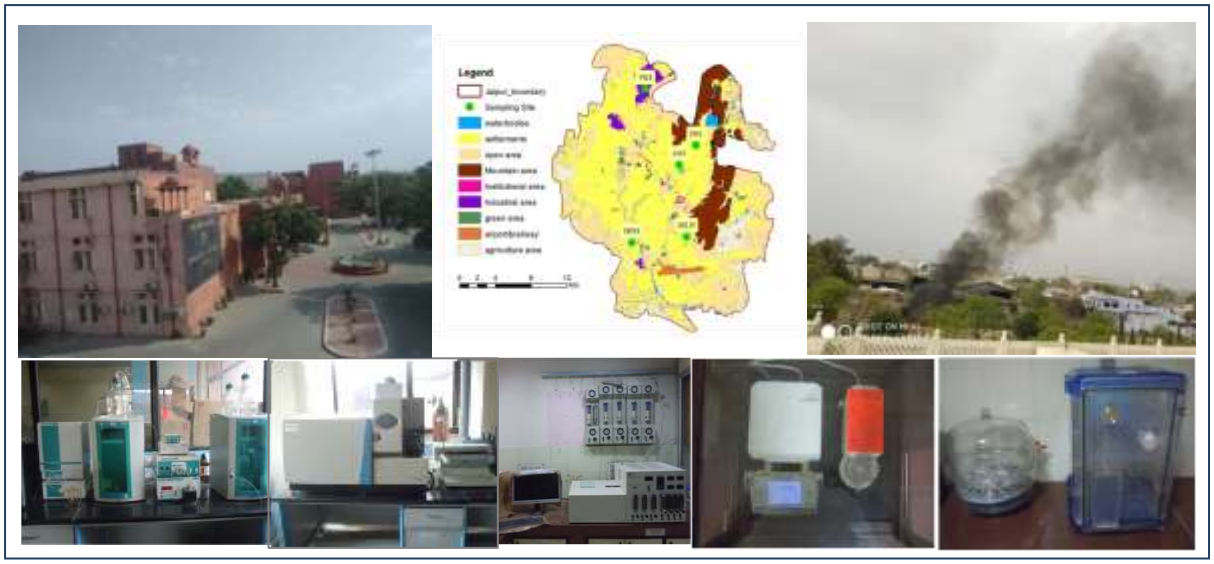
Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Jaipur City

(Final Report)

Submitted to

Rajasthan State Pollution Control Board, Jaipur



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Executive Summary

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

To address the air pollution issues of the City of Jaipur, the Rajasthan State Pollution Control Board (RSPCB), Jaipur has sponsored the study "Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Jaipur City" to the Indian Institute of Technology Kanpur (IITK). The study/project commenced on April 13, 2017. 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, training of RSPCB personnel and development of pollution control plan. The project has the following specific major objectives:

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

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

Air Quality: Measurements

A total of five air quality sites were categorized based on the predominant land-use pattern (Table 1) to cover varying land-use prevailing in the city. PM_{10} (particulate matter of size less than and equal to 10 µm diameter), $PM_{2.5}$ (particulate matter of size less than and equal to 2.5 µm diameter), SO_2, NO_2, VOCs (volatile organic compounds), OC (organic carbon), EC (elemental carbon), Ions, Elements, PAHs (polyaromatic hydrocarbons) and molecular markers were considered for sampling and measurements. The air quality sampling was conducted for two seasons: winter (2017-18) and summer (2018).

Table 1: Description of Sampling Sites of Jaipur

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	Ajmeri Gate	AJG	Commercial	Vehicles, road dust, garbage burning, restaurants
2.	Vishwakarma Industrial Area	VKI	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning
3.	Jorawar Singh Gate	JSG	Residential cum commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
4.	Malviya Nagar	MLN	Residential cum commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
5.	Man Sarovar	MNS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning

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

- Particulate pollution is the main concern in the city where PM_{10} levels are 2 - 4 times higher than the national air quality standards in summer and winter months and $PM_{2.5}$ levels are 1.2 – 3 times higher than the national standard in winter months.

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

Winter - PM_{10}

The overall average concentration of PM_{10} in the winter season is 256±77 µg/m^3 against the acceptable level of 100 µg/m^3. The highest levels were observed at VKI and lowest at MLN.

The crustal component (Si + Al + Fe + Ca) accounts for about 19% (much less compared to 33% in summer). This suggests soil and road dust has reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.32 (of the fraction of crustal component) which suggests the crustal source contributes consistently even in winter though much less compared to the summer season.

The other important component is the secondary inorganic particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for about 22% of total PM_{10} and combustion-related total carbon (TC = EC + OC) accounts for about 16%; both fractions of secondary particles and combustion-related carbons have increased in winter and account for 38% of PM_{10}.

The Cl^- content in PM_{10} in winter is not consistent and varies between 2 - 9 percent, which is an indicator of the burning of municipal and plastic solid waste (MSW); recall polyvinyl chloride (PVC) is a major part of MSW. The highest Cl^- content is observed at VKI at 36 µg/m^3 compared to the overall city level of 13 µg/m^3. The high level at VKI signifies some local burning of waste either in industrial processes or as a means of disposal of solid waste.

Winter - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 114±38 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at VKI 175±52 µg/m^3 and lowest at MLN 74±118 µg/m^3. The crustal component is reduced dramatically to 7% in $PM_{2.5}$ in winter compared to 16% in summer.

The important components are the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for 27% of total $PM_{2.5}$ and combustion-related total carbon (EC+OC) accounts for 26%; both secondary particles and combustion-related carbon are consistent contributors to $PM_{2.5}$ at about 53%. The highest level of TC was observed at VKI and AJG at about 40 µg/m^3.

The Cl^- content in $PM_{2.5}$ winter is not consistent and varies between 2 – 10 percent which is an indicator of the burning of municipal solid waste (MSW).

Summer - PM_{10}

The overall average concentration of PM_{10} in the summer season was 261±32 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 33 percent of total PM_{10} in summer. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.12, which suggests the sources are consistent all around the city forming a layer which envelopes the city. The areas of AJG and JSG have the highest crustal fraction (around 34% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are widespread and present all around in Jaipur and are more prominent in summer when soil and dust are dry and high-speed winds make the particles airborne. It was observed that in summer the atmosphere looks light brownish which can be attributed to the presence of large amounts of soil dust particles in the atmosphere.

The second significant component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for 8.3 percent of total PM_{10} and combustion-related total carbon (EC+OC) accounts for about 5.7 percent. The secondary particles are formed in the atmosphere because of the reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^-, SO_4^{-2}, and NH_4^+. The combustion-related contribution is relatively less in PM_{10} in summer.

The Cl^- content in PM_{10} in summer is consistent at 1-3 percent, which is an indicator of the burning of municipal solid waste (MSW) and has a relatively lower contribution in summer than winter.

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer season is 55 µg/m^3 (except at VKI where the level is 81±15 µg/m^3) within the acceptable level of 60 µg/m^3.

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

The second important component is combustion-related total carbon (EC+OC), which accounts for 21% of total $PM_{2.5}$ and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) account for 15%; both fractions of secondary particles and combustion-related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles and combustion contribute consistently to $PM_{2.5}$ in summer.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 1-2 percent except at VKI (5%), which is an indicator of the burning of municipal solid waste (MSW) and has a similar contribution to $PM_{2.5}$ and PM_{10}. This is relatively lower in summer than in winter.

Potassium levels

In general potassium levels are high and variable for PM_{10} (4.6 to 9.6 µg/m^3) in winter and summer and in $PM_{2.5}$ (2.1 to 4.9 µg/m^3) in winter. In general potassium level should be less than 2 µg/m^3. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.30) show significant biomass burning and it is consistent both in summer and winter.

NO_2 levels

NO_2 levels in winter are higher than those in summer at all sites and the levels meet the national air quality standard of 80 µg/m^3. The highest NO_2 levels were at AJG, a traffic site. In addition, high levels of NO_2 are expected to undergo chemical transformation to form fine secondary particles in the form of nitrates, adding to high

levels of existing PM_{10} and $PM_{2.5}$. SO_2 levels in the city were well within the air quality standard.

General inferences

Levels of $PM_{2.5}$ and NO_2 are statistically higher (at all locations) in winter months than in summer months by about 42-60%. The levels of PM_{10} are statistically similar except for VKI. 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, VKI is most polluted followed by AJG and JSG. MLN is the least polluted area.

It is to be noted that OC3/TC ratio is above 0.20 and 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 Jaipur.

Total PAH levels (19 compounds; particulate phase) in winter is very high at 68 ng/m^3 and B(a)P at 7.3 ng/m^3 (annual standard is 1 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 16 ng/m^3. The highest PAH levels observed at VKI (winter 167 ng/m^3 and summer 36 ng/m^3).

The concentrations of molecular markers in $PM_{2.5}$ (total of 7 compounds) are also higher in winter (21 ng/m^3) than in summer (14 ng/m^3) indicating the presence of common sources of emissions from coal, gasoline and domestic fuel.

The total BTX (benzene, toluene and xylene) levels are higher in winter (20 $\mu g/m^3$) than in summer (11 $\mu g/m^3$). Although the emission rate is expected to be high in summer due to higher temperatures, the concentration is low due to better dispersion and a large ventilation coefficient. The benzene generally exceeded the annual national standard (5 $\mu g/m^3$) in winter (except at AJG).

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

In a broad sense, fractions of secondary particles of both PM_{10} and $PM_{2.5}$ in two seasons were consistent and need to be controlled for better air quality in Jaipur. Combustion sources, vehicles, coal, biomass burning and MSW burning are other consistent sources in winter and require a strategy to control these sources.

Trend analysis

The long-term (2010-2018) temporal PM_{10} and NO_2 levels were analyzed for annual and seasonal variations and trends. The air quality data were obtained for 2010–2018 from RSPCB, Jaipur. The results provide information in terms of trends such as (i) Significant downward, (ii) Significant upward, (iii) Firstly decreasing and then increasing, (iv) Firstly increasing then decreasing and (iv) No trend.

Both PM_{10} and NO_2 showed a sharp increase in the levels during post-monsoon and continue to gradually increase in winter or tend to stabilize. It is interesting to note that in the second half of March, PM_{10} levels increase and show significant variability. There is no specific trend in PM_{10} and NO_2 data from the adopted approach.

Emission Inventory

Emission inventory (EI) is a basic necessity for planning air pollution control activities. The overall baseline EI for both Jaipur Development Authority boundary (JDA) and Jaipur City Boundary (JCB) is developed for the base year 2018. The pollutant wise contribution is shown in Figures 1 to 5. Spatial Distribution of pollutant emissions from all sources is presented in Figure 6.

The total PM_{10} emission load in the city is estimated to be 92 t/d. The top four contributors to PM_{10} emissions are road dust (71%), industries (8%), vehicles (8%) and construction (4%); 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 34 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (46 %), vehicles (20 %), industries (19%) and domestic fuel

burning (5 %); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

NOx emissions load in the city is estimated to be 75 t/d. Nearly 85 % of emissions are attributed to vehicular emissions followed by DG set (6%) and industries (4%). Vehicular emissions occur at ground level and probably making it the most important source. NOx apart from being a pollutant itself is an important component in the formation of secondary particles (nitrates) and ozone. NOx emissions from vehicles and from industry are potential sources for controlling NOx emissions.

SO_2 emission load in the city is estimated to be 9 t/d. Industry account for 55 percent of the total emission. Hotels and Restaurants contribute to 19% followed by vehicles (13%).

The estimated CO emission is about 199 t/d. Nearly 73 % emission of CO is from vehicles, followed by industries (15%), domestic (6%) and MSW burning (4%). Vehicles could be the main target for controlling CO for improving air quality with respect to CO.

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

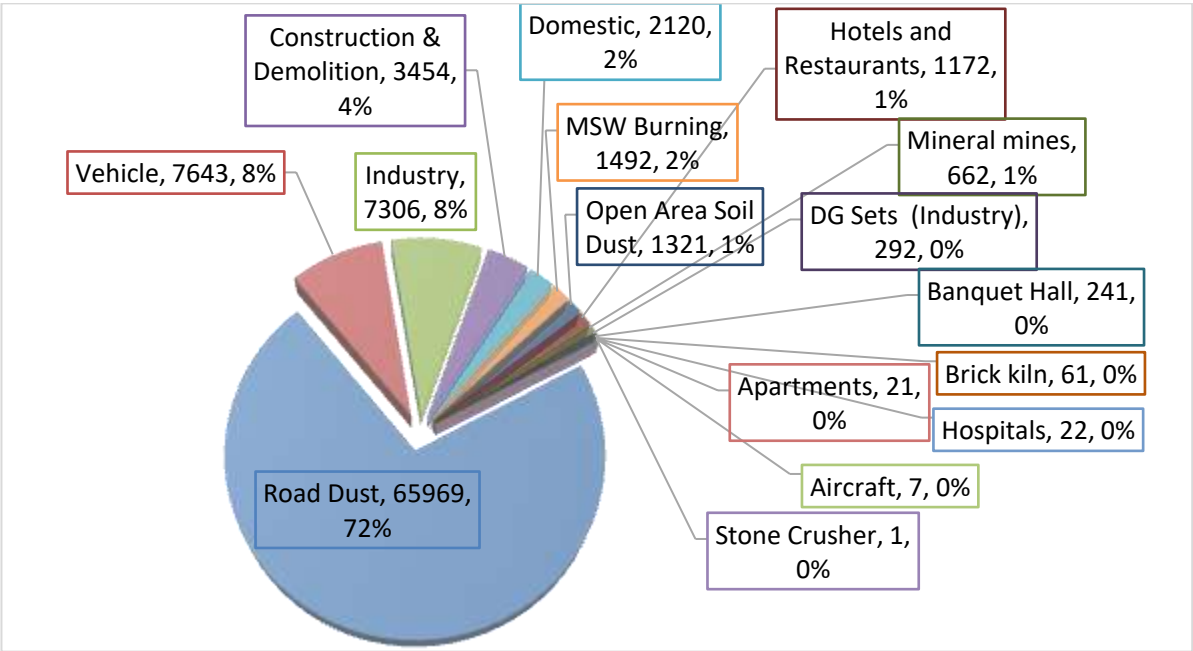


Figure 1: PM_{10} emission Inventory of different sources in the city of Jaipur (kg/d)

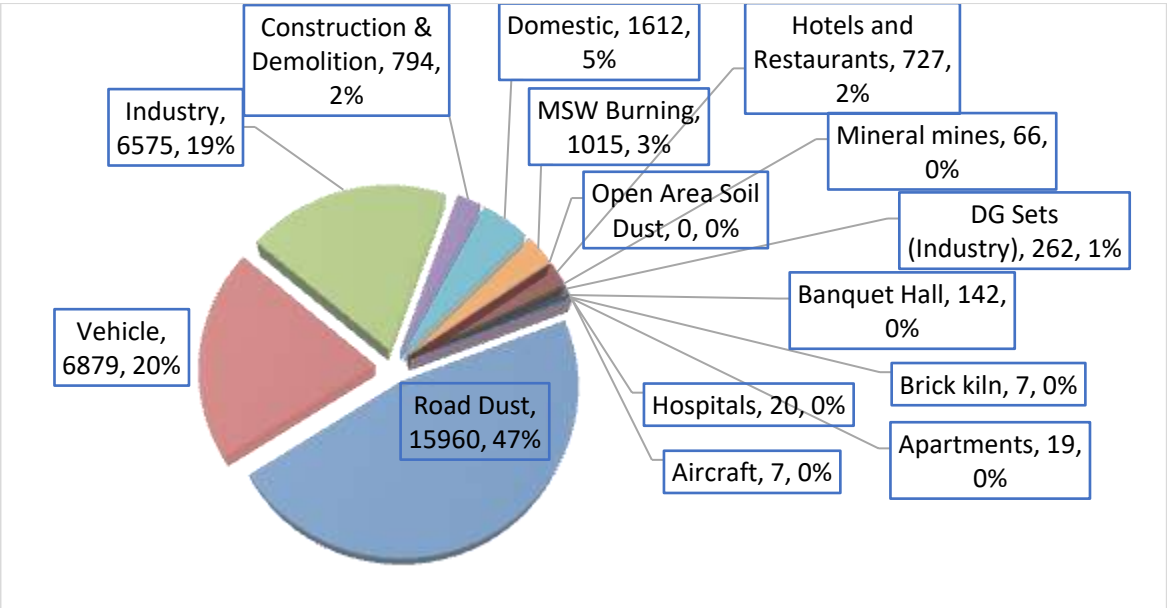


Figure 2: $PM_{2.5}$ emission load of different sources in the city of Jaipur (kg/d)

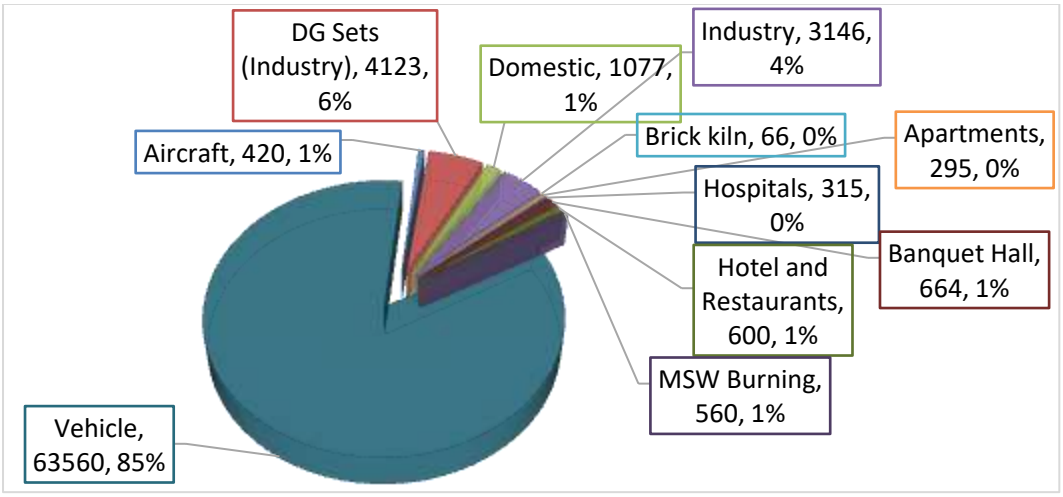


Figure 3: NO_x emission load of different sources in the city of Jaipur (Kg/d)

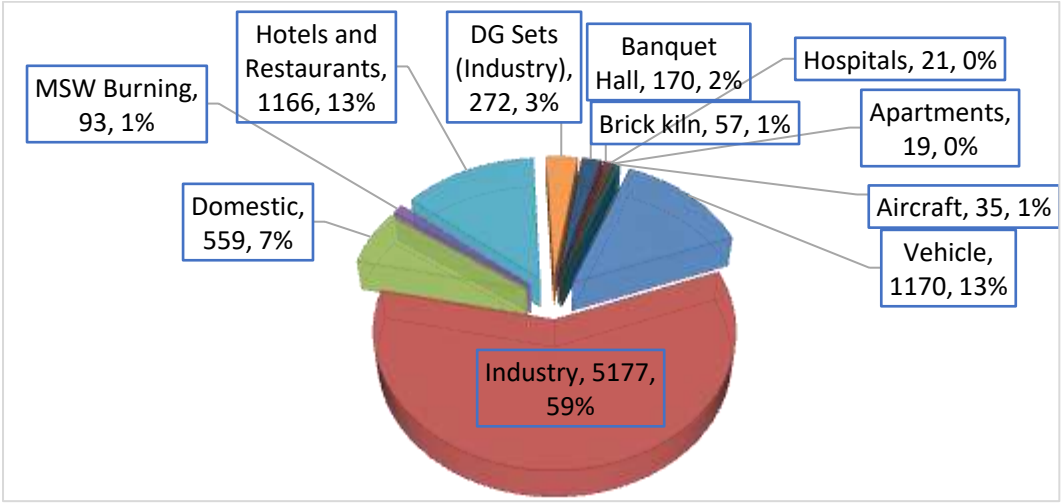


Figure 4: SO_2 emission load of different sources in the city of Jaipur (kg/d)

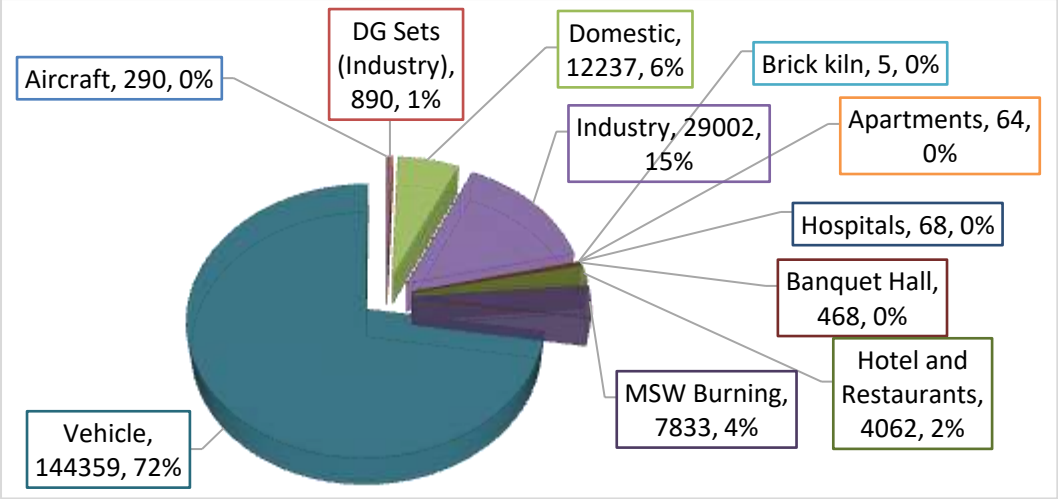


Figure 5: CO emission load of different sources in the city of Jaipur (kg/d)

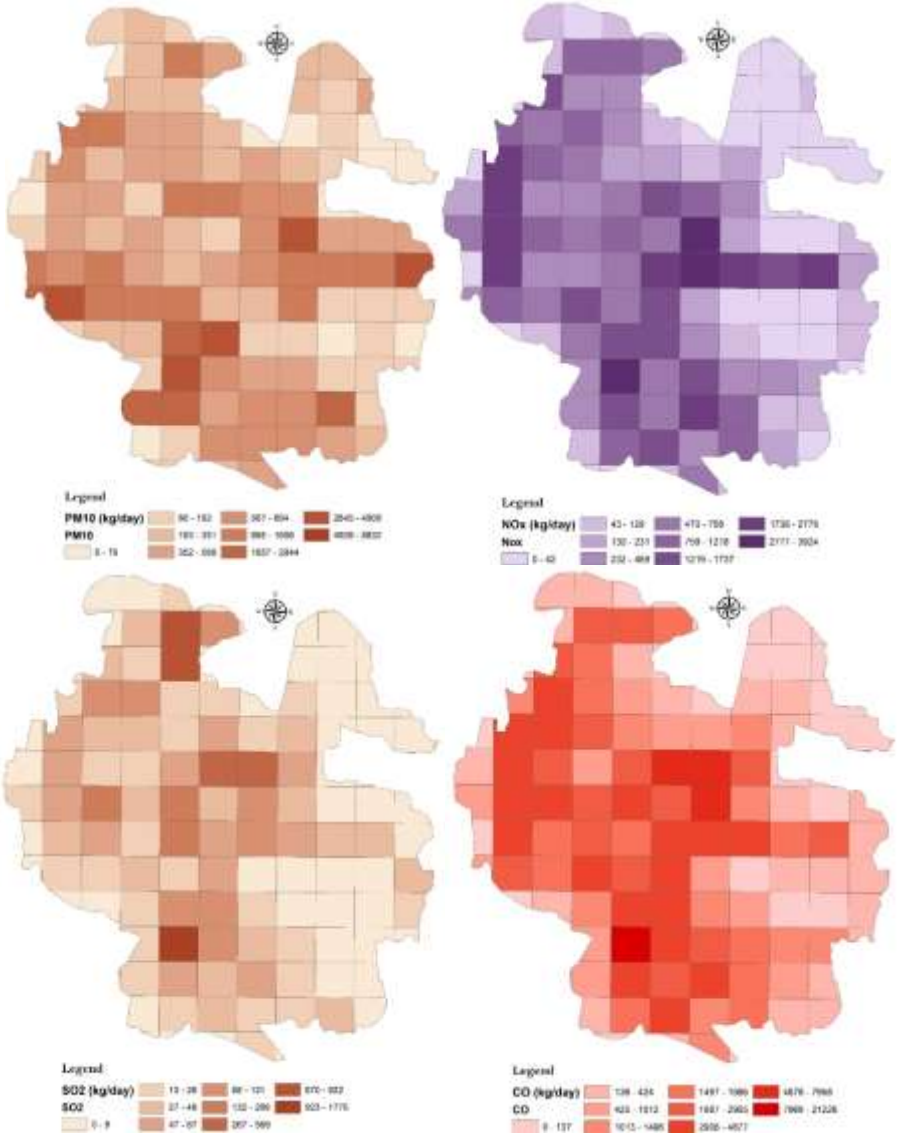


Figure 6: Spatial Distribution of PM_{10} , NOx, SO_2 and CO Emissions in the City

Air Quality Modeling

Receptor Modeling

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

- The sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter.
    - The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include: soil and road dust (41 – 18%), SIA (secondary inorganic aerosol) (17 - 23%), biomass burning (19 – 32%), vehicles (11 - 17%) and MSW burning (6 - 8%). It is noteworthy that in winter, major sources for PM_{10} and $PM_{2.5}$ are generally the same.
    - The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include: soil and road dust (69 – 36%), biomass burning (10 - 30%), vehicles (5 – 14%), MSW burning (4 – 6%), coal and flyash (7 - 5%) and SIA particles (3 - 6%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The three most consistent sources for PM_{10} and $PM_{2.5}$ in both the seasons are SIA, biomass burning and vehicles. The other sources on average may contribute more (or less) but their contributions are variable from one day to another. The most variable source was MSW burning. Soil and road dust and construction material sources were consistent for PM_{10} but somewhat variable for $PM_{2.5}$.
- The consistent presence of SIA, biomass burning and vehicles in PM_{10} and $PM_{2.5}$ across all sites and in both the seasons, suggests these particles encompass the entire Jaipur region as a layer.
- Similar to the above point, in winter consistent presence of soil and road dust (in PM_{10}) encompass the entire Jaipur region as a layer.
- Soil and road dust in summer contribute 36 – 69% and the coal and flyash contribute 5 – 7% to $PM_{2.5}$ and PM_{10}. It is observed that in summer the atmosphere looks light brownish indicating the presence of large amounts of dust; re-

suspension of dust appears to be the cause of large contribution of these sources. This hypothesis can be argued from the fact that the contribution of road and soil dust reduces significantly both in PM_{10} and $PM_{2.5}$ in winter when winds are low and prevalent atmospheric conditions are calm.

- The contribution of the biomass burning in winter is quite high at 19% (for PM_{10}) 32% (for $PM_{2.5}$). The presence of sizeable biomass is consistent in PM both winter and summer indicates to local sources present in Jaipur and nearby areas. As per the report on biomass fuel supply by Rajasthan Renewable Energy Corporation Limited (RRECL, 2015), juliflora wood consumption is about 1159 tonnes/day by local people as a domestic fuel, local bakery and hotels industries, biomass power plant and other local thermal energy-consuming industries in Jaipur district. There is an immediate need to control or find alternatives to completely eliminate biomass emissions to observe any significant improvements in air quality.
- The recent study by Singh (2015) has estimated 256 tons/day of MSW was not collected (~20 % of generated MSW (1280 tons/day). Form the uncollected waste, a major part would be burned. It is clearly seen that MSW burning is a major source that contributes to both PM_{10} and $PM_{2.5}$. This emission is expected to be large in the regions of economically lower strata of the society which does not have proper infrastructure for the collection and disposal of MSW.
- Vishwakarma industrial area has the movement of large trucks ferrying raw material and finishes products. Poor road conditions were spotted due to the dumping and burning of MSW and plastic waste along the roadside. The contribution of MSW/plastic burning is exceptionally high in PM_{10} (winter: 16%, summer: 13%) and $PM_{2.5}$ (winter: 17%, summer: 14%) both in winter and summer season. Probably there is poor management of waste generated from industries which are subjected to open burning.

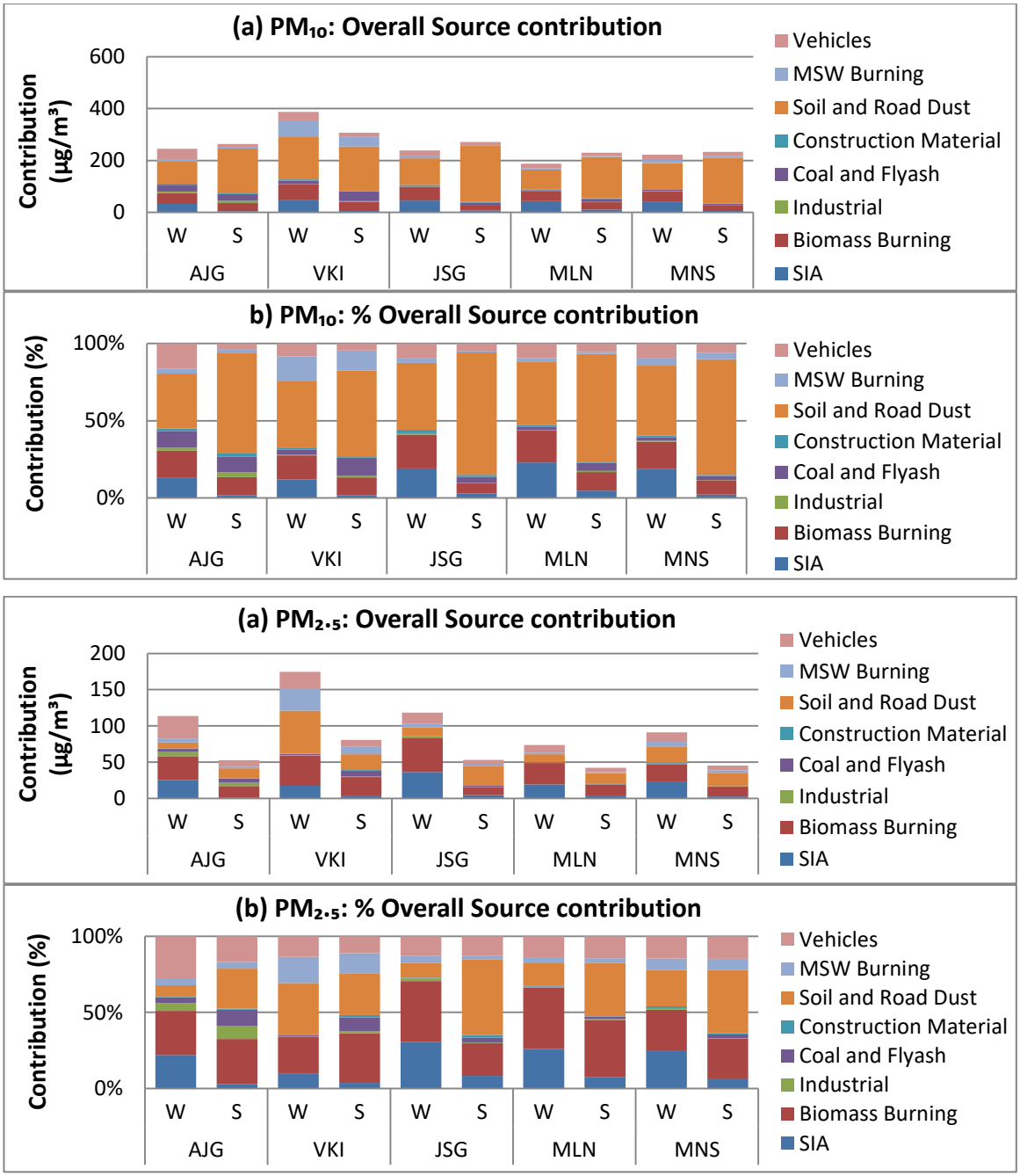
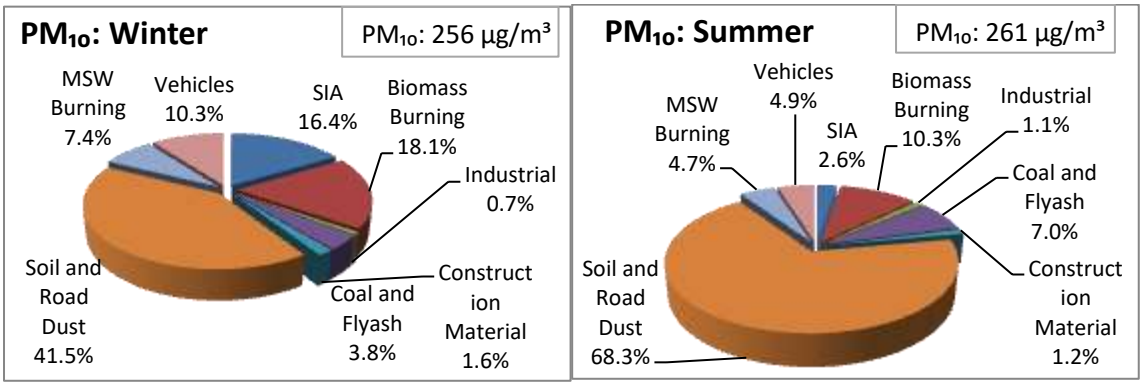


Figure 7: Overall Results of CMB Modeling for PM_{10} and $PM_{2.5}$ at five sites



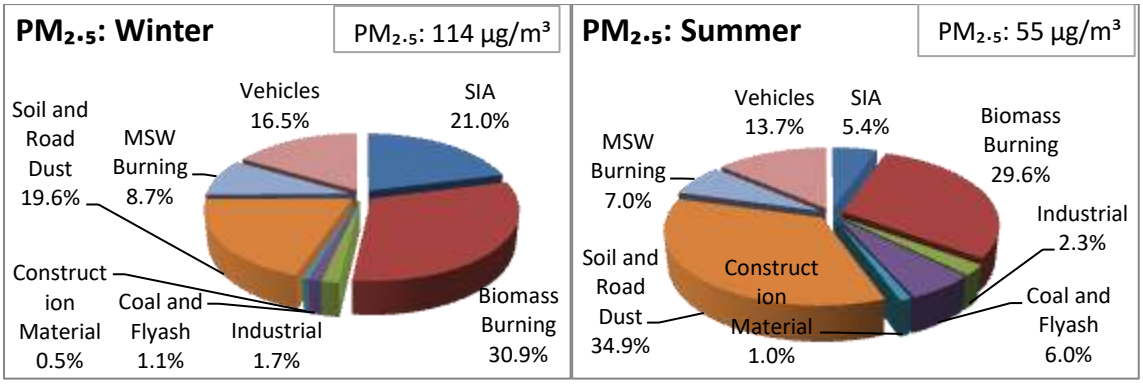


Figure 8: City level source contribution to ambient air PM_{10} and $PM_{2.5}$ levels

Control Options and Actions

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

- Hotels/Restaurants

  There are approximately 1500 large Hotels/Restaurants (sitting capacity of more than 10 persons) in the city which use LPG and coal (mostly in tandoors). The PM emission in the form of flyash from this source is large and contributes to air pollution. It is proposed that all restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances. The Jaipur 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 maybe enforced by Jaipur Municipal Corporation, Department of Food, Civil Supplies and Consumer Affairs, and oil Companies (Indian Oil, HP,etc.)

- Domestic Sector

  Although in Jaipur, 81% of the households use LPG for cooking, the remaining 19% uses wood, crop residue, cow dung, kerosene and coal for cooking (Census-India, 2012). The LPG should be made available to the remaining 21% of households to make the city 100% LPG-fuelled. It is recommended that by the year 2030, the city may plan to shift to electrical or PNG cooking. 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.

- MSW burning

  One of the reasons for burning MSW is the lack of infrastructure for timely collection of MSW and it is conveniently burned or it may smolder slowly for a long time. The Jaipur municipal corporation should prioritize the MSW collection mechanism starting in a systematic manner in each ward. Special attention is required for fruits, vegetable markets and commercial areas and high-rise residential buildings, where MSW burning is common. A mechanism should be developed to carry out mass balance of MSW generation and disposal on daily and monthly basis. Any type of garbage burning should be stopped and ensured by Jaipur Municipal Corporation.

  Desilting and cleaning of municipal drains by Jaipur 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; this must stop and ensured under the supervision of RIICO and RSPCB. 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 front of the industry. Probably there are unauthorized industries, especially in the VKI area which use solid waste of all kinds for energy extraction. Such industries should be identified and suitable action is taken. Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Jaipur Municipal Corporation and RSPCB.

  Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Jaipur Municipal Corporation, RSPCB and NGOs.

- 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. It can be seen from Chapters 4 and 5 that this source is one of the significant ground-level emission sources and a significant contributor to PM_{10} and importantly it is a consistent source all through the year; this source is more prominent outside the city boundary. The control measures for emission may include:

- Wet suppression
- Wind speed reduction (for large construction site)
- Enforcement of C&D Waste Management Rules. The waste should be sent to construction and demolition processing facility
- 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.
- Actual construction area should be 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)
- Builders should leave 25% area for green belt in residential colonies to be made mandatory.
- Sensitize construction workers and contract agency through workshops.

  The above control measures should be coordinated and supervised by Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD and RSPCB. 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.

- Soil and road dust

  It can be seen from Chapters 4 and 5, 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 on roads varies from 4 to 32 g/m^2 which is exceptionally high. 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. Specifically, the roads at the following locality showed very high silt load: Badi chopad, Yadgaar Chauraha, Agra Road, Triveni Chauraha, Jaipur-Kishangarh highway and Pradhan Guest House.

  The following control measures are suggested to reduce the dust emissions on major roads are:

- Convert unpaved roads to paved roads and maintain pothole-free roads.
- Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.
- Increase green cover and plantation. Undertake greening of open areas, community places, schools and housing societies.
- vacuum assisted sweeping carried out four times in a month, this will reduce road dust emission by 71% (resultant emissions: $PM_{2.5}$=4 ton/day).
- If the silt load on the roads is greater than 3 gm/m^2, the vacuum-assisted sweeping should be carried out on a regular basis.

The above control measures should be coordinated and supervised by Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

- Vehicular pollution

  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 7 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.) for the infrastructure and supply of CNG.

  Various control options include the use of Retro-fitment of Diesel Particulate Filter (DPF), implementation of BS VI, and PUC checks are the means to check emissions from on-road vehicles, restriction on plying and phasing out of 10 years old commercial diesel-driven vehicles, introduction of cleaner fuels (e.g. CNG) for vehicles, introduction of electric and hybrid vehicles, check overloading, depot spaces should be rationalized to ensure more efficient utilization traffic planning and restriction of movement of vehicles, route rationalization, improvement in

public transport etc have been proposed which can be undertaken by the State Transport Department.

The number of PUC centres should be increased to 350 based on a thumb rule of 3 PUC centres per ten thousand registered vehicles. Maintenance and calibration of equipment must be ensured by regular surveillance.

Public transport is an important option for quick and pollution-free mobility for the city dwellers. However, it should be an efficient, reliable, punctual and comfortable system. The system should also gear to last-mile connectivity. There are many variables that decide the minimum requirement of buses but typically it is in the range of 0.5 to 1.2 buses per 1,000 population. It is, therefore, recommended that the city should have 1000 buses to provide efficient and reliable public transport.

- Decongestion of Roads

The actions listed below may be coordinated and supervised by Jaipur Development Authority, Jaipur Municipal Corporations, Jaipur City Transport Services Pvt. Ltd, and Traffic Police, Jaipur. The suggested control measures are:

- Strict action on roadside encroachment.
- Disciplined Public transport (designate one lane stop).
- Identify traffic bottleneck intersections and develop a smooth traffic plan. The identified highly congested areas are Badi chopad, BSNL CSC circle, Chomu pulia, D-circle, Collectrate circle, Gopalpura circle and Ghandi circle.
- Sindhi camp bus stand handles over 500 public buses every day and this causes extreme congestion and increased emissions. To decongest the area, it is recommended that the city should have three more large inter-district/inter-state bus stations in the north-west (towards Sikar and Bikaner), east (towards Bharatpur – Agra) and south (towards Tonk).
- There is no place for parking in the Sindhi camp bus stand except for the government buses (that is also limited). However, many private buses of long distances from the same area cause early morning and night time congestion. This affects the traffic and leads to congestion up to Chandpole, Collectorate and other nearby areas. It is recommended to shift the private bus stands to other locations similar to one suggested in the above point.

- Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.
- Mechanized multi-story parking at bus stands, railway stations and big commercial areas.
- Parking policy in the congestion area (high parking cost at city centers) on an hourly basis.
- The Jaipur railway station is the hub of urban activities for transport of man and material, hotels, shops, etc., which cause severe traffic congestion in the area. It is recommended that other railway stations in the city are developed and modernized to cater to more railway traffic so as to decongest the main railway station.
- It is recommended to add more metro railway lines for a rapid public transport system to discourage the use of personalized vehicles and preventing traffic congestions.

The following additional control actions should be undertaken through a coordinated effort among various agencies, as listed below:

- Industries must be encouraged to use Bharat stage VI vehicles for transportation of raw material and finished products. Agency: Industrial Associations.
- Restriction on plying and phasing out of 10 years old commercial diesel driven vehicles. Agency: Transport Department.
- Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Jaipur. Agencies: Transport Department, Traffic Police, Jaipur, NHAI, Toll agencies.
- Electric/Hybrid Vehicles should be encouraged; New residential and commercial buildings to have charging facilities. Buses should be CNG or Electric. Agencies: Transport Department, Jaipur City Transport Services Pvt. Ltd.
- 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. Agencies: Transport Department, Jaipur City Transport Services Pvt. Ltd.
- Enforcement of bus lanes and keeping them free from obstruction and encroachment. Agencies: Jaipur Development Authority, Jaipur Municipal

Corporation, Jaipur City Transport Services Pvt. Ltd.

- Ensure integration of existing metro system with bus services. Agencies: Jaipur Metro Rail Corporation, Jaipur Development Authority, Jaipur Municipal Corporation, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur.
- Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification. Agencies: Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur.
- IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring. Agencies: Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur.
- Movement of materials (raw and product) should be allowed between 10 PM to 5 AM. Agencies: Transport Department, Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur.

- Industries and Diesel Generator Sets

    - Shifting of polluting industries: Many polluting industries like Stone crushers / Brick kilns have been closed and shifted in the past due to pollution load. Further, all the brick kilns nearby and around the city shall be converted to cleaner technology (i.e. Zigzag) within the stipulated period.
    - Approximately 500 boilers/furnaces are operational in Jaipur and contribute heavily to particulate as well as in gaseous emissions. The heavy contribution is due to the use of coal, wood, and other solid fuels; the industry should shift to clean fuel such as natural gas and electricity. The majority of solid fuel-based industries used 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 hazardous 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.
- Ensuring emission standards in industries. Shifting of polluting industries: There are many highly polluting induction furnaces in the city with almost no pollution control devices. The maximum emissions occur when the furnace lids and doors are opened during charging, back charging, alloying, oxygen lancing (if done), poking, slag removal, and tapping operations. These emissions escape from sides and top the building. To address the pollution caused by fugitive emissions using induction furnaces a fume gas capturing device has been developed and commercially available which should be installed and monitored. It is further suggested that induction furnaces are shifted from the city area to some other remote areas. A coordinated effort under the supervision of RSPCB, RIICO and Industries Departments is suggested.

Environmental Surveillance

- A system should be developed for monitoring environmental quality in order to detect areas of pollution concentration in time for remedial measures.
- GRAP System (Graded Response Action Plan) should be developed: It is an emergency plan through which pollution control strategizes to act according to air quality status so that suitable and rapid actions can be implemented quickly.
- RSPCB should regularly visit to check the status of road dust as it is seen that road dust is a major emission source for particulate matter.
- Visual emissions must be informed and properly documented so that data of industries or sectors are causing pollution can be identified.
- For doing the above steps manpower must be increased in the respective departments so that the surveillance can be conducted uninterrupted.
- Industries illegally running night shifts must be checked through surveillance. At night dispersion is more difficult that will cause more impact of pollution.
- Jaipur has a suitable location for installing a solar plant as a number of sunny days is more in Jaipur. Solar power should be installed in Jaipur to reduce the

running hours of Diesel Generators as well as to power infrastructural facilities in the commercial area.

Strengthening of Jaipur Regional Offices

- 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 personnel
- Laboratory Upgradation

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

Table 2: Action Plan for City of Jaipur

Source	Control Action	Responsible authorities	Time Frame
Hotels/ Restaurants	Restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances.	Jaipur Municipal Corporation	1 year
	Link Commercial license to clean fuel	Jaipur 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.	Jaipur 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 year
	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 year
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped.	Jaipur Municipal Corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Jaipur Municipal Corporation, RSPCB	
	Desilting and cleaning of municipal drains	Jaipur Municipal Corporation	
	Waste burning in Industrial area should be stopped.	RIICO, RSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Jaipur Municipal Corporation	
	Sensitize people and media through workshops and literature distribution.	Jaipur Municipal Corporation, RSPCB and NGO	
Construction and Demolition	Wet suppression	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction site)	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The	Jaipur Development Authority, Rajasthan Housing	Immediate

Source	Control Action	Responsible authorities	Time Frame
	waste should be sent to construction and demolition processing facility	Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Actual construction area should be covered by a fine screen.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur 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)	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Sensitize construction workers and contract agency through workshops.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD, RSPCB and NGO	
Road Dust	The silt load in Jaipur varies from 4 to 32 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 $gm/m^{2.}$	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD	Immediate
	Convert unpaved roads to paved roads. Maintain pot hole free roads.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National	

Source	Control Action	Responsible authorities	Time Frame
	for all haul routes.	Highway Authority, PWD	
	Increase green cover and plantation. Undertake greening of open areas, community places, schools and housing societies.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur 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% (resultant emissions: PM2.5=4 ton/day)	Jaipur Development Authority, Rajasthan Housing Board, Jaipur 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
	Introduction of cleaner fuels (CNG/ LPG) for vehicles.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 year
	Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Jaipur.	Transport Department, Traffic Police, Jaipur, 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, Jaipur City Transport Services Pvt. Ltd	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, Jaipur City Transport Services Pvt. Ltd	1year
	Enforcement of bus lanes and keeping them free from	Jaipur Development Authority, Jaipur Municipal	1 year

Source	Control Action	Responsible authorities	Time Frame
	obstruction and encroachment.	Corporation, Jaipur City Transport Services Pvt. Ltd	
	Ensure integration of existing metro system with bus services.	Jaipur Metro Rail Corporation, Jaipur Development Authority, Jaipur Municipal Corporation, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
	IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
	Movement of materials (raw and product) should be allowed between 10 PM to 5 AM.	Transport Department, Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	RSPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and RSPCB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, RIICO, Industries Department, RSPCB	2 year
	Industrial waste burning should be stopped immediately	Industrial Associations, RIICO, RSPCB	Immediate
	Follow best practices to minimize fugitive emission within the industry premises, all leakages within the industry should be controlled	Industrial Associations, RIICO, RSPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, RIICO, RSPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 500 boilers and furnaces in Jaipur are running over coal, wood, and other dirty solid fuels which should	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.),	2 years

Source	Control Action	Responsible authorities	Time Frame
	be shifted to natural gas and electricity	Industrial Associations, RSPCB	
	Almost all rotary furnace having significant emissions are running on coal that needs to be shifted to natural gas and electricity	Industrial Associations, RSPCB	2 year
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, RSPCB	2 year
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, RSPCB	2 year
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, JVVNL	2 years
	Renewable energy should be used to cater the need of office requirement in the absence of power failure to stop the use of DG Set	Industrial Associations	2 year
Decongestion of Roads at high traffic areas	Strict action on roadside encroachment.	Jaipur Development Authority, Jaipur Municipal Corporations, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	6 months
	Disciplined Public transport (designate one lane stop).	Jaipur City Transport Services Pvt. Ltd., Traffic Police, Jaipur	
	Removal of free parking zone	Jaipur Development Authority, Jaipur Municipal Corporation, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	
	Examine existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, NHAI, Traffic Police, Jaipur	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, NHAI, Traffic Police, Jaipur	

Source	Control Action	Responsible authorities	Time Frame
	Mechanized multi storey parking at bus stands, railway stations and big commercial areas.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, NHAI, Traffic Police, Jaipur	
	Identify traffic bottleneck intersections and develop smooth traffic plan. For example, Badi chopad, BSNL CSC circle, Chomu pulia, D-circle, Collectrate circle, Gopalpura circle and Ghandi circle are the main bottlenecks for traffic.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Traffic Police, Jaipur	
	Parking policy in congestion area (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, NHAI, Traffic Police, Jaipur	
	Sindhi Camp Central Bus Stand causes extreme congestion and increased emissions and should be decongested at priority. it is recommended that the city should have three more large inter-district/inter-state bus stations in north-west (towards Sikar and Bikaner), east (towards Bharatpur – Agra) and south (towards Tonk). It is also recommended to shift the private bus stands (currently near Sindhi Camp, Polovictory and nearby areas) to other locations similar to one suggested in the above point.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Traffic Police, Jaipur	
	The Jaipur railway station is the hub of urban activities for transport of man and material, hotels, shops, etc., which cause severe traffic congestion in the area. It is recommended that other railway stations in the city are developed and modernized to cater more railway traffic so to decongest the main railway station.	Indian Railways, Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Jaipur	
	It is recommended to add more metro railway lines for	Jaipur Metro Rail Corporation Ltd, Jaipur	

Source	Control Action	Responsible authorities	Time Frame
	rapid public transport system to discourage the use of personalized vehicles and preventing traffic congestions.	Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Jaipur	
*The above steps should not only be implemented in Jaipur 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 of the Study

Air pollution has emerged as a major challenge, particularly in urban areas. The problem becomes more complex due to multiplicity and complexity of air polluting source mix (e.g., industries, automobiles, generator sets, domestic fuel burning, road side dusts, construction activities, etc.). Being a major centre of commerce, industry and education, Jaipur has experienced a phenomenal 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 Jaipur.

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) deduce 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 measured mass (USEPA, 1991). These shortcomings are largely the result of difficulty in developing accurate 24-hour particulate emission inventories and meteorological database. Although traditional techniques using dispersion modelling for source impact apportionment will remain an important tool in air-shed management, recent advances in receptor-oriented technique are now beginning to 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 communities have benefited from these control programs. Nonetheless, most cities in the country still face continuing particulate non-attainment problems from aerosols of unknown origin (or those not considered for pollution control) despite the high level of control applied to many point sources. It is in 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 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 modelling 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 a receptor modelling is promising tool for source identification and apportionment in the complex urban condition. This is particularly true when there are many unorganized activities releasing particulate to atmosphere, which are typically true for our urban cities. In order to apply receptor modelling, it is essential to identify sources (small or large), generate emission profile in terms of fingerprints and elemental composition. The next vital step is the determining the chemical characterization of collected particulate matter on filter paper. In fact, it is easily conceivable that receptor and dispersion modelling can complement at each other for better interpretations and decision making and can be applied at tandem.

To address the air pollution issues of City of Jaipur, the Rajasthan State Pollution Control Board (RSPCB), Jaipur has sponsored the study "Air Quality Assessment, Trend Analysis, Emission Inventory and Source Apportionment Study in Jaipur City" to the Indian Institute of Technology Kanpur (IITK). The study/project has commenced on April 13, 2017. 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, training of RSPCB personnel and development of pollution control plan.

1.2 General Description of City

1.2.1 Geography and Demography

Jaipur (latitudes 26°42′57.44″ N and 27°04′39.13″ N and longitudes 75°40′12.26″ E and 75°51′37.02″ E), the capital city of Rajasthan is situated between in the foot hills of Aravali range, surrounded by hillock in northern and eastern sides and vast stretch of plains in western and southern sides (Dadhich et al., 2018, Mathew et al., 2018). The total area is 485 sq km with a maximum width of 25 km and maximum length of 32 km. In Jaipur, key business activities are tourism, trade and commerce and local handicraft industries. The manufacturing and fabrication industries sectors in Jaipur are categorised as clothing and

textiles, chemicals, electronics and computers, transport, petroleum and plastics, metals, minerals, wood, paper, leather and food industries etc.

The population of Jaipur city is 3,046,163 (as per 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 91 wards.

1.2.2 Climate

The city experiences semi-arid climatic conditions with high temperature in summer and winters are mild to moderate. The average annual rainfall in Jaipur is 650 mm, most of rainfall occurs in the monsoon months of July to September. The maximum temperature ranges are experienced in summer up to 48°C and minimum temperature in winter season is in the range of 5 – 10°C in coldest period of December-January. The average monthly wind speed varies in between 2.5 and 10.0 km/h with maximum during summer (6–10 km/h) and minimum in winters (Dadhich et al., 2018).

1.2.3 Emission Source Activities

The source activities for air pollution in the city of Jaipur 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 (buses), 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 the industrial activities are concerned, lots of small and medium scale industries are also responsible for the air pollution. In most of the institutions and offices, the diesel generators are used at the time of power failure.

1.3 Need for the Study

1.3.1 Current Air Pollution Levels: Earlier Studies

$PM_{2.5}$ and PM_{10} concentrations varied seasonally with atmospheric processes and the anthropogenic activities in Jaipur. The Maximum levels were observed during winter months (PM_{10}: 362.1 $\mu g/m^3$ and $PM_{2.5}$:163.1 $\mu g/m^3$) and the minimum levels in the month of August (PM_{10}: 154.0 $\mu g/m^3$ and $PM_{2.5}$: 51.5 $\mu g/m^3$) during 2014 (Sharma and Sharma, 2016). In the

year 2014, monthly average concentration of NO_2 was maximum (63.5µg/m^3) in January and minimum (9.7 µg/m^3) in monsoon season and CO concentration ranged from 0.40 - 0.76 mg/m^3 (Sharma and Sharma, 2016).

The range for monthly mean PM_{10} and $PM_{2.5}$ levels were 150-450 and 50-300 µg/m^3 during the years 2005-2015 (Jain and Mandowara, 2019). Half-monthly variations in PM_{10} are shown in Figure 1.1 at different locations for the period 2005-2013 (Nagar et al., 2019).

Although, Jaipur city faces air pollution problem due to the number of sources, no detailed study of chemical composition of PM_{10} and $PM_{2.5}$ has been undertaken to identify the sources and their contributions to air pollution. One of the common sources is the vehicular pollution and it significantly contributes to air pollution; total registered motor vehicles in the city increased from 4.2 million to 12.4 million (as on march 2015) in 10 years (Nama et al., 2017). Other sources are refuse and biomass burning, construction dust and unregulated sources that can be major cause of air pollution.

1.3.2 Seasonal Variation of Air Quality

To get a clearer picture of the seasonal variability in the concentration of PM_{10} and NO_2, average, half-monthly concentrations are plotted as an example for air quality data at Vishwakarma industrial area (VWK) and RSPCB office (RPB) in Jaipur. Figures 1.1 and 1.2 present half monthly mean concentrations averaged over 2005-2013 for PM_{10} and NO_2 at VWK) and RPB.

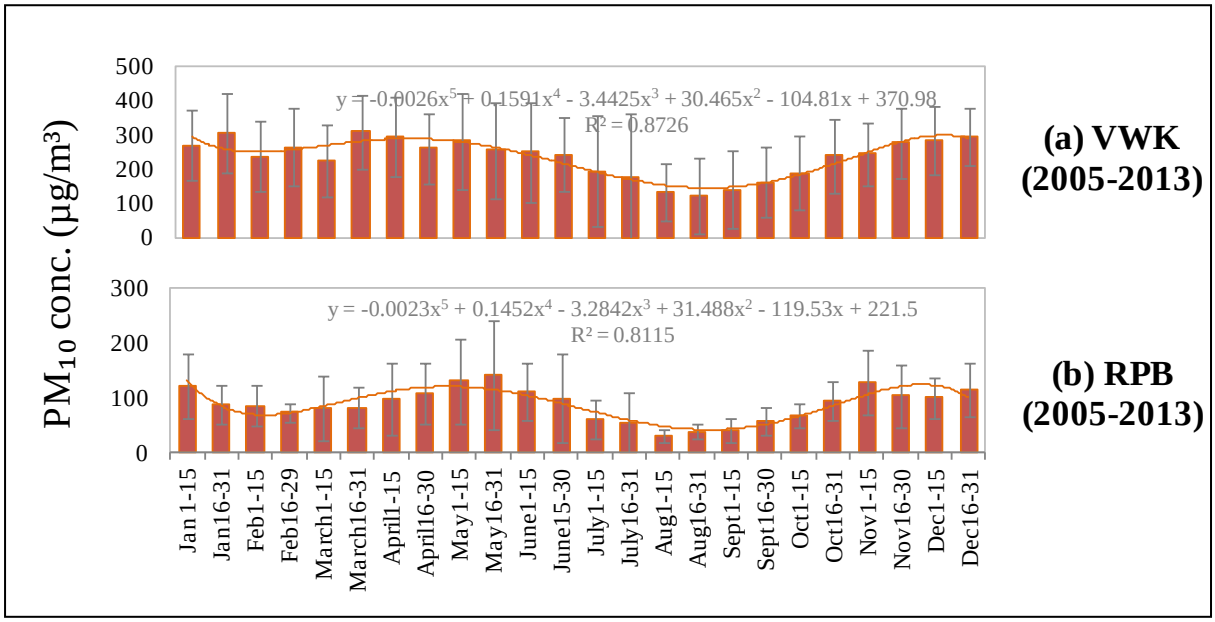


Figure 1.1: Seasonal Variation in PM_{10} (Source: Nagar et al., 2019)

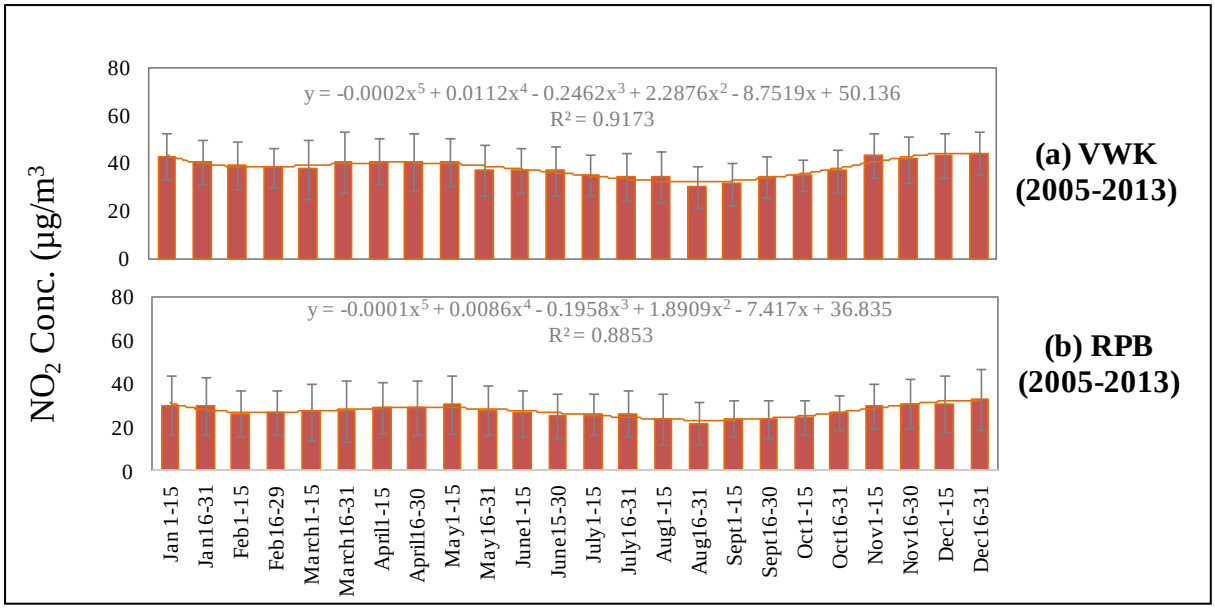


Figure 1.2: Seasonal Variation in NO_2 (Source: Das, 2015)

Two peaks were observed (Figures 1.1 and 1.2), one during pre-monsoon season and the other during post-monsoon to winter. The sharp increase in the levels during post monsoon is not apparent, as the PM_{10} levels continue to gradually increase in winter or tend to stabilize. It is interesting to note that in the second half of March, levels increase and levels show very high variability. The city of Jaipur is close to the Thar Desert in the west and is characterized to have dust storms in the months of March and April. However, PM_{10} levels except monsoon months (July – September), exceed the 24-h national air quality standard (Nagar et al., 2019).

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), volatile organic compounds (VOCs) and polyaromatic hydrocarbons (PAHs) for the base year, 2018.
- 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 (Iso Phorone (IsP), Di methyl Phthalate (DmP), Acenaphthylene (AcP), Di ethyl Phthalate (DEP), Fluorene (Flu), Hexachlorobenzene (HcB), Phenanthrene (Phe), Anthracene (Ant), Pyrene (Pyr), Butyl benzyl phthalate (BbP), Bis(2-ethylhexyl) adipate (BeA), Benzo(a)anthracene (B(a)A), Chrysene (Chr), Benzo(b)fluoranthene (B(b)F), Benzo(k)fluoranthene (B(k)F), Benzo(a)pyrene (B(a)P), Indeno(1,2,3-cd)pyrene (InP), Dibenzo(a,h)anthracene (D(a,h)A) and Benzo(ghi)perylene (B(ghi)P)).
- Reconstruction of chemical species of PM and assessment for primary and secondary sources of air pollutants.
- Application of receptor model to establish source receptor linkages of PM_{10}, and $PM_{2.5}$ using state-of the-art modeling to arrive at source apportionments at various sampling sites.
- Identification of various control options (e.g. adoption of EURO IV/V, diesel filter, etc) and assessment of their efficacies for air quality improvements and development of control scenarios (in a techno economical perspective) consisting of combinations of several control options.
- Selection of most effective control options for implementation and development of time-bound action plan.

1.5 Approach to the Study

The approach to the study is based on attainment of its objectives within the scope of work, as explained in the section 1.4. The summary of the approach is presented in Figure 1.3. The overall approach to the study is broadly described below.

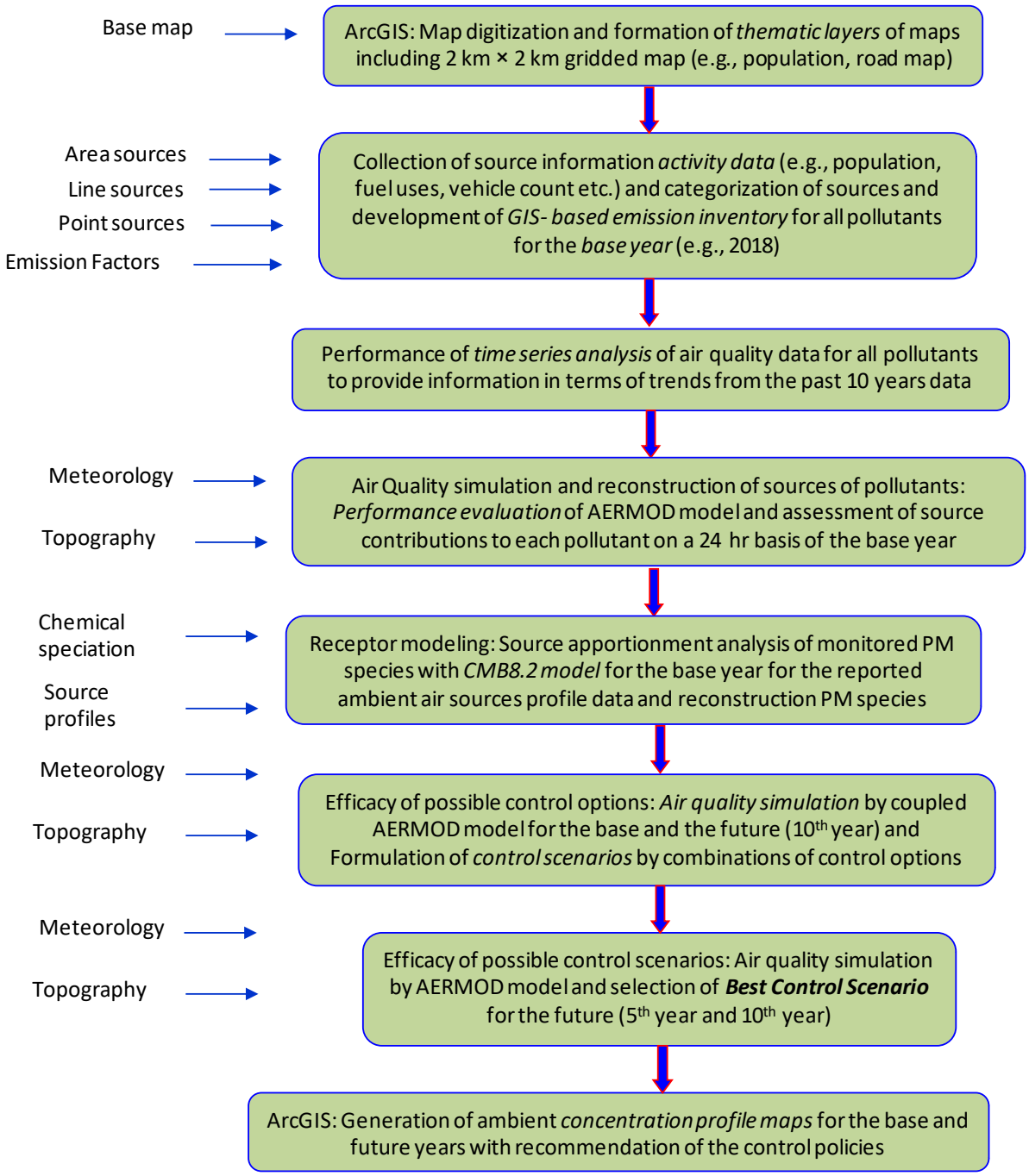


Figure 1.3: Approach to the Study and Major Tasks

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

It was considered appropriate that five sites in a city like Jaipur can represent typical land-use patterns. It needs to be ensured that at all sites, there is a free flow of air without any obstruction (e.g. buildings, trees etc.). In view of the safety of the stations, public buildings

could be better choices as sampling sites. Sites were finalized in consultation with the officials of RSPCB, Jaipur.

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

1.5.3 Emission Source Profiles

Since for $PM_{2.5}$, Indian or Jaipur 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 Jaipur 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 Time Series Analysis

There are several techniques that provide trends including simple plotting of data to more complex autoregressive integrated moving average (ARIMA) models. This analysis was done for all pollutants and results provide information in terms of trends such as: (i) Significant downward, (ii) Significant upward, (iii) Firstly decreasing and then increasing, (iv) Firstly increasing then decreasing (iv) No trend. This analysis clearly establishes the benefits of air pollution control measures and need for future measures.

1.5.5 Application of Receptor Modeling

There are several methods and available commercial software those can be used for apportioning the sources if the emission profiles and measurements are available in the ambient air particulate in terms of elemental composition. The most common software is USEPA CMB 8.2 (USEPA, 2004). This model should be able to provide 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.

1.5.6 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 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 6 chapters. The brief descriptions of the chapters are given below.

Chapter 1

This chapter presents 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 term 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 on the basis of the monitoring and chemical characterization results of various air pollutants of all sampling locations for two seasons, i.e. winter and summer carried out in this study. In addition to the above

information, this chapter also enumerates methodologies adopted for the monitoring, laboratory analyses and quality assessment and quality control (QA/QC). This chapter also compares the results of all sites both diurnally and seasonally.

Chapter 3

This chapter presents the methodology used for trend analyses in long-term time series and the results of trends in historical pollution data of last 10 years.

Chapter 4

This chapter describes the methodology of developing 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 5

This chapter presents the methodology used for CMB8.2 modeling for source apportionment study for PM_{10} and $PM_{2.5}$ in summer and winter seasons. The contribution of various sources at receptor sites and overall scenario of sources that influences the air quality in city 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 4 and 5.

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

2 Air Quality: Measurements, Data Analyses and Inferences

2.1 Introduction

Air pollution 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'. The 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 air quality of Jaipur 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 safety of the stations, public buildings (institutions, office buildings etc.) were selected. The sites were selected in consultation with RSPCB, Jaipur. 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 overall land-use pattern of the city.

Table 2.1: Description of Sampling Sites of Jaipur

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	Ajmeri Gate	AJG	Commercial	Vehicles, road dust, garbage burning, restaurants
2.	Vishwakarma Industrial Area	VKI	Industrial	Industries, DG sets, vehicles, road dust, garbage/industrial waste burning
3.	Jorawar Singh Gate	JSG	Residential cum commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
4.	Malviya Nagar	MLN	Residential cum commercial	Domestic cooking, vehicles, road dust, garbage/MSW burning, restaurants
5.	Man Sarovar	MNS	Residential	Domestic cooking, vehicles, road dust, garbage/MSW burning

Figure 2.1: Photographs of Sampling Sites showing the physical features

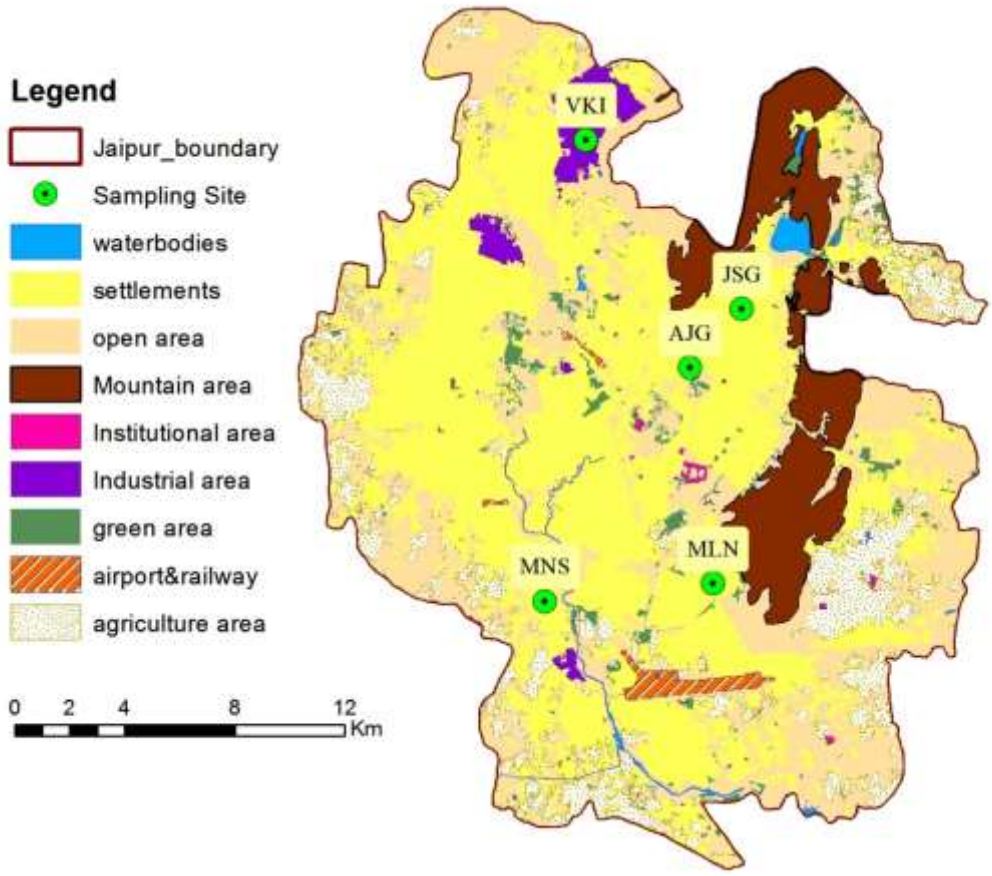


Figure 2.2: Land-use Pattern and Locations of Sampling Sites

The parameters for sampling and their monitoring methodologies including 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	Mass spectrometry
8.	Molecular Markers	Gas chromatography- mass spectrometry (GC-MS)	Mass spectrometry
9.	PAHs	GC-MS	Mass spectrometry
10.	VOCs	GC-MS	Mass spectrometry

Table 2.3: Target Chemical components for Characterization of PM

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

2.2.2 Instruments and Accessories

The Partisol® Model 2300 4-CSS (Thermo Fisher Scientific Inc, USA), USEPA approved equivalent speciation samplers (with mass flow controller) are used in this study for monitoring of particulate matter (Figure 2.4(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 analysis of ions and elements and quartz filters are used for OC-EC, PAHs and molecular markers.

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 2.4(b)).

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 2.4(e)). Ion recovery efficiencies were determined by spiking 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 fraction of organic carbon (OC) and elemental carbon (EC) by thermal optical transmittance (DRI Model 2001A Themal/Optical Carbon Analyzer; Figure 2.4(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 2.4(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 rotary evaporator (up to 10 mL) and Turbo Vap (Work Station-II, Caliper Life Sciences, Hopkinton, USA) for 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 2.4(d)).

To analyze the molecular markers, QMA filters were used. In view of small quantity of molecular markers on filters, filter papers of seven days were combined and extracted. Extractions were carried out in DCM and acetone (1:1) solution in soxhlet apparatus followed by concentration of extract using rotary evaporator and nitrogen purging on turbovap; the extract volume was reduced to 2 ml. The samples were analyzed for alkanes and hopanes on GCMS. For levoglucosan and stigmasterol analysis, the derivatives were developed by silylation using BSTFA+TMCS (99:1) solution (Zhang et al., 2009).

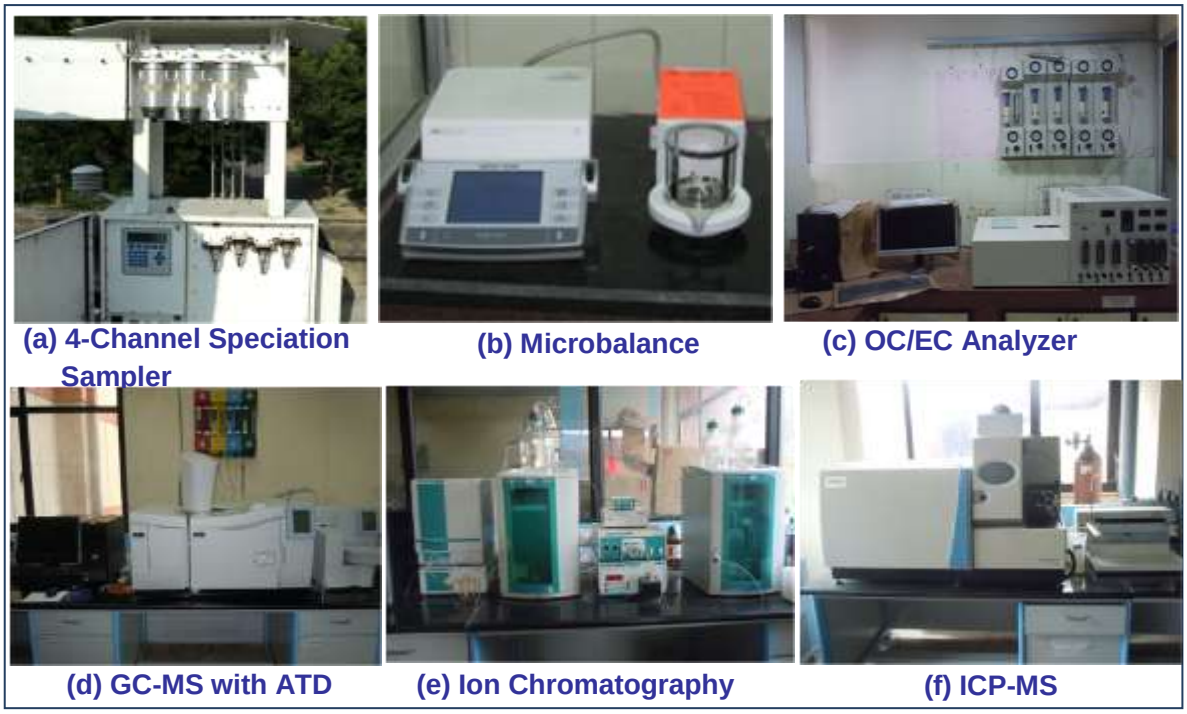


Figure 2.3: Instruments for Sampling and Characterization

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 hands-on training was imparted to project team before 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 Jaipur. 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 havebeen trained in the field and in the laboratory. Whenever necessary, the SOPs were adjusted to meet the field challenges.
- SOPs include type of equipment (with specifications), sampling and calibration methods with their frequency.

- SOPs for chemical analysis include description of methods, standards to be used, laboratory and field blanks, internal and external standards, development of data base, screening of data, record keeping including backups, traceability of calculations and standards.

There are dedicated computers for instruments and data storage with passwords. To ensure that the computers do not get infected, these computers are not hooked to Internet connections.

Sampling periods: The ambient air sampling has been completed for 20 days at each site for winter (November 19, 2017 - February 14, 2018) and summer (April 15, 2018 - June 20, 2018). The analysis of SO_2 and NO_2 are carried out daily on a regular basis while gravimetric analysis for particulate matters was done after completion of the sampling in the season. All efforts were made for the 100% achievement of the sampling and analysis. However, NO_2 sampling at VKI and JSG in winter was captured for 60 percent of time and VOC capture was 80% at JSG in summer. Rest all data capture and sampling was achieved over 95% of 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 2.8 and Table 2.9 to 2.13 for winter and summer season respectively.

Table 2.4: Sampling days of various pollutants in winter (2017-18) at AJG

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

Table 2.5: Sampling days of various pollutants in winter (2017-18) at VKI

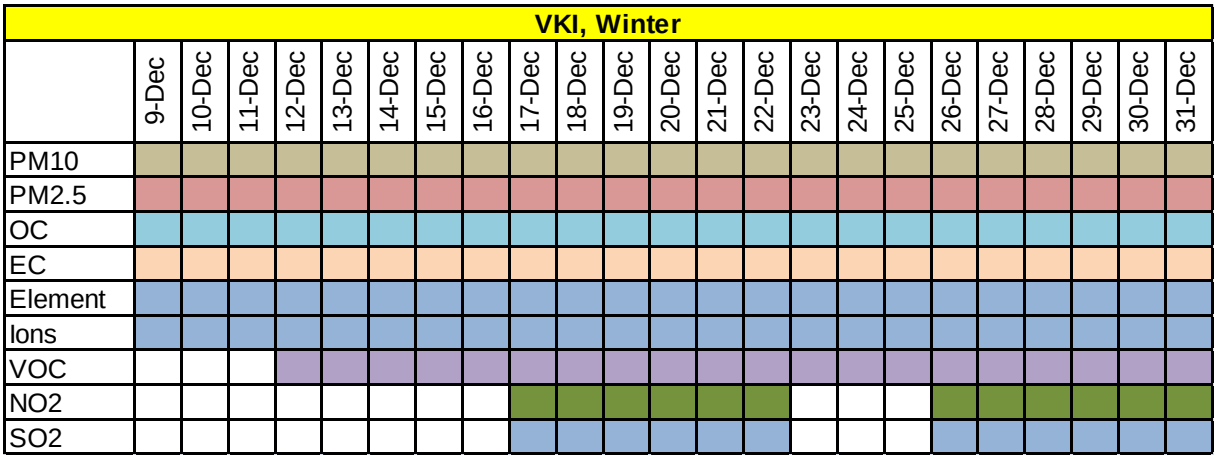


Table 2.6: Sampling days of various pollutants in winter (2017-18) at JSG

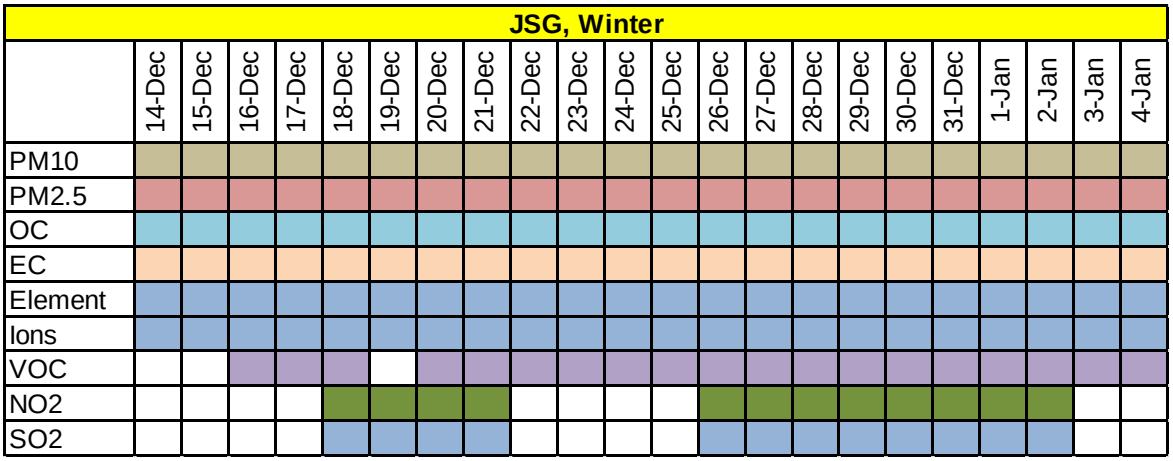


Table 2.7: Sampling days of various pollutants in winter (2017-18) at MLN

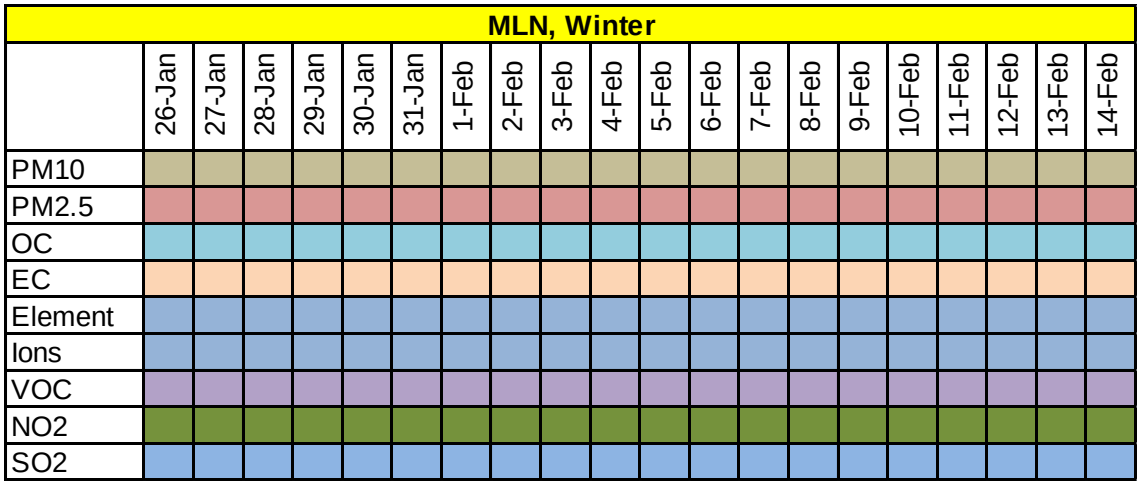


Table 2.8: Sampling days of various pollutants in winter (2017-18) at MNS

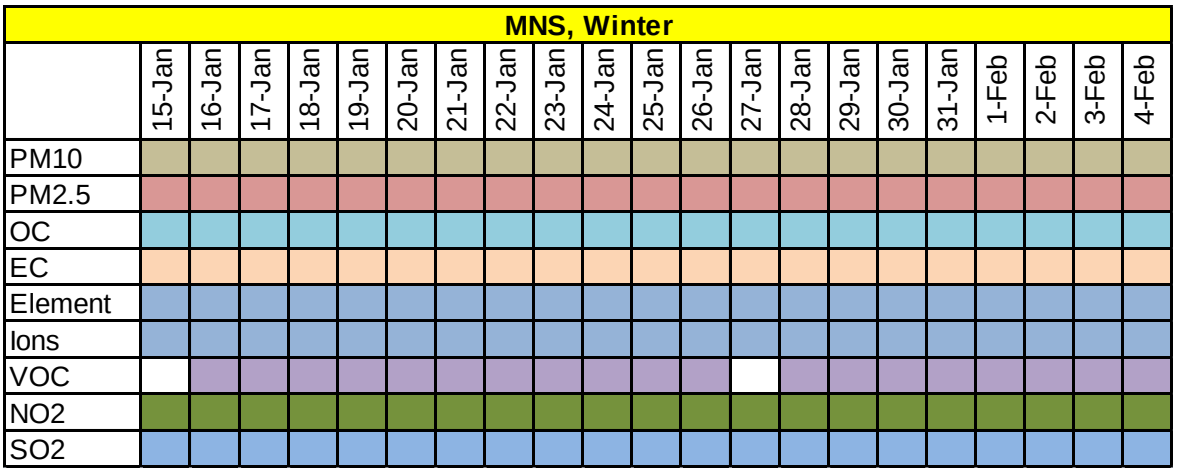


Table 2.9: Sampling days of various pollutants in summer (2018) at AJG

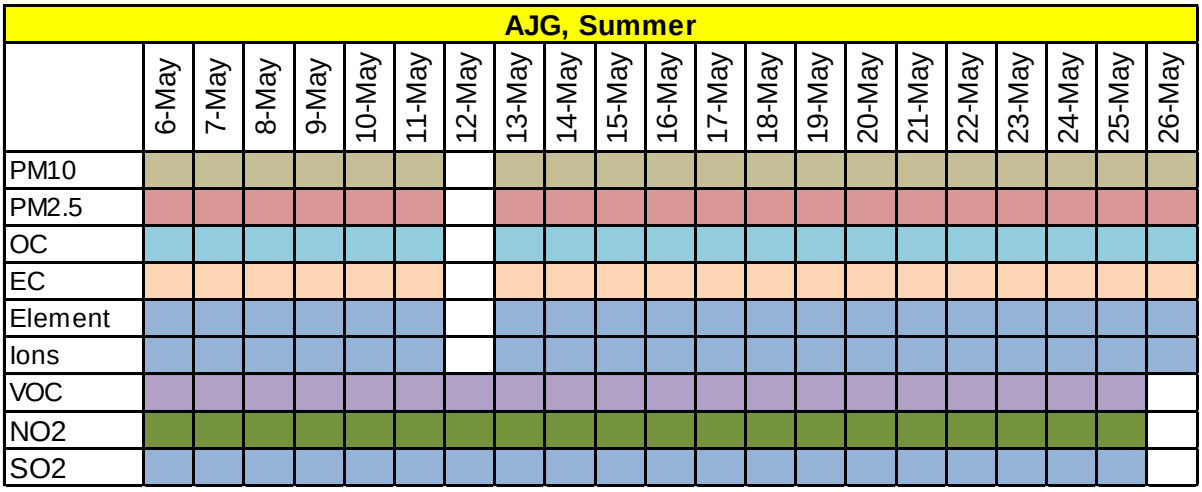


Table 2.10: Sampling days of various pollutants in summer (2018) at VKI

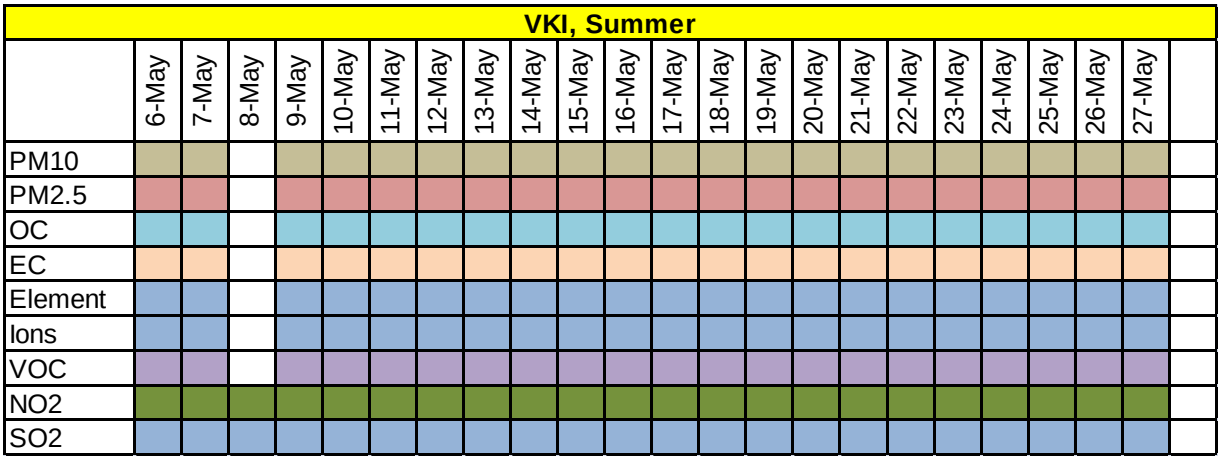


Table 2.11: Sampling days of various pollutants in summer (2018) at JSG

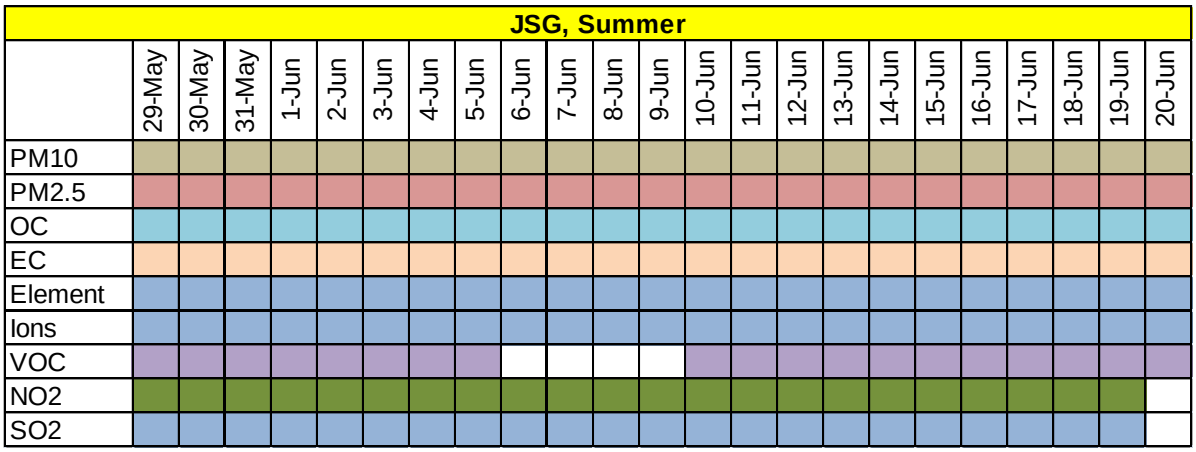


Table 2.12: Sampling days of various pollutants in summer (2018) at MLN

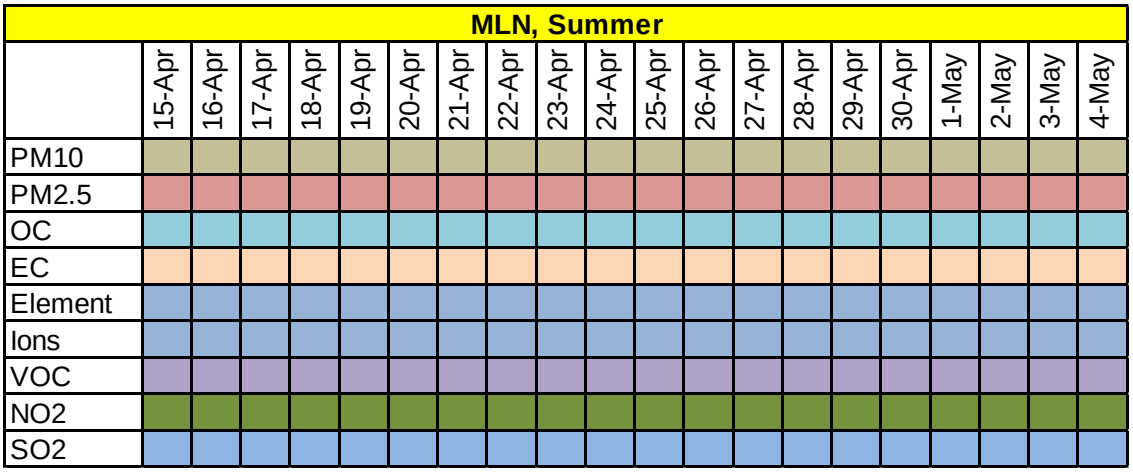
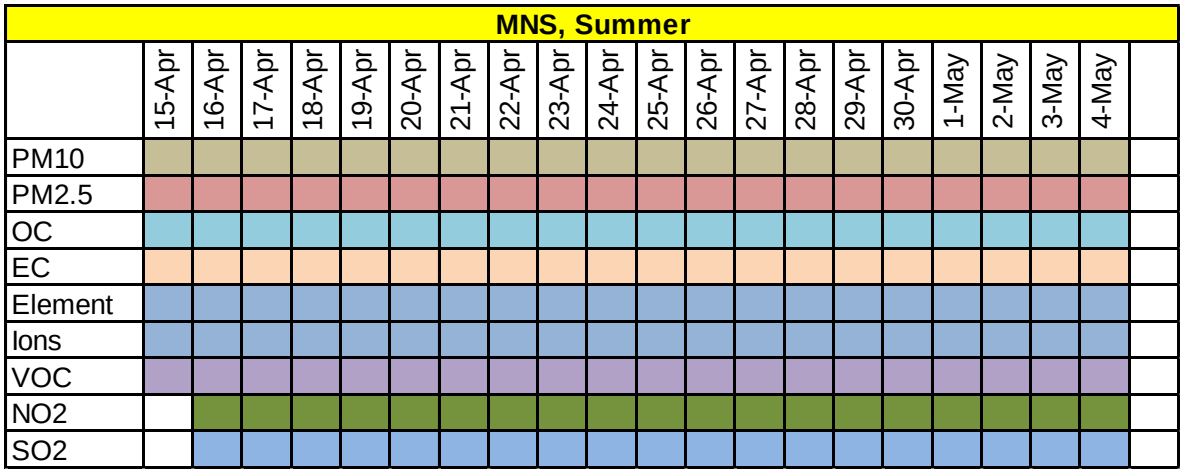


Table 2.13: Sampling days of various pollutants in summer (2018) at MNS



2.4 Ambient Air Quality - Results

2.4.1 Ajmeri Gate

The sampling period was November 19 – December 08, 2017 (PM_{10} and $PM_{2.5}$, VOCs) and January 03 – 23, 2018 (SO_2 and NO_2) for winter and May 6 – 26, 2018 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 AJG is shown for winter (Figure 2.4) and summer (Figure 2.5). Average levels at this site were: $PM_{2.5}$:114±23 (winter) and 53±12 µg/m^3 (summer) and PM_{10}: 245±46 (winter) and 263±84 µg/m^3 (summer). In winter, the $PM_{2.5}$ levels were about two times higher than the national air quality standard (NAQS: 60 µg/m^3) and PM_{10} levels were 2.5 times higher than the NAQS (100 µg/m^3). In summer, the $PM_{2.5}$ levels generally meet the standards while PM_{10} is 2.6 times higher than the NAQS.

A statistical summary of PM concentrations is presented in Tables 2.18 – 2.21 for winter and summer season. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards but PM_{10} levels were slightly increased and continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from soil during dust storms in the dry months of summer can contribute significantly in coarse fraction (i.e. $PM_{2.5\text{-}10}$).

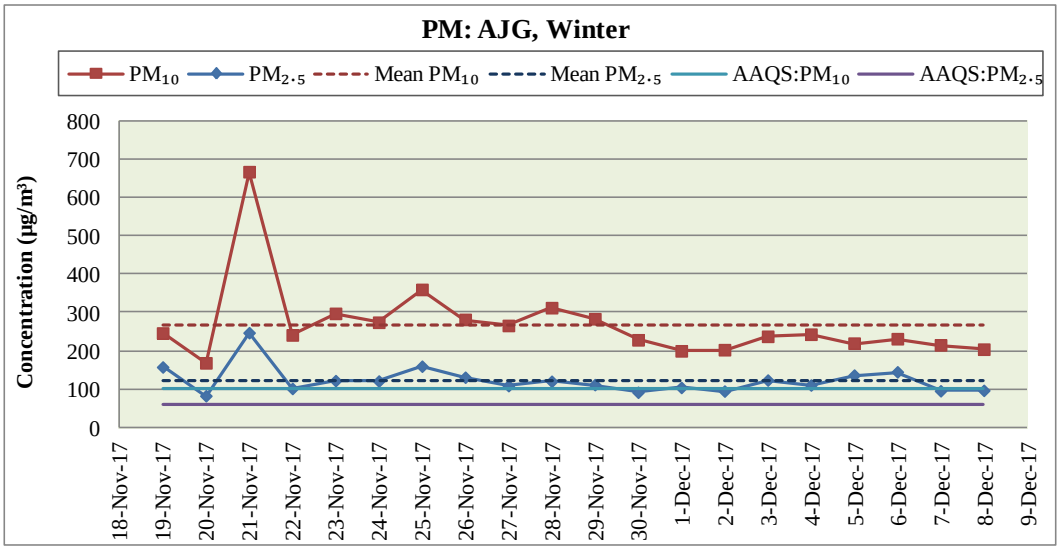


Figure 2.4: PM Concentrations at AJG for Winter Season

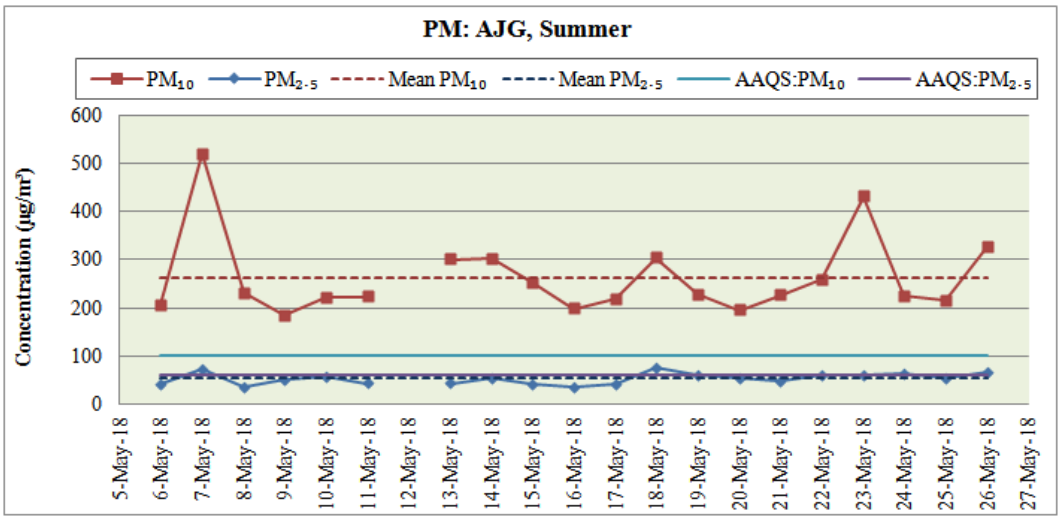


Figure 2.5: PM Concentrations at AJG for Summer Season

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) but are much higher than SO_2 with an average at 45±9 µg/m^3 in winter and 25±13 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 matter of concern as NO_2 is largely attributed to vehicular pollution, which is on rise. Variation in NO_2 is due to variability in meteorology and 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 statistical summary in Table 2.14. The total BTX level is observed 12.3±10.5 µg/m^3 (Benzene: 3.1 and Toluene: 5.4 µg/m^3) in winter and 18.9±10.6 µg/m^3 (Benzene: 7.0 and Toluene: 7.0 µg/m^3) in summer seasons. The maximum BTX concentration was observed at about 40 µg/m^3 in both the seasons. The BTX levels were higher during summer than in the winter.

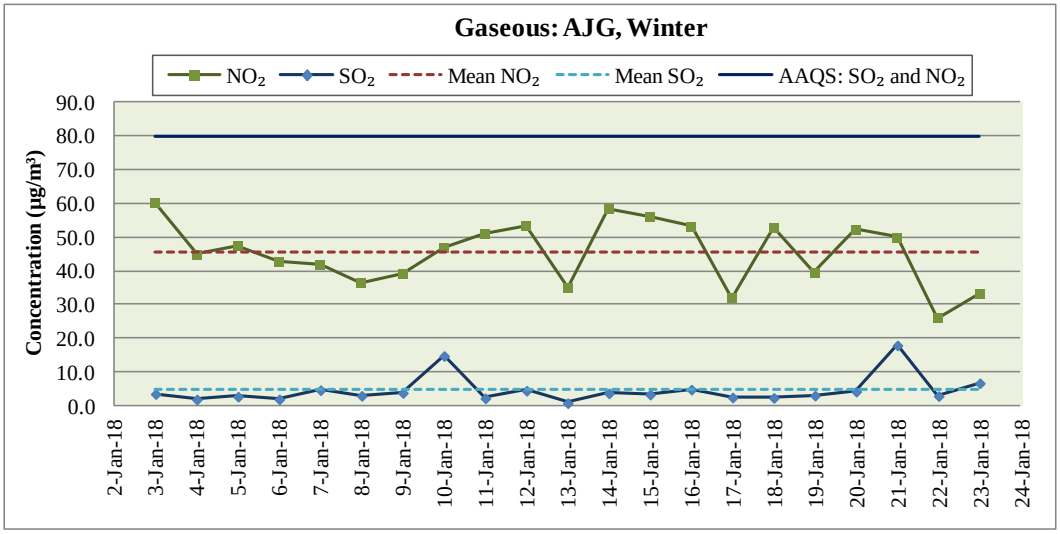


Figure 2.6: SO_2 and NO_2 Concentrations at AJG for Winter Season

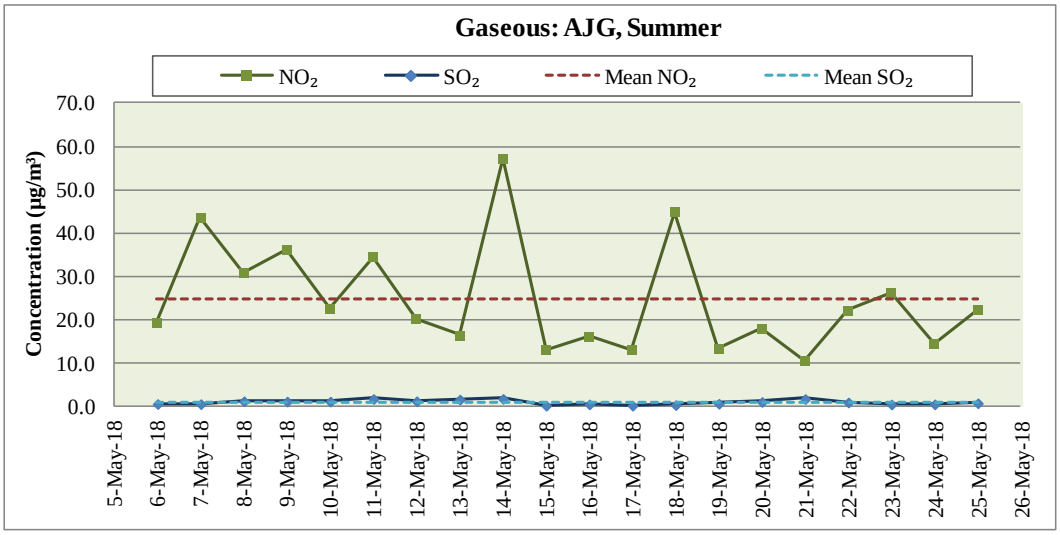


Figure 2.7: SO_2 and NO_2 Concentrations at AJG for Summer Season

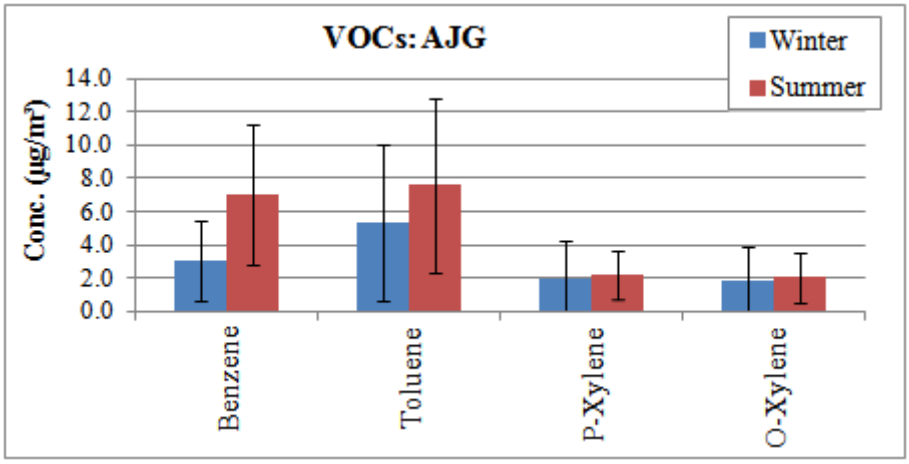


Figure 2.8: VOCs concentration at AJG

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.9 (a) and (b) for winter and summer seasons. Organic carbon is observed slightly higher (winter: 20.9±4.1 and summer: 7.8±2.0 µg/m^3) than the elemental carbon (winter: 19.8±7.1 and summer: 6.5±2.3 µg/m^3). However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at AJG. It is also observed that the OC and EC are higher in winter season than in 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 2.15 for winter and summer seasons.

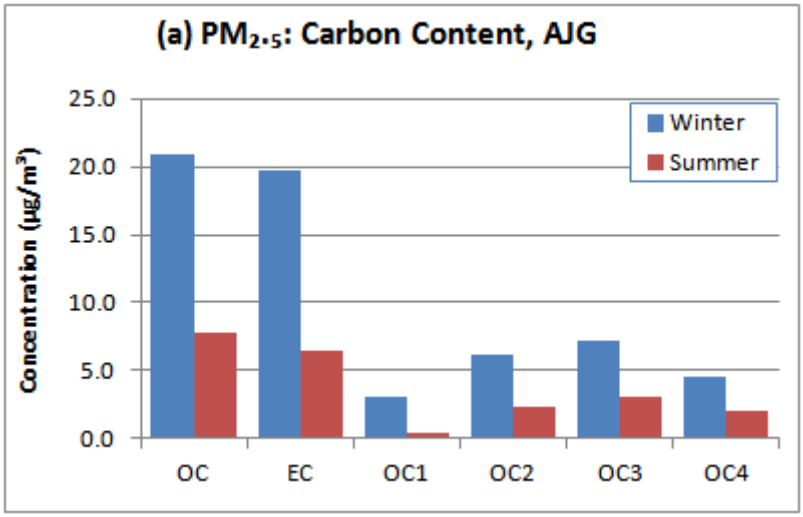


Figure 2.9: EC and OC Content in $PM_{2.5}$ at AJG

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 AJG 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) Iso Phorone (IsP), (ii) Di methyl Phthalate (DmP), (iii) Acenaphthylene (AcP), (iv) Di ethyl Phthalate (DEP), (v) Fluorene (Flu), (vi) Hexachlorobenzene (HcB), (vii) Phenanthrene (Phe), (viii) Anthracene (Ant), (ix) Pyrene (Pyr), (x) Butyl benzyl phthalate (BbP), (xi) Bis(2-ethylhexyl) adipate (BeA), (xii) Benzo(a)anthracene (B(a)A), (xiii) Chrysene (Chr), (xiv) Benzo(b)fluoranthene (B(b)F), (xv) Benzo(k)fluoranthene (B(k)F), (xvi) Benzo(a)pyrene (B(a)P), (xvii) Indeno(1,2,3-cd)pyrene (InP), (xviii) Dibenzo(a,h)anthracene (D(a,h)A) and (xix)

Benzo(ghi)perylene (B(ghi)P). It is observed that Total PAHs concentrations are much higher in winter season (53±26 ng/m^3) compared to summer season (13±7 ng/m^3). Major PAHs (mostly higher molecular weight compounds) are B(b)F (12 ng/m^3), B(ghi)P (7 ng/m^3), BaP (7 ng/m^3), Chr ((6 ng/m^3) and InP (6 ng/m^3) for winter season and AcP (1.9 ng/m^3), B(b)F (1.5 ng/m^3), Phe (1.4 ng/m^3), B(ghi)P (1.2 ng/m^3) and Pyr (1.0 ng/m^3) for summer season.

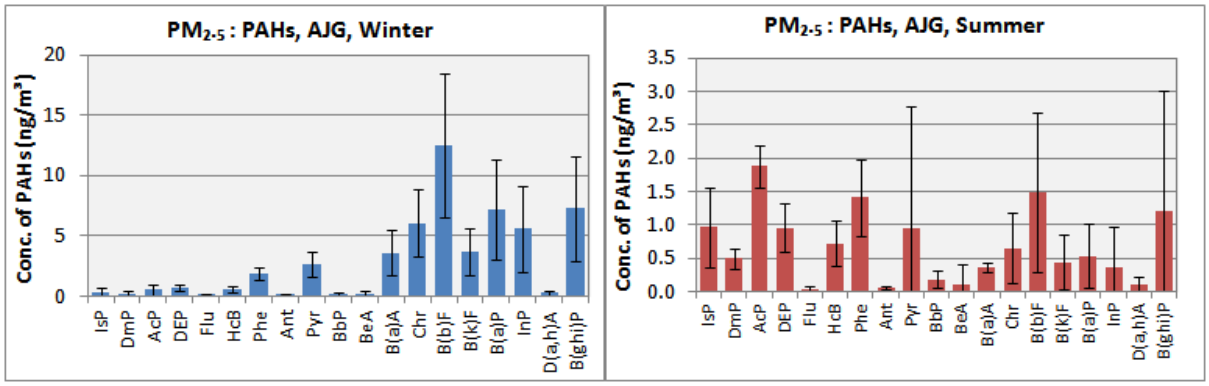


Figure 2.10: PAHs Concentrations in $PM_{2.5}$ at AJG

2.4.1.5 Molecular Markers in $PM_{2.5}$

Total seven molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, n-Hentriacontane, n-Tritriacontane, n-Pentatriacontane, Stigmasterol and Levoglucosan. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D). Levoglucosan is used as a tracer for biomass burning and stigmasterol for domestic cooking and biomass (Zhang et al., 2009).

