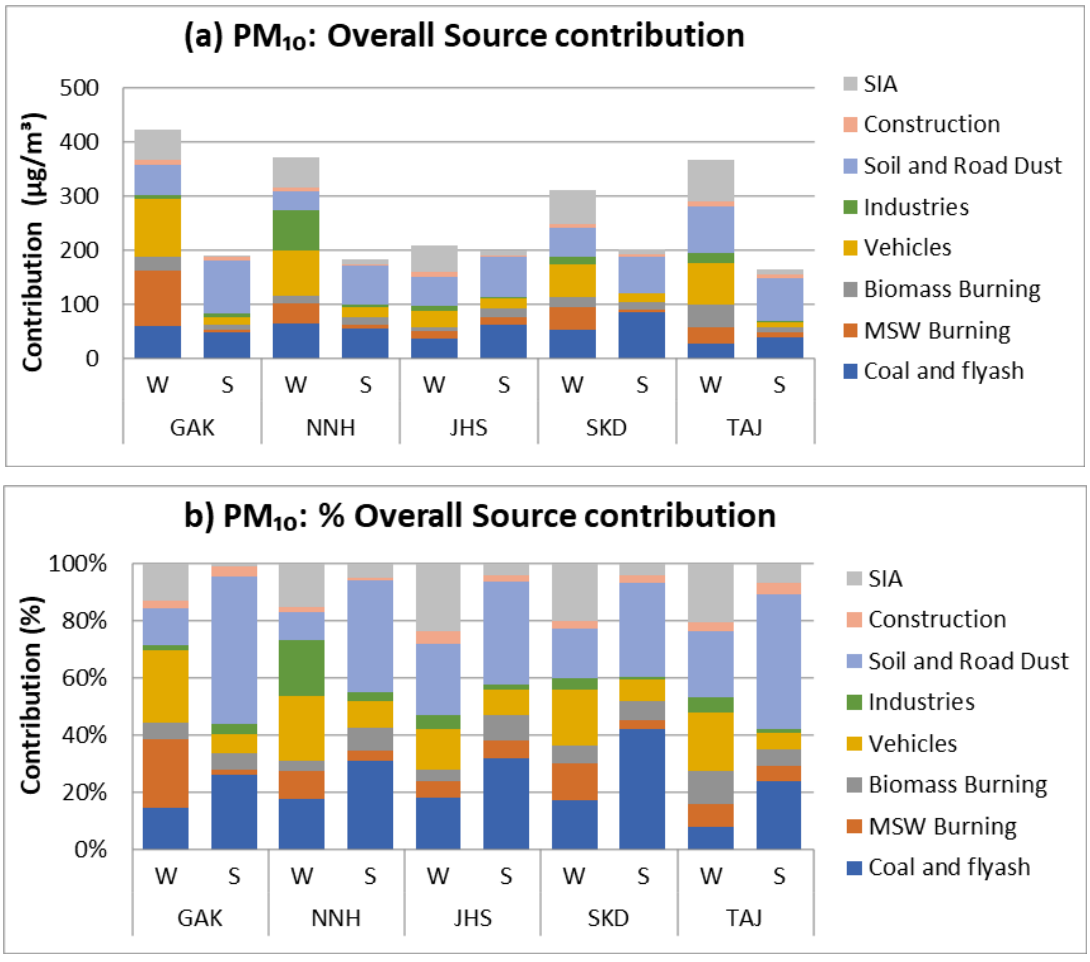


Figure 4.33: Overall results of PMF modeling for PM_{10}

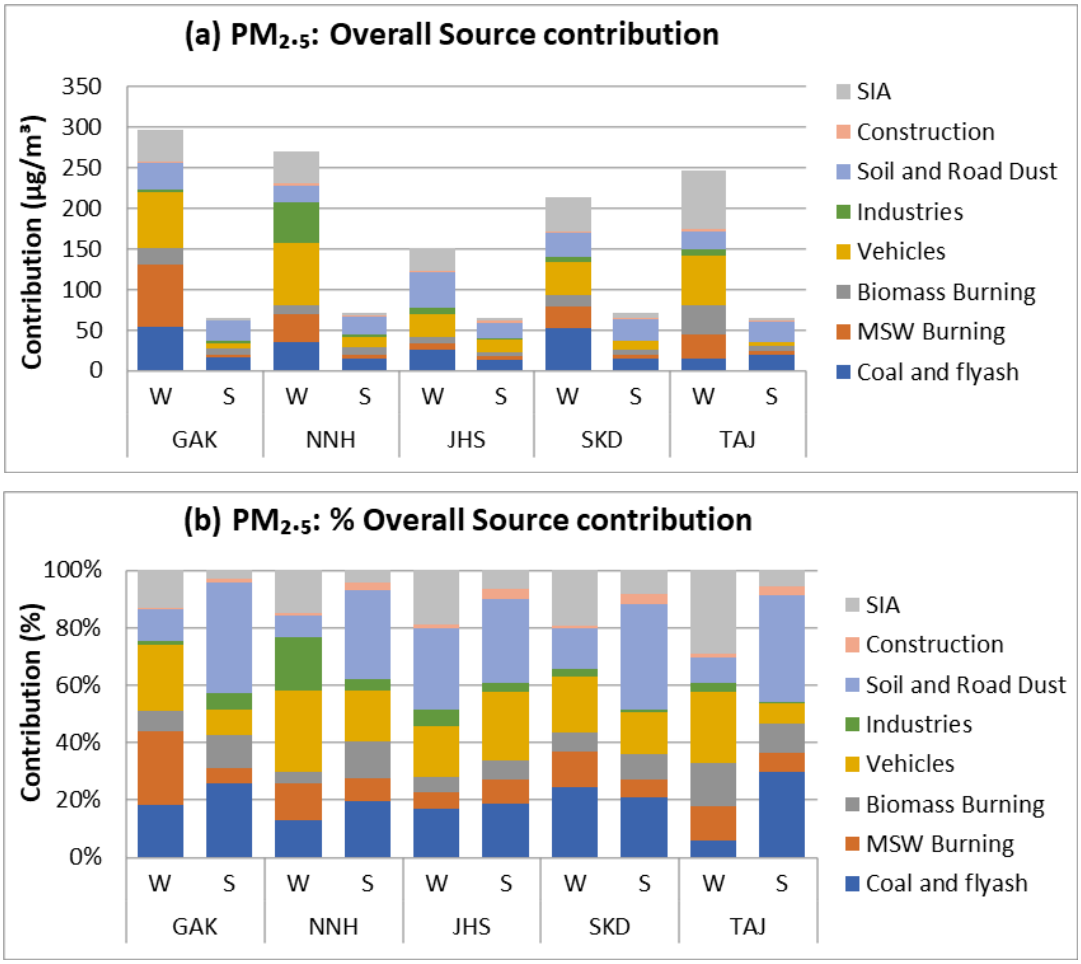
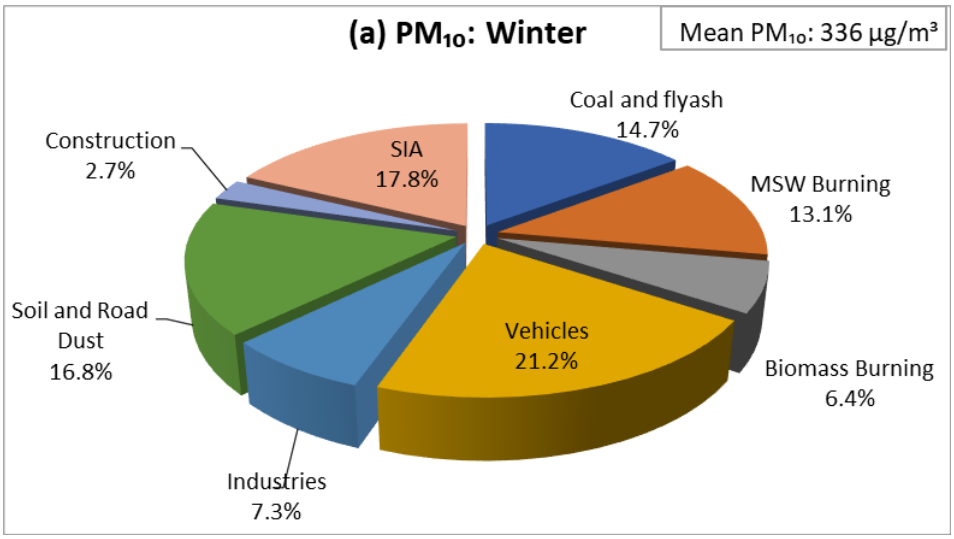


Figure 4.34: Overall results of PMF modeling for $PM_{2.5}$



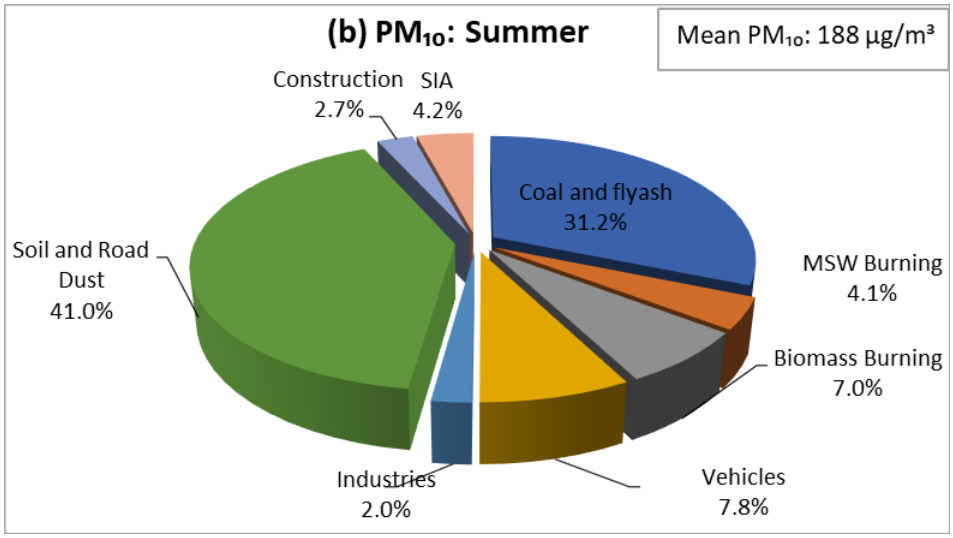


Figure 4.35: Overall source contribution to PM_{10} in (a) winter and (b) summer

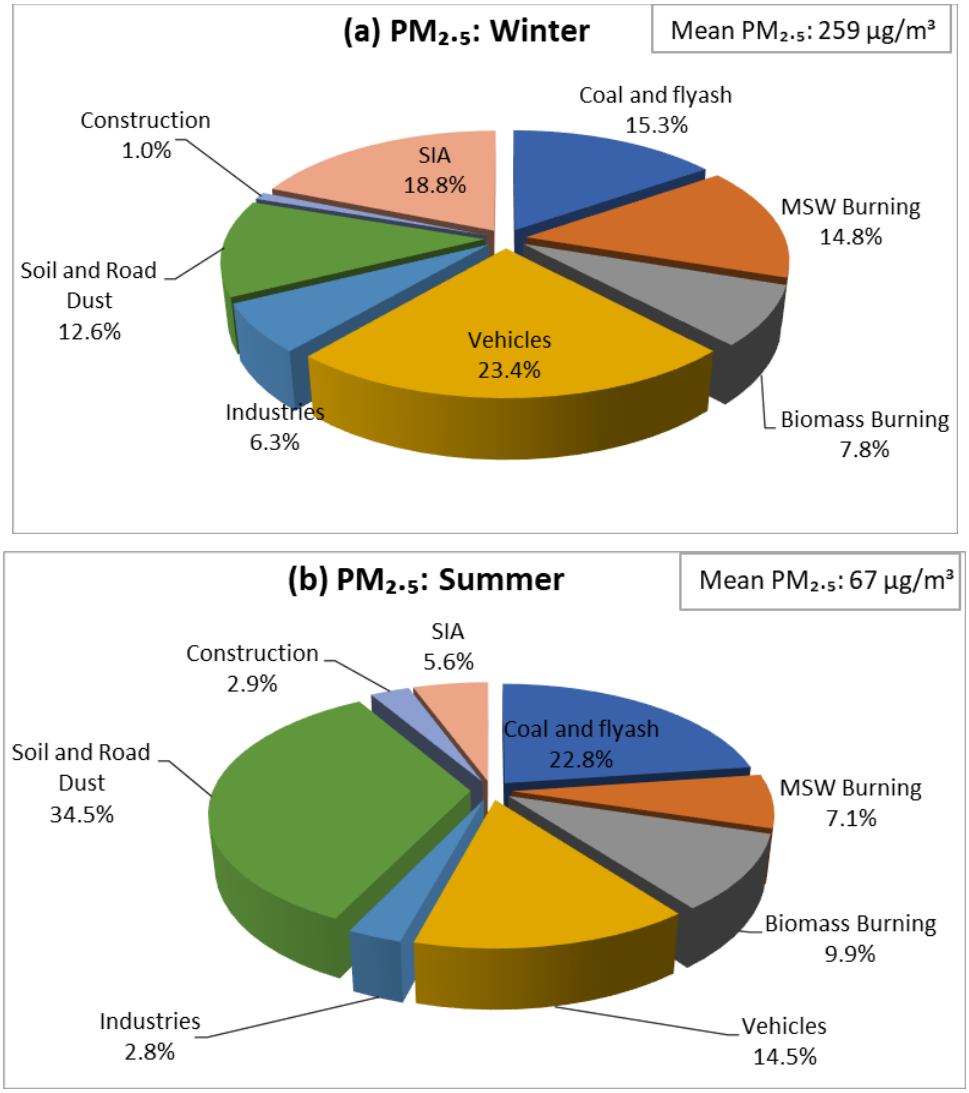


Figure 4.36: Overall source contribution to $PM_{2.5}$ in (a) winter and (b) summer

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

Site location	Parameter	Measured PM_{10} ($\mu g/m^3$)	Calculated PM_{10} ($\mu g/m^3$)	% Mass	% Source Contribution							
					Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	Mean	423	425	101.0	14.4	24.2	5.6	25.4	1.8	13.1	2.3	13.2
	SD	100	93	5.2	10.7	9.8	4.6	9.7	1.0	8.6	1.5	7.3
	CV	0.24	0.22	0.05	0.74	0.40	0.81	0.38	0.57	0.65	0.63	0.55
	Max	595	564	111.9	39.3	39.7	19.2	43.1	3.8	26.8	5.4	24.5
	Min	211	228	93.4	3.4	11.8	0.0	6.9	0.4	0.0	0.0	0.0
NNH	Mean	372	379	102.4	17.7	9.6	3.8	22.6	19.6	9.7	1.9	15.1
	SD	94	88	4.2	5.6	8.6	2.8	14.6	8.6	6.7	1.9	14.3
	CV	0.25	0.23	0.04	0.31	0.89	0.72	0.65	0.44	0.69	0.99	0.95
	Max	516	515	110.7	31.8	39.4	8.6	57.7	36.3	26.8	6.4	56.9
	Min	192	210	93.1	11.0	0.8	0.0	0.6	3.5	0.8	0.0	0.0
JHS	Mean	209	213	102.4	18.2	5.7	3.8	14.2	5.0	24.8	4.4	23.8
	SD	46	45	4.3	4.0	4.0	2.9	9.2	4.9	12.8	6.0	6.9
	CV	0.22	0.21	0.04	0.22	0.69	0.76	0.65	0.99	0.52	1.37	0.29
	Max	293	285	108.7	26.7	14.9	10.5	33.7	20.4	42.9	27.5	38.1
	Min	126	134	94.2	10.1	0.0	0.4	2.1	0.7	0.3	0.0	10.1
SKD	Mean	312	305	99.5	17.5	12.8	6.3	19.5	4.1	17.1	2.5	20.2
	SD	162	139	7.7	7.8	7.8	4.2	11.8	3.6	8.9	1.8	11.0
	CV	0.52	0.46	0.08	0.45	0.61	0.67	0.60	0.88	0.52	0.72	0.54
	Max	929	792	113.2	37.7	29.4	17.0	52.5	13.5	42.5	6.8	38.8
	Min	132	137	83.1	7.4	2.6	1.9	0.8	0.0	1.1	0.0	4.4
TAJ	Mean	366	372	101.5	7.8	8.3	11.4	20.4	5.4	23.2	3.0	20.5
	SD	77	78	3.8	4.5	3.6	3.8	10.2	4.0	4.9	1.0	9.5
	CV	0.21	0.21	0.04	0.58	0.44	0.34	0.50	0.75	0.21	0.34	0.47
	Max	521	516	108.1	14.9	13.8	18.6	39.1	17.0	35.3	5.7	38.6
	Min	252	255	96.3	2.2	3.2	5.7	0.4	1.4	14.2	2.1	7.6

