Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi

(Final Report: Air Pollution component)

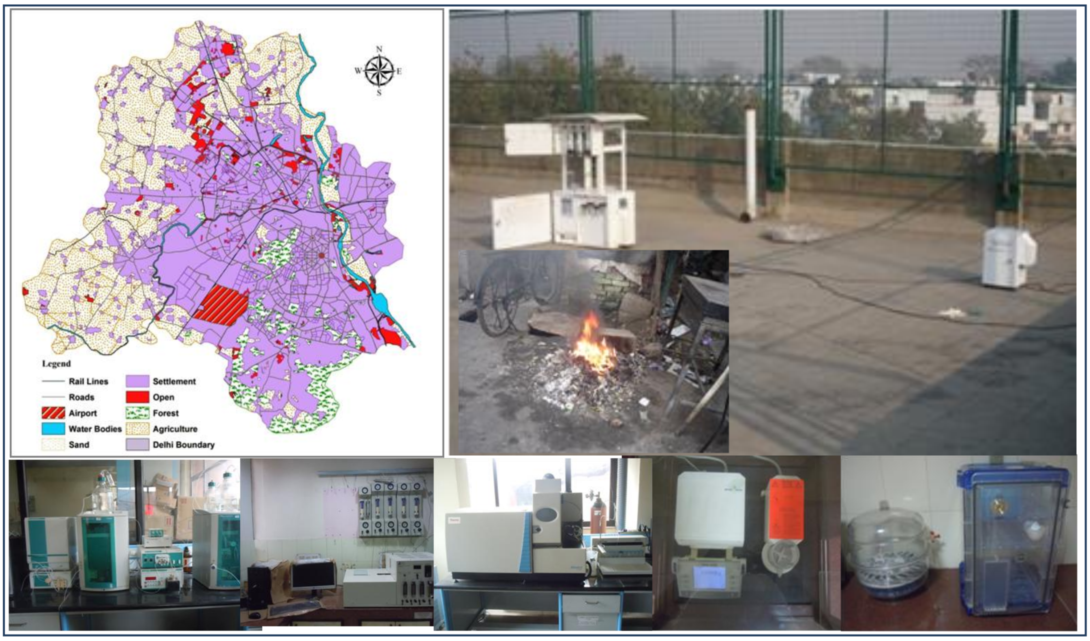
Submitted to

Department of Environment

Government of National Capital Territory of Delhi

and

Delhi Pollution Control Committee, Delhi



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January 2016

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 problem in the city of Delhi by identifying major air pollution sources, their contributions to ambient air pollution levels and develop an air pollution control plan, Government of National Capital Territory of Delhi (NCTD) and Delhi Pollution Control Committee (DPCC), Delhi have sponsored this project "Comprehensive Study on Air Pollution and Green House Gases in Delhi" to IIT Kanpur. 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 Delhi.
- 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;
- Project emission inventories using mathematical models taking into account vehicle population/ improvements in vehicle technology, fuel quality changes and other activities having impact on ambient air quality
- 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

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 or equal to 10 µm), $PM_{2.5}$ (particulate matter of size less than or equal to 2.5µm), SO_2, NO_2, CO, OC (organic carbon), EC (elemental carbon), Ions, Elements and PAHs (poly aromatic hydrocarbons) were considered for sampling and measurements. The air quality sampling was conducted for two seasons: winter (2013-14) and summer (2014).

Table 1: Description of Sampling Sites in Delhi

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	DAV School, Dwarka	DWK	Residential	Domestic cooking, vehicles, road dust
2.	Delhi Technical University, Rohini	RHN	Residential and Industrial	Industries, Domestic cooking, DG sets, vehicles, road dust, garbage burning
3.	Envirotech, Okhla	OKH	Industrial	Industries, DG sets, vehicles, road dust
4.	Indian Spinal Injuries Centre, Vasantkunj	VKJ	Residential cum commercial	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
5.	Arwachin International School, Dilshad Garden	DSG	Industrial	Industries, DG sets, vehicles, road dust
6.	DTEA School, Pusa Road New Delhi	PUS	Residential cum commercial	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants

Based on the air quality measurements in summer and winter months and critical analyses of air quality data (Chapter 2), the following inferences and insights are drawn for understanding current status of air quality. The season-wise, site specific average air concentrations of PM_{10}, $PM_{2.5}$ and their compositions (Tables 2.14 (a, b, c, d) and 2.16 (a, b, c, d)) have been referred to bring the important inferences to the fore.

- Particulate pollution is the main concern in the city where levels of PM_{10} and $PM_{2.5}$ are 4-7 times higher than the national air quality standards in summer and 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.

Summer - PM_{10}

The overall average concentration of PM_{10} in summer season is over 500 $\mu g/m^3$ against the acceptable level of 100 $\mu g/m^3$.

The crustal component (Si + Al + Fe + Ca) accounts for about 40 percent of total PM_{10} in summer. This suggests soil and road dust and airborne flyash are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.25, which suggests the sources are consistent all around the city forming a layer which envelopes the city. The areas of DSG and OKH have the highest crustal fraction (around 44% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are wide spread and present all around in Delhi and NCR and are more prominent in summer when soil and ash-ponds (active or abandoned) are dry and high speed winds make the particles airborne. It was observed that in summer the atmosphere looks whitish to grayish which can be attributed to the presence of large amounts of flyash and dust particles in the atmosphere.

The second important component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for about 13 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about seven percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NOx 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 also consistent at 4-6 percent, which is an indicator of burning of municipal solid waste (MSW).

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer season is around 300 $\mu g/m^3$ against the acceptable level of 60 $\mu g/m^3$.

The crustal component (Si + Al + Fe + Ca) accounts for about 20 percent of total $PM_{2.5}$. This suggests soil and road dust and airborne flyash is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.23, which suggests the source is consistent all around the city. The area of OKH has the highest crustal fraction around 28% of total $PM_{2.5}$.

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

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 4-10 percent, which is an indicator of burning of municipal solid waste (MSW) and has a relatively higher contribution to $PM_{2.5}$ than that to PM_{10}.

Winter - PM_{10}

The overall average concentration of PM_{10} in winter season is around 600 $\mu g/m^3$ against the acceptable level of 100 $\mu g/m^3$.

The crustal component (Si + Al + Fe + Ca) accounts for only 13% (much less compared to 40 percent in summer). This suggests soil and road dust and airborne flyash have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.36, which suggests the crustal source is variable and not as consistent as it was in summer.

The most important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for about 26 percent of total PM_{10} and combustion related total carbon (TC = EC + OC) accounts for about 19 percent; both fraction of secondary particles and combustion related carbons have increased in winter and account for 45 percent of PM_{10}.

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

Winter - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 375 µg/m^3 against the acceptable level of 60 µg/m^3. The crustal component is reduced dramatically to only 3.5 percent in $PM_{2.5}$ in winter.

The single important component is the secondary particles (NO_3^- + SO_4^{-2} + NH_4^+), which account for about 28 percent of total $PM_{2.5}$ and combustion related total carbon (EC+OC) accounts for about 23 percent; both secondary particles and combustion related carbon are consistent contributor to $PM_{2.5}$ at about 51 percent having CV of 0.22.

The Cl^- content in $PM_{2.5}$ winter is also consistent at 7 percent, which is an indicator of burning of municipal solid waste (MSW); which is relatively higher in winter than in summer

It was observed that in winter the atmosphere looks very hazy and characterized by smoky and unhealthy air. The consistent and major contributors appear to be secondary particles and combustion related emission with modest contribution of burning of MSW.

Potassium levels

In general potassium levels are high and at the same time highly variable; 18 to 7 µg/m^3 in PM_{10} and 15 to 4 µg/m^3 in $PM_{2.5}$. In general potassium level is less than 2 µg/m^3. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.66) show large biomass burning and it is variable. Highest potassium levels (~ 15 µg/m^3) were seen in the beginning of November and early winter perhaps due to crop residue burning in Punjab and Haryana. Potassium levels stabilize around 4 µg/m^3 (which is also high) in rest of the winter months suggesting the biomass burning is prevalent throughout winter, locally and regionally.

NO_2 levels

NO_2 levels in winter are high and they do exceed national air quality standard of 80 µg/m^3 at a few locations; more frequently at PUS sampling 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_{10}, $PM_{2.5}$ and NO_2 are statistically higher (at most locations) in winter months than in summer months by about 25-30 percent. 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, OKH is most polluted and PUS followed by DWK is the least polluted for PM pollution.

The CO levels are well within the ambient air quality standard during summer while at PUS, the concentration exceeds the standards during peak traffic hours in winter.

The entire city is enveloped by pollution layer all around with contribution from multiple sources within Delhi, nearby region and even from long distances.

It is to be noted that OC3/TC ratio is above 0.22 and highest among ratio of fraction of OC to TC (Chapter 2). 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 (VOCs and SVOCs), which again suggests emissions within and outside of Delhi.

Total PAH levels (14 compounds; particulate phase) in winter is very high at 80 ng/m^3 and B(a)P at 8 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 15 ng/m^3.

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.

During Diwali days, PM levels nearly double from the average level and organic content of PM increases more than twice. It is noteworthy that levels of potassium and barium, the main components of fire crackers can increase by about ten times.

- Limited sampling was undertaken in summer and winter seasons at three sites in NCR (Noida, Gaziabad and Faridabad), as a part of other study that indicated the levels in Delhi and NCR are similar and comparable; it suggests that air pollution levels could be contiguously high in the NCR. To get a further insight into this matter, a sampling of PM, SO_2 and NO_2 was also carried out winter season (2014 -15) and as expected levels in Delhi and NCR were comparable.

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 Delhi and NCR. Combustion sources, vehicles, 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, concrete batching and MSW burning.

Emission Inventory

The overall baseline emission inventory for the entire city is developed for the period November 2013 to June 2014. The pollutant wise contribution is shown in Figures 1 to 3. Spatial Distribution of pollutant Emissions from all sources is presented in Figure 4.

The total PM_{10} emission load in the city is estimated to be 143 t/d (based on average annual activity data). The top four contributors to PM_{10} emissions are road dust (56%), concrete batching (10%), industrial point sources (10%) and vehicles (9%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. For example, fugitive road and soil dust re-suspension from ash pond and emission from concrete batching will be significantly lower in winter than in summer. 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 59 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (38 %), vehicles (20 %), domestic fuel burning (12 %) and industrial point sources (11%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

NOx emissions are even higher than PM_{10} emission ~ 312 t/d. Nearly 52 % of emissions are attributed to industrial point source (largely from power plants) followed by vehicular emissions (36%) that occur at ground level, probably making it the most important emission. DG sets contributes 6% to NOx emission and is followed by Aircraft emission (2%). NOx apart from being a pollutant itself, it is important component in 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 141 t/d. Industrial point sources account for above 90 percent of total emission; most of the emissions are from power plants. It appears there may be a need to control SO_2 from power plants. SO_2 is known to contribute to secondary particles (sulfates).

Estimated CO emission is 387 t/d. Nearly 83 % emission of CO is from vehicles, followed by domestic sources 7 %, MSW burning 3% and about 3 % from industrial point source. 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 down town area, north and east of the city show higher emissions than other parts.

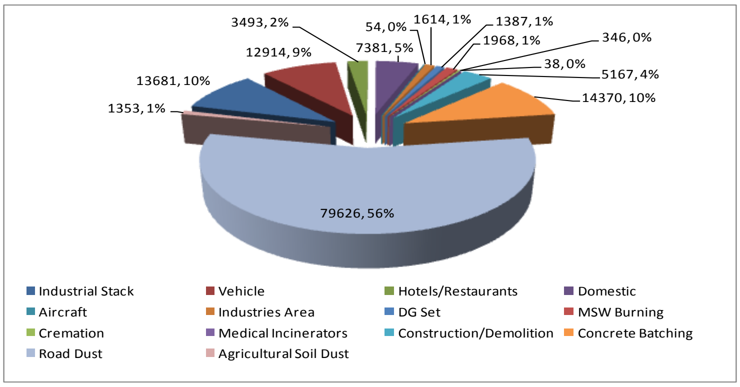


Figure 1: PM_{10} Emission Load of Different Sources in the City Of Delhi

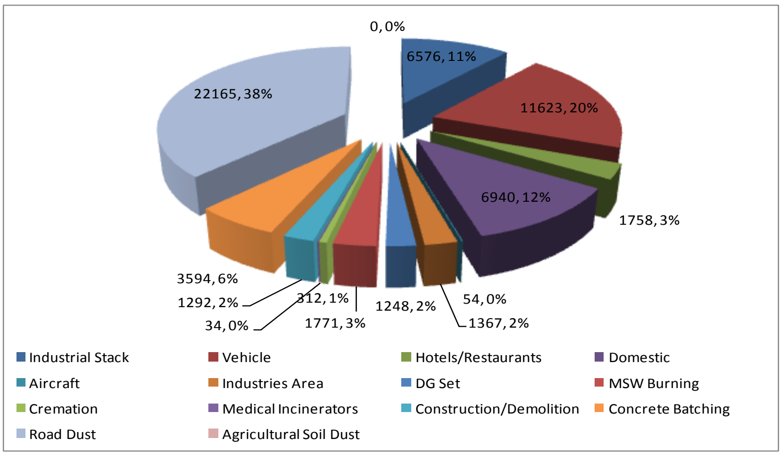


Figure 2: $PM_{2.5}$ Emission Load of Different Sources in the City Of Delhi

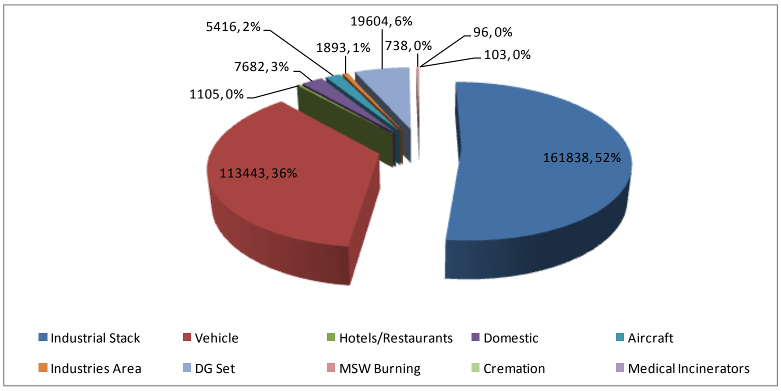


Figure 3: NOx Emission Load of Different Sources in the City Of Delhi

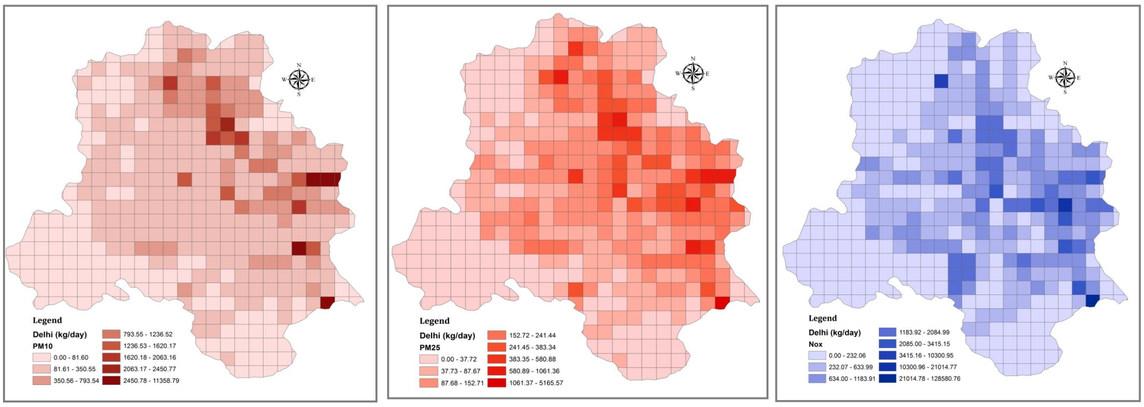


Figure 4: Spatial Distribution of PM_{10}, $PM_{2.5}$ and NOx Emissions in the City of Delhi

Air Quality Modeling

Receptor Modeling

Based on the CMB (chemical mass balance) modeling results (Figures 5 and 6) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for preparation of action plan. Tables 4.17 to 4.20 (in Chapter 4), 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: secondary particles (25 - 30%), vehicles (20 - 25%), biomass burning (17 – 26%), MSW burning (9 - 8%) and to a lesser extent soil and road dust. It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same. A significant contribution in secondary nitrate is from vehicles. It is estimated that secondary nitrate particles of vehicles origin contribute to 3% of total $PM_{2.5}$ in ambient air that makes average vehicle contribution to $PM_{2.5}$ at about 28%.

  The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include: coal and flyash (37 - 26%), soil and road dust (26 – 27%), secondary particles (10 - 15%), biomass burning (7 - 12%), vehicles (6 – 9%) and MSW burning (8 – 7%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

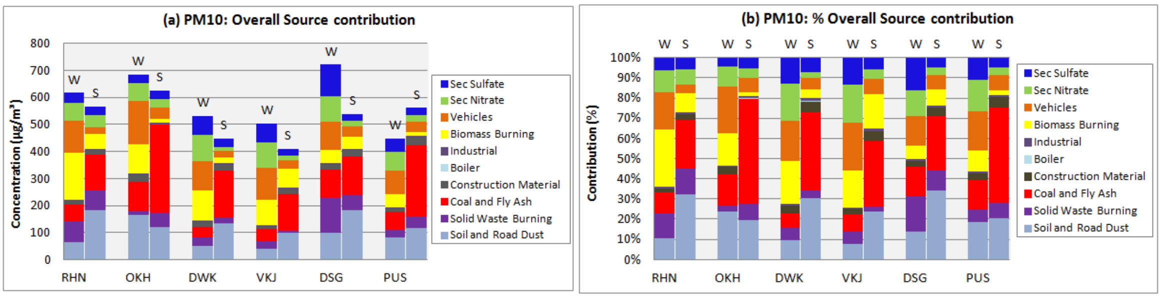
- The two most consistent sources for PM_{10} and $PM_{2.5}$ in both the seasons are secondary particles and vehicles. The other sources on average may contribute more (or less) but their contributions are variable from one day to another. Most variable source was biomass burning followed by MSW burning. Soil and road dust and coal and flyash sources were consistent for PM_{10} but it was not true for $PM_{2.5}$.

- Consistent presence of secondary and vehicular PM_{10} and $PM_{2.5}$ across all sites and in two seasons, suggests these particles encompass entire Delhi region as a layer.

- Similar to the above point, in summer, consistent presence of soil and road dust and coal and flyash particles encompass entire Delhi region as a layer.

- Coal and flyash and road and soil dust in summer contribute 26-37% 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 flyash and 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 17% (for PM_{10}) 26% (for $PM_{2.5}$). Biomass burning is prohibited in Delhi and it is not a common practice at a large scale. The enhanced concentration of PM in October-November is possibly due to the effect of post-monsoon crop residue burning (CRB). It can be seen that the biomass contribution in PM_{10} in the month of November could be as high as 140 $\mu g/m^3$ and about 120 $\mu g/m^3$ for $PM_{2.5}$ (mean of contribution in entire winter season: 97 $\mu g/m^3$ and 86 $\mu g/m^3$ respectively). In all likelihood, the PM from biomass burning is contributed from CRB prevalent in Punjab and Haryana in winter. The back trajectory analyses suggest that the CRB and other biomass emissions may be transported to Delhi from the sources upwind of Delhi (in NW direction). There is an immediate need to control or find alternatives to completely eliminate CRB emissions to observe significant improvement in air quality in Delhi. However, contribution of sizeable biomass burning to PM in December and January indicates to local sources present in Delhi and nearby areas.
- The contribution of MSW burning may surprise many persons. The recent study by Nagpure et al. (2015) has estimated 190 to 246 tons/day of MSW burning (~2−3% of MSW generated; 8390 tons/day). 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.



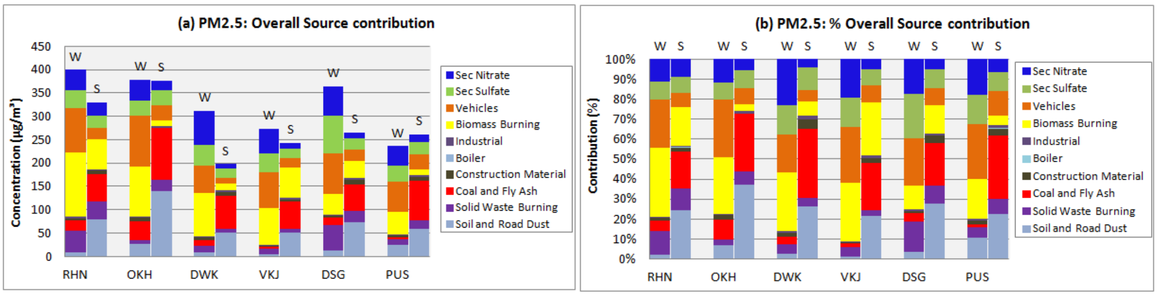
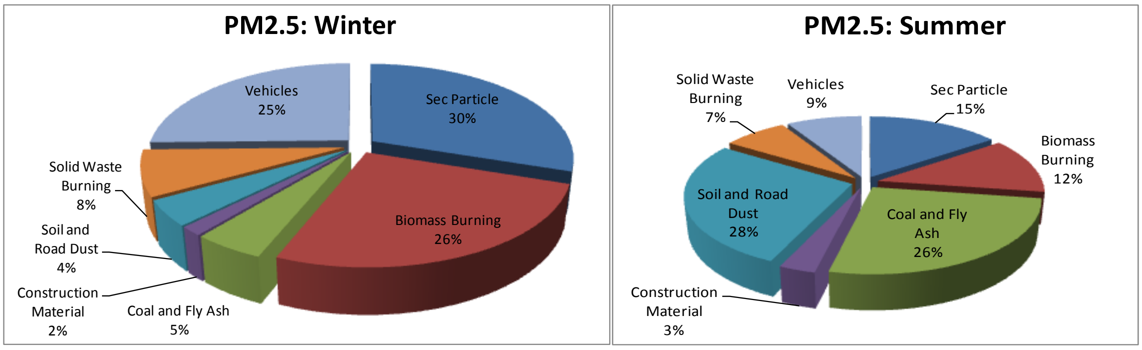


Figure 5: Overall Results of CMB Modeling for PM_{10} and $PM_{2.5}$ at six sites



*Solid waste burning refers to MSW burning

Figure 6: City level source contribution to ambient air $PM_{2.5}$ levels

Dispersion Modeling

A liner relationship between observed and model-computed levels of PM_{10} and $PM_{2.5}$ in winter months with R-square, 0.53 – 0.88 shows that model describes the physics of dispersion and captures the impact of emission quite well.

What is interesting to note is that the best fit lines have very high intercepts for PM_{10} (170 $\mu g/m^3$) and $PM_{2.5}$ (100 $\mu g/m^3$). Since model performance in terms linear association is established for observed and computed concentrations, the large intercept concentration can be attributed to the background pollution in Delhi that appears to be contributed from outside Delhi. In other words, almost about one-third of pollution in PM levels can be attributed to emissions from outside Delhi. This analysis makes it clear that pollution control will have to focus both inside and outside Delhi for improvements in air quality not only in Delhi but also in NCR.

Control Options

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

- Hotels/Restaurants

  There are approximately 9000 Hotels/Restaurants in the city of Delhi, which use 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.

- Domestic Sector

  Although Delhi is kerosene free and 90% of the households use LPG for cooking, the remaining 10% uses wood, crop residue, cow dung, and coal for cooking (Census-India, 2012). The LPG should be made available to remaining 10% households to make the city 100% free from solid fuels.

- Coal and flyash

  In summer, coal and fly ash contribute about 30 percent of PM_{10} and unless sources contributing to flyash are controlled, one cannot expect significant improvement in air quality. It appears that these sources are more of fugitive in nature than regular point sources. However, two large power plants in city are also important sources of flyash. Probably the major part is re-suspension of flyash from flyash ponds (in use or abandoned) which are not maintained properly and become dry in summer. Flyash emission from hotels, restaurants and tandoors also cause large emissions and requires better housekeeping and proper flyash disposal.

- MSW burning

  One of the reasons for burning MSW is lack of infrastructure for timely collection of MSW and it is conveniently burned or it may smolder slowly for a long time. In this regard, infrastructure for collection and disposal (landfill and waste to energy plants) of MSW has to improve and burning of MSW should be banned completely.

- Construction and Demolition

  The construction and demolition emission can be classified as temporary or short term. In city like Delhi which is high in urban agglomeration, these activities are frequent. It can be seen from Chapter 3 that this source is the third most contributor to area source emission in PM_{10} and importantly it is a consistent source all through the year. The control measures for emission may include: wet suppression, wind speed reduction (for large construction site), proper disposed of waste, proper handling and storage of raw material and store the waste inside premises with proper cover. At the time of on-road movement of construction material, it should be fully covered.

- Ready Mix Concrete Batching

  The ready mix concrete is used for construction activities. As large amount of flyash emission is also expected from this source because pozzalan cement used in the process has about 35 percent flyash in it. The control measures include: wind breaker, bag filter at silos, enclosures, hoods, curtains, telescopic chutes, covering of transfer points and conveyer belts.

- 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 BS VI, introduction of electric and hybrid vehicles, traffic planning and restriction of movement of vehicles, retro-fitment in diesel exhaust, improvement in public transport etc have been proposed and their effectiveness has been assessed.

- Soil and road dust

  In summer, this source can contribute about 26% to PM_{10} and $PM_{2.5}$. The silt load on some of the Delhi’s road is very high and silt can become airborne with the movement of vehicles, particularly in dry summer season. 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 re-suspension of dust.

- Industries and Diesel Generator Sets

  Industries: Several measures have been taken to control emissions in the industry (including relocation), especially in small and medium size industries. However, it is recommended industries use light diesel oil (LDO) and high speed diesel (HSD) of sulphur content of 500 ppm or less in boilers or furnaces, if not already being used;

expected PM control will be about 15 to 30 % from this source and SO_2 emissions will become negligible.

Diesel Generator Sets: The primary pollutants from internal combustion engines are oxides of nitrogen and PM. For Delhi and NCR, the sulphur content should be reduced to 500 ppm in HSD (if not already in use) as has been done for vehicles; a reduction of 15 to 30% of PM emission from this source is expected. It will have a major impact on reduction of SO_2 and secondary particles. The DG sets should be properly maintained and regular inspection should be done. All efforts should be made to minimize uses of DG sets and regular power supply should be strengthened. Since small DG sets are used at the ground level and create nuisance and high pollution, it is recommended that all DG sets of size 2 KVA or less should not be allowed to operate; solar powered generation, storage and inverter should be promoted.

- Secondary particles

  What are the sources of secondary particles, the major contributors to Delhi'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. The NW wind is expected to transport SO_2 and transformed it into sulfates emitted from large power plants and refineries situated in the upwind of Delhi. 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.

  There are 13 thermal power plants (TPP) with a capacity of over 11000 MW in the radius of 300km of Delhi, which are expected to contribute to secondary particles. Based on the study done by Quazi (2013), it was shown that power plants contribute nearly 80% of sulfates and 50% nitrates to the receptor concentration. A calculation assuming 90% reduction in SO_2 from these plants can reduce 72% of sulphates. This will effectively reduce PM_{10} and $PM_{2.5}$ concentration by about 62 $\mu g/m^3$ and 35 $\mu g/m^3$ respectively. Similarly 90% reduction in NO_x can reduce the nitrates by 45%. This will effectively reduce PM_{10} and $PM_{2.5}$ concentration by about 37 µg/m^3 and 23 µg/m^3 respectively. It implies that control of SO_2 and NO_x from power plant can reduce PM_{10} concentration approximately by 99 µg/m^3 and for $PM_{2.5}$ the reduction could be about 57 µg/m^3.

- Secondary Organic Aerosols

  The contribution of secondary organic aerosols (SOA) in Delhi has not been done. However, Behera and Sharma (2010) have estimated that the SOA is about 17 percent of total $PM_{2.5}$ in Kanpur, another city in Ganga basin. This implies that emissions of VOCs (volatile organic compounds) need to be controlled both in and outside of Delhi, as SOA can be formed from VOC sources at far distance from the receptor. It is recommended that all petrol pumps in Delhi should install vapour recovery system to reduce VOC emissions both at the time of dispensing petrol/diesel but also at the time of filling of storage tank at the petrol pumps.

- Biomass burning

  The enhanced concentration in October-November is possibly due to the effect of post-monsoon crop residue burning (CRB). The CRB should be minimized if not completely stopped. All biomass burning in Delhi should be stopped and strictly implemented. Managing crop residue burning in Haryana, Punjab and other local biomass burning is important. Potential alternatives to CRB: energy production, Biogas generation, commercial feedstock for cattle, composting, conversion in biochar, Raw material for industry

Action Plan

The study recommends that the following control options for improving the air quality, these must be implemented in a progressive manner.

- Stop use of Coal in hotels/restaurants
- LPG to all
- Stop MSW burning: Improve collection and disposal (landfill and waste to energy plants)
- Construction and demolition: Vertically cover the construction area with fine screens, Handling and Storage of Raw Material (completely cover the material), Water spray and wind breaker and store the waste inside premises

with proper cover. At the time of on-road movement of construction material, it should be fully covered.

- Concrete batching: water spray, wind breaker, bag filter at silos, enclosures, hoods, curtains, telescopic chutes, cover transfer points and conveyer belts
- Road Dust : Vacuum Sweeping of major roads (Four Times a Month), Carpeting of shoulders, Mechanical sweeping with water wash
- Soil Dust: plant small shrubs, perennial forages, grass covers
- Vehicles:
    - Retro Fitment of Diesel Particulate Filter
    - Implementation of BS – VI for all diesel vehicles including heavy duty vehicles (non-CNG buses and trucks) and LCVs (non-CNG)
    - Inspection/ Maintenance of Vehicles
    - Ultra Low Sulphur Fuel (<10 PPM)); BS-VI compliant
    - 2-Ws with Multi Point Fuel Injection (MPFI) system or equivalent
    - Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws: New residential and commercial buildings to have charging facilities
- Industry and DG Sets:
    - Reduce sulphur content in Industrial Fuel (LDO, HSD) to less than 500 PPM
    - Minimize uses, uninterrupted power supply, banning 2-KVA or smaller DG sets
- De-SOx-ing at Power Plants within 300 km radius of Delhi
- De-NOx-ing at Power Plants within 300 km radius of Delhi
- Controlling Evaporative Loss during fuel unloading and re-fueling through Vapour Recovery System at petrol pumps
- Managing crop residue burning in Haryana, Punjab and other local biomass burning, Potential alternatives: energy production, Biogas generation,

commercial feedstock for cattle, composting, conversion in biochar, Raw material for industry

- Wind Breaker, Water Spraying, plantation, reclamation

It appears that even with implementation of all control options (Tables 6.1: Chapter 6), the national air quality standards will not be achieved for PM_{10} (100 µg/m^3) and $PM_{2.5}$ (60 µg/m^3). With implementation of all control options in Delhi, expected PM_{10} concentration (including emissions from outside Delhi) would be 200 µg/m^3 and for $PM_{2.5}$ it would be 115 µg/m^3. As a next step towards attaining air quality standards, since the NCR is a contiguous area with similarities in emitting sources, it is proposed that the control options (developed for Delhi: Tables 6.1) are implemented for the entire NCR. With the implementation of control options in Delhi as well as NCR, the overall air quality in Delhi will improve significantly and expected PM_{10} levels will be 120 µg/m^3 and $PM_{2.5}$ will be 72 µg/m^3. In addition to the above control options, some local efforts will be required to ensure that city of Delhi and NCR attain the air quality standards all through the year and possibly for many years to come.

The above analyses are based on air quality modeling results and calculations by simplifying some factors. The action plan will certainly be effective in a broad sense and air quality standard will be attained and health and aesthetic benefits will be enjoyed by all citizens in NCR including Delhi. The overall action plan that will ensure compliance with air quality standards for PM_{10} (100 µg/m^3), $PM_{2.5}$ (60 µg/m^3) and NO_2 (80 µg/m^3) is presented Table 1.

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, dispersion modeling, identification of control options, their efficacies and action plan for attaining air quality standards. It was observed that NCR is a contiguous extension of activities similar to that of NCTD. The pollution levels in NCR were also similar to that of NCTD. It is expected the findings and action plan of this study are applicable for NCR and will bring air quality improvement in the entire region. In view of limited financial resources, it is suggested that no separate or repetitive study is required in NCR and Delhi for re-establishing source-receptor impacts; the focus should be early implementation of action plan.

Table 1: Action Plan for NCT of Delhi

Source	Option No.	Description Option	2016	2017	2018	2019	2020-2023	Percent improvement in AQ
Hotels/ Restaurants	1	Stop use of Coal	■	■	■	■	■	80.56
Domestic Cooking	2	LPG to all	■	■	■	■	■	50.00
MSW Burning	3	Stop MSW burning: Improve collection and disposal (landfill and waste to energy plants)	■	■	■	■	■	100.00
Construction and Demolition	4	Vertically cover the construction area with fine screens	■	■	■	■	■	50.00
		Handling and Storage of Raw Material: completely cover the material						
		Water spray and wind breaker						
		Store the waste inside premises with proper cover						
Concrete Batching	5	Water Spray	■	■	■	■	■	40.00
		Wind Breaker						
		Bag Filter at Silos						
		Enclosures, Hoods, Curtains, Telescopic Chutes, Cover Transfer Points and Conveyer Belts						
Road Dust and Soil dust	6.1	Vacuum Sweeping of major roads (Four Times a Month)	■	■	■	■	■	70.00
		Carpeting of shoulders						
		Mechanical sweeping with water wash						
	6.2	plant small shrubs, perennial forages, grass covers in open areas	■	■	■	■	■	--
Vehicles	7.1	Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws wef July 2017: New residential and commercial buildings to have charging facilities		■	■	■	■	50.0
	7.2	Retrofitment of Diesel Particulate Filter: wef July 2018			■	■	■	
	7.3	Implementation of BS – VI for all diesel vehicles including heavy duty vehicles (non-CNG buses and trucks) and LCVs (non-CNG): wef January 2019				■	■	
	7.4	Inspection/ Maintenance of Vehicles	■	■	■	■	■	
	7.5	Ultra Low Sulphur Fuel (<10 PPM); BS-VI compliant: wef January 2018			■	■	■	

Source	Option No.	Description Option	2016	2017	2018	2019	2020-2023	Percent improvement in AQ
	7.6	2-Ws with Multi Point Fuel Injection (MPFI) system or equivalent: wef January 2019				🟥	🟥	
Industry and DG Sets	8.1	Reduce sulphur content in Industrial Fuel (LDO, HSD) to less than 500 PPM		🟦	🟦	🟦	🟦	30.00
	8.2	Minimize uses, uninterrupted power supply, Banning 2-KVA or smaller DG sets		🟦	🟦	🟦	🟦	--
Secondary Particles	9.1	De-SOx-ing at Power Plants within 300 km of Delhi			🟩	🟩	🟩	90.0
	9.2	De-NOx-ing at Power Plants within 300 km of Delhi			🟪	🟪	🟪	90.1
Secondary Organic Aerosols	10	Controlling Evaporative emissions: Vapour Recovery System at petrol pumps (Fuel unloading and dispensing)		🟦	🟦	🟦	🟦	80.0
Biomass Burning	11	Managing crop residue burning in Haryana, Punjab and other local biomass burning, Potential alternatives: energy production, biogas generation, commercial feedstock for cattle, composting, conversion in biochar, Raw material for industry: wef July 2016	🟥	🟥	🟥	🟥	🟥	90.0
Fly Ash	12	Wind Breaker, Water Spraying, plantation, reclamation		🟧	🟧	🟧	🟧	--

Notes: for implementation year 2016 may begin from July 2016

Note (1) The above plan is also effective for control of PM_{10}. The expected reduction is about 81% in PM_{10}. (2) The model computed concentrations are 9-month average. Specific reduction in winter or summer can be estimated from source apportionment in chapter 4 (refer to Tables 4.17 to 4.20).

* Vehicle growth rate calculated for 2019. It is assumed 80% of the vehicles added per year will go out of vehicle fleet because of being 15 years (or more) old.

**Air quality standards cannot be achieved unless stringent measures are also taken at sources outside Delhi. It is recommended that the above actions are implemented in NCR, else 24-hr $PM_{2.5}$ levels are likely to exceed 110 $\mu g/m^3$.

Acknowledgments

This project on “Comprehensive Study on Air Pollution and Green House Gases (GHGs) in Delhi” was sponsored by Department of Environment and Delhi Pollution Control Committee (DPCC), Government of National Capital Territory of Delhi (NCTD) to Indian Institute of Technology Kanpur. The project was quite vast in terms of activities including field sampling, data collection, laboratory analyses, computational work and interpretation of results. Support of different institutions and individuals at all levels is gratefully acknowledged. Although it will be an endeavor to remember and acknowledge all those who assisted in the project, we seek pardon in anticipation, if we err.

We gratefully acknowledge assistance and guidance received from Mr. Ashwani Kumar, Secretary, Environment, Mr. Sanjiv Kumar and Mr Keshav Chandra, Former Secretaries, Environment, Mr. Kulanand Joshi, Special Secretary Environment and Mr. Sandip Misra Former Member Secretary, Govt. of NCTD. Dr. Anil Kumar, Director, Department of Environment was always available for heeding to all problems and providing workable solutions; thank you Dr. Anil Kumar. We are thankful to Dr. M. P George, Scientist (DPCC), Mrs Nigam Agarwal Sr. Scientific Officer, Department of Environment for acting promptly to all requests and concerns.

We are grateful to Dr. S. Velmurugan, Principal Scientist, Central Road Research Institute, New Delhi for sharing traffic data for over 50 locations in Delhi. The analytical facilities of Centre for Environmental Science and Engineering, IIT Kanpur (created under MPLADS, Govt of India) were of great help in carrying out trace level analyses.

Mr. Pavan Kumar Nagar, P.hD Scholar and Mr. Dhirendra Singh, Senior Project Engineer, IIT Kanpur worked tirelessly from field sampling to analysis and preparation of report; thanks to Pavan and Dhirendra for their inestimable support. Sincere thanks are also due to the entire IITK team engaged in the project including Preeti Singh, Sandhya Anand, Akshay Singh, Nitish Kumar Verma, Harvendra Singh, Pravin Kumar, Toofan Singh, Gaurav, Gulab Singh, Saurabh, Deepak Panwar, Durga Prasad Yadav and Virendra. Special thanks to Mr. Anu N, Assistant Professor, UKF College of Engineering and Technology for his support.

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Chapter 1

Introduction

1.1 Background of the Study

Air pollution professionals responsible for the development of air pollution control strategies and other pollution impact analysis programs, have long been faced with the basic need to understand the relative importance of specific source impacts within air-sheds.

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.

Being a major centre of commerce, industry and education, Delhi has experienced a phenomenal growth in recent years. Like many other large cities, the City of Delhi is adversely affected by problems of urbanization. The burgeoning population coupled with rapid growth in terms of vehicles, construction, and energy consumption has resulted in serious environmental concerns in Delhi.

Air pollution in Delhi is caused mainly by industry and vehicular traffic present both inside and outside the Delhi. Delhi's annual average concentration of PM_{10} is highest among major Asian cities, and was between three and four times the Indian standard in 2001– 2004 (HEI, 2004). Balachandran et al. (2000) reported that PM_{10} concentrations exceeded national standards at all three locations in their study, and that roughly half the PM_{10} mass in Delhi could be attributed to fine particulate matter. The number of vehicles in Delhi is ever increasing causing a great concern regarding concentration of NOx. In some studies, the pollution levels were reported worse in winter compared to other seasons due to emissions from heating and unfavourable meteorological conditions for dispersion (Guttikunda and Gurjar, 2012).

To effectively address the air pollution problem in the city of Delhi by identifying major air pollution sources, their contributions to ambient air pollution levels and develop an air pollution control plan, Government of National Capital Territory of Delhi (NCTD) and Delhi Pollution Control Committee (DPCC), Delhi have sponsored this project "Comprehensive Study on Air Pollution and Green House Gases in Delhi" to IIT Kanpur. This document constitutes the first draft report that has addressed all important points of scope of work except inventory and sinks of greenhouse gases.

1.2 General Description of City

1.2.1 Demography

Delhi is situated between the mountain ranges of the Great Himalayas and Aravalis in northern India with a coordinates of 28.6100° N, 77.2300° E. The total area is 1,483 sq kms (573.0 sq mi) with a maximum width of 48.48 kms and maximum length of 51.90 kms. It shares boundaries with the States of Haryana, Uttar Pradesh and Rajasthan. The main geographical features of the city can be divided in three different parts, the plains, the Yamuna flood plain, and the ridges part of Aravali hills (Gupta and Mohan, 2013). The Aravali hill ranges are covered with forest and are called the Ridges; they are the city's lungs and help maintain its environment city (Delhi, 2006). In Delhi, key industries include Telecommunications, Hotels, Information Technology, Tourism, Media and Banking. The manufacturing and fabrication industries in Delhi are also in large in numbers like automobile industries, Power plants, Home Textiles sector, Leather industries, Home Consumable industries sector, Metals and Minerals etc.

The population in Delhi increased rapidly. Current population (in 2011) is 16,779,294 (Census-India, 2012). Literary rate in Delhi is approximately 86%. Delhi is divided into 11 districts and further in sub-divisions. Languages spoken in and around Delhi include Hindi, English, Urdu and some Bengali and Punjabi.

1.2.2 Climate

The average annual rainfall in Delhi is 714 mm, 3/4th of which falls in July, August and September. Heavy rainfall in the catchment area of the Yamuna can result in a dangerous flood situation for the city (Delhi, 2006). The maximum temperature ranges are experienced in summer from 41 to 45°C and minimum temperature in winter season is in the range of 3–6°C in coldest period of December-January (Mohan and Bhati, 2011).

1.2.3 Emission Source Activities

The source activities for air pollution in the city of Delhi can be broadly classified as: transport sector (motor vehicles and railways), commercial activities, industrial activities, domestic activities, institutional & official activities and fugitive sources. Under commercial activities, diesel generators and tandoors in restaurants are the most prevailing sources for air pollution in the city. For transport of men, mostly public transport (buses), tempos and taxies (CNG-powered) 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, the dominant source is the 1000 MW power generation. 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. Unlike other cities, at several locations, garbage burning (mostly in the morning and evening) is a common practice; it can be an important contributor to air pollution. The road condition in some parts of the city is quite bad as roads are broken, poorly maintained and partially paved and it is observed that movements of vehicle may cause non-exhaust road dust emission in a significant amount.

1.3 Need for the Study

1.3.1 Current Air Pollution Levels: Earlier Studies

PM_1, $PM_{2.5}$ and PM_{10} concentrations varied seasonally with atmospheric processes and the anthropogenic activities in Delhi. PM_{10} decreases during monsoon by ~25–80 $\mu g/m^3$ and PM_1 and $PM_{2.5}$ by ~10–15 $\mu g/m^3$ from their pre-monsoon levels. Emissions were from fireworks during Deepawali in the post-monsoon season increases in PM_1, $PM_{2.5}$ and PM_{10} levels by 300, 350 and 400 $\mu g/m^3$, respectively over their monsoon levels (Tiwari et.al, 2012). The concentration of PAHs, SO_2, and CO shows decreasing trend after the implementation of CNG as an alternative fuel with to petrol or diesel fuelled vehicles, but an increase in NO_x concentration was noticed. The concentrations of BTX, SPM and PM_{10} show no significant changes (Ravindra et al., 2006).

Several studies were done for the analysis of ambient air quality of Delhi city. One of the important analyses was done by CPCB (2010), which shows the snapshot of air quality at that time for Delhi city. On the basis of this project data, the ambient air quality of Delhi can be summarized below.

Delhi faces a severe air pollution problem due to the number of sources which are impacting the ambient air quality. Vehicular pollution in Delhi has grown from 64% to 72% from 1990 to 2000, whereas petrol and diesel consumption have grown by 400% and 300% respectively.

Other sources such as biomass burning, refuse burning, construction dust and other unregulated sources are becoming major sources in some areas of high pollution levels.

Main pollutant which was covered in the CPCB study (CPCB, 2010) was carbon monoxide, 1-3 butadiene benzene, NMHC, aldehydes, alkanes, THC, PM_{10}, $PM_{2.5}$, ozone, PAHs, SPM, SO_2 and NO_2. Ambient air quality status in Delhi with respect to average concentration of major pollutants is presented in below Figure 1.1.

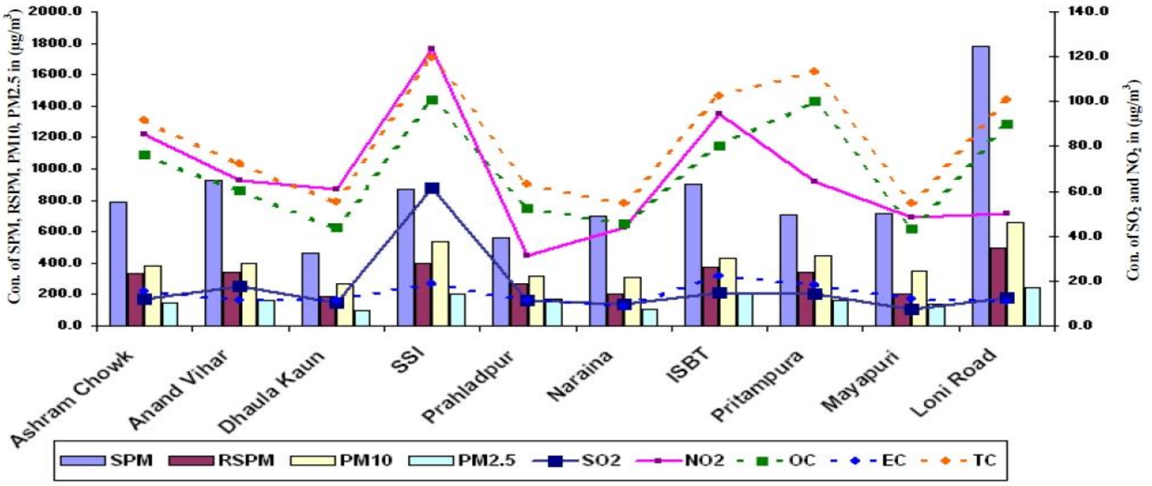


Figure 1.1: Average Concentration of Particulate and Gaseous Pollutants at Ten Sites (Source: CPCB, 2010)

In the CPCB (2010) study, Prahladpur site was taken as a background site and it shows that the level of fine particulate matter and coarse matter exceeds the standard limit. In the same manner, remaining sites show similar trend for particulate pollution. It is noted that SPM concentrations were highest in Loni, followed by Anand Vihar, ISBT, SSI, whereas RSPM concentration were higher at Loni, SSI-GTK and ISBT. SSI-GTK is an industrial site shows high concentration of PM_{10} due to large scale industrial density as well as construction activities. Range of PM_{10} values at Pitampura and ISBT lies between 200-400 $\mu g/m^3$. Lowest value of PM_{10} concentration is in Dhaula Kuan. At all sites $PM_{2.5}$ concentrations exceeds the USEPA standard of 35 $\mu g/m^3$.

Another pollutant whose value exceeds the CPCB standard is a criteria pollutant NO_2 at the Kerb sites of ISBT and Ashram Chowk, which clearly shows the high movement of vehicles at these sites. Levels of NO_2 & SO_2 are in within the limit as per the CPCB norms in remaining all seven locations.

Level of total carbon (TC) and organic carbon (OC) shows highest value at SSI-GTK site. Value of OC is highest at Pitampura which indicates biomass burning at this site, whereas at Mayapuri, Naraina and Prahaladpur it shows lower values. SSI site shows higher OC concentrations followed by ISBT, Ashram Chowk, Pitrampura and Loni Road, whereas lower at Mayapuri, Naraina and Dhaula Kuan. Higher EC concentration were observed at ISBT, SSI and lowest at Naraina. Loni shows maximum OC/EC ratio followed by Anand Vihar, Naraina, Mayapuri and ISBT.

In the CPCB report (2010), it was observed that total PM emission is 147 t/d, major contributor in PM is by Road dust which is approx. 52.5 % of total estimated pollution. Total NOx and SO_2 emission was approximately 460t/d and 268t/d respectively; major contributors to these pollutants are Industries which account for 78.4% and 98.8% of total emission. Similarly CO and HC emissions is approx. 374 t/d and 131 t/d respectively and major contributor in this pollutant is by vehicles which is approx. 58.2% and 50.7%. Estimated quantity of the emissions from different sources is presented in Table 1.1.

Table 1.1: summary of emissions sources (CPCB, 2010)

Source	Pollutant Emission Rate (kg/day)				
	PM_{10}	SO_2	NO_x	CO	HC
Industrial	32479	264399	360526	23771	4765
Area sources	27730	2608	15332	132552	59968
Vehicular	9750	720	84200	217800	66700
Road Dust	77275	--	--	--	--
Total	147234	267727	460058	374123	131433

To get a clearer picture of the seasonal variability in the concentration of RSPM and NO_2, average, half-monthly concentrations are plotted as an example for air quality data of Mayapuri.

1.3.2 Seasonal Variation of Air Quality

Figures 1.2 and 1.3 present half monthly mean concentrations averaged over 2005-2013 for PM_{10} and NO_2 at Mayapuri in Delhi.

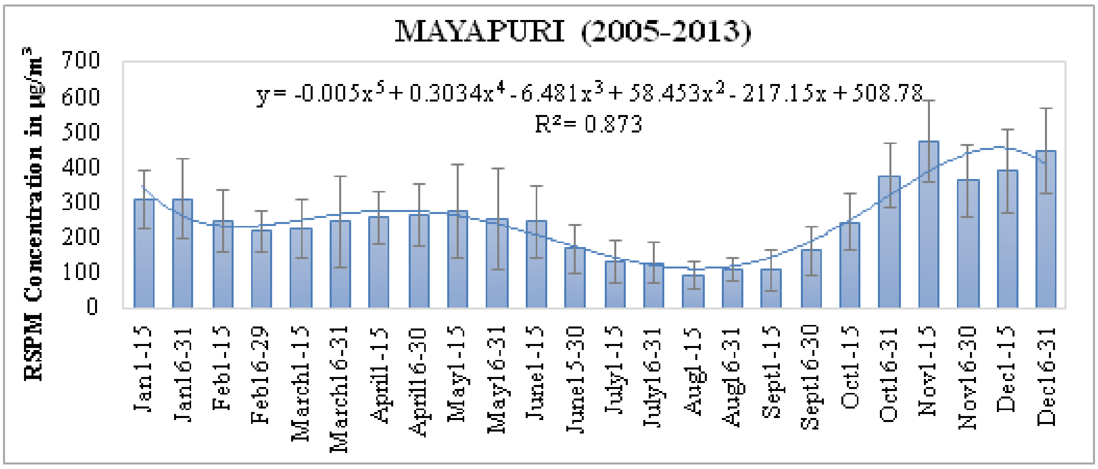


Figure 1.2: Seasonal Variation of PM_{10}

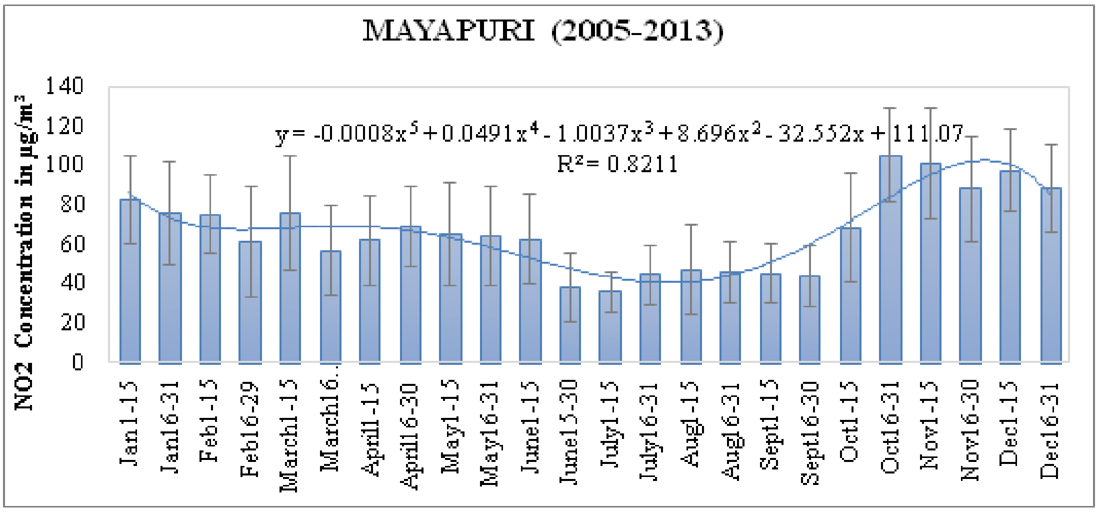


Figure 1.3: Seasonal Variation of NO_2

From the equation, concentration C = k. (Q/(u.H)), it can be seen that concentration, C is inversely proportional to mixing height (H) and wind speed (u). It is found that mixing height in Delhi during post-monsoon is about 800m and that during winter is about 500m (CPCB, 2002). Also, the wind speed is found to be the same during both the periods. It is seen, a sudden increase in PM_{10} concentration is observed from the latter half of October to the first half of November, after which it drops gradually during winter. Therefore, from the above equation it can be concluded that emission rate (Q) during post monsoon is greater than that during winter.

A second peak is observed in the pre-monsoon season from second half of March to first half of May. The enhanced concentration in October-November is possibly due to the effect of post-monsoon crop residue burning. It is plausible to assume that the pre-monsoonal rise in concentration is caused by the dust transport by North-Westerly and Westerly winds (Mishra and Shibata, 2012) with possible contribution from the crop residue burning during pre-monsoon season. The PM levels in Delhi do not show significant trend during 2005-2013.

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) air pollution emission inventory for air pollutants (Particulate Matter less than 10 µm (PM_{10}), Particulate Matter less than 2.5 µm ($PM_{2.5}$), Sulphur dioxide (SO_2),Carbon monoxide (CO), Oxides of nitrogen (NOx) and benzene in Delhi;
- Compilation and interpretation of the past 10 years ambient air quality data at the specified sampling sites for PM_{10}, $PM_{2.5}$, SO_2, CO, NOx and benzene (24 hr average data) and perform time series analyses of air quality data to 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;
- Monitoring of above air pollutants and chemical speciation of PM_{10}/$PM_{2.5}$ in terms of elements, ions and carbons (inorganic and organic);
- Performing receptor modelling to establish the source-receptor linkages of air pollutants;
- Chemical speciation of particulates and life cycle analysis of various air pollutants;
- 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;
- Selection of best control options from the developed control scenarios and recommend implementation of control options in a time-bound manner;
- Identification of source/sinks of greenhouse gases (GHGs) (CO_2, CH_4, N_2O, and anthropogenic fluorinated gases);
- Development of GIS-based gridded emission inventory of GHGs (2 km × 2 km resolution) from identified sources;
- Estimation of losses of GHGs through various sinks;
- Generation of GIS-based carbon emission maps from various sources, such as transportation, industrial, residential, commercial, and power plants; and

- Comparative analysis of the results with previous studies and from other geographical regions.

1.5 Approaches to the Study

The approach of 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 1.4. The overall approach to the study is broadly described below.

1.5.1 Selection of sampling: Representation of Urban Land-Use

It was considered appropriate that six sites in a city like Delhi can represent typical land use pattern. 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 (institutions, and schools) could be better choices as sampling locations. Finalization of sites was done in consultation with the officials of DPCC, Delhi.

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 locations. This exercise included emission sources like refuses burning, road dust, and coal/coke burnt by street vendors/small restaurants to large units like power plants and various vehicle types. It was necessary to group some of the similar sources to keep the modeling 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 $PM_{2.5}$ and software for emission database and information/data retrieval system were designed and implemented.

1.5.3 Emission Source Profiles

Since for $PM_{2.5}$, Indian or Delhi 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 Delhi'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).

1.5.4 Application of Receptor Modeling

There are several methods and available commercial software those can be used for apportioning the sources if the emission profile 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.

1.5.5 Application of Dispersion Modeling

In addition to receptor modeling, dispersion modeling in the study area will also be undertaken. The hourly meteorological data were generated through WRF “Version 3.4” 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 1.4. The report is divided into eight chapters and annexure at the end. The brief descriptions of the chapters are given below.

Chapter 1

This chapter presents background of the study, general description of the city including 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 approaches for this project 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 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 4

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 season.

Chapter 5

This chapter enumerates the methodology used in conducting dispersion modeling (AERMOD View model). The chapter also describes the results from the above approach of dispersion modeling for the existing emission scenario of the city

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

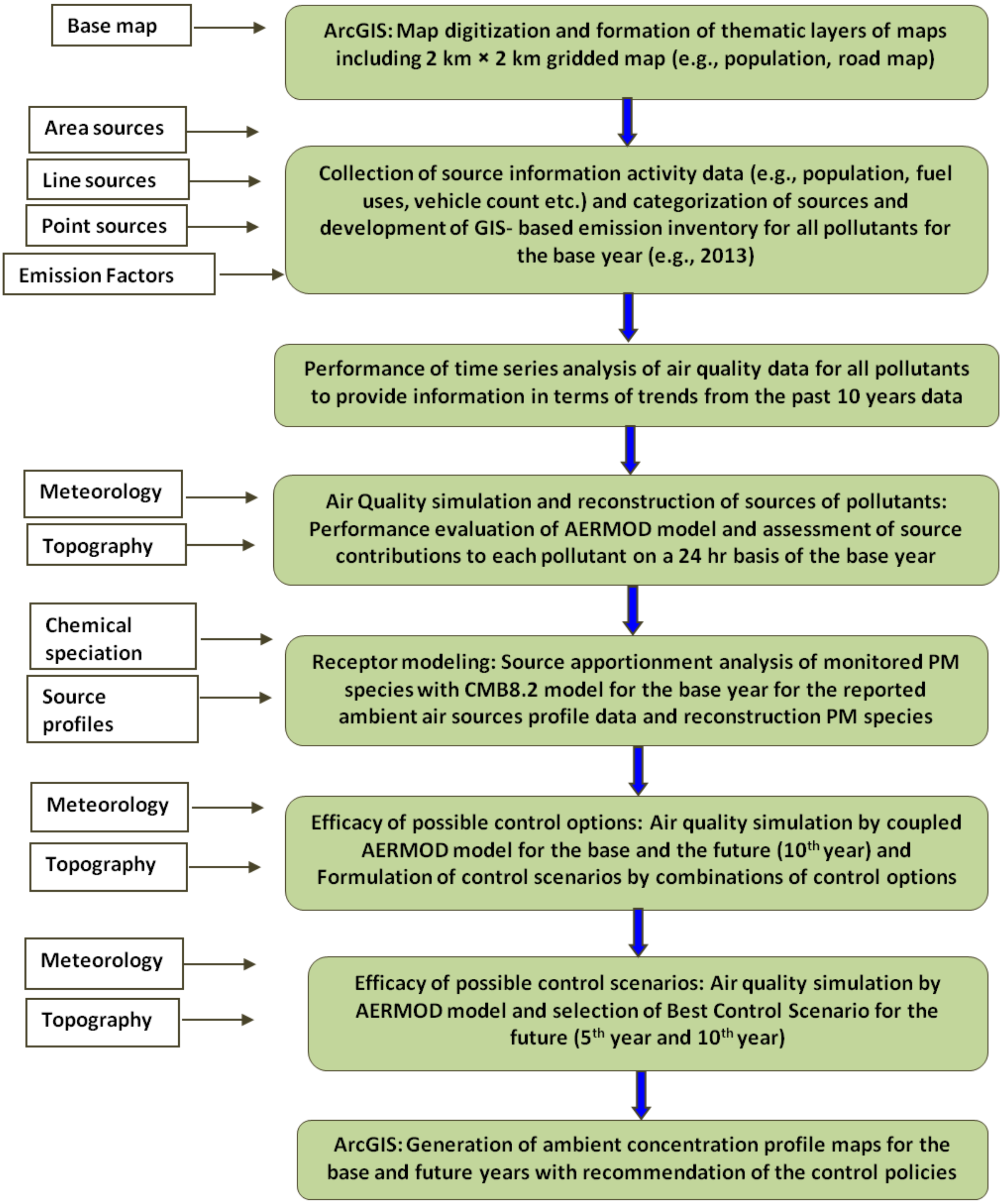


Figure 1.4: Steps for Methodology for Criteria and Toxic Air Pollutants for the Study

Chapter 2

Air Quality: Measurements, Data Analyses and Inferences

2.1 Introduction

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, Delhi has experienced a phenomenal growth in recent years. Like many other large cities, the City of Delhi is adversely affected by problems of urbanization. The burgeoning population coupled with rapid growth in terms of vehicles, construction, and energy consumption has resulted in serious environmental concerns in Delhi.

Air pollution continues to remain a public health concern despite various actions taken to control air pollution. Delhi has taken actions in nearly all sectors to control air pollution over the past two decades – relocation of polluting industries, introduction of improved emission norms for vehicles, phasing out lead from gasoline, reduction of sulphur in diesel and benzene in gasoline, city public transport fleet on CNG, banning of 15-year old commercial vehicles, restriction on transit freight traffic, prohibiting open incineration/combustion, introduction of metro rail, etc. 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).

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

2.2 Methodology

2.2.1 Site selection and details

Total six air quality sites were selected to cover varying land-use prevailing in the city. It is ensured that at all sites, there is 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, schools etc.) were selected. The sites were selected in consultation with DPCC, Delhi. 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 is shown in Figure 2.3.