Figure 2.11 and Table 2.17 show the levels of seven molecular markers. Total concentration of markers was 28.2±2.5 ng/m^3 in winter and 17.8±3.0 ng/m^3 in summer. Stigmasterol has also been found in appreciable quantity, indicating emissions from biomass burning and cooking. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

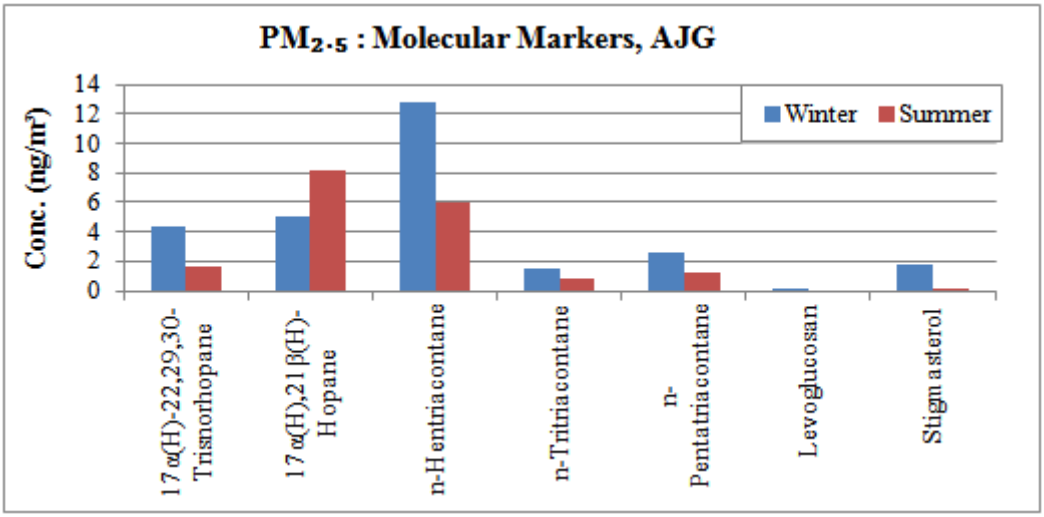


Figure 2.11: Molecular Markers in $PM_{2.5}$ at AJG

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

Graphical presentations of chemical species are shown for winter and summer season for PM_{10} (Figure 2.12) and $PM_{2.5}$ (Figure 2.13). Statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content (EC and OC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb)] along with mass percentage (% R) recovered from PM are presented in the Tables 2.18 – 2.21 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 2.22 – 2.25 for both season. It is seen that most of parameters showed good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM are presented in Figure 2.14 (a) and (b) for winter season and Figure 2.15 (a) and (b) for summer season.

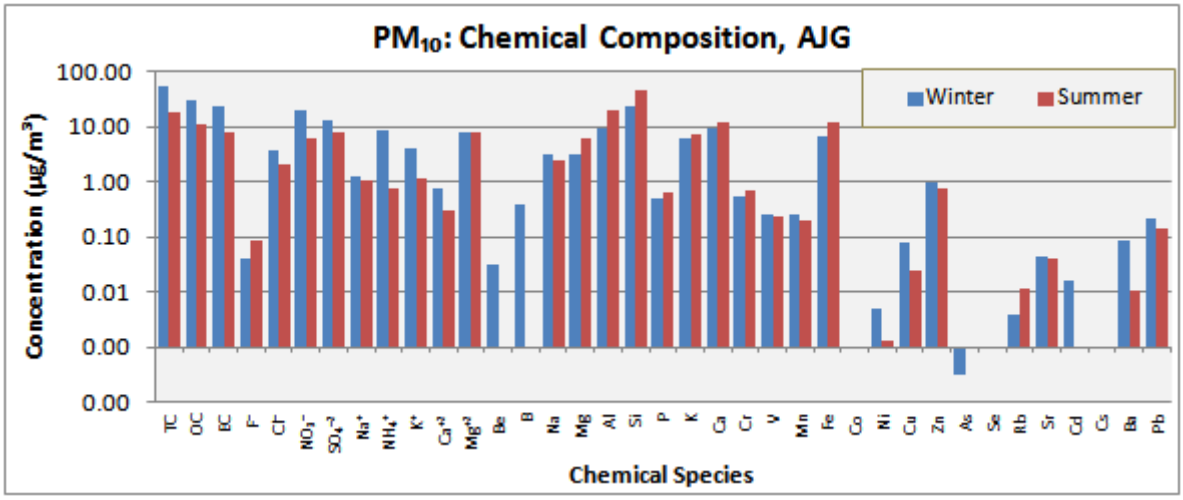


Figure 2.12: Concentrations of species in PM_{10} at AJG

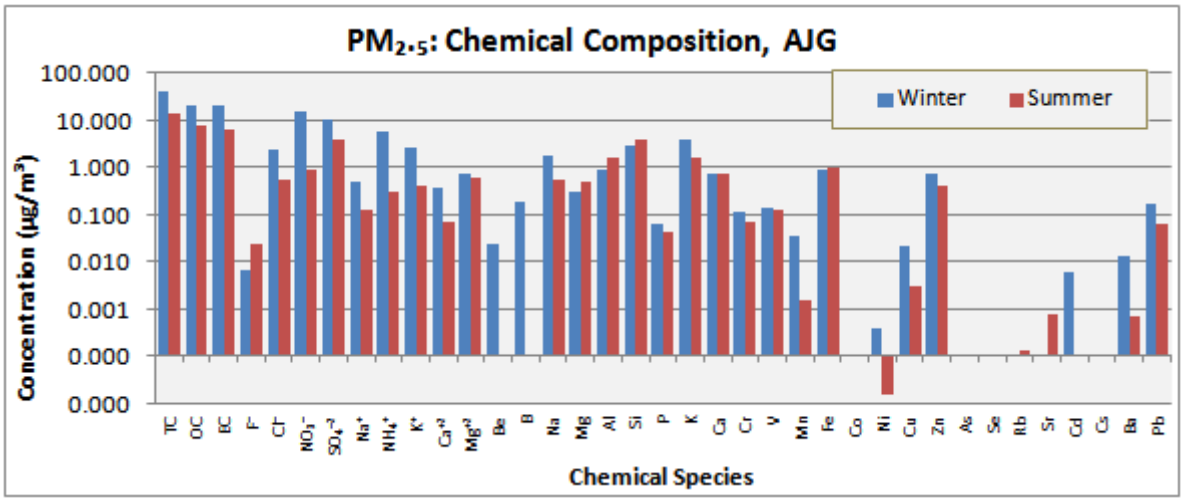
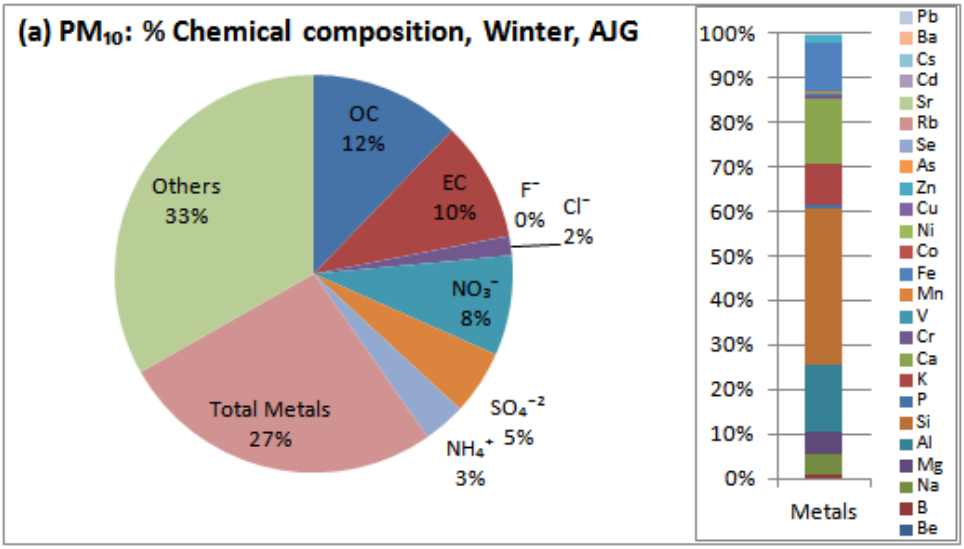


Figure 2.13: Concentrations of species in $PM_{2.5}$ at AJG



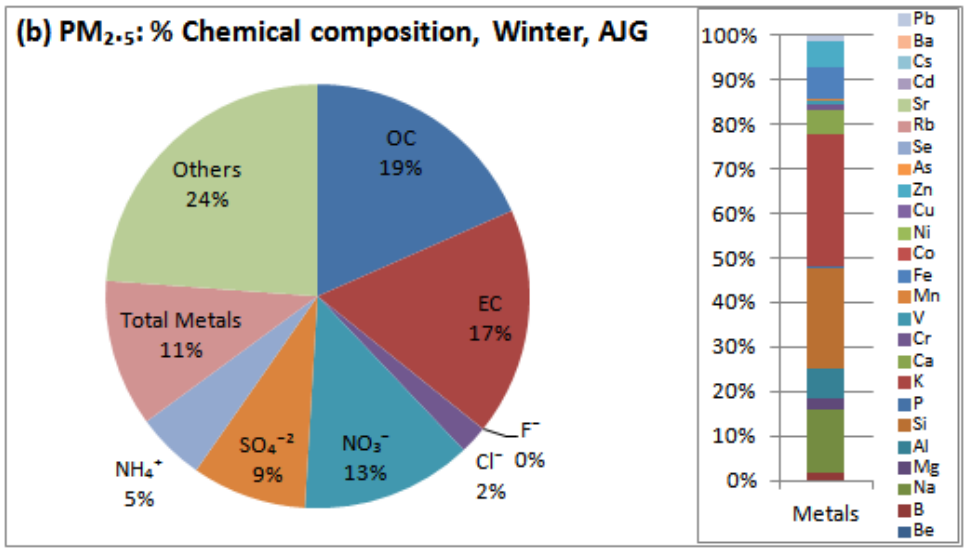
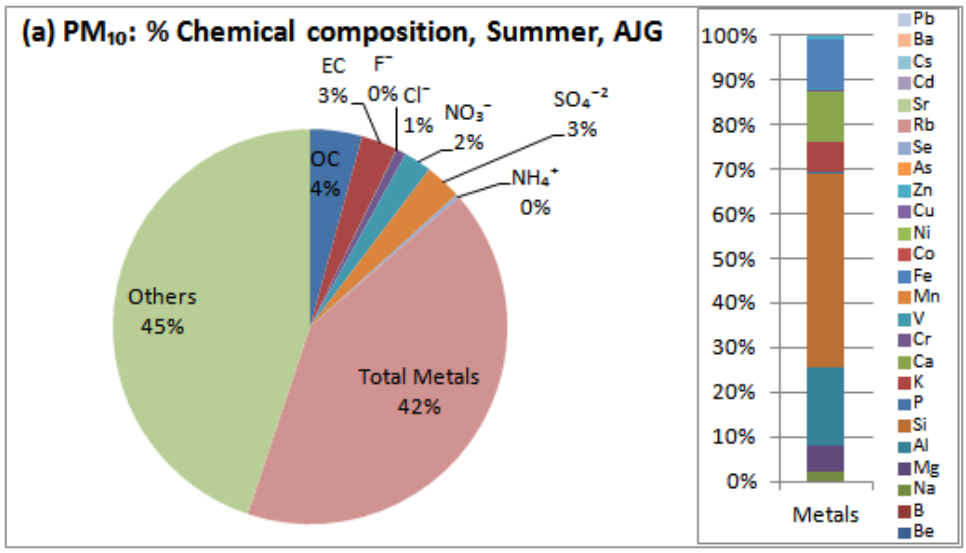


Figure 2.14: Percentage distribution of species in PM at AJG for Winter Season



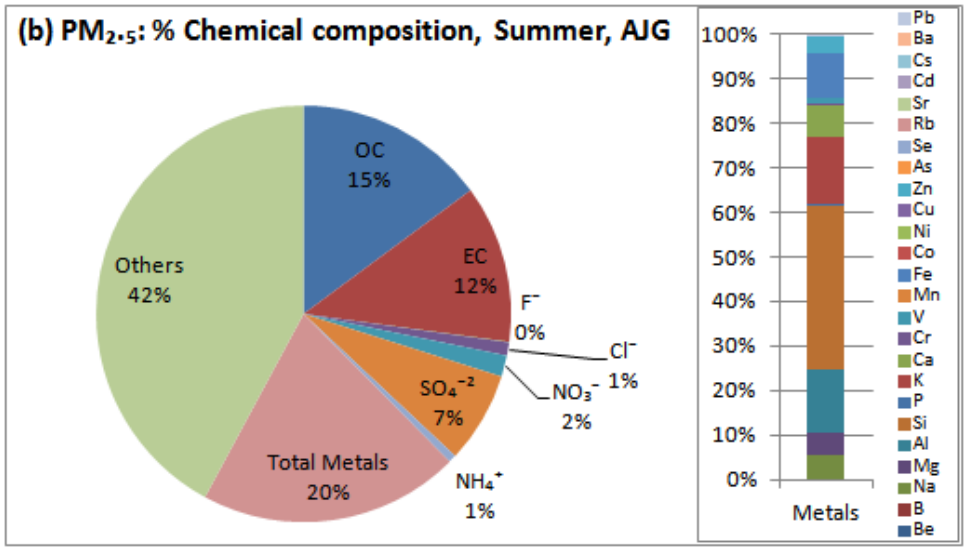


Figure 2.15: Percentage distribution of species in PM at AJG for Summer Season

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

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

The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM is having fine mode during winter (46 %) than summer (20 %). The major species contributing to fine mode are TC, OC, EC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Zn and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Ca, Cr, Fe and Ni.

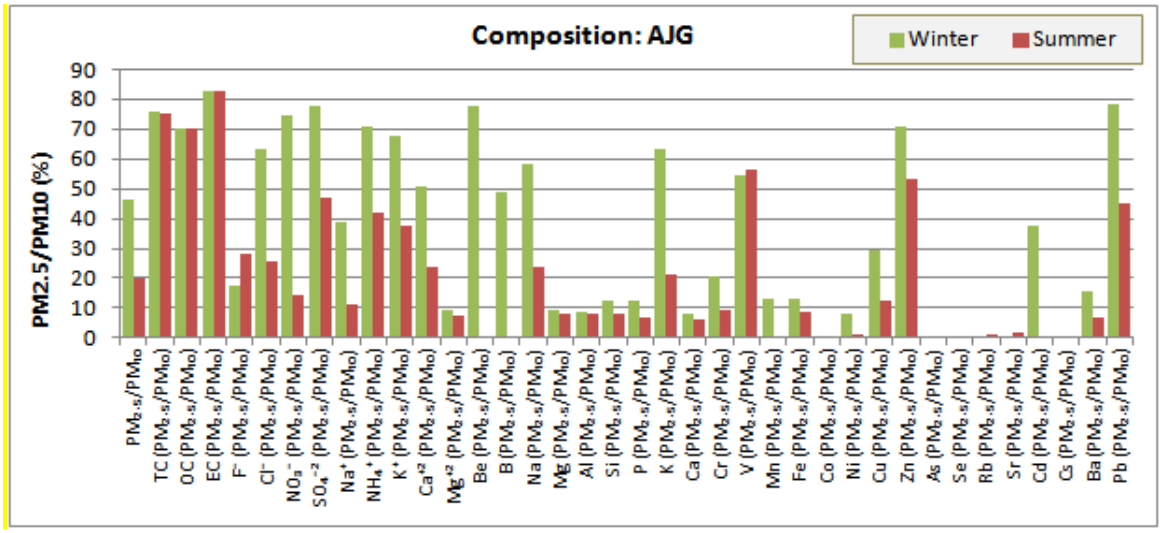


Figure 2.16: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at AJG

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

AJG (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	45.34	4.61	3.07	5.38	2.01	1.87	12.33
SD	9.40	4.16	2.44	4.70	2.26	2.07	10.51
Max	60.27	18.00	8.94	15.06	8.84	8.10	40.94
Min	25.98	0.86	0.07	0.00	0.00	0.00	0.22
CV	0.21	0.90	0.79	0.87	1.13	1.10	0.85
AJG (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	24.71	0.94	6.99	7.60	2.19	2.05	18.83
SD	12.67	0.52	4.20	5.21	1.45	1.50	10.62
Max	57.17	1.80	15.23	18.21	5.58	5.88	39.54
Min	10.43	0.22	0.42	0.02	0.00	0.00	1.23
CV	0.51	0.55	0.60	0.69	0.66	0.73	0.56

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

AJG (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	113.7	40.66	20.92	19.76	3.04	6.14	7.16	4.57	0.072	0.152	0.182	0.118
SD	23.2	10.87	4.13	7.11	1.45	1.58	1.25	0.75	0.014	0.012	0.033	0.031
Max	158.9	66.33	30.53	35.79	7.45	9.93	10.05	5.74	0.112	0.179	0.254	0.179
Min	75.2	25.60	14.58	11.02	1.54	4.37	4.98	3.35	0.049	0.130	0.126	0.072
CV	0.20	0.27	0.20	0.36	0.48	0.26	0.17	0.16	0.198	0.078	0.181	0.265
AJG (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	52.7	14.31	7.83	6.48	0.39	2.35	3.03	2.05	0.028	0.165	0.215	0.144
SD	11.7	3.94	1.97	2.25	0.13	0.62	0.84	0.61	0.008	0.010	0.039	0.020
Max	74.7	22.74	11.12	11.74	0.80	3.50	4.99	3.67	0.045	0.195	0.314	0.188
Min	35.0	7.70	4.20	3.48	0.21	1.36	1.62	1.01	0.018	0.148	0.162	0.109
CV	0.22	0.28	0.25	0.35	0.33	0.26	0.28	0.30	0.283	0.061	0.182	0.139

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

AJG(W)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.34	0.19	0.52	0.67	0.15	0.53	1.86	0.11	2.62	0.14	0.15	3.55	6.07	12.49	3.72	7.18	5.59	0.27	7.27	53.43
SD	0.37	0.26	0.47	0.28	0.07	0.27	0.50	0.05	0.99	0.11	0.23	1.89	2.79	5.96	1.95	4.14	3.58	0.22	4.32	25.71
Max	1.38	0.89	1.62	1.08	0.25	0.92	2.81	0.22	4.49	0.45	0.60	6.29	10.37	22.12	6.67	13.46	11.80	0.68	15.45	91.09
Min	0.15	0.00	0.17	0.24	0.00	0.14	0.99	0.05	1.36	0.09	0.00	1.01	2.12	4.13	1.07	1.62	1.42	0.06	2.20	19.74
CV	1.11	1.35	0.90	0.41	0.48	0.52	0.27	0.40	0.38	0.76	1.55	0.53	0.46	0.48	0.52	0.58	0.64	0.79	0.59	0.48
AJG(S)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.96	0.49	1.88	0.96	0.02	0.72	1.41	0.06	0.95	0.18	0.11	0.35	0.65	1.49	0.44	0.53	0.35	0.10	1.21	12.89
SD	0.60	0.15	0.31	0.36	0.05	0.34	0.58	0.02	1.82	0.13	0.31	0.07	0.53	1.19	0.41	0.47	0.61	0.13	1.79	7.17
Max	2.52	0.70	2.50	1.52	0.16	1.28	2.88	0.09	5.78	0.51	0.92	0.49	2.00	4.04	1.39	1.67	1.91	0.40	5.88	30.56
Min	0.46	0.30	1.48	0.48	0.00	0.16	1.01	0.04	0.11	0.08	0.00	0.28	0.29	0.53	0.16	0.16	0.00	0.00	0.29	6.78
CV	0.63	0.31	0.17	0.38	2.50	0.47	0.41	0.32	1.91	0.71	2.86	0.20	0.82	0.80	0.93	0.89	1.74	1.39	1.48	0.56

Table 2.17: **Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at AJG for winter (W) and summer (S) seasons**

AJG (W)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	4.39	5.05	12.80	1.50	2.60	0.10	1.81	28.24
SD	1.27	1.93	2.34	0.84	1.39	0.17	0.51	2.45
CV	0.29	0.38	0.18	0.56	0.54	1.73	0.28	0.09
AJG (S)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.59	8.11	6.01	0.78	1.27	0.00	0.08	17.83
SD	0.01	0.57	2.48	0.81	0.27	0.00	0.13	2.99
CV	0.01	0.07	0.41	1.04	0.21		1.73	0.17

Table 2.18: Statistical results of chemical characterization (µg/m^3) of PM_{10} at AJG for winter (W) season

AJG (W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	245	29.9	23.8	0.0	3.8	19.9	12.8	1.2	8.4	3.9	0.8	7.9	0.0	0.4	3.1	3.3	9.8	22.7	0.5
SD	46	5.9	8.6	0.0	2.0	8.2	5.2	1.1	4.0	1.6	0.5	2.2	0.0	0.8	0.9	0.8	2.2	4.7	0.1
Max	359	43.6	43.1	0.1	9.7	37.8	22.1	4.7	18.5	7.7	2.5	12.1	0.1	3.9	5.8	4.8	13.9	31.3	0.8
Min	168	20.8	13.3	0.0	1.5	7.7	5.9	0.4	4.3	1.9	0.3	4.3	0.0	0.2	2.3	2.1	5.9	15.5	0.3
CV	0.19	0.20	0.36	0.55	0.52	0.41	0.40	0.86	0.48	0.39	0.61	0.28	0.28	2.09	0.30	0.25	0.22	0.21	0.28
AJG (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	5.9	9.5	0.6	0.2	0.3	7.0	0.0	0.0	0.1	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	67.1
SD	1.6	2.6	0.5	0.1	0.4	3.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	5.3
Max	11.2	14.2	2.1	0.4	1.4	16.2	0.0	0.0	0.1	2.1	0.0	0.0	0.0	0.1	0.0	0.0	0.2	0.4	78.3
Min	3.9	4.9	0.2	0.1	0.0	3.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	60.0
CV	0.27	0.28	0.90	0.29	1.44	0.48	0.00	1.88	0.37	0.44	3.46	0.00	1.53	0.62	0.56	0.00	0.63	0.47	0.08
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.19: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at AJG for winter (W) season

AJG (W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	114	20.9	19.8	0.0	2.4	14.8	9.9	0.5	6.0	2.7	0.4	0.7	0.0	0.2	1.8	0.3	0.9	2.9	0.1
SD	23	4.1	7.1	0.0	1.7	8.2	4.9	0.3	4.4	1.0	0.4	0.4	0.0	0.1	1.3	0.1	0.2	1.0	0.0
Max	159	30.5	35.8	0.1	8.2	32.6	20.2	1.2	18.1	5.4	1.8	2.2	0.0	0.4	5.7	0.5	1.2	4.8	0.1
Min	75	14.6	11.0	0.0	0.7	4.3	4.1	0.2	1.8	1.5	0.2	0.4	0.0	0.1	0.9	0.2	0.1	0.7	0.0
CV	0.20	0.20	0.36	1.93	0.69	0.55	0.49	0.52	0.75	0.38	0.95	0.51	0.23	0.34	0.73	0.25	0.29	0.33	0.31
AJG (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.8	0.7	0.1	0.1	0.0	0.9	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	75.8
SD	1.5	0.3	0.1	0.0	0.0	0.4	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	4.1
Max	8.4	1.6	0.4	0.2	0.0	1.7	0.0	0.0	0.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	83.2
Min	2.1	0.5	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.1
CV	0.39	0.37	0.81	0.28	0.19	0.39		4.47	0.90	0.48					0.56		0.40	0.58	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.20: Statistical results chemical characterization (µg/m^3) of PM_{10} at AJG for summer (S) season

AJG (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	263	11.2	7.8	0.1	2.1	6.0	7.9	1.1	0.8	1.1	0.3	8.2	0.0	0.0	2.4	6.2	19.4	47.2	0.6
SD	84	2.8	2.7	0.1	1.0	2.3	3.1	0.6	0.3	0.6	0.4	2.7	0.0	0.0	0.4	1.8	8.9	16.7	0.4
Max	520	15.9	14.1	0.3	5.2	11.0	15.2	2.7	1.8	2.3	1.5	12.0	0.0	0.0	3.4	12.1	54.1	108.9	2.3
Min	183	6.0	4.2	0.0	1.1	1.7	2.8	0.3	0.4	0.3	0.0	4.2	0.0	0.0	1.6	4.5	13.7	34.1	0.3
CV	0.32	0.25	0.35	0.67	0.46	0.39	0.40	0.58	0.45	0.52	1.37	0.33			0.18	0.29	0.46	0.35	0.67
AJG (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	7.4	12.0	0.7	0.2	0.2	11.8	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	56.0
SD	2.5	3.1	0.3	0.1	0.1	5.1	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	5.1
Max	16.1	19.9	1.9	0.5	0.4	31.3	0.0	0.0	0.1	1.8	0.0	0.0	0.1	0.1	0.0	0.0	0.2	0.4	62.4
Min	4.9	8.5	0.4	0.1	0.0	8.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	39.9
CV	0.33	0.26	0.41	0.34	0.39	0.43		4.32	0.84	0.54			1.36	0.78			3.54	0.78	0.09
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.21: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at AJG for summer (S) season

AJG(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	53	7.8	6.5	0.0	0.5	0.9	3.7	0.1	0.3	0.4	0.1	0.6	0.0	0.0	0.6	0.5	1.5	3.9	0.0
SD	12	2.0	2.2	0.0	0.2	0.8	1.8	0.1	0.2	0.3	0.2	0.9	0.0	0.0	0.3	0.2	0.7	1.8	0.0
Max	75	11.1	11.7	0.1	1.1	2.7	8.1	0.3	0.6	1.1	1.1	3.3	0.0	0.0	1.2	1.1	4.0	9.9	0.1
Min	35	4.2	3.5	0.0	0.3	0.2	1.3	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.8	2.0	0.0
CV	0.22	0.25	0.35	0.69	0.41	0.91	0.49	0.72	0.51	0.74	3.50	1.47			0.55	0.39	0.46	0.46	0.68
AJG(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.6	0.8	0.1	0.1	0.0	1.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	57.8
SD	0.8	0.3	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1
Max	3.2	1.6	0.2	0.2	0.0	2.5	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	69.1
Min	0.0	0.4	0.0	0.1	0.0	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	42.2
CV	0.52	0.42	0.47	0.32	3.07	0.43		4.47	3.32	0.52			4.47	4.47			4.47	0.70	0.11
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.22: Correlation matrix for PM_{10} and its composition at AJG for winter season

AJG (W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.91	0.82	0.92	0.43	0.73	0.17	-0.31	0.50	-0.15	0.19	0.32	0.76	0.90
TC		1.00	0.95	0.98	0.36	0.69	0.17	-0.38	0.50	-0.23	0.20	0.43	0.67	0.77
OC			1.00	0.86	0.39	0.66	0.32	-0.20	0.47	-0.03	0.34	0.38	0.50	0.63
EC				1.00	0.32	0.68	0.05	-0.48	0.48	-0.35	0.09	0.44	0.75	0.82
NO_3^-					0.04	-0.02	1.00	0.59	0.03	0.68	0.60	0.35	-0.21	-0.17
SO_4^{-2}					0.18	-0.22		1.00	-0.12	0.83	0.62	-0.23	-0.41	-0.48
NH_4^+					0.31	-0.02			-0.11	1.00	0.56	-0.10	-0.36	-0.42
Metals					0.34	0.66			0.43		-0.01	0.12	0.77	1.00

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

AJG (W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.64	0.78	0.53	0.09	0.58	0.75	0.44	0.42	0.61	0.79	0.01	0.05	0.49
TC		1.00	0.94	0.98	-0.21	0.73	0.18	-0.35	0.16	-0.18	0.56	0.31	0.32	0.20
OC			1.00	0.86	-0.12	0.70	0.38	-0.14	0.25	0.06	0.64	0.26	0.22	0.28
EC				1.00	-0.25	0.71	0.06	-0.45	0.10	-0.30	0.48	0.32	0.36	0.14
NO_3^-					0.19	0.12	1.00	0.64	0.30	0.78	0.52	0.26	0.14	0.23
SO_4^{-2}					0.39	-0.26		1.00	0.21	0.93	0.31	-0.34	-0.38	0.27
NH_4^+					0.28	-0.01			0.30	1.00	0.36	-0.23	-0.28	0.24
Metals					0.40	0.32			0.40		0.69	-0.35	-0.04	1.00

Table 2.24: Correlation matrix for PM_{10} and its composition at AJG for summer season

AJG (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.15	0.28	0.00	-0.07	0.17	0.12	0.20	0.00	0.06	0.24	0.17	0.51	0.91
TC		1.00	0.94	0.93	0.49	-0.09	0.15	0.68	0.14	0.10	0.71	0.45	0.36	0.05
OC			1.00	0.75	0.47	-0.02	0.33	0.75	0.22	0.12	0.80	0.36	0.46	0.13
EC				1.00	0.44	-0.15	-0.06	0.52	0.03	0.08	0.53	0.48	0.21	-0.04
NO_3^-					0.17	0.44	1.00	0.40	0.40	-0.07	0.44	0.08	0.59	0.04
SO_4^{-2}					0.49	0.12		1.00	0.28	0.13	0.91	0.40	0.64	-0.04
NH_4^+					0.27	0.11			0.11	1.00	0.15	0.07	-0.16	-0.02
Metals					-0.11	0.20			-0.04		0.08	0.12	0.45	1.00

Table 2.25: Correlation matrix for $PM_{2.5}$ and its composition at AJG for summer season

AJG (S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.74	0.76	0.63	-0.02	0.50	0.54	0.55	0.26	0.67	0.69	-0.14	0.45	0.56
TC		1.00	0.93	0.94	0.03	-0.05	0.51	0.42	0.16	0.57	0.65	0.11	0.41	0.01
OC			1.00	0.75	0.09	0.01	0.47	0.54	0.10	0.63	0.75	-0.06	0.50	0.12
EC				1.00	-0.02	-0.09	0.48	0.26	0.18	0.45	0.49	0.24	0.29	-0.08
NO_3^-					0.10	0.37	1.00	0.52	-0.02	0.74	0.67	-0.12	0.13	0.19
SO_4^{-2}					0.31	0.32		1.00	0.23	0.77	0.90	-0.18	0.59	0.32
NH_4^+					0.07	0.39			0.23	1.00	0.85	-0.05	0.59	0.25
Metals					0.12	0.76			0.20		0.25	-0.30	0.14	1.00

2.4.2 Vishwakarma Industrial Area

The sampling period was December 09 – 31, 2017 for winter and May 06 – 27, 2018 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 VKI for winter (Figure 2.17) and summer (Figure 2.18). Average levels for winter and summer season were 175±52 and 81±19 µg/m^3 (for $PM_{2.5}$) and 388±119 and 308±72 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are about 3 times higher than the NAQS and PM_{10} is about 4 times higher than the NAQS in winter. The $PM_{2.5}$ levels are about 1.3 times higher and PM_{10} levels are 3 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 Table 2.30 – 2.33 for winter and summer season. In summer, $PM_{2.5}$ levels drop significantly compared to PM_{10} levels that were continue to be high in spite of improvement in meteorology and better dispersion.

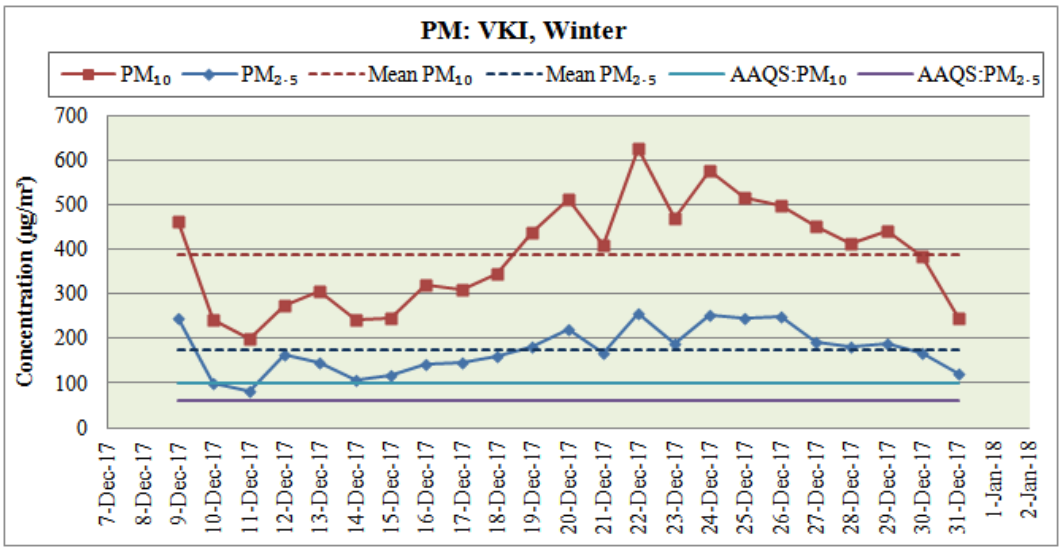


Figure 2.17: PM Concentrations at VKI for Winter Season

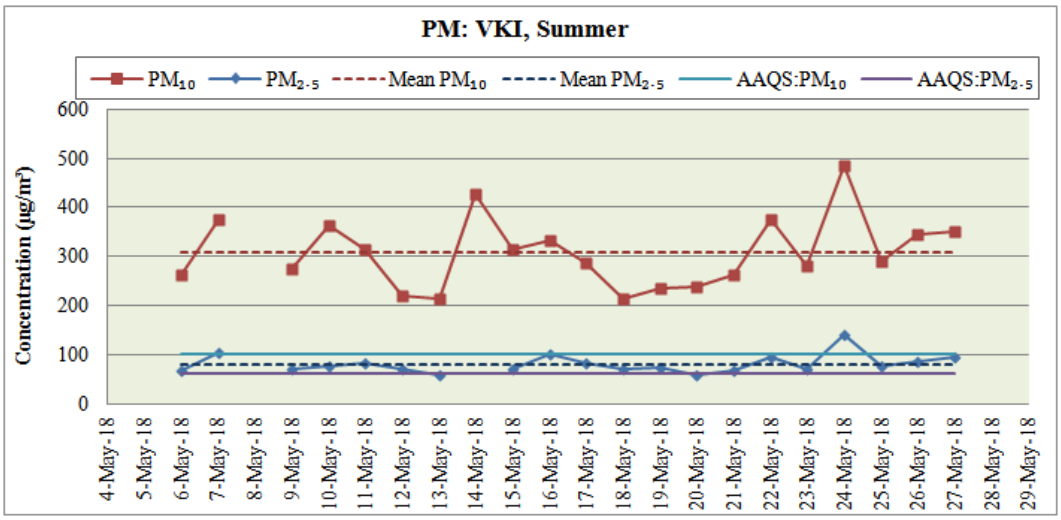


Figure 2.18: PM Concentrations at VKI for Summer Season

2.4.2.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.19) and summer (Figure 2.20) seasons. It was observed that SO_2 levels were higher in winter (19±8 µg/m^3) than summer and meets the NAQS. NO_2 levels also under the NAQS with an average of 20 days at 40±8 µg/m^3 in winter and 15±7 µg/m^3 in summer season (Table 2.26). The summer concentration of SO_2 and NO_2 dropped dramatically similarly $PM_{2.5}$ levels. Although, the NO_2 and SO_2 is certainly matter of concern in 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 presence of occasional local sources like DG sets, traffic jams or local open and coal burning etc.

The Mean concentrations of BTX were presented in Figure 2.21 and statistical summary in Table 2.26. The total BTX level is observed 31±29 µg/m^3 (Benzene: 10 and Toluene: 13 µg/m^3) in winter and 17±9 µg/m^3 (Benzene: 8.1 and Toluene: 7.4 µg/m^3) in summer seasons. The maximum BTX concentration was observed 100 µg/m^3 in winter and 37 µg/m^3 in summer seasons. The BTX levels were high during winter than the summer. The high levels of BTX may be due to high consumption of BTX based solvents in the area.

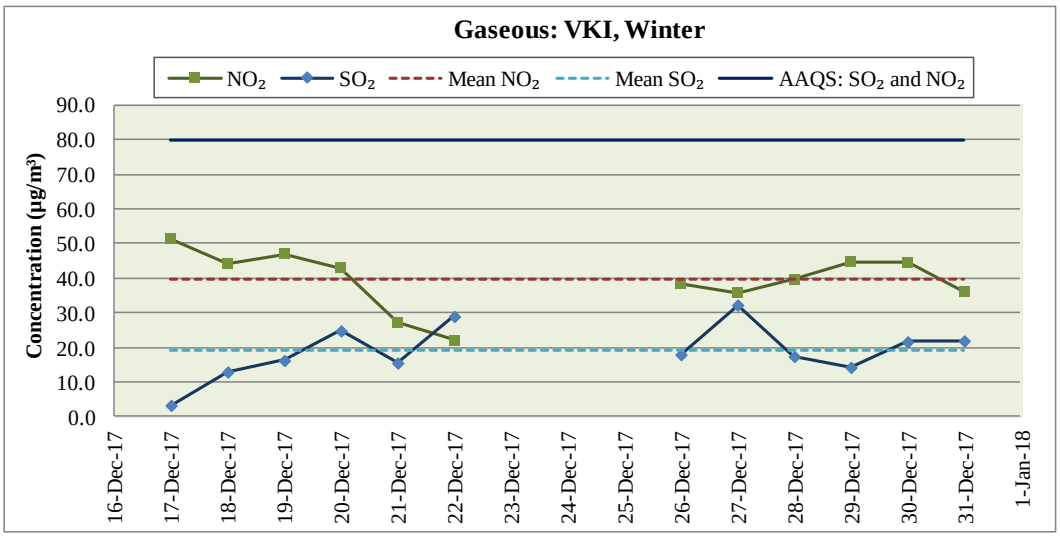


Figure 2.19: SO_2 and NO_2 Concentrations at VKI for Winter Season

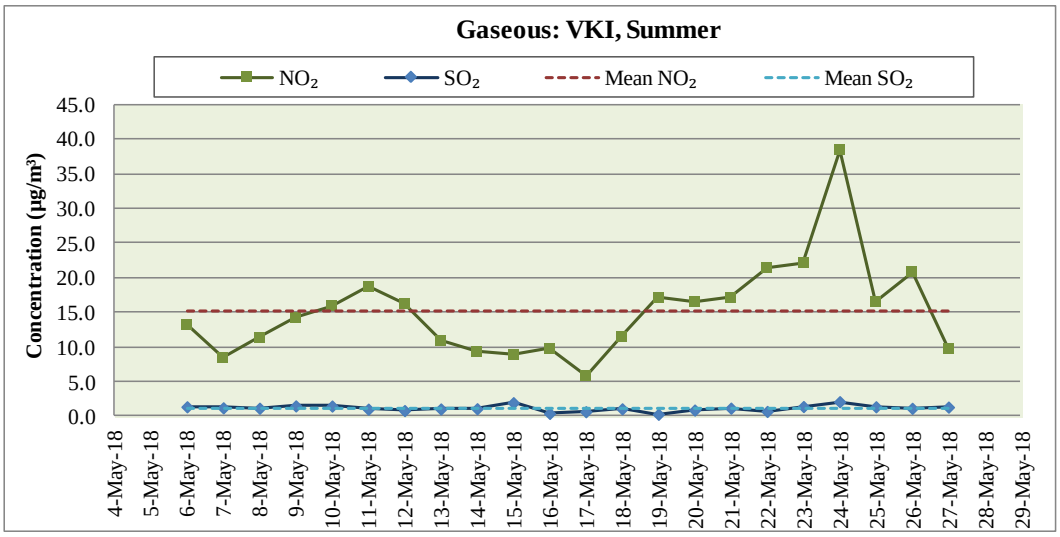


Figure 2.20: SO_2 and NO_2 Concentrations at VKI for Summer Season

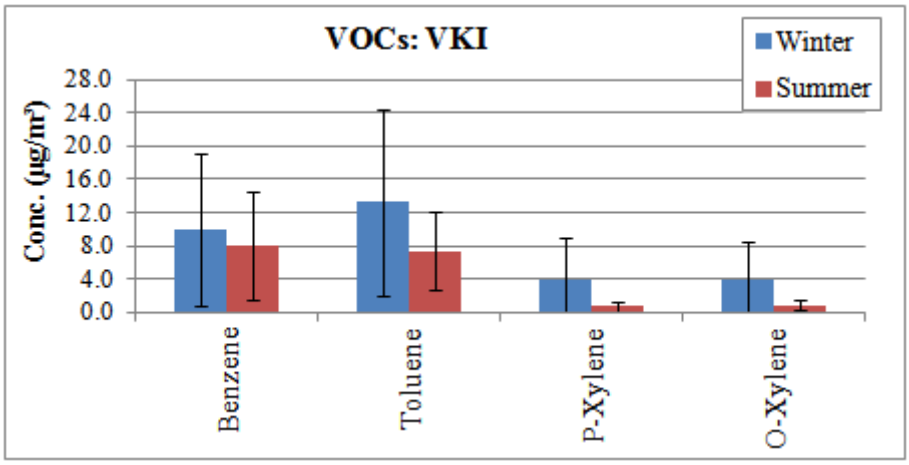


Figure 2.21: VOCs concentration at VKI

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.22 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (winter: 22.2±6.0 and summer: 9.8±3.4 µg/m^3) than the elemental carbon (winter: 16.8±9.0 and summer: 6.4±2.6 µg/m^3). However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at VKI. It is also observed that the OC and EC are higher in winter season than in 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 2.27 for winter and summer seasons.

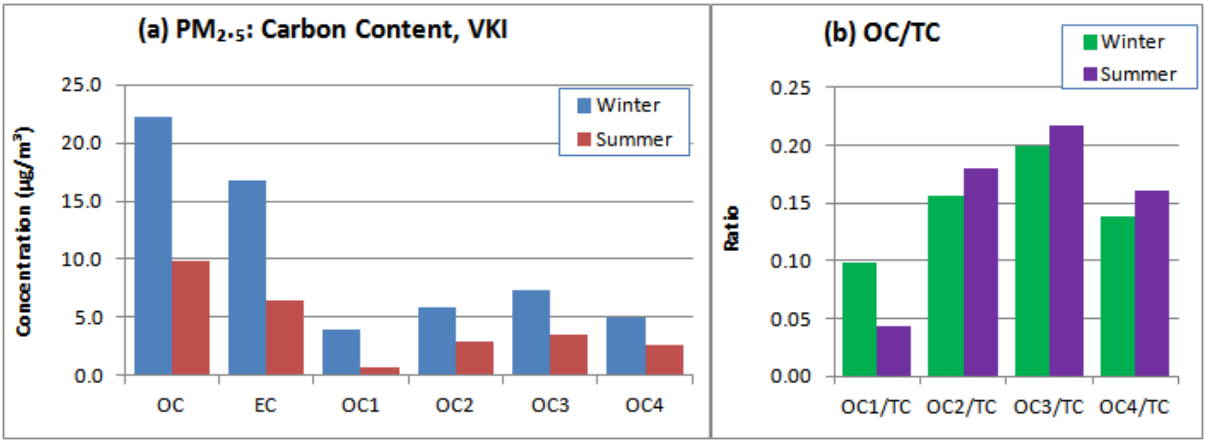


Figure 2.22: EC and OC Content in $PM_{2.5}$ at VKI

2.4.2.4 PAHs in $PM_{2.5}$

Figure 2.23 shows the average measured concentration of PAHs at VKI for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.28 for winter and summer seasons. The PAHs compounds analyzed were: (i) IsP, (ii) DmP, (iii) AcP, (iv) DEP, (v) Flu, (vi) HcB, (vii) Phe, (viii) Ant, (ix) Pyr, (x) BbP, (xi) BeA, (xii) B(a)A, (xiii) Chr, (xiv) B(b)F, (xv) B(k)F, (xvi) B(a)P, (xvii) InP, (xviii) D(a,h)A and (xix) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (167±68 ng/m^3) compared to summer season (36±26 ng/m^3). Major PAHs are B(b)F (36 ng/m^3) , B(ghi)P (26 ng/m^3), InP (25 ng/m^3), Chr (20 ng/m^3) and B(a)A (11 ng/m^3) for winter season and B(b)F (9.7 ng/m^3), B(ghi)P (4.0 ng/m^3), B(a)P (3.9 ng/m^3), B(k)F (3.2 ng/m^3), InP (3.2 ng/m^3) and Chr (3.2 ng/m^3) for summer season.

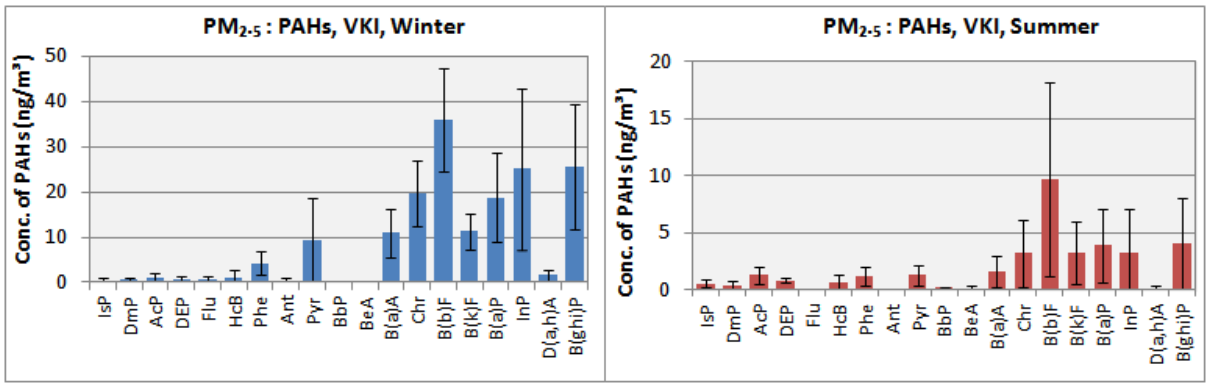


Figure 2.23: PAHs Concentrations in $PM_{2.5}$ at VKI

2.4.2.5 Molecular Markers in $PM_{2.5}$

Total seven molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, n-Hentriacontane, n-Tritriacontane, n-Pentatriacontane, Stigmasterol and Levoglucosan. The n-alkanes are generally emitted from all types of combustion sources and hopanes from combustion of coal (C), gasoline (G) and diesel (D). Levoglucosan is used as a tracer for biomass burning and stigmasterol for domestic cooking and biomass (Zhang et al., 2009).

Figure 2.24 and Table 2.29 show the levels of seven molecular markers. Total concentration of markers was 22.8±17.9 ng/m^3 in winter and 12.7±5.6 ng/m^3 in summer. Stigmasterol has also been found in appreciable quantity, indicating emissions from biomass burning and cooking. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

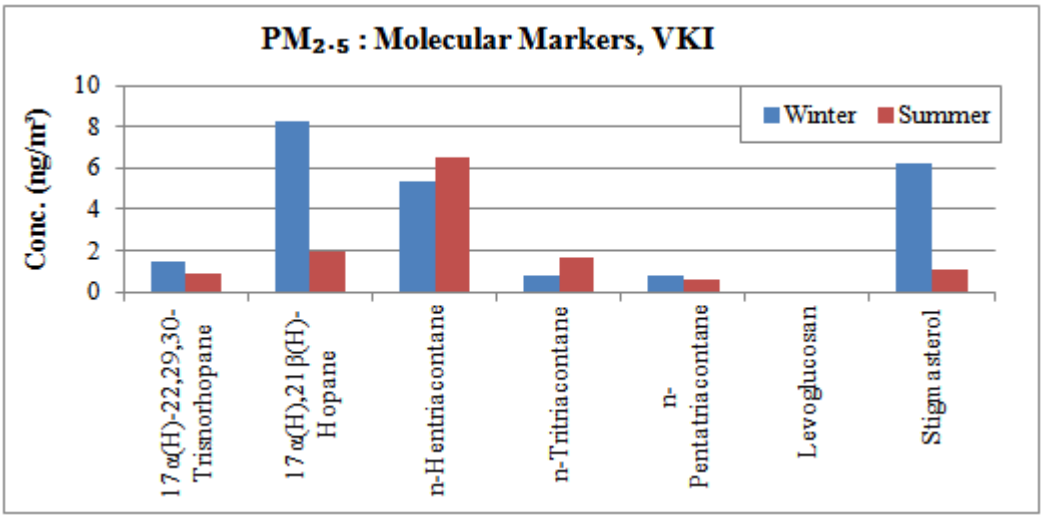


Figure 2.24: Molecular Markers in $PM_{2.5}$ at VKI

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

Graphical presentations of chemical species are shown for winter and summer season for PM_{10} (Figure 2.25) and $PM_{2.5}$ (Figure 2.26). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content, ionic species and elements] along with mass percentage (% R) recovered from PM are presented in the Tables 2.30 – 2.33 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 2.34 – 2.37 for both season. It is seen that most of parameters showed good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM are presented in Figure 2.27 (a) and (b) for winter season and Figure 2.28 (a) and (b) for summer season.

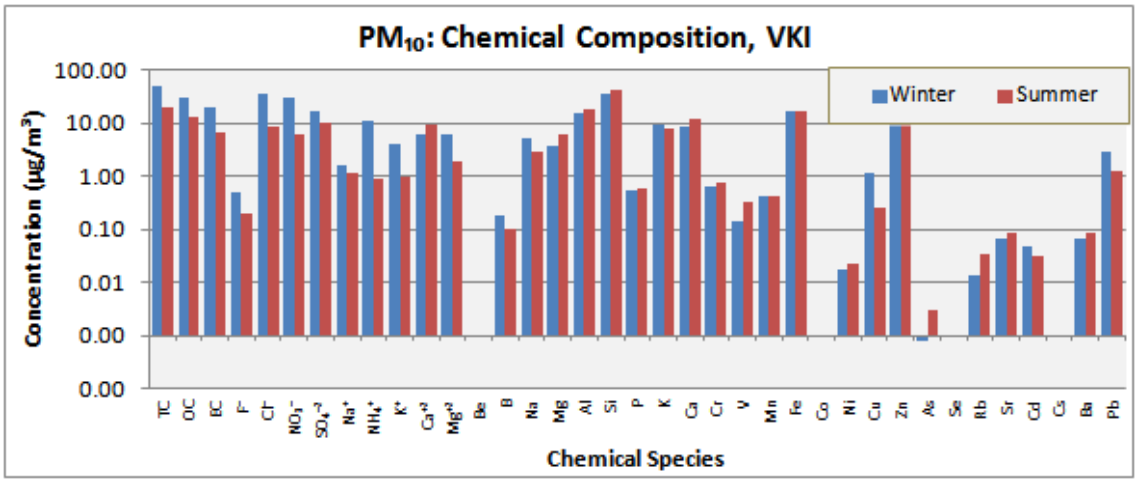


Figure 2.25: Concentrations of species in PM_{10} at VKI

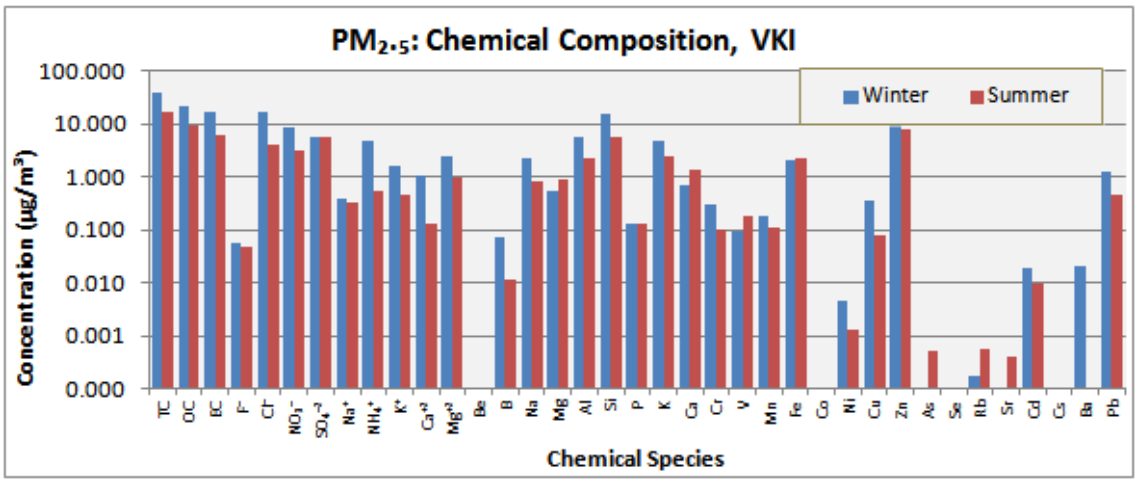


Figure 2.26: Concentrations of species in $PM_{2.5}$ at VKI

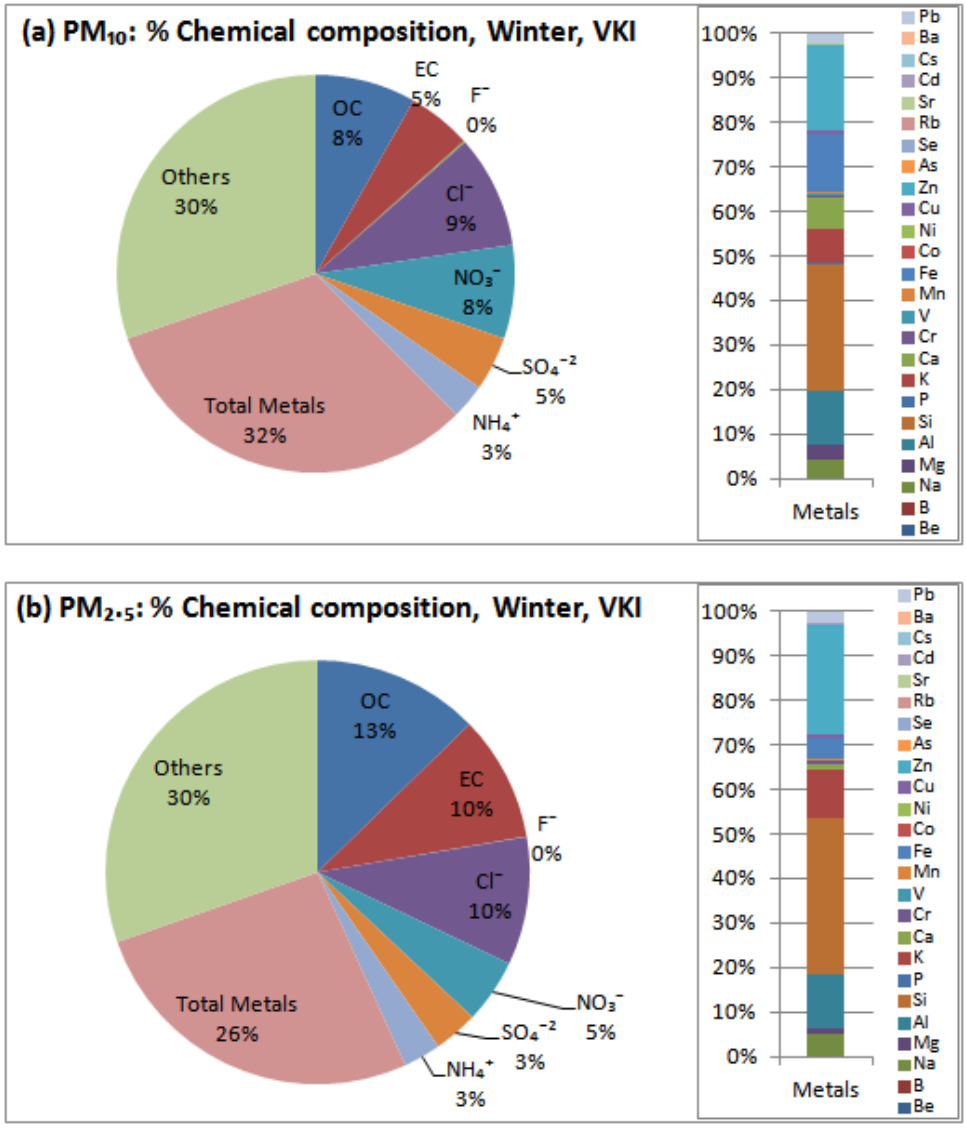
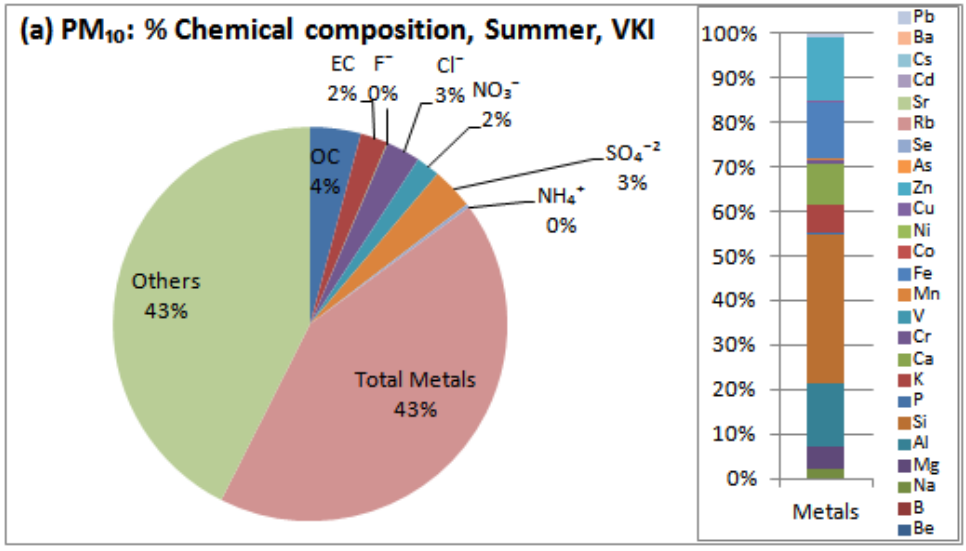


Figure 2.27: Percentage distribution of species in PM at VKI for Winter Season



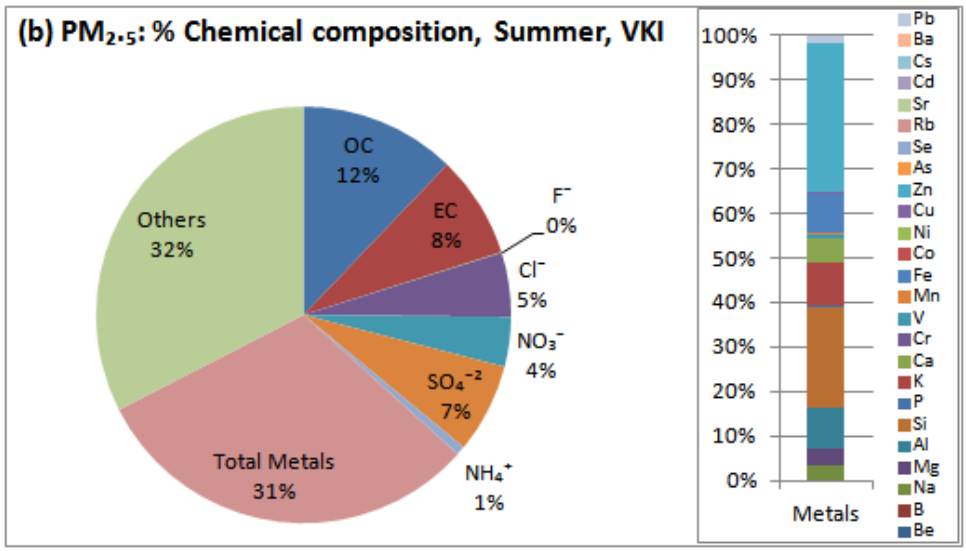


Figure 2.28: Percentage distribution of species in PM at VKI for Summer Season

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

The graphical presentation is the better option for understanding the compositional variation. Compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.16) at VKI. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM is having fine mode during winter (45 %) than summer (26 %). The major species contributing to fine mode are TC, OC, EC, Cl^-, NO_3^-, SO_4^{-2}, NH_4^+, K^+, Mg^{2+}, V, Zn and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Al, Si, Ca, Cr, Fe and Ni.

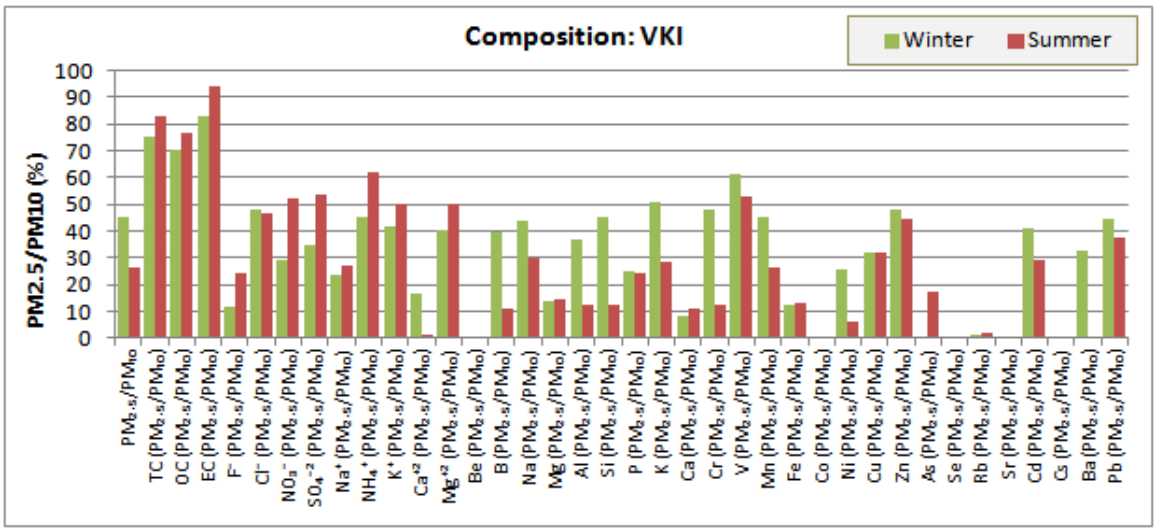


Figure 2.29: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at VKI

Table 2.26: Statistical results of gaseous pollutants (µg/m^3) at VKI for winter (W) and summer (S) seasons

VKI (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	39.51	18.97	9.96	13.24	3.95	3.91	31.05
SD	8.34	7.71	9.25	11.19	5.06	4.69	28.54
Max	51.36	32.31	33.85	39.11	20.59	19.01	99.70
Min	22.09	3.33	0.66	0.53	0.61	0.64	4.27
CV	0.21	0.41	0.93	0.85	1.28	1.20	0.92
VKI (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	15.19	1.15	8.13	7.37	0.77	0.92	17.19
SD	6.91	0.43	6.52	4.74	0.62	0.61	9.23
Max	38.45	2.11	30.50	22.76	2.64	2.49	37.38
Min	5.86	0.29	0.73	0.53	0.00	0.00	1.52
CV	0.46	0.37	0.80	0.64	0.81	0.66	0.54

Table 2.27: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at VKI for winter (W) and summer (S) seasons

VKI (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	174.6	38.91	22.16	16.75	3.94	5.89	7.42	4.92	0.098	0.157	0.199	0.138
SD	52.1	13.43	6.02	9.04	2.11	1.71	2.02	0.92	0.031	0.024	0.035	0.043
Max	255.4	64.89	33.36	46.38	8.09	9.14	11.46	7.06	0.161	0.190	0.252	0.252
Min	82.1	18.47	12.67	5.79	1.20	3.02	4.66	2.59	0.047	0.069	0.096	0.073
CV	0.30	0.35	0.27	0.54	0.53	0.29	0.27	0.19	0.321	0.153	0.175	0.309
VKI (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	80.7	16.23	9.79	6.44	0.70	2.94	3.52	2.63	0.044	0.181	0.218	0.161
SD	18.8	5.87	3.42	2.63	0.33	1.13	1.18	0.98	0.018	0.026	0.024	0.028
Max	139.9	36.80	20.85	15.94	1.61	6.78	7.04	5.43	0.102	0.277	0.245	0.204
Min	59.1	10.65	5.19	3.22	0.27	1.55	1.47	1.04	0.025	0.145	0.134	0.094
CV	0.23	0.36	0.35	0.41	0.47	0.38	0.34	0.37	0.418	0.144	0.109	0.172

Table 2.28: **Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at VKI for winter (W) and summer (S) seasons**

VKI(W)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.47	0.57	1.12	0.82	0.56	1.12	4.26	0.41	9.20	0.22	0.09	10.91	19.56	35.80	11.27	18.68	25.10	1.57	25.52	167.24
SD	0.43	0.49	1.00	0.46	0.90	1.66	2.64	0.63	9.45	0.20	0.21	5.24	7.28	11.44	3.98	9.79	17.78	1.12	13.86	68.44
Max	1.28	1.28	3.56	1.64	3.05	5.74	9.40	2.14	35.23	0.67	0.68	20.06	31.88	52.82	16.33	38.67	68.94	3.28	57.02	289.97
Min	0.16	0.06	0.35	0.20	0.09	0.07	1.72	0.04	2.40	0.07	0.00	3.85	7.91	14.17	4.48	4.62	5.32	0.16	7.51	57.86
CV	0.91	0.85	0.90	0.56	1.59	1.49	0.62	1.55	1.03	0.88	2.30	0.48	0.37	0.32	0.35	0.52	0.71	0.72	0.54	0.41
VKI(S)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.57	0.36	1.28	0.82	0.01	0.71	1.22	0.05	1.30	0.18	0.12	1.58	3.22	9.68	3.23	3.89	3.24	0.16	4.03	35.64
SD	0.34	0.42	0.78	0.24	0.02	0.65	0.81	0.02	0.89	0.09	0.22	1.36	2.95	8.52	2.69	3.19	3.78	0.21	3.94	26.41
Max	1.38	1.46	3.36	1.20	0.06	2.29	3.13	0.09	2.87	0.32	0.70	4.19	8.49	26.28	8.83	10.61	13.17	0.65	14.25	92.99
Min	0.22	0.00	0.73	0.46	0.00	0.20	0.52	0.03	0.25	0.10	0.00	0.31	0.38	0.07	0.28	0.42	0.22	0.00	0.61	10.96
CV	0.60	1.16	0.60	0.30	2.52	0.92	0.66	0.38	0.68	0.49	1.86	0.86	0.92	0.88	0.83	0.82	1.17	1.32	0.98	0.74

Table 2.29: **Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at VKI for winter (W) and summer (S) seasons**

VKI (W)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.46	8.29	5.31	0.74	0.77	0.00	6.23	22.80
SD	0.49	10.69	0.82	0.52	0.30	0.00	5.53	17.92
CV	0.34	1.29	0.16	0.69	0.40		0.89	0.79
VKI (S)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	0.87	1.91	6.55	1.62	0.61	0.00	1.09	12.65
SD	0.28	1.15	2.70	0.50	0.10	0.00	1.74	5.57
CV	0.32	0.60	0.41	0.31	0.16		1.60	0.44

Table 2.30: Statistical results of chemical characterization (µg/m^3) of PM_{10} at VKI for winter (W) season

VKI (W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	388	31.7	20.2	0.5	35.5	29.5	17.0	1.6	11.0	3.9	6.3	6.2	0.0	0.2	5.3	3.8	15.4	35.3	0.5
SD	119	8.6	10.9	0.3	17.1	9.0	10.9	0.9	3.9	2.0	2.4	2.0	0.0	0.1	2.3	2.0	8.1	13.7	0.3
Max	625	47.7	55.9	1.3	71.7	51.0	59.6	3.5	20.2	8.2	12.3	11.1	0.0	0.4	10.4	9.0	42.0	73.1	1.2
Min	199	18.1	7.0	0.0	8.9	15.7	7.7	0.3	5.2	0.6	2.8	3.5	0.0	0.1	1.4	0.8	7.0	18.6	0.1
CV	0.31	0.27	0.54	0.67	0.48	0.30	0.64	0.58	0.35	0.52	0.39	0.33		0.58	0.43	0.53	0.53	0.39	0.57
VKI (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	9.6	8.7	0.6	0.1	0.4	16.5	0.0	0.0	1.1	24.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	2.9	69.8
SD	3.7	5.0	0.4	0.1	0.2	10.1	0.0	0.0	0.5	10.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	2.4	3.1
Max	19.5	22.0	1.9	0.3	0.8	46.7	0.0	0.0	2.3	51.7	0.0	0.0	0.1	0.2	0.1	0.0	0.2	9.1	77.0
Min	1.7	1.9	0.3	0.1	0.2	2.7	0.0	0.0	0.4	11.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	64.9
CV	0.38	0.57	0.55	0.35	0.43	0.62	0.00	0.48	0.42	0.41	3.24	0.00	1.10	0.77	0.38	0.00	0.55	0.85	0.04
% 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 VKI for winter (W) season

VKI (W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	175	22.2	16.7	0.1	17.0	8.5	5.9	0.4	5.0	1.6	1.1	2.5	0.0	0.1	2.3	0.5	5.6	16.0	0.1
SD	52	6.0	9.0	0.1	9.4	4.9	2.3	0.2	1.3	0.7	0.5	0.9	0.0	0.0	1.1	0.3	2.3	5.9	0.1
Max	255	33.4	46.4	0.4	33.9	25.7	11.2	0.8	9.1	2.7	2.0	4.1	0.0	0.2	4.1	1.2	11.7	28.7	0.3
Min	82	12.7	5.8	0.0	1.1	2.9	1.9	0.1	2.7	0.5	0.3	0.9	0.0	0.0	0.6	0.1	2.1	7.5	0.0
CV	0.30	0.27	0.54	1.40	0.55	0.57	0.39	0.51	0.27	0.40	0.44	0.34		0.60	0.47	0.52	0.40	0.37	0.51
VKI (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.9	0.7	0.3	0.1	0.2	2.0	0.0	0.0	0.4	11.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	69.7
SD	2.2	0.3	0.1	0.0	0.1	1.1	0.0	0.0	0.2	5.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	3.7
Max	8.5	1.4	0.5	0.2	0.4	3.6	0.0	0.0	1.1	23.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	3.2	79.7
Min	0.6	0.2	0.1	0.0	0.1	0.2	0.0	0.0	0.1	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	61.1
CV	0.45	0.42	0.38	0.35	0.40	0.54		0.45	0.63	0.50			3.73		0.48		0.49	0.68	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.32: Statistical results chemical characterization (µg/m^3) of PM_{10} at VKI for summer (S) season

VKI (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	308	12.8	6.9	0.2	8.6	6.0	10.5	1.2	0.9	1.0	9.4	2.0	0.0	0.1	2.8	6.3	18.5	43.9	0.6
SD	72	3.0	1.5	0.1	4.7	2.4	4.1	0.6	0.4	0.5	5.2	0.9	0.0	0.0	0.7	1.7	4.8	14.0	0.2
Max	484	17.6	10.8	0.5	22.1	13.8	17.6	2.8	2.1	2.2	28.1	4.2	0.0	0.2	4.4	9.3	27.7	64.8	1.0
Min	213	7.4	3.9	0.0	2.4	3.0	4.1	0.0	0.5	0.3	0.0	0.8	0.0	0.0	1.7	3.5	10.8	9.1	0.3
CV	0.23	0.24	0.22	0.74	0.55	0.39	0.39	0.49	0.41	0.54	0.55	0.45		0.49	0.24	0.27	0.26	0.32	0.33
VKI (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	8.3	12.1	0.8	0.3	0.4	16.6	0.0	0.0	0.3	18.4	0.0	0.0	0.0	0.1	0.0	0.0	0.1	1.3	57.7
SD	1.8	3.6	0.2	0.2	0.1	5.2	0.0	0.0	0.1	10.6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.5	4.5
Max	13.0	18.4	1.3	0.8	0.7	27.7	0.0	0.1	0.5	47.2	0.0	0.0	0.1	0.1	0.2	0.0	0.2	2.2	68.0
Min	5.7	5.8	0.4	0.2	0.2	8.0	0.0	0.0	0.1	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	46.3
CV	0.22	0.30	0.31	0.54	0.36	0.31		0.58	0.46	0.58	1.12		0.42	0.47	1.32		0.69	0.41	0.08
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.33: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at VKI for summer (S) season

VKI(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	81	9.8	6.4	0.0	4.0	3.1	5.6	0.3	0.6	0.5	0.1	1.0	0.0	0.0	0.8	0.9	2.3	5.6	0.1
SD	19	3.4	2.6	0.0	2.2	1.8	2.8	0.3	0.2	0.2	0.2	0.3	0.0	0.0	0.2	0.3	0.7	1.9	0.1
Max	140	20.9	15.9	0.1	10.6	7.3	11.8	1.4	1.1	0.9	0.7	1.5	0.0	0.1	1.4	1.6	4.3	11.4	0.3
Min	59	5.2	3.2	0.0	1.5	1.0	0.0	0.0	0.2	0.0	0.0	0.5	0.0	0.0	0.4	0.4	1.1	2.7	0.0
CV	0.23	0.35	0.41	0.44	0.56	0.57	0.49	0.95	0.43	0.43	1.74	0.29		1.14	0.29	0.31	0.32	0.34	0.53
VKI(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.4	1.3	0.1	0.2	0.1	2.2	0.0	0.0	0.1	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	67.6
SD	0.6	0.4	0.0	0.1	0.0	0.7	0.0	0.0	0.1	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	3.9
Max	3.4	2.3	0.2	0.3	0.2	3.6	0.0	0.0	0.3	20.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	76.2
Min	0.9	0.6	0.0	0.1	0.0	0.9	0.0	0.0	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	62.4
CV	0.27	0.30	0.34	0.29	0.39	0.31		1.39	0.78	0.58	3.33		2.12	4.47	0.72			0.54	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.34: Correlation Matrix for PM_{10} and its composition at VKI for winter season

VKI (W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.78	0.90	0.53	0.55	0.74	0.16	0.26	0.26	0.49	0.30	0.57	0.21	0.90
TC		1.00	0.86	0.91	0.48	0.57	0.10	0.26	0.20	0.37	0.15	0.46	0.20	0.61
OC			1.00	0.57	0.55	0.70	0.19	0.29	0.29	0.51	0.28	0.52	0.24	0.71
EC				1.00	0.33	0.35	0.01	0.18	0.10	0.18	0.02	0.33	0.13	0.41
NO_3^-					0.23	0.56	1.00	0.19	0.78	0.78	0.70	0.43	0.74	-0.10
SO_4^{-2}					0.69	0.35		1.00	0.19	0.32	0.30	0.15	0.31	-0.04
NH_4^+					0.47	0.87			0.75	1.00	0.79	0.64	0.80	0.17
Metals					0.30	0.46			0.04		0.03	0.40	-0.08	1.00

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

VKI (W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.80	0.92	0.57	0.23	0.79	0.44	0.00	0.24	0.29	0.52	-0.35	0.38	0.90
TC		1.00	0.83	0.93	0.24	0.56	0.29	-0.11	0.05	0.09	0.32	-0.43	0.10	0.62
OC			1.00	0.57	0.29	0.75	0.47	-0.09	0.25	0.17	0.50	-0.44	0.35	0.76
EC				1.00	0.16	0.34	0.11	-0.11	-0.09	0.02	0.14	-0.35	-0.09	0.41
NO_3^-					0.19	0.32	1.00	0.39	0.39	0.16	0.36	0.30	0.56	0.21
SO_4^{-2}					0.14	0.03		1.00	0.38	0.27	0.37	0.41	0.37	-0.20
NH_4^+					-0.17	0.47			0.32	1.00	0.30	0.03	0.42	0.15
Metals					0.23	0.62			0.05		0.38	-0.37	0.17	1.00

Table 2.36: Correlation matrix for PM_{10} and its composition at VKI for summer season

VKI (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.37	0.35	0.27	-0.13	0.06	0.23	0.65	0.30	0.21	0.16	0.17	0.26	0.96
TC		1.00	0.94	0.72	0.08	0.35	0.39	0.36	0.50	-0.13	0.02	0.54	0.06	0.33
OC			1.00	0.43	0.20	0.29	0.47	0.32	0.42	0.12	0.23	0.56	0.24	0.32
EC				1.00	-0.18	0.33	0.09	0.29	0.45	-0.56	-0.40	0.28	-0.33	0.21
NO_3^-					0.58	0.53	1.00	0.33	0.67	0.46	0.58	0.66	0.66	0.16
SO_4^{-2}					-0.02	0.17		1.00	0.32	0.13	-0.06	0.54	0.13	0.72
NH_4^+					0.59	0.18			0.18	1.00	0.86	0.20	0.89	0.23
Metals					-0.15	0.04			0.23		0.15	0.22	0.27	1.00

Table 2.37: Correlation matrix for $PM_{2.5}$ and its composition at VKI for summer season

VKI (S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.70	0.61	0.77	0.29	0.47	0.07	0.24	0.16	-0.08	0.21	0.10	0.28	0.89
TC		1.00	0.98	0.96	0.32	-0.04	0.25	-0.04	0.07	-0.27	0.00	0.36	-0.02	0.35
OC			1.00	0.88	0.39	-0.14	0.28	-0.07	-0.02	-0.26	-0.04	0.36	-0.09	0.26
EC				1.00	0.20	0.09	0.18	0.01	0.19	-0.25	0.04	0.34	0.08	0.44
NO_3^-					-0.05	0.11	1.00	-0.22	0.19	0.33	0.10	0.30	0.39	-0.14
SO_4^{-2}					-0.30	0.00		1.00	-0.28	0.25	0.22	0.00	0.15	0.29
NH_4^+					-0.42	0.27			-0.17	1.00	0.61	-0.30	0.39	0.03
Metals					0.20	0.60			0.04		0.24	-0.11	0.29	1.00

2.4.3 Jorawar Singh Gate

The sampling period was December 14, 2017 – January 04, 2018 for winter and May 29 – June 20, 2018 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.30) and summer (Figure 2.31). Average levels for winter and summer season were 118±44 and 53±14 µg/m^3 (for $PM_{2.5}$) and 238±74 and 272±79 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are about two times higher than the NAQS and PM_{10} is 2.4 times higher than the NAQS in winter. The $PM_{2.5}$ levels generally meet the standards while PM_{10} is 2.7 times higher than the national standard in summer. A statistical summary of PM concentrations is presented in Table 2.42 – 2.45 for winter and summer season. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards but PM_{10} levels were slightly increased and continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from soil surface during dust storms in the dry months of summer can contribute significantly in coarse fraction.

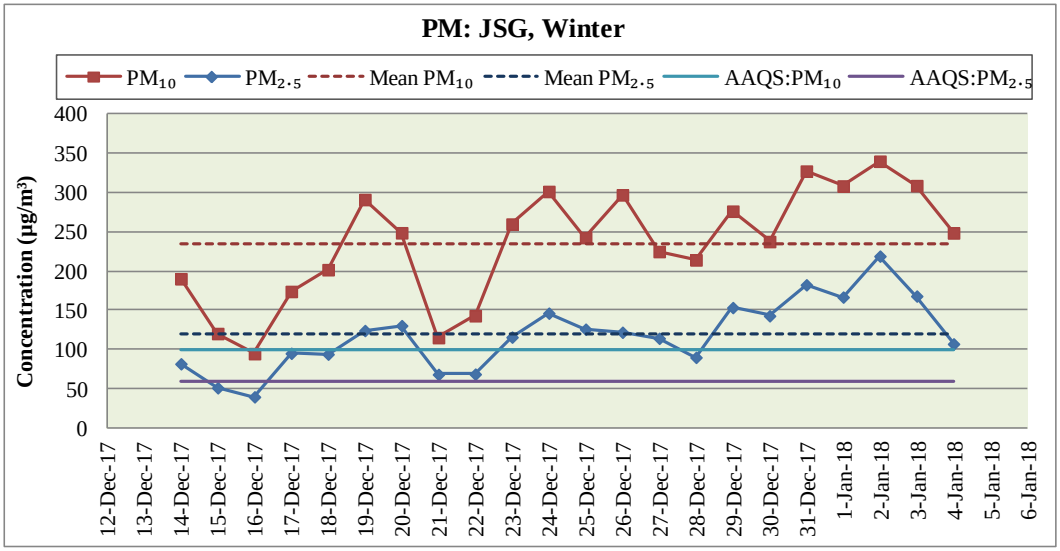


Figure 2.30: PM Concentrations at JSG for Winter Season

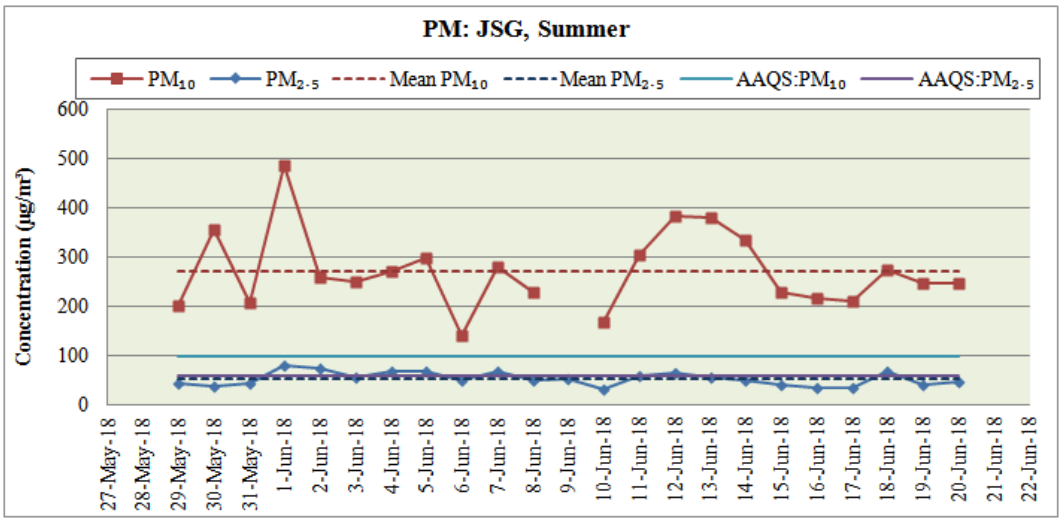


Figure 2.31: PM Concentrations at JSG for Summer Season

2.4.3.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.32) and summer (Figure 2.33) seasons. It was observed that SO_2 concentrations were low and meets the air quality standard. NO_2 levels also under the national standard with an average of 20 days at 37±13 µg/m^3 in winter and 14±10 µg/m^3 in summer season (Table 2.38). The summer concentration of NO_2 dropped dramatically similarly $PM_{2.5}$ levels. Although, the NO_2 is certainly 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 presence of occasional local sources like DG sets, traffic jams or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.34 and statistical summary in Table 2.38. The total BTX level is observed 25±17 µg/m^3 (Benzene: 7.4 and Toluene: 11.4 µg/m^3) in winter and 7.4±4.6 µg/m^3 (Benzene: 2.1 and Toluene: 4.0 µg/m^3) in summer seasons. The maximum BTX concentration was observed 69 µg/m^3 in winter and 17 µg/m^3 in summer seasons. The BTX levels were high during winter than the summer.

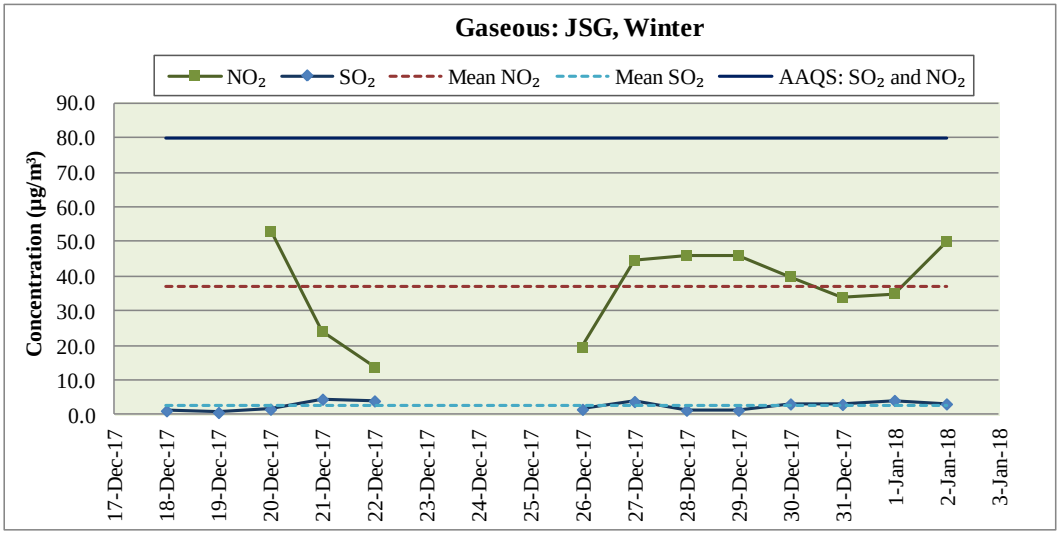


Figure 2.32: SO_2 and NO_2 Concentrations at JSG for Winter Season

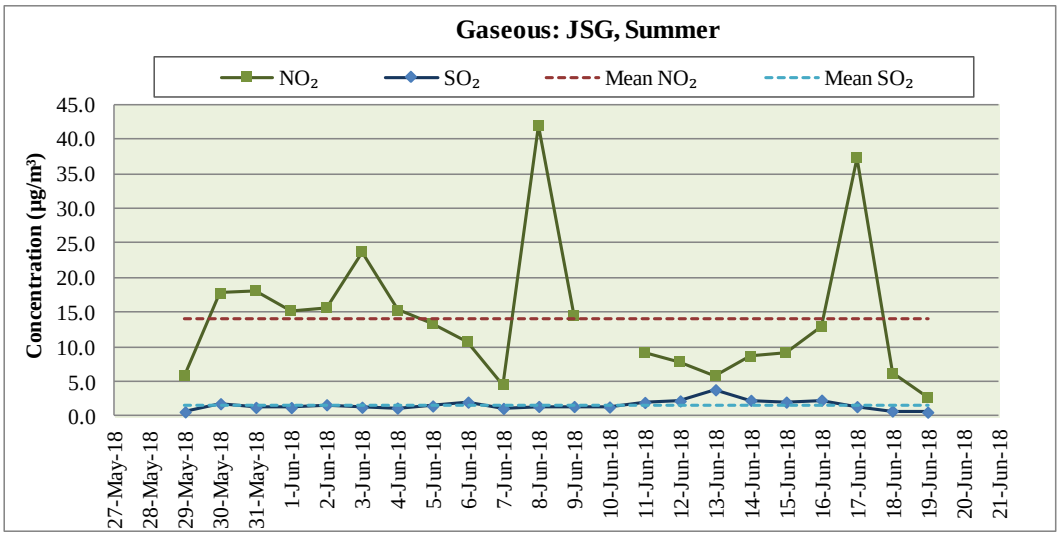


Figure 2.33: SO_2 and NO_2 Concentrations at JSG for Summer Season

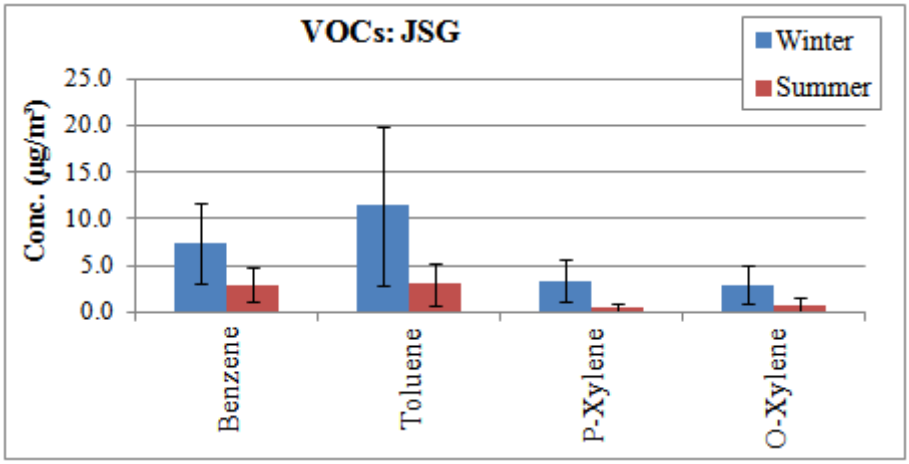


Figure 2.34: VOCs concentration at JSG

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.35 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (winter: 17.4±4.8 and summer: 4.5±1.4 µg/m^3) than the elemental carbon (winter: 11.3±3.8 and summer: 2.3±0.9 µg/m^3). However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at JSG. It is also observed that the OC and EC are higher in winter season than in 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 2.39 for winter and summer seasons.

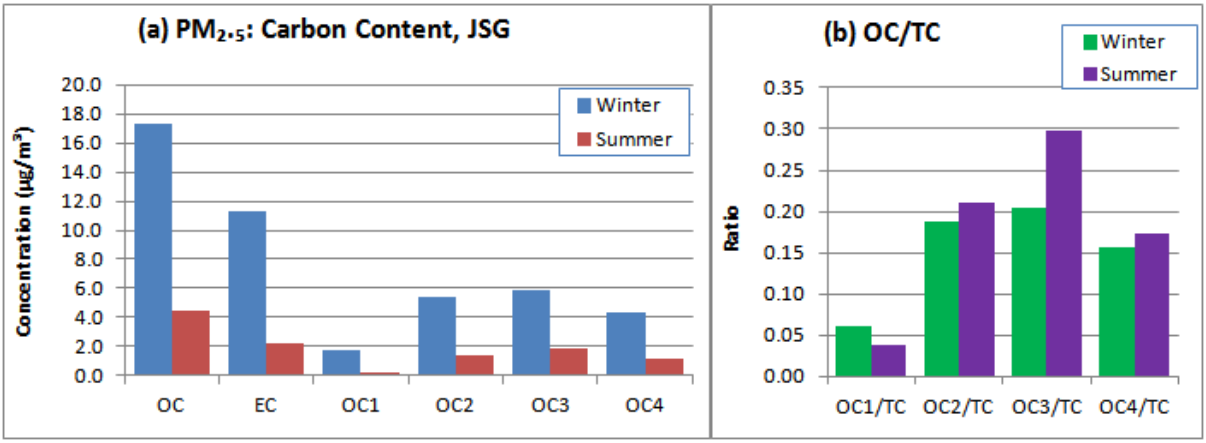


Figure 2.35: EC and OC Content in $PM_{2.5}$ at JSG

2.4.3.4 PAHs in $PM_{2.5}$

Figure 2.36 shows the average measured concentration of PAHs at JSG for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.40 for winter and summer seasons. The PAHs compounds analyzed were: (i) IsP, (ii) DmP, (iii) AcP, (iv) DEP, (v) Flu, (vi) HcB, (vii) Phe, (viii) Ant, (ix) Pyr, (x) BbP, (xi) BeA, (xii) B(a)A, (xiii) Chr, (xiv) B(b)F, (xv) B(k)F, (xvi) B(a)P, (xvii) InP, (xviii) D(a,h)A and (xix) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (57±26 ng/m^3) compared to summer season (8.6±2.6 ng/m^3). Major PAHs are DmP (15.0 ng/m^3), B(b)F (8.9 ng/m^3), B(ghi)P (5.2 ng/m^3), B(a)P (4.7 ng/m^3), InP (4.3 ng/m^3) and Chr (4.0 ng/m^3) for winter season and AcP (1.4 ng/m^3), DEP (1.3 ng/m^3), B(b)F (1.1 ng/m^3), Phe (0.9 ng/m^3) and Ant (0.8 ng/m^3) for summer season.

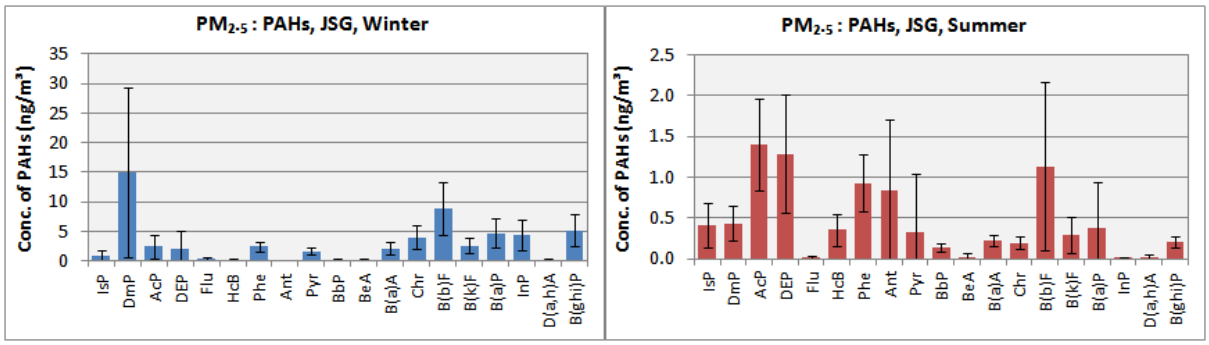


Figure 2.36: PAHs Concentrations in $PM_{2.5}$ at JSG

2.4.3.5 Molecular Markers in $PM_{2.5}$

Total seven molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, n-Hentriacontane, n-Tritriacontane, n-Pentatriacontane, Stigmasterol and Levoglucosan. Figure 2.37 and Table 2.41 show the levels of seven molecular markers. Total concentration of markers was 21.0±2.5 ng/m^3 in winter and 8.8±3.1 ng/m^3 in summer. Stigmasterol has also been found in appreciable quantity, indicating emissions from biomass burning and cooking. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

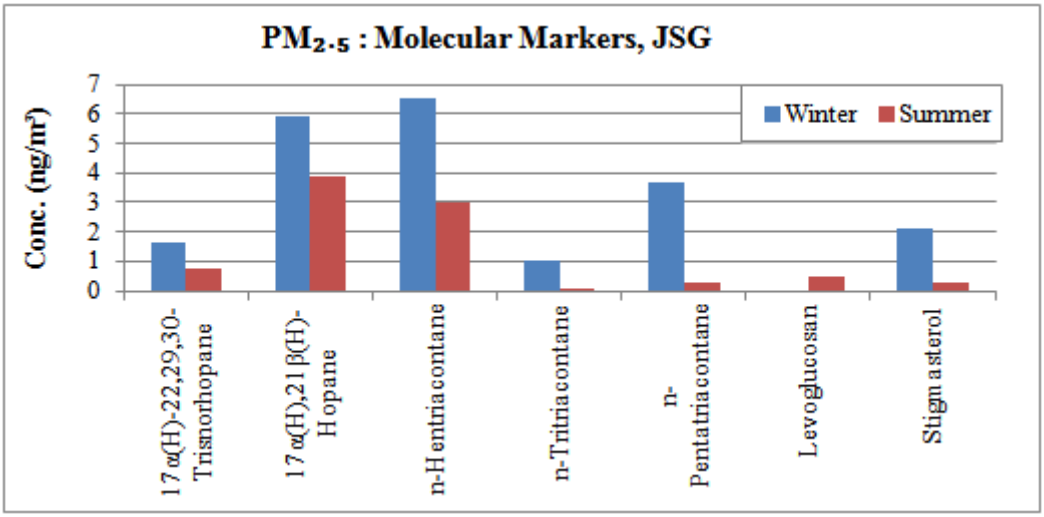


Figure 2.37: Molecular Markers in $PM_{2.5}$ at JSG

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

Graphical presentations of chemical species are shown for winter and summer season for PM_{10} (Figure 2.38) and $PM_{2.5}$ (Figure 2.39). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content, ionic species and elements] along with

mass percentage (% R) recovered from PM are presented in the Tables 2.42 – 2.45 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 2.46 – 2.49 for both season. It is seen that most of parameters showed good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM are presented in Figure 2.40 (a) and (b) for winter season and Figure 2.41 (a) and (b) for summer season.

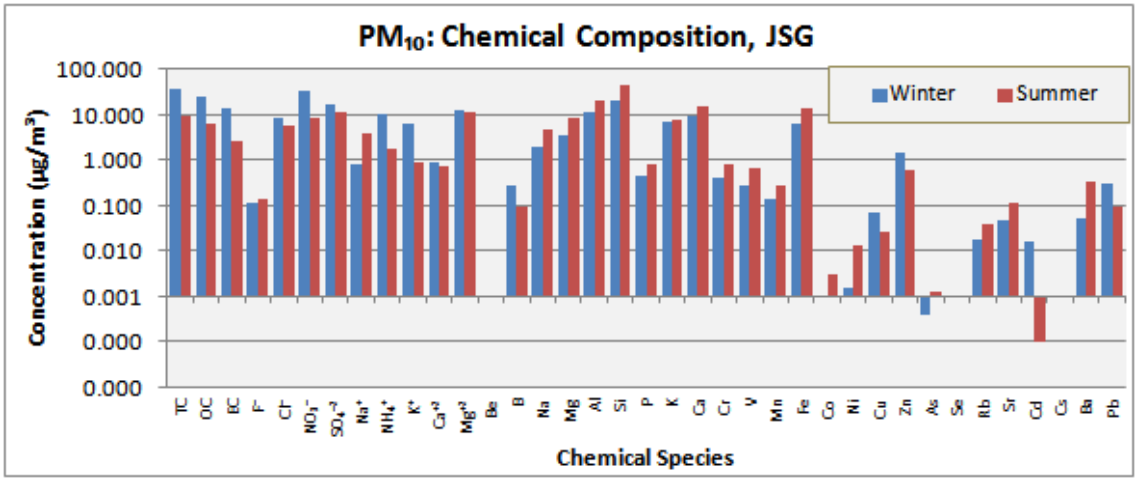


Figure 2.38: Concentrations of species in PM_{10} at JSG

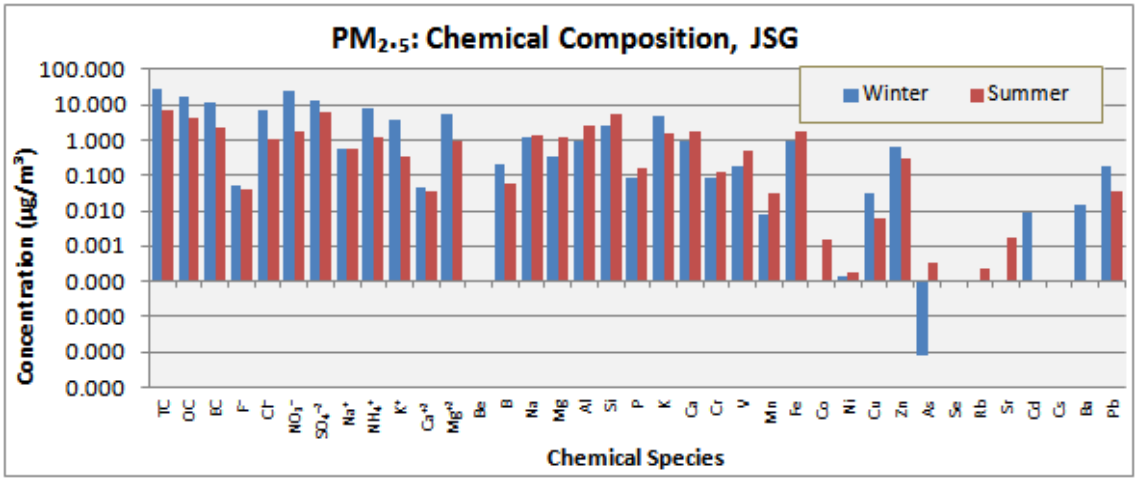


Figure 2.39: Concentrations of species in $PM_{2.5}$ at JSG

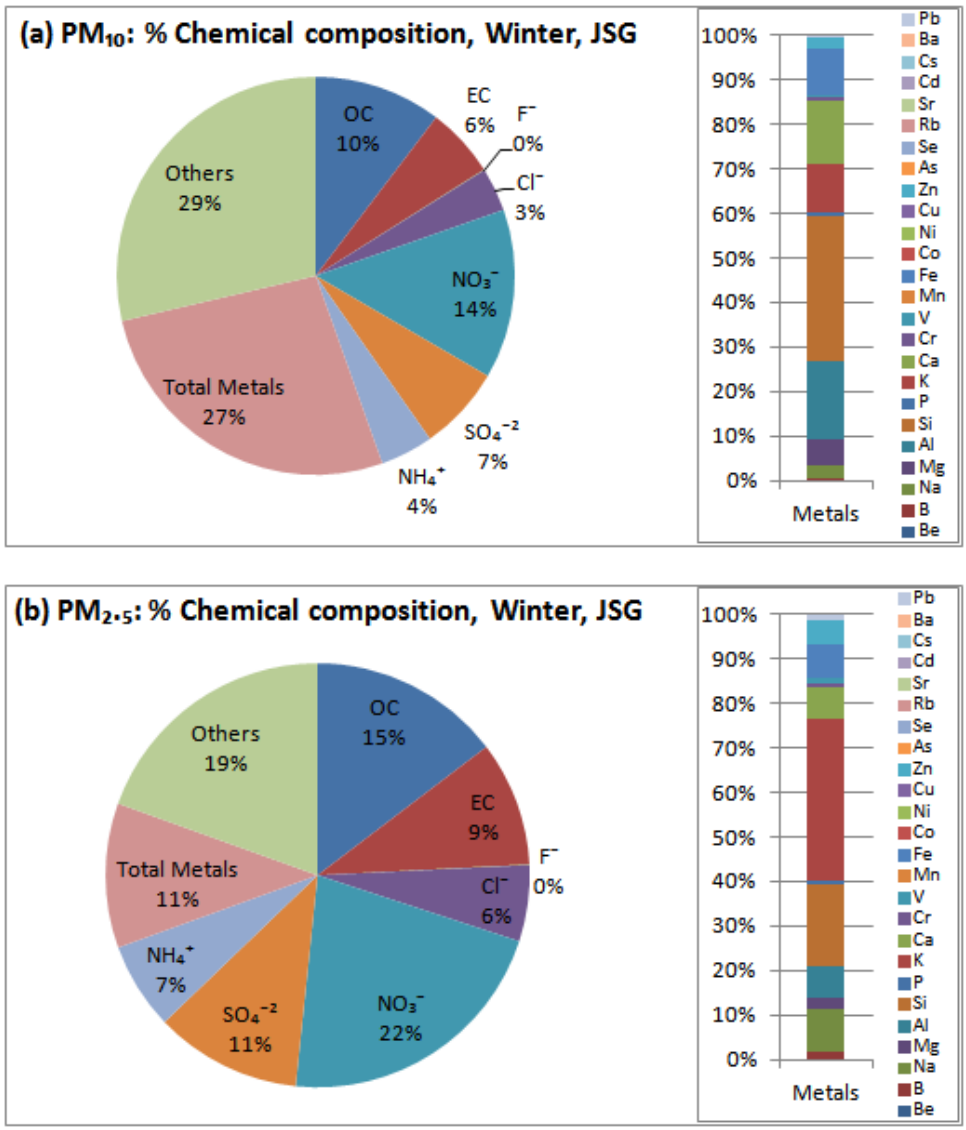
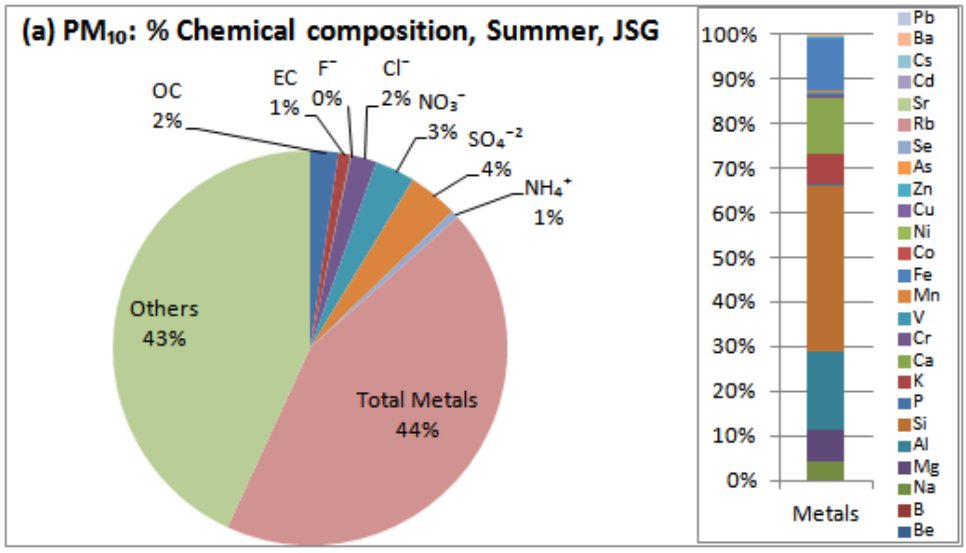


Figure 2.40: Percentage distribution of species in PM at JSG for Winter Season



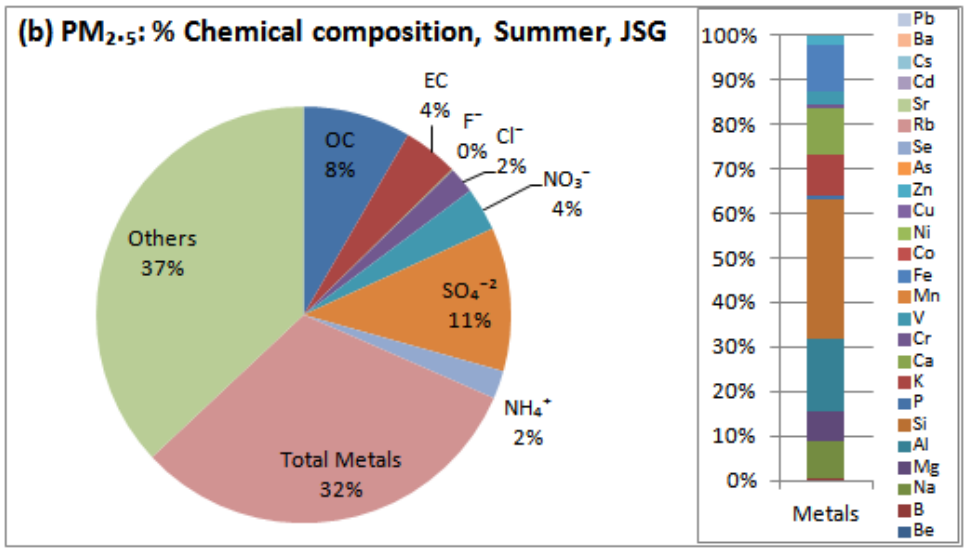


Figure 2.41: Percentage distribution of species in PM at JSG for Summer Season

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

The graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.42) at JSG. 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 significant portion of PM is having fine mode during winter (50 %) than summer (20 %). The major species contributing to fine mode are TC, OC, EC, SO_4^{-2}, NH_4^+, K^+, B, V, Zn and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg, Al, Si, Ca, Cr, Mn, Fe and Ni.