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

Site location	Parameter	Measured PM_{10} ($\mu g/m^3$)	Calculated PM_{10} ($\mu g/m^3$)	% Mass	% Source Contribution							
					Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	Mean	189	195	102.9	25.9	2.1	5.6	6.6	3.8	51.3	3.6	1.1
	SD	96	99	5.0	11.6	1.3	4.2	7.8	2.2	16.9	3.2	2.2
	CV	0.51	0.51	0.05	0.45	0.63	0.75	1.17	0.58	0.33	0.88	2.06
	Max	479	484	113.5	52.3	5.7	12.9	23.8	8.2	82.7	9.4	8.1
	Min	91	98	94.5	6.1	0.5	0.7	0.2	0.9	20.1	0.0	0.0
NNH	Mean	182	183	101.1	30.9	3.8	7.9	9.4	2.9	39.1	1.2	4.8
	SD	57	53	4.1	8.3	1.8	3.3	7.8	1.5	12.8	1.7	3.9
	CV	0.31	0.29	0.04	0.27	0.47	0.42	0.83	0.53	0.33	1.34	0.80
	Max	308	279	107.6	51.5	7.1	15.4	23.6	6.3	56.7	7.2	13.8
	Min	113	119	90.6	13.9	0.4	3.7	0.0	0.4	16.0	0.0	0.0
JHS	Mean	200	207	103.6	31.7	6.3	8.9	9.1	1.4	36.3	1.9	4.3
	SD	42	43	4.0	4.0	3.1	3.2	6.6	0.8	12.2	1.5	4.4
	CV	0.21	0.21	0.04	0.13	0.49	0.35	0.73	0.59	0.34	0.76	1.03
	Max	273	282	110.5	39.0	11.1	15.4	26.1	3.6	52.6	5.9	16.1
	Min	136	138	92.2	23.3	2.2	2.1	0.9	0.3	4.8	0.0	0.0
SKD	Mean	201	203	101.1	42.3	2.9	6.6	7.6	1.1	32.6	2.7	4.2
	SD	60	59	6.0	6.8	1.5	3.3	6.5	1.1	13.2	2.3	3.2
	CV	0.30	0.29	0.06	0.16	0.51	0.50	0.86	1.02	0.40	0.84	0.75
	Max	314	320	110.6	52.7	6.7	15.9	19.9	4.6	52.2	9.1	10.5
	Min	73	67	89.9	28.6	0.8	0.5	0.0	0.2	0.0	0.6	0.0
TAJ	Mean	166	167	101.7	23.7	5.5	5.8	5.8	1.1	47.2	3.9	6.9
	SD	63	64	7.2	8.2	1.6	2.8	5.5	0.8	15.6	5.4	4.9
	CV	0.38	0.38	0.07	0.35	0.30	0.49	0.93	0.72	0.33	1.37	0.72
	Max	364	381	125.9	49.1	9.5	10.1	21.5	3.1	67.7	15.7	16.0
	Min	53	67	92.9	12.5	2.2	0.8	0.0	0.0	0.0	0.0	0.0

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

Site location	Parameter	Measured $PM_{2.5}$ ($\mu g/m^3$)	Calculated $PM_{2.5}$ ($\mu g/m^3$)	% Mass	% Source Contribution							
					Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	Mean	296	292	100.1	18.4	25.4	7.3	22.9	1.2	11.2	0.6	13.0
	SD	76	64	7.8	13.5	9.7	5.4	13.0	1.1	8.5	1.2	5.7
	CV	0.26	0.22	0.08	0.73	0.38	0.74	0.57	0.87	0.75	1.94	0.44
	Max	436	389	108.0	63.2	36.0	20.5	41.9	4.0	27.7	3.9	24.9
	Min	144	155	78.4	7.2	3.8	0.6	0.0	0.0	0.0	0.0	0.0
NNH	Mean	270	274	102.2	12.8	13.0	4.1	28.4	18.4	7.3	1.1	14.9
	SD	87	83	5.4	9.0	9.5	3.3	13.8	8.3	6.1	1.9	14.7
	CV	0.32	0.30	0.05	0.70	0.73	0.82	0.49	0.45	0.84	1.71	0.99
	Max	406	411	111.6	47.0	36.3	12.8	53.5	33.5	23.9	8.4	61.2
	Min	82	91	91.6	7.1	3.7	0.0	7.7	3.3	0.0	0.0	0.0
JHS	Mean	150	153	102.4	17.0	5.6	5.3	18.0	5.4	28.6	1.1	19.0
	SD	47	46	6.5	7.6	4.1	4.8	11.4	6.1	9.6	0.8	9.0
	CV	0.31	0.30	0.06	0.45	0.72	0.91	0.63	1.12	0.34	0.74	0.47
	Max	236	227	123.0	41.1	18.4	21.3	38.9	21.7	42.8	3.4	32.8
	Min	67	71	92.4	7.7	0.3	0.0	2.6	0.0	0.0	0.0	0.0
SKD	Mean	213	211	100.3	24.4	12.3	6.6	19.5	2.7	14.2	0.6	19.6
	SD	70	66	9.1	12.0	4.1	6.0	12.9	2.3	7.6	0.7	9.7
	CV	0.33	0.31	0.09	0.49	0.33	0.90	0.66	0.86	0.53	1.18	0.49
	Max	375	352	119.4	51.5	20.9	28.6	57.3	9.6	26.6	2.5	40.8
	Min	104	111	81.5	12.7	6.6	0.8	0.3	0.0	0.0	0.0	0.0
TAJ	Mean	366	372	101.5	5.7	12.1	14.9	25.0	3.0	8.8	1.4	29.2
	SD	77	78	3.8	5.9	6.5	4.9	12.2	1.7	6.4	1.3	8.5
	CV	0.21	0.21	0.04	1.05	0.54	0.33	0.49	0.59	0.73	0.95	0.29
	Max	521	516	108.1	20.1	25.9	25.9	39.6	5.6	17.9	3.6	44.7
	Min	252	255	96.3	0.3	3.0	9.0	0.0	0.0	0.0	0.0	15.4

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

Site location	Parameter	Measured $PM_{2.5}$ ($\mu g/m^3$)	Calculated $PM_{2.5}$ ($\mu g/m^3$)	% Mass	% Source Contribution							
					Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	Mean	64	66	102.4	25.5	5.6	11.3	8.8	5.9	38.4	1.4	3.0
	SD	18	22	9.9	5.1	2.2	4.1	9.5	3.1	11.4	0.5	4.9
	CV	0.29	0.33	0.10	0.20	0.39	0.36	1.08	0.53	0.30	0.36	1.63
	Max	121	133	125.6	39.3	9.6	19.6	26.6	13.1	52.5	2.7	13.7
	Min	42	42	85.8	18.6	2.5	3.6	0.0	1.2	15.7	0.4	0.0
NNH	Mean	71	75	105.6	19.6	8.0	12.8	17.6	3.7	31.2	2.7	4.2
	SD	30	30	8.1	6.8	4.1	6.0	9.2	2.1	7.1	0.7	4.9
	CV	0.42	0.40	0.08	0.35	0.50	0.47	0.52	0.56	0.23	0.26	1.15
	Max	189	193	123.0	38.9	19.7	25.7	35.3	8.9	55.2	4.2	17.2
	Min	44	52	90.2	6.8	3.6	4.5	0.4	0.6	21.6	1.0	0.0
JHS	Mean	65	68	105.1	18.7	8.5	6.5	23.9	3.2	29.3	3.5	6.5
	SD	12	10	12.6	5.7	3.9	3.8	5.9	2.0	5.1	0.8	5.8
	CV	0.18	0.15	0.12	0.30	0.46	0.58	0.25	0.65	0.17	0.23	0.89
	Max	89	89	133.3	28.8	16.5	15.0	33.3	7.7	38.0	5.4	16.7
	Min	47	49	83.2	6.7	3.0	1.9	14.0	0.2	20.2	2.5	0.0
SKD	Mean	71	68	96.5	20.9	6.2	9.0	14.3	0.9	36.7	3.6	8.4
	SD	23	21	8.0	9.0	2.1	3.3	9.4	0.9	6.2	1.2	6.0
	CV	0.32	0.31	0.08	0.43	0.34	0.37	0.66	1.07	0.17	0.33	0.72
	Max	143	145	113.7	52.8	10.5	17.6	31.3	4.1	47.0	7.9	19.1
	Min	35	37	79.2	7.4	2.1	4.8	0.2	0.0	25.3	1.7	0.0
TAJ	Mean	65	70	108.2	29.5	6.9	9.9	7.2	0.7	37.0	3.3	5.5
	SD	18	19	6.7	9.6	3.4	3.7	7.9	1.5	8.5	0.9	6.1
	CV	0.28	0.27	0.06	0.32	0.49	0.37	1.09	2.29	0.23	0.29	1.10
	Max	106	107	121.7	53.2	17.3	18.7	32.0	6.1	55.3	5.5	19.1
	Min	30	31	94.7	18.6	2.0	5.1	0.8	0.0	25.3	2.0	0.0

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

Site location	PM_{10} (µg/m^3)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	423	60.8	102.5	23.9	107.3	7.6	55.6	9.7	55.7
NNH	372	65.7	35.9	14.3	84.1	72.8	36.0	7.1	56.1
JHS	209	38.1	11.9	7.9	29.7	10.4	51.8	9.2	49.8
SKD	312	54.4	40.0	19.7	60.8	12.7	53.5	7.8	63.1
TAJ	366	28.6	30.3	41.8	74.5	19.6	85.1	11.0	74.9
Overall	336	49.6	44.1	21.5	71.3	24.7	56.4	9.0	59.9
SD	81	15.7	34.3	12.8	28.8	27.3	17.8	1.6	9.6

Table 4.6: Percentage apportionment: winter PM_{10}

Site location	PM_{10} (µg/m^3)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	423	14.4	24.2	5.6	25.4	1.8	13.1	2.3	13.2
NNH	372	17.7	9.6	3.8	22.6	19.6	9.7	1.9	15.1
JHS	209	18.2	5.7	3.8	14.2	5.0	24.8	4.4	23.8
SKD	312	17.5	12.8	6.3	19.5	4.1	17.1	2.5	20.2
TAJ	366	7.8	8.3	11.4	20.4	5.4	23.2	3.0	20.5
Overall	336	15.1	12.1	6.2	20.4	7.2	17.6	2.8	18.6
SD	81	4.3	7.2	3.1	4.1	7.1	6.5	1.0	4.3

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

Site location	$PM_{2.5}$ (µg/m^3)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	296	54.4	75.3	21.5	67.6	3.6	33.3	1.8	38.4
NNH	270	34.4	35.0	11.0	76.6	49.7	19.8	3.0	40.3
JHS	150	25.5	8.4	7.9	27.1	8.2	43.0	1.7	28.6
SKD	213	52.0	26.1	14.1	41.5	5.7	30.2	1.3	41.7
TAJ	366	13.9	29.6	36.7	61.5	7.3	21.7	3.4	71.8
Overall	259	36.0	34.9	18.2	54.9	14.9	29.6	2.3	44.2
SD	82	17.3	24.7	11.5	20.2	19.6	9.4	0.9	16.3

Table 4.8: Percentage apportionment: winter $PM_{2.5}$

Site location	$PM_{2.5}$ (µg/m^3)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	296	18.4	25.4	7.3	22.9	1.2	11.2	0.6	13.0
NNH	270	12.8	13.0	4.1	28.4	18.4	7.3	1.1	14.9
JHS	150	17.0	5.6	5.3	18.0	5.4	28.6	1.1	19.0
SKD	213	24.4	12.3	6.6	19.5	2.7	14.2	0.6	19.6
TAJ	366	5.7	12.1	14.9	25.0	3.0	8.8	1.4	29.2
Overall	259	15.6	13.7	7.6	22.8	6.1	14.0	1.0	19.1
SD	82	7.0	7.2	4.3	4.2	7.0	8.5	0.3	6.3

Table 4.9: Concentration apportionment: summer PM_{10} (Concentration in $\mu g/m^3$)

Site location	PM_{10} ($\mu g/m^3$)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	189	49.1	3.9	10.7	12.6	7.2	97.1	6.8	2.0
NNH	182	56.3	7.0	14.4	17.1	5.3	71.3	2.3	8.8
JHS	200	63.3	12.7	17.8	18.2	2.8	72.6	3.8	8.5
SKD	201	85.1	5.8	13.3	15.4	2.1	65.7	5.5	8.5
TAJ	166	39.4	9.1	9.6	9.7	1.9	78.3	6.5	11.4
Overall	188	58.6	7.7	13.2	14.6	3.8	77.0	5.0	7.8
SD	15	17.2	3.4	3.2	3.5	2.3	12.1	1.9	3.5

Table 4.10: Percentage apportionment: summer PM_{10}

Site location	PM_{10} ($\mu g/m^3$)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	189	25.9	2.1	5.6	6.6	3.8	51.3	3.6	1.1
NNH	182	30.9	3.8	7.9	9.4	2.9	39.1	1.2	4.8
JHS	200	31.7	6.3	8.9	9.1	1.4	36.3	1.9	4.3
SKD	201	42.3	2.9	6.6	7.6	1.1	32.6	2.7	4.2
TAJ	166	23.7	5.5	5.8	5.8	1.1	47.2	3.9	6.9
Overall	188	30.9	4.1	7.0	7.7	2.1	41.3	2.7	4.2
SD	15	7.2	1.8	1.4	1.5	1.2	7.7	1.1	2.1

Table 4.11: Concentration apportionment: summer $PM_{2.5}$ (Concentration in µg/m^3)

Site location	$PM_{2.5}$ (µg/m^3)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	64	16.3	3.6	7.2	5.6	3.8	24.5	0.9	1.9
NNH	71	14.0	5.7	9.1	12.6	2.7	22.2	2.0	3.0
JHS	65	12.2	5.5	4.2	15.6	2.1	19.1	2.3	4.2
SKD	71	14.8	4.4	6.4	10.1	0.6	26.0	2.6	6.0
TAJ	65	19.2	4.5	6.4	4.7	0.4	24.0	2.1	3.6
Overall	67	15.3	4.7	6.7	9.7	1.9	23.2	2.0	3.7
SD	4	2.6	0.9	1.7	4.6	1.4	2.6	0.6	1.5

Table 4.12: Percentage apportionment: summer $PM_{2.5}$

Site location	$PM_{2.5}$ (µg/m^3)	Coal and flyash	MSW Burning	Biomass Burning	Vehicles	Industries	Soil and Road Dust	Construction	SIA
GAK	64	25.5	5.6	11.3	8.8	5.9	38.4	1.4	3.0
NNH	71	19.6	8.0	12.8	17.6	3.7	31.2	2.7	4.2
JHS	65	18.7	8.5	6.5	23.9	3.2	29.3	3.5	6.5
SKD	71	20.9	6.2	9.0	14.3	0.9	36.7	3.6	8.4
TAJ	65	29.5	6.9	9.9	7.2	0.7	37.0	3.3	5.5
Overall	67	22.9	7.0	9.9	14.4	2.9	34.5	2.9	5.5
SD	4	4.6	1.2	2.4	6.8	2.2	4.0	0.9	2.1

4.6 Interpretations and Inferences

Based on the PMF modeling results (Figures 4.33 to 4.36) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and pave the path for preparing an action plan. Tables 4.5 to 4.12 show season-wise, site-specific average source contribution to PM_{10} and $PM_{2.5}$, and these tables are frequently referred to bring the important inferences to the fore.

- The sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter.
    - In winter, % contribution of PM_{10} – $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: vehicles (20 – 23%), secondary inorganic aerosol (SIA) (19 – 19%), soil and road dust (18 – 14%), coal and fly ash (15 – 16%; includes ash from burning of residual oil), MSW burning (12 - 14%), biomass burning (6 – 8%), industrial (7 – 6%; also includes the contribution from trye wear and burning) and construction material (3 – 1%). It is noteworthy, in winter, major sources for PM_{10} and $PM_{2.5}$ are generally the same.
    - In summer, % contribution of PM_{10} - $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: soil and road dust (41 – 35%), coal and fly ash (31 - 23%; includes burning of residual oil), vehicles (8 – 14%), biomass burning (7 - 10%), MSW burning (4 – 7%), SIA (4 - 6%), industrial (2 – 3%) and construction material (3 – 3%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The most consistent sources for PM_{10} and $PM_{2.5}$ in both seasons are soil and road dust (including construction material), SIA, vehicles that includes a small contribution (less than 0.1%) of DG sets, coal and fly ash and industry. The other sources on average may contribute more (or less), but their contributions are variable from one day to another.
- The consistent presence of biomass and MSW burning (in $PM_{2.5}$) at all sites envelops the entire region.
- In summer, soil and road dust, coal and fly ash and construction activities contribute 75% to PM_{10} and 60% to $PM_{2.5}$. It is observed that in summer, the atmosphere looks brownish indicating presence of large amounts of dust. In winter, the contributions of

coal and fly ash, soil and road dust and construction material reduce significantly both in PM_{10} and $PM_{2.5}$ (by 36 and 31%) when winds are low and prevalent atmospheric conditions are calm.

- Coal and fly ash (includes residual oil) are the second most contributor to PM_{10} and $PM_{2.5}$ in summer. High and consistent contributions suggest the combustion of coal in different sectors, i.e., hotel and restaurants, industries, and brick kilns within the 50 km radius of the city.
- The contribution of the biomass burning in summer is at 10% (for $PM_{2.5}$) and 7% (for PM_{10}) and in winter at 8% (for PM_{10}) and 6% (for $PM_{2.5}$). The presence of sizeable biomass is consistent in winter and summer, indicates that local sources present in Agra and nearby areas.
- The contribution of MSW burning is higher in the winter than in the summer. In winter, contribution of MSW burning is very high at GAK in $PM_{10} – PM_{2.5}$ (24 – 25%) followed by SKD (13 – 12%) and NNH (10 – 13%). In summer, contribution of MSW burning varied 2 - 6% in PM_{10} and 6 - 8% in $PM_{2.5.}$ Nagpure et al. (2015) have reported number MSW burning incidents (39 − 202 /km^2/day) and estimated that 223 tons/day of MSW was burnt (∼24% of 923 tons/day of generated MSW).
- The Industrial contribution (including the contribution of tyre wear and burning) is high in winter months (7 − 6%) in $PM_{10} − PM_{2.5}$. The maximum contribution was in winter at NNH; $PM_{2.5}$ (18%) and PM_{10} (20%)

Directions for PM control

- Soil and road dust

  In summer, this source contributes about 41% to PM_{10}. The silt load on most of the roads is very high and silt can become airborne with the movement of vehicles. The estimated PM_{10} emission from road dust is about 30 tons per day. Similarly, soil from the open fields gets airborne in summer. The potential control options can be sweeping and watering of roads, better construction and maintenance, growing plants, grass etc., to prevent re-suspension of dust.