Table 2.1: Description of Sampling Sites of Delhi

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	DAV School, Dwarka	DWK	Residential	Domestic cooking, vehicles, road dust
2.	Delhi Technical University, Rohini	RHN	Residential and Industrial	Industries, Domestic cooking, DG sets, vehicles, road dust, garbage burning
3.	Envirotech, Okhla	OKH	Industrial	Industries, DG sets, vehicles, road dust
4.	Indian Spinal Injuries Centre, Vasantkunj	VKJ	Residential cum commercial	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
5.	Arwachin International School, Dilshad Garden	DSG	Industrial	Industries, DG sets, vehicles, road dust
6.	DTEA School, Pusa Road New Delhi	PUS	Residential cum commercial	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants


DTU, Rohini Envirotech, Okhla DAV, Dwarka

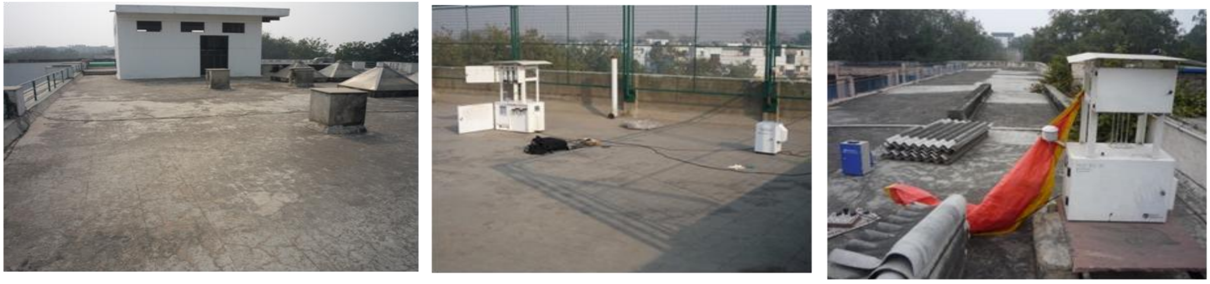

ISIC, VasantKunj AWIS, Dilshad Garden DTEA, Pusa Road

Figure 2.1: Photographs of Sampling Sites showing the physical features

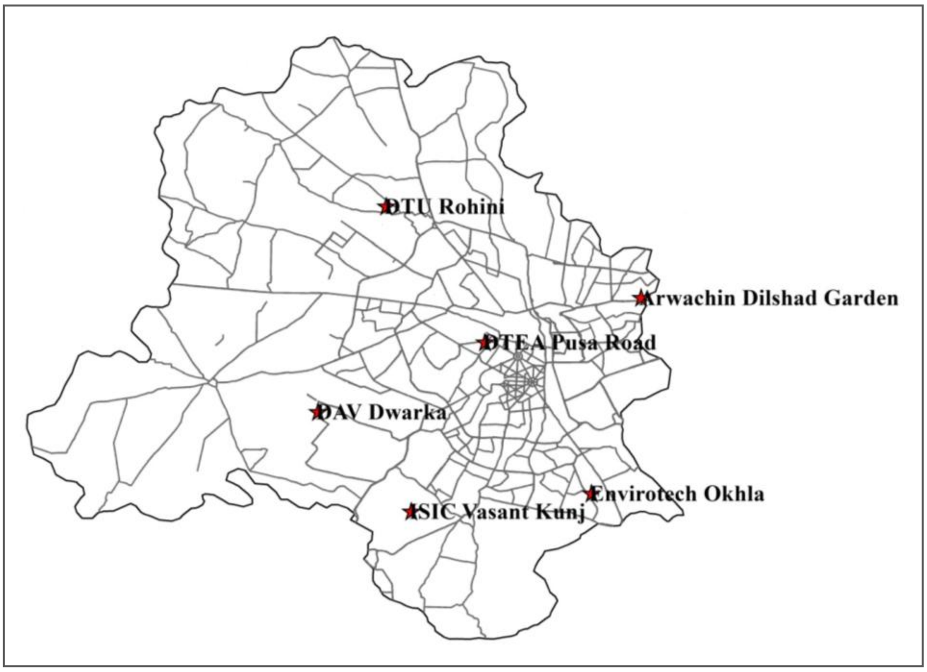


Figure 2.2: Sampling Location Map of Delhi

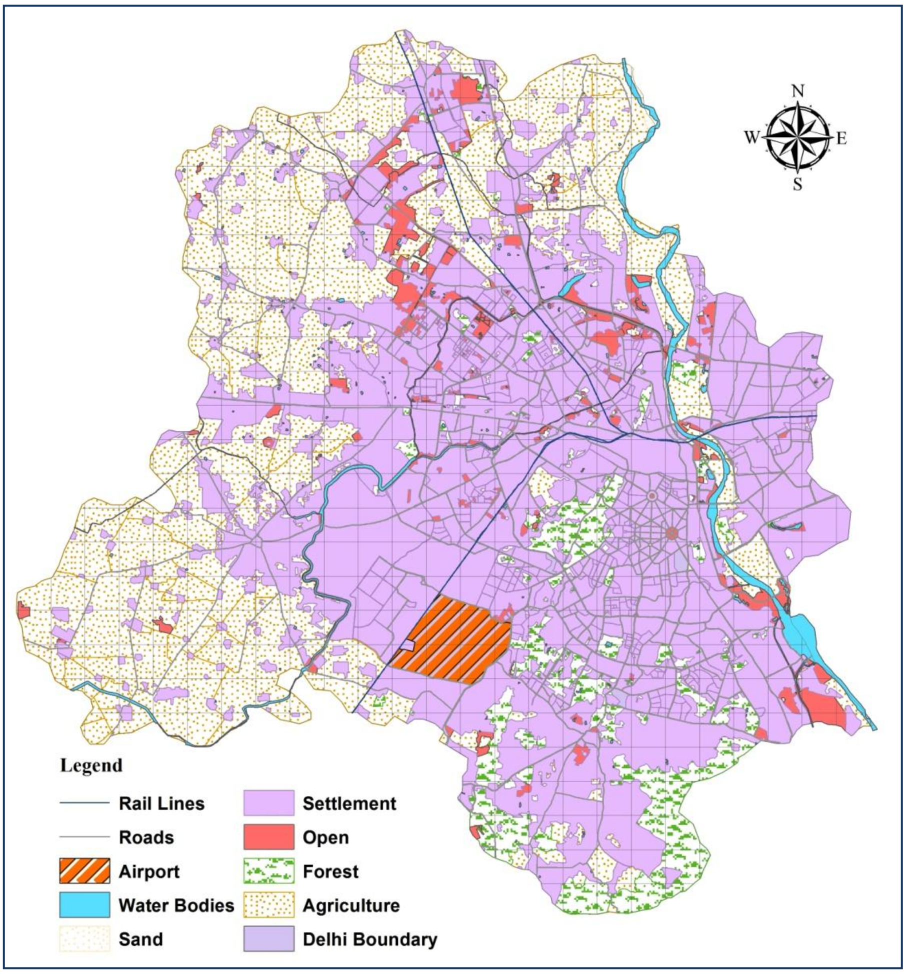


Figure 2.3: Grid Map Showing Land-use Pattern

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), CO, volatile organic carbon (VOC) etc 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 targeted 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.	CO	Continuous online CO analyzer	Non-dispersive infrared
6.	OC/EC	OC/EC Analyzer	Thermal Optical Reflectance
7.	Ions	Ion-Chromatograph	Ion-Chromatography
8.	Elements	ED-XRF Spectrophotometer/ ICP-MS	USEPA
9.	PAHs	GC-MS	Florescence /UV detector

Table 2.3: Target Chemical components for Characterization of PM

Components	Required filter matrix	Analytical methods
PM_{10}/$PM_{2.5}$	Teflon filter paper.	Gravimetric
Elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba and Pb)	Teflon filter paper	ED-XRF or ICP-MS
Ions (F^-, Cl^-, Br^-, NO_2^-, 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 Speciation Samplers 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 and PAHs.

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

PM_{10} and $PM_{2.5}$ concentrations are determined gravimetrically by weighing the PTFE filters before and after the sampling using a digital microbalance (Metler-Toledo MX-5, USA; sensitivity of 1µg; Figure 2.4(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 are 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: TC - OC
- 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% O2 atmospheres.

For elemental analysis, PTFE filters were digested in hydrochloric/nitric acid solution using the microwave digestion system (Anton-Paar, Austria) (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 (upto 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)).

(a) 4-Channel Speciation Sampler (b) Microbalance (c) OC/EC Analyzer

(d) GC-MS with ATD (e) Ion Chromatography (f) ICP-MS

Figure 2.4: 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 parameters like SO_2, NO_2, PM_{10}, $PM_{2.5}$, analyses were done regularly just after the sampling following the standard operating procedures (SOPs). The analyses for elements, ions were done immediately after the season capture of the samples. 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.

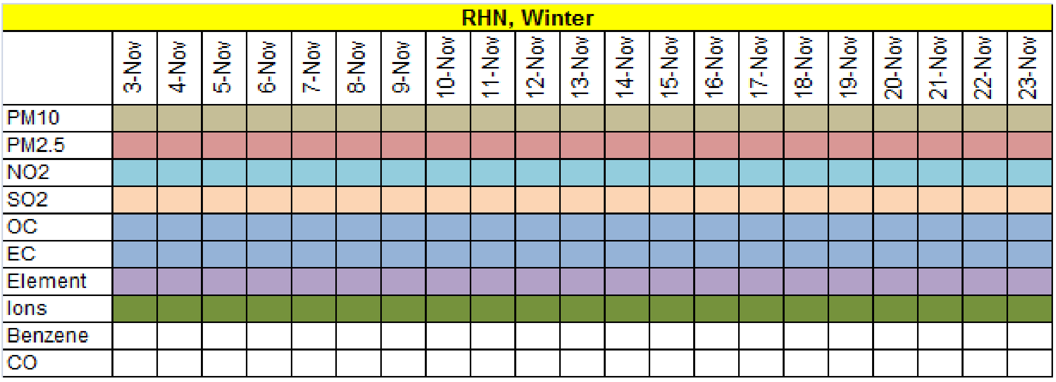
- SOPs for entire project planning and implementation were developed, peer reviewed by other experts and project personnel havebeen trained in the field and in the laboratory. Whenever necessary, the SOPs were adjusted to meet the field challenges.
- SOPs include type of equipment (with specifications), sampling and calibration methods with their frequency and height and distance of measurement from source.

- SOPs for chemical analysis include description of methods, standards to be used, laboratory and field blanks, internal and recovery standards, 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.

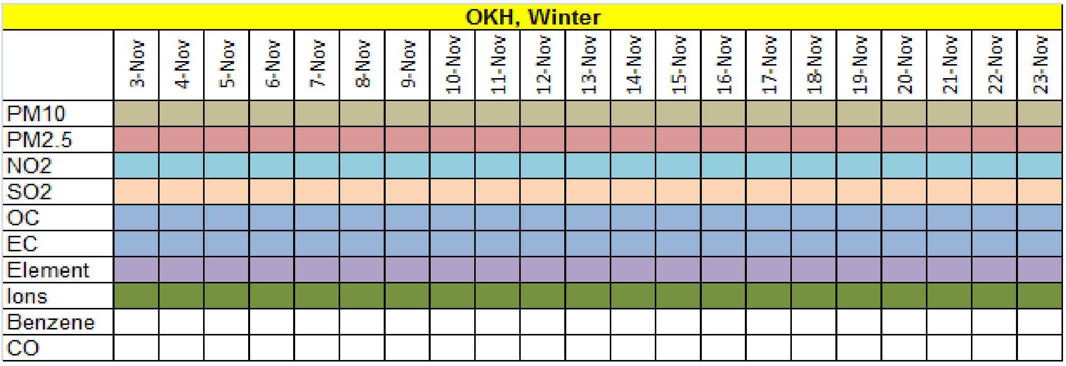
Sampling periods: The sampling has been completed in winter season (November 3, 2013 - February 20, 2014) and summer season (April 4, 2014 - June 19, 2014). In addition, one day sampling has been carried out at three locations outside the boundary of Delhi. The analysis of SO_2 and NO_2 are carried out daily on a regular basis while gravimetric analysis for particulate matters was done after completion of the sampling in the season. CO analyzer (Environment, SA, France) produced the online measurements and data was averaged for every hour of the day. All efforts were made for 100% achievement of the sampling and analysis. The details of sampling days for all pollutants at all monitoring locations are presented in Table 2.4 (Table 2.4(a) to 2.4(f)) and Table 2.5 (Table 2.5(a) to 2.5(f)) for winter and summer season respectively.

Table 2.4(a): Sampling Days of Various Pollutants in Winter (2013-14) at RHN



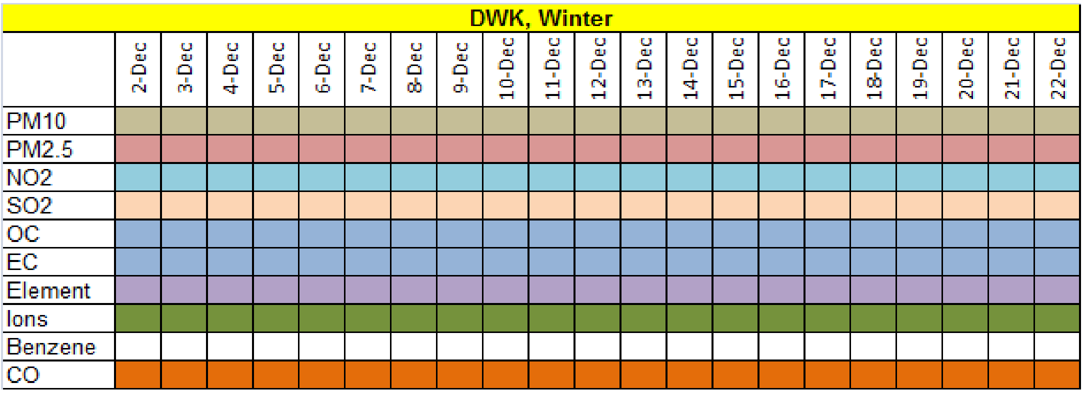
RHN, Winter																					
	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov	9-Nov	10-Nov	11-Nov	12-Nov	13-Nov	14-Nov	15-Nov	16-Nov	17-Nov	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	23-Nov
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO																					

Table 2.5(b): Sampling Days of Various Pollutants in Winter (2013-14) at OKH



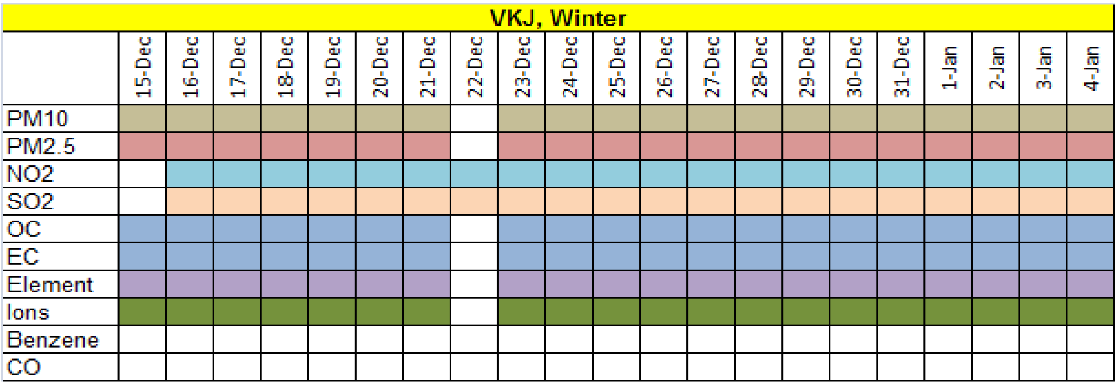
OKH, Winter																					
	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov	9-Nov	10-Nov	11-Nov	12-Nov	13-Nov	14-Nov	15-Nov	16-Nov	17-Nov	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	23-Nov
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO																					

Table 2.6(c): Sampling Days of Various Pollutants in Winter (2013-14) at DWK



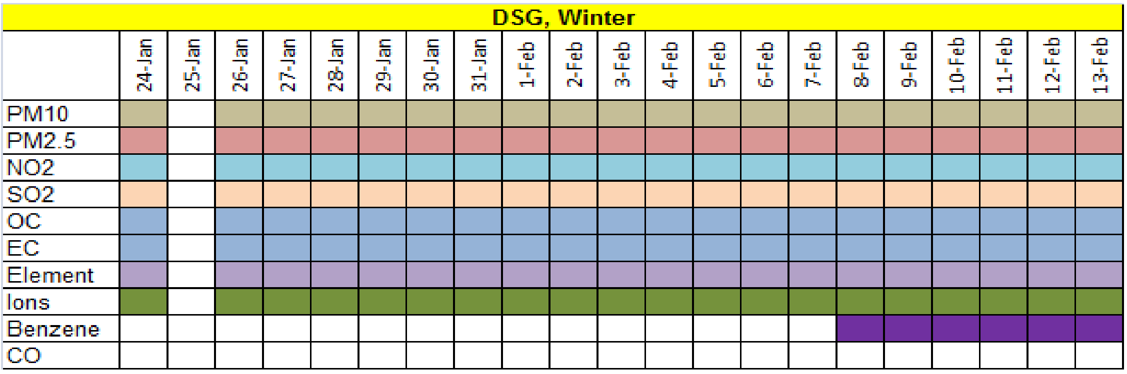
	DWK, Winter																				
	2-Dec	3-Dec	4-Dec	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.7(d): Sampling Days of Various Pollutants in Winter (2013-14) at VKJ



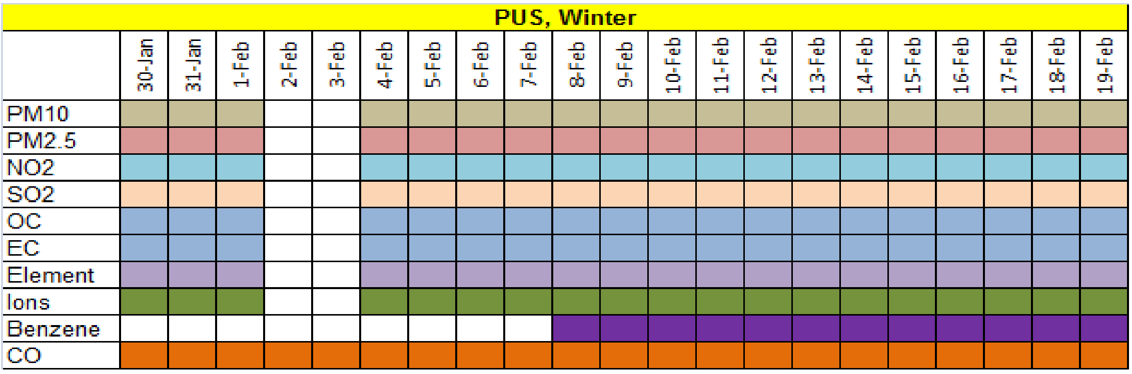
	VKJ, Winter																				
	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec	1-Jan	2-Jan	3-Jan	4-Jan
PM10	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
NO2		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO																					

Table 2.8(e): Sampling Days of Various Pollutants in Winter (2013-14) at DSG



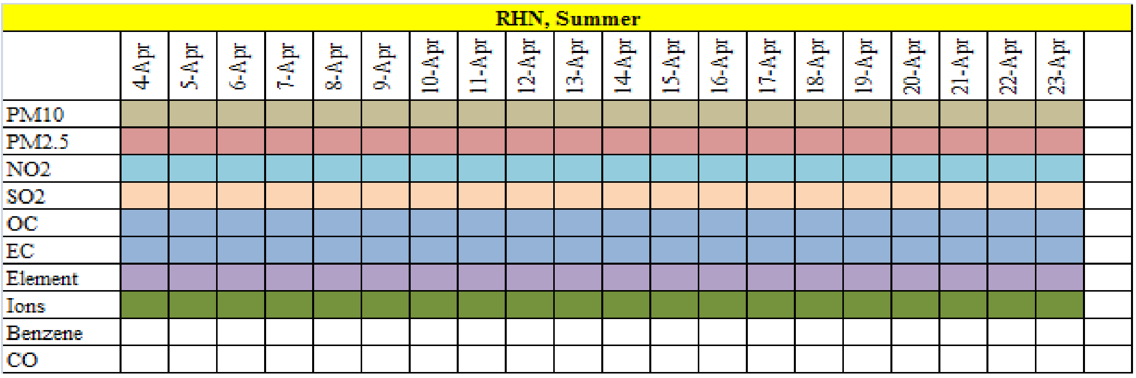
	DSG, Winter																				
	24-Jan	25-Jan	26-Jan	27-Jan	28-Jan	29-Jan	30-Jan	31-Jan	1-Feb	2-Feb	3-Feb	4-Feb	5-Feb	6-Feb	7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb
PM10	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																■	■	■	■	■	■
CO																					

Table 2.9(f): Sampling Days of Various Pollutants in Winter (2013-14) at PUS



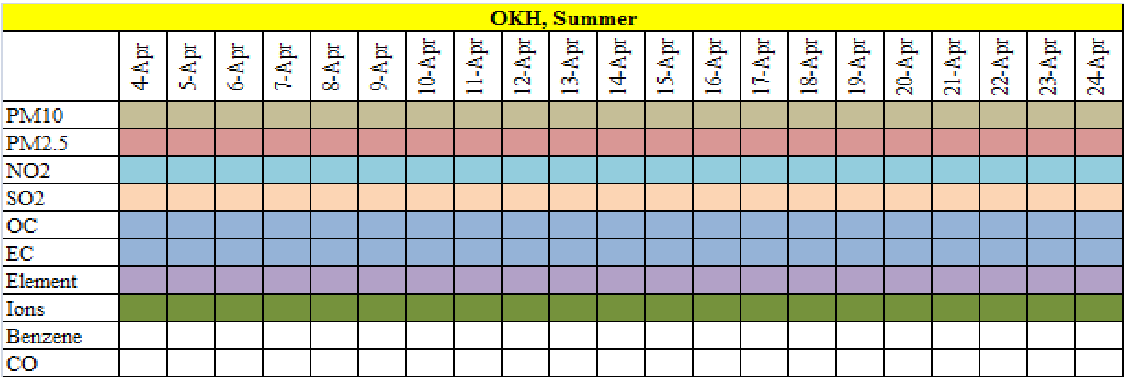
	PUS, Winter																				
	30-Jan	31-Jan	1-Feb	2-Feb	3-Feb	4-Feb	5-Feb	6-Feb	7-Feb	8-Feb	9-Feb	10-Feb	11-Feb	12-Feb	13-Feb	14-Feb	15-Feb	16-Feb	17-Feb	18-Feb	19-Feb
PM10	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene										■	■	■	■	■	■	■	■	■	■	■	■
CO	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.10(a): Sampling Days of Various Pollutants in Summer (2014) at RHN



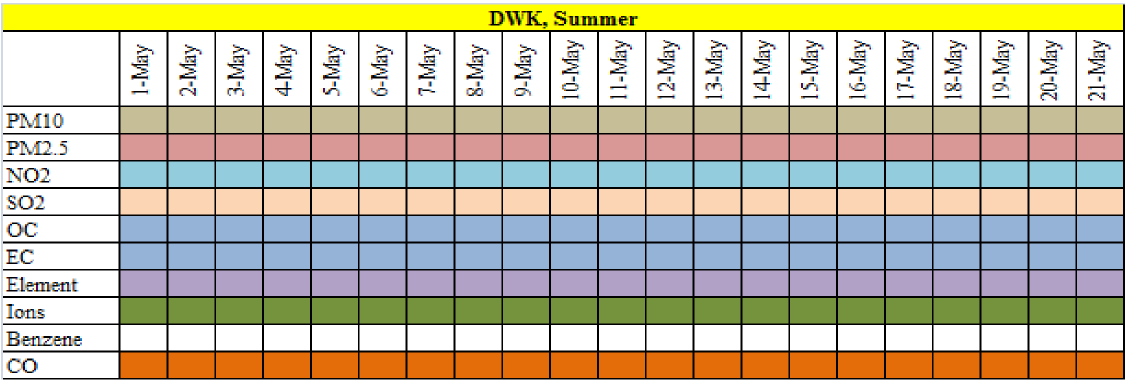
RHN, Summer																					
	4-Apr	5-Apr	6-Apr	7-Apr	8-Apr	9-Apr	10-Apr	11-Apr	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Benzene																					
CO																					

Table 2.11(b): Sampling Days of Various Pollutants in Summer (2014) at OKH



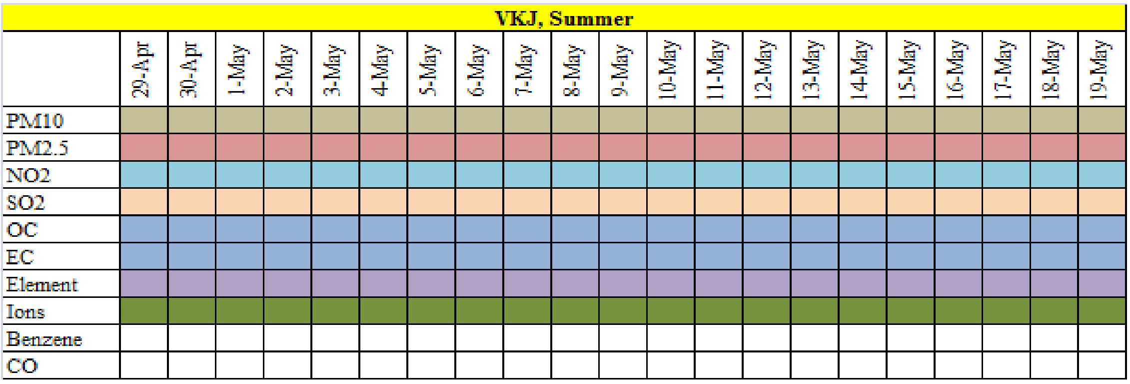
OKH, Summer																					
	4-Apr	5-Apr	6-Apr	7-Apr	8-Apr	9-Apr	10-Apr	11-Apr	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO																					

Table 2.12(c): Sampling Days of Various Pollutants in Summer (2014) at DWK



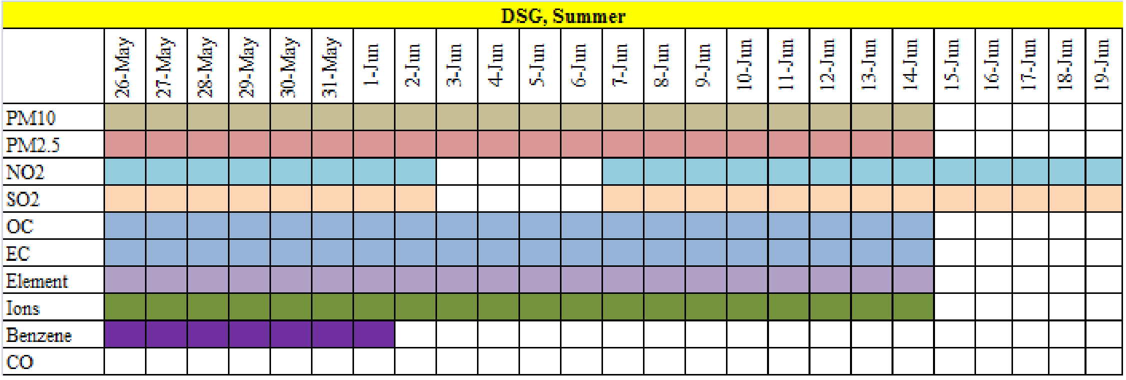
DWK, Summer																					
	1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May	9-May	10-May	11-May	12-May	13-May	14-May	15-May	16-May	17-May	18-May	19-May	20-May	21-May
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.13(d): Sampling Days of Various Pollutants in Summer (2014) at VKJ



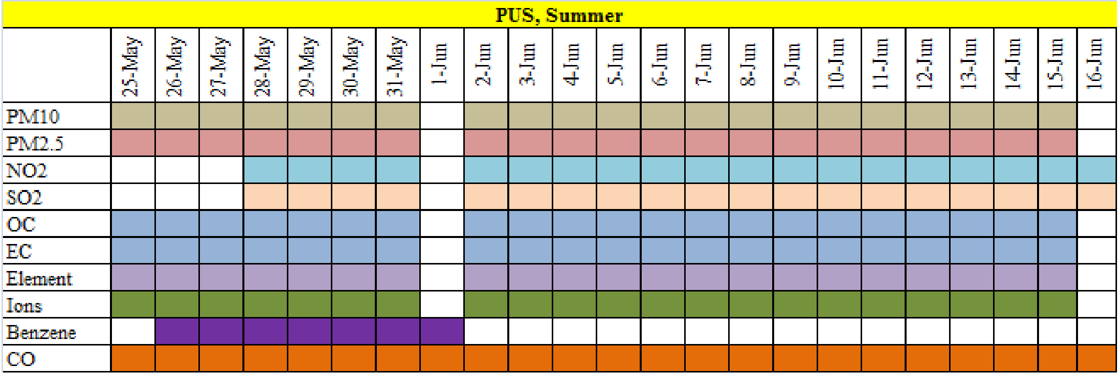
VKJ, Summer																					
	29-Apr	30-Apr	1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May	9-May	10-May	11-May	12-May	13-May	14-May	15-May	16-May	17-May	18-May	19-May
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Benzene																					
CO																					

Table 2.14(e): Sampling Days of Various Pollutants in Summer (2014) at DSG



DSG, Summer																									
	26-May	27-May	28-May	29-May	30-May	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun
PM10	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
PM2.5	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
NO2	■	■	■	■	■	■	■	■					■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■					■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
EC	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Element	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Ions	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■					
Benzene	■	■	■	■	■	■	■																		
CO																									

Table 2.15(f): Sampling Days of Various Pollutants in Summer (2014) at PUS



PUS, Summer																							
	25-May	26-May	27-May	28-May	29-May	30-May	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun
PM10	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
PM2.5	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
NO2				■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2				■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
OC	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
EC	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Element	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Ions	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
Benzene		■	■	■	■	■	■	■															
CO	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

2.4 Ambient Air Quality - Results

2.4.1 Delhi Technical University, Rohini (RHN)

The sampling period for winter was November 03- 23, 2013 and for summer it was April 04-23, 2014.

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

For sampling of PM_{10} and $PM_{2.5}$, the developed SOPs were followed. As a part of QA/QC, 20% of PM-laden filters (of PM_{10} and $PM_{2.5}$) were reconditioned for 24 hrs and reweighed. The variation in the concentration was less than 5%, which was acceptable.

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.5) and summer (Figure 2.6). Average levels for winter and summer season were 438 and 323 µg/m^3 (for $PM_{2.5}$) and 622 and 534 µg/m^3 (for PM_{10}) respectively; nearly six times higher than national standards. The air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although winter conditions provide low dispersion and high concentrations, the levels of PM_{10} and $PM_{2.5}$ are alarmingly high. It is to be noted that on Diwali day (November

3, 2013), the concentration 655 (for $PM_{2.5}$) and 894 (for PM_{10}) in µg/m^3 were indeed extremely high. A statistical summary of PM concentrations is presented in Table 2.6 (c), (d), (e) and (f) for winter and summer season. In summer, PM_{10} and $PM_{2.5}$ levels drop (in a statistical sense at most sites) but continue to be very high in spite of improvement in meteorology and better dispersion.

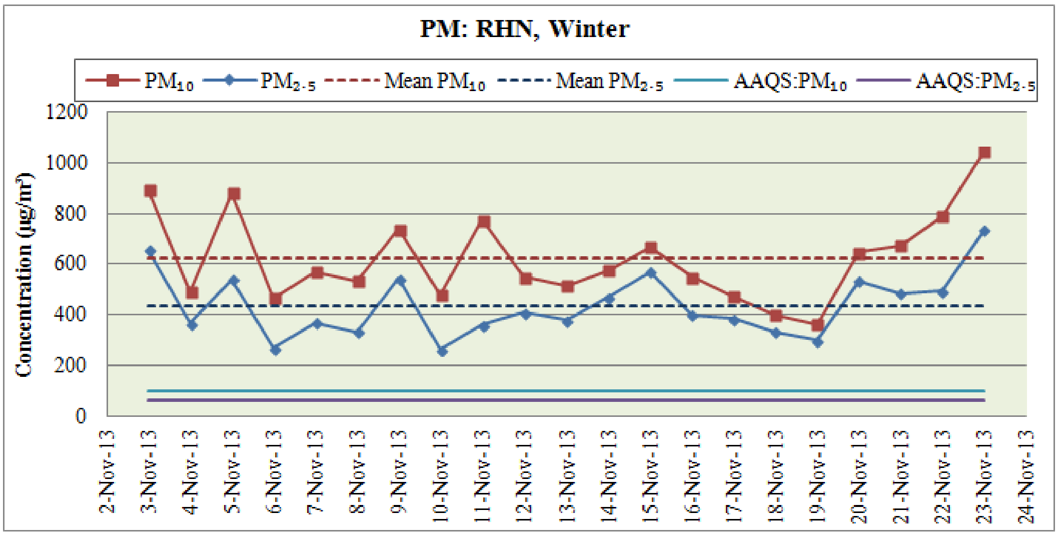


Figure 2.5: PM Concentrations at RHN for Winter Season

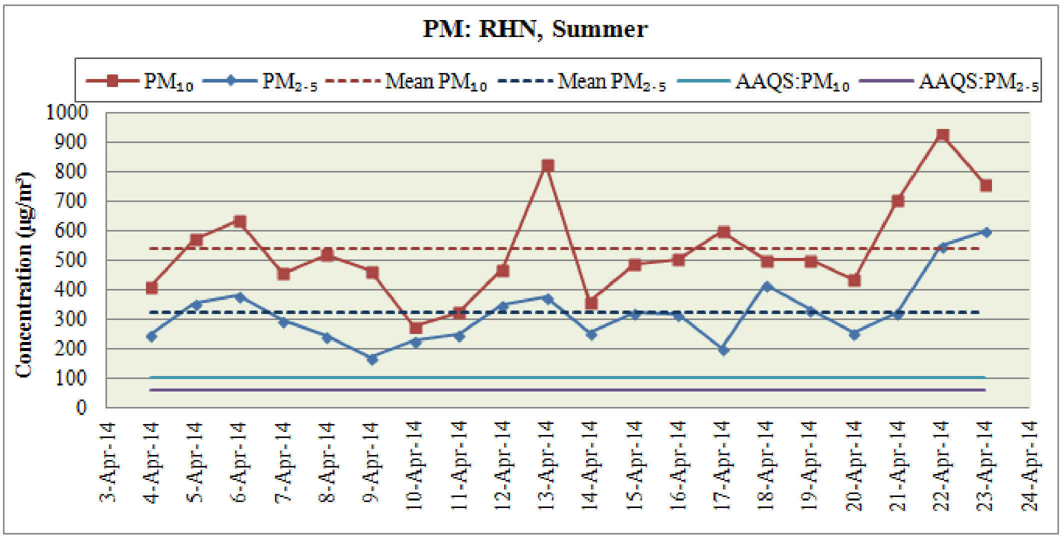


Figure 2.6: PM Concentrations at RHN for Summer Season

2.4.1.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.7) and summer (Figure 2.8) seasons. It was observed that SO_2 concentrations were low and meets the air quality standard. However, on Diwali day, a peak concentration of 28 µg/m^3 was observed, which is about 3 times higher than normal values. NO_2 levels exceed the air quality standard on 5 days in winter with an average of 20 days at 69 µg/m^3 for winter and 40 µg/m^3 for summer season (Table 2.6(c), (e)). The summer concentration of NO2 dropped dramatically – in much larger proportion than did the PM levels. The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets, traffic jams or local open burning etc.

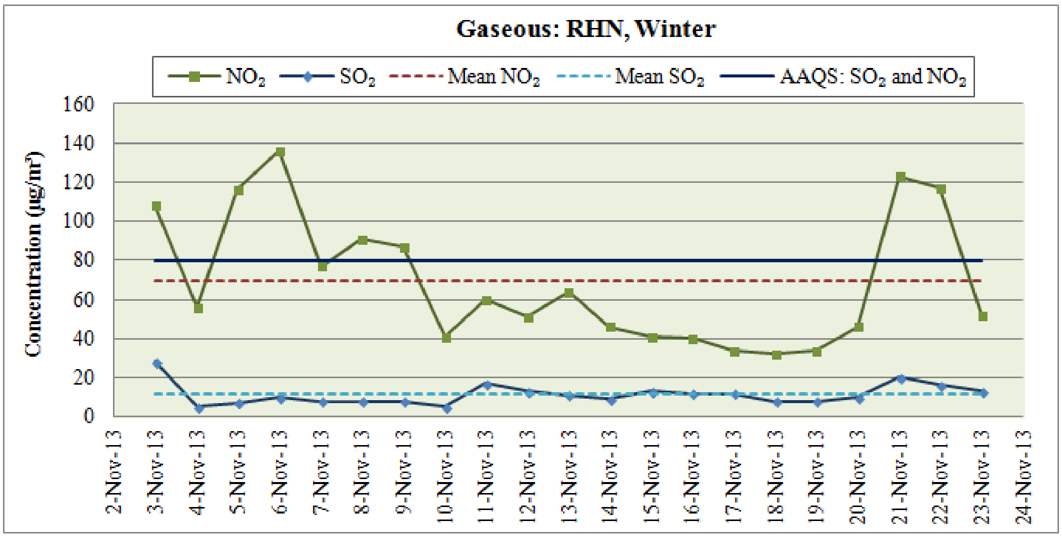


Figure 2.7: SO_2 and NO_2 Concentrations at RHN for Winter Season

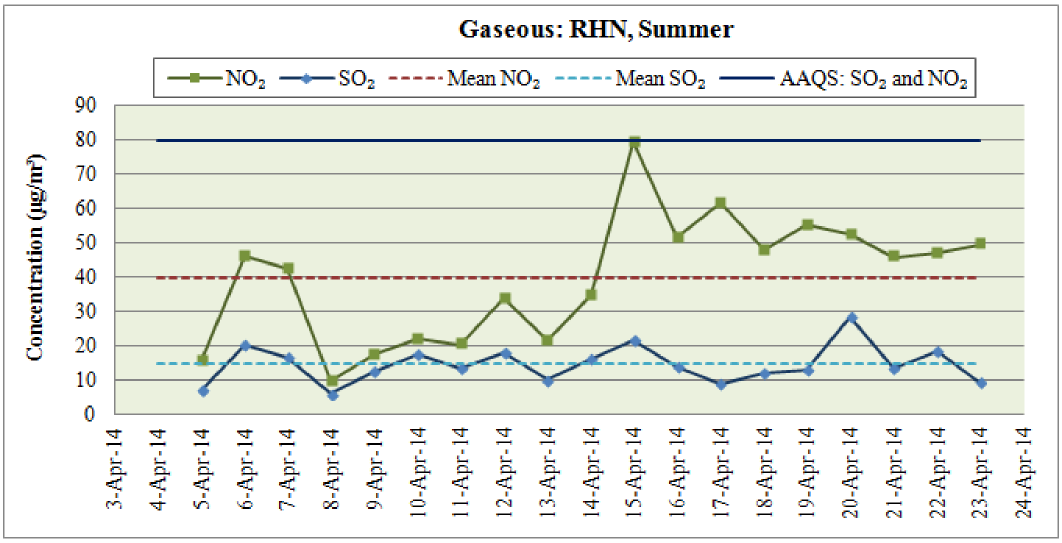


Figure 2.8: SO_2 and NO_2 Concentrations at RHN for Summer Season

2.4.1.3 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs (from solid phase only) with some specific markers were measured for winter and summer seasons. Figure 2.9 shows the measured concentration of PAHs at RHN. A statistical summary of PAHs is presented in Table 2.6 (a) for winter and summer seasons. The PAHs compounds analyzed were: (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAHs concentrations are much higher in winter season (133 ng/m^3) compared to summer season (18 ng/m^3). Major PAHs are B(ghi)P (28 ng/m^3), InP (26 ng/m^3), B(b)F (21 ng/m^3) and Chr ((13 ng/m^3) for winter season and B(ghi)P (4 ng/m^3), InP (3 ng/m^3), B(b)F (3.8 ng/m^3) and Phe (2.3 ng/m^3) for summer season.

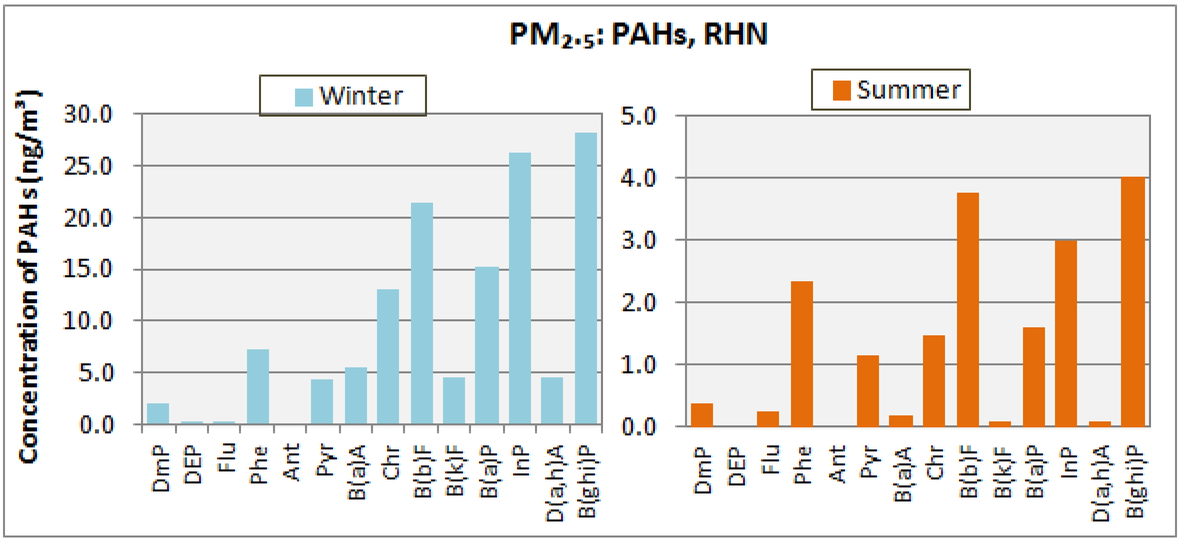


Figure 2.9: PAHs Concentrations in $PM_{2.5}$ at RHN for Winter and Summer Seasons

2.4.1.4 Elemental and Organic 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 2.10 (a) and (b) for winter and summer seasons. Organic carbon is observed higher (79 µg/m^3) than the elemental carbon (40 µg/m^3). However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at RHN. 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 2.6 (b) for winter and summer seasons.

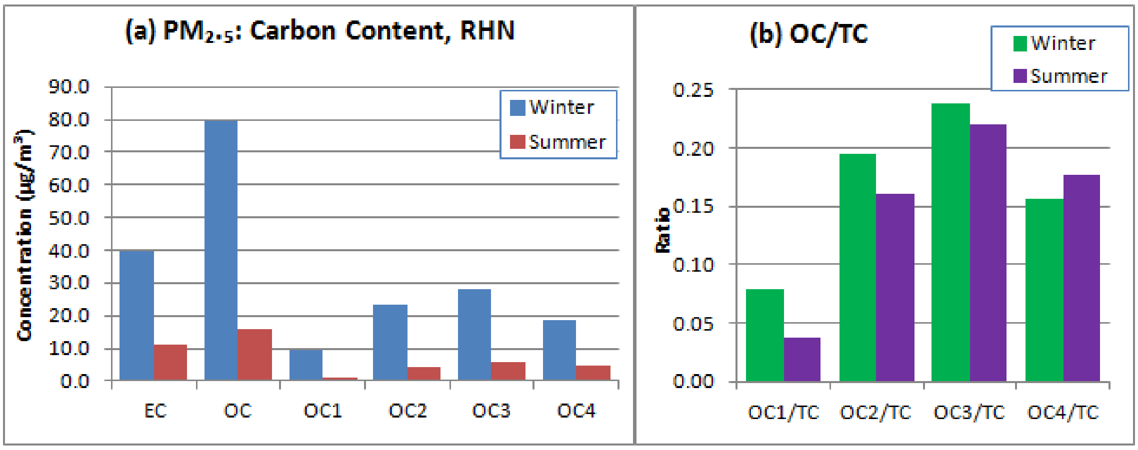


Figure 2.10: EC and OC Content in $PM_{2.5}$ at RHN for Winter and Summer Seasons

2.4.1.5 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 2.11) and $PM_{2.5}$ (Figure 2.12). 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 and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.6 (c), (d), (e) and (f) for winter and summer season.

The correlation between different parameters (i.e PM, NO_2, SO_2, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.6 (g), (h), (i) and (j) 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 2.13 (a) and (b) for winter season and Figure 2.14 (a) and (b) for summer season.

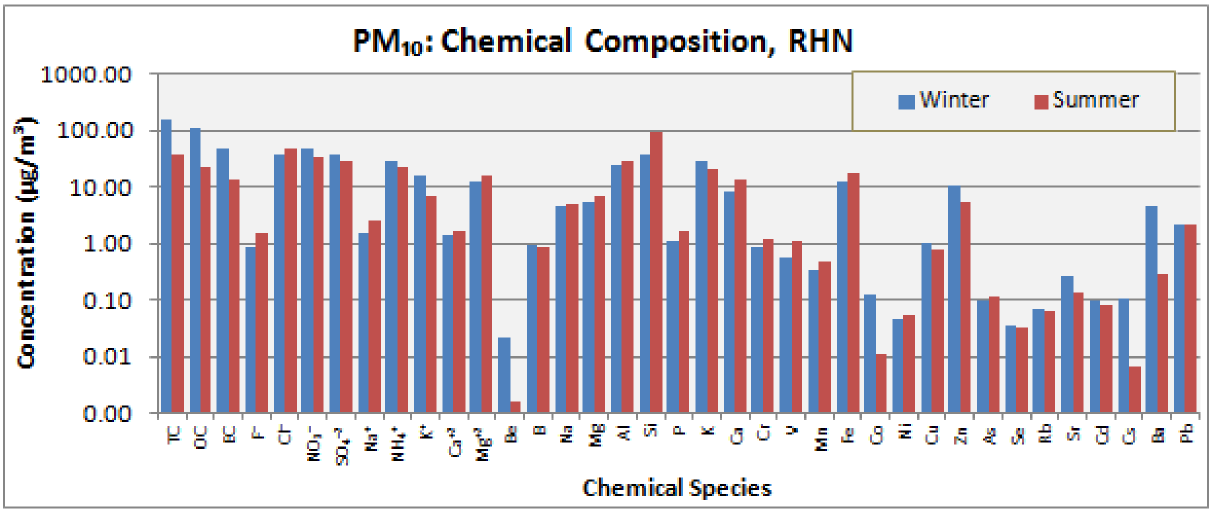


Figure 2.11: Concentrations of species in PM$_{10}$ at RHN for Winter and Summer Seasons

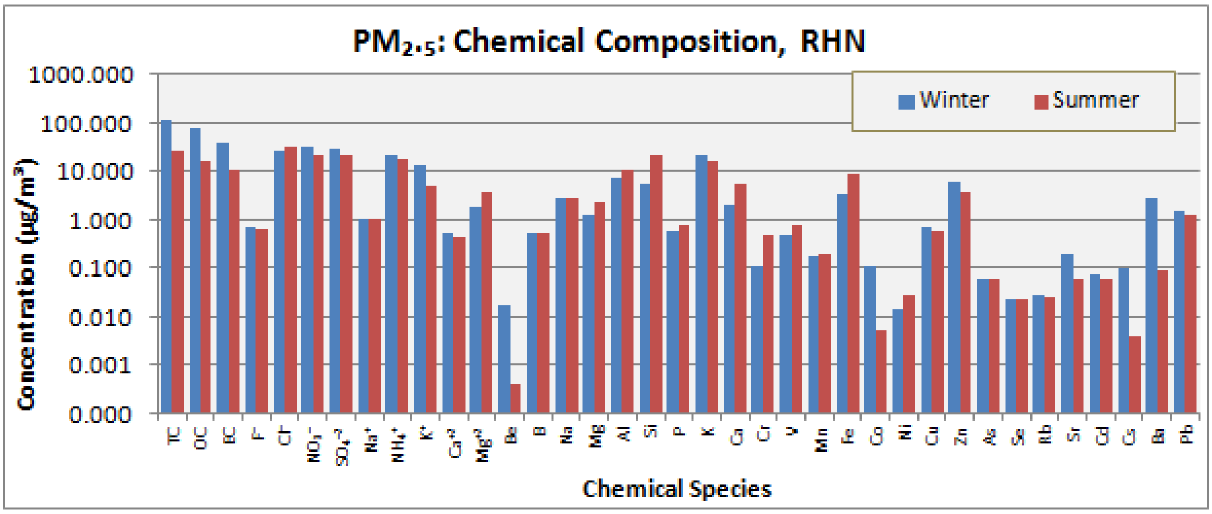
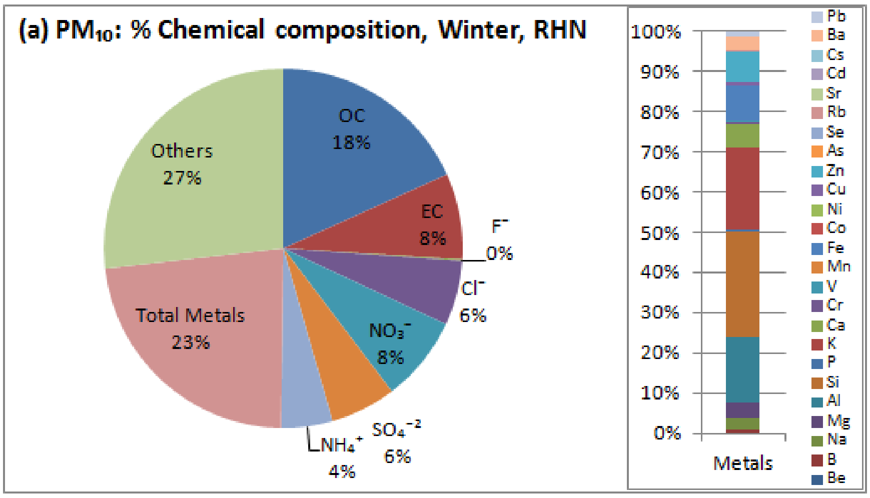


Figure 2.12: Concentrations of species in PM$_{2.5}$ at RHN for Winter and Summer Seasons



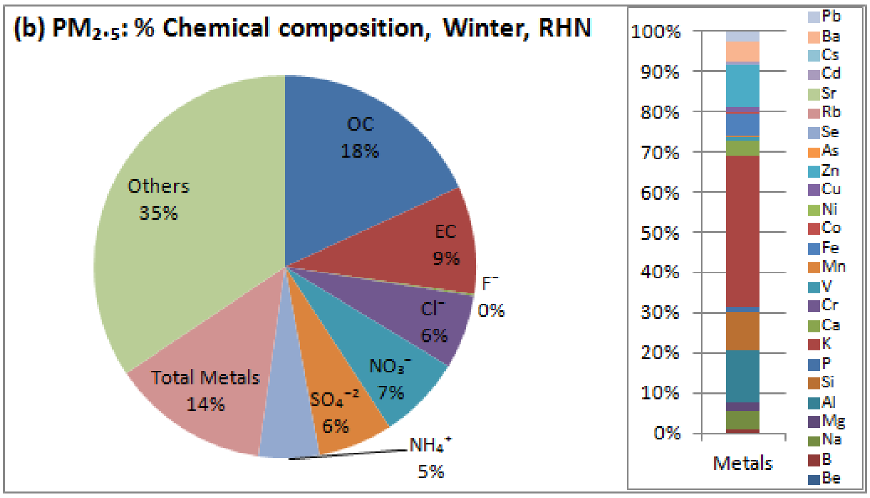


Figure 2.13: Percentage distribution of species in PM at RHN for Winter Season

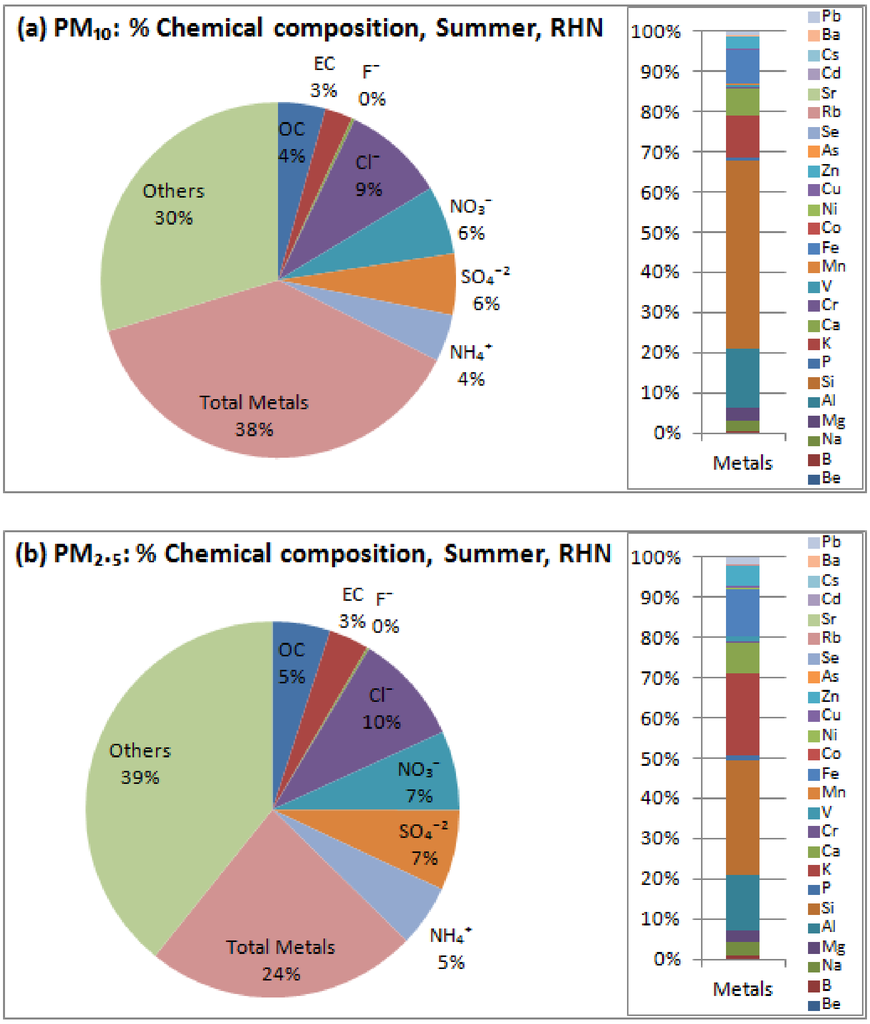


Figure 2.14: Percentage distribution of species in PM at RHN for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. The graphical presentation is the better option for understanding the compositional variation. Compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species are shown for winter season (Figure 2.15) and summer season (figure 2.16) at RHN.

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 (70 %) than summer (60 %). The major species contributing to fine mode are TC, EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Sr, Cd, Cs and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, Fe and Ni.

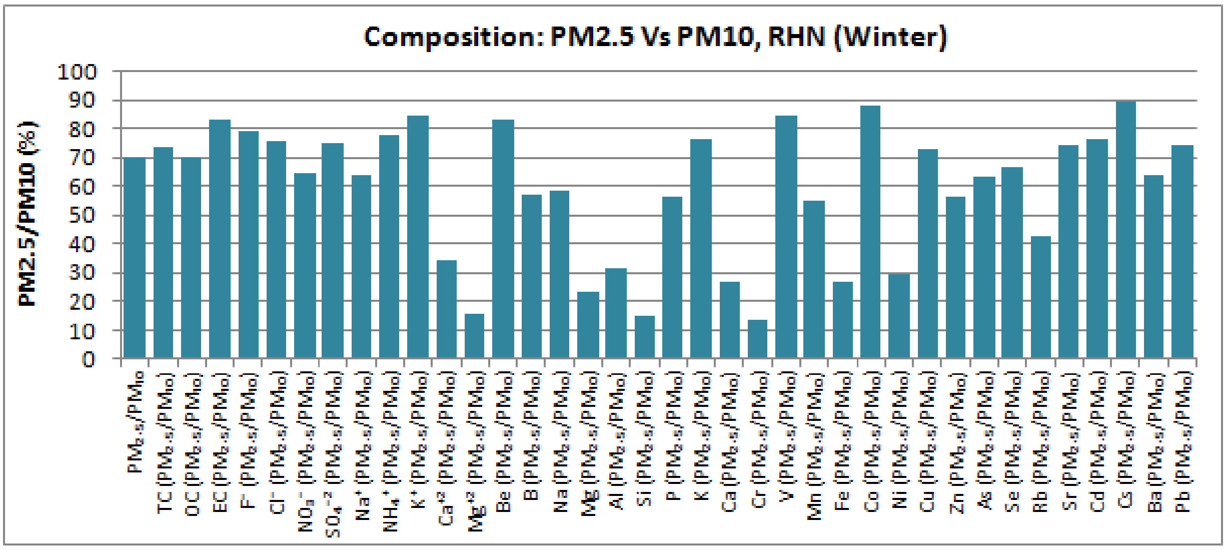


Figure 2.15: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at RHN for Winter Season

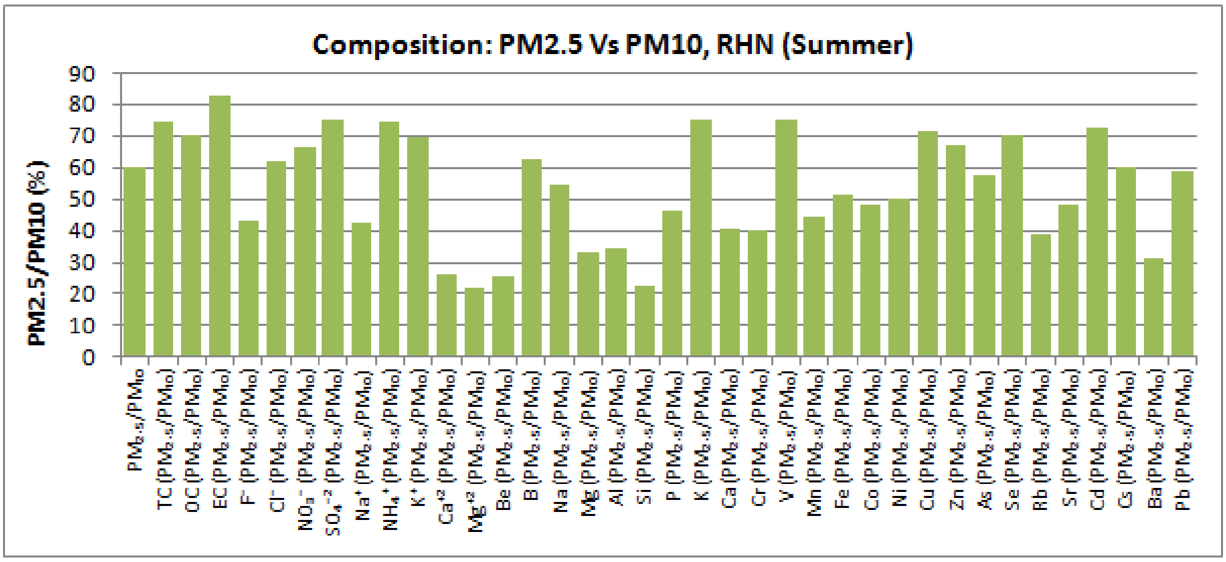


Figure 2.16: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at RHN for Summer Season

Table 2.16(a): Statistical Results of PAHs (ng/m^3) in PM$_{2.5}$ at RHN for Winter (W) and Summer (S) Seasons

RHN(W)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	2.07	0.21	0.25	7.21	0.00	4.44	5.53	13.13	21.38	4.54	15.17	26.26	4.64	28.16	133.00
SD	1.89	0.62	0.27	5.72	0.01	6.57	4.10	8.48	10.64	2.70	6.79	14.79	2.81	15.50	72.84
Max	6.95	1.98	0.67	20.84	0.03	23.03	16.59	36.25	40.43	9.20	26.23	53.91	9.04	57.19	288.51
Min	0.26	0.00	0.00	0.00	0.00	1.18	2.16	5.95	10.75	2.01	7.39	10.49	1.99	10.36	64.41
CV	0.92	2.91	1.08	0.79	3.16	1.48	0.74	0.65	0.50	0.59	0.45	0.56	0.61	0.55	0.55
RHN(S)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	0.37	0.00	0.25	2.34	0.00	1.15	0.18	1.47	3.75	0.08	1.60	3.00	0.07	4.01	18.27
SD	0.22	0.00	0.14	0.60	0.00	0.46	0.29	0.93	2.35	0.19	1.33	2.81	0.21	2.94	11.13
Max	0.68	0.00	0.50	3.64	0.00	1.78	0.89	3.31	7.55	0.62	3.24	7.47	0.67	8.98	35.54
Min	0.02	0.00	0.04	1.50	0.00	0.58	0.00	0.33	0.66	0.00	0.00	0.00	0.00	0.33	5.56
CV	0.61	0.00	0.57	0.26	0.00	0.40	1.60	0.63	0.63	2.58	0.83	0.94	3.12	0.73	0.61

Table 2.17(b): Statistical Results of Carbon Contents (µg/m^3) in PM$_{2.5}$ at RHN for Winter (W) and Summer (S) Seasons

RHN (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	438	119.4	39.9	79.5	9.6	23.4	28.2	18.3	0.079	0.195	0.237	0.156
Max	734	201.9	65.0	137.2	18.5	40.4	50.8	30.3	0.112	0.239	0.287	0.210
Min	261	68.6	23.8	44.8	3.4	12.4	16.7	7.8	0.043	0.173	0.199	0.092
SD	125	32.3	13.3	21.7	4.1	6.9	7.8	5.0	0.020	0.016	0.021	0.034
CV	0.29	0.27	0.33	0.27	0.43	0.30	0.28	0.28	0.252	0.081	0.090	0.218
RHN (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	323	27.2	11.1	16.1	1.0	4.4	5.9	4.8	0.038	0.161	0.221	0.178
Max	598	40.2	19.5	23.9	1.9	7.0	9.5	8.9	0.054	0.192	0.299	0.260
Min	170	15.4	5.8	9.1	0.6	2.6	3.3	2.4	0.019	0.145	0.181	0.115
SD	108	8.2	4.3	4.5	0.4	1.3	1.6	1.7	0.009	0.014	0.032	0.036
CV	0.33	0.30	0.38	0.28	0.43	0.30	0.27	0.35	0.245	0.085	0.147	0.203

Table 2.18(c): Statistical Results of SO_2, NO_2 and Chemical Characterization (μg/m^3) of PM_{10} at RHN for Winter (W) Season

RHN(W)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	622	69	11	113.5	48.1	0.87	36.23	48.08	36.76	1.59	28.83	15.61	1.46	12.40	0.02	0.91	4.66	5.20	23.60	37.18
Max	1043	136	28	196.0	78.3	2.21	117.89	131.01	104.25	3.13	87.77	94.65	5.98	27.58	0.05	1.87	9.72	12.54	138.66	81.99
Min	363	32	5	64.0	28.7	0.30	15.24	18.37	14.45	0.73	8.75	6.48	0.24	4.44	0.00	0.30	1.98	1.02	4.61	11.49
SD	177	34	5	31.1	16.0	0.56	22.59	26.11	24.73	0.77	18.19	18.87	1.30	6.11	0.02	0.44	2.12	2.93	27.98	20.69
CV	0.28	0.48	0.47	0.27	0.33	0.65	0.62	0.54	0.67	0.49	0.63	1.21	0.89	0.49	0.74	0.48	0.45	0.56	1.19	0.56
RHN(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.06	29.01	8.10	0.82	0.56	0.33	12.30	0.12	0.05	1.01	10.92	0.10	0.03	0.07	0.25	0.10	0.11	4.48	2.09	72.4
Max	2.71	159.99	16.98	1.90	1.27	0.67	26.59	0.26	0.17	3.30	39.35	0.24	0.09	0.37	1.74	0.38	0.23	73.66	9.77	91.7
Min	0.34	12.23	2.23	0.28	0.24	0.09	5.32	0.05	0.01	0.12	0.96	0.02	0.01	0.02	0.06	0.01	0.04	0.06	0.16	59.0
SD	0.66	31.48	4.31	0.48	0.34	0.17	6.50	0.07	0.04	0.95	11.67	0.06	0.02	0.07	0.35	0.10	0.07	16.01	2.10	10.4
CV	0.62	1.09	0.53	0.58	0.60	0.50	0.53	0.61	0.82	0.94	1.07	0.67	0.65	1.11	1.38	1.06	0.61	3.57	1.01	0.14
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.19(d): Statistical Results of SO_2, NO_2 and Chemical Characterization (μg/m^3) of $PM_{2.5}$ at RHN for Winter (W) Season

RHN(W)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	438	69	11	79.5	39.9	0.69	27.35	31.11	27.66	1.02	22.47	13.19	0.51	1.93	0.02	0.52	2.72	1.21	7.45	5.70
Max	734	136	28	137.2	65.0	1.93	88.01	103.78	86.56	2.72	73.80	85.10	4.13	4.62	0.04	1.13	6.39	7.57	89.33	14.44
Min	261	32	5	44.8	23.8	0.25	10.10	11.34	12.72	0.32	3.60	4.45	0.13	0.53	0.00	0.15	1.15	0.18	0.54	0.80
SD	125	34	5	21.7	13.3	0.47	16.84	19.73	18.75	0.66	14.96	17.02	0.84	1.34	0.01	0.27	1.27	1.57	18.98	3.97
CV	0.29	0.48	0.47	0.27	0.33	0.69	0.62	0.63	0.68	0.65	0.67	1.29	1.67	0.69	0.76	0.52	0.47	1.30	2.55	0.70
RHN(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.60	22.13	2.15	0.11	0.47	0.18	3.26	0.11	0.01	0.74	6.18	0.06	0.02	0.03	0.19	0.07	0.10	2.88	1.56	65.6
Max	2.19	134.84	4.45	0.43	1.14	0.36	8.70	0.23	0.05	2.56	26.79	0.13	0.05	0.27	1.38	0.35	0.21	49.21	7.62	90.9
Min	0.17	8.74	0.66	0.02	0.20	0.07	0.96	0.04	0.00	0.05	0.55	0.02	0.01	0.01	0.05	0.00	0.04	0.03	0.12	49.7
SD	0.47	26.76	1.01	0.09	0.28	0.10	2.03	0.07	0.01	0.71	6.16	0.04	0.01	0.06	0.28	0.08	0.06	10.72	1.65	12.5
CV	0.78	1.21	0.47	0.76	0.60	0.54	0.62	0.62	0.79	0.96	1.00	0.66	0.56	2.01	1.48	1.14	0.62	3.72	1.06	0.19
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.20(e): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of PM_{10} at RHN for Summer (S) Season

RHN(S)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	536	40	15	23.0	13.4	1.53	49.75	33.36	29.85	2.51	23.06	6.91	1.63	16.30	0.00	0.84	4.88	6.73	30.22	94.94
Max	928	80	28	34.1	23.5	8.14	179.16	61.46	59.83	7.75	60.03	9.95	4.33	44.67	0.00	1.73	8.72	14.40	62.77	183.78
Min	275	10	6	13.0	7.0	0.57	21.44	13.42	12.62	0.66	10.40	4.62	0.16	5.35	0.00	0.24	2.74	2.23	10.60	29.45
SD	166	18	5	6.4	5.1	1.67	35.99	13.82	13.04	1.66	11.60	1.66	1.21	9.33	0.00	0.45	1.56	3.08	12.23	38.43
CV	0.31	0.46	0.37	0.28	0.38	1.09	0.72	0.41	0.44	0.66	0.50	0.24	0.74	0.57	0.51	0.53	0.32	0.46	0.40	0.40
RHN(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.72	20.82	13.62	1.16	1.08	0.46	17.32	0.01	0.06	0.80	5.56	0.11	0.03	0.06	0.13	0.08	0.01	0.28	2.20	72.8
Max	3.74	49.66	35.08	3.49	2.34	1.47	43.88	0.03	0.12	1.84	15.36	0.43	0.07	0.12	0.41	0.24	0.03	0.69	6.01	88.1
Min	0.57	7.42	4.40	0.35	0.59	0.12	4.94	0.00	0.01	0.10	1.08	0.04	0.01	0.02	0.04	0.01	0.00	0.08	0.54	45.1
SD	0.75	11.97	6.89	0.67	0.45	0.29	10.54	0.01	0.03	0.52	3.41	0.08	0.01	0.02	0.08	0.06	0.01	0.15	1.23	13.1
CV	0.44	0.57	0.51	0.58	0.42	0.62	0.61	0.70	0.49	0.64	0.61	0.75	0.38	0.36	0.62	0.73	1.27	0.55	0.56	0.18
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.21(f): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of $PM_{2.5}$ at RHN for Summer (S) Season

RHN(S)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	323	40	15	16.1	11.1	0.66	30.92	22.12	22.41	1.07	17.23	4.80	0.43	3.58	0.00	0.52	2.65	2.25	10.48	21.59
Max	598	80	28	23.9	19.5	1.93	110.67	45.97	42.54	2.24	42.39	8.03	1.73	9.52	0.00	1.61	4.27	6.83	30.25	58.97
Min	170	10	6	9.1	5.8	0.32	10.56	8.69	6.67	0.26	2.76	1.83	0.03	0.26	0.00	0.03	1.13	0.34	1.66	4.58
SD	108	18	5	4.5	4.3	0.40	23.22	10.07	10.66	0.57	8.31	1.52	0.45	2.88	0.00	0.42	0.96	1.75	7.83	15.47
CV	0.33	0.46	0.37	0.28	0.38	0.61	0.75	0.46	0.48	0.53	0.48	0.32	1.05	0.80	0.77	0.80	0.36	0.78	0.75	0.72
RHN(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.80	15.65	5.52	0.47	0.81	0.21	8.89	0.01	0.03	0.57	3.73	0.06	0.02	0.02	0.06	0.06	0.00	0.09	1.29	62.8
Max	1.57	31.57	12.00	1.24	2.12	0.51	33.97	0.02	0.09	1.64	6.69	0.14	0.06	0.06	0.27	0.23	0.03	0.24	3.13	93.5
Min	0.30	5.58	0.77	0.09	0.42	0.03	0.81	0.00	0.01	0.03	1.03	0.03	0.01	0.01	0.01	0.01	0.00	0.01	0.35	43.7
SD	0.35	7.81	3.19	0.31	0.42	0.12	8.01	0.01	0.02	0.43	1.93	0.02	0.01	0.02	0.07	0.05	0.01	0.07	0.76	14.2
CV	0.44	0.50	0.58	0.66	0.52	0.60	0.90	1.13	0.76	0.74	0.52	0.39	0.48	0.63	1.07	0.89	2.09	0.84	0.59	0.23
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.22(g): Correlation Matrix for PM_{10} and its composition for Winter (W) Season

RHN (W)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.39	0.51	0.66	0.58	0.66	0.57	0.76	0.64	0.70	0.59	0.64	0.50	0.38	0.40	0.65
TC		0.46	0.19	1.00	0.96	0.85	0.30	0.23	0.13	0.09	0.14	0.19	0.19	0.19	0.27	0.26
OC		0.42	0.12		1.00	0.68	0.27	0.18	0.05	0.04	0.07	0.15	0.15	0.21	0.17	0.16
EC		0.45	0.29			1.00	0.28	0.29	0.24	0.18	0.23	0.24	0.23	0.11	0.40	0.39
NO_3^-		0.04	0.08				0.59	0.81	1.00	0.54	0.69	0.85	0.01	0.03	0.48	0.26
SO_4^{-2}		0.30	0.58				0.53	0.63		1.00	0.47	0.49	0.76	0.58	0.26	0.83
NH_4^+		-0.10	-0.02				0.78	0.88			0.55	1.00	-0.05	-0.13	0.53	0.24
Metals		0.33	0.71				0.40	0.46			0.51		0.86	0.61	0.41	1.00

Table 2.23(h): Correlation Matrix for $PM_{2.5}$ and its composition for Winter (W) Season

RHN (W)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.16	0.49	0.46	0.31	0.61	0.50	0.77	0.59	0.72	0.68	0.59	0.54	0.43	-0.32	0.52
TC		0.47	0.20	1.00	0.95	0.87	0.18	0.23	0.20	0.14	0.05	0.16	0.20	0.14	-0.19	0.13
OC		0.42	0.12		1.00	0.68	0.17	0.15	0.10	0.04	-0.02	0.08	0.15	0.09	-0.15	0.09
EC		0.45	0.29			1.00	0.15	0.32	0.32	0.27	0.14	0.24	0.23	0.19	-0.23	0.18
NO_3^-		-0.01	0.07				0.39	0.81	1.00	0.36	0.62	0.84	-0.10	-0.21	-0.10	-0.07
SO_4^{-2}		0.31	0.63				0.44	0.63		1.00	0.50	0.38	0.82	0.75	-0.26	0.82
NH_4^+		-0.09	-0.09				0.70	0.86			0.60	1.00	-0.11	-0.25	-0.04	-0.08
Metals		0.21	0.70				0.15	0.31			0.33		0.98	0.96	-0.11	1.00

Table 2.24(i): Correlation Matrix for PM_{10} and its composition for Summer (S) Season

RHN (S)	PM_{10}	NO_2	SO_2	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	-0.22	-0.32	-0.29	-0.32	0.17	0.03	0.33	0.41	0.45	0.03	0.73	0.40	0.52	0.80
TC		0.23	0.18	1.00	0.95	0.93	-0.07	0.15	-0.63	0.08	-0.01	0.05	-0.06	-0.45	-0.31	-0.13
OC		0.19	0.21		1.00	0.77	-0.09	0.19	-0.55	0.06	0.08	0.10	0.02	-0.34	-0.27	-0.15
EC		0.24	0.13			1.00	-0.04	0.09	-0.65	0.08	-0.12	-0.02	-0.16	-0.54	-0.33	-0.08
NO_3^-		-0.10	-0.09				0.49	-0.16	1.00	0.45	0.46	0.06	0.37	0.58	0.71	0.32
SO_4^{-2}		0.37	0.13				0.73	-0.35		1.00	0.70	-0.15	0.47	-0.01	0.68	0.70
NH_4^+		-0.43	-0.39				-0.06	0.91			-0.10	1.00	0.20	0.07	-0.14	-0.25
Metals		0.33	0.09				0.39	-0.29			0.42		0.64	0.17	0.64	1.00

Table 2.25(j): Correlation Matrix for $PM_{2.5}$ and its composition for Summer Season

RHN (S)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.26	-0.04	0.02	0.10	-0.07	0.38	0.16	0.27	0.38	0.05	0.25	0.47	-0.20	0.11	0.71
TC		0.23	0.18	1.00	0.94	0.94	-0.24	0.21	-0.60	0.12	-0.10	0.18	0.31	-0.29	0.10	0.17
OC		0.19	0.21		1.00	0.77	-0.24	0.29	-0.54	0.03	-0.17	0.26	0.34	-0.30	0.04	0.21
EC		0.24	0.13			1.00	-0.20	0.11	-0.58	0.20	-0.01	0.07	0.25	-0.25	0.14	0.10
NO_3^-		-0.08	-0.04				0.59	-0.15	1.00	0.45	0.42	0.11	0.23	0.29	-0.02	-0.13
SO_4^{-2}		0.48	0.29				0.75	-0.45		1.00	0.58	-0.20	0.61	-0.11	0.12	-0.04
NH_4^+		-0.38	-0.25				-0.17	0.92			-0.16	1.00	0.26	0.26	-0.19	0.15
Metals		0.25	-0.14				-0.08	0.22			-0.30		0.21	-0.31	0.24	1.00

2.4.2 Envrirotech, Okhla (OKH)

The sampling period for winter was November 03 - 23, 2013 and April 04 - 24, 2014 for the summer Season.