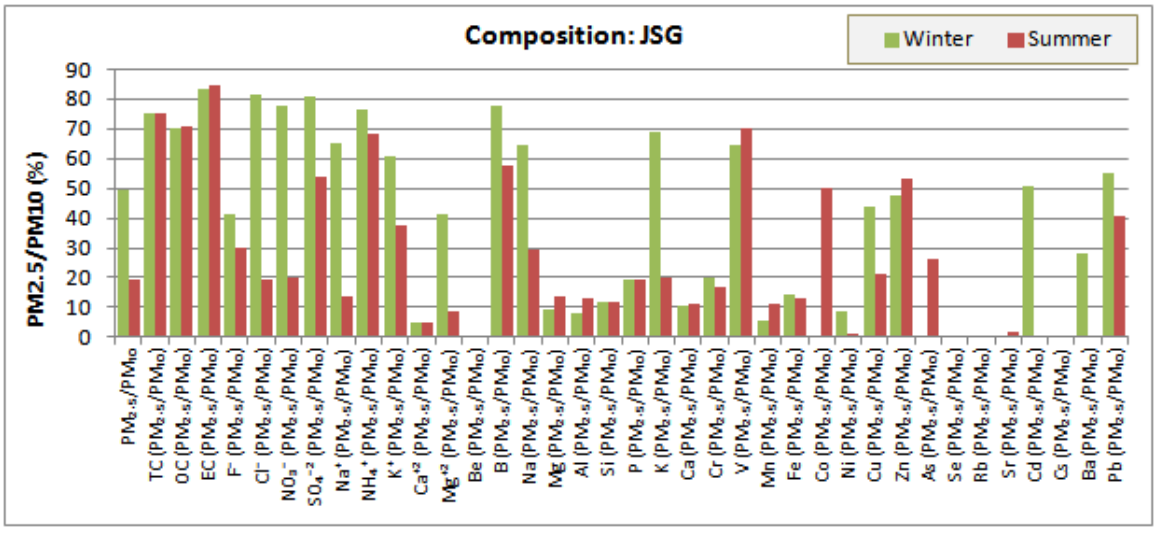


Figure 2.42: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at JSG

Table 2.38: Statistical results of gaseous pollutants (µg/m^3) at JSG for winter (W) and summer (S) seasons

JSG (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	36.84	2.61	7.35	11.40	3.40	2.95	25.09
SD	12.95	1.33	4.36	8.42	2.20	2.10	16.69
Max	52.92	4.54	17.03	34.73	9.30	8.41	69.46
Min	13.63	0.70	0.19	0.00	0.01	0.00	0.26
CV	0.35	0.51	0.59	0.74	0.65	0.71	0.67
JSG (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	14.13	1.62	2.97	3.04	0.59	0.78	7.38
SD	9.97	0.71	1.86	2.28	0.45	0.70	4.64
Max	41.97	3.83	6.06	7.28	1.51	2.94	17.37
Min	2.73	0.60	0.04	0.01	0.00	0.00	0.05
CV	0.71	0.44	0.63	0.75	0.76	0.90	0.63

Table 2.39: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at JSG for winter (W) and summer (S) seasons

JSG (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	118.5	28.65	17.36	11.29	1.81	5.37	5.85	4.33	0.062	0.188	0.205	0.156
SD	44.2	8.48	4.76	3.78	0.64	1.55	1.74	0.99	0.007	0.011	0.013	0.024
Max	219.0	40.97	25.22	17.27	2.97	7.72	9.58	5.76	0.076	0.206	0.234	0.216
Min	39.6	13.16	8.58	4.51	0.69	2.50	2.84	2.36	0.051	0.168	0.185	0.127
CV	0.37	0.30	0.27	0.33	0.36	0.29	0.30	0.23	0.115	0.057	0.063	0.152
JSG (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	53.2	6.72	4.45	2.28	0.25	1.36	1.91	1.14	0.038	0.211	0.297	0.173
SD	13.9	2.17	1.37	0.92	0.13	0.62	0.68	0.51	0.024	0.110	0.118	0.072
Max	81.7	11.70	7.71	4.35	0.68	3.39	3.91	2.33	0.133	0.664	0.766	0.457
Min	33.3	3.56	2.72	0.77	0.03	0.74	1.14	0.51	0.006	0.115	0.199	0.079
CV	0.26	0.32	0.31	0.40	0.54	0.46	0.36	0.45	0.624	0.521	0.398	0.420

Table 2.40: **Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at JSG for winter (W) and summer (S) seasons**

JSG(W)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.89	14.95	2.40	2.12	0.32	0.25	2.48	0.09	1.65	0.23	0.11	2.06	4.03	8.93	2.54	4.69	4.31	0.16	5.21	57.42
SD	0.80	14.40	1.95	2.95	0.20	0.09	0.82	0.05	0.52	0.15	0.19	1.07	2.08	4.43	1.30	2.44	2.59	0.15	2.79	25.85
Max	2.73	42.07	7.23	10.45	0.78	0.37	4.40	0.19	2.66	0.53	0.49	3.51	6.85	14.83	4.27	8.22	8.93	0.49	9.92	115.10
Min	0.28	0.76	0.74	0.21	0.06	0.10	1.42	0.04	0.86	0.09	0.00	0.38	0.66	1.30	0.21	0.69	0.14	0.00	0.47	29.57
CV	0.90	0.96	0.81	1.39	0.61	0.35	0.33	0.58	0.31	0.64	1.76	0.52	0.52	0.50	0.51	0.52	0.60	0.90	0.54	0.45
JSG(S)	IsP	DmP	AcP	DEP	Flu	HcB	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	0.41	0.44	1.40	1.29	0.01	0.35	0.93	0.83	0.33	0.14	0.02	0.22	0.19	1.13	0.29	0.37	0.00	0.02	0.21	8.59
SD	0.27	0.22	0.56	0.72	0.03	0.20	0.35	0.88	0.70	0.05	0.06	0.07	0.08	1.03	0.22	0.57	0.02	0.03	0.07	2.59
Max	0.94	1.00	2.70	3.32	0.09	0.64	1.63	2.53	2.53	0.23	0.20	0.38	0.33	4.20	0.70	2.14	0.06	0.11	0.33	13.83
Min	0.17	0.13	0.56	0.53	0.00	0.11	0.58	0.02	0.00	0.08	0.00	0.16	0.11	0.40	0.06	0.06	0.00	0.00	0.14	5.19
CV	0.66	0.50	0.40	0.56	3.46	0.56	0.38	1.05	2.12	0.35	3.46	0.33	0.39	0.91	0.74	1.53	3.33	1.64	0.35	0.30

Table 2.41: **Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at JSG for winter (W) and summer (S) seasons**

JSG (W)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.62	5.93	6.55	1.04	3.70	0.00	2.11	20.95
SD	0.19	0.36	0.75	0.12	2.70	0.00	1.10	2.49
CV	0.12	0.06	0.11	0.11	0.73		0.52	0.12
JSG (S)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	0.75	3.86	3.01	0.09	0.29	0.51	0.25	8.77
SD	0.29	0.55	2.46	0.08	0.15	0.43	0.34	3.06
CV	0.38	0.14	0.82	0.91	0.52	0.85	1.33	0.35

Table 2.42: Statistical results of chemical characterization (µg/m^3) of PM_{10} at JSG for winter (W) season

JSG (W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	238	24.7	13.6	0.1	8.4	32.9	16.4	0.8	10.2	6.5	0.9	13.2	0.0	0.3	2.0	3.6	11.4	20.8	0.4
SD	74	7.1	4.6	0.2	3.5	19.4	5.5	0.4	4.1	2.3	0.6	4.2	0.0	0.1	0.5	1.2	4.3	7.3	0.1
Max	340	36.0	20.8	1.0	16.7	85.5	27.9	1.7	21.0	11.5	2.5	24.4	0.0	0.6	2.8	5.4	17.6	32.4	0.7
Min	95	9.2	5.0	0.0	3.5	7.3	9.1	0.3	4.8	3.1	0.1	6.1	0.0	0.1	0.9	1.0	3.0	5.6	0.1
CV	0.31	0.29	0.34	1.71	0.42	0.59	0.34	0.47	0.40	0.35	0.63	0.32		0.47	0.25	0.33	0.38	0.35	0.34
JSG (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	7.0	9.1	0.4	0.3	0.1	6.6	0.0	0.0	0.1	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	71.6
SD	2.7	2.7	0.1	0.1	0.1	2.1	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	4.7
Max	12.1	13.9	0.6	0.5	0.2	9.4	0.0	0.0	0.1	4.1	0.0	0.0	0.0	0.1	0.0	0.0	0.6	0.9	81.8
Min	1.6	3.0	0.2	0.1	0.0	2.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63.6
CV	0.39	0.30	0.35	0.31	0.45	0.31	0.00	2.81	0.44	0.78	4.67	0.00	0.79	0.66	0.29	0.00	2.48	0.78	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.43: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at JSG for winter (W) season

JSG (W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	118	17.4	11.3	0.0	6.9	25.6	13.2	0.5	7.8	3.9	0.0	5.5	0.0	0.2	1.3	0.3	0.9	2.4	0.1
SD	44	4.8	3.8	0.0	4.2	15.5	5.6	0.3	3.5	2.3	0.0	2.5	0.0	0.1	0.5	0.2	0.5	2.3	0.1
Max	219	25.2	17.3	0.1	16.5	62.9	25.6	1.3	15.7	7.9	0.2	14.4	0.0	0.4	2.0	0.7	2.4	9.2	0.2
Min	40	8.6	4.5	0.0	0.7	2.1	5.9	0.2	3.8	0.4	0.0	3.6	0.0	0.1	0.4	0.1	0.3	0.6	0.0
CV	0.37	0.27	0.33	0.59	0.61	0.60	0.42	0.56	0.45	0.58	0.78	0.46		0.51	0.37	0.46	0.57	0.94	0.66
JSG (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.8	0.9	0.1	0.2	0.0	1.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	79.9
SD	2.8	0.4	0.1	0.1	0.0	0.6	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	4.2
Max	10.3	1.5	0.3	0.3	0.1	2.5	0.0	0.0	0.1	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.5	90.7
Min	0.7	0.4	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	74.0
CV	0.58	0.41	0.73	0.51	2.06	0.62		4.69	0.71	0.80	4.69				0.52		4.69	0.90	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.44: Statistical results chemical characterization (µg/m^3) of PM_{10} at JSG for summer (S) season

JSG (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	272	6.3	2.7	0.1	5.7	8.9	11.1	4.1	1.7	0.9	0.7	10.9	0.0	0.1	4.8	8.3	21.0	43.6	0.8
SD	79	2.0	1.1	0.2	3.3	3.9	3.3	2.0	1.0	0.6	0.4	3.4	0.0	0.0	2.2	2.5	7.2	15.3	0.3
Max	486	11.0	5.2	0.9	12.6	20.1	21.0	7.6	5.0	3.0	1.4	20.7	0.0	0.1	8.6	13.5	41.8	80.6	1.4
Min	142	3.9	0.9	0.0	2.0	3.7	5.0	1.3	0.5	0.4	0.0	6.0	0.0	0.1	2.2	2.7	6.1	14.9	0.4
CV	0.29	0.31	0.41	1.37	0.58	0.43	0.30	0.49	0.58	0.67	0.51	0.31		0.24	0.45	0.30	0.34	0.35	0.36
JSG (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	7.9	14.9	0.8	0.7	0.3	13.7	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.1	57.9
SD	2.7	4.4	0.3	0.3	0.1	4.2	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.1	0.0	0.0	1.4	0.1	5.3
Max	17.1	25.4	1.7	1.5	0.6	25.1	0.1	0.0	0.1	2.9	0.0	0.0	0.1	0.2	0.0	0.0	6.7	0.5	75.9
Min	4.5	5.6	0.3	0.4	0.2	5.1	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.2
CV	0.34	0.30	0.35	0.42	0.34	0.31	4.69	0.71	0.43	0.93	2.39		0.51	0.58	4.69		4.38	1.32	0.09
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.45: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at JSG for summer (S) season

JSG(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	53	4.4	2.3	0.0	1.1	1.8	6.0	0.5	1.2	0.3	0.0	0.9	0.0	0.1	1.4	1.1	2.7	5.3	0.2
SD	14	1.4	0.9	0.0	0.6	1.1	1.9	0.4	0.6	0.2	0.1	1.0	0.0	0.0	0.5	0.5	1.6	2.2	0.1
Max	82	7.7	4.4	0.1	2.2	5.3	10.4	1.4	3.1	0.8	0.5	4.6	0.0	0.1	3.1	2.6	8.8	8.7	0.5
Min	33	2.7	0.8	0.0	0.0	0.5	2.6	0.0	0.4	0.1	0.0	0.0	0.0	0.0	0.8	0.5	1.1	0.9	0.1
CV	0.26	0.31	0.40	0.69	0.53	0.63	0.32	0.70	0.53	0.66	3.24	1.06		0.36	0.35	0.42	0.59	0.41	0.71
JSG(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.5	1.7	0.1	0.5	0.0	1.8	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	63.9
SD	0.9	0.7	0.0	0.1	0.0	0.7	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
Max	3.1	3.8	0.2	0.7	0.1	3.2	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	74.1
Min	0.0	0.8	0.1	0.2	0.0	0.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.6
CV	0.59	0.42	0.31	0.30	0.41	0.40	4.80	3.45	0.68	0.78	4.75		3.32	4.32				1.06	0.08
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.46: Correlation matrix for PM_{10} and its composition at JSG for winter season

JSG (W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.86	0.85	0.85	0.05	0.74	0.80	0.55	0.48	0.61	0.37	0.00	0.34	0.96
TC		1.00	1.00	0.99	0.08	0.58	0.46	0.22	0.13	0.36	0.14	0.03	0.23	0.84
OC			1.00	0.98	0.09	0.56	0.47	0.24	0.15	0.38	0.19	0.03	0.26	0.83
EC				1.00	0.06	0.59	0.45	0.19	0.11	0.32	0.05	0.03	0.18	0.84
NO_3^-					0.06	0.67	1.00	0.73	0.74	0.80	0.58	-0.05	0.43	0.66
SO_4^{-2}					-0.02	0.70		1.00	0.69	0.70	0.62	0.02	0.19	0.41
NH_4^+					-0.07	0.42			0.63	1.00	0.75	-0.04	0.60	0.44
Metals					0.06	0.65			0.37		0.20	0.03	0.25	1.00

Table 2.47: Correlation matrix for $PM_{2.5}$ and its composition at JSG for winter season

JSG (W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.72	0.72	0.71	-0.06	0.86	0.94	0.86	0.69	0.66	0.89	0.02	-0.37	0.90
TC		1.00	1.00	0.99	0.04	0.65	0.53	0.38	0.27	0.49	0.72	0.14	-0.31	0.50
OC			1.00	0.98	0.07	0.65	0.54	0.38	0.27	0.51	0.73	0.14	-0.29	0.49
EC				1.00	0.00	0.65	0.51	0.36	0.26	0.46	0.70	0.14	-0.33	0.50
NO_3^-					-0.14	0.75	1.00	0.93	0.78	0.64	0.87	0.05	-0.30	0.83
SO_4^{-2}					-0.12	0.69		1.00	0.82	0.68	0.81	0.16	-0.34	0.78
NH_4^+					0.01	0.51			0.61	1.00	0.82	0.34	-0.10	0.50
Metals					-0.08	0.76			0.60		0.72	-0.10	-0.32	1.00

Table 2.48: Correlation matrix for PM_{10} and its composition at JSG for summer season

JSG (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.17	-0.01	0.47	0.44	0.22	0.05	0.25	0.05	-0.24	0.15	0.51	0.69	0.97
TC		1.00	0.97	0.91	-0.04	-0.27	0.14	0.06	-0.22	0.54	0.76	-0.03	-0.16	0.05
OC			1.00	0.78	-0.15	-0.36	0.09	0.02	-0.28	0.55	0.68	-0.15	-0.29	-0.13
EC				1.00	0.17	-0.07	0.22	0.12	-0.07	0.45	0.78	0.17	0.09	0.35
NO_3^-					0.03	0.51	1.00	0.26	0.48	0.39	0.59	0.39	0.26	-0.05
SO_4^{-2}					0.19	0.46		1.00	0.42	0.08	0.28	0.44	0.23	0.14
NH_4^+					-0.22	-0.15			-0.16	1.00	0.72	-0.31	-0.22	-0.31
Metals					0.44	0.18			0.00		0.02	0.45	0.69	1.00

Table 2.49: Correlation matrix for $PM_{2.5}$ and its composition JSG for summer season

JSG (S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.65	0.54	0.72	0.08	-0.02	-0.12	0.39	0.01	0.25	0.70	0.38	0.53	0.94
TC		1.00	0.97	0.92	-0.05	-0.36	-0.18	0.53	-0.10	0.59	0.54	0.07	0.31	0.39
OC			1.00	0.79	-0.08	-0.47	-0.19	0.48	-0.16	0.60	0.38	-0.03	0.18	0.28
EC				1.00	0.00	-0.14	-0.14	0.54	0.00	0.49	0.73	0.20	0.46	0.50
NO_3^-					-0.07	0.30	1.00	-0.26	0.29	-0.12	-0.15	-0.03	0.10	-0.10
SO_4^{-2}					0.33	0.00		1.00	0.20	0.52	0.49	0.38	0.40	0.21
NH_4^+					0.22	-0.15			0.06	1.00	0.42	-0.12	0.08	0.00
Metals					0.09	0.06			0.07		0.61	0.48	0.55	1.00

2.4.4 Malviya Nagar

The sampling period was Jaunary 26 – February 14, 2018 for winter and April 15 – May 04, 2018 for summer.

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

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.43) and summer (Figure 2.44). Average levels for winter and summer season were 74±18 and 42±10 µg/m^3 (for $PM_{2.5}$) and 188±39 and 230±108 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are higher than the NAQS and PM_{10} about 1.9 times higher than the NAQS in winter. The $PM_{2.5}$ levels generally meet the standards while PM_{10} is 2.3 times higher than the national standard. A statistical summary of PM concentrations is presented in Table 2.54 – 2.57 for winter and summer season. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards but PM_{10} levels were increased and continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from soil surface during dust storms in the dry months of summer can contribute significantly in coarse fraction.

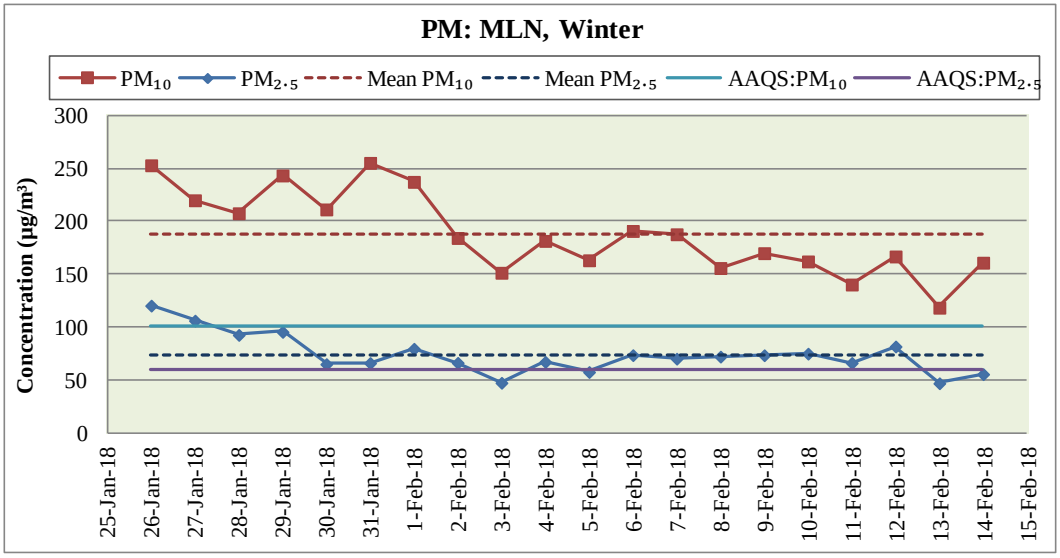


Figure 2.43: PM Concentrations at MLN for Winter Season

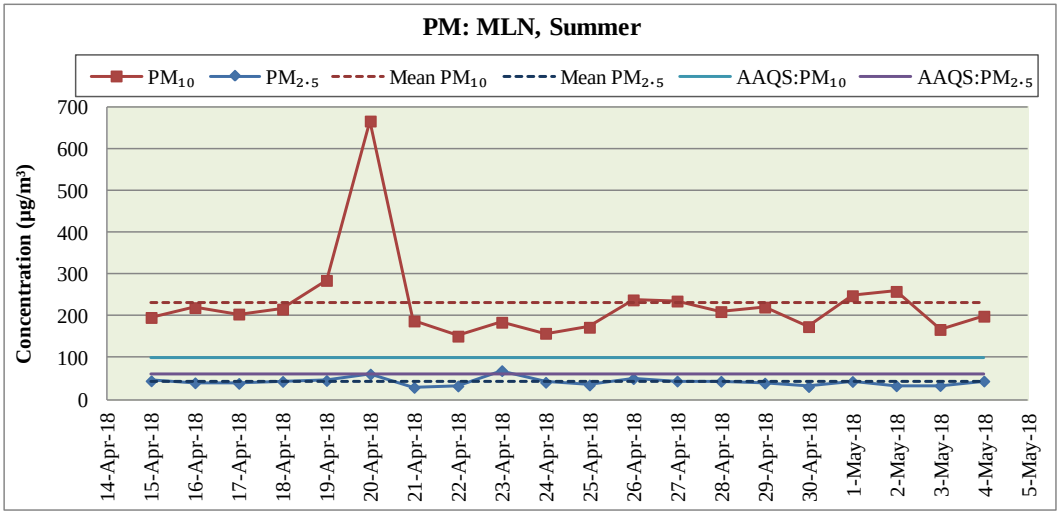


Figure 2.44: PM Concentrations at MLN for Summer Season

2.4.4.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.45) and summer (Figure 2.46) seasons. It was observed that SO_2 concentrations were low and meets the air quality standard. NO_2 levels also under the national standard with an average of 20 days at 35.0±8.1 µg/m^3 in winter and 13.8±5.5 µg/m^3 in summer season (Table 2.50). The summer concentration of NO_2 dropped dramatically similarly $PM_{2.5}$ levels. Although, the NO_2 is certainly 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 presence of occasional local sources like DG sets, traffic jams or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.47 and statistical summary in Table 2.51. The total BTX level is observed 17.4±9.5 µg/m^3 (Benzene: 6.2 and Toluene: 6.9 µg/m^3) in winter and 7.6±3.3 µg/m^3 (Benzene: 2.1 and Toluene: 4.0 µg/m^3) in summer seasons. The maximum BTX concentration was observed 37 µg/m^3 in winter and 16 µg/m^3 in summer seasons. The BTX levels were high during winter than the summer.

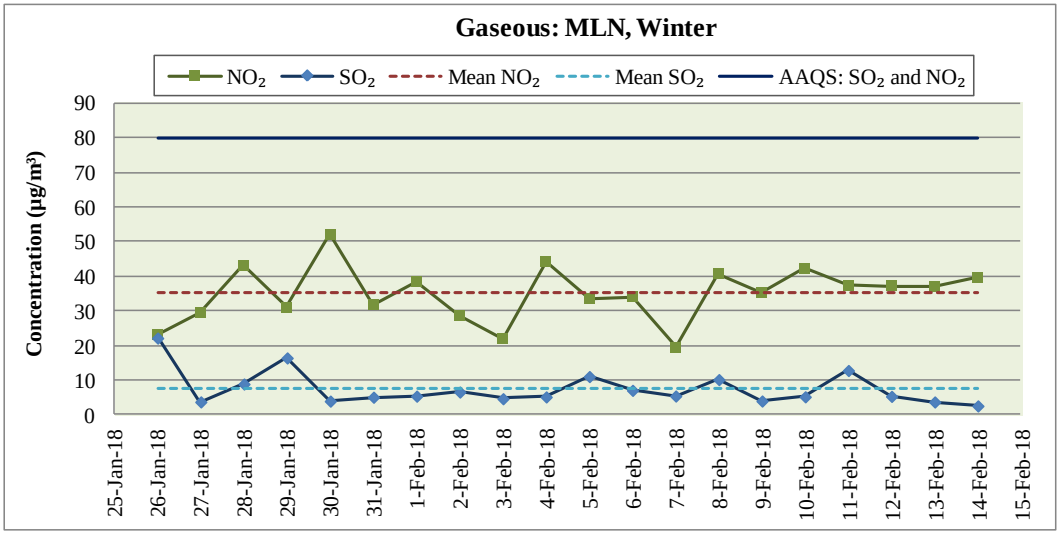


Figure 2.45: SO_2 and NO_2 Concentrations at MLN for Winter Season

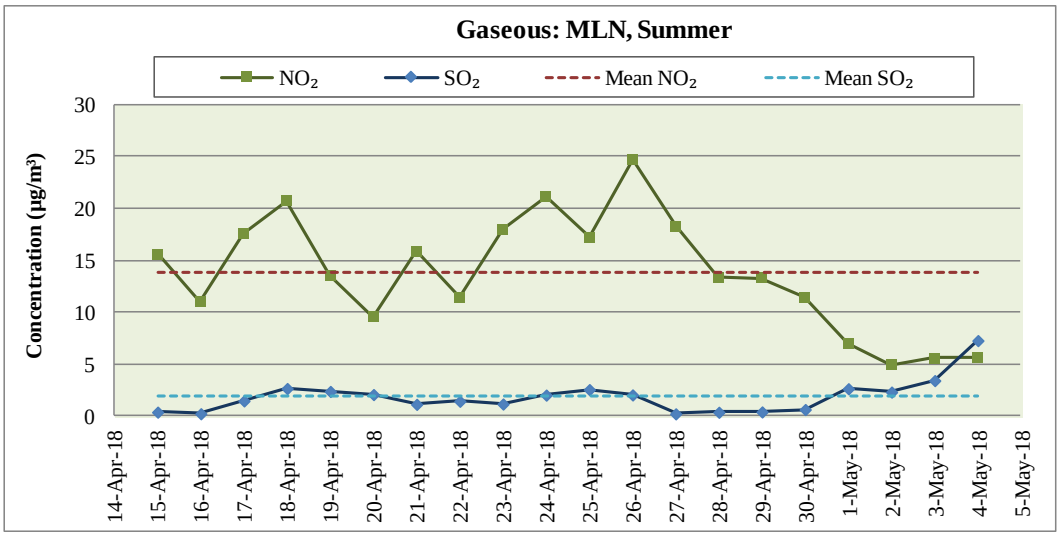


Figure 2.46: SO_2 and NO_2 Concentrations at MLN for Summer Season

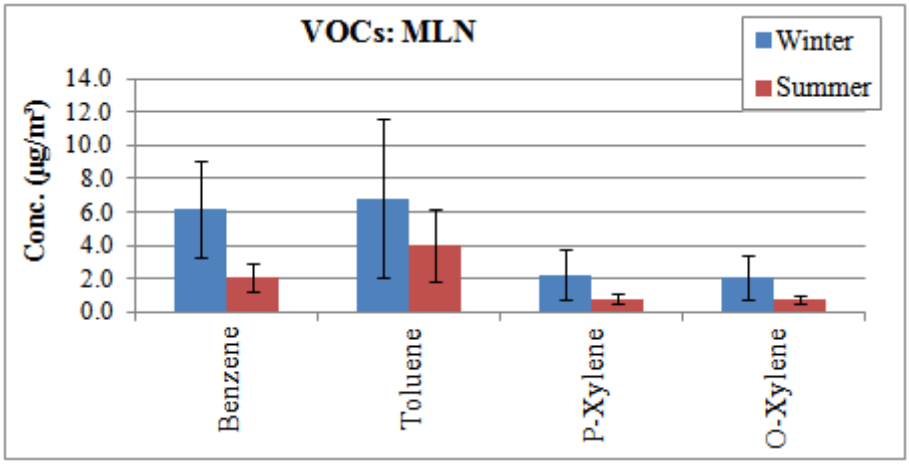


Figure 2.47: VOCs concentration at MLN

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.48 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (winter: 12.0±2.9 and summer: 6.7±1.4 µg/m^3) than the elemental carbon (winter: 6.8±2.3 and summer: 3.9±0.9 µg/m^3). However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at MLN. It is also observed that the OC and EC are higher in winter season than in 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 2.51 for winter and summer seasons.

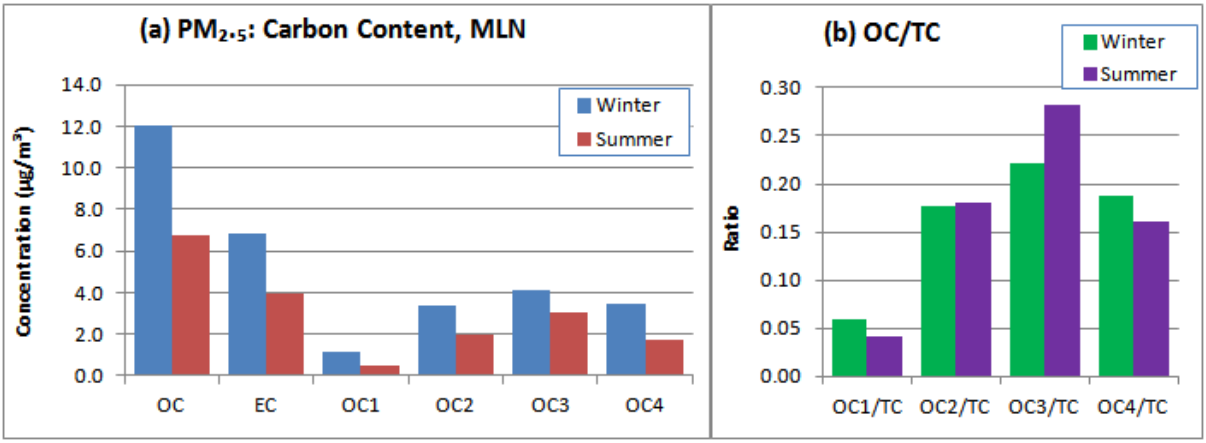


Figure 2.48: EC and OC Content in $PM_{2.5}$ at MLN

2.4.4.4 PAHs in $PM_{2.5}$

Figure 2.49 shows the average measured concentration of PAHs at MLN for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.52 for winter and summer seasons. The PAHs compounds analyzed were: (i) IsP, (ii) DmP, (iii) AcP, (iv) DEP, (v) Flu, (vi) HcB, (vii) Phe, (viii) Ant, (ix) Pyr, (x) BbP, (xi) BeA, (xii) B(a)A, (xiii) Chr, (xiv) B(b)F, (xv) B(k)F, (xvi) B(a)P, (xvii) InP, (xviii) D(a,h)A and (xix) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (21.0±11.5 ng/m^3) compared to summer season (8.8±1.7 ng/m^3). Major PAHs are B(b)F (5.4 ng/m^3), B(a)P (2.2 ng/m^3), Chr (2.2 ng/m^3), B(ghi)P (2.0 ng/m^3) and InP (1.5 ng/m^3) for winter season and Ant (1.9 ng/m^3), B(b)F (1.8 ng/m^3), AcP (1.2 ng/m^3) and DEP (1.0 ng/m^3) for summer season.

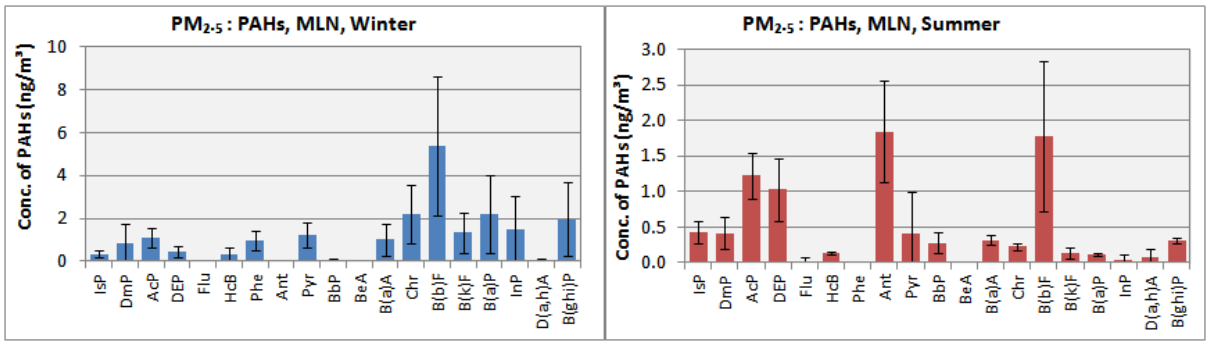


Figure 2.49: PAHs Concentrations in $PM_{2.5}$ at MLN

2.4.4.5 Molecular Markers in $PM_{2.5}$

Total seven molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, n-Hentriacontane, n-Tritriacontane, n-Pentatriacontane, Stigmasterol and Levoglucosan. Figure 2.50 and Table 2.53 show the levels of seven molecular markers atMLN. Total concentration of markers was 15.0±2.1 ng/m^3 in winter and 15.8±7.2 ng/m^3 in summer. Stigmasterol has also been found in appreciable quantity, indicating emissions from biomass burning and cooking. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

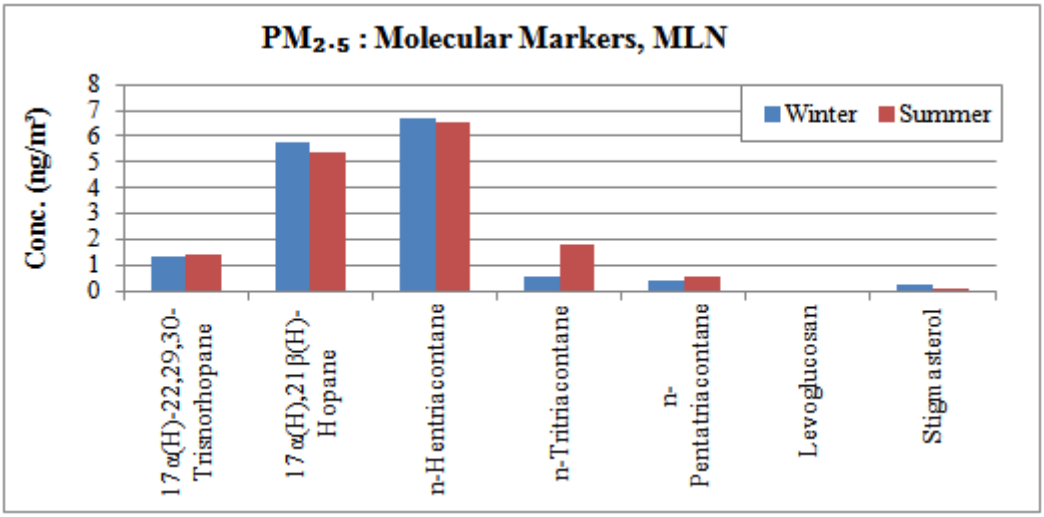


Figure 2.50: Molecular Markers in $PM_{2.5}$ at MLN

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

Graphical presentations of chemical species are shown for winter and summer season at MLN for PM_{10} (Figure 2.51) and $PM_{2.5}$ (Figure 2.52). Statistical summary for particulate matter (PM_{10} and $PM_{2.5}$), its chemical composition [carbon content, ionic species and

elements] along with mass percentage (% R) recovered from PM are presented in the Tables 2.54 – 2.57 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 2.58 – 2.61 for both season. It is seen that most of parameters showed good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM are presented in Figure 2.53 (a) and (b) for winter season and Figure 2.54 (a) and (b) for summer season.

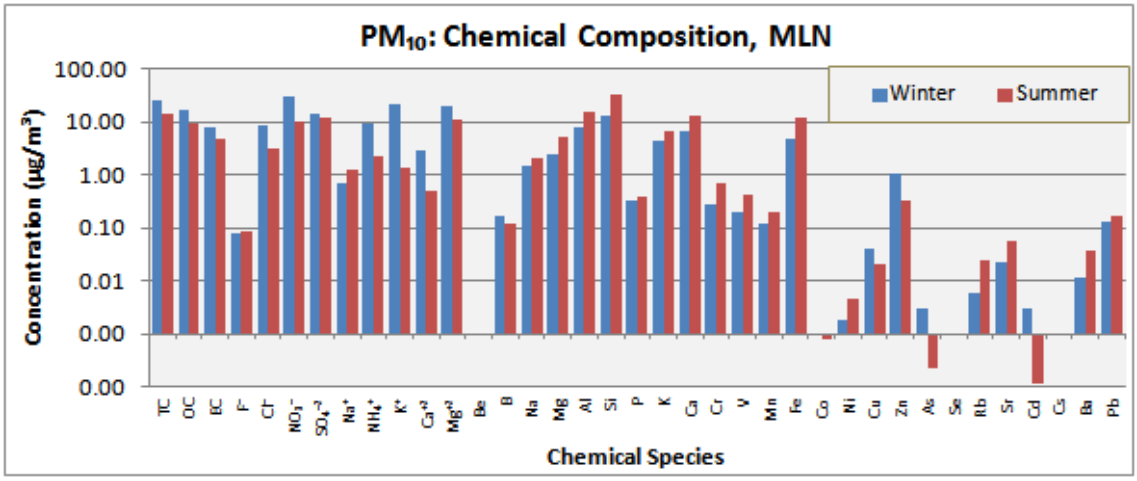


Figure 2.51: Concentrations of species in PM_{10} at MLN

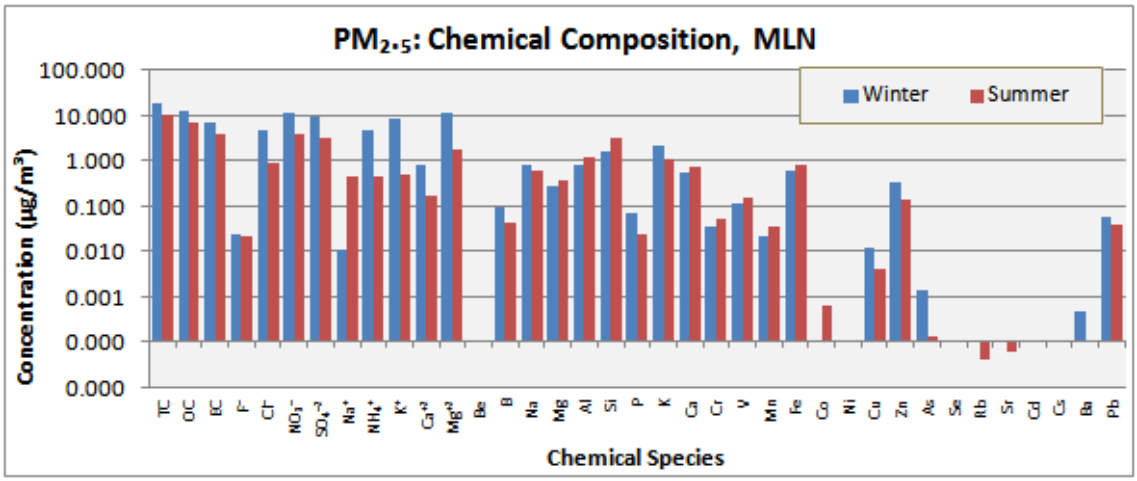


Figure 2.52: Concentrations of species in $PM_{2.5}$ at MLN

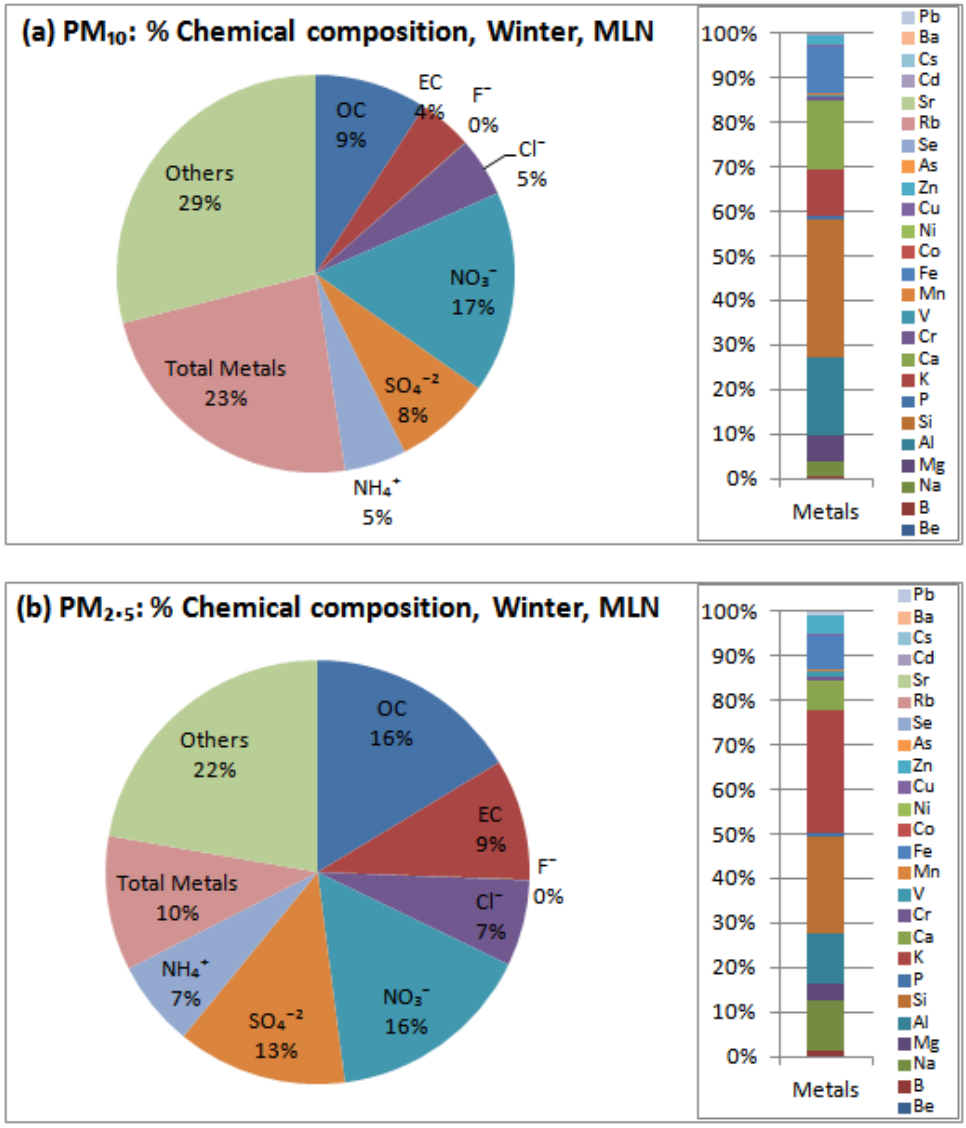
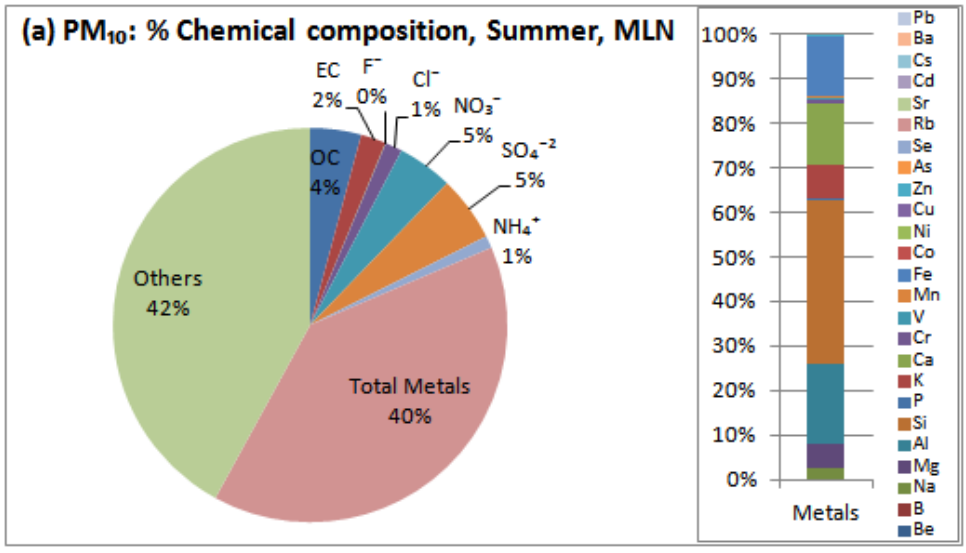


Figure 2.53: Percentage distribution of species in PM at MLN for Winter Season



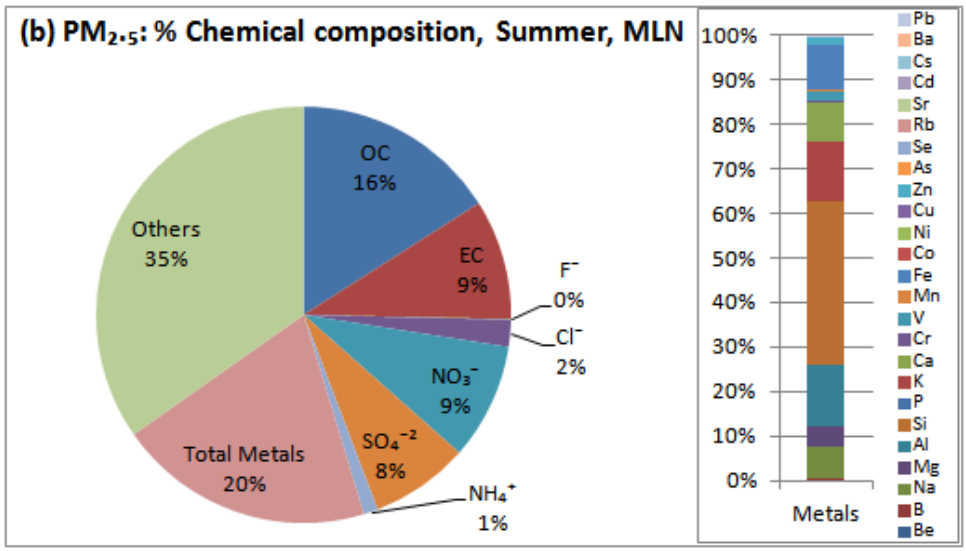


Figure 2.54: Percentage distribution of species in PM at MLN for Summer Season

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

The graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.55) at MLN. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM is having fine mode during winter (39 %) than summer (18 %). The major species contributing to fine mode are TC, OC, EC, NO_3^-, SO_4^{-2}, Na^+, V and As; whereas, major species contributing in coarse mode are Ca, Mg, Al, Si, P, Ca, Cr, Fe and Cu.

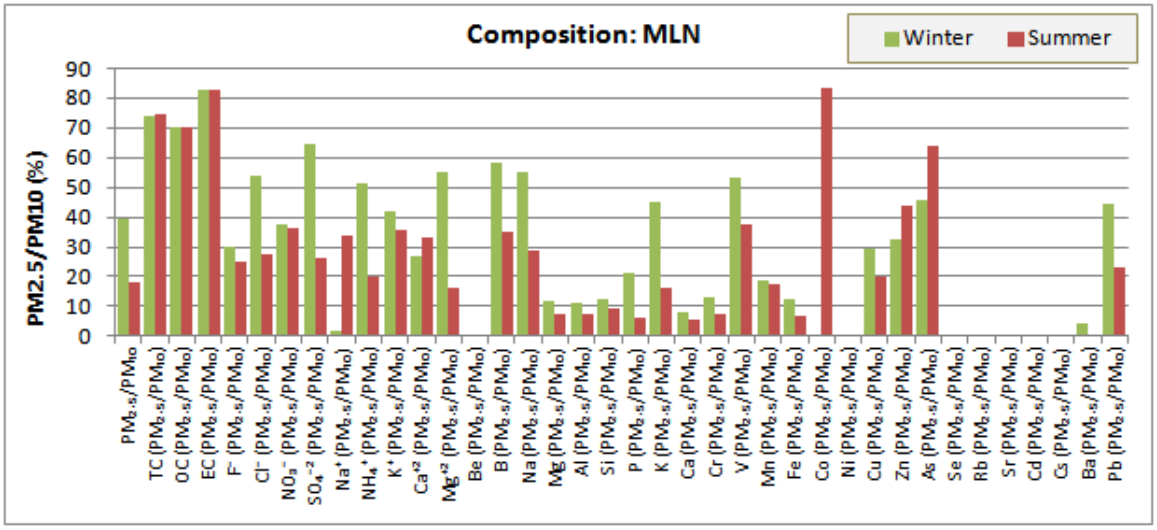


Figure 2.55: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at MLN

Table 2.50: Statistical results of gaseous pollutants (µg/m^3) at MLN for winter (W) and summer (S) seasons

MLN (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	35.03	7.50	6.17	6.85	2.25	2.13	17.39
SD	8.06	4.93	2.92	4.79	1.47	1.34	9.45
Max	51.99	22.20	12.93	15.80	5.51	5.02	36.85
Min	19.43	2.61	0.87	0.03	0.01	0.00	0.92
CV	0.23	0.66	0.47	0.70	0.65	0.63	0.54
MLN (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	13.79	1.86	2.09	3.97	0.80	0.76	7.63
SD	5.56	1.60	0.81	2.17	0.27	0.25	3.28
Max	24.68	7.29	3.94	9.77	1.44	1.34	15.54
Min	4.92	0.24	1.01	1.10	0.35	0.34	2.80
CV	0.40	0.86	0.38	0.55	0.33	0.32	0.43

Table 2.51: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at MLN for winter (W) and summer (S) seasons

MLN (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	73.8	18.86	12.04	6.81	1.10	3.34	4.12	3.47	0.059	0.177	0.221	0.188
SD	18.5	5.06	2.88	2.30	0.30	0.96	0.96	0.73	0.008	0.009	0.014	0.020
Max	120.2	29.49	18.84	11.74	1.87	5.45	6.38	5.13	0.072	0.196	0.246	0.231
Min	46.8	12.11	7.93	3.55	0.74	2.11	2.62	2.40	0.047	0.162	0.196	0.158
CV	0.25	0.27	0.24	0.34	0.27	0.29	0.23	0.21	0.128	0.053	0.064	0.108
MLN (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	42.1	10.65	6.72	3.93	0.45	1.97	3.03	1.73	0.041	0.181	0.283	0.162
SD	9.8	2.06	1.39	0.93	0.24	0.84	1.04	0.57	0.015	0.048	0.074	0.035
Max	69.2	14.89	9.75	5.40	1.22	4.98	5.90	3.55	0.085	0.345	0.501	0.245
Min	29.0	7.00	4.42	1.81	0.20	1.06	1.87	1.15	0.018	0.119	0.201	0.113
CV	0.23	0.19	0.21	0.24	0.53	0.43	0.34	0.33	0.366	0.263	0.261	0.214

Table 2.52: Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at MLN for winter (W) and summer (S) seasons

MLN(W)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.35	0.86	1.10	0.45	0.00	0.32	0.98	0.03	1.22	0.09	0.00	1.01	2.20	5.37	1.35	2.20	1.47	0.06	1.97	21.03
SD	0.18	0.86	0.44	0.26	0.01	0.31	0.44	0.01	0.59	0.02	0.00	0.76	1.37	3.24	0.95	1.84	1.58	0.06	1.73	11.53
Max	0.68	2.26	1.68	1.03	0.03	1.00	1.72	0.04	2.74	0.13	0.00	2.50	4.70	10.79	3.10	5.42	4.88	0.19	5.77	42.11
Min	0.18	0.17	0.16	0.17	0.00	0.09	0.59	0.02	0.70	0.07	0.00	0.21	0.40	1.12	0.17	0.26	0.15	0.00	0.43	6.33
CV	0.53	1.00	0.40	0.59	2.32	0.99	0.45	0.19	0.48	0.24	3.16	0.75	0.62	0.60	0.70	0.83	1.07	1.13	0.88	0.55
MLN(S)	IsP	DmP	AcP	DEP	Flu	HcB	Phe	Ant	Pyr	BbP	BeA	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	0.43	0.42	1.22	1.03	0.02	0.13	0.00	1.85	0.40	0.28	0.00	0.32	0.22	1.78	0.13	0.11	0.04	0.07	0.31	8.75
SD	0.16	0.23	0.32	0.45	0.06	0.01	0.00	0.71	0.59	0.15	0.00	0.06	0.04	1.06	0.08	0.02	0.07	0.12	0.05	1.69
Max	0.77	0.84	1.76	1.65	0.19	0.15	0.00	3.12	1.80	0.60	0.00	0.49	0.33	3.71	0.33	0.15	0.20	0.38	0.41	11.47
Min	0.30	0.12	0.83	0.27	0.00	0.12	0.00	1.04	0.00	0.12	0.00	0.27	0.19	0.56	0.08	0.08	0.00	0.00	0.25	6.56
CV	0.37	0.56	0.26	0.43	3.11	0.09		0.39	1.48	0.53		0.20	0.19	0.60	0.58	0.16	1.83	1.69	0.15	0.19

Table 2.53: Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at MLN for winter (W) and summer (S) seasons

MLN (W)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.32	5.74	6.70	0.52	0.43	0.00	0.27	14.98
SD	0.13	2.89	1.56	0.13	0.23	0.00	0.29	2.14
CV	0.10	0.50	0.23	0.26	0.53		1.05	0.14
MLN (S)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.43	5.40	6.55	1.77	0.55	0.00	0.05	15.76
SD	0.66	3.20	2.81	0.54	0.12	0.00	0.04	7.18
CV	0.46	0.59	0.43	0.31	0.22		0.87	0.46

Table 2.54: Statistical results of chemical characterization (µg/m^3) of PM_{10} at MLN for winter (W) season

MLN (W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	188	17.2	8.2	0.1	9.0	30.9	14.8	0.7	9.5	21.0	3.0	19.8	0.0	0.2	1.5	2.5	7.8	13.6	0.3
SD	39	4.1	2.8	0.0	5.5	11.8	6.9	0.3	4.0	6.2	0.9	7.7	0.0	0.1	0.7	0.8	2.0	5.3	0.2
Max	255	26.9	14.1	0.1	20.1	60.6	30.0	1.3	18.2	31.1	5.2	34.5	0.0	0.3	4.0	4.9	10.5	21.7	0.9
Min	118	11.3	4.3	0.0	1.7	15.9	5.8	0.3	4.6	12.5	1.4	9.0	0.0	0.1	0.9	1.4	3.6	1.5	0.2
CV	0.21	0.24	0.34	0.34	0.61	0.38	0.46	0.40	0.42	0.29	0.30	0.39		0.36	0.46	0.33	0.26	0.39	0.51
MLN (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.6	6.8	0.3	0.2	0.1	4.7	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	70.8
SD	1.8	2.9	0.1	0.1	0.0	1.5	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	5.7
Max	9.3	15.8	0.4	0.5	0.2	9.0	0.0	0.0	0.2	3.1	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.4	82.0
Min	1.6	3.8	0.1	0.0	0.1	2.8	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	63.5
CV	0.40	0.43	0.26	0.46	0.34	0.32	0.00	1.91	1.08	0.80	4.01	0.00	0.93	1.02	2.30	0.00	1.45	0.60	0.08
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.55: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at MLN for winter (W) season

MLN (W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	74	12.0	6.8	0.0	4.9	11.6	9.6	0.0	4.9	8.8	0.8	10.9	0.0	0.1	0.8	0.3	0.8	1.7	0.1
SD	18	2.9	2.3	0.0	3.5	4.1	4.1	0.0	3.5	5.1	0.4	5.5	0.0	0.0	0.2	0.1	0.4	0.7	0.0
Max	120	18.8	11.7	0.1	12.0	21.3	17.1	0.0	12.0	20.6	1.7	22.6	0.0	0.1	1.3	0.5	1.6	3.0	0.1
Min	47	7.9	3.6	0.0	0.4	6.9	5.2	0.0	0.4	1.7	0.4	5.2	0.0	0.1	0.5	0.2	0.1	0.0	0.0
CV	0.25	0.24	0.34	0.51	0.73	0.35	0.43	0.95	0.73	0.58	0.45	0.51		0.24	0.25	0.28	0.42	0.44	0.36
MLN (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	2.1	0.5	0.0	0.1	0.0	0.6	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	77.6
SD	1.0	0.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
Max	5.0	0.9	0.1	0.2	0.0	1.2	0.0	0.0	0.1	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	95.3
Min	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	67.8
CV	0.49	0.25	0.62	0.43	0.40	0.44			1.35	0.28	4.47						2.71	0.33	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.56: Statistical results chemical characterization (µg/m^3) of PM_{10} at MLN for summer (S) season

MLN (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	230	9.6	4.7	0.1	3.2	10.4	12.3	1.3	2.3	1.4	0.5	10.9	0.0	0.1	2.0	5.2	16.0	33.4	0.4
SD	108	2.0	1.1	0.0	1.4	4.9	6.6	0.5	0.9	0.5	0.2	4.7	0.0	0.0	0.9	3.0	11.6	21.7	0.1
Max	666	13.9	6.5	0.2	6.7	28.3	30.1	2.4	5.3	2.9	0.9	27.3	0.0	0.3	5.2	16.4	62.2	118.1	0.9
Min	152	6.3	2.2	0.0	1.2	4.5	6.7	0.6	1.4	0.7	0.2	6.4	0.0	0.1	1.1	1.1	3.1	7.3	0.2
CV	0.47	0.21	0.24	0.41	0.45	0.47	0.54	0.36	0.38	0.39	0.41	0.43		0.40	0.43	0.58	0.73	0.65	0.35
MLN (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.9	12.7	0.7	0.4	0.2	12.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	59.0
SD	3.1	8.4	0.4	0.1	0.1	7.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	6.0
Max	18.8	42.8	2.1	0.8	0.3	39.1	0.0	0.0	0.0	0.6	0.0	0.0	0.1	0.3	0.0	0.0	0.2	0.5	79.9
Min	4.1	6.6	0.4	0.3	0.1	5.9	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	51.4
CV	0.45	0.66	0.63	0.29	0.32	0.63	4.47	2.12	0.56	0.34	4.47		0.88	0.99	4.47		1.45	0.54	0.10
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.57: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at MLN for summer (S) season

MLN(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	42	6.7	3.9	0.0	0.9	3.8	3.2	0.4	0.5	0.5	0.2	1.8	0.0	0.0	0.6	0.4	1.2	3.1	0.0
SD	10	1.4	0.9	0.0	0.6	1.8	1.5	0.4	0.2	0.3	0.1	0.9	0.0	0.0	0.3	0.2	0.7	1.8	0.0
Max	69	9.8	5.4	0.1	2.2	8.9	5.3	1.5	1.0	1.4	0.5	4.4	0.0	0.1	1.3	1.1	3.7	9.0	0.1
Min	29	4.4	1.8	0.0	0.2	0.8	0.6	0.1	0.1	0.1	0.0	0.6	0.0	0.0	0.1	0.2	0.6	1.3	0.0
CV	0.23	0.21	0.24	0.75	0.69	0.48	0.47	0.98	0.52	0.69	0.53	0.53		0.69	0.57	0.55	0.62	0.58	0.67
MLN(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.1	0.7	0.1	0.2	0.0	0.8	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	65.3
SD	0.8	0.4	0.0	0.1	0.0	0.5	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9
Max	3.3	2.2	0.1	0.4	0.1	2.3	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	72.6
Min	0.4	0.3	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.5
CV	0.68	0.56	0.72	0.47	0.29	0.56	4.47		1.85	0.70	4.47		4.47	4.47				0.67	0.07
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.58: Correlation Matrix for PM_{10} and its composition at MLN for winter season

MLN (W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.91	0.91	0.86	0.06	0.61	0.75	0.68	0.43	0.50	0.20	0.17	0.71	0.46
TC		1.00	0.99	0.97	0.02	0.58	0.79	0.73	0.50	0.55	0.22	0.37	0.67	0.24
OC			1.00	0.91	0.07	0.61	0.83	0.76	0.54	0.64	0.23	0.41	0.70	0.16
EC				1.00	-0.06	0.49	0.69	0.64	0.42	0.39	0.19	0.30	0.59	0.33
NO_3^-					0.32	0.59	1.00	0.86	0.76	0.83	0.46	0.54	0.87	-0.13
SO_4^{-2}					0.52	0.62		1.00	0.74	0.83	0.44	0.48	0.86	-0.16
NH_4^+					0.51	0.66			0.79	1.00	0.44	0.54	0.73	-0.41
Metals					-0.37	-0.02			-0.33		-0.14	-0.58	0.07	1.00

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

MLN (W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.78	0.82	0.70	-0.04	0.75	0.44	0.81	-0.02	0.75	0.58	0.20	0.79	0.18
TC		1.00	0.98	0.97	-0.25	0.41	0.10	0.60	-0.12	0.41	0.24	0.25	0.52	0.07
OC			1.00	0.91	-0.27	0.45	0.12	0.61	-0.11	0.45	0.21	0.17	0.53	0.13
EC				1.00	-0.21	0.33	0.08	0.55	-0.13	0.33	0.26	0.34	0.48	-0.02
NO_3^-					0.60	0.30	1.00	0.44	0.08	0.30	0.72	0.34	0.51	-0.24
SO_4^{-2}					0.13	0.50		1.00	0.24	0.50	0.55	0.36	0.93	-0.05
NH_4^+					0.04	1.00			-0.08	1.00	0.55	0.06	0.62	0.02
Metals					-0.60	0.02			-0.33		-0.30	-0.62	-0.20	1.00

Table 2.60: Correlation matrix for PM_{10} and its composition at MLN for summer season

MLN (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	-0.08	0.16	-0.47	0.50	-0.04	0.07	-0.09	0.01	-0.18	0.00	0.04	0.20	1.00
TC		1.00	0.94	0.81	0.02	-0.04	-0.19	0.12	0.11	-0.08	0.44	-0.23	-0.11	-0.10
OC			1.00	0.57	0.09	-0.03	-0.18	0.14	0.19	-0.14	0.40	-0.16	-0.08	0.13
EC				1.00	-0.11	-0.05	-0.15	0.05	-0.06	0.05	0.38	-0.27	-0.12	-0.48
NO_3^-					0.28	0.29	1.00	0.31	0.25	0.83	0.35	0.68	0.72	0.11
SO_4^{-2}					-0.06	0.12		1.00	0.77	0.11	0.23	0.36	0.31	-0.13
NH_4^+					0.17	0.31			0.19	1.00	0.28	0.57	0.63	-0.13
Metals					0.51	-0.06			-0.03		-0.01	0.05	0.24	1.00

Table 2.61: Correlation matrix for $PM_{2.5}$ and its composition at MLN for summer season

MLN (S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.47	0.51	0.29	0.85	0.49	0.50	0.29	0.25	0.15	0.58	0.61	0.54	0.90
TC		1.00	0.93	0.83	0.27	0.64	0.20	-0.01	0.20	0.01	0.59	0.19	0.27	0.19
OC			1.00	0.57	0.34	0.53	0.10	-0.16	0.18	-0.05	0.47	0.10	0.22	0.33
EC				1.00	0.10	0.63	0.30	0.22	0.17	0.10	0.61	0.27	0.27	-0.08
NO_3^-					0.38	0.57	1.00	0.67	0.37	0.46	0.77	0.74	0.57	0.24
SO_4^{-2}					0.15	0.42		1.00	0.54	0.49	0.66	0.53	0.53	0.05
NH_4^+					0.20	0.35			0.16	1.00	0.41	0.23	0.22	-0.04
Metals					0.83	0.17			0.08		0.23	0.46	0.37	1.00

2.4.5 Mansarovar

The sampling period was January 15 – February 04, 2018 for winter and April 15 – May 04, 2018 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 2.56) and summer (Figure 2.57). Average levels for winter and summer season were 91±21 and 45±10 µg/m^3 (for $PM_{2.5}$) and 222±38 and 233±43 µg/m^3 (for PM_{10}) respectively. The $PM_{2.5}$ levels are 1.5 times higher than the NAQS and PM_{10} is 2.2 times higher than the NAQS in winter. The $PM_{2.5}$ levels generally meet the standards while PM_{10} is 2.3 times higher than the national standard in summer. A statistical summary of PM concentrations is presented in Table 2.66 – 2.69 for winter and summer season. In summer, $PM_{2.5}$ levels drop significantly and meet the national standards but PM_{10} levels were slightly increased and continue to be high in spite of improvement in meteorology and better dispersion. The particles airborne from soil surface during dust storms in the dry months of summer can contribute significantly in coarse fraction.

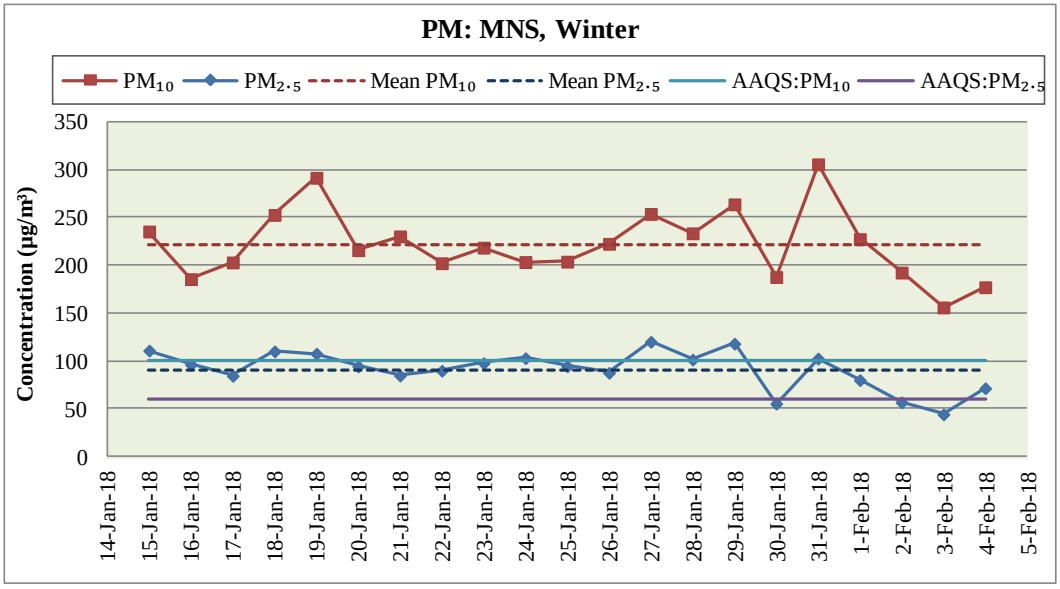


Figure 2.56: PM Concentrations at MNS for Winter Season

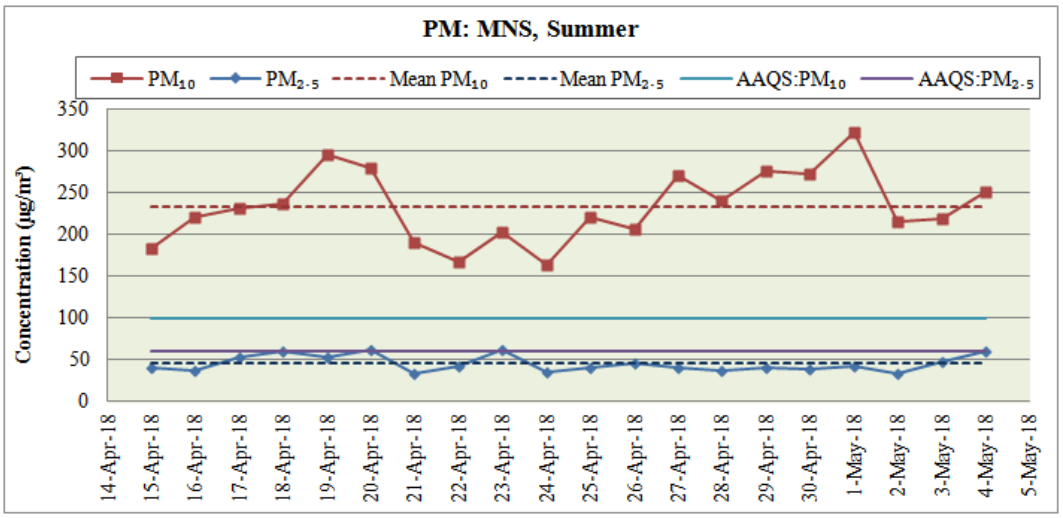


Figure 2.57: PM Concentrations at MNS for Summer Season

2.4.5.2 Gaseous pollutants

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.58) and summer (Figure 2.59) seasons. It was observed that SO_2 concentrations were low and meets the air quality standard. NO_2 levels also under the national standard with an average of 20 days at 40±14 µg/m^3 in winter and 16±4 µg/m^3 in summer season (Table 2.62). The summer concentration of NO_2 dropped dramatically similarly $PM_{2.5}$ levels. Although, the NO_2 is certainly 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 presence of occasional local sources like DG sets, traffic jams or local open burning etc.

The Mean concentrations of BTX were presented in Figure 2.60 and statistical summary in Table 2.62. The total BTX level is observed 16±11 µg/m^3 (Benzene: 5.9 and Toluene: 6.1 µg/m^3) in winter and 6.1±7.6 µg/m^3 (Benzene: 5.0 and Toluene: 0.9 µg/m^3) in summer seasons. The maximum BTX concentration was observed 42 µg/m^3 in winter and 30 µg/m^3 in summer seasons. The BTX levels were high during winter than the summer.

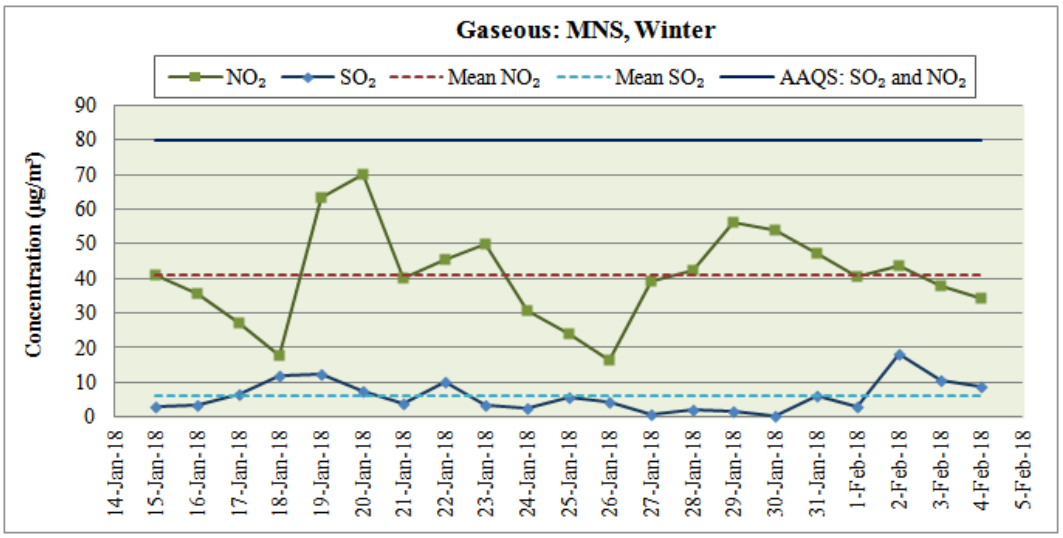


Figure 2.58: SO_2 and NO_2 Concentrations at MNS for Winter Season

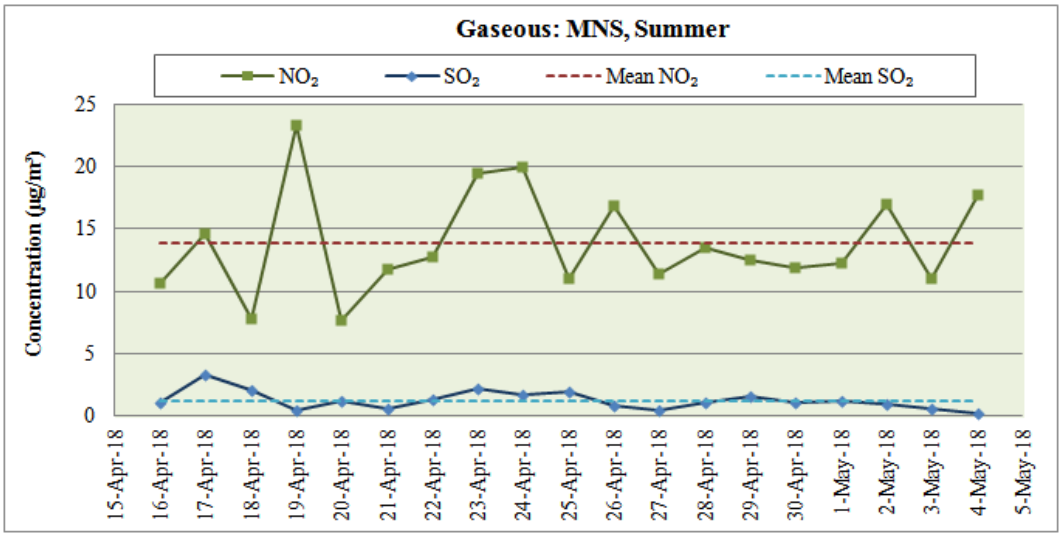


Figure 2.59: SO_2 and NO_2 Concentrations at MNS for Summer Season

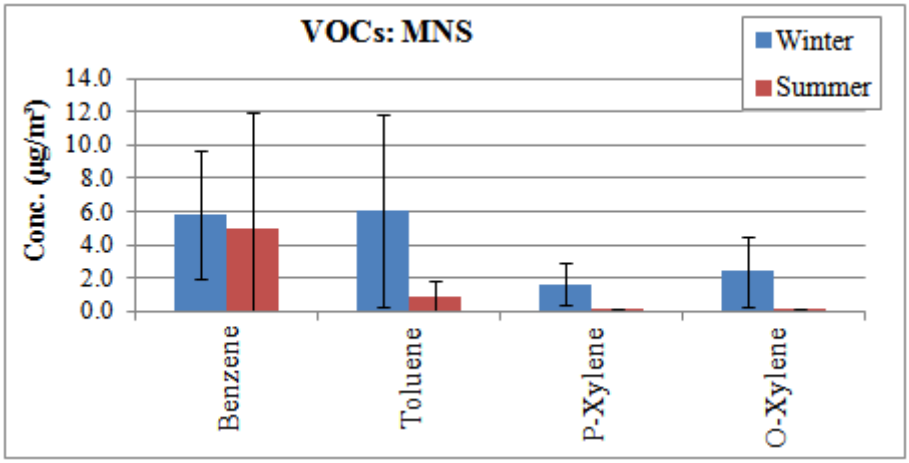


Figure 2.60: VOCs concentration at MNS

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

Average concentrations of EC, OC (OC1, OC2, OC3 and OC4) and ratio of OC fraction to TC are shown in Figure 2.61 (a) and (b) for winter and summer seasons. Organic carbon is observed slightly higher (winter: 13.0±2.9 and summer: 5.4±1.0 µg/m^3) than the elemental carbon (winter: 8.0±2.6 and summer: 4.1±1.2 µg/m^3). However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at MNS. It is also observed that the OC and EC are higher in winter season than in 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 2.63 for winter and summer seasons.

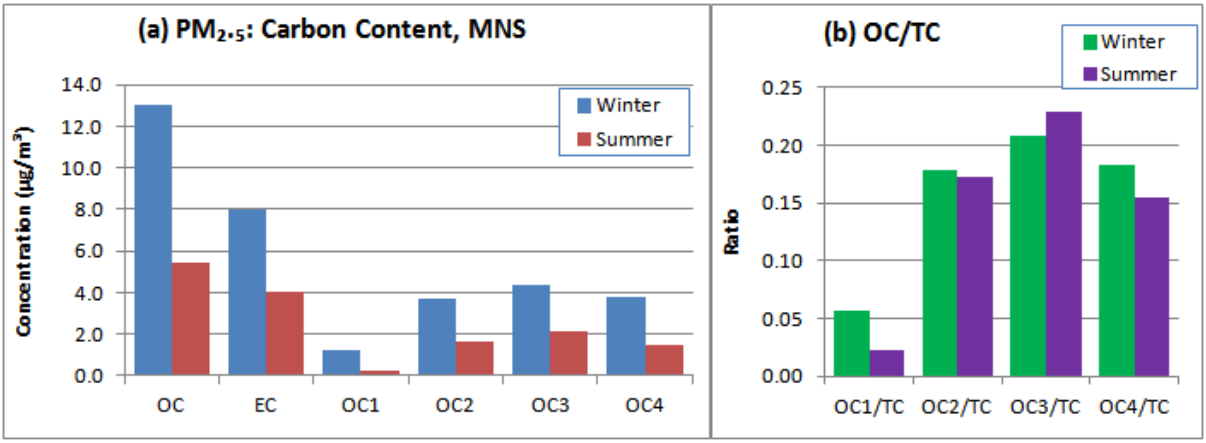


Figure 2.61: EC and OC Content in $PM_{2.5}$ at MNS

2.4.5.4 PAHs in $PM_{2.5}$

Figure 2.62 shows the average measured concentration of PAHs at MNS for winter and summer seasons. A statistical summary of PAHs is presented in Table 2.64 for winter and summer seasons. The PAHs compounds analyzed were: (i) IsP, (ii) DmP, (iii) AcP, (iv) DEP, (v) Flu, (vi) HcB, (vii) Phe, (viii) Ant, (ix) Pyr, (x) BbP, (xi) BeA, (xii) B(a)A, (xiii) Chr, (xiv) B(b)F, (xv) B(k)F, (xvi) B(a)P, (xvii) InP, (xviii) D(a,h)A and (xix) B(ghi)P. It is observed that Total PAHs concentrations are much higher in winter season (40±16 ng/m^3) compared to summer season (13±6 ng/m^3). Major PAHs are B(b)F (8.5 ng/m^3), Phe (4.2 ng/m^3), Pyr (4.1 ng/m^3), B(a)P (3.8 ng/m^3), Chr (3.8 ng/m^3), B(ghi)P (3.4 ng/m^3)and InP (2.5 ng/m^3) for winter season and BbP (2.7 ng/m^3), B(b)F (2.0 ng/m^3), Ant (1.8 ng/m^3) and AcP (1.6 ng/m^3) for summer season.

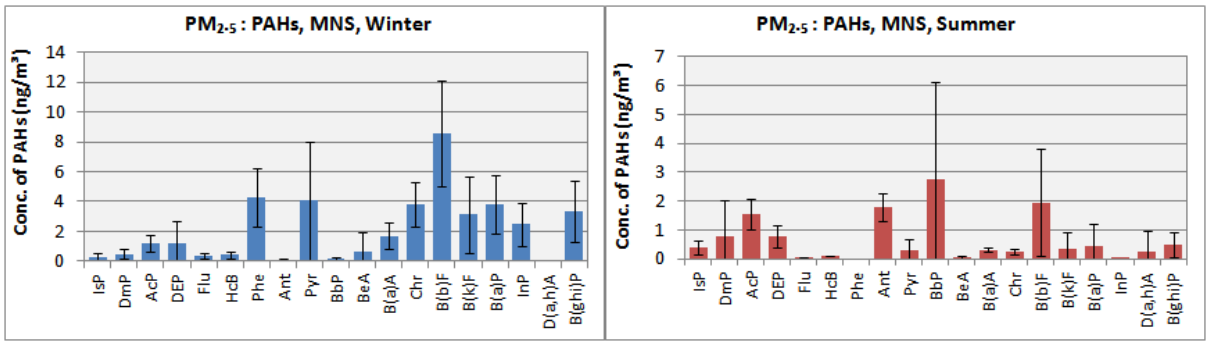


Figure 2.62: PAHs Concentrations in $PM_{2.5}$ at MNS

2.4.5.5 Molecular Markers in $PM_{2.5}$

Total seven molecular markers analyzed were: 17α(H)-22,29,30–Trisnorhopane, 17α(H),21β(H)-hopane, n-Hentriacontane, n-Tritriacontane, n-Pentatriacontane, Stigmasterol and Levoglucosan. Figure 2.63 and Table 2.65 show the levels of seven molecular markers. Total concentration of markers was 17.1±12.4 ng/m^3 in winter and 13.8±1.4 ng/m^3 in summer. Stigmasterol has also been found in low quantity, indicating emissions from biomass burning and cooking. The presence of significant quantities of molecular markers, especially hopanes conclusively establishes contribution of CGD.

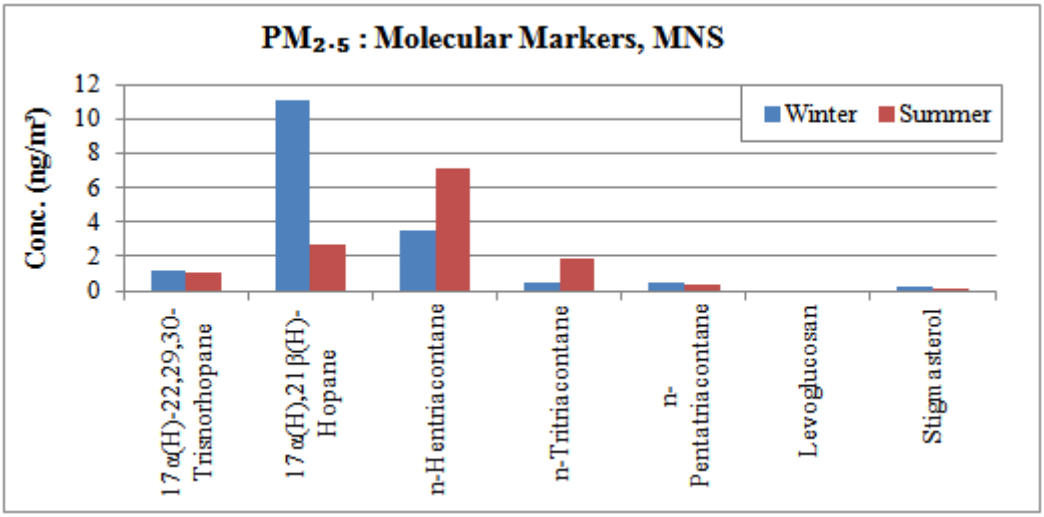


Figure 2.63: Molecular Markers in $PM_{2.5}$ at MNS

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

Graphical presentations of chemical species are shown for winter and summer season at MNS for PM_{10} (Figure 2.64) and $PM_{2.5}$ (Figure 2.65). 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 the Tables 2.66 – 2.69 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 2.70 – 2.73 for both season. It is seen that most of parameters showed good correlation (>0.30) with PM_{10} and $PM_{2.5}$. The percentage constituent of the PM are presented in Figure 2.66 (a) and (b) for winter season and Figure 2.67 (a) and (b) for summer season.

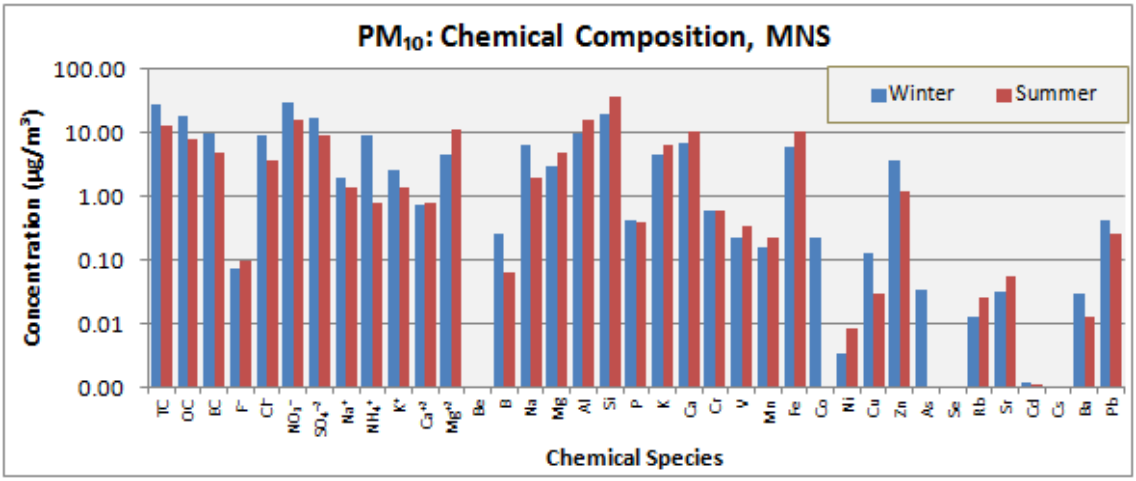


Figure 2.64: Concentrations of species in PM_{10} at MNS

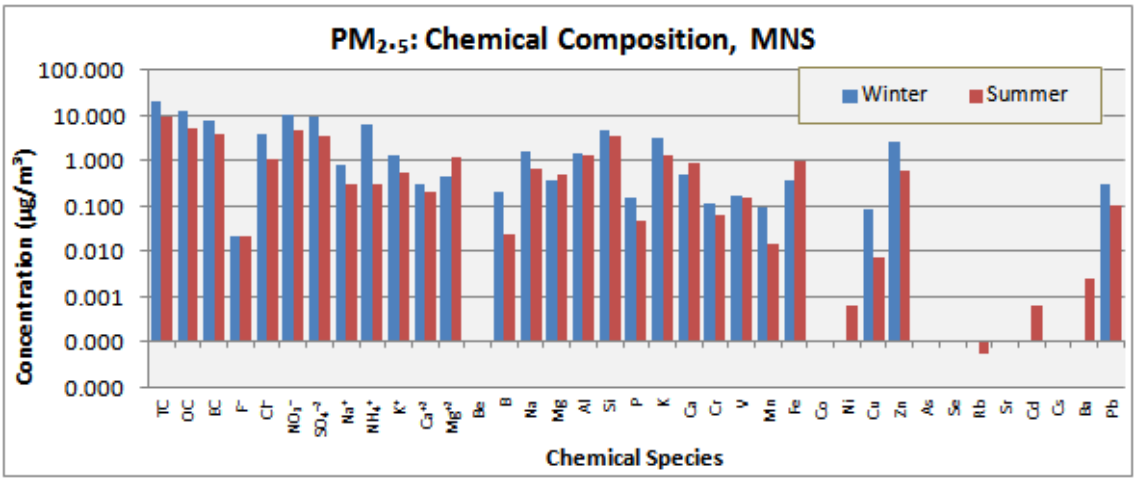


Figure 2.65: Concentrations of species in $PM_{2.5}$ at MNS

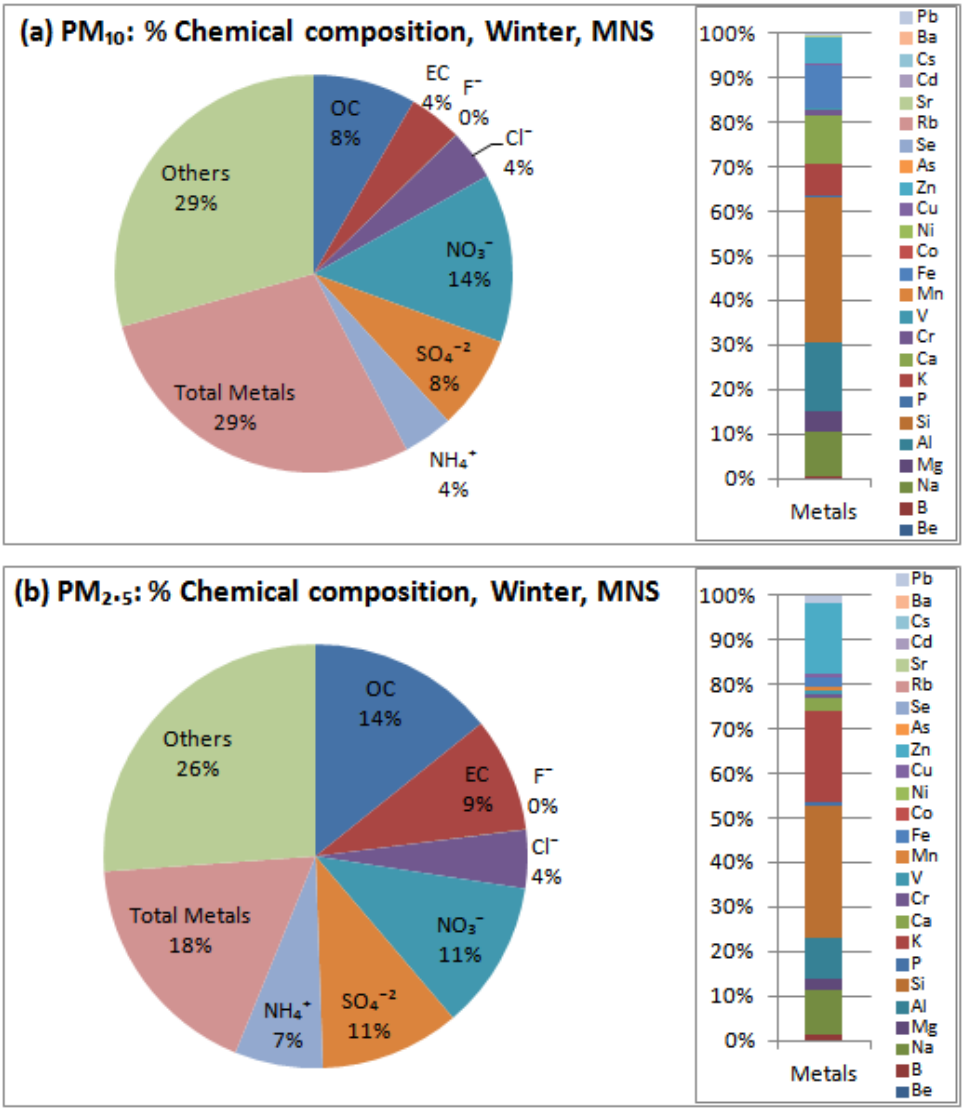
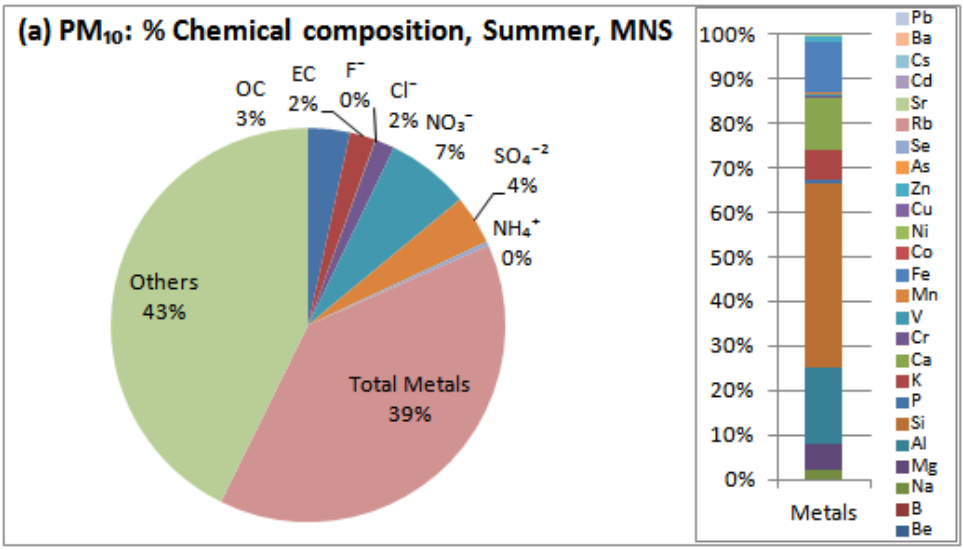


Figure 2.66: Percentage distribution of species in PM at MNS for Winter Season



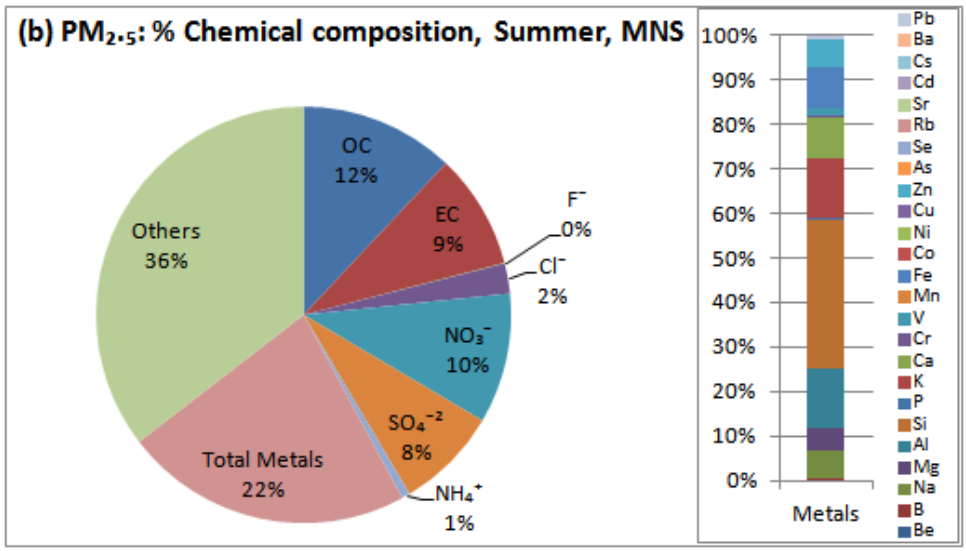


Figure 2.67: Percentage distribution of species in PM at MNS for Summer Season

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

Graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species is shown for winter and summer seasons (Figure 2.68) at MNS. The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM is having fine mode during winter (41 %) than summer (20 %). The major species contributing to fine mode are TC, OC, EC, SO_4^{-2}, Na^+, NH_4^+, K^+, B, K, V, Cu, Zn, Cd and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Mg, Al, Si, P, Ca, Cr, Ni and Fe are contributing significantly in fine mode.

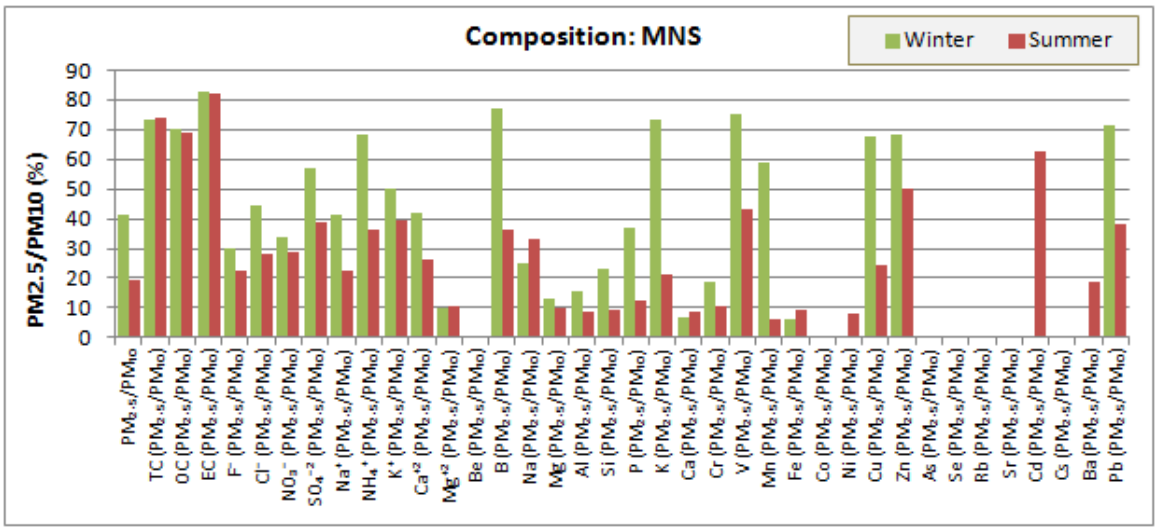


Figure 2.68: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at MNS

Table 2.62: Statistical results of gaseous pollutants (µg/m^3) at MNS for winter (W) and summer (S) seasons

MNS (W)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	40.79	5.98	5.86	6.07	1.65	2.40	15.97
SD	13.65	4.55	3.88	5.83	1.29	2.12	11.00
Max	70.01	18.10	14.96	22.83	3.95	6.89	42.26
Min	16.25	0.54	0.56	0.01	0.00	0.00	2.17
CV	0.33	0.76	0.66	0.96	0.78	0.88	0.69
MNS (S)	NO_2	SO_2	Benzene	Toluene	p-Xylene	o-Xylene	Total (BTX)
Mean	13.84	1.26	5.00	0.94	0.07	0.07	6.07
SD	4.17	0.76	6.93	0.96	0.13	0.12	7.58
Max	23.25	3.32	28.15	4.22	0.57	0.54	29.91
Min	7.65	0.16	0.17	0.04	0.00	0.00	0.34
CV	0.30	0.60	1.39	1.01	1.90	1.81	1.25

Table 2.63: Statistical results of carbon contents (µg/m^3) in $PM_{2.5}$ at MNS for winter (W) and summer (S) seasons

MNS (W)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	91.0	20.98	13.02	7.97	1.20	3.72	4.35	3.75	0.057	0.179	0.209	0.182
SD	20.4	5.34	2.86	2.57	0.39	0.91	1.03	0.71	0.009	0.014	0.013	0.023
Max	120.1	29.28	17.07	12.21	2.02	5.24	6.05	4.88	0.087	0.199	0.239	0.230
Min	44.2	12.22	8.13	4.08	0.66	2.38	2.79	2.18	0.043	0.135	0.186	0.144
CV	0.22	0.25	0.22	0.32	0.33	0.24	0.24	0.19	0.167	0.080	0.061	0.128
MNS (S)	$PM_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	45.4	9.52	5.44	4.07	0.22	1.63	2.14	1.45	0.022	0.172	0.229	0.154
SD	9.7	1.96	0.95	1.21	0.19	0.34	0.30	0.34	0.015	0.020	0.031	0.031
Max	61.9	14.55	7.86	6.68	0.69	2.44	2.94	2.07	0.058	0.196	0.290	0.195
Min	33.1	6.46	4.14	2.31	0.00	0.91	1.68	0.60	0.000	0.122	0.189	0.056
CV	0.21	0.21	0.17	0.30	0.85	0.21	0.14	0.24	0.694	0.114	0.134	0.203

Table 2.64: **Statistical results of PAHs (ng/m^3) in $PM_{2.5}$ at MNS for winter (W) and summer (S) seasons**

MNS(W)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.3	0.5	1.2	1.2	0.3	0.4	4.3	0.1	4.1	0.2	0.6	1.7	3.8	8.5	3.1	3.8	2.5	0.1	3.4	40.0
SD	0.3	0.3	0.6	1.6	0.2	0.2	1.9	0.1	4.0	0.1	1.3	0.9	1.5	3.5	2.6	2.0	1.5	0.0	2.0	15.5
Max	1.1	1.1	2.5	5.5	0.6	0.8	7.5	0.2	11.9	0.5	4.3	2.6	5.0	11.8	9.7	5.4	4.5	0.1	6.8	62.9
Min	0.2	0.2	0.4	0.3	0.1	0.2	1.8	0.0	0.8	0.1	0.0	0.4	1.0	2.5	0.5	0.6	0.3	0.0	0.5	11.8
CV	0.94	0.63	0.48	1.33	0.50	0.53	0.46	0.90	0.98	0.74	2.18	0.51	0.39	0.42	0.82	0.51	0.59	0.78	0.60	0.39
MNS(S)	IsP	DmP	AcP	DEP	Flu	HcB	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	0.4	0.8	1.6	0.8	0.0	0.1	0.0	1.8	0.3	2.7	0.0	0.3	0.2	2.0	0.4	0.5	0.0	0.3	0.5	12.5
SD	0.3	1.3	0.5	0.4	0.0	0.0	0.0	0.5	0.4	3.4	0.1	0.1	0.1	1.9	0.5	0.8	0.0	0.7	0.4	5.5
Max	1.1	4.3	2.2	1.6	0.1	0.1	0.0	2.4	1.3	10.9	0.3	0.5	0.5	7.0	1.9	2.4	0.0	2.3	1.4	23.5
Min	0.3	0.1	0.6	0.3	0.0	0.1	0.0	0.7	0.0	0.1	0.0	0.3	0.2	0.4	0.1	0.1	0.0	0.0	0.2	6.8
CV	0.66	1.67	0.34	0.51	2.92	0.04		0.27	1.21	1.24	3.16	0.25	0.36	0.96	1.51	1.65	3.16	2.82	0.93	0.44

Table 2.65: **Statistical results of molecular markers (ng/m^3) in $PM_{2.5}$ at MNS for winter (W) and summer (S) seasons**

MNS (W)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.18	11.08	3.52	0.53	0.52	0.00	0.22	17.05
SD	0.22	12.26	0.45	0.16	0.22	0.00	0.01	12.36
CV	0.19	1.11	0.13	0.30	0.43		0.04	0.73
MNS (S)	17α(H)-22,29,30 –Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Stigmasterol	Levoglucosan	Total
Mean	1.09	2.71	7.07	1.91	0.39	0.00	0.02	13.18
SD	0.38	1.53	1.49	0.79	0.20	0.00	0.04	1.36
CV	0.35	0.56	0.21	0.42	0.52		1.73	0.10

Table 2.66: Statistical results of chemical characterization (µg/m^3) of PM_{10} at MNS for winter (W) season

MNS (W)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	222	18.6	9.6	0.1	9.1	30.5	17.0	2.0	9.0	2.7	0.7	4.5	0.0	0.3	6.5	2.9	9.7	20.4	0.4
SD	38	4.2	3.2	0.0	3.3	8.0	5.2	0.7	2.9	1.0	0.3	1.7	0.0	0.1	6.7	0.8	3.0	5.8	0.2
Max	306	24.4	14.7	0.1	16.9	48.3	27.4	3.6	14.1	4.5	1.5	8.8	0.0	0.5	22.9	5.3	16.4	33.1	0.9
Min	156	11.6	4.9	0.0	3.7	20.7	5.8	0.5	2.7	0.8	0.4	2.0	0.0	0.2	1.5	1.4	3.1	10.1	0.2
CV	0.17	0.23	0.33	0.45	0.36	0.26	0.31	0.37	0.33	0.37	0.41	0.38		0.31	1.03	0.27	0.31	0.28	0.38
MNS (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	4.5	6.9	0.6	0.2	0.2	5.9	0.2	0.0	0.1	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	70.8
SD	1.1	2.0	1.1	0.1	0.1	1.6	1.0	0.0	0.1	2.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.4	4.0
Max	7.4	12.8	5.3	0.4	0.3	9.6	4.5	0.0	0.2	8.0	0.7	0.0	0.0	0.1	0.0	0.0	0.1	1.4	78.8
Min	2.5	3.2	0.1	0.1	0.1	3.6	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	64.1
CV	0.24	0.30	1.83	0.37	0.42	0.26	0.00	1.07	0.40	0.56	4.44	0.00	0.50	0.70	2.98	0.00	1.24	0.83	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.67: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at MNS for winter (W) season

MNS (W)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	91	13.0	8.0	0.0	4.1	10.4	9.7	0.8	6.1	1.3	0.3	0.5	0.0	0.2	1.6	0.4	1.5	4.7	0.2
SD	21	2.9	2.6	0.0	2.3	6.1	3.4	0.6	2.5	0.7	0.1	0.1	0.0	0.1	0.5	0.3	0.8	1.2	0.1
Max	120	17.1	12.2	0.1	8.4	24.7	15.2	2.2	10.3	2.6	0.5	0.7	0.0	0.3	2.8	1.4	3.2	7.2	0.4
Min	44	8.1	4.1	0.0	0.3	1.6	2.9	0.1	1.8	0.1	0.1	0.2	0.0	0.1	0.9	0.2	0.3	2.2	0.0
CV	0.23	0.23	0.33	0.47	0.57	0.59	0.35	0.77	0.41	0.49	0.31	0.28		0.35	0.34	0.69	0.52	0.25	0.53
MNS (W)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	3.3	0.5	0.1	0.2	0.1	0.4	0.0	0.0	0.1	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	73.9
SD	1.2	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	4.2
Max	6.5	0.8	0.2	0.3	0.2	0.6	0.0	0.0	0.2	7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	83.5
Min	1.1	0.2	0.0	0.1	0.1	0.2	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	68.8
CV	0.37	0.27	0.44	0.29	0.32	0.28			0.46	0.66								0.93	0.06
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.68: Statistical results chemical characterization (µg/m^3) of PM_{10} at MNS for summer (S) season

MNS (S)	PM_{10}	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	233	7.9	4.9	0.1	3.7	15.9	9.4	1.4	0.8	1.4	0.8	11.6	0.0	0.1	1.9	5.0	15.6	37.8	0.4
SD	43	1.4	1.4	0.0	1.2	1.9	2.9	0.6	0.3	0.5	0.3	2.8	0.0	0.0	0.4	1.3	3.9	9.4	0.1
Max	321	11.2	8.0	0.2	6.7	20.2	13.7	2.8	1.4	2.5	1.8	19.4	0.0	0.1	2.6	7.1	23.4	56.3	0.6
Min	164	5.9	2.8	0.0	1.6	12.2	4.4	0.6	0.5	0.8	0.3	7.9	0.0	0.0	1.3	3.1	9.8	24.6	0.2
CV	0.18	0.18	0.29	0.50	0.31	0.12	0.30	0.45	0.32	0.33	0.40	0.24		0.29	0.19	0.25	0.25	0.25	0.22
MNS (S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	6.4	10.3	0.6	0.3	0.2	10.3	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.3	57.6
SD	1.3	2.3	0.1	0.0	0.1	2.4	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.7
Max	9.1	14.3	0.9	0.5	0.3	14.9	0.0	0.0	0.1	2.6	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.5	63.8
Min	4.4	6.6	0.4	0.3	0.2	6.7	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	52.8
CV	0.20	0.23	0.23	0.13	0.24	0.23		0.75	0.51	0.52			0.29	0.38	3.21		0.99	0.48	0.05
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.69: Statistical results of chemical characterization (µg/m^3) of $PM_{2.5}$ at MNS for summer (S) season

MNS(S)	$PM_{2.5}$	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
Mean	45	5.4	4.1	0.0	1.1	4.6	3.6	0.3	0.3	0.6	0.2	1.2	0.0	0.0	0.6	0.5	1.4	3.4	0.0
SD	10	1.0	1.2	0.0	0.8	2.1	1.9	0.2	0.1	0.3	0.1	1.1	0.0	0.0	0.3	0.2	0.7	1.6	0.0
Max	62	7.9	6.7	0.1	3.6	8.4	8.3	0.9	0.5	1.3	0.4	4.1	0.0	0.0	1.4	1.0	3.7	8.6	0.1
Min	33	4.1	2.3	0.0	0.3	0.8	0.9	0.1	0.1	0.1	0.1	0.3	0.0	0.0	0.3	0.2	0.6	0.9	0.0
CV	0.21	0.17	0.30	0.61	0.77	0.46	0.52	0.73	0.46	0.49	0.44	0.87		0.33	0.44	0.42	0.50	0.48	0.65
MNS(S)	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.4	0.9	0.1	0.1	0.0	0.9	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	64.7
SD	0.8	0.4	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	5.5
Max	3.4	1.9	0.1	0.3	0.0	2.2	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	73.3
Min	0.0	0.5	0.0	0.1	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	54.7
CV	0.56	0.43	0.49	0.43	0.59	0.44		4.36	1.38	0.77			4.47		3.77		1.91	0.79	0.09
% R is the % recovery of mass of collected particle through compositional analysis																			

Table 2.70: Correlation matrix for PM_{10} and its composition at MNS for winter season

MNS (W)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.76	0.78	0.72	0.45	0.46	0.39	0.37	0.34	0.54	0.55	0.31	0.23	0.82
TC		1.00	0.98	0.98	0.35	0.63	0.01	0.20	0.19	0.36	0.49	-0.09	0.02	0.62
OC			1.00	0.93	0.34	0.62	-0.03	0.25	0.25	0.42	0.55	-0.02	0.10	0.64
EC				1.00	0.35	0.62	0.05	0.15	0.12	0.28	0.40	-0.16	-0.06	0.56
NO_3^-					0.22	0.01	1.00	0.40	0.28	0.31	0.09	0.51	0.21	0.07
SO_4^{-2}					0.34	0.39		1.00	0.63	0.54	0.48	0.53	0.78	0.03
NH_4^+					0.59	0.60			0.72	1.00	0.49	0.43	0.54	0.26
Metals					0.13	0.20			0.23		0.39	0.26	0.08	1.00

Table 2.71: Correlation matrix for $PM_{2.5}$ and its composition at MNS for winter season

MNS (W)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.77	0.82	0.69	0.44	0.64	0.40	0.72	0.20	0.83	0.62	0.62	0.69	0.59
TC		1.00	0.98	0.98	0.02	0.48	0.11	0.21	-0.17	0.44	0.64	0.38	0.50	0.48
OC			1.00	0.93	0.07	0.51	0.16	0.29	-0.13	0.50	0.65	0.42	0.55	0.48
EC				1.00	-0.03	0.42	0.04	0.12	-0.22	0.35	0.60	0.31	0.42	0.45
NO_3^-					0.30	0.42	1.00	0.45	0.28	0.32	0.12	0.25	0.64	-0.32
SO_4^{-2}					0.75	0.59		1.00	0.35	0.82	0.39	0.67	0.50	0.30
NH_4^+					0.62	0.55			0.42	1.00	0.50	0.60	0.61	0.51
Metals					0.15	0.11			0.12		0.25	0.44	0.16	1.00

Table 2.72: Correlation matrix for PM_{10} and its composition at MNS for summer season

MNS (S)	PM_{10}	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	-0.23	-0.03	-0.38	0.29	0.13	0.09	0.51	0.16	0.52	0.16	0.06	0.77	0.97
TC		1.00	0.90	0.90	-0.04	-0.45	-0.07	0.11	-0.14	-0.19	0.14	0.00	-0.25	-0.29
OC			1.00	0.61	-0.13	-0.44	0.08	0.39	-0.06	-0.07	0.07	0.03	-0.08	-0.11
EC				1.00	0.05	-0.37	-0.21	-0.19	-0.19	-0.28	0.18	-0.03	-0.37	-0.40
NO_3^-					0.07	-0.12	1.00	0.27	0.41	-0.02	0.37	0.48	0.24	0.03
SO_4^{-2}					0.10	-0.20		1.00	0.12	0.38	0.19	0.37	0.52	0.43
NH_4^+					-0.06	0.26			0.36	1.00	0.15	-0.01	0.35	0.49
Metals					0.31	0.14			0.05		0.06	0.04	0.70	1.00

Table 2.73: Correlation matrix for $PM_{2.5}$ and its composition at MNS for summer season

MNS (S)	$PM_{2.5}$	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.39	0.27	0.42	0.18	0.27	0.18	0.39	0.30	-0.39	0.49	0.32	0.60	0.84
TC		1.00	0.88	0.93	-0.15	0.04	-0.31	0.29	0.09	-0.31	0.31	-0.01	0.32	-0.07
OC			1.00	0.64	-0.06	-0.26	-0.12	0.42	0.01	-0.13	0.07	-0.14	0.04	-0.22
EC				1.00	-0.20	0.27	-0.42	0.15	0.14	-0.40	0.44	0.09	0.48	0.07
NO_3^-					0.58	-0.07	1.00	0.54	0.08	0.38	0.20	0.28	-0.14	0.09
SO_4^{-2}					0.49	-0.17		1.00	0.14	0.22	0.39	0.43	-0.08	0.02
NH_4^+					0.49	0.16			0.26	1.00	0.24	0.25	-0.30	-0.37
Metals					0.13	0.39			0.29		0.36	0.29	0.57	1.00

2.4.6 Overall Summary and results

The sampling period for winter is November 19, 2017 to February 14, 2018 and April 15, 2018 to June 20, 2018 for Summer Season

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

The seasonal comparison is shown for PM_{10} (Figure 2.69), $PM_{2.5}$ (Figure 2.70) and ratio of $PM_{2.5}$ to PM_{10} for all sites. The overall summary of experimental results for PM is shown for winter and summer seasons (Table 2.74).

Winter

The overall city average of $PM_{2.5}$ in winter was 114 µg/m^3 and PM_{10} was 256 µg/m^3. The $PM_{2.5}$ levels are about two times higher than the NAQS (60 µg/m^3) and PM_{10} about 2.6 times higher than the NAQS (100 µg/m^3). Both $PM_{2.5}$ and PM_{10} levels were highest at VKI, the industrial site (175 and 388 µg/m^3) followed by levels at AJG (114 and 245 µg/m^3), a commercial and traffic site. The $PM_{2.5}$ and PM_{10} levels were lowest at MLN (74 and 188 µg/m^3); these levels also exceed the air quality standards. The highest variability was seen at JSG (CV: 0.37) for $PM_{2.5}$ followed by VKI (CV: 0.30). The levels were quite steady at AJG (CV: 0.20), MNS and MLN (CV: 0.23). The highest variation for PM_{10} was seen at VKI (CV: 0.31) and least at MNS (CV: 0.17).

Ratio of $PM_{2.5}$ to PM_{10} is a useful parameter to indicate relative abundance of fine particulate (i.e. $PM_{2.5}$) and toxicity of particulate matter. The overall city ratio is 0.44 and it was highest at JSG (0.49), followed by AJG (0.47) and VKI (0.45). The relative high $PM_{2.5}$ at these sites could be attributed to heavy traffic in the area and industrial units at VKI.