- Coal and fly ash

In summer, coal and fly ash contribute about 31% to PM_{10} and 23% to $PM_{2.5}$. It is a fugitive non-point source. Fly ash emissions from hotels, restaurants, tandoors, brick kilns (within 50 km radius) and some unauthorized use of coal cause emissions and require better housekeeping, fly ash collection, disposal and adoption of improved zigzag technologies in brick kilns. It is important to note that a significant part of fly ash may include construction-related emissions as the cement has up to 35% of fly ash. The construction work of smart city and metro is another potential source of fly ash. It is learnt that there are about 40 registered coal depots in the city. A rough estimate of sale of coal could be 25-30 tonnes per day. A smaller contribution of a large power plant of 665 MW in a 100 km radius is possible in the city depending on meteorology.

- Vehicular pollution

  This source is the third-largest source and most consistently contributing source to PM_{10} and $PM_{2.5}$ in winter and summer. Various control options include the implementation of BS-VI, introduction of electric and hybrid vehicles, traffic planning and restriction of movement of vehicles, retro-fitment in diesel exhaust, improvement in public transport etc. These options are further discussed in Chapter 6.

- 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. All biomass burning in Agra should be banned and strictly implemented.

- MSW burning

  One of the reasons for the burning of MSW/plastic waste is the lack of infrastructure for timely collection of MSW and people conveniently burn or it may smolder slowly for a long time. In this regard, infrastructure for collection and disposal of MSW has to improve and the burning of MSW should be completely banned.

- Secondary particles

What are the sources of secondary particles, the major contributors to Agra's PM? 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, refineries and brick kilns. However, the 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 a significant mass of $PM_{2.5}$ (about 34%) and any particulate control strategy should also include control of primary precursor gases.

- Industrial sources

  The industrial unit in the NNH must comply with the norms notified by the government. There might be some unauthorized industries in the surroundings of JHS and TAJ that must be enforced to close such units. At SKD and JHS, a significant contribution might be from trye wear and burning as there were many open tyre burning incidents seen in the Transport Nagar during the monitoring period situated between these sites. The burning of tyres must stop and be collected at the authorized centers for proper disposal.

The effectiveness of the pollution control options and selection of optimal mix of control options are analyzed in Chapter 6.

5 Dispersion Modeling

5.1 Introduction

The current state-of-the-science, comprehensive meteorological and regulatory air dispersion modeling systems have been used in the study to conduct the dispersion modeling. The American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD) has been used to assess the impact from short-range transport (<50 km) on $PM_{2.5}$ emitting from the sources within the Agra City,

5.1.1 AERMOD

AERMOD is a dispersion model having the ability to characterize the planetary boundary layer (PBL) through both surface and mixed layer scaling. This model is a complete and powerful air dispersion modeling package that seamlessly incorporates the following popular United States Environmental Protection Agency (EPA) air dispersion models into one integrated interface:

- AERMOD
- ISCST3
- ISC-PRIME

The AERMOD modeling system consists of one main program (AERMOD) and two pre-processors (AERMET and AERMAP). AERMOD uses terrain, boundary layer, and source data to model pollutant transport and dispersion for calculating temporally averaged air pollution concentrations.

The approach for modeling using AERMOD is shown in Figure 5.1. Onsite hourly meteorological data was generated by the WRF model. The model run was performed for a defined study period (the year 2018). The output of the WRF model was fed as the input of AERMOD in the pre-processor RAMMET and AERMET of the model. The observed meteorological data was collected from the UPPCB monitoring station located at Sanjay Palace, Agra and compared with the WRF results for validation.

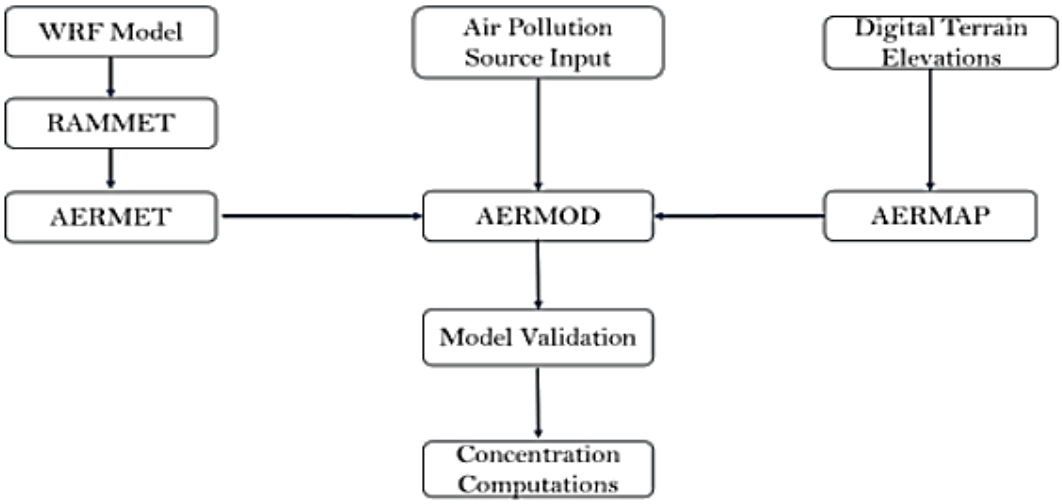


Figure 5.1: Approach for Dispersion Modelling using AERMOD

The meteorological parameters from the WRF model (wind speed, wind direction, rainfall, temperature, humidity, pressure, ceiling height, global horizontal radiation, and cloud cover) with one-hour resolution were organized in a spreadsheet. This spreadsheet was reprocessed in AERMET, which is the meteorological pre-processor of AERMOD. The terrain data at 90 m resolution of Shuttle Radar Topography Mission (SRTM) was used in AERMAP, which is also the pre-processor of AERMOD. This provided a physical relationship between terrain features and the behavior of air pollution plumes and generated location and height data for each receptor location. AERMOD was further used to model air quality in the study for the prediction of pollutants concentration from different sources within the Agra City.

5.2 Meteorological Data

In evaluating the emission dispersion using the AERMOD, the meteorological dataset was generated using the WRF model from January 01, 2018 to December 30, 2018. The frequency distribution and frequency count data were obtained by processing the hourly surface file in AERMET. The AERMET program is a meteorological pre-processor that prepares hourly surface data and upper-air data for use in the USEPA air quality dispersion model, AERMOD.

The wind rose plots for winter (January, February, October, November and December) and summer (March, April, May and June) months of 2018 are shown in Figure 5.2. The predominant wind blowing direction was observed to be northwest in all the winter and summer months. Also, a relatively high wind speed was observed in the summer season. The modeled

wind speed and ambient temperature data were validated using the data obtained from the UPPCB's ambient air quality monitoring station located at Sanjay Palace, Agra. In addition, the 24-hour moving average from hourly wind speed data for each month of 2018 was also plotted (Figure 5.3). The Pearson's correlation coefficient (R), normalized mean square error (NMSE), and fractional bias (FB) were calculated for winter and summer month's hourly wind speed data to assess the model performance (Table 5.1). The quality of an ideal and perfect model is to have both the fractional bias and normalized mean square error equal to zero. The performance of a model can be deemed as acceptable if, NMSE ≤ 0.5, and $-0.5 \leq FB \leq +0.5$.

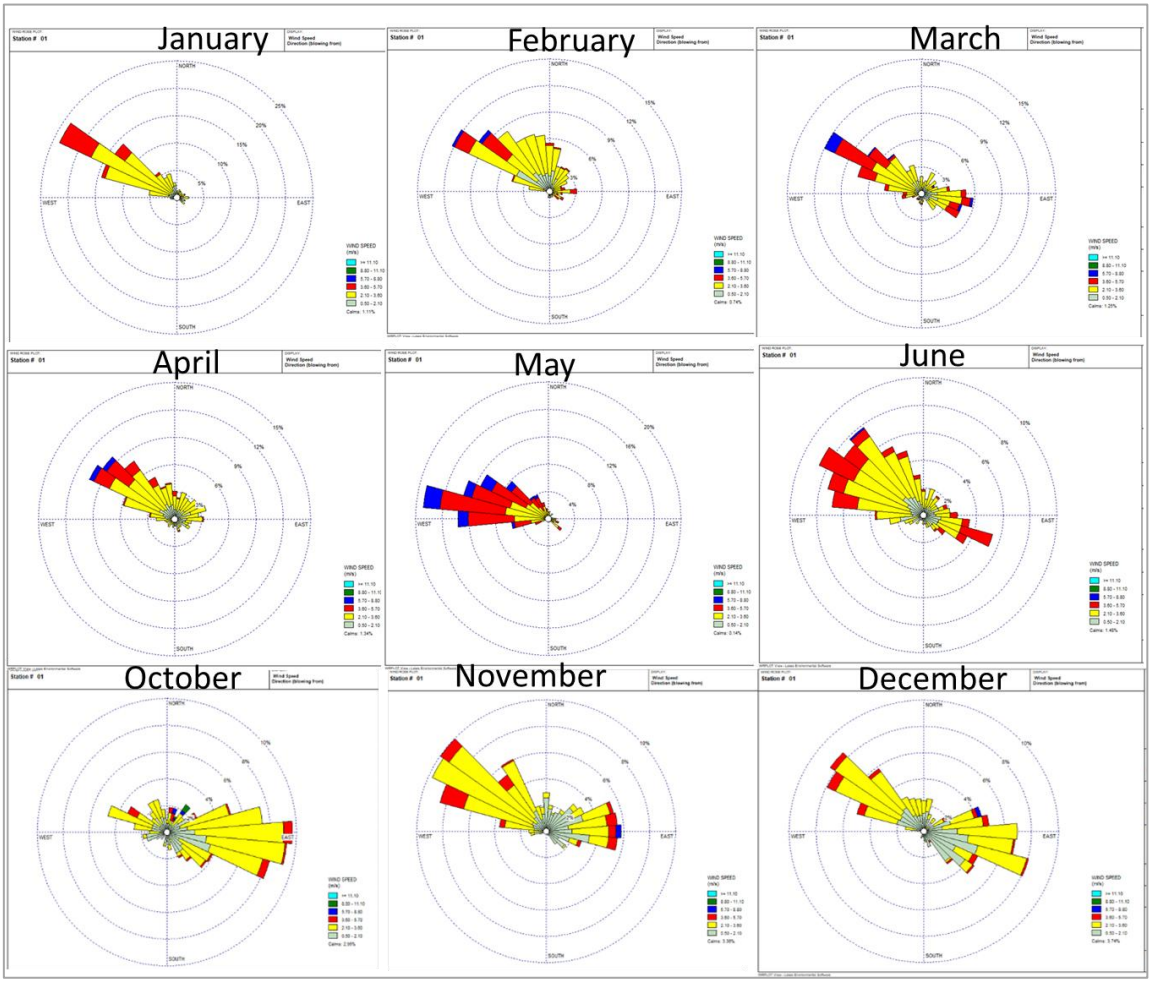


Figure 5.2: Wind Rose Plots for winter and summer months for 2018

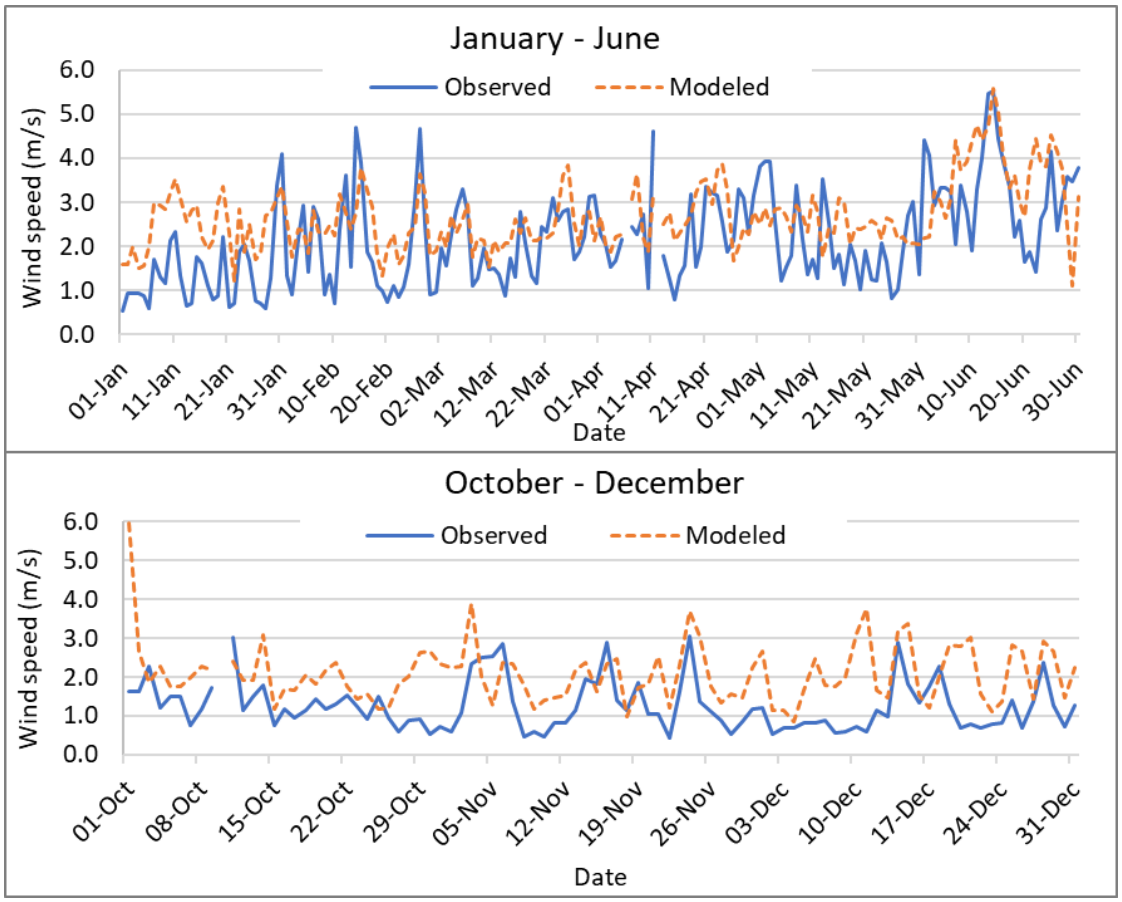


Figure 5.3: Time-Series Plot of 24-hour mean wind speed (Modeled vs. Observed) for winter and summer months, 2018

Table 5.1: Statistical summary of wind speed for WRF validation

Months	Observed (m/s)	Modeled (m/s)	NMSE	FB	R
January	1.36	2.45	0.79	0.57	0.48
February	1.99	2.44	0.51	-0.20	0.51
March	2.06	2.38	0.55	0.14	0.29
April	2.28	2.68	0.42	0.16	0.36
May	2.01	2.50	0.68	0.22	0.11
June	3.23	3.71	0.32	0.14	0.24
October	1.25	2.12	1.10	0.52	0.16
November	1.40	2.03	0.71	0.37	0.33
December	1.11	2.12	1.09	0.62	0.24

The model performed satisfactorily for predicting wind speeds in the months of February, March, April and June while overestimating the wind speeds in general. Furthermore, the time-series plot of observed hourly ambient temperature values with modeled values shows a good

agreement for all the months of 2018, four of which are shown in Figure 5.4. The statistical parameters assessing the performance of the model are listed in Table 5.2.

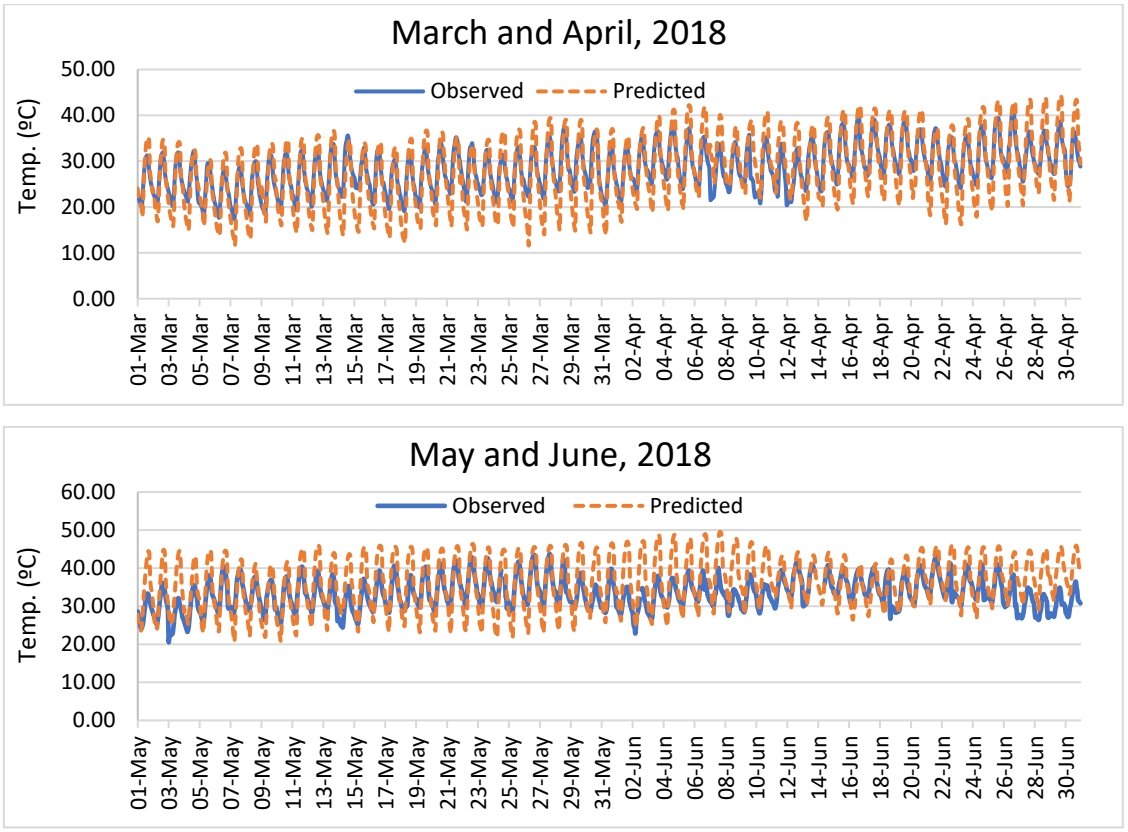


Figure 5.4: Time-Series Plot of Ambient Temperature Data for Four Months of 2018

Table 5.2: Statistical summary of ambient temperature for WRF validation

Months	Observed (°C)	Predicted (°C)	NMSE	FB	R
March	26.46	25.11	0.02	0.05	0.90
April	30.35	30.71	0.02	-0.01	0.85
May	33.00	34.76	0.03	-0.05	0.82
June	33.71	37.52	0.05	-0.11	0.61

It is concluded that model performance to predict wind speed is acceptable. The correlation coefficient is statistically significant and other performance parameters FB and NMSE are acceptable for the months having an acceptable coefficient of correlation.