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

For sampling PM_{10} and $PM_{2.5}$, the developed SOPs were followed. As a part of QA/QC, 20% of PM-laden filters (of PM_{10} and $PM_{2.5}$) were reconditioned for 24 hrs and reweighed. The variation in the concentration was less than 5%, which was acceptable.

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.17) and summer (Figure 2.18). Average levels for winter and summer seasons are 433 and 412 µg/m^3 (for $PM_{2.5}$) and 721 and 635 µg/m^3 (for PM_{10}) respectively. The air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although winter conditions provide low dispersion and high concentrations, the levels of PM_{10} and $PM_{2.5}$ even in summer are alarmingly high. It is to be noted that the Diwali day (November 3, 2013) shows the concentration 882 (for $PM_{2.5}$) and 1183 (for PM_{10}) µg/m^3 which is about twice of normal concentration. A statistical summary of PM concentrations is presented in Table 2.7 (c), (d), (e) and (f) for winter and summer seasons.

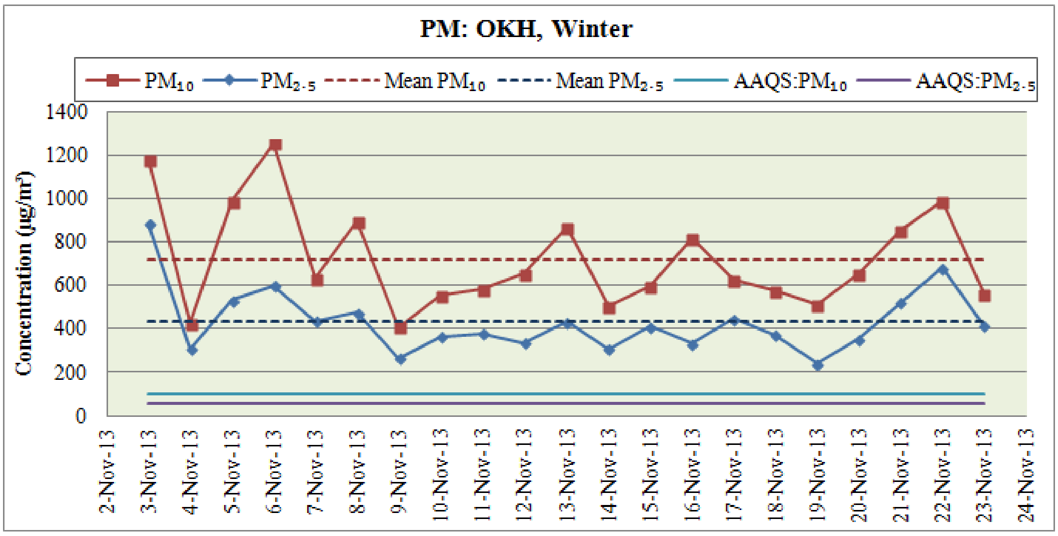


Figure 2.17: PM Concentrations at OKH for Winter Season

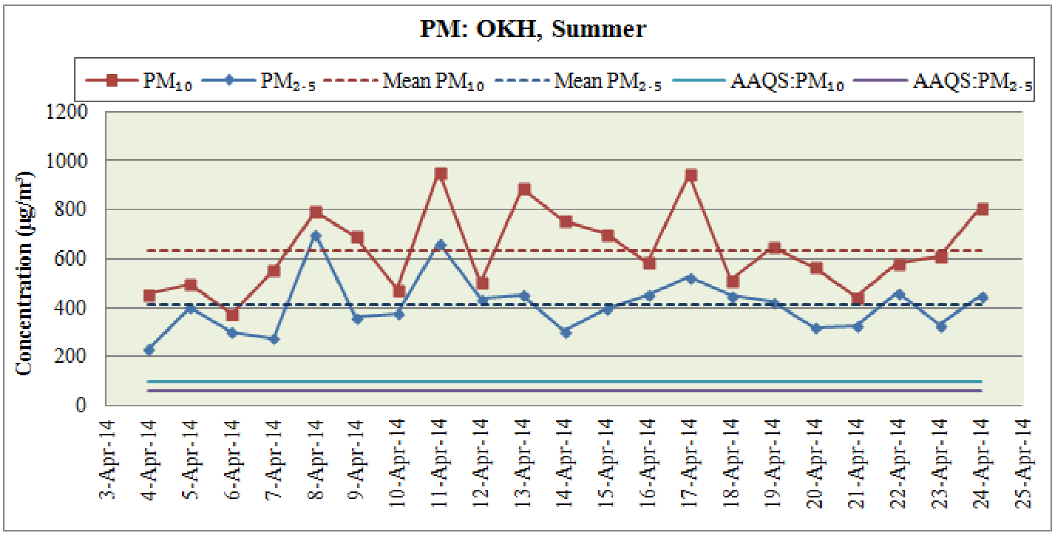


Figure 2.18: PM Concentrations at OKH for Summer Season

2.4.2.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

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). It was observed that SO_2 concentrations were low and meet the air quality standard. However, on Diwali day, a peak concentration of 55 µg/m^3 was observed, which is about 3 times higher than normal values. NO_2 levels exceed the air quality standard. The average NO_2 concentration at OKH was 101 µg/m^3 for winter and 74 µg/m^3 for summer season (Table 2.7(c), (e)). The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. The NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets or open burning etc.

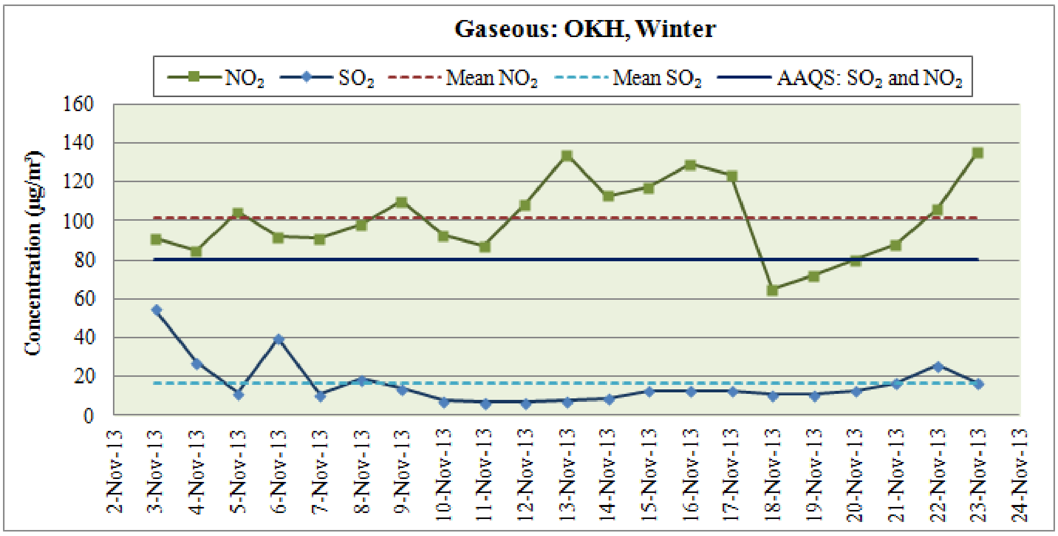


Figure 2.19: SO_2 and NO_2 Concentrations at OKH for Winter Season

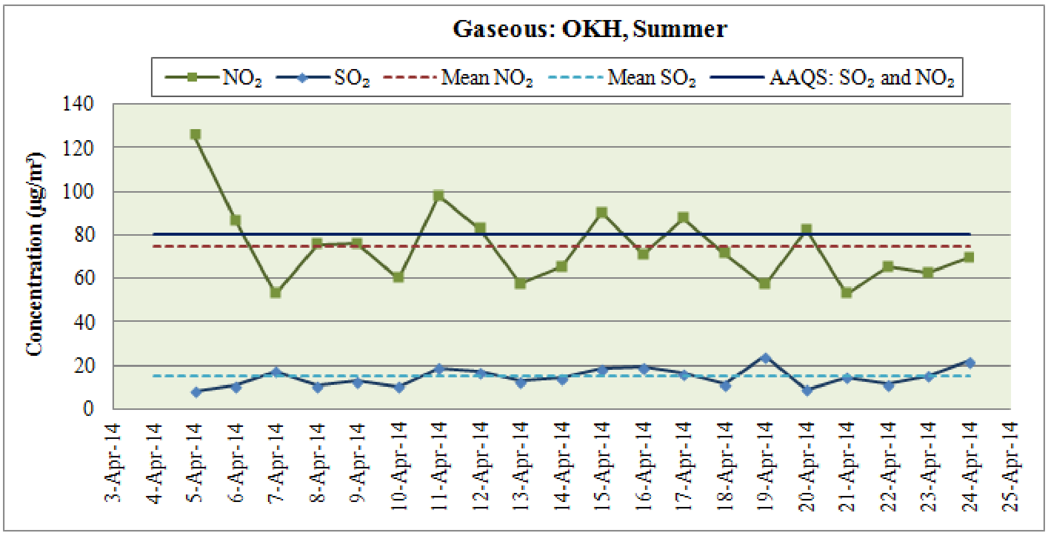


Figure 2.20: SO_2 and NO_2 Concentrations at OKH for Summer Season

2.4.2.3 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs with some specific markers were measured in winter and summer seasons (Figure 2.21) The PAHs compounds analyzed include: (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAH concentrations are much higher in winter compared to summer season. Major PAHs are B(ghi)P (19 ng/m^3), InP (18 ng/m^3), Phe (7 ng/m^3) and Chr ((13 ng/m^3) for winter season and B(ghi)P (3.4 ng/m^3), B(b)F (3.6 ng/m^3) and Phe (1.7 ng/m^3). The total PAHs were measured much higher in winter (91 ng/m^3) compared to summer (17 ng/m^3). A statistical summary of PAHs concentration is presented in Table 2.7 (a) for winter and summer season.

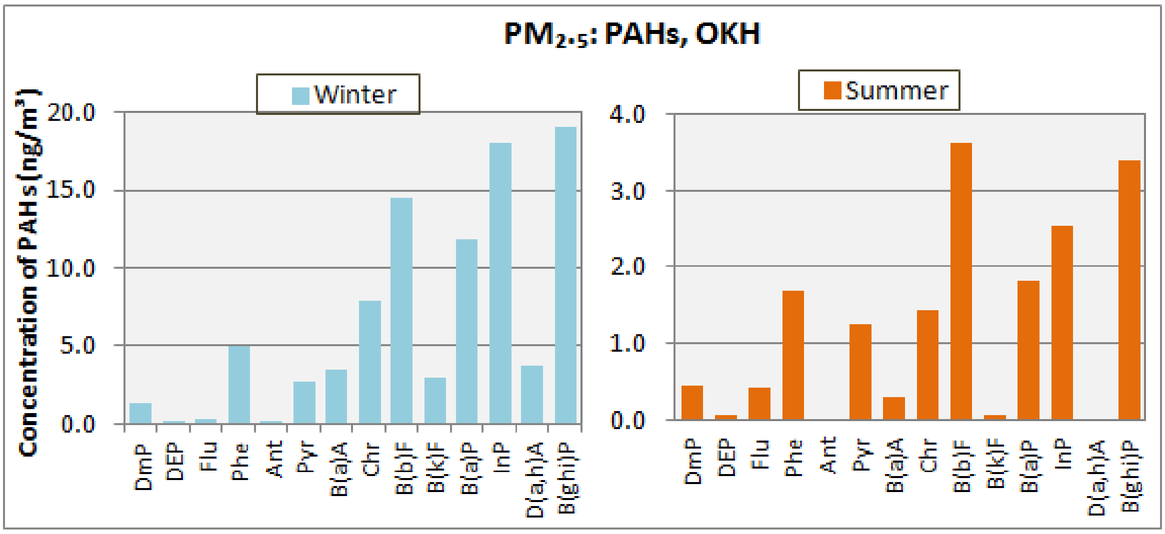


Figure 2.21: PAHs Concentrations in $PM_{2.5}$ at OKH for winter and Summer Seasons

2.4.2.4 Elemental and Organic 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 season. Organic carbon is observed higher than the elemental carbon. However the ratio of OC3/TC is observed higher than other fractions that indicate the formation of secondary organic carbon in atmosphere at OKH. It is also observed that the OC and EC are higher in winter than in summer season. A statistical summary 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 2.7 (b) for winter and summer seasons.

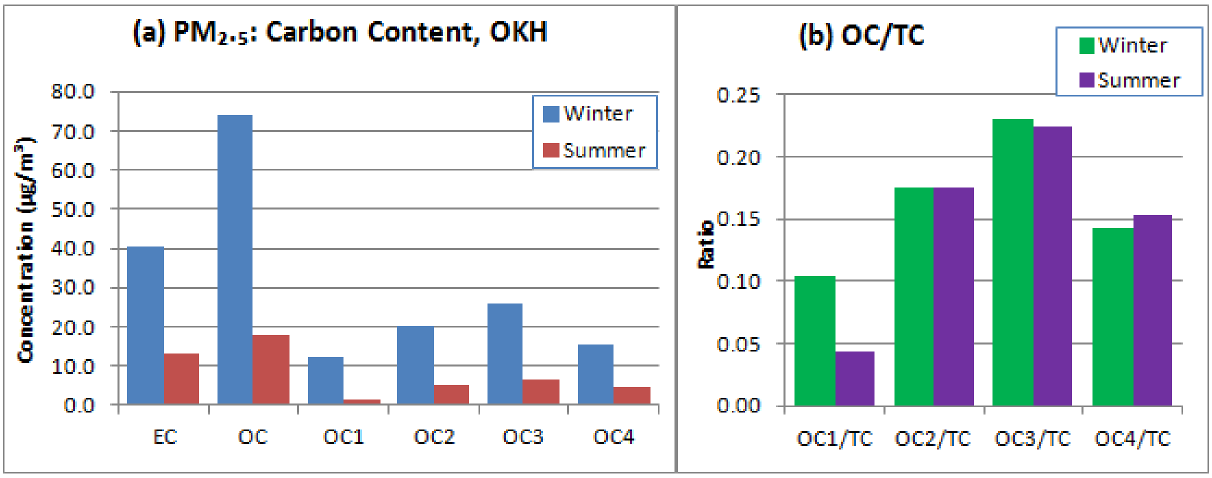


Figure 2.22: EC and OC Content in $PM_{2.5}$ at OKH for Winter and Summer Seasons

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

Graphical presentations of chemical species are shown for winter and summer season for PM_{10} (Figure 2.23) and $PM_{2.5}$ (Figure 2.24). Statistical summary (mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of analysis 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) measured in PM and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.7 (c), (d), (e) and (f) for winter and summer season. The correlation between different parameters (i.e PM, NO_2, SO_2, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.7 (g), (h), (i) and (j) for both the seasons. 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 2.25 (a) and (b) for winter season and Figure 2.26 (a) and (b) for summer season.

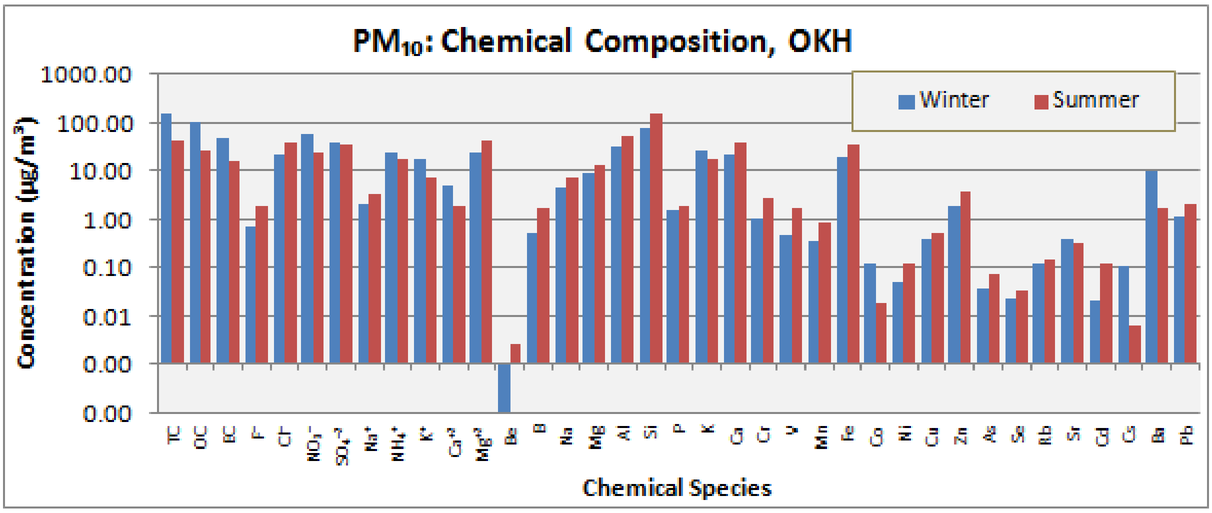


Figure 2.23: Concentrations of species in PM_{10} at OKH for Winter and Summer Season

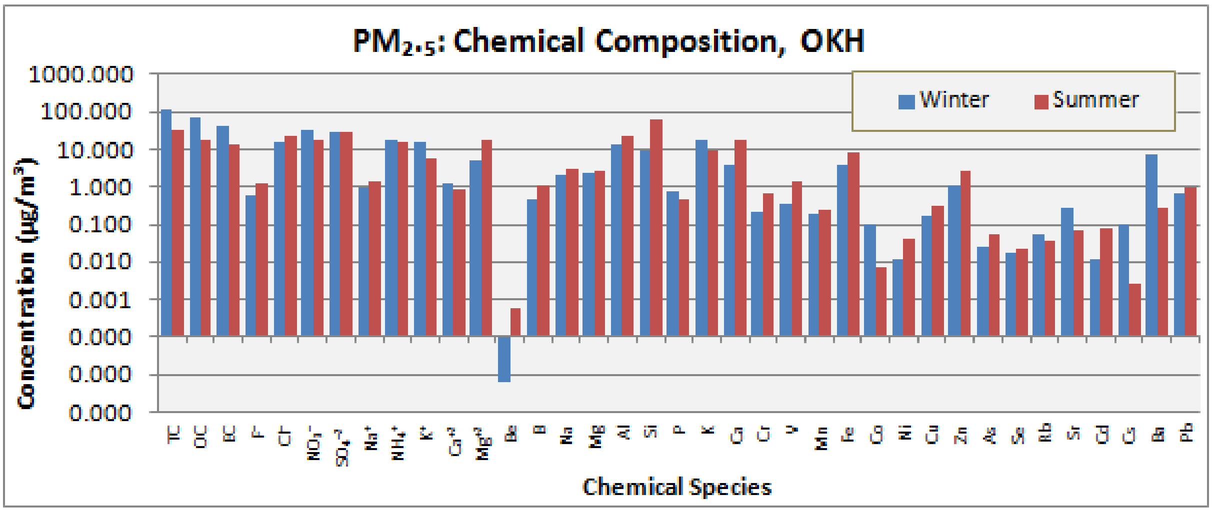


Figure 2.24: Concentrations of species in $PM_{2.5}$ at OKH for Winter and Summer Season

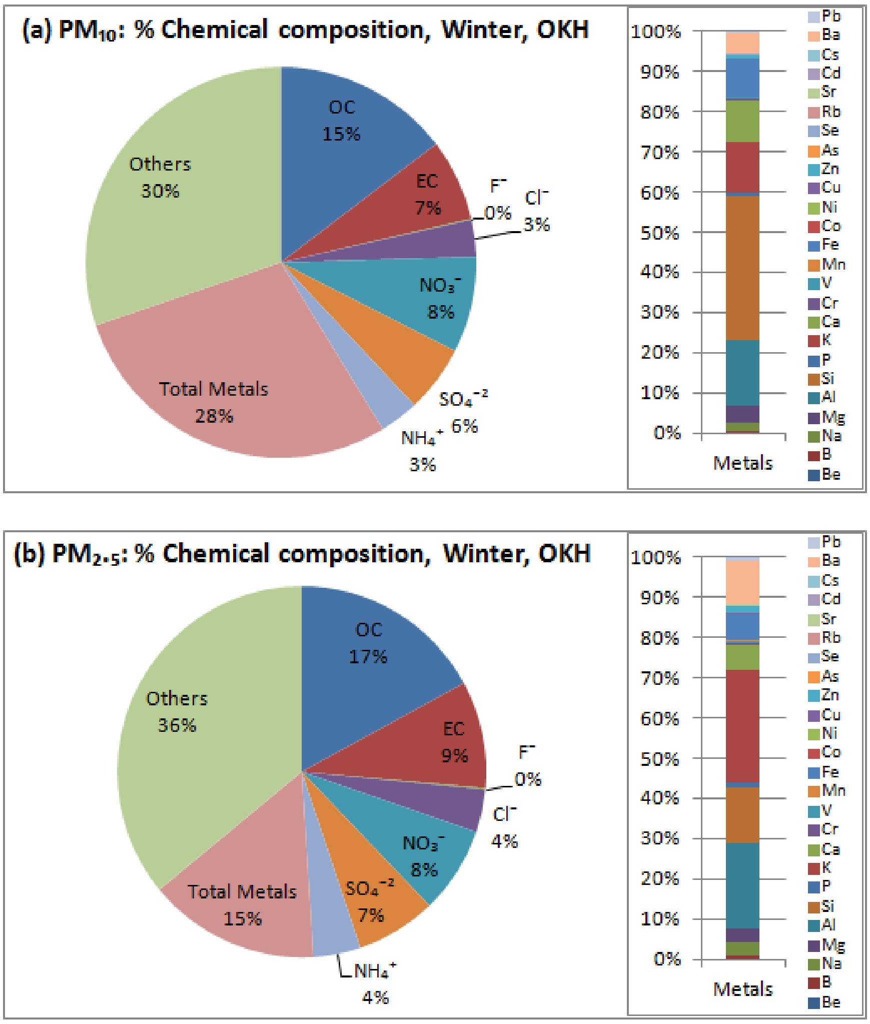
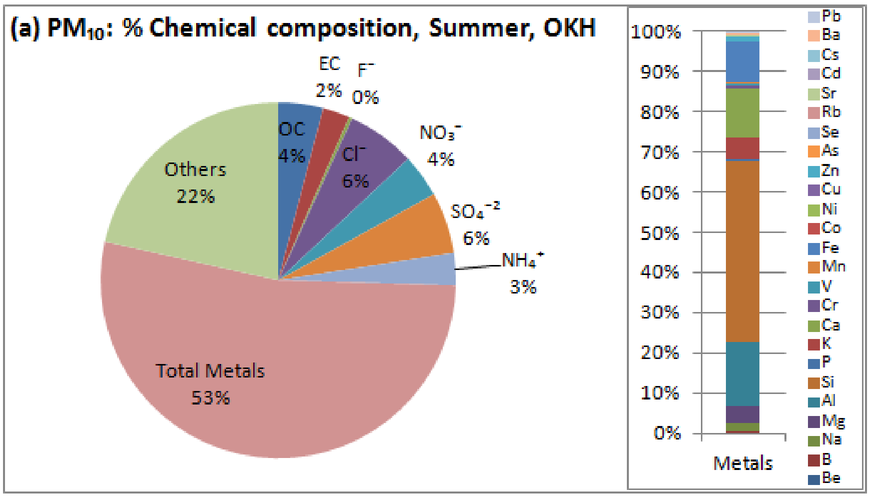


Figure 2.25: Percentage distribution of species in PM at OKH for Winter Season



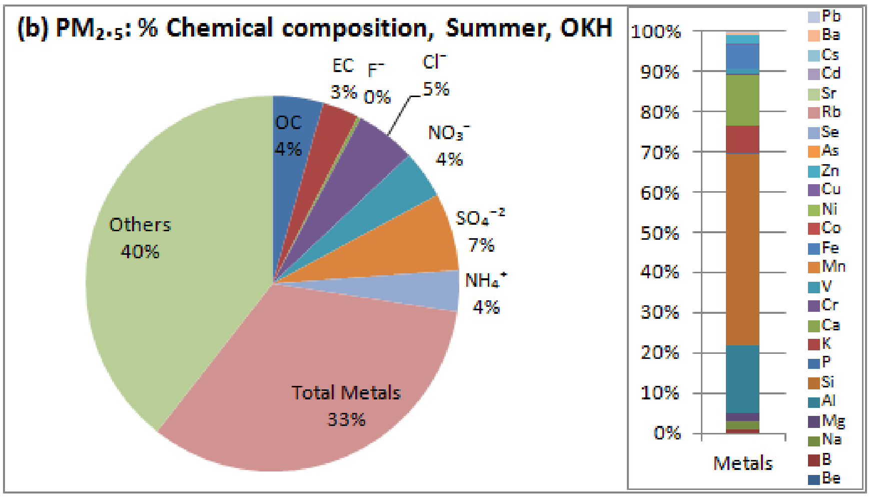


Figure 2.26: Percentage distribution of species in PM at OKH for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. The graphical presentation is a better option for understanding the compositional variation. Compositional comparisons of $PM_{2.5}$ Vs PM_{10} for all species are shown for winter season (Figure 2.27) and summer season (Figure 2.28) at OKH.

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). The major species contributing to fine mode are TC, EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Sr, Cd, Cs and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, Fe and Ni.

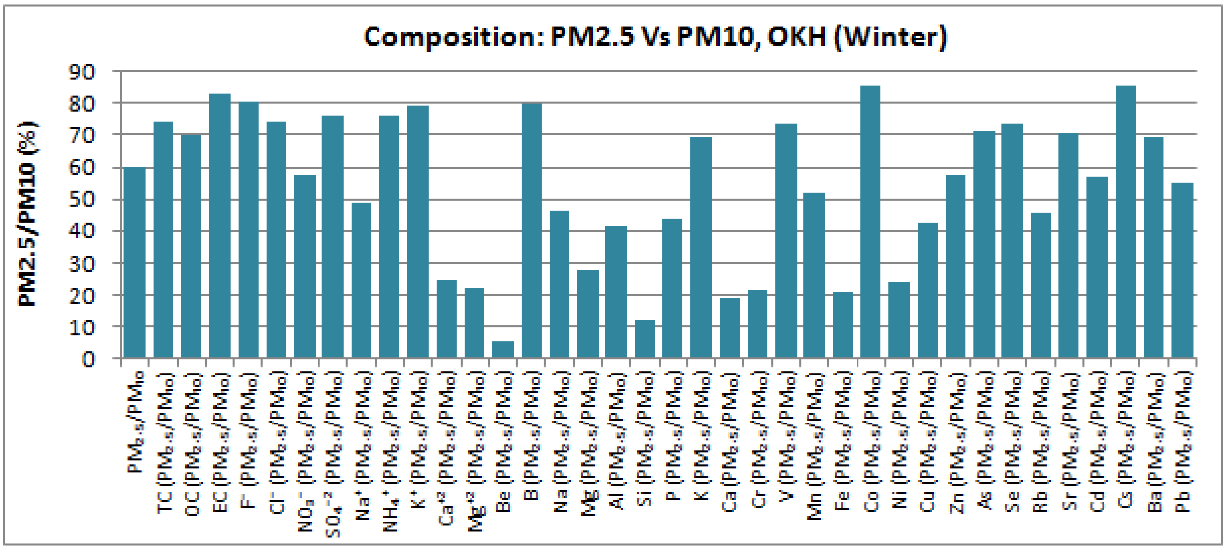


Figure 2.27: Compositional comparison of species in PM$_{2.5}$ Vs PM$_{10}$ at OKH for Winter Season

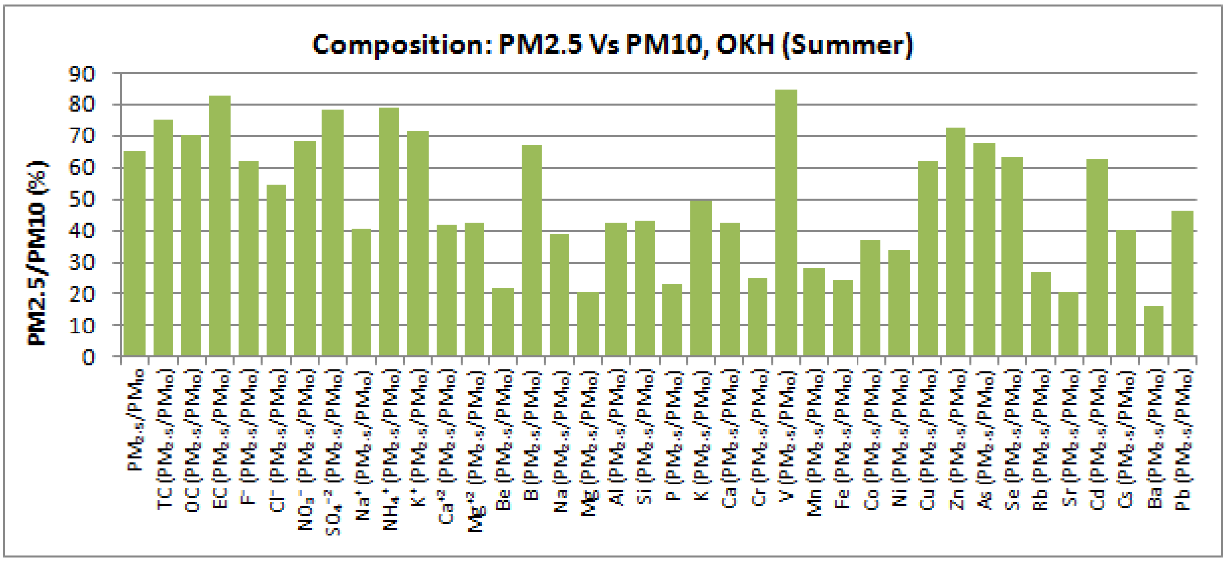


Figure 2.28: Compositional comparison of species in PM$_{2.5}$ Vs PM$_{10}$ at OKH for Summer Season

Table 2.26(a): Statistical Results of PAHs (ng/m^3) in PM$_{2.5}$ at OKH for Winter (W) and Summer (S) Seasons

OKH(W)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.36	0.03	0.31	5.02	0.05	2.76	3.51	7.85	14.44	2.90	11.88	18.09	3.75	19.04	91.00
SD	0.70	0.09	0.24	1.38	0.11	1.88	1.91	2.89	5.34	1.32	5.29	8.39	1.66	8.45	34.47
Max	2.99	0.29	0.81	7.74	0.35	7.50	7.29	13.69	26.72	6.03	22.69	37.09	7.29	37.81	169.59
Min	0.59	0.00	0.00	3.05	0.00	1.52	1.82	5.26	9.18	1.60	6.88	11.82	1.90	12.53	63.95
CV	0.51	2.75	0.78	0.27	2.39	0.68	0.55	0.37	0.37	0.45	0.45	0.46	0.44	0.44	0.38
OKH(S)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	0.44	0.07	0.44	1.69	0.00	1.25	0.29	1.43	3.63	0.07	1.83	2.55	0.00	3.41	17.09
SD	0.40	0.21	0.66	0.86	0.00	0.58	0.48	1.02	2.42	0.21	1.78	2.17	0.00	2.51	10.64
Max	1.23	0.67	2.25	2.87	0.00	2.57	1.37	3.96	9.52	0.66	6.10	7.60	0.00	8.89	43.46
Min	0.00	0.00	0.00	0.35	0.00	0.57	0.00	0.10	0.50	0.00	0.00	0.00	0.00	0.00	4.62
CV	0.90	3.16	1.51	0.51	0.00	0.46	1.61	0.71	0.67	3.16	0.97	0.85	0.00	0.74	0.62

Table 2.27(b): Statistical Results of Carbon Contents (µg/m^3) in PM$_{2.5}$ at OKH for Winter (W) and Summer (S) Seasons

OKH (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	433	114.4	40.5	73.9	12.3	20.2	25.9	15.4	0.104	0.176	0.230	0.143
Max	882	271.2	117.1	154.0	41.5	45.2	47.9	27.5	0.153	0.204	0.290	0.204
Min	240	64.5	19.8	44.4	6.2	10.7	14.8	7.5	0.062	0.144	0.171	0.064
SD	149	46.0	20.8	26.7	7.7	8.4	9.1	4.6	0.024	0.014	0.028	0.039
CV	0.34	0.40	0.51	0.36	0.62	0.42	0.35	0.30	0.233	0.078	0.122	0.272
OKH (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	412	31.0	12.9	18.0	1.4	5.3	6.7	4.6	0.043	0.176	0.225	0.153
Max	704	60.6	28.9	33.0	3.7	9.7	12.1	8.7	0.064	0.211	0.300	0.202
Min	232	13.6	4.2	9.4	0.4	2.9	3.6	2.1	0.023	0.146	0.179	0.101
SD	117	13.0	6.8	6.4	0.9	2.0	2.2	1.6	0.012	0.017	0.028	0.024
CV	0.28	0.42	0.52	0.35	0.63	0.38	0.32	0.35	0.283	0.095	0.123	0.154

Table 2.28(c): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of PM_{10} at OKH for Winter (W) Season

OKH(W)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	721	101	17	105.5	48.8	0.69	21.86	57.32	39.93	2.09	23.38	18.49	4.85	23.30	0.00	0.55	4.68	8.69	32.98	74.46
Max	1255	136	55	220.0	141.1	2.08	50.48	220.14	127.37	3.42	60.68	136.40	33.58	44.04	0.00	1.12	7.69	30.48	180.26	182.55
Min	408	65	7	63.4	23.9	0.32	9.28	11.91	14.17	0.66	2.40	4.98	0.54	6.31	0.00	0.22	1.99	2.30	7.34	20.42
SD	238	20	12	38.2	25.0	0.42	11.96	46.40	26.81	0.79	13.70	28.78	7.66	10.62	0.00	0.23	1.46	6.04	35.23	41.77
CV	0.33	0.19	0.71	0.36	0.51	0.60	0.55	0.81	0.67	0.38	0.59	1.56	1.58	0.46	3.17	0.42	0.31	0.70	1.07	0.56
OKH(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.61	26.21	21.09	1.00	0.49	0.37	19.25	0.12	0.05	0.41	1.87	0.04	0.02	0.12	0.38	0.02	0.11	10.06	1.16	70.2
Max	3.25	173.22	41.80	2.02	1.31	0.72	44.34	0.31	0.12	1.67	4.11	0.09	0.06	0.65	2.89	0.09	0.30	129.02	7.42	92.2
Min	0.63	8.39	4.57	0.24	0.21	0.13	4.63	0.06	0.01	0.10	0.80	0.01	0.01	0.03	0.11	0.00	0.06	0.33	0.21	48.1
SD	0.68	35.03	9.23	0.42	0.26	0.16	9.79	0.06	0.03	0.41	0.94	0.02	0.01	0.13	0.59	0.02	0.06	27.87	1.74	12.4
CV	0.42	1.34	0.44	0.41	0.54	0.43	0.51	0.53	0.66	1.00	0.50	0.62	0.54	1.08	1.54	1.13	0.56	2.77	1.51	0.18

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

Table 2.29(d): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of $PM_{2.5}$ at OKH for Winter (W) Season

OKH(W)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	433	101	17	73.9	40.5	0.56	16.25	32.84	30.39	1.02	17.81	14.65	1.20	5.23	0.00	0.44	2.18	2.41	13.72	9.05
Max	882	136	55	154.0	117.1	1.82	31.64	62.71	112.23	2.49	40.52	111.62	3.56	18.99	0.00	0.90	4.28	20.10	147.60	28.65
Min	240	65	7	44.4	19.8	0.24	6.51	9.89	9.44	0.24	1.56	3.07	0.15	0.41	0.00	0.17	0.57	0.24	0.78	2.12
SD	149	20	12	26.7	20.8	0.34	7.54	14.73	22.11	0.55	9.26	23.61	0.92	5.10	0.00	0.21	1.07	4.24	31.32	7.58
CV	0.34	0.19	0.71	0.36	0.51	0.61	0.46	0.45	0.73	0.54	0.52	1.61	0.76	0.97	3.24	0.47	0.49	1.76	2.28	0.84
OKH(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.71	18.24	4.03	0.21	0.36	0.19	4.06	0.10	0.01	0.17	1.08	0.03	0.02	0.05	0.27	0.01	0.10	6.96	0.64	62.9
Max	1.51	161.05	11.57	0.68	0.59	0.36	9.80	0.29	0.04	0.66	2.60	0.08	0.04	0.53	2.54	0.06	0.27	111.65	4.62	84.2
Min	0.24	2.82	0.83	0.01	0.12	0.07	0.82	0.05	0.00	0.03	0.18	0.01	0.01	0.00	0.07	0.00	0.05	0.01	0.09	45.7
SD	0.44	33.30	3.47	0.19	0.15	0.09	2.88	0.05	0.01	0.17	0.71	0.02	0.01	0.11	0.53	0.01	0.05	24.28	1.01	11.7
CV	0.62	1.83	0.86	0.91	0.41	0.48	0.71	0.50	0.84	0.99	0.65	0.69	0.48	2.12	1.96	1.14	0.52	3.49	1.59	0.19

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

Table 2.30(e): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of PM_{10} at OKH for Summer (S) Season

OKH(S)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	635	74	15	25.8	15.6	1.94	39.51	24.90	35.25	3.37	18.60	7.59	1.96	43.24	0.00	1.69	7.39	13.32	53.86	151.70
Max	955	126	24	47.2	34.8	4.44	147.91	64.31	49.70	7.65	45.49	12.92	5.54	83.56	0.01	4.80	11.08	25.77	91.75	250.19
Min	374	53	8	13.5	5.0	0.65	11.42	8.76	18.39	1.31	8.74	3.22	0.31	20.55	0.00	0.62	4.14	5.43	30.29	93.55
SD	169	18	4	9.1	8.1	0.94	30.73	14.28	8.53	1.57	8.17	2.55	1.52	17.07	0.00	0.89	1.98	5.21	15.04	48.36
CV	0.27	0.24	0.30	0.35	0.52	0.49	0.78	0.57	0.24	0.47	0.44	0.34	0.78	0.39	0.48	0.52	0.27	0.39	0.28	0.32
OKH(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.94	18.06	40.47	2.83	1.73	0.84	33.93	0.02	0.12	0.52	3.69	0.08	0.03	0.14	0.33	0.12	0.01	1.68	2.10	79.7
Max	5.32	28.77	84.88	5.80	3.18	1.96	57.05	0.05	0.20	2.22	6.45	0.28	0.05	0.29	1.00	0.37	0.01	4.11	3.70	93.1
Min	0.66	10.03	20.76	1.09	0.82	0.30	14.91	0.01	0.06	0.21	1.36	0.04	0.01	0.06	0.13	0.02	0.00	0.31	0.93	55.9
SD	1.01	4.94	17.91	1.26	0.69	0.40	11.74	0.01	0.05	0.43	1.73	0.05	0.01	0.05	0.19	0.10	0.00	0.99	0.82	10.1
CV	0.52	0.27	0.44	0.44	0.40	0.48	0.35	0.50	0.41	0.82	0.47	0.64	0.31	0.39	0.57	0.80	0.32	0.59	0.39	0.13

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

Table 2.31(f): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of $PM_{2.5}$ at OKH for Summer (S) Season

OKH(S)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	412	74	15	18.0	12.9	1.20	21.41	17.05	27.57	1.36	14.63	5.42	0.82	18.53	0.00	1.13	2.85	2.73	22.76	65.35
Max	704	126	24	33.0	28.9	2.46	56.48	36.76	46.60	4.37	31.27	9.06	3.35	41.73	0.00	3.50	6.85	14.33	51.66	143.41
Min	232	53	8	9.4	4.2	0.51	4.33	6.41	10.51	0.27	1.58	3.04	0.05	3.69	0.00	0.39	1.27	0.54	10.69	26.35
SD	117	18	4	6.4	6.8	0.54	14.38	7.78	8.70	0.99	6.80	1.78	0.83	10.19	0.00	0.73	1.53	3.44	9.96	28.54
CV	0.28	0.24	0.30	0.35	0.52	0.45	0.67	0.46	0.32	0.73	0.46	0.33	1.00	0.55	1.01	0.64	0.54	1.26	0.44	0.44
OKH(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.45	8.97	17.22	0.70	1.47	0.24	8.17	0.01	0.04	0.32	2.68	0.05	0.02	0.04	0.07	0.08	0.00	0.27	0.98	61.6
Max	1.32	15.14	49.81	2.24	2.63	0.63	29.17	0.02	0.09	1.68	5.47	0.09	0.04	0.11	0.27	0.22	0.01	0.95	2.18	86.2
Min	0.02	3.59	6.11	0.19	0.64	0.06	2.34	0.00	0.00	0.09	0.94	0.03	0.01	0.01	0.01	0.01	0.00	0.05	0.44	42.5
SD	0.42	3.29	10.64	0.56	0.61	0.16	7.58	0.01	0.03	0.33	1.51	0.02	0.01	0.03	0.07	0.07	0.00	0.26	0.47	10.3
CV	0.94	0.37	0.62	0.79	0.42	0.69	0.93	0.90	0.67	1.02	0.56	0.40	0.38	0.77	1.10	0.87	0.60	0.97	0.48	0.17

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

Table 2.32(g): Correlation Matrix for PM_{10} and its composition for Winter (W) Season

OKH (W)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.04	0.65	0.46	0.45	0.44	0.31	0.71	0.18	0.73	0.72	0.53	0.55	0.24	0.51	0.71
TC		0.15	0.23	1.00	0.98	0.95	0.00	0.24	-0.05	0.15	0.38	0.18	0.09	0.65	0.13	0.10
OC		0.19	0.19		1.00	0.87	0.01	0.23	-0.03	0.14	0.34	0.16	0.12	0.56	0.10	0.05
EC		0.07	0.27			1.00	-0.01	0.23	-0.07	0.15	0.42	0.20	0.04	0.73	0.18	0.17
NO_3^-		0.30	-0.03				0.22	0.12	1.00	-0.05	0.14	0.34	-0.17	0.08	0.46	-0.10
SO_4^{-2}		-0.16	0.87				0.18	0.66		1.00	0.64	0.28	0.83	0.05	0.24	0.85
NH_4^+		0.08	0.12				0.63	0.76			0.55	1.00	-0.16	0.24	0.63	0.13
Metals		-0.21	0.79				0.13	0.59			0.61		0.81	-0.06	0.28	1.00

Table 2.33(h): Correlation Matrix for $PM_{2.5}$ and its composition for Winter (W) Season

OKH (W)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.00	0.77	0.50	0.47	0.50	0.16	0.59	0.06	0.78	0.71	0.26	0.71	0.77	0.12	0.74
TC		0.14	0.23	1.00	0.98	0.96	0.04	0.34	0.04	0.18	0.55	0.27	0.09	0.56	-0.16	0.02
OC		0.19	0.19		1.00	0.87	0.07	0.33	0.09	0.20	0.50	0.27	0.14	0.46	-0.17	0.04
EC		0.07	0.27			1.00	-0.01	0.32	-0.03	0.14	0.58	0.26	0.03	0.64	-0.13	-0.01
NO_3^-		0.33	-0.35				0.43	0.30	1.00	-0.08	0.14	0.67	-0.31	0.06	0.38	-0.22
SO_4^{-2}		-0.13	0.79				0.06	0.53		1.00	0.52	0.05	0.88	0.48	0.03	0.91
NH_4^+		0.17	-0.07				0.33	0.60			0.15	1.00	-0.29	0.13	0.37	-0.23
Metals		-0.16	0.75				0.03	0.38			0.45		0.96	0.42	0.03	1.00

Table 2.34(i): Correlation Matrix for PM_{10} and its composition for Summer (S) Season

OKH (S)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.07	0.36	0.14	0.12	0.17	0.73	-0.03	0.37	0.45	0.29	0.14	0.47	0.27	0.56	0.87
TC		0.23	0.36	1.00	0.99	0.99	0.45	-0.17	-0.32	0.14	-0.08	-0.11	0.18	0.10	-0.04	0.32
OC		0.29	0.37		1.00	0.96	0.43	-0.19	-0.32	0.16	-0.14	-0.16	0.19	0.13	-0.01	0.31
EC		0.17	0.35			1.00	0.46	-0.14	-0.32	0.12	-0.02	-0.06	0.16	0.06	-0.09	0.33
NO_3^-		0.03	0.02				0.35	-0.01	1.00	0.37	0.29	0.06	0.11	0.42	0.54	0.37
SO_4^{-2}		-0.05	0.52				0.39	-0.03		1.00	-0.10	0.11	0.45	0.39	0.65	0.41
NH_4^+		0.01	-0.01				-0.29	0.78			0.01	1.00	0.47	0.10	-0.05	-0.07
Metals		0.17	0.34				0.87	-0.20			0.23		0.37	0.30	0.55	1.00

Table 2.35(j): Correlation Matrix for $PM_{2.5}$ and its composition for Summer (S) Season

OKH (S)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.28	0.13	-0.15	-0.15	-0.14	0.73	0.00	0.55	0.17	-0.03	0.23	0.38	0.07	0.63	0.80
TC		0.23	0.36	1.00	0.99	0.99	-0.23	-0.01	-0.35	0.13	0.08	0.05	0.46	0.39	-0.45	-0.15
OC		0.29	0.37		1.00	0.96	-0.20	-0.05	-0.35	0.15	0.06	0.01	0.47	0.42	-0.41	-0.11
EC		0.17	0.35			1.00	-0.25	0.02	-0.34	0.11	0.10	0.09	0.44	0.36	-0.49	-0.18
NO_3^-		-0.01	0.00				0.55	-0.18	1.00	0.30	0.35	0.03	0.11	0.31	0.53	0.53
SO_4^{-2}		-0.13	0.52				0.39	-0.33		1.00	0.14	-0.03	0.51	0.40	0.36	0.07
NH_4^+		0.24	-0.07				-0.06	0.77			-0.28	1.00	0.39	0.07	-0.12	-0.16
Metals		0.16	0.25				0.76	-0.15			-0.04		0.22	-0.04	0.63	1.00

2.4.3 DAV School, Dwarka (DWK)

The sampling period for winter is December 02 - 22, 2013 and May 01- 24, 2014 for Summer season

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

For sampling of PM_{10} and $PM_{2.5}$, the developed SOPs were followed. As a part of QA/QC, 20% of PM-laden filters (of PM_{10} and $PM_{2.5}$) were reconditioned for 24 hrs and reweighed. The variation in the concentration was less than 5%, which was acceptable.

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figure 2.29) and summer (Figure 2.30). The air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although winter conditions provide low dispersion and high concentrations, the levels of PM_{10} and $PM_{2.5}$ are alarmingly high even in summer months. Average levels for winter and summer season are 362 and 233 μg/m^3 (for $PM_{2.5}$) and 544 and 458 μg/m^3 (for PM_{10}) respectively.

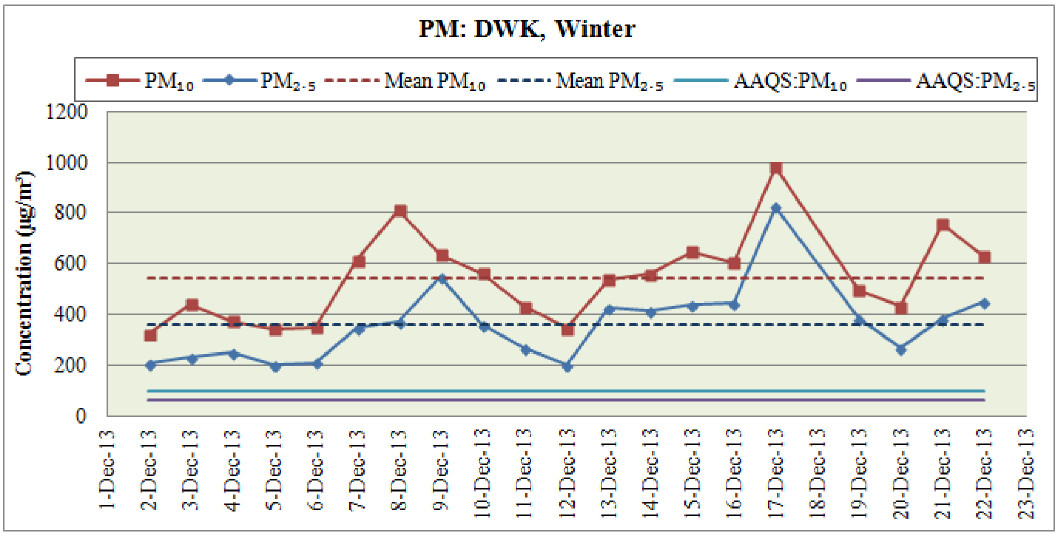


Figure 2.29: PM Concentrations at DWK for Winter Season

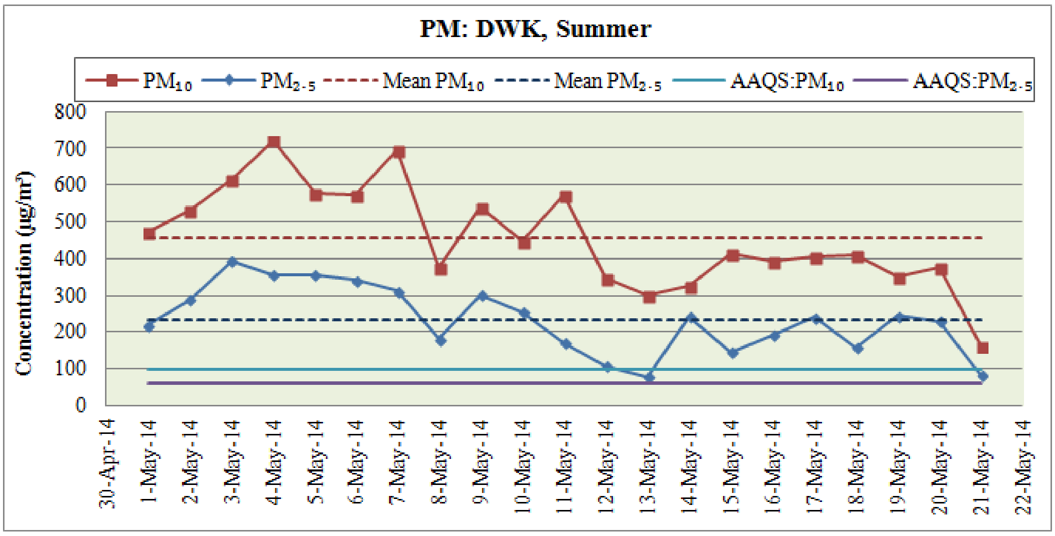


Figure 2.30: PM Concentrations at DWK for Summer Season

2.4.3.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.31) and summer (Figure 2.32). It was observed that SO_2 concentrations were low and meet the air quality standard. NO_2 levels exceed the air quality standard. The average NO_2 concentration at DWK was 85 µg/m^3 for winter and 40 µg/m^3 for summer season (Table 2.8 (c), (e)). The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. The NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets or open burning etc.

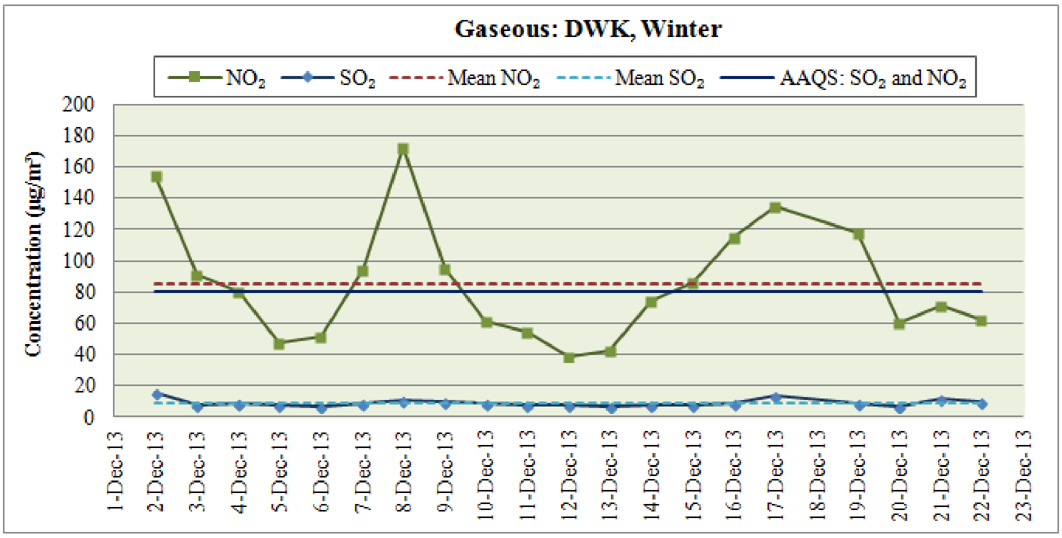


Figure 2.31: SO_2 and NO_2 Concentrations at DWK for Winter Season

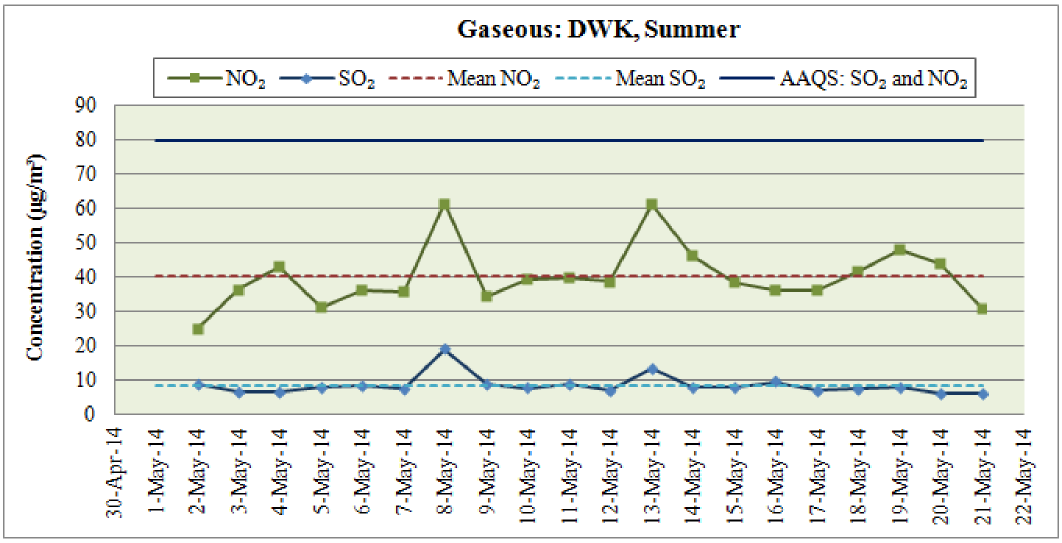


Figure 2.32: SO_2 and NO_2 Concentrations at DWK for Summer Season

2.4.3.3 Carbon monoxide (CO)

Hourly concentration of CO was observed at DWK for winter and summer seasons. From Figures 2.33, it can be seen that the maximum concentration is observed during the peak hours of traffic the day (both in morning as well as evening). It was observed that maximum concentration occurs at the time peak traffic (winter - 1.9 mg/m^3 and summer 1.3 mg/m^3); higher in evening hours than in morning hours. The levels meet the hourly CO standard (4 mg/m^3) at DWK in both the seasons.