Summer

The overall city average of $PM_{2.5}$ level in summer drops sharply to 55 µg/m^3 but not the PM_{10} levels as the concentration of 261 µg/m^3 was almost same as in winter. The $PM_{2.5}$ levels generally meet the standards while PM_{10} is 2.6 times higher than the standard. Both $PM_{2.5}$ and PM_{10} levels were highest at VKI, the industrial site at 81 and 308 µg/m^3 followed by levels at JSG (53 and 272 µg/m^3), a traffic site. The PM_{10} and $PM_{2.5}$ levels were lowest at MLN (42 and 230 µg/m^3); PM_{10} levels exceed the air quality standards. The variability was seen at JSG (CV: 0.26) for $PM_{2.5}$ followed by VKI (CV: 0.23) and MLN (CV: 0.23). The highest variation for PM_{10} was seen at MLN (CV: 0.47) and least at MNS (CV: 0.18). The overall $PM_{2.5}$ to PM_{10}

city ratio is 0.22 and it was highest at VKI (0.27). The ratio was similar at other sites. The relative high $PM_{2.5}$ at VKI could be attributed to heavy industrial units.

The time series data also reveal that within winter, levels of PM_{10} and $PM_{2.5}$ may show increasing or decreasing pattern. It is seen that levels are highest and increase during last two weeks of December and first week of January (Figures 2.17 and 2.38). In the later part of January, more so in February, the levels drop rapidly (Figure 2.43). 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.

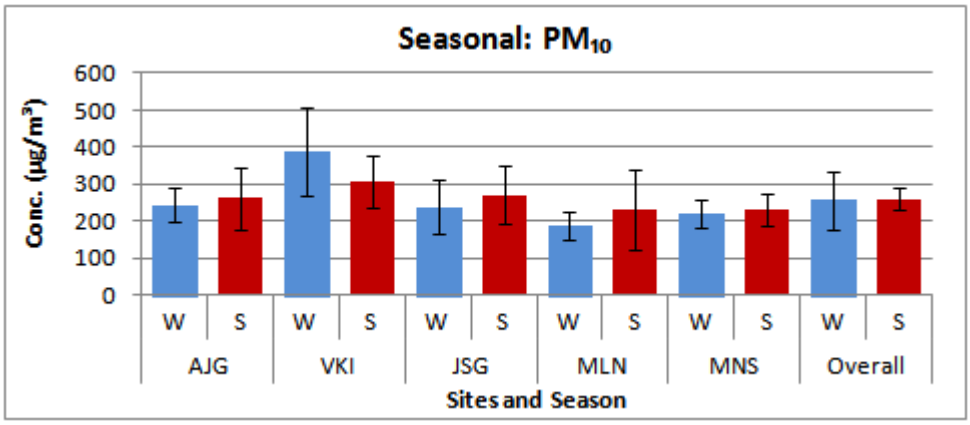


Figure 2.69: Seasonal comparison of PM_{10} levels for all Sites

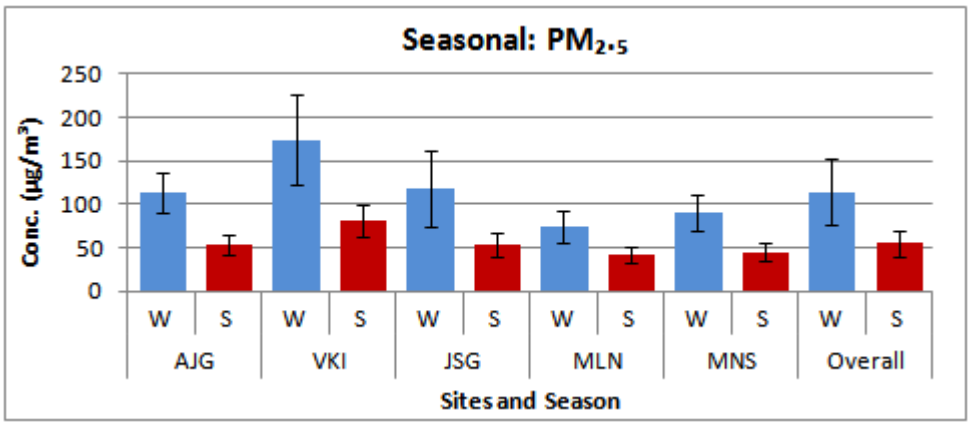


Figure 2.70: Seasonal comparison of $PM_{2.5}$ concentrations for all Sites

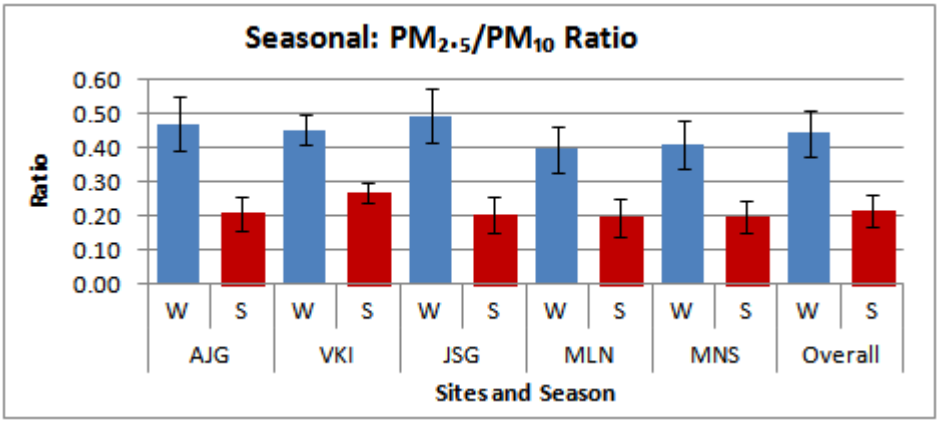


Figure 2.71: Seasonal comparison of $PM_{2.5}$ /PM_{10} ratio

2.4.6.2 Gaseous Pollutants (NO_2 and SO_2)

The seasonal comparison is shown for NO_2 and SO_2 (Figure 2.72). The overall average concentrations with statistical summary are presented in Table 2.75 and Table 2.76 for all sites for winter and summer seasons.

The SO_2 levels were quite low and were always within the air quality standards (80 µg/m^3) with some peaks at VKI at 20 µg/m^3 in winter; levels were below detection limit in summer at all sites (Figures 2.72). 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 the seasons. The overall city level average NO_2 levels are 39.5 µg/m^3 in winter and 16.3 µg/m^3 in summer. The highest NO_2 concentration was observed at AJG during both seasons: 45 (winter) and 25 µg/m^3 (summer). At AJG, 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 the emerging pollutants which can largely be attributed to vehicular emissions. What is noteworthy is the fact that NO_2 levels are remarkably similar at all sites (range: 37–45 µg/m^3). AJG area is the commercial area having the higher vehicular emission 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 winter season as it will be difficult to reduce the emission after-the-fact at a later stage.

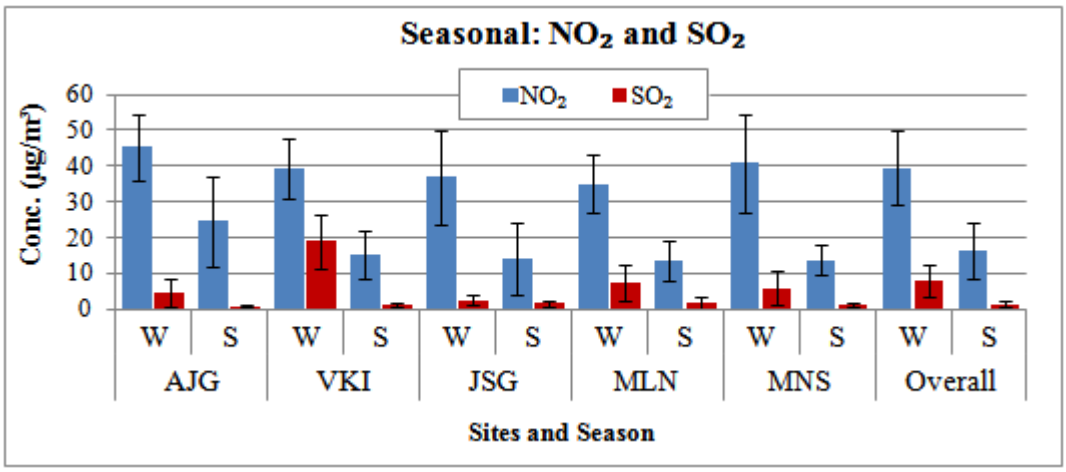


Figure 2.72: Seasonal Comparison of NO_2 and SO_2 levels for all Sites

2.4.6.3 Volatile Organic Compounds (VOCs: BTX)

The seasonal comparison for VOCs (BTX) is shown in Figure 2.73. The overall statistical summary in presented in Tables 2.75 – 2.76 for all sites for winter and summer seasons.

The overall city level average of BTX levels are 20.4 µg/m^3 in winter and 11.4 µg/m^3 in summer. The highest BTX concentration was observed at VKI (31 µg/m^3) in winter and AJG (19 µg/m^3) in summer seasons.

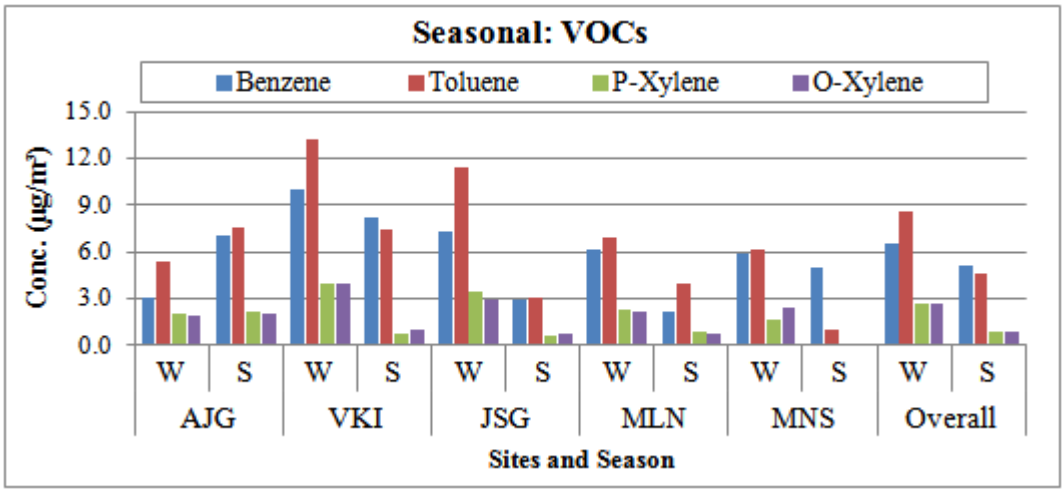


Figure 2.73: Seasonal comparison of VOCs for all Sites

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

The seasonal comparison for OC and EC are presented in Figure 2.74 for PM_{10} and Figure 2.75 for $PM_{2.5}$. The $PM_{2.5}$ contained the high fraction of TC (OC+EC) 26% in winter and 21% in summer seasons. The organic carbon is observed higher than the elemental carbon at each site during winter than summer; this is generally true that in 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 atmosphere is an important process. It is also observed that the OC and EC are higher in winter season than in summer season probably because of poor dispersion in winter and more combustion sources including biomass and solid waste burning. It is observed that average TC to $PM_{2.5}$ ratio were maximum (36%) at AJG followed by MLN and minimum (22%) at VKI in winter (Table 2.89) and maximum (27%) at AJG and minimum (13%) at JSG in summer (Table 2.90).

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 2.77 - 2.78 for winter and summer seasons.

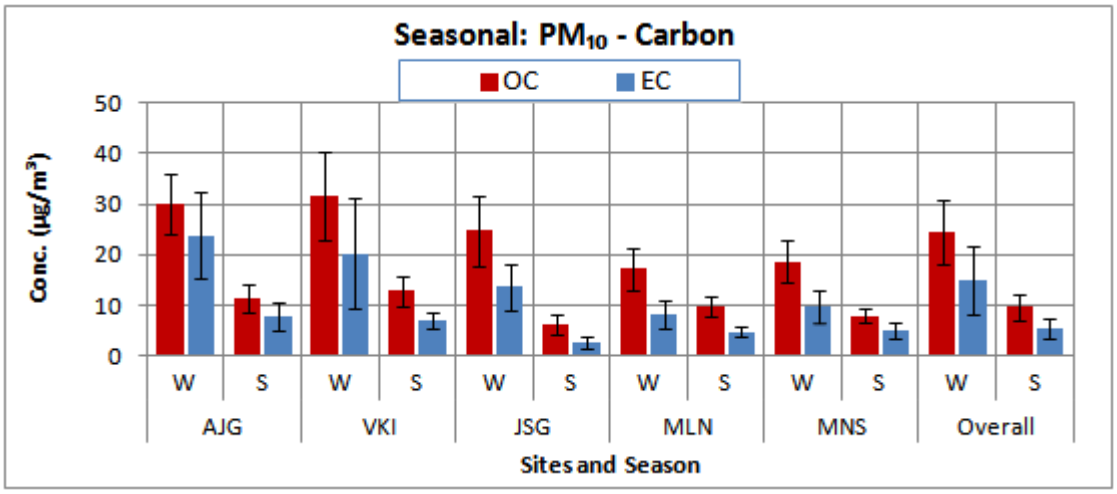


Figure 2.74: Seasonal Comparison of EC and OC in PM_{10} for all Sites

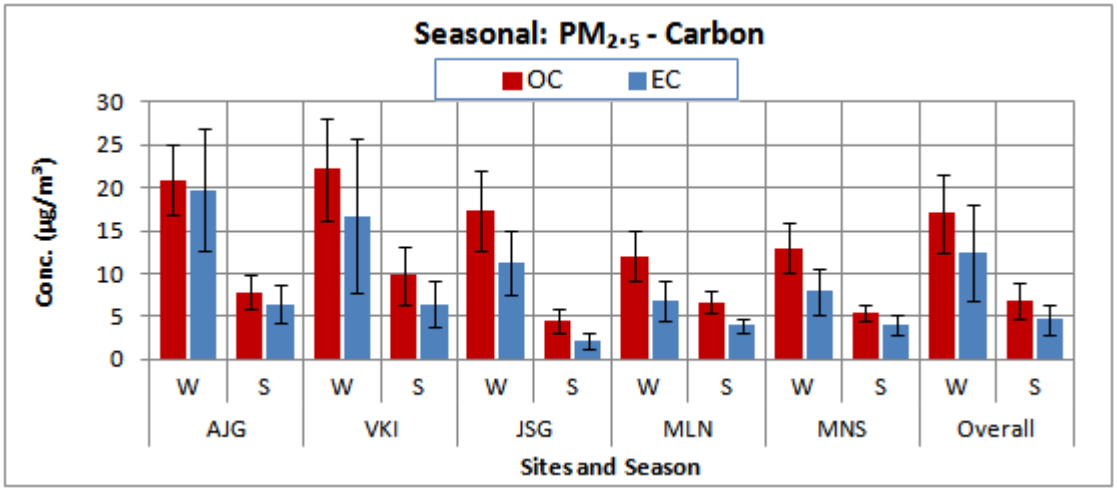


Figure 2.75: Seasonal Comparison of EC and OC in $PM_{2.5}$ for all Sites

2.4.6.5 PAHs in $PM_{2.5}$

The average concentrations of PAHs are shown graphically for winter season (Figure 2.76) and summer season (Figure 2.77) for all sites along with overall average concentration for Jaipur. Average concentrations are shown in Tables 2.79 – 2.80 with the standard deviation and coefficient of variation CV for Jaipur. The PAHs compounds analyzed are (i) IsP, (ii) DmP, (iii) AcP, (iv) DEP, (v) Flu, (vi) HcB, (vii) Phe, (viii) Ant, (ix) Pyr, (x) BbP, (xi) BeA, (xii) B(a)A, (xiii) Chr, (xiv) B(b)F, (xv) B(k)F, (xvi) B(a)P, (xvii) InP, (xviii) D(a,h)A and (xix) B(ghi)P. Seasonal comparison for PAHs are shown in Figure 2.78 which indicates the concentrations are significantly much higher in winter season compared to summer season. Major PAHs are B(b)F, B(ghi)P, InP, B(a)P, Phe, Pyr and Chr. The overall average total PAHs were much higher in winter (68 ng/m^3) in winter compared to summer (16 ng/m^3). B(a)P although has 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: 7.3 and summer mean: 1.1 ng/m^3) were are very high and annual standard is most likely to exceed by fair margin at all sites in winter season and at VKI in 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 (0.47 in winter and 0.37 in summer) is comparable to the reported values for coal combustion in winter season and diesel emissions in summer season. It is inferred that the major sources of PAHs are diesel vehicles and coal combustion.

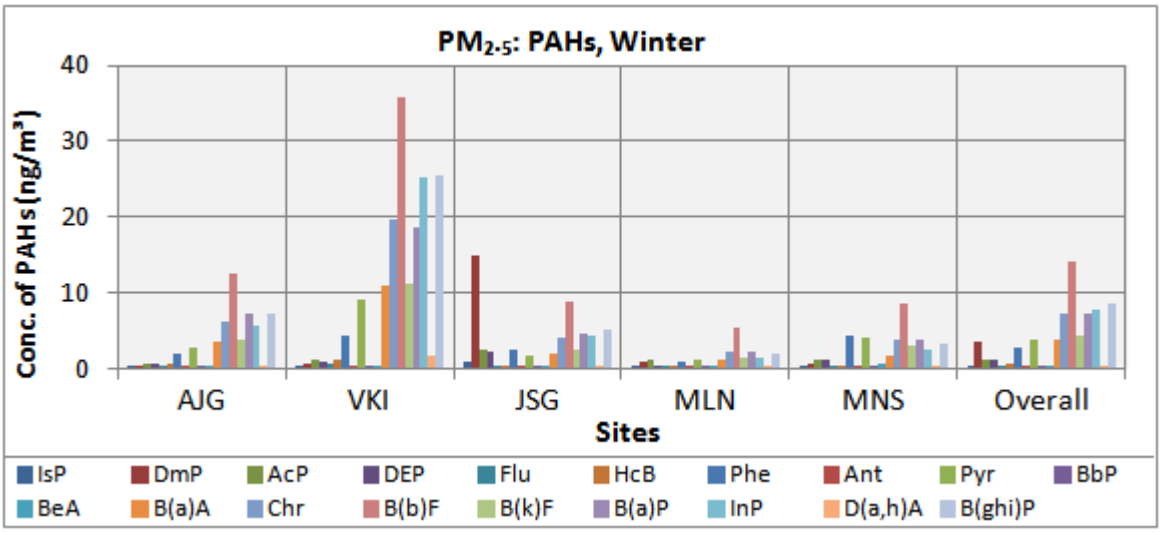


Figure 2.76: Variation in PAHs in $PM_{2.5}$ for winter season

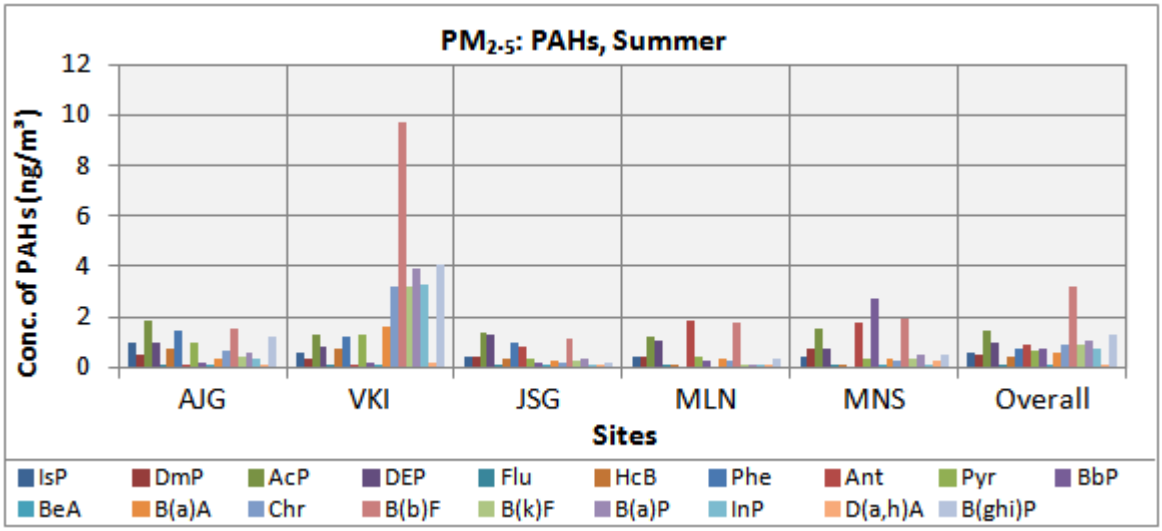


Figure 2.77: Variation in PAHs in $PM_{2.5}$ for summer season

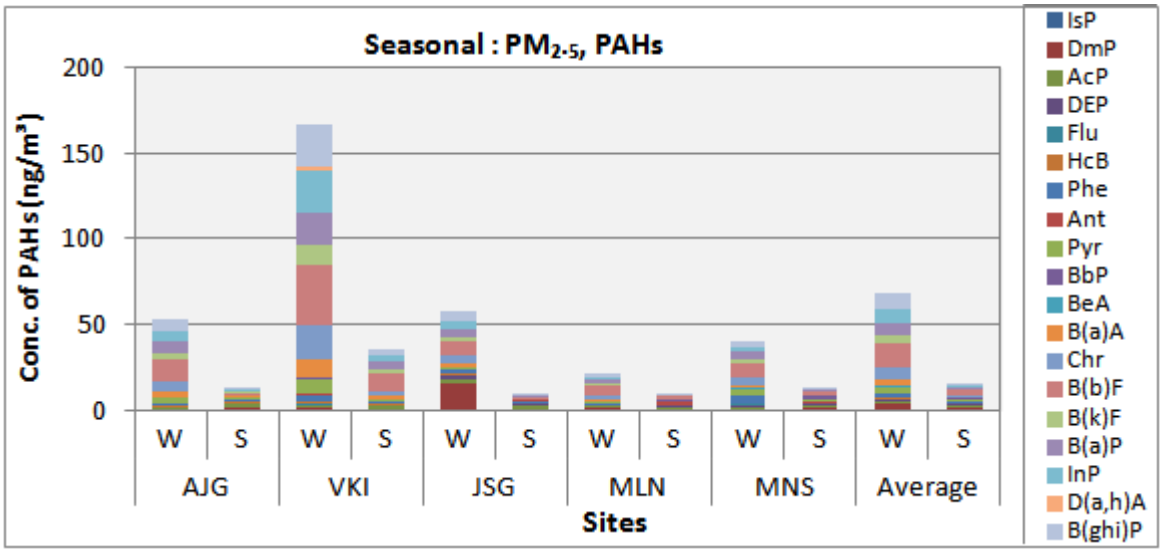


Figure 2.78: Seasonal comparison of in PAHs in $PM_{2.5}$

2.4.6.6 Molecular Markers in $PM_{2.5}$

The average concentrations of molecular markers are shown graphically for winter season (Figure 2.79) and summer season (Figure 2.80) for all sites along with overall average concentration for Jaipur. Average concentrations are shown in Tables 2.81 - 2.82 with the standard deviation and coefficient of variation CV for Jaipur. Seasonal comparison is shown in Figure 2.81 which indicates the concentrations of molecular markers are higher in winter compared to summer season compared to summer season except at MLN. The overall average of molecular markers were measured higher in winter (21 ng/m^3) compared to summer (14 ng/m^3). Stigmasterol has also been found in low quantity, indicating emissions from biomass burning and cooking. Levoglucosan is found at AJG in winter and JSG in summer that

indicated the biomass burning in city. The presence of significant quantities of molecular markers, especially alkanes and hopanes conclusively establishes contribution of coal burning, gasoline and diesel combustion in vehicles.

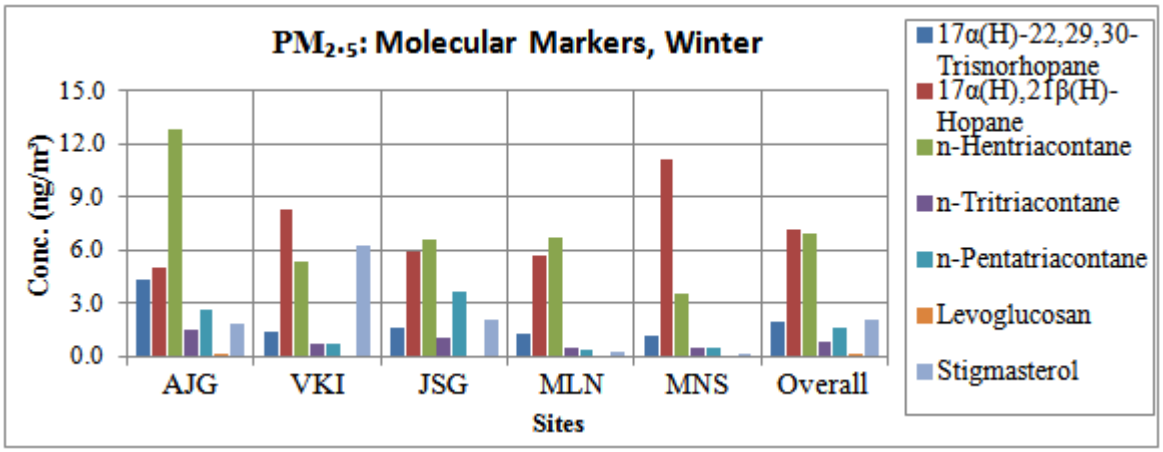


Figure 2.79: Variation in molecular markers in $PM_{2.5}$ for winter season

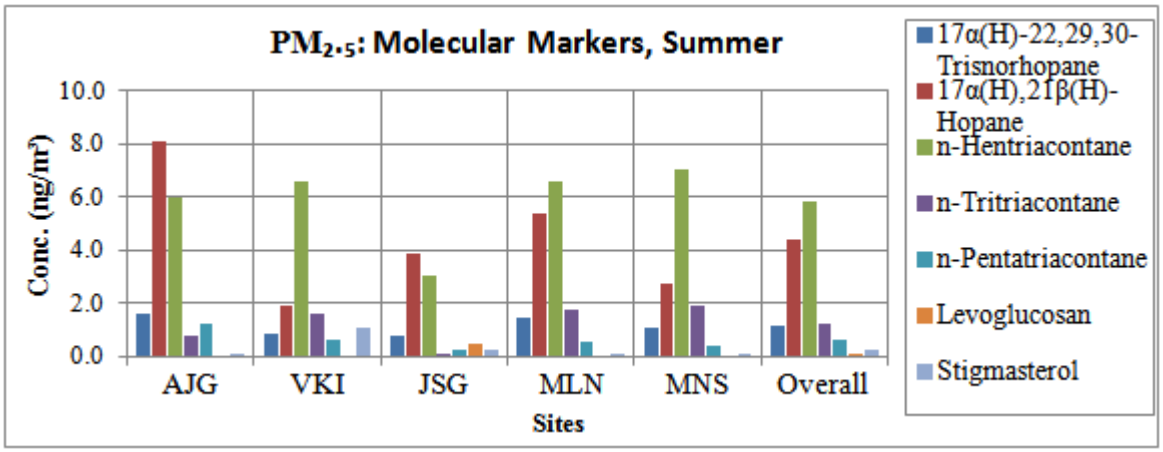


Figure 2.80: Variation in molecular markers in $PM_{2.5}$ for summer season

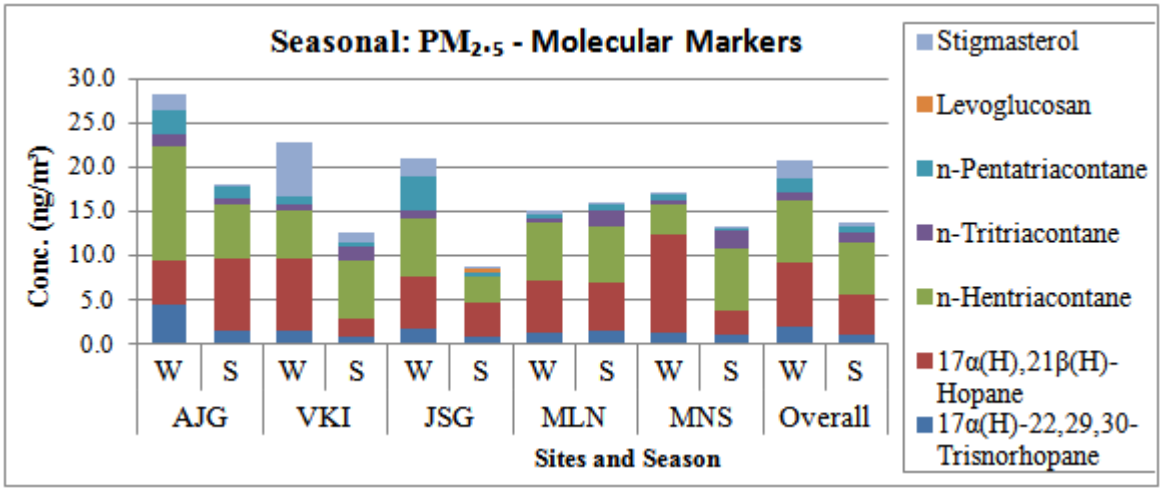
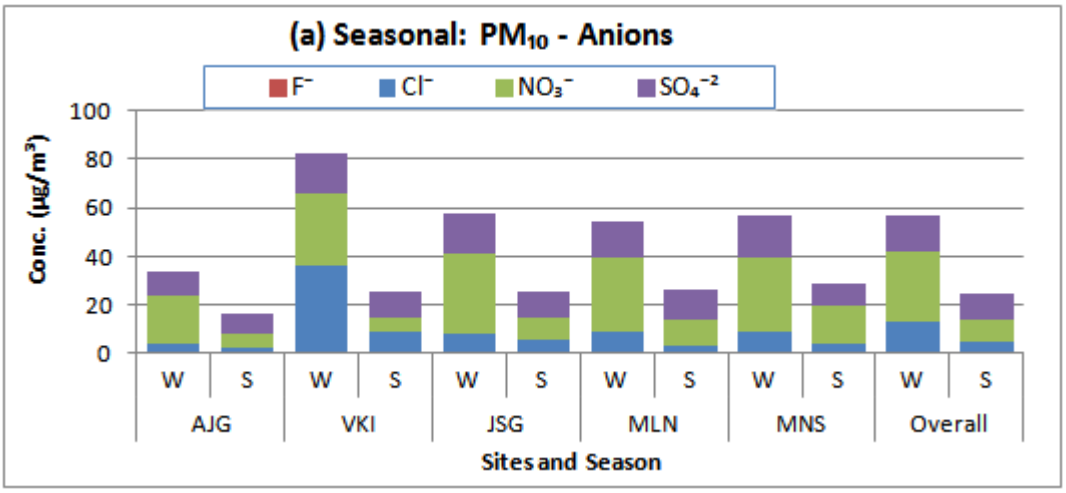


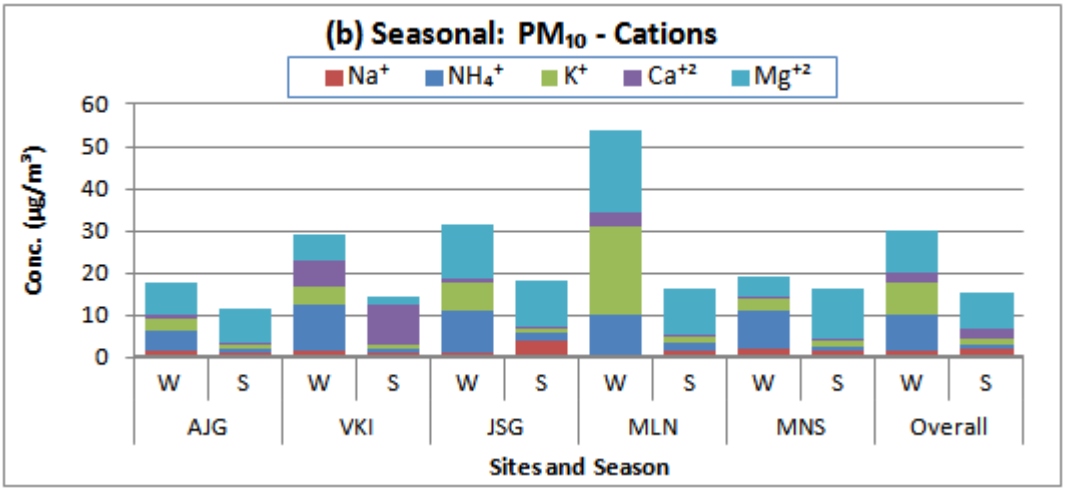
Figure 2.81: Seasonal comparison of molecular markers in $PM_{2.5}$

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

Graphical presentation for seasonal comparison for chemical species [(a) Anions, (b) Cations and (c) Elements) are shown for PM_{10} (Figure 2.82 (a), (b) and (c)) and $PM_{2.5}$ (Figure 2.83 (a), (b) and (c)). Overall summary of average concentrations for all sites along with overall average, standard deviation (SD) and coefficient of variation (CV) for PM (PM_{10} and $PM_{2.5}$), its composition [carbon content (EC and OC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb)] along with mass percentage (% R) estimated in composition are presented in the Tables 2.83 – 2.86 for winter and summer seasons.

The statistical summary of the major components (i.e. crustal elements – Si, Ai, Fe, Ca; Sceondary ions - NO_3^-, SO_4^{-2}, NH_4^+; TC) in PM_{10} and $PM_{2.5}$ are presented in Tables 2.88 – 2.91 for winter and summer seasons.





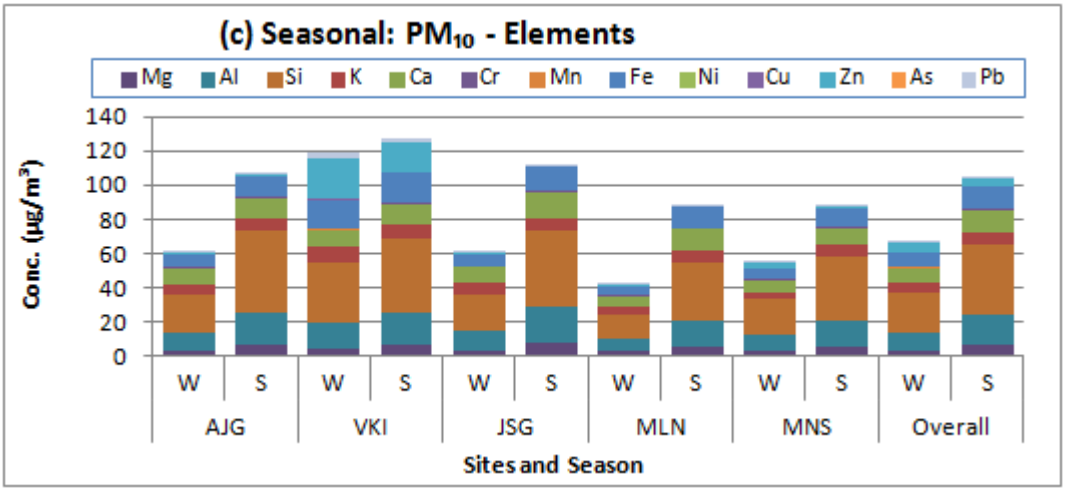
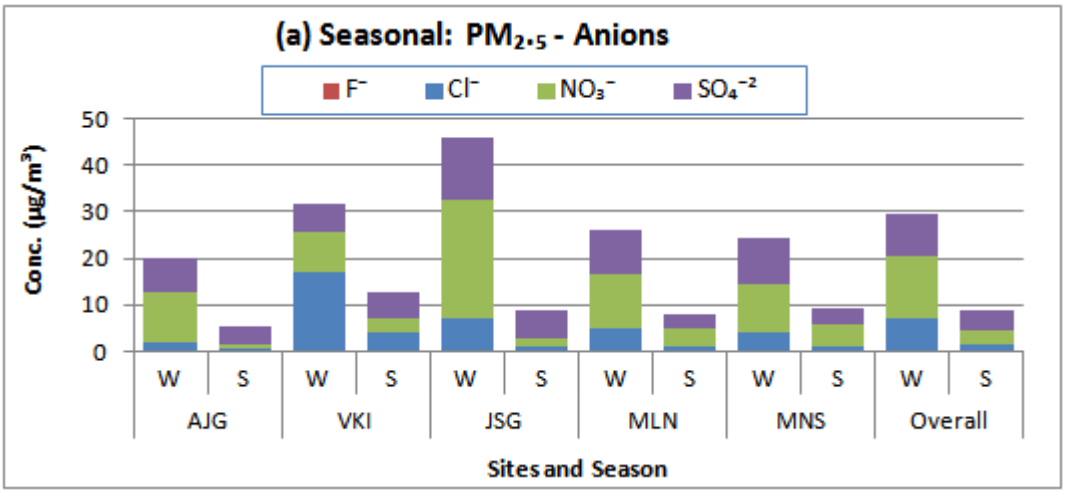
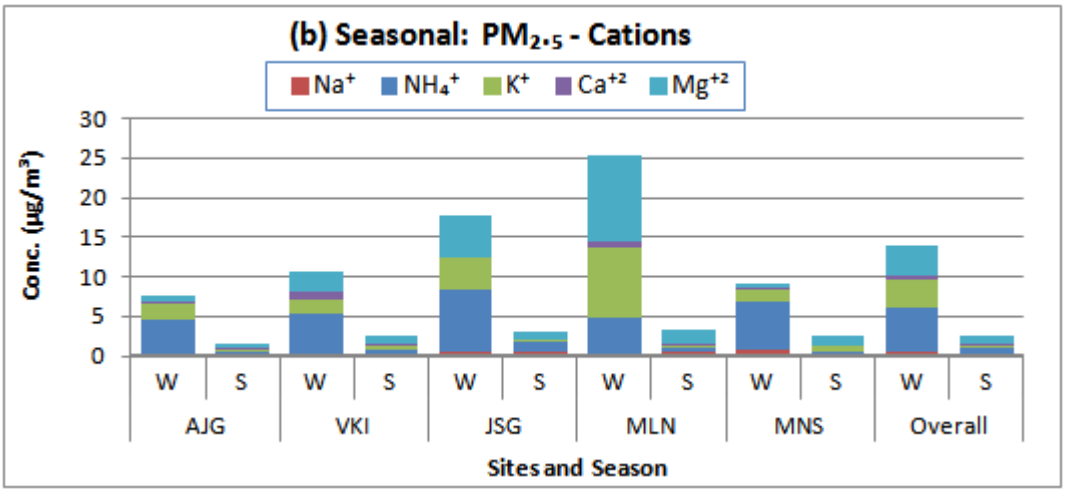


Figure 2.82: Seasonal comparison of ionic and elemental species concentrations in PM_{10} for all sites





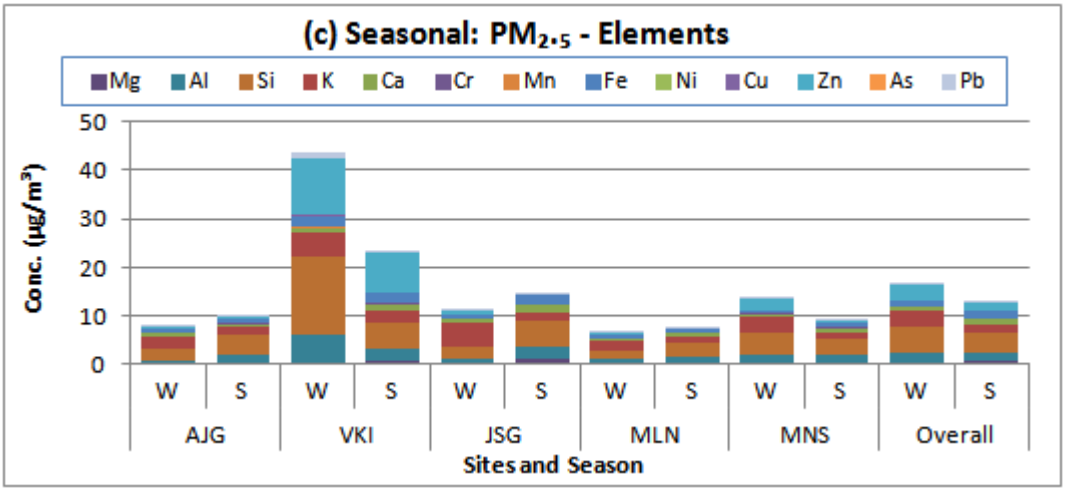


Figure 2.83: Seasonal comparison of ionic and elemental species concentrations in $PM_{2.5}$ for all sites

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

The graphical presentation is the better option for understanding the compositional variation. The major chemical species considered for overall compositional comparisons are carbon (OC and EC), ions (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Al, Si, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Cd and Pb). 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 Jaipur. The overall compositional comparison is also presented in Table 2.87 for all sites.

It is observed that significant portion of PM is having more fine-mode particles during winter (44%) than summer (22%). The major species contributing to fine mode are EC, OC, NO_3^-, SO_4^{-2}, NH_4^+, K^+, Na, V, Zn and Pb; whereas, major species contributing in coarse mode are Ca, Mg, Al, Si, Cr, Mn, Fe and Ni (Figure 2.90 and Figure 2.91).

The average ratio ($PM_{2.5}/PM_{10}$) were 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}.

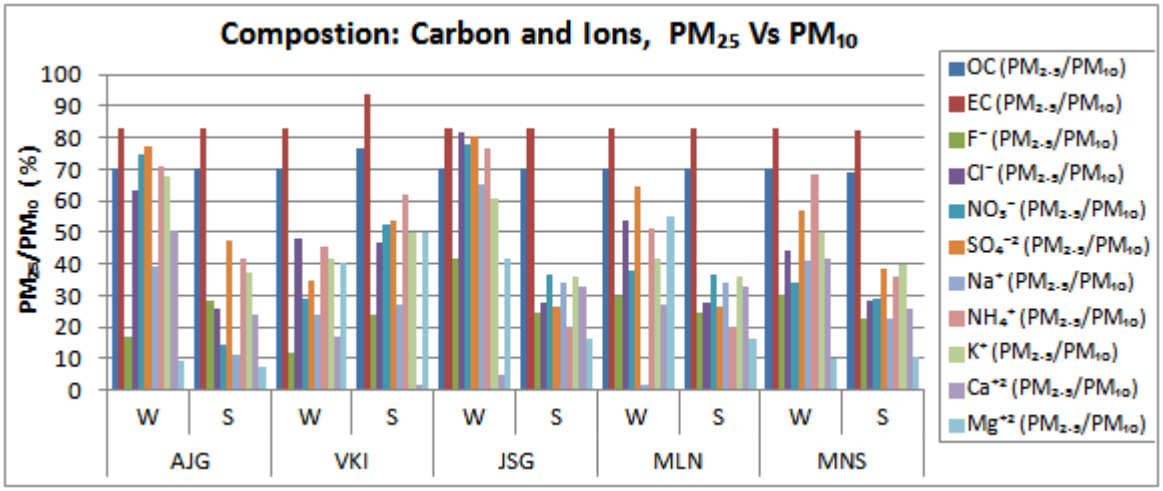


Figure 2.84: Compositional comparison of carbon and ions species in $PM_{2.5}$ Vs PM_{10}

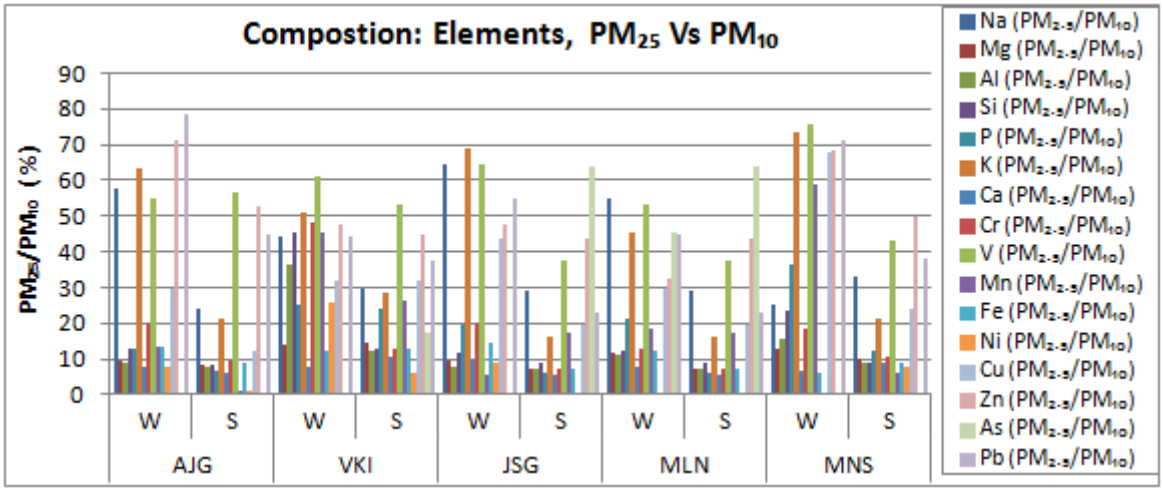


Figure 2.85: Compositional comparison of elemental species in $PM_{2.5}$ Vs PM_{10}

2.4.6.9 Mercury (Hg) in PM_{10}

The average concentration of mercury (Hg) in PM_{10} is shown graphically for winter season (Figure 2.86) for all sites. The statistical summary presented in Table 2.74. The overall mean of city is 1.36 ng/m^3. Hg is observed below detection limit (BDL) at AJG and MLN and highest at JSG. As per WHO, of Hg levels 2 ng/m^3 in rural and 10 ng/m^3 in urban environment may be observed. From Hg levels point of view, pollution levels are far below the levels typically found in urban areas.

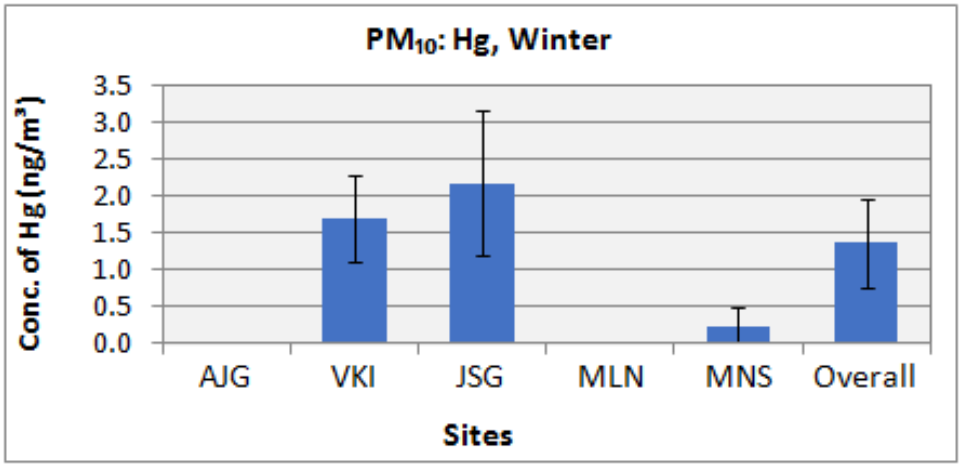


Figure 2.86: Variation in Hg in PM_{10} for winter season

Table 2.74: Overall summary of experimental results of PM (mean±SD µg/m^3) and Hg

PM	PM_{10}		$PM_{2.5}$		$PM_{2.5}/PM_{10}$		Hg (ng/m^3)
Sites	Winter	Summer	Winter	Summer	Winter	Summer	Winter
AJG	245±46 (0.19)	263±84 (0.32)	114±23 (0.20)	53±12 (0.22)	0.47±0.08 (0.17)	0.21±0.05 (0.23)	BDL
VKI	388±119 (0.31)	308±72 (0.23)	175±52 (0.30)	81±19 (0.23)	0.45±0.05 (0.10)	0.27±0.03 (0.11)	1.68±0.59 (0.35)
JSG	238±74 (0.31)	272±79 (0.29)	118±44 (0.37)	53±14 (0.26)	0.49±0.08 (0.16)	0.20±0.05 (0.27)	2.17 ±0.99 (0.46)
MLN	188±39 (0.21)	230±108 (0.47)	74±18 (0.25)	42±10 (0.23)	0.40±0.07 (0.17)	0.20±0.06 (0.28)	BDL
MNS	222±37 (0.17)	233±43 (0.18)	91±20 (0.22)	45±10 (0.21)	0.41±0.07 (0.17)	0.20±0.05 (0.23)	0.23±0.25 (1.07)
Overall	256±77 (0.30)	261±32 (0.12)	114±38 (0.33)	55±15 (0.28)	0.44±0.04 (0.09)	0.22±0.03 (0.14)	1.36±0.61 (0.45)
Values show in parenthesis are the coefficient of variation (CV)							

Table 2.75: 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)
AJG	45.34	4.61	3.07	5.38	2.01	1.87	12.33
VKI	39.51	18.97	9.96	13.24	3.95	3.91	31.05
JSG	36.84	2.61	7.35	11.40	3.40	2.95	25.09
MLN	35.03	7.50	6.17	6.85	2.25	2.13	17.39
MNS	40.79	5.98	5.86	6.07	1.65	2.40	15.97
Overall	39.50	7.93	6.48	8.59	2.65	2.65	20.37
SD	10.48	4.54	4.57	6.99	2.45	2.46	15.24
CV	0.27	0.57	0.70	0.81	0.93	0.93	0.75

Table 2.76: 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)
AJG	24.71	0.94	6.99	7.60	2.19	2.05	18.83
VKI	15.19	1.15	8.13	7.37	0.77	0.92	17.19
JSG	14.13	1.62	2.97	3.04	0.59	0.78	7.38
MLN	13.79	1.86	2.09	3.97	0.80	0.76	7.63
MNS	13.84	1.26	5.00	0.94	0.07	0.07	6.07
Overall	16.33	1.37	5.04	4.58	0.88	0.91	11.42
SD	7.86	0.80	4.06	3.07	0.58	0.64	7.07
CV	0.48	0.59	0.81	0.67	0.66	0.70	0.62

Table 2.77: 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
AJG	113.7	40.7	20.9	19.8	3.04	6.14	7.16	4.57	0.072	0.152	0.182	0.118
VKI	174.6	38.9	22.2	16.7	3.94	5.89	7.42	4.92	0.098	0.157	0.199	0.138
JSG	118.5	28.7	17.4	11.3	1.81	5.37	5.85	4.33	0.062	0.188	0.205	0.156
MLN	73.8	18.9	12.0	6.8	1.10	3.34	4.12	3.47	0.059	0.177	0.221	0.188
MNS	91.0	21.0	13.0	8.0	1.20	3.72	4.35	3.75	0.057	0.179	0.209	0.182
Overall	114	29.6	17.1	12.5	2.22	4.89	5.78	4.21	0.069	0.171	0.203	0.156
SD	34	8.9	4.1	5.0	1.10	1.14	1.37	0.53	0.015	0.014	0.013	0.026
CV	0.30	0.30	0.24	0.40	0.50	0.23	0.24	0.13	0.217	0.081	0.062	0.168

Table 2.78: Overall summary of average concentration of carbon content in $PM_{2.5}$ for all sites for summer season

Summer	PM2.5	TC	OC	EC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
AJG	52.7	14.3	7.8	6.5	0.39	2.35	3.03	2.05	0.028	0.165	0.215	0.144
VKI	80.7	16.2	9.8	6.4	0.70	2.94	3.52	2.63	0.044	0.181	0.218	0.161
JSG	53.2	6.7	4.4	2.3	0.25	1.36	1.91	1.14	0.038	0.211	0.297	0.173
MLN	42.1	10.6	6.7	3.9	0.45	1.97	3.03	1.73	0.041	0.181	0.283	0.162
MNS	45.4	9.5	5.4	4.1	0.22	1.63	2.14	1.45	0.022	0.172	0.229	0.154
Overall	54.8	11.5	6.8	4.6	0.40	2.05	2.73	1.80	0.035	0.182	0.248	0.159
SD	13.6	3.4	1.9	1.6	0.17	0.55	0.61	0.51	0.008	0.016	0.035	0.009
CV	0.25	0.30	0.27	0.35	0.43	0.27	0.22	0.29	0.236	0.087	0.139	0.059

Table 2.79: Overall summary of average concentration (ng/m^3) of PAHs in $PM_{2.5}$ all sites for winter season

Winter	IsP	DmP	AcP	DEP	Flu	HcB	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
AJG	0.34	0.19	0.52	0.67	0.15	0.53	1.86	0.11	2.62	0.14	0.15	3.55	6.07	12.49	3.72	7.18	5.59	0.27	7.27	53.43
VKI	0.47	0.57	1.12	0.82	0.56	1.12	4.26	0.41	9.20	0.22	0.09	10.91	19.56	35.80	11.27	18.68	25.10	1.57	25.52	167.24
JSG	0.89	14.95	2.40	2.12	0.32	0.25	2.48	0.09	1.65	0.23	0.11	2.06	4.03	8.93	2.54	4.69	4.31	0.16	5.21	57.42
MLN	0.35	0.86	1.10	0.45	0.00	0.32	0.98	0.03	1.22	0.09	0.00	1.01	2.20	5.37	1.35	2.20	1.47	0.06	1.97	21.03
MNS	0.30	0.49	1.18	1.17	0.34	0.41	4.27	0.08	4.05	0.17	0.60	1.69	3.83	8.53	3.12	3.82	2.47	0.06	3.38	39.97
Overall	0.47	3.41	1.26	1.05	0.27	0.52	2.77	0.14	3.75	0.17	0.19	3.85	7.14	14.22	4.40	7.32	7.79	0.42	8.67	67.82
SD	0.41	3.26	0.88	1.10	0.27	0.51	1.27	0.16	3.10	0.12	0.39	1.96	3.00	5.72	2.15	4.03	5.40	0.32	4.95	29.40
CV	0.88	0.96	0.70	1.05	0.98	0.97	0.46	1.11	0.83	0.70	2.04	0.51	0.42	0.40	0.49	0.55	0.69	0.75	0.57	0.43

Table 2.80: Overall summary of average concentration (ng/m^3) of PAHs in $PM_{2.5}$ for all sites for summer season

Summer	IsP	DmP	AcP	DEP	Flu	HcB	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
AJG	0.96	0.49	1.88	0.96	0.02	0.72	1.41	0.06	0.95	0.18	0.11	0.35	0.65	1.49	0.44	0.53	0.35	0.10	1.21	12.89
VKI	0.57	0.36	1.28	0.82	0.01	0.71	1.22	0.05	1.30	0.18	0.12	1.58	3.22	9.68	3.23	3.89	3.24	0.16	4.03	35.64
JSG	0.41	0.44	1.40	1.29	0.01	0.35	0.93	0.83	0.33	0.14	0.02	0.22	0.19	1.13	0.29	0.37	0.00	0.02	0.21	8.59
MLN	0.43	0.42	1.22	1.03	0.02	0.13	0.00	1.85	0.40	0.28	0.00	0.32	0.22	1.78	0.13	0.11	0.04	0.07	0.31	8.75
MNS	0.39	0.76	1.56	0.76	0.01	0.12	0.00	1.78	0.31	2.74	0.03	0.32	0.24	1.95	0.36	0.46	0.00	0.25	0.48	12.51
Overall	0.55	0.49	1.47	0.97	0.01	0.41	0.71	0.92	0.66	0.70	0.05	0.56	0.91	3.21	0.89	1.07	0.73	0.12	1.25	15.67
SD	0.33	0.46	0.50	0.43	0.04	0.24	0.35	0.42	0.88	0.76	0.13	0.33	0.74	2.73	0.79	1.00	0.90	0.24	1.26	8.67
CV	0.59	0.93	0.34	0.44	2.86	0.59	0.49	0.46	1.33	1.08	2.48	0.59	0.81	0.85	0.88	0.93	1.23	2.02	1.01	0.55

Table 2.81: Overall summary of average concentration (ng/m^3) of molecular markers in $PM_{2.5}$ for winter season

Winter	17α(H)-22,29,30-Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Levoglucosan	Stigmasterol	Total
AJG	4.39	5.05	12.80	1.50	2.60	0.10	1.81	28.24
VKI	1.46	8.29	5.31	0.74	0.77	0.00	6.23	22.80
JSG	1.62	5.93	6.55	1.04	3.70	0.00	2.11	20.95
MLN	1.32	5.74	6.70	0.52	0.43	0.00	0.27	14.98
MNS	1.18	11.08	3.52	0.53	0.52	0.00	0.22	17.05
Overall	1.99	7.22	6.97	0.87	1.60	0.02	2.13	20.80
SD	0.46	5.62	1.18	0.35	0.97	0.03	1.49	7.47
CV	0.23	0.78	0.17	0.41	0.60	1.73	0.70	0.36

Table 2.82: Overall summary of average concentration (ng/m^3) of molecular markers in $PM_{2.5}$ for summer season

Summer	17α(H)-22,29,30-Trisnorhopane	17α(H),21β(H)-Hopane	n-Hentriacontane	n-Tritriacontane	n-Pentatriacontane	Levoglucosan	Stigmasterol	Total
AJG	1.59	8.11	6.01	0.78	1.27	0.00	0.08	17.83
VKI	0.87	1.91	6.55	1.62	0.61	0.00	1.09	12.65
JSG	0.75	3.86	3.01	0.09	0.29	0.51	0.25	8.77
MLN	1.43	5.40	6.55	1.77	0.55	0.00	0.05	15.76
MNS	1.09	2.71	7.07	1.91	0.39	0.00	0.02	13.18
Overall	1.15	4.40	5.84	1.23	0.62	0.10	0.30	13.64
SD	0.33	1.40	2.39	0.55	0.17	0.09	0.46	4.03
CV	0.28	0.32	0.41	0.44	0.27	0.85	1.54	0.30

Table 2.83: 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^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
AJG	245	29.9	23.8	0.04	3.83	19.85	12.82	1.25	8.38	3.95	0.76	7.86	0.030	0.39	3.14	3.27	9.81	22.72	0.51
VKI	388	31.7	20.2	0.50	35.55	29.50	17.02	1.62	10.99	3.93	6.26	6.19	0	0.18	5.30	3.82	15.45	35.33	0.53
JSG	238	24.7	13.6	0.12	8.45	32.85	16.42	0.81	10.23	6.47	0.93	13.17	0	0.27	1.96	3.57	11.36	20.81	0.44
MLN	188	17.2	8.2	0.08	9.00	30.85	14.77	0.70	9.45	21.04	2.98	19.75	0	0.16	1.53	2.50	7.76	13.61	0.34
MNS	222	18.6	9.6	0.07	9.11	30.51	17.00	2.00	8.97	2.66	0.74	4.46	0	0.26	6.46	2.92	9.70	20.43	0.41
Overall	256	24.4	15.1	0.16	13.19	28.71	15.61	1.28	9.61	7.61	2.33	10.29	0.01	0.25	3.68	3.21	10.82	22.58	0.44
SD	77	6.5	6.7	0.19	12.69	5.10	1.81	0.55	1.03	7.64	2.39	6.22	0.01	0.09	2.13	0.53	2.89	7.92	0.08
CV	0.30	0.27	0.45	1.18	0.96	0.18	0.12	0.43	0.11	1.00	1.02	0.60	2.24	0.36	0.58	0.16	0.27	0.35	0.17
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
AJG	5.94	9.47	0.56	0.25	0.26	7.00	0	0.005	0.08	1.00	3E-4	0	0.004	0.046	0.016	0	0.08	0.22	67.08
VKI	9.62	8.75	0.65	0.15	0.41	16.46	0	0.018	1.14	24.10	8E-4	0	0.014	0.065	0.047	0	0.06	2.87	69.77
JSG	6.97	9.06	0.40	0.28	0.14	6.64	0	0.002	0.07	1.42	4E-4	0	0.018	0.049	0.017	0	0.05	0.31	71.56
MLN	4.59	6.83	0.28	0.21	0.12	4.72	0	0.002	0.04	1.04	3E-3	0	0.006	0.023	0.003	0	0.01	0.13	70.83
MNS	4.49	6.89	0.61	0.23	0.16	5.93	2E-1	0.003	0.13	3.78	0.034	0	0.013	0.032	0.001	0	0.03	0.43	70.75
Overall	6.32	8.20	0.50	0.22	0.22	8.15	4E-2	0.006	0.29	6.27	8E-3	0	0.011	0.043	0.017	0	0.05	0.79	70.00
SD	2.11	1.25	0.16	0.05	0.12	4.73	1E-1	0.007	0.48	10.04	1E-2	0	0.006	0.016	0.018	0	0.03	1.17	1.75
CV	0.33	0.15	0.31	0.22	0.56	0.58	2.24	1.14	1.63	1.60	1.91		0.54	0.38	1.10		0.60	1.47	0.03

Table 2.84: 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^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
AJG	114	20.9	19.8	0.01	2.43	14.84	9.95	0.49	5.95	2.68	0.38	0.75	0.023	0.19	1.82	0.30	0.86	2.89	0.06
VKI	175	22.2	16.7	0.06	17.04	8.54	5.93	0.38	4.97	1.63	1.06	2.52	0	0.07	2.33	0.54	5.65	16.03	0.13
JSG	118	17.4	11.3	0.05	6.88	25.61	13.24	0.53	7.85	3.93	0.05	5.48	0	0.21	1.27	0.34	0.89	2.43	0.09
MLN	74	12.0	6.8	0.02	4.85	11.64	9.56	0.01	4.85	8.80	0.80	10.88	0	0.10	0.84	0.29	0.85	1.66	0.07
MNS	91	13.0	8.0	0.02	4.06	10.35	9.72	0.82	6.13	1.33	0.31	0.45	0	0.20	1.62	0.38	1.52	4.75	0.15
Overall	114	17.1	12.5	0.03	7.05	14.20	9.68	0.45	5.95	3.68	0.52	4.01	0.005	0.15	1.58	0.37	1.95	5.55	0.10
SD	38	4.5	5.6	0.02	5.81	6.79	2.59	0.29	1.20	3.04	0.41	4.32	0.010	0.07	0.56	0.10	2.08	5.97	0.04
CV	0.33	0.27	0.45	0.66	0.82	0.48	0.27	0.66	0.20	0.83	0.78	1.08	2.24	0.43	0.36	0.27	1.07	1.08	0.38
Winter	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
AJG	3.75	0.74	0.11	0.14	0.03	0.92	0	0	0.02	0.71	0	0	0	0	6E-3	0	0.013	0.17	75.76
VKI	4.90	0.70	0.31	0.09	0.19	2.01	0	0.005	0.37	11.53	0	0	0	0	2E-2	0	0.021	1.28	69.66
JSG	4.78	0.93	0.08	0.18	0.01	0.97	0	0	0.03	0.68	0	0	0	0	8E-3	0	0.015	0.17	79.87
MLN	2.07	0.53	0.04	0.11	0.02	0.59	0	0	0.01	0.34	1E-3	0	0	0	0	0	5E-4	0.06	77.64
MNS	3.30	0.47	0.11	0.17	0.09	0.37	0	0	0.09	2.57	0	0	0	0	0	0	0	0.30	73.89
Overall	3.76	0.68	0.13	0.14	0.07	0.97	0	0.001	0.10	3.17	3E-4	0	3E-5	0	7E-3	0	1E-2	0.40	75.36
SD	1.16	0.18	0.11	0.04	0.07	0.63	0	0.002	0.15	4.76	6E-4	0	7E-5	0	8E-3	0	9E-3	0.50	3.89
CV	0.31	0.27	0.81	0.29	1.07	0.65		1.95	1.44	1.50	2.23		2.24		1.17		0.94	1.26	0.05

Table 2.85: 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^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
AJG	263	11.2	7.8	0.08	2.12	5.98	7.93	1.09	0.77	1.12	0.29	8.21	0	0.00	2.40	6.22	19.43	47.21	0.65
VKI	308	12.8	6.9	0.19	8.59	5.99	10.50	1.20	0.91	0.95	9.38	1.96	0	0.10	2.85	6.25	18.55	43.86	0.57
JSG	272	6.3	2.7	0.13	5.72	8.92	11.09	4.06	1.70	0.90	0.70	10.95	0	0.10	4.85	8.28	20.98	43.58	0.78
MLN	230	9.6	4.7	0.09	3.21	10.44	12.29	1.27	2.31	1.40	0.49	10.91	0	0.12	2.00	5.19	15.99	33.37	0.38
MNS	233	7.9	4.9	0.10	3.73	15.89	9.40	1.38	0.82	1.43	0.78	11.64	0	0.07	1.94	5.05	15.55	37.76	0.39
Overall	261	9.6	5.4	0.12	4.68	9.44	10.24	1.80	1.30	1.16	2.33	8.73	0	0.08	2.81	6.20	18.10	41.16	0.55
SD	32	2.6	2.0	0.05	2.55	4.09	1.66	1.27	0.68	0.25	3.95	4.01	0	0.05	1.20	1.29	2.30	5.52	0.17
CV	0.12	0.27	0.37	0.39	0.55	0.43	0.16	0.70	0.52	0.21	1.69	0.46		0.61	0.43	0.21	0.13	0.13	0.31
Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
AJG	7.41	12.00	0.73	0.23	0.19	11.81	0	0.001	0.02	0.77	0	0	0.01	0.04	0	0	0.01	0.15	55.97
VKI	8.26	12.09	0.76	0.33	0.41	16.63	0	0.022	0.26	18.39	3E-3	0	0.03	0.09	0.032	0	0.09	1.26	57.74
JSG	7.86	14.86	0.80	0.69	0.28	13.74	3E-3	0.014	0.03	0.59	1E-3	0	0.04	0.11	1E-4	0	0.33	0.09	57.90
MLN	6.86	12.68	0.69	0.43	0.20	12.03	8E-4	0.005	0.02	0.33	2E-4	0	0.02	0.05	1E-4	0	0.04	0.17	58.97
MNS	6.38	10.31	0.62	0.34	0.22	10.30	0	0.008	0.03	1.24	0	0	0.03	0.06	0.001	0	0.01	0.26	57.59
Overall	7.35	12.39	0.72	0.41	0.26	12.90	8E-4	0.010	0.07	4.26	9E-4	0	0.03	0.07	0.007	0	0.10	0.39	57.63
SD	0.76	1.64	0.07	0.18	0.09	2.41	1E-3	0.008	0.10	7.91	1E-3	0	0.01	0.03	0.014	0	0.13	0.49	1.08
CV	0.10	0.13	0.10	0.43	0.34	0.19	1.73	0.82	1.45	1.85	1.43		0.40	0.41	2.13		1.40	1.28	0.02

Table 2.86: 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^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si	P
AJG	53	7.8	6.5	0.02	0.54	0.87	3.75	0.12	0.32	0.42	0.07	0.59	0	0.000	0.58	0.52	1.54	3.93	0.04
VKI	81	9.8	6.4	0.05	4.02	3.13	5.64	0.32	0.56	0.48	0.13	0.98	0	0.011	0.84	0.90	2.25	5.60	0.14
JSG	53	4.4	2.3	0.04	1.10	1.80	5.96	0.55	1.16	0.33	0.03	0.92	0	0.056	1.43	1.13	2.68	5.25	0.15
MLN	42	6.7	3.9	0.02	0.89	3.81	3.23	0.43	0.46	0.50	0.16	1.79	0	0.042	0.58	0.38	1.16	3.07	0.02
MNS	45	5.4	4.1	0.02	1.06	4.61	3.63	0.32	0.30	0.57	0.20	1.22	0	0.024	0.65	0.50	1.37	3.42	0.05
Overall	55	6.8	4.6	0.03	1.52	2.84	4.44	0.35	0.56	0.46	0.12	1.10	0	0.027	0.82	0.69	1.80	4.25	0.08
SD	15	2.1	1.8	0.01	1.41	1.51	1.26	0.16	0.35	0.09	0.07	0.45	0	0.023	0.36	0.32	0.64	1.12	0.06
CV	0.28	0.30	0.39	0.38	0.93	0.53	0.28	0.45	0.63	0.19	0.58	0.41		0.85	0.44	0.46	0.35	0.26	0.73
Summer	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
AJG	1.59	0.77	0.07	0.13	0.00	1.04	0	1E-5	0.003	0.41	0	0	1E-4	7E-4	0	0	7E-4	0.066	57.84
VKI	2.38	1.31	0.10	0.18	0.11	2.18	0	1E-3	0.081	8.24	5E-4	0	6E-4	4E-4	9E-3	0	0	0.477	67.55
JSG	1.55	1.69	0.13	0.49	0.03	1.76	2E-3	2E-4	0.006	0.31	3E-4	0	2E-4	2E-3	0	0	0	0.037	63.85
MLN	1.11	0.74	0.05	0.16	0.04	0.84	6E-4	0	0.004	0.14	1E-4	0	4E-5	6E-5	0	0	0	0.039	65.28
MNS	1.36	0.90	0.07	0.15	0.01	0.94	0	7E-4	0.007	0.62	0	0	5E-5	0	6E-4	0	2E-3	0.099	64.74
Overall	1.59	1.08	0.08	0.22	0.04	1.35	4E-4	4E-4	0.020	1.94	2E-4	0	2E-4	6E-4	2E-3	0	6E-4	0.143	63.85
SD	0.48	0.41	0.03	0.15	0.04	0.59	7E-4	6E-4	0.034	3.52	2E-4	0	2E-4	7E-4	4E-3	0	1E-3	0.188	3.63
CV	0.30	0.38	0.39	0.68	1.08	0.43	1.56	1.28	1.69	1.81	1.14		1.06	1.22	2.06		1.67	1.31	0.06

Table 2.87: Ratios of chemical species of $PM_{2.5}$ and PM_{10} for all sites for winter (W) and summer (S) seasons

Sites	AJG		VKI		JSG		MLN		MNS		Overall	
Season	W	S	W	S	W	W	W	S	W	S	W	S
PM_{10}	245	263	388	308	238	272	188	230	222	233	256	261
$PM_{2.5}$	114	53	175	81	118	53	74	42	91	45	114	55
$PM_{2.5}/PM_{10}$	46	20	45	26	50	18	39	18	41	20	45	21
OC ($PM_{2.5}/PM_{10}$)	76	75	75	83	75	74	74	74	73	74	75	77
EC ($PM_{2.5}/PM_{10}$)	70	70	70	77	70	70	70	70	70	69	70	72
F^- ($PM_{2.5}/PM_{10}$)	83	83	83	94	83	83	83	83	83	82	83	86
Cl^- ($PM_{2.5}/PM_{10}$)	17	28	12	24	42	25	30	25	30	23	20	26
NO_3^- ($PM_{2.5}/PM_{10}$)	63	26	48	47	82	28	54	28	44	28	53	33
SO_4^{-2} ($PM_{2.5}/PM_{10}$)	75	15	29	52	78	37	38	37	34	29	49	30
Na^+ ($PM_{2.5}/PM_{10}$)	78	47	35	54	81	26	65	26	57	39	62	43
NH_4^+ ($PM_{2.5}/PM_{10}$)	39	11	24	27	65	34	2	34	41	23	35	19
K^+ ($PM_{2.5}/PM_{10}$)	71	42	45	62	77	20	51	20	68	36	62	43
Ca^{+2} ($PM_{2.5}/PM_{10}$)	68	37	41	50	61	36	42	36	50	40	48	40
Mg^{+2} ($PM_{2.5}/PM_{10}$)	51	24	17	1	5	33	27	33	42	26	22	5
Na ($PM_{2.5}/PM_{10}$)	10	7	41	50	42	16	55	16	10	10	39	13
Mg ($PM_{2.5}/PM_{10}$)	58	24	44	30	65	29	55	29	25	33	43	29
Al ($PM_{2.5}/PM_{10}$)	9	8	14	14	9	7	12	7	13	10	11	11
Si ($PM_{2.5}/PM_{10}$)	9	8	37	12	8	7	11	7	16	9	18	10
P ($PM_{2.5}/PM_{10}$)	13	8	45	13	12	9	12	9	23	9	25	10
K ($PM_{2.5}/PM_{10}$)	13	7	25	24	20	6	21	6	37	13	23	15
Ca ($PM_{2.5}/PM_{10}$)	63	21	51	29	69	16	45	16	74	21	60	22
Cr ($PM_{2.5}/PM_{10}$)	8	6	8	11	10	6	8	6	7	9	8	9
V ($PM_{2.5}/PM_{10}$)	20	9	48	13	20	7	13	7	19	11	26	12
Mn ($PM_{2.5}/PM_{10}$)	55	57	61	53	65	37	53	37	75	43	62	54
Fe ($PM_{2.5}/PM_{10}$)	13	1	45	26	6	18	19	18	59	6	32	15
Ni ($PM_{2.5}/PM_{10}$)	13	9	12	13	15	7	12	7	6	9	12	10
Cu ($PM_{2.5}/PM_{10}$)	8	1	26	6	9	0	0	0	0	8	17	4
Zn ($PM_{2.5}/PM_{10}$)	29	13	32	32	44	20	30	20	68	24	36	28
As ($PM_{2.5}/PM_{10}$)	71	53	48	45	48	44	33	44	68	50	51	46
Pb ($PM_{2.5}/PM_{10}$)	0		0	17	0	64	46	64	0		4	22

Table 2.88: 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}
AJG	245	49.0	0.200	41.1	0.168	53.7	0.219
VKI	388	76.0	0.196	57.5	0.148	51.8	0.134
JSG	238	47.9	0.201	59.5	0.250	38.2	0.160
MLN	188	32.9	0.175	55.1	0.293	25.4	0.135
MNS	222	42.9	0.194	56.5	0.254	28.7	0.129
Overall	256	49.7	0.193	53.9	0.223	39.6	0.156
SD	77	16.0	0.010	7.4	0.062	12.9	0.038
CV	0.300	0.321	0.054	0.137	0.277	0.327	0.242

Table 2.89: 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/$PM_{2.5}$
AJG	114	5.41	0.048	30.74	0.270	40.7	0.358
VKI	175	24.39	0.140	19.44	0.111	38.9	0.223
JSG	118	5.22	0.044	46.70	0.394	28.7	0.242
MLN	74	3.62	0.049	26.05	0.353	18.9	0.256
MNS	91	7.12	0.078	26.21	0.287	20.9	0.230
Overall	114	9.15	0.072	29.83	0.283	29.6	0.262
SD	38	8.61	0.040	10.26	0.108	10.0	0.055
CV	0.33	0.94	0.56	0.34	0.38	0.34	0.21

Table 2.90: 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}
AJG	263	90.5	0.344	14.7	0.056	19.0	0.072
VKI	308	91.1	0.296	17.4	0.057	19.7	0.064
JSG	272	93.2	0.343	21.7	0.080	9.0	0.033
MLN	230	74.1	0.322	25.0	0.109	14.3	0.062
MNS	233	73.9	0.318	26.1	0.112	12.9	0.055
Overall	261	84.5	0.325	21.0	0.083	15.0	0.057
SD	32	9.7	0.020	4.9	0.027	4.4	0.015
CV	0.122	0.115	0.061	0.233	0.330	0.297	0.259

Table 2.91: 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/$PM_{2.5}$
AJG	53	7.3	0.138	4.9	0.094	14.3	0.272
VKI	81	11.3	0.141	9.3	0.116	16.2	0.201
JSG	53	11.4	0.214	8.9	0.168	6.7	0.127
MLN	42	5.8	0.138	7.5	0.178	10.6	0.253
MNS	45	6.6	0.146	8.5	0.188	9.5	0.210
Overall	55	8.5	0.155	7.8	0.149	11.5	0.212
SD	15	2.7	0.033	1.8	0.042	3.8	0.056
CV	0.278	0.315	0.212	0.224	0.279	0.331	0.265

2.4.7 Statistical Summary

For the comparison of winter and summer air quality levels, box plot 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 2.87 to 2.92 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 possibly due the local activities (i.e. DG sets emission, biomass burning, traffic congestion etc) near the monitoring stations. The VKI, JSG and AJG sites show the largest variability and high pollution level whereas residential areas show low variability. The same trend and pattern is applicable for $PM_{2.5}$. It is to be noted that variability is much higher in winter than in summer.

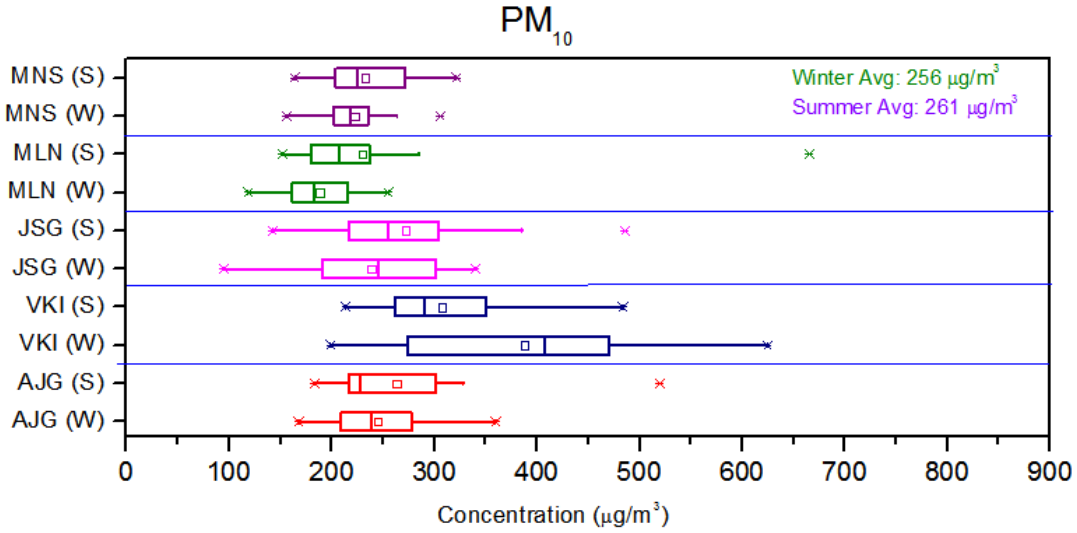


Figure 2.87: Box plot distribution for PM_{10} (winter and summer)

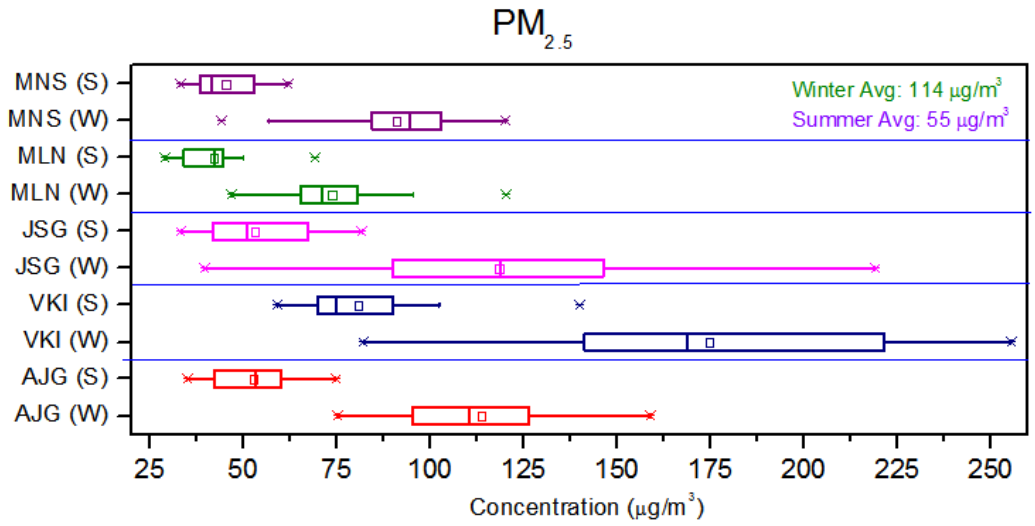


Figure 2.88: Box plot distribution for $PM_{2.5}$ (winter and summer)

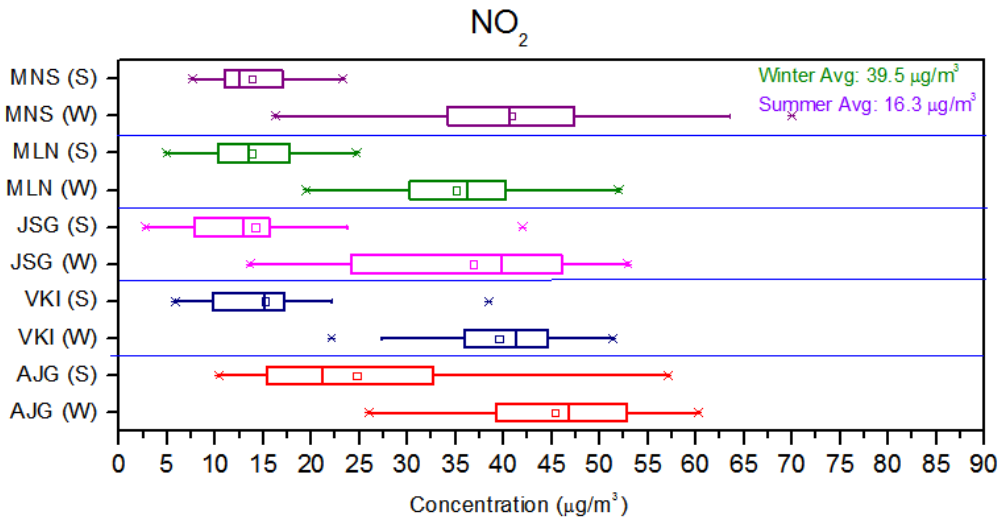


Figure 2.89: Box plot distribution for NO_2 (winter and summer)

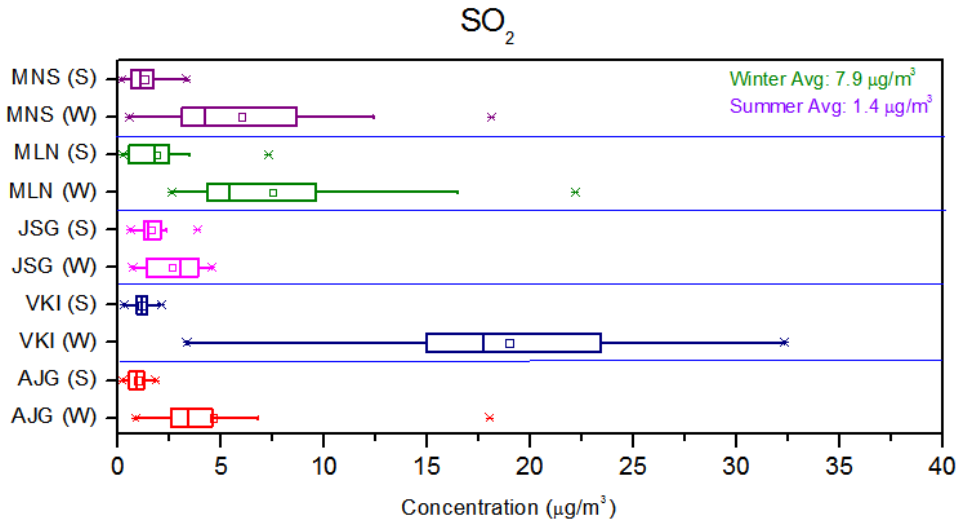


Figure 2.90: Box plot distribution for SO_2 (winter and summer)

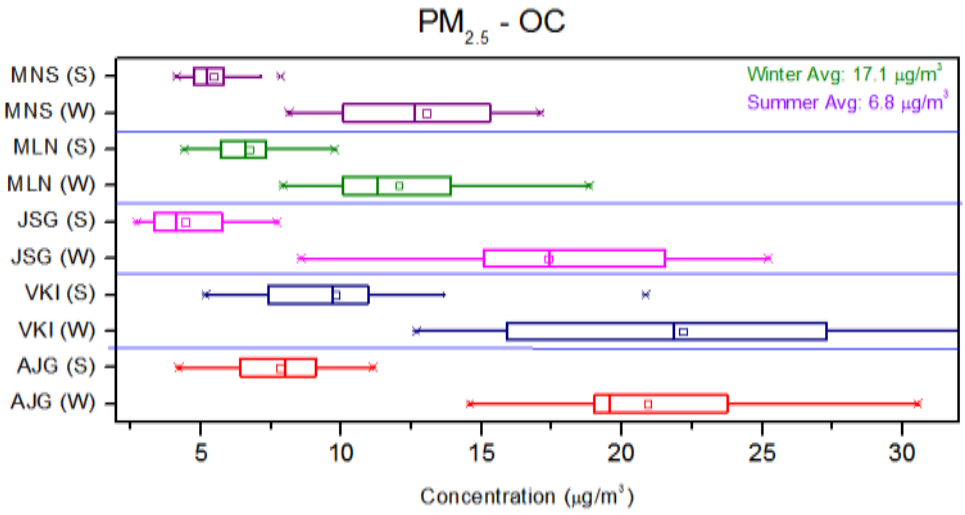


Figure 2.91: Box plot distribution for OC (winter and summer)

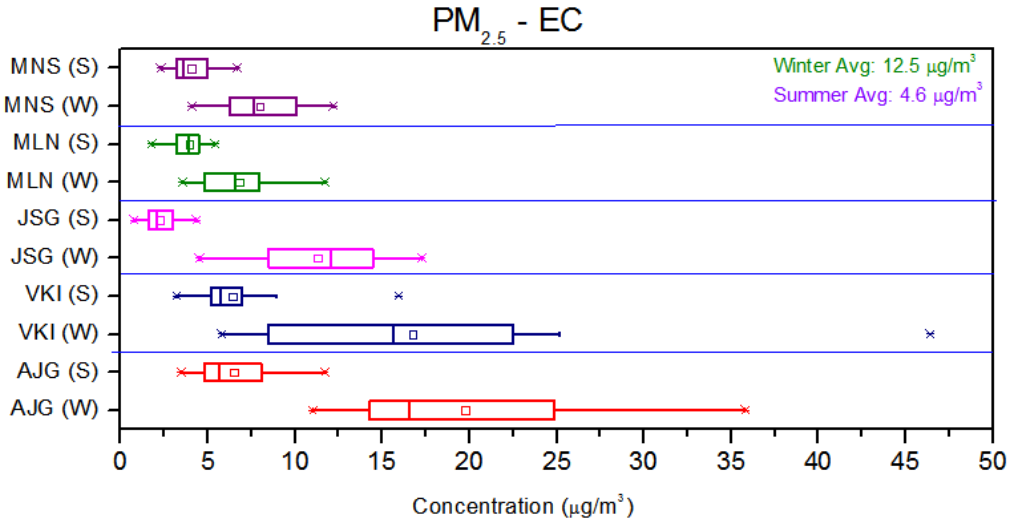


Figure 2.92: Box plot distribution for EC (winter and summer)

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 2.92 that $PM_{2.5}$, OC, EC and NO_2 levels are higher at all sites, PM_{10} is higher at VKI and SO_2 is higher at AJG, VKI, MLN and MNS in winter. There is no significant difference in PM_{10} levels except VKI and SO_2 levels at JSG in summer and winter.

In general, PM_{10} in winter and summer are not different in a statistical sense at 5% level of significance. It suggests that there is no respite from pollution level in summer in Jaipur except VKI. The information on seasonal composition of PM can assist in identifying the various sources contributing to ambient pollution level.

Table 2.92: Statistical Comparison Winter Vs Summer

Parameter / Site	PM_{10}	$PM_{2.5}$	OC	EC	NO_2	SO_2
AJG	⇔	↑	↑	↑	↑	↑
VKI	↑	↑	↑	↑	↑	↑
JSG	⇔	↑	↑	↑	↑	⇔
MLN	⇔	↑	↑	↑	↑	↑
MNS	⇔	↑	↑	↑	↑	↑

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

* No pollutant showed lower concentration in winter

2.5 Chemical Characterization of Field Soil Dust

Since crustal component is the major constituent in PM_{10}, it was decided to characterize the potential sources of these emissions; field soil dust from nearby fields. Field dust samples were collected from ten locations. The samples were sieved with BSS200 sieve (equivalent to 75µm) using sieve shaker. After sieving, the samples were acid digested in microwave digestion system. Metals were analyzed on ICPMS.

The mean percentage fraction of metals is presented in Table 2.93. Soil dust has about 47% metals. Major metals are Si, Al, Ca, Fe and Mg. These results will be further used in CMB modelling for PM_{10}.

Table 2.93: Percentage composition of field soil dust sample

Element	Fraction (%)	SD (%)	Element	Fraction (%)	SD (%)
F^-	0.001	0.001	Ca	7.092	4.289
Cl^-	0.357	0.418	Cr	0.648	0.288
NO_3^-	0.014	0.040	V	0.123	0.040
SO_4^{-2}	1.179	0.573	Mn	0.245	0.079
Na^+	0.641	0.154	Fe	8.755	2.009
NH_4^+	0.200	0.141	Co	0.005	0.000
K^+	0.099	0.058	Ni	0.013	0.002
Mg^{+2}	0.014	0.043	Cu	0.025	0.014
Ca^{+2}	1.2163	0.7483	Zn	0.125	0.044
Be	0.003	0.000	As	0.008	0.001
B	0.000	0.000	Se	0.002	0.000
Na	0.789	0.166	Rb	0.024	0.007
Mg	2.596	0.882	Sr	0.048	0.028
Al	7.195	1.962	Cd	0.004	0.000
Si	15.796	5.954	Cs	0.000	0.000
P	0.280	0.061	Ba	0.059	0.015
K	1.692	0.670	Pb	0.010	0.012
			Total	**47.29**	**17.70**
Note: Na^+, K^+, Mg^{+2} and Ca^{+2} is excluded in total fraction as these are in element form					

2.6 Interpretations and Inferences

Based on the extensive air quality measurements in summer and winter months and critical analyses of air quality data, the following inferences and insights are drawn for developing causal relationship between emission and impact through receptor modeling (Chapters 5). The season-wise, site specific average air concentration of PM_{10}, $PM_{2.5}$ and their compositions (Tables 2.82 – 2.86 and 2.88 – 2.91) 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 - 4 times higher than the national air quality standards in summer and winter months and $PM_{2.5}$ levels are 1.2 – 3 times higher than the national standard in winter months.

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

Winter - PM_{10}

The overall average concentration of PM_{10} in winter season is 256±77 µg/m^3 against the acceptable level of 100 µg/m^3. Highest levels were observed at VKI and lowest at MLN.

The crustal component (Si + Al + Fe + Ca) accounts for about 19% (much less compared to 33% in summer). This suggests soil and road dusts have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.32 (of fraction of crustal component) which suggests the crustal source contributes consistently even in winter though much less compared to summer season.

The other important component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for about 22% of total PM_{10} and combustion related total carbon (TC = EC + OC) accounts for about 16%; both fractions of secondary particles and combustion related carbons have increased in winter and account for 38% of PM_{10}.

The Cl^- content in PM_{10} in winter is not consistent and varies between 2 - 9 percent, which is an indicator of burning of municipal and plastic solid waste (MSW); recall

poly vinyl chloride (PVC) is a major part of MSW. The highest Cl^- content is observed at VKI at 36 µg/m^3 compared to overall city level of 13 µg/m^3. The high level at VKI signifies some local burning of waste either in industrial processes of as a means of disposal of solid waste.

Winter - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 114±38 µg/m^3 against the acceptable level of 60 µg/m^3. The highest levels are observed at VKI 175±52 µg/m^3 and lowest at MLN 74±18 µg/m^3. The crustal component is reduced dramatically to 7% in $PM_{2.5}$ in winter compared to 16% in summer.

The important components are the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for 27% of total $PM_{2.5}$ and combustion related total carbon (EC+OC) accounts for 26%; both secondary particles and combustion related carbon are consistent contributors to $PM_{2.5}$ at about 53%. Highest level of TC was observed at VKI and AJG at about 40 µg/m^3.

The Cl^- content in $PM_{2.5}$ winter is not consistent and varies between 2 – 10 percent which is an indicator of burning of municipal solid waste (MSW).

Summer - PM_{10}

The overall average concentration of PM_{10} in summer season was 261±32 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 33 percent of total PM_{10} in summer. This suggests airborne soil and road dust are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.12, which suggests the sources are consistent all around the city forming a layer which envelopes the city. The areas of AJG and JSG have the highest crustal fraction (around 34% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are wide spread and present all around in Jaipur and are more prominent in summer when soil and dust are dry and high speed winds make the particles airborne. It was observed that in summer the atmosphere looks light brownish which can be attributed to the presence of large amounts of soil dust particles in the atmosphere.

The second significant component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for 8.3 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about 5.7 percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NO_x and NH_3) to form NO_3^-, SO_4^{-2}, and NH_4^+. The combustion related contribution is relatively less in PM_{10} in summer.

The Cl^- content in PM_{10} in summer is consistent at 1-3 percent, which is an indicator of burning of municipal solid waste (MSW) and has a relatively lower contribution in summer than winter.

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer season is 55 µg/m^3 (except at VKI where level is 81±15 µg/m^3) within the acceptable level of 60 µg/m^3.

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

The second important component is combustion related total carbon (EC+OC), which account for 21% of total $PM_{2.5}$ and secondary particles (NO_3^- + SO_4^{-2} + NH_4^+) accounts for 15%; both fractions of secondary particles and combustion related carbons account for a larger fraction in $PM_{2.5}$ than in PM_{10}. All three potential sources, crustal component, secondary particles and combustion contribute consistently to $PM_{2.5}$ in summer.

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 1-2 percent except at VKI (5%), which is an indicator of burning of municipal solid waste (MSW) and has a similar contribution to $PM_{2.5}$ and PM_{10}. This is relatively lower in summer than in winter.

Potassium levels

In general potassium levels are high and variable for PM_{10} (4.6 to 9.6 µg/m^3) in winter and summer and in $PM_{2.5}$ (2.1 to 4.9 µg/m^3) in winter. In general potassium level should be less than 2 µg/m^3. Potassium is an indicator of biomass burning and high levels and

variability (CV ~ 0.30) show significant biomass burning and it is consistent both in summer and winter.

NO_2 levels

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

General inferences

Levels of $PM_{2.5}$ and NO_2 are statistically higher (at all locations) in winter months than in summer months by about 42-60%. The levels of PM_{10} are statistically similar except VKI. In general air pollution levels in ambient air (barring traffic intersections) are uniform across the city suggesting entire city is stressed under high pollution; in a relative sense, VKI is most polluted followed by AJG and JSG. MLN is the least polluted area.

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

Total PAH levels (19 compounds; particulate phase) in winter is very high at 68 ng/m^3 and B(a)P at 7.3 ng/m^3 (annual standard is 1 ng/m^3); the comparison with annual standard is not advisable due to different averaging times. However, PAH levels in summer drop significantly to about 16 ng/m^3. The highest PAH levels observed at VKI (winter 167 ng/m^3 and summer 36 ng/m^3).

The concentrations of molecular markers in $PM_{2.5}$ (total of 7 compounds) are also higher in winter (21 ng/m^3) than in summer (14 ng/m^3) indicating presence of common sources of emissions from coal, gasoline and domestic fuel.

The total BTX levels are higher in winter (20 µg/m^3) than in summer (11 µg/m^3). Although the emission rate is expected to be high in summer due to higher temperature

but the concentration is low due to better dispersion and large ventilation coefficient. The benzene generally exceeded the annual national standard (5 µg/m^3) in winter (except at AJG).

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

In a broad sense, fractions of secondary particles of both PM_{10} and $PM_{2.5}$ in two seasons were consistent and need to be controlled for better air quality in Jaipur. 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. Possible effective mixture of control options are discussed in Chapter 6.

3 Time Series Analysis and Trend

3.1 Introduction

The regulatory agencies at federal and urban levels have taken actions in nearly all sectors to control air pollution over the past decade. Despite taking several initiatives and data generated over the years to reveals the air pollution trend pattern.

There are several techniques that provide trends including simple plotting of data to more complex autoregressive integrated moving average (ARIMA) models. This analysis is done for PM_{10} and NO_2 and the results provide information in terms of trends such as: (i) Significant downward, (ii) Significant upward, (iii) Firstly decreasing and then increasing, (iv) Firstly increasing then decreasing and (iv) No trend.

The long-term (2010-2018) temporal PM_{10} and NO_2 levels at six locations are analyzed for (i) annual and seasonal variations and (ii) understand the rate at which the concentrations are varying over the years (trend analysis).

3.2 Methodology

The air quality databases of six sites were considered for Jaipur city. The sites are Vishwakarma (VKI) and Malviya Nagar (MLN); industrial areas, Ajmeri Gate (AJG) and Chandpole (CNP); commercial areas, Rajasthan State Pollution Control Board (RPB); institutional area and Vidyadhar Nagar (VDN); commercial cum residential area. The air quality data for these sites were obtained for 2010–2018 from RSPCB, Jaipur.

The summary of methodology and major tasks are presented in Fig. 3.1. The collected data were organized, classified, analyzed, compared and interpreted with statistical techniques and visual presentations in the form of graphs and tables. Mean half-monthly PM_{10} concentrations (starting from 1^{st} January) over the years were calculated and plotted against the corresponding time slot (e.g. Jan 1-15, Jan 16-31) for each site. A fifth degree polynomial was fitted by regression analysis to each plot to obtain a minimum R^2 value of 0.70 (lower degree polynomial did not fill well). These plots help in understanding the pattern of concentrations with the changing time slots and seasons.

To detect the long-term trends in air quality parameters (PM_{10} and NO_2), one needs to

examine the rate of change of slope of the fitted polynomial over the years. By differentiating the fifth degree polynomial equation and evaluating its numerical value (for each year) at the average concentration of 45-day slot (i.e. total eight slots in a year, representing two levels of slope in one season of 90 days), one can get the rate of change of slope for each year for all eight time slots. The rates of change of slope were plotted against the years and a linear trend line was fitted. The statistical significance of the trend (of the linear fit) is tested at 5% level of significance using the t-statistics. If the trend is positive and significant, it is a rising trend in PM_{10} (in that 45-day slot) and if it is negative and significant, it is a decreasing trend. A statistical insignificant trend suggests no trend in PM_{10}. The numerical value of the slope of linear fit shows the intensity of the trend. The results of detected trends obtained from the above method were compared with Mann-Kendall statistics (Nagar et al., 2019).

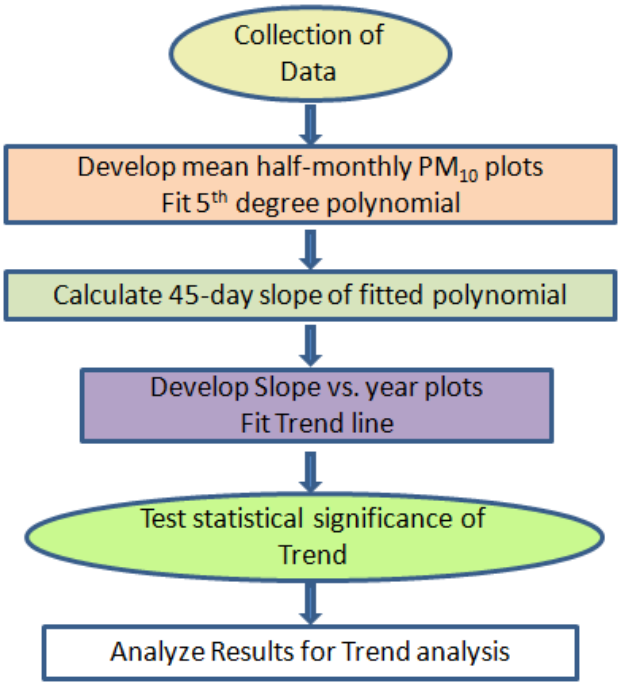
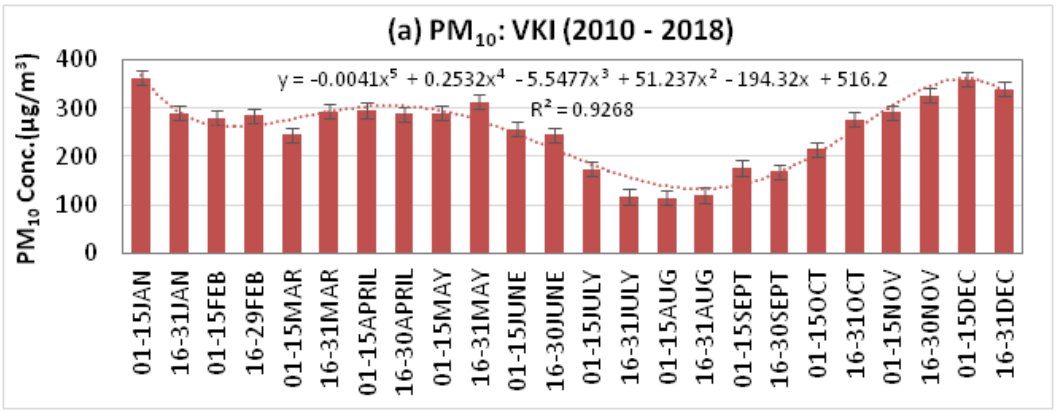


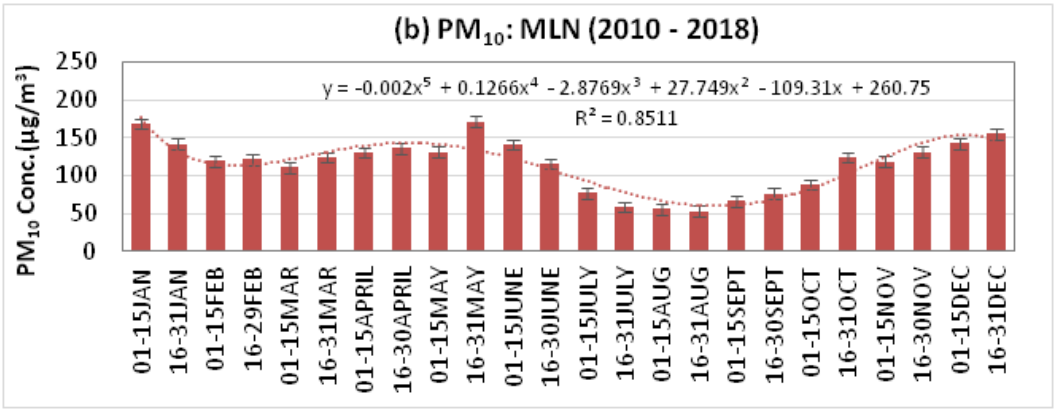
Figure 3.1: Stepwise methodology and major tasks (Nagar et al., 2019)

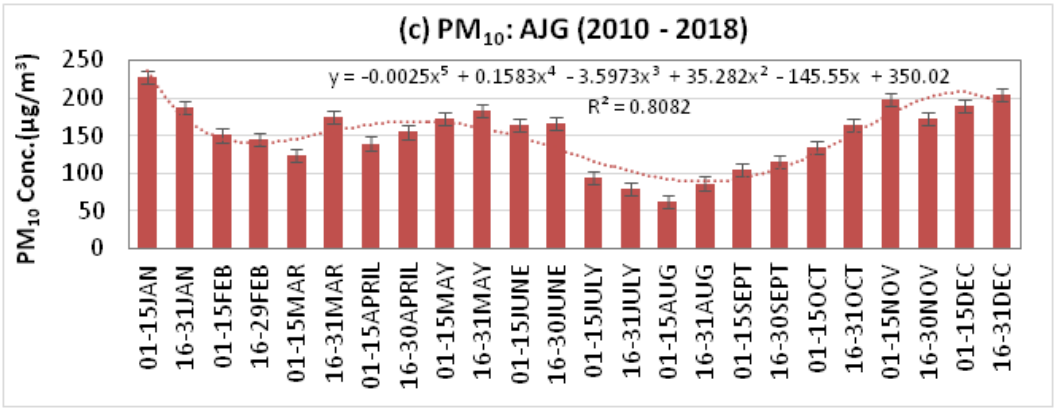
3.3 Results and Interpretations

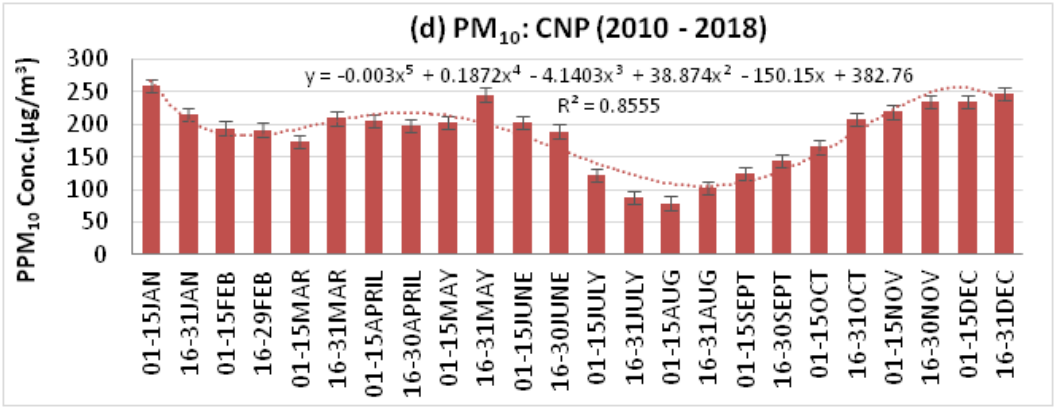
3.3.1 Annual Pattern in PM_{10} and NO_2

The total number of 24-hr PM_{10} and NO_2 measurement in Jaipur was 10132 (at all sites). The half-monthly mean concentration of PM_{10} and NO_2 averaged over 2010-2018 for six sites presented in Figures 3.2 - 3.3.