The model performance for the prediction of temperature is also acceptable with the coefficient of correlation in the range of 0.61 to 0.90 (Table 5.2).

5.3 Digital Elevation Model (DEM) and receptor grid network

The Digital Terrain Elevation Model (DEM) is the most critical information required for complex terrain. The terrain affects the dispersion significantly. DEM is required to predict wind flow patterns and dispersion. AERMOD processes DEM data and creates an elevation and height scale (the terrain height and location that has the greatest influence on dispersion) for each receptor in the domain. The terrain is the vertical dimension of the land surface. Gridded terrain elevations for the proposed modeling domain were derived from 3 arc-second digital elevation models (DEMs) produced by the United States Geological Survey (USGS). The processed terrain elevation data is shown in Figure 5.5. Receptor locations were defined using a set of non-uniform cartesian grid networks, uniform polar grid networks, and discrete cartesian grid networks. Five non-uniform cartesian grid networks (Figure 5.6) were employed to assess the impact within the Agra City boundary and six discrete cartesian receptors (Figure 5.7) were used to assess the impact at the locations where the manual ground observations were being recorded. A total of 333 receptors were defined for the analysis of ground-level $PM_{2.5}$ concentrations.

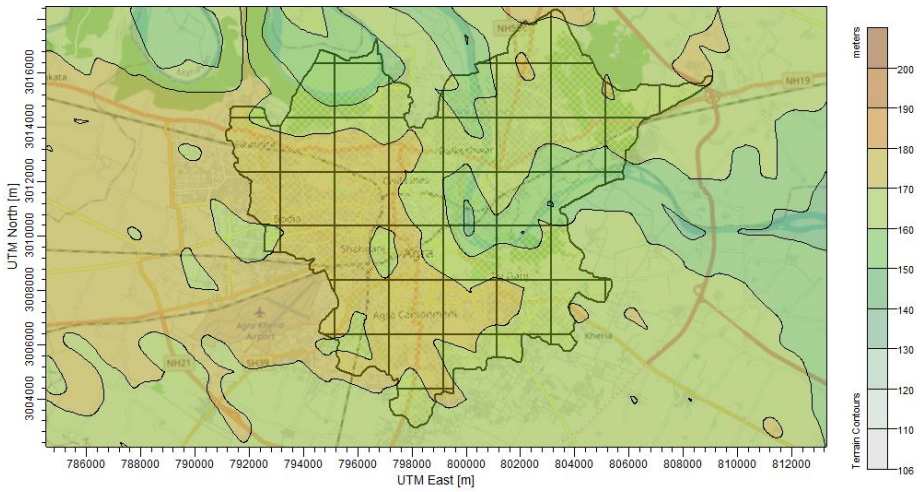


Figure 5.5: Terrain Contour Map of the Agra City

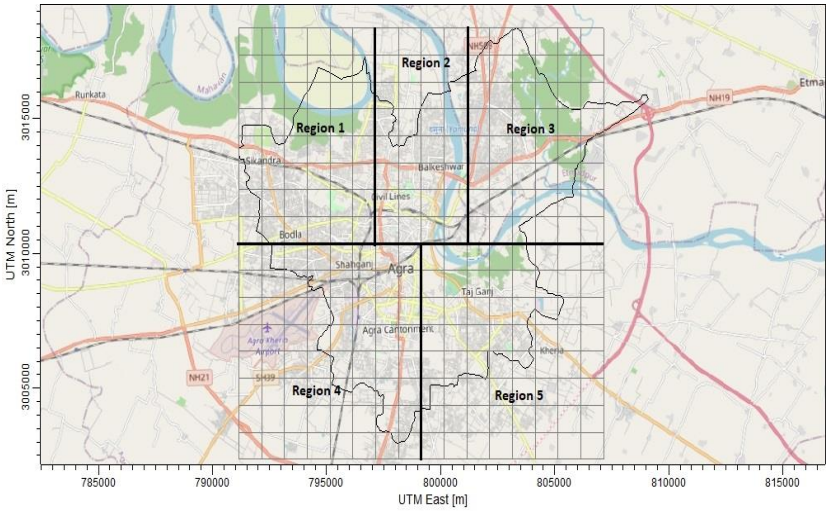


Figure 5.6: Non-Uniform Cartesian Grid Receptor Network

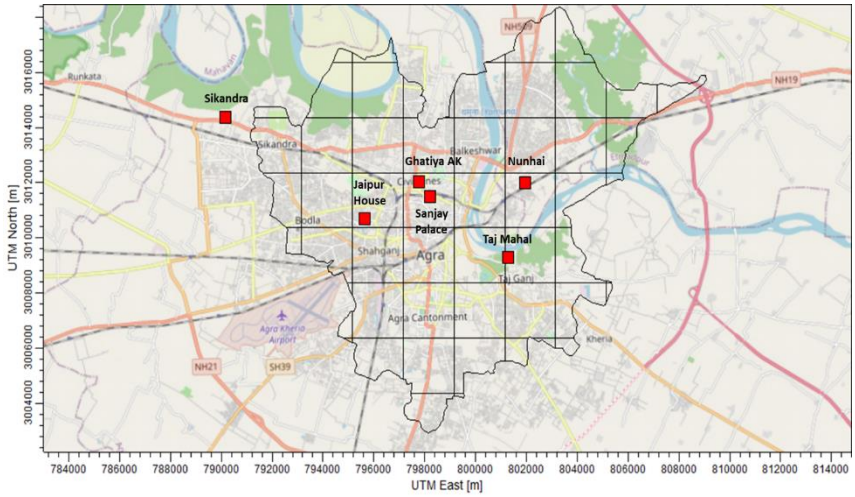


Figure 5.7: Discrete Cartesian Receptor (red squares show where air quality is monitored)

Table 5.3: Receptor Networks defined for Impact Assessment

Receptor Type	No. of Networks	No. of Receptors
Uniform Cartesian Grid	0	-
Non-Uniform Cartesian Grid	5	-
REGION 1	-	63
REGION 2	-	45
REGION 3	-	63
REGION 4	-	81
REGION 5	-	81

5.4 Evaluation of Dispersion Modeling Results

The air dispersion modeling was done with complex terrain (using the elevation heights in Agra City). By this approach, all the elevations of terrain were accounted for, and the air dispersion reflected more accurate results as compared to flat terrain. The model was run considering only the sources within Agra City.

The time-series and scatter plot of 24-hour average $PM_{2.5}$ concentration observed at the UPPCB's continuous ambient monitoring station located at Sanjay Palace, Agra and the modeled $PM_{2.5}$ concentrations considering all the major sources of $PM_{2.5}$ was plotted (Figure 5.8) and it was observed that the model predicted well with a root mean square error of 79.5 $\mu g/m^3$ (Table 5.4). During winter, high concentrations of $PM_{2.5}$ were observed, which the model could not account for. It appeared that there was a significant contribution of sources located outside the Agra City, including the formation of secondary aerosols from distantly located emission sources.

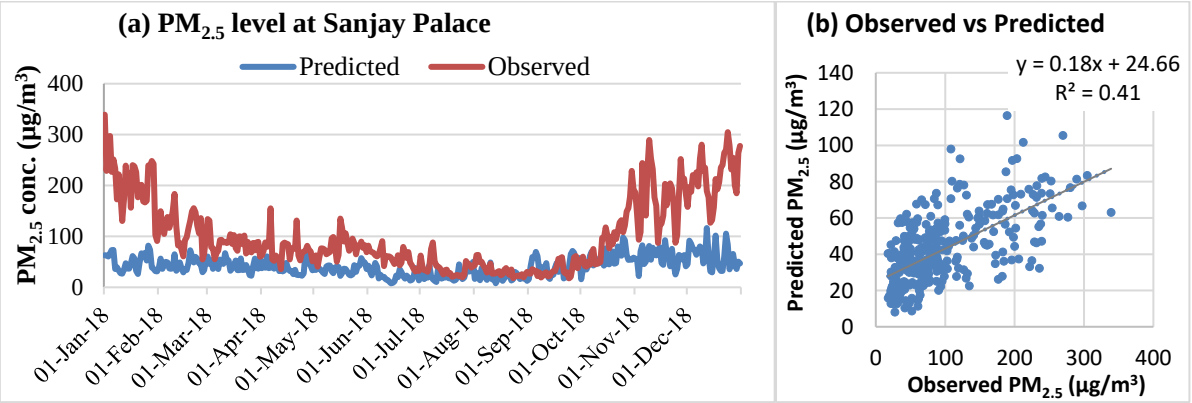


Figure 5.8: (a) Time series plot and (b) scattered plot for observed vs. predicted $PM_{2.5}$ levels at Sanjay Palace in 2018

Table 5.4: Statistical parameters for validation of model for $PM_{2.5}$

Observed Mean $PM_{2.5}$, $\mu g/m^3$	96.7
Predicted Mean $PM_{2.5}$, $\mu g/m^3$	42.5
Mean Bias (MB), $\mu g/m^3$	54.2
Root Mean Square Error (RMSE), $\mu g/m^3$	79.51
Normalised Mean Square Error (NMSE)	1.54
Fractional Bias (FB)	0.78
Pearson Correlation Coefficient (R)	0.64

It is seen (Figure 5.8 (b)) that the modeled and observed $PM_{2.5}$ concentrations show a good association (R^2 =0.414) (for over 350 data points). However, the noteworthy point is that the model under-predicts the concentration by a factor of more than 2. The probable reasons for underestimation by the model are because of (i) over-prediction of wind speed by the WRF model, (ii) inventory may be incomplete and some source may be missing, and (iii) there is a substantial contribution of sources present outside the Agra City. Since the linear association in the model-computed and observed levels is very good, the model could be used for decision-making and useful insights.

The deficit in the model and measured (referred to as unidentified) $PM_{2.5}$ levels were highest during the January-February and November-December months. Also, it is worth noting that there was a sudden spike in these unidentified concentrations of $PM_{2.5}$ during the first week of November. This episodic spike in the unidentified $PM_{2.5}$ concentrations with an average value was 119 $\mu g/m^3$ in the city, which can be attributed to the influx from the surrounding regions outside the city.

5.5 Region-wise impact assessment

Agra City was divided into five regions (Figure 5.9) for a better assessment of the impacts from different sources, which could enable efficient planning of mitigation strategies in these regions. Major localities in these regions are given in Table 5.5. Dispersion modeling was carried out using state-of-the-art models to apportion the contribution of sources (sector-wise; industries, power plants, brick kilns, vehicles, open fires, dust, domestic, etc.) to air pollution in the Agra City.

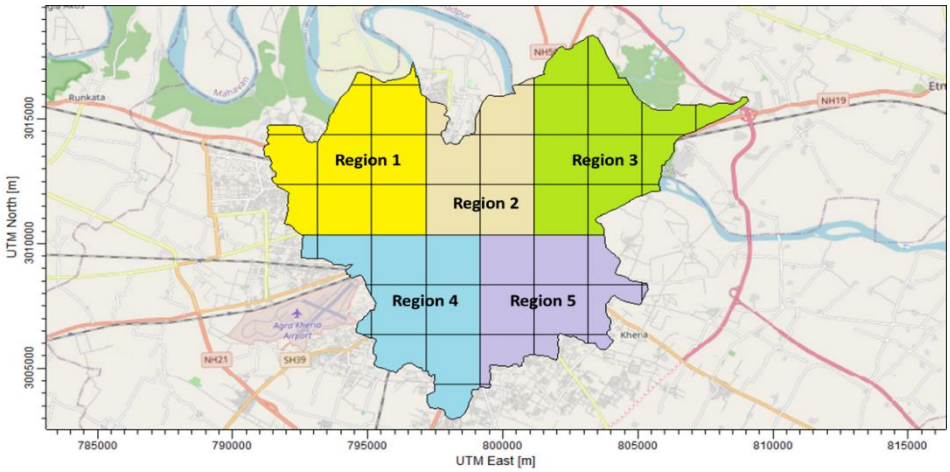


Figure 5.9: Demarcation of Five Regions for Impact Assessment

Table 5.5: Major Localities in Different Regions of Agra

Region 1	Region 2	Region 3	Region 4	Region 5
Transport Nagar	Jeoni Mandi	Tedhi Bagiya	Shahganj	Bijli Ghar
Sikandra	Langde ki Chowki	Nunhai	Bhogipura	Tajganj
Loha Mandi	Ghatia Azam Khan	Trans Yamuna	Chipi Tola	Shaheed Nagar
Awas Vikas	Mantola	Foundary Nagar	Pachkuiyan	Shamsabad Road

The highest 24-hour average $PM_{2.5}$ concentrations were plotted and tabulated for these regions in the winter and summer months of 2018 (Figure 5.10 and Table 5.6). The monthly average $PM_{2.5}$ levels are given in Table 5.7 and percentage contribution from the different sources is given in Table 5.8. It was observed that region 3 has the highest 24-hour average $PM_{2.5}$ concentration among all with an average value of 298 ± 62 µg/m^3 followed by region 2 with 175 ± 63 µg/m^{3}and region 1 with 140 ± 44 µg/m^3. Region 5 has the least 24-hour average $PM_{2.5}$ concentration among all with an average value of 76 ± 24 µg/m^3. The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winters (November to February), while the lowest during the peak summers (May and June).

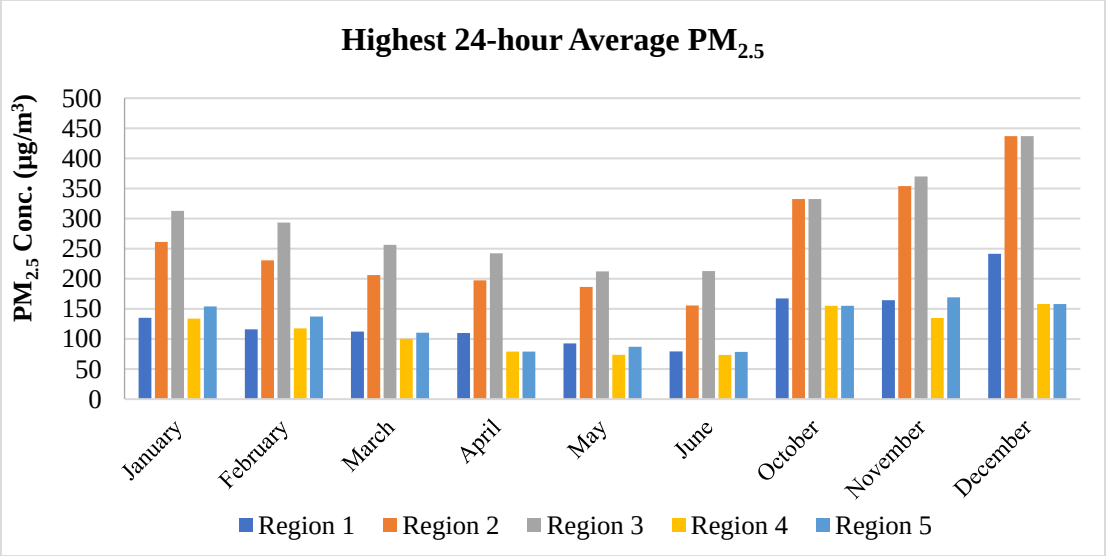


Figure 5.10: Region-wise highest 24-hour average $PM_{2.5}$ levels in 2018

It was observed that the $PM_{2.5}$ concentration in the ambient air increases as the winter season approaches. During peak summer and monsoon seasons, the $PM_{2.5}$ concentration was minimum and increased steadily with the fall in temperature, which promoted stable atmospheric conditions and reduced dispersion of pollutants. From the annual average plot, the envelope of $PM_{2.5}$ concentration was seen to be elongated along the prevailing wind direction (N-E).