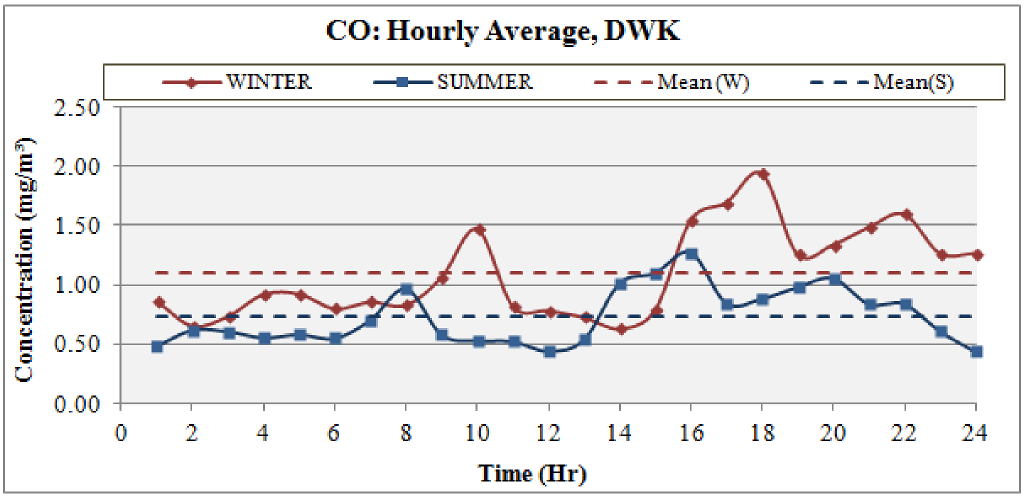


Figure 2.33: Hourly average concentration of CO at DWK for winter and summer seasons

2.4.3.4 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs with some specific markers measured for winter and summer season are shown in Figure 2.34. The PAHs compounds analyzed are (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAHs concentrations are much higher in winter (89 ng/m^3) than in summer (5 ng/m^3) season. Major PAHs are B(ghi)P (18 ng/m^3), InP (17 ng/m^3), B(b)F (14 ng/m^3) and B(a)P ((11 ng/m^3) for winter season and B(b)F (1.0 ng/m^3), B(ghi)P (0.9 ng/m^3), Phe (0.9 ng/m^3) and Pyr (0.6 ng/m^3) for summer season. A statistical summary of PAHs concentration is presented in Table 2.8 (a) for winter and summer season.

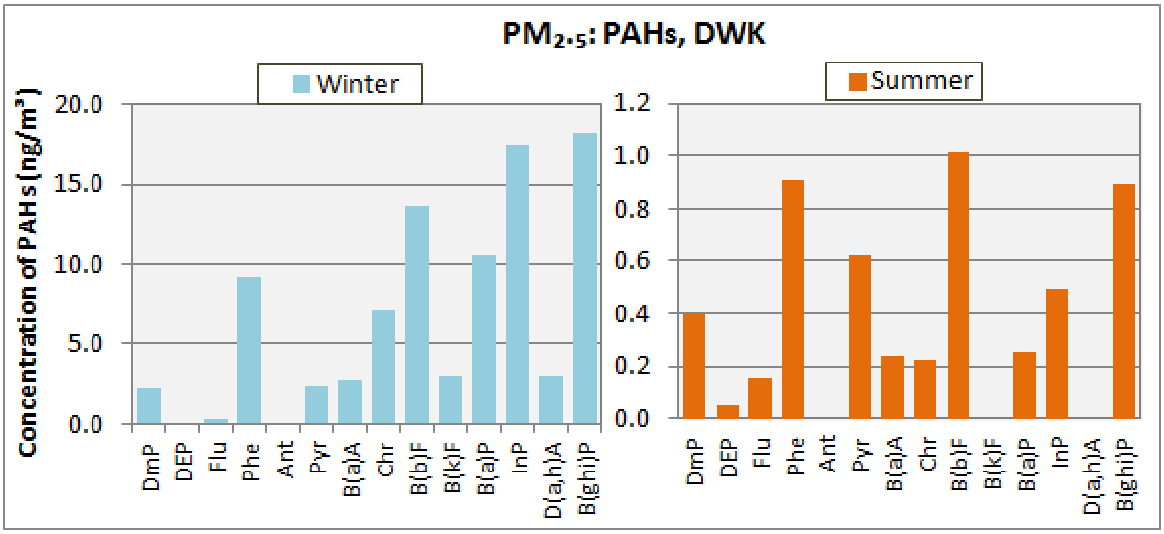


Figure 2.34: PAHs Concentrations in $PM_{2.5}$ at DWK for winter and Summer Seasons

2.4.3.5 Elemental and Organic 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 season. OC is observed higher than the EC. However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at DWK. It is also observed that the OC and EC are higher in winter than 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 2.8 (b) for winter and summer season.

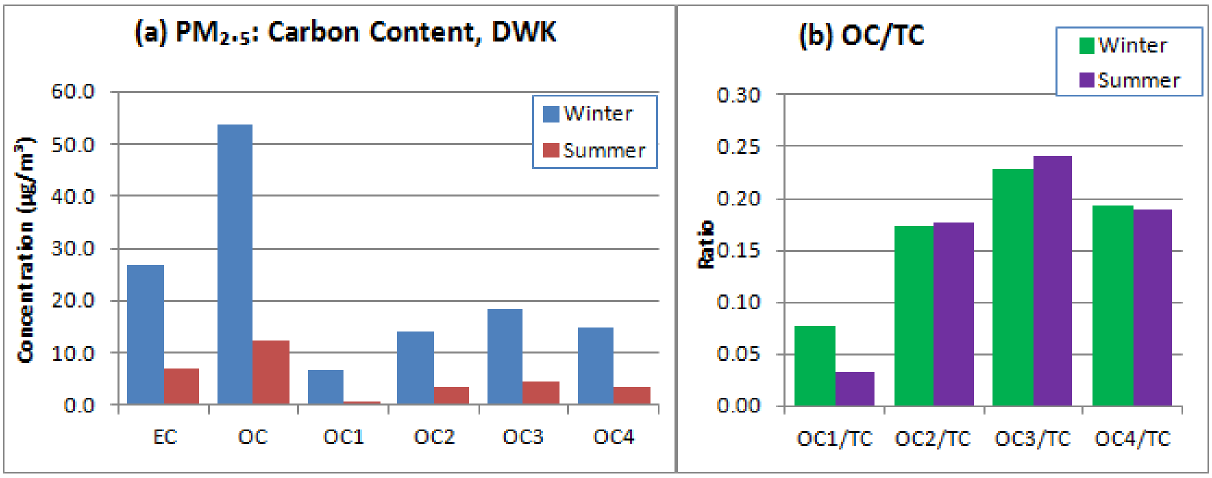


Figure 2.35: EC and OC Content in $PM_{2.5}$ at DWK for Winter and Summer Seasons

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

Graphical presentation of chemical species are shown for winter and summer season for PM_{10} (Figure 2.36) and $PM_{2.5}$ (Figure 2.37). Statistical summary (mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of analysis 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) determined in composition and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.8 (c), (d), (e) and (f) for winter and summer season. The correlation between different parameters (i.e PM, NO_2, SO_2, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.8 (g), (h), (i) and (j) 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 2.38 (a) and (b) for winter season and Figure 2.39 (a) and (b) for summer season.

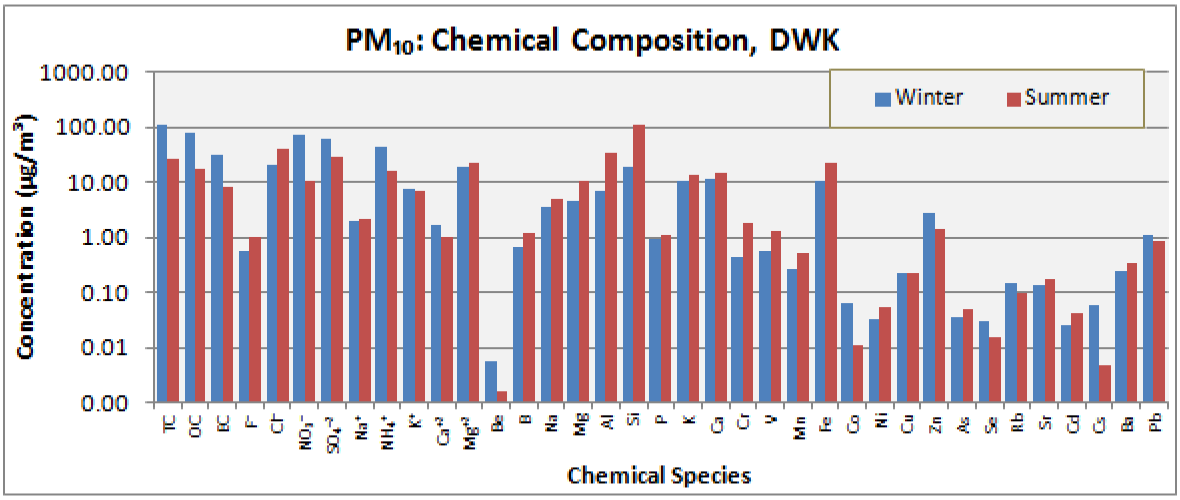


Figure 2.36: Concentrations of species in PM_{10} at DWK for Winter and Summer Seasons

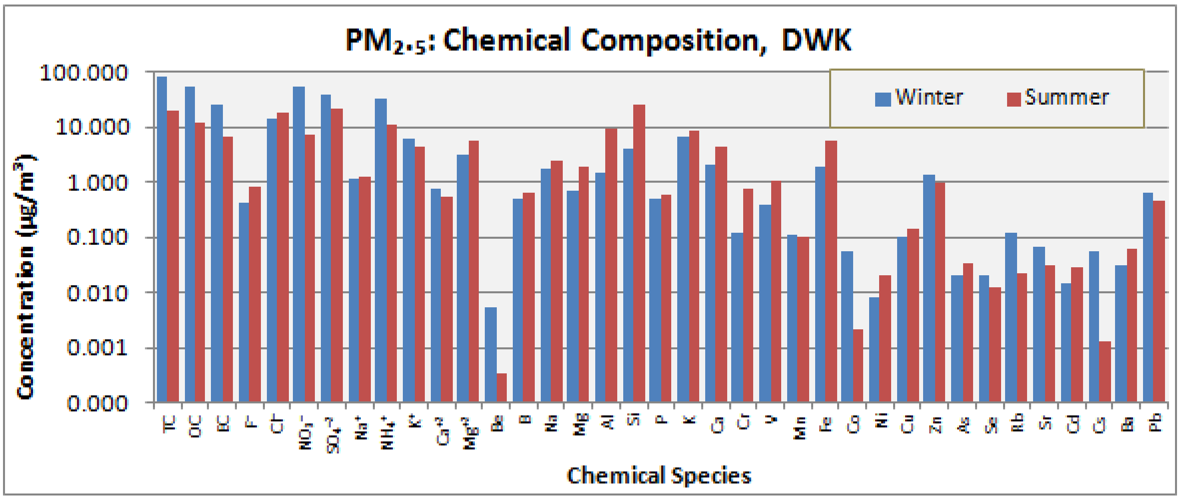
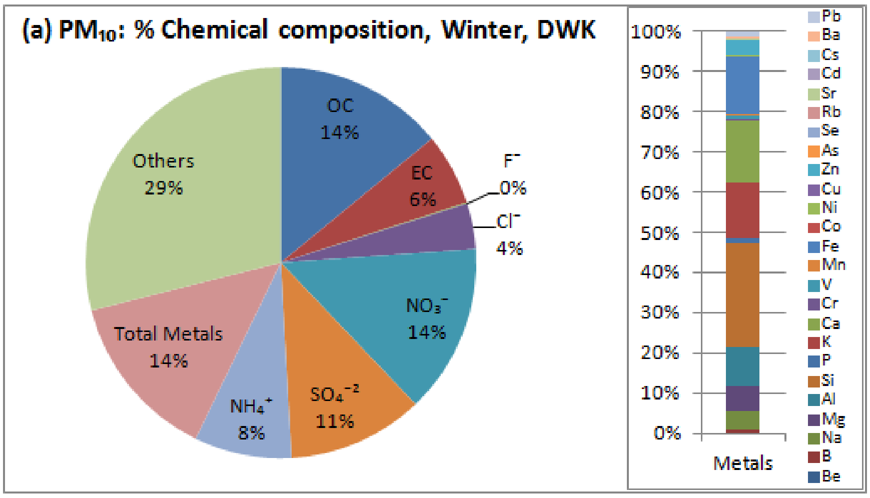


Figure 2.37: Concentrations of species in $PM_{2.5}$ at DWK for Winter and Summer Seasons



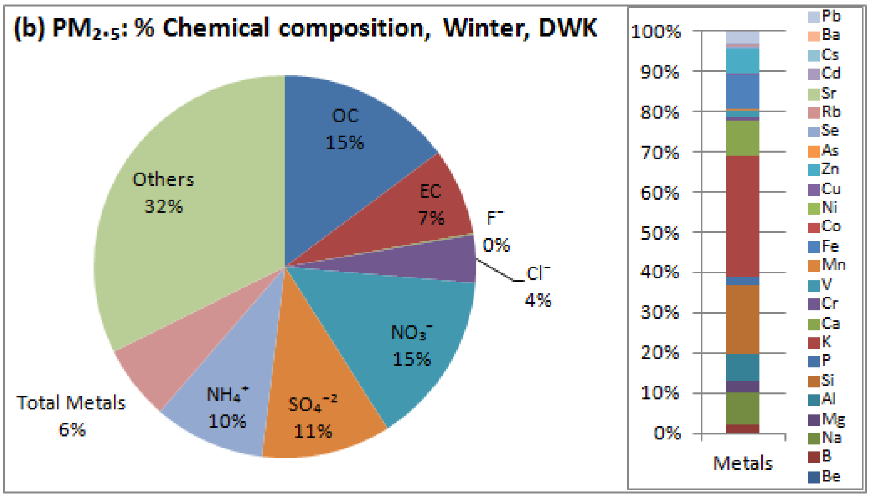


Figure 2.38: Percentage distribution of species in PM at DWK for Winter Seasons

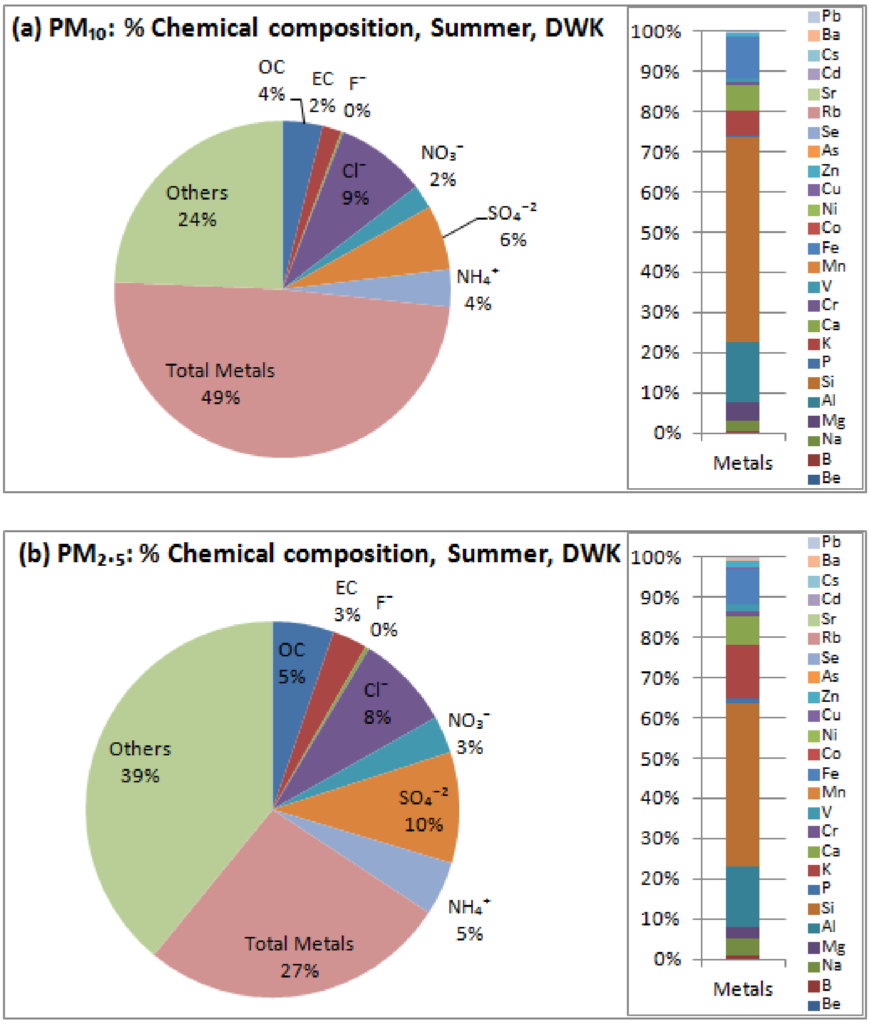


Figure 2.39: Percentage distribution of species in PM at DWK for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. The graphical presentation is the better option for understanding the compositional variation. Compositional comparisons of $PM_{2.5}$ Vs PM_{10} for all species are shown for winter season (Figure 2.40) and summer season (Figure 2.41) at DWK.

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 (67 %) than summer (51 %). The major species contributing to fine mode are TC, EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Sr, Cd, Cs and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, Fe and Ni.

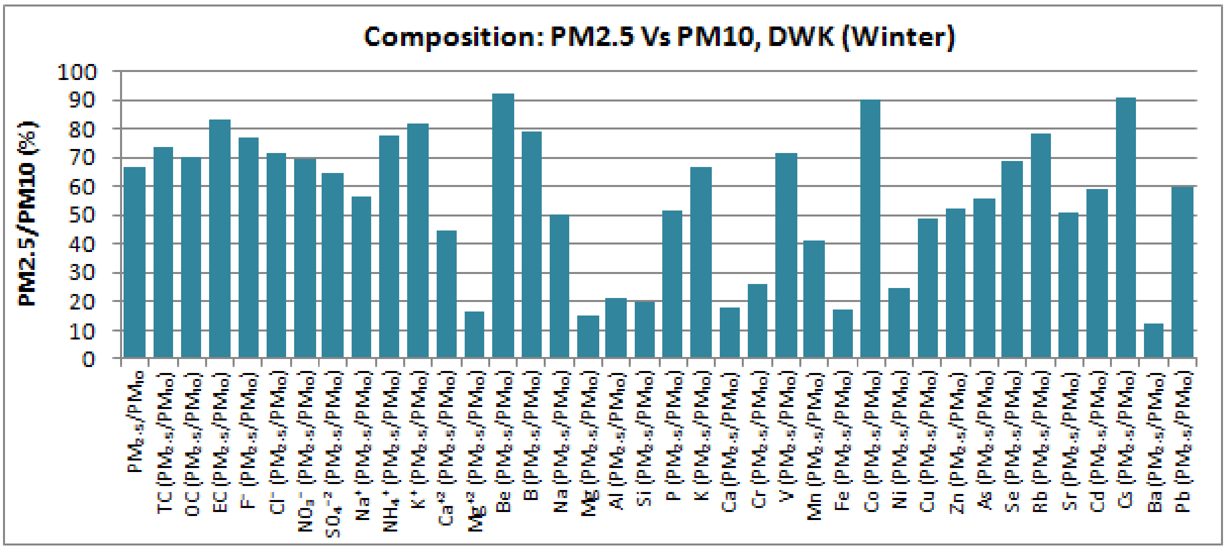


Figure 2.40: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at DWK for Winter Season

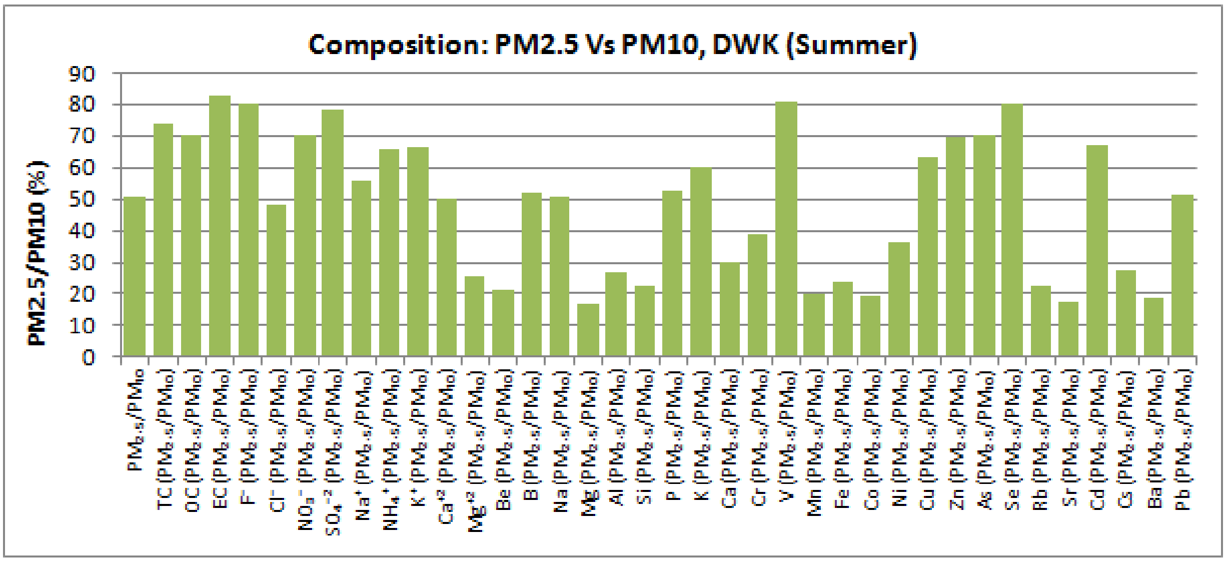


Figure 2.41: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at DWK for Summer Season

Table 2.36(a): Statistical Results of PAHs (ng/m^3) in PM$_{2.5}$ at DWK for Winter (W) and Summer (S) Seasons

DWK(W)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	2.22	0.00	0.24	9.17	0.00	2.33	2.80	7.09	13.65	2.97	10.61	17.54	2.95	18.22	89.80
SD	1.95	0.00	0.41	6.55	0.00	1.93	1.52	3.18	6.38	2.27	5.64	8.97	1.82	9.46	42.25
Max	7.13	0.00	1.41	22.83	0.00	7.59	5.59	11.18	23.38	8.62	21.82	29.73	6.12	32.99	146.53
Min	0.64	0.00	0.00	3.26	0.00	0.82	0.98	3.28	5.46	0.67	3.87	5.37	0.57	6.69	37.78
CV	0.88	0.00	1.69	0.71	0.00	0.83	0.54	0.45	0.47	0.76	0.53	0.51	0.62	0.52	0.47
DWK(S)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	0.39	0.05	0.15	0.90	0.00	0.62	0.24	0.22	1.01	0.00	0.25	0.50	0.00	0.90	5.24
SD	0.47	0.10	0.20	0.54	0.00	0.40	0.75	0.39	1.27	0.00	0.56	0.94	0.00	1.31	5.21
Max	1.22	0.31	0.48	1.94	0.00	1.50	2.38	1.29	4.38	0.00	1.71	2.98	0.00	4.30	19.04
Min	0.00	0.00	0.00	0.23	0.00	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.53
CV	1.20	1.94	1.32	0.60	0.00	0.64	3.16	1.77	1.26	0.00	2.23	1.90	0.00	1.47	0.99

Table 2.37(b): Statistical Results of Carbon Contents (μg/m^3) in PM$_{2.5}$ at DWK for Winter (W) and Summer (S) Seasons

DWK (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	362	80.4	26.8	53.6	6.7	14.0	18.3	14.6	0.077	0.173	0.229	0.193
Max	826	142.7	51.7	94.3	17.5	24.3	34.6	27.9	0.133	0.188	0.264	0.259
Min	202	30.5	8.6	21.9	1.5	5.0	7.8	7.2	0.048	0.161	0.188	0.103
SD	149	33.2	12.5	21.6	4.2	6.0	7.7	5.7	0.022	0.007	0.017	0.052
CV	0.41	0.41	0.47	0.40	0.63	0.43	0.42	0.39	0.291	0.043	0.075	0.270
DWK (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	233	19.3	7.0	12.3	0.6	3.4	4.7	3.6	0.032	0.178	0.241	0.189
Max	392	41.4	19.7	27.1	1.9	6.9	11.0	7.4	0.049	0.236	0.280	0.231
Min	79	11.1	3.7	7.3	0.2	2.0	2.7	1.9	0.015	0.148	0.198	0.125
SD	91	8.2	3.5	5.2	0.4	1.5	2.1	1.4	0.009	0.019	0.021	0.029
CV	0.39	0.42	0.50	0.42	0.64	0.43	0.45	0.40	0.283	0.108	0.088	0.151

Table 2.38(c): Statistical Results of SO_2, NO_2 and Chemical Characterization (μg/m^3) of PM_{10} at DWK for Winter (W) Season

DWK(W)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	544	85	9	76.6	32.3	0.57	20.52	76.15	61.20	1.98	43.74	7.32	1.72	19.54	0.01	0.64	3.55	4.70	7.18	19.74
Max	981	173	16	134.7	62.3	1.04	44.26	165.55	158.06	3.14	107.23	11.56	6.61	33.55	0.01	1.06	6.00	8.12	11.63	31.46
Min	321	39	7	31.3	10.3	0.24	8.27	25.07	17.81	0.77	15.32	4.09	0.65	4.57	0.00	0.34	1.56	1.25	1.94	5.27
SD	174	37	2	30.8	15.1	0.24	9.03	34.80	40.99	0.69	22.27	2.26	1.37	8.01	0.00	0.22	1.15	1.95	2.92	7.94
CV	0.32	0.44	0.25	0.40	0.47	0.43	0.44	0.46	0.67	0.35	0.51	0.31	0.79	0.41	0.37	0.35	0.32	0.41	0.41	0.40
DWK(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.93	10.37	11.48	0.45	0.56	0.26	10.92	0.06	0.03	0.22	2.67	0.04	0.03	0.15	0.13	0.02	0.06	0.25	1.09	70.8
Max	1.47	16.97	21.34	0.75	1.48	0.47	18.01	0.14	0.08	0.57	5.35	0.08	0.06	0.29	0.23	0.08	0.13	0.74	4.00	86.0
Min	0.47	6.23	2.78	0.15	0.30	0.10	2.97	0.04	0.01	0.06	1.22	0.02	0.02	0.09	0.07	0.00	0.04	0.00	0.18	55.7
SD	0.31	2.91	5.55	0.16	0.32	0.11	4.80	0.02	0.02	0.15	1.17	0.02	0.01	0.05	0.04	0.02	0.02	0.19	1.05	8.9
CV	0.34	0.28	0.48	0.37	0.56	0.41	0.44	0.36	0.62	0.68	0.44	0.51	0.43	0.32	0.33	0.85	0.39	0.76	0.96	0.13
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.39(d): Statistical Results of SO_2, NO_2 and Chemical Characterization (μg/m^3) of $PM_{2.5}$ at DWK for Winter (W) Season

DWK(W)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	362	85	9	53.6	26.8	0.44	14.61	53.02	39.63	1.12	34.05	5.97	0.78	3.22	0.01	0.50	1.77	0.71	1.52	3.94
Max	826	173	16	94.3	51.7	0.93	28.17	132.01	96.71	1.97	89.48	8.97	3.83	11.32	0.01	0.87	4.17	2.46	8.43	13.57
Min	202	39	7	21.9	8.6	0.19	6.68	18.23	15.12	0.55	10.39	2.98	0.09	0.48	0.00	0.24	0.55	0.22	0.25	0.66
SD	149	37	2	21.6	12.5	0.19	5.52	24.36	22.18	0.38	17.52	1.82	0.85	3.25	0.00	0.21	0.85	0.65	1.78	3.08
CV	0.41	0.44	0.25	0.40	0.47	0.44	0.38	0.46	0.56	0.34	0.51	0.30	1.10	1.01	0.39	0.41	0.48	0.92	1.17	0.78
DWK(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.48	6.88	2.03	0.12	0.40	0.11	1.90	0.06	0.01	0.11	1.40	0.02	0.02	0.12	0.07	0.01	0.05	0.03	0.65	68.9
Max	1.03	13.62	5.49	0.39	1.05	0.34	5.98	0.12	0.02	0.35	3.73	0.04	0.05	0.26	0.16	0.05	0.12	0.08	2.45	84.0
Min	0.13	2.45	0.49	0.02	0.23	0.05	0.57	0.04	0.00	0.03	0.44	0.00	0.01	0.07	0.04	0.00	0.03	0.00	0.13	52.7
SD	0.19	2.57	1.49	0.11	0.19	0.06	1.54	0.02	0.01	0.10	0.83	0.01	0.01	0.04	0.03	0.01	0.02	0.03	0.63	10.1
CV	0.39	0.37	0.73	0.91	0.48	0.60	0.81	0.35	0.76	0.91	0.59	0.57	0.50	0.39	0.39	1.02	0.39	0.85	0.96	0.15
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.40(e): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of PM_{10} at DWK for Summer (S) Season

DWK(S)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	458	40	8	17.6	8.4	1.00	39.65	10.62	28.42	2.17	16.45	6.84	1.04	22.33	0.00	1.24	4.90	10.75	33.99	113.80
Max	723	61	19	38.7	23.7	1.87	131.76	19.45	53.86	10.14	50.50	15.08	2.00	45.83	0.00	3.29	8.19	21.46	75.24	266.35
Min	163	25	6	10.5	4.4	0.25	2.94	4.60	11.25	0.48	3.90	2.50	0.25	9.69	0.00	0.49	1.73	2.68	7.63	21.48
SD	138	9	3	7.4	4.2	0.51	34.07	4.13	13.69	2.03	12.53	3.25	0.44	11.06	0.00	0.63	1.74	5.66	19.23	64.52
CV	0.30	0.23	0.35	0.42	0.50	0.51	0.86	0.39	0.48	0.93	0.76	0.47	0.42	0.50	0.56	0.51	0.36	0.53	0.57	0.57
DWK(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.12	13.99	14.42	1.89	1.30	0.50	22.99	0.01	0.06	0.22	1.43	0.05	0.02	0.10	0.17	0.04	0.00	0.34	0.86	75.4
Max	1.91	27.05	33.43	3.15	2.93	1.17	52.07	0.02	0.11	0.55	2.97	0.09	0.03	0.22	0.31	0.31	0.01	0.76	2.50	93.3
Min	0.47	4.34	3.68	0.74	0.66	0.13	6.15	0.00	0.02	0.04	0.53	0.02	0.01	0.03	0.05	0.00	0.00	0.11	0.10	47.8
SD	0.50	6.41	7.54	0.85	0.56	0.28	13.38	0.01	0.02	0.15	0.84	0.02	0.01	0.05	0.08	0.07	0.00	0.19	0.69	13.9
CV	0.44	0.46	0.52	0.45	0.43	0.57	0.58	0.50	0.44	0.70	0.59	0.48	0.44	0.52	0.46	1.66	0.53	0.54	0.80	0.19

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

Table 2.41(f): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of $PM_{2.5}$ at DWK for Summer (S) Season

DWK(S)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	233	40	8	12.3	7.0	0.80	19.12	7.47	22.32	1.20	10.83	4.54	0.52	5.65	0.00	0.65	2.48	1.83	9.20	25.36
Max	392	61	19	27.1	19.7	1.61	68.18	13.90	47.75	6.99	34.93	9.60	1.62	19.73	0.00	1.32	4.04	6.47	42.23	113.15
Min	79	25	6	7.3	3.7	0.17	0.10	3.43	2.75	0.17	3.22	0.75	0.04	0.79	0.00	0.21	0.93	0.33	1.78	5.58
SD	91	9	3	5.2	3.5	0.45	19.05	2.61	12.04	1.44	7.78	2.36	0.36	6.01	0.00	0.32	0.79	1.50	8.82	23.69
CV	0.39	0.23	0.35	0.42	0.50	0.56	1.00	0.35	0.54	1.19	0.72	0.52	0.68	1.06	1.03	0.49	0.32	0.82	0.96	0.93
DWK(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.59	8.41	4.34	0.74	1.05	0.10	5.47	0.00	0.02	0.14	1.00	0.03	0.01	0.02	0.03	0.03	0.00	0.06	0.44	63.9
Max	1.25	14.85	17.94	1.68	2.45	0.36	17.71	0.01	0.09	0.42	2.36	0.08	0.03	0.07	0.11	0.21	0.00	0.29	1.40	89.0
Min	0.31	2.07	0.99	0.40	0.52	0.03	2.08	0.00	0.01	0.02	0.27	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.05	41.6
SD	0.26	3.39	3.72	0.35	0.47	0.08	3.35	0.00	0.02	0.11	0.61	0.03	0.01	0.01	0.03	0.05	0.00	0.06	0.34	14.7
CV	0.43	0.40	0.86	0.47	0.45	0.75	0.61	0.83	0.90	0.83	0.61	0.76	0.48	0.59	0.83	1.70	0.62	0.95	0.76	0.23

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

Table 2.42(g): Correlation Matrix for PM_{10} and its composition for Winter (W) Season

DWK (W)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.45	0.40	0.82	0.81	0.80	0.69	0.71	0.79	0.73	0.37	0.88	0.73	0.28	0.57	0.32
TC		0.59	0.39	1.00	0.99	0.95	0.65	0.54	0.63	0.46	0.37	0.63	0.69	0.27	0.60	0.32
OC		0.53	0.39		1.00	0.89	0.68	0.56	0.62	0.47	0.31	0.65	0.65	0.24	0.55	0.28
EC		0.67	0.37			1.00	0.53	0.45	0.62	0.42	0.45	0.54	0.71	0.29	0.65	0.39
NO_3^-		0.38	0.20				0.43	0.56	1.00	0.80	0.28	0.81	0.50	0.42	0.41	0.06
SO_4^{-2}		0.20	0.35				0.58	0.59		1.00	0.01	0.84	0.30	0.16	0.13	-0.10
NH_4^+		0.25	0.37				0.72	0.76			0.32	1.00	0.60	0.28	0.42	0.20
Metals		0.44	0.25				0.14	0.38			0.71		0.64	0.14	0.68	1.00

Table 2.43(h): Correlation Matrix for $PM_{2.5}$ and its composition for Winter (W) Season

DWK(W)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.34	0.36	0.76	0.79	0.65	0.82	0.76	0.85	0.75	0.56	0.93	0.61	0.31	0.07	0.37
TC		0.60	0.39	1.00	0.99	0.96	0.66	0.55	0.65	0.52	0.46	0.64	0.62	0.19	0.31	0.14
OC		0.53	0.39		1.00	0.89	0.70	0.56	0.65	0.52	0.41	0.66	0.59	0.17	0.24	0.16
EC		0.67	0.37			1.00	0.54	0.48	0.59	0.49	0.51	0.55	0.64	0.21	0.40	0.09
NO_3^-		0.38	0.25				0.65	0.60	1.00	0.78	0.48	0.87	0.47	0.06	-0.02	0.36
SO_4^{-2}		0.23	0.35				0.70	0.53		1.00	0.38	0.90	0.32	0.12	0.02	0.34
NH_4^+		0.25	0.36				0.78	0.67			0.51	1.00	0.50	0.22	0.00	0.35
Metals		-0.01	0.04				0.33	0.28			0.27		0.09	-0.16	-0.15	1.00

Table 2.44(i): Correlation Matrix for PM_{10} and its composition for Summer (S) Season

DWK (S)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	-0.32	-0.17	0.33	0.22	0.47	0.23	-0.05	0.73	0.72	0.16	0.21	0.47	0.55	0.62	0.81
TC		-0.12	0.04	1.00	0.97	0.90	-0.22	0.63	0.22	0.17	0.30	0.53	0.79	0.30	0.04	0.13
OC		-0.09	0.04		1.00	0.77	-0.25	0.57	0.10	0.04	0.25	0.42	0.71	0.24	0.00	0.07
EC		-0.15	0.04			1.00	-0.15	0.64	0.41	0.39	0.34	0.63	0.79	0.35	0.11	0.21
NO_3^-		-0.28	-0.08				0.54	-0.11	1.00	0.79	0.05	0.22	0.35	0.28	0.59	0.79
SO_4^{-2}		-0.31	0.02				0.61	-0.20		1.00	0.23	0.14	0.39	0.41	0.55	0.78
NH_4^+		-0.08	-0.21				-0.31	0.75			0.11	1.00	0.37	-0.02	-0.33	-0.14
Metals		-0.39	-0.13				0.62	-0.43			0.14		0.37	0.44	0.80	1.00

Table 2.45(j): Correlation Matrix for $PM_{2.5}$ and its composition for Summer (S) Season

DWK (S)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	-0.36	-0.26	0.32	0.25	0.38	0.41	0.01	0.65	0.73	0.07	0.27	0.54	0.35	0.38	0.59
TC		-0.12	0.04	1.00	0.96	0.91	-0.24	0.57	0.03	0.10	0.08	0.68	0.67	-0.01	-0.22	-0.06
OC		-0.09	0.04		1.00	0.77	-0.24	0.52	-0.06	-0.03	0.08	0.57	0.57	-0.05	-0.26	-0.07
EC		-0.15	0.04			1.00	-0.20	0.57	0.17	0.28	0.07	0.74	0.73	0.05	-0.14	-0.02
NO_3^-		-0.20	-0.03				0.60	-0.17	1.00	0.61	0.16	0.01	0.30	0.45	0.29	0.22
SO_4^{-2}		-0.21	-0.03				0.51	-0.20		1.00	0.08	0.03	0.51	0.17	0.35	0.63
NH_4^+		-0.06	-0.18				-0.36	0.79			0.08	1.00	0.54	0.00	-0.07	-0.25
Metals		-0.26	-0.14				0.25	-0.39			-0.07		0.18	0.02	0.33	1.00

2.4.4 Indian Spinal Injuries Centre, Vasantkunj (VKJ)

The sampling period for winter is December 15, 2013 to January 04, 2014and April 29, 2014 to May 19, 2014 for summer Season.

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

For sampling of PM_{10} and $PM_{2.5}$, the developed SOPs were followed. As a part of QA/QC, 20% of PM-laden filters (of PM_{10} and $PM_{2.5}$) were reconditioned for 24 hrs and reweighed. The variation in the concentration was less than 5%, which was acceptable.

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figures 2.42) and summer (Figure 2.43). The air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although winter conditions provide low dispersion and high concentrations, the levels of PM_{10} and $PM_{2.5}$ are alarmingly high even in summer. Average levels for winter and summer season are 315 and 252 μg/m^3 (for $PM_{2.5}$) and 548 and 410 μg/m^3 (for PM_{10}) respectively.

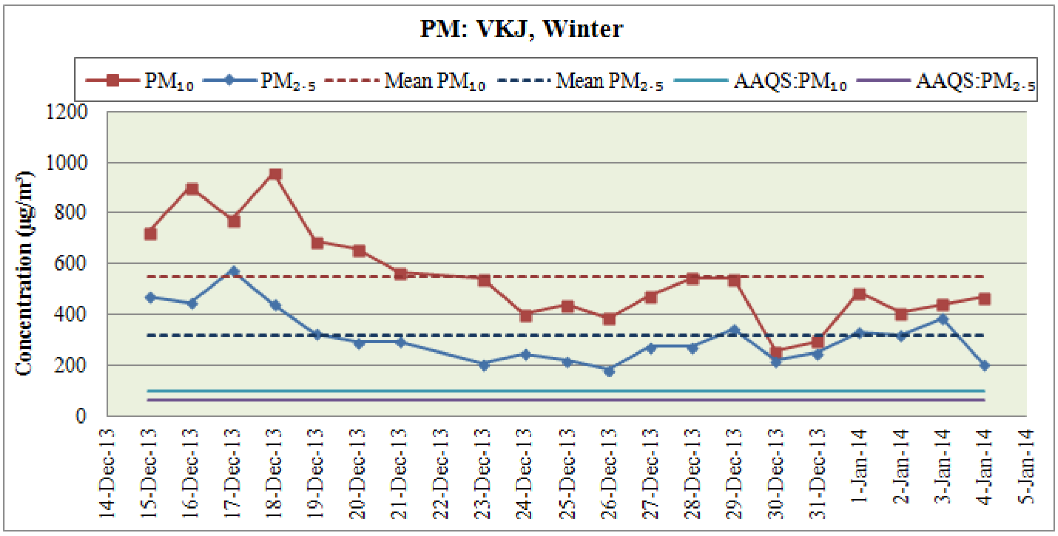


Figure 2.42: PM Concentrations at VKJ for Winter Season

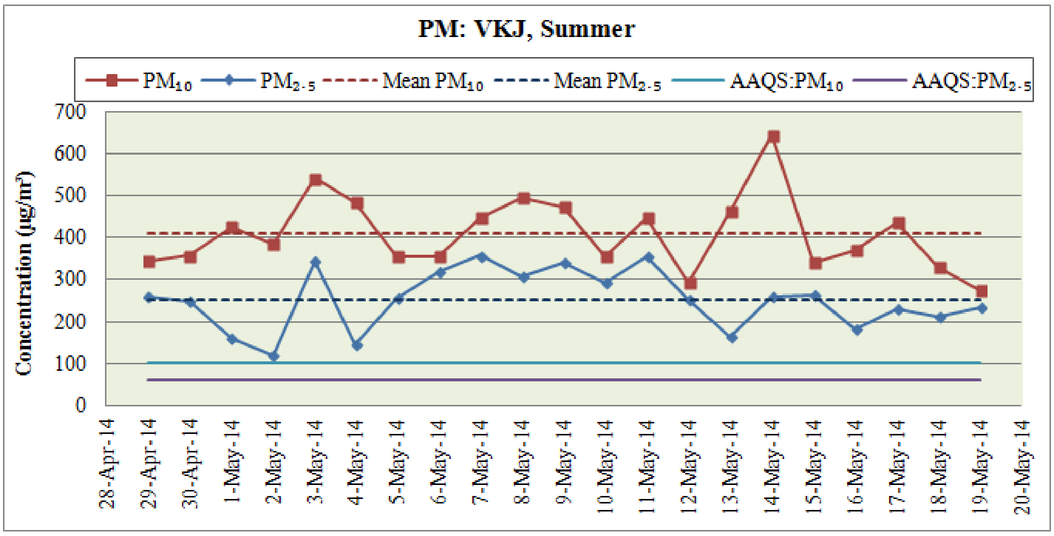


Figure 2.43: PM Concentrations at VKJ for Summer Season

2.4.4.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.44) and summer (Figure 2.45). It was observed that SO_2 concentrations were low and meet the air quality standard but NO_2 levels exceed the air quality standard. The average NO_2 concentration at VKJ was 78 µg/m^3 for winter and 47 µg/m^3 for summer season (Table 2.9 (c), (e)). The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. The NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets or open burning etc.

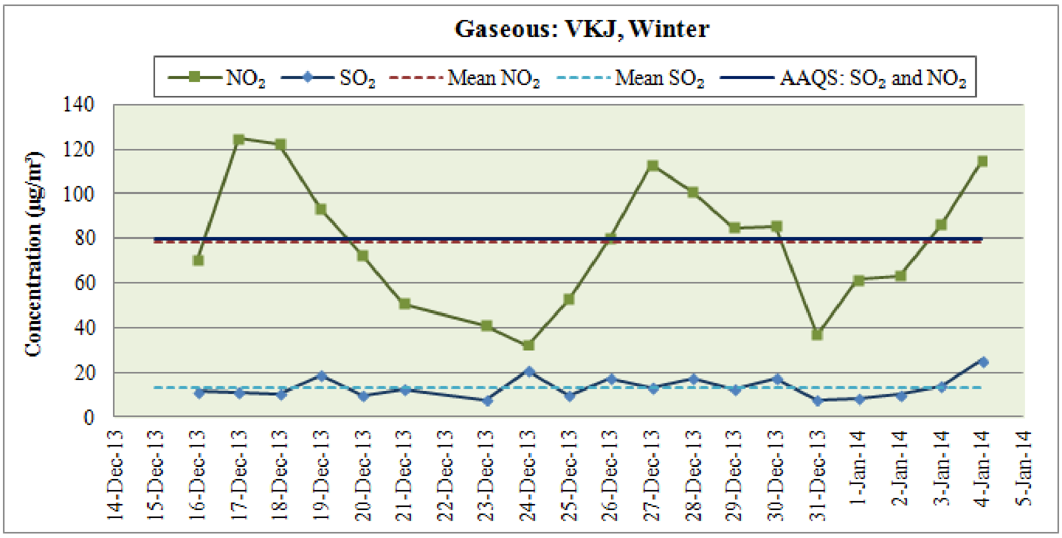


Figure 2.44: SO_2 and NO_2 Concentrations at VKJ for Winter Season

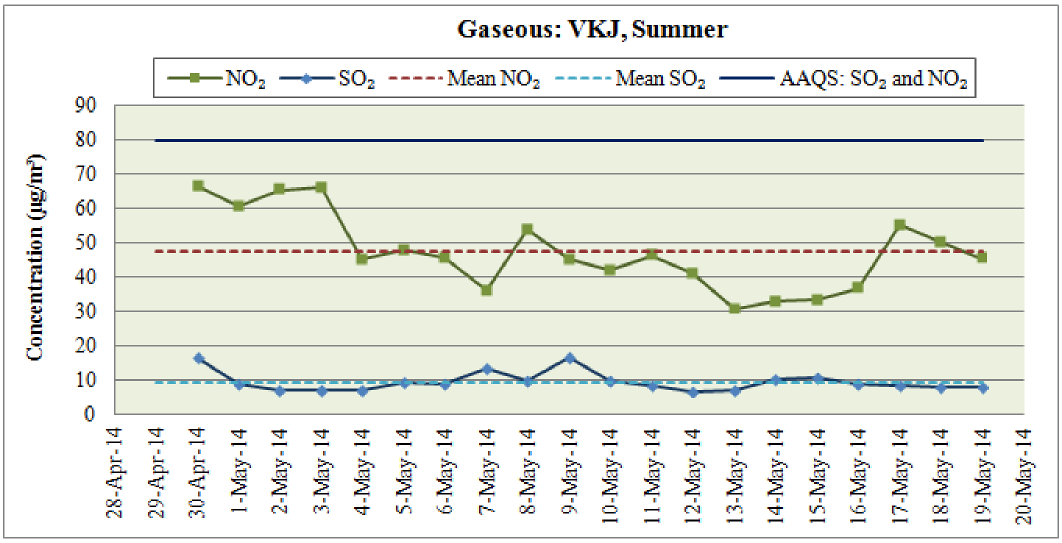


Figure 2.45: SO_2 and NO_2 Concentrations at VKJ for Summer Season

2.4.4.3 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs with some specific markers measured for winter and summer season. Figure 2.46 shows the measured concentration of some markers of PAHs at VKJ. The PAHs compounds analyzed are (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAHs concentrations are much higher in winter compared to summer season. Major PAHs are Phe (19 ng/m^3), B(b)F (11 ng/m^3), B(ghi)P (11 ng/m^3) and InP (9 ng/m^3) for winter season and B(ghi)P (1.6 ng/m^3), Phe (1.3 ng/m^3), B(b)F (1.3 ng/m^3) and Pyr (1.3 ng/m^3). The total PAHs were measured much higher in winter (87 ng/m^3) compared to summer (11 ng/m^3). A statistical summary of PAHs concentration is presented in Table 2.9 (a) for winter and summer season.

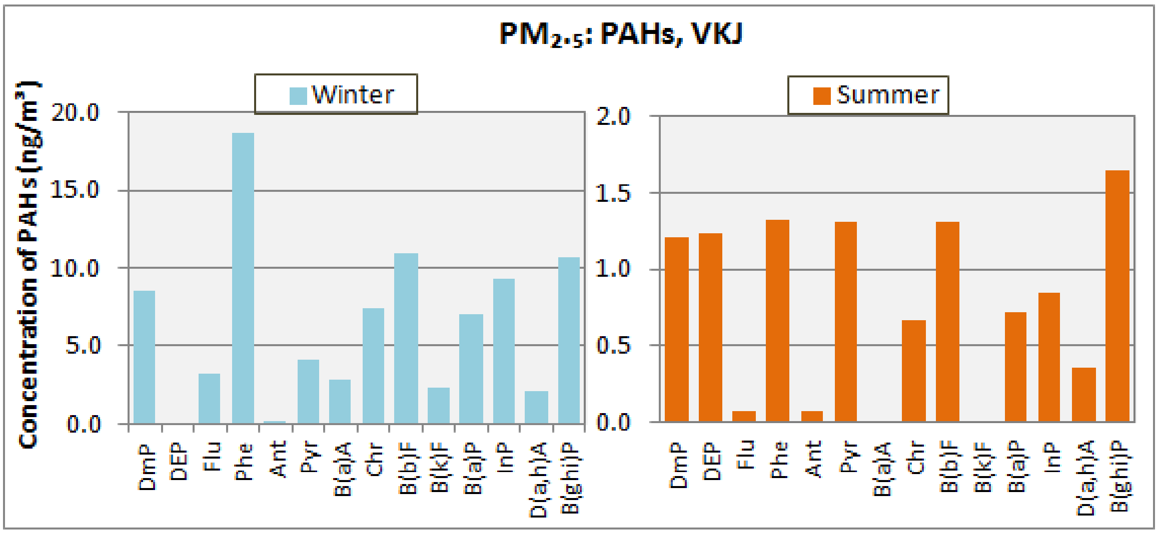


Figure 2.46: PAHs Concentrations in $PM_{2.5}$ at VKJ for winter and Summer Seasons

2.4.4.4 Elemental and Organic 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 2.47 (a) and (b) for winter and summer season. Organic carbon is observed higher than the elemental carbon. However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at VKJ. It is also observed that the OC and EC are higher in winter than 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 2.9 (b) for winter and summer seasons.

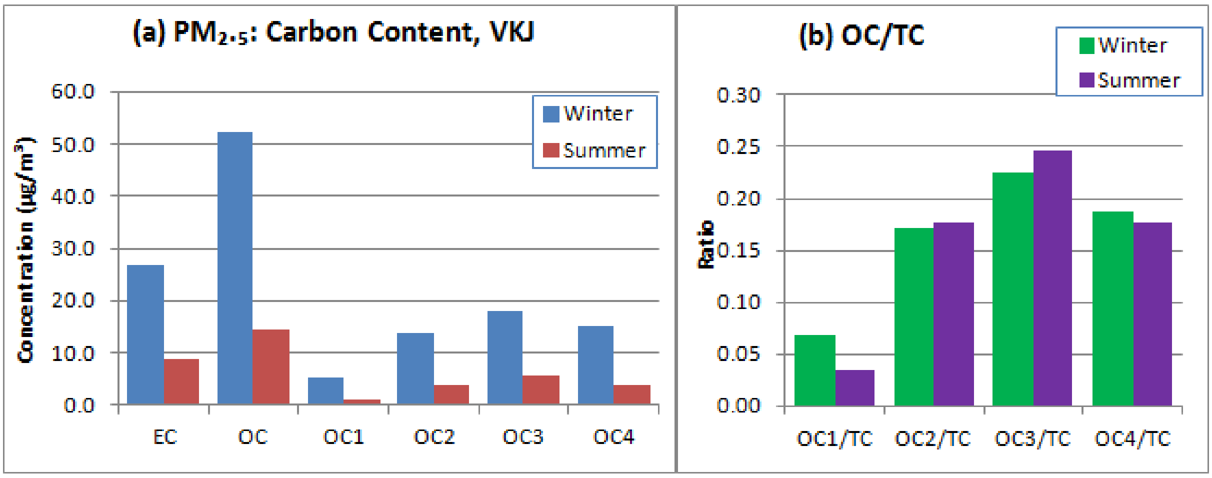


Figure 2.47: EC and OC Content in $PM_{2.5}$ at VKJ for Winter and Summer Seasons

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

Graphical presentations of chemical species are shown for winter and summer season for PM_{10} (Figure 2.48) and $PM_{2.5}$ (Figure 2.49). Statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of analysis 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) estimated in composition and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.9 (c), (d), (e) and (f) for winter and summer season. The correlation between different parameters (i.e PM, NO_2, SO_2, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.9 (g), (h), (i) and (j) 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 2.50 (a) and (b) for winter season and Figure 2.51 (a) and (b) for summer season.

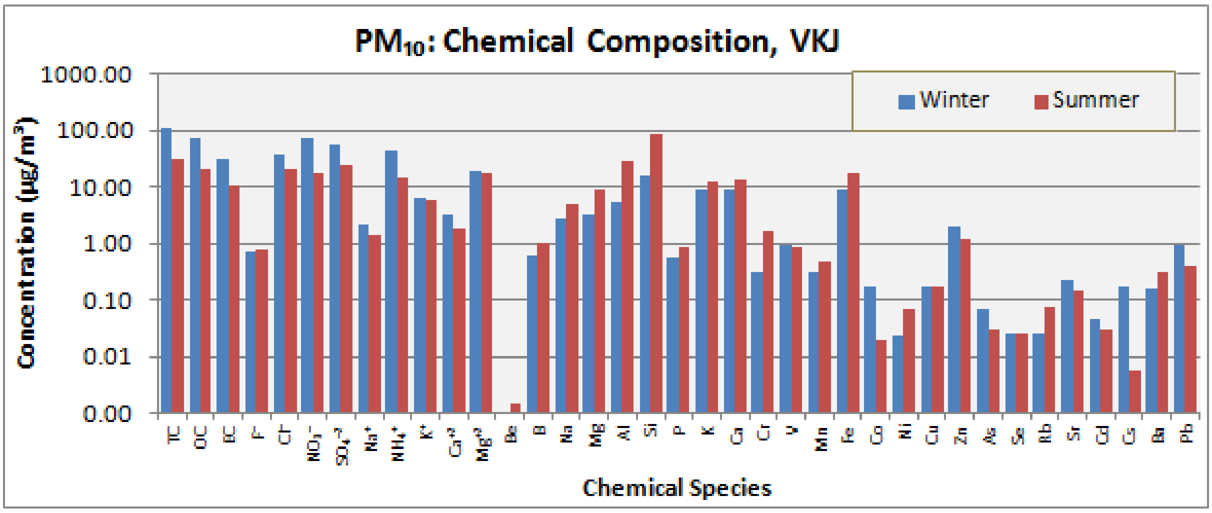


Figure 2.48: Concentrations of species in PM_{10} at VKJ for Winter and Summer Seasons

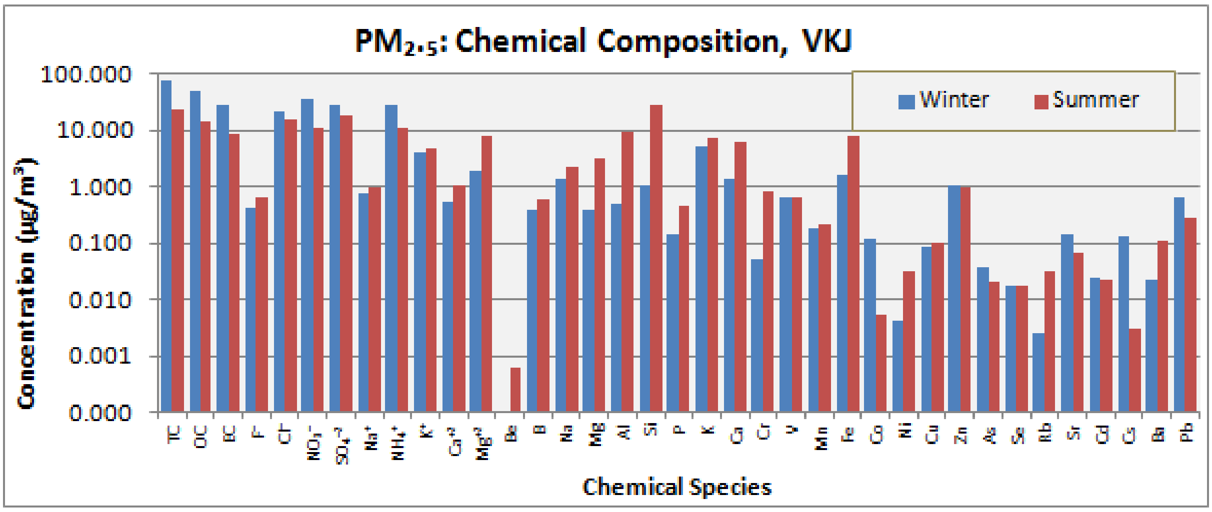


Figure 2.49: Concentrations of species in $PM_{2.5}$ at VKJ for Winter and Summer Seasons

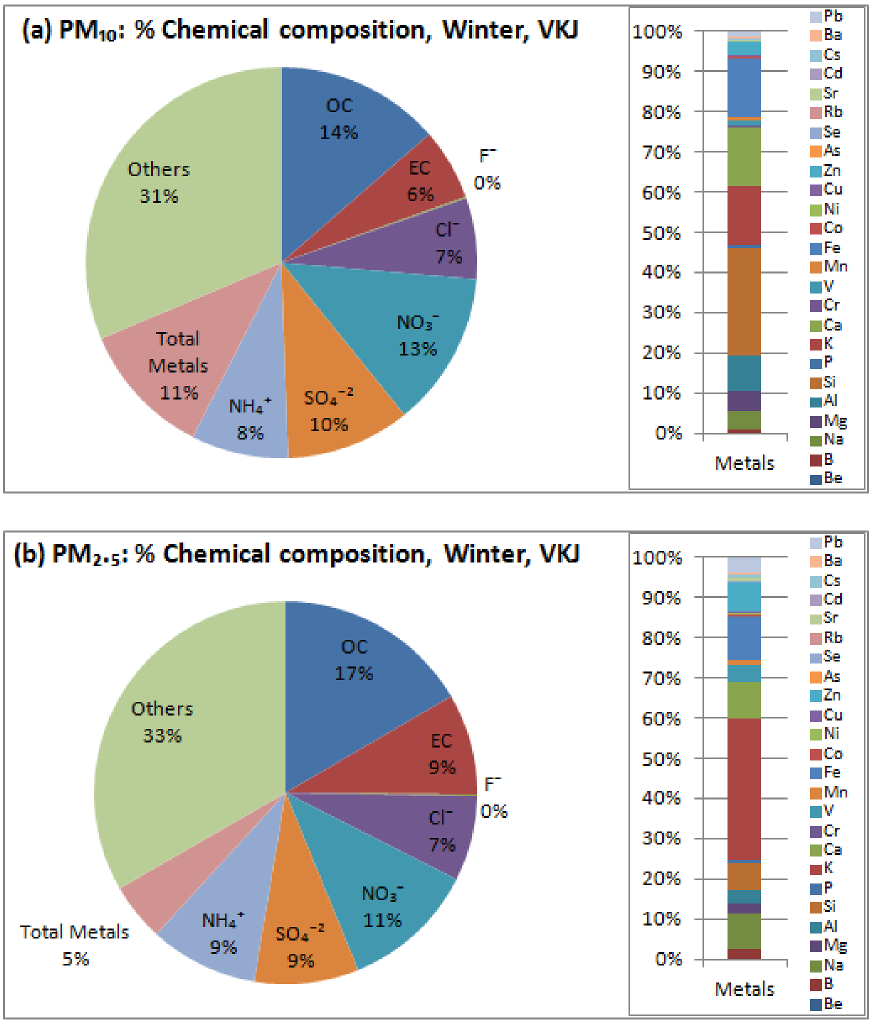


Figure 2.50: Percentage distribution of species in PM at VKJ for Winter Season

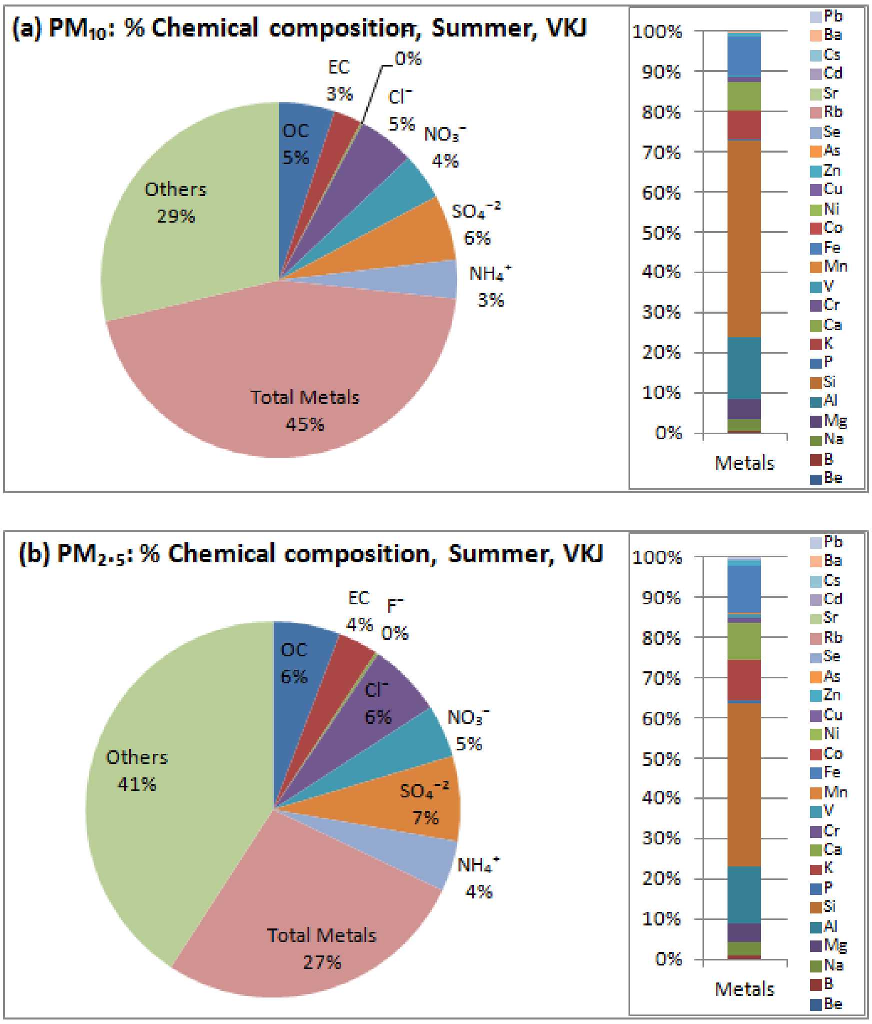


Figure 2.51: Percentage distribution of species in PM at VKJ for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. The graphical presentation is the better option for understanding the compositional variation. Compositional comparisons of $PM_{2.5}$ Vs PM_{10} for all species are shown for winter season (Figure 2.52) and summer season (Figure 2.53) at VKJ.

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 (57 %) than summer (61 %). The major species contributing to fine mode are TC, EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Sr, Cd, Cs and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, Fe and Ni.