(a) PM10: VKI (2010 - 2018)
y = -0.0041x5 + 0.2532x4 - 5.5477x3 + 51.237x2 - 194.32x + 516.2
R² = 0.9268
PM10 Conc.(µg/m³)
400
300
200
100
0
01-15JAN
16-31JAN
01-15FEB
16-29FEB
01-15MAR
16-31MAR
01-15APRIL
16-30APRIL
01-15MAY
16-31MAY
01-15JUNE
16-30JUNE
01-15JULY
16-31JULY
01-15AUG
16-31AUG
01-15SEPT
16-30SEPT
01-15OCT
16-31OCT
01-15NOV
16-30NOV
01-15DEC
16-31DEC


(b) PM10: MLN (2010 - 2018)
y = -0.002x5 + 0.1266x4 - 2.8769x3 + 27.749x2 - 109.31x + 260.75
R² = 0.8511
PM10 Conc.(µg/m³)
250
200
150
100
50
0
01-15JAN
16-31JAN
01-15FEB
16-29FEB
01-15MAR
16-31MAR
01-15APRIL
16-30APRIL
01-15MAY
16-31MAY
01-15JUNE
16-30JUNE
01-15JULY
16-31JULY
01-15AUG
16-31AUG
01-15SEPT
16-30SEPT
01-15OCT
16-31OCT
01-15NOV
16-30NOV
01-15DEC
16-31DEC


(c) PM10: AJG (2010 - 2018)
y = -0.0025x5 + 0.1583x4 - 3.5973x3 + 35.282x2 - 145.55x + 350.02
R² = 0.8082
PM10 Conc.(µg/m³)
250
200
150
100
50
0
01-15JAN
16-31JAN
01-15FEB
16-29FEB
01-15MAR
16-31MAR
01-15APRIL
16-30APRIL
01-15MAY
16-31MAY
01-15JUNE
16-30JUNE
01-15JULY
16-31JULY
01-15AUG
16-31AUG
01-15SEPT
16-30SEPT
01-15OCT
16-31OCT
01-15NOV
16-30NOV
01-15DEC
16-31DEC


(d) PM10: CNP (2010 - 2018)
y = -0.003x5 + 0.1872x4 - 4.1403x3 + 38.874x2 - 150.15x + 382.76
R² = 0.8555
PPM10 Conc.(µg/m³)
300
250
200
150
100
50
0
01-15JAN
16-31JAN
01-15FEB
16-29FEB
01-15MAR
16-31MAR
01-15APRIL
16-30APRIL
01-15MAY
16-31MAY
01-15JUNE
16-30JUNE
01-15JULY
16-31JULY
01-15AUG
16-31AUG
01-15SEPT
16-30SEPT
01-15OCT
16-31OCT
01-15NOV
16-30NOV
01-15DEC
16-31DEC

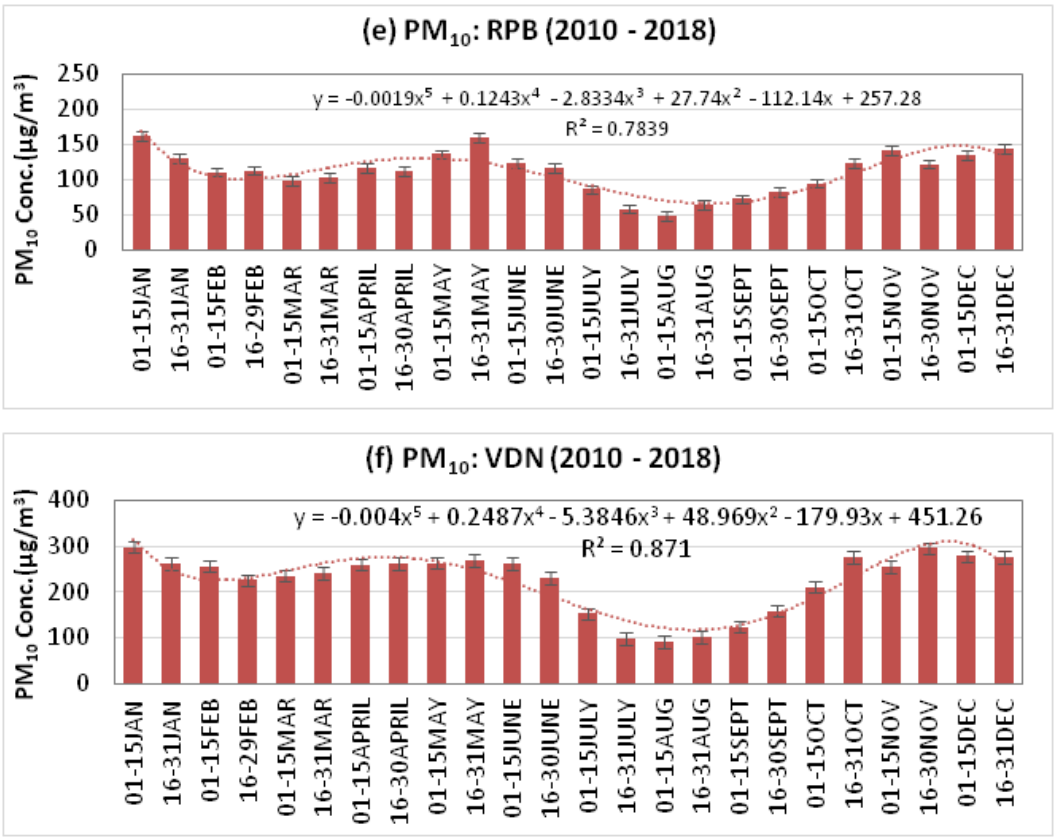
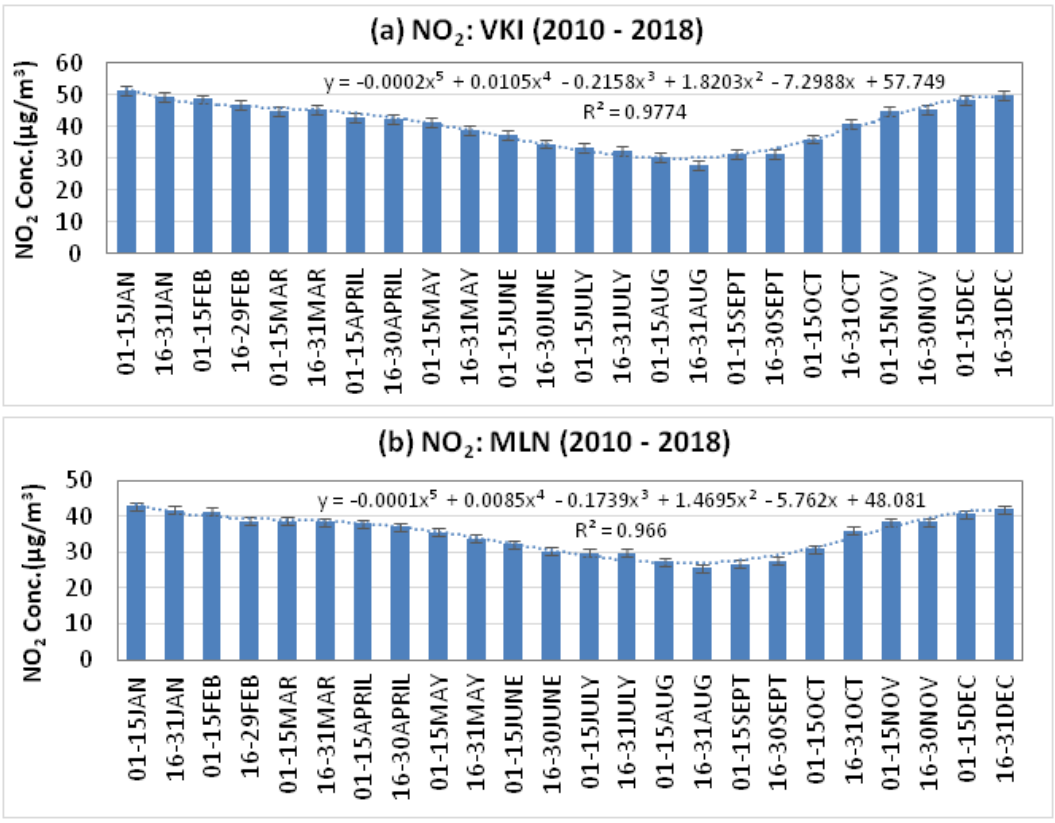


Figure 3.2: Variation in PM_{10} at various sites in Jaipur



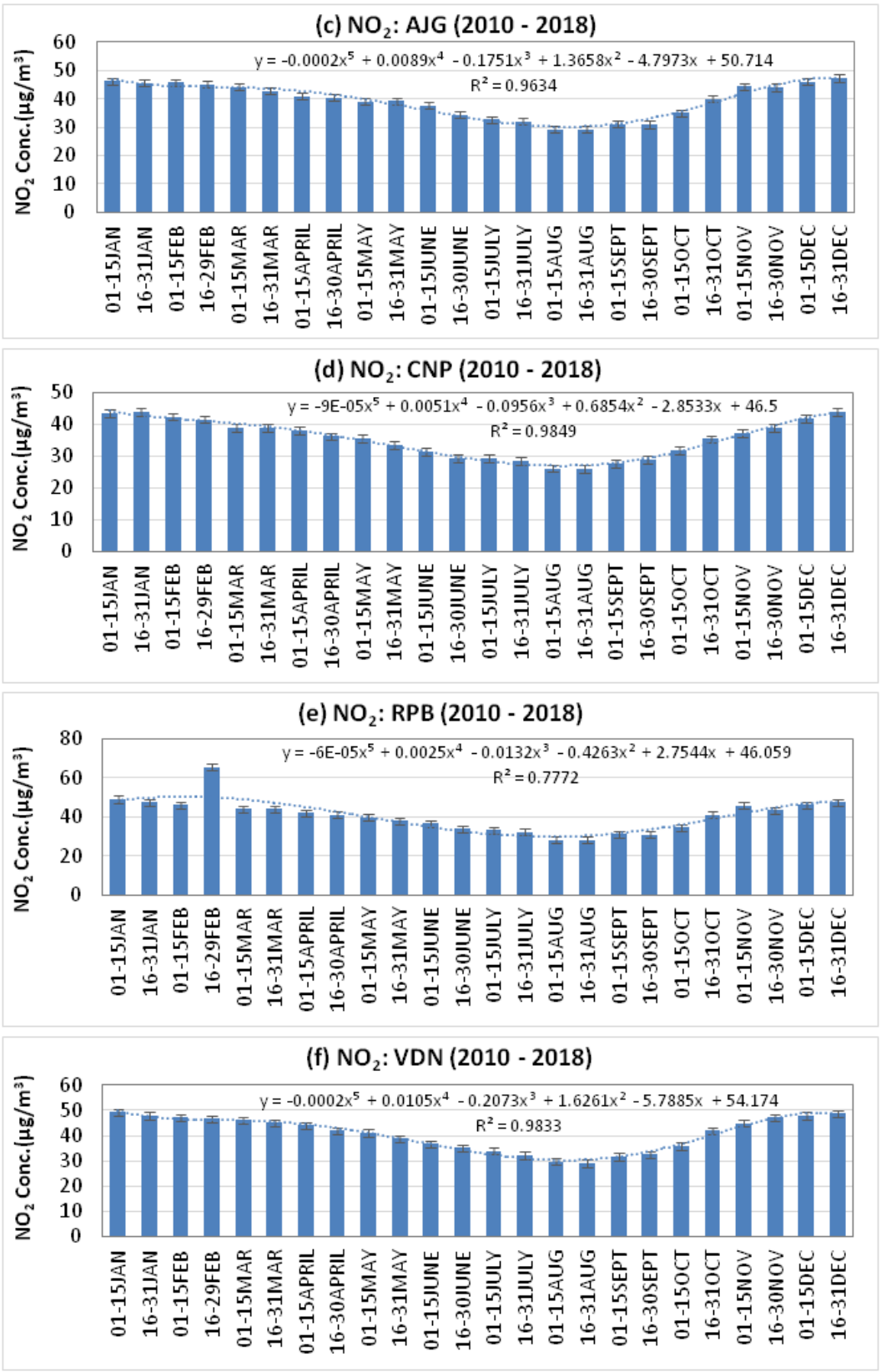


Figure 3.3: Variation in NO_2 at various sites in Jaipur

Two peaks were observed (Figure 3.2) in PM_{10}, one during pre-monsoon season and the other during post-monsoon to winter. The sharp increase in the levels during post monsoon is observed. The PM_{10} levels continue to gradually increase in winter or tend to stabilize. It is interesting to note that in the second half of March, levels increase and levels show significant variability. The city of Jaipur is close to the Thar desert in the west and is characterized to have dust storms in the months of March and April. However, PM_{10} levels except monsoon months (July – September), exceed the 24-hr national air quality standard.

The NO_2 levels are highest in winter months (December and January) and observed lowest in monsoon months (Figure 3.3). The sharp increase is seen in post monsoon and continues to increase in winter months. A slight drop in levels has seen after second half of January month. The NO_2 levels meet the 24-hr national standard. However, it is the concerned in winter months to take necessary measures to prevent high levels of NO_2.

3.3.2 Variation in the slope: Trend analyses

As seen, levels may increase or decrease depending on the season (especially due to changes in meteorology and emissions). To estimate the long-term trends in PM_{10} and NO_2, rates of change of slope over the years were examined. Tables 3.1–3.2 present the obtained mean slope and trend in each of eight slots of 45-days along with the trends obtained using Mann-Kendall test in PM_{10} and NO_2 at six sites in Jaipur. The statistically significant trends in the rate of change of slopes are shown as upward arrow (↑: increasing trend) and downward arrow (↓: decreasing trend) and left-right arrow (↔: no trend). In other words, both slope and trend can acquire negative or positive numerical values. The trends obtained by the New method and that from Mann-Kendall test were identical (similarity in trends: 81% in PM_{10} and 71% in NO_2).

There is no specific trend in PM_{10} and NO_2 data from the new approach. However, in PM_{10} in some time slots the increasing trend is observed and in NO_2 in some time slots the decreasing trend found by Mann-Kendall test.

Table 3.1: Comparison of mean PM_{10} slopes (in µg/m^3/day) and trends (in µg/m^3/day/year) at various sites in 45-day slots during 2010-2018

Sites	PM_{10} Slope/ Trend	1st Jan-15th Feb	16th Feb-31st Mar	1st April-15th May	16th May-30th June	1st July-15th Aug	16th Aug-30th Sep	1st Oct - 15th Nov	16th Nov-31st Dec
VKI	Slope	13.525	25.147	-6.130	-38.585	-13.898	28.235	63.678	26.725
	Trend	-38.963 (↔)	-7.401 (↔)	1.616 (↔)	-5.707 (↔)	-0.489 (↔)	1.131 (↔)	4.244 (↔)	-0.859 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↔)	(↔)	(↔)	(↔)	(↑)
MLN	Slope	-14.983	11.444	2.618	-11.263	-14.231	0.109	11.640	-15.136
	Trend	-8.321 (↔)	-4.384 (↔)	-0.052 (↔)	2.036 (↔)	1.531 (↔)	1.241 (↔)	-0.421 (↔)	-4.291 (↔)
	Trend (MK)	(↑)	(↔)	(↔)	(↔)	(↔)	(↑)	(↔)	(↔)
AJG	Slope	-37.061	8.761	8.529	6.527	22.137	54.786	77.390	40.459
	Trend	-5.840 (↔)	-1.383 (↔)	-2.713 (↔)	-7.179 (↔)	-18.835 (↔)	-24.612 (↔)	-25.465 (↔)	-18.652 (↔)
	Trend (MK)	(↔)	(↔)	(↑)	(↔)	(↔)	(↑)	(↔)	(↔)
CNP	Slope	-44.987	6.957	4.660	-25.695	-13.853	14.622	37.781	-2.781
	Trend	5.858 (↔)	-3.361 (↓)	1.125 (↔)	-4.434 (↔)	2.133 (↔)	2.556 (↔)	0.496 (↔)	-2.821 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↔)	(↔)	(↔)	(↔)	(↔)
RPB	Slope	13.668	18.847	2.665	-10.522	-9.249	7.076	20.071	-2.231
	Trend	-23.803 (↔)	-9.115 (↔)	-0.944 (↔)	2.091 (↔)	2.481 (↔)	1.880 (↔)	1.240 (↔)	0.542 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↔)	(↔)	(↑)	(↔)	(↔)
VDN	Slope	-10.242	23.632	-2.854	-24.115	-18.527	18.748	42.679	-23.923
	Trend	-18.540 (↔)	-6.275 (↔)	0.219 (↔)	3.492 (↑)	0.881 (↔)	-0.724 (↔)	-1.436 (↔)	-0.569 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↔)	(↔)	(↑)	(↔)	(↔)

MK : Mann-Kendall Test | ↑ Increasing Trend | ↓ Decreasing Trend | ↔ Statistically Insignificant Trend

Note: The trends marked in gray show that trends estimated by two approaches (MK and New method) were at variance.

Table 3.2: Comparison of mean NO_2 slopes (in µg/m^3/day) and trends (in µg/m^3/day/year) at various sites in 45-day slots during 2010-2018

Sites	NO_2 Slope/ Trend	1st Jan-15th Feb	16th Feb-31st Mar	1st April-15th May	16th May-30th June	1st July-15th Aug	16th Aug-30th Sep	1st Oct - 15th Nov	16th Nov-31st Dec
VKI	Slope	-3.998	-2.762	-5.729	-10.840	-13.510	-15.291	-17.382	-23.357
	Trend	0.931 (↔)	-0.442 (↔)	-0.781 (↔)	-1.612 (↔)	-2.578 (↔)	-3.951 (↔)	-6.496 (↔)	-10.688 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↔)	(↓)	(↔)	(↔)	(↔)
MLN	Slope	-6.565	-3.933	-6.254	-10.441	5.541	10.980	16.874	19.771
	Trend	-0.781 (↔)	-2.382 (↔)	-4.188 (↔)	-6.693 (↔)	2.991 (↔)	5.187 (↔)	7.879 (↔)	11.128 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↓)	(↓)	(↓)	(↔)	(↔)
AJG	Slope	-1.507	-0.536	-1.296	-3.319	-2.707	-2.527	-5.628	-17.495
	Trend	0.031 (↔)	-0.373 (↔)	0.135 (↔)	-0.229 (↔)	0.401 (↔)	1.000 (↔)	2.381 (↔)	5.301 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↔)	(↓)	(↓)	(↔)	(↔)
CNP	Slope	0.579	-3.032	-9.294	-19.748	-42.008	-72.68	-118.36	-183.66
	Trend	0.307 (↔)	-0.944 (↔)	-2.358 (↔)	-5.175 (↔)	-19.474 (↔)	-35.294 (↔)	-58.165 (↔)	-88.783 (↔)
	Trend (MK)	(↔)	(↔)	(↓)	(↔)	(↓)	(↓)	(↔)	(↔)
RPB	Slope	2.624	0.023	-1.450	-2.071	-1.275	0.159	0.781	-1.554
	Trend	-1.900 (↔)	-0.727 (↔)	-0.088 (↔)	0.098 (↔)	0.815 (↔)	2.018 (↔)	3.507 (↔)	4.659 (↔)
	Trend (MK)	(↔)	(↔)	(↔)	(↓)	(↓)	(↔)	(↔)	(↔)
VDN	Slope	-1.791	-0.580	-1.943	-3.551	-4.650	-5.936	-10.884	-24.814
	Trend	0.464 (↔)	-0.220 (↔)	-0.180 (↔)	0.004 (↔)	0.079 (↔)	0.107 (↔)	-0.370 (↔)	-1.606 (↔)
	Trend (MK)	(↔)	(↔)	(↓)	(↓)	(↓)	(↔)	(↔)	(↔)

MK : Mann-Kendall Test | ↑ Increasing Trend | ↓ Decreasing Trend | ↔ Statistically Insignificant Trend

Note: The trends marked in gray show that trends estimated by two approaches (MK and New method) were at variance.

4 Emission Inventory

4.1 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, emission inventory of the study area for the year 2018 is presented.

4.2 Methodology

The stepwise methodology adopted for this study is presented in Figure 4.1.

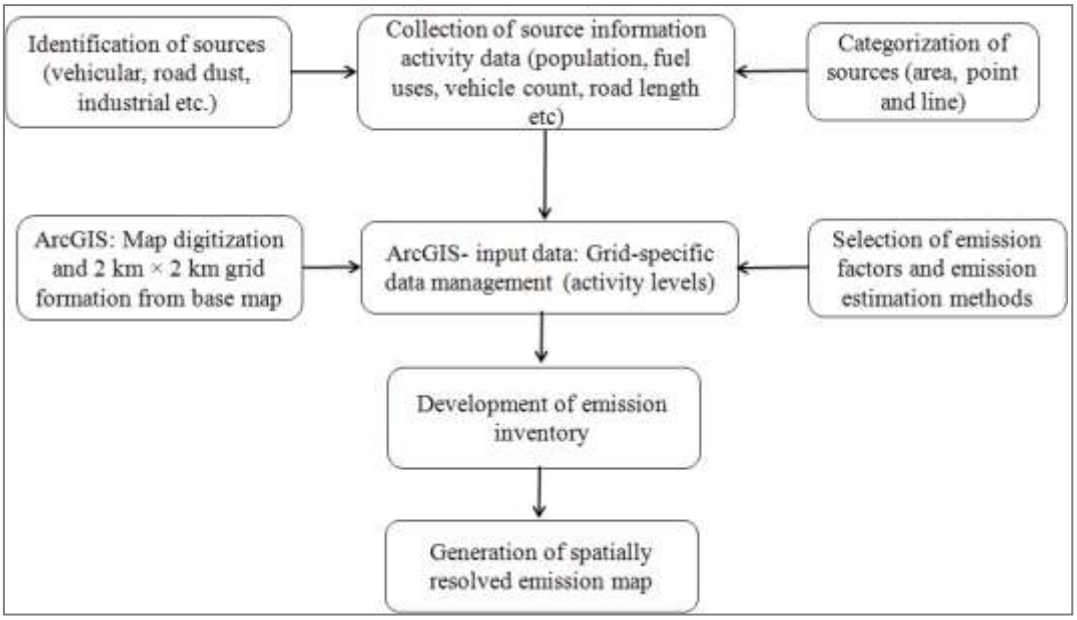


Figure 4.1: Stepwise Methodology adopted for the Study

4.2.1 Data Collection

The primary and secondary data were collected by IITK team. For example, parking lane survey at 20 locations was done to assess types of vehicles on the road. Construction and demolition data were collected by field survey and validated by satellite imagery. Road dust sampling at 20 locations was conducted. Physical survey of industrial areas was also done. The main sources of secondary data collection are from RPCB, Census of India, CPCB website, AAI (Airport Authority of India), Indian Railways, Jaipur Development Authority,

Public Works Department, Transport Department, and Toll Plazas. Information has also been collected through Internet by visiting various websites. Although all possible efforts have been made to collect the data, some information/data could be missing.

4.2.2 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, agriculture, road network, water bodies, etc (Figure 4.2 to 4.14).

Figure 4.2: Jaipur City Boundary

Figure 4.3: Ward Map

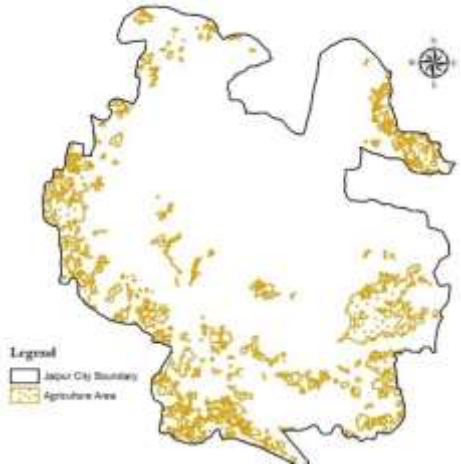


Figure 4.4: Agricultural Area Map

Figure 4.5: Green Area Map

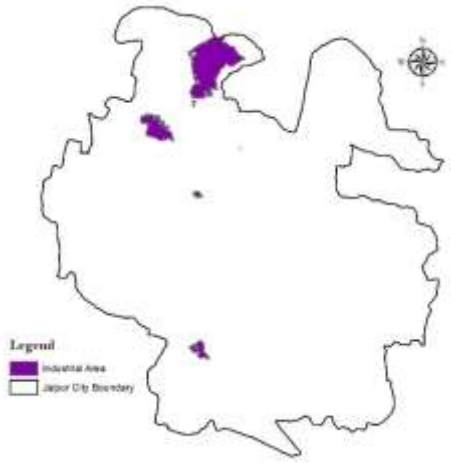


Figure 4.6: Industrial Area Map

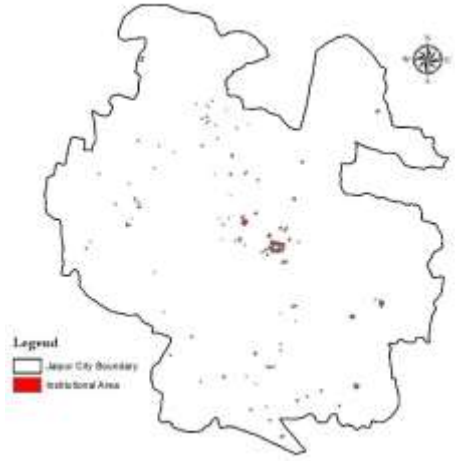


Figure 4.7: Institutional Area Map

Figure 4.8: Waterbodies Area Map

Figure 4.9: Major Road Network Map

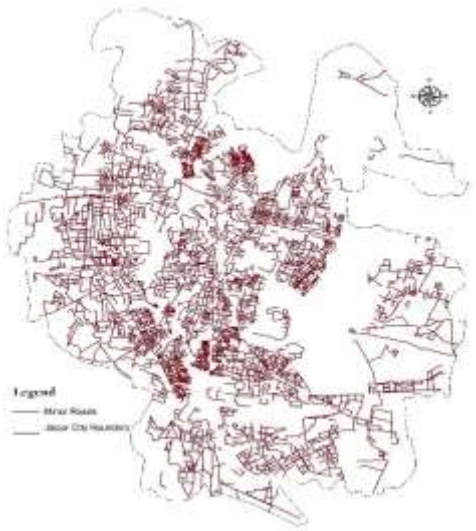


Figure 4.10: Minor Road Network Map

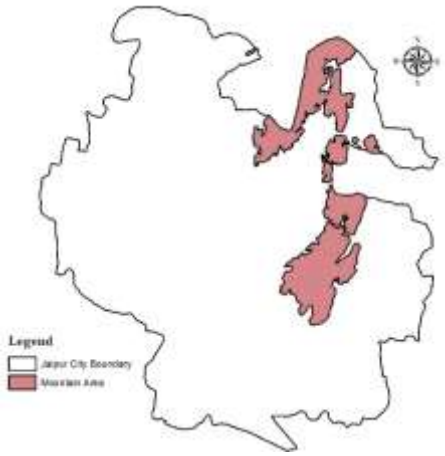


Figure 4.11: Physical features: Hills

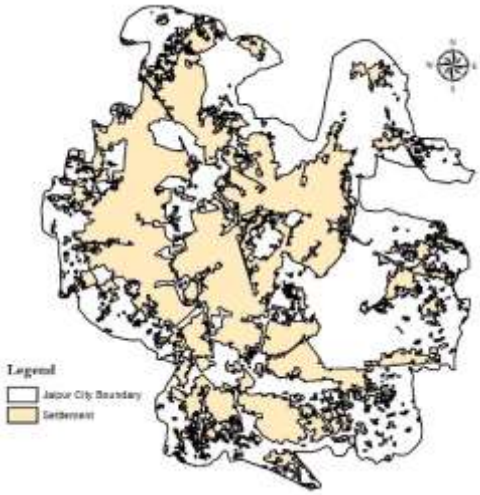


Figure 4.12: Settlement Area Map

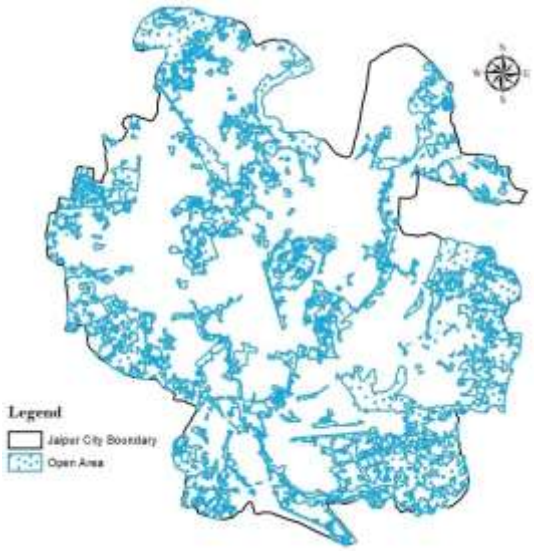


Figure 4.13: Open Area Map

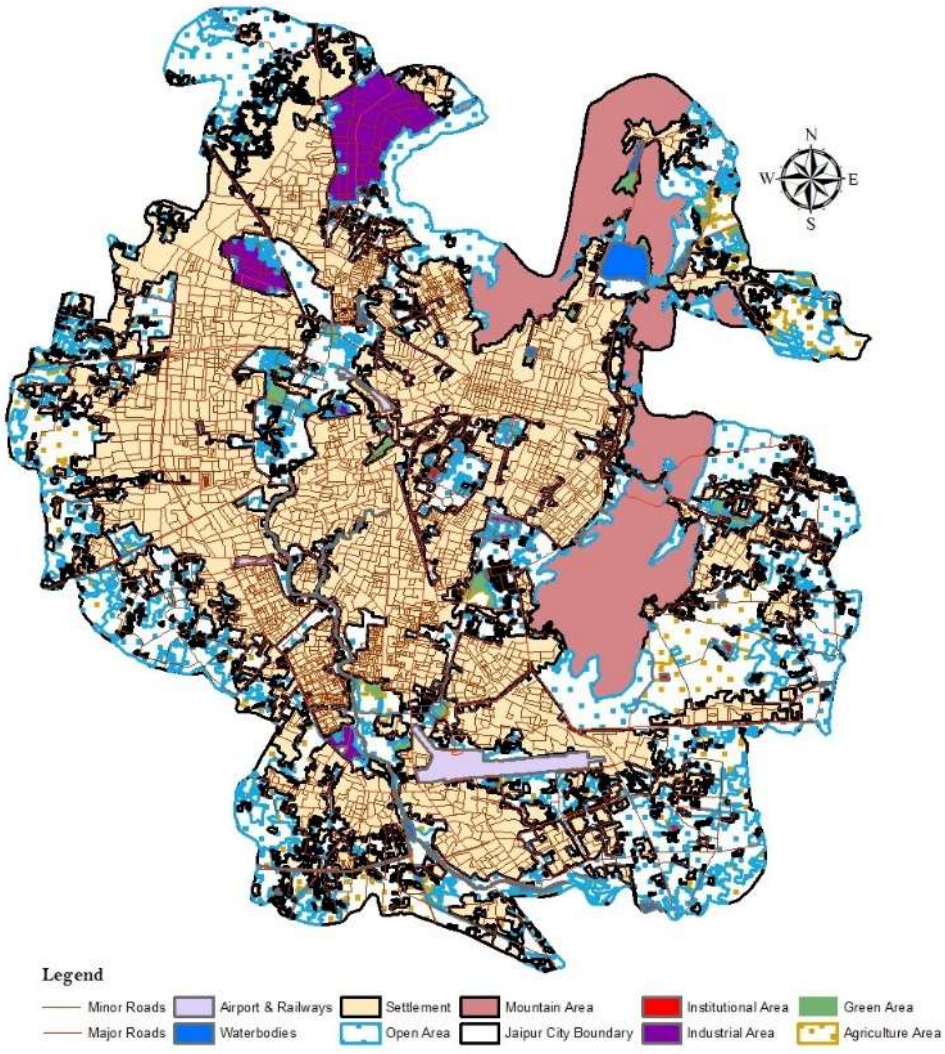
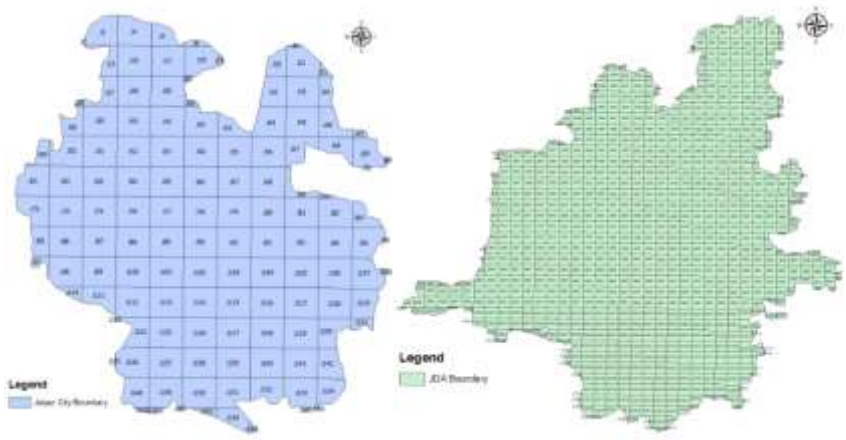


Figure 4.14: Landuse Map of the Jaipur city

At the time of development of the emission inventory a suitable coding system was adopted to avoid the confusion and misrepresentation of results and interpretation. The emissions have been calculated for both Jaipur Development Authority boundary and Jaipur city boundary represented by JDA and JCB respectively. The map of JDA and JCB with grid identity numbers is shown in Figure 4.15. The entire study area was divided into grid cell of 2 km x 2 km.



JCB **JDA**

Figure 4.15: Grid Map of JCB and JDA Showing Grid Identity Numbers

4.2.3 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. These factors are usually expressed as the mass of pollutant per unit mass of raw material, volume, distance travelled, or duration of the activity (e.g., grams of particulate emitted per kilogram of coal burnt). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category.

The general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100) \qquad (4.1)$$

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

4.2.4 Domestic Sector

The interior boundaries in the map (Figure 4.16) show the administrative boundaries of wards and villages in JCB and JDA limits. After obtaining the area of wards and villages, the emission density for each ward is calculated for different pollutants (PM_{10}, $PM_{2.5}$, SO_2, NOx, and CO). The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

JDA **JCB**

Figure 4.16: Wards and Villages

The overall emission from domestic sources is presented in Figure 4.17. For spatial distribution of different pollutants, emission per capita, in each ward and village was calculated, as activity data was available on the basis of per capita. The fuel usage pattern of the households for the study area (JDA) is presented in Table 4.1.

Table 4.1: Fuel Usage Pattern (households)

Fuel Type	Urban (%)	Rural (%)
Firewood	14.6	42.5
Crop Residue	0.7	4.5
Cowdung Cake	0.5	0.8
Coal	0.3	0.2
Kerosene	3.2	1.9
LPG/PNG	80.7	50.1
Total	100	100

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.

Emission Density (kg/day/m^2) = Emission of Ward (kg/day) / Ward Area (m^2) (4.2)

For calculating emission in a grid which 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.

$$Grid.Emission = \sum_{i=1}^{N} (\text{area of fraction ward i in grid X emission density of ward, i}) \quad (4.3)$$

Where, N= no. of wards in the grid

The emission contribution from different fuel types to different pollutants is shown in Figures 4.18 to 4.27. spatial distribution of emissions from the domestic sector is shown in Figure 4.28 to 4.32.

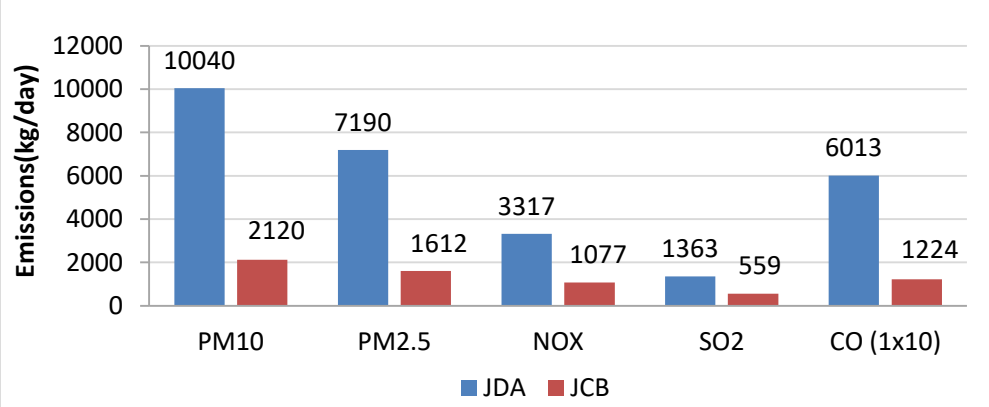


Figure 4.17: Emission Load from Domestic Cooking (kg/day)

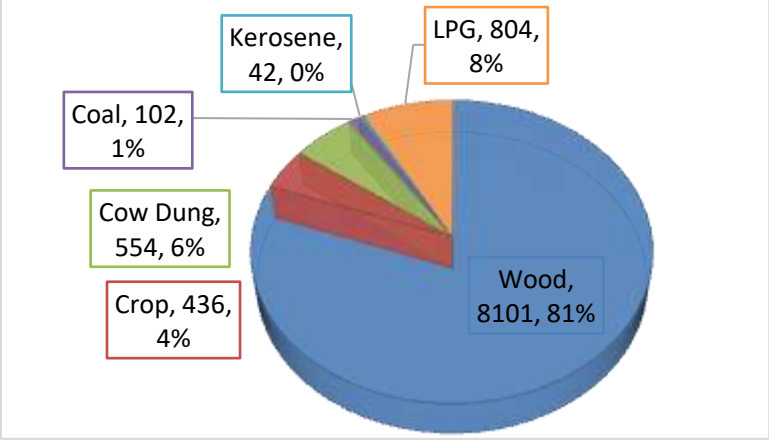


Figure 4.18: PM_{10} Emission Load from Domestic Cooking in JDA (kg/day, %)

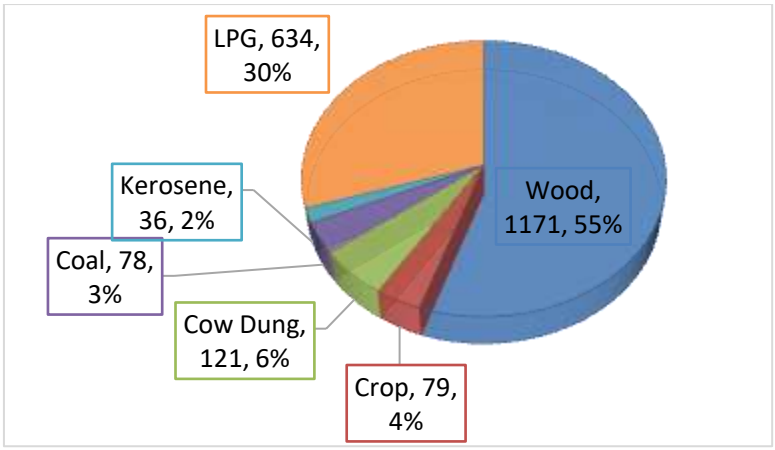


Figure 4.19: PM_{10} Emission Load from Domestic Cooking in JCB (kg/day, %)

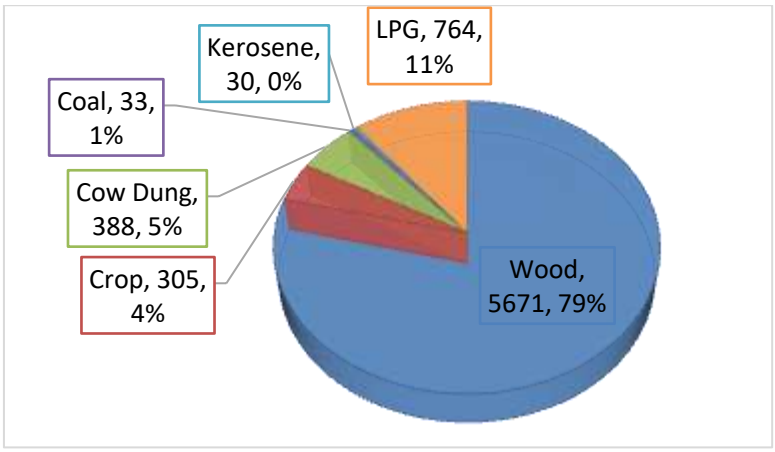


Figure 4.20: $PM_{2.5}$ Emission Load from Domestic Cooking in JDA (kg/day, %)

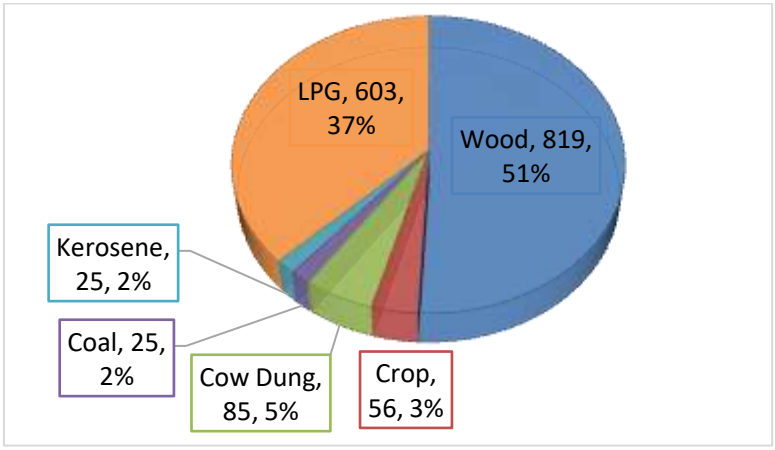


Figure 4.21: $PM_{2.5}$ Emission Load from Domestic Cooking in JCB (kg/day, %)

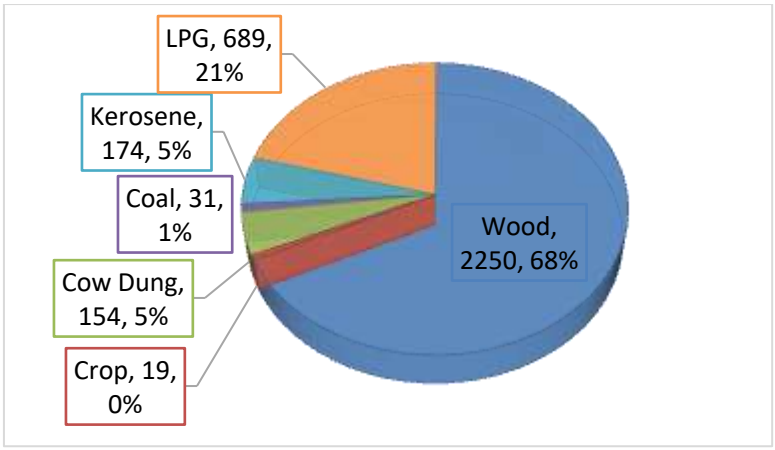


Figure 4.22: NOx Emission Load from Domestic Cooking in JDA (kg/day, %)

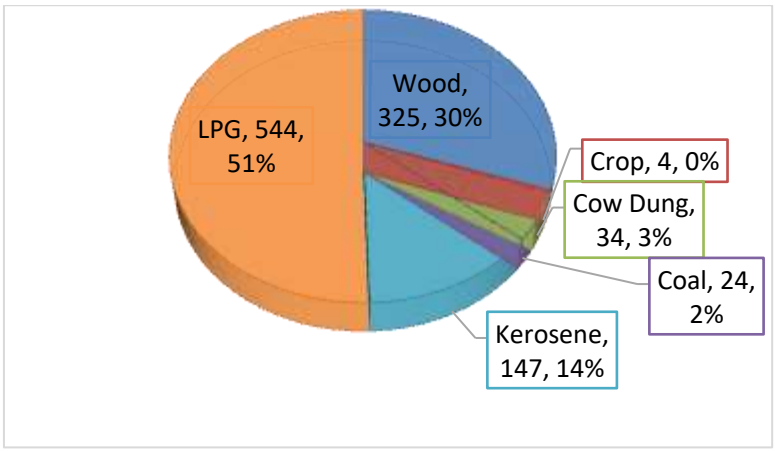


Figure 4.23: NOx Emission Load from Domestic Cooking in JCB (kg/day, %)

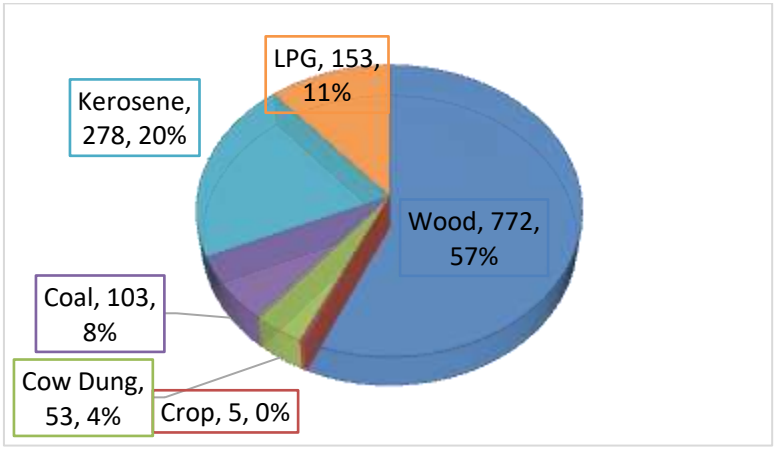


Figure 4.24: SO_2 Emission Load from Domestic Cooking in JDA(kg/day, %)

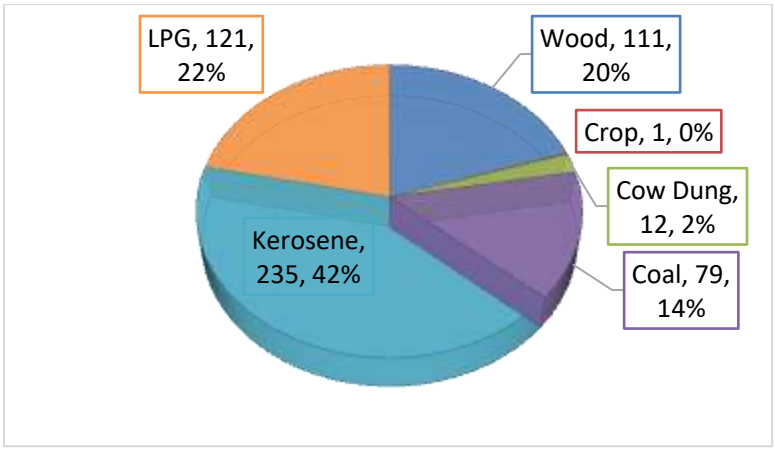


Figure 4.25: SO_2 Emission Load from Domestic Cooking in JCB (kg/day, %)

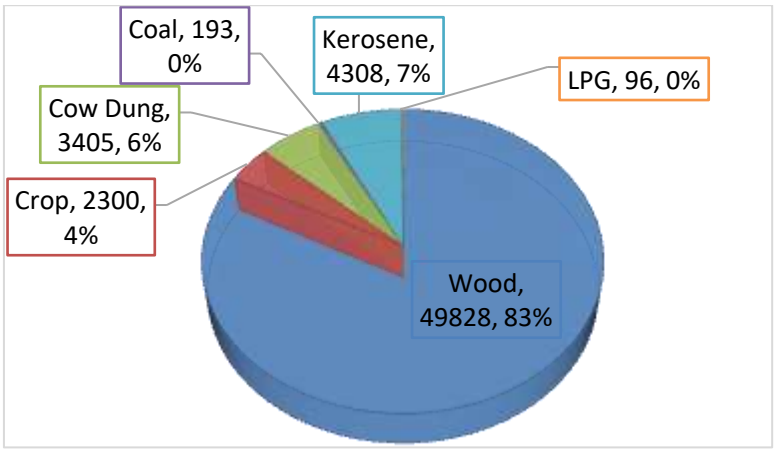


Figure 4.26: CO Emission Load from Domestic Cooking in JDA(kg/day, %)

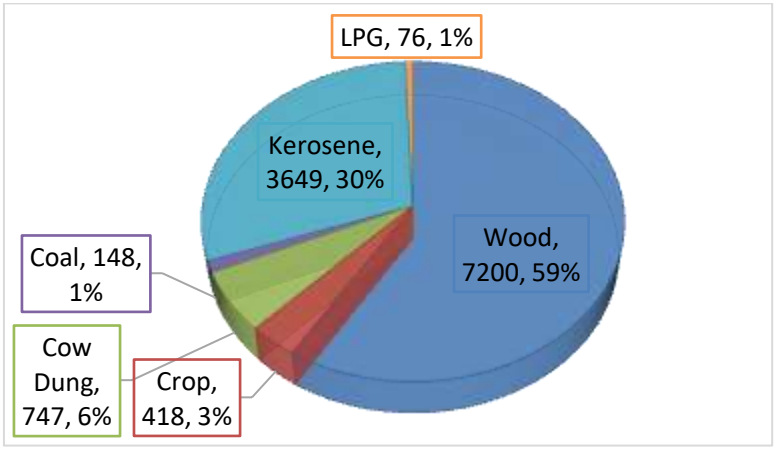
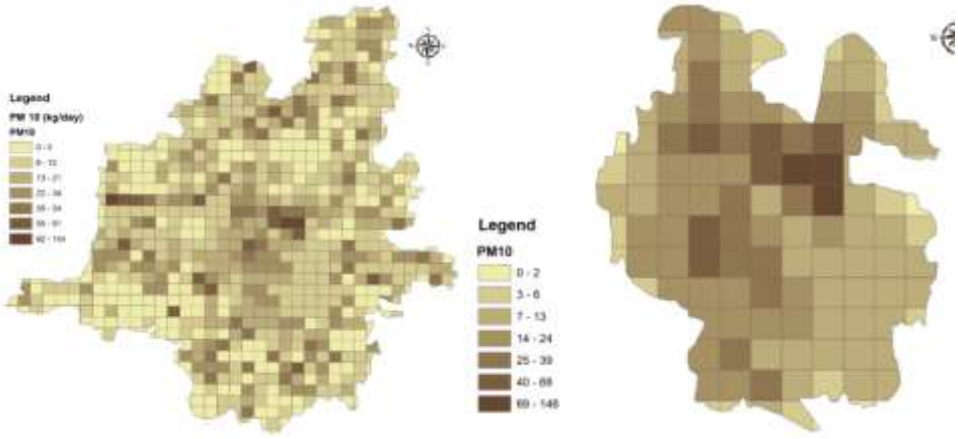
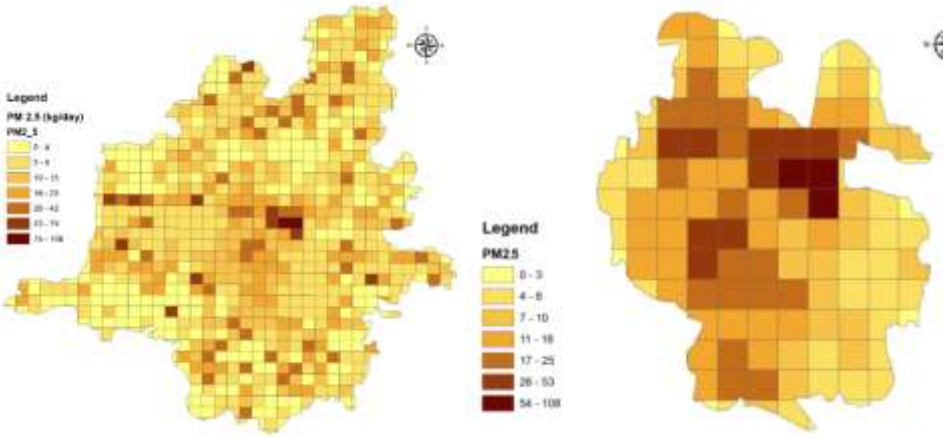


Figure 4.27: CO Emission Load from Domestic Cooking in JCB (kg/day, %)



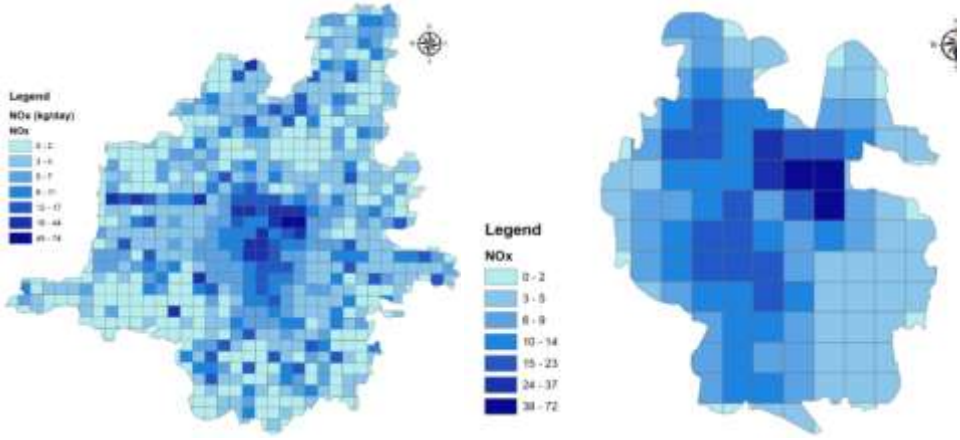
JDA **JCB**

Figure 4.28: Spatial Distribution of PM_{10} Emissions from Domestic Sector



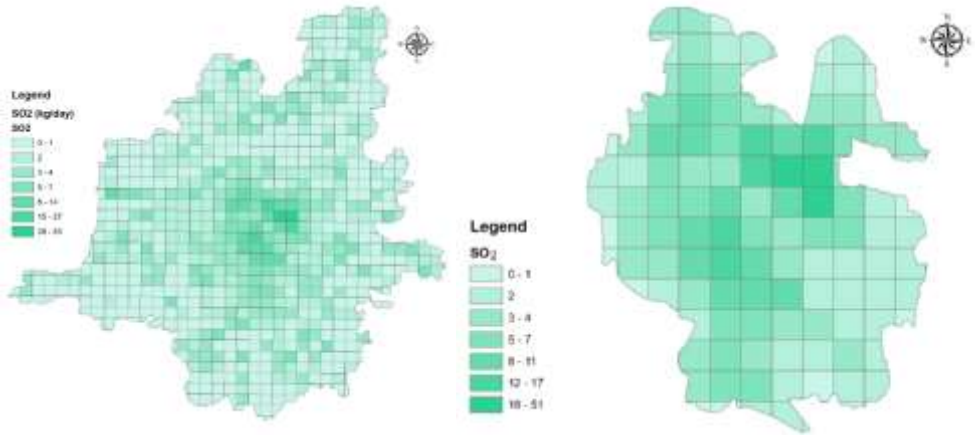
JDA **JCB**

Figure 4.29: Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector



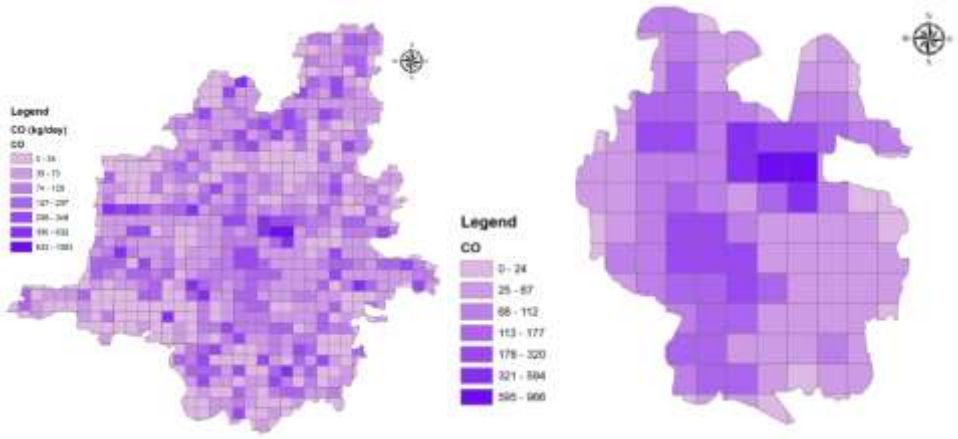
JDA **JCB**

Figure 4.30: Spatial Distribution of NOx Emissions from Domestic Sector



JDA **JCB**

Figure 4.31: Spatial Distribution of SO_2 Emissions from Domestic Sector



JDA **JCB**

Figure 4.32: Spatial Distribution of CO Emissions from Domestic Sector

4.2.5 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. These construction activities are geotagged in JCB and JDA boundary limits (Figure 4.33). The emission factors given by AP-42 (USEPA, 2000) were used for estimating the construction and demolition emissions. The major construction activities include buildings (including residential housing and apartments) and canal development. The construction and demolition locations were then verified with satellite imagery. The areas under construction activities were calculated on the basis of survey data and GIS.

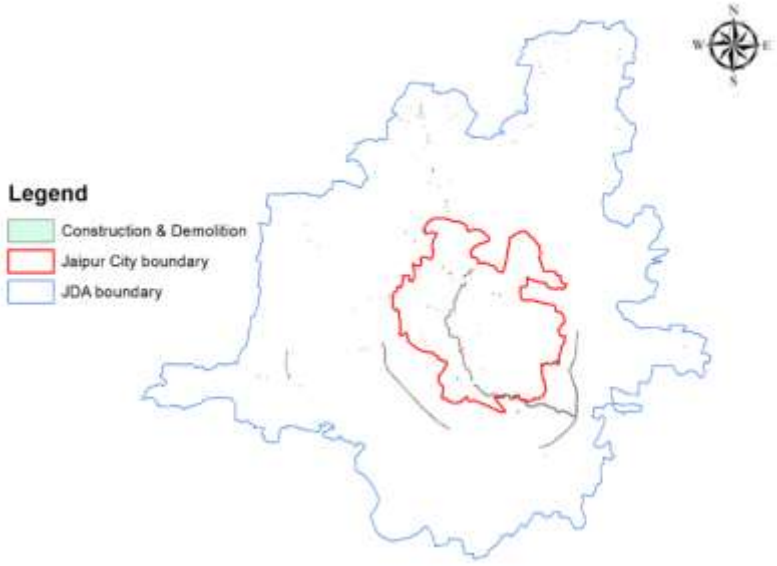


Figure 4.33: Construction/Demolition Sites

Total emissions from construction and demolition activities are presented in Table 4.2 and Figure 4.34. The spatially resolved map of construction and demolition activities is shown in Figures 4.35 to 4.36.

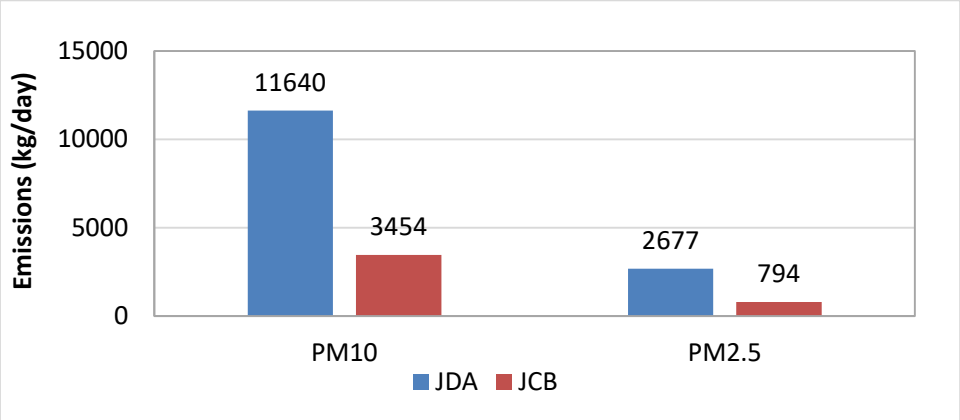
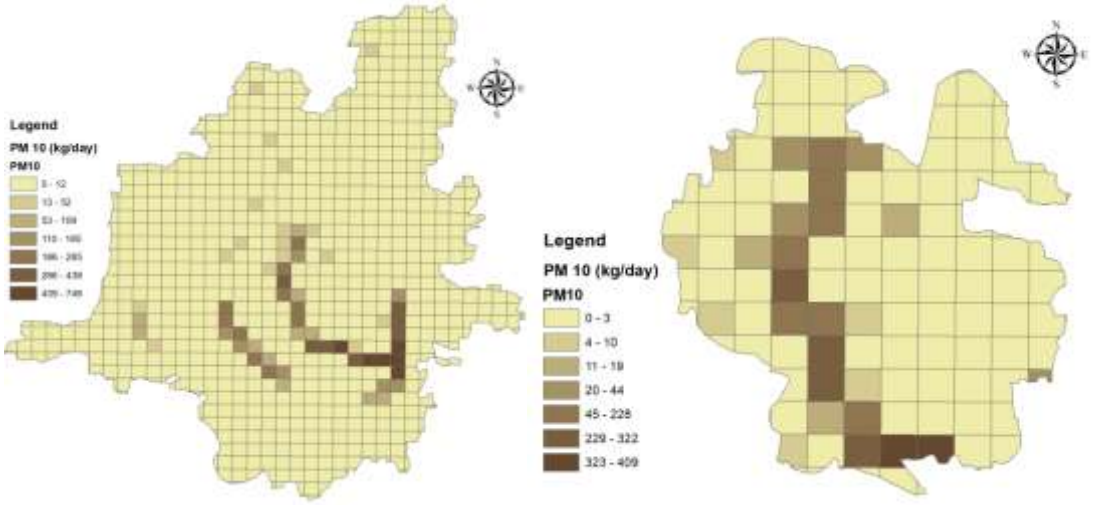


Figure 4.34: Emission Load from Construction and Demolition activities (kg/day)

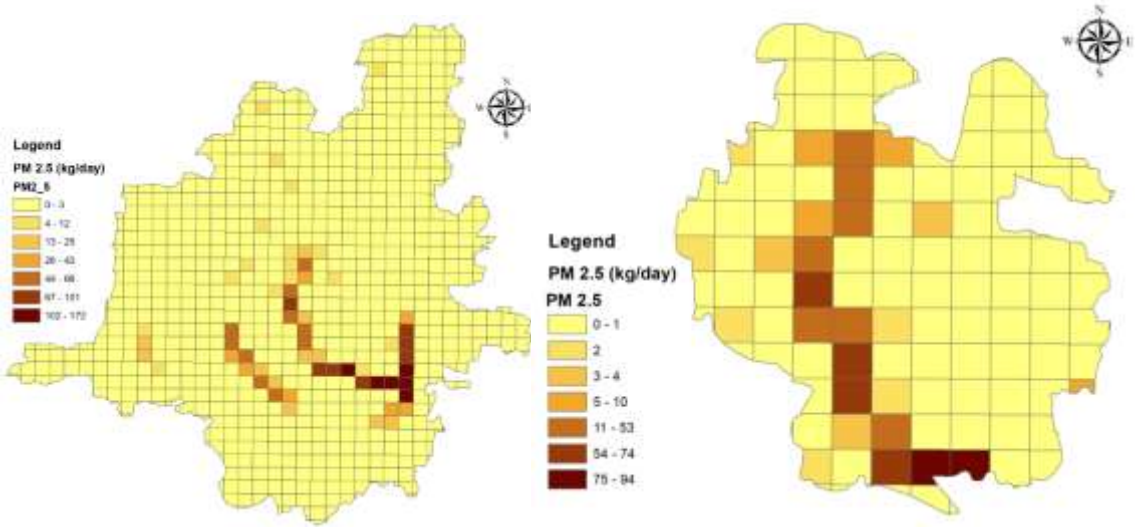
Table 4.2: Classification of Construction Activities Emission Load (kg/day)

	Canals		Buildings		Flyover & Roads	
	JDA	JCB	JDA	JCB	JDA	JCB
PM_{10}	10943	602	544	138	153	32
$PM_{2.5}$	2517	172	125	39	35	9



JDA **JCB**

Figure 4.35: Spatial Distribution of PM_{10} Emissions from Construction/Demolition



JDA **JCB**

Figure 4.36: Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition

4.2.6 Diesel Generator Sets (DG sets)

The location of the DG set is shown in Figure 4.37. The industries use DG sets as backup, approximately 750 DG sets are installed in industries (source: consent data). It is assumed that DG sets operate for two hours per day. The unit of the activity data is KWh power generation. The emissions from DG sets installed in commercial complexes, hospitals, apartments, institutes and industries were estimated and then were summed up for each grid.

The calculation is based on Eq (4.1), 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 4.38, the breakup of emissions is presented in Table 4.3 and 4.4. Spatial distribution of emissions from DG Sets is shown in Figures 4.39 to 4.43.

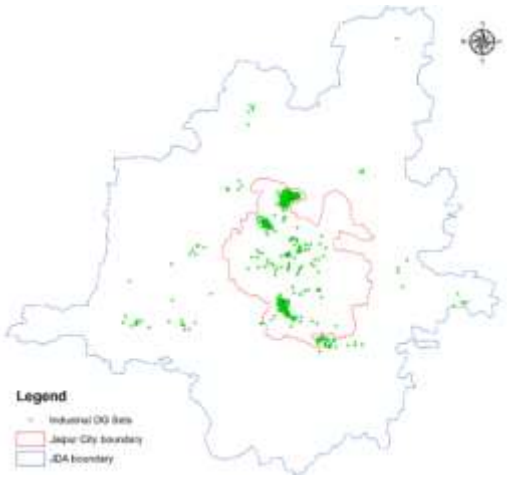


Figure 4.37: Location of Industrial DG Sets

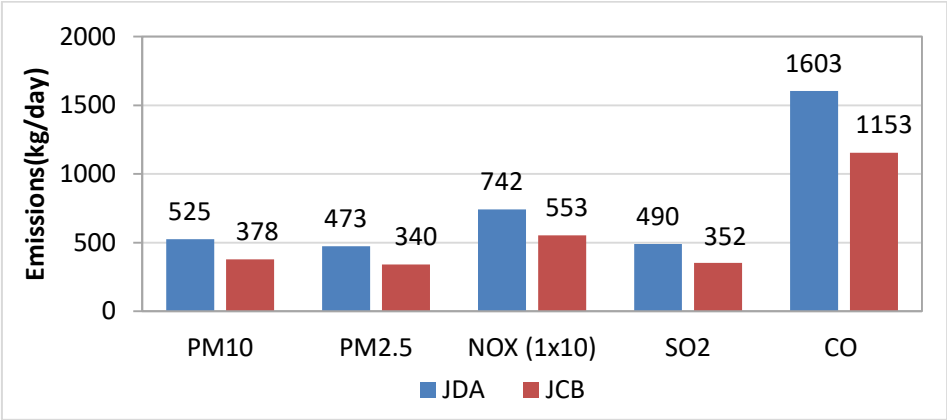


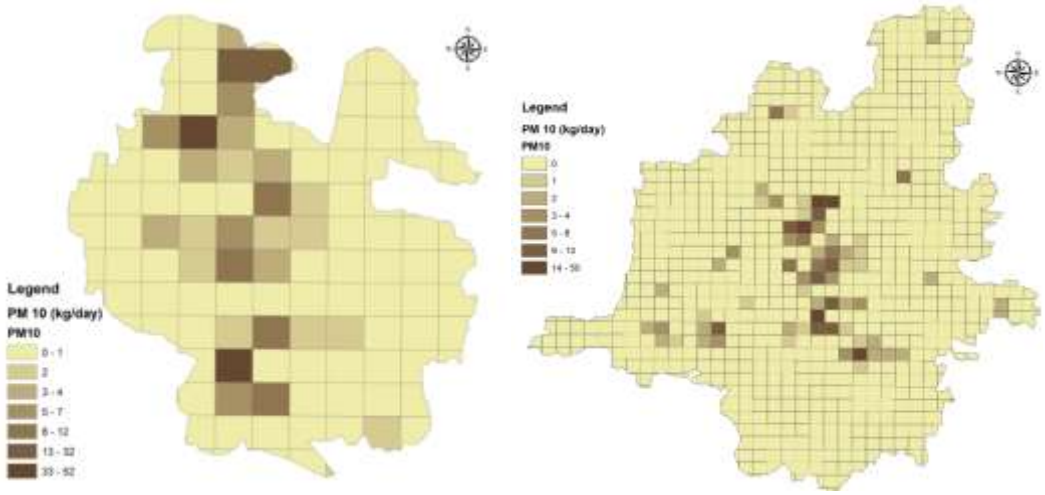
Figure 4.38: Emission Load (kg/day) from DG sets

Table 4.3: Emission Load (kg/day) from DG sets (JDA)

	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO
Industry	427	384	6030	398	1302
Apartments	21	19	295	19	64
Hospitals	32	29	454	30	98
Banquet	45	41	643	42	139
Total	**525**	**473**	**7423**	**490**	**1603**

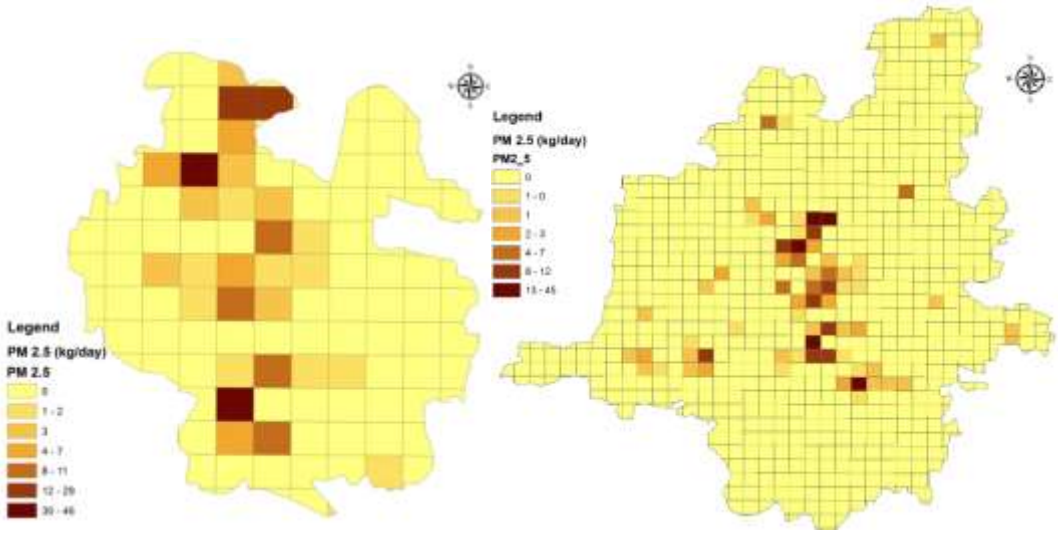
Table 4.4: Emission Load (kg/day) from DG sets (JCB)

	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO
Industry	292	262	4123	272	890
Apartments	21	19	295	19	64
Hospitals	22	20	315	21	68
Banquet	43	39	602	40	131
Total	**378**	**340**	**5334**	**352**	**1153**



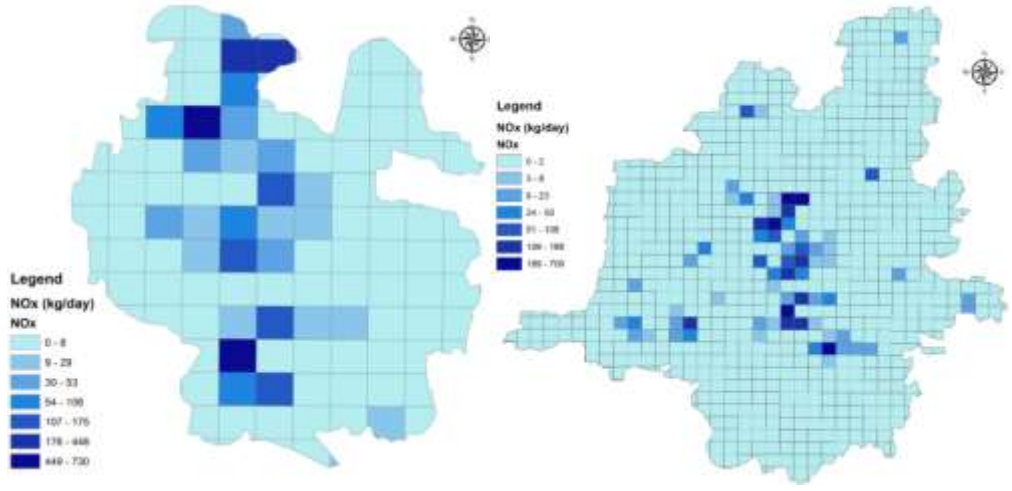
JCB **JDA**

Figure 4.39: Spatial Distribution of PM_{10} Emissions from DG Sets



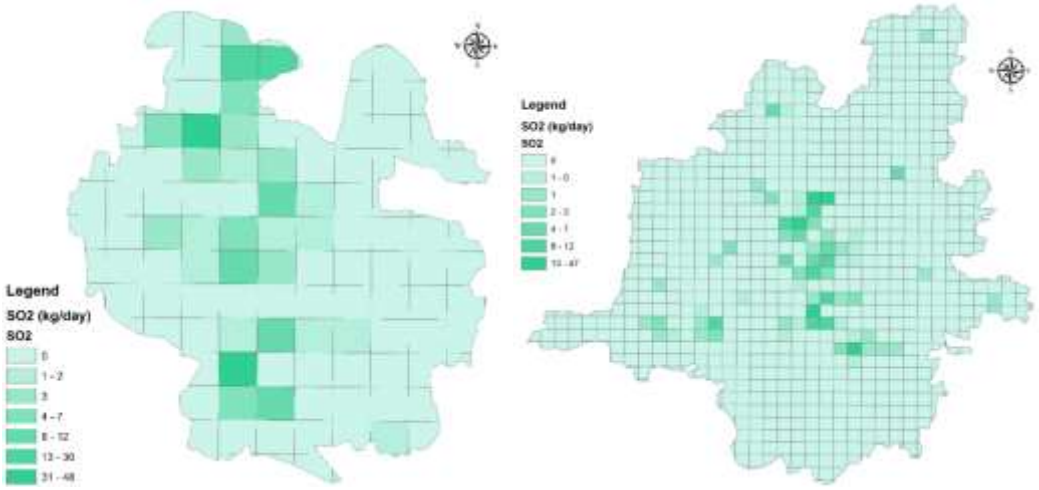
JCB **JDA**

Figure 4.40: Spatial Distribution of $PM_{2.5}$ Emissions from DG Sets



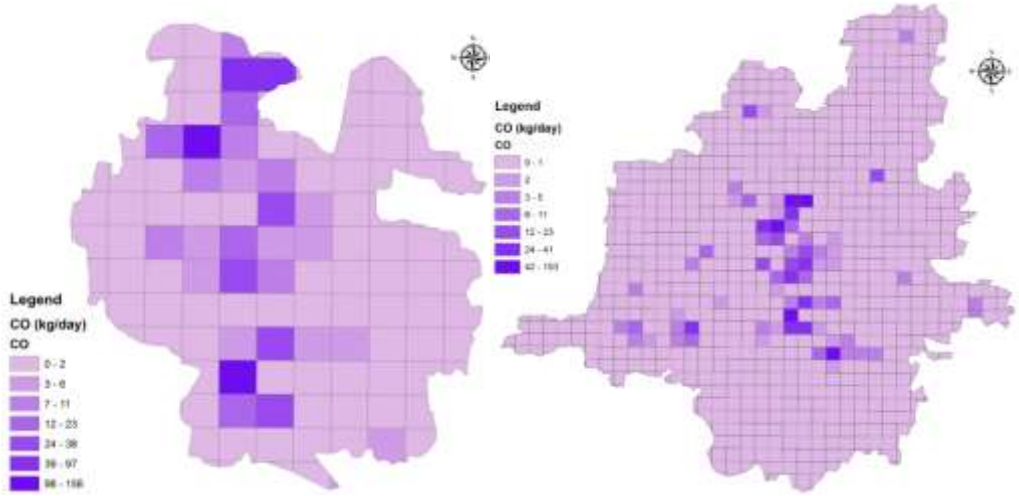
JCB **JDA**

Figure 4.41: Spatial Distribution of NOx Emissions from DG Set



JCB **JDA**

Figure 4.42: Spatial Distribution of SO_2 Emissions from DG Set



JCB **JDA**

Figure 4.43: Spatial Distribution of CO Emissions from DG Sets

The DG set emissions were separately estimated for banquet, apartments, and hospitals. The emissions are presented in Table 4.3 and 4.4. The locations and spatial distribution of these sources are shown in Figure 4.44 to 4.61.

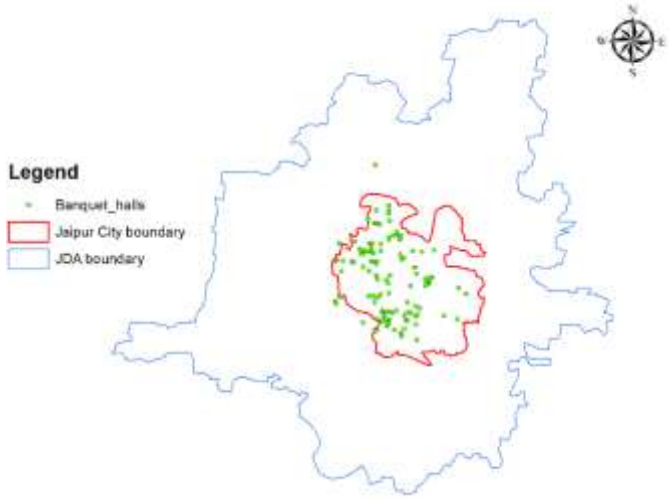
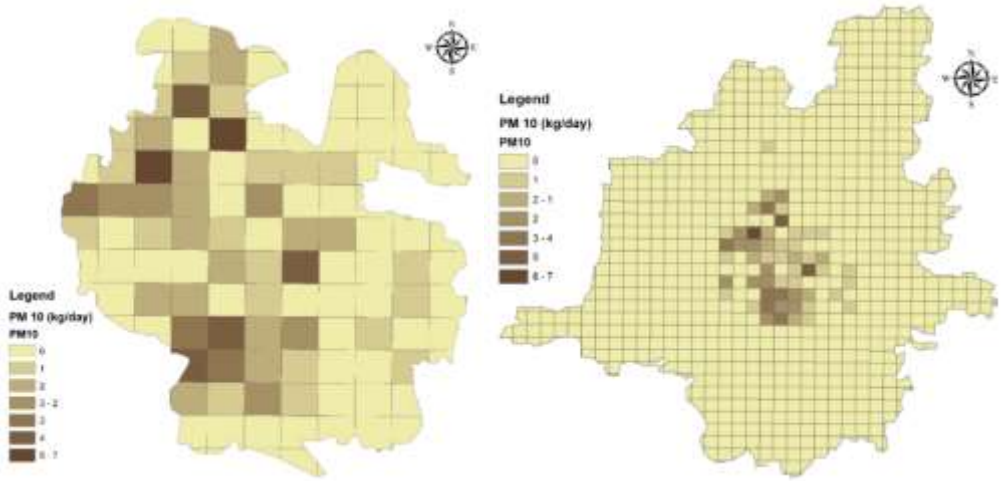
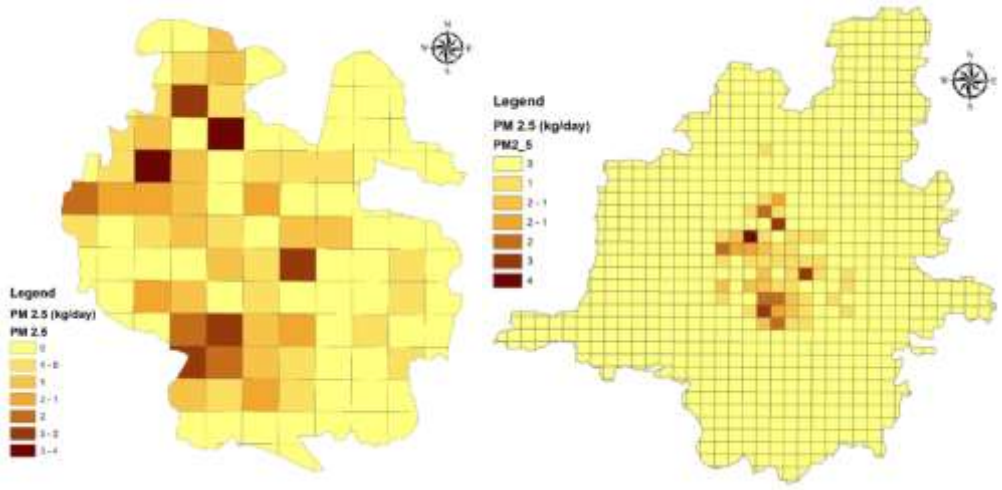


Figure 4.44: Location of DG Sets installed in Banquet Halls



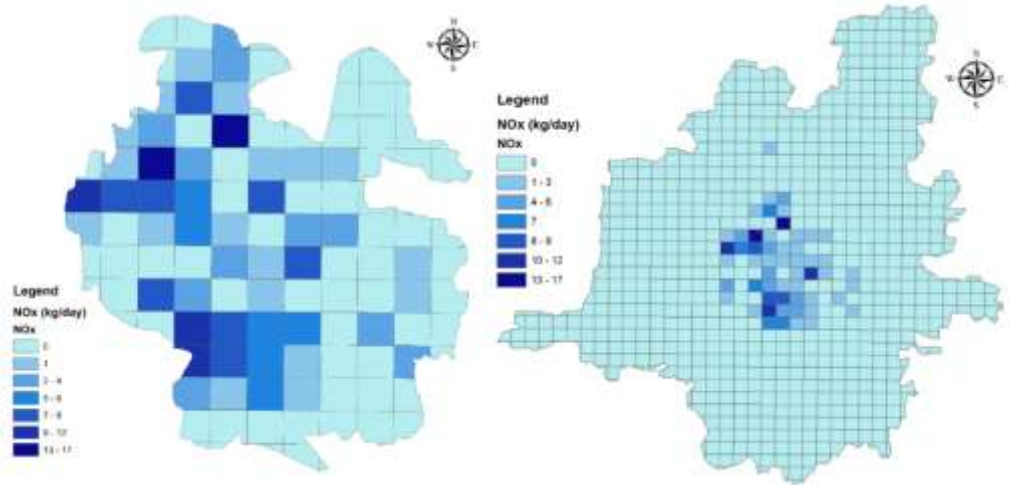
JCB **JDA**

Figure 4.45: Spatial Distribution of PM_{10} Emissions from Banquets DG sets



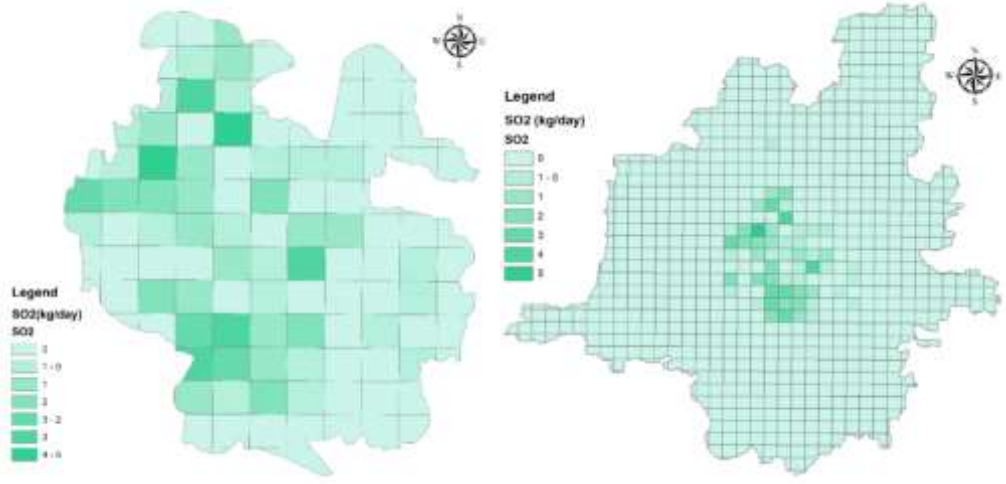
JCB **JDA**

Figure 4.46: Spatial Distribution of $PM_{2.5}$ Emissions from Banquets DG sets



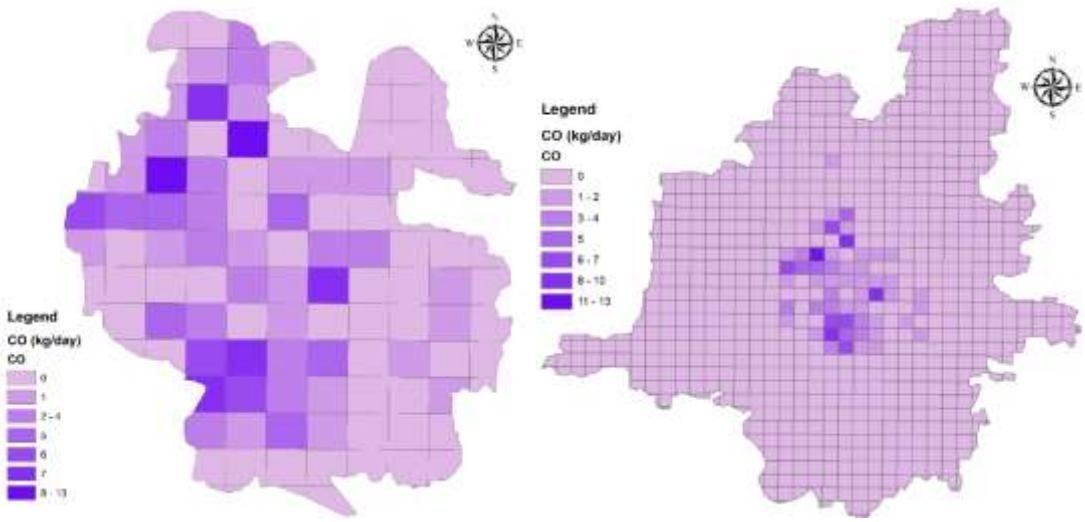
JCB **JDA**

Figure 4.47: Spatial Distribution of NOx Emissions from Banquets DG sets



JCB **JDA**

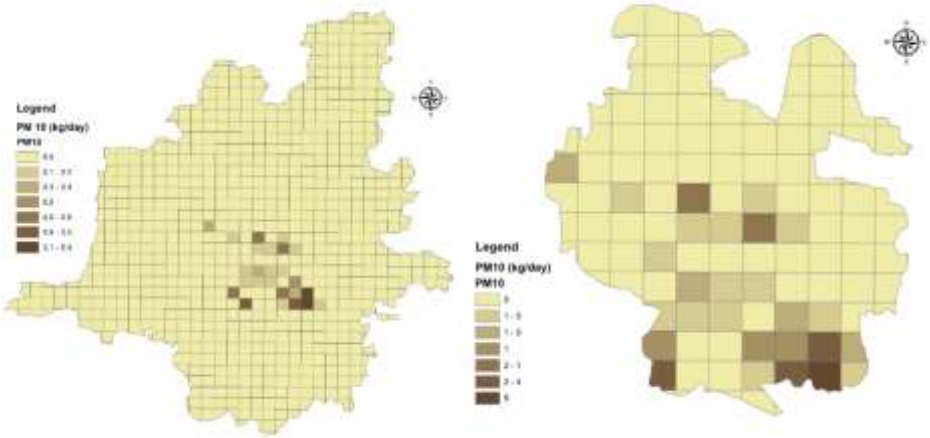
Figure 4.48: Spatial Distribution of SOx Emissions from Banquets DG sets



JCB **JDA**

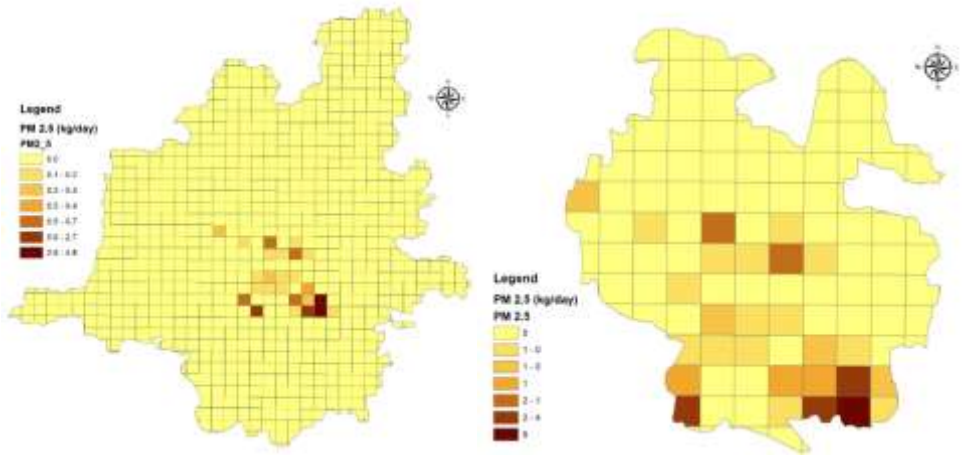
Figure 4.49: Spatial Distribution of CO Emissions from Banquets DG sets

Figure 4.50: Location of DG Sets installed in Apartments



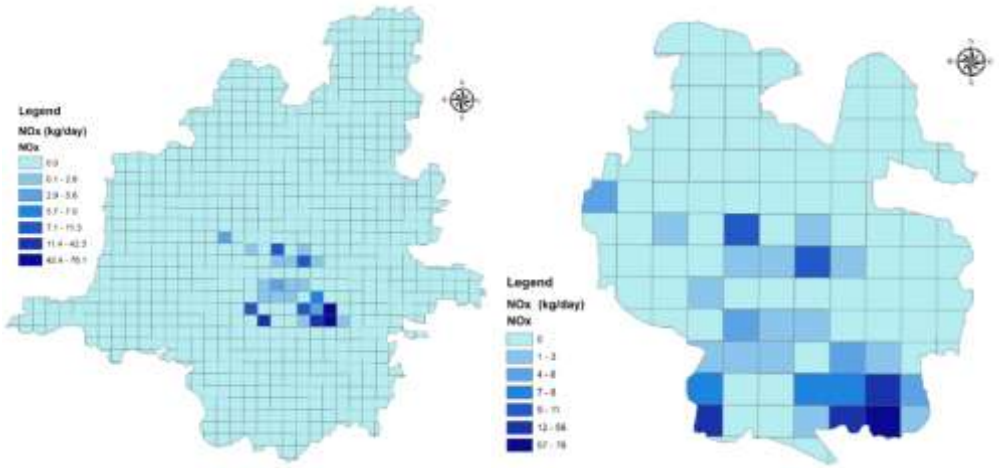
JDA **JCB**

Figure 4.51: Spatial Distribution of PM_{10} Emissions from Apartments



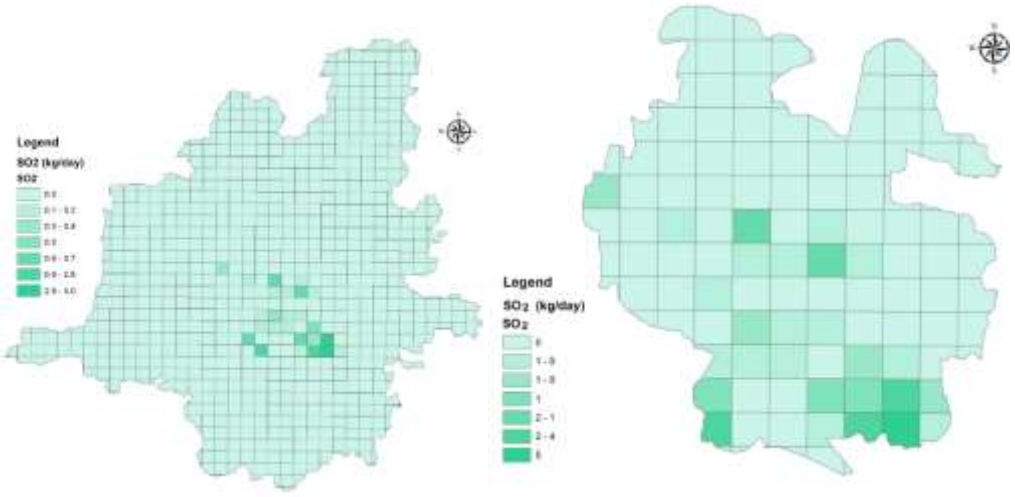
JDA **JCB**

Figure 4.52*:* Spatial Distribution of $PM_{2.5}$ Emissions from Apartments



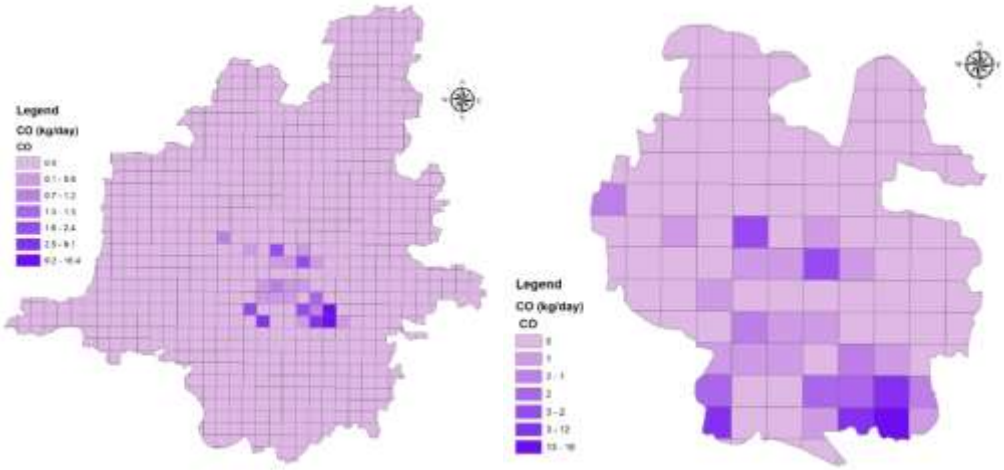
JDA **JCB**

Figure 4.53*:* Spatial Distribution of NO_X Emissions from Apartments



JDA **JCB**

Figure 4.54*:* Spatial Distribution of SO_2 Emissions from Apartments



JDA **JCB**

Figure 4.55*:* Spatial Distribution of CO Emissions from Apartments

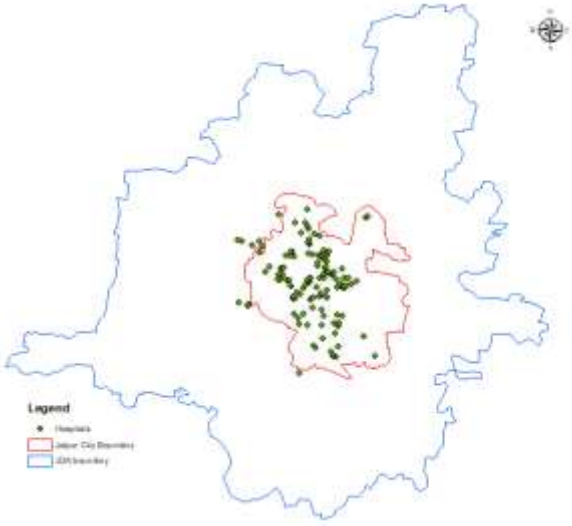
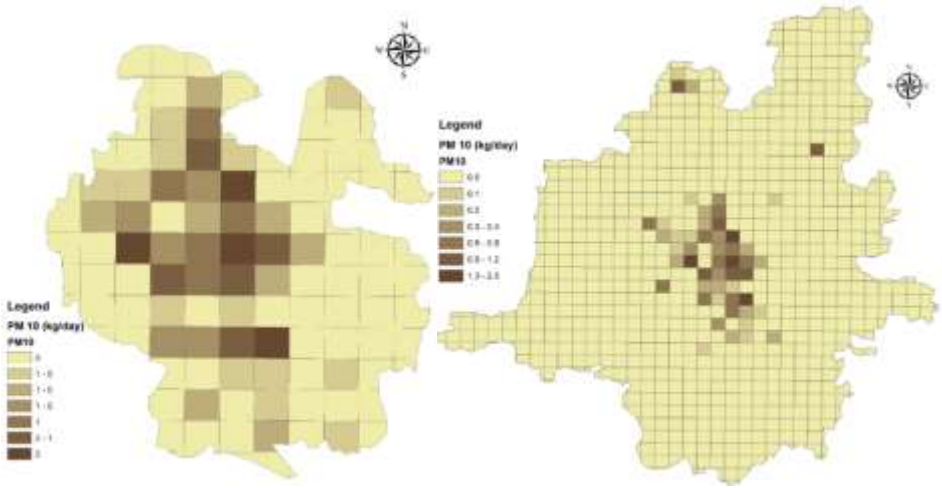
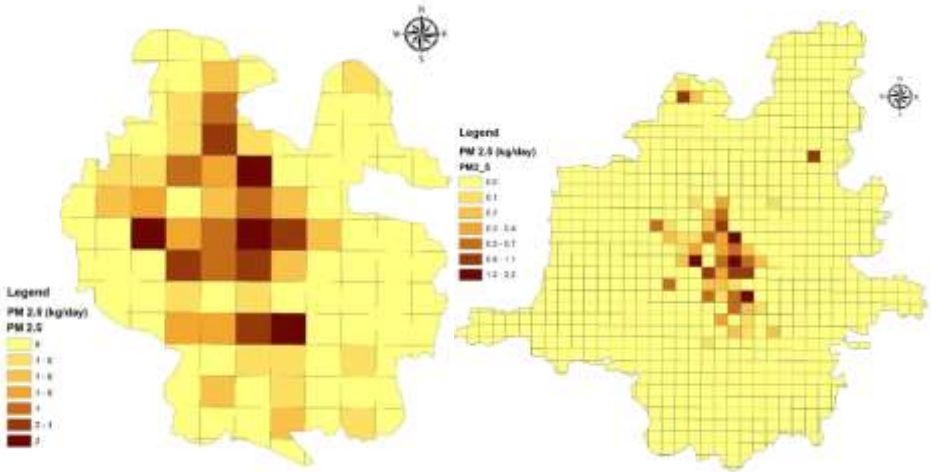


Figure 4.56: Location of DG Sets installed in Hospitals



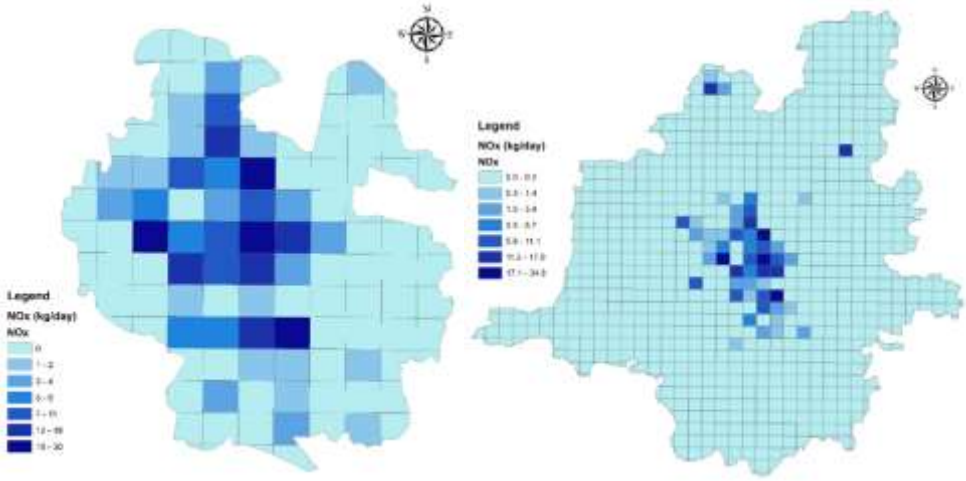
JCB **JDA**

Figure 4.57: Spatial Distribution of PM_{10} Emissions from Hospitals



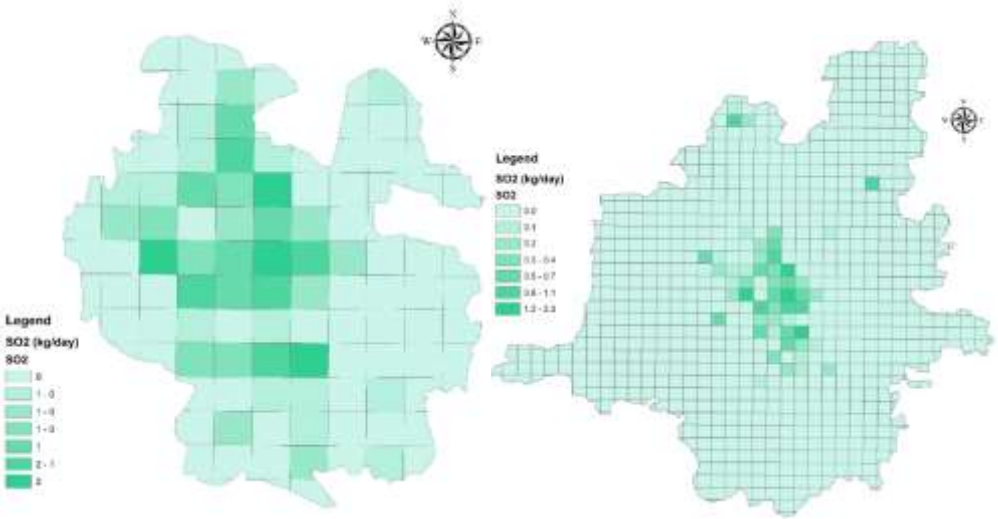
JCB **JDA**

Figure 4.58: Spatial Distribution of $PM_{2.5}$ Emissions from Hospitals



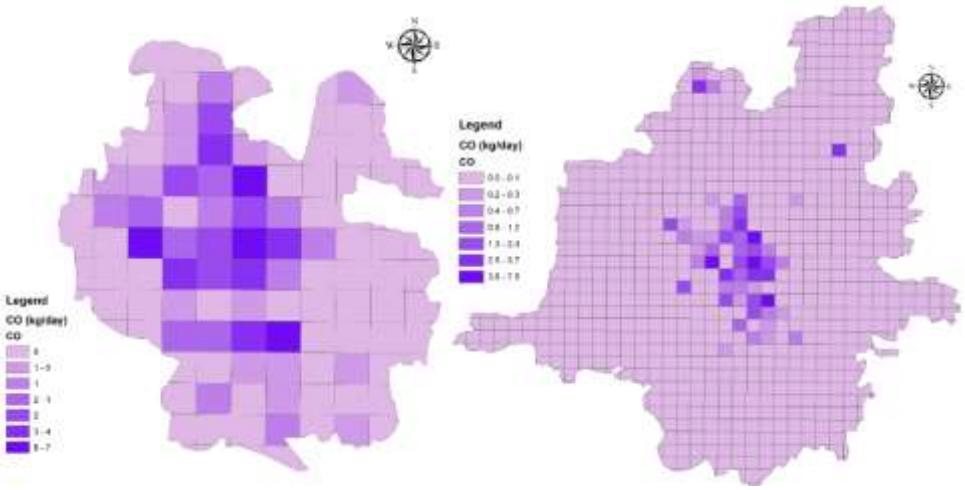
JCB **JDA**

Figure 4.59: Spatial Distribution of NOx Emissions from Hospitals



JCB **JDA**

Figure 4.60: Spatial Distribution of SOx Emissions from Hospitals



JCB **JDA**

Figure 4.61: Spatial Distribution of CO Emissions from Hospitals

4.2.7 Stone Crusher

The total Stone crusher unit present in the JDA boundary is 56, these units are located outside the city boundary (Figure 4.62). Tier 2 emission factors are obtained from the Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP) and (Visschedijk et al., 2004) and have been used to estimate the emissions from stone crushers. The total emissions from stone crushers are shown in Figure 4.63. Spatial distribution of emissions from stone crushers is shown in Figures 4.64 to 4.65.

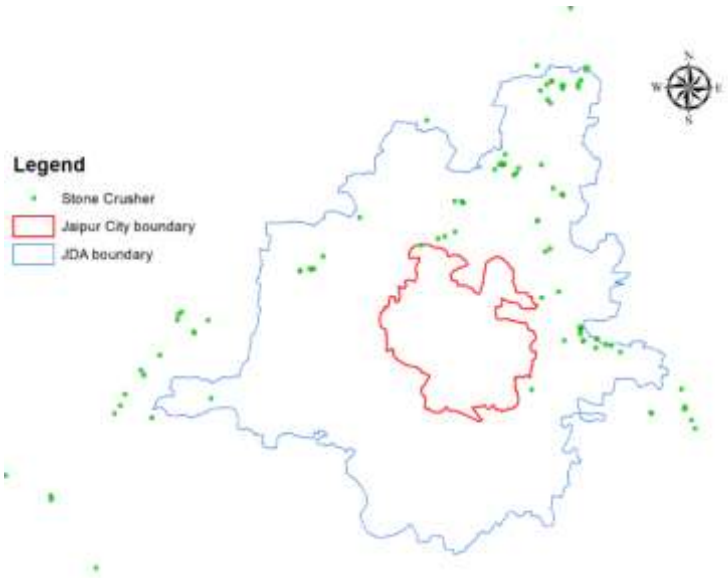


Figure 4.62: Location of Stone Crushers

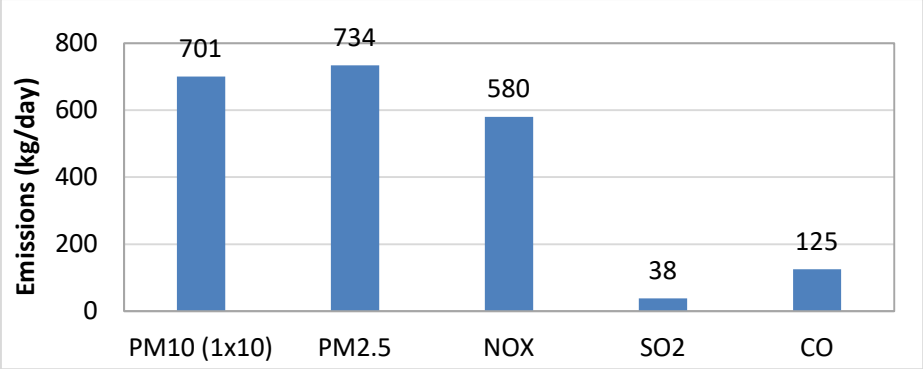
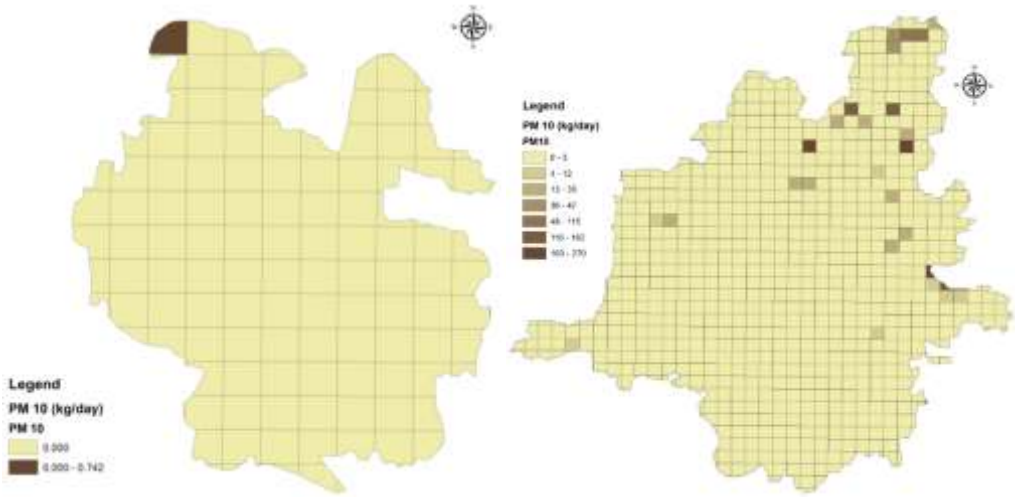
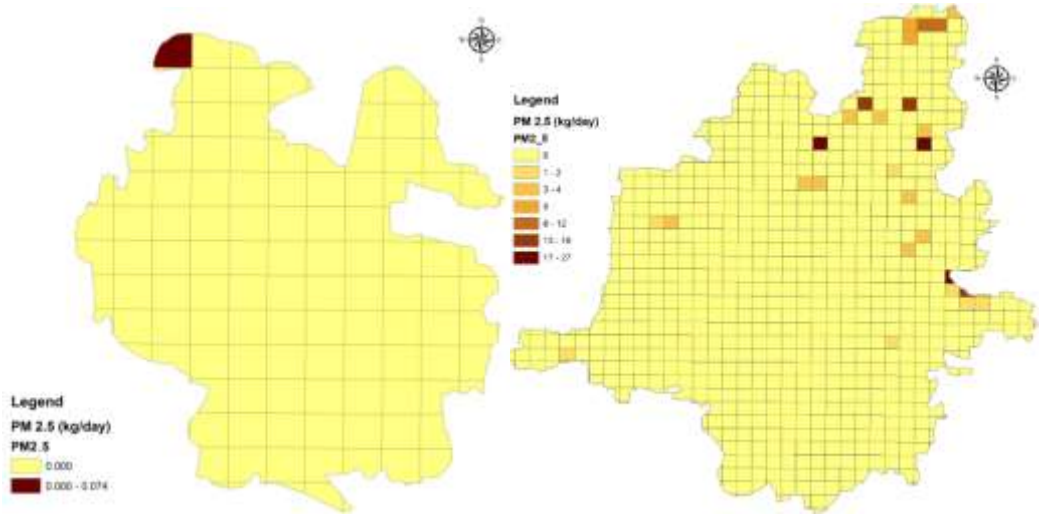


Figure 4.63: Emission Load from Stone Crusher in JDA Limits



JCB **JDA**

Figure 4.64: Spatial Distribution of PM_{10} Emissions from Stone crusher



JCB **JDA**

Figure 4.65: Spatial Distribution of $PM_{2.5}$ Emissions from Stone crusher

4.2.8 Hotels and restaurants

The primary survey was conducted by IITK team to identify the hotels and restaurants of more than sitting capacity of ten persons and other eating joints (Figure 4.66).

Figure 4.66: Hotel and Restaurant Survey

During the field survey it was observed that hotels, restaurants, etc use coal as fuel in tandoors. The average consumption of coal in tandoor based on survey was 30 kg/day. The total number of big hotel and restaurant enterprise was approximately 1500 (Figure 4.67). The common fuel other than in tandoor is LPG. 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 the activity data from each fuel type and then were summed up in each grid cell. The emission factors given by CPCB (2011) were used. The overall emission from this area source (Hotels/Restaurants) is shown in Figure 4.68. Spatial distribution of emissions from hotels/restaurant is shown in Figures 4.69 to 4.73.