Table 5.6: Region-wise highest 24-hour average $PM_{2.5}$ levels in 2018

Months	Concentration (µg/m^3)				
	Region 1	Region 2	Region 3	Region 4	Region 5
January	135.23	261.17	312.78	133.89	153.91
February	115.98	230.67	293.37	117.57	137.35
March	112.24	206.16	256.41	100.22	110.27
April	109.74	197.45	242.27	79.14	79.14
May	92.59	186.49	212.31	73.67	86.99
June	79.28	155.47	212.85	73.43	78.36
October	167.38	332.35	332.35	155.1	155.1
November	164.25	354	370	134.92	169.17
December	241.43	436.79	436.79	157.91	157.91

Table 5.7: Region-wise monthly average $PM_{2.5}$ levels from all sources in 2018

Months	Concentration (µg/m^3)				
	Region 1	Region 2	Region 3	Region 4	Region 5
January	23.42	34.37	31.87	17.52	23.98
February	21.91	31.96	33.24	19.94	24.17
March	23.21	33.98	31.07	19.51	18.78
April	109.74	197.45	242.27	79.14	79.14
May	20.85	29.83	29.37	13.65	15.87
September	37.02	46.75	27.23	14.42	5.77
October	35.11	47.96	37.6	20.75	15.6
November	38.4	50.53	40.43	20.34	20.03
December	33.23	46.41	40.49	24.34	22.41

Table 5.8: $PM_{2.5}$ percentage contribution from different sources

Sources	Contribution (%)					
	Region 1	Region 2	Region 3	Region 4	Region 5	Overall
Construction	1.7	0.9	1.3	1.2	1.5	1.3
Domestic	6.8	5.9	2.4	12.3	8.1	7.1
Hotel	1.8	1.5	0.5	4.0	6.4	2.9
Industry	4.0	12.4	16.4	3.7	8.9	9.1
MSW	2.6	2.0	0.8	5.1	2.9	2.7
Road Dust	70.3	66.6	71.3	55.2	57.8	64.2
Vehicle	12.6	10.4	7.1	18.2	14.0	12.5
Others	0.2	0.2	0.1	0.3	0.3	0.2

5.5.1 Summary

The highest contributing source among all was road dust in all the regions followed by vehicular emissions in regions 1, 4 and 5. Industries were the second-highest contributors in regions 2 and 3.

Domestic sources were the third-highest contributors in regions 3 and 4, where the residential population is concentrated. Hotel sources were the third-highest contributors in region 5, where the tourist hotspots are located. MSW burning and construction sources contributed least in all the regions (Table 5.8). The rank of different sources based on their $PM_{2.5}$ contribution in all the regions is given in Table 5.9.

Overall, the top contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic sources (7%), and hotels (3%).

Table 5.9: Rank to sources in different regions based on their contribution to $PM_{2.5}$

Rank	Region 1	Region 2	Region 3	Region 4	Region 5	Overall
1	Road Dust	Road Dust	Road Dust	Road Dust	Road Dust	Road Dust
2	Vehicle	Industry	Industry	Vehicle	Vehicle	Vehicle
3	Domestic	Vehicle	Vehicle	Domestic	Industry	Industry
4	Industry	Domestic	Domestic	MSW	Domestic	Domestic
5	MSW	MSW	Construction	Hotel	Hotel	Hotel
6	Hotel	Hotel	MSW	Industry	MSW	MSW
7	Construction	Construction	Hotel	Construction	Construction	Construction

5.5.2 The combined impact of all the sources

The highest 24-hour average, monthly average, and annual average $PM_{2.5}$ concentration plots for all sources in the Agra City are given in Figure 5.11, Figure 5.12 and Figure 5.13, respectively. The highest values of $PM_{2.5}$ concentration were obtained from road dust, industrial, and vehicular sources. DG sets, hospital areas, and open area sources contributed the least to the $PM_{2.5}$ concentration (Table 5.10). In Agra City, the standard annual average $PM_{2.5}$ concentration (40) is exceeded mostly in the area surrounding the National Highway 19 (NH-19) (Figure 5.13).

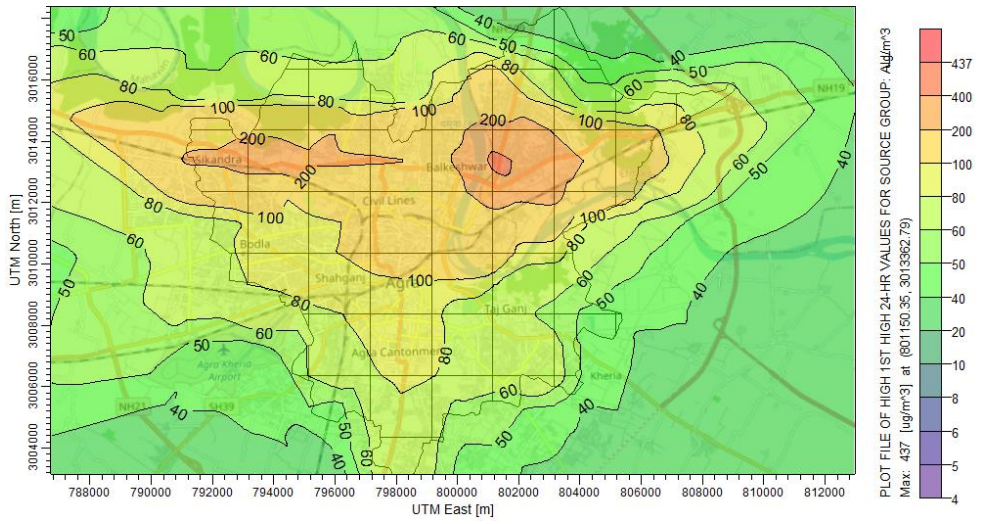


Figure 5.11: Highest 24-hour Average $PM_{2.5}$ Levels from All Sources

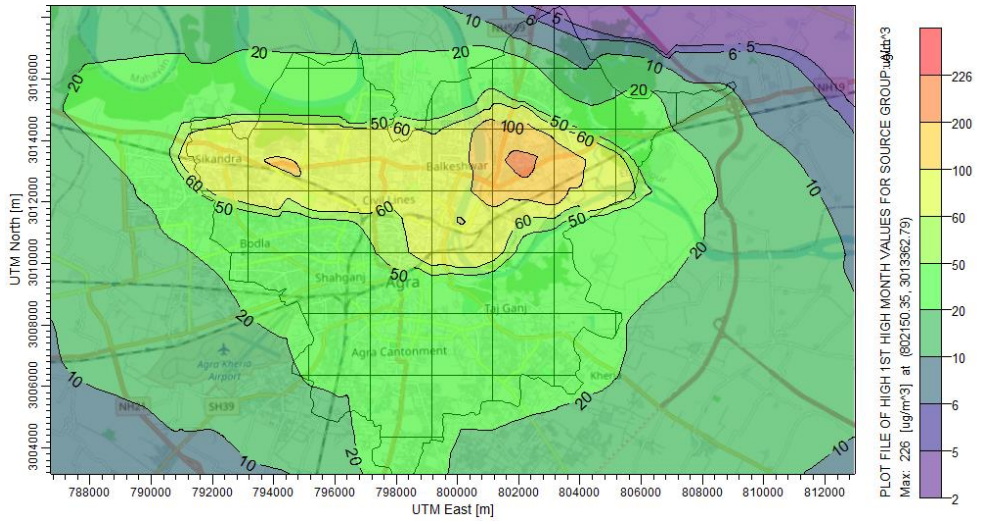


Figure 5.12: Highest Monthly Average $PM_{2.5}$ Levels All Sources

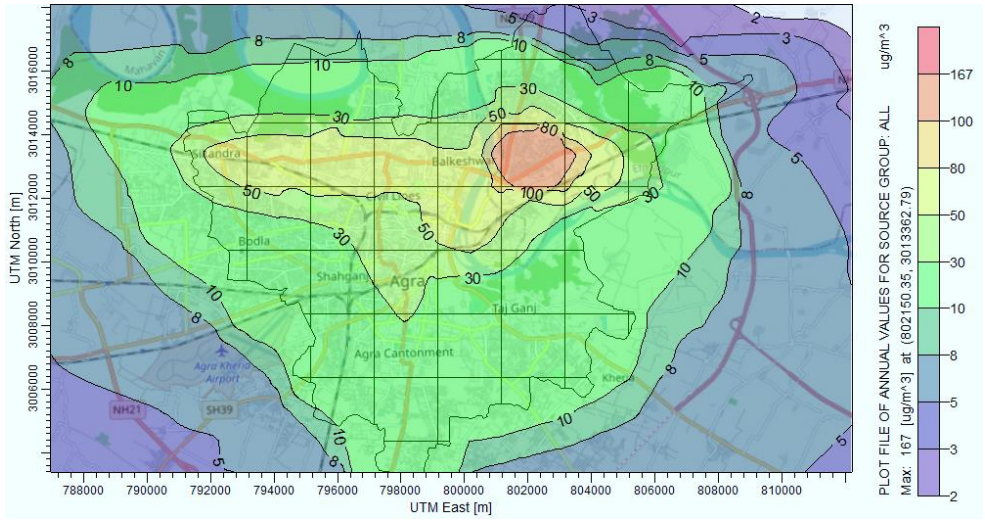


Figure 5.13: Annual Average $PM_{2.5}$ Levels from All Sources in the City

Table 5.10: Maximum $PM_{2.5}$ Levels averaged over different time periods for All Sources

Source	Maximum $PM_{2.5}$ Levels ($\mu g/m^3$)		
	24-hr average	Monthly average	Annual average
Construction	7.4	3.8	2.8
DG set	1.2	0.6	0.5
Domestic	12.0	7.0	5.0
Hospital	0.9	0.5	0.3
Hotel	23.9	13.3	9.8
Industry	78.9	38.3	28.2
MSW	6.7	3.4	2.5
Open Area	0.1	0.1	0.0
Road dust	319.0	166.0	123.0
Vehicle	28.0	15.1	11.3
All Sources	**437**	**226**	**167**

5.6 Scenario Analysis

(Develop and demonstrate sector-wise (including industry) policy control measures (two-three scenarios) on air quality improvements)

The study has taken into account three scenarios to assess the improvement in the air quality of Agra City. Maximum 24-hour average $PM_{2.5}$ concentration is the parameter considered to analyze different scenarios. Road dust, vehicular, and industrial sources have been focused upon as they are the major contributors to $PM_{2.5}$ concentration in the city. The three scenarios are presented below.

5.6.1 Scenario: Baseline Scenario

Table 5.11 represents the current status of modeled air quality (maximum $PM_{2.5}$ concentration) in different regions of Agra when no intervention has been taken.

Table 5.11: Highest 24-hour Average $PM_{2.5}$ Levels ($\mu g/m^3$) in Different Regions

Months	Region 1	Region 2	Region 3	Region 4	Region 5
January	135	261	313	134	154
February	116	231	293	118	137
March	112	206	256	100	110
April	110	197	242	79	79
May	93	186	212	74	87
June	79	155	213	73	78
October	167	332	332	155	155
November	164	354	370	135	169
December	241	437	437	158	158

5.6.2 Scenario 1. 30% Reduction in Road Dust, Vehicular, and Industrial Sources Emissions

Table 5.12 represents the status of air quality (maximum $PM_{2.5}$ concentration) in different regions of Agra when the emissions from road dust, vehicles, and industrial sources are reduced by 30%.

Table 5.12: Highest 24-hour Average $PM_{2.5}$ Levels (µg/m^3) in Different Regions (Scenario 1)

Months	Region 1	Region 2	Region 3	Region 4	Region 5
January	101	196	235	100	115
February	87	173	220	88	103
March	84	155	192	75	83
April	82	148	182	59	59
May	69	140	159	55	65
June	59	117	160	55	59
October	126	249	249	116	116
November	123	266	278	101	127
December	181	328	328	118	118

5.6.3 Scenario 2: 50% Reduction in Road Dust, Vehicular, and Industrial Sources Emissions

Table 5.13 represents the status of air quality (maximum $PM_{2.5}$ concentration) in different regions of Agra when the emissions from road dust, vehicles, and industrial sources are reduced by 50%.

Table 5.13: Highest 24-hour Average $PM_{2.5}$ Levels (µg/m^3) in Different Regions under Scenario 2

Months	Region 1	Region 2	Region 3	Region 4	Region 5
January	88	170	203	87	100
February	75	150	190	77	89
March	73	134	166	65	72
April	72	128	157	51	51
May	60	121	138	48	57
June	51	101	138	47	51
October	109	216	216	101	101
November	107	230	241	88	110
December	157	284	284	103	103

The overall improvement in air quality for $PM_{2.5}$ under the two scenarios will be close to 25% in Scenario 1 and 45% in Scenario 2 in the peak 24- hourly concentration (Figure 5.14). Since the maximum contribution is from road dust, the maximum advantage will be by improving road conditions. Sweeping, road washing and paved shoulders will be effective ways to control road dust emissions.

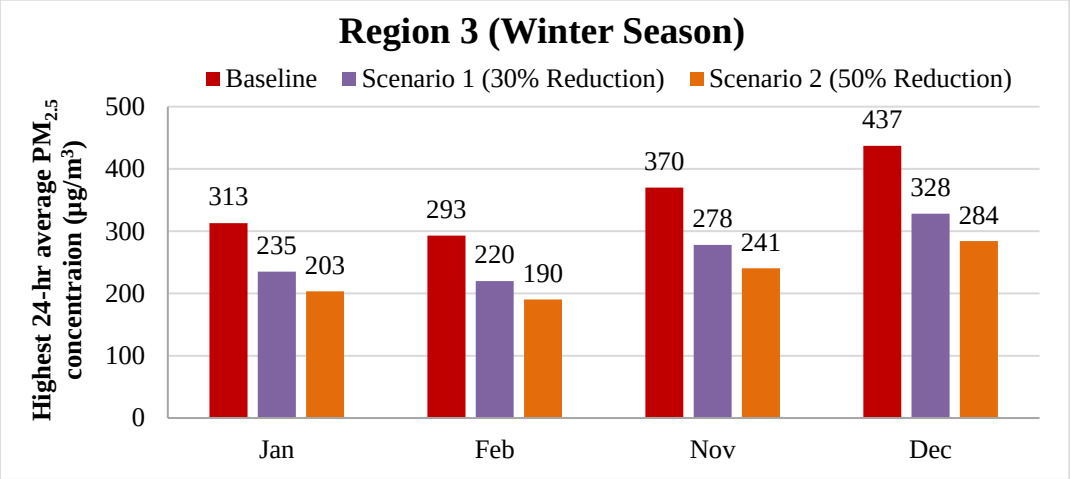


Figure 5.14: Air Quality Improvement in Scenarios 1 and 2 in Peak 24-hour Average $PM_{2.5}$ Levels

5.7 Summary of the Dispersion Modeling and interpretations

The major findings from the dispersion modeling are summarized below:

The WRF (Weather Research and Forecasting) model for meteorology parameters was validated against the measured data from continuous air quality monitoring station, Agra. The model performed satisfactorily with a statistically significant correlation coefficient ($r > 0.15$; n = 8750) for predicting wind speeds in February, March, April, and June. In general, the wind speeds were overestimated by a factor of 1.2. Furthermore, the time-series plot of observed hourly ambient temperature levels with modeled levels showed a good agreement ($r = 0.86$; n=2900) for all months of 2018. It was concluded that the WRF model provided realistic meteorology and the WRF outputs were used in air quality modeling.

The $PM_{2.5}$ modeled and observed levels over one year showed a good linear association (r = 0.64 n= 350). It is noteworthy that the model under-predicts the concentration by a factor of more than 2.0. The probable reasons for underestimation by the model are (i) over prediction

of wind speed by the WRF model, (ii) inventory may be incomplete and some source may be missing, and (iii) there is a substantial contribution of sources present outside the Agra City. Since the linear association in the model-computed and observed levels is very good, the model could be used for decision-making and useful insights.

The deficit in the model and measured (referred to as unidentified) $PM_{2.5}$ levels were highest during the January-February and November-December months. Also, it is worth noting that there was a sudden spike in these unidentified concentrations of $PM_{2.5}$ during the first week of November. This episodic spike in the unidentified $PM_{2.5}$ concentrations with an average value was 119 $\mu g/m^3$ in the city can be attributed to the influx from the surrounding regions outside the city.

For better insight, Agra city was divided into five regions (Figure 5.9). Regions 2 (north) and 3 (north-east) showed the highest $PM_{2.5}$ levels. Regions 2 and 3 are densely populated, and region 2 also has a major industrial area. The highest 24-hour average $PM_{2.5}$ concentrations were computed for the winter and summer months of the year 2018. It was observed that region 3 had the 24-hour peak $PM_{2.5}$ concentration at 298 ± 62 $\mu g/m^3$ followed by region 2 with 175 ± 63 $\mu g/m^3$, and region 1 with 140 ± 44 $\mu g/m^3$. Region 5 (south-east) had the least 24-hour average $PM_{2.5}$ at 76 ± 24 $\mu g/m^3$. The highest 24-hour average $PM_{2.5}$ concentrations were observed during the winter (November to February) while the lowest during the summer (May to June).

The highest contributing source was road dust in all the regions followed by vehicular sources in regions 1, 4 and 5. Industrial sources were the second-highest contributors in regions 2 and 3. Domestic sources were the third-highest contributors in regions 1 and 4, where the residential population is concentrated, and industry in region 5.

Overall city-level contributors to $PM_{2.5}$ were road dust (64%), vehicles (13%), industry (9%), domestic (7%), and hotels and restaurants (3%).

From the annual average plots, it is seen that $PM_{2.5}$ envelops a large area that gets elongated along the prevailing wind direction (N-E) within the Agra City. The annual standard for $PM_{2.5}$ concentration (40 $\mu g/m^3$) is exceeded in the area surrounding the National Highway 19 (NH-19).

6 Control options, Analyses and Prioritization for Actions

6.1 Air Pollution Scenario in the City of Agra

The city of Agra has a complex urban environment with respect to air pollution and faces severe air pollution of PM_{10} and $PM_{2.5}$. Several prominent sources within and outside Agra contribute to PM_{10} and $PM_{2.5}$ in ambient air; these pollutants can be taken as a surrogate of other pollutants also, as most of the pollutants coexist and have common sources. Chapter 3 presents the emission inventory and Chapter 4 describes the contributions of sources to the ambient air concentrations. Based on the comprehensive source apportionment study, the sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter. The highlights of the source apportionment study are presented below.