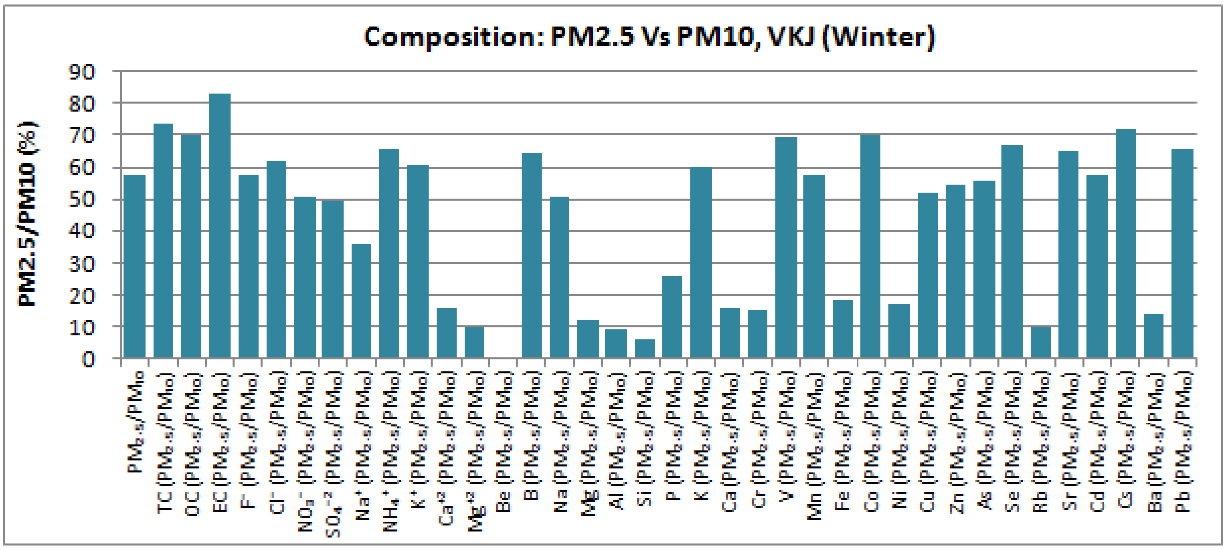


Figure 2.52: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at VKJ for Winter Season

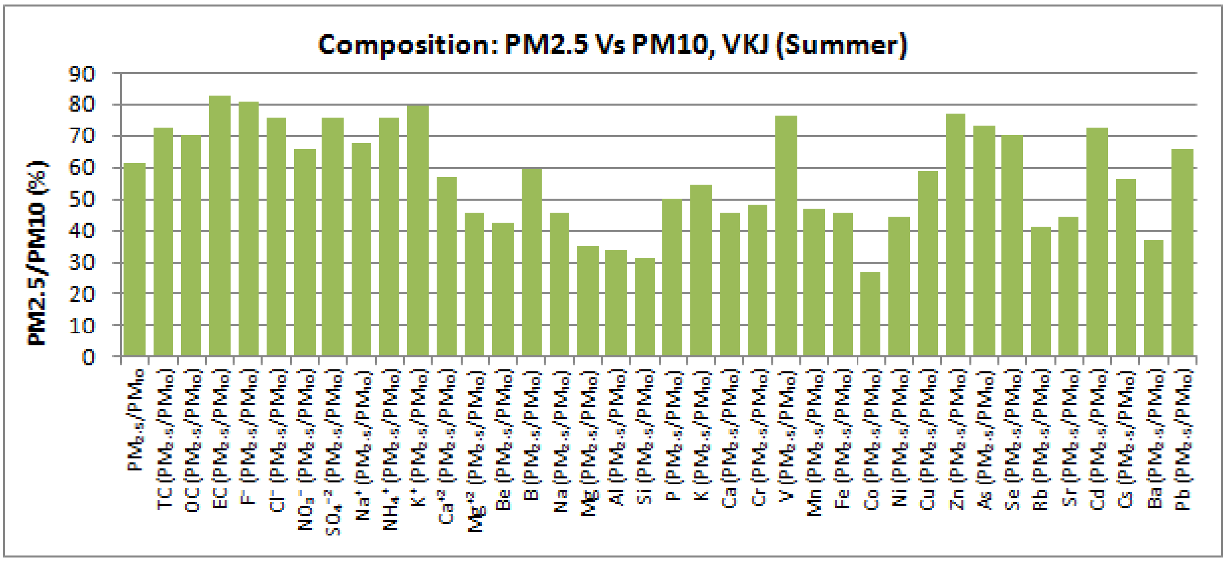


Figure 2.53: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at VKJ for Summer Season

Table 2.46(a): Statistical Results of PAHs (ng/m^3) in PM$_{2.5}$ at VKJ for Winter (W) and Summer (S) Seasons

VKJ(W)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	8.52	0.00	3.23	18.64	0.08	4.04	2.84	7.37	10.91	2.35	6.98	9.35	2.07	10.68	87.05
SD	7.22	0.00	2.68	12.99	0.14	1.88	2.52	3.68	4.92	1.16	4.66	5.84	2.28	5.05	31.11
Max	25.07	0.00	8.47	40.78	0.41	7.87	8.14	14.59	20.99	4.26	16.39	19.57	6.57	19.85	132.07
Min	2.36	0.00	0.78	6.33	0.00	1.65	0.32	3.11	4.73	0.81	2.14	0.95	0.00	3.91	30.83
CV	0.85	0.00	0.83	0.70	1.68	0.47	0.89	0.50	0.45	0.49	0.67	0.62	1.10	0.47	0.36
VKJ(S)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.21	1.23	0.07	1.33	0.07	1.31	0.00	0.66	1.31	0.00	0.72	0.84	0.36	1.64	10.75
SD	0.37	3.17	0.10	0.44	0.10	1.26	0.00	0.67	0.92	0.00	0.90	0.82	0.91	1.29	4.93
Max	2.05	10.17	0.33	2.17	0.27	4.40	0.00	2.33	3.27	0.00	3.03	2.59	2.91	4.35	18.06
Min	0.88	0.00	0.00	0.81	0.00	0.30	0.00	0.08	0.16	0.00	0.00	0.00	0.00	0.00	5.57
CV	0.30	2.58	1.45	0.33	1.53	0.96	0.00	1.01	0.70	0.00	1.25	0.97	2.55	0.78	0.46

Table 2.47(b): Statistical Results of Carbon Contents (µg/m^3) in PM$_{2.5}$ at VKJ for Winter (W) and Summer (S) Seasons

VKJ (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	315	79.1	26.9	52.2	5.4	13.6	18.0	15.2	0.068	0.171	0.226	0.188
Max	574	129.4	39.9	92.1	9.9	24.1	31.0	30.4	0.103	0.198	0.262	0.270
Min	181	37.5	16.0	19.9	1.8	6.2	7.7	4.2	0.042	0.154	0.204	0.103
SD	104	25.4	7.8	19.2	2.2	4.7	6.5	7.5	0.020	0.013	0.016	0.051
CV	0.33	0.32	0.29	0.37	0.41	0.35	0.36	0.49	0.292	0.076	0.073	0.272
VKJ (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	252	22.7	8.7	14.5	0.8	4.0	5.6	3.9	0.035	0.177	0.246	0.178
Max	357	53.6	20.2	33.3	3.2	8.7	15.0	7.8	0.064	0.269	0.361	0.245
Min	120	11.2	4.2	7.0	0.3	1.8	2.7	1.6	0.018	0.153	0.201	0.121
SD	71	11.5	4.3	7.1	0.7	1.9	3.1	1.6	0.012	0.025	0.034	0.030
CV	0.28	0.51	0.50	0.49	0.86	0.49	0.56	0.41	0.354	0.140	0.138	0.166

Table 2.48(c): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of PM_{10} at VKJ for Winter (W) Season

VKJ(W)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	548	78	13	74.6	32.4	0.74	36.73	70.33	56.32	2.16	43.92	6.59	3.28	18.40	0.00	0.61	2.66	3.20	5.42	16.19
Max	960	125	25	131.5	48.1	2.24	101.38	164.05	154.10	5.18	79.70	11.78	27.15	43.78	0.00	1.14	5.23	6.55	11.04	32.09
Min	254	32	8	28.5	19.2	0.20	11.18	27.18	13.57	0.85	20.71	3.47	0.28	3.54	0.00	0.32	1.31	1.10	1.72	4.60
SD	187	29	5	27.4	9.4	0.50	22.28	38.25	43.00	1.23	18.08	2.72	6.11	11.41	0.00	0.27	1.13	1.63	2.80	8.14
CV	0.34	0.37	0.36	0.37	0.29	0.68	0.61	0.54	0.76	0.57	0.41	0.41	1.86	0.62	0.00	0.43	0.42	0.51	0.52	0.50
VKJ(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.55	9.02	8.78	0.32	0.90	0.31	9.19	0.17	0.02	0.17	1.99	0.07	0.03	0.02	0.23	0.04	0.18	0.16	0.96	69.9
Max	1.06	23.87	19.19	0.68	3.11	0.73	20.85	0.59	0.06	0.35	4.59	0.26	0.06	0.06	0.66	0.17	0.61	0.35	4.59	92.7
Min	0.14	4.46	2.87	0.11	0.23	0.12	3.91	0.05	0.01	0.05	0.66	0.02	0.01	0.01	0.09	0.00	0.05	0.05	0.13	53.2
SD	0.28	4.56	4.57	0.16	0.67	0.17	4.91	0.13	0.02	0.09	1.04	0.06	0.01	0.02	0.14	0.04	0.13	0.09	0.99	12.3
CV	0.51	0.51	0.52	0.51	0.75	0.54	0.53	0.75	0.65	0.54	0.52	0.82	0.49	0.62	0.63	0.95	0.75	0.58	1.03	0.18

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

Table 2.49(d): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of $PM_{2.5}$ at VKJ for Winter (W) Season

VKJ(W)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	315	78	13	52.2	26.9	0.43	22.68	35.77	27.73	0.78	28.77	3.98	0.53	1.86	0.00	0.40	1.36	0.39	0.51	1.02
Max	574	125	25	92.1	39.9	1.22	56.11	91.11	61.44	2.12	53.16	7.61	4.39	8.03	0.00	0.81	3.18	1.57	1.62	3.15
Min	181	32	8	19.9	16.0	0.11	6.48	15.45	6.30	0.19	10.36	2.27	0.08	0.25	0.00	0.14	0.57	0.13	0.20	0.35
SD	104	29	5	19.2	7.8	0.30	15.49	20.47	17.20	0.54	12.43	1.69	0.97	1.80	0.00	0.19	0.63	0.35	0.35	0.64
CV	0.33	0.37	0.36	0.37	0.29	0.70	0.68	0.57	0.62	0.69	0.43	0.43	1.83	0.97	0.00	0.48	0.47	0.91	0.68	0.63
VKJ(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.14	5.43	1.40	0.05	0.62	0.18	1.68	0.12	0.00	0.09	1.08	0.04	0.02	0.00	0.15	0.03	0.13	0.02	0.63	67.4
Max	0.30	11.75	2.67	0.12	1.41	0.37	3.79	0.28	0.02	0.23	3.20	0.15	0.03	0.01	0.33	0.13	0.28	0.17	3.30	92.8
Min	0.04	2.20	0.60	0.02	0.22	0.07	0.59	0.04	0.00	0.01	0.46	0.01	0.01	0.00	0.05	0.00	0.04	0.00	0.12	51.2
SD	0.08	2.59	0.70	0.03	0.37	0.10	1.07	0.07	0.00	0.06	0.68	0.03	0.01	0.00	0.09	0.03	0.08	0.03	0.70	11.1
CV	0.56	0.48	0.50	0.60	0.60	0.54	0.64	0.63	1.09	0.69	0.63	0.90	0.43	1.06	0.59	1.12	0.61	1.53	1.11	0.16

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

Table 2.50(e): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of PM_{10} at VKJ for Summer (S) Season

VKJ(S)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	410	47	10	20.8	10.5	0.77	21.15	17.42	24.46	1.40	14.53	6.10	1.87	17.95	0.00	0.99	4.86	9.32	28.52	89.33
Max	645	67	17	47.6	24.4	1.70	95.74	52.90	50.50	2.72	69.83	17.82	7.93	31.80	0.00	1.91	7.19	21.47	47.56	150.45
Min	275	31	7	10.0	5.1	0.41	1.78	6.50	10.53	0.47	1.74	1.76	0.50	10.93	0.00	0.18	2.79	3.73	12.34	30.59
SD	89	11	3	10.2	5.2	0.32	20.57	10.84	10.35	0.66	15.87	4.06	1.85	5.37	0.00	0.48	1.34	3.75	9.97	29.56
CV	0.22	0.23	0.31	0.49	0.50	0.42	0.97	0.62	0.42	0.47	1.09	0.66	0.99	0.30	0.69	0.48	0.27	0.40	0.35	0.33
VKJ(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.89	12.95	13.29	1.71	0.87	0.46	17.25	0.02	0.07	0.18	1.23	0.03	0.02	0.08	0.15	0.03	0.01	0.30	0.41	73.0
Max	1.59	22.03	20.63	2.93	1.35	0.84	28.80	0.11	0.23	0.51	2.99	0.07	0.07	0.12	0.23	0.13	0.02	0.52	1.02	91.0
Min	0.14	5.63	5.50	0.54	0.43	0.11	4.59	0.00	0.03	0.06	0.64	0.01	0.01	0.03	0.06	0.01	0.00	0.10	0.11	41.4
SD	0.40	4.73	3.75	0.48	0.26	0.20	6.25	0.03	0.04	0.13	0.58	0.02	0.01	0.03	0.05	0.03	0.00	0.11	0.24	13.3
CV	0.45	0.37	0.28	0.28	0.29	0.44	0.36	1.52	0.61	0.70	0.47	0.58	0.59	0.33	0.32	1.05	0.66	0.35	0.59	0.18

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

Table 2.51(f): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of $PM_{2.5}$ at VKJ for Summer (S) Season

VKJ(S)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	252	47	10	14.5	8.7	0.62	16.08	11.46	18.54	0.94	10.98	4.87	1.06	8.18	0.00	0.59	2.22	3.27	9.61	27.72
Max	357	67	17	33.3	20.2	1.09	68.41	28.47	42.44	2.33	53.39	12.25	7.05	17.98	0.00	1.24	5.84	6.91	18.71	54.88
Min	120	31	7	7.0	4.2	0.23	0.72	3.95	1.27	0.17	1.41	1.32	0.06	1.80	0.00	0.04	0.48	0.63	2.88	8.38
SD	71	11	3	7.1	4.3	0.24	15.87	5.78	10.01	0.55	12.29	3.06	1.56	5.23	0.00	0.35	1.28	2.13	4.73	14.02
CV	0.28	0.23	0.31	0.49	0.50	0.39	0.99	0.50	0.54	0.58	1.12	0.63	1.47	0.64	0.77	0.60	0.58	0.65	0.49	0.51
VKJ(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.45	7.03	6.10	0.83	0.66	0.22	7.93	0.01	0.03	0.11	0.95	0.02	0.02	0.03	0.07	0.02	0.00	0.11	0.27	59.8
Max	1.26	17.43	10.81	1.64	1.07	0.53	17.25	0.01	0.07	0.27	2.40	0.05	0.05	0.08	0.17	0.11	0.01	0.28	0.59	89.4
Min	0.08	0.46	1.44	0.11	0.34	0.07	1.99	0.00	0.01	0.02	0.35	0.00	0.00	0.01	0.01	0.01	0.00	0.04	0.07	43.5
SD	0.31	4.03	3.09	0.42	0.20	0.12	4.91	0.00	0.02	0.07	0.48	0.01	0.01	0.02	0.04	0.02	0.00	0.06	0.17	11.6
CV	0.69	0.57	0.51	0.51	0.30	0.56	0.62	0.70	0.57	0.65	0.51	0.69	0.65	0.66	0.64	1.12	1.03	0.58	0.61	0.19

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

Table 2.52(g): Correlation Matrix for PM_{10} and its composition for Winter (W) Season

VKJ (W)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.43	-0.21	0.73	0.76	0.52	0.54	0.02	0.74	0.58	0.74	0.75	0.79	0.53	0.65	0.60
TC		0.63	0.03	1.00	0.98	0.84	0.27	-0.20	0.33	0.15	0.44	0.19	0.43	0.30	0.34	0.22
OC		0.57	0.02		1.00	0.72	0.34	-0.25	0.39	0.23	0.49	0.26	0.48	0.33	0.37	0.25
EC		0.65	0.06			1.00	0.01	-0.01	0.08	-0.09	0.20	-0.04	0.17	0.16	0.20	0.06
NO_3^-		0.42	0.04				0.61	-0.08	1.00	0.78	0.72	0.85	0.84	0.40	0.68	0.66
SO_4^{-2}		0.07	-0.17				0.87	-0.14		1.00	0.56	0.78	0.64	0.20	0.43	0.50
NH_4^+		0.15	-0.26				0.63	0.27			0.67	1.00	0.86	0.43	0.57	0.56
Metals		0.35	0.17				0.47	0.11			0.57		0.72	0.19	0.65	1.00

Table 2.53(h): Correlation Matrix for $PM_{2.5}$ and its composition for Winter (W) Season

VKJ (W)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.45	-0.33	0.79	0.77	0.70	0.37	0.12	0.68	0.59	0.53	0.70	0.66	0.27	-0.04	0.61
TC		0.64	0.04	1.00	0.98	0.85	0.52	-0.13	0.49	0.37	0.66	0.41	0.60	0.32	0.16	0.54
OC		0.57	0.02		1.00	0.72	0.61	-0.22	0.56	0.44	0.72	0.46	0.64	0.36	0.24	0.60
EC		0.65	0.06			1.00	0.19	0.11	0.24	0.11	0.37	0.19	0.38	0.16	-0.06	0.28
NO_3^-		0.22	-0.19				0.53	-0.06	1.00	0.73	0.56	0.88	0.87	0.61	0.26	0.85
SO_4^{-2}		0.17	-0.30				0.54	-0.24		1.00	0.31	0.83	0.55	0.29	0.33	0.80
NH_4^+		0.14	-0.30				0.42	0.19			0.49	1.00	0.82	0.45	0.27	0.83
Metals		0.31	-0.19				0.63	-0.11			0.41		0.76	0.29	0.29	1.00

Table 2.54(i): Correlation Matrix for PM_{10} and its composition for Summer (S) Season

VKJ (S)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	-0.03	0.09	0.07	0.10	0.03	-0.22	0.48	-0.18	0.24	-0.05	0.41	0.03	-0.46	-0.43	0.11
TC		0.15	0.85	1.00	0.99	0.97	-0.22	0.16	-0.31	0.07	0.55	0.15	0.53	0.11	0.09	0.04
OC		0.21	0.81		1.00	0.94	-0.22	0.19	-0.31	0.07	0.58	0.17	0.54	0.09	0.11	0.05
EC		0.01	0.88			1.00	-0.21	0.11	-0.29	0.05	0.47	0.11	0.48	0.15	0.06	0.03
NO_3^-		-0.31	-0.10				0.50	0.18	1.00	0.20	0.02	0.10	-0.25	0.31	0.19	-0.58
SO_4^{-2}		-0.15	0.13				0.50	0.25		1.00	0.31	0.60	0.53	-0.05	-0.05	-0.20
NH_4^+		-0.18	0.14				0.09	0.62			0.35	1.00	0.58	-0.09	-0.20	-0.25
Metals		0.45	-0.13				-0.17	-0.48			-0.13		0.05	-0.29	0.23	1.00

Table 2.55(j): Correlation Matrix for $PM_{2.5}$ and its composition for Summer (S) Season

VKJ (S)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	-0.09	0.45	0.31	0.36	0.40	0.26	0.26	-0.01	0.41	0.07	0.32	0.43	0.04	0.23	0.61
TC		0.04	0.88	1.00	0.96	0.97	-0.15	0.25	-0.26	-0.05	0.46	0.19	0.66	-0.07	0.16	-0.16
OC		0.21	0.81		1.00	0.94	-0.19	0.24	-0.33	-0.06	0.47	0.20	0.64	-0.11	0.07	-0.10
EC		0.01	0.88			1.00	-0.16	0.18	-0.27	-0.06	0.42	0.13	0.59	-0.04	0.18	-0.04
NO_3^-		-0.34	-0.10				0.38	0.08	1.00	0.00	-0.11	-0.07	-0.34	0.42	0.01	-0.07
SO_4^{-2}		0.01	0.11				0.37	-0.08		1.00	0.11	0.38	0.43	0.00	0.12	0.43
NH_4^+		-0.19	0.15				0.20	0.68			0.27	1.00	0.53	-0.15	0.08	0.18
Metals		0.17	-0.02				0.40	-0.18			0.18		0.23	0.30	0.51	1.00

2.4.5 Arwachin International School, Dilshad Garden (DSG)

The sampling period for winter is January 24, 2014 to February 13, 2014 and May 26, 2014 to June 14, 2014 for summer season.

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

For sampling of PM_{10} and $PM_{2.5}$, the developed SOPs were followed. As a part of QA/QC, 20% of PM-laden filters (of PM_{10} and $PM_{2.5}$) were reconditioned for 24 hrs and reweighed. The variation in the concentration was less than 5%, which was acceptable.

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figures 2.54) and summer (Figure 2.55). The air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although winter conditions provide low dispersion and high concentrations, the levels of PM_{10} and $PM_{2.5}$ are alarmingly high even in summer. Average levels for winter and summer season are 435 and 276 μg/m^3 (for $PM_{2.5}$) and 675 and 503 μg/m^3 (for PM_{10}) respectively

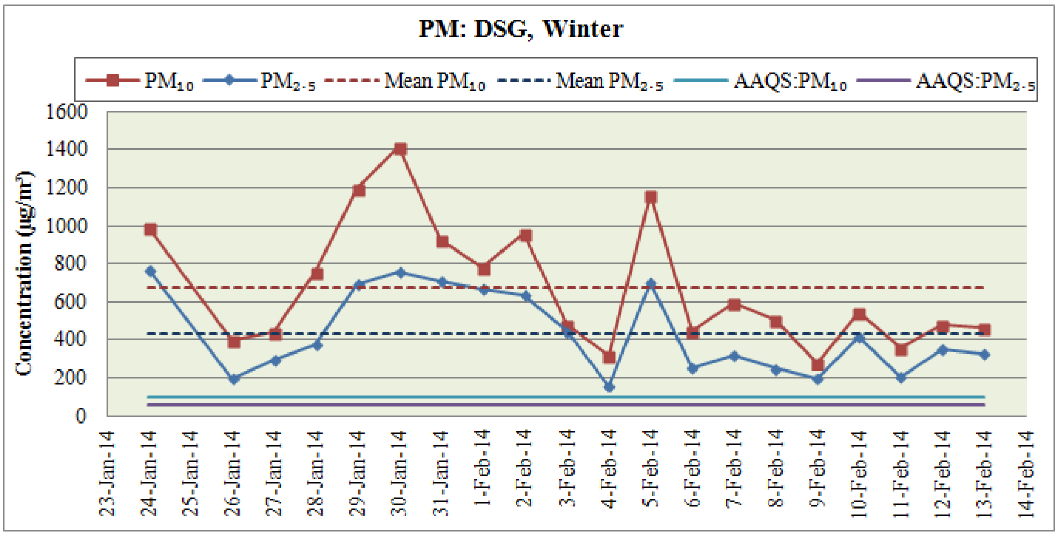


Figure 2.54: PM Concentrations at DSG for Winter Season

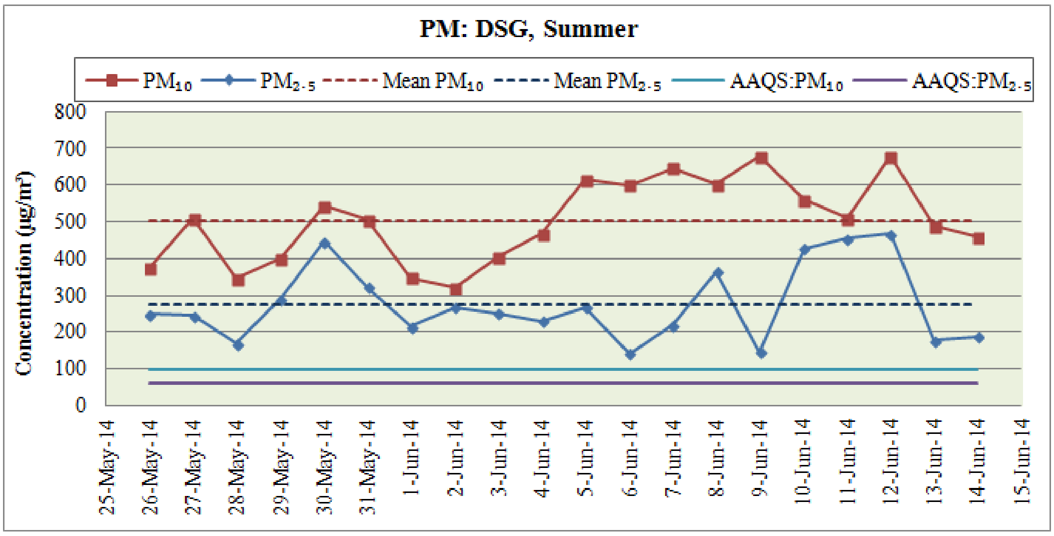


Figure 2.55: PM Concentrations at DSG for Summer Season

2.4.5.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.56) and summer (Figure 2.57). It was observed that SO_2 concentrations were low and meet the air quality standard. NO_2 levels also exceed the air quality standard. The average NO_2 concentration at DSG was 75 µg/m^3 for winter and 69 µg/m^3 for summer season (Table 2.10 (c), (e)). The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. The NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets or open burning etc.

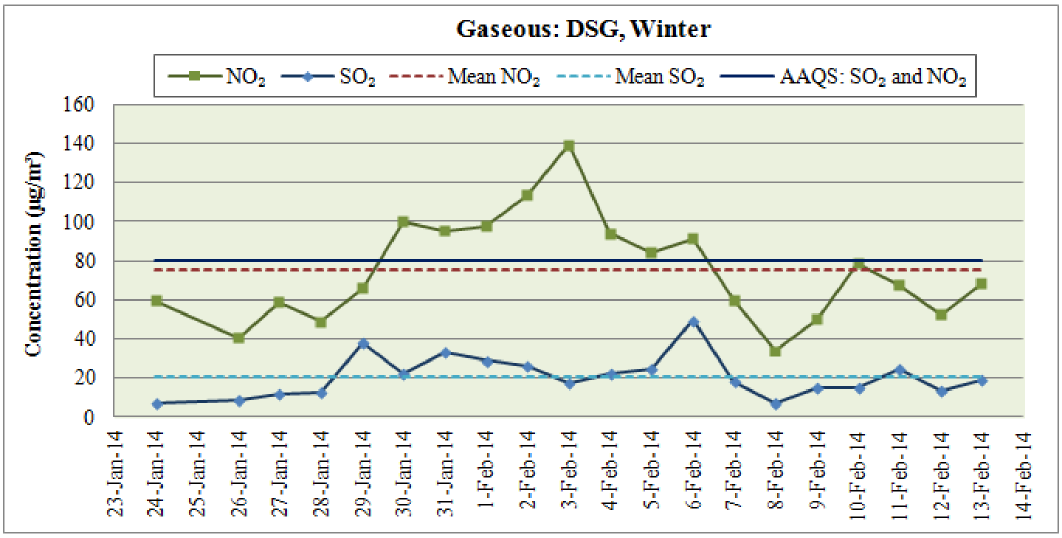


Figure 2.56: SO_2 and NO_2 Concentrations at DSG for Winter Season

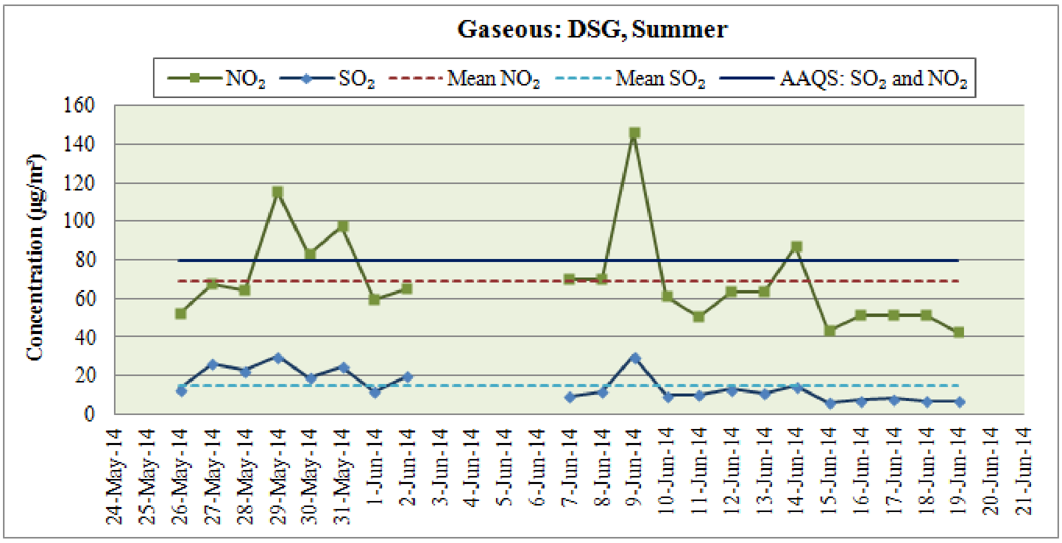


Figure 2.57: SO_2 and NO_2 Concentrations at DSG for Summer Season

2.4.5.3 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs with some specific markers measured for winter and summer season. Figure 2.58 shows the measured concentration of some markers of PAHs at DSG. The PAHs compounds analyzed are (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAHs concentrations are much higher (46 ng/m^3) in winter than in summer season (10 ng/m^3). Major PAHs are Phe (12 ng/m^3), B(ghi)P (6 ng/m^3), B(b)F (6 ng/m^3) and InP (4 ng/m^3) for winter season and B(ghi)P (2.7 ng/m^3), B(b)F (1.8 ng/m^3), InP (1.7 ng/m^3) and Phe (1.1 ng/m^3). The total PAHs were measured higher in winter (46 ng/m^3) compared to summer (11 ng/m^3). A statistical summary of PAHs concentration is presented in Table 2.10 (a) for winter and summer season.

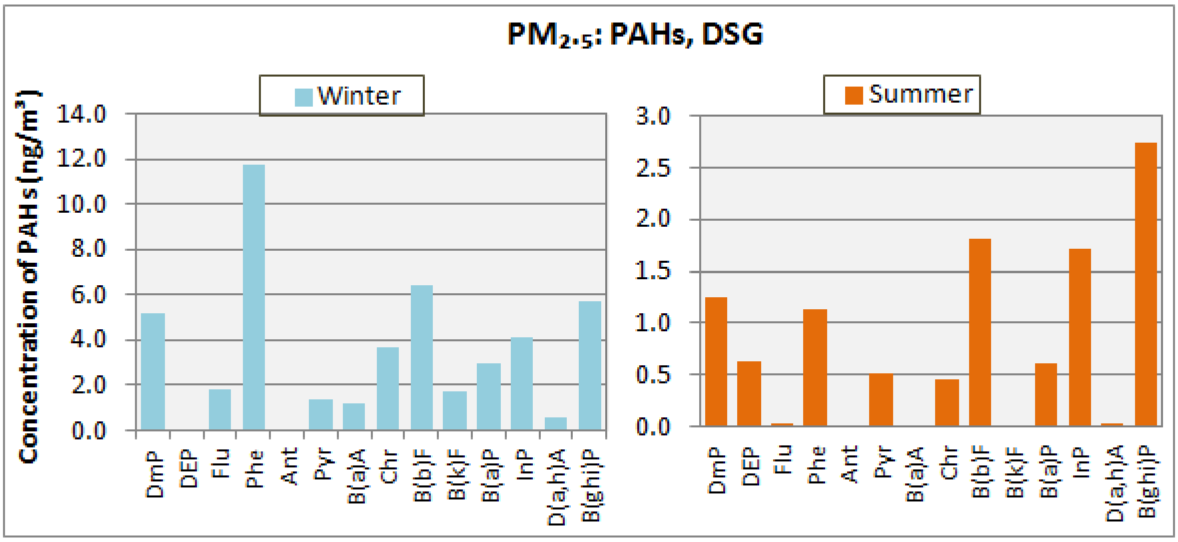


Figure 2.58: PAHs Concentrations in $PM_{2.5}$ at DSG for winter and Summer Seasons

2.4.5.4 Elemental and Organic 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 2.59 (a) and (b) for winter and summer season. Organic carbon is observed higher than the elemental carbon. However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at DSG. It is also observed that the OC and EC are higher in winter than 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 2.10 (b) for winter and summer seasons.

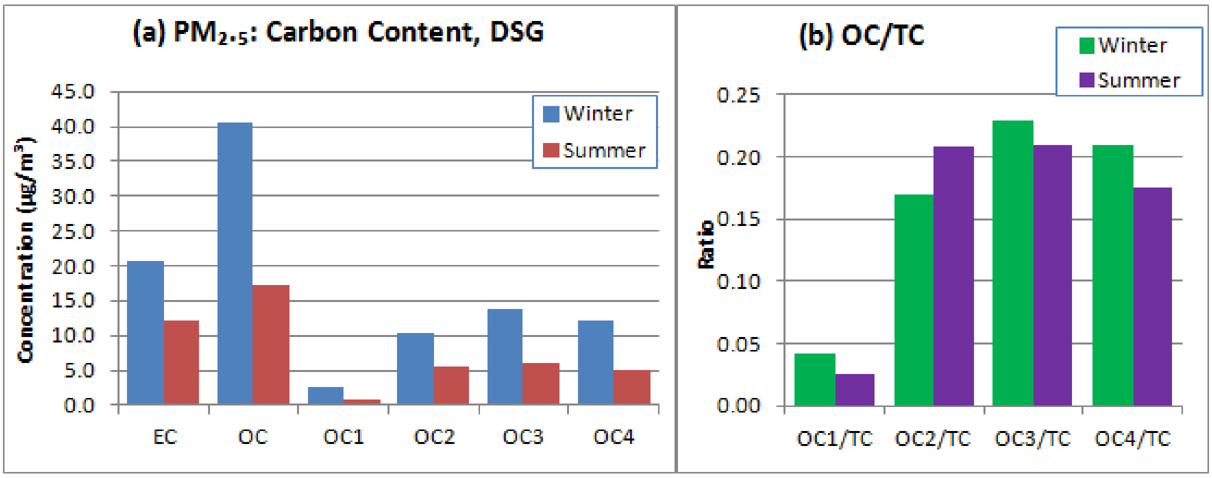


Figure 2.59: EC and OC Content in $PM_{2.5}$ at DSG for Winter and Summer Seasons

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

Graphical presentation of chemical species are shown for winter and summer season for PM_{10} (Figure 2.60) and $PM_{2.5}$ (Figure 2.61). Statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of analysis 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) estimated in composition and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.10 (c), (d), (e) and (f) for winter and summer season. The correlation between different parameters (i.e PM, NO_2, SO_2, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.10 (g), (h), (i) and (j) 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 2.62 (a) and (b) for winter season and Figure 2.63 (a) and (b) for summer season.

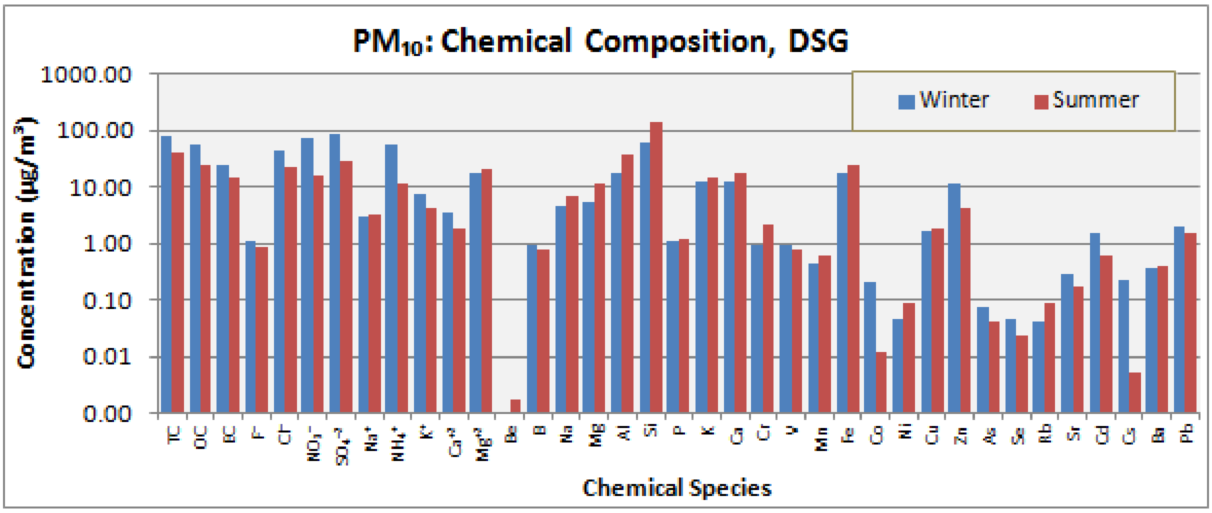


Figure 2.60: Concentrations of species in PM_{10} at DSG for Winter and Summer Seasons

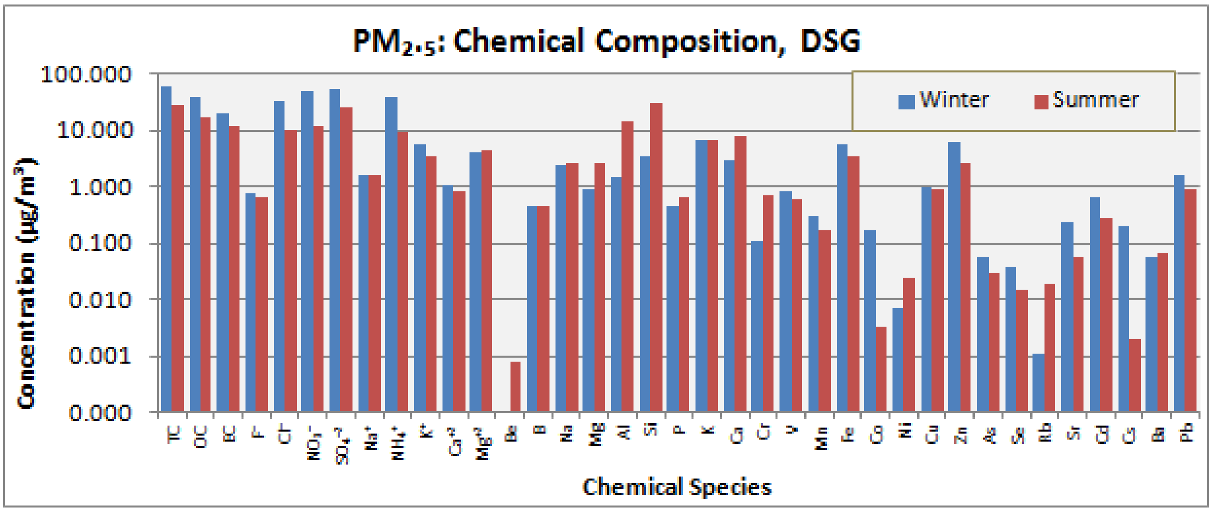


Figure 2.61: Concentrations of species in $PM_{2.5}$ at DSG for Winter and Summer Seasons

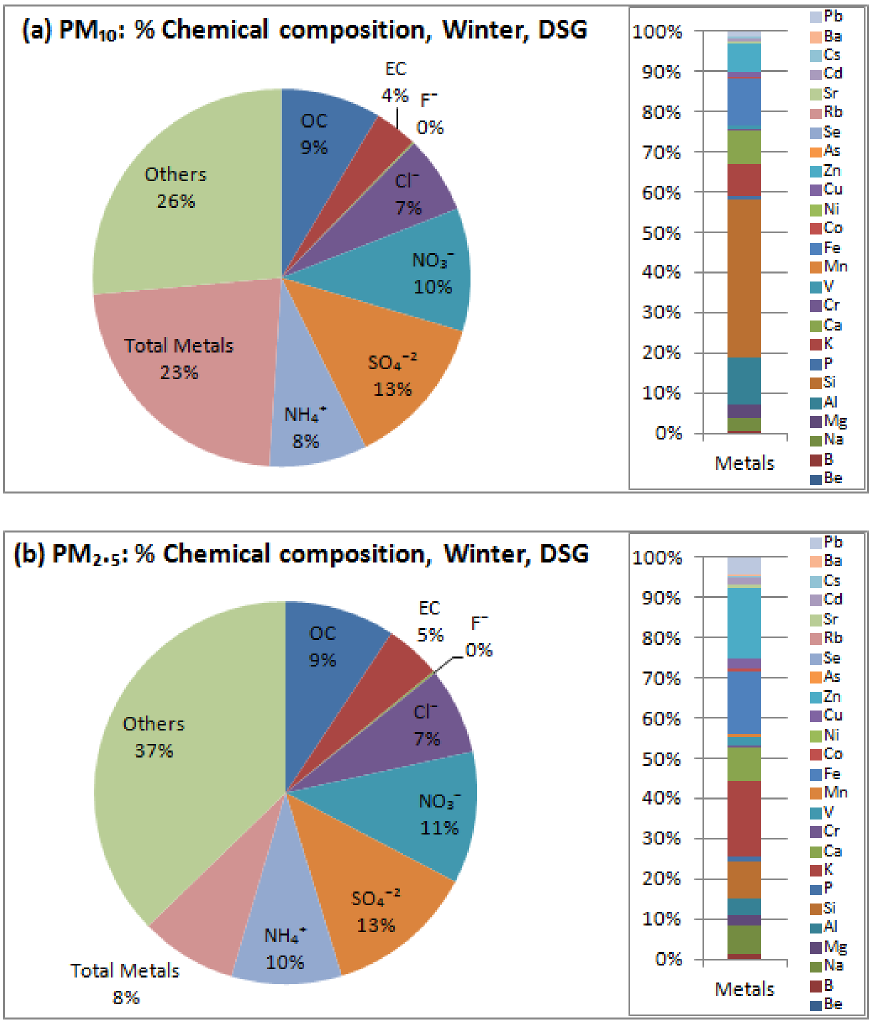
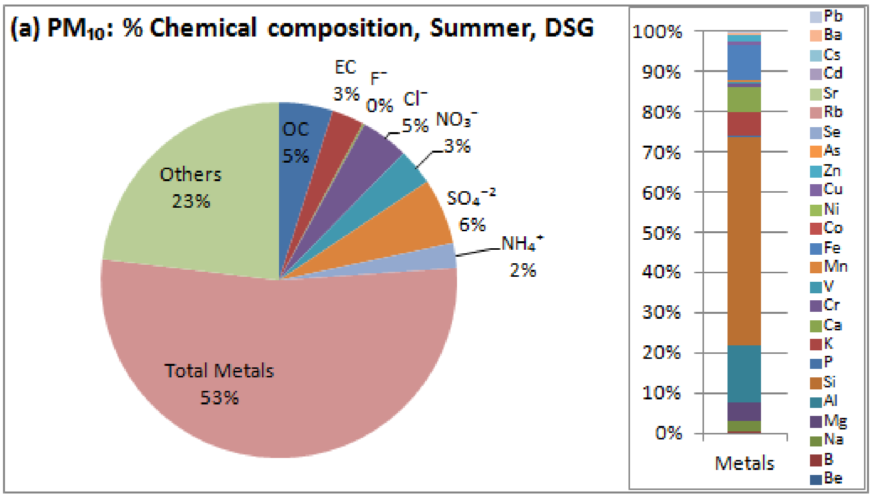


Figure 2.62: Percentage distribution of species in PM at DSG for Winter Season



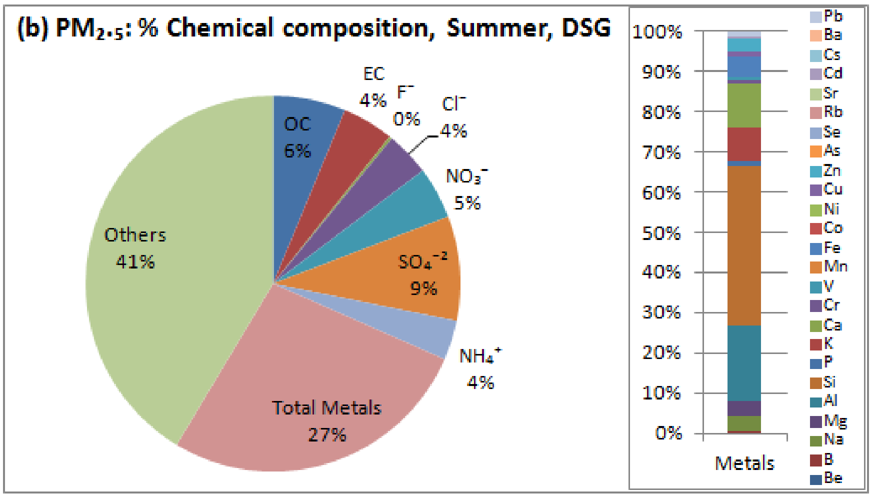


Figure 2.63: Percentage distribution of species in PM at DSG for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. The graphical presentation is the better option for understanding the compositional variation. Compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species are shown for winter season (Figure 2.64) and summer season (figure 2.65) at DSG.

The chemical species considered for the comparisons are carbon content (TC, OC and EC), ionic species (F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2}) and elements (Be, B, Na, Mg, Al, Si, P, K, Ca, Cr, V, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Rb, Sr, Cd, Cs, Ba, Pb). It is concluded that most portion of PM is having fine mode during winter (64 %) than summer (65 %). The major species contributing to fine mode are TC, EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Sr, Cd, Cs and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, Fe and Ni.

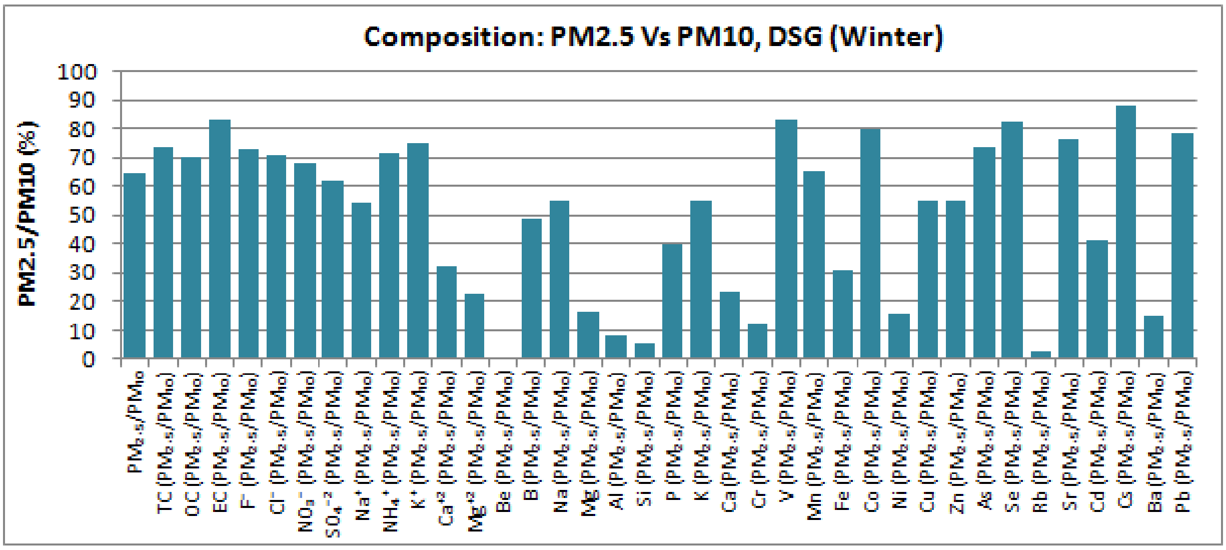


Figure 2.64: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at DSG for Winter Season

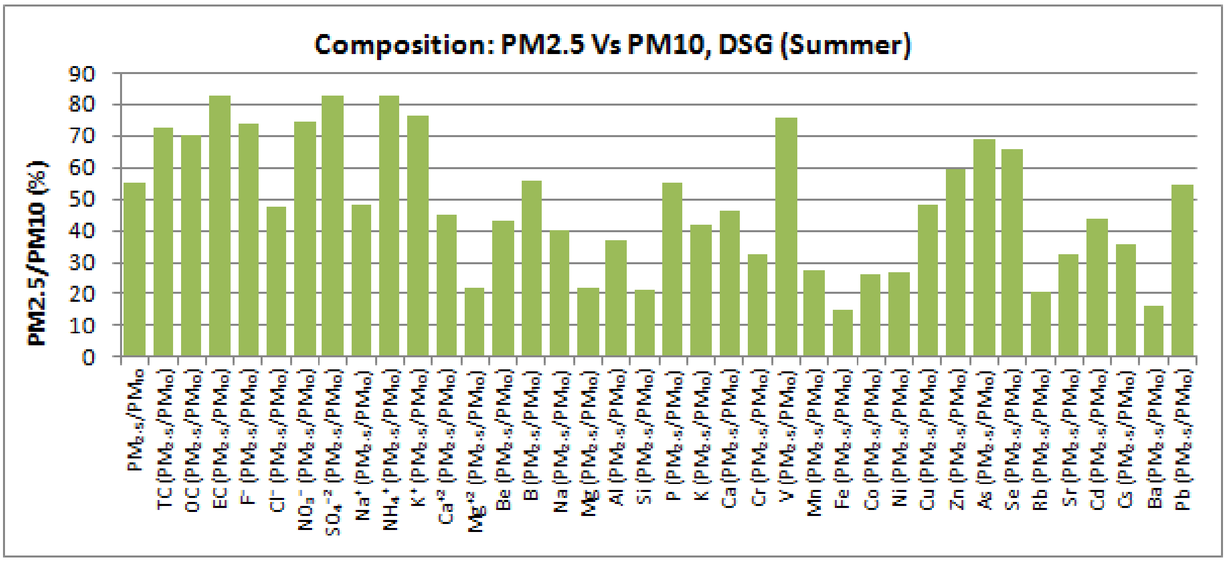


Figure 2.65: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at DSG for Summer Season

Table 2.56(a): Statistical Results of PAHs (ng/m^3) in PM$_{2.5}$ at DSG for Winter (W) and Summer (S) Seasons

DSG(W)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	5.16	0.00	1.80	11.71	0.00	1.35	1.15	3.68	6.46	1.74	2.98	4.13	0.54	5.68	46.40
SD	3.57	0.00	1.07	6.19	0.00	0.48	0.96	2.17	3.62	0.94	1.94	3.09	0.67	3.02	19.27
Max	9.72	0.00	3.92	22.94	0.00	2.34	2.94	7.88	14.35	3.88	7.24	10.45	2.08	12.85	88.03
Min	0.76	0.00	0.38	4.30	0.00	0.81	0.00	1.86	3.36	0.58	0.73	0.00	0.00	2.64	25.39
CV	0.69	0.00	0.59	0.53	0.00	0.36	0.84	0.59	0.56	0.54	0.65	0.75	1.24	0.53	0.42
DSG(S)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	1.25	0.62	0.03	1.13	0.00	0.52	0.00	0.45	1.80	0.00	0.60	1.70	0.02	2.73	10.86
SD	0.31	1.82	0.04	0.20	0.00	0.22	0.00	0.31	1.11	0.00	0.75	1.89	0.07	1.67	6.09
Max	1.83	5.78	0.13	1.45	0.00	0.91	0.00	0.95	4.20	0.00	2.17	5.31	0.22	6.15	22.78
Min	0.86	0.00	0.00	0.85	0.00	0.15	0.00	0.00	0.37	0.00	0.00	0.00	0.00	0.41	3.50
CV	0.25	2.93	1.56	0.18	0.00	0.42	0.00	0.68	0.62	0.00	1.24	1.11	3.16	0.61	0.56

Table 2.57(b): Statistical Results of Carbon Contents (μg/m^3) in PM$_{2.5}$ at DSG for Winter (W) and Summer (S) Seasons

DSG (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	435	61.0	20.6	40.4	2.7	10.2	13.7	12.3	0.042	0.169	0.230	0.210
Max	769	125.2	43.9	83.1	8.7	23.6	29.2	26.0	0.070	0.200	0.255	0.298
Min	158	26.5	8.7	17.8	0.6	4.4	6.4	5.5	0.016	0.092	0.120	0.053
SD	217	29.6	10.9	19.0	1.9	5.2	6.4	5.7	0.014	0.022	0.028	0.050
CV	0.50	0.48	0.53	0.47	0.70	0.51	0.47	0.47	0.322	0.128	0.121	0.238
DSG (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	276	28.7	12.2	17.2	0.7	5.5	5.9	5.1	0.025	0.209	0.209	0.176
Max	467	46.8	19.9	27.2	1.5	18.2	10.7	9.2	0.045	0.984	0.265	0.225
Min	140	12.8	4.3	8.5	0.4	2.7	3.4	1.8	0.015	0.146	0.164	0.143
SD	104	9.8	4.4	5.7	0.2	3.3	2.0	2.1	0.008	0.183	0.020	0.026
CV	0.38	0.34	0.36	0.33	0.34	0.60	0.33	0.41	0.328	0.878	0.094	0.146

Table 2.58(c): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of PM_{10} at DSG for Winter (W) Season

DSG(W)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	675	75	21	57.8	24.8	1.06	44.87	71.27	88.38	3.04	56.59	7.86	3.45	17.60	0.00	0.94	4.62	5.52	17.82	59.78
Max	1419	140	50	118.7	52.9	2.35	104.62	201.88	275.17	16.36	132.89	15.68	29.42	38.16	0.00	2.63	9.67	11.41	42.14	155.09
Min	280	34	7	25.4	10.5	0.30	8.94	27.40	32.33	1.21	15.74	4.37	0.51	5.52	0.00	0.27	1.94	1.87	4.54	8.26
SD	331	27	11	27.1	13.2	0.59	26.76	44.67	73.09	3.28	31.49	2.95	6.64	8.93	0.00	0.72	2.17	2.67	11.06	41.42
CV	0.49	0.36	0.52	0.47	0.53	0.56	0.60	0.63	0.83	1.08	0.56	0.38	1.93	0.51	0.00	0.77	0.47	0.48	0.62	0.69
DSG(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.15	12.06	12.61	0.93	0.96	0.45	17.81	0.21	0.05	1.74	11.13	0.08	0.05	0.04	0.29	1.59	0.22	0.36	1.98	73.8
Max	2.37	25.60	26.00	2.44	1.88	0.86	38.97	0.45	0.26	9.19	58.09	0.20	0.10	0.12	0.54	27.04	0.46	0.88	7.46	90.9
Min	0.45	5.91	3.89	0.29	0.37	0.22	6.18	0.08	0.00	0.15	1.45	0.03	0.02	0.01	0.13	0.01	0.08	0.09	0.53	51.0
SD	0.58	5.96	6.49	0.56	0.45	0.20	9.48	0.11	0.06	2.20	14.81	0.05	0.02	0.03	0.13	6.00	0.11	0.21	1.84	9.7
CV	0.50	0.49	0.51	0.60	0.47	0.45	0.53	0.51	1.28	1.26	1.33	0.60	0.50	0.74	0.43	3.77	0.50	0.57	0.93	0.13
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.59(d): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of $PM_{2.5}$ at DSG for Winter (W) Season

DSG(W)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	435	75	21	40.4	20.6	0.78	31.79	48.53	54.68	1.65	40.50	5.92	1.10	3.96	0.00	0.46	2.55	0.90	1.43	3.30
Max	769	140	50	83.1	43.9	2.12	79.27	124.02	133.71	6.36	91.43	10.53	8.16	13.93	0.00	1.06	5.20	3.14	4.84	8.62
Min	158	34	7	17.8	8.7	0.25	6.34	17.49	20.91	0.41	13.90	2.98	0.15	0.24	0.00	0.20	0.99	0.14	0.30	0.76
SD	217	27	11	19.0	10.9	0.46	20.59	26.99	34.41	1.32	23.58	2.07	1.89	4.53	0.00	0.28	1.13	0.84	1.22	1.96
CV	0.50	0.36	0.52	0.47	0.53	0.59	0.65	0.56	0.63	0.80	0.58	0.35	1.72	1.14	0.00	0.62	0.45	0.93	0.85	0.59
DSG(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.46	6.65	2.91	0.11	0.80	0.29	5.54	0.16	0.01	0.96	6.15	0.06	0.04	0.00	0.23	0.66	0.19	0.06	1.55	65.5
Max	0.86	12.78	10.16	0.34	1.66	0.58	17.79	0.44	0.04	5.32	23.46	0.16	0.08	0.01	0.48	9.91	0.44	0.21	6.12	85.5
Min	0.12	2.54	0.79	0.00	0.31	0.11	1.01	0.05	0.00	0.03	0.49	0.01	0.01	0.00	0.09	0.00	0.07	0.01	0.31	41.6
SD	0.24	2.65	2.31	0.10	0.40	0.14	4.19	0.10	0.01	1.32	6.78	0.04	0.02	0.00	0.12	2.19	0.11	0.05	1.60	10.9
CV	0.52	0.40	0.79	0.89	0.50	0.49	0.76	0.63	1.67	1.38	1.10	0.69	0.47	2.46	0.51	3.32	0.55	0.91	1.03	0.17
% R is the % recovery of mass of collected particle through compositional analysis																				

Table 2.60(e): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of PM_{10} at DSG for Summer (S) Season

DSG(S)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	503	69	15	24.6	14.7	0.88	21.90	16.64	30.15	3.24	11.40	4.38	1.87	20.98	0.00	0.82	6.83	12.02	38.41	138.44
Max	680	146	30	38.8	24.0	2.04	51.89	51.48	54.88	7.50	34.34	7.68	6.74	35.48	0.00	1.70	10.90	20.28	63.97	229.11
Min	323	42	6	12.2	5.2	0.28	7.45	4.93	13.74	0.97	4.22	2.22	0.50	11.34	0.00	0.28	4.38	6.03	21.49	80.40
SD	113	25	8	8.1	5.4	0.44	15.65	10.96	12.34	1.74	6.87	1.52	1.59	7.15	0.00	0.33	1.94	4.58	14.03	47.19
CV	0.22	0.36	0.52	0.33	0.36	0.50	0.71	0.66	0.41	0.54	0.60	0.35	0.85	0.34	0.28	0.41	0.28	0.38	0.37	0.34
DSG(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.19	15.40	17.08	2.10	0.79	0.60	23.92	0.01	0.09	1.87	4.35	0.04	0.02	0.09	0.17	0.62	0.01	0.42	1.60	78.2
Max	2.57	21.06	36.74	3.15	1.91	0.83	36.34	0.03	0.18	7.99	10.46	0.07	0.05	0.14	0.38	4.66	0.02	0.81	3.83	92.6
Min	0.74	9.94	10.16	1.33	0.40	0.35	14.03	0.01	0.04	0.30	1.19	0.02	0.01	0.06	0.10	0.01	0.00	0.27	0.62	42.9
SD	0.41	3.58	6.88	0.58	0.39	0.16	7.25	0.00	0.04	1.97	2.55	0.02	0.01	0.03	0.07	1.16	0.00	0.12	0.76	13.9
CV	0.35	0.23	0.40	0.28	0.50	0.26	0.30	0.38	0.47	1.05	0.59	0.37	0.56	0.29	0.40	1.88	0.72	0.28	0.48	0.18

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

Table 2.61(f): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of $PM_{2.5}$ at DSG for Summer (S) Season

DSG(S)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	276	69	15	17.2	12.2	0.65	10.48	12.36	24.90	1.55	9.46	3.33	0.85	4.61	0.00	0.46	2.75	2.59	14.23	29.59
Max	467	146	30	27.2	19.9	1.86	46.18	40.98	48.63	4.02	32.91	6.13	4.06	17.12	0.00	1.15	9.06	5.01	27.58	61.93
Min	140	42	6	8.5	4.3	0.18	1.05	4.17	13.22	0.20	2.76	1.47	0.19	0.38	0.00	0.09	1.49	1.50	5.10	11.82
SD	104	25	8	5.7	4.4	0.42	9.71	8.63	10.40	1.13	6.67	1.21	1.08	5.23	0.00	0.28	1.78	1.08	6.28	15.68
CV	0.38	0.36	0.52	0.33	0.36	0.64	0.93	0.70	0.42	0.73	0.71	0.36	1.27	1.13	0.80	0.61	0.65	0.42	0.44	0.53
DSG(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.65	6.46	7.89	0.69	0.60	0.16	3.53	0.00	0.02	0.90	2.60	0.03	0.01	0.02	0.06	0.27	0.00	0.07	0.87	61.7
Max	1.47	11.03	23.99	2.02	1.64	0.68	8.31	0.02	0.07	3.26	5.59	0.05	0.04	0.11	0.19	2.30	0.02	0.32	1.70	87.5
Min	0.24	3.35	2.71	0.27	0.28	0.04	1.61	0.00	0.01	0.10	0.65	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.27	42.6
SD	0.35	2.17	5.47	0.43	0.37	0.16	1.65	0.00	0.02	0.88	1.53	0.01	0.01	0.02	0.04	0.51	0.00	0.07	0.45	14.8
CV	0.54	0.34	0.69	0.62	0.61	0.97	0.47	1.32	0.78	0.98	0.59	0.36	0.57	1.18	0.73	1.89	1.93	1.05	0.52	0.24

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

Table 2.62(g): Correlation Matrix for PM_{10} and its composition for Winter (W) Season

DSG (W)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.27	0.26	0.87	0.89	0.79	0.71	0.70	0.63	0.84	0.37	0.83	0.79	0.07	0.58	0.83
TC		0.28	0.19	1.00	0.99	0.98	0.59	0.80	0.45	0.58	0.33	0.55	0.72	0.26	0.70	0.79
OC		0.32	0.21		1.00	0.95	0.63	0.79	0.49	0.62	0.36	0.59	0.73	0.24	0.69	0.80
EC		0.19	0.14			1.00	0.48	0.81	0.34	0.48	0.25	0.45	0.67	0.30	0.69	0.72
NO_3^-		0.37	0.00				0.78	0.43	1.00	0.55	0.48	0.72	0.45	-0.09	0.30	0.41
SO_4^{-2}		0.26	0.39				0.57	0.40		1.00	0.20	0.90	0.66	-0.13	0.32	0.60
NH_4^+		0.27	0.20				0.65	0.46			0.33	1.00	0.61	-0.06	0.30	0.53
Metals		0.36	0.34				0.69	0.63			0.52		0.71	0.16	0.77	1.00

Table 2.63(h): Correlation Matrix for $PM_{2.5}$ and its composition for (W) Winter Season

DSG (W)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.42	0.25	0.76	0.80	0.67	0.68	0.49	0.74	0.83	0.52	0.74	0.62	0.36	0.45	0.92
TC		0.28	0.18	1.00	0.99	0.98	0.36	0.76	0.40	0.55	0.44	0.49	0.69	0.53	0.24	0.71
OC		0.32	0.21		1.00	0.95	0.41	0.74	0.46	0.61	0.49	0.53	0.71	0.51	0.25	0.75
EC		0.19	0.14			1.00	0.27	0.79	0.27	0.43	0.35	0.40	0.64	0.53	0.22	0.62
NO_3^-		0.61	0.25				0.62	0.09	1.00	0.79	0.70	0.80	0.39	-0.06	0.30	0.68
SO_4^{-2}		0.40	0.40				0.50	0.25		1.00	0.45	0.89	0.56	-0.04	0.26	0.78
NH_4^+		0.37	0.35				0.45	0.31			0.43	1.00	0.52	-0.10	0.21	0.72
Metals		0.43	0.26				0.71	0.49			0.55		0.76	0.43	0.56	1.00

Table 2.64(i): Correlation Matrix for PM_{10} and its composition for Summer (S) Season

DSG (S)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.30	-0.12	-0.35	-0.25	-0.45	0.58	0.25	0.40	0.38	0.66	0.23	0.07	0.27	0.62	0.58
TC		0.36	0.70	1.00	0.96	0.91	-0.61	-0.34	-0.59	0.04	-0.32	-0.16	0.34	-0.44	-0.44	-0.56
OC		0.42	0.75		1.00	0.77	-0.59	-0.37	-0.57	0.06	-0.23	-0.16	0.26	-0.46	-0.40	-0.42
EC		0.26	0.62			1.00	-0.54	-0.25	-0.54	0.02	-0.40	-0.12	0.41	-0.36	-0.43	-0.70
NO_3^-		-0.28	-0.39				0.66	0.25	1.00	0.20	0.41	0.47	-0.06	0.45	0.67	0.53
SO_4^{-2}		0.35	0.28				0.55	0.05		1.00	0.48	0.53	0.44	0.07	0.58	0.29
NH_4^+		0.00	0.13				0.66	0.52			0.25	1.00	0.12	-0.24	0.39	0.16
Metals		-0.31	-0.54				0.49	0.12			0.66		-0.06	0.49	0.74	1.00

Table 2.65(j): Correlation Matrix for $PM_{2.5}$ and its composition for Summer (S) Season

DSG (S)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	-0.29	-0.30	-0.30	-0.45	-0.30	0.57	0.46	0.63	0.57	0.38	0.45	0.27	0.19	0.51	0.73
TC		0.36	0.70	1.00	0.81	0.99	-0.67	-0.32	-0.58	0.05	-0.23	-0.09	0.38	-0.34	-0.41	-0.33
OC		0.42	0.75		1.00	0.77	-0.67	-0.43	-0.63	-0.01	-0.33	-0.15	0.22	-0.40	-0.48	-0.36
EC		0.26	0.62			1.00	-0.70	-0.33	-0.62	-0.03	-0.28	-0.15	0.36	-0.32	-0.40	-0.33
NO_3^-		-0.25	-0.36				0.83	0.64	1.00	0.27	0.57	0.53	-0.06	0.42	0.53	0.69
SO_4^{-2}		0.26	0.20				0.34	0.20		1.00	0.55	0.55	0.42	-0.02	0.25	0.35
NH_4^+		0.00	0.10				0.54	0.84			0.27	1.00	0.03	-0.18	-0.15	0.24
Metals		-0.38	-0.30				0.62	0.28			0.60		0.49	0.58	0.65	1.00

2.4.6 DTEA School, Pusa Road (PUS)

The sampling period for winter is January 30, 2014 to February 22, 2014 and May 25, 2014 to June 16, 2014 for summer season.