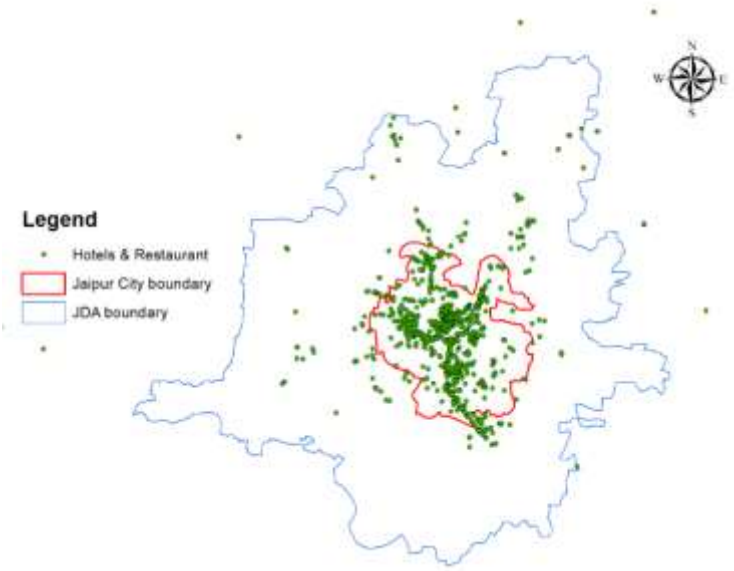


Figure 4.67: Location of Hotels and Restaurants

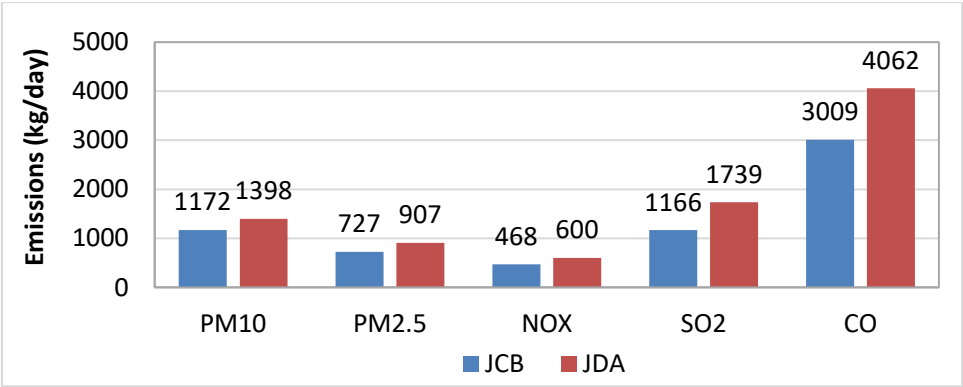
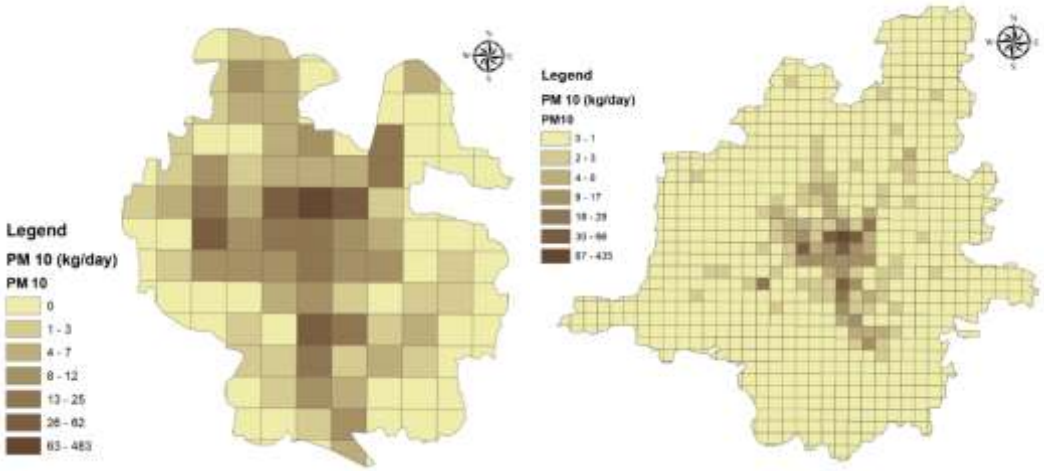
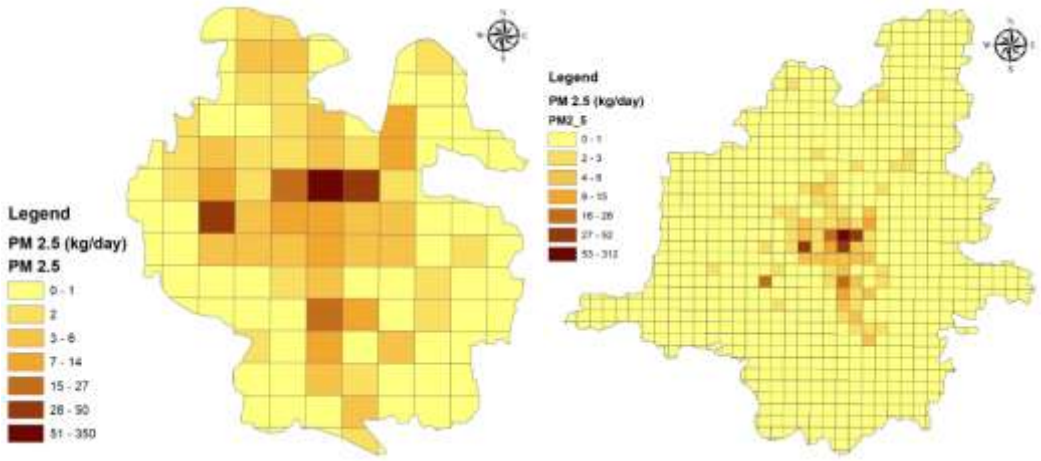


Figure 4.68: Emission Load from Hotels and Restaurants



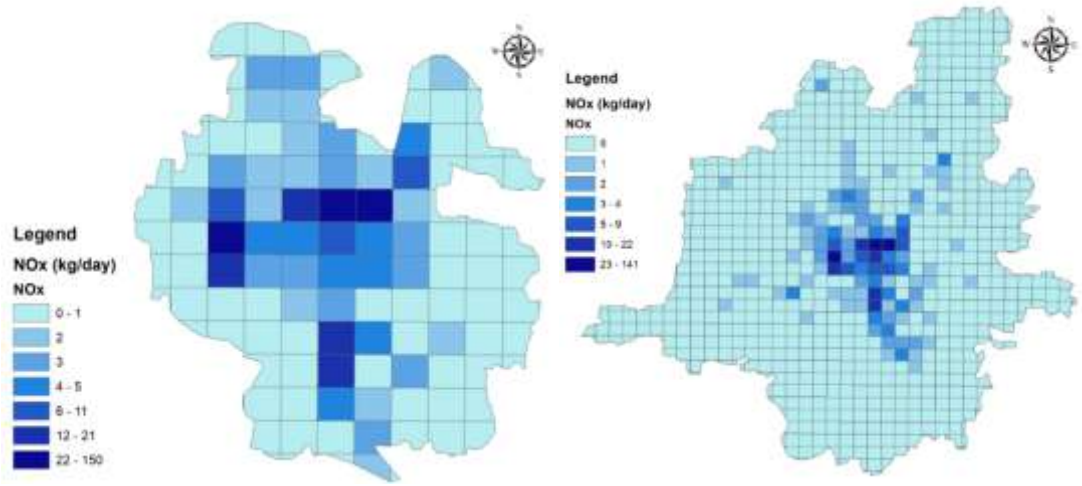
JCB **JDA**

Figure 4.69: Spatial Distribution of PM_{10} Emissions from Hotels and Restaurants



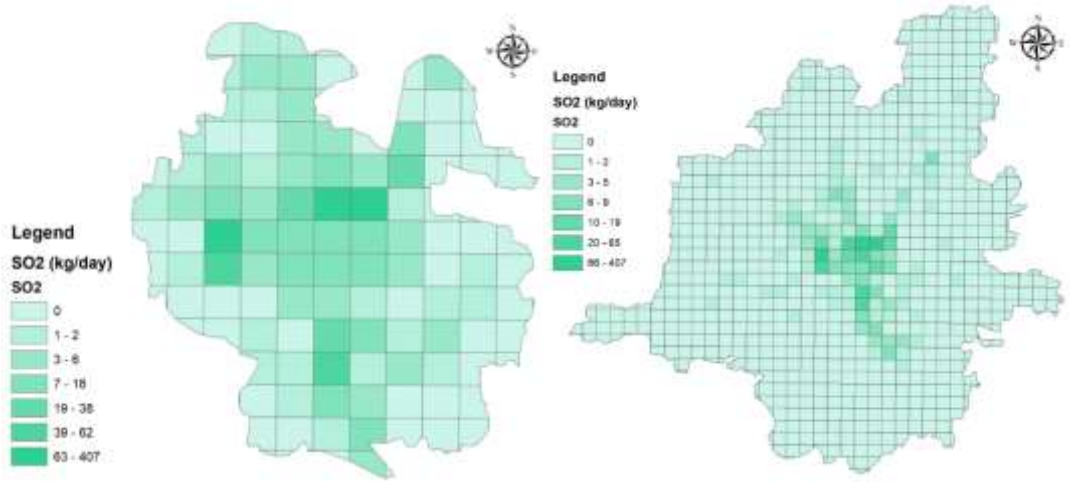
JCB **JDA**

Figure 4.70: Spatial Distribution of $PM_{2.5}$ Emissions from Hotels and Restaurants



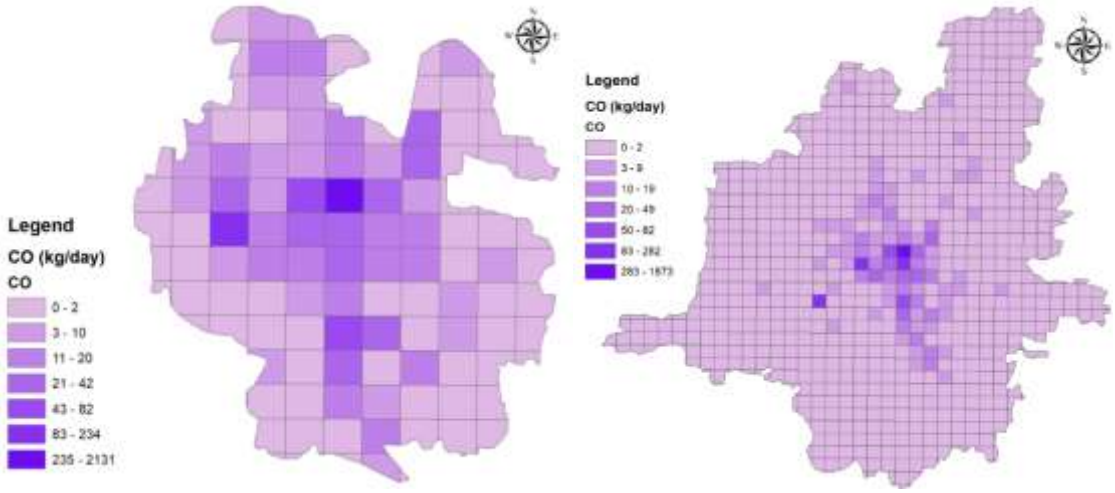
JCB **JDA**

Figure 4.71: Spatial Distribution of NO_X Emissions from Hotels and Restaurant



JCB **JDA**

Figure 4.72: Spatial Distribution of SO_2 Emissions from Hotels and Restaurants



JCB **JDA**

Figure 4.73: Spatial Distribution of CO Emissions from Hotels and Restaurants

4.2.9 Brick Kiln

Brick kiln are one of the major contributors to air pollution. Detailed survey and activity data were collected. There are approximately 250 brick kiln presents in Jaipur (outside the city boundary; Figure 4.74). These kiln uses wood and coal as fuel. The emissions of various parameters such as SO_2, NOx, PM_{10}, $PM_{2.5}$, and CO were estimated from the activity data from each fuel type and then were summed up in each grid cell. The emission factors given by CPCB (2011) were used. The overall emission from brick kilns is shown in Figure 4.75. Spatial distribution of emissions from brick kilns is shown in Figures 4.76 to 4.80.

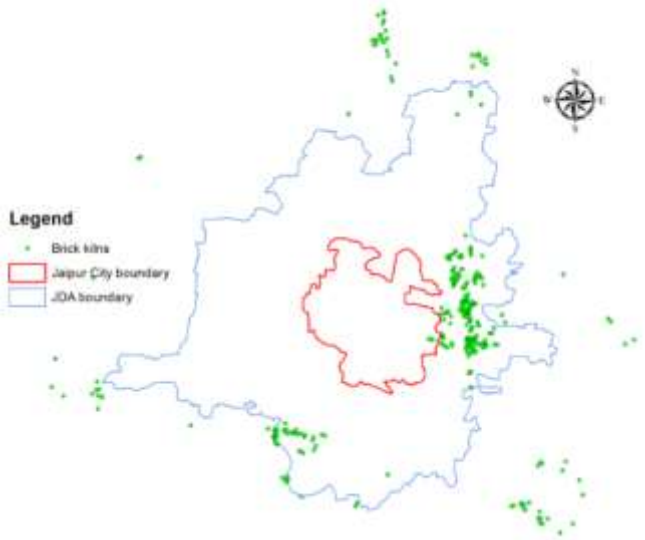


Figure 4.74: Location of Brick Kilns

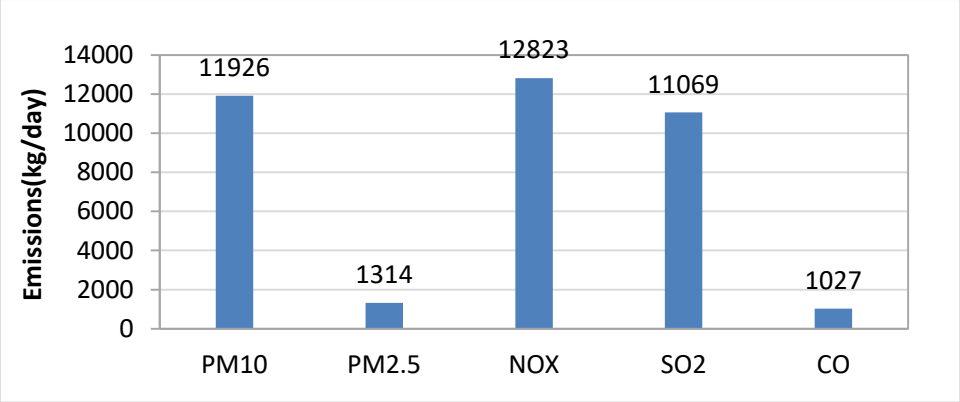
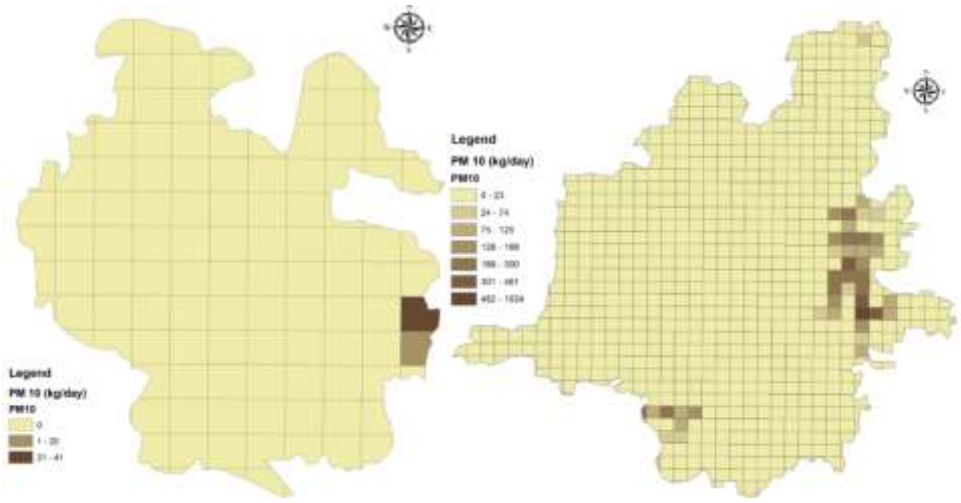


Figure 4.75: Emission Load from Brick Kiln in JDA

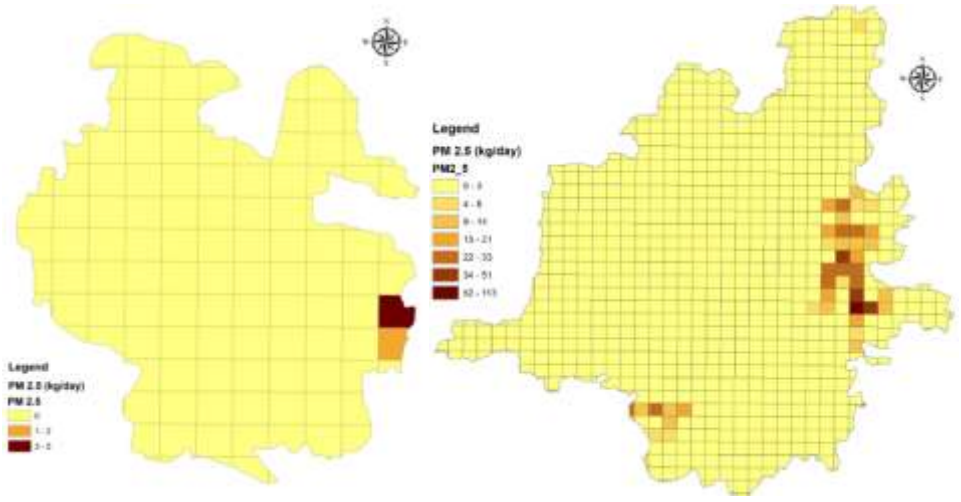
Two numbers of kilns were in Jaipur city boundary, the emissions are presented in table below:

	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO
JCB	61	7	66	57	5



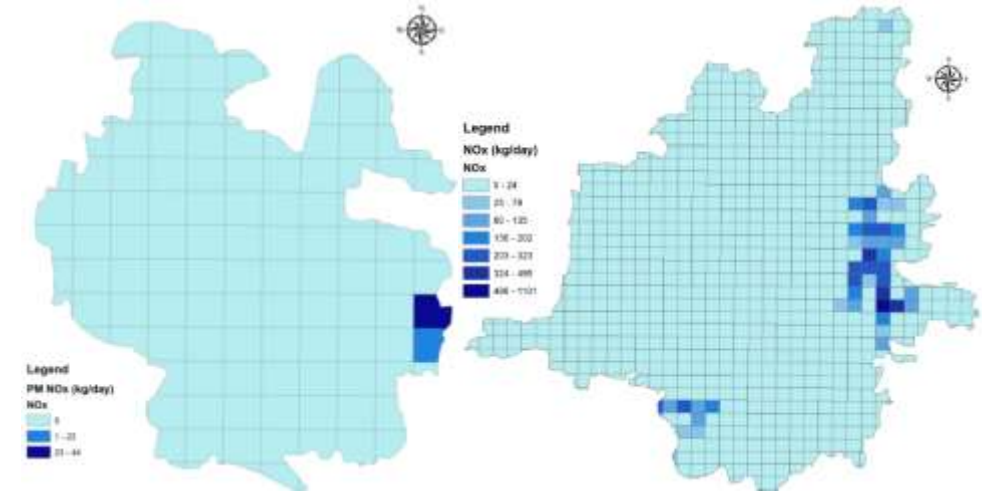
JCB **JDA**

Figure 4.76: Spatial Distribution of PM_{10} Emissions from Brick kilns



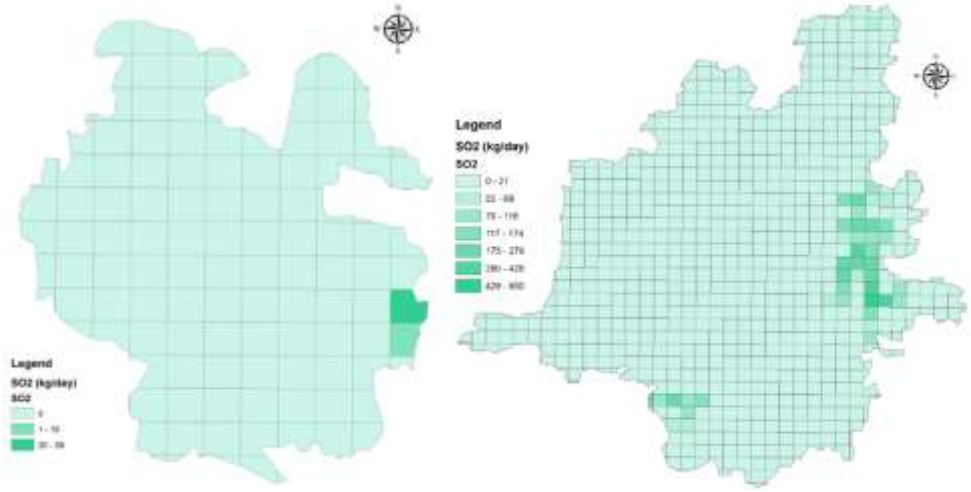
JCB **JDA**

Figure 4.77: Spatial Distribution of $PM_{2.5}$ Emissions from Brick kilns



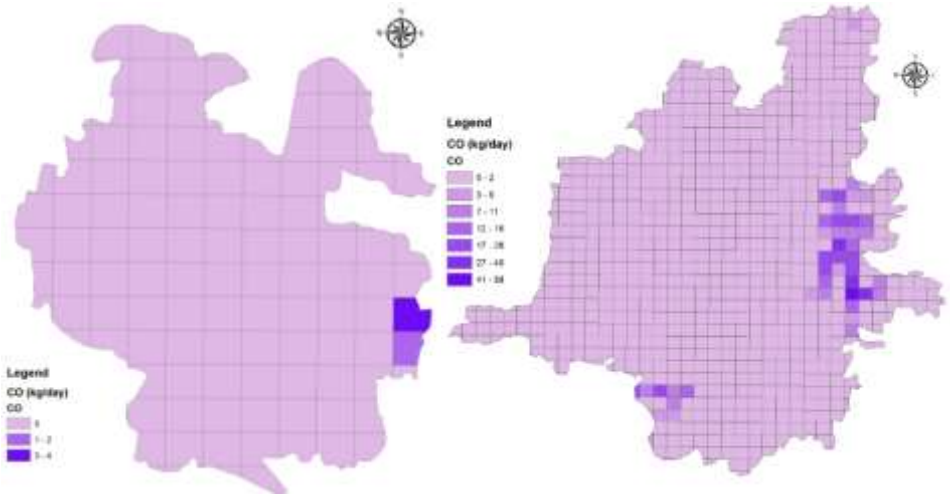
JCB **JDA**

Figure 4.78: Spatial Distribution of NO_X Emissions from Brick kilns



JCB **JDA**

Figure 4.79: Spatial Distribution of SO_2 Emissions from Brick kiln



JCB **JDA**

Figure 4.80: Spatial Distribution of CO Emissions from Brick kilns

4.2.10 Municipal Solid Waste burning

Open burning activities are broadly classified into refuse and biomass burning. The refuse or municipal solid waste (MSW) burning depends on solid waste generation and extent of disposal and infrastructure for collection. The contribution of MSW burning may surprise many persons. It is a myth that MSW is not burned in Jaipur. This emission is expected to be large in the regions of economically lower strata of the society which do not have proper infrastructure for collection and disposal of MSW.

The emission factors 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 4.81 and spatial distribution of in Figures 4.82 to 4.86.

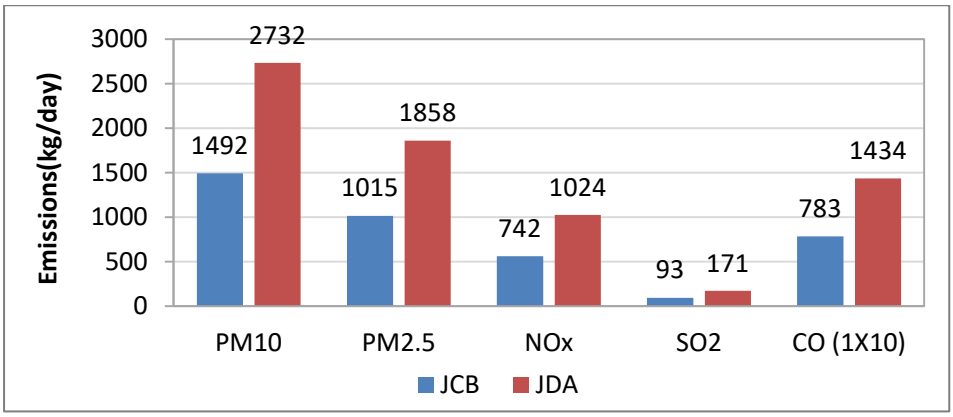
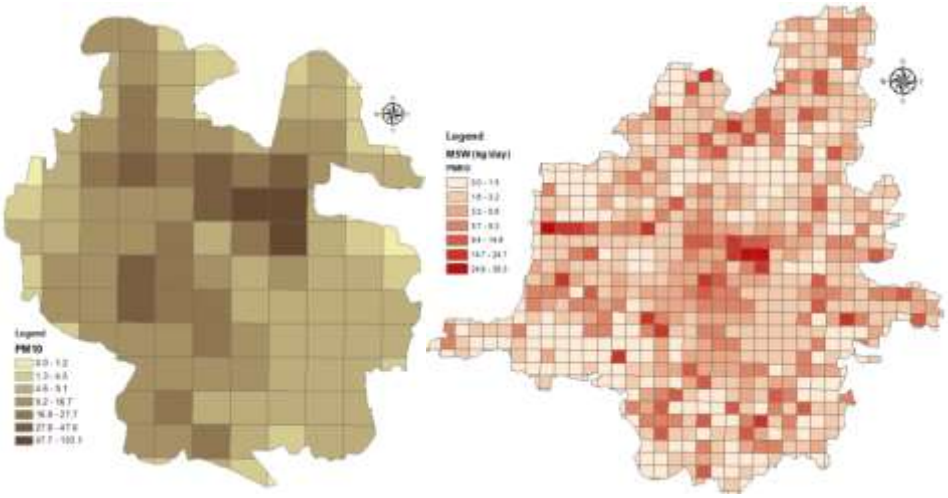
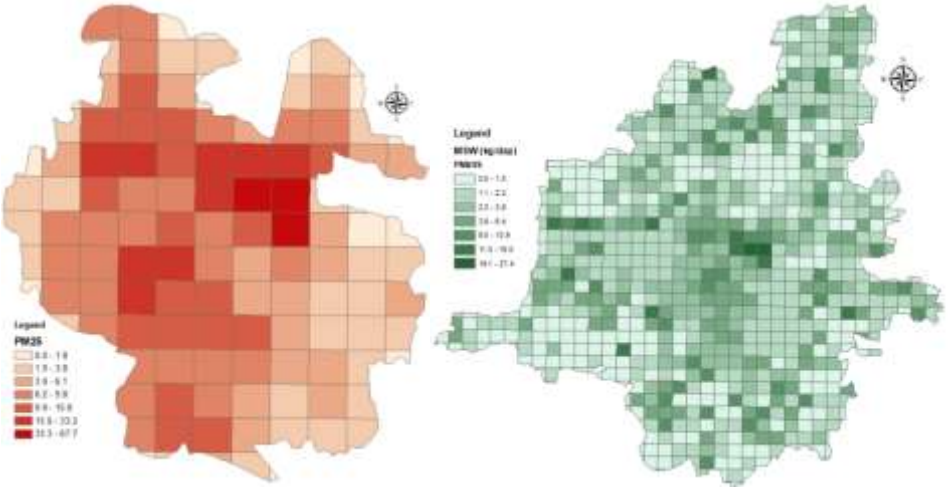


Figure 4.81: Emission Load from MSW Burning



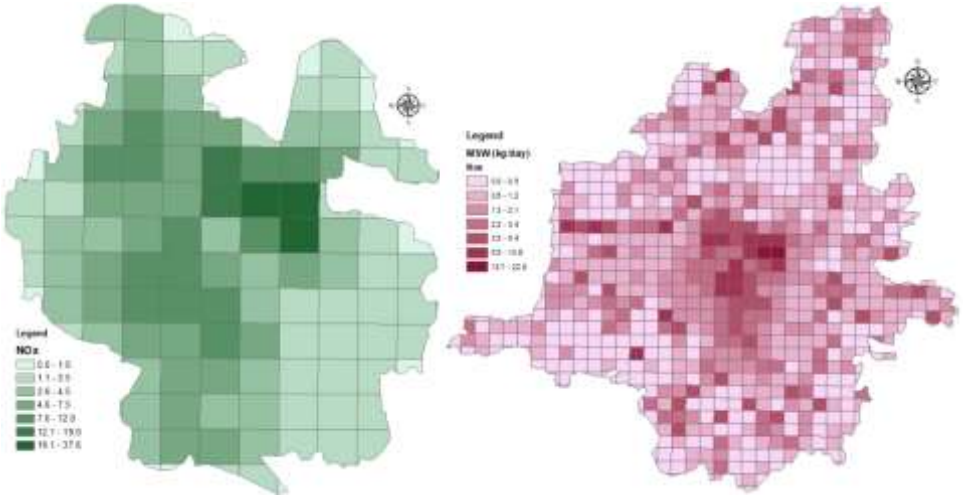
JCB **JDA**

Figure 4.82: Spatial Distribution of PM_{10} Emissions from MSW Burning



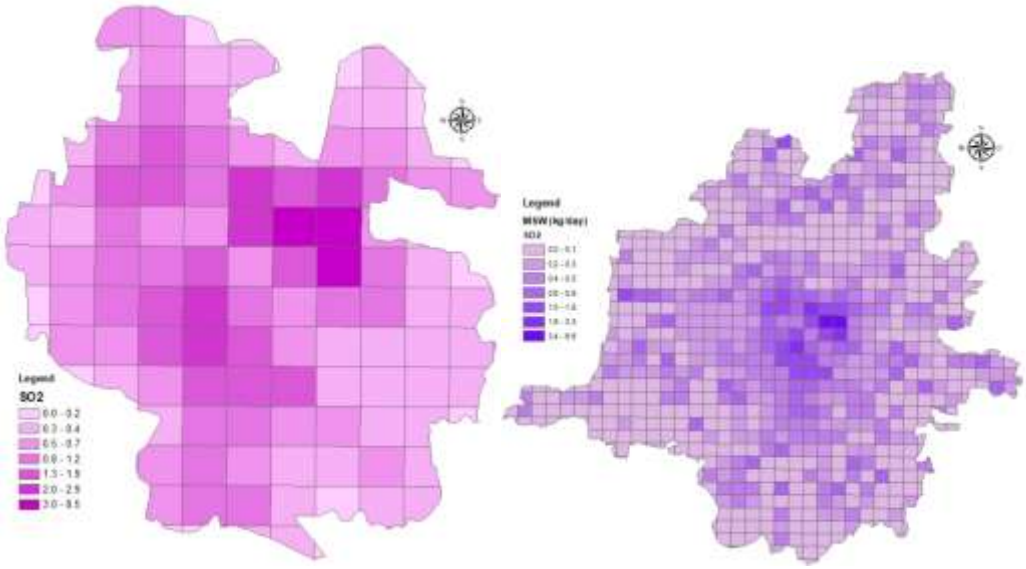
JCB **JDA**

Figure 4.83: Spatial Distribution of $PM_{2.5}$ Emissions from MSW Burning



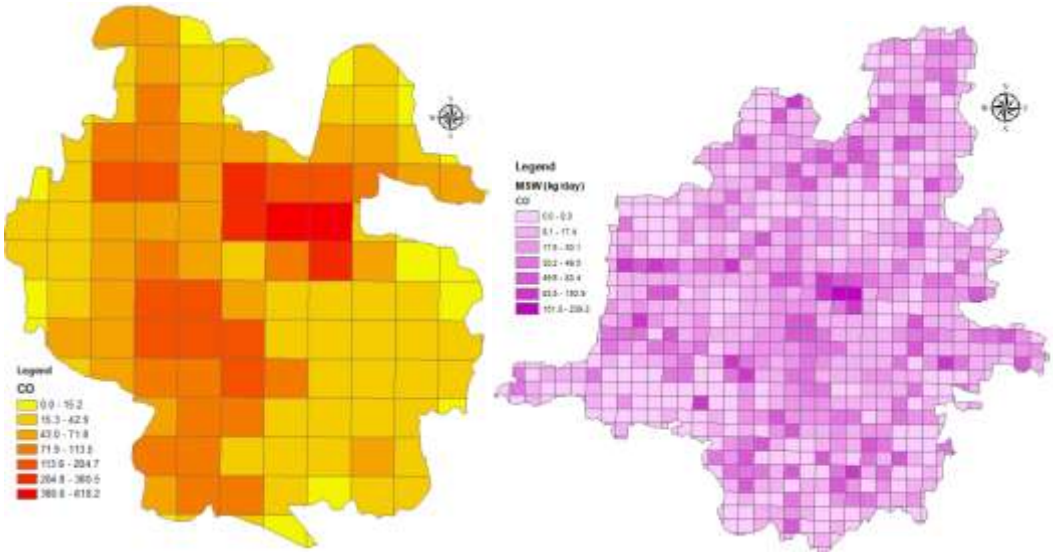
JCB **JDA**

Figure 4.84: Spatial Distribution of NO_X Emissions from MSW Burning



JCB **JDA**

Figure 4.85: Spatial Distribution of SO_2 Emissions from MSW Burning



JCB **JDA**

Figure 4.86: Spatial Distribution of CO Emissions from MSW Burning

4.2.11 Mining

The total mining unit present in the JDA boundary is approximately 450, these units are located outside the city boundary (4.87). Tier 2 emission factors are obtained from the Coordinated European Particulate Matter Emission Inventory Program (CEPMEIP) and (Visschedijk et al., 2004) and have been used to estimate the emissions from stone crushers.

The total emissions from stone crushers are shown in Figure 4.88. Spatial distribution of emissions from stone crushers is shown in Figures 4.89 to 4.90.

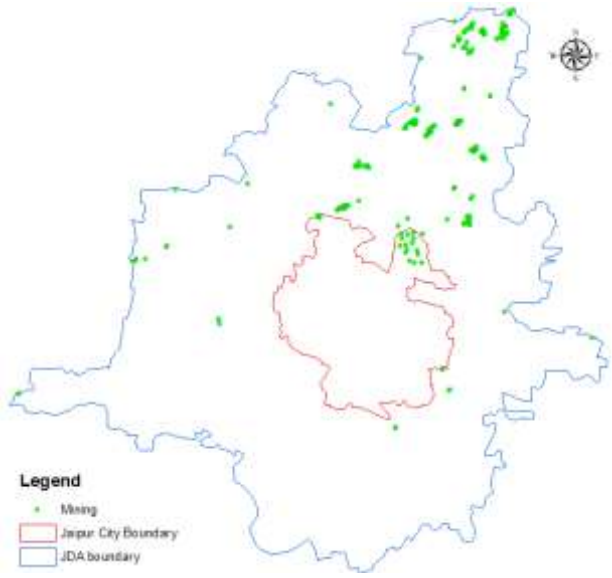


Figure 4.87: Location of Mines

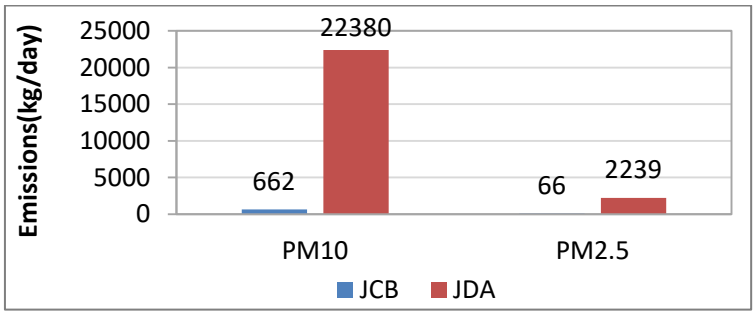
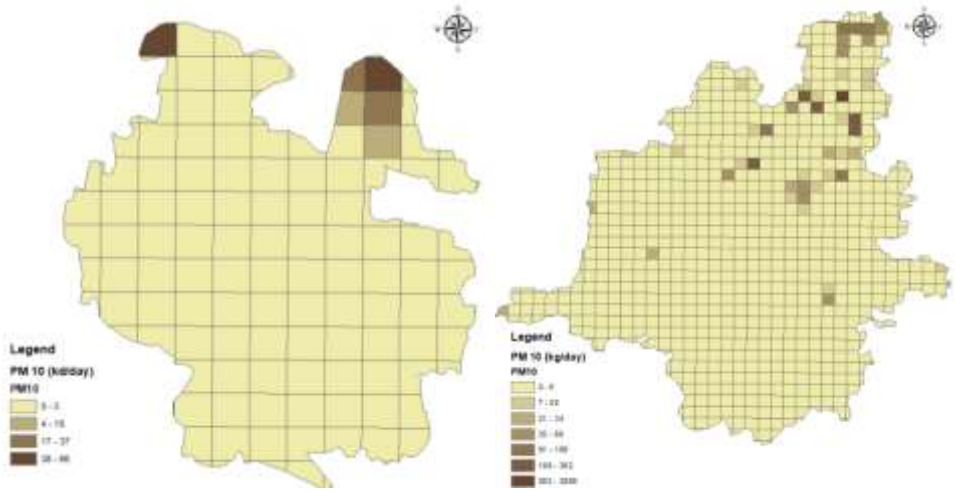
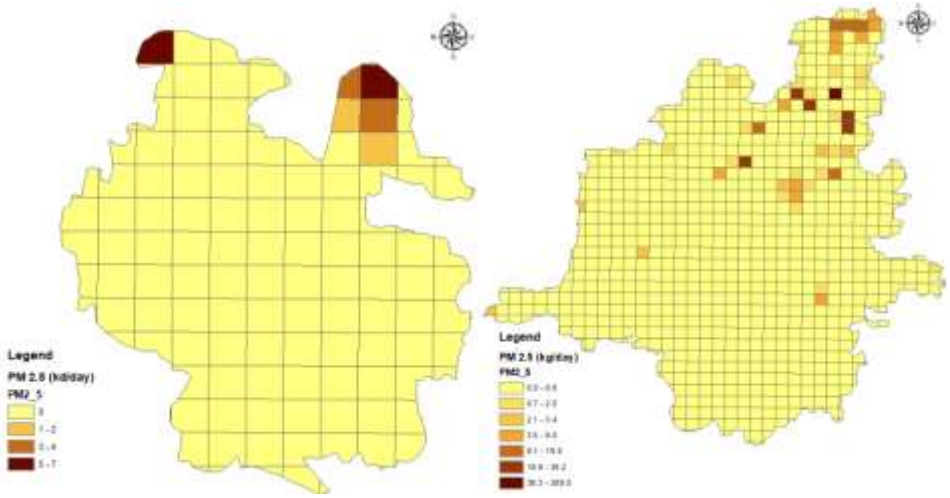


Figure 4.88: Emission Load from Mining



JCB **JDA**

Figure 4.89: Spatial Distribution of PM_{10} Emissions from Mining



JCB **JDA**

Figure 4.90: Spatial Distribution of $PM_{2.5}$ Emissions from Mining

4.2.12 Aircraft

Jaipur International Airport (IATA: JAI, ICAO: VIJP) is the primary airport of Jaipur. Total number of flight (arrival + departure) is approximately 60 per day at Jaipur Airport. The aircraft arriving and departing is categorized according to their companies and engine capacity. The emission factors used have been adopted from ICAO (International Civil Aviation Organization; http://www.icao.int). From aircrafts most of the emissions is during the LTO (landing and takeoff) cycle, compared to time of flight within the Jaipur border. The estimated emission is shown in Figure 4.91. This emission is expected to be dispersing in upper part of atmosphere.

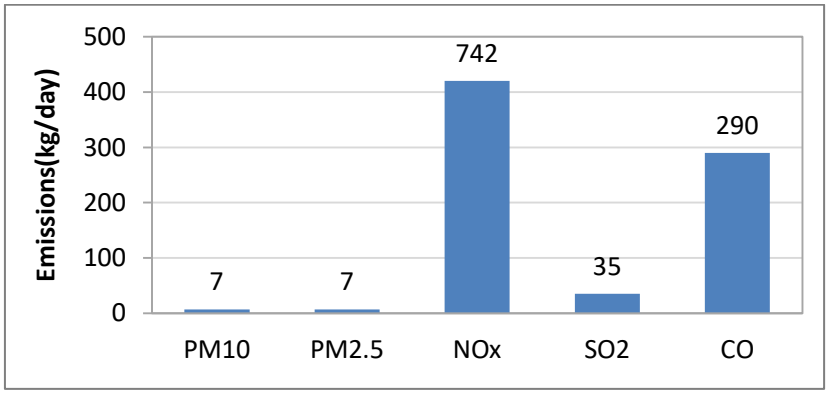


Figure 4.91: Emission Load from Aircraft

4.2.13 Open Area Soil Dust

The total open area within JCB (49300 ha) was calculated in GIS. The emission factor for crop type is obtained from EMEP/EEA air pollutant emission inventory guide book (EEA, 2013). The total PM_{10} emission from open area soil dust is estimated to be 1321 kg/day. The $PM_{2.5}$ emission is negligible.

4.2.14 Industries

There are 48 industrial areas in Jaipur (source: RIICO). There are about 500 boilers/furnaces (smaller in size) that are operational in Jaipur and contribute to particulate as well as in gaseous emissions (Figure 4.92). The overall emissions estimated from the different types of boilers, furnaces, etc are presented in Table 4.5. The large contribution is due to the use of coal, wood, and other dirty fuels, the industry should shift to clean fuel such as Natural gas and electricity will significantly reduce the emissions.

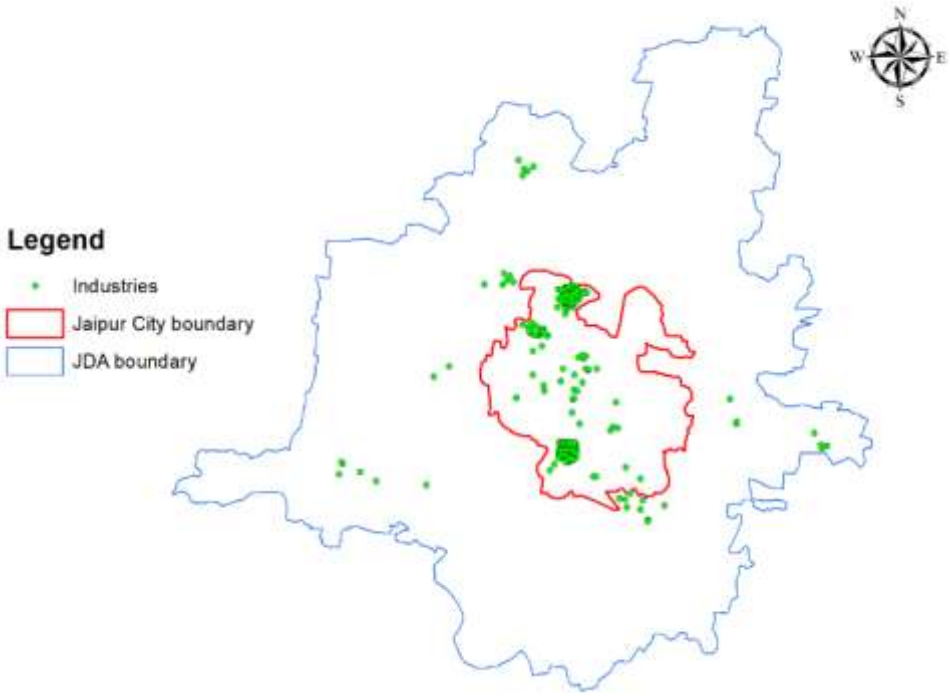


Figure 4.92: Location of Industries

Table 4.5: **Furnace/Boiler Details in Jaipur (Source: Consent Data)**

Source	Fuel used	Numbers of sources	Fuel Quantity (kg/day)	PM_{10}	$PM_{2.5}$	NO_X	SO_2	CO
Boiler	F.O., Agro waste fired, Coal, Wood, HSD, Gas, LPG,	154	687085	2365	2128	1344	1458	9310
Bhatti	HSD FIRED	7	1280	1	1	3	7	0
Cupola Furnace	LPG, Coal	46	264020	802	721	869	750	20
Induction Furnace	Electricity	62	909338	866	780	0	0	0
Lead Furnace	F.O. Fired	2	320	0	0	1	7	0
Melting Furnace	Coal, F.O.	8	22083	64	58	70	104	2
Paint Booth	HSD, Oil fired	14	501	0	0	1	3	0
Uncategorised Furnace	LDO, Coal, Diesel, Electric, F.O., Wood, HSD	62	250480	600	540	609	944	1284
Galvanizing Furnace	LSHS FIRED	9	10032	7	6	20	102	2
Hot Water and Air Generator	HSD, Diesel	9	8512	4	3	17	48	2
Reactor	Wood	58	647874	3362	3026	253	39	24548
Re Heating Furnace	Coal, F.O.	13	126020	266	240	319	1805	17
Roasters	wood	2	2280	12	11	1	0	86
Thermopack	F.O., HSD, Agro waste, Wood	11	83296	44	40	163	501	47
Thermic Fluid Heater	Coal, HSD, Wood, Agro waste,Oil	32	50864	89	80	83	212	496
Zinc Furnace	Oil Fired	9	1080	2	1	2	24	0
Annealing Furnace	Coal	3		134	121	145	125	3
Pulveriser	Coal	4	16000	49	44	54	46	1
Total		505	3081065	8666	7799	3954	6177	35819

Industries as Area Source

Figure 4.93 presents the overall emissions from industries (stack height < 20 m) as an area source.

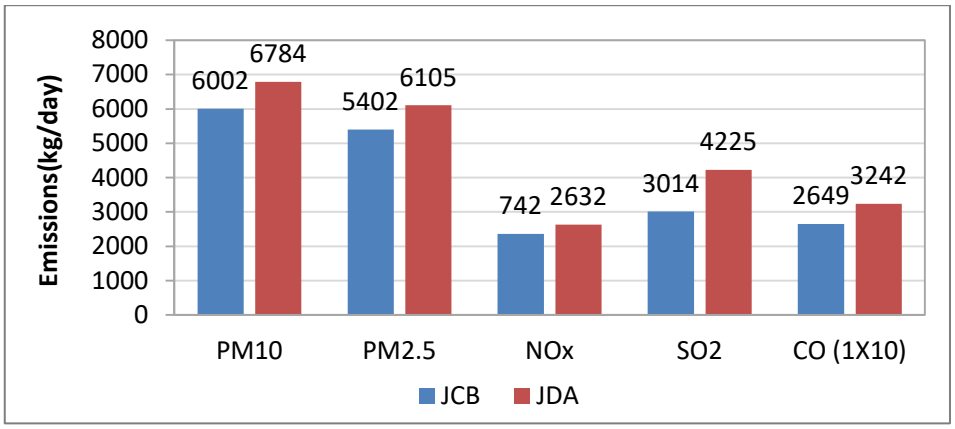


Figure 4.93: Emission Load from Industries as Area Source

Industries as Point Source

The industries having stack height of more than 20 m have been taken as point source. The information on stacks, fuel and its consumption were obtained from RSPCB. The industries have been numbered and located on the map (Figure 4.92). The major emission is from coal-based power plants at Badarpur and Rajghat. The AP-42 (USEPA, 2000) emission factors were used to calculate the emission. The emission of pollutants from large industry is shown in Figure 4.94.

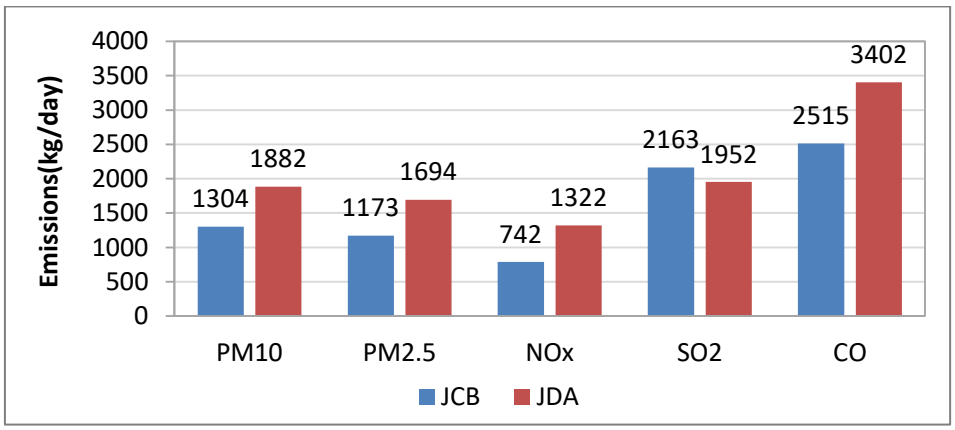
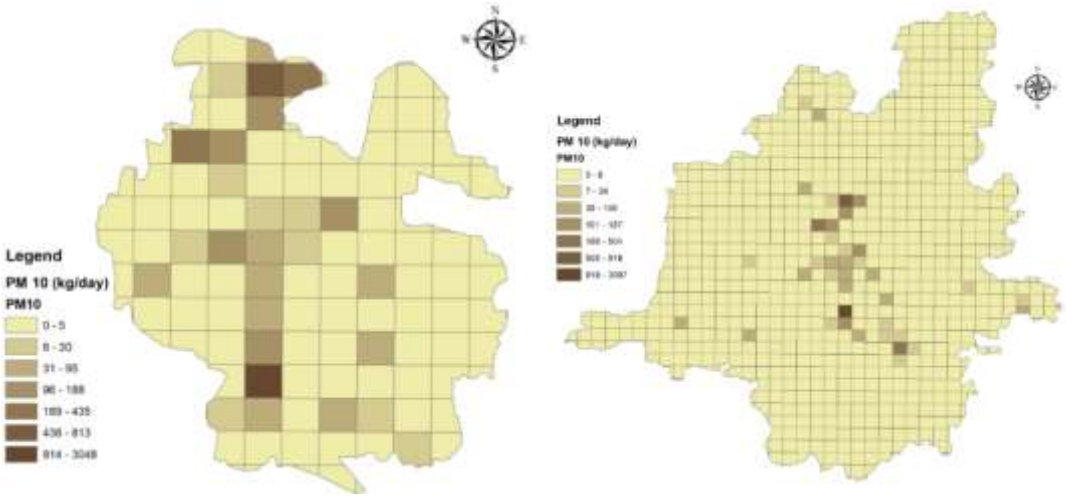


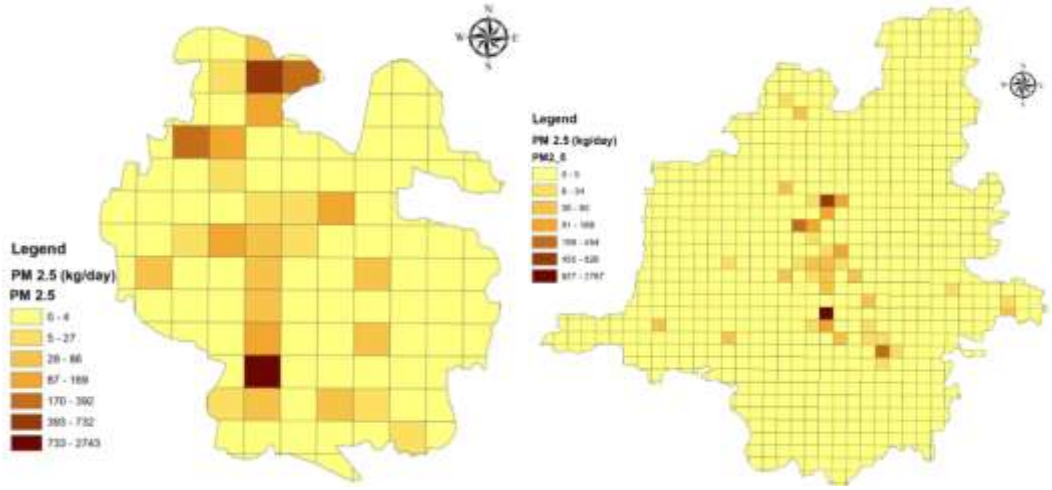
Figure 4.94: Emission Load from Industrial Point Source

Spatial distribution of emissions from industries as an area source is presented in Figures 4.95 from 4.99.



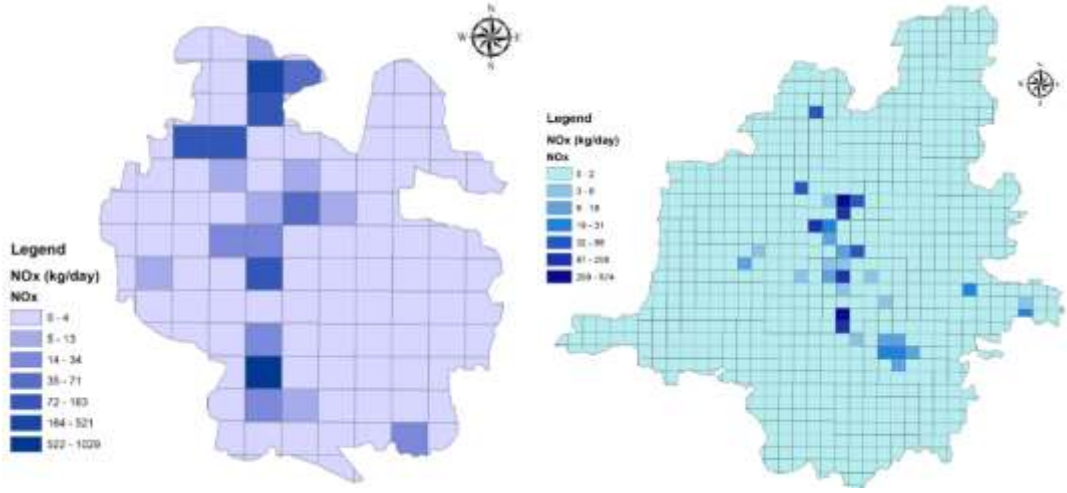
JCB **JDA**

Figure 4.95: Spatial Distribution of PM_{10} Emissions from Industries



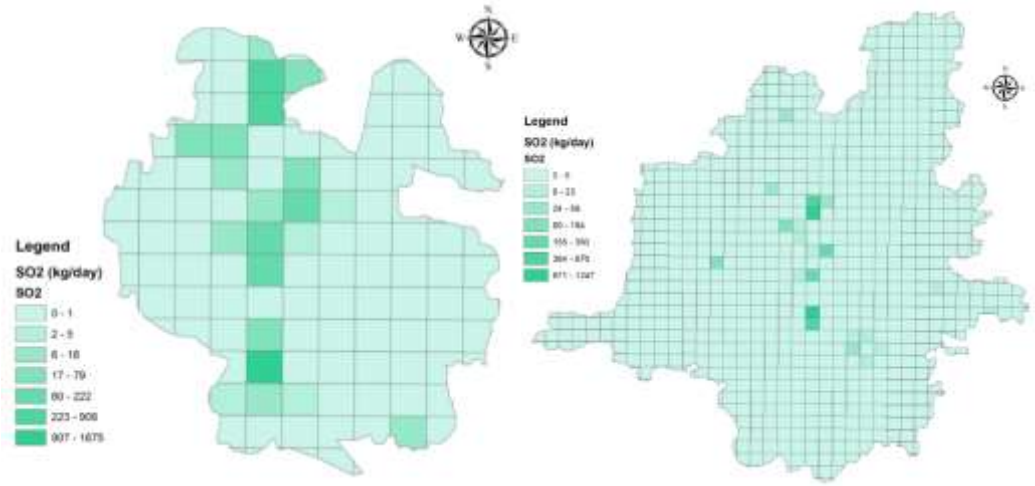
JCB **JDA**

Figure 4.96: Spatial Distribution of $PM_{2.5}$ Emissions from Industries



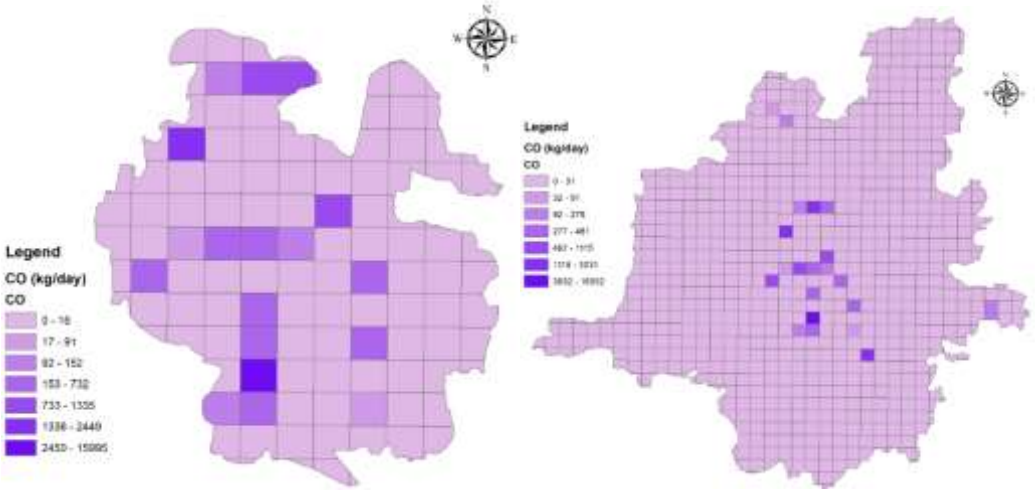
JCB **JDA**

Figure 4.97: Spatial Distribution of NOx Emissions from Industries



JCB **JDA**

Figure 4.98: Spatial Distribution of SOx Emissions from Industries



JCB **JDA**

Figure 4.99: Spatial Distribution of CO Emissions from Industries

4.2.15 Vehicular - Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, Buses and Trucks at 20 locations were obtained by video recording at crossings (Figure 4.100). From these 20 traffic locations, the data were extrapolated for 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 is estimated and summed up.

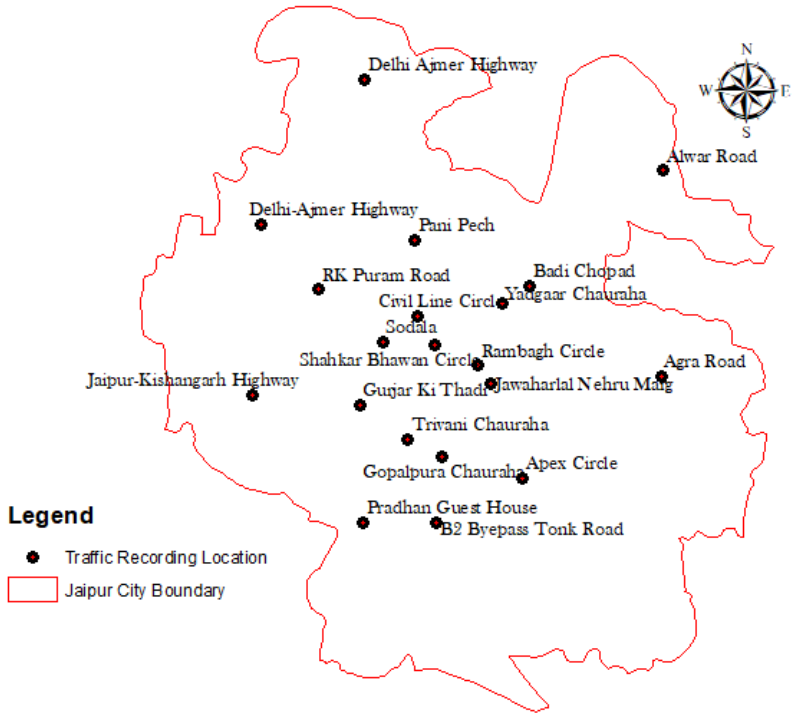


Figure 4.100: Traffic location considered for vehicle emission in the city of Jaipur.

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

4.2.16 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 20 locations (B2 Bye Pass Tonk Road, Gopalpura, Gurjar Ki Thadi, Rambagh Circle, Panipech, Sadola, Yadgaar Chauraha, Apex Circle, Civil Line, Pradhan Guest House, Badi Chopad, Shahkar Bhawan Circle, Trivani Circle, MI Road, Railway Station, Sindhi Camp Bus Station, Jhalana Doongri, NH-11, Agra Road and Sikar Road) in the city of Jaipur. Out of total 15329 vehicles surveyed, the breakdown was: 4896 2-Ws; 785 3-Ws; 5753 4-Ws, 613 LCVs, 1426 Buses, and 1856 Trucks. During parking lot survey, it was found out that LCVs, Buses, and Trucks runs on diesel fuel and 95% fleet are post 2005. All the city buses and trucks run on diesel and are of post 2000. The traffic flow from outside Jaipur is also accounted in this inventory. The data from five toll booth in the city were obtained. Approximately 20% percent of 4-Ws use diesel and the remaining 80% use gasoline. 3-Ws runs on petrol and diesel and all 2-Ws use gasoline. ARAI (2011) and CPCB (2011) emission

factors were used to calculate the emissions. Figures 4.101 to 4.103 present parking lane survey results (for 2Ws, 3Ws, and 4Ws) in terms of engine size and year of manufacturing. This information is vital in calculating the emission from vehicles on the road. The emission factors vary considerably for engine size, fuel uses and age of the vehicles.

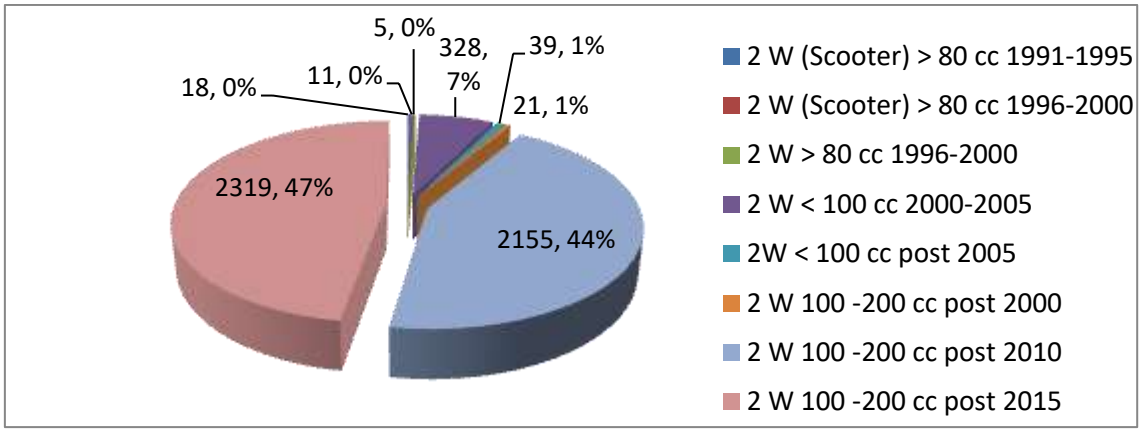


Figure 4.101: Distribution of 2-Ws in study area (parking lot survey)

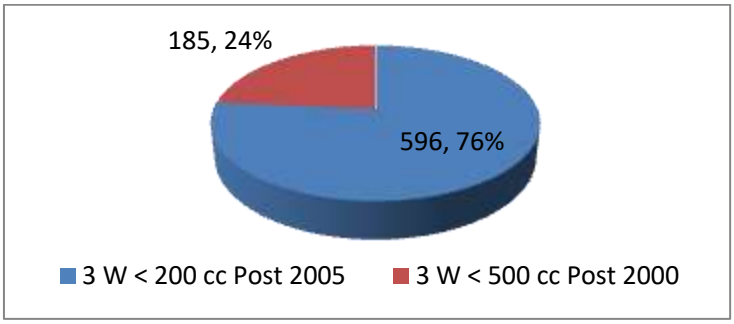


Figure 4.102: Distribution of 3-Ws in study area (parking lot survey)

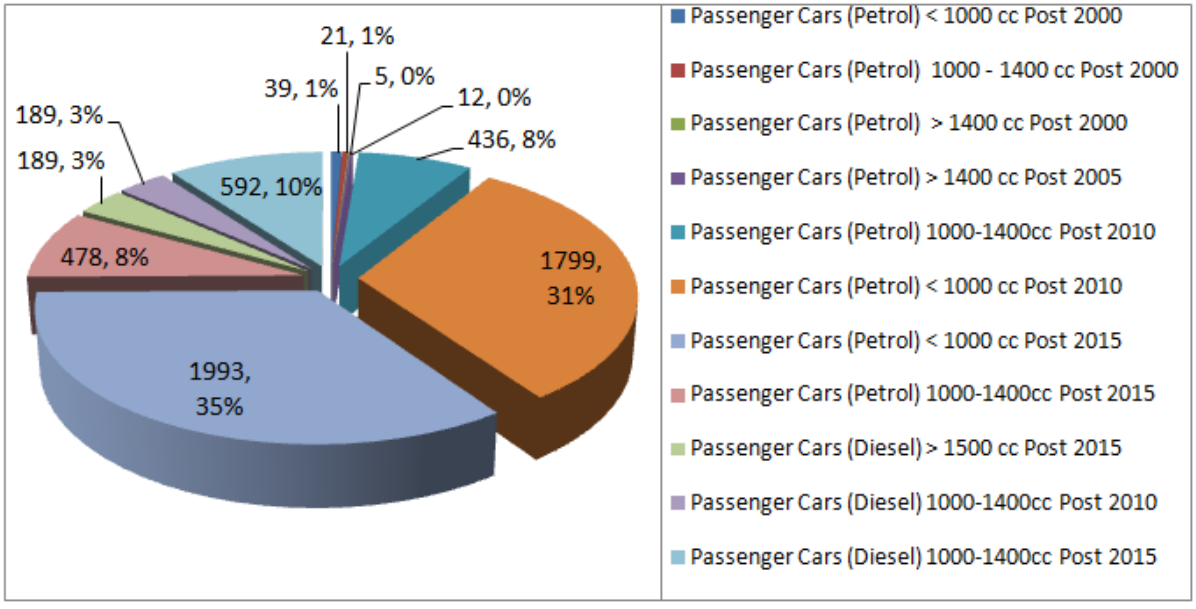


Figure 4.103: Distribution of 4-Ws in study area (parking lot survey)

The emission from vehicles is shown in Figure 4.104. Emission contribution of each vehicle type in city of Jaipur is presented in Figures 4.105 to 4.109. The spatial distribution of emissions from vehicles is presented in Figures 4.110 to 4.114.

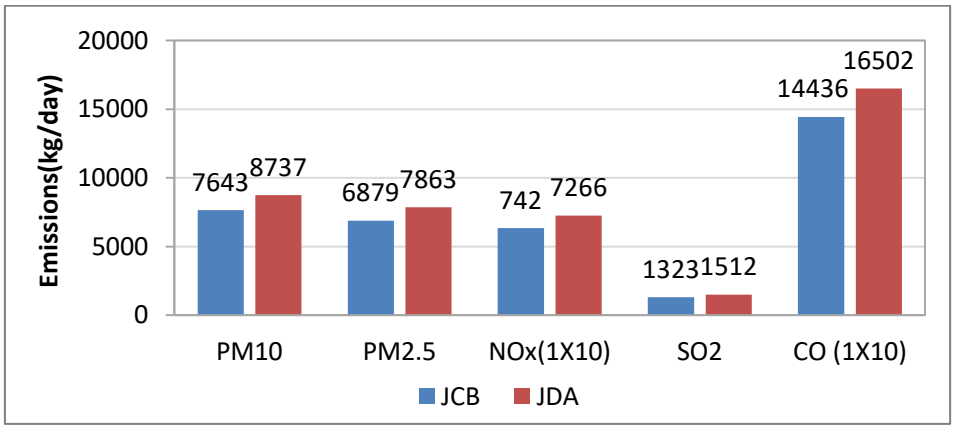


Figure 4.104: Emission Load from Vehicles (kg/day)

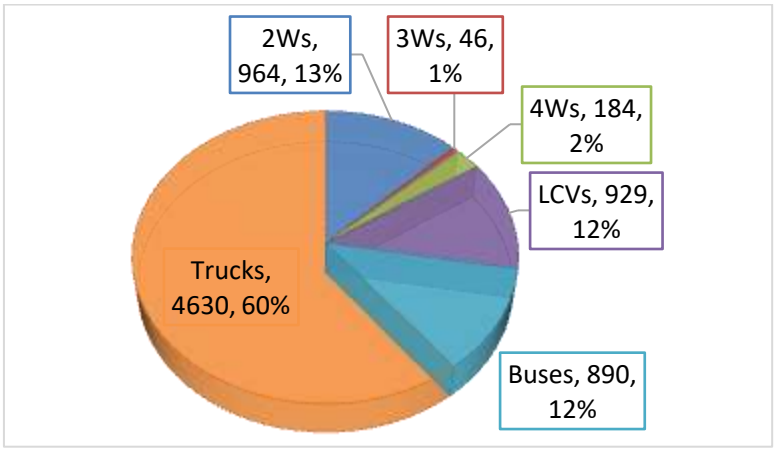


Figure 4.105: PM_{10} Emission Load contribution of each vehicle type in city of Jaipur

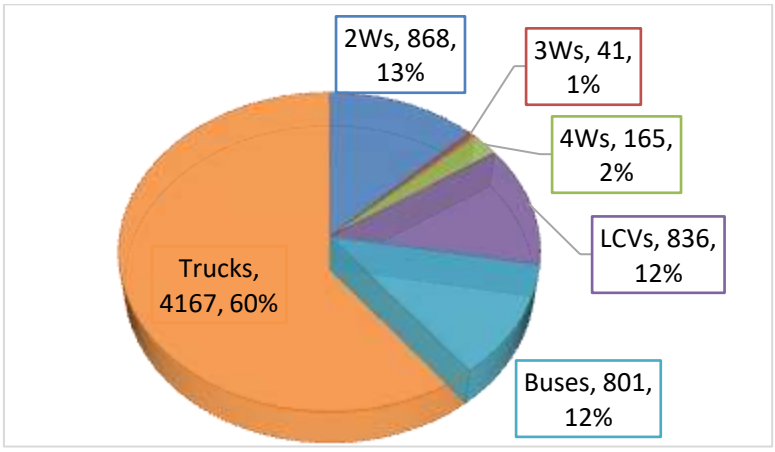


Figure 4.106: $PM_{2.5}$ Emission Load contribution of each vehicle type in city of Jaipur

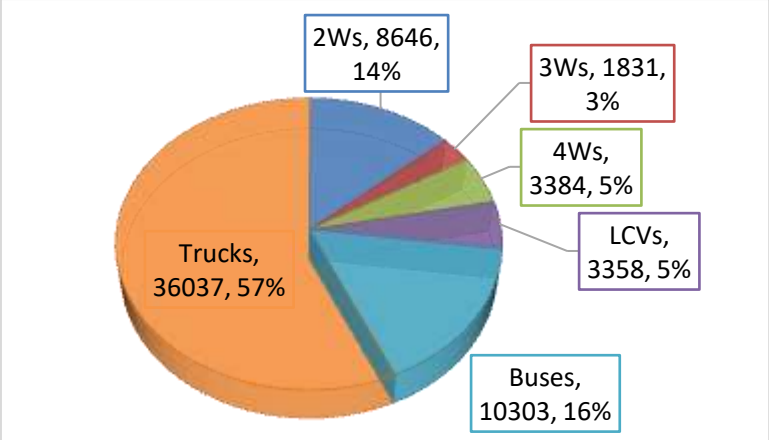


Figure 4.107: NOx Emission Load contribution of each vehicle type in city of Jaipur

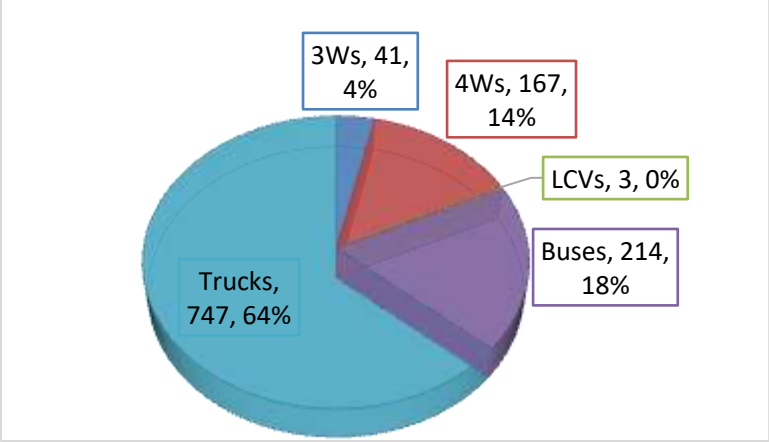


Figure 4.108: SO_2 Emission Load contribution of each vehicle type in city of Jaipur

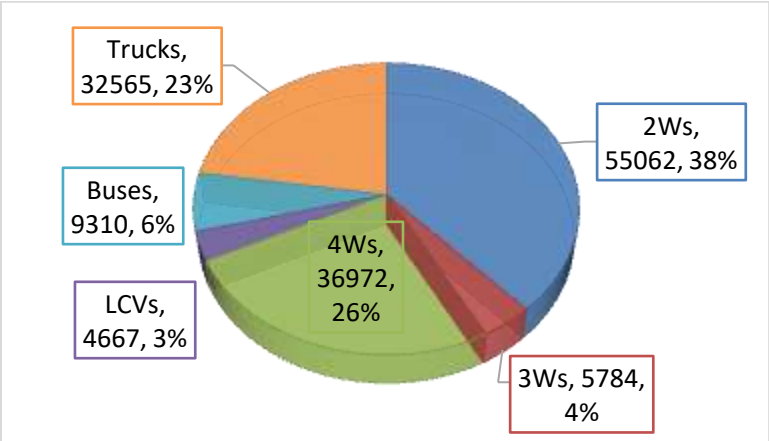


Figure 4.109: CO Emission Load contribution of each vehicle type in city of Jaipur

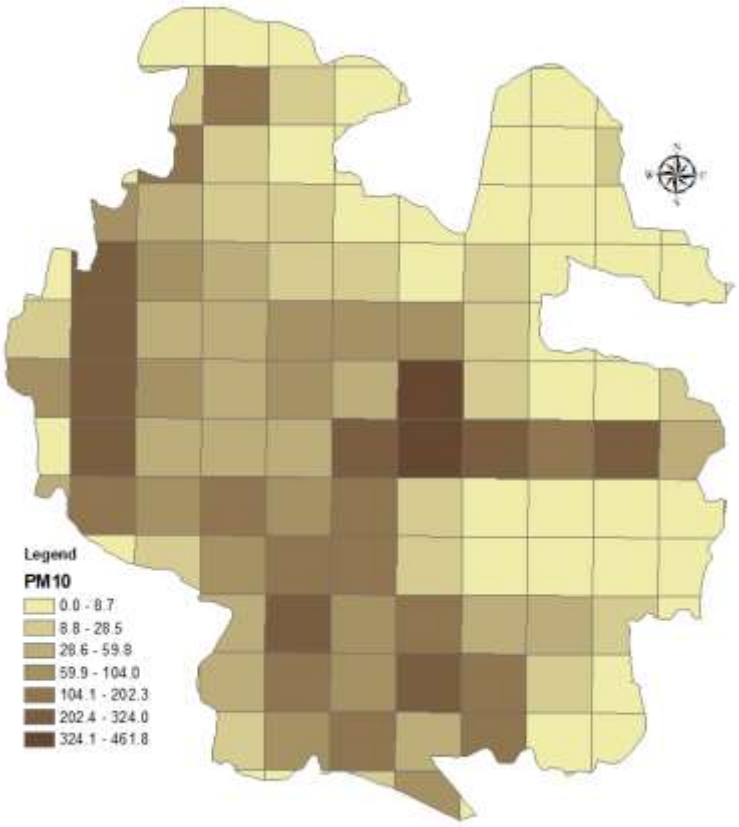


Figure 4.110: Spatial Distribution of PM_{10} Emissions from Vehicles

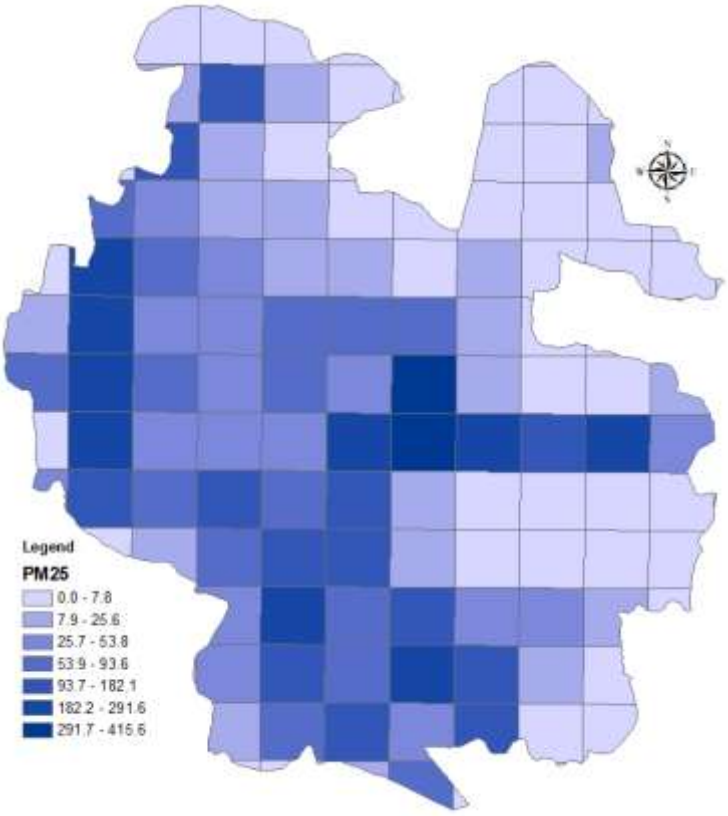


Figure 4.111: Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles

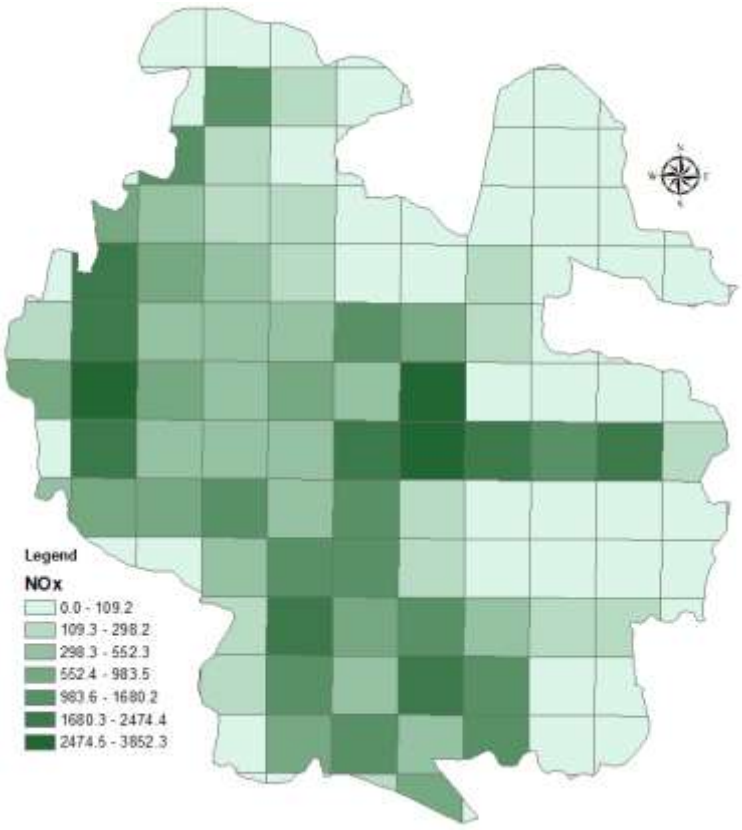


Figure 4.112: Spatial Distribution of NOx Emissions from Vehicles

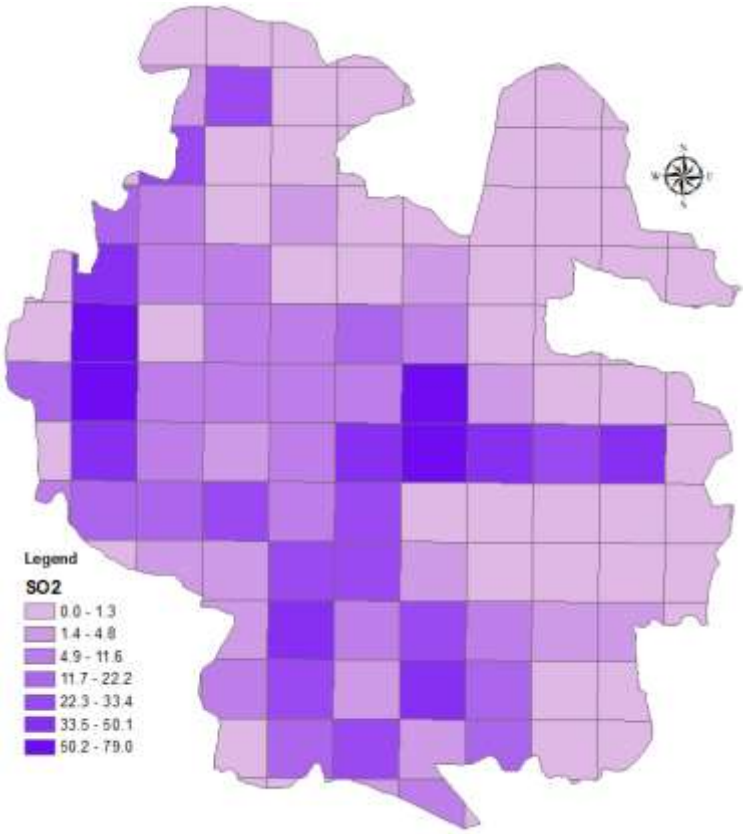


Figure 4.113: Spatial Distribution of SO_2 Emissions from Vehicles

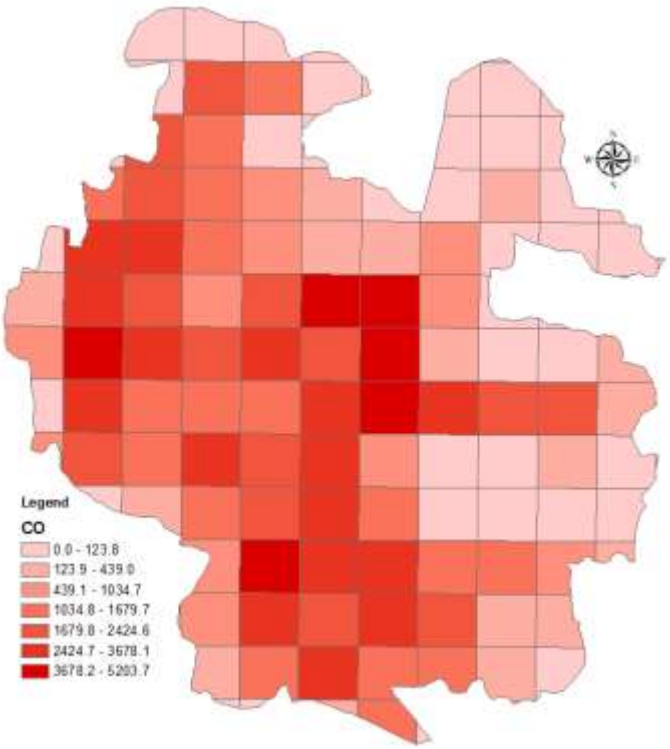


Figure 4.114: Spatial Distribution of CO Emissions from Vehicles

4.2.17 Paved and Unpaved Road Dust

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

$$E_{ext} = [\, k\,(sL)^{0.91} \times (W)^{1.02} \,]\,(1 - P/4N) \qquad (4.5)$$

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 silt loads (sL) samples from 20 locations were collected (Figure 4.115 and 4.116). 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(4.5). 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(4.5). The PM_{10} and $PM_{2.5}$ emission from road dust is 65969 kg/day and 15960 kg/day respectively. Silt load varies a lot. In winter and monsoon season it is less due to moisture and dew atmospheric condition The Spatial Distribution of Emissions from Road Dust Re-suspension is presented in Figure 4.117 to 4.118.

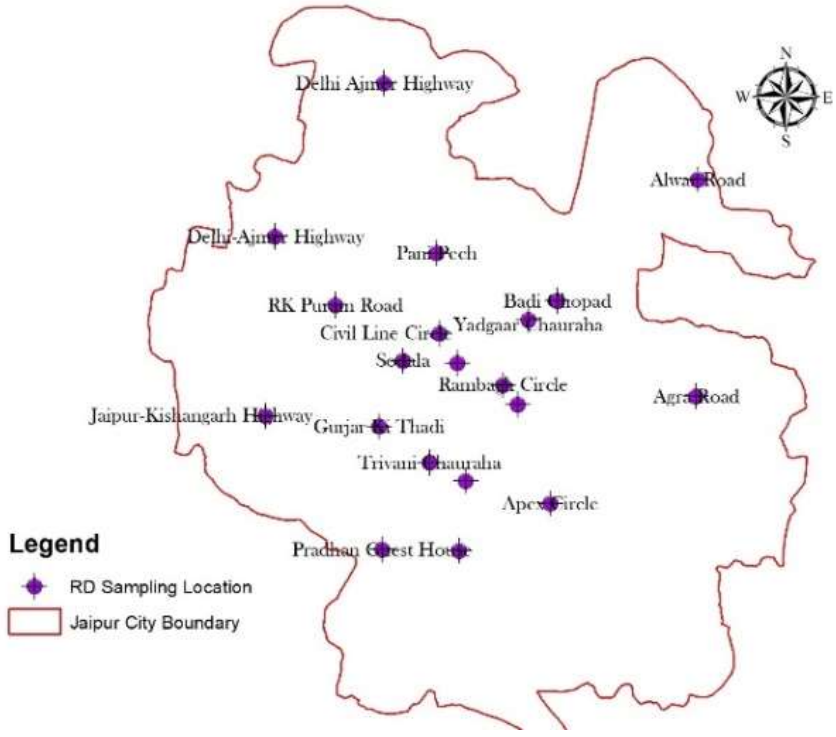


Figure 4.115: Road Dust Sampling Location

Figure 4.116: Road Dust Sampling in Jaipur

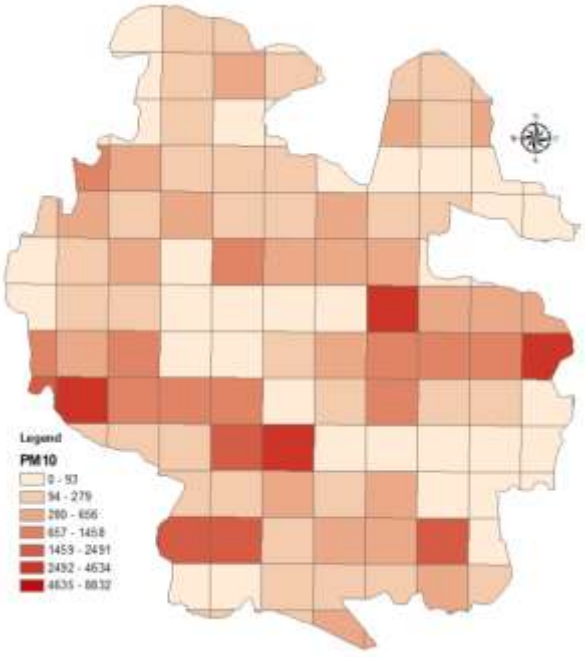


Figure 4.117: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

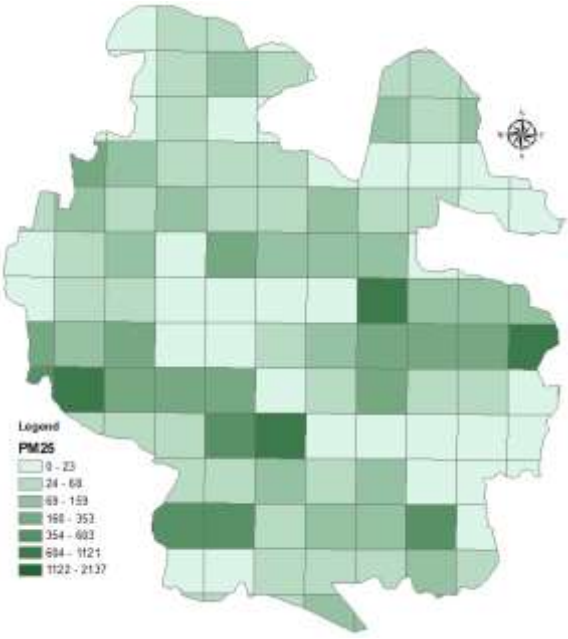


Figure 4.118: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

4.3 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 4.6. The pollutant wise contribution is shown in Figures 4.119 to 4.123. Spatial Distribution of pollutant Emissions from all sources is presented in figures from 4.124 to 4.128.

Table 4.6: Jaipur City Level Inventory (JCB) (kg/day)

Sources	PM_{10}	$PM_{2.5}$	NO_X	SO_2	CO
Road Dust	65969	15960	-	-	-
Vehicle	7643	6879	63560	1170	144359
Industry	7306	6575	3146	5177	29002
Construction & Demolition	3454	794	0	0	0
Domestic	2120	1612	1077	559	12237
MSW Burning	1492	1015	560	93	7833
Open Area Soil Dust	1321	-	-	-	-
Hotels and Restaurants	1172	727	468	1166	3009
Mineral mines	662	66	-	-	-
DG Sets (Industry)	292	262	4123	272	890
Banquet Hall	241	142	664	170	468
Brick kiln	61	7	66	57	5
Hospitals	22	20	315	21	68
Apartments	21	19	295	19	64
Aircraft	7	7	420	35	290
Stone Crusher	1	-	-	-	-
Total	91784	34086	74692	8739	198224

The total PM_{10} emission load in the city is estimated to be 92 t/d. The top four contributors to PM_{10} emissions are road dust (71%), industries (8%), vehicles (8%) and construction (4%); 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 34 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (46 %), vehicles (20 %), industries (19%) and domestic fuel burning (5 %); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

NOx emissions load in the city is estimated to be 75 t/d. Nearly 85 % of emissions are attributed to vehicular emissions followed by DG set (6%) and industries (4%). Vehicular emissions that occur at ground level, probably making it the most important emission. NOx apart from being a pollutant itself, it is important component in the formation of secondary particles (nitrates) and ozone. NOx from vehicles and from industry are potential sources for controlling of NOx emissions.

SO_2 emission load in the city is estimated to be 9 t/d. Industry account for 55 percent of total emission. Hotels and Restaurants contributes to 19% followed by vehicles (13%).

Estimated CO emission is about 199 t/d. Nearly 73 % emission of CO is from vehicles, followed by industries (15%), domestic (6%) and about 4 % MSW burning. Vehicles could be the main target for controlling CO for improving air quality with respect to CO.

The wood is used in domestic cooking and small-scale industries in Rajasthan (Rajasthan State Action Plan on Climate Change, GoR). *Prosopis Juliflora* is grown commonly in cultivable waste land and other fallow land, which includes all type unproductive lands of Govt. & Private. The average firewood yield of *Prosopis Juliflora* in the region has been estimated to be approximately 5 tons/ha/year or 20 tons/ha/ 4 years cycle, when it grows unorganized without due care or attention. The Prosopis Juliflora Wood Generation in Jaipur region is about 459985 Tons/Year and the consumption 423186 Tons/year i.e. 92% of the wood is consumed by local people for domestic fuel, local bakery and hotels industries, biomass power plant and other local thermal energy consuming industries (Biomass Fuel Supply Study, 2015).

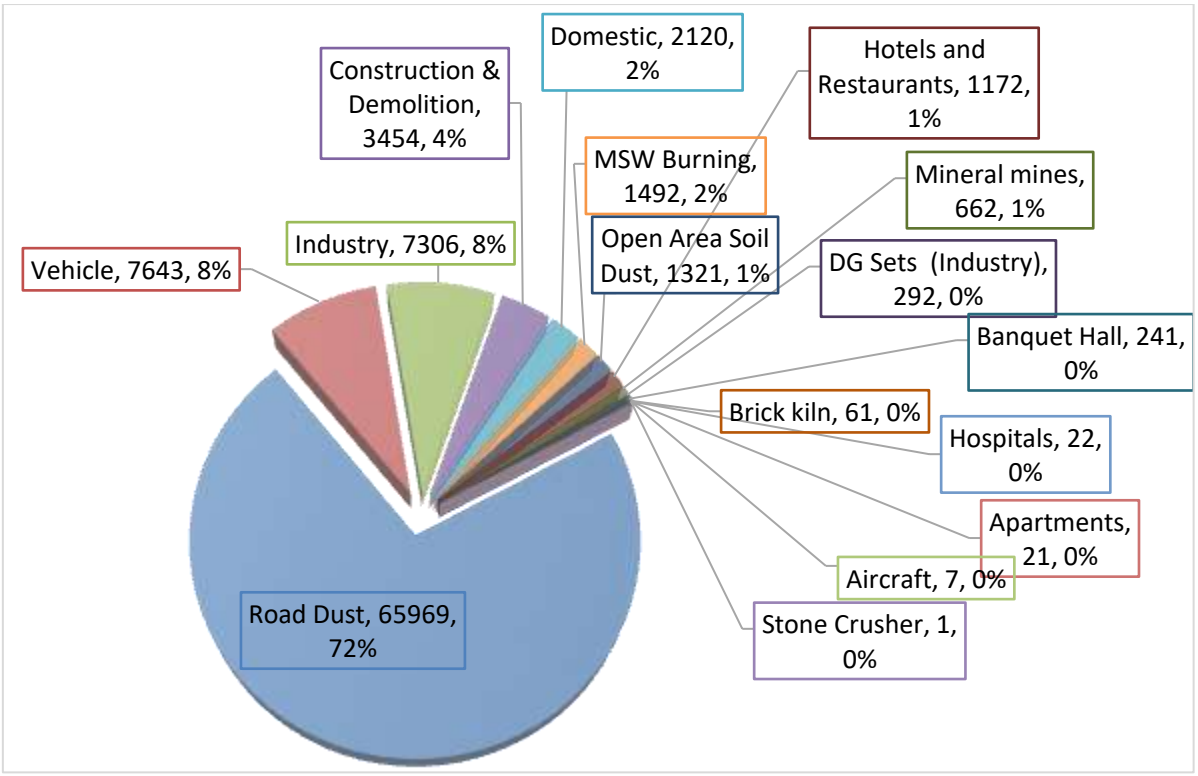


Figure 4.119: PM_{10} Emission Load of Different Sources in the JCB

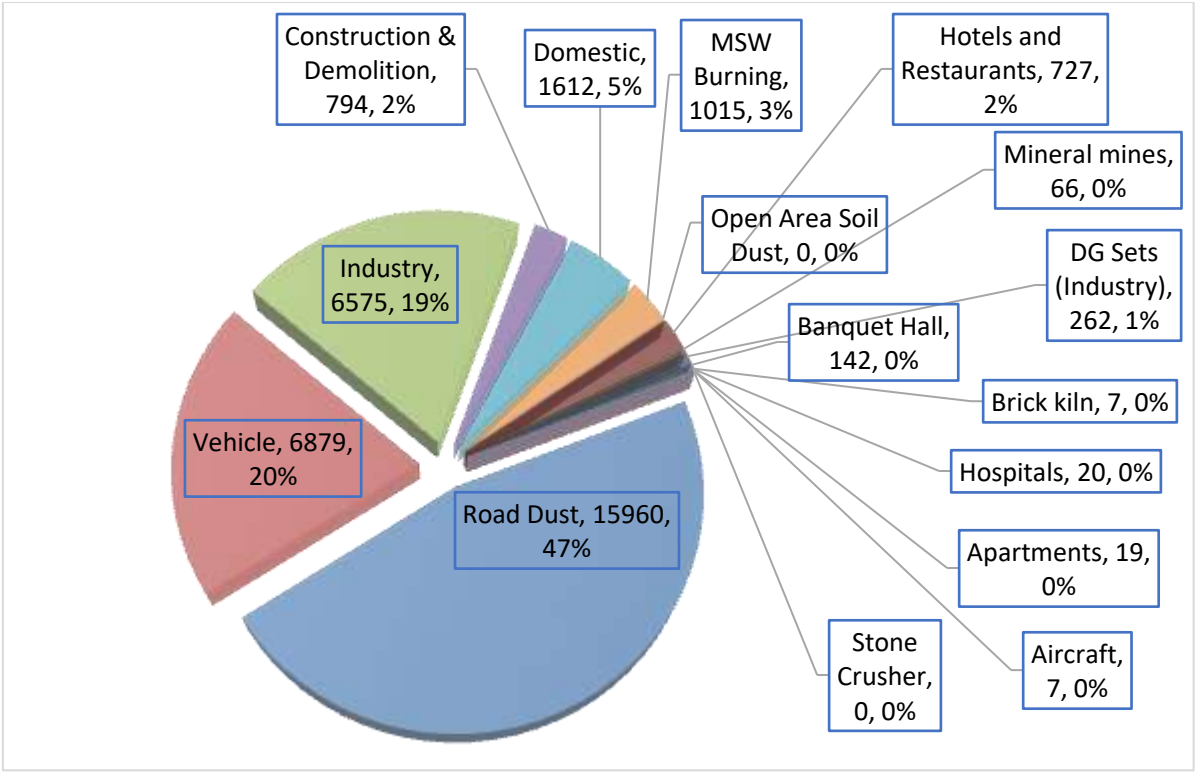


Figure 4.120: $PM_{2.5}$ Emission Load of Different Sources in the JCB

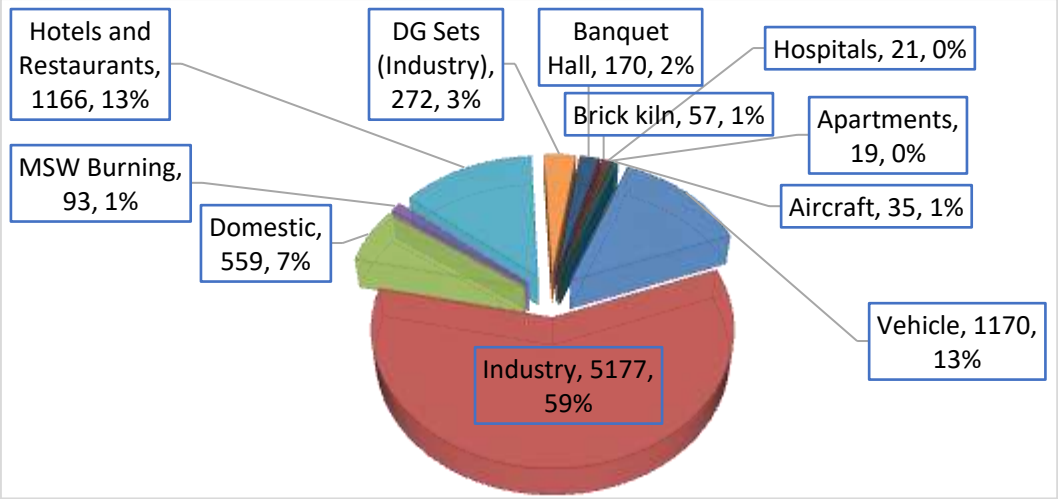


Figure 4.121: SO_2 Emission Load of Different Sources in the JCB

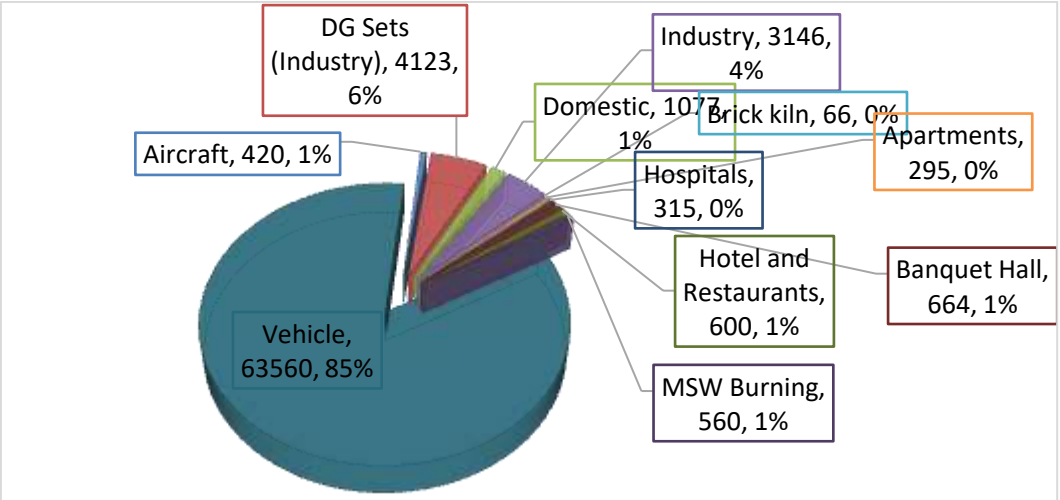


Figure 4.122: NOx Emission Load of Different Sources in the JCB

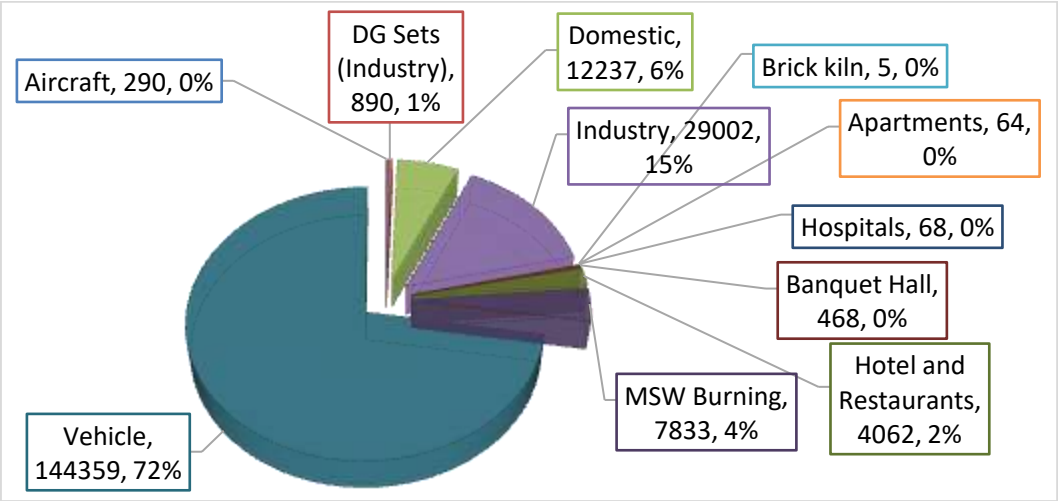


Figure 4.123: CO Emission Load Contribution of Different Sources in the JCB

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

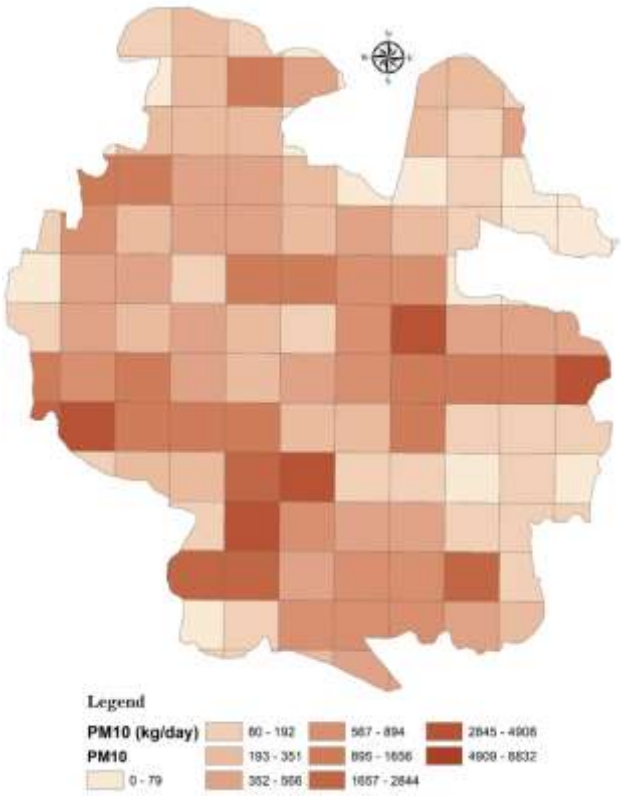


Figure 4.124: Spatial Distribution of PM_{10} Emissions in the City of Jaipur

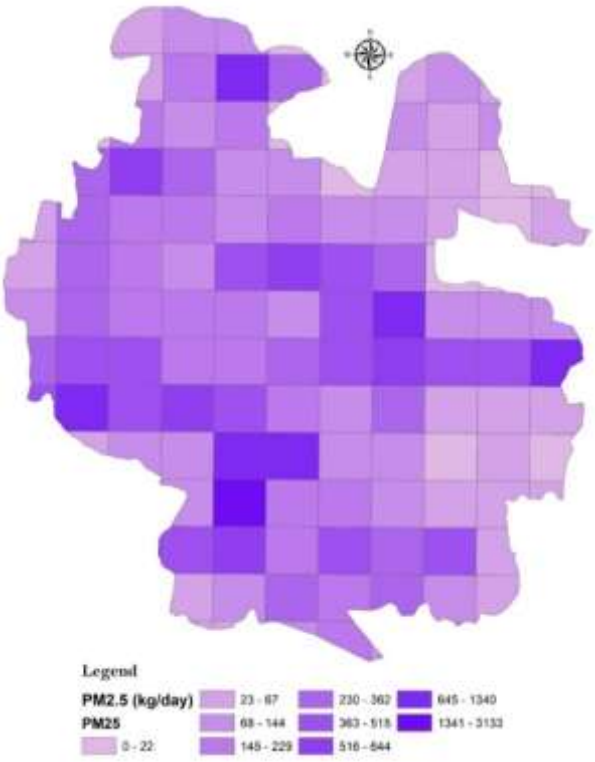


Figure 4.125: Spatial Distribution of $PM_{2.5}$ Emissions in the City of Jaipur

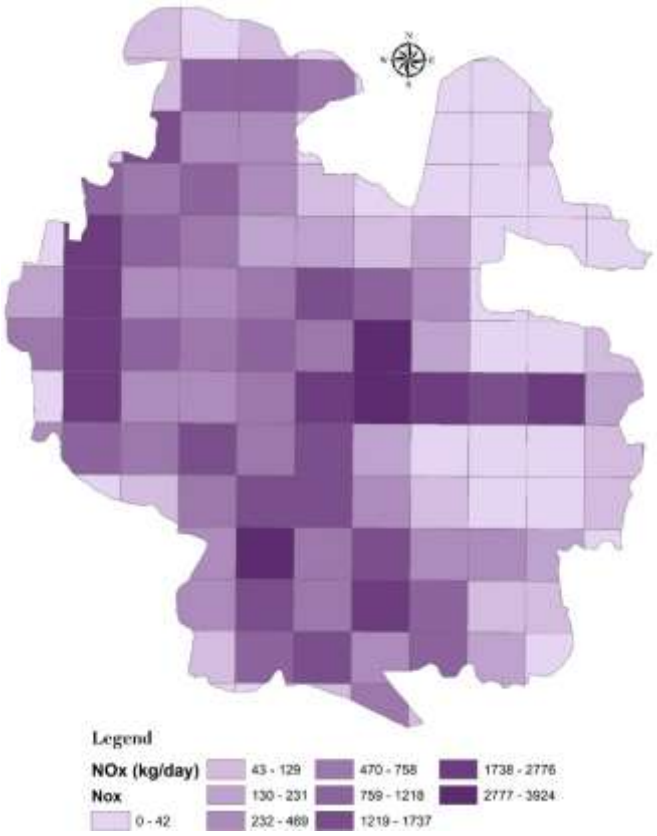


Figure 4.126: Spatial Distribution of NOx Emissions in the City of Jaipur

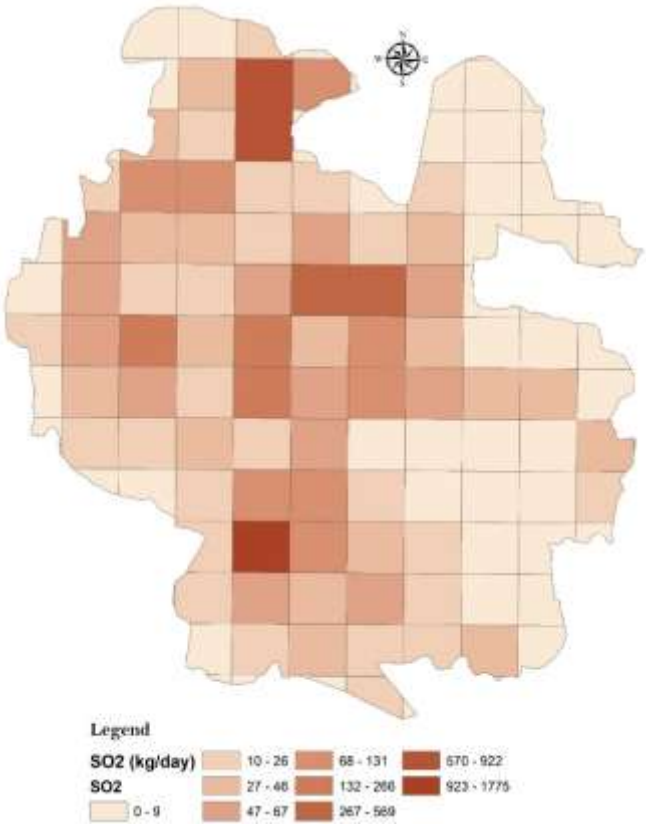


Figure 4.127: Spatial Distribution of SO_2 Emissions in the City of Jaipur

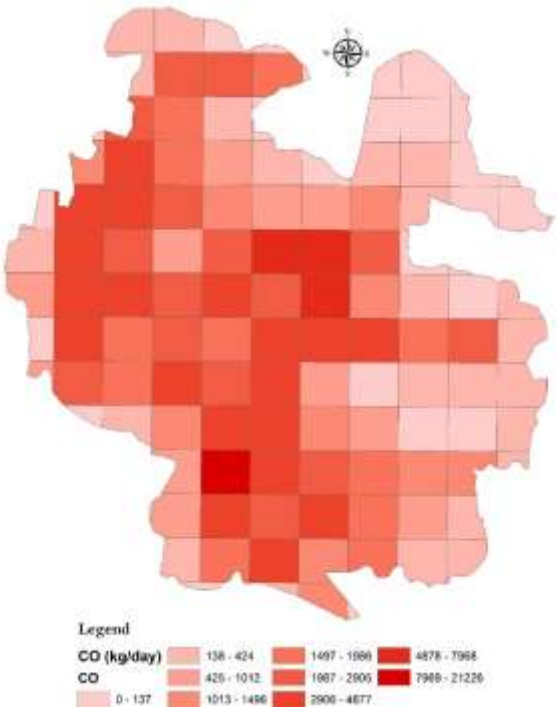


Figure 4.128: Spatial Distribution of CO Emissions in the City of Jaipur

4.4 JDA Level Emission Inventory

The overall baseline emission inventory for the entire JDA limits is presented in Table 4.7. The pollutant wise contribution is shown in Figures 4.129 to 4.133.

Table 4.7: JDA Level Inventory (kg/day)

Sources	**PM_{10}**	**$PM_{2.5}$**	**NO_X**	**SO_2**	**CO**
Road Dust	75409	18244			
Mineral Mines	22380	2239	14	1	3
Brick kiln	11926	1314	12823	11069	1027
Construction & Demolition	11640	2677	0	0	0
Domestic	10040	7190	3317	1363	60131
Vehicle	8737	7863	72655	1512	165017
Industry	8666	7799	3954	6177	35819
Stone Crusher	7009	734	580	38	125
MSW Burning	2732	1858	1024	171	14341
Hotels and Restaurants	1172	727	468	1166	3009
DG Sets (Industry)	427	384	6030	398	1302
Banquet Hall	255	150	709	179	494
Hospitals	32	29	454	30	98
Apartments	21	19	295	19	64
Aircraft	7	7	420	35	290
Total	**160452**	**51233**	**102743**	**22158**	**281719**

The total PM_{10} emission load in the JDA limits is estimated to be 160 t/d. The top four contributors to PM_{10} emissions are road dust (41%), industries (8%), mineral mines (14%) and brick kilns & construction and demolition (7%).

$PM_{2.5}$ emission load in the JDA limits is estimated to be 51 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (35 %), vehicles and industries (15%) and domestic fuel burning (14 %).

NOx emissions load in the JDA limits is estimated to be 103 t/d. Nearly 63 % of emissions are attributed to vehicular emissions followed by MSW burning (12%) and brick kilns (11%).

SO_2 emission load in the JDA limits is estimated to be 22 t/d. Brick kilns account for 49 percent of total emission. Industries contribute to 27% followed by hotels and restaurants (8%).

Estimated CO emission is about 282 t/d. Nearly 61 % emission of CO is from vehicles, followed by domestic (22%) and about 13% from industries.