In winter, % contribution of PM_{10} - $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: vehicles (20 – 23%), SIA (19 – 19%), soil and road dust (18 – 14%), coal and fly ash (15 – 16%; includes burning of residual oil), MSW burning (12 - 14%), biomass burning (6 – 8%), industrial (7 – 6%; also includes the contribution from trye wear and burning) and construction material (3 – 1%). It is noteworthy, in winter, major sources for PM_{10} and $PM_{2.5}$ are generally the same.

In summer, % contribution of PM_{10} - $PM_{2.5}$ sources (given in parenthesis) to the ambient air level are: soil and road dust (41 – 35%), coal and fly ash (31 - 23%; includes burning of residual oil), vehicles (8 – 14%), biomass burning (7 - 10%), MSW burning (4 – 7%), SIA (4 - 6%), industrial (2 – 3%) and construction material (3 – 3%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

Although sources contributing to summer and winter air pollution are different but the overall action plan should include control of all sources regardless of the season. This chapter presents various air pollution control options. Since pollution levels are very high it is suggested that efforts are required to control all small or large as far as possible and to the best practices level.

6.2 Source Control Options

It may be noted that polluting air sources are plenty and efforts are required for every sector/source. In addition, there is a need to explore various options for controlling air

pollutants for increased emission in the future. A list of potential control options that include technological and management interventions is presented in Table 6.2 for $PM_{2.5}$ and PM_{10}.

6.2.1 Hotels/Restaurant

There are approximately 1300 big Hotels/Restaurants (more than sitting capacity of 10 persons) in the city of Agra, mainly situated in the Tajganj area, which is near to the Taj Mahal. It was observed that coal/wood is being used as fuel in the tandoor, the common fuel other than wood is LPG. The PM emission in the form of fly ash contributes to air pollution. It is proposed that all restaurants of sitting capacity more than 10 should not use coal in any form and shift fully to electric or gas-based appliances. A 70% reduction of PM_{10} (466 kg/d) and $PM_{2.5}$ (239 kg/d) emission from this source can be achieved by stopping uses of coal/wood.

It is also seen that the ash/residue from the tandoor and other activities are indiscriminately disposed near the roadside. This contributes to road dust emissions. The Agra Municipal Corporation may limit this source and have proper disposal of ash and residues. One may consider linking the commercial license to clean fuel, which may be enforced by Agra Municipal Corporation, Department of Food, Civil Supplies and Consumer Affairs, and oil Companies (Indian Oil, HP, etc.).

6.2.2 Domestic Sector

Although in Agra, 85% of the households use LPG (CRISIL report) for cooking, the remaining 15% uses wood, crop residue, cow dung, kerosene, and coal for cooking (Census-India, 2012). The LPG should be made available to the remaining 15% of households to make the city 100% LPG-fuelled. The LPG should be made available to the remaining 21% of households to make the city 100% LPG-fuelled. This action is expected to reduce 85% of PM_{10} (1009 kg/day) and 84% of $PM_{2.5}$ (764 kg/d) emissions from domestic sector. The Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil, HP, etc.) may formulate a time-bound plan for every household.

6.2.3 Municipal Solid Waste (MSW) Burning

Any form of garbage burning should be strictly stopped and monitored for its compliance. It will require the development of infrastructure (including access to remote and congested areas)

for effective collection of MSW and disposal at the scientific landfill site. The banning of MSW waste reduce emission by 100% of PM_{10} (505 kg/day) and $PM_{2.5}$ (303 kg/d) emissions from this sector.

The Agra municipal corporation should prioritize the MSW collection mechanism starting in a systematic manner in each ward. Special attention is required for fruits, vegetable markets and commercial areas and high-rise residential buildings, where MSW burning is common (Trans Yamuna Mandi and Sikandra Mandi).

A mechanism should be developed to carry out mass balance of MSW generation and disposal on daily and monthly basis. Any type of garbage burning should be stopped and ensured by Agra Municipal Corporation. Major commercial areas identified were Sanjay Palace, Shahganj, Subhash Bazaar, Agra Fort, Fatehabad road, Jaipur House, Sikandra Bosla sector 6,7, and 8. Bhagwan talkies, Belanganj, Baluganj, Sadar Bazaar, Raja Ki Mandi market, St. Johns Crossing, Maithan, Pathwari, Bagh Muzaffar Khan, Wazirpura and Hari Parwat Crossing. Major residential areas (having high density) were Ghatia Azam khan, Mantola, Tajganj, Nai ki Mandi, Loha Mandi, and Idgah. The residential area having moderate population density was Jaipur house colony, Saket Nagar, Janakpuri, Vijay Nagar Colony, Khandari, and Kamla Nagar. Residential Areas having low population density were Sanjay palace, Subhash Park, Sadar bazaar, Laweys colony, and Dayalbagh. Major institutional areas were Dayalbagh, Khandari, and MG Road. Also, landfill and waste to energy plants can be established for its efficient handling. Some evidences are shown for MSW burning in city (Figure 6.1) and burning of used trye in Transport Nagar (Figure 6.2).

Desilting and cleaning of municipal drains by Agra Municipal Corporation should be undertaken on a regular interval, as the silt with biological activities can cause emission of air pollutants like H_2S, NH_3, VOCs, etc. It is seen that waste is sometimes burnt in industrial areas (Foundry nagar, Nunhai, Sikandra industrial area and Transport nagar. Hazardous waste is being dump on the roads (oil, grease, and paint). Several residents in the locality of Sikandra industrial area have reported instances of leather burning. This must be stopped under the supervision of UPPCB. It is recommended that there should be a separate industrial non-hazardous dump site for industrial waste, and they should not be allowed to dispose of the waste on roads or in front of the industry. Strict compliance and surveillance are required that

hazardous waste goes to TSDF under the supervision of Agra Municipal Corporation and UPPCB.

The major drain of city Mantola should be covered, diverted fully to wastewater treatment plant of tertiary level and then only discharge in river Yamuna or perhaps recycled. This will remove the problem NH_3, H_2S and smell in the city and Tajmahal area.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Agra Municipal Corporation, UPPCB and NGOs.

Figure 6.1: MSW Burning in several parts of city

Figure 6.2: Storage of used tyre and open burning of tyre in Transport Nagar

6.2.4 Construction and Demolition

The construction and demolition (C&D) emission can be classified as temporary or short term. In the industrial area, these activities are frequent. This source is one of the significant ground-level emission sources. Nearly at all the construction sites, the construction material and their debris (lying open, without cover) are being stored outside the construction premises, near the road. The flyover construction at ISBT showing the construction material dumped in the middle of the road.

Every C&D activity should fully comply with C&D Waste Management Rules, 2016. If required, C&D waste recycling facility must be created, which is a common practice in large cities. The control measures for emission may include:

- Wet suppression
- wind speed reduction (for large construction site)
- Waste should be properly disposed of. It should not be kept lying near the roads as it may contribute to road dust emission.
- Proper handling and storage of raw material: covered the storage and provide the windbreakers.
- vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.
- The actual construction area is covered by a fine screen.
- No storage (no matter how small) of construction material near roadside (up to 10 m from the edge of the road)

The above control measures should be coordinated and supervised under Agra Development Authority, Uttar Pradesh Housing Board, Agra Municipal Corporation, Urban Development Department, PWD and UPPCB. Every C&D activity should fully comply with C&D Waste Management Rules, 2016. If required, C&D waste recycling facility must be created, which is a common practice in large cities.

The suggested control measures will reduce the emission by 50% in PM_{10} (422 kg/day) and 72% in $PM_{2.5}$ (92 kg/day). This will also reduce the road dust and fly ash contribution to ambient air concentration.

6.2.5 Soil and Road Dust

It has been observed that the soil and road dust emission and its contribution to ambient air concentration is consistent and it is one of the largest sources of PM_{10} and $PM_{2.5}$ emissions. The silt load varies from 7.4 to 55.1 g/m^2. The industrial area, where the heavy vehicle movement is seen, also shows the high road dust emission. It is suggested that high traffic density roads should be properly maintained, paved carpet, shrubs should be planted on road divider and the unpaved area near the roadside.

The following control measures are evaluated and suggested to reduce the dust emissions on major roads:

1. Convert unpaved roads to paved roads. PWD (Public Works Department) and city administration should act immediately to reduce the pollution load from road dust.
2. Municipal Council should carry out vacuum assisted Sweeping. The efficiency of vacuum-assisted sweeping is taken as 90% (Amato et al., 2010). If the sweeping is done twice a month, the road dust emission will be reduced by 42% (PM_{10} = 12430 kg/day and $PM_{2.5}$ = 3875 kg/day) (FHWA)and efficiency of different vacuum sweeping machines.
3. If the silt road is greater than 3 gm/m^2, the vacuum-assisted sweeping should be carried out by the municipal council and the UPPCB should surveillance.
4. NHAI should ensure that the silt load on NH-2 be maintained to a minimum of 3gm/m^2.
5. Abandoned construction sites and delayed projects should be monitored for adding on to the dust load in the nearby areas.
6. It is more important that the condition of the roads is maintained properly, and shoulder paved by interlocking concrete blocks.
7. The truck carrying construction material, or any airborne material should be covered.
8. Vacuum Sweeping of major roads (NH-19, MG Road, Mall Road and Fatehabad Road) and high silt load locations (Sikandra, Bhagwan Talkies, Shahdara Chungi, Rambagh, Hariparwat, Ghatia Azam Khan, Bodla Crossing, Subhash Park, Agra Fort, Taj Mahal West Gate, Prathvinath Fatak, Pratapura, Kheria Mod, Circuit House, Tajmahal East Road, and Rohta Road) should be carried out at least four times a month also carpeting

of shoulders, maintenance of road, dividers and Krebs should be carried out at regular intervals.

9. Mechanical sweeping with water wash can also be opted and small shrubs, perennial forages or grass covers should be planted on the medians wherever possible.
10. Vacuum Sweeping of major roads (NH-2) should be carried out at least four times a month also carpeting of shoulders, maintenance of road, dividers and Krebs should be carried out at regular intervals. These actions should be practiced focusing on region 1, 2 and 3 from where the NH-2 passes.

The above control measures should be coordinated and supervised by Agra Development Authority, Uttar Pradesh Housing Board, Agra Municipal Corporation, National Highway Authority, PWD and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

Riverfront Observations

The Ghats of the Yamuna River are not cleaned or maintained properly, and haphazard new development is coming up all along the Ghats. The river Yamuna which reduces to a trickle in the lean season exposes vast stretches of sand on its beds. The Yamuna-Kinara road get a high dust loading from the dried-up riverbed during summer seasons which substantially add up to the Suspended Particulate Matter loading in the ambient air. The low humidity prevalent in this region, also promotes wind-blown emission of SPM. It is important that the dust emissions from riverbed are controlled by stabilizing the top surface. This can best be achieved by keeping the river-bed moist and having more water in the river. A good water management in the river during summer will be useful in stopping the emission of dust from riverbed. An arrangement should be made that there is always sufficient water in the river round the year by constructing a well-designed barrage upstream or downstream of the Taj Mahal.

6.2.6 Vehicles

The vehicle emission contribution is significant for CO, NOx, PM_{10} and $PM_{2.5.}$ There is a relatively large contribution of diesel vehicles (trucks, buses, LCVs, cars, etc.) to PM_{10}, $PM_{2.5}$ CO, $SO_{2,}$ and NOx. Out of about 3.5 t/d emission of PM_{10} and $PM_{2.5}$ from vehicles, over 80% is from diesel vehicles, especially from trucks and buses. Therefore, control measures have to focus on advanced technological intervention for diesel vehicles or change in fuel to CNG

(compressed natural gas) especially local transport of buses and light commercial vehicles. A coordinated effort should be made by Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.). Following additional points must be taken into account:

1. Retro-fitment of Diesel Particulate Filter (DPF): These filters have PM emission reduction efficiency of 60-90%. If the diesel vehicle entering the city has been equipped with DPF, there is a reduction of 40% emission. This option must be explored once Bharat stage VI fuel is available.
2. Industries must be encouraged by the transportation department to use Bharat stage IV vehicles for transportation of the raw and finished product.
3. PUC checks are the means to check emissions from on-road vehicles; this should be strengthened. Emissions from in-use vehicles also depend on the maintenance and upkeep of vehicles. In this regard, it is suggested that each vehicle manufacturing company should have its own service centres in sufficient number to cater to the need of their vehicles in the city. The automobiles manufacturing company owned service centres (AMCOSC) should be fully equipped for complete inspection and maintenance of vehicles ensuring vehicles conforming to emission norms and fuel economy after servicing.
4. The number of PUC centers should be increased to 90 based on thumb rule of 3 PUC centers per ten thousand registered vehicles. Maintenance and calibration of equipment must be ensured by regular surveillance
5. Restriction on plying and phasing out of 10 years old commercial diesel driven vehicles.
6. Introduction of cleaner fuels (CNG/ LPG) for vehicles.
7. Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities.
8. No registration of Petrol 2-wheelers after two years from now. Electric charging points in public building s and parking lots should be implemented. Battery swapping facility in coordination with companies like IOCL.
9. Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Agra.

10. Depot spaces should be rationalized to ensure more efficient utilization. Multi-modal, multi-use bus depots to be developed to provide high-class bus services and terminal experience to passengers. Should include well-equipped maintenance workshops. Charging stations shall be set-up.
11. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification. Ensure integration of existing metro system with bus services.
12. IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring.
13. Improved public mobility systems.
14. Zero traffic zones (Sanjay Palace, Sadar Bazaar, Hospital Road and Raja ki Mandi Market).
15. The state of Uttar Pradesh and Agra administration should make a time-bound plan for dipper penetration of electric vehicles (EVs). It is suggested that government may consider the tax break and other financial incentive for EVs parallelly effort must be made for charging infrastructure including facilities for swiping the batteries. As a first step, two and three-wheeler should be considered for EVs.

It is proposed that above control options may be coordinated under the supervision of State Transport Department.

6.2.7 Decongestion of Roads

Agra is a commercial city. A major part of its industrial activity is in the form of small-scale and house-hold industries. These are mainly located in the old Mughal city particularly Lohamandi, Rakabganj, Kotwali, Tajganj areas. The large-scale units are located in Chatta and Hariparvat areas. The commercial activities and high population density need better road infrastructure and smooth traffic movement. The road network within the city is not developed enough to cater to these requirements. Intermediate Public Transport (IPT) is the popular mode of transport due to the lack of a proper public transport system. The road network of the city offers a poor level of service affecting safety, efficiency, and economy of traffic operating within the city. The lack of connecting roads with other parts of the city and within the slums poses a grave issue and affects the transport connectivity. This is one of the fundamental issues

that is generally neglected in city developments and needs thorough planning and execution. The roads in the central part (which is a commercial area) of Agra are narrow (2-4 meters) in width, occupied with on-road parking. The unavailability of proper parking spots near the market area results in roadside parking, which decreases the road availability for the plying vehicles and hinders the traffic movements (Figure 6.3).

There is a need to improve the U-turns on the major roads of Agra as they create heavy traffic density (congestion) on highways and main roads during peak hours e.g., Guru ka Tal (Figure 6.3). One of the major problems that contribute to slow traffic movement is encroachments along the road by temporary extension of shops.

Figure 6.3: Heavy Traffic Congestion on Highways/Roads in Agra city

During the traffic recording and survey done by IIT Kanpur, following major intersections are identified as traffic bottlenecks. Out of the 31 locations examined for traffic congestion, the major Traffic bottlenecks are mentioned in Table 6.1 and Figure 6.4. The major issue is the slow traffic movement that refers to the congestion conditions on the road. Hence decongestion plan for the major Traffic Bottleneck intersections of Agra city is recommended. There must be no Parking zone (up to 100m) near the congested intersection listed in Table 6.1. Certain Parking policy in congestion areas (high parking costs, at city centres, only parking is limited for physically challenged people, etc) must be implemented. The introduction of one-way traffic routes (e.g., Madiakatra, Jeoni Mandi) can play a vital role in the decongestion plan.

Table 6.1: Major Traffic Bottleneck at Agra City

Bhogipura Crossing	Nagar Nigam Intersection
Rakabganj Intersection	Deewani Intersection
Raja mandi Intersection	Sultan Ganj Intersection
Pachkuian Intersection	Jiwani Mandi Intersection
Hariparwat Intersection	Langre Ki chowki Intersection
Professor Colony Intersection	Bijali Ghar Intersection
RBS Crossing	Kinari Bazar Intersection
Lohamandi Intersection	Pipal Mandi Intersection
Madiakatra Intersection	Mantola Intersection
Church Road Khandari Intersection	Rambagh Intersection
Idgah Intersection	NH3 NH11 Bypass road.
Shahganj Crossing	Rui Ki Mandi Crossing

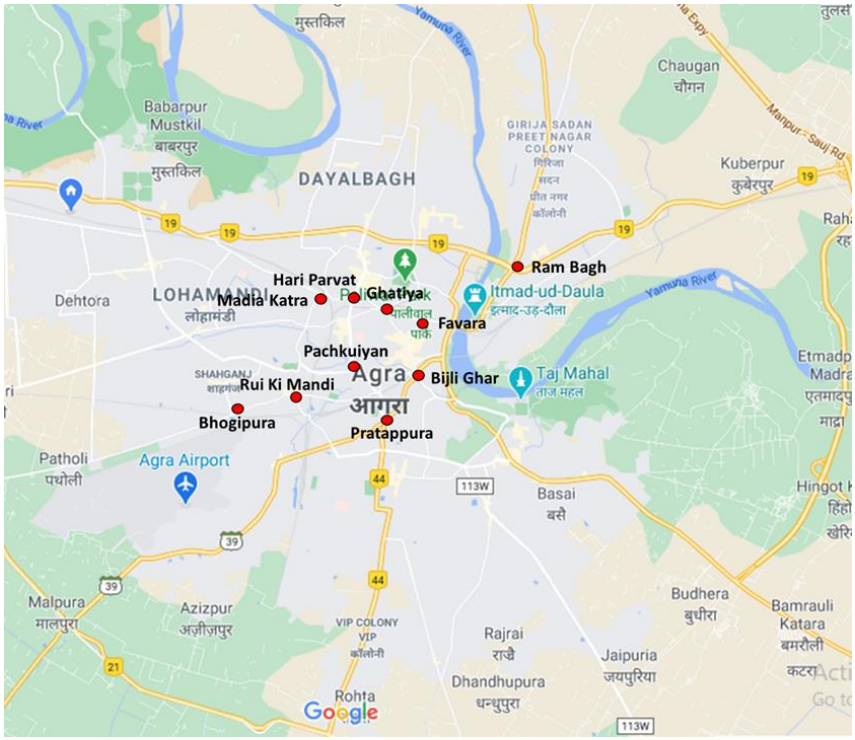


Figure 6.4: Location of traffic bottlenecks in Agra city

Commercial Area Observations

Due to traffic congestion the vehicular speeds for all vehicles reduce and more so for the public transport vehicles. Since the travel times by public transport vehicles gets increased to a higher extent than a private vehicle, commuters prefer to travel by private modes of transport. The city has been witnessing an unprecedented increase in vehicle registration. This rapid

motorization has led to severe congestion problems, longer journeys and higher per capita trips. The average vehicular speed in Agra is about 25.3 km/h (Source: Draft CMP Agra, 2017). This further adds on to the air pollution.