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

For sampling of PM_{10} and $PM_{2.5}$, the developed SOPs were followed. As a part of QA/QC, 20% of PM-laden filters (of PM_{10} and $PM_{2.5}$) were reconditioned for 24 hrs and reweighed. The variation in the concentration was less than 5%, which was acceptable.

Time series of 24-hr average concentrations of PM_{10} and $PM_{2.5}$ are shown for winter (Figures 2.66) and summer season (Figure 2.67). The air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although summer conditions (e.g. wind storms, low humidity and high temperature) provide high turbulence to dispersion, the levels of PM_{10} and $PM_{2.5}$ are alarmingly high in summer for PM_{10}. Average levels for winter and summer season are 278 and 269 µg/m^3 (for $PM_{2.5}$) and 473 and 534 µg/m^3 (for PM_{10}) respectively.

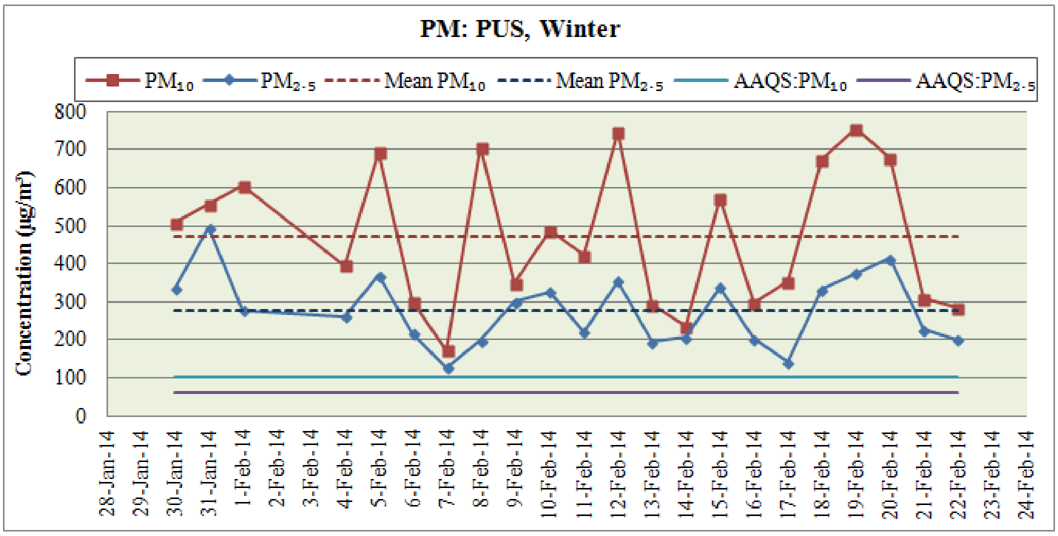


Figure 2.66: PM Concentrations at PUS for Winter Season

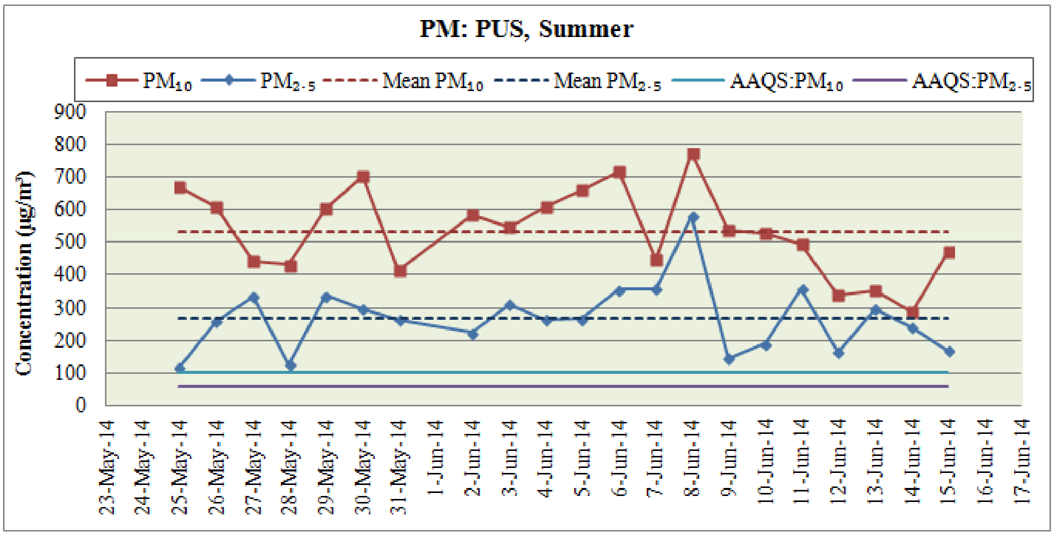


Figure 2.67: PM Concentrations at PUS for Summer Season

2.4.6.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

Time series of 24-hr average concentrations of SO_2 and NO_2 are shown for winter (Figure 2.68) and summer (Figure 2.69). It was observed that SO_2 concentrations were low and meet the air quality standard. NO_2 levels also exceed the air quality standard. The average NO_2 concentration at PUS was 87 µg/m^3 for winter and 85 µg/m^3 for summer season (Table 2.11 (c), (e)). The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. The NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets or open burning etc.

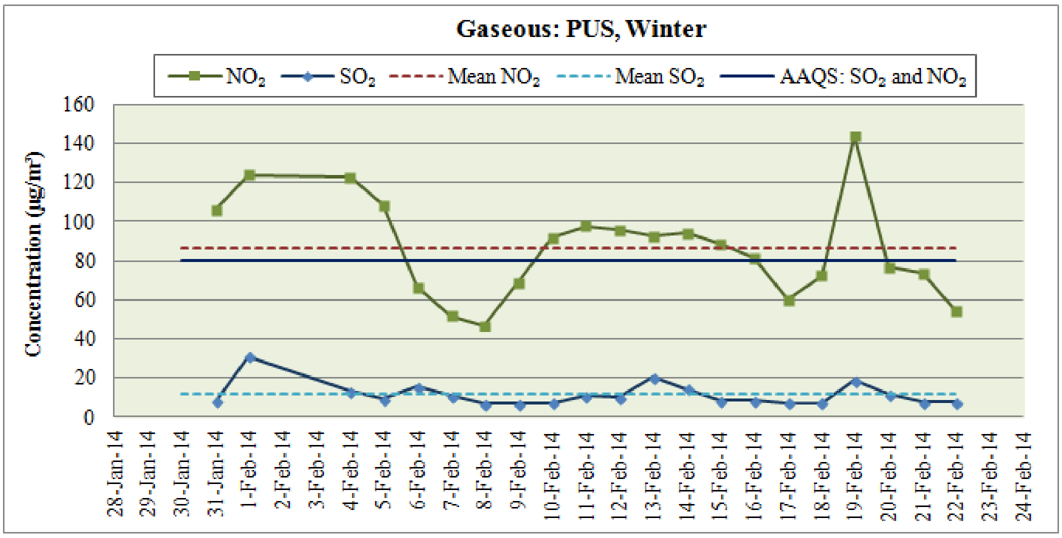


Figure 2.68: SO_2 and NO_2 Concentrations at PUS for Winter Season

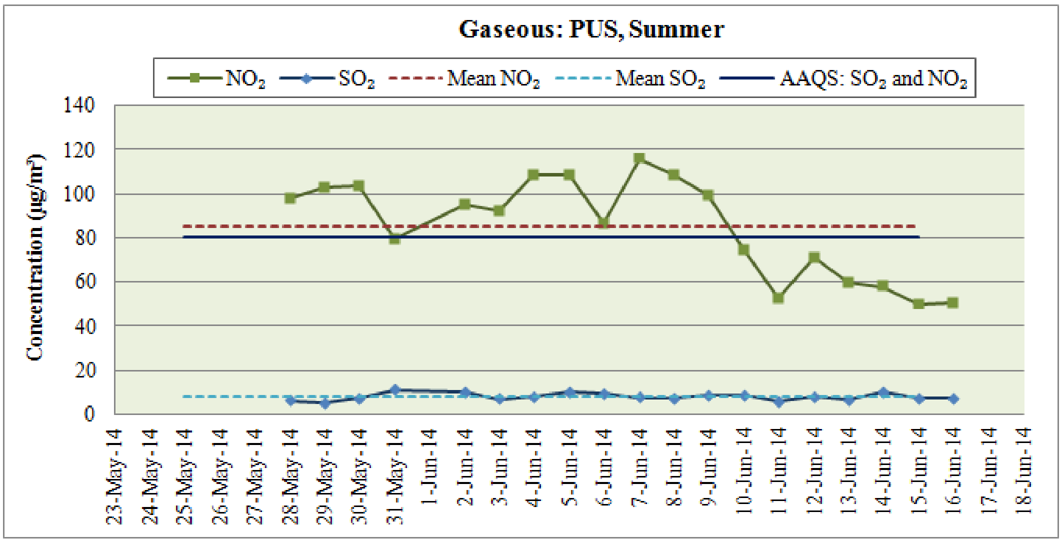


Figure 2.69: SO_2 and NO_2 Concentrations at PUS for Summer Season

2.4.6.3 Carbon monoxide (CO)

Hourly concentration of CO was observed at PUS for winter and summer seasons (Figure 2.45). It can be that the maximum concentration is observed during the peak traffic hours of the day (both in morning as well as evening). It was observed that maximum concentration peak (winter – 5.0 mg/m^3 and summer - 2.6 mg/m^3) was higher in evening hours than in the morning hours. The levels exceed the CO standard (4 mg/m^3) at PUS in winter season during peak traffic hours. However in summer CO levels meet the standard.

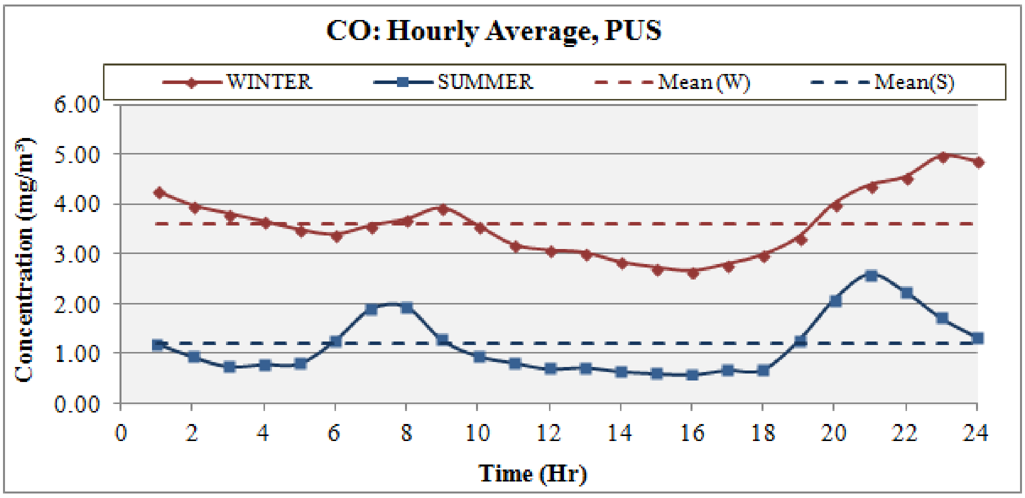


Figure 2.70: Hourly average concentration of CO at PUS for winter and summer seasons

2.4.6.4 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs with some specific markers measured for winter and summer season. Figure 2.71 shows the measured concentration of some markers of PAHs at

PUS. The PAHs compounds analyzed are (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAHs concentrations are much higher in winter compared to summer season. Major PAHs are Phe (6.6 ng/m^3), B(b)F (4.4 ng/m^3), B(ghi)P (4.1 ng/m^3) and DmP ((2.7 ng/m^3) for winter season and B(ghi)P (2.3 ng/m^3), DEP (2.1 ng/m^3), Phe (1.1 ng/m^3) and InP (0.9 ng/m^3). The total PAHs were measured higher in winter (29 ng/m^3) compared to summer (9 ng/m^3). A statistical summary of PAHs concentration is presented in Table 2.11 (a) for winter and summer seasons.

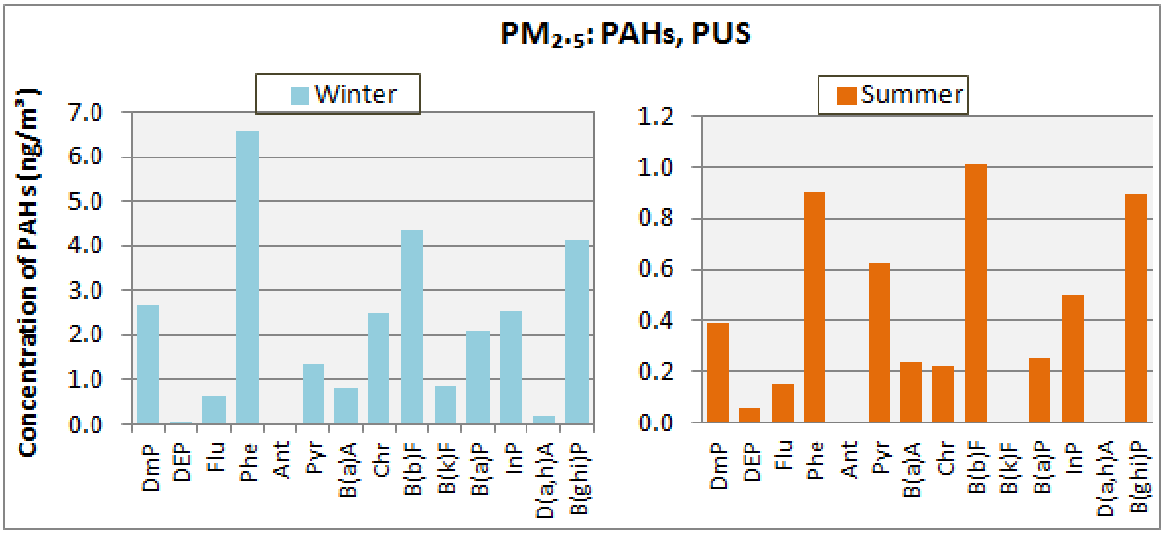


Figure 2.71: PAHs Concentrations in $PM_{2.5}$ at PUS for Winter and Summer Seasons

2.4.6.5 Elemental and Organic 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 2.72 (a) and (b) for winter and summer season. Organic carbon is observed higher than the elemental carbon. However the ratio of OC3/TC is observed higher that indicates the formation of secondary organic carbon in atmosphere at PUS. It is also observed that the OC and EC are higher in winter than 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 2.11 (b) for winter and summer seasons.

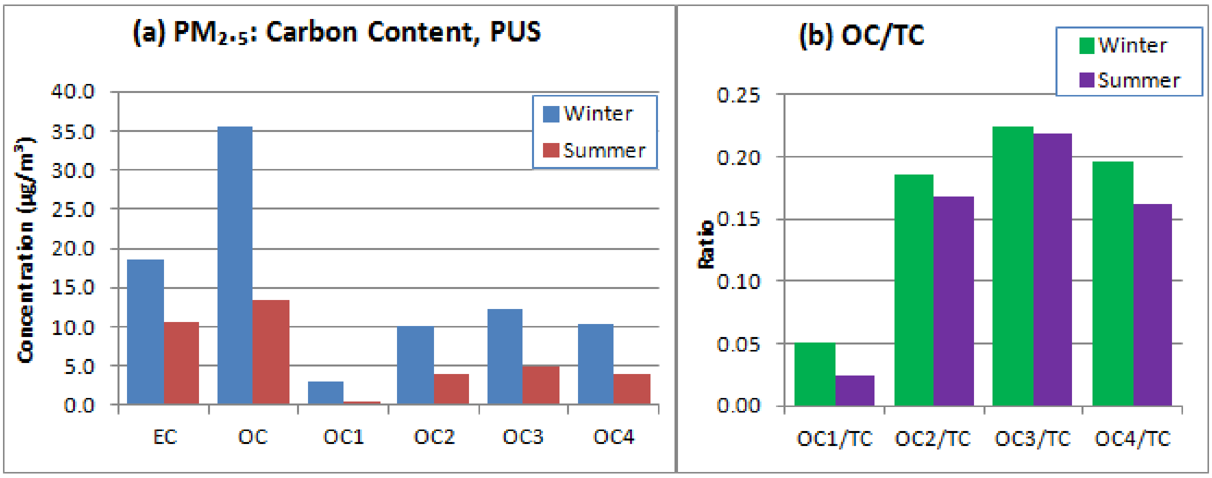


Figure 2.72: EC and OC Content in $PM_{2.5}$ at PUS for Winter and Summer Seasons

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

Graphical presentation of chemical species are shown for winter and summer season for PM_{10} (Figure 2.73) and $PM_{2.5}$ (Figure 2.74). Statistical summary (Mean, maximum, minimum, standard deviation (SD) and coefficient of variation (CV)) of analysis 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) estimated in composition and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.11 (c), (d), (e) and (f) for winter and summer season. The correlation between different parameters (i.e PM, NO_2, SO_2, TC, OC, EC, F^-, Cl^-, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, Ca^{+2}, Mg^{+2} and Metals (elements) with major species (PM, TC, OC, EC, NO_3^-, SO_4^{-2}, NH_4^+, Metals) for PM_{10} and $PM_{2.5}$ composition is presented in Table 2.11 (g), (h), (i) and (j) 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 2.75 (a) and (b) for winter season and Figure 2.76 (a) and (b) for summer season.

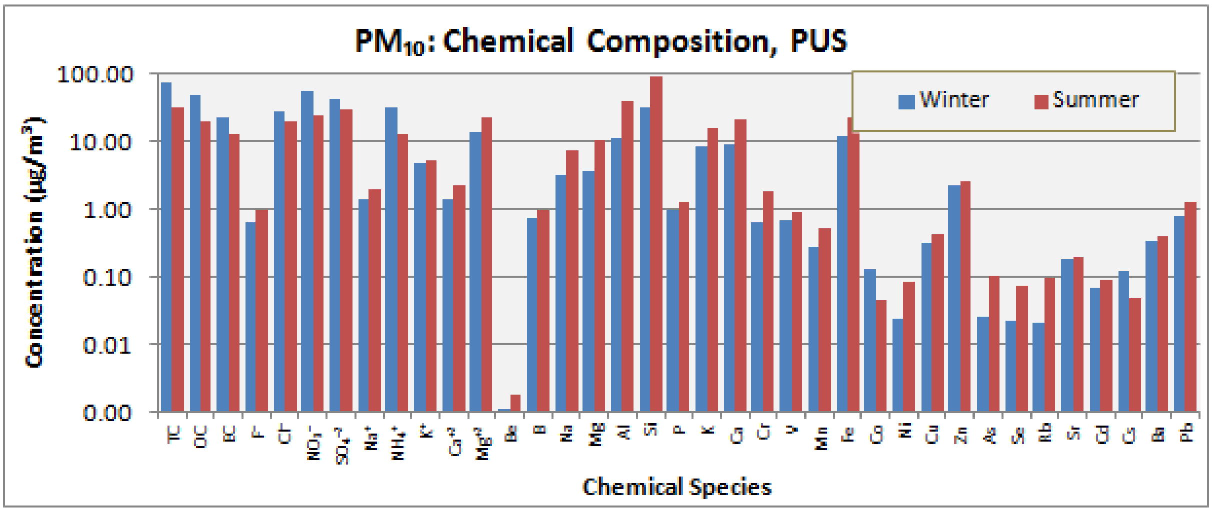


Figure 2.73: Concentrations of species in PM_{10} at PUS for Winter and Summer Seasons

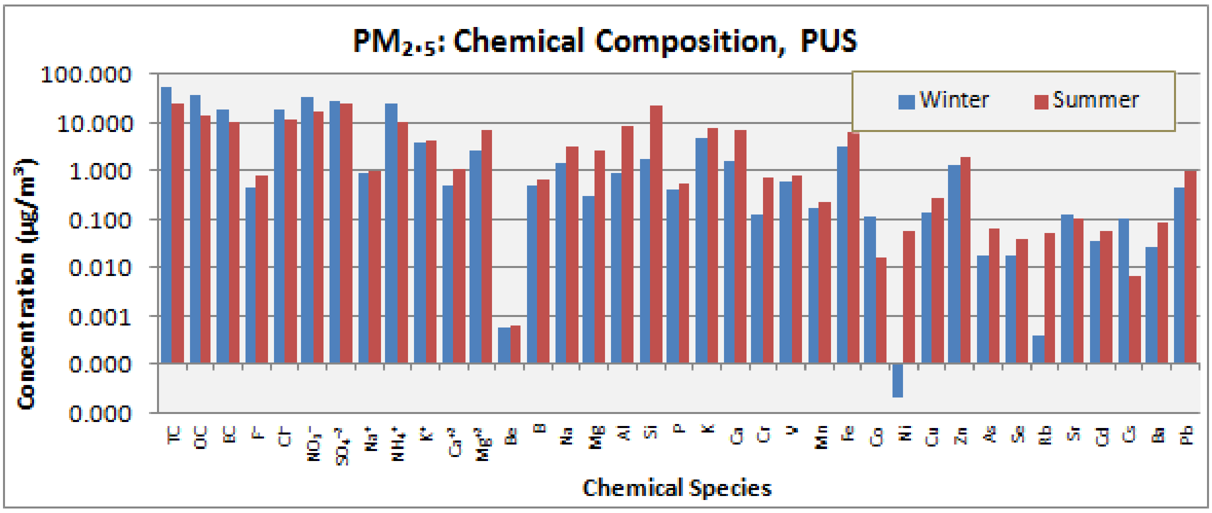
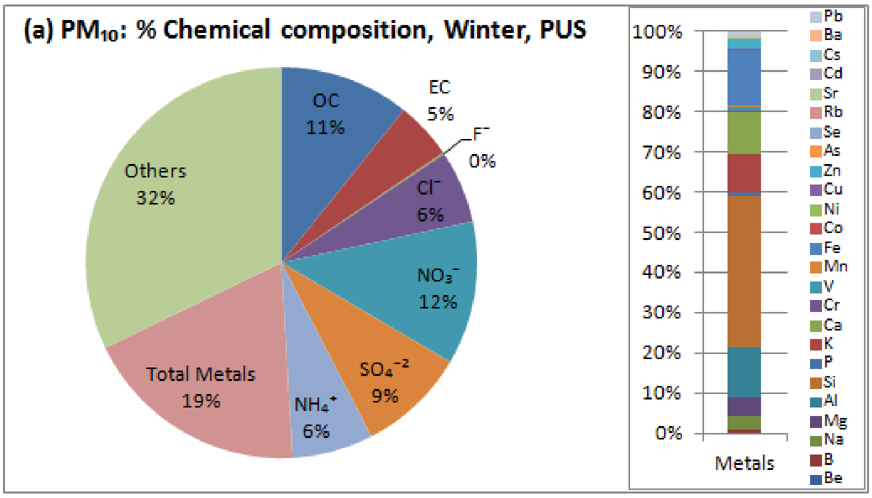


Figure 2.74: Concentrations of species in $PM_{2.5}$ at PUS for Winter and Summer Seasons



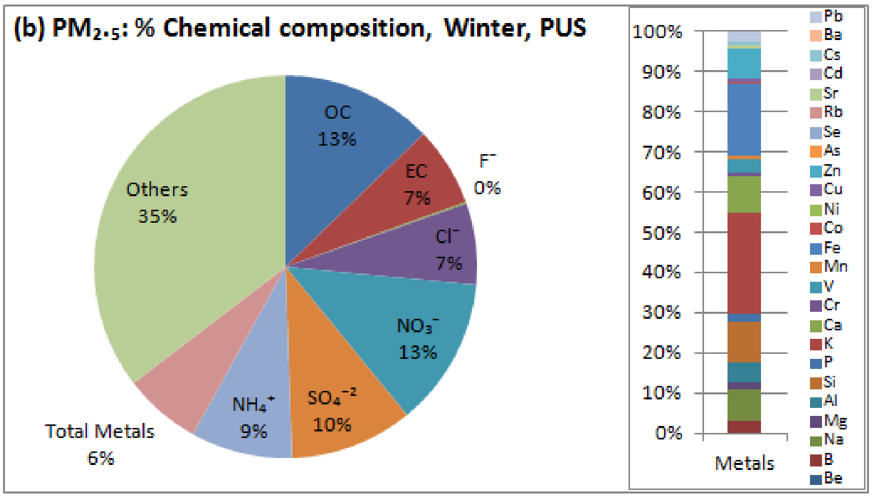
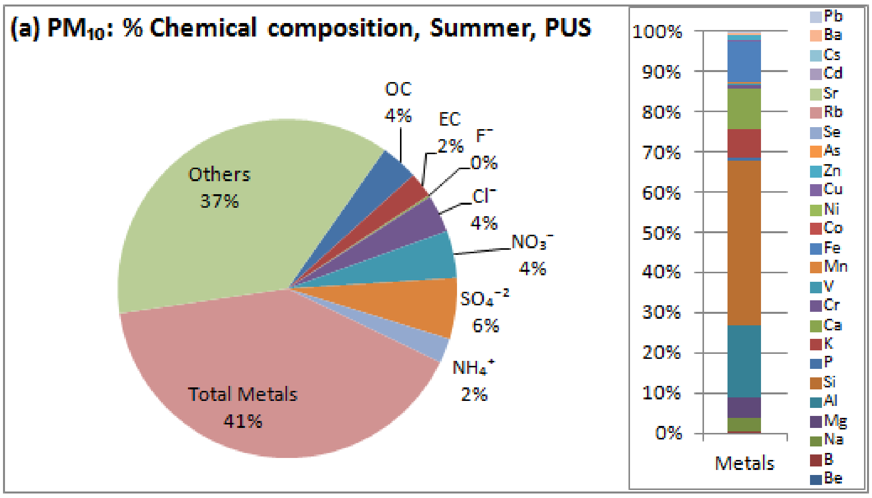


Figure 2.75: Percentage distribution of species in PM at PUS for Winter Season



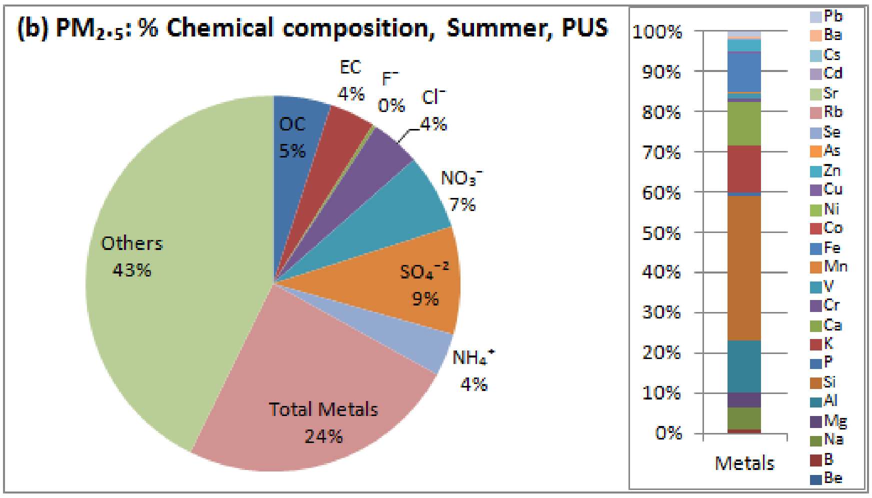


Figure 2.76: Percentage distribution of species in PM at PUS for Summer Season

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. The graphical presentation is the better option for understanding the compositional variation. Compositional comparisons of $PM_{2.5}$ Vs PM_{10} for all species are shown for winter season (Figure 2.77) and summer season (Figure 2.78) at PUS.

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 (70 %) than summer (60 %). The major species contributing to fine mode are TC, EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Sr, Cd, Cs and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, Fe and Ni.

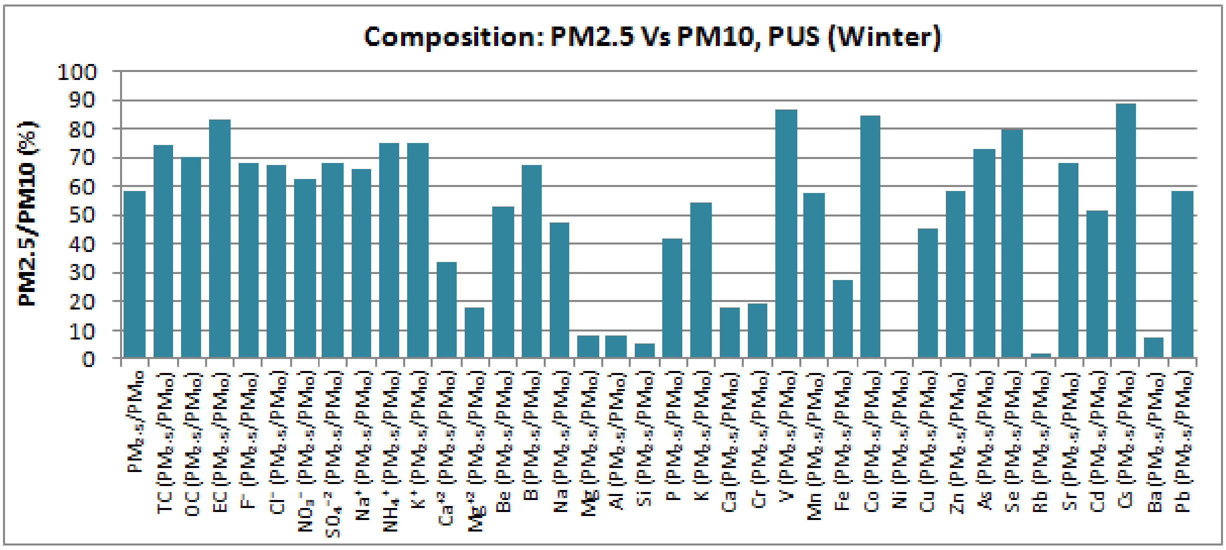


Figure 2.77: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at PUS for Winter Season

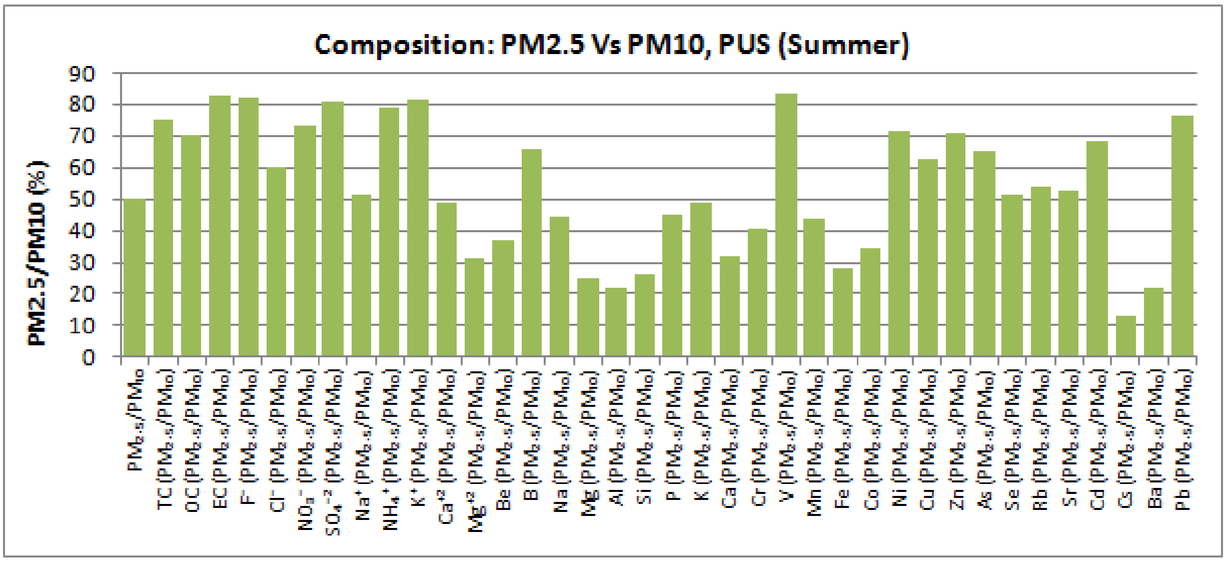


Figure 2.78: Compositional comparison of species in $PM_{2.5}$ Vs PM_{10} at PUS for Summer Season

Table 2.66(a): Statistical Results of PAHs (ng/m^3) in PM$_{2.5}$ at PUS for Winter (W) and Summer (S) Seasons

PUS(W)	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
Mean	2.67	0.06	0.63	6.59	0.00	1.33	0.82	2.52	4.38	0.84	2.08	2.56	0.18	4.13	28.80
SD	1.88	0.20	0.41	4.14	0.00	1.23	0.63	1.53	2.68	0.50	1.69	2.59	0.45	3.17	17.42
Max	6.53	0.66	1.49	16.90	0.00	4.89	2.13	6.32	9.94	1.84	5.61	8.81	1.49	10.83	70.05
Min	0.86	0.00	0.13	2.30	0.00	0.44	0.00	0.94	1.69	0.31	0.10	0.00	0.00	1.33	9.13
CV	0.71	3.32	0.65	0.63	0.00	0.92	0.77	0.61	0.61	0.60	0.81	1.01	2.49	0.77	0.60
PUS(S)	DmP	DEP	Flu	Phe	Ant	Pyr	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	2.06	0.08	1.12	0.00	0.55	0.00	0.28	0.84	0.00	0.27	0.86	0.00	2.28	8.81
SD	0.22	3.78	0.12	0.55	0.00	0.25	0.00	0.19	0.43	0.00	0.27	0.85	0.00	0.96	4.50
Max	0.76	10.71	0.35	2.36	0.00	0.96	0.00	0.53	1.39	0.00	0.64	2.18	0.00	3.32	19.78
Min	0.13	0.00	0.00	0.57	0.00	0.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.58	1.84
CV	0.5	1.8	1.5	0.5	0.0	0.5	0.0	0.7	0.5	0.0	1.0	1.0	0.0	0.4	0.5

Table 2.67(b): Statistical Results of Carbon Contents (μg/m^3) in PM$_{2.5}$ at PUS for Winter (W) and Summer (S) Seasons

PUS (W)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	278	54.2	18.6	35.5	2.9	10.2	12.1	10.3	0.050	0.186	0.224	0.196
Max	496	118.7	39.7	78.9	7.2	23.5	27.4	20.8	0.093	0.209	0.261	0.247
Min	127	23.2	8.0	15.2	0.6	4.0	4.8	4.8	0.027	0.165	0.199	0.138
SD	93	25.5	9.0	16.6	2.0	5.1	5.6	4.3	0.017	0.012	0.015	0.032
CV	0.34	0.47	0.48	0.47	0.70	0.50	0.46	0.42	0.329	0.064	0.065	0.161
PUS (S)	PM$_{2.5}$	TC	EC	OC	OC1	OC2	OC3	OC4	OC1/TC	OC2/TC	OC3/TC	OC4/TC
Mean	269	24.0	10.5	13.4	0.5	4.0	5.0	4.0	0.024	0.168	0.218	0.162
Max	578	38.5	20.1	19.8	0.8	5.9	7.3	6.8	0.035	0.192	0.492	0.197
Min	116	11.7	2.8	7.0	0.3	2.0	2.8	1.2	0.015	0.142	0.178	0.094
SD	105	8.3	4.5	4.0	0.1	1.2	1.4	1.6	0.006	0.013	0.065	0.026
CV	0.39	0.35	0.43	0.30	0.22	0.30	0.28	0.40	0.251	0.075	0.299	0.161

Table 2.68(c): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of PM_{10} at PUS for Winter (W) Season

PUS(W)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	473	87	12	50.8	22.4	0.63	28.35	56.08	42.27	1.41	31.62	5.01	1.41	14.27	0.00	0.75	3.13	3.79	11.38	33.00
Max	757	144	31	112.7	47.9	1.61	88.81	167.49	122.78	4.40	66.72	9.93	3.81	28.19	0.00	1.74	5.86	7.31	25.96	75.23
Min	172	47	7	21.7	9.7	0.20	7.33	14.07	13.59	0.50	11.46	1.88	0.36	3.28	0.00	0.32	1.32	1.05	3.18	8.90
SD	185	25	6	23.7	10.8	0.40	19.22	33.38	23.94	0.90	14.26	2.36	1.10	7.18	0.00	0.37	1.48	1.79	6.01	18.43
CV	0.39	0.29	0.51	0.47	0.48	0.63	0.68	0.60	0.57	0.64	0.45	0.47	0.78	0.50	0.49	0.49	0.47	0.47	0.53	0.56
PUS(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.95	8.40	9.19	0.65	0.70	0.29	11.99	0.13	0.02	0.31	2.30	0.02	0.02	0.02	0.18	0.07	0.12	0.34	0.80	68.4
Max	2.08	22.66	17.90	1.37	1.77	0.73	23.27	0.46	0.07	0.88	4.66	0.07	0.05	0.07	0.38	0.34	0.19	1.22	1.99	83.7
Min	0.39	3.18	3.52	0.22	0.28	0.11	3.98	0.06	0.00	0.07	0.80	0.01	0.01	0.00	0.08	0.00	0.06	0.07	0.15	53.0
SD	0.44	4.77	4.48	0.33	0.35	0.15	5.69	0.09	0.02	0.22	1.12	0.01	0.01	0.02	0.08	0.09	0.04	0.27	0.58	8.4
CV	0.47	0.57	0.49	0.51	0.49	0.51	0.47	0.65	0.75	0.71	0.49	0.58	0.43	0.83	0.45	1.31	0.38	0.79	0.72	0.12

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

Table 2.69(d): Statistical Results of SO_2, NO_2 and Chemical Characterization ($\mu g/m^3$) of $PM_{2.5}$ at PUS for Winter (W) Season

PUS(W)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	278	87	12	35.5	18.6	0.43	19.06	34.98	28.87	0.93	23.79	3.76	0.48	2.56	0.00	0.50	1.49	0.31	0.92	1.80
Max	496	144	31	78.9	39.7	1.58	57.92	91.08	60.26	3.60	48.63	7.78	2.65	12.43	0.00	1.25	3.30	0.76	3.15	5.71
Min	127	47	7	15.2	8.0	0.17	3.24	7.35	12.31	0.23	9.04	1.17	0.10	0.16	0.00	0.22	0.62	0.12	0.26	0.45
SD	93	25	6	16.6	9.0	0.30	12.40	17.96	13.57	0.68	10.49	1.88	0.57	3.39	0.00	0.24	0.69	0.18	0.76	1.28
CV	0.34	0.29	0.51	0.47	0.48	0.69	0.65	0.51	0.47	0.73	0.44	0.50	1.18	1.32	0.76	0.47	0.47	0.60	0.83	0.71
PUS(W)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.40	4.58	1.67	0.13	0.61	0.16	3.28	0.11	0.00	0.14	1.34	0.02	0.02	0.00	0.12	0.04	0.10	0.03	0.47	64.2
Max	0.95	8.58	6.26	0.51	1.53	0.42	11.59	0.29	0.00	0.46	3.24	0.04	0.04	0.01	0.20	0.25	0.17	0.12	1.39	86.8
Min	0.17	1.82	0.40	0.03	0.26	0.07	0.55	0.05	0.00	0.02	0.45	0.01	0.01	0.00	0.06	0.00	0.05	0.00	0.14	49.3
SD	0.23	2.11	1.51	0.12	0.30	0.09	2.52	0.06	0.00	0.13	0.72	0.01	0.01	0.00	0.05	0.05	0.04	0.03	0.31	11.0
CV	0.57	0.46	0.91	0.97	0.49	0.53	0.77	0.50	4.69	0.90	0.53	0.56	0.44	3.38	0.39	1.49	0.39	1.32	0.66	0.17

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

Table 2.70(e): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of PM_{10} at PUS for Summer (S) Season

PUS(S)	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	534	85	8	19.2	12.7	0.97	19.25	24.04	31.03	1.98	12.63	5.09	2.27	22.05	0.00	0.97	7.47	10.20	39.20	89.01
Max	772	116	11	28.2	24.2	1.64	52.44	54.12	53.43	3.81	25.06	11.46	6.94	43.52	0.00	1.47	12.75	18.06	81.35	146.60
Min	285	50	5	10.0	3.4	0.52	3.49	11.24	11.60	0.61	2.18	1.25	0.48	3.69	0.00	0.37	4.74	4.25	15.26	42.14
SD	133	22	2	5.7	5.5	0.36	16.42	13.89	11.93	0.88	6.74	2.23	1.59	8.70	0.00	0.31	2.42	4.30	14.88	30.38
CV	0.25	0.26	0.20	0.30	0.43	0.37	0.85	0.58	0.38	0.44	0.53	0.44	0.70	0.39	0.51	0.32	0.32	0.42	0.38	0.34
PUS(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	1.25	15.60	21.79	1.84	0.93	0.51	22.08	0.05	0.08	0.43	2.64	0.10	0.08	0.10	0.19	0.09	0.05	0.39	1.28	64.1
Max	1.97	27.81	41.62	3.25	1.47	0.91	54.15	0.10	0.12	0.61	4.58	0.18	0.13	0.19	0.36	0.23	0.09	0.70	4.63	82.7
Min	0.58	6.92	11.43	0.81	0.52	0.21	7.40	0.03	0.05	0.27	1.54	0.06	0.05	0.05	0.10	0.03	0.04	0.14	0.45	41.5
SD	0.44	6.03	7.48	0.71	0.26	0.19	10.98	0.02	0.02	0.11	0.78	0.03	0.02	0.04	0.08	0.05	0.02	0.16	0.98	10.7
CV	0.35	0.39	0.34	0.39	0.28	0.37	0.50	0.40	0.25	0.25	0.30	0.32	0.30	0.43	0.42	0.51	0.31	0.40	0.77	0.17

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

Table 2.71(f): Statistical Results of SO_2, NO_2 and Chemical Characterization (µg/m^3) of $PM_{2.5}$ at PUS for Summer (S) Season

PUS(S)	$PM_{2.5}$	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
Mean	269	85	8	13.4	10.5	0.79	11.52	17.62	25.04	1.02	9.93	4.13	1.11	6.96	0.00	0.64	3.32	2.52	8.46	23.31
Max	578	116	11	19.8	20.1	1.39	37.79	45.59	44.74	2.69	21.59	9.47	4.05	21.89	0.00	1.12	6.89	9.62	18.78	46.70
Min	116	50	5	7.0	2.8	0.40	0.96	6.29	9.95	0.24	1.22	1.05	0.07	0.78	0.00	0.12	1.12	0.60	2.81	6.48
SD	105	22	2	4.0	4.5	0.29	11.32	10.78	10.03	0.58	5.81	1.98	1.17	6.12	0.00	0.25	1.51	2.16	4.64	12.02
CV	0.39	0.26	0.20	0.30	0.43	0.36	0.98	0.61	0.40	0.57	0.58	0.48	1.06	0.88	0.35	0.39	0.46	0.86	0.55	0.52
PUS(S)	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
Mean	0.56	7.64	6.92	0.75	0.77	0.23	6.24	0.02	0.06	0.27	1.87	0.07	0.04	0.05	0.10	0.06	0.01	0.09	0.98	61.6
Max	1.20	14.37	16.45	1.37	1.35	0.42	18.35	0.04	0.09	0.49	3.47	0.11	0.08	0.10	0.18	0.20	0.02	0.14	4.42	96.4
Min	0.22	2.69	2.80	0.33	0.47	0.12	2.70	0.00	0.03	0.09	0.84	0.02	0.00	0.03	0.05	0.01	0.00	0.03	0.17	40.7
SD	0.23	3.20	3.97	0.27	0.27	0.08	3.90	0.01	0.02	0.12	0.69	0.03	0.02	0.02	0.03	0.04	0.00	0.03	0.92	16.1
CV	0.41	0.42	0.57	0.37	0.34	0.34	0.63	0.62	0.25	0.45	0.37	0.45	0.55	0.30	0.33	0.70	0.51	0.32	0.94	0.26

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

Table 2.72(g): Correlation Matrix for PM_{10} and its composition for Winter (W) Season

PUS (W)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.40	0.06	0.66	0.64	0.69	0.64	0.62	0.63	0.57	0.39	0.71	0.80	0.48	0.88	0.90
TC		0.57	0.16	1.00	1.00	0.99	0.75	0.21	0.46	0.44	0.38	0.58	0.73	0.41	0.59	0.65
OC		0.59	0.19		1.00	0.98	0.77	0.21	0.44	0.43	0.38	0.57	0.72	0.39	0.58	0.64
EC		0.52	0.09			1.00	0.71	0.22	0.49	0.45	0.40	0.59	0.74	0.43	0.59	0.65
NO_3^-		0.33	0.28				0.35	0.05	1.00	0.53	0.07	0.47	0.30	0.21	0.38	0.44
SO_4^{-2}		0.40	0.53				0.54	0.05		1.00	-0.07	0.83	0.31	0.08	0.27	0.40
NH_4^+		0.42	0.31				0.56	0.42			0.13	1.00	0.58	0.34	0.49	0.59
Metals		0.52	0.08				0.68	0.60			0.51		0.86	0.50	0.94	1.00

Table 2.73(h): Correlation Matrix for $PM_{2.5}$ and its composition for Winter (W) Season

PUS (W)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.51	-0.04	0.80	0.78	0.83	0.44	0.48	0.62	0.59	0.44	0.79	0.73	0.58	0.59	0.63
TC		0.57	0.15	1.00	1.00	0.99	0.75	0.27	0.60	0.61	0.25	0.73	0.74	0.23	0.62	0.58
OC		0.59	0.19		1.00	0.98	0.76	0.27	0.59	0.60	0.23	0.72	0.73	0.20	0.62	0.57
EC		0.52	0.09			1.00	0.72	0.28	0.61	0.61	0.27	0.73	0.74	0.27	0.61	0.59
NO_3^-		0.67	0.35				0.13	0.04	1.00	0.79	0.18	0.57	0.61	0.09	0.05	0.37
SO_4^{-2}		0.57	0.43				0.23	0.02		1.00	0.00	0.81	0.49	0.22	0.28	0.20
NH_4^+		0.49	0.18				0.42	0.40			0.10	1.00	0.56	0.43	0.62	0.33
Metals		0.26	-0.20				0.68	0.57			0.78		0.78	0.31	0.34	1.00

Table 2.74(i): Correlation Matrix for PM_{10} and its composition for Summer (S) Season

PUS (S)	PM_{10}	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
PM_{10}	1.00	0.61	-0.05	0.07	0.10	0.04	0.34	0.53	0.35	0.47	0.26	0.48	0.65	0.00	0.52	0.59
TC		0.53	-0.11	1.00	0.98	0.97	-0.14	0.19	-0.48	0.24	-0.30	0.53	-0.09	-0.43	-0.05	0.03
OC		0.58	-0.02		1.00	0.90	-0.11	0.28	-0.52	0.23	-0.26	0.59	-0.09	-0.52	-0.01	0.08
EC		0.45	-0.21			1.00	-0.16	0.10	-0.42	0.25	-0.34	0.43	-0.09	-0.32	-0.09	-0.03
NO_3^-		-0.18	-0.30				0.16	0.19	1.00	-0.02	0.24	-0.19	0.41	0.71	0.60	0.18
SO_4^{-2}		0.59	0.13				0.38	-0.02		1.00	-0.09	0.44	0.72	-0.18	0.19	0.04
NH_4^+		0.67	0.41				0.37	0.75			-0.17	1.00	0.46	-0.33	0.28	0.12
Metals		0.46	-0.15				-0.10	0.23			0.21		0.08	-0.22	0.58	1.00

Table 2.75(j): Correlation Matrix for $PM_{2.5}$ and its composition for Summer (S) Season

PUS (S)	$PM_{2.5}$	NO_2	SO_2	TC	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Metals
$PM_{2.5}$	1.00	0.28	-0.20	-0.02	-0.03	0.00	0.41	0.14	0.51	0.42	-0.15	0.15	0.26	0.22	0.22	0.71
TC		0.52	-0.12	1.00	0.97	0.98	-0.25	0.17	-0.48	0.41	-0.35	0.44	-0.05	-0.38	-0.56	-0.39
OC		0.58	-0.02		1.00	0.90	-0.24	0.28	-0.51	0.42	-0.33	0.52	-0.05	-0.46	-0.57	-0.38
EC		0.45	-0.21			1.00	-0.25	0.07	-0.44	0.38	-0.35	0.36	-0.05	-0.29	-0.53	-0.38
NO_3^-		-0.09	-0.35				0.30	0.06	1.00	-0.21	0.26	-0.18	0.36	0.77	0.72	0.53
SO_4^{-2}		0.56	0.19				0.38	0.01		1.00	-0.22	0.52	0.41	-0.33	-0.30	0.21
NH_4^+		0.64	0.44				0.29	0.78			-0.30	1.00	0.48	-0.18	-0.18	-0.26
Metals		-0.09	-0.22				0.15	-0.13			0.17		-0.03	0.09	0.27	1.00

2.4.7 Overall Summary and presentation of results

The sampling period for winter is November 03, 2013 to February 22, 2014 and April 04, 2014 to June 19, 2014 for Summer Season

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

The seasonal comparison is shown for PM_{10} (Figure 2.79) and $PM_{2.5}$ (Figure 2.80) for all sites. It is observed that the air quality standards for both PM_{10} and $PM_{2.5}$ are exceeded. Although winter conditions provide low dispersion and high concentrations, the levels of PM_{10} and $PM_{2.5}$ are quite high during summer also. At PUS concentrations are observed higher in summer. It is also seen that maximum concentration for PM_{10} are observed at OKH in both seasons while in $PM_{2.5}$ the maximum concentration was observed at DSG (winter) and OKH (summer).

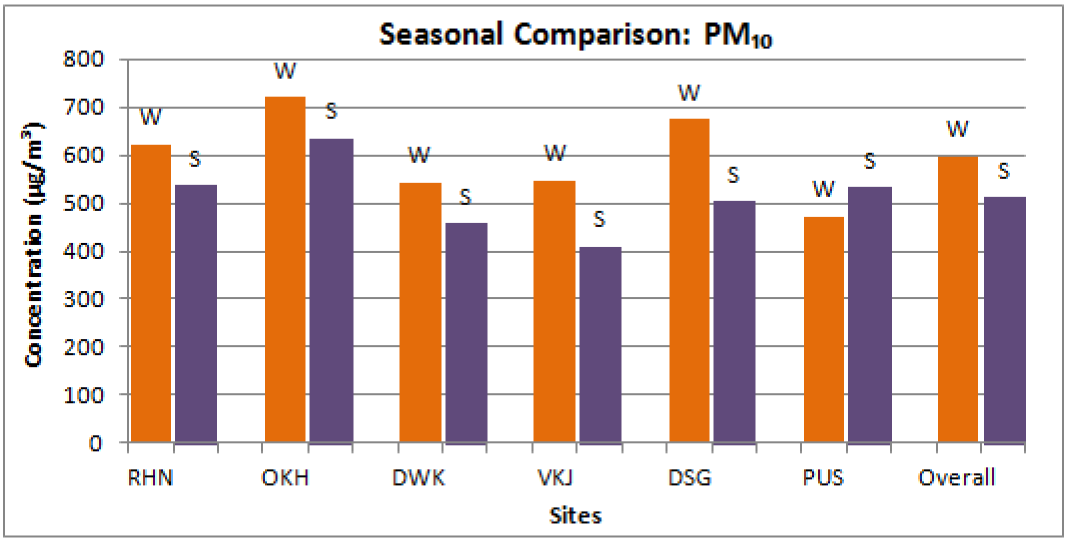


Figure 2.79: Seasonal Comparison of PM_{10} Concentrations for all Sites

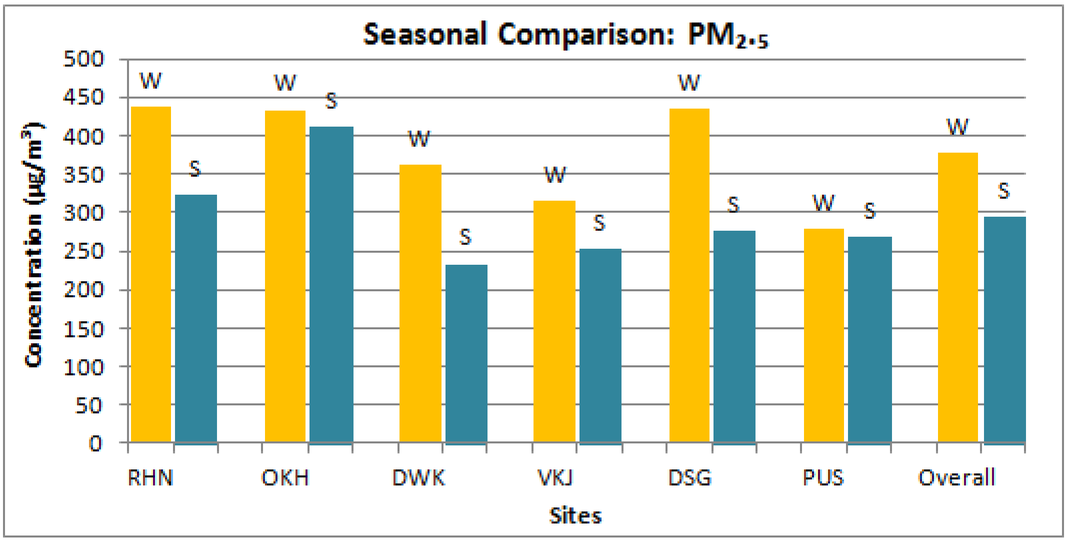


Figure 2.80: Seasonal Comparison of $PM_{2.5}$ Concentrations for all Sites

2.4.7.2 Sulphur Dioxide (SO_2) and Nitrogen Dioxide (NO_2)

The seasonal comparison for SO_2 and NO_2 are shown in Figure 2.81 for all sites. It was observed that SO_2 concentrations were low and meets the air quality standard at all sites. Average NO_2 levels are exceeded the air quality standard (80 µg/m^3) at OKH, DWK and PUS in winter and at PUS in summer. The overall average NO_2 concentration estimated was 83µg/m^3 for winter and 59 µg/m^3 for summer season (Table 2.14 (a) and (c)). The NO_2 is certainly matter of concern and these values can largely be attributed to vehicular pollution and DG sets. Like for PM pollution, massive efforts will be required to improve the air quality for NO_2. The NO_2 is showing some episodic behavior which may be due to variability in meteorology and presence of occasional local sources like DG sets or open burning etc.

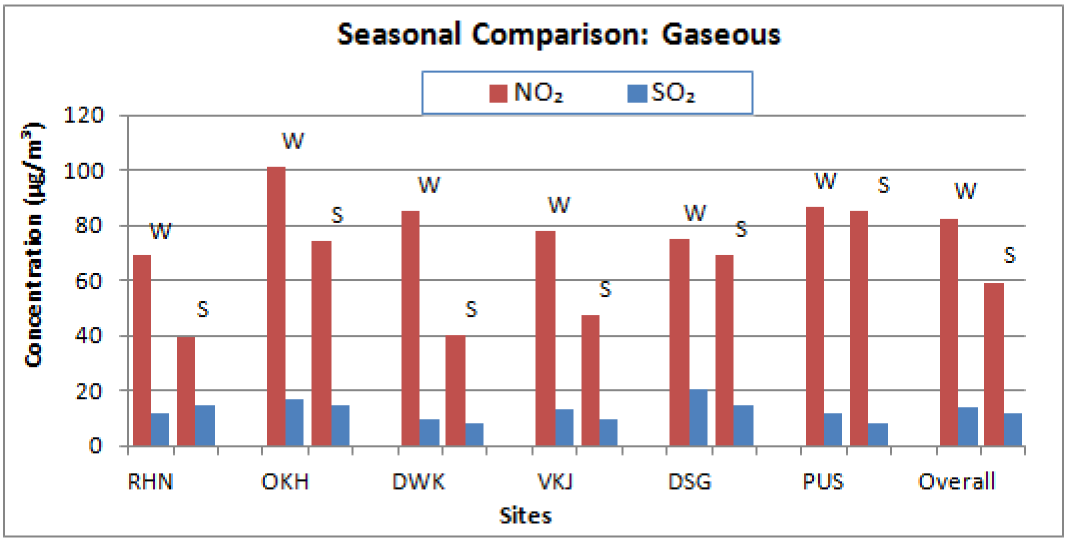


Figure 2.81: Seasonal Comparison of SO_2 and NO_2 Concentrations for all Sites

2.4.7.3 Carbon monoxide (CO)

Seasonal comparison is presented in Figure 2.82 for average CO levels for DWK and PUS. It is observed that CO concentration meets the hourly standard.

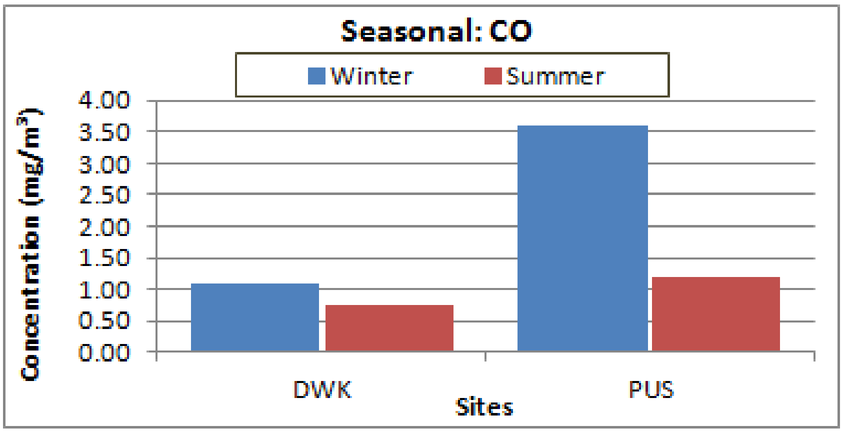


Figure 2.82: Seasonal comparison of CO

2.4.7.4 Volatile Organic Compounds – Benzene

Benzene was estimated for winter and summer seasons at two sites. The measured average concentrations at (i) DSG is 13.2 ± 8.4 µg/m^3 in winter and 38.4 ± 26.1 µg/m^3 in summer and (ii) PUS is 5.3 ± 6.9 µg/m^3 in winter and 39.9 ± 18.8 µg/m^3 in summer. It is observed that the benzene concentrations are high in summer. The possible reason for higher concentrations in summer could be high ambient temperature which may cause large evaporative losses from petrol pumps, solvent industries and fuel tanks of vehicles.

2.4.7.5 Polycyclic Aromatic Hydrocarbons (PAHs) in $PM_{2.5}$

The average concentrations of PAHs are shown graphically for winter season (Figure 2.83) and summer season (Figure 2.84) for all sites along with overall average concentration for Delhi. Average concentrations are shown in Table 2.12 (c) and (d) with the standard deviation and coefficient of variation CV for Delhi. The PAHs compounds analyzed are (i) Di methyl Phthalate (DmP), (ii) Di ethyl Phthalate (DEP), (iii) Fluorene (Flu), (iv) Phenanthrene (Phe), (v) Anthracene (Ant), (vi) Pyrene (Pyr), (vii) Benzo(a)anthracene (B(a)A), (viii) Chrysene (Chr), (ix) Benzo(b)fluoranthene (B(b)F), (x) Benzo(k)fluoranthene (B(k)F), (xi) Benzo(a)pyrene (B(a)P), (xii) Indeno(1,2,3-cd)pyrene (InP), (xiii) Dibenzo(a,h)anthracene (D(a,h)A) and (xiv) Benzo(ghi)perylene (B(ghi)P). It is observed that PAHs concentrations are much higher in winter compared to summer season. Major PAHs are Phe, Pyr, B(ghi)P, InP, B(b)F, and Chr. Seasonal comparison is shown in Figure 2.85 which indicates the concentrations are much higher in winter season compared to summer season. The overall average total PAHs were measured higher in winter (79 ng/m^3) compared to summer (12 ng/m^3). B(a)P has annual national standard of 1 ng/m^3. Although the average of 20 days cannot be compared with annual standard, high levels of B(a)P (i.e. about 10 – 15 ng/m^3) suggests that annual levels will exceed the standard by fair margin. B(a)P although has annual standard and we cannot compare it with levels of 20 days, however levels were are very high and annual standard is most likely to exceed at all sites in winter season and at RHN and OKH in summer season.