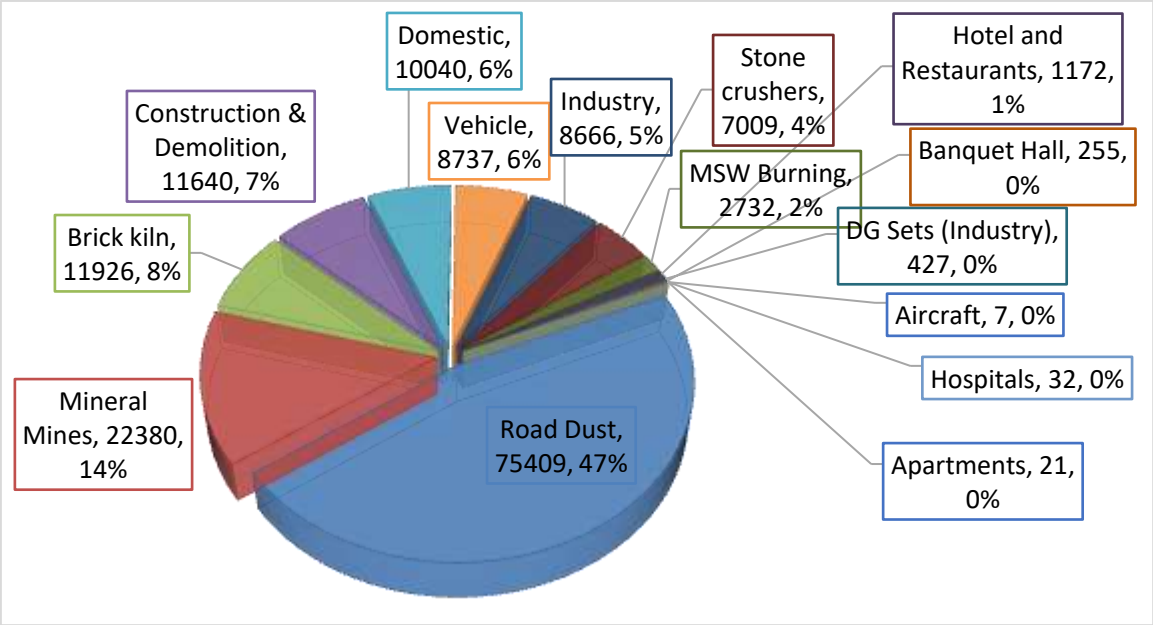


Figure 4.129: PM_{10} Emission Load of Different Sources in the JDA Limits

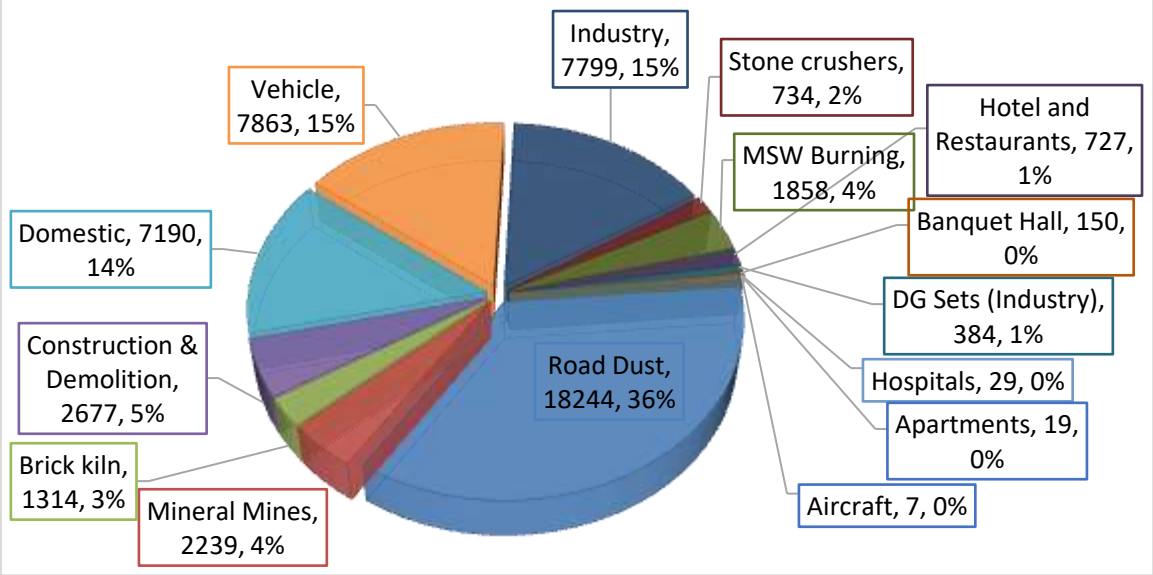


Figure 4.130: $PM_{2.5}$ Emission Load of Different Sources in the JDA Limits

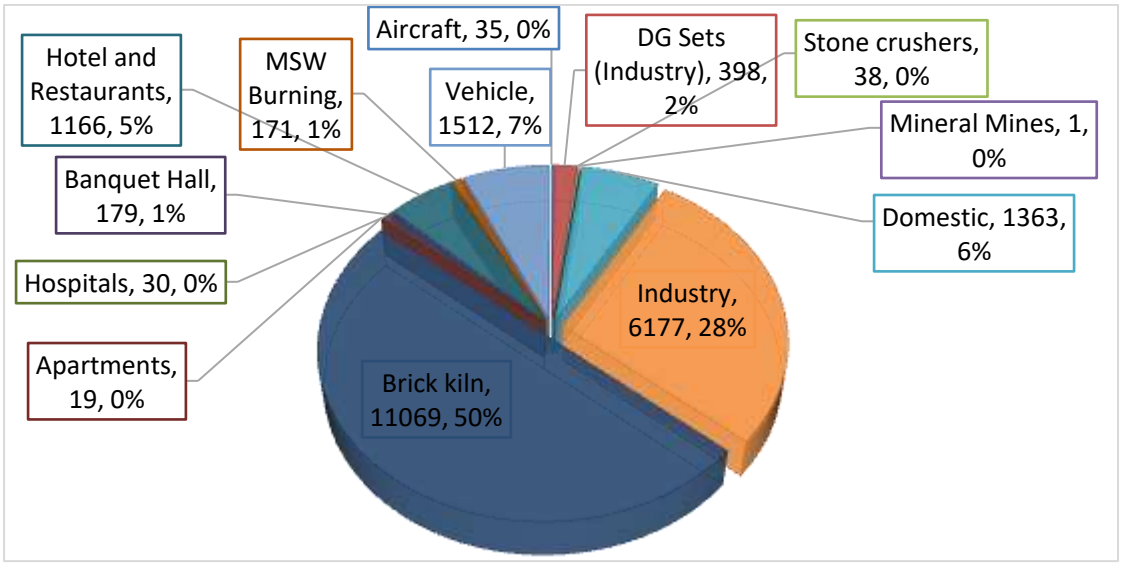


Figure 4.131: SO_2 Emission Load of Different Sources in the JDA Limits

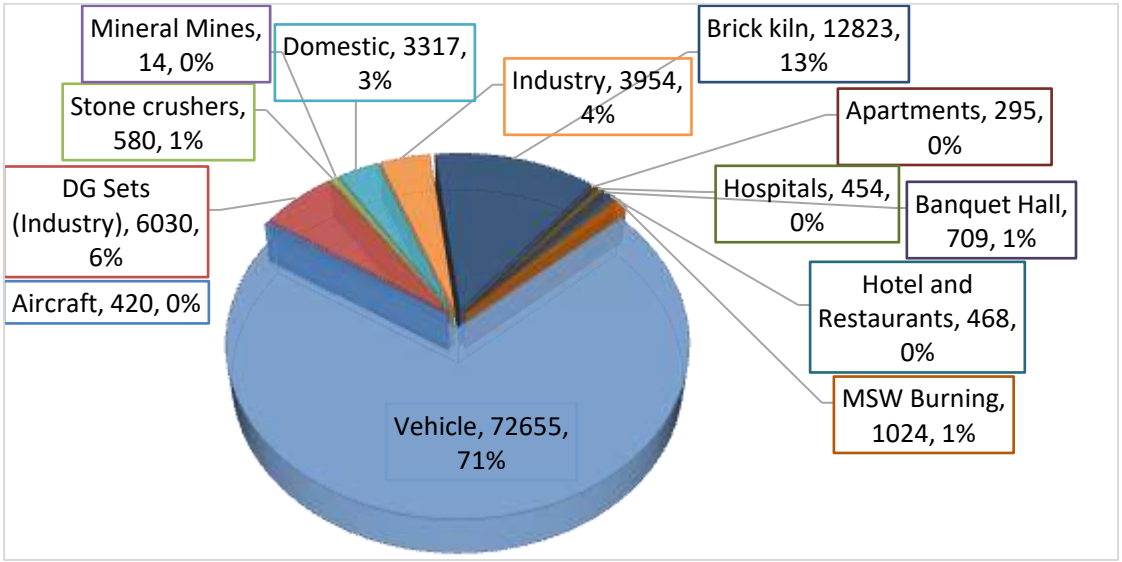


Figure 4.132: NOx Emission Load of Different Sources in the JDA Limits

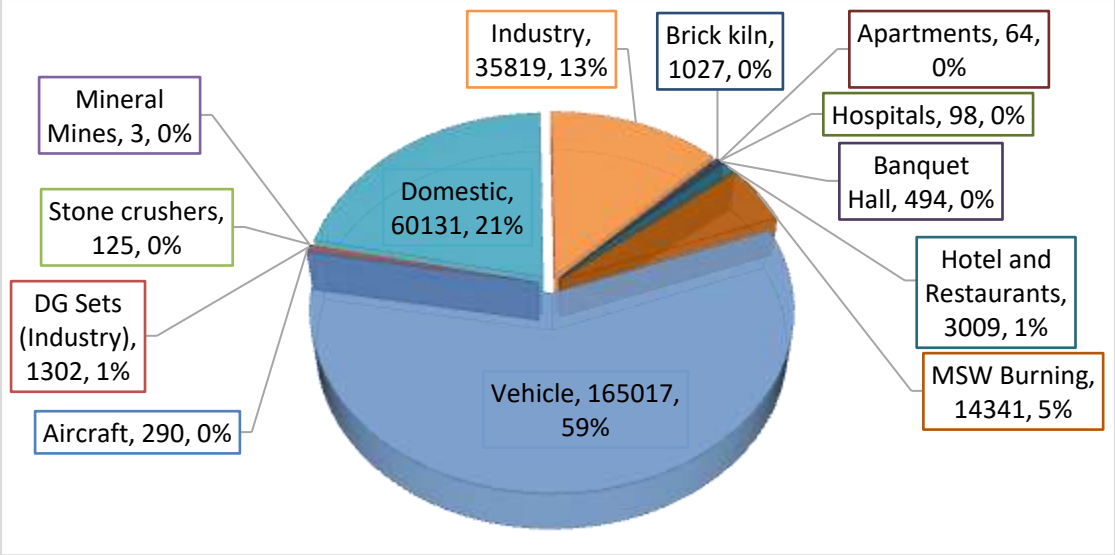


Figure 4.133: CO Emission Load Contribution of Different Sources in the JDA Limits

5 Receptor Modelling and Source Apportionment

5.1 Receptor Modeling

In a complicated urban atmosphere, to identify and quantify contribution of multiple emitting sources to air quality, is challenging. However, recent advancements in chemical characterization of PM has 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.

Focus of modeling in this chapter is receptor modeling. 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.

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

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

is, if p sources are contributing M_j mass of particulates to the receptor (Watson et al., 2004),

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

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

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

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

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

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

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

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

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

Since for $PM_{2.5}$, Indian or Jaipur 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 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

Jaipur's environment. For the sake of uniformity, source profiles for non-vehicular sources for PM_{10} and $PM_{2.5}$ were adopted from USEPA (2006). The source profile for local soil dust is adopted from soil dust results (section 2.5, characterization of field soil dust).

The PM_{10} and $PM_{2.5}$ monitoring data along with results of chemical speciation (described in Chapter 2) have been used in the application of CMB 8.2 model of USEPA (2004). The CMB model was run for each site for each day of sampling for two seasons (summer and winter) for PM_{10} and $PM_{2.5}$ separately. The model results were analyzed in terms of R-square (model fitting) and model-computed percent mass (compared to the measured mass). The CMB results for most measurements (over 85 percent) showed the R-square was above 0.60. Model-computed mass accounted for more than 70 percent of measured mass. In this study, the degree of freedom (number species – number of sources) being more than 24, modeling results which gave R-square more than 0.55 were considered for further analyses. The results of CMB 8.2 at each location for each season are described in Section 4.3.

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

5.3 CMB Modeling Results and interpretation

It may be noted that vehicular sources include all vehicles powered by gasoline, diesel and CNG. The CMB model could provide contribution of vehicles as a single entity. However, the model could not fully resolve the source contribution from various vehicular fuels due to co-linearity in source profiles. In addition, LPG from domestic cooking is also the part of vehicular emission due co-linearity in profiles.

5.3.1 Ajmeri Gate (AJG)

5.3.1.1 Winter Season [sampling period: Nov 19 – Dec 8, 2017]

PM_{10} (winter)

The average PM_{10} concentration was 245 $\mu g/m^3$. Figure 5.1 (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 AJG. Table 5.1 presents summary of performance and acceptability of

CMB model. It is observed that the major PM_{10} source contributing to PM_{10} was soil and road dust (87 µg/m^3 ~ 35%) followed by biomass burning (42 µg/m^3 ~ 17%). The other major sources are vehicular emissions (40 µg/m^3 ~ 16%), secondary inorganic aerosols (SIA; 33 µg/m^3 ~ 13%), coal and flyash (26 µg/m^3 ~ 11%), municipal solid waste (MSW) burning (3%) and industrial emission (2%). Contribution of the construction material was estimated at less than 2% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 114 µg/m^3 (i.e. about 0.46 of PM_{10}). Figure 5.2 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at AJG. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (33 µg/m^3 ~ 29%) followed by vehicular emission (31 µg/m^3 ~ 28%) and SIA (25 µg/m^3 ~ 22%). Other sources are soil and road dust (8%), industrial emissions (5.1%), MSW burning (4.5%) and coal and flyash (3.7%). Contribution of the construction material was less than 1%

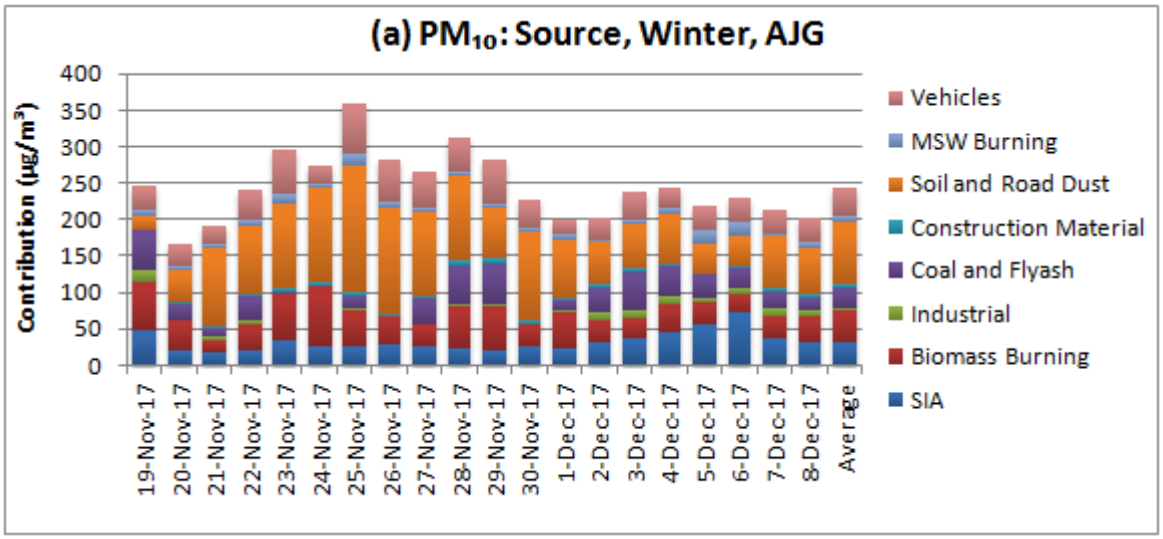
HYSPLIT back trajectories (Figure 5.3) indicate that wind is flowing from NW and SE direction. Winds can pick up the pollutants on the way especially from large sources (e.g. desert soil and crop residue burning (CRB)) and tall emitting sources but these contributions have not been quantifies.

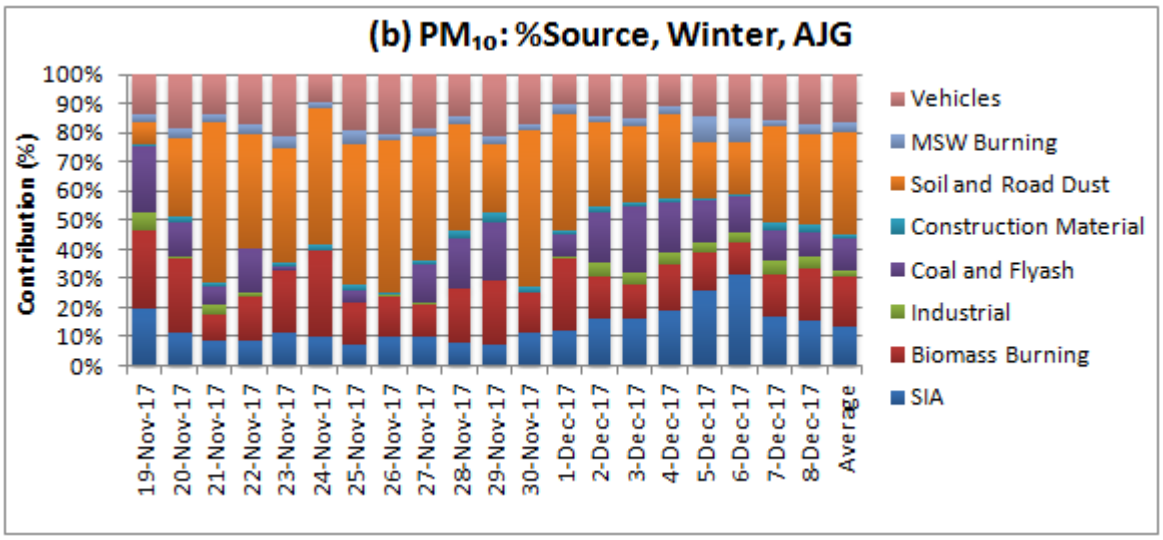
Inferences

- The biomass burning has major contribution (17% for PM_{10} and 29% for $PM_{2.5}$) to the PM at AJG.
- Vehicles contribute significantly to PM_{10} and PM $_{2.5}$ (16% for PM_{10} and 28% for $PM_{2.5}$).
- Road and soil dust emission reduced to 8% in $PM_{2.5}$ compared to 35% in PM_{10}. These reductions in emissions during winter season may be due to low wind speed (more calm conditions). It can be seen that $PM_{2.5}$ is relatively small in comparison with PM_{10}.
- The secondary particles contribute to PM_{10} (13%) and $PM_{2.5}$ (22%). These particles are expected to source from precursor gases (SO_2 and NO_x) emitted from far distances. However, 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 distance.

- The MSW burning contribution has significant. It is clearly seen that MSW burning is major source that contributes to PM_{10} and $PM_{2.5}$. This emission is expected to be large from regions of economically lower strata of society which do not have proper infrastructure for collection and disposal of solid waste.





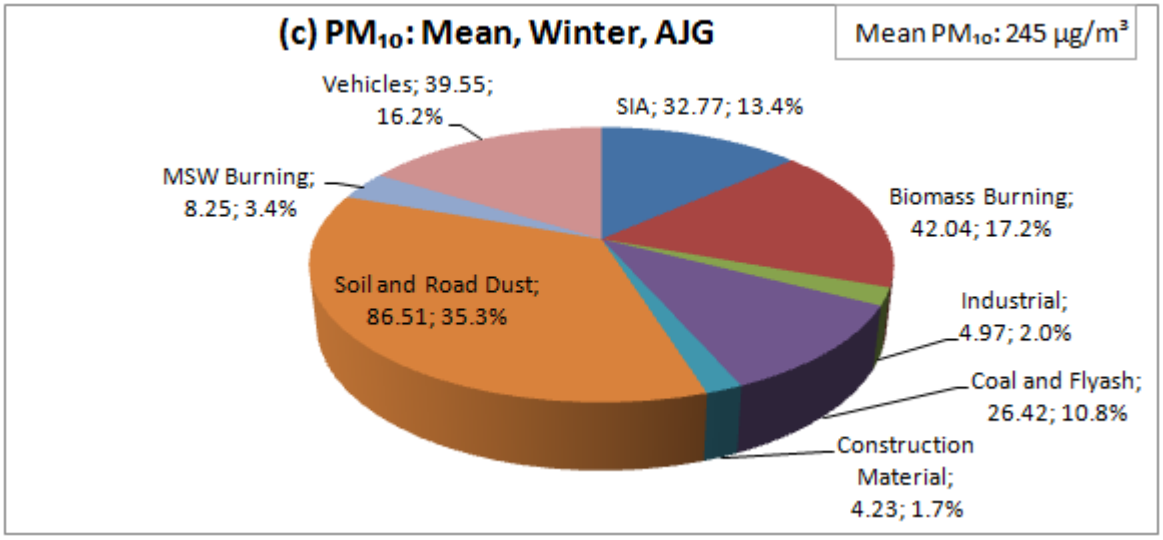
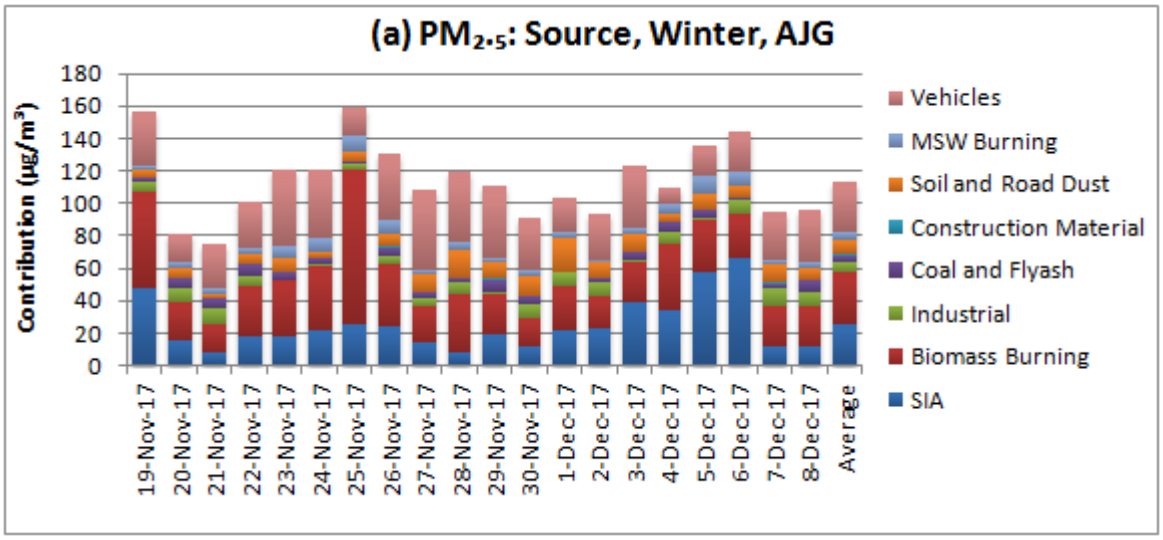
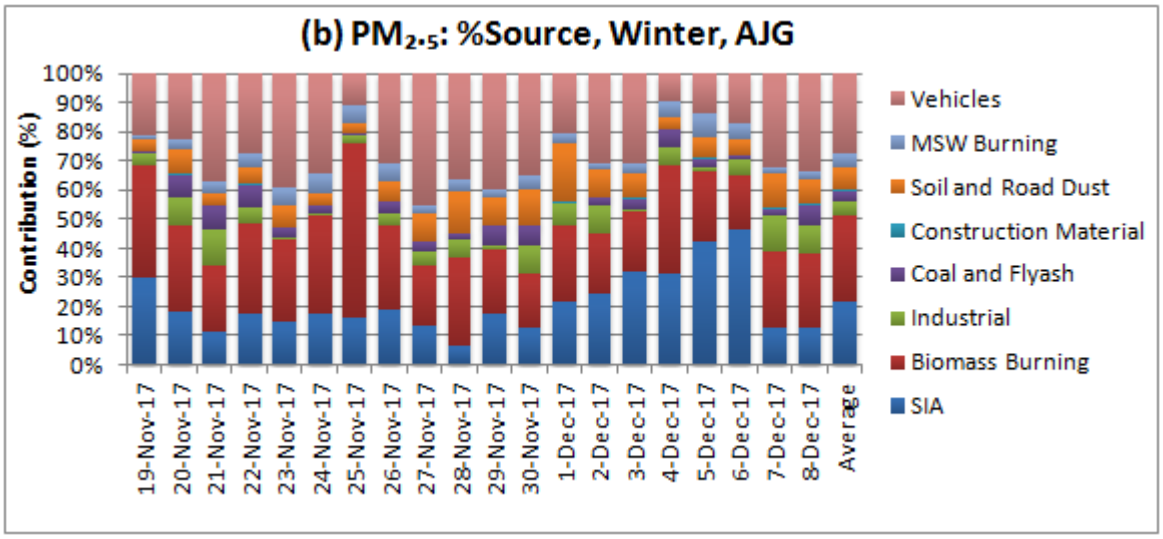


Figure 5.1: CMB modeling for PM_{10} at AJG for winter season





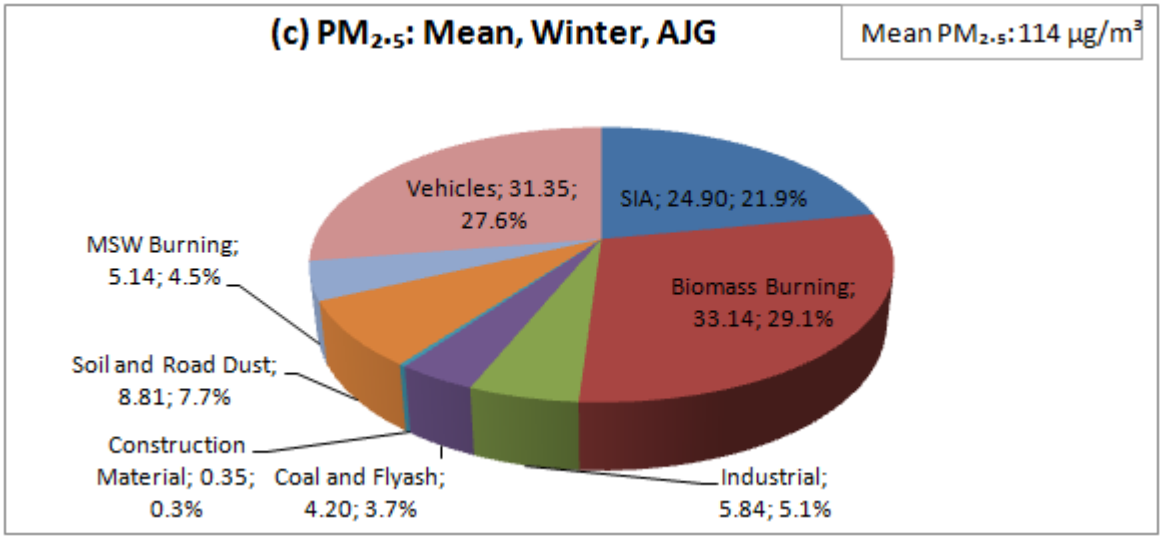


Figure 5.2: CMB modeling for $PM_{2.5}$ at AJG for winter season

Table 5.1: Statistical summary: AJG, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	245	253	103.5	0.72	114	113	100.8	0.71
SD	46	45	3.9	0.07	23	22	2.3	0.06
CV	0.19	0.18	0.04	0.10	0.20	0.19	0.02	0.08
Maximum	360	360	113.8	0.81	159	163	104.0	0.79
Minimum	168	169	99.0	0.59	75	77	95.6	0.55

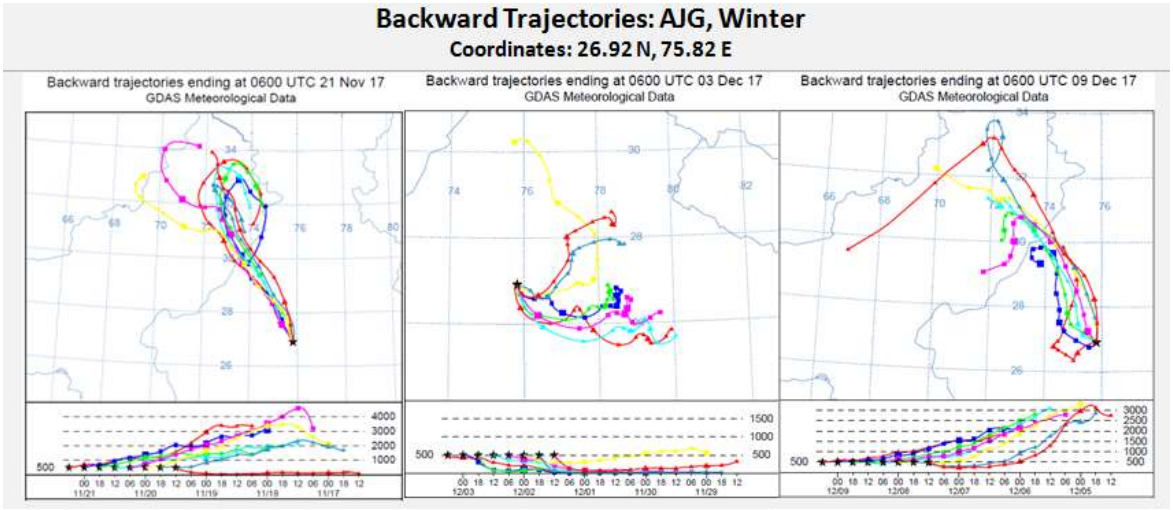


Figure 5.3: Backward trajectories at AJG for winter season

5.3.1.2 Summer Season [sampling period: May 06 – 26, 2018]

PM_{10} (summer)

The average PM_{10} concentration was 263 µg/m^3. Figure 5.4 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at AJG. Table 5.2 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (171 µg/m^3 ~ 65%) followed by biomass burning (31 µg/m^3 ~ 12%) and coal and fly ash (26 µg/m^3 ~ 10%) in PM_{10}. Other significant sources are vehicular emissions (11 µg/m^3 ~ 4%), industrial (3.2%), MSW burning (2.3%) and construction material (2.1%) in PM_{10}. Contribution of the SIA was estimated less than 2 % in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 53 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.2. Figure 5.5 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at AJG. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (16 µg/m^3 ~ 30%) followed by soil and road dust (14 µg/m^3 ~ 26%). Other major sources are vehicular emission (8.8 µg/m^3 ~ 17%), coal and fly ash (11%), industrial (9%), MSW burning (5%) and SIA (3%). Contribution of the construction material was less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.6) show that most of the time wind is from NW and West and wind mass travels over Thar Desert before entering in Jaipur. These winds pick up the pollutants on the way especially from tall emitting sources.

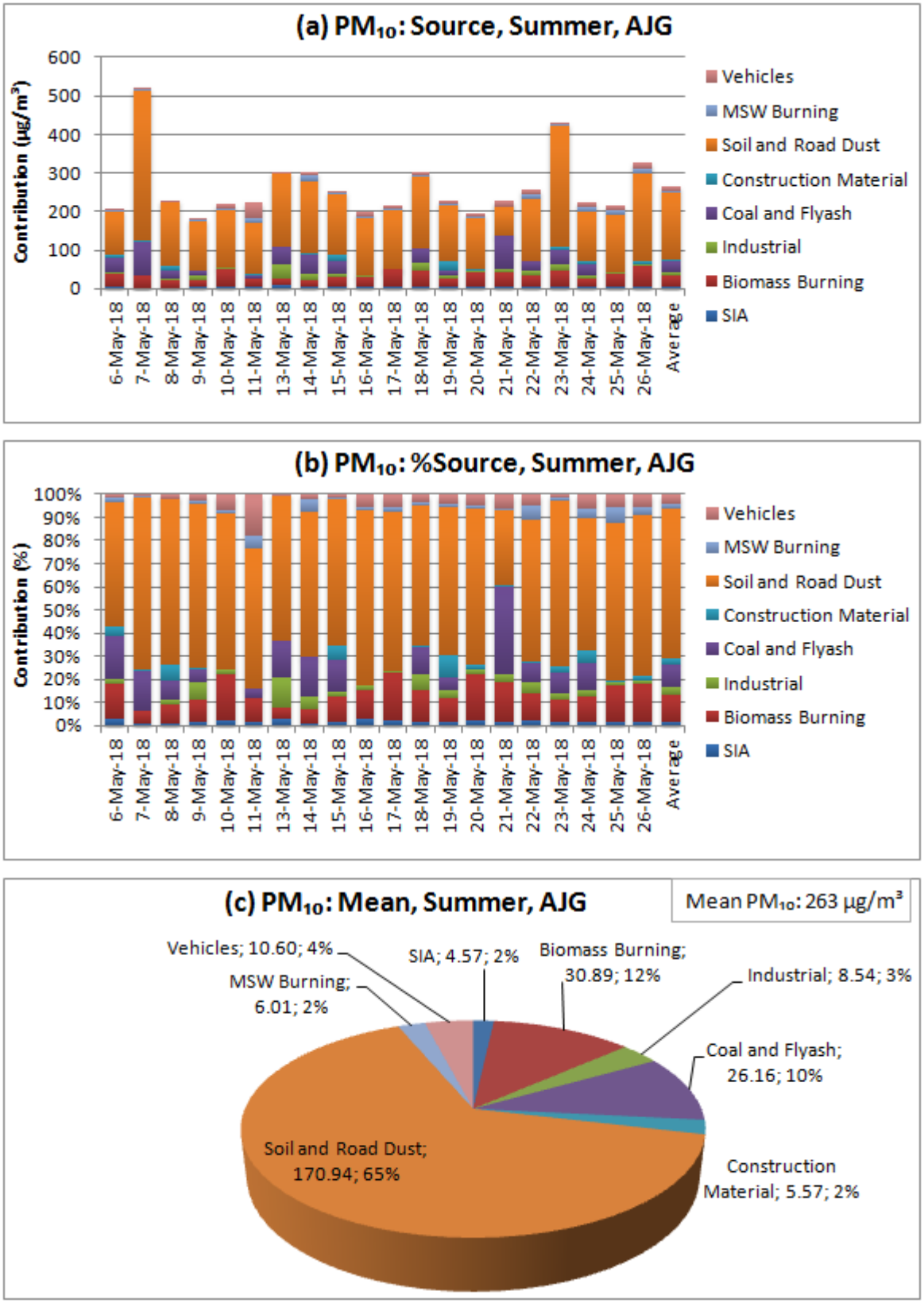


Figure 5.4: CMB modeling for PM_{10} at AJG for summer season

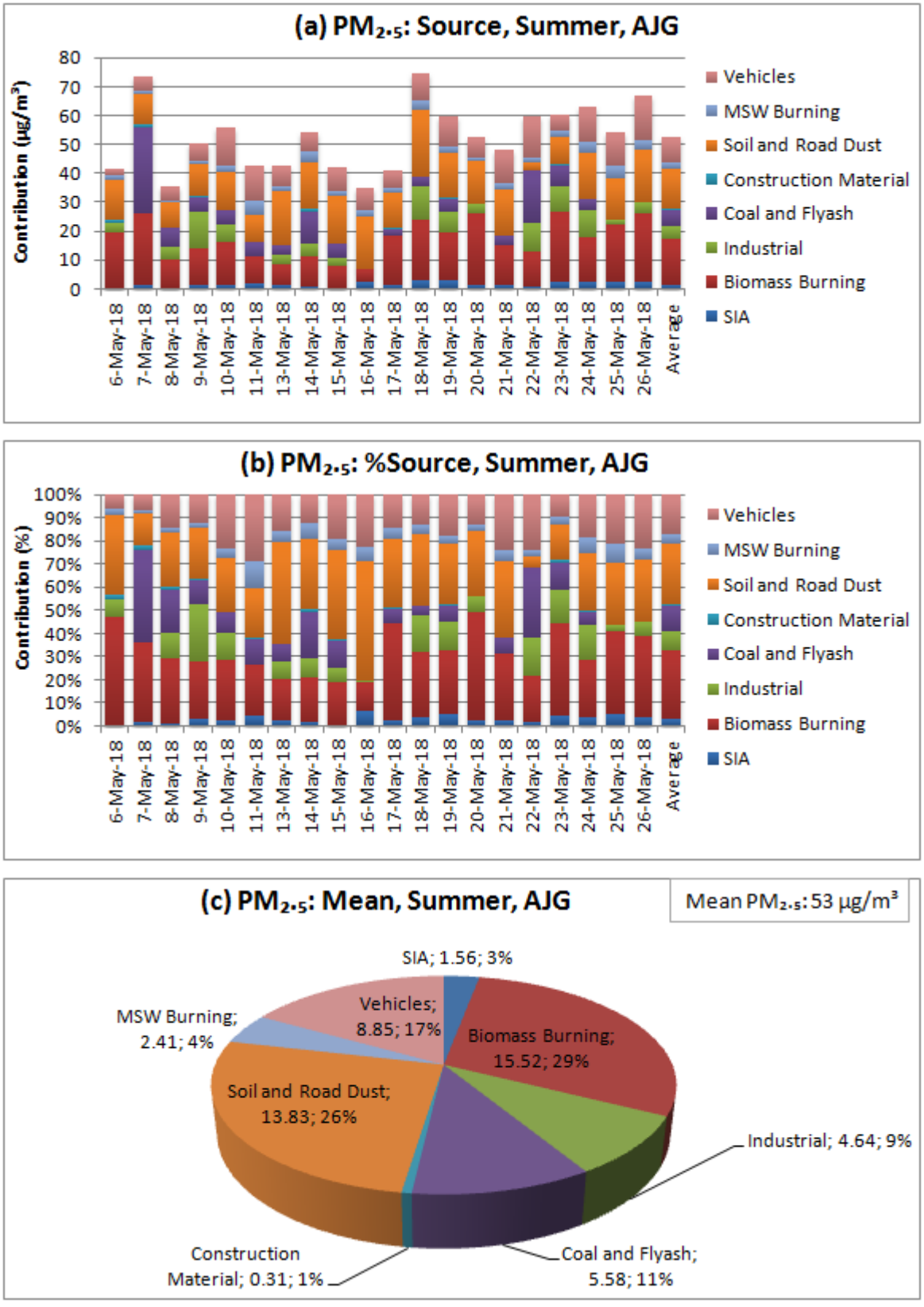


Figure 5.5: CMB modeling for $PM_{2.5}$ at AJG for summer season

Table 5.2: Statistical summary: AJG, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	263	257	98.3	0.74	53	53	99.9	0.68
SD	84	79	8.1	0.07	12	12	8.3	0.06
CV	0.32	0.31	0.08	0.09	0.22	0.23	0.08	0.09
Maximum	520	515	126.1	0.87	75	79	115.1	0.75
Minimum	183	177	86.9	0.59	35	32	83.8	0.56

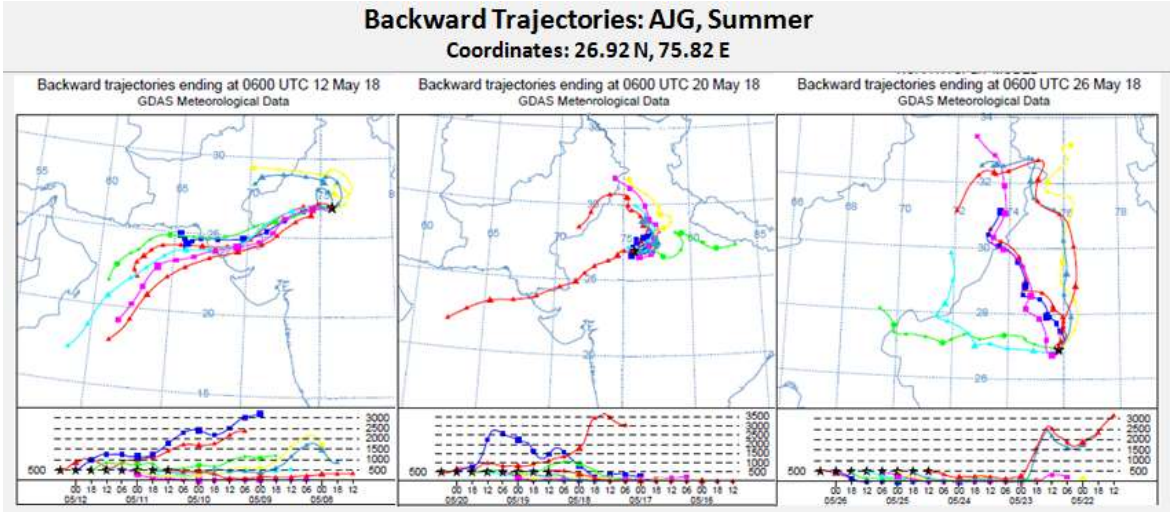


Figure 5.6: Backward trajectories at AJG for summer season

Inferences

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

5.3.2 Vishwakarma Industrial Area (VKI)

5.3.2.1 Winter Season [sampling period: Dec 9 - 31, 2017]

PM_{10} (winter)

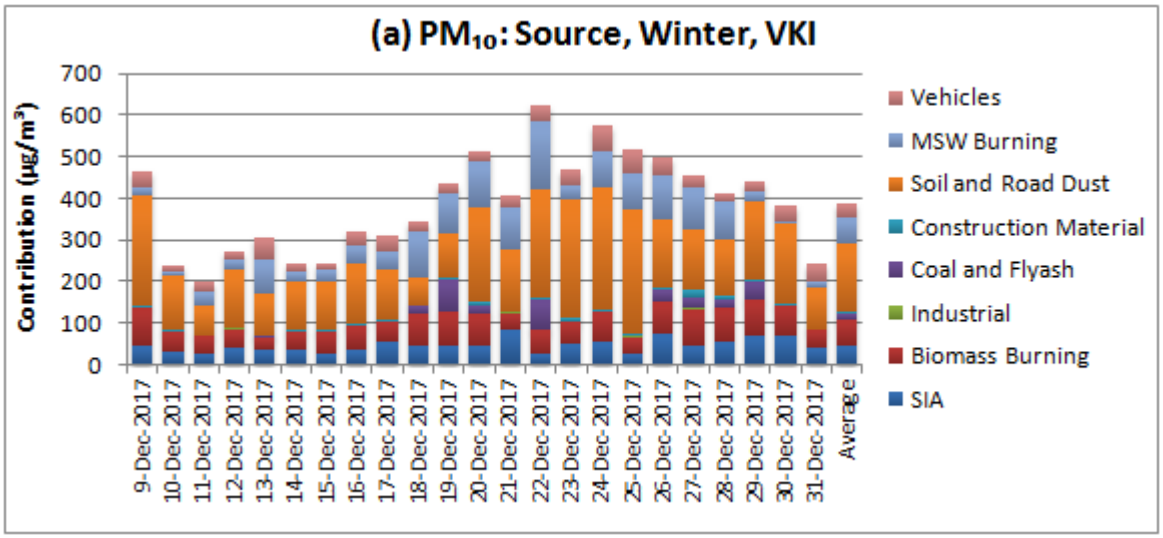
The average PM_{10} concentration was 388 µg/m^3. Figure 5.7 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage

respectively at VKI. Table 5.3 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (166 µg/m^3 ~ 43%) followed by MSW burning (62 µg/m^3 ~ 16%) in PM_{10} and biomass burning (61 µg/m^3 ~ 16%). The other sources are SIA (47 µg/m^3 ~ 12%), vehicular emission (33 µg/m^3 ~ 8%), coal and fly ash (3.4%) and construction material (1.5%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 175 µg/m^3. Figure 5.8 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKI. It is observed that the major source contributing in $PM_{2.5}$ was soil and road dust (59 µg/m^3 ~ 34%) followed by biomass burning (42 µg/m^3 ~ 24%). Other predominant sources are MSW burning (30 µg/m^3 ~ 17%), vehicular emission (24 µg/m^3 ~ 14%) and coal and fly ash (1.7%). Contribution of the industrial emission and construction material was estimated less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.9) show that most of the time wind is from NW and wind mass travels over Thar Desert and part of Punjab State before entering in Jaipur. These winds pick up the pollutants on the way especially from large and tall emitting sources.



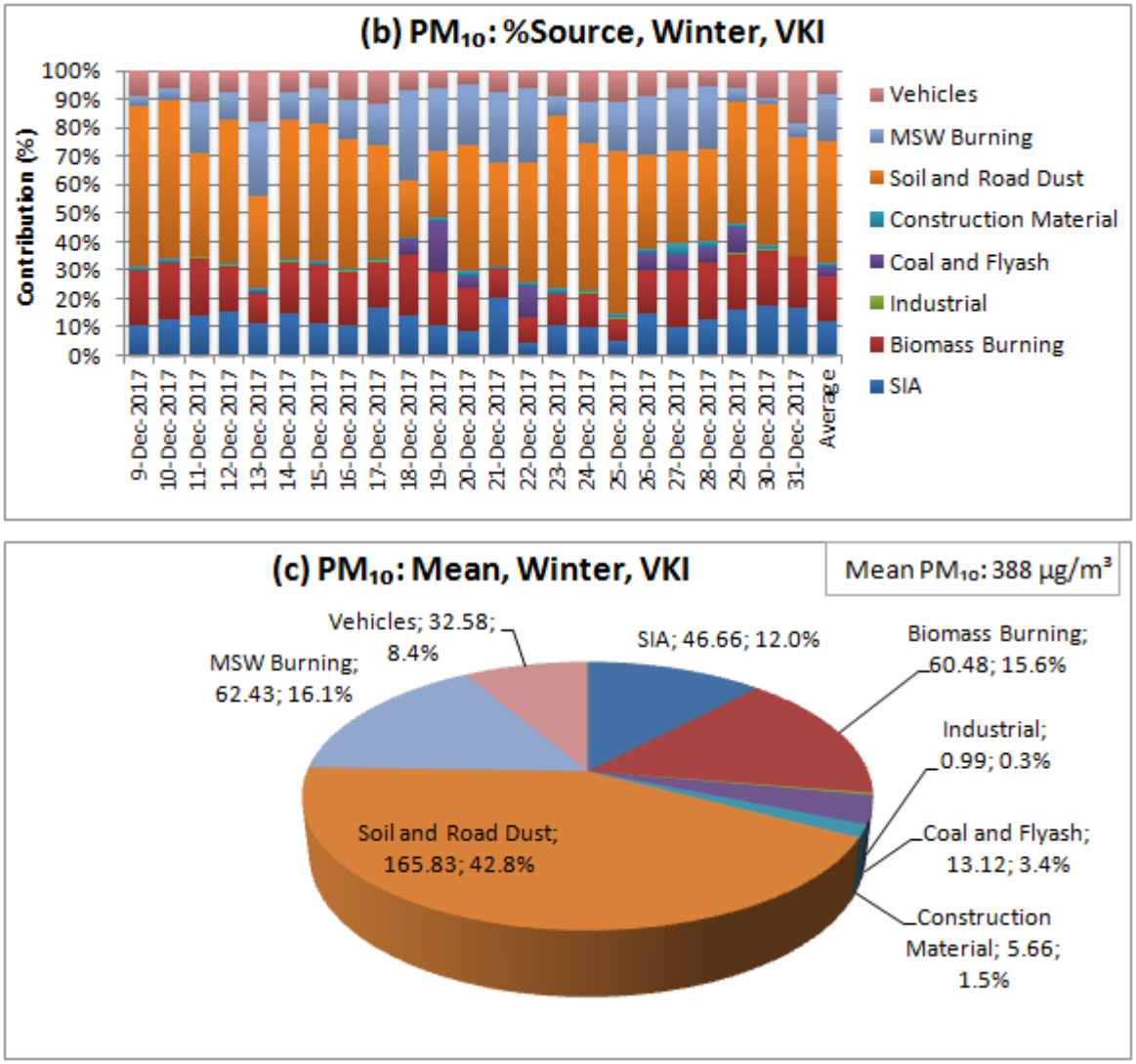
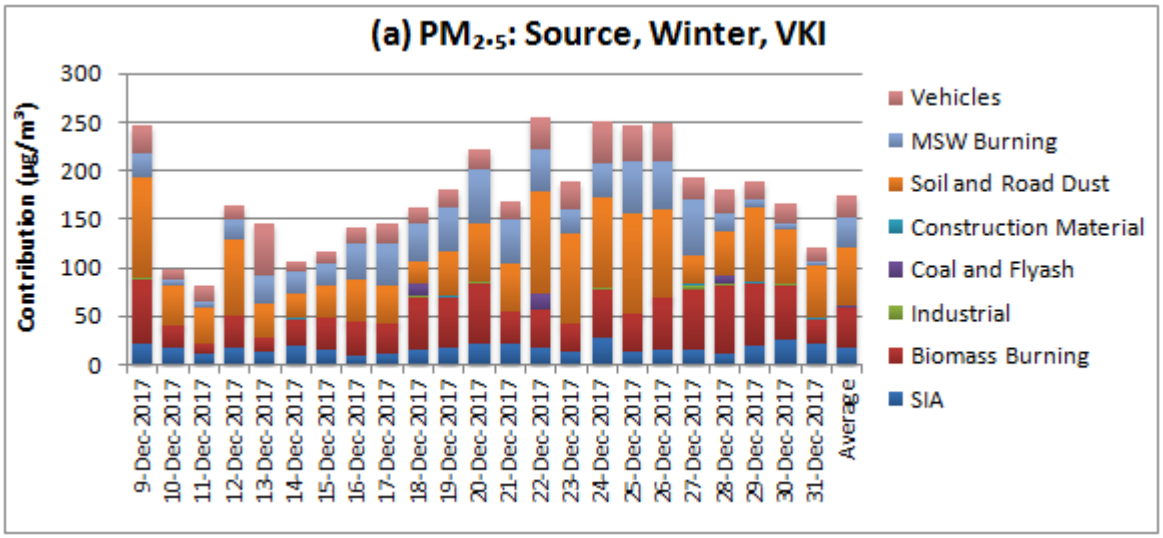


Figure 5.7: CMB modeling for PM_{10} at VKI for winter season



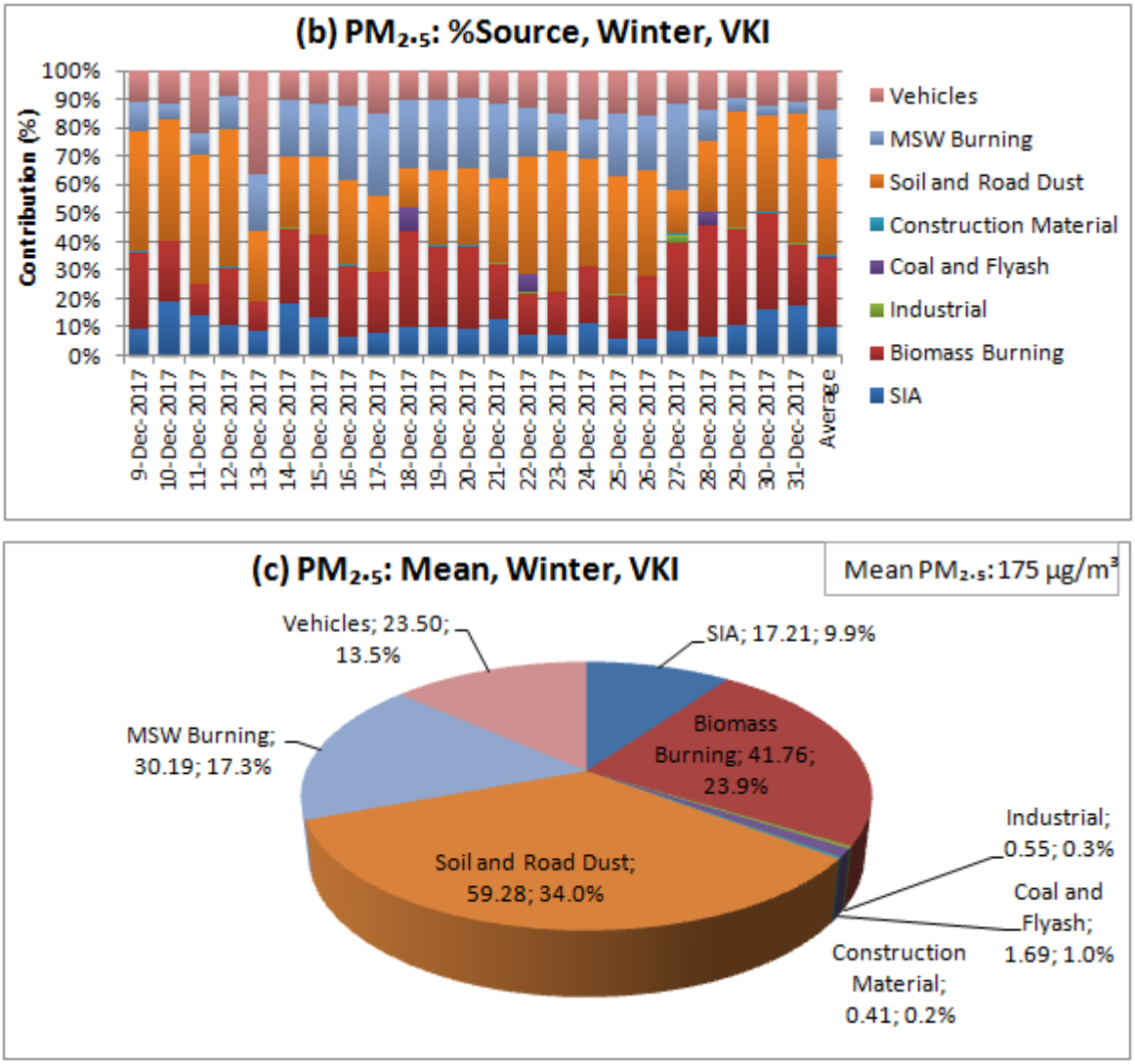


Figure 5.8: CMB modeling for $PM_{2.5}$ at VKI for winter season

Table 5.3: Statistical summary: VKI, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	388	403	102.9	0.72	175	184	104.7	0.71
SD	119	140	7.05	0.08	52	58	7.76	0.07
CV	0.31	0.35	0.07	0.11	0.30	0.32	0.07	0.10
Maximum	625	715	116.1	0.91	255	277	119.5	0.83
Minimum	199	208	87.9	0.60	82	81	84.0	0.53

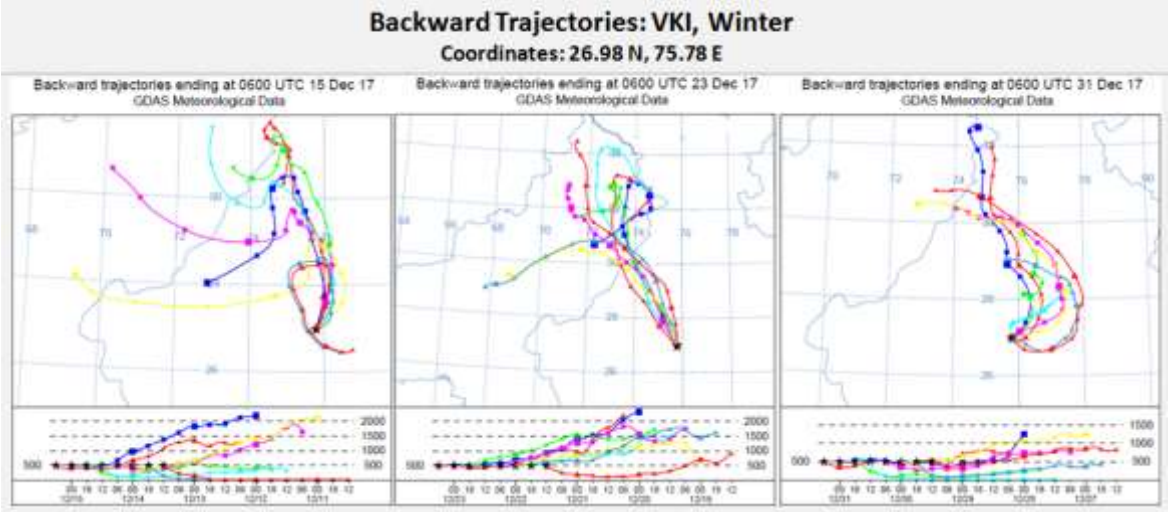


Figure 5.9: Backward trajectories at VKI for winter season

Inferences

For PM_{10}, biomass burning and MSW burning contribute about equally at about 16% and soil and road dust 43%. For $PM_{2.5}$, soil and road dust contribution is consistent and slightly reduced to about 34% (from 43% in PM_{10}). Vehicles and biomass burning contribution increases significantly in $PM_{2.5}$. The MSW burning is exceptionally high at VKI that indicates irregular management of waste generated from industries which succeeds for open burning.

5.3.2.2 Summer Season [sampling period: May 06 - 26, 2018]

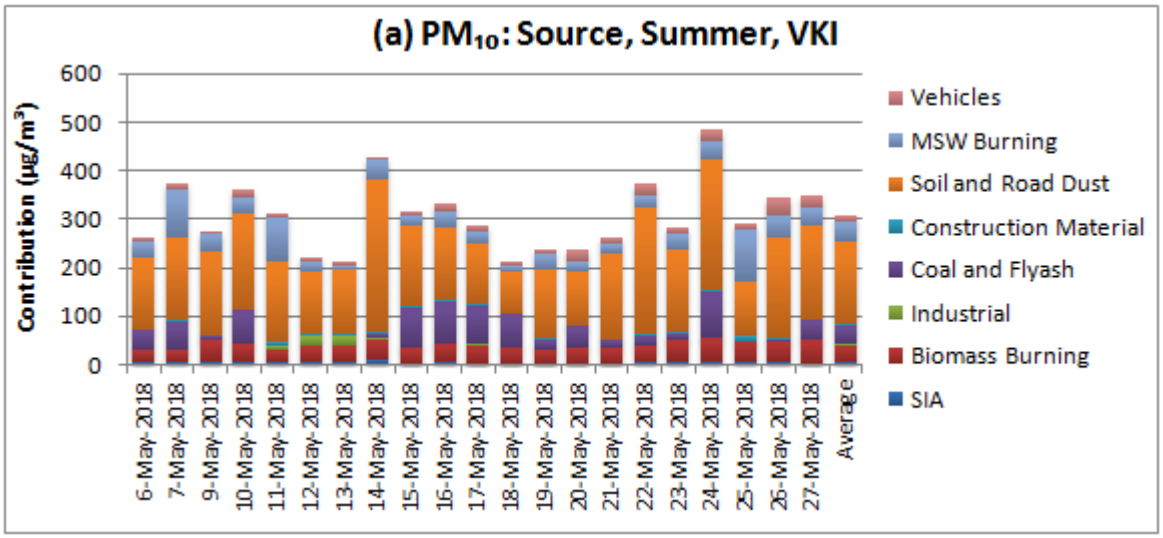
PM_{10} (summer)

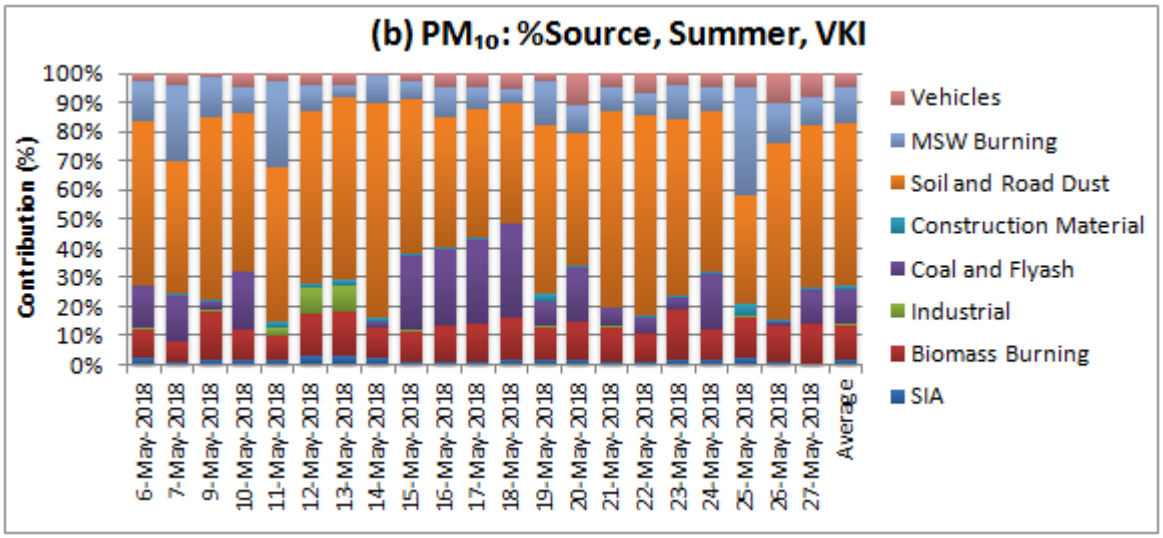
The average PM_{10} concentration was 308 µg/m^3. Figure 5.10 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKI. Table 5.4 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (171 µg/m^3 ~ 56%) followed by MSW burning (39 µg/m^3 ~ 13%). The other significant sources are coal and fly ash (36 µg/m^3 ~ 12%) and biomass burning (36 µg/m^3 ~ 12%), vehicular emission (5%) and SIA (2%). Contribution of the construction material and industrial emission were estimated less than 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 81 µg/m^3. Figure 5.11 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKI. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (26 µg/m^3 ~ 32%) followed by soil and road dust (22 µg/m^3 ~ 27%). Other significant sources are MSW burning (11 µg/m^3 ~ 14%), vehicular emission (9 µg/m^3 ~ 11%), coal and fly ash (8 µg/m^3 ~ 9 %) and SIA (7%). Contribution of the construction material and industrial emission were estimated less than 2% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.12) show that most of the time wind is from NW and SW. Wind mass travels over Thar Desert before entering in Jaipur. These winds pick up the pollutants on the way especially from large and tall emitting sources.





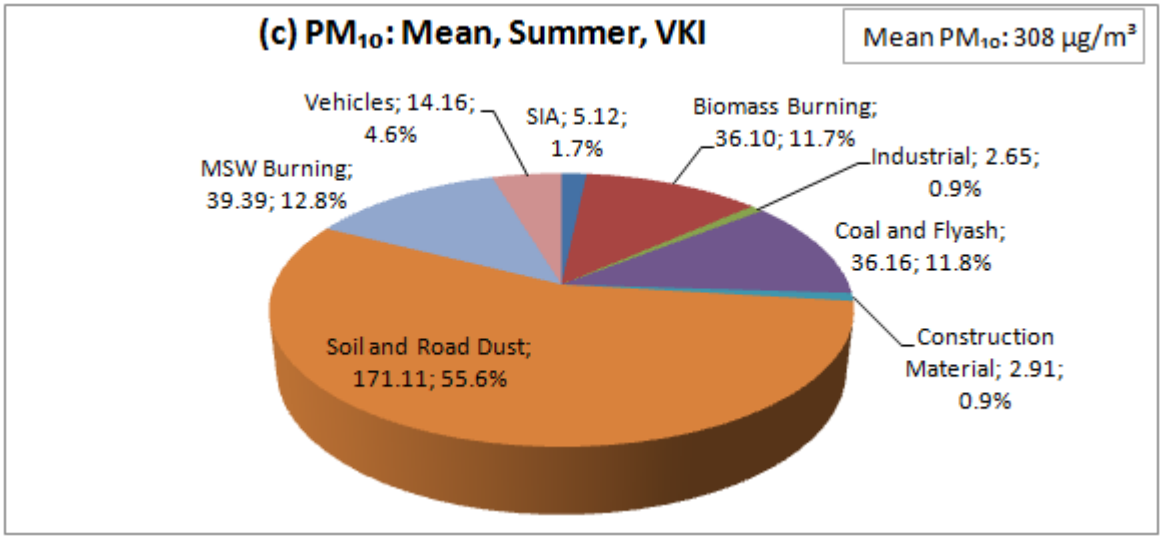
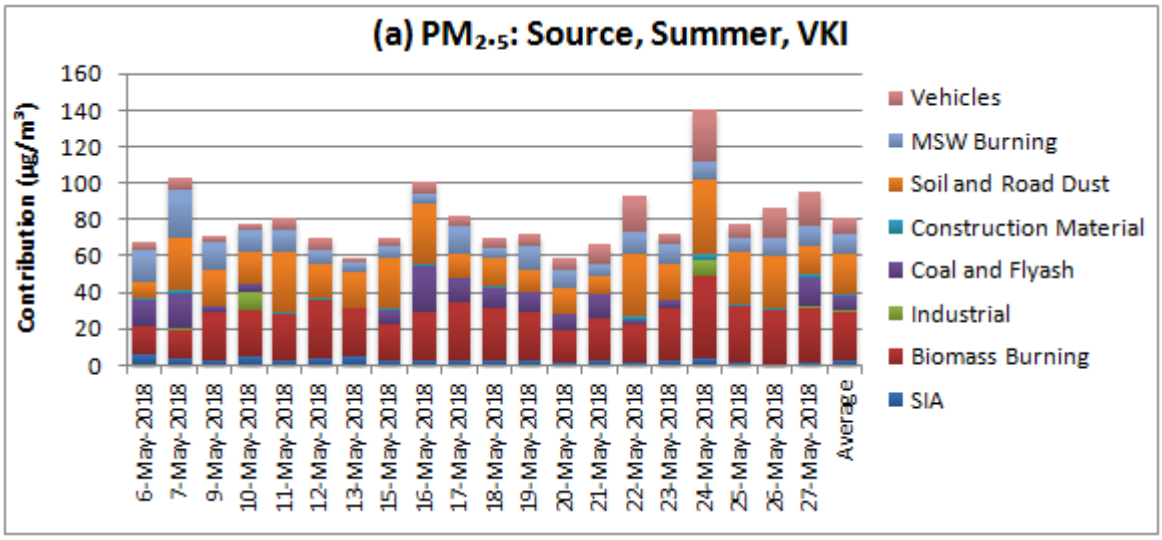
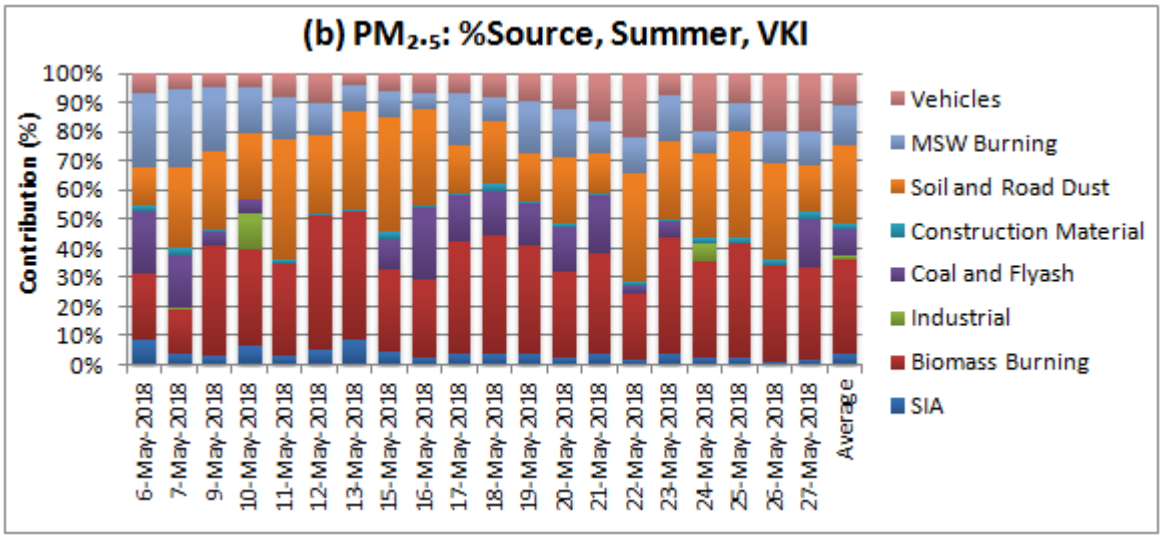


Figure 5.10: CMB modeling for PM_{10} at VKI for summer season





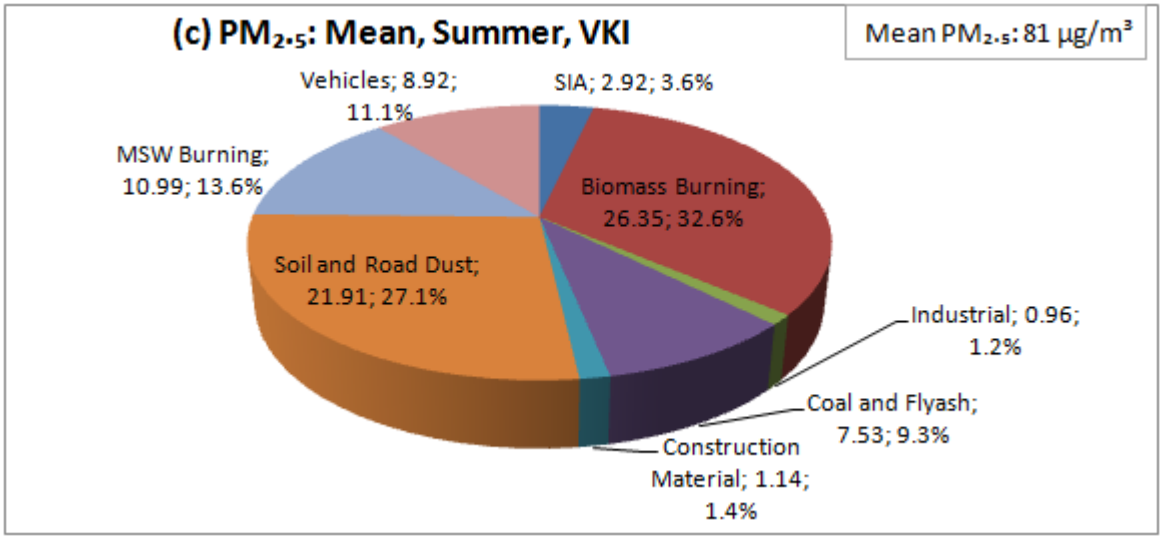


Figure 5.11: CMB modeling for $PM_{2.5}$ at VKI for summer season

Table 5.4: Statistical summary: VKI, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	308	307	100.2	0.75	81	87	107.5	0.66
SD	72	71	9.7	0.09	19	20	8.1	0.06
CV	0.23	0.23	0.10	0.13	0.23	0.23	0.08	0.09
Maximum	484	441	117.5	0.87	140	135	118.1	0.78
Minimum	213	178	80.5	0.56	59	64	95.4	0.59

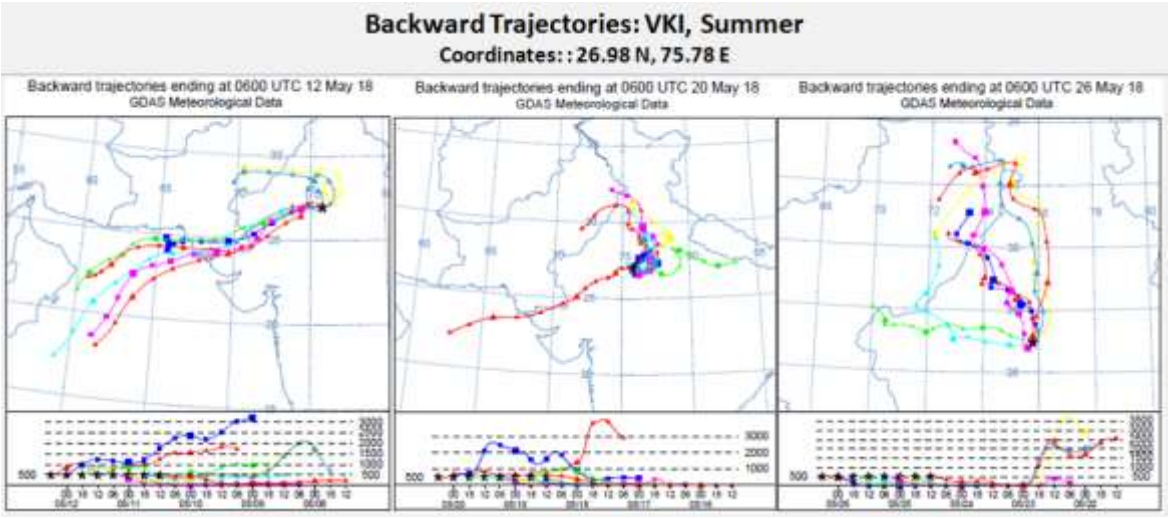


Figure 5.12: Backward trajectories at VKI for Summer Season

Inference

Biomass and MSW burning are the major contributors in summer both for PM_{10} and $PM_{2.5}$, at the same time road and soil dust is prominent both in PM_{10} and $PM_{2.5}$. The sampling site was in the middle of the industrial area which had movement of large trucks

ferrying raw material and finishes products. Poor road conditions due to dumping and burning of MSW and plastic waste along the roadsides were spotted. The MSW burning is exceptionally high at VKI that indicates irregular management of waste generated from industries which succeeds for open burning.

5.3.3 Jorawar Singh Gate (JSG)

5.3.3.1 Winter Season [sampling period: Dec 14, 2017 – Jan 04, 2018]

PM_{10} (winter)

The average PM_{10} concentration was 238 µg/m^3. Figure 5.13 (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 JSG. Table 5.5 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (103 µg/m^3 ~ 43%) followed by biomass burning (52 µg/m^3 ~ 22%) and SIA (46 µg/m^3 ~ 19%). The other significant contributing sources are vehicular emission (22 µg/m^3 ~ 9%), MSW burning (8 µg/m^3 ~ 3%) and construction material (2%). Contribution of the industrial emission and coal and fly ash were estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 118 µg/m^3. Figure 5.14 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at JSG. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (47 µg/m^3 ~ 40%) followed by SIA (36 µg/m^3 ~ 31%). Other major sources are vehicular emission (15 µg/m^3 ~ 13%), soil and road dust (12 µg/m^3 ~ 10%), MSW burning (4%) and industrial emission (1.4%). Contribution of the construction material and coal and fly ash were estimated less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.15) show that most of the time wind is from NW and wind mass travels over Thar desert and part of Punjab state before entering in Jaipur. These winds pick up the pollutants on the way especially from large and tall emitting sources.

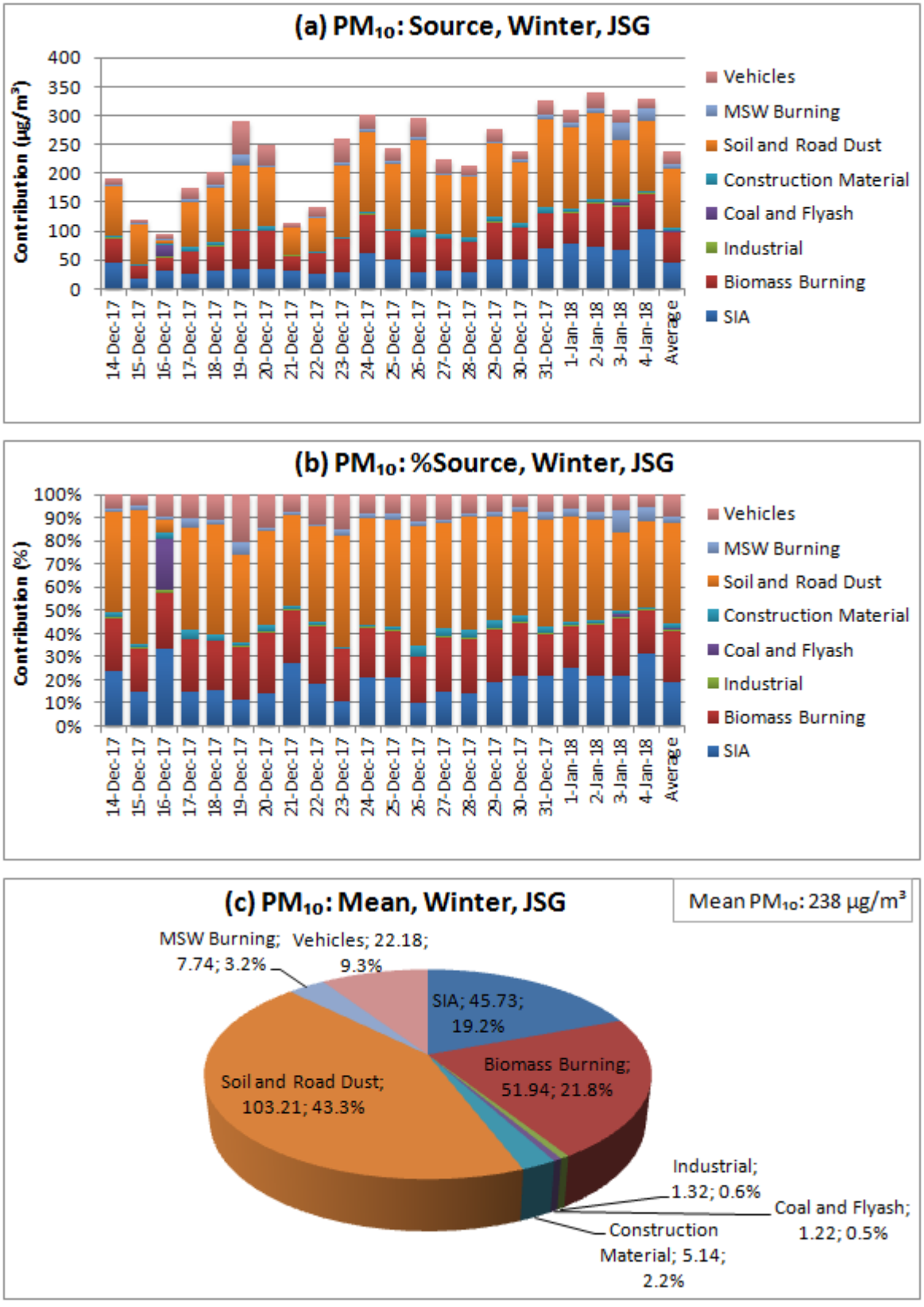


Figure 5.13: CMB modeling for PM_{10} at JSG winter season

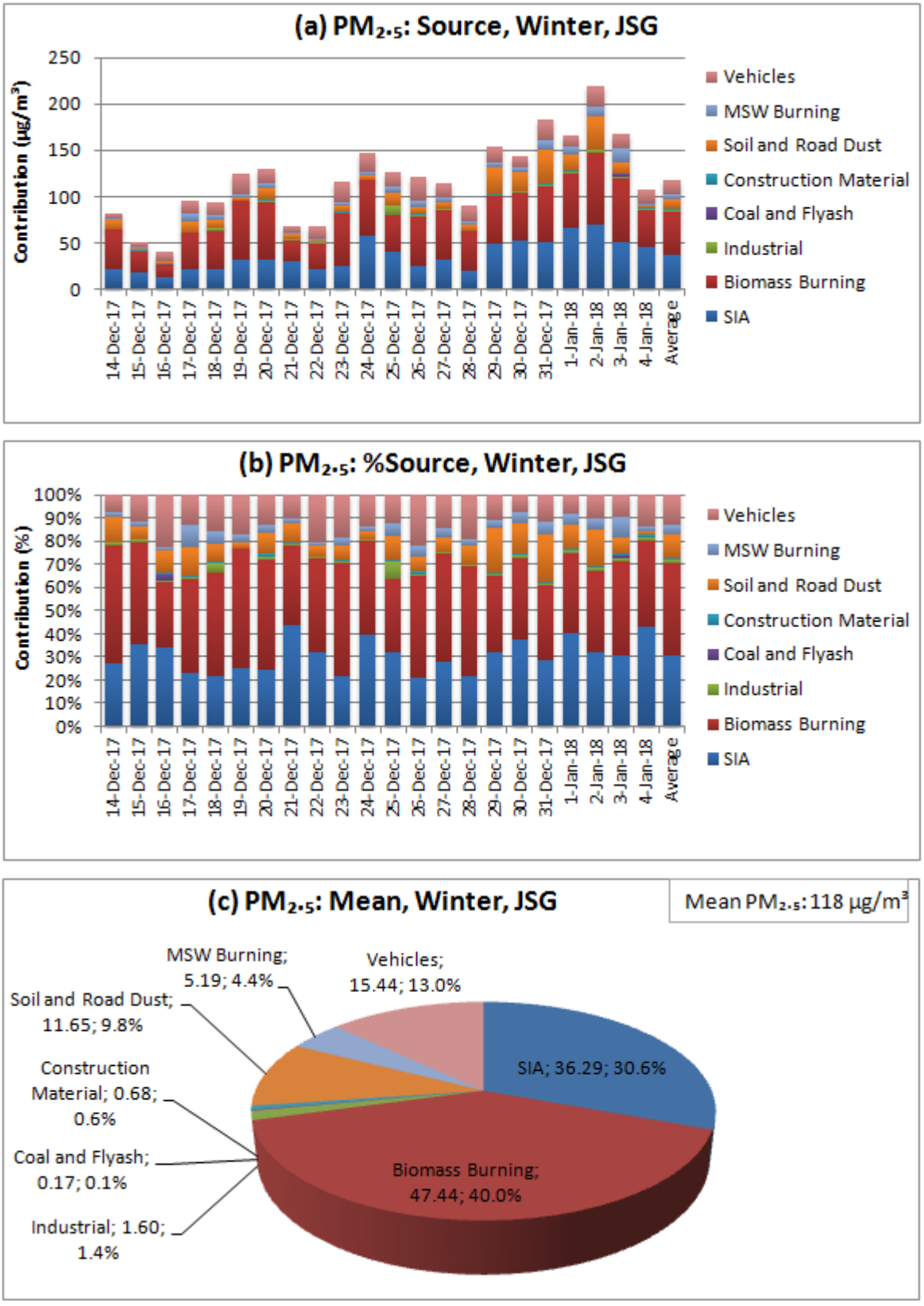


Figure 5.14: CMB modeling for $PM_{2.5}$ at JSG, winter season

Table 5.5: Statistical summary: JSG, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	238	249	105.5	0.68	118	120	101.4	0.76
SD	74	73	6.0	0.08	44	43	5.6	0.05
CV	0.31	0.29	0.06	0.12	0.37	0.36	0.06	0.06
Maximum	340	341	118.8	0.89	219	198	113.8	0.84
Minimum	95	101	96.8	0.59	40	37	90.2	0.66

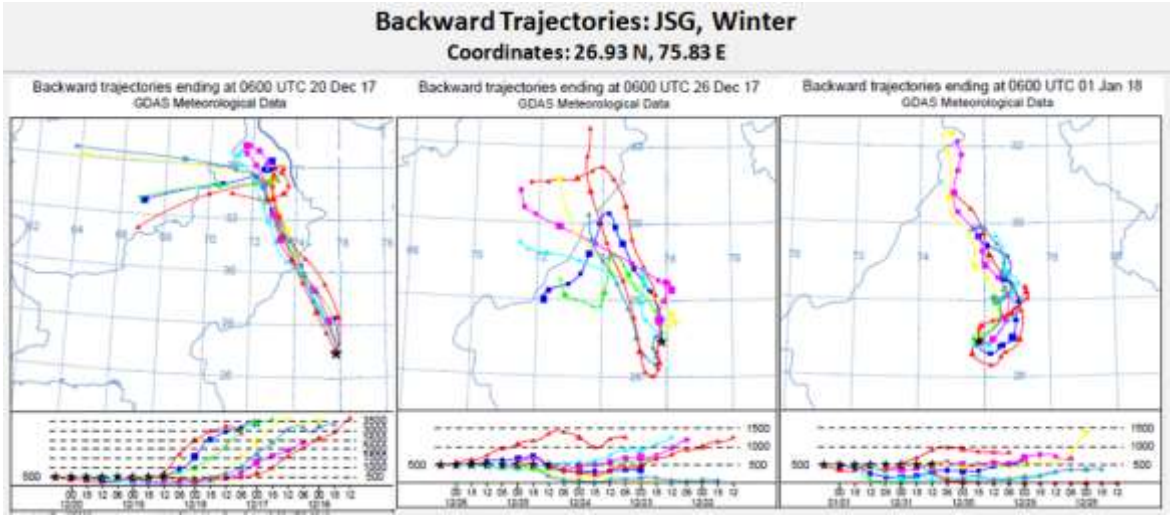


Figure 5.15: Backward trajectories at JSG for winter season

Inferences

Secondary PM (19-31%) and biomass burning (22-40%) are the major sources followed by vehicular contribution (9-15%) – this finding is true for both PM_{10} and $PM_{2.5}$. It is bit surprising that secondary PM has such a high contributors to $PM_{2.5}$.

5.3.3.2 Summer Season [sampling period: May 29 - June 20, 2018]

PM_{10} (summer)

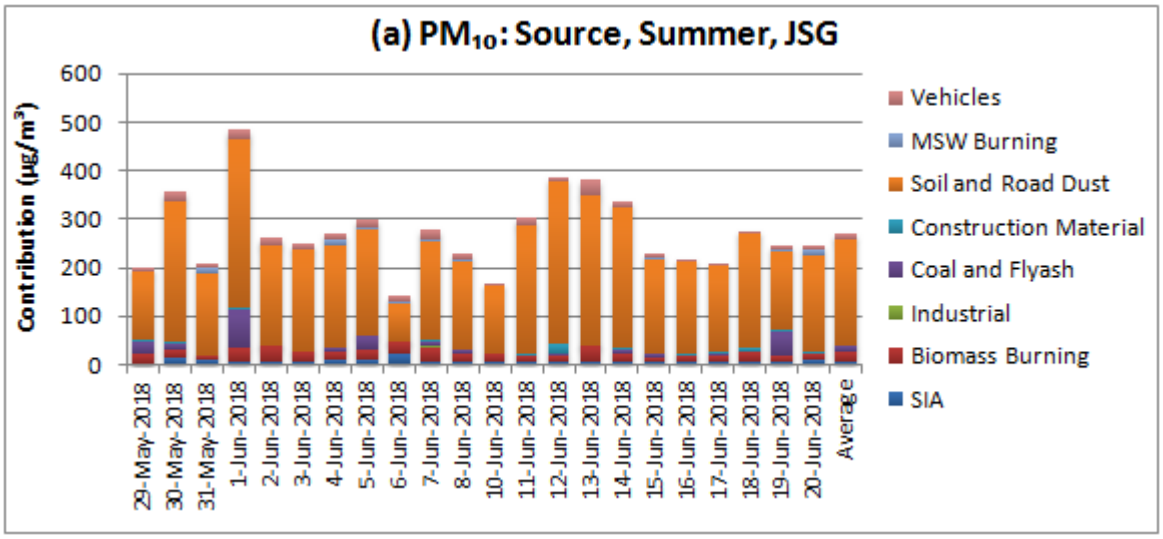
The average PM_{10} concentration was 272 µg/m^3. Figure 5.16 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at JSG. Table 5.6 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (215 µg/m^3 ~ 79%) followed by biomass burning (18 µg/m^3 ~ 7%) in PM_{10}. The other significant sources are vehicular emission (13 µg/m^3 ~ 5%), coal and flyash (11 µg/m^3 ~

4%), SIA (3%), construction material (1%) and MSW burning (1%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 53 µg/m^3. Figure 5.17 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at JSG. It is observed that the major source contributing in $PM_{2.5}$ was soil and road dust (26 µg/m^3 ~ 50%) followed by biomass burning (11 µg/m^3 ~ 21%). Other significant sources are vehicular emission (7 µg/m^3 ~ 13%), SIA (8%), coal and flyash (3%), MSW burning (3%) and construction material (2%). Contribution of the industrial emission was estimated less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.18) show that most of the time wind is from SW and wind mass travels over Thar Desert before entering in Jaipur. These winds pick up the pollutants on the way especially from large.



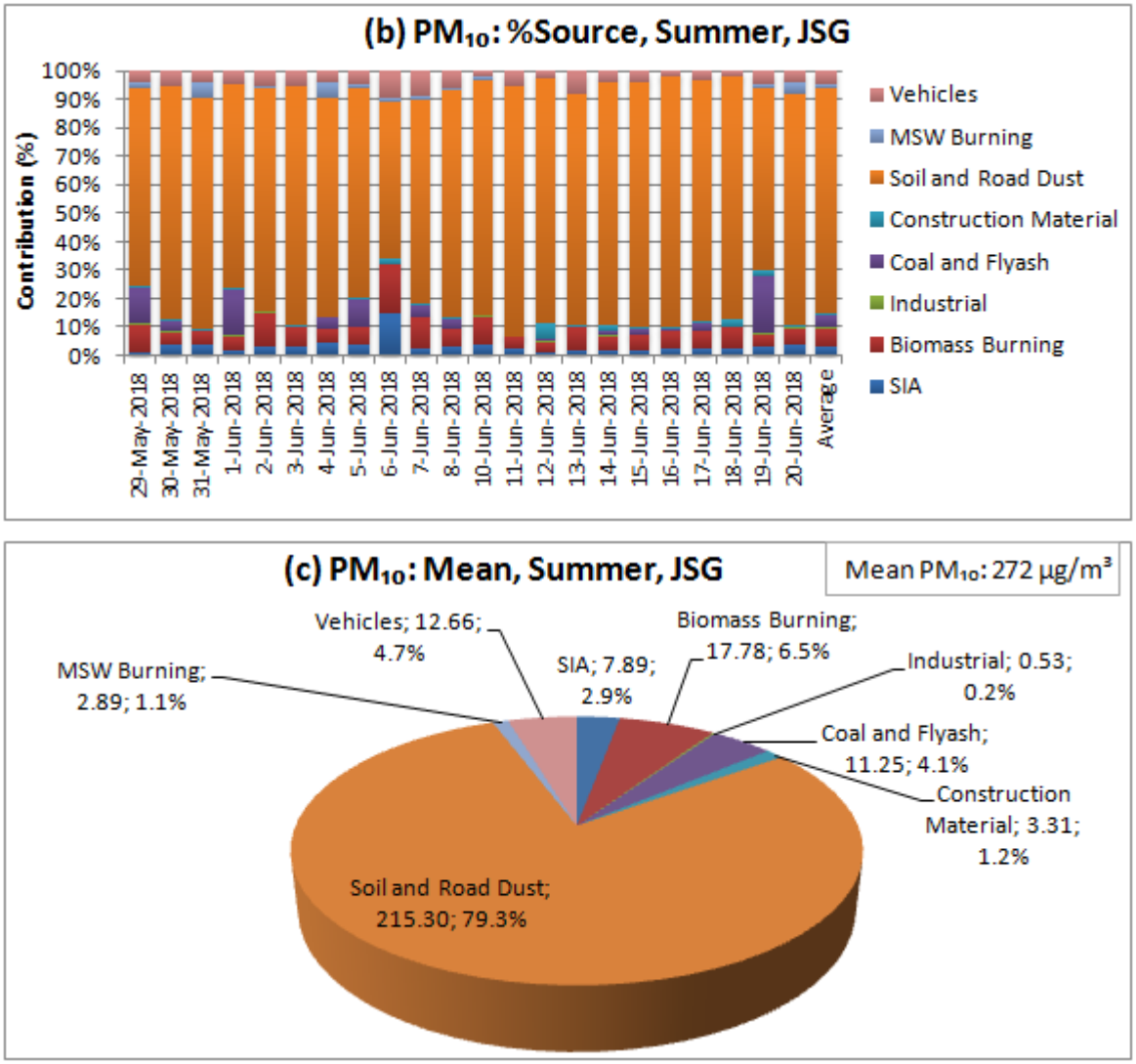
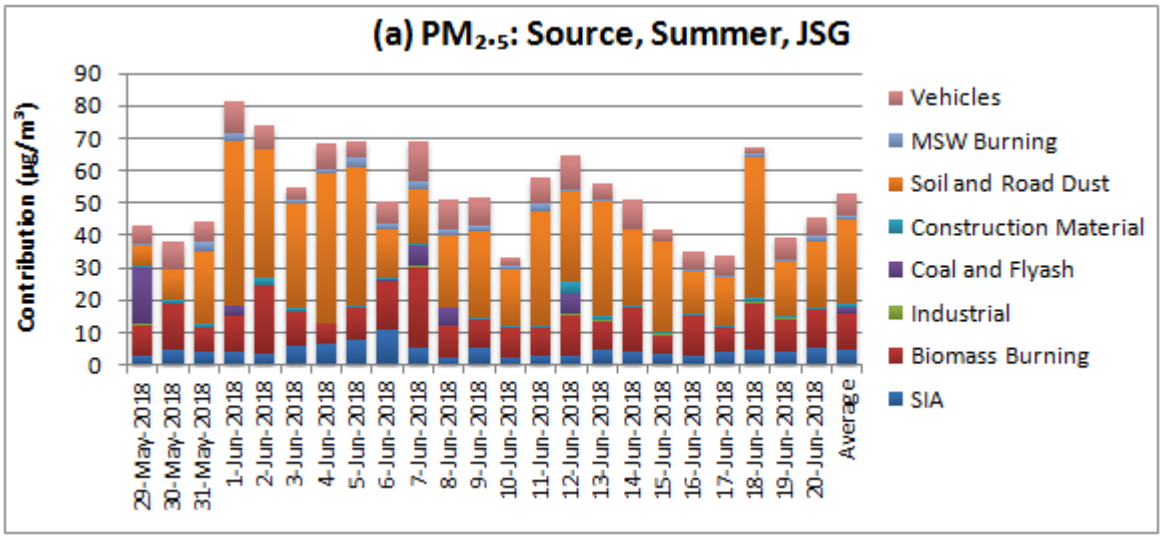


Figure 5.16: CMB modeling for PM_{10} at JSG for summer season



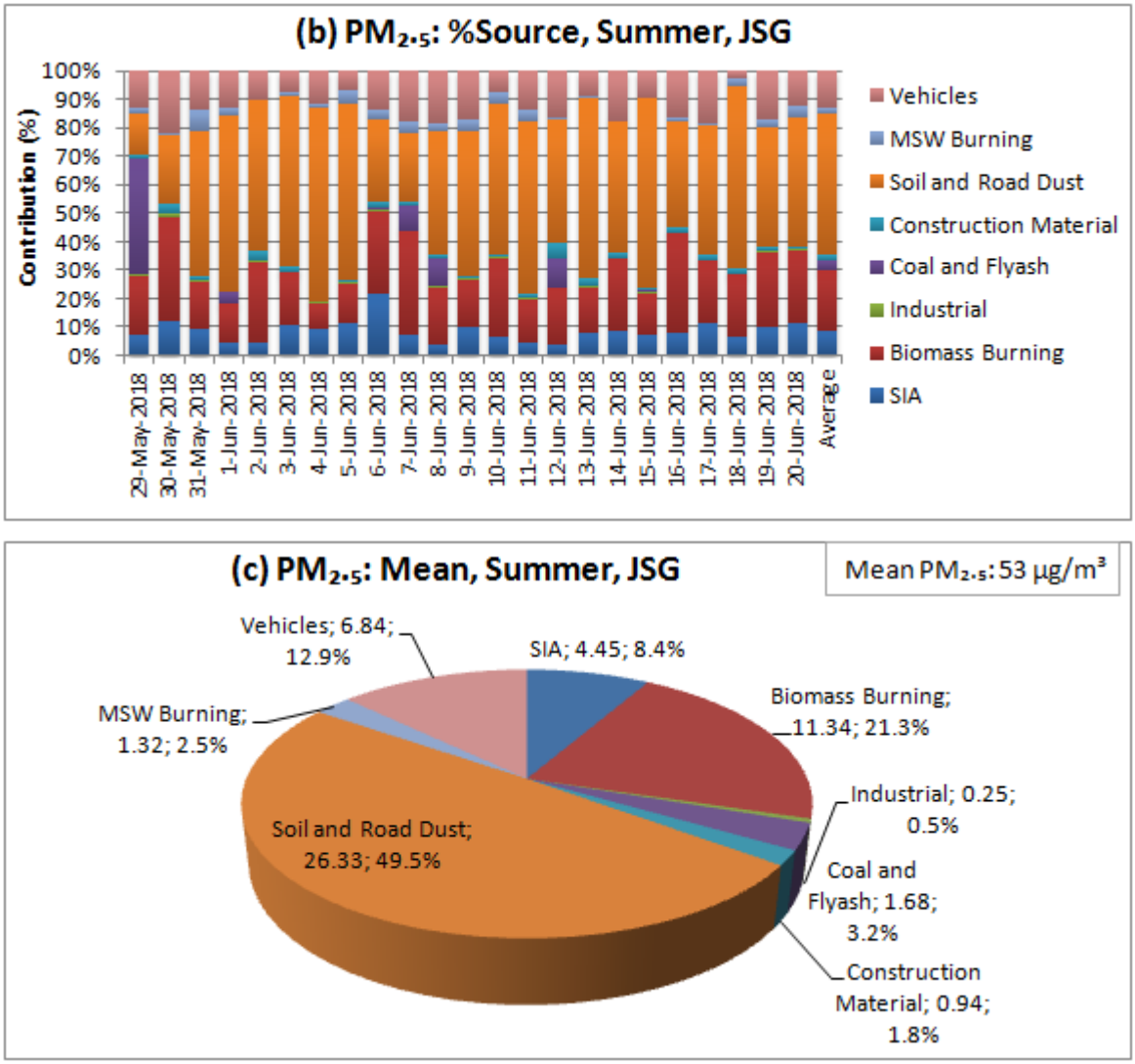


Figure 5.17: CMB modeling for $PM_{2.5}$ at JSG for summer season

Table 5.6: Statistical summary: JSG, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	272	287	106.8	0.62	53	59	111.8	0.62
SD	79	72	6.7	0.08	14	16	4.7	0.07
CV	0.29	0.25	0.06	0.12	0.26	0.27	0.04	0.11
Maximum	486	472	117.9	0.78	82	88	118.3	0.78
Minimum	142	161	93.6	0.50	33	36	102.7	0.51

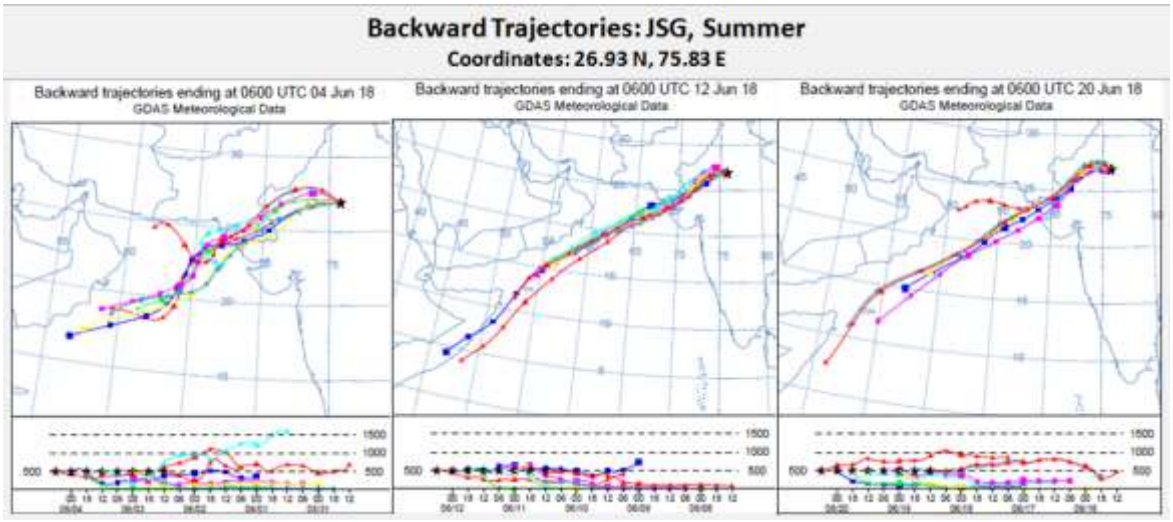


Figure 5.18: Backward trajectories at JSG for summer season

Inference

Soil and road dust is the major contributors in summer both for PM_{10} and $PM_{2.5}$, at the same time desert soil dust is prominent both in PM_{10} and $PM_{2.5}$.

5.3.4 Malviya Nagar (MLN)

5.3.4.1 Winter Season [sampling period: Jan 26 – Feb 14, 2018]

PM_{10} (winter)

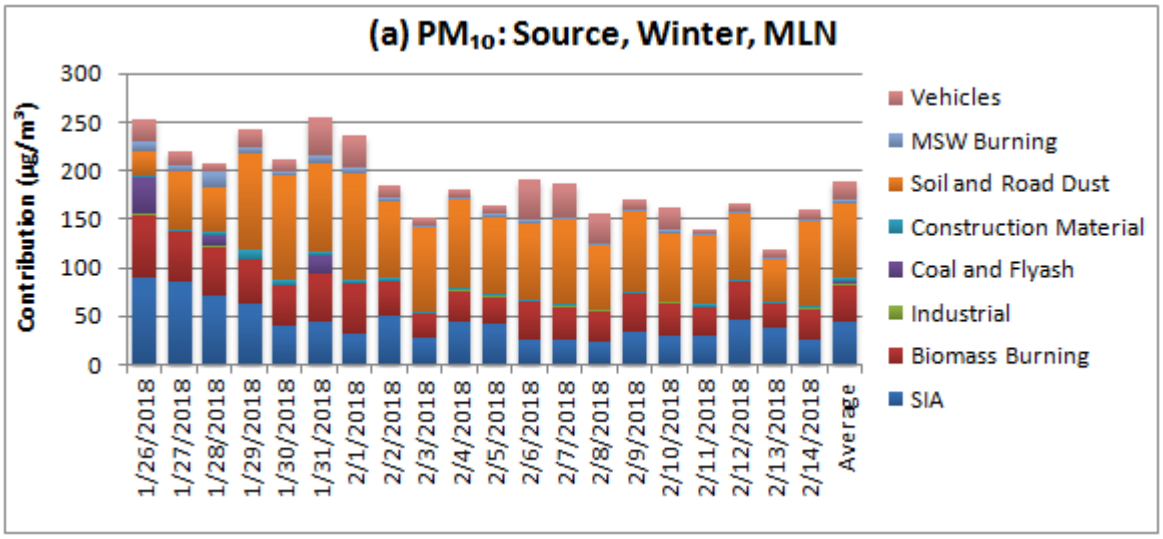
The average PM_{10} concentration was 188 µg/m^3. Figure 5.19 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at MLN. Table 5.7 presents summary of performance and acceptability of CMB model. It is observed that the major contributing source was soil and road dust (76 µg/m^3 ~ 41%) followed by SIA (43 µg/m^3 ~ 23%) and biomass burning (39 µg/m^3 ~ 21%). The other significant contributing sources are vehicular emission (18 µg/m^3 ~ 9%), MSW burning (3%), coal and flyash (2%) and construction material (2%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

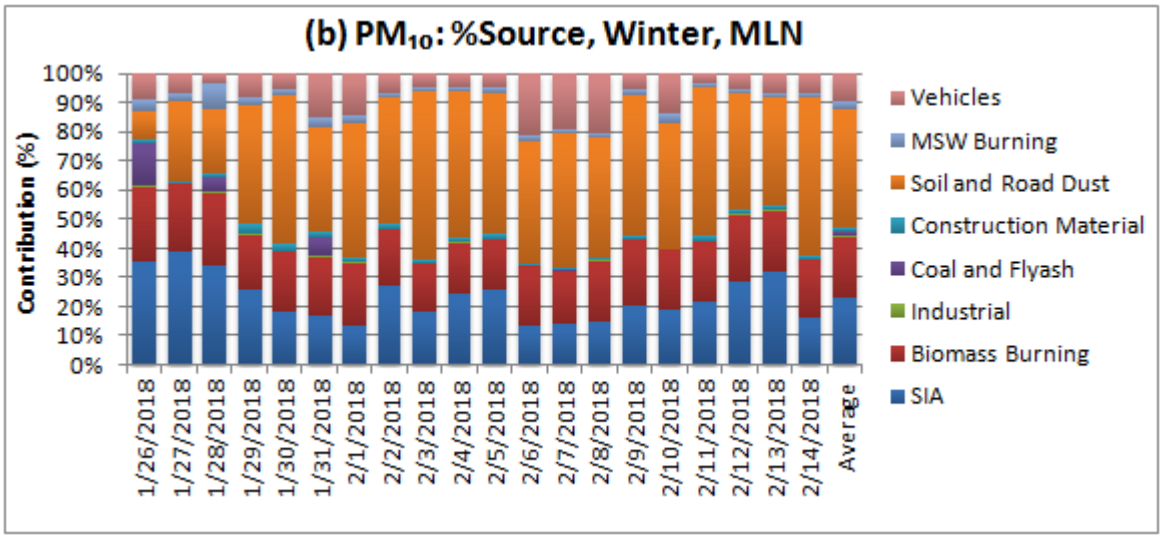
$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 74 µg/m^3. Figure 5.20 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage

respectively at MLN. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (30 µg/m^3 ~ 40%) followed by SIA (19 µg/m^3 ~ 26%). Other significant sources are soil and road dust (11 µg/m^3 ~ 15%), vehicular emission (11 µg/m^3 ~ 14%) and MSW burning (4%). The minor source are coal and flyash (<1%), construction material (<1%) and industrial emission (<1%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.21) show that wind is not stable in any particular direction and wind mass travel over to neighboring districts before entering into Jaipur. These winds pick up the pollutants on the way especially from large and tall emitting sources.





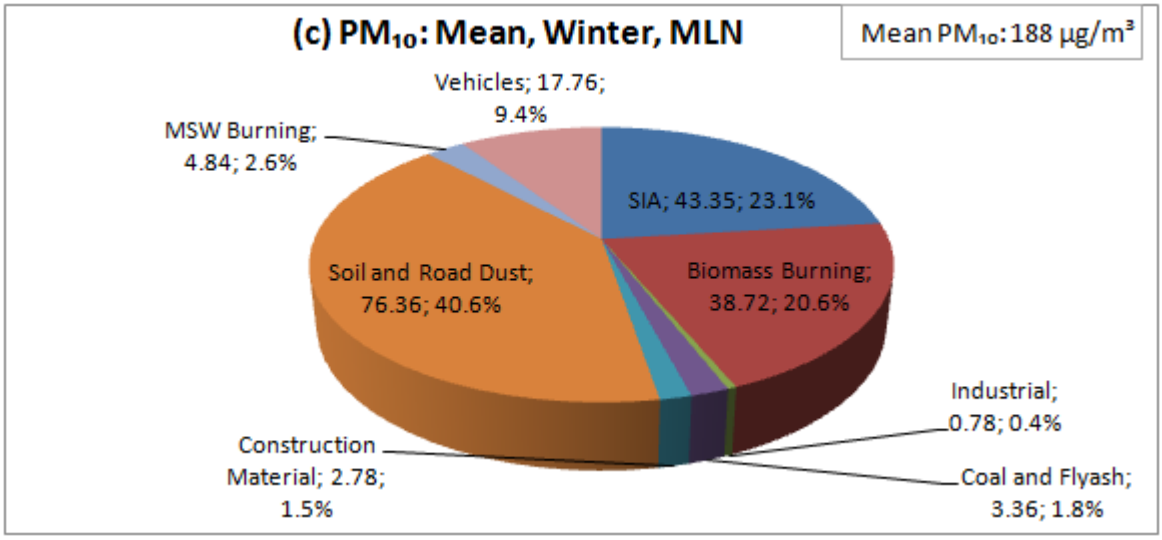
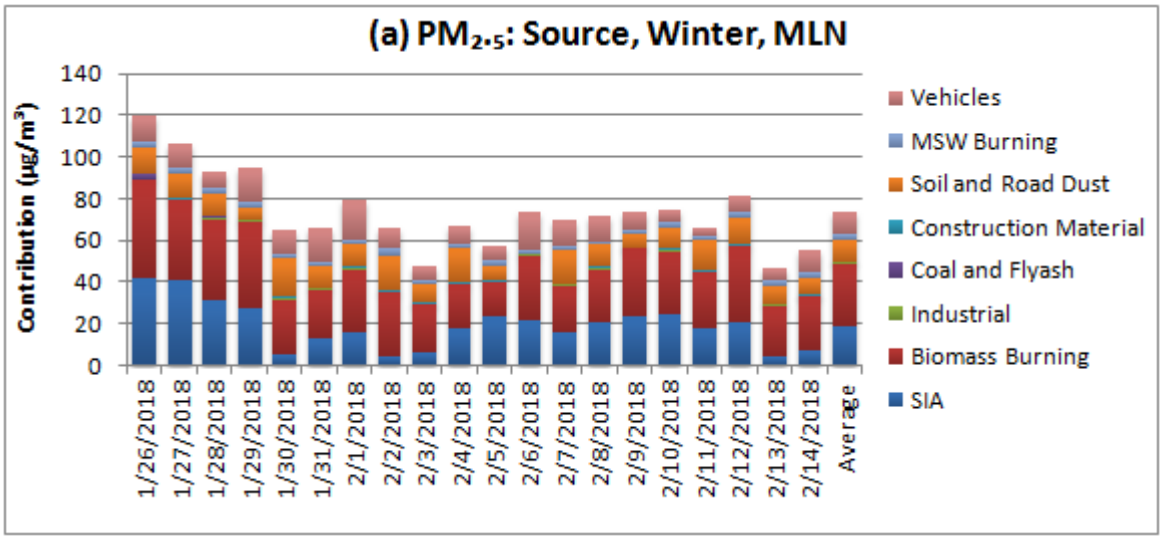
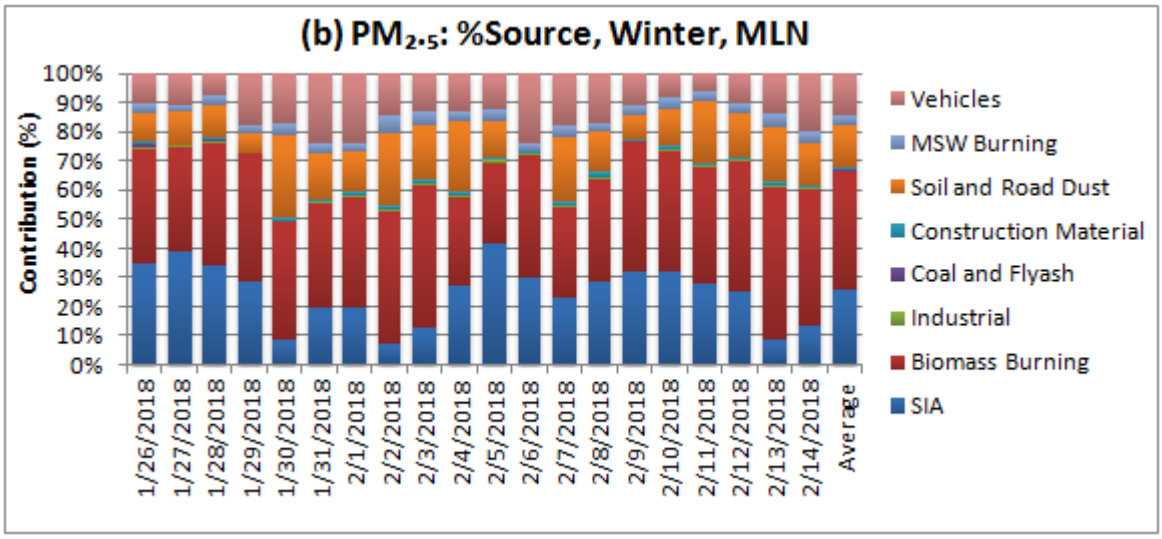


Figure 5.19: CMB modeling for PM_{10} at MLN for winter season





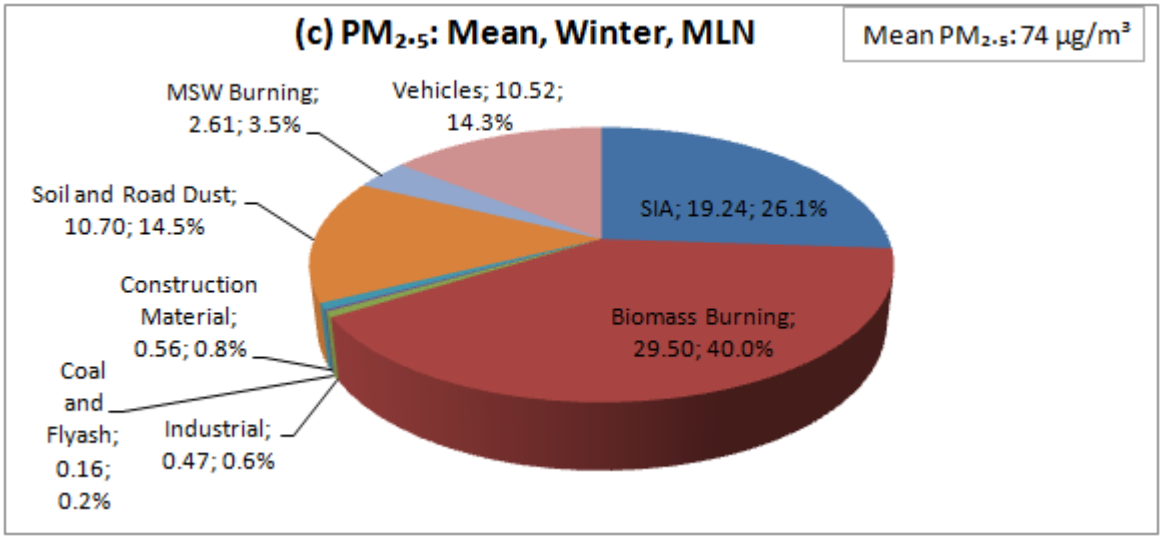


Figure 5.20: CMB modeling for $PM_{2.5}$ at MLN for winter season

Table 5.7: Statistical summary: MLN, winter season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	188	196	104.5	0.68	74	76	102.8	0.72
SD	39	38	4.8	0.05	18	19	3.7	0.06
CV	0.21	0.20	0.05	0.07	0.25	0.25	0.04	0.08
Maximum	255	265	114.4	0.78	120	118	109.8	0.84
Minimum	118	126	97.7	0.59	47	45	96.5	0.60

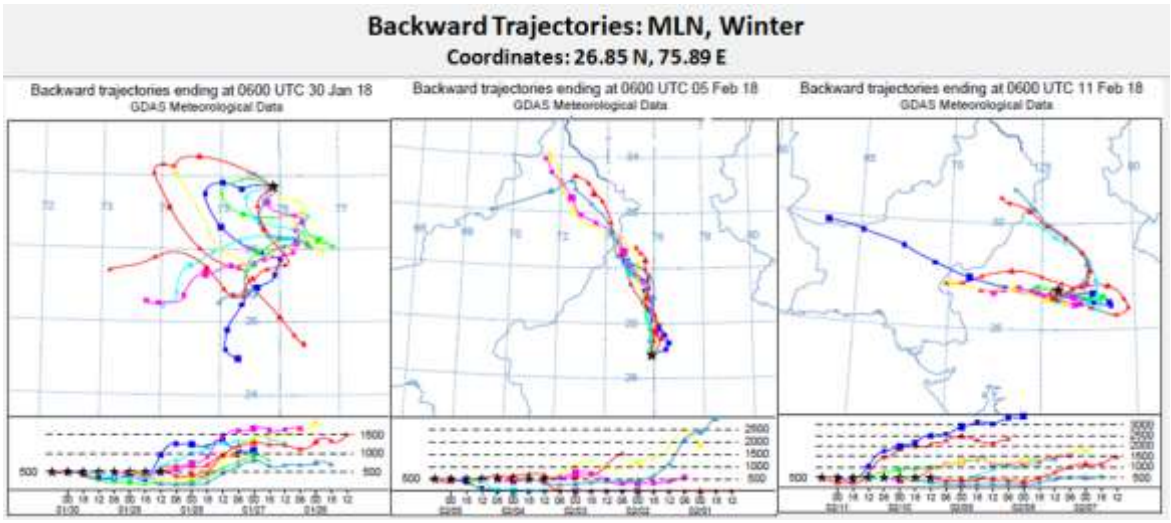


Figure 5.21: Backward trajectories at MLN for winter season

Inference

It is to be noted that at MLN, secondary inorganic particles contribute about 23-26% and biomass burning 21-40% for $PM_{2.5}$ and PM_{10}. Soil and road dust is significantly reduces to 15% in $PM_{2.5}$ compared to 41% of PM_{10}.