Additionally, most of the tourist footfalls limit to the Taj Mahal and the Agra fort. Festive season and holidays result in greater congestion and pollution in the core. Most trips are day trips and most of the hotels and Restaurants are also located in Fatehabad Road area. This adds to the traffic and congestion in the area since it also houses most of the residents of Agra.

Areas adjacent to the market centres like Sanjay Palace and Shah Market exhibit dense traffic congestion issue owing to the unregulated parking and encroachment by local shop owners. The Sanjay Palace is a commercial and mixed-use area and encroachments along the road and corridors are commonly seen. The open and parking spaces are being encroached upon by commercial activities. All the blocks in Sanjay Palace do not provide pedestrian friendly environment. Major commercial areas like Sanjay Palace and Hospital Road in the city consists of mixed-use lanes of commercial and residential characters (Picture -1). This is creating congestion and affecting normal life of the people. The unhygienic streets (stagnant drains, foul smell) need an early attention. Pathways interconnecting blocks are used by shop owners for storage and parking.

The unorganised vehicle servicing centres at roadsides refilling used oil in old vehicles, performing uncontrolled open painting, greasing and oil spilling in the open area were observed in Pratappura, Bhagwan Talkies, Belanganj and Transport Nagar. These are contributing to hazardous air pollutants in the air due to poor practices and thus needs urgent attention.

Industrial Area observations

Sikandra Industrial area experience large volume of heavy-duty vehicles throughout the year. The present condition of roads in these area leads to addition of dust in the ambient air when heavy duty vehicles ply on it. Also, there is a flyover under construction (appeared to be abandoned presently) linking the inner road in Mohammadpur (within Sikandra Industrial Area) with the NH-19. The improper management of construction debris from this project and the already degraded condition of roads in this area is making the condition worse.

Parking spaces

The on-street parking is another major concern in the city, which is making the roads chaotic, and conflict ridden. Stretches like Sanjay Palace, Naalband Crossing, Raja ki Mandi Market, MG road (near Devi Ram Crossing), Shahganj Market, Ajit Nagar Crossing, Bijli Ghar Chowk and Yamuna Kinara road in Agra have their effective road widths reduced due to on-street parking. Mostly, the parking is done on the walkways, and there is insufficient street space for pedestrians, cyclists, and public transport. At places, there does exist parking places but still people prefer to park on-street because of lower convenience and high prices at designated parking.

The major terminals in the city like Agra Cantt railway station has various issues like on-street parking, encroachments by temporary vendors on both sides of the road, congested road conditions and others. Similar conditions were observed near Bhagwan Talkies and ISBT where the boarding/ alighting of passengers was observed along the carriageway causing congestion. No designated spaces are earmarked for parking of autos and cars.

Pedestrian and Non-motorized transport spaces

In Agra, most of the roads are devoid of any pedestrian/non-motorized transport (NMT) infrastructure even though the city has about 33% NMT share (Source, Draft CMP, 2017). This forces the pedestrians to either walk on busy roads or cross the roads amid heavy motorized traffic. Most of the roads lack footpaths posing safety issues to the pedestrians. At several locations along the MG Road and Mall Road it was observed that there is no continuity of footpaths and at places the curb height exceeds up to 300-350 mm against the standard norms of 150mm. Also, another difficulty added to the pedestrian pathways is the encroachments by vendors (Raja ki Mandi, Naalbandh crossing and Hari Parvat crossing) and for parking leaving no space for pedestrians to walk.

There are no dedicated bays for intermediate public transport stops and boarding/alighting occurs on the carriageway near Bhagwan Talkies and on NH-19 near ISBT, creating chaotic environment. Due to this intermixing of fast and slow-moving traffic, there is hindrance to smooth traffic flow.

Site Specific Short-term interventions:

Sanjay Palace

- Parking consolidation across blocks, along with improved, seamless operations of pedestrian-friendly infrastructure within the plaza can help integrate and maximize the operations of individual parking blocks.
- Improve the walking environment within the plaza (inadequate and poorly designed staircases, cleaning up of open sewers, continuous, unobstructed pathways across blocks, and along the footpaths around the edges (Improved walking experience may make customers/visible more amenable to walk extra when considering re-organization of parking operations.)
- Evaluating the overall capacity of parking across blocks as whole: segregation of long-term vs short-term parking, two-wheeler vs four-wheeler parking, for efficient usage of space and pricing.
- Different pricing may also be considered for different time periods, vehicles, and people (shop owners, shoppers, others). There should not be any free parking space in the complex. See Pune's pricing structure as an example:
- https://www.pmc.gov.in/sites/default/files/project-glimpses/PMC-public-parking-policy-English-revised-March2016-Final.pdf
- Evaluating the feasibility of one-way traffic circulation around the blocks for smoother circulation of traffic.
- Critically evaluating the super built-up area occupied by shops.
- Removal of on-street parking and introduction of multi-level parking
- Identification of optimal bus stop locations nearby and last-mile/first-mile walking connectivity to and from these locations.
- Operation of charcoal-based tandoor was also observed in the restaurants within the Sanjay Palace area. Inspection should be carried out at regular intervals to stop this.

MG Road

- Many intersections along MG road seemed to have skewed signal phase timings across different legs, specifically Hari Parvat Crossing. Conducting traffic count and delay surveys at each leg for a period of time to ascertain the conditions and revising the signal timings and quantifying improvement can be undertaken.

- A service lane coming from Nagar Nigam's office and merging left at Soor sadan crossing is demarcated by a median of a relatively small curb height, thus is a hotspot for accidents (Figure 6.5). This needs to be corrected by raising the curb height and providing with the proper signage for the traffic. There should be a dedicated U-turn Lane either side of the median on this stretch and U-turn should be restricted at the intersection.

Figure 6.5: Location of traffic conflict and accident hotspot near Nagar Nigam crossing

- The narrow railway bridge between St. John's crossing and Hari Parvat Crossing is a traffic bottleneck. The bridge should be widened, and U-turns should be restricted.
- Road-side parking near Bhagwan Talkies crossing in front of shops; parked city buses waiting to be filled up by passengers; parked rickshaws, autos and e-rickshaws leads to the shortening of effective road width and thus causes traffic congestion and reduced traffic speed. Designated bus bays and last-minute connectivity services bay should be built at a distance from the crossing. For those having private owned vehicles, the parking charges, location of parking bay and strict penalty for unauthorized parking could play a major role in how an individual would prefer to travel.

- Construction of commercial spaces adjacent to the MG road near Namner crossing exhibit improper storage of construction material and poor construction practices. This need be checked and such activities should be penalised accordingly.

Fatehabad Road and Mall Road

- The small bridge which passes over Gobar Chowki Road on Fatehabad Road near ITC Mughal is a traffic bottleneck and needs to be widened.
- The base of the electric poles on the Mall Road and Fatehabad Road (for street lighting) has gaps which is potential site for dust accumulation and thus needs to be covered or filled appropriately.
- Many hotels and restaurants have extended their operations beyond their designated premises on these roads. This temporary encroachment must not be allowed as it reduces the effective width of the adjacent road thus leading to traffic congestions at times.
- On several locations along these roads, it was observed that the parking was done next to the road on unpaved shoulder. Such types of unpaved areas next to the road which are Infront of hotels and restaurants should be paved with concrete blocks.
- Also, animals were seen roaming around on the roads. This not only increase congestion but also cause dirt and filth on the roads. Hence, they need be managed too.

NH-19 (formerly known as NH-2)

- The unpaved and open area under the fly-overs constructed over NH-19 at Ram Bagh crossing, Water works crossing, Bhagwan Talkies crossing and Khandari crossing needs to covered with plantations to avoid influx of dust into the air by winds. Also, the region under flyovers should be declared as no-parking and no-vending zone.
- The traffic going into the city from NH-19 at Guru ka taal causes continuous traffic congestion due to the improper U-turn on highway (Figure 6.6). The Guru ka taal flyover merging into the NH-19 should be provide with a lane joining the NH-19 directly by avoiding the U-turn so that it smoothens out the turning of traffic towards the city.

Figure 6.6: Improper U-turn leading to traffic conflict near Guru ka taal

- Buses were seen to wait on the highway near ISBT area instead of waiting inside the designated bus station. Moreover, the autos dropping off the passengers were observed to be parked on the highway. This needs to be regulated and the last mile connectivity services bay needs to build at a distance from the NH-19.
- Transport nagar experiences large volumes of heavy-duty vehicles. The condition of roads within transport nagar which is adjacent to NH-19 and ISBT is poor. Also, tyre burning, oil and grease spills, cleaning of vehicles in the open area was observed as there were several repair shops in this area. Hazardous pollutants with a potential of much severe impact could be emitting from this region and thus needs to be regulated.
- A flyover previously under construction (appears to be abandoned presently) is linking the inner road in Mohammadpur (within Sikandra Industrial Area) with the NH-19. The improper management of construction debris from this project and the already degraded condition of roads in this Sikandra industrial area makes the condition worse when the heavy-duty vehicles ply on it. The delayed project should be finished at the earliest and the road conditions should be upgraded.
- The stretch of road between Raja Balwant Singh crossing and Madia Katra Crossing exhibit major traffic congestion most of the time due to narrow roads and a narrow bridge crossing Raja ki mandi railway station (Figure 6.7). This area has several major hospitals and due to lack of proper parking facilities, vehicles are parked on the roadside further aggravating the congestion. The piling up of vehicles on Raja Balwant Singh road ultimately affect the traffic at the Hari Parvat crossing. There is a need of multilevel parking for vehicles in this area. The parking facility available at the Raja ki

Mandi railway station can be utilised for decongestion of this region. Also, this stretch should be declared as a strict no-parking no-vending zone.

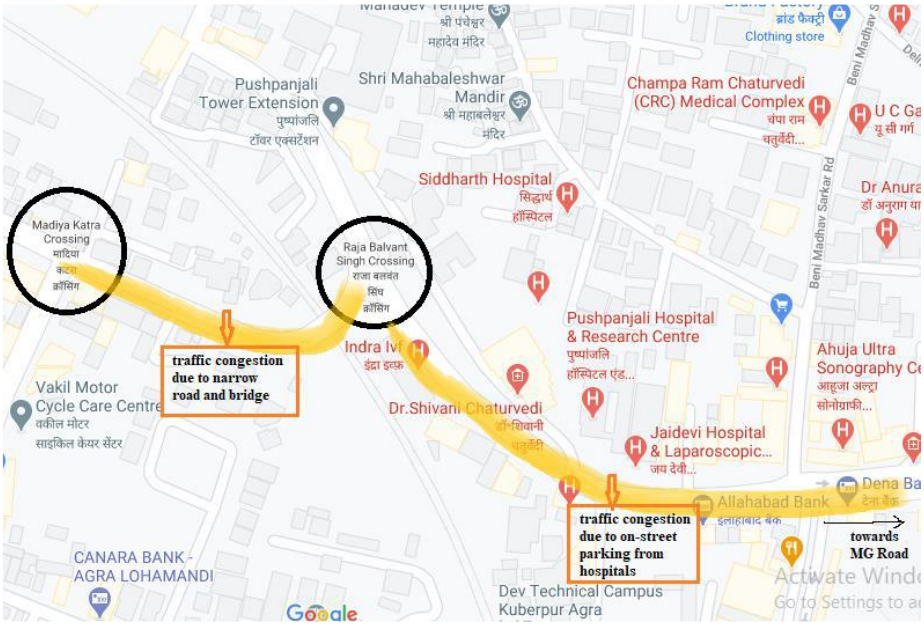


Figure 6.7: Traffic congestion at Madia Katra and Raja Balwant Singh crossing

- Two major railway crossings just 200 m apart in Shahganj area (Figures 6.8 – 6.9) is a major traffic bottleneck both due to large volume of traffic and narrow roads. The high frequency of railway traffic through there crossings results in long queues of vehicle on both sides of the boom barrier. Further, there is no median dividing the roads approaching these crossings. The commuters have the tendency to barge into wrong/opposite lane further aggravating the congestion. It is therefore recommended that the medians should be extended till the boom barrier and one-way road spikes (see picture below) should also be employed to check the nuisance causing traffic tending to go in the opposite lane. For a long-term solution, elvated road or floyovers should be considered.
- Two major railway crossings just 200 m apart in Shahganj area (Figures 6.8 – 6.9) is a major traffic bottleneck both due to large volume of traffic and narrow roads. The high frequency of railway traffic through there crossings results in long queues of vehicle on both sides of the boom barrier. Further, there is no median dividing the roads approaching these crossings. The commuters have the tendency to barge into wrong/opposite lane further aggravating the congestion. It is therefore recommended that the medians should be extended till the boom barrier and one-way road spikes

(Figure 6.10) should also be employed to check the nuisance causing traffic tending to go in the opposite lane.

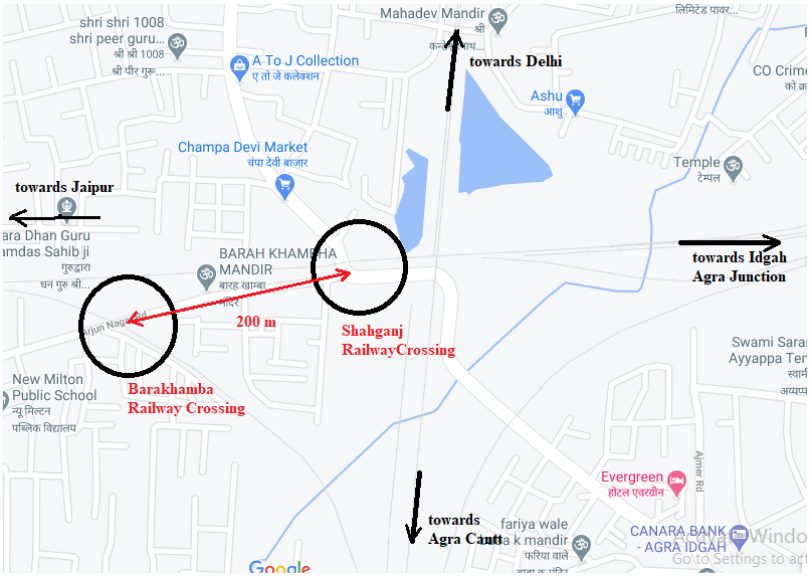


Figure 6.8: Traffic congestion due to two major railway crossings

Figure 6.9: Traffic congestion at the Shahganj level crossing due to vehicle in the wrong lane

Figure 6.10: One-way traffic spike strips

Medium to long-term interventions:

Transitioning towards electric vehicles:

It is proposed to replace the existing fossil fuel operated buses and complement the proposed pedestrian friendly environment with modernized non–polluting electric taxis, public and intermediate public transport system. As a first step, fossil fuel based new two-wheelers may be banned within one year. This electric mobility needs to be encouraged in conjunction with developing requisite infrastructure (charging stations at multiple places). Further, the city is witnessing a growth in the market of e-rickshaws, which aid in reducing vehicular emissions in comparison with diesel fleet autos. However, considering the long-term vision of environment sustainability, the market of e-rickshaws with lead acid batteries needs to be replaced with lithium-ion batteries.

Restoring pedestrian walkways and non-motorized transport traffic facilities:

Since the city attracts huge number of tourists the safety of the tourists must not be compromised. All the transport system developments should be with the objective of improving accessibility, road safety and air quality. The entire pedestrian infrastructure shall be designed as per the IRC guidelines and can be physically protected from incursions by motorized vehicles by placing bollards. Adequate road signages must also be provided to guide the commuters.

It is recommended to improve the functioning and environmental compatibility of pedestrian mobility components by promoting cycling and walking thereby supporting the objective of sustainable development. These mobility components must simultaneously adapt well-designed infrastructure to support nonmotorized transport i.e., considering the extreme weather conditions, the roads must be provided with shaded sidewalks or built to pavement edge building with overhangs or arcades, proper signages and other facilities like information desk, toilets, and water dispensers. In addition, high albedo materials must be used for paving road surfaces to reduce urban heat island effect. Several pathways like Aram Bagh road, road connecting Taj Mahal and Agra Fort in the Agra City should be the exclusive domain of pedestrians with necessary amenities and visually attractive environment.