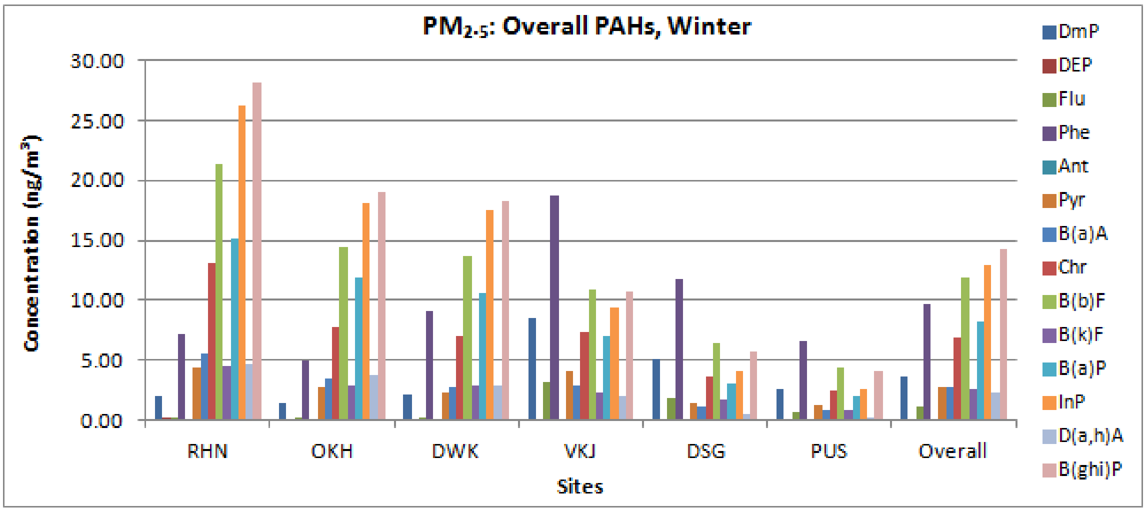


Figure 2.83: Variation in PAHs in $PM_{2.5}$ for Winter Season

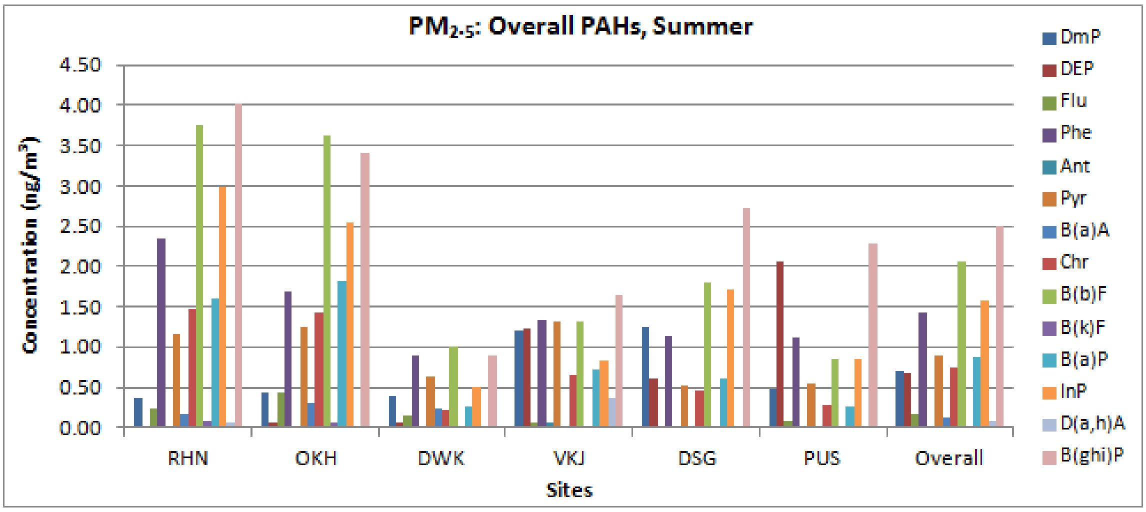


Figure 2.84: Variation in PAHs in $PM_{2.5}$ for Summer Season

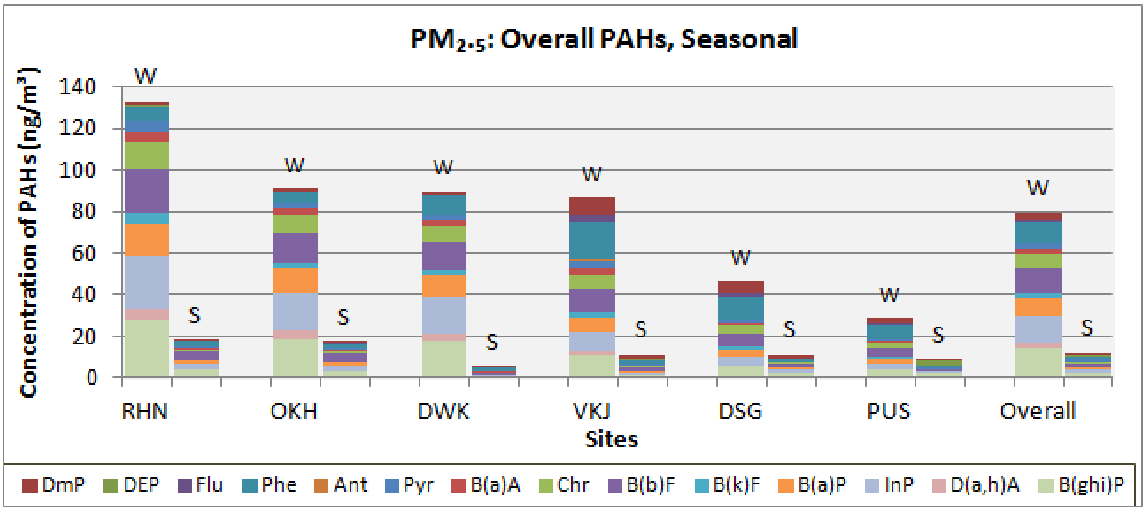


Figure 2.85: Seasonal comparison of in PAHs in $PM_{2.5}$

2.4.7.6 Elemental and Organic Carbon Content (EC/OC) in $PM_{2.5}$

The seasonal comparison for OC and EC are presented in Figure 2.86 for PM_{10} and Figure 2.87 for $PM_{2.5}$. The $PM_{2.5}$ contained the quantity of the carbon less than 10% for the all sites. Low quantity of carbon indicates that non-carbonaceous species are high. There are possible reason are the combustion based emission decreased but contribution from other local emissions sources (i.e. local dust, fly ashes, road side dust, construction materials, loose soil) due to high wind speed and dry weather conditions. It is also observed OC2 and OC3 also higher than the OC1. The possible reason behind that may be the crop biomass burning significantly contributed to PM as secondary particles during November and TC decreased later in December to February when measured at DWK, VKJ, DSG and PUS sites. It is observed that average TC to $PM_{2.5}$ ratio were maximum (27%) at RHN followed by OKH and minimum (14%) at DSG followed by PUS (Table 2.13 (a) and (b)).

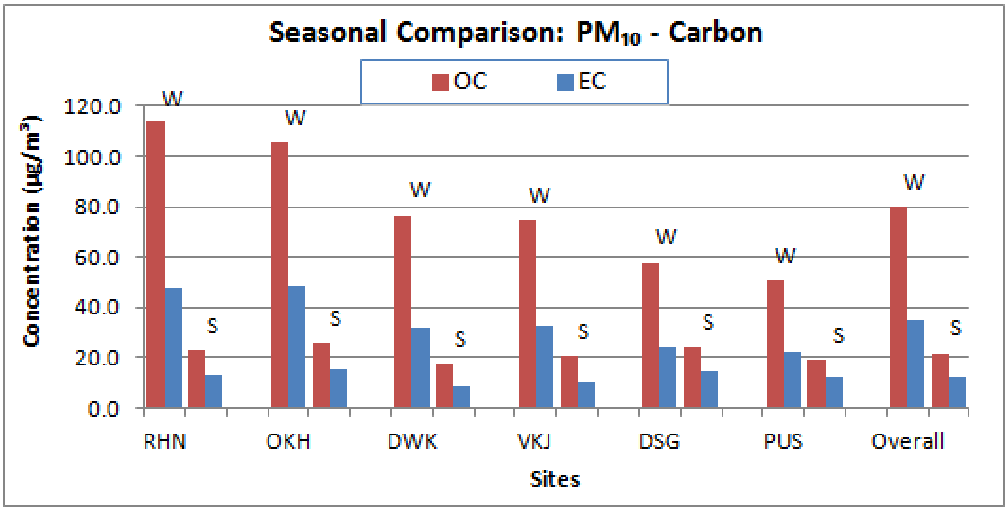


Figure 2.86: Seasonal Comparison of EC and OC in PM_{10} for all Sites

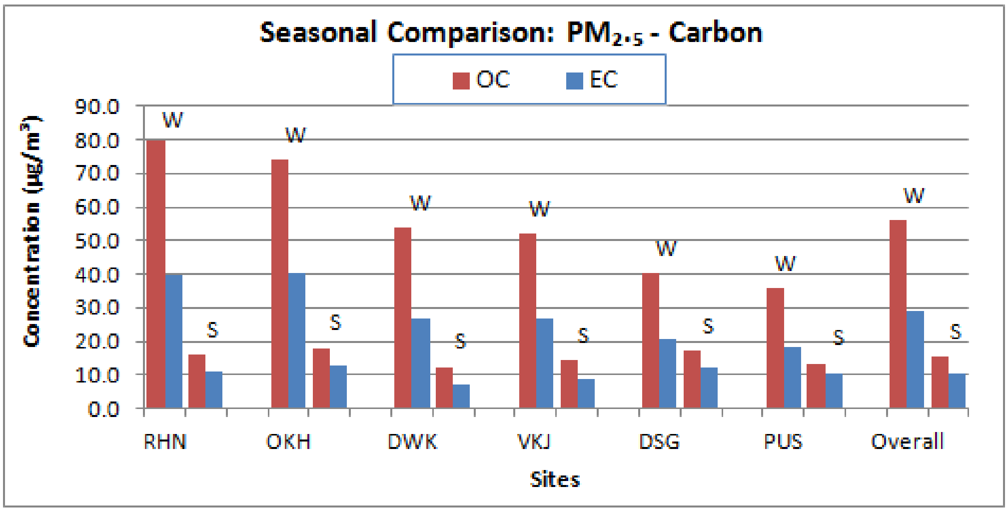
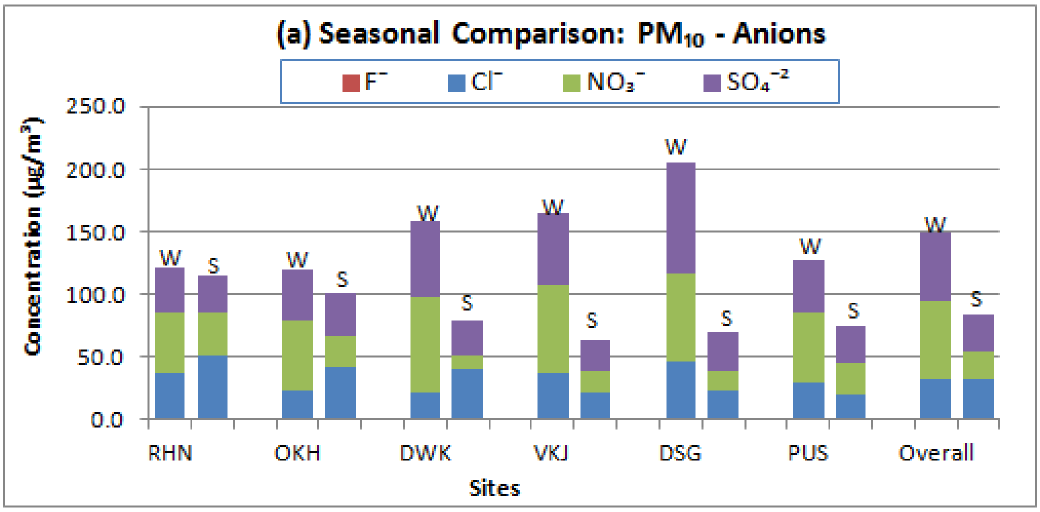


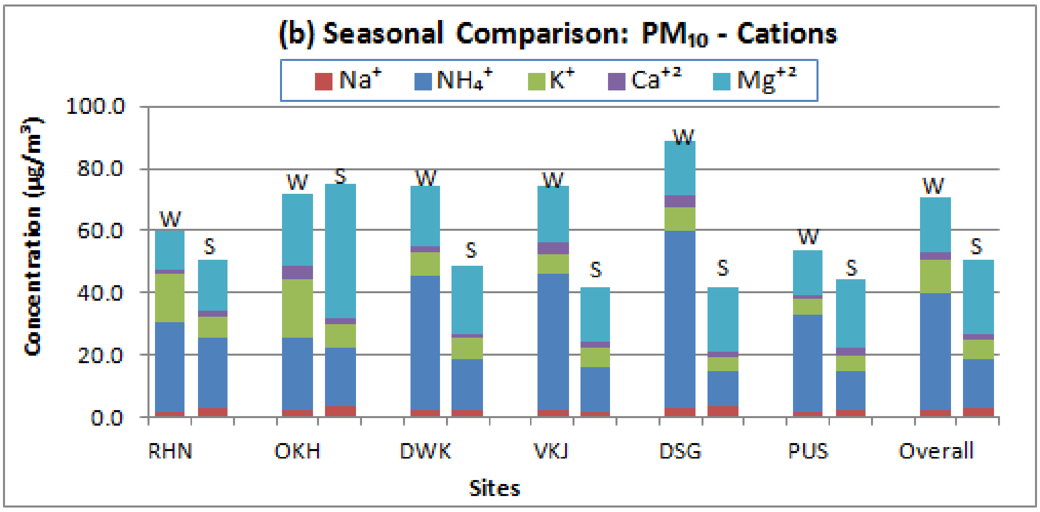
Figure 2.87: Seasonal Comparison of EC and OC in $PM_{2.5}$ for all Sites

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

Graphical presentation for seasonal comparison for chemical species [(a) Anions, (b) Cations and (c) Elements) are shown for PM_{10} (Figure 2.88 (a), (b) and (c)) and $PM_{2.5}$ (Figure 2.89 (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 particulate matter chemical (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 and gaseous pollutant (NO_2 and SO_2) are presented in the Table 2.13 (a), (b), (c) and (d) 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 Table 2.16 (a), (b), (c), (d) for winter and summer seasons.





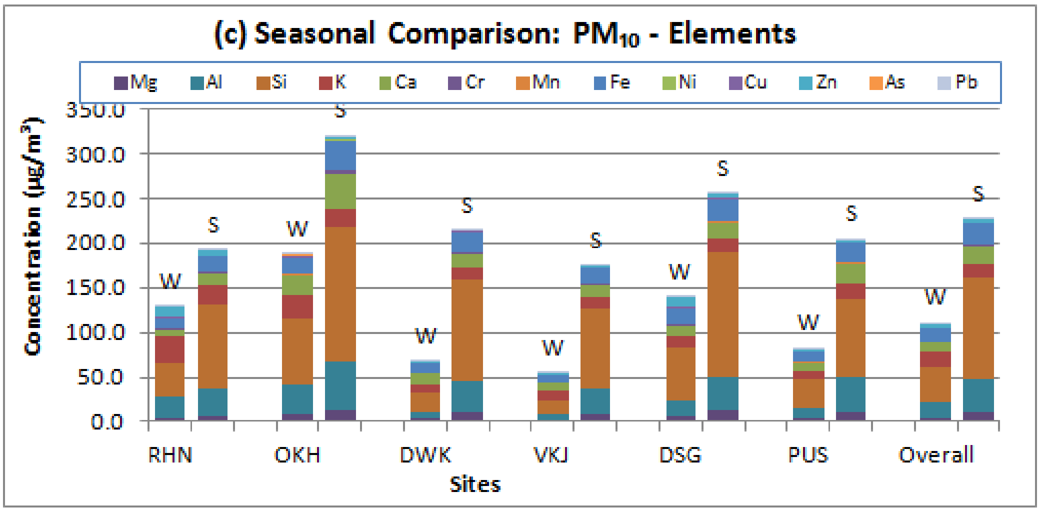


Figure 2.88: Seasonal Comparison of Ionic and Elemental Species Concentrations in PM_{10} for all Sites

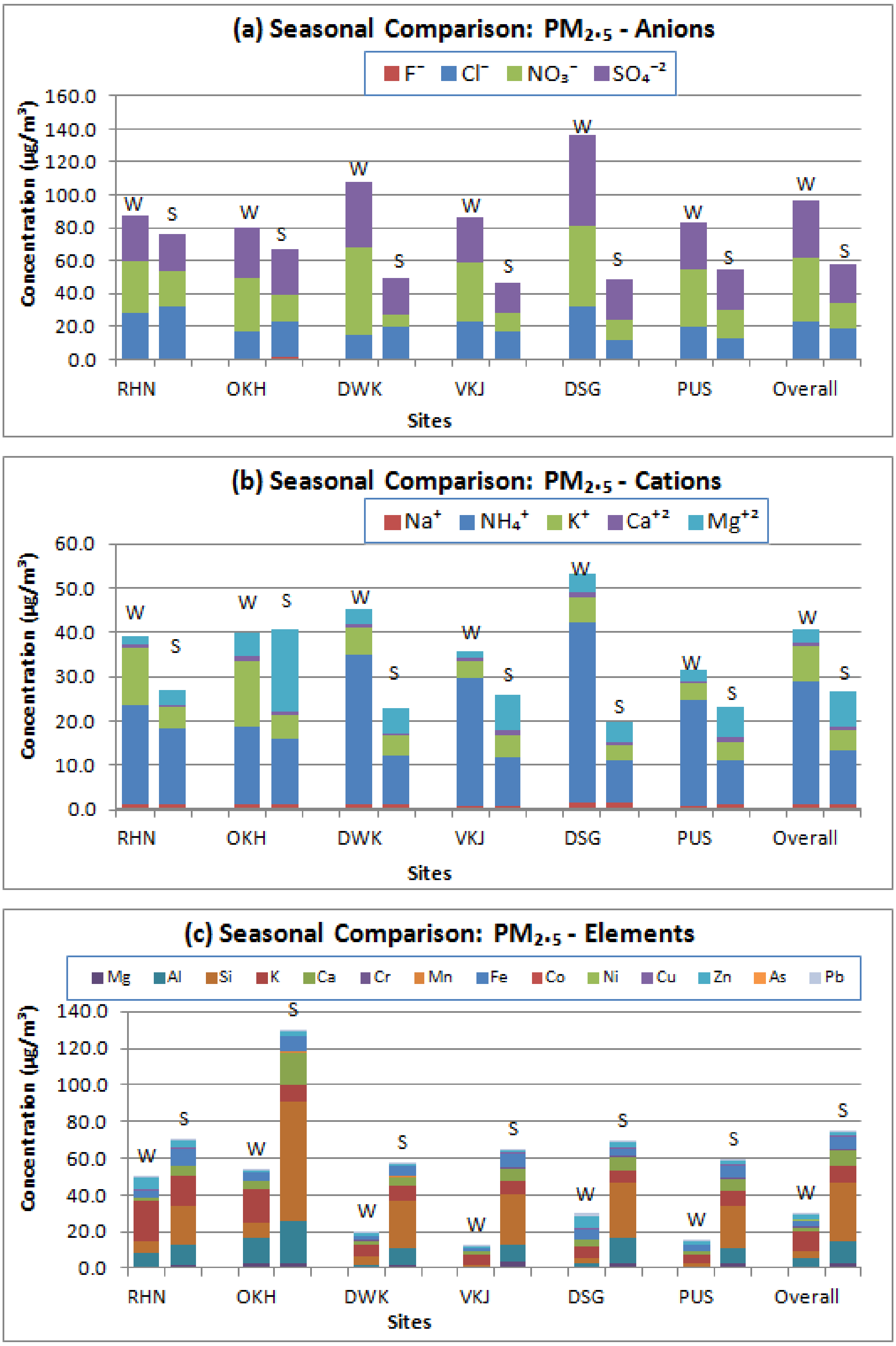


Figure 2.89: Seasonal Comparison of Ionic and Elemental Species Concentrations in $PM_{2.5}$ for all Sites

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

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. 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 2.96) and elements (Figure 2.97) for all sites and both seasons in Delhi. The overall compositional comparison is also presented in Table 2.15 for all sites.

It is observed that most portion of PM is having fine mode during winter (70 %) than summer (60 %). The major species contributing to fine mode are EC, OC, NO_3^-, SO_4^{-2}, Na^+, NH_4^+, K^+, V, Co, Cu, Cd, and Pb; whereas, major species contributing in coarse mode are Ca^{2+}, Mg^{2+}, Al, Si, Cr, 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 TC (0.75), EC (0.70) and OC (0.83) to estimate the carbon content in PM_{10}. Therefore, the percentage of TC (75%), EC (70%) and OC (83%) are constant for all sites in $PM_{2.5}$ to PM_{10}.

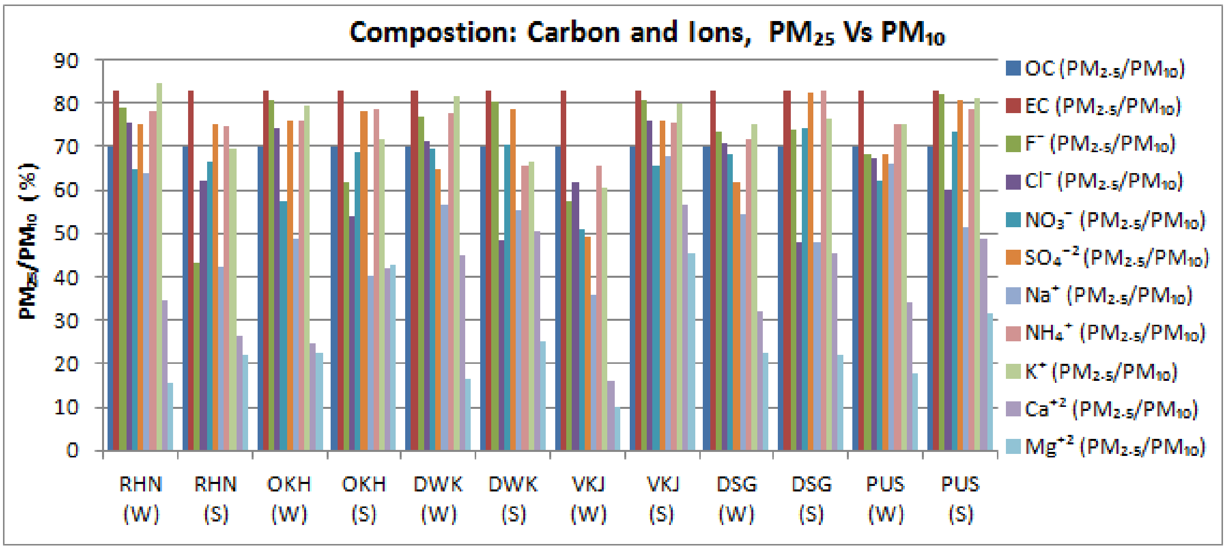


Figure 2.90: Compositional comparison of Carbon and Ions Species in $PM_{2.5}$ Vs PM_{10}

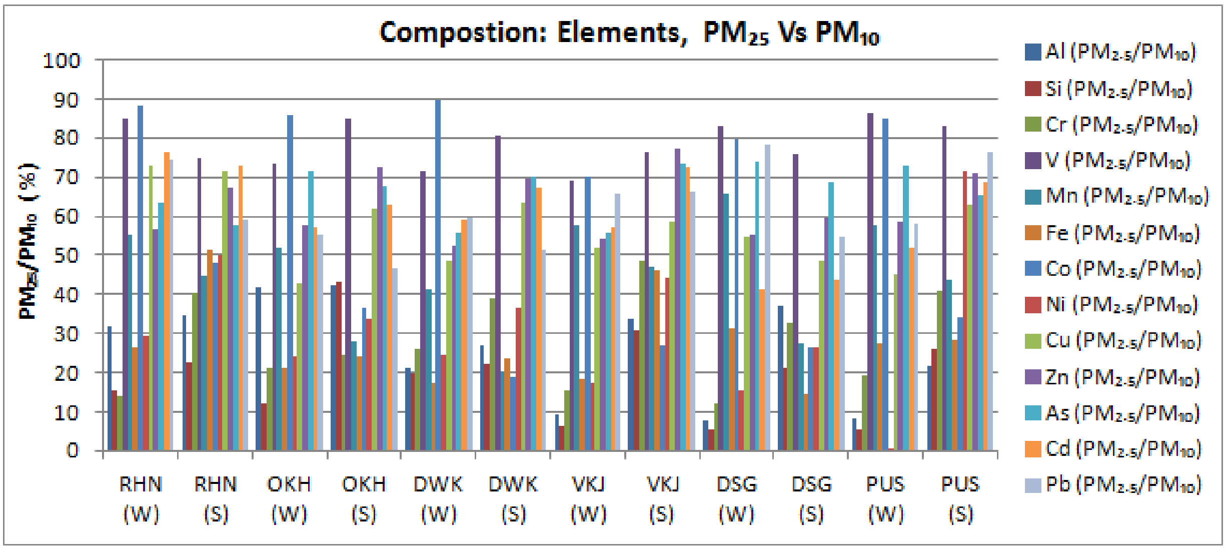


Figure 2.91: Compositional comparison of Elemental Species in $PM_{2.5}$ Vs PM_{10}

Table 2.76(a): Overall Summary of Average Concentration of PAHs in $PM_{2.5}$ all Sites for Winter Season

Winter	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
RHN	2.07	0.21	0.25	7.21	0.00	4.44	5.53	13.13	21.38	4.54	15.17	26.26	4.64	28.16	133.00
OKH	1.36	0.03	0.31	5.02	0.05	2.76	3.51	7.85	14.44	2.90	11.88	18.09	3.75	19.04	91.00
DWK	2.22	0.00	0.24	9.17	0.00	2.33	2.80	7.09	13.65	2.97	10.61	17.54	2.95	18.22	89.80
VKJ	8.52	0.00	3.23	18.64	0.08	4.04	2.84	7.37	10.91	2.35	6.98	9.35	2.07	10.68	87.05
DSG	5.16	0.00	1.80	11.71	0.00	1.35	1.15	3.68	6.46	1.74	2.98	4.13	0.54	5.68	46.40
PUS	2.67	0.06	0.63	6.59	0.00	1.33	0.82	2.52	4.38	0.84	2.08	2.56	0.18	4.13	28.80
Overall	3.67	0.05	1.08	9.73	0.02	2.71	2.77	6.94	11.87	2.56	8.28	12.99	2.36	14.32	79.34
SD	2.71	0.08	1.21	4.94	0.03	1.32	1.71	3.73	6.11	1.25	5.18	9.20	1.77	9.17	36.94
CV	0.74	1.63	1.12	0.51	1.59	0.49	0.62	0.54	0.51	0.49	0.63	0.71	0.75	0.64	0.47

Table 2.77(b): Overall Summary of Average Concentration of PAHs in $PM_{2.5}$ for all Sites for Summer Season

Summer	DmP	DEP	Flu	Phe	Ant	Pyr	B(a)A	Chr	B(b)F	B(k)F	B(a)P	InP	D(a,h)A	B(ghi)P	Total PAHs
RHN	0.37	0.00	0.25	2.34	0.00	1.15	0.18	1.47	3.75	0.08	1.60	3.00	0.07	4.01	18.27
OKH	0.44	0.07	0.44	1.69	0.00	1.25	0.29	1.43	3.63	0.07	1.83	2.55	0.00	3.41	17.09
DWK	0.39	0.05	0.15	0.90	0.00	0.62	0.24	0.22	1.01	0.00	0.25	0.50	0.00	0.90	5.24
VKJ	1.21	1.23	0.07	1.33	0.07	1.31	0.00	0.66	1.31	0.00	0.72	0.84	0.36	1.64	10.75
DSG	1.25	0.62	0.03	1.13	0.00	0.52	0.00	0.45	1.80	0.00	0.60	1.70	0.02	2.73	10.86
PUS	0.47	2.06	0.08	1.12	0.00	0.55	0.00	0.28	0.84	0.00	0.27	0.86	0.00	2.28	8.81
Overall	0.69	0.67	0.17	1.42	0.01	0.90	0.12	0.75	2.06	0.02	0.88	1.58	0.07	2.49	11.84
SD	0.42	0.83	0.15	0.52	0.03	0.38	0.14	0.56	1.30	0.04	0.68	1.02	0.14	1.14	4.97
CV	0.61	1.23	0.90	0.37	2.45	0.42	1.14	0.75	0.63	1.55	0.77	0.65	1.90	0.46	0.42

Table 2.78(a): Overall Summary of Average Concentration of carbon content in $PM_{2.5}$ for all Sites for Winter Season

Winter	**PM2.5**	**TC**	**EC**	**OC**	**OC1**	**OC2**	**OC3**	**OC4**	**OC1/TC**	**OC2/TC**	**OC3/TC**	**OC4/TC**
RHN	438	119.4	39.9	79.5	9.60	23.37	28.22	18.29	0.079	0.195	0.237	0.156
OKH	433	114.4	40.5	73.9	12.32	20.17	25.95	15.41	0.104	0.176	0.230	0.143
DWK	362	80.4	26.8	53.6	6.66	13.99	18.31	14.63	0.077	0.173	0.229	0.193
VKJ	315	79.1	26.9	52.2	5.39	13.59	18.01	15.21	0.068	0.171	0.226	0.188
DSG	435	61.0	20.6	40.4	2.68	10.23	13.74	12.27	0.042	0.169	0.230	0.210
PUS	278	54.2	18.6	35.5	2.92	10.22	12.11	10.27	0.050	0.186	0.224	0.196
Overall	377	84.7	28.9	55.8	6.59	15.26	19.39	14.35	0.070	0.178	0.229	0.181
SD	63	24.6	8.6	16.1	3.47	4.92	5.90	2.53	0.020	0.009	0.004	0.024
CV	0.17	0.29	0.30	0.29	0.53	0.32	0.30	0.18	0.289	0.051	0.018	0.131

Table 2.79(b): Overall Summary of Average Concentration of carbon content in $PM_{2.5}$ for all Sites for Summer Season

Summer	**PM2.5**	**TC**	**EC**	**OC**	**OC1**	**OC2**	**OC3**	**OC4**	**OC1/TC**	**OC2/TC**	**OC3/TC**	**OC4/TC**
RHN	323	27.2	11.1	16.1	1.04	4.35	5.90	4.80	0.038	0.161	0.221	0.178
OKH	412	31.0	12.9	18.0	1.40	5.35	6.72	4.58	0.043	0.176	0.225	0.153
DWK	233	19.3	7.0	12.3	0.64	3.41	4.66	3.61	0.032	0.178	0.241	0.189
VKJ	252	22.7	8.7	14.5	0.84	3.97	5.62	3.90	0.035	0.177	0.246	0.178
DSG	276	28.7	12.2	17.2	0.68	5.50	5.94	5.12	0.025	0.209	0.209	0.176
PUS	269	24.0	10.5	13.4	0.53	3.96	5.00	3.95	0.024	0.168	0.218	0.162
Overall	294	25.5	10.4	15.3	0.85	4.42	5.64	4.33	0.033	0.178	0.227	0.173
SD	59	3.9	2.0	2.0	0.29	0.76	0.67	0.54	0.007	0.015	0.013	0.012
CV	0.20	0.15	0.20	0.13	0.34	0.17	0.12	0.12	0.208	0.084	0.056	0.069

Table 2.804(a): Overall Summary of Average Concentration of Chemical Species in PM_{10} for all Sites for Winter Season

Winter	**PM_{10}**	**NO_2**	**SO_2**	**OC**	**EC**	**F^-**	**Cl^-**	**NO_3^-**	**SO_4^{-2}**	**Na^+**	**NH_4^+**	**K^+**	**Ca^{+2}**	**Mg^{+2}**	**Be**	**B**	**Na**	**Mg**	**Al**	**Si**
RHN	622	69	11	113.5	48.1	0.9	36.2	48.1	36.8	1.6	28.8	15.6	1.5	12.4	0.0	0.9	4.7	5.2	23.6	37.2
OKH	721	101	17	105.5	48.8	0.69	21.86	57.32	39.93	2.09	23.38	18.49	4.85	23.30	0.00	0.55	4.68	8.69	32.98	74.46
DWK	544	85	9	76.6	32.3	0.57	20.52	76.15	61.20	1.98	43.74	7.32	1.72	19.54	0.01	0.64	3.55	4.70	7.18	19.74
VKJ	548	78	13	74.6	32.4	0.74	36.73	70.33	56.32	2.16	43.92	6.59	3.28	18.40	0.00	0.61	2.66	3.20	5.42	16.19
DSG	675	75	21	57.8	24.8	1.06	44.87	71.27	88.38	3.04	56.59	7.86	3.45	17.60	0.00	0.94	4.62	5.52	17.82	59.78
PUS	473	87	12	50.8	22.4	0.63	28.35	56.08	42.27	1.41	31.62	5.01	1.41	14.27	0.00	0.75	3.13	3.79	11.38	33.00
Overall	597	83	14	79.78	34.80	0.76	31.43	63.20	54.14	2.05	38.01	10.15	2.69	17.58	0.00	0.73	3.88	5.18	16.40	40.06
SD	93	11	4	25.16	11.29	0.18	9.51	10.93	19.35	0.57	12.26	5.51	1.39	3.87	0.01	0.16	0.89	1.93	10.58	22.86
CV	0.15	0.14	0.30	0.32	0.32	0.24	0.30	0.17	0.36	0.28	0.32	0.54	0.52	0.22	1.78	0.22	0.23	0.37	0.65	0.57
Winter	**P**	**K**	**Ca**	**Cr**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Rb**	**Sr**	**Cd**	**Cs**	**Ba**	**Pb**	**% R**
RHN	1.1	29.0	8.1	0.8	0.6	0.3	12.3	0.1	0.0	1.0	10.9	0.1	0.0	0.1	0.3	0.1	0.1	4.5	2.1	72.4
OKH	1.61	26.21	21.09	1.00	0.49	0.37	19.25	0.12	0.05	0.41	1.87	0.04	0.02	0.12	0.38	0.02	0.11	10.06	1.16	70.2
DWK	0.93	10.37	11.48	0.45	0.56	0.26	10.92	0.06	0.03	0.22	2.67	0.04	0.03	0.15	0.13	0.02	0.06	0.25	1.09	70.8
VKJ	0.55	9.02	8.78	0.32	0.90	0.31	9.19	0.17	0.02	0.17	1.99	0.07	0.03	0.02	0.23	0.04	0.18	0.16	0.96	69.9
DSG	1.15	12.06	12.61	0.93	0.96	0.45	17.81	0.21	0.05	1.74	11.13	0.08	0.05	0.04	0.29	1.59	0.22	0.36	1.98	73.8
PUS	0.95	8.40	9.19	0.65	0.70	0.29	11.99	0.13	0.02	0.31	2.30	0.02	0.02	0.02	0.18	0.07	0.12	0.34	0.80	68.4
Overall	1.04	15.84	11.87	0.70	0.70	0.33	13.58	0.14	0.04	0.64	5.15	0.06	0.03	0.07	0.24	0.31	0.13	2.61	1.35	70.91
SD	0.35	9.24	4.83	0.27	0.20	0.07	4.01	0.05	0.01	0.62	4.56	0.03	0.01	0.05	0.09	0.63	0.06	4.02	0.55	1.93
CV	0.33	0.58	0.41	0.39	0.28	0.20	0.30	0.36	0.32	0.96	0.89	0.49	0.30	0.74	0.36	2.05	0.43	1.54	0.41	0.03

Table 2.81(b): Overall Summary of Average Concentration of Chemical Species in $PM_{2.5}$ for all Sites for Winter Season

Winter	**$PM_{2.5}$**	**NO_2**	**SO_2**	**OC**	**EC**	**F^-**	**Cl^-**	**NO_3^-**	**SO_4^{-2}**	**Na^+**	**NH_4^+**	**K^+**	**Ca^{+2}**	**Mg^{+2}**	**Be**	**B**	**Na**	**Mg**	**Al**	**Si**
RHN	438	69	11	79.5	39.9	0.7	27.4	31.1	27.7	1.0	22.5	13.2	0.5	1.9	0.0	0.5	2.7	1.2	7.4	5.7
OKH	433	101	17	73.9	40.5	0.56	16.25	32.84	30.39	1.02	17.81	14.65	1.20	5.23	0.00	0.44	2.18	2.41	13.72	9.05
DWK	362	85	9	53.6	26.8	0.44	14.61	53.02	39.63	1.12	34.05	5.97	0.78	3.22	0.01	0.50	1.77	0.71	1.52	3.94
VKJ	315	78	13	52.2	26.9	0.43	22.68	35.77	27.73	0.78	28.77	3.98	0.53	1.86	0.00	0.40	1.36	0.39	0.51	1.02
DSG	435	75	21	40.4	20.6	0.78	31.79	48.53	54.68	1.65	40.50	5.92	1.10	3.96	0.00	0.46	2.55	0.90	1.43	3.30
PUS	278	87	12	35.5	18.6	0.43	19.06	34.98	28.87	0.93	23.79	3.76	0.48	2.56	0.00	0.50	1.49	0.31	0.92	1.80
Overall	377	83	14	55.85	28.88	0.55	21.96	39.37	34.83	1.09	27.90	7.91	0.77	3.13	0.00	0.47	2.01	0.99	4.26	4.13
SD	69	11	4	17.61	9.37	0.15	6.65	9.09	10.72	0.30	8.31	4.77	0.32	1.30	0.01	0.05	0.56	0.77	5.30	2.92
CV	0.18	0.14	0.30	0.32	0.32	0.27	0.30	0.23	0.31	0.27	0.30	0.60	0.42	0.42	1.79	0.10	0.28	0.78	1.24	0.71
Winter	**P**	**K**	**Ca**	**Cr**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Rb**	**Sr**	**Cd**	**Cs**	**Ba**	**Pb**	**% R**
RHN	0.6	22.1	2.1	0.1	0.5	0.2	3.3	0.1	0.0	0.7	6.2	0.1	0.0	0.0	0.2	0.1	0.1	2.9	1.6	65.6
OKH	0.71	18.24	4.03	0.21	0.36	0.19	4.06	0.10	0.01	0.17	1.08	0.03	0.02	0.05	0.27	0.01	0.10	6.96	0.64	62.9
DWK	0.48	6.88	2.03	0.12	0.40	0.11	1.90	0.06	0.01	0.11	1.40	0.02	0.02	0.12	0.07	0.01	0.05	0.03	0.65	68.9
VKJ	0.14	5.43	1.40	0.05	0.62	0.18	1.68	0.12	0.00	0.09	1.08	0.04	0.02	0.00	0.15	0.03	0.13	0.02	0.63	67.4
DSG	0.46	6.65	2.91	0.11	0.80	0.29	5.54	0.16	0.01	0.96	6.15	0.06	0.04	0.00	0.23	0.66	0.19	0.06	1.55	65.5
PUS	0.40	4.58	1.67	0.13	0.61	0.16	3.28	0.11	0.00	0.14	1.34	0.02	0.02	0.00	0.12	0.04	0.10	0.03	0.47	64.2
Overall	0.47	10.65	2.36	0.12	0.54	0.19	3.29	0.11	0.01	0.37	2.87	0.04	0.02	0.03	0.17	0.14	0.11	1.66	0.92	65.75
SD	0.19	7.53	0.97	0.05	0.16	0.06	1.43	0.03	0.00	0.38	2.55	0.02	0.01	0.05	0.07	0.26	0.05	2.83	0.50	2.14
CV	0.42	0.71	0.41	0.43	0.30	0.32	0.43	0.31	0.67	1.03	0.89	0.50	0.37	1.35	0.43	1.88	0.41	1.70	0.54	0.03

Table 2.82(c): Overall Summary of Average Concentration of Chemical Species in PM_{10} for all Sites for Summer Season

Summer	PM_{10}	NO_2	SO_2	OC	EC	F^-	Cl^-	NO_3^-	SO_4^{-2}	Na^+	NH_4^+	K^+	Ca^{+2}	Mg^{+2}	Be	B	Na	Mg	Al	Si
RHN	536	40	15	23.0	13.4	1.53	49.75	33.36	29.85	2.51	23.06	6.91	1.63	16.30	0.00	0.84	4.88	6.73	30.22	94.94
OKH	635	74	15	25.8	15.6	1.94	39.51	24.90	35.25	3.37	18.60	7.59	1.96	43.24	0.00	1.69	7.39	13.32	53.86	151.70
DWK	458	40	8	17.6	8.4	1.00	39.65	10.62	28.42	2.17	16.45	6.84	1.04	22.33	0.00	1.24	4.90	10.75	33.99	113.80
VKJ	410	47	10	20.8	10.5	0.77	21.15	17.42	24.46	1.40	14.53	6.10	1.87	17.95	0.00	0.99	4.86	9.32	28.52	89.33
DSG	503	69	15	24.6	14.7	0.88	21.90	16.64	30.15	3.24	11.40	4.38	1.87	20.98	0.00	0.82	6.83	12.02	38.41	138.44
PUS	534	85	8	19.2	12.7	0.97	19.25	24.04	31.03	1.98	12.63	5.09	2.27	22.05	0.00	0.97	7.47	10.20	39.20	89.01
Overall	513	59	11.7	21.83	12.53	1.18	31.87	21.16	29.86	2.44	16.11	6.15	1.77	23.81	0.00	1.09	6.05	10.39	37.37	112.87
SD	77	19	3.4	3.18	2.69	0.45	12.74	7.96	3.51	0.76	4.28	1.21	0.41	9.81	0.00	0.33	1.31	2.28	9.13	26.86
CV	0.15	0.33	0.29	0.15	0.21	0.38	0.40	0.38	0.12	0.31	0.27	0.20	0.23	0.41	0.23	0.30	0.22	0.22	0.24	0.24

Summer	P	K	Ca	Cr	V	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Rb	Sr	Cd	Cs	Ba	Pb	% R
RHN	1.72	20.82	13.62	1.16	1.08	0.46	17.32	0.01	0.06	0.80	5.56	0.11	0.03	0.06	0.13	0.08	0.01	0.28	2.20	72.8
OKH	1.94	18.06	40.47	2.83	1.73	0.84	33.93	0.02	0.12	0.52	3.69	0.08	0.03	0.14	0.33	0.12	0.01	1.68	2.10	79.7
DWK	1.12	13.99	14.42	1.89	1.30	0.50	22.99	0.01	0.06	0.22	1.43	0.05	0.02	0.10	0.17	0.04	0.00	0.34	0.86	75.4
VKJ	0.89	12.95	13.29	1.71	0.87	0.46	17.25	0.02	0.07	0.18	1.23	0.03	0.02	0.08	0.15	0.03	0.01	0.30	0.41	73.0
DSG	1.19	15.40	17.08	2.10	0.79	0.60	23.92	0.01	0.09	1.87	4.35	0.04	0.02	0.09	0.17	0.62	0.01	0.42	1.60	78.2
PUS	1.25	15.60	21.79	1.84	0.93	0.51	22.08	0.05	0.08	0.43	2.64	0.10	0.08	0.10	0.19	0.09	0.05	0.39	1.28	64.1
Overall	1.35	16.13	20.11	1.92	1.12	0.56	22.91	0.02	0.08	0.67	3.15	0.07	0.03	0.09	0.19	0.16	0.01	0.57	1.41	73.87
SD	0.40	2.87	10.46	0.55	0.35	0.14	6.11	0.01	0.02	0.63	1.70	0.03	0.02	0.03	0.07	0.22	0.02	0.55	0.70	5.54
CV	0.29	0.18	0.52	0.28	0.31	0.26	0.27	0.69	0.30	0.94	0.54	0.49	0.62	0.28	0.37	1.37	1.38	0.96	0.50	0.07

Table 2.834(d): Overall Summary of Average Concentration of Chemical Species in $PM_{2.5}$ for all Sites for Summer Season

Summer	**$PM_{2.5}$**	**NO_2**	**SO_2**	**OC**	**EC**	**F^-**	**Cl^-**	**NO_3^-**	**SO_4^{-2}**	**Na^+**	**NH_4^+**	**K^+**	**Ca^{+2}**	**Mg^{+2}**	**Be**	**B**	**Na**	**Mg**	**Al**	**Si**
RHN	323	40	15	16.1	11.1	0.7	30.9	22.1	22.4	1.1	17.2	4.8	0.4	3.6	0.0	0.5	2.7	2.2	10.5	21.6
OKH	412	74	15	18.0	12.9	1.20	21.41	17.05	27.57	1.36	14.63	5.42	0.82	18.53	0.00	1.13	2.85	2.73	22.76	65.35
DWK	233	40	8	12.3	7.0	0.80	19.12	7.47	22.32	1.20	10.83	4.54	0.52	5.65	0.00	0.65	2.48	1.83	9.20	25.36
VKJ	252	47	10	14.5	8.7	0.62	16.08	11.46	18.54	0.94	10.98	4.87	1.06	8.18	0.00	0.59	2.22	3.27	9.61	27.72
DSG	276	69	15	17.2	12.2	0.65	10.48	12.36	24.90	1.55	9.46	3.33	0.85	4.61	0.00	0.46	2.75	2.59	14.23	29.59
PUS	269	85	8	13.4	10.5	0.79	11.52	17.62	25.04	1.02	9.93	4.13	1.11	6.96	0.00	0.64	3.32	2.52	8.46	23.31
Overall	294	59	11.7	15.28	10.40	0.79	18.26	14.68	23.46	1.19	12.18	4.52	0.80	7.92	0.00	0.66	2.71	2.53	12.45	32.15
SD	65	19	3.4	2.23	2.24	0.21	7.50	5.24	3.10	0.23	3.07	0.72	0.28	5.45	0.00	0.24	0.37	0.48	5.44	16.52
CV	0.22	0.33	0.29	0.15	0.21	0.27	0.41	0.36	0.13	0.19	0.25	0.16	0.34	0.69	0.29	0.36	0.14	0.19	0.44	0.51
Summer	**P**	**K**	**Ca**	**Cr**	**V**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**As**	**Se**	**Rb**	**Sr**	**Cd**	**Cs**	**Ba**	**Pb**	**% R**
RHN	0.8	15.6	5.5	0.5	0.8	0.2	8.9	0.0	0.0	0.6	3.7	0.1	0.0	0.0	0.1	0.1	0.0	0.1	1.3	62.8
OKH	0.45	8.97	17.22	0.70	1.47	0.24	8.17	0.01	0.04	0.32	2.68	0.05	0.02	0.04	0.07	0.08	0.00	0.27	0.98	61.6
DWK	0.59	8.41	4.34	0.74	1.05	0.10	5.47	0.00	0.02	0.14	1.00	0.03	0.01	0.02	0.03	0.03	0.00	0.06	0.44	63.9
VKJ	0.45	7.03	6.10	0.83	0.66	0.22	7.93	0.01	0.03	0.11	0.95	0.02	0.02	0.03	0.07	0.02	0.00	0.11	0.27	59.8
DSG	0.65	6.46	7.89	0.69	0.60	0.16	3.53	0.00	0.02	0.90	2.60	0.03	0.01	0.02	0.06	0.27	0.00	0.07	0.87	61.7
PUS	0.56	7.64	6.92	0.75	0.77	0.23	6.24	0.02	0.06	0.27	1.87	0.07	0.04	0.05	0.10	0.06	0.01	0.09	0.98	61.6
Overall	0.58	9.03	8.00	0.70	0.89	0.19	6.70	0.01	0.03	0.38	2.14	0.04	0.02	0.03	0.06	0.09	0.00	0.11	0.80	61.92
SD	0.13	3.37	4.67	0.12	0.32	0.05	2.01	0.00	0.01	0.30	1.08	0.02	0.01	0.01	0.02	0.09	0.00	0.08	0.38	1.37
CV	0.23	0.37	0.58	0.18	0.36	0.27	0.30	0.77	0.43	0.79	0.50	0.43	0.44	0.41	0.35	1.08	0.59	0.69	0.47	0.02

Table 2.84: Ratios of Chemical Species of $PM_{2.5}$ and PM_{10} for all sites for Winter (W) and Summer (S) Seasons

Sites (Season)	RHN (W)	RHN (S)	OKH (W)	OKH (S)	DWK (W)	DWK (S)	VKJ (W)	VKJ (S)	DSG (W)	DSG (S)	PUS (W)	PUS (S)
PM_{10} (µg/m^3)	622	536	721	635	544	458	548	410	675	503	473	534
$PM_{2.5}$ (µg/m^3)	438	323	433	412	362	233	315	252	435	276	278	269
$PM_{2.5}/PM_{10}$ (%)	70	60	60	65	67	51	57	61	64	55	59	50
F^- ($PM_{2.5}/PM_{10}$) (%)	79	43	81	62	77	80	58	81	73	74	68	82
Cl^- ($PM_{2.5}/PM_{10}$) (%)	76	62	74	54	71	48	62	76	71	48	67	60
NO_3^- ($PM_{2.5}/PM_{10}$) (%)	65	66	57	68	70	70	51	66	68	74	62	73
SO_4^{-2}($PM_{2.5}/PM_{10}$) (%)	75	75	76	78	65	79	49	76	62	83	68	81
Na^+ ($PM_{2.5}/PM_{10}$) (%)	64	43	49	40	57	55	36	68	54	48	66	52
NH_4^+ ($PM_{2.5}/PM_{10}$) (%)	78	75	76	79	78	66	65	76	72	83	75	79
K^+ ($PM_{2.5}/PM_{10}$) (%)	85	70	79	71	82	66	60	80	75	76	75	81
Ca^{+2} ($PM_{2.5}/PM_{10}$) (%)	35	26	25	42	45	50	16	57	32	45	34	49
Mg^{+2} ($PM_{2.5}/PM_{10}$) (%)	16	22	22	43	16	25	10	46	22	22	18	32
Al ($PM_{2.5}/PM_{10}$) (%)	32	35	42	42	21	27	9	34	8	37	8	22
Si ($PM_{2.5}/PM_{10}$) (%)	15	23	12	43	20	22	6	31	6	21	5	26
Cr ($PM_{2.5}/PM_{10}$) (%)	14	40	21	25	26	39	16	48	12	33	19	41
V ($PM_{2.5}/PM_{10}$) (%)	85	75	74	85	71	81	69	76	83	76	87	83
Mn ($PM_{2.5}/PM_{10}$) (%)	55	45	52	28	41	20	58	47	66	28	57	44
Fe ($PM_{2.5}/PM_{10}$) (%)	27	51	21	24	17	24	18	46	31	15	27	28
Co ($PM_{2.5}/PM_{10}$) (%)	88	48	86	37	90	19	70	27	80	26	85	34
Ni ($PM_{2.5}/PM_{10}$) (%)	29	50	24	34	24	37	18	44	16	27	0	71
Cu ($PM_{2.5}/PM_{10}$) (%)	73	72	43	62	49	63	52	59	55	48	45	63
Zn ($PM_{2.5}/PM_{10}$) (%)	57	67	58	73	52	70	54	77	55	60	58	71
As ($PM_{2.5}/PM_{10}$) (%)	63	58	71	67	55	70	56	73	74	69	73	65
Cd ($PM_{2.5}/PM_{10}$) (%)	76	73	57	63	59	67	57	72	41	44	52	69
Pb ($PM_{2.5}/PM_{10}$) (%)	74	59	55	47	60	51	66	66	78	55	58	76

Table 2.85(a): 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}
RHN	622	81.2	0.130	113.7	0.183	161.6	0.260
OKH	721	147.8	0.205	120.6	0.167	154.3	0.214
DWK	544	49.3	0.091	181.1	0.333	108.8	0.200
VKJ	548	39.6	0.072	170.6	0.311	107.0	0.195
DSG	675	108.0	0.160	216.2	0.320	82.6	0.122
PUS	473	65.6	0.139	130.0	0.275	73.2	0.155
Overall	597	81.9	0.133	155.4	0.265	114.6	0.191
SD	93	40.4	0.048	40.5	0.072	36.4	0.048
CV	0.155	0.493	0.360	0.260	0.273	0.318	0.250

Table 2.86(b): Statistical summary of major components: $PM_{2.5}$, Winter ($\mu g/m^3$)

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/$PM_{2.5}$
RHN	438	18.6	0.042	81.2	0.186	119.4	0.273
OKH	433	30.9	0.071	81.0	0.187	114.4	0.264
DWK	362	9.4	0.026	126.7	0.350	80.4	0.222
VKJ	315	4.6	0.015	92.3	0.293	79.1	0.251
DSG	435	13.2	0.030	143.7	0.331	61.0	0.140
PUS	278	7.7	0.028	87.6	0.315	54.2	0.195
Overall	377	14.0	0.035	102.1	0.277	84.7	0.224
SD	69	9.5	0.020	26.5	0.073	26.9	0.050
CV	0.184	0.680	0.558	0.260	0.262	0.318	0.224

Table 2.87(c): Statistical summary of major components: PM_{10}, Summer ($\mu g/m^3$)

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}
RHN	536	156.1	0.291	86.3	0.161	36.4	0.068
OKH	635	280.0	0.441	78.7	0.124	41.3	0.065
DWK	458	185.2	0.405	55.5	0.121	26.0	0.057
VKJ	410	148.4	0.362	56.4	0.137	31.2	0.076
DSG	503	217.8	0.433	58.2	0.116	39.3	0.078
PUS	534	172.1	0.322	67.7	0.127	31.9	0.060
Overall	513	193.3	0.376	67.1	0.131	34.4	0.067
SD	77	49.0	0.061	12.9	0.016	5.7	0.009
CV	0.150	0.254	0.162	0.192	0.125	0.167	0.127

Table 2.88(d): Statistical summary of major components: $PM_{2.5}$, Summer ($\mu g/m^3$)

Summer	$PM_{2.5}$	Crustal (Si + Al + Fe + Ca)	Ratio Crustal/$PM_{2.5}$	Sec Ions (NO_3^- + SO_4^{-2} + NH_4^+)	Ratio Sec Ions/$PM_{2.5}$	TC	Ratio TC/$PM_{2.5}$
RHN	323	46.5	0.144	61.8	0.191	27.2	0.084
OKH	412	113.5	0.276	59.2	0.144	31.0	0.075
DWK	233	44.4	0.191	40.6	0.174	19.3	0.083
VKJ	252	51.4	0.204	41.0	0.163	22.7	0.090
DSG	276	55.2	0.200	46.7	0.169	28.7	0.104
PUS	269	44.9	0.167	52.6	0.196	24.0	0.089
Overall	294	59.3	0.197	50.3	0.173	25.5	0.088
SD	65	26.9	0.045	9.1	0.019	4.3	0.010
CV	0.221	0.453	0.227	0.180	0.110	0.168	0.110

2.5 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.

2.5.1Box Plot Distribution

Statistical box plots are shown in Figures 2.92 to 2.97 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. It is seen from these plots the concentrations of various pollutants higher in winter and varying in wider range.

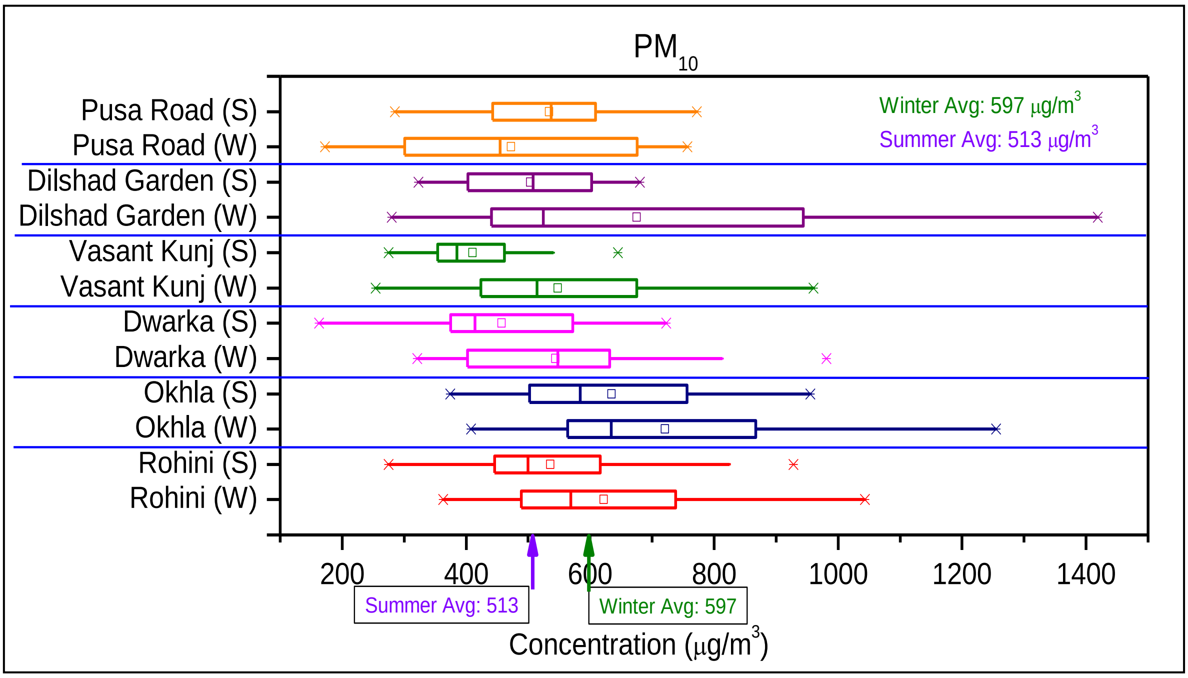


Figure 2.92: Box plot distribution of 24-hr average concentration of PM_{10} during winter (W) and summer (S) seasons

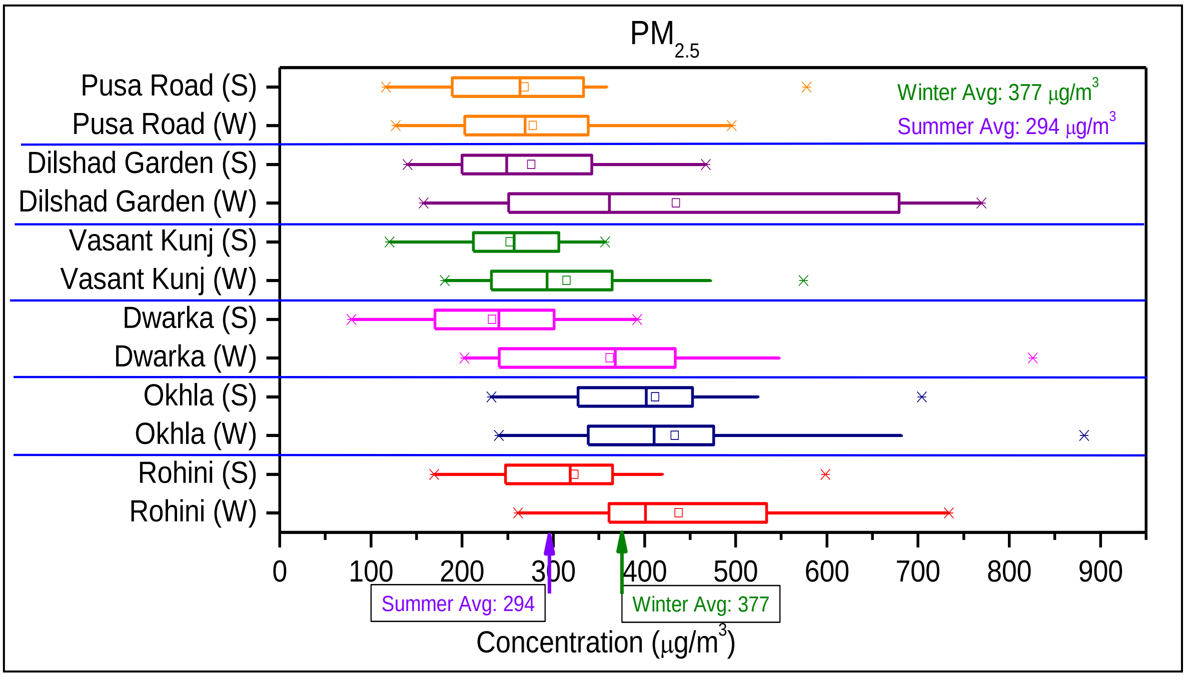


Figure 2.93: Box plot distribution of 24-hr average concentration of $PM_{2.5}$ during winter (W) and summer (S) seasons

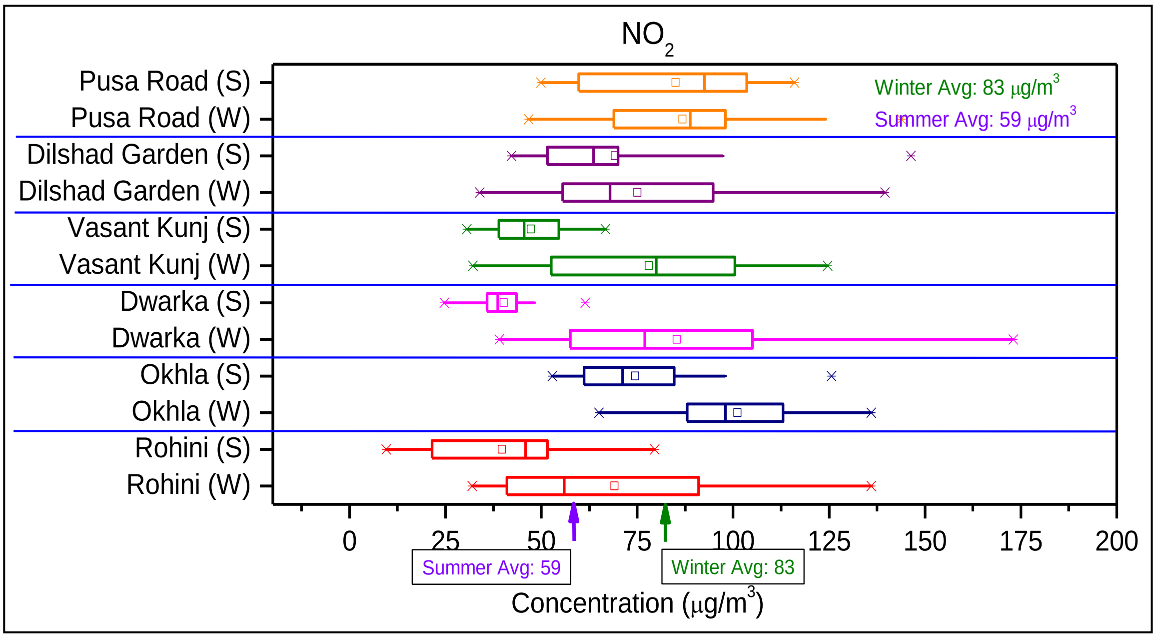


Figure 2.94: Box plot distribution of 24-hr average concentration of NO_2 during winter (W) and summer (S) seasons

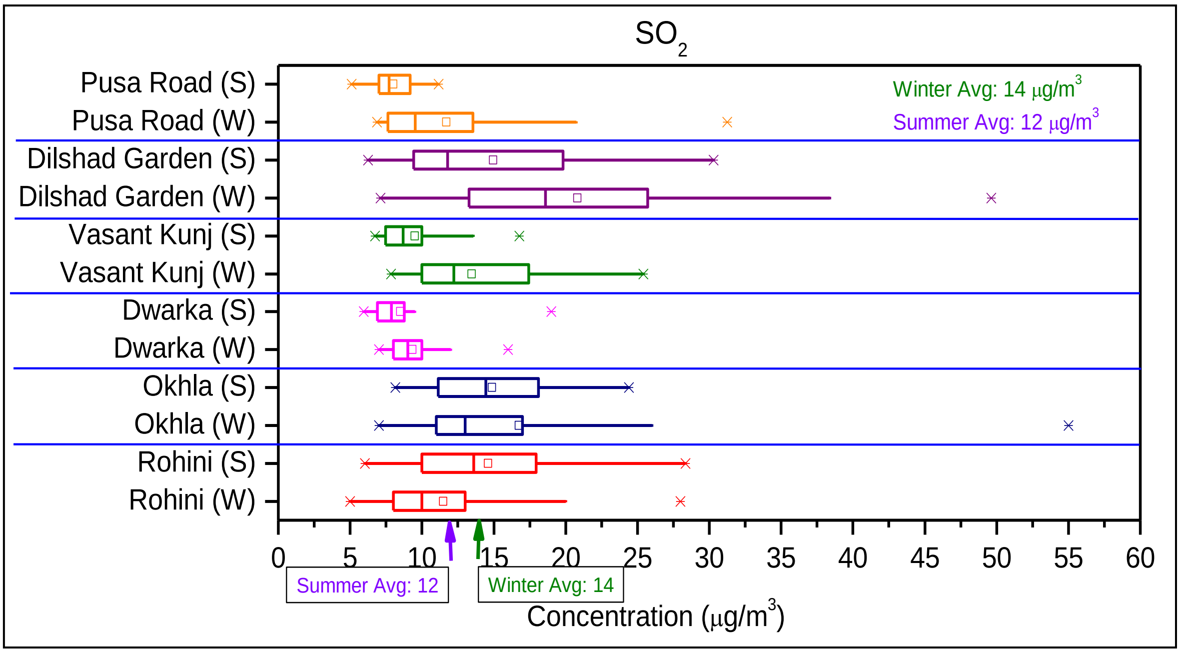


Figure 2.95: Box plot distribution of 24-hr average concentration of SO_2 during winter (W) and summer (S) seasons

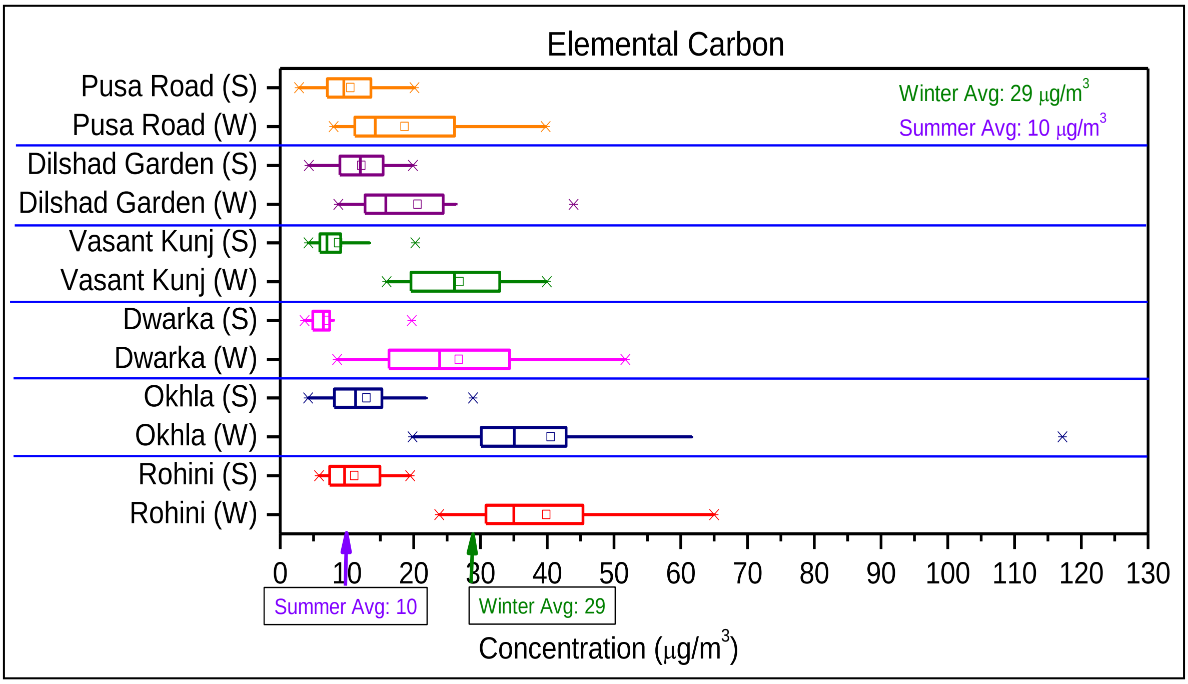


Figure 2.96: Box plot distribution of 24-hr average concentration of EC during winter (W) and summer (S) seasons

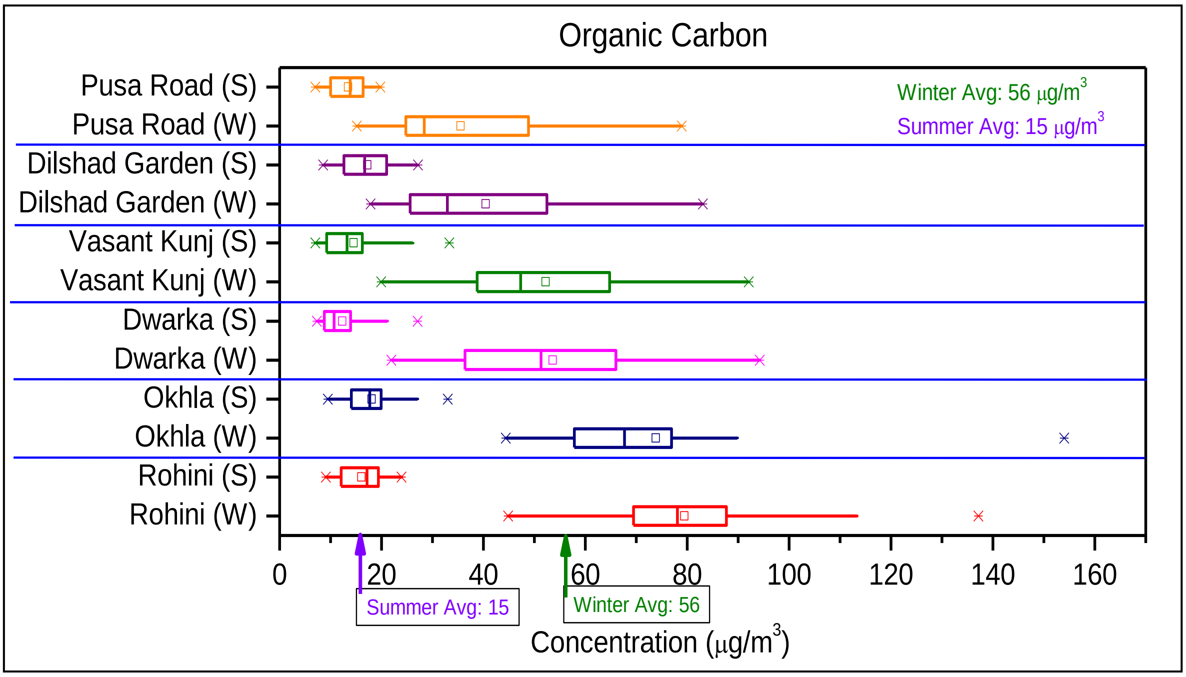


Figure 2.97: Box plot distribution of 24-hr average concentration of OC during winter (W) and summer (S) seasons

2.5.2 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, OC and TC). It is observed from Table 2.17 that levels are higher at the following sites: (i) PM_{10} at Vasantkunj and Dilshad Garden, (ii) $PM_{2.5}$ at Rohini, Dwarka, Vasantkunj and Dilshad Garden, (iii) NO_2 at Rohini, Okhla, Dwarka and Vasantkunj, (iv) SO_2 at Vasantkunj, Dilshad Garden and Pusa Road and (v) Carbon Content (EC, OC and TC) at all sites. For other sites and pollutants, there is no significant difference in levels of 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 Delhi except Vasantkunj and Dilshad Garden. The information on seasonal composition of PM can assist in identifying the various sources contributing to ambient pollution level.