5.3.4.2 Summer Season [sampling period: April 15 – May 04, 2018]

PM_{10} (summer)

The average PM_{10} concentration was 230 µg/m^3. Figure 5.22 (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 MLN. Table 5.8 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (160 µg/m^3 ~ 70%) followed by biomass burning (28 µg/m^3 ~ 12%). The other significant sources are vehicular emission (12 µg/m^3 ~ 5%), coal and flyash (5%), SIA (5%) and MSW burning (1.4%). Other minor sources are construction material (<1%) and industrial emission (<1%).

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 42 µg/m^3. Figure 5.23 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at MLN. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (16 µg/m^3 ~ 38%) followed by soil and road dust (15 µg/m^3 ~ 35%). Other major sources are vehicular emission (6 µg/m^3 ~ 15%), SIA (7%), MSW burning (3%), coal and flyash (2%). Other minor sources are construction material (<1%) and industrial emission (<1%).

HYSPLIT back trajectories (Figure 5.24) show that most of the time wind is from NW and wind mass travels over Thar Desert before entering in Jaipur. These winds pick up the pollutants on the way especially from large sources.

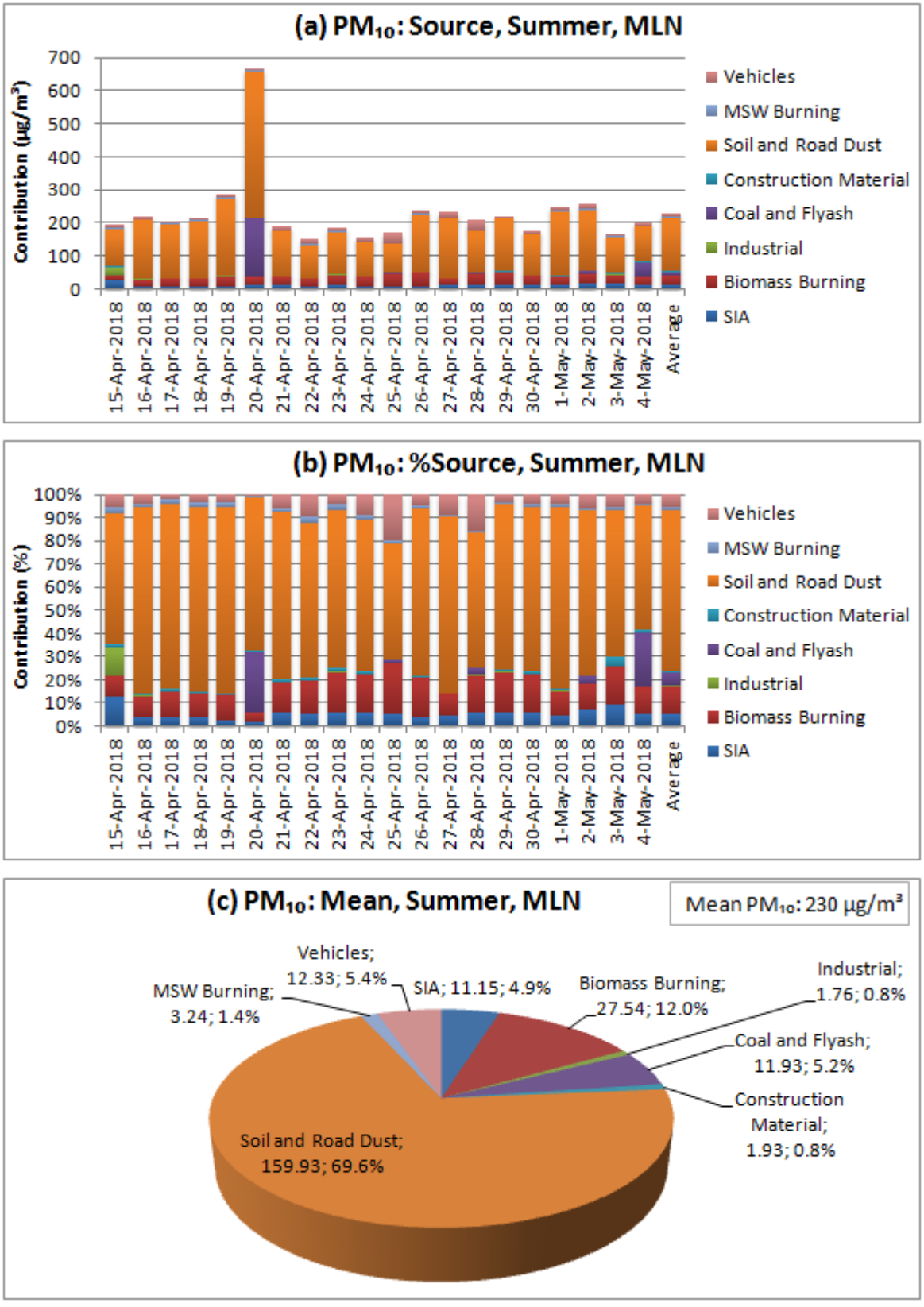


Figure 5.22: CMB modeling for PM_{10} at MLN for summer season

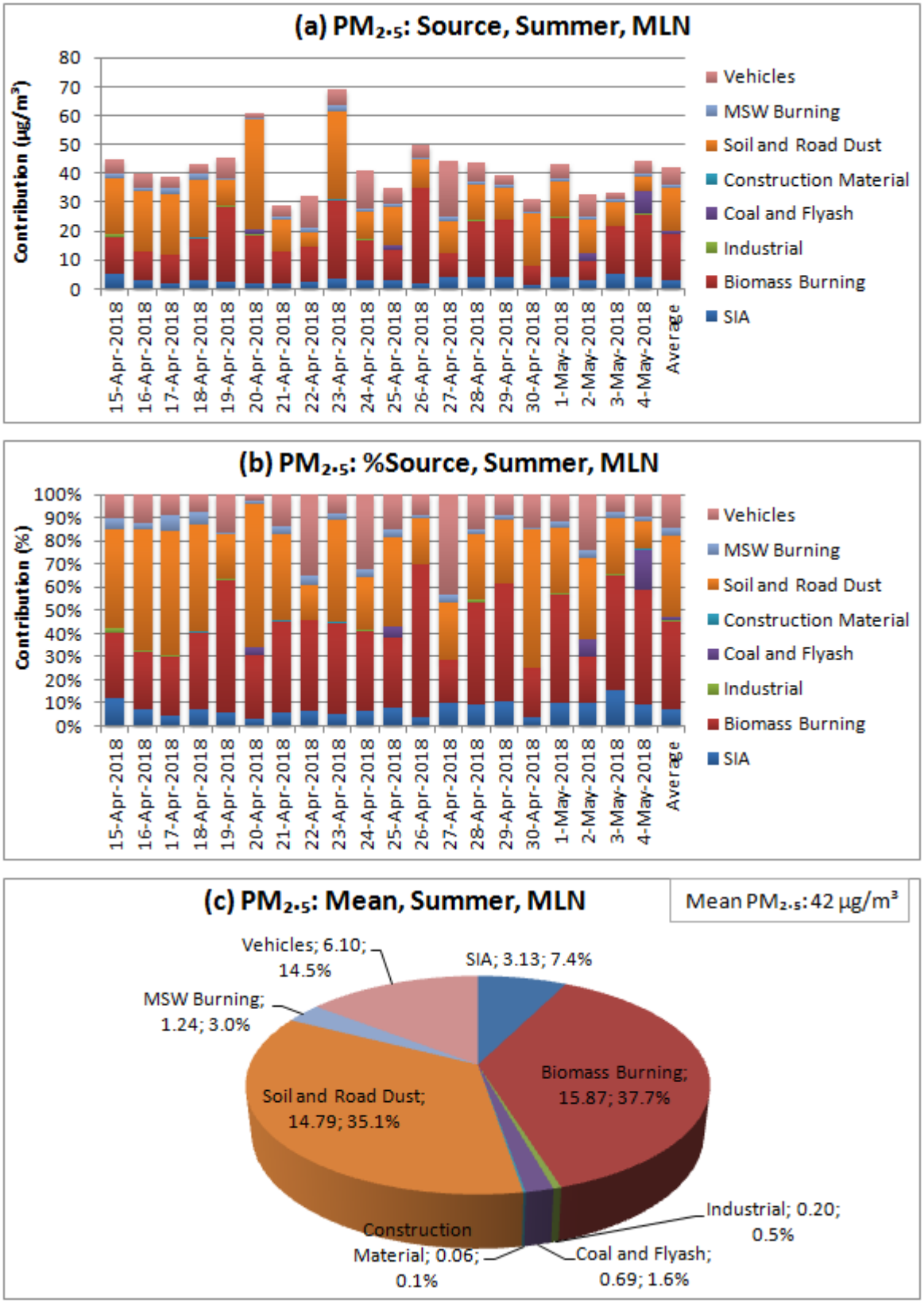


Figure 5.23: CMB modeling for $PM_{2.5}$ at MLN for summer season

Table 5.8: Statistical summary: MLN, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	230	229	100.4	0.66	42	44	104.5	0.71
SD	108	99	5.7	0.08	10	13	9.0	0.07
CV	0.47	0.43	0.06	0.12	0.23	0.29	0.09	0.09
Maximum	666	624	113.0	0.86	69	82	118.9	0.90
Minimum	152	155	88.2	0.56	29	30	87.1	0.64

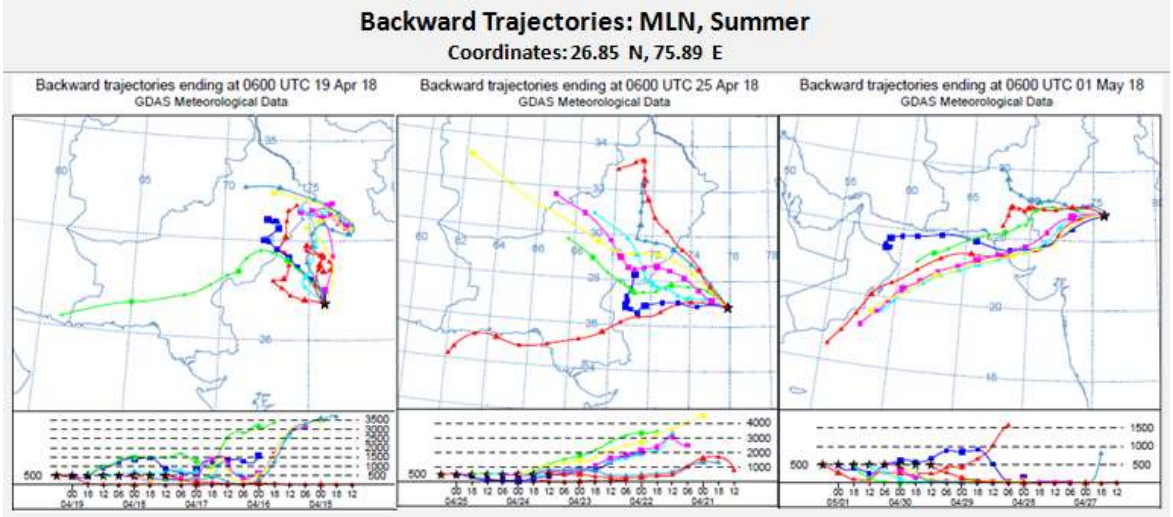


Figure 5.24: Backward trajectories at MLN for summer season

Inference

In summer both PM_{10} and $PM_{2.5}$ emissions by soil and road dust and biomass burning are the major source which requires control in fugitive sources.

5.3.5 Mansarovar (MNS)

5.3.5.1 Winter Season [sampling period: Jan 15 – Feb 04, 2018]

PM_{10} (winter)

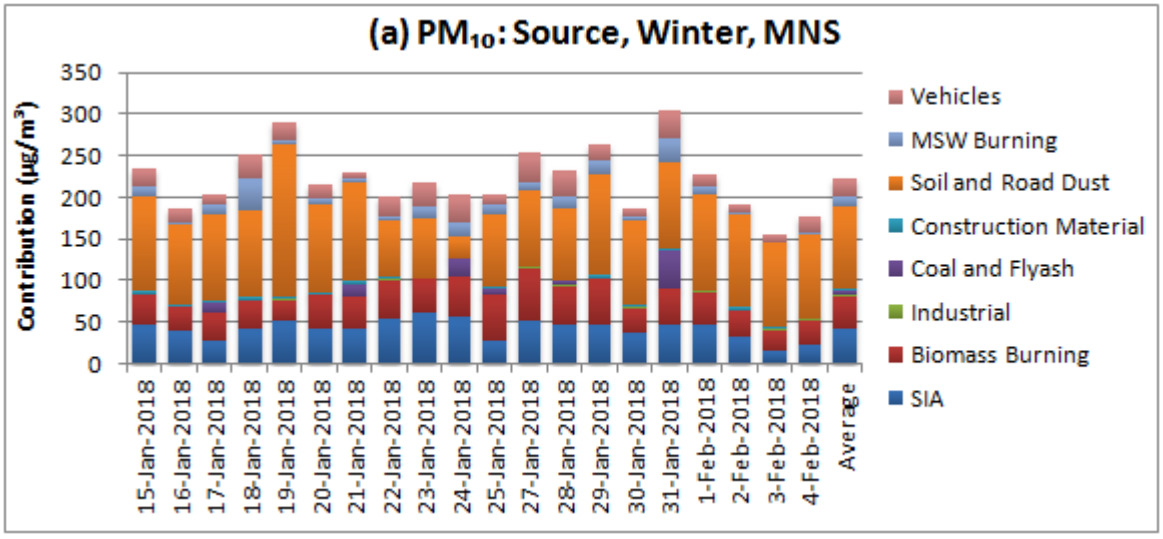
The average PM_{10} concentration was 222 µg/m^3. Figure 5.25 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at MNS. Table 5.9 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (100 µg/m^3 ~ 45%) followed by SIA (42 µg/m^3 ~ 19%) and biomass burning (39 µg/m^3 ~ 18%). The other significant contributing sources are vehicular emission (21 µg/m^3~ 9%),

MSW burning (11 µg/m^3 ~ 5%), coal and flyash (2%) and construction material (1%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 91 µg/m^3. Figure 5.26 (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 MNS. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (25 µg/m^3 ~ 27%) followed by SIA (23 µg/m^3 ~ 25%) and soil and road dust (22 µg/m^3 ~ 24%). Other significant sources are vehicular emission (13 µg/m^3 ~ 15%) and MSW burning (7 µg/m^3 ~ 8%). The minor source are construction material (1%), industrial emission (1%) and coal and flyash (<1%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.27) show that most of the time wind is from NW and some time from SW. The wind mass travels over Thar Desert and part of Punjab state before entering in Jaipur. These winds pick up the pollutants on the way especially from large sources.



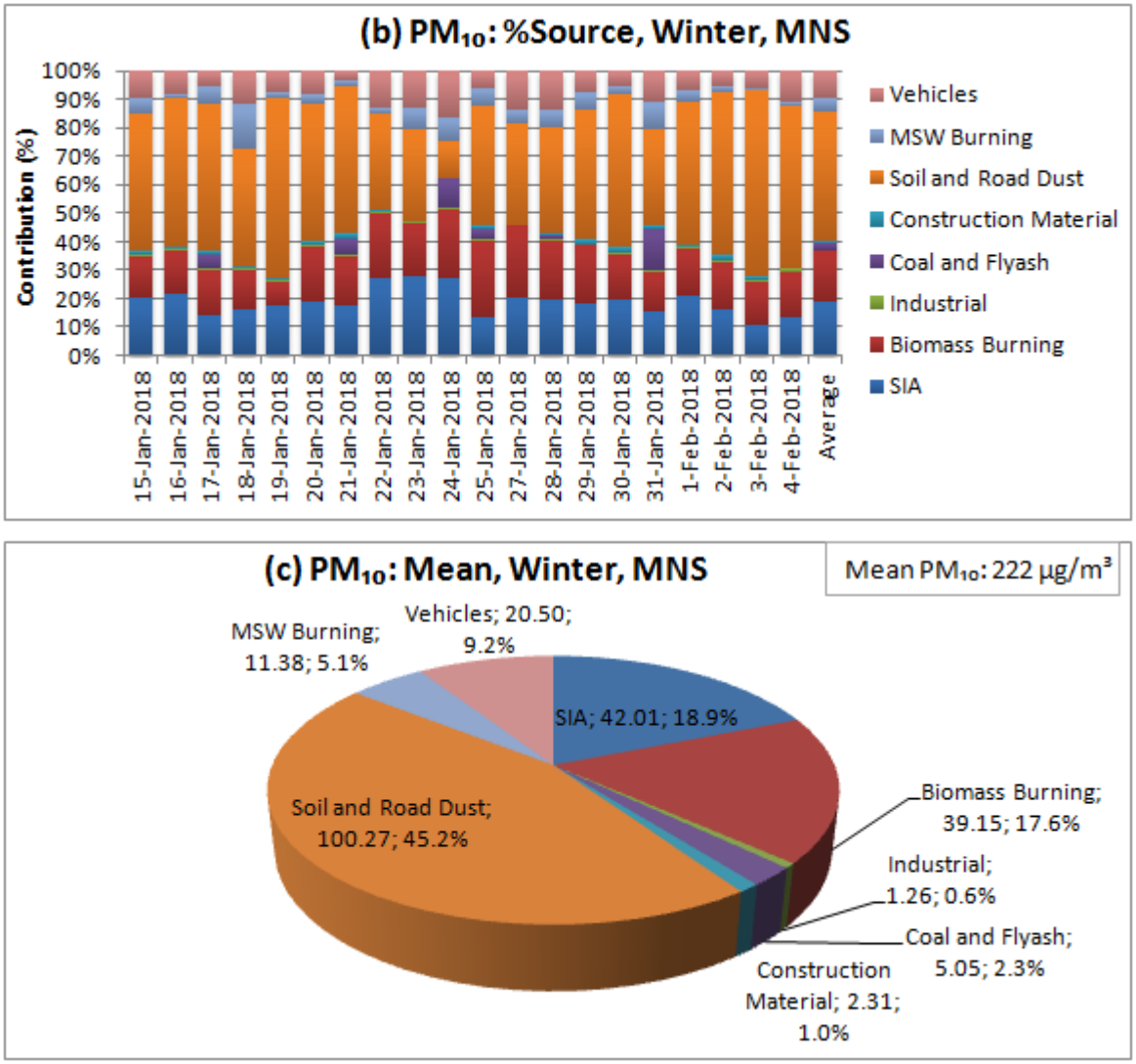
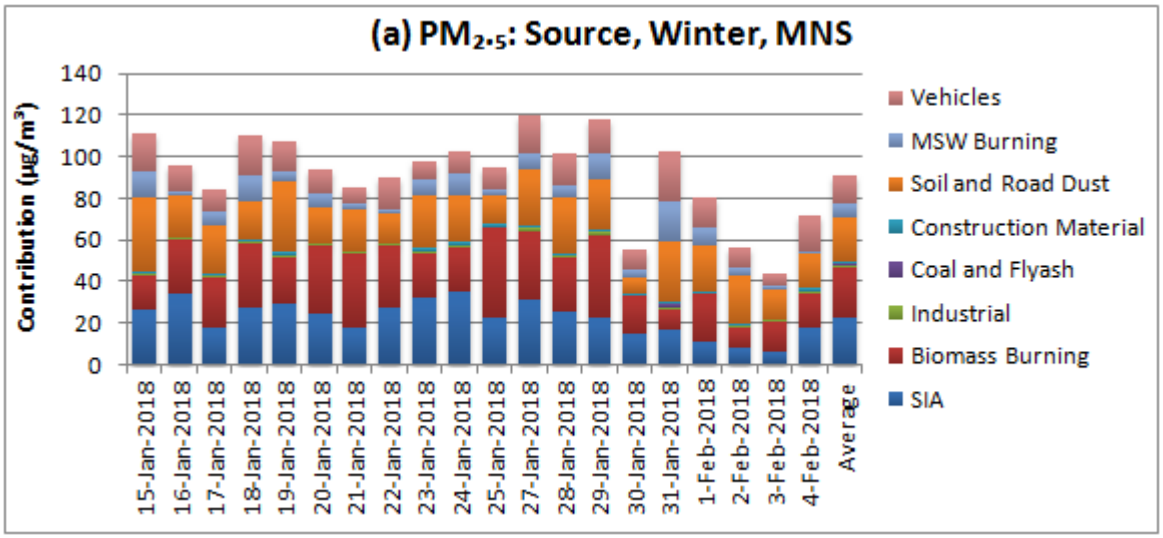


Figure 5.25: CMB modeling for PM_{10} at MNS for winter season



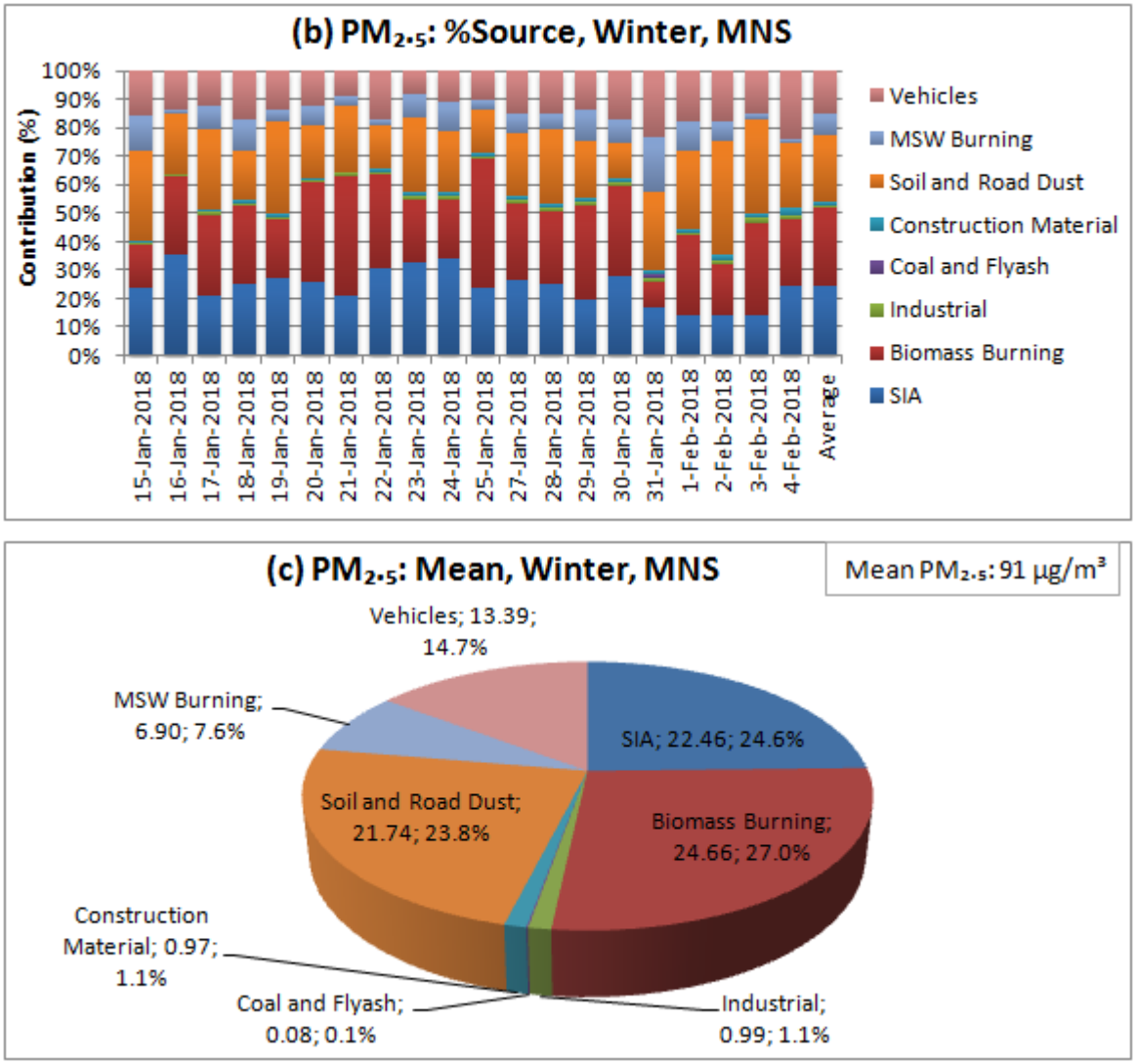


Figure 5.26: CMB modeling for $PM_{2.5}$ at MNS for winter season

Table 5.9: Statistical summary: MNS, winter season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	222	228	102.9	0.66	91	97	105.7	0.67
SD	38	38	3.0	0.07	21	23	5.0	0.04
CV	0.17	0.17	0.03	0.10	0.23	0.24	0.05	0.07
Maximum	306	308	108.5	0.86	120	134	113.1	0.77
Minimum	156	157	98.1	0.60	44	42	96.0	0.60

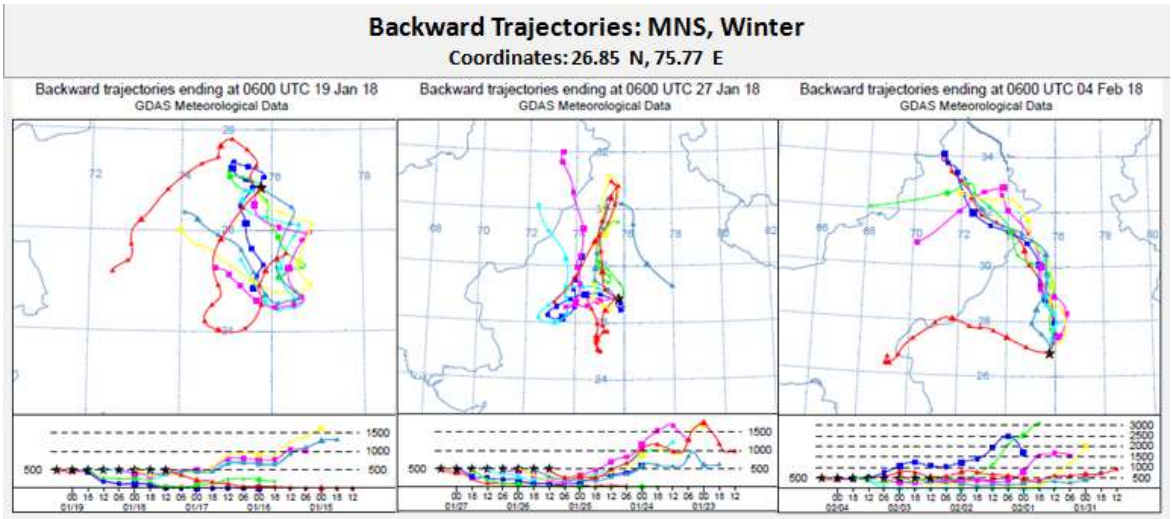


Figure 5.27: Backward trajectories at MNS for winter season

Inference

Contributions of soil and road dust, secondary inorganic particles and biomass burning are consistently high both in PM_{10} and $PM_{2.5}$. MSW burning also appears to be wide spread and consistently contributing to both PM_{10} and $PM_{2.5}$.

5.3.5.2 Summer Season [sampling period: April 15 – May 04, 2018]

PM_{10} (summer)

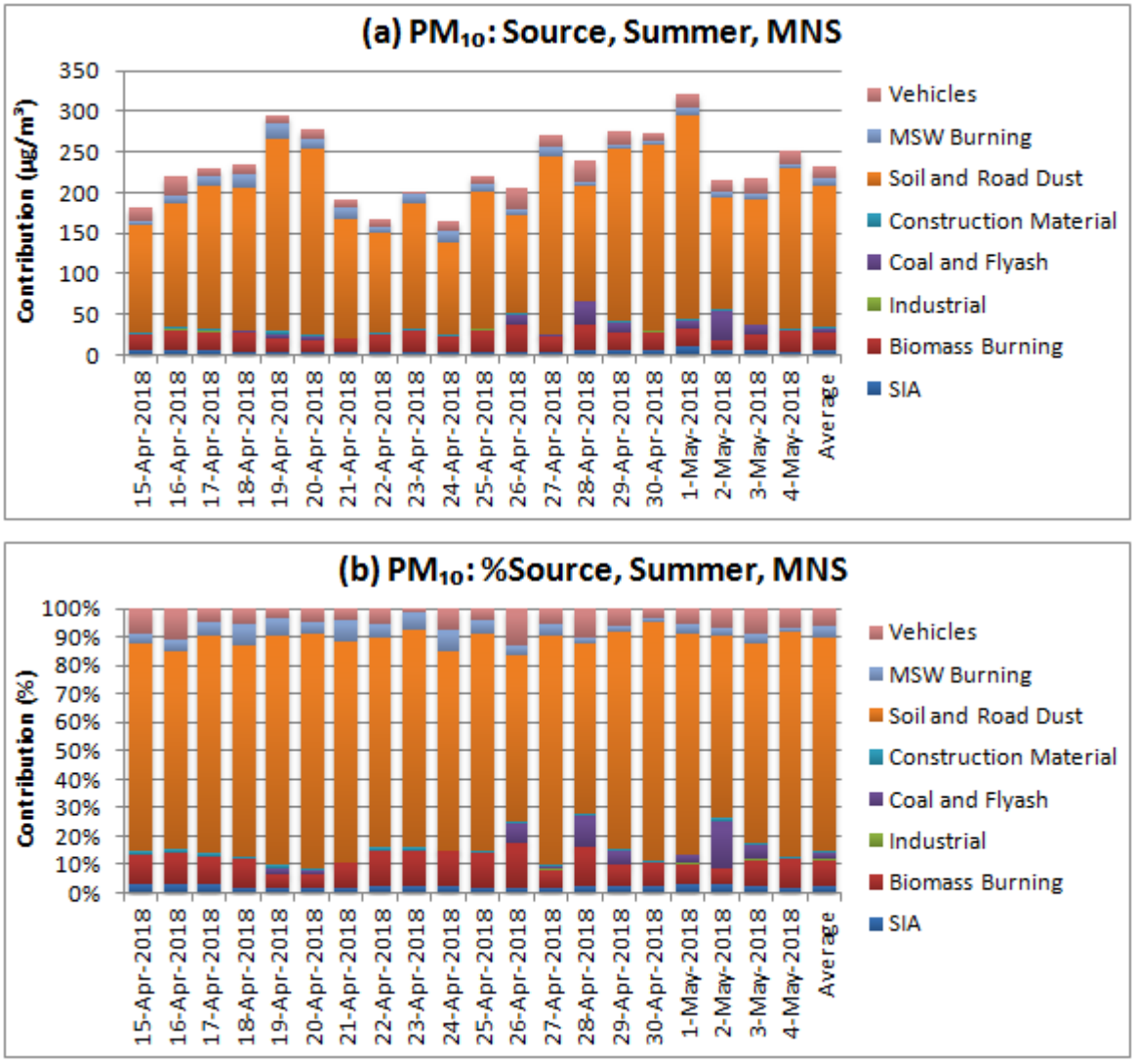
The average PM_{10} concentration was 233 µg/m^3. Figure 5.28 (a), (b), (c) shows PM_{10} concentration contribution of sources, percent contribution of sources and summary of sources (average over about 20 days) at MNS. Table 5.10 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (174 µg/m^3 ~ 75%) followed by biomass burning (22 µg/m^3 ~ 9%). The other significant contributing sources are vehicular emission (14 µg/m^3 ~ 6%), MSW burning (10 µg/m^3 ~ 4%), coal and flyash (3%) and SIA (2%). and. The minor Contributing sources are construction material (<1%) and industrial emission (<1%) in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 45 µg/m^3. Figure 5.29 (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 MNS. It is observed that the major source contributing in $PM_{2.5}$ was soil

and road dust (19 µg/m^3 ~ 42%) followed by biomass burning (12 µg/m^3 ~ 27%). Other significant sources are vehicular emission (7 µg/m^3 ~ 15%), MSW burning (7%), SIA (6%) and coal and flyash (2%). Contribution of the construction material and industrial emission were estimated less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 5.30) show that most of the time wind is from NW and wind mass travels over Thar Desert before entering in Jaipur. These winds pick up the pollutants on the way especially from large sources.



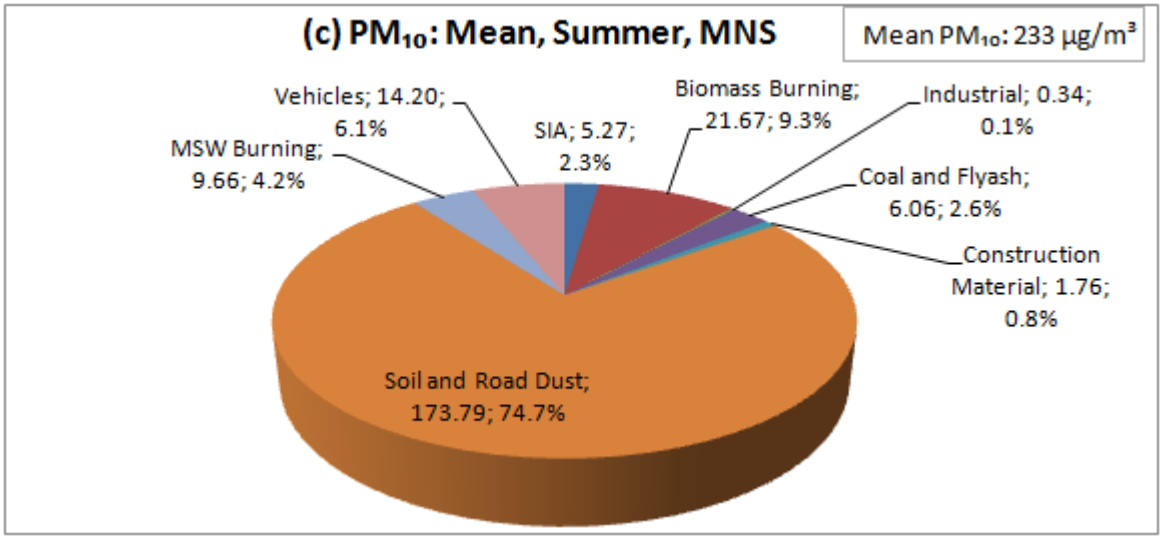
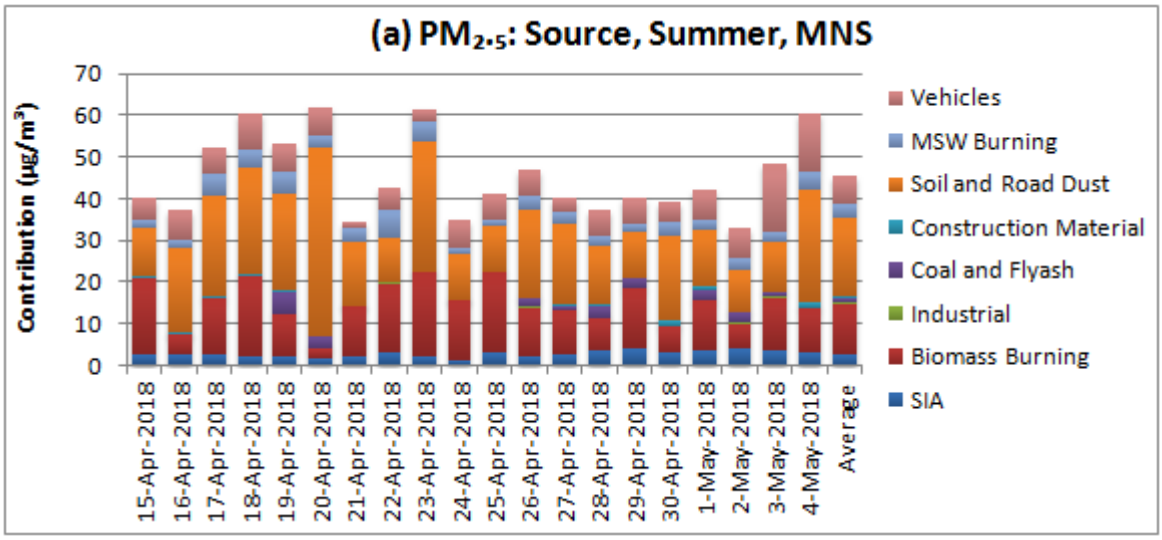
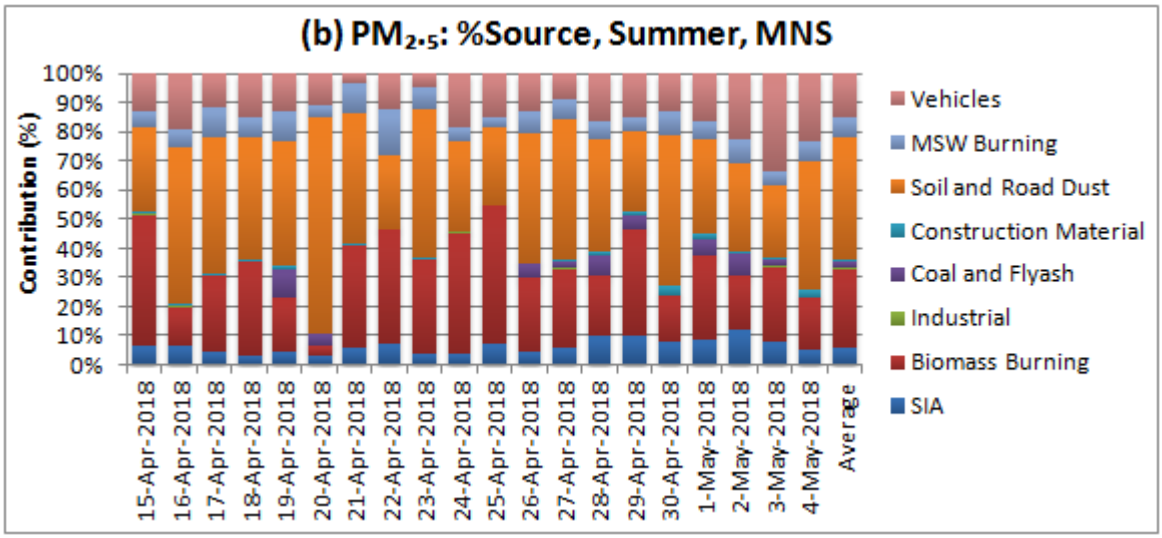


Figure 5.28: CMB modeling for PM_{10} at MNS for summer season





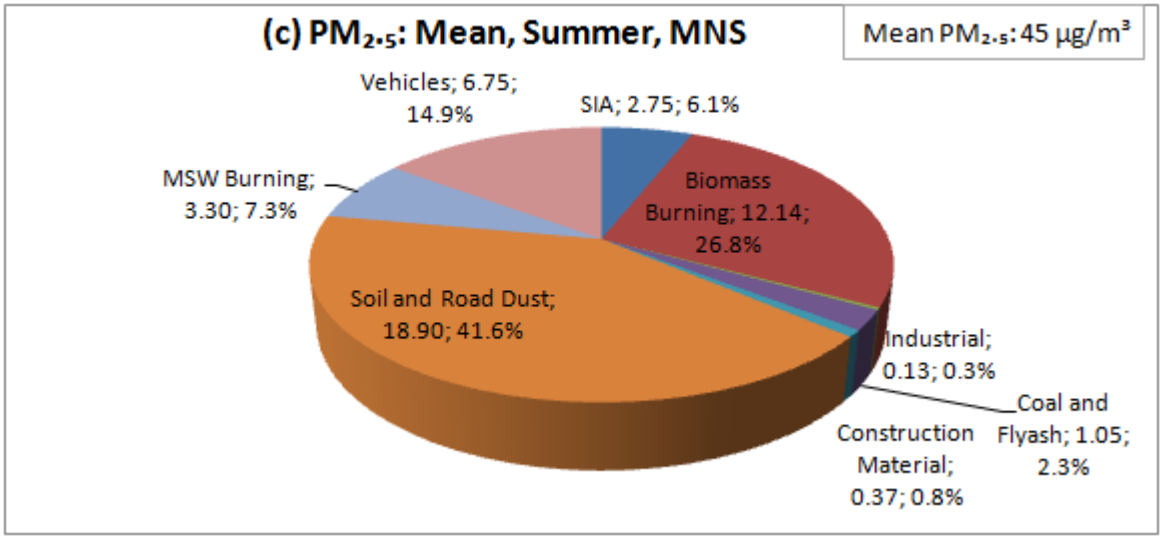


Figure 5.29: CMB modeling for $PM_{2.5}$ at MNS for summer season

Table 5.10: Statistical summary: MNS, summer season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	233	238	102.3	0.65	45	47	103.3	0.65
SD	43	45	4.7	0.06	10	13	8.9	0.06
CV	0.18	0.19	0.05	0.10	0.21	0.27	0.09	0.09
Maximum	321	314	113.8	0.72	62	70	115.0	0.75
Minimum	164	164	93.1	0.55	33	32	88.4	0.54

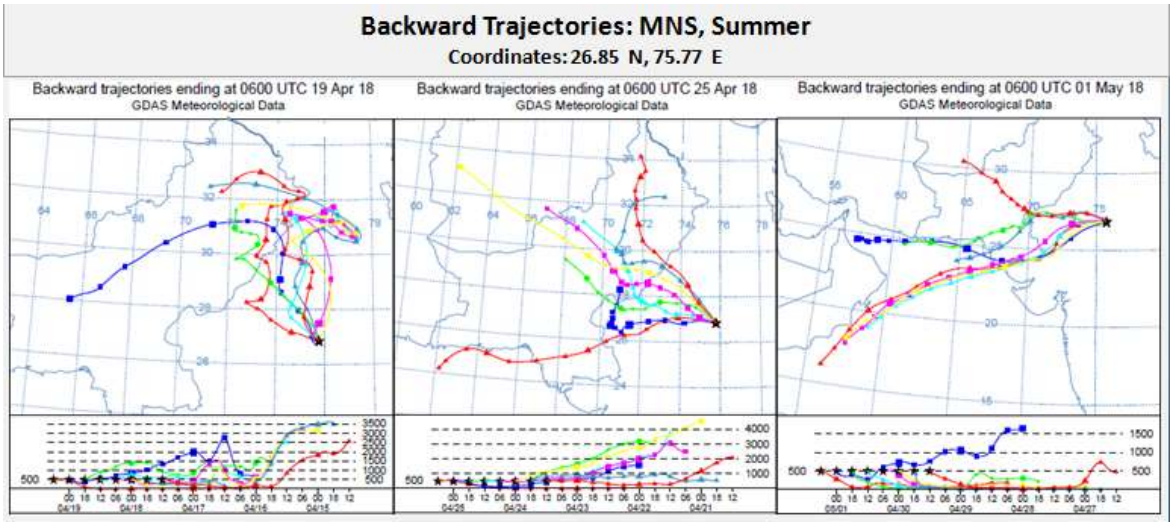


Figure 5.30: Backward trajectories at MNS for summer season

Inference

In summer, soil and road dust, biomass burning, vehicles and MSW burning are the major sources which requires control in fugitive sources.

5.4 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 part of Punjab State before entering in Jaipur 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 quantifies. There is no assessment made on emissions upstream of Jaipur and their contribution in Jaipur.

5.5 Overall Summary and Source Apportionment at a Glance

The overall summary of CMB modeling results is shown in Figure 5.32 and Figure 5.33. Tables 5.11-5.14 provide summary with overall statistics. The mail highlights of CMB results are summarized below.

- Ranges of source contributions to PM_{10} are: secondary inorganic aerosols (SIA; 0.6 – 39 %), biomass burning (3 – 30 %), industrial (0 – 13 %), coal and flyash (0 – 50 %), soil and road dust (6 - 88 %), vehicles (0.4 - 21%), MSW burning (0 – 37 %) and construction material (0 - 10 %).
- Ranges of source contributions to $PM_{2.5}$ are: SIA (0.6 – 46 %), biomass burning (4 – 66 %), industrial (0 – 24 %), coal and flyash (0 – 40 %), soil and road dust (0 - 74 %), vehicles (2 – 46 %), MSW burning (0 – 30 %) and construction material (0 - 6 %).
- Contribution of SIA particles (PM_{10}: 17 – 3 % and $PM_{2.5}$: 23 – 6 %), biomass burning (PM_{10}: 19 – 10 % and $PM_{2.5}$: 32 – 30 %), vehicles (PM_{10}: 11 – 5 % and $PM_{2.5}$: 17 – 14 %) and MSW burning (PM_{10}: 6 – 4 % and $PM_{2.5}$: 8 – 6 %) are higher during winter season compared to summer season both in $PM_{2.5}$ and $PM_{10.}$
- Contribution of coal and flyash is higher during summer season (PM_{10}: 7% and $PM_{2.5}$: 5 %) compared to winter season (PM_{10}: 4 % and $PM_{2.5}$: 1 %).
- Contribution of soil and road dust is higher during summer season (PM_{10}: 69 % and $PM_{2.5}$: 36%) compared to winter season (PM_{10}: 41 % and $PM_{2.5}$:18 %).

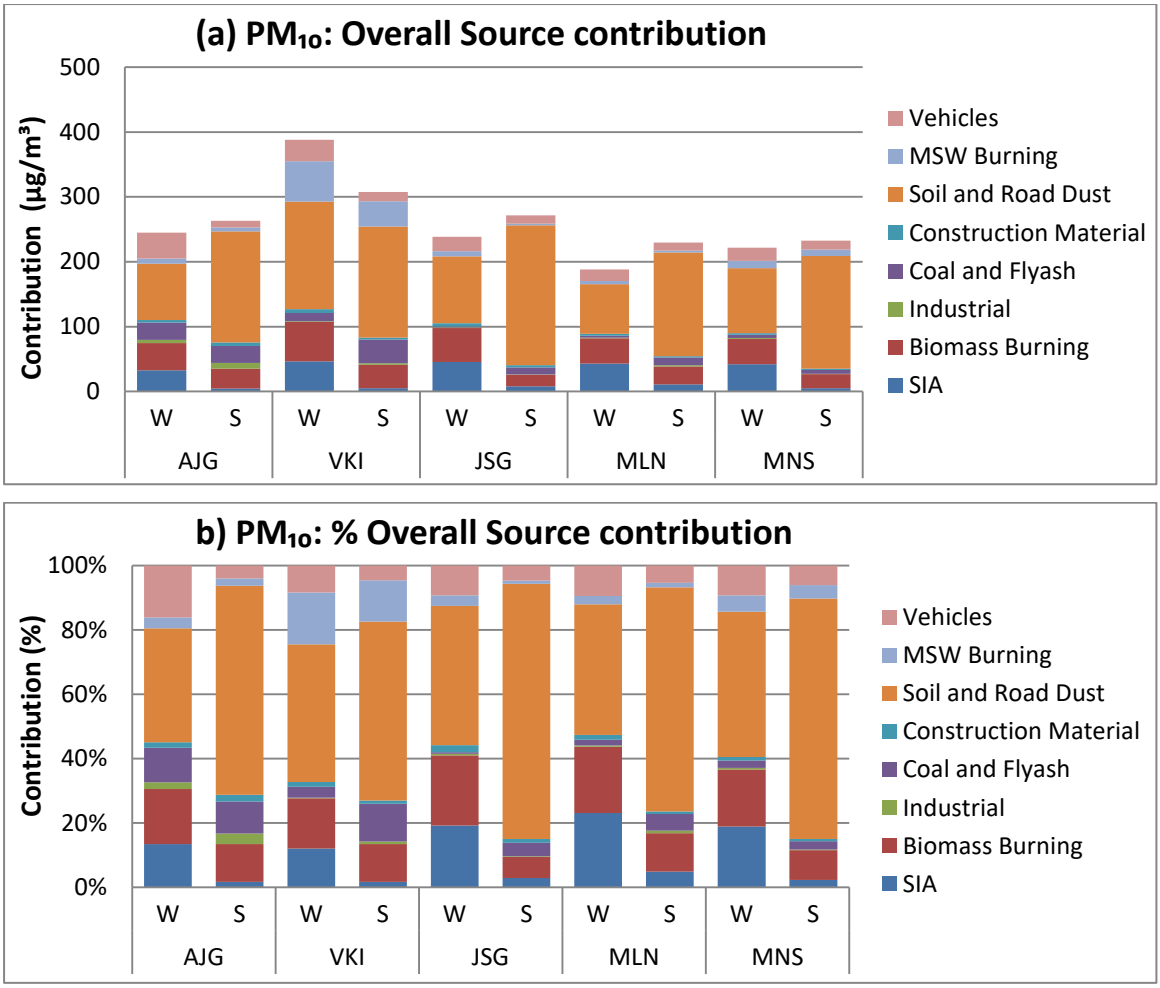
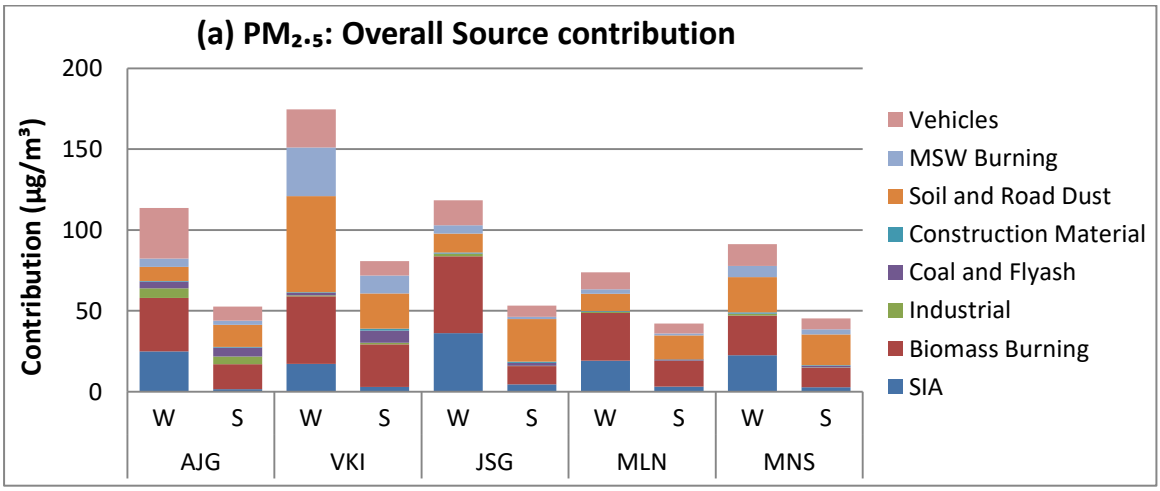


Figure 5.31: Overall results of CMB modeling for PM_{10}



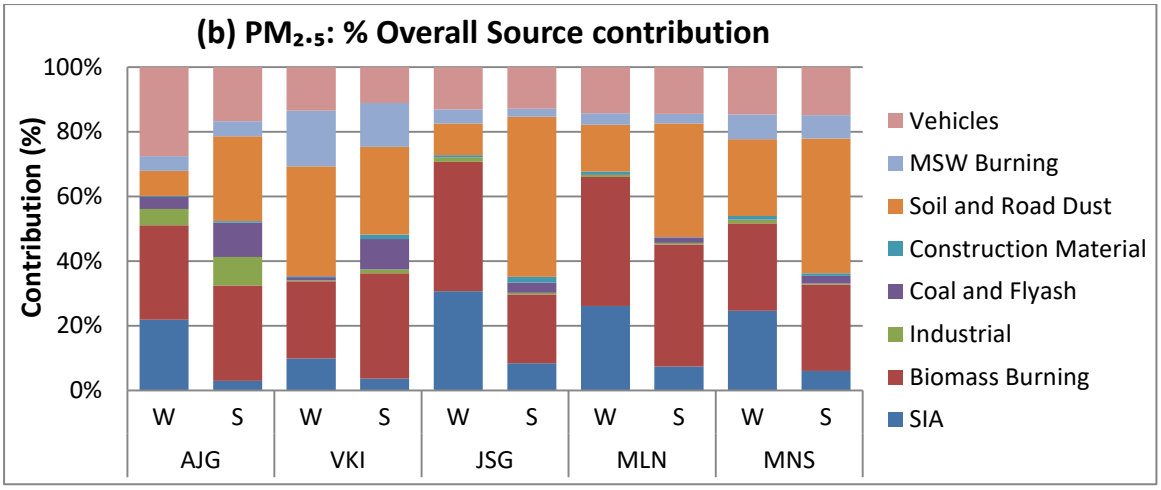


Figure 5.32: Overall results of CMB modeling for $PM_{2.5}$

Table 5.11: Statistical summary of the source apportionment in PM_{10} for winter season

Site location	Parameter	Measured PM_{10} (µg/m^3)	Calculated PM_{10} (µg/m^3)	% Mass	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	Mean	245	253	103.5	0.72	13.4	17.2	2.0	10.8	1.7	35.3	3.4	16.2
	SD	46	45	3.9	0.07	6.4	5.9	2.1	7.4	0.7	12.8	2.0	3.5
	CV	0.19	0.18	0.04	0.10	0.5	0.3	1.0	0.7	0.4	0.4	0.6	0.2
	Max	360	360	113.8	0.81	31.4	29.6	6.4	22.7	3.0	54.9	8.8	21.3
	Min	168	169	99.0	0.59	7.2	8.8	0.2	0.0	0.4	7.9	1.5	9.3
VKI	Mean	388	403	102.9	0.72	12.0	15.6	0.3	3.4	1.5	42.8	16.1	8.4
	SD	119	140	7.1	0.08	3.9	4.1	0.1	4.6	0.8	10.9	8.7	3.6
	CV	0.31	0.35	0.07	0.11	0.3	0.3	0.4	1.4	0.6	0.3	0.5	0.4
	Max	625	715	116.1	0.91	20.2	21.3	0.5	17.3	4.2	61.0	32.2	18.5
	Min	199	208	87.9	0.60	4.4	7.8	0.1	0.0	0.0	19.5	2.0	5.0
JSG	Mean	238	249	105.5	0.68	19.2	21.8	0.6	0.5	2.2	43.3	3.2	9.3
	SD	74	73	6.0	0.08	6.3	2.4	0.2	4.7	1.2	9.7	2.1	3.8
	CV	0.31	0.29	0.06	0.12	0.3	0.1	0.4	9.1	0.6	0.2	0.7	0.4
	Max	340	341	118.8	0.89	33.3	26.2	1.2	21.9	4.6	58.0	10.2	20.3
	Min	95	101	96.8	0.59	9.8	17.7	0.3	0.0	0.3	5.8	1.2	4.8
MLN	Mean	188	196	104.5	0.68	23.1	20.6	0.4	1.8	1.5	40.6	2.6	9.4
	SD	39	38	4.8	0.05	7.8	2.5	0.1	3.7	0.8	11.4	1.7	5.8
	CV	0.21	0.20	0.05	0.07	0.3	0.1	0.3	2.0	0.5	0.3	0.6	0.6
	Max	255	265	114.4	0.78	38.6	25.6	0.8	14.8	3.5	57.7	8.6	21.2
	Min	118	126	97.7	0.59	13.1	16.1	0.3	0.0	0.0	9.7	1.2	3.2
MNS	Mean	222	228	102.9	0.66	18.9	17.6	0.6	2.3	1.0	45.2	5.1	9.2
	SD	38	38	3.0	0.07	4.7	4.5	0.2	4.1	0.6	12.3	3.6	3.6
	CV	0.17	0.17	0.03	0.10	0.2	0.3	0.3	1.8	0.5	0.3	0.7	0.4
	Max	306	308	108.5	0.86	27.8	27.4	0.9	15.0	2.0	65.2	15.9	16.2
	Min	156	157	98.1	0.60	10.5	8.0	0.4	0.0	0.0	13.1	0.7	3.3

Table 5.12: Statistical summary of the source apportionment in PM_{10} for summer season

Site location	Parameter	Measured PM_{10} (µg/m^3)	Calculated PM_{10} (µg/m^3)	% Mass	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	Mean	263	257	98.3	0.74	1.7	11.7	3.2	9.9	2.1	64.9	2.3	4.0
	SD	84	79	8.1	0.07	0.6	4.7	3.0	9.4	2.7	9.5	2.0	3.8
	CV	0.32	0.31	0.08	0.09	0.34	0.40	0.93	0.95	1.29	0.15	0.87	0.95
	Max	520	515	126.1	0.87	2.7	20.5	12.8	37.9	9.7	75.5	6.7	18.2
	Min	183	177	86.9	0.59	0.6	5.2	0.0	0.0	0.0	32.4	0.1	0.8
VKI	Mean	308	307	100.1	0.75	1.7	11.7	0.9	11.8	0.9	55.6	12.8	4.6
	SD	72	71	9.7	0.09	0.7	2.7	2.6	10.7	1.0	9.6	8.4	2.6
	CV	0.23	0.23	0.10	0.13	0.4	0.2	3.0	0.9	1.1	0.2	0.7	0.6
	Max	484	441	117.5	0.87	3.4	17.3	8.9	32.2	4.5	73.6	37.2	10.6
	Min	213	178	80.5	0.56	0.7	6.6	0.1	0.0	0.1	37.4	4.0	0.4
JSG	Mean	272	287	106.8	0.62	2.9	6.5	0.2	4.1	1.2	79.3	1.1	4.7
	SD	79	72	6.7	0.08	2.7	3.2	0.1	5.7	1.2	8.4	1.8	2.1
	CV	0.29	0.25	0.06	0.12	0.9	0.5	0.3	1.4	1.0	0.1	1.7	0.4
	Max	486	472	117.9	0.78	14.7	17.2	0.3	20.4	5.5	87.9	5.9	9.5
	Min	142	161	93.6	0.50	1.1	3.6	0.1	0.0	0.0	54.8	0.0	1.8
MLN	Mean	230	229	100.4	0.66	4.9	12.0	0.8	5.2	0.8	69.6	1.4	5.4
	SD	108	99	5.7	0.08	2.4	4.1	2.7	7.5	0.8	9.2	0.7	4.6
	CV	0.47	0.43	0.06	0.12	0.5	0.3	3.6	1.5	1.0	0.1	0.5	0.8
	Max	666	624	113.0	0.86	12.6	21.9	12.5	26.3	3.8	81.0	3.2	19.7
	Min	152	155	88.2	0.56	1.5	4.1	0.1	0.0	0.0	50.1	0.5	0.9
MNS	Mean	233	238	102.3	0.65	2.3	9.3	0.1	2.6	0.8	74.7	4.2	6.1
	SD	43	45	4.7	0.06	0.6	2.9	0.0	4.4	0.4	7.0	1.8	2.9
	CV	0.18	0.19	0.05	0.10	0.3	0.3	0.3	1.7	0.5	0.1	0.4	0.5
	Max	321	314	113.8	0.72	3.2	15.7	0.2	16.4	1.5	83.7	7.6	12.6
	Min	164	164	93.1	0.55	1.5	5.1	0.1	0.0	0.3	58.7	1.8	1.5

Table 5.13: Statistical summary of the source apportionment in $PM_{2.5}$ for winter season

Site location	Parameter	Measured $PM_{2.5}$ (µg/m^3)	Calculated $PM_{2.5}$ (µg/m^3)	% Mass	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	Mean	114	113	100.8	0.71	21.9	29.1	5.1	3.7	0.3	7.7	4.5	27.6
	SD	23	22	2.3	0.06	10.5	9.4	3.9	2.6	0.2	4.2	1.9	10.1
	CV	0.20	0.19	0.02	0.08	0.48	0.32	0.76	0.71	0.77	0.54	0.41	0.37
	Max	159	163	104.0	0.79	46.2	59.8	12.0	8.5	0.9	20.0	8.4	45.6
	Min	75	77	95.6	0.55	6.7	18.9	0.5	0.0	0.0	3.2	1.4	9.7
VKI	Mean	175	184	104.7	0.71	9.9	23.9	0.3	1.0	0.2	34.0	17.3	13.5
	SD	52	58	7.8	0.07	4.0	7.8	0.4	2.3	0.3	10.1	8.4	5.8
	CV	0.30	0.32	0.07	0.10	0.4	0.3	1.4	2.4	1.1	0.3	0.5	0.4
	Max	255	277	119.5	0.83	18.6	39.5	2.3	8.2	1.1	49.1	30.2	36.6
	Min	82	81	84.0	0.53	5.7	9.9	0.1	0.0	0.0	13.8	3.6	8.7
JSG	Mean	118	120	101.4	0.76	30.6	40.0	1.4	0.1	0.6	9.8	4.4	13.0
	SD	44	43	5.6	0.05	7.1	6.7	1.6	0.6	0.3	5.0	2.1	4.6
	CV	0.37	0.36	0.06	0.06	0.2	0.2	1.2	4.4	0.6	0.5	0.5	0.4
	Max	219	198	113.8	0.84	43.4	51.3	7.8	2.8	1.1	20.4	9.2	22.7
	Min	40	37	90.2	0.66	20.8	28.6	0.3	0.0	0.0	1.3	1.4	7.1
MLN	Mean	74	76	102.8	0.72	26.1	40.0	0.6	0.2	0.8	14.5	3.5	14.3
	SD	18	19	3.7	0.06	10.3	6.3	0.2	0.5	0.4	6.9	0.9	5.5
	CV	0.25	0.25	0.04	0.08	0.4	0.2	0.3	2.1	0.5	0.5	0.3	0.4
	Max	120	118	109.8	0.84	41.5	52.5	1.0	2.0	1.6	28.2	6.1	24.1
	Min	47	45	96.5	0.60	7.2	28.0	0.4	0.0	0.1	0.0	2.5	6.2
MNS	Mean	91	97	105.7	0.67	24.6	27.0	1.1	0.1	1.1	23.8	7.6	14.7
	SD	21	23	5.0	0.04	6.4	8.7	0.3	0.3	0.6	6.9	4.4	4.1
	CV	0.23	0.24	0.05	0.07	0.3	0.3	0.3	4.0	0.6	0.3	0.6	0.3
	Max	120	134	113.1	0.77	35.4	45.7	1.9	1.6	2.9	39.8	18.7	24.0
	Min	44	42	96.0	0.60	13.8	9.6	0.5	0.0	0.0	12.4	1.5	8.4

Table 5.14: Statistical summary of the source apportionment in $PM_{2.5}$ for summer season

Site location	Parameter	Measured $PM_{2.5}$ (µg/m^3)	Calculated $PM_{2.5}$ (µg/m^3)	% Mass	R^2	% Source Contribution							
						SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	Mean	53	53	99.9	0.68	3.0	29.5	8.8	10.6	0.6	26.2	4.6	16.8
	SD	12	12	8.3	0.06	1.6	9.8	6.8	10.5	0.7	10.4	2.4	6.3
	CV	0.22	0.23	0.08	0.09	0.53	0.33	0.77	0.99	1.20	0.39	0.52	0.38
	Max	75	79	115.1	0.75	6.4	47.2	24.2	40.2	2.3	51.4	11.8	28.8
	Min	35	32	83.8	0.56	0.6	12.7	0.0	0.0	0.0	4.5	1.7	6.0
VKI	Mean	81	87	107.5	0.66	3.6	32.6	1.2	9.3	1.4	27.1	13.6	11.1
	SD	19	20	8.1	0.06	2.0	7.7	3.0	8.5	0.8	8.8	5.9	5.9
	CV	0.23	0.23	0.08	0.09	0.6	0.2	2.5	0.9	0.6	0.3	0.4	0.5
	Max	140	135	118.1	0.78	8.8	46.1	12.1	24.6	2.8	41.0	26.2	22.2
	Min	59	64	95.4	0.59	0.9	15.6	0.0	0.0	0.3	13.2	5.2	4.3
JSG	Mean	53	59	111.8	0.62	8.4	21.3	0.5	3.2	1.8	49.5	2.5	12.9
	SD	14	16	4.7	0.07	3.8	7.6	0.2	8.7	1.3	14.9	1.9	4.7
	CV	0.26	0.27	0.04	0.11	0.5	0.4	0.5	2.8	0.7	0.3	0.8	0.4
	Max	82	88	118.3	0.78	21.7	36.6	1.1	40.3	5.6	67.9	7.4	22.2
	Min	33	36	102.7	0.51	4.0	8.6	0.1	0.0	0.0	14.1	0.0	2.9
MLN	Mean	42	44	104.5	0.71	7.4	37.7	0.5	1.6	0.1	35.1	3.0	14.5
	SD	10	13	9.0	0.07	3.1	13.2	0.4	4.2	0.2	14.9	1.4	10.5
	CV	0.23	0.29	0.09	0.09	0.4	0.4	0.8	2.6	1.3	0.4	0.5	0.7
	Max	69	82	118.9	0.90	15.3	65.9	1.7	17.3	0.6	61.8	6.7	43.4
	Min	29	30	87.1	0.64	2.9	18.6	0.2	0.0	0.0	11.6	0.8	2.4
MNS	Mean	45	47	103.3	0.65	6.1	26.8	0.3	2.3	0.8	41.6	7.3	14.9
	SD	10	13	8.9	0.06	2.5	11.4	0.1	3.1	0.8	12.3	2.8	6.6
	CV	0.21	0.27	0.09	0.09	0.4	0.4	0.5	1.3	1.0	0.3	0.4	0.4
	Max	62	70	115.0	0.75	11.7	47.3	0.7	10.0	3.1	73.8	15.8	33.4
	Min	33	32	88.4	0.54	2.9	3.8	0.1	0.0	0.0	25.1	3.5	3.6

Table 5.15: Concentration apportionment: winter PM_{10} (Concentration in µg/m^3)

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	245	32.8	42.0	5.0	26.4	4.2	86.5	8.3	39.5
VKI	388	46.7	60.5	1.0	13.1	5.7	165.8	62.4	32.6
JSG	238	45.7	51.9	1.3	1.2	5.1	103.2	7.7	22.2
MLN	188	43.3	38.7	0.8	3.4	2.8	76.4	4.8	17.8
MNS	222	42.0	39.1	1.3	5.0	2.3	100.3	11.4	20.5
Overall	256	42.1	46.5	1.9	9.8	4.0	106.4	18.9	26.5
SD	77	5.5	9.5	1.7	10.3	1.5	34.9	24.4	9.2

Table 5.16: Concentration apportionment: winter $PM_{2.5}$ (Concentration in µg/m^3)

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	114	24.9	33.1	5.8	4.2	0.4	8.8	5.1	31.4
VKI	175	17.2	41.8	0.5	1.7	0.4	59.3	30.2	23.5
JSG	118	36.3	47.4	1.6	0.2	0.7	11.7	5.2	15.4
MLN	74	19.2	29.5	0.5	0.2	0.6	10.7	2.6	10.5
MNS	91	22.5	24.7	1.0	0.1	1.0	21.7	6.9	13.4
Overall	114	24.0	35.3	1.9	1.3	0.6	22.4	10.0	18.8
SD	38	7.5	9.2	2.3	1.8	0.2	21.2	11.4	8.5

Table 5.17: Percentage apportionment: winter PM_{10}

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	245	13.4	17.2	2.0	10.8	1.7	35.3	3.4	16.2
VKI	388	12.0	15.6	0.3	3.4	1.5	42.8	16.1	8.4
JSG	238	19.2	21.8	0.6	0.5	2.2	43.3	3.2	9.3
MLN	188	23.1	20.6	0.4	1.8	1.5	40.6	2.6	9.4
MNS	222	18.9	17.6	0.6	2.3	1.0	45.2	5.1	9.2
Overall	256	17.3	18.6	0.8	3.8	1.6	41.4	6.1	10.5
SD	77	4.5	2.6	0.7	4.1	0.4	3.8	5.7	3.2

Table 5.18: Percentage apportionment: winter $PM_{2.5}$

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	114	21.9	29.1	5.1	3.7	0.3	7.7	4.5	27.6
VKI	175	9.9	23.9	0.3	1.0	0.2	34.0	17.3	13.5
JSG	118	30.6	40.0	1.4	0.1	0.6	9.8	4.4	13.0
MLN	74	26.1	40.0	0.6	0.2	0.8	14.5	3.5	14.3
MNS	91	24.6	27.0	1.1	0.1	1.1	23.8	7.6	14.7
Overall	114	22.6	32.0	1.7	1.0	0.6	18.0	7.5	16.6
SD	38	7.8	7.5	2.0	1.5	0.3	10.9	5.7	6.2

Table 5.19: Concentration apportionment: summer PM_{10} (Concentration in µg/m^3)

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	263	4.6	30.9	8.5	26.2	5.6	170.9	6.0	10.6
VKI	308	5.1	36.1	2.6	36.2	2.9	171.1	39.4	14.2
JSG	272	7.9	17.8	0.5	11.3	3.3	215.3	2.9	12.7
MLN	230	11.2	27.5	1.8	11.9	1.9	159.9	3.2	12.3
MNS	233	5.3	21.7	0.3	6.1	1.8	173.8	9.7	14.2
Overall	261	6.8	26.8	2.8	18.3	3.1	178.2	12.2	12.8
SD	32	2.8	7.3	3.4	12.5	1.5	21.4	15.4	1.5

Table 5.20: Concentration apportionment: summer $PM_{2.5}$ (Concentration in µg/m^3)

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	53	1.6	15.5	4.6	5.6	0.3	13.8	2.4	8.8
VKI	81	2.9	26.3	1.0	7.5	1.1	21.9	11.0	8.9
JSG	53	4.4	11.3	0.2	1.7	0.9	26.3	1.3	6.8
MLN	42	3.1	15.9	0.2	0.7	0.1	14.8	1.2	6.1
MNS	45	2.7	12.1	0.1	1.1	0.4	18.9	3.3	6.7
Overall	55	3.0	16.2	1.2	3.3	0.6	19.2	3.9	7.5
SD	15	1.0	6.0	1.9	3.1	0.5	5.2	4.1	1.3

Table 5.21: Percentage apportionment: summer PM_{10}

Site location	PM_{10} (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	263	1.7	11.7	3.2	9.9	2.1	64.9	2.3	4.0
VKI	308	1.7	11.7	0.9	11.8	0.9	55.6	12.8	4.6
JSG	272	2.9	6.5	0.2	4.1	1.2	79.3	1.1	4.7
MLN	230	4.9	12.0	0.8	5.2	0.8	69.6	1.4	5.4
MNS	233	2.3	9.3	0.1	2.6	0.8	74.7	4.2	6.1
Overall	261	2.7	10.3	1.0	6.7	1.2	68.8	4.3	5.0
SD	32	1.3	2.3	1.3	3.9	0.6	9.1	4.9	0.8

Table 5.22: Percentage apportionment: summer $PM_{2.5}$

Site location	$PM_{2.5}$ (µg/m^3)	SIA	Biomass Burning	Industrial	Coal and Flyash	Construction Material	Soil and Road Dust	MSW Burning	Vehicles
AJG	53	3.0	29.5	8.8	10.6	0.6	26.2	4.6	16.8
VKI	81	3.6	32.6	1.2	9.3	1.4	27.1	13.6	11.1
JSG	53	8.4	21.3	0.5	3.2	1.8	49.5	2.5	12.9
MLN	42	7.4	37.7	0.5	1.6	0.1	35.1	3.0	14.5
MNS	45	6.1	26.8	0.3	2.3	0.8	41.6	7.3	14.9
Overall	55	5.7	29.6	2.2	5.4	0.9	35.9	6.2	14.0
Std	15	2.4	6.2	3.7	4.2	0.6	9.9	4.6	2.2

5.6 Interpretations and Inferences

Based on the CMB modeling results (Figures 5.31 and 5.32) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for preparation of action plan. Tables 5.15 to 5.22, 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.
    - The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include: soil and road dust (41 – 18 %), SIA particles (17 - 23%), biomass burning (19 – 32%), vehicles (11 - 17%) and MSW burning (6 - 8%). It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.
    - The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include: soil and road dust (69 – 36%), biomass burning (10 - 30%), vehicles (5 – 14%), MSW burning (4 – 6%), coal and flyash (7 - 5%) and SIA particles (3 - 6%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The three most consistent sources for PM_{10} and $PM_{2.5}$ in both the seasons are SIA, biomass burning and vehicles. The other sources on average may contribute more (or less) but their contributions are variable from one day to another. Most variable source was MSW burning followed by coal and flyash. Soil and road dust and construction material sources were consistent for PM_{10} but it was not true for $PM_{2.5}$.
- Consistent presence of SIA, biomass burning and vehicles in PM_{10} and $PM_{2.5}$ across all sites and in two seasons, suggests these particles encompass entire Jaipur region as a layer.
- Similar to the above point, in winter, consistent presence of soil and road dust encompass entire Jaipur region as a layer.
- Soil and road dust in summer contribute 36 – 69% and the coal and flyash contribute 5 – 7% to $PM_{2.5}$ and PM_{10}. It is observed that in summer the atmosphere looks whitish

to grayish indicating presence of large amounts of dust; re-suspension of dust appears to be the cause of large contribution of these sources. This hypothesis can be argued from the fact that the contribution of flyash and road dust reduces significantly both in PM_{10} and $PM_{2.5}$ in winter when winds are low and prevalent atmospheric conditions are calm.

- The contribution of the biomass burning in winter is quite high at 19% (for PM_{10}) 32% (for $PM_{2.5}$). the presence of sizeable biomass is consistent in PM both winter and summer indicates to local sources present in Jaipur and nearby areas. As per the report on biomass fuel supply by Rajasthan Renewable Energy Corporation Limited (RRECL, 2015), juliflora wood consumed about 1159 tonnes/day by local people for domestic fuel, local bakery and hotels industries, biomass power plant and other local thermal energy consuming industries in Jaipur district. There is an immediate need to control or find alternatives to completely eliminate biomass emissions to observe any significant improvement in air quality in Jaipur.
- The contribution of MSW burning may surprise many persons. The recent study by Singh (2015) has estimated 256 tons/day of MSW was not collected (~20 % of MSW generated; 1280 tons/day). Form the uncollected waste, major part would be burned. It is a myth that MSW is not burned in Jaipur. It is clearly seen that MSW burning is a major source that contributes to both PM_{10} and $PM_{2.5}$. This emission is expected to be large in the regions of economically lower strata of the society which does not have proper infrastructure for collection and disposal of MSW.
- In Vishwakarma industrial area (VKI) has the movement of large trucks ferrying raw material and finishes products. Poor road conditions were spotted due to dumping and burning of MSW and plastic waste along the roadsides. The MSW/plastic burning is exceptionally higher in PM_{10} (winter: 16%, summer: 13%) and $PM_{2.5}$ (winter: 17%, summer: 14%) in both winter and summer season that indicates irregular management of waste generated from industries which succeeds for open burning.

Directions for PM control

- Secondary particles

  What are the sources of secondary particles, the major contributors to Jaipur'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 and refineries. However, contribution of NO_x from local sources, especially vehicles and power plants can also contribute to nitrates. Behera and Sharma (2010) for Kanpur have concluded that secondary inorganic aerosol accounted for significant mass of $PM_{2.5}$ (about 34%) and any particulate control strategy should also include control of primary precursor gases.

- Vehicular pollution

  This source is the second largest source and most consistently contributing source to PM_{10} and $PM_{2.5}$ in winters. Various control options include the implementation of Euro VI, introduction of electric and hybrid vehicles, traffic planning and restriction of movement of vehicles, retro-fitment in diesel exhaust, improvement in public transport etc. These options are further discussed in Chapter 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 in industries. All biomass burning in Jaipur should be banned and strictly implemented.

- MSW burning

  One of the reasons for burning MSW is 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 burning of MSW should be completely banned.

- Coal and flyash

  In summer coal and flyash contribute about 7 percent of PM_{10} and unless sources contributing to flyash are controlled, one cannot expect improvement in air quality. It appears these sources are more of fugitive in nature than regular point sources. Flyash emission from hotels, restaurants and tandoors also cause large emissions and requires better housekeeping and flyash disposal.

- Soil and road dust

In summer this source contributes about 69 % to PM_{10}. The silt load on some of the Jaipur's road is very high and silt can become airborne with the movement of vehicles. The estimated PM_{10} emission from road dust is over 65 tons per day. Similarly soil from the open fields gets airborne in summer. The potential control options can be sweeping and watering of roads, better construction and maintenance, growing plants, grass etc. to prevent resuspension of dust.

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

6 Control options, Analyses and Prioritization for Actions

6.1 Air Pollution Scenario in the City of Jaipur

The city of Jaipur has a complex urban environment with respect to air pollution and faces severe air pollution of PM_{10} and $PM_{2.5}$. There are several prominent sources within and outside Jaipur contributing to PM_{10} and $PM_{2.5}$ in ambient air; these pollutants can be taken as surrogate of other pollutants also, as most of the pollutants coexist and have common sources. Chapter 4 presents the emission inventory and Chapter 5 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 source apportionment study are presented below.

The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air levels) include: soil and road dust (41 – 18 %), SIA particles (17 - 23%), biomass burning (19 – 32%), vehicles (11 - 17%) and MSW burning (6 - 8%). It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.

The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include: soil and road dust (69 – 36%), biomass burning (10 - 30%), vehicles (5 – 14%), MSW burning (4 – 6%), coal and flyash (7 - 5%) and SIA particles (3 - 6%). 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 season. This chapter presents various air pollution control options and their effectiveness in improving the air quality. At the end of the chapter, a time sensitive action plan is presented.

6.2 Source Control Options

It may be noted that air polluting sources are plenty and efforts are required for every sector/source. In addition, there is a need to explore various options for controlling air pollutants for increased emission in future. A list of potential control options that includes technological and management interventions is presented in Table 6.1 for $PM_{2.5}$ and PM_{10}.

Table 6.1: Control Options, Emission Load and Reductions in PM

Source	Control Action	Responsible authorities	Time Frame
Hotels/ Restaurants	Restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances.	Jaipur Municipal Corporation	1 year
	Link Commercial license to clean fuel	Jaipur 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.	Jaipur 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 year
	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 year
Municipal Solid Waste (MSW) Burning	Any type of garbage burning should be strictly stopped.	Jaipur Municipal Corporation	Immediate
	Surveillance is required that hazardous waste goes to TSDF.	Jaipur Municipal Corporation, RSPCB	
	Desilting and cleaning of municipal drains	Jaipur Municipal Corporation	
	Waste burning in Industrial area should be stopped.	RIICO, RSPCB	
	Daily, Monthly mass balance of MSW generation and disposal	Jaipur Municipal Corporation	
	Sensitize people and media through workshops and literature distribution.	Jaipur Municipal Corporation, RSPCB and NGO	
Construction and Demolition	Wet suppression	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	Immediate
	Wind speed reduction (for large construction site)	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Enforcement of C&D Waste Management Rules. The waste should be sent to construction and demolition	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban	Immediate

Source	Control Action	Responsible authorities	Time Frame
	processing facility	Development Department, PWD	
	Proper handling and storage of raw material: covered the storage and provide the windbreakers.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Vehicle cleaning and specific fixed wheel washing on leaving the site and damping down of haul routes.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Actual construction area should be covered by a fine screen.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur 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)	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Builders should leave 25% area for green belt in residential colonies to be made mandatory.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD	
	Sensitize construction workers and contract agency through workshops.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD, RSPCB and NGO	
Road Dust	The silt load in Jaipur varies from 4 to 32 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 $gm/m^{2.}$	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD	Immediate
	Convert unpaved roads to paved roads. Maintain pot hole free roads.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD	
	Implementation of truck loading guidelines; use appropriate enclosures for haul trucks and gravel paving for all haul routes.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD	

Source	Control Action	Responsible authorities	Time Frame
	Increase green cover and plantation. Undertake greening of open areas, community places, schools and housing societies.	Jaipur Development Authority, Rajasthan Housing Board, Jaipur 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% (resultant emissions: PM2.5=4 ton/day)	Jaipur Development Authority, Rajasthan Housing Board, Jaipur 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
	Introduction of cleaner fuels (CNG/ LPG) for vehicles.	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.)	2 year
	Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Jaipur.	Transport Department, Traffic Police, Jaipur, 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, Jaipur City Transport Services Pvt. Ltd	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, Jaipur City Transport Services Pvt. Ltd	1year
	Enforcement of bus lanes and keeping them free from obstruction and encroachment.	Jaipur Development Authority, Jaipur Municipal Corporation, Jaipur City Transport Services Pvt. Ltd	1 year

Source	Control Action	Responsible authorities	Time Frame
	Ensure integration of existing metro system with bus services.	Jaipur Metro Rail Corporation, Jaipur Development Authority, Jaipur Municipal Corporation, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
	Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
	IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
	Movement of materials (raw and product) should be allowed between 10 PM to 5 AM.	Transport Department, Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	1 year
Industries and DG Sets	Ensuring emission standards in industries. Shifting of polluting industries.	RSPCB, Industries Department	1 year
	Strict action to stop unscientific disposal of hazardous waste in the surrounding area	Municipal council and RSPCB	
	There should be separate Treatment, Storage, and Disposal Facilities (TSDFs) for hazardous waste.	Industrial Associations, RIICO, Industries Department, RSPCB	2 year
	Industrial waste burning should be stopped immediately	Industrial Associations, RIICO, RSPCB	Immediate
	Follow best practices to minimize fugitive emission within the industry premises, all leakages within the industry should be controlled	Industrial Associations, RIICO, RSPCB	Immediate
	Area and road in front of the industry should be the responsibility of the industry	Industrial Associations, RIICO, RSPCB	
	Category A Industries (using coal and other dirty fuels)		
	About 500 boilers and furnaces in Jaipur are running over coal, wood, and other dirty solid fuels which should be shifted to natural gas and electricity	Department of Food, Civil Supplies and Consumer Affairs and Oil Companies (Indian Oil/HP, etc.), Industrial Associations, RSPCB	2 years

Source	Control Action	Responsible authorities	Time Frame
	Almost all rotary furnace having significant emissions are running on coal that needs to be shifted to natural gas and electricity	Industrial Associations, RSPCB	2 year
	Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.	Industrial Associations, RSPCB	2 year
	Category B Industries (Induction Furnace)		
	Recommended Fume gas capturing hood followed by Baghouse should be used to control air pollution	Industrial Associations, RSPCB	2 year
	Diesel Generator Sets		
	Strengthening of grid power supply, uninterrupted power supply to the industries	State Energy Department, JVVNL	2 years
	Renewable energy should be used to cater the need of office requirement in the absence of power failure to stop the use of DG Set	Industrial Associations	2 year
Decongestion of Roads at high traffic areas	Strict action on roadside encroachment.	Jaipur Development Authority, Jaipur Municipal Corporations, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	6 months
	Disciplined Public transport (designate one lane stop).	Jaipur City Transport Services Pvt. Ltd., Traffic Police, Jaipur	
	Removal of free parking zone	Jaipur Development Authority, Jaipur Municipal Corporation, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur	
	Examine existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, NHAI, Traffic Police, Jaipur	
	Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, NHAI, Traffic Police, Jaipur	
	Mechanized multi storey parking at bus stands, railway	Jaipur Development Authority, Jaipur City Transport	

Source	Control Action	Responsible authorities	Time Frame
	stations and big commercial areas.	Services Pvt. Ltd, Jaipur Municipal Corporations, NHAI, Traffic Police, Jaipur	
	Identify traffic bottleneck intersections and develop smooth traffic plan. For example, Badi chopad, BSNL CSC circle, Chomu pulia, D-circle, Collectrate circle, Gopalpura circle and Ghandi circle are the main bottlenecks for traffic.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Traffic Police, Jaipur	
	Parking policy in congestion area (high parking cost, at city centers, only parking is limited for physically challenged people, etc).	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, NHAI, Traffic Police, Jaipur	
	Sindhi Camp Central Bus Stand causes extreme congestion and increased emissions and should be decongested at priority. it is recommended that the city should have three more large inter-district/inter-state bus stations in north-west (towards Sikar and Bikaner), east (towards Bharatpur – Agra) and south (towards Tonk). It is also recommended to shift the private bus stands (currently near Sindhi Camp, Polovictory and nearby areas) to other locations similar to one suggested in the above point.	Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Traffic Police, Jaipur	
	The Jaipur railway station is the hub of urban activities for transport of man and material, hotels, shops, etc., which cause severe traffic congestion in the area. It is recommended that other railway stations in the city are developed and modernized to cater more railway traffic so to decongest the main railway station.	Indian Railways, Jaipur Development Authority, Jaipur City Transport Services Pvt. Ltd, Jaipur Municipal Corporations, Jaipur	
	It is recommended to add more metro railway lines for rapid public transport system to discourage the use of	Jaipur Metro Rail Corporation Ltd, Jaipur Development Authority, Jaipur City Transport	

Source	Control Action	Responsible authorities	Time Frame
	personalized vehicles and preventing traffic congestions.	Services Pvt. Ltd, Jaipur Municipal Corporations, Jaipur	
*The above steps should not only be implemented in Jaipur 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.			

6.2.1 Hotels/Restaurant

There are approximately 1500 big Hotels/Restaurants (more than sitting capacity of 10 persons) in the city of Jaipur, which use LPG and coal (mostly in tandoors). The PM emission in the form of flyash contributes to air pollution. It is proposed that all restaurants of sitting capacity more than 10 should not use coal and shift to electric or gas-based appliances. A 70 % reduction of PM_{10} (351 kg/d) and $PM_{2.5}$ (218 kg/d) emission from this source can be achieved by stopping uses of coal.

It is also seen that the ash/residue from the tandoor and other activities are disposed near the roadside. This will contribute to road dust emissions. The Jaipur 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 Jaipur Municipal Corporation, Department of Food, Civil Supplies and Consumer Affairs, and oil Companies (Indian Oil, HP,etc.).

6.2.2 Domestic Sector

Although in Jaipur, 81% of the households use LPG for cooking, the remaining 19 % uses wood, crop residue, cow dung, kerosene and coal for cooking (Census-India, 2012). 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} (317kg/day) and 84% of $PM_{2.5}$ (257 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 Jaipur municipal corporation should prioritize the MSW collection mechanism starting in a systematic manner in each ward. Special attention is required for fruits, vegetable markets and commercial areas and high-rise residential buildings, where MSW burning is common. A mechanism should be developed to carry out mass balance of MSW generation and disposal

on daily and monthly basis. Any type of garbage burning should be stopped and ensured by Jaipur Municipal Corporation.

Desilting and cleaning of municipal drains by Jaipur 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; this must stop and ensured under the supervision of RIICO and RSPCB. 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 front of the industry. Probably there are unauthorized industries, especially in VKI area which use the solid waste of all kind for energy extraction. Such industries should be identified and suitable action is taken. Strict compliance and surveillance are required that hazardous waste goes to TSDF under the supervision of Jaipur Municipal Corporation and RSPCB.

Sensitize people and media through workshops and literature distribution to prevent waste burning and its unauthorized disposal; this activity may be undertaken by Jaipur Municipal Corporation, RSPCB and NGOs.

The banning of MSW waste reduce emission by 100% of PM_{10} (1492kg/day) and $PM_{2.5}$ (1015 kg/d) emissions from this sector.

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. It can be seen from Chapters 4 and 5 that this source is one of the significant ground-level emission sources and a significant contributor to PM_{10} and importantly it is a consistent source all through the year; this sources is more prominent outside the city boundary. 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 (Figure 6.1)
- wind speed reduction (for large construction site) (Figure 6.2)

- 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 Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, Urban Development Department, PWD and RSPCB. 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} (1727kg/day) and 72% in $PM_{2.5}$ (651 kg/day). This will also reduce the road dust and fly ash contribution to ambient air concentration.

Figure 6.1: Dust Suppression System; Sprays are used to capture airborne dust

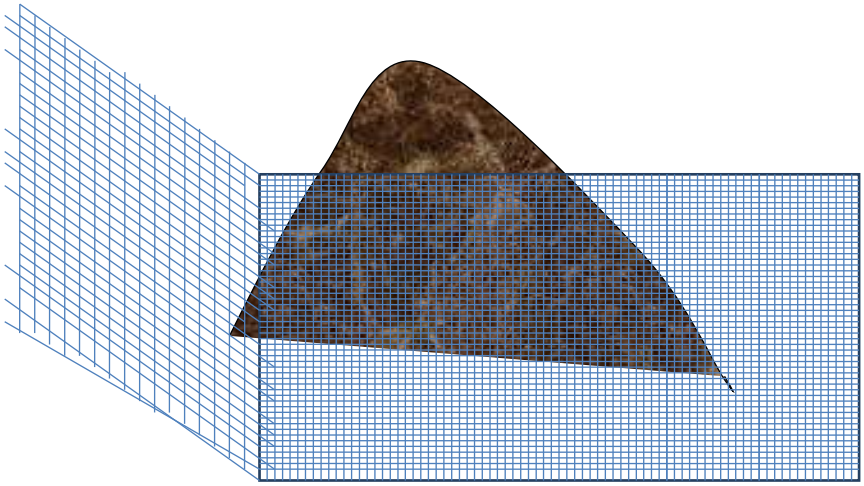


Figure 6.2: Windscreen for dust control from the storage area

6.2.5 Soil and Road Dust

It can be seen from chapters 4, 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 silt load varies from 4 to 32 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. Specifically, the roads at the following locality showed very high silt load: Badi chopad, Yadgaar Chauraha, Agra Road, Triveni Chauraha, Jaipur-Kishangarh highway and Pradhan Guest House.

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% i.e road dust PM_{10} emission at the end of the month will be 38 ton/day. If the frequency of sweeping is increased to four times in a month, then the road dust emission will be reduced by 71% (19 t/day).
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 RSPCB should surveillance.

4. It is more important that the condition of the roads is maintained properly, and shoulder paved by interlocking concrete blocks.
5. The truck carrying construction material, or any airborne material should be covered.

The above control measures should be coordinated and supervised by Jaipur Development Authority, Rajasthan Housing Board, Jaipur Municipal Corporation, National Highway Authority, PWD and State Forest Department (for increasing green cover and plantation) as per their jurisdictions.

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 7 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.).

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 centers in sufficient number to cater to the need of their vehicles in the city. The automobiles manufacturing company owned service centers (AMCOSC) should be fully equipped for complete inspection and maintenance of vehicles ensuring vehicles conforming to emission norms and fuel economy after servicing.
4. The number of PUC centres should be increased to 350 based on thumb rule of 3 PUC centres 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. Check overloading: Expedited installation of weigh-in-motion bridges and machines at all entry points to Jaipur.
9. 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.
10. Route rationalization: Improvement of availability by rationalizing routes and fleet enhancement with requisite modification. Ensure integration of existing metro system with bus services.
11. IT systems in buses, bus stops and control centre and passenger information systems for reliability of bus services and monitoring.

It is proposed that above control options may be coordinated under the supervision of State Transport Department.

6.2.7 Decongestion of Roads

The actions listed below may be coordinated and supervised by Jaipur Development Authority, Jaipur Municipal Corporations, Jaipur City Transport Services Pvt. Ltd, Traffic Police, Jaipur. The suggested control measures are:

- Strict action on roadside encroachment.
- Disciplined Public transport (designate one lane stop).
- Identify traffic bottleneck intersections and develop smooth traffic plan. During the traffic recording and survey done by IIT Kanpur, following major intersections are identified as traffic bottlenecks: The frequency of traffic at different locations is shown in Figure 6.
    - Traffic intersection near VKI (Delhi Ajmer Highway-Benar Road (coordinates: 26.97, 75.75)
    - Jaipur-Jhunjhunu Bye-pass (coordinates: 26.99, 75.77)

- Niwaru road (near Jhotwara)
- Kalwar Road
- Ajay circle (coordinates: 26.94, 75.76)
- Near BRTS Chomu Puliya Bus Stop (coordinates: 26.94,75.77)
- Khatipura circle (coordinates: 26.92, 75.74)
- Purani Chungi (coordinates:26.89, 75.75)
- Near 200 feet bye-pass bus stop, Ajmer road (coordinates: 26.88, 75.73)
- Near Veer Teja Temple, Mansarovar (coordinates:26.85, 75.75)
- Pradhan Crossing (coordinates:26.83, 75.76)
- Near SFS crossing, Bikaner-Agra road (coordinates:26.83, 75.77)
- Near Dada Gurudev Nagar, New Sanganer road – Diggi Malpura road (coordinates: 26.81, 75.78)
- Main Malpura gate intersection (coordinates:26.81, 75.78)
- Near Raigarh Chotta Mohalla intersection (coordinates:26.8128, 75.7844)
- Airport Circle (coordinates:26.81, 75.79)
- Haldighati road – Tonk road intersection (coordinates:26.803, 75.808)
- Jai-jawan-2, Bikaner-Agra and Tonk road intersection (coordinates:26.838, 75.793)
- Mahavir Nagar Chauraha (coordinates:26.856, 75.792)
- Gopalpura Mod (coordinates:26.862, 75.795)
- Jawaharlal Nehru Marg-Sansthan Path intersection (coordinates: 26.867, 75.808)
- Gautamnagar, Lalkothi (coordinates:26.880, 75.799)
- Bus stop, Lal Kothi (coordinates:26.891, 75.794)
- 22 Godam Circle (coordinates:26.902, 75.792)
- Near Ramnagar Metro Station, Ajmer road (coordinates:26.902, 75.774)
- Rambagh Circle (coordinates:26.894, 75.808)
- Hatroi Chowk (coordinates:26.914, 75.795)
- Sardar Patel Marg-Ashok Marg intersection (coordinates: 26.915, 75.804)
- Ambar Tower, MI road (coordinates:26.917, 75.801)
- Paanch Batti Circle (coordinates:26.916, 75.809)
- MI road-Agra road (coordinates:26.915, 75.824)
- Sindhi Camp-Station road (coordinates: 26.922, 75.800)
- Choti Chaupad Circle (coordinates:26.924, 75.818)

- Badi Chaupad Circle (coordinates:26.922, 75.826)
- Ramganj Chaupad (coordinates:26.921, 75.834)
- New Ramgarh road- Amer road intersection (coordinates:26.946, 75.840)

- Sindhi camp bus stand handles over 500 public buses every day and this causes extreme congestion and increased emissions. To decongest the area, it is recommended that the city should have three more large inter-district/inter-state bus stations in north (towards Sikar and Bikaner), east (towards Bharatpur – Agra) and south (towards Tonk).
- There is no place for parking in Sindhi camp bus stand except for government bus (that is also limited). However, many private buses of long distance from the same area cause early morning and night time congestion. This affects the traffic and leads to congestion up to Chandpole, Collectorate and other nearby areas. It is recommended to shift the private bus stands to other locations similar to one suggested in the above point.
- Removal of free parking zone (MI road, Badi chaupad, choti chaupad, other commercial areas)
- Examine existing framework for removing broken vehicles from roads and create a system for speedy removal and ensure minimal disruption to traffic.
- Synchronize traffic movements or introduce intelligent traffic systems for lane-driving.
- Mechanized multi storey parking at bus stands, railway stations and big commercial areas.
- Parking policy in congestion area (high parking cost, at city centers, only parking is limited for physically challenged people, etc).
- The Jaipur railway station is the hub of urban activities for transport of man and material, hotels, shops, etc., which cause severe traffic congestion in the area. It is recommended that other railway stations in the city are developed and modernized to cater more railway traffic so to decongest the main railway station.
- It is recommended to add more metro railway lines for rapid public transport system to discourage the use of personalized vehicles and preventing traffic congestions.

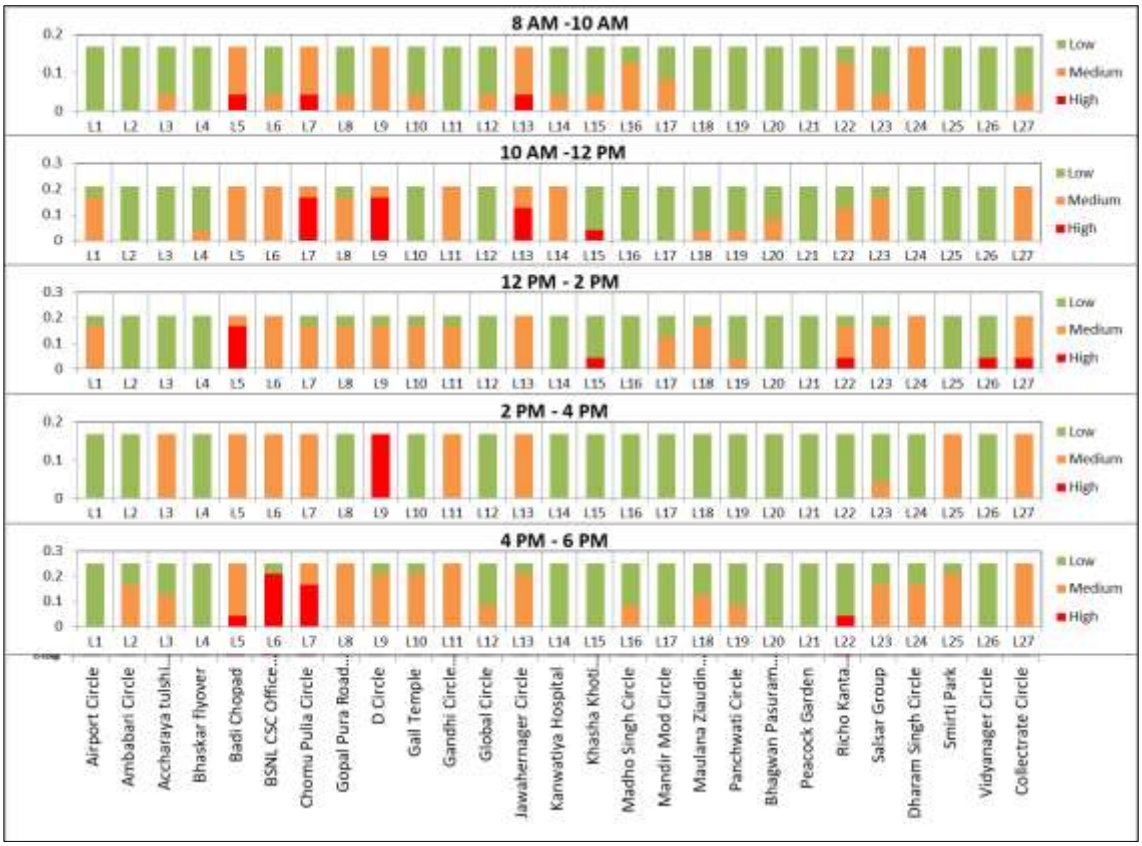


Figure 6.3: Frequency of traffic at different time slots

6.2.8 Industries and Diesel Generator Sets

Industries

A coordinated effort under the supervision of RSPCB, RIICO and Industries Departments is suggested to implement the following control measures (please see table 6.1):

- Shifting of polluting industries: Many polluting industries like Stone crushers / Brick kilns have been closed and shifted in the past due to pollution load. Further, all the brick kilns nearby and around the city shall be converted to cleaner technology within stipulated period.
- The types of industrial fuel, boilers, furnaces, etc are presented in Table 6.2 Approximately 500 boilers/furnaces are operational in Jaipur and contributes heavily in particulate as well as in gaseous emissions. The heavy contribution is due to the use of coal, wood, and other solid fuels, the industry should shift to clean fuel such as natural gas and electricity. Majority of solid fuel based industries used 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 hazardous 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.
- Multi-cyclones should be replaced by baghouses. Ensure installation and operation of air pollution control devices in industries.

Table 6.2: Furnace/Boiler Details in Jaipur

Source	Fuel used	Numbers of sources	Fuel Quantity (kg/day)	PM_{10}	$PM_{2.5}$	NO_X	SO_2	CO
Boiler	F.O., Agro waste fired, Coal, Wood, HSD, Gas, LPG,	154	687085	2365	2128	1344	1458	9310
Bhatti	HSD FIRED	7	1280	1	1	3	7	0
Cupola Furnace	LPG, Coal	46	264020	802	721	869	750	20
Induction Furnace	Electricity	62	909338	866	780	0	0	0
Lead Furnace	F.O. Fired	2	320	0	0	1	7	0
Melting Furnace	Coal, F.O.	8	22083	64	58	70	104	2
Paint Booth	HSD, Oil fired	14	501	0	0	1	3	0
Uncategorised Furnace	LDO, Coal, Diesel, Electric, F.O., Wood, HSD	62	250480	600	540	609	944	1284
Galvanizing Furnace	LSHS FIRED	9	10032	7	6	20	102	2
Hot Water and Air Generator	HSD, Diesel	9	8512	4	3	17	48	2
Reactor	Wood	58	647874	3362	3026	253	39	24548
Re Heating Furnace	Coal, F.O.	13	126020	266	240	319	1805	17
Roasters	wood	2	2280	12	11	1	0	86
Thermopack	F.O., HSD, Agro waste, Wood	11	83296	44	40	163	501	47
Thermic Fluid Heater	Coal, HSD, Wood, Agro waste,Oil	32	50864	89	80	83	212	496
Zinc Furnace	Oil Fired	9	1080	2	1	2	24	0
Annealing Furnace	Coal	3		134	121	145	125	3
Pulveriser	Coal	4	16000	49	44	54	46	1
Total		505	3081065	8666	7799	3954	6177	35819

- There are many 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 using induction furnaces a fume gas capturing device has been developed and commercially available. A side-based suction (Figure 6.4 to 6.6) is far more effective than top suction, which interferes with the movement of the crane.

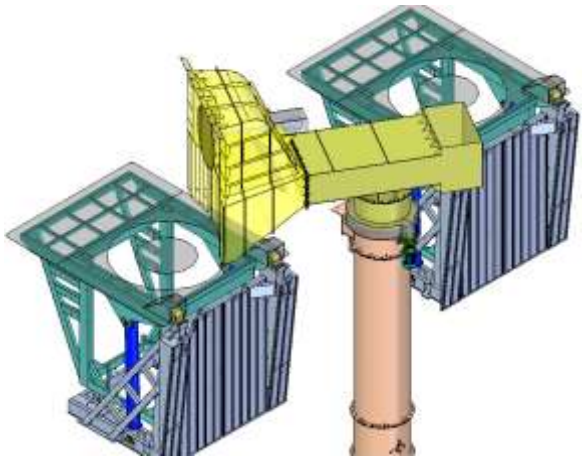


Figure 6.4: Proposed Suction Hood (Pic courtesy: Electrotherm)

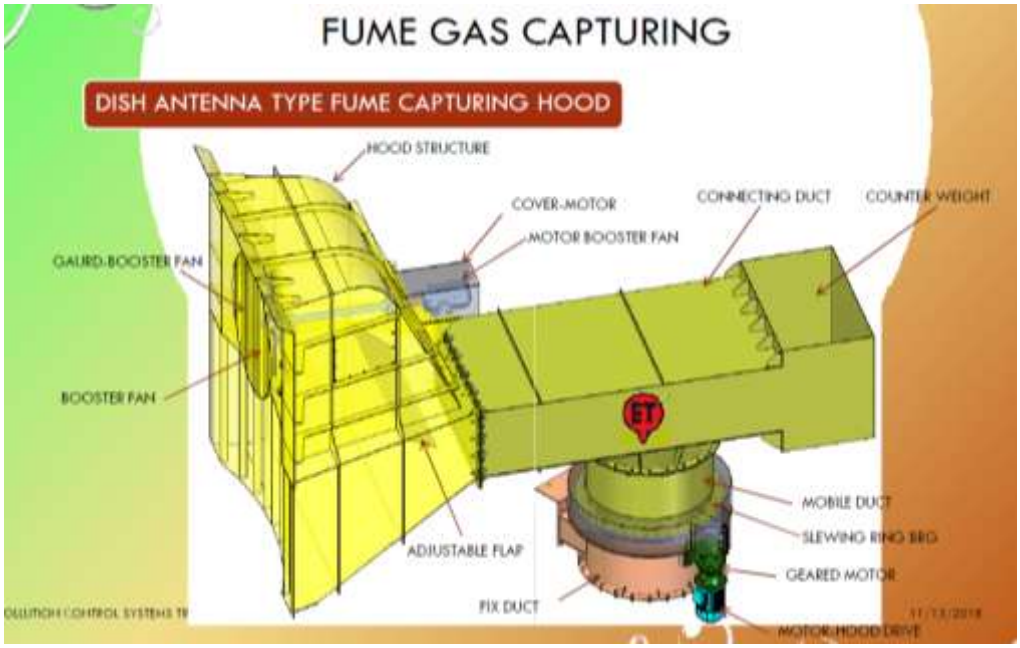


Figure 6.5: Side-based Suction Hood (Pic courtesy: Electrotherm)

Figure 6.6: Working of side-based Suction Hood

- It is recommended that fume gas capturing hood followed by baghouse should be used to control air pollution.

The economics of the side-based suction hood for an induction furnace:

Assume capacity 8 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 cr
Per year operational cost (including maintenance) = Rs. 30 lakhs
Turnover of the company per year = Rs. 3 crore

Pollution control cost is 10% of turnover. Which is somewhat high and may raise the question of the economic viability of the industry, especially when other such industries in the country do not do such level of investment. The industry will need some support in terms of soft loans or even some subsidy.

- 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.
- The Rajasthan government should supply sufficient grid power to industries for an effective industrial run.
- Follow best practices to minimize fugitive emission within the industry premises
- It is seen that industrial waste (hazardous in nature) is mixed with MSW and burnt in several parts of Jaipur. 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 RSPCB.

- 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.

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. Jaipur has a suitable location for installing a solar plant as a number of sunny days is more in Jaipur. Solar power should be installed in Jaipur to reduce the running hours of Diesel Generators as well as to power infrastructural facilities in the commercial area.

6.4 Strengthening of Jaipur 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

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