Parking Management:

Since, on-street parking has been a major concern within the region (Figure 6.11), strict guidelines need to be adopted discourage private vehicles in the settlements. High parking charges needs to be introduced in the city along with provision of public transport. Also, the building norms must have mandatory provision of parking at everyone's house. Un-authorized on-street parking must be penalized and strict monitoring of compliance of defined rules to be enforced. "No parking zone" signs should be placed at all the locations exhibiting parking issues and it should also be painted on roads with clear markings.

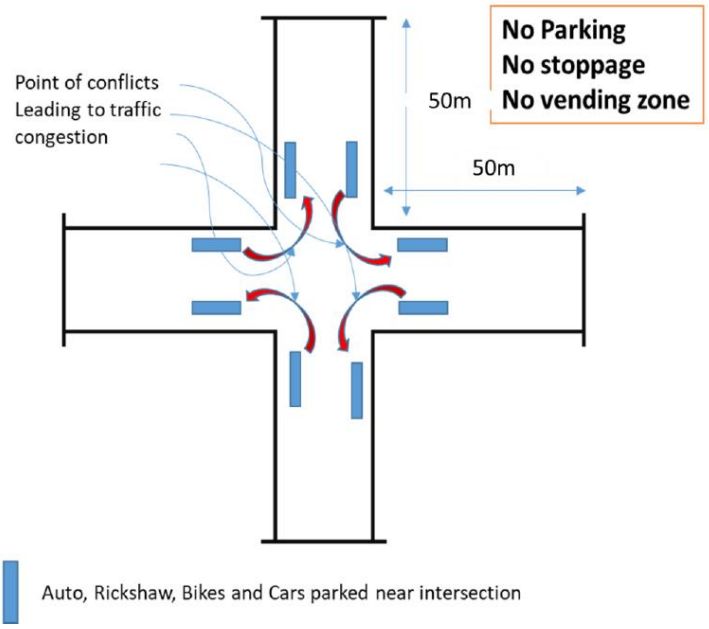


Figure 6.11: Conflicts due to on-street parking near intersections

Promoting Public Transport Travel

Increasing the efficiency of public transport can deliver benefits of enhanced road capacities, accessibility and safety and security. Thus, it is proposed to improve the efficiency of existing public transport system and bring in new fleet. The size of these buses should be decided keeping in mind the limited road width available at several locations in the city. Since, the oversized buses tend to occupy most of the carriageway and further leads to congestion at bottlenecks.

In addition, common mobility card for residents and separate tourist cards must be introduced. These tourist cards must comprise of parking charges at the entry/exit points of the settlements, local public transport travel and entry fee to various tourist spots within the city.

Decongesting the Bus Stand

Bijli Ghar and Idgah Bus Stands are situated in centre of the city and cause extreme congestion and increased emissions. It is recommended that the city should relocate these bus stands to outskirts of the city (Bijli Ghar may be shifted to trans Yamuna and Idgah may be shifted to near to Patholi Village, Jaipur Road).

The approach to ISBT bus stand is partially paved and poorly maintained (uneven and undulated). The approach road should be fully paved, well maintained and should have smooth entry and exit to ISBT bus stand.

Construction of Ring Roads and Bypass highways

An outer road from Keetham connects to Gwalior Road. This road may be connected to Agra ring road (connecting Yamuna Expressway and Agra-Lucknow express way); this will restrict the movement (within Agra city) of those vehicles destined to Jaipur or Gwalior. The ring road should further extend to the Agra-Jaipur highway.

There should be a bypass for heavy vehicles and major godowns should be shifted away from the city at outside areas to prevent the movement of heavy vehicles in the city.

6.2.8 Industries and Diesel Generator Sets

A coordinated effort under the supervision of UPPCB and Industries Departments is suggested to implement the following control measures:

- Although the petha industries in Agra have been shifted to natural gas but in certain areas the use of coal and other solid fuel was observed and most probably these are small house based industries and may be not registered (Charsoo gate, Tajganj, Sadar Bhatti, Nai ki mandi and Bagh Muzaffar Khan).
- Majority of industries use multi-cyclone as an air pollution control device. It is recommended that these cyclones should be replaced by baghouses for effective control of particulate emission.
- Ensuring compliance of 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.
- Area and road in front of the industry should be free from any storage or disposal of any waste or raw material.
- The industry should follow best practices to minimize fugitive emission within the industry premises; all leakages, transfer points, loading and unloading, material handling within the industry should be controlled.
- The industry should use renewable energy to cater the need of office requirement in absence of power failure i.e., zero loads of office on DG Set.
- Air pollution control equipment should be installed at all the industrial sources and an inspection should be carried out at regular intervals. Region 3 and 5 were the most impacted ones due to industrial sources.
- The UP government should supply sufficient grid power to industries for an effective industrial run.
- It is seen that industrial waste (hazardous in nature) is mixed with MSW and burnt in several parts of Agra. It is recommended that no industrial waste should be mixed with MSW. There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste should be developed under the guidance of UPPCB.
- The area inside and outside the industry premises should be properly maintained. The respective industry should be held responsible for not maintaining the area properly.
- There are industries with induction furnaces, which is very pollution process, with almost no pollution control devices. The maximum emissions occur when the furnace lids and doors are opened during charging, back charging, alloying, oxygen lancing (if done), poking, slag removal, and tapping operations. These emissions escape from sides and top the building.
- To address the pollution caused by fugitive emissions in induction furnaces (applicable for large furnace capacity > 4 tonne (scrap material/day) a fume gas capturing device has been developed and commercially available. A side-based suction (Figures 6.12 – 6.14) is far more effective than top suction, which interferes with the movement of the crane.

- It is recommended that fume gas capturing hood followed by baghouse should be used to control air pollution.
- The economics of the side-based suction hood for an induction furnace:
    - Assume capacity 8 ton per batch
    - Running time = 8 hrs.
    - Capital Cost of Suction Hood= Rs. 40 lakhs
    - Electricity cost for Running for year = Rs. 26.5 lakhs
    - Running + Capital Cost for ten years = Rs. 3.0 crores
    - 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. Which is somewhat high and may raise the question of the economic viability of the industry, especially when other such industries in the country do not do such level of investment. The industry will need some support in terms of soft loans or even some subsidy.

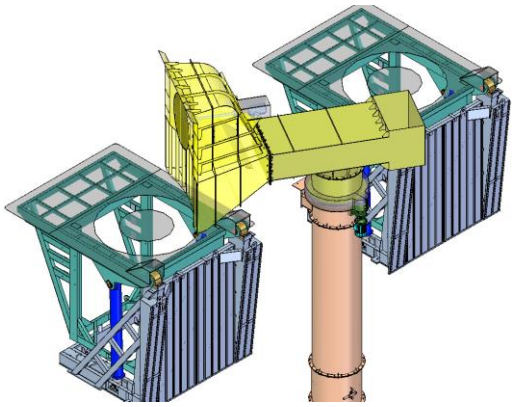


Figure 6.12: Proposed Suction Hood (Pic courtesy: Electrotherm)

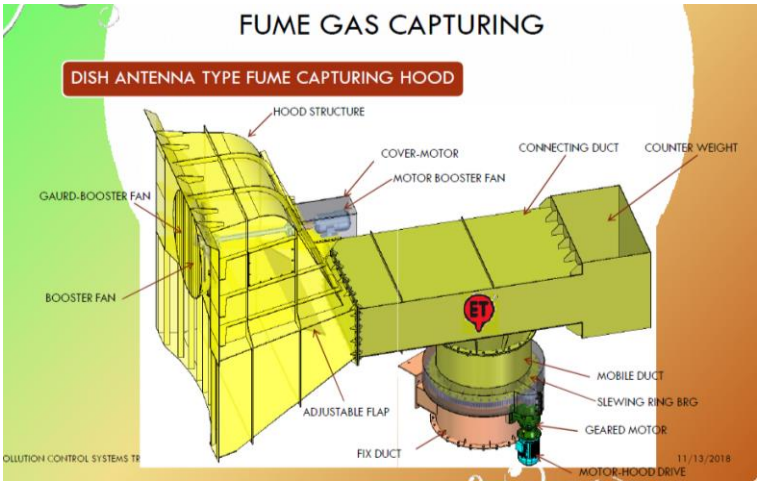


Figure 6.13: Side-based Suction Hood (Pic courtesy: Electrotherm)

Figure 6.14: Working of side-based Suction Hood

6.3 Environmental Surveillance

1. A system should be developed for monitoring environmental quality in order to detect areas of pollution concentration in time for remedial measures.
2. GRAP System (Graded Response Action Plan) should be developed: It is an emergency plan through which pollution control strategize to act according to air quality status suitable and rapid action that can be implemented quickly.
3. Pollution Control Board should take regularly do visits to check the status of road dust as it is seen that road dust is a major emission source for particulate matter.
4. Visual emissions must be informed and properly documented so that data of industries or sector is causing pollution can be identified.
5. For doing the above steps manpower must be increased in the respective departments so that the surveillance can be conducted uninterrupted.
6. Industries illegally running night shifts must be checked through surveillance. At night dispersion is more difficult that will cause more impact of pollution.
7. Agra has a suitable location for installing a solar plant as a number of sunny days is more in Agra. Solar power should be installed in Agra to reduce the running hours of Diesel Generators as well as to power infrastructural facilities in the commercial area.
8. Secondary particles SO_4, NO_3, and NH_4 constitute about 20 percent of $PM_{2.5}$ in winter. A significant emission of SO_2 from hundreds of brick kilns operating in the radius of about 50 kms, Mathura refinery and a large power plant of 665 MW in

100 km radius could be the primary cause of high SO_4^{2-}. Efforts should be made to reduce SO_2 emission from these large sources in a time-bound manner.

9. The certain areas have relatively high levels of ammonia (Nagar et al 2021). The potential source is from septic conditions in the river (and open drains) and decomposition of organic matter. It is a matter of urgency that only treated waste water (to the tertiary levels) is discharged into river Yamuna. It will dispel any fear of H_2S and NH_3 emission from the river
10. Ensure on-time implementation of BS-6 fuel and emission standards. State and district authorities can device a better vehicle scrapping polices for an early influx of BS-6 vehicles.
11. Workout and implement electric vehicle programme and infrastructural requirements for zero emissions for two-wheelers, three-wheelers/para transit, buses and large delivery fleet.
12. The nearby villages and towns to fully shift to LPG and people are educated not to use biomass/burning for cooking and waste disposal.

6.4 Strengthening of UPPCB Agra Regional Office

- New manpower recruitment for sampling, analysis, assessment, and surveillance
- Automated Stack Testing Kit
- Surveillance team should work in two shifts (day and night)
- Strict action against visible emission
- Proper documentation of violation of emission norms
- Capacity building should be done through regular training of personals
- Laboratory Upgradation

Table 6.2: A Glance of Control Options and Action Plan for City of Agra (for details read section 6.2)

Source	Control Action	Responsible authorities/agencies	Time Frame
Hotels/ Restaurants	Restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances.	Agra Municipal Corporation	1 year
	Link Commercial license to clean fuel	Agra Municipal Corporation, Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	1 years
	Ash/residue from the tandoor and other activities should not be disposed near the roadside.	Agra Municipal Corporations	1 year
Domestic Sector	LPG to all. Slums are using wood as cooking fuel.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	By 2030, city may plan to shift to electric cooking or PNG.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped.	Agra Municipal Corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Agra Municipal Corporation, UPPCB	
	Desilting and cleaning of municipal drains	Agra Municipal Corporation	
	Waste burning in Industrial area should be stopped.	UPSIDC, UPPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Agra Municipal Corporation	
	Sensitize people and media through workshops and literature distribution.	Agra Municipal Corporation, UPPCB and NGO	
Construction and Demolition	Wet suppression	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, Urban Development Department, PWD	Immediate

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

Source	Control Action	Responsible authorities/agencies	Time Frame
Road Dust	The silt load in Agra varies from 7.4 to 55.1 g/m^2. The silt load on each road should be reduced under 3 gm/m^2. Regular vacuum sweeping should be done on the road having silt load above 3 gm/$m^{2.}$	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	Immediate
	Convert unpaved roads to paved roads. Maintain pothole free roads.	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	
	Increase green cover and plantation. Undertake greening of open areas, community places, schools and housing societies.	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, State Forest Department, PWD	
	vacuum assisted sweeping carried out four times in a month, this will reduce road dust emission by 71%	Agra Development Authority, Agra Housing Board / ADA, Agra Municipal Corporation, National Highway Authority, PWD	
Vehicles	Diesel vehicle entering the city should be equipped with DPF which will bring a reduction of 40% in emissions (This option must be explored once Bharat stage VI fuel is available.)	State Transportation Department	3 years
	Industries must be encouraged to use Bharat stage VI vehicles for transportation of raw and finished products	Industrial Associations	Immediate
	Restriction on plying and phasing out of 10 years old commercial diesel driven vehicles.	Transport Department	2 years

Source	Control Action	Responsible authorities/agencies	Time Frame
	Introduction of cleaner fuels (CNG/ LPG) for vehicles.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 years
	Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Agra.	Transport Department, Traffic Police, Agra, NHAI, Toll agencies	Immediate
	Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. Buses should be CNG or Electric.	Transport Department, Agra City Transport Services Pvt. Ltd	1 year
	Make a time-bound plan for dipper penetration of electric vehicles (EVs), parallelly effort must be made for charging infrastructure including facilities for swiping the batteries. As a first step, two and three-wheeler should be considered for EVs.	The state of Uttar Pradesh and Agra administration	1 year
	Depot spaces should be rationalized to ensure more efficient utilization. Multi-modal, multi-use bus depots to be developed to provide high-class bus services and terminal experience to passengers. Should include well-equipped maintenance workshops. Charging stations shall be set-up.	Transport Department, Agra City Transport Services Pvt. Ltd	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Agra Development Authority, Agra Municipal Corporation, Agra City Transport Services Pvt. Ltd	1 year
	Ensure integration of existing metro system with bus services.	Agra Metro Rail Corporation, Agra Development Authority, Agra Municipal Corporation, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year

Source	Control Action	Responsible authorities/agencies	Time Frame
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year
	IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year
	Movement of materials (raw and product) should be allowed between 10 PM to 5 AM.	Transport Department, Agra Development Authority, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	1 year
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	UPPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and UPPCB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, UPSIDC, Industries Department, UPPCB	2 years
	Industrial waste burning should be stopped immediately	Industrial Associations, UPSIDC, UPPCB	Immediate
	Follow best practices to minimize fugitive emission within the industry premises, all leakages within the industry should be controlled	Industrial Associations, UPSIDC, UPPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, UPSIDC, UPPCB	
	Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, UPPCB	2 years
	Diesel Generator Sets		

Source	Control Action	Responsible authorities/agencies	Time Frame
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, JVVNL	2 years
	The standby power from DG sets should also be on clean fuel. All industrial DG sets which have gas connections should shift to gas-based generators. The battery-backed UPS/inverters should be considered for other commercial places and hospitals. Renewable energy-based generation should be encouraged.	Industrial Associations, Agra Municipal Corporations, Agra	2 years
Decongestion of Roads at high traffic areas	Strict action on roadside encroachment.	Agra Development Authority, Agra Municipal Corporations, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	6 months
	Disciplined Public transport (designate one lane stop).	Agra City Transport Services Pvt. Ltd., Traffic Police, Agra	
	Removal of free parking zone	Agra Development Authority, Agra Municipal Corporation, Agra City Transport Services Pvt. Ltd, Traffic Police, Agra	
	Examine existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI, Traffic Police, Agra	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI, Traffic Police, Agra	
	Mechanized multi storey parking at bus stands, railway stations and big commercial areas.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, NHAI, Traffic Police, Agra	

Source	Control Action	Responsible authorities/agencies	Time Frame
	Identify traffic bottleneck intersections and develop smooth traffic plan. For example, Lohamandi, Rakabganj, Kotwali, Tajganj, Hari-parwat are the main bottlenecks for traffic.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, Traffic Police, Agra	
	Parking policy in congestion area (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, NHAI, Traffic Police, Agra	
	Bijli Ghar and Idgah Bus Stand causes extreme congestion and increased emissions and should be decongested at priority. It is recommended that the city should relocate these bus stations to outskirts of the city (Bijli Ghar may be shifted to trans Yamuna and Idgah may be shifted to near to Patholi Village, Jaipur Road).	Agra Development Authority, Agra City Transport Services Pvt. Ltd, Agra Municipal Corporations, Traffic Police, Agra	
	An outer road from Keetham connects to Gwalior Road. This road may be connected to Agra ring road (connecting Yamuna Expressway and Agra-Lucknow express way); this will restrict the movement (within Agra city) of those vehicles destined to Jaipur or Gwalior. The ring road should further extend to the Agra-Jaipur highway.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI	2-3 years
	There should be a bypass for heavy vehicles and major godowns should be shifted away from the city at outside areas to prevent the movement of heavy vehicles in the city.	Agra Development Authority, Agra City Transport Services Pvt. Ltd, NHAI	2-3 years
Mantola and other major Drains	The major drains of city (Mantola Drain, Taj East Drain/ Kolhai Nala, Water Works Drain, Naraich Nala, Bhairo Nala, Nagla Budhi Nala, Anurag Nagar Nala, Peelakhar	Municipal Corporation and Agra Development Authority	2-3 years

Source	Control Action	Responsible authorities/agencies	Time Frame
	Nala) should be covered, diverted fully to wastewater treatment plant of tertiary level and then only discharge in river Yamuna or perhaps recycled. This will remove the problem NH_3, H_2S and smell in the city and Taj Mahal area		
Crematoriums	Electric, or gas-based crematorium should be installed	Municipal Corporation and Agra Development Authority	1-2 years
*The above steps should not only be implemented in Agra municipal limits rather these should be extended to up to at least 25 km beyond the boundary. This will need support from the central government.			

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