Table 2.89: Statistical Comparison Winter Vs Summer

Parameter → Site ↓	PM_{10}	$PM_{2.5}$	NO_2	SO_2	EC	OC	TC
RHN	↔	↑	↑	↔	↑	↑	↑
OKH	↔	↔	↑	↔	↑	↑	↑
DWK	↔	↑	↑	↔	↑	↑	↑
VKJ	↑	↑	↑	↑	↑	↑	↑
DSG	↑	↑	↔	↑	↑	↑	↑
PUS	↔	↔	↔	↑	↑	↑	↑
↔ No significant difference		↑ (Levels higher in winter)			↓ (Levels lower in winter)		
* No pollutant showed lower concentration in winter							

2.6 Interpretations and Inferences

Based on the 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 and dispersion modeling (Chapter 4 and 5). The season-wise, site specific average air concentration of PM_{10}, $PM_{2.5}$ and their compositions (Tables 2.14 (a, b, c, d) and 2.16 (a, b, c, d)) have been referred to bring the important inferences to the fore.

- Particulate pollution is the main concern in the city where levels of PM_{10} and $PM_{2.5}$ are 4-7 times higher than the national air quality standards in summer and 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.

Summer - PM_{10}

The overall average concentration of PM_{10} in summer season is over 500 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 40 percent of total PM_{10} in summer. This suggests soil and road dust and airborne flyash are the major sources of PM_{10} pollution in summer. The coefficient of variation (CV) is about 0.25, which suggests the sources are consistent all around the city forming a layer which envelopes the city. The areas of DSG and OKH have the highest crustal fraction (around 44% of total PM_{10}). It is difficult to pinpoint the crustal sources as these are wide spread and present all around in Delhi and NCR and are more prominent in summer when soil and ash-ponds (active or abandoned) are dry and high speed winds make the particles airborne. It was observed that in summer the atmosphere looks whitish to grayish which can be attributed to the presence of large amounts of flyash and dust particles in the atmosphere.

The second important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for about 13 percent of total PM_{10} and combustion related total carbon (EC+OC) accounts for about seven percent. The secondary particles are formed in the atmosphere because of reaction of precursor gases (SO_2, NOx 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 also consistent at 4-6 percent, which is an indicator of burning of municipal solid waste (MSW); recall poly vinyl chloride (PVC) is a major part of MSW.

Summer - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in summer season is around 300 µg/m^3 against the acceptable level of 60 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for about 20 percent of total $PM_{2.5}$. This suggests soil and road dust and airborne flyash is a significant source of $PM_{2.5}$ pollution in summer. The CV is about 0.23, which suggests the source is consistent all around the city. The area of OKH has the highest crustal fraction around 28% of total $PM_{2.5}$.

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

The Cl^- content in $PM_{2.5}$ in summer is also consistent at 4-10 percent, which is an indicator of burning of municipal solid waste (MSW) and has a relatively higher contribution to $PM_{2.5}$ than that to PM_{10}.

Winter - PM_{10}

The overall average concentration of PM_{10} in winter season is around 600 µg/m^3 against the acceptable level of 100 µg/m^3.

The crustal component (Si + Al + Fe + Ca) accounts for only 13% (much less compared to 40 percent in summer). This suggests soil and road dust and airborne flyash have reduced significantly in PM_{10} in winter. The coefficient of variation (CV) is about 0.36, which suggests the crustal source is variable and not as consistent as it was in summer.

The most important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which accounts for about 26 percent of total PM_{10} and combustion related total carbon (TC = EC: elemental carbon + OC: organic carbon) accounts for about 19 percent; both fraction of secondary particles and combustion related carbons have increased in winter and account for 45 percent of PM_{10}.

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

Winter - $PM_{2.5}$

The overall average concentration of $PM_{2.5}$ in winter is 375 µg/m^3 against the acceptable level of 60 µg/m^3. The crustal component is reduced dramatically to only 3.5 percent in $PM_{2.5}$ in winter.

The single important component is the secondary particles ($NO_3^- + SO_4^{-2} + NH_4^+$), which account for about 28 percent of total $PM_{2.5}$ and combustion related total carbon (EC+OC) accounts for about 23 percent; both secondary particles and combustion related carbon are consistent contributor to $PM_{2.5}$ at about 51 percent having CV of 0.22.

The Cl^- content in $PM_{2.5}$ winter is also consistent at 7 percent, which is an indicator of burning of municipal solid waste (MSW); which is relatively higher in winter than in summer

It was observed that in winter the atmosphere looks very hazy and characterized by smoky and unhealthy air. The consistent and major contributors appear to be secondary particles and combustion related emission with modest contribution of burning of MSW.

Potassium levels

In general potassium levels are high and at the same time highly variable; 18 to 7 $\mu g/m^3$ in PM_{10} and 15 to 4 $\mu g/m^3$ in $PM_{2.5}$. In general potassium level should be less than 2 $\mu g/m^3$. Potassium is an indicator of biomass burning and high levels and variability (CV ~ 0.66) show large biomass burning and it is variable. Highest potassium levels (~ 15 $\mu g/m^3$) were seen in the beginning of November and early winter perhaps due to massive crop residue burning in Punjab and Haryana. Potassium levels stabilize around 4 $\mu g/m^3$ (which is also high) in rest of the winter months suggesting the biomass burning is prevalent throughout winter, locally and regionally.

NO_2 levels

NO_2 levels in winter are high and they do exceed national air quality standard of 80 $\mu g/m^3$ at a few locations; more frequently at PUS sampling 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_{10}, $PM_{2.5}$ and NO_2 are statistically higher (at most locations) in winter months than in summer months by about 25-30 percent. 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, OKH is most polluted and PUS followed by DWK is the least polluted for PM pollution.

The CO levels are well within the ambient air quality standard during summer while at PUS the concentration exceeds the standards during peak traffic hours in winter.

The entire city is enveloped by pollution layer all around with contribution from multiple sources within Delhi, nearby region and even from long distances.

It is to be noted that OC3/TC ratio is above 0.22 and highest among ratio of fraction of OC to TC (Chapter 2). 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 (VOCs and SVOCs), which again suggests emissions within and outside of Delhi.

Total PAH levels (14 compounds; particulate phase) in winter is very high at 80 ng/m^3 and B(a)P at 8 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 15 ng/m^3.

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.

During Diwali days, PM levels nearly double from the average level and organic content of PM increases more than twice. It is noteworthy that levels of potassium and barium, the main components of fire crackers can increase by about ten times.

- Limited sampling was undertaken in summer and winter seasons at three sites in NCR (Noida, Gaziabad and Faridabad) that indicated the levels in Delhi and NCR are similar and comparable; it suggests that air pollution levels could be contiguously high in the NCR. To get a further insight into this matter, a sampling of PM, SO_2 and NO_2 was also carried out winter season (2014 -15) and as expected levels in Delhi and NCR were comparable.

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 Delhi and NCR.

Combustion sources, vehicles, 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, concrete batching and MSW burning. Possible effective mixture of control options are discussed in Chapter 6.

Chapter 3

Emission Inventory

3.1 Introduction

Air pollution has emerged as a major challenge, particularly in urban areas. The problem becomes more complex due to the multiplicity and complexity of the air polluting source mix (e.g., industries, automobiles, generators, domestic fuel burning, road side dusts, construction activities, etc.). Indian cities have experienced a phenomenal growth in terms of population, industry, and vehicles. The broad emission source categories of air pollution in an urban area include; (i) transport (motor vehicles and railways), (ii) commercial establishments, (iii) industrial, (iv) domestic cooking/heating, (v) fugitive dust and (vi) biomass burning. There could also be some unique or specific sources in a particular area. Procedures and reliability of emission inventory for regular point, area and line sources are well-established. However, identification and quantification of fugitive/non-point emission sources (emissions not released through stacks, vents, ducts or pipes) are quite challenging.

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. The ultimate goal of the planning process is to identify and achieve emission patterns that do not result in violations of ambient air quality standards. In this chapter, emission inventory of the study area for the period of 1st October 2013 to 30th June 2014 is presented.

3.2 Methodology

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

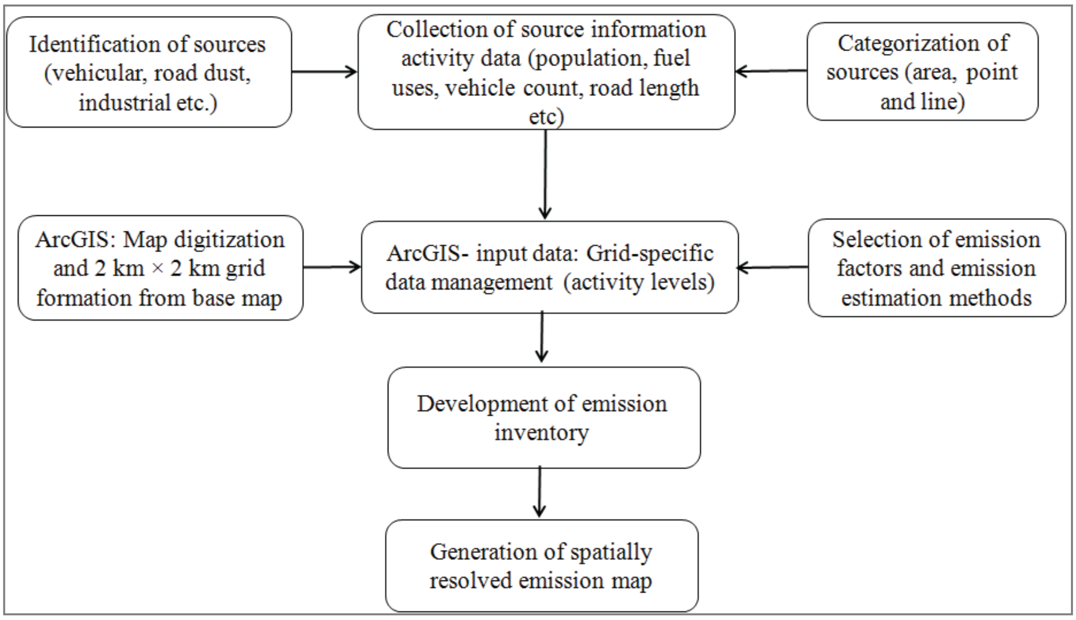


Figure 3.1: Stepwise Methodology adopted for the Study

3.2.1 Data Collection

The primary data were collected by IITK team. Parking lane survey at 18 locations was done to assess types of vehicles on the road. Construction and demolition data was 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 DPCC, Delhi Metro Rail Corporation (DMRC), Census of India, CPCB website, AAI (Airport Authority of India), Indian Railways, and Central Electricity Authority (CEA). 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.

3.2.2 Digital Data Generation

The land-use map of the study area is prepared in terms of settlements, forests, agriculture, road network, water bodies, etc (Figure 3.2). The entire city was divided into 441 grid cell of 2 km x 2 km (Figure 3.3).

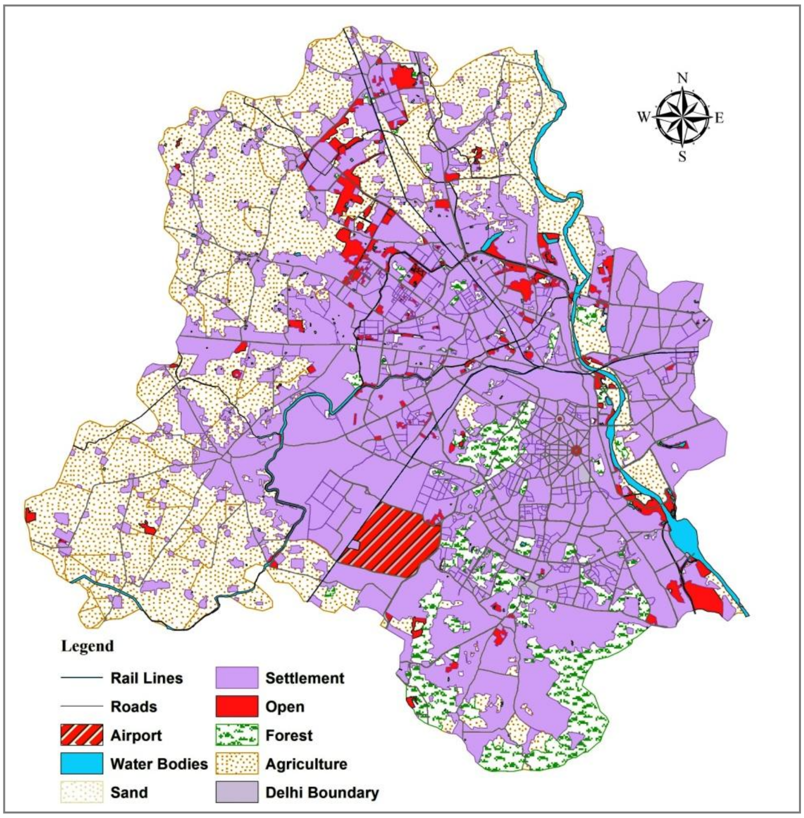


Figure 3.2: Landuse Map of the Study Area

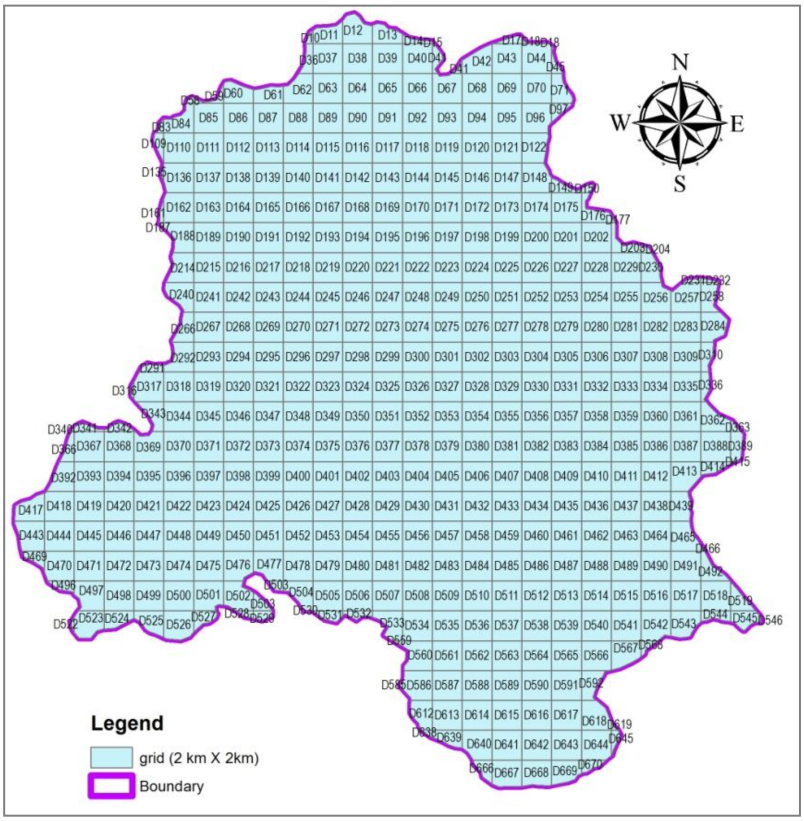


Figure 3.3: Grid Map of the City Showing Grid Identity Numbers

At the time of development of the emission inventory for the city, a suitable coding system has been adopted to avoid the confusion and misrepresentation of results and interpretation. The map with grid identity numbers is shown in Figure 3.3.

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:

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

Where:

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

3.3 Area Sources

3.3.1 Hotels/Restaurants

The details of the hotels and restaurants were obtained from DPCC, and related websites. 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 hotel and restaurant enterprise was 36,099 (Delhi Statistical Hand Book, 2014). We assume that 25% of these enterprises use tandoor for food preparation. 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 was 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 presented in Figure 3.4.

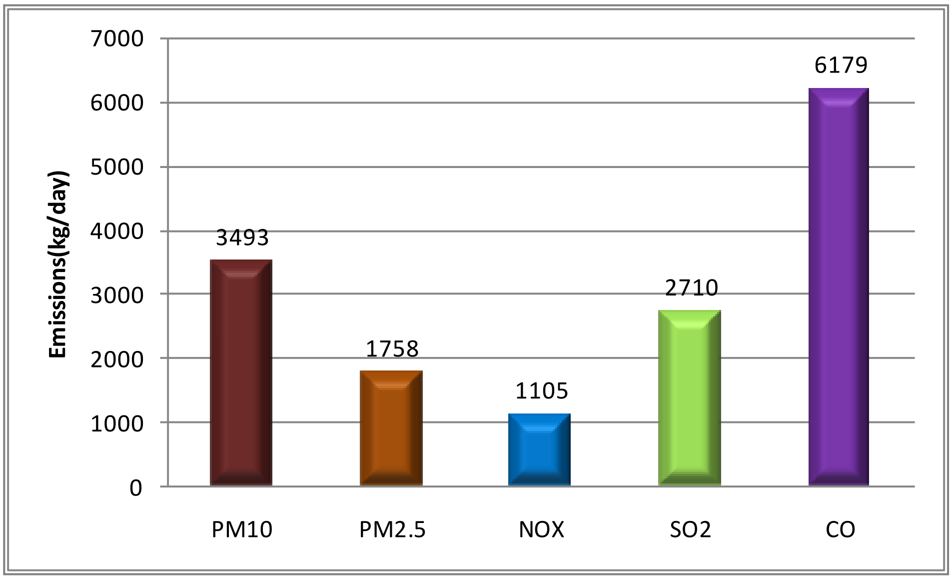


Figure 3.4: Emission Load from Hotels/Restaurant

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

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

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.

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

Where, N= no. of wards in the grid

The spatial distribution of emissions of PM_{10}, $PM_{2.5}$, NOx, SO_2 and CO from Hotel/Restaurants is presented in Figure 3.5 to 3.9.

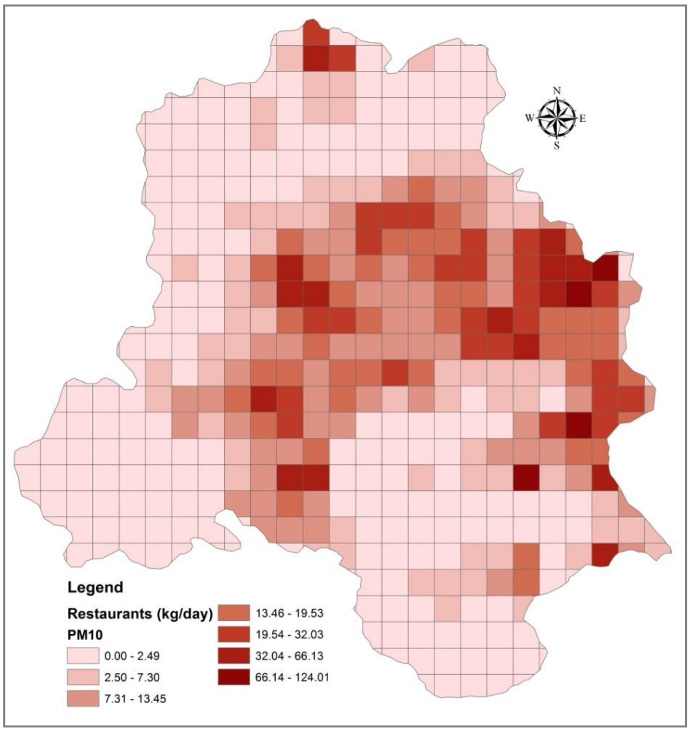


Figure 3.5: Spatial Distribution of PM_{10} Emissions from Hotel/Restaurants

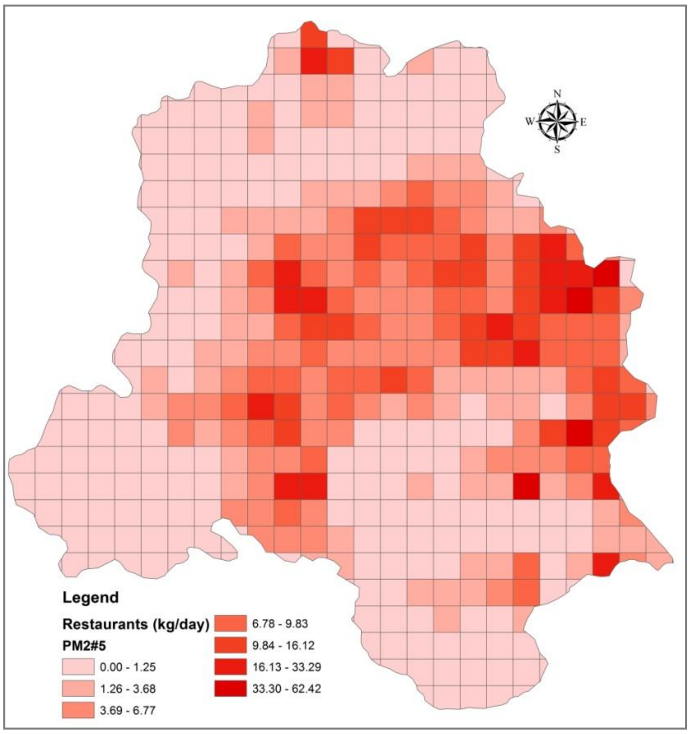


Figure 3.6: Spatial Distribution of $PM_{2.5}$ Emissions from Hotel/Restaurants

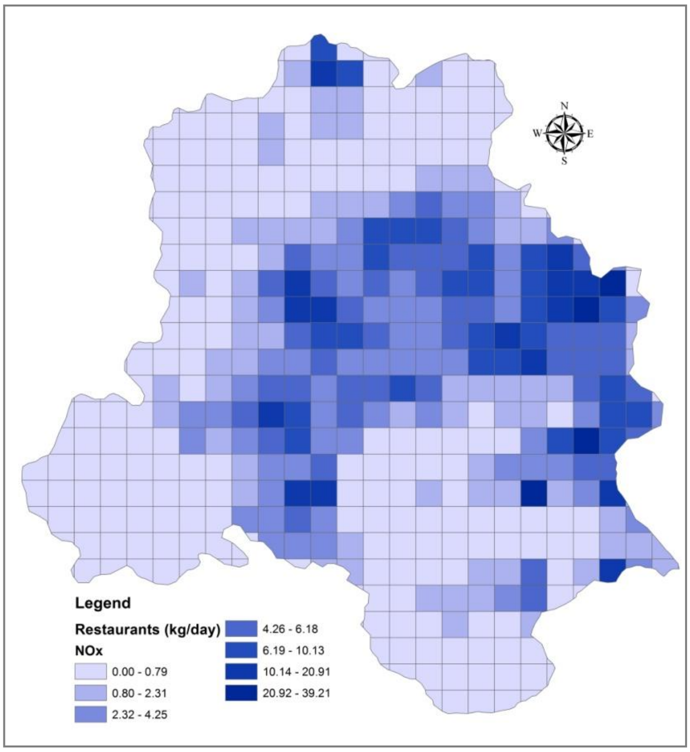


Figure 3.7: Spatial Distribution of NOx Emissions from Hotel/Restaurants

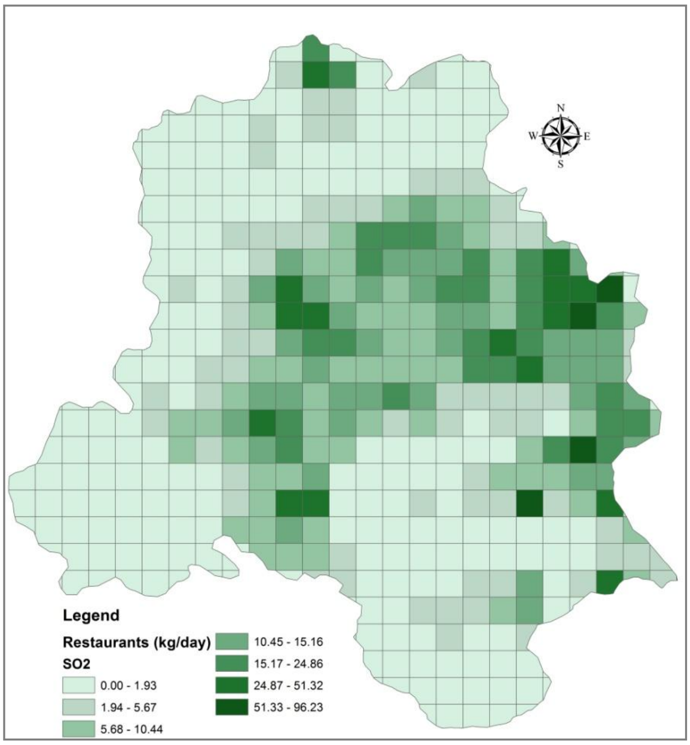


Figure 3.8: Spatial Distribution of SO_2 Emissions from Hotel/Restaurants

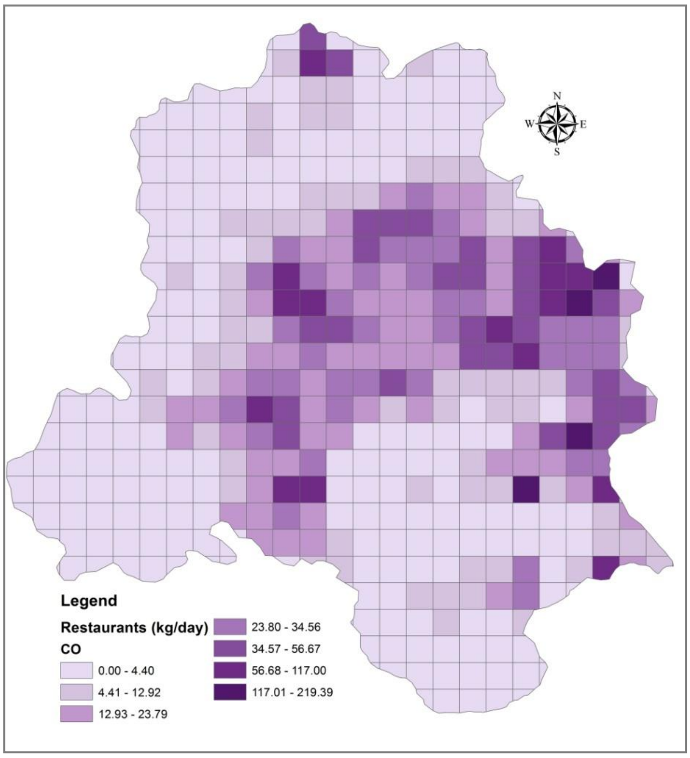


Figure 3.9: Spatial Distribution of CO Emissions from Hotel/Restaurants

3.3.2 Domestic Sector

The administrative division (2011) map of Delhi was obtained from Census of India and it was digitized. The NCT of Delhi consists of 113 towns and 112 villages as shown in Figure3.10. The data on number of household, fuel usage (coal, LPG, crop residue, cow dung and wood) and population were collected from Census-India (2012). The emission factors given by CPCB (2011) and AP-42 (USEPA, 2000) were used for each fuel type.

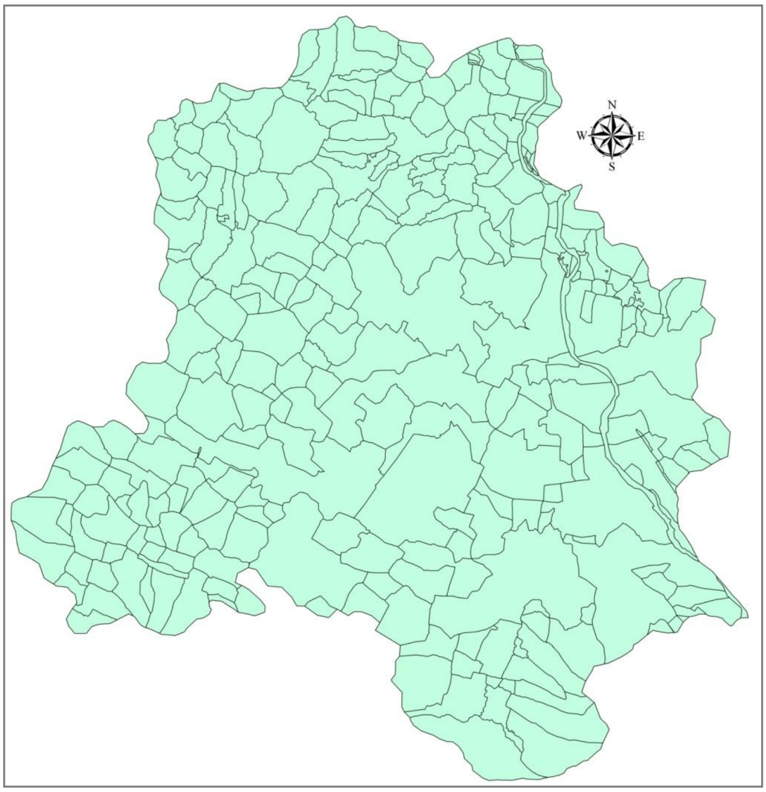


Figure 3.10: Administrative Boundaries of Wards and Village

The interior boundaries in the map (Figure 3.10) show the administrative boundaries of wards and villages. 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).

Emissions of various pollutants were calculated from the activity data assuming no control device was installed. The overall emission from domestic sources is presented in Figure 3.11. The emission contribution from different fuel types to different pollutants is shown in Figures 3.12 to 3.16. Spatial Distribution of Emissions from Domestic Sector is shown in Figure 3.17 to 3.21.

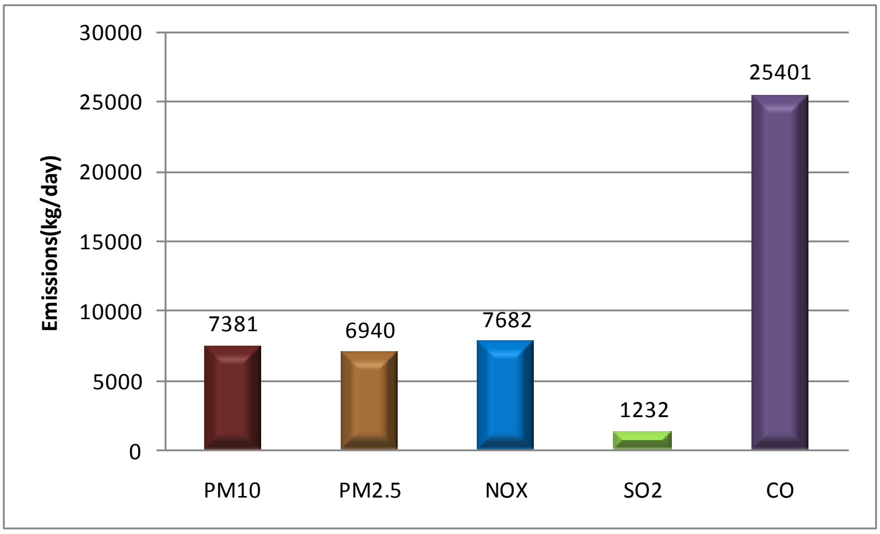


Figure 3.11: Emission Load from domestic sources (kg/day)

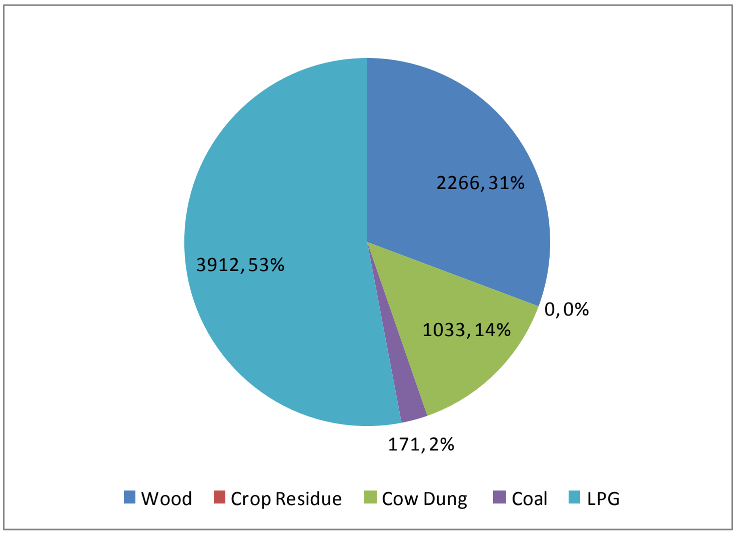


Figure 3.12:PM$_{10}$ Emission Load from domestic sources (kg/day, %)

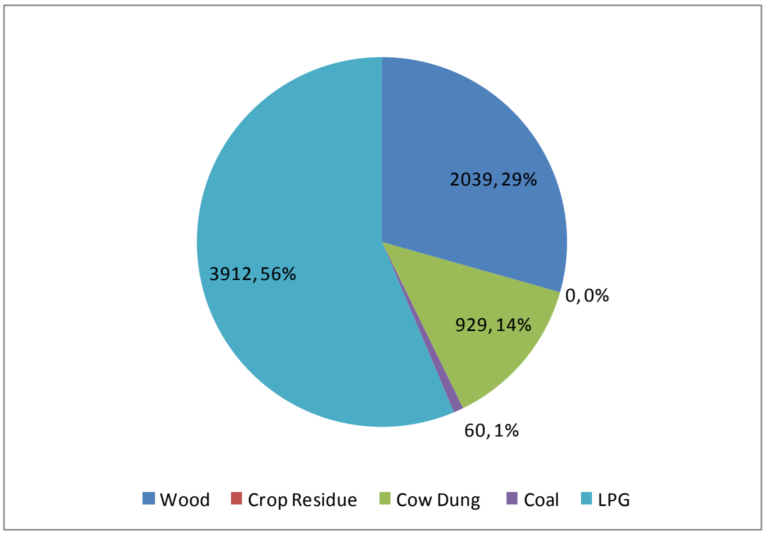


Figure 3.13:PM$_{2.5}$ Emission Load from domestic sources (kg/day, %)

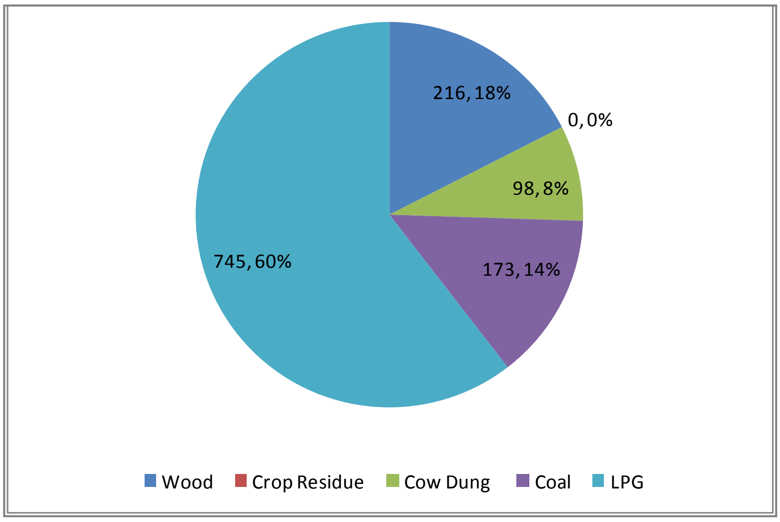


Figure 3.14: SO_2 Emission Load from domestic sources (kg/day, %)

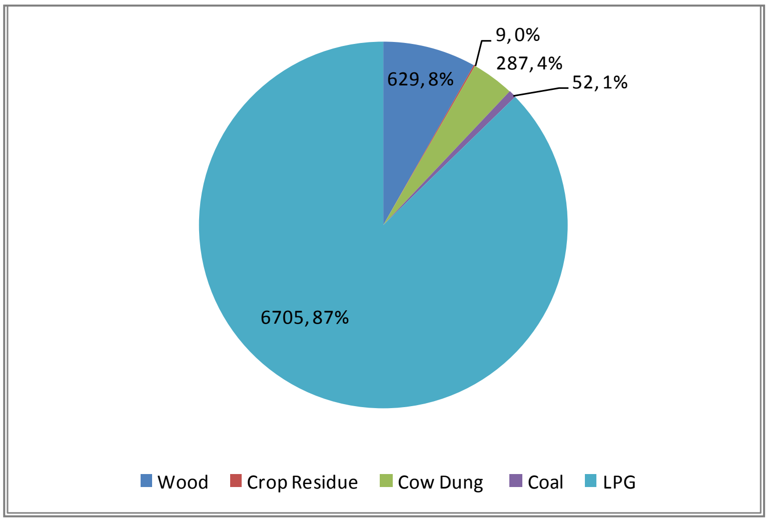


Figure 3.15: NOx Emission Load from domestic sources (kg/day, %)

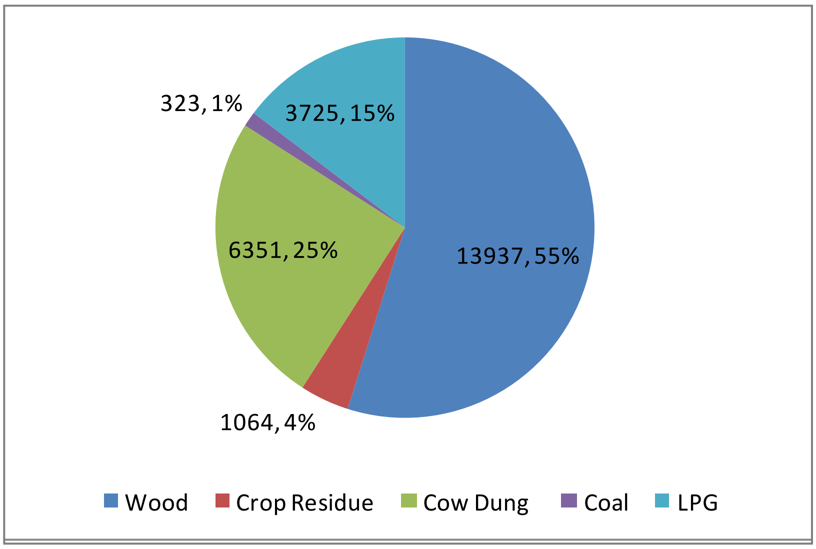


Figure 3.16: CO Emission Load from domestic sources (kg/day, %)

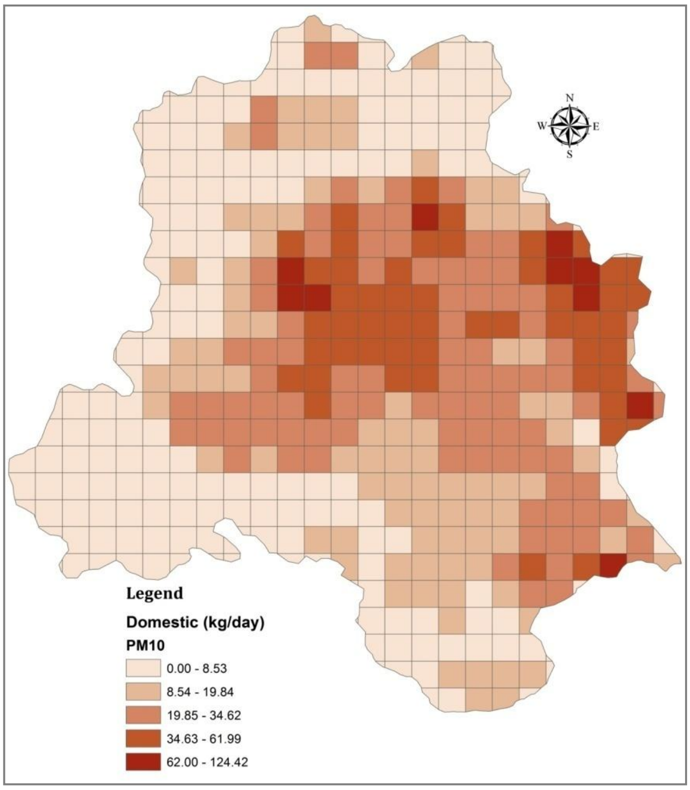


Figure 3.17: Spatial Distribution of PM_{10} Emissions from Domestic Sector

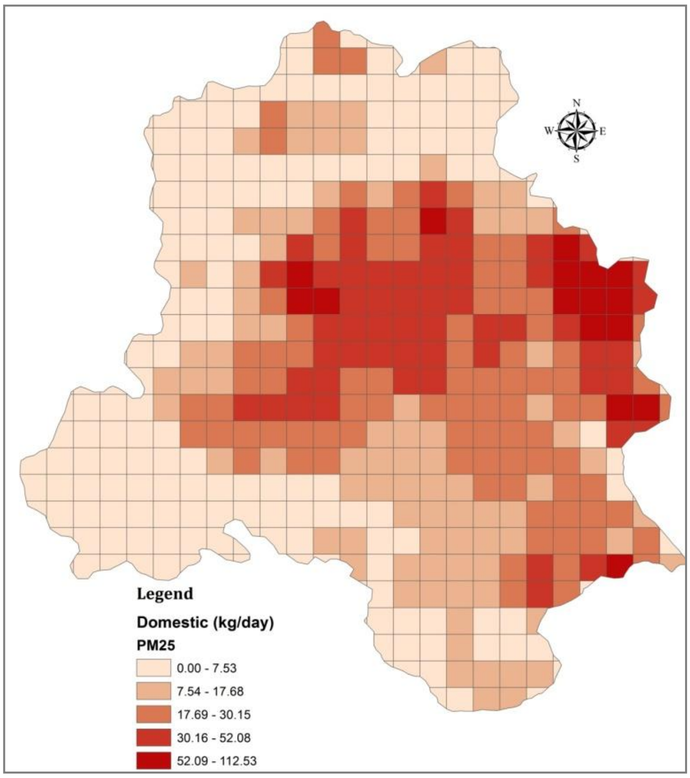


Figure 3.18: Spatial Distribution of $PM_{2.5}$ Emissions from Domestic Sector

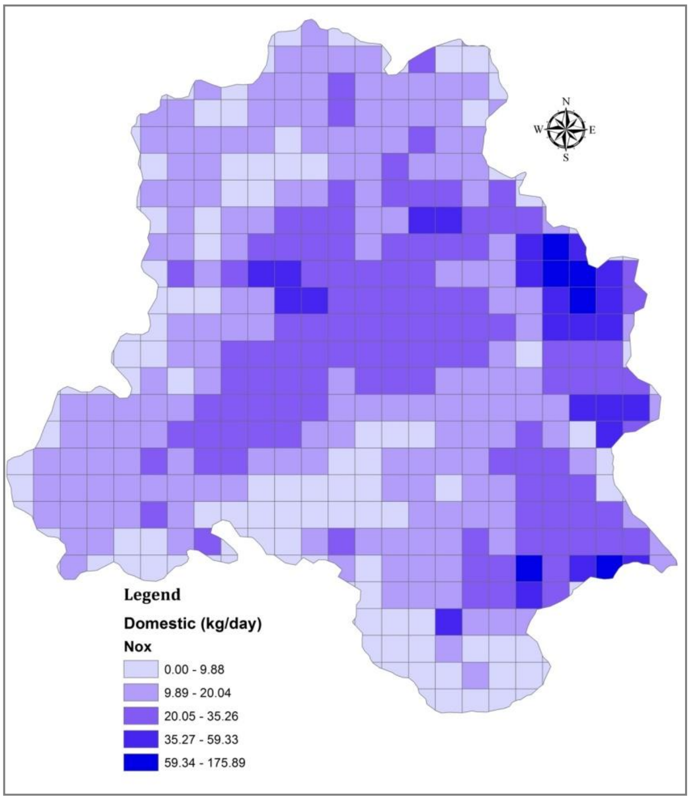


Figure 3.19: Spatial Distribution of NOx Emissions from Domestic Sector

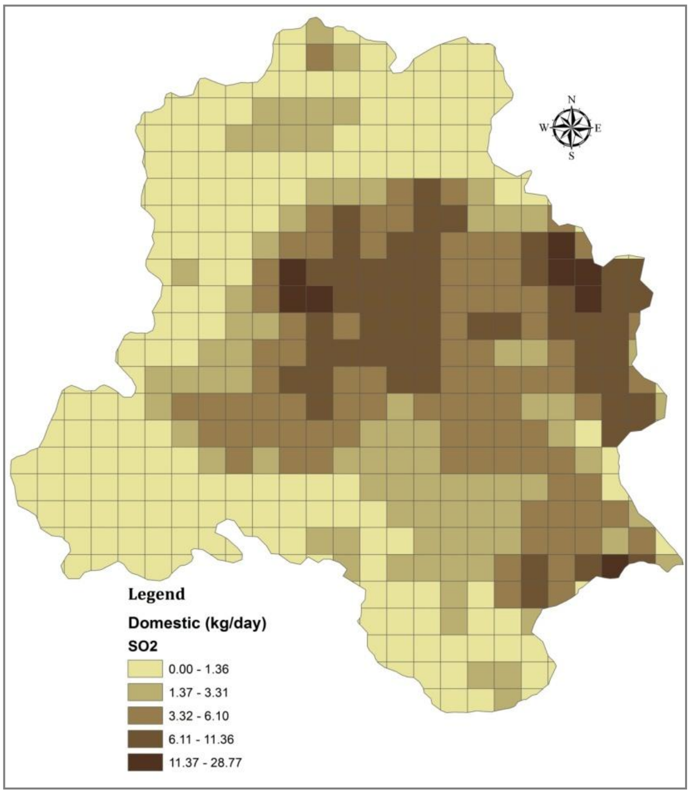


Figure 3.20: Spatial Distribution of SO_2 Emissions from Domestic Sector

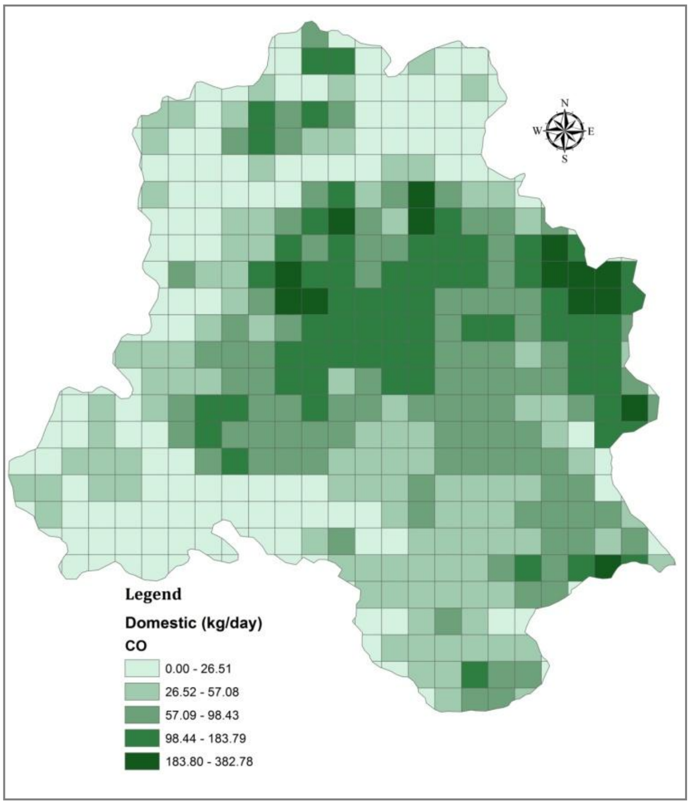


Figure 3.21: Spatial Distribution of CO Emissions from Domestic Sector

3.3.3 Municipal Solid Waste

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. The recent study by Nagpure et al. (2015), in Delhi has estimated 190 to 246 tons/day of MSW burning (~2−3% of MSW generated; 8390 tons/day). It is a myth that MSW is not burned in Delhi. 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 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 open burning are presented in Figure 3.22 and spatial distribution of in Figures 3.23 to 3.27.

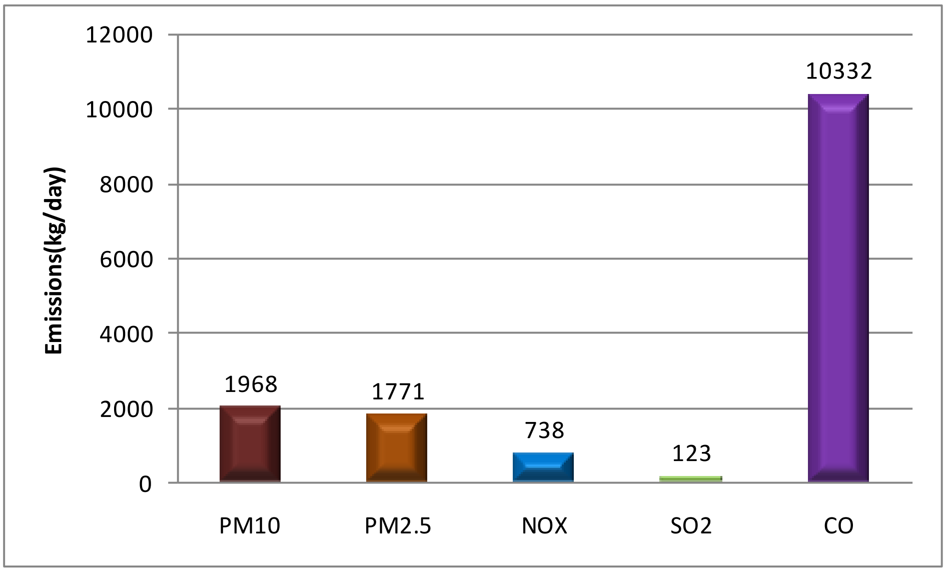


Figure 3.22: Emission Load from MSW (kg/day)

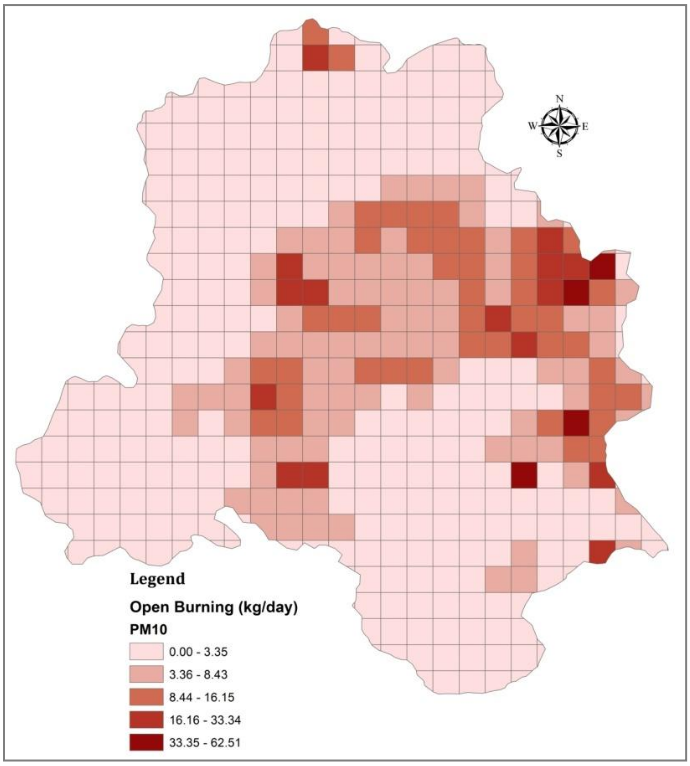


Figure 3.23: Spatial Distribution of PM_{10} Emissions from MSW

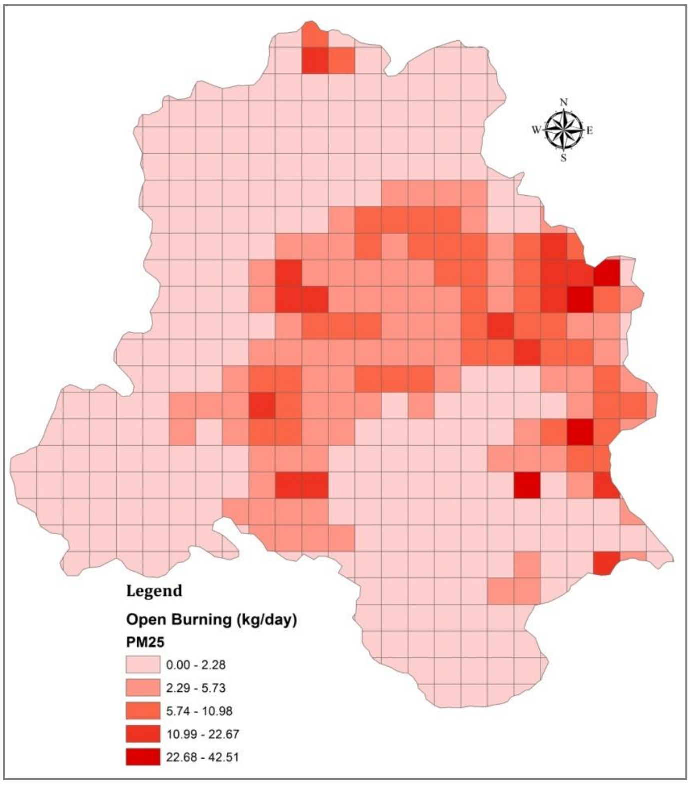


Figure 3.24: Spatial Distribution of $PM_{2.5}$ Emissions from MSW

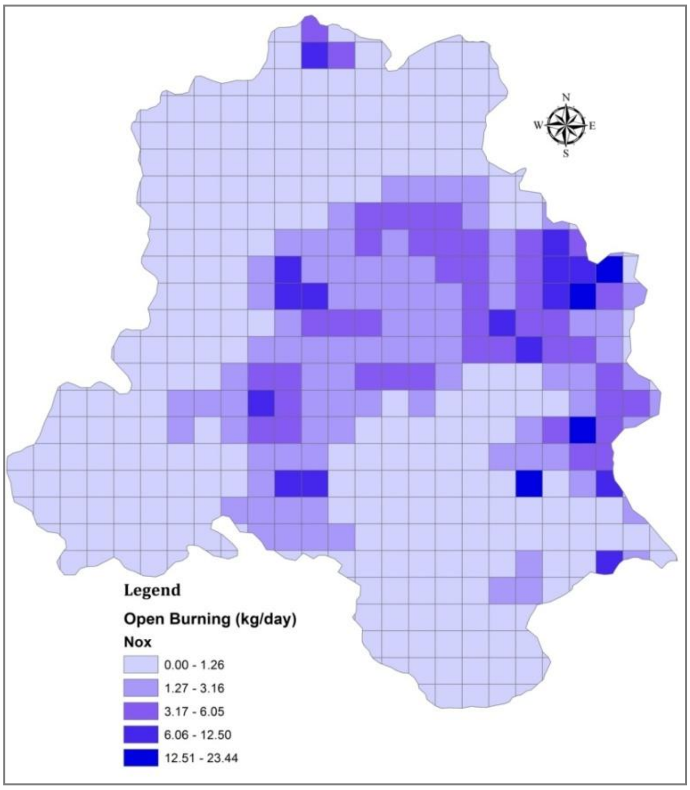


Figure 3.25: Spatial Distribution of NOx Emissions from MSW

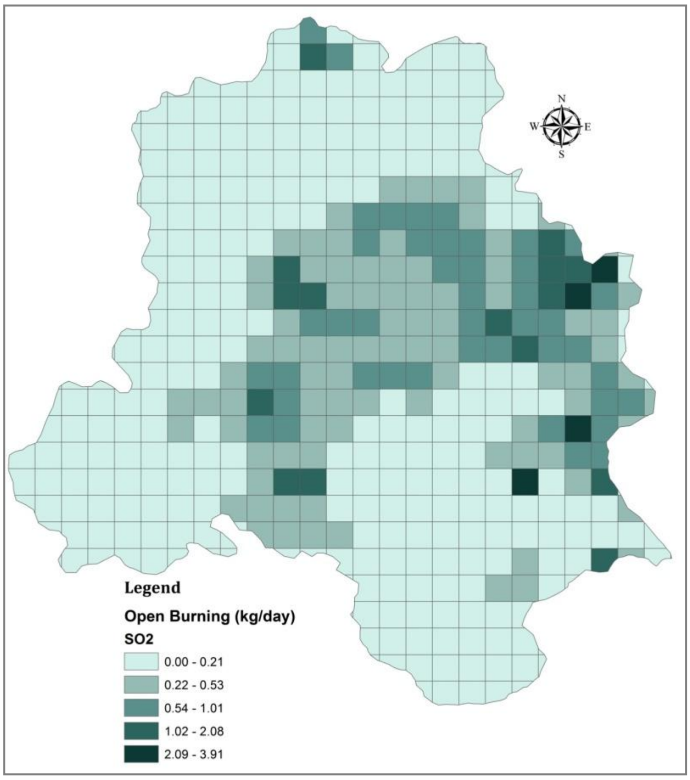


Figure 3.26: Spatial Distribution of SO_2 Emissions from MSW

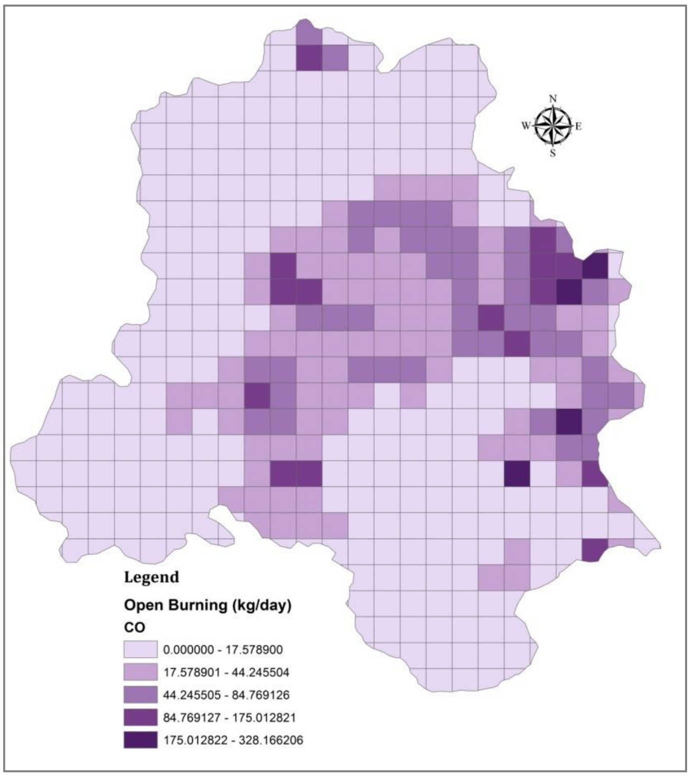


Figure 3.27: Spatial Distribution of CO Emissions from MSW

3.3.4 Construction and Demolition

A detailed survey was undertaken to assess construction and demolition activities in the study area. The construction and demolition locations were then verified with satellite imagery (Figure 3.28). Information on number of buildings, roads and flyovers under construction information was collected from DMRC, Public Works Department (PWD), Central Public Works Department (CPWD), and Delhi Development Authority websites and sites were physically surveyed. Then areas under construction activities were calculated on the basis of survey data and GIS. The emissions were estimated using Eq (3.4) given by AP-42 (USEPA, 2000). The unit of the activity data is m^2, i.e. area of these activities.

$$E = 1.2 \text{ tons/acre/month of activity (tons/m}^2\text{/month)} \qquad (3.4)$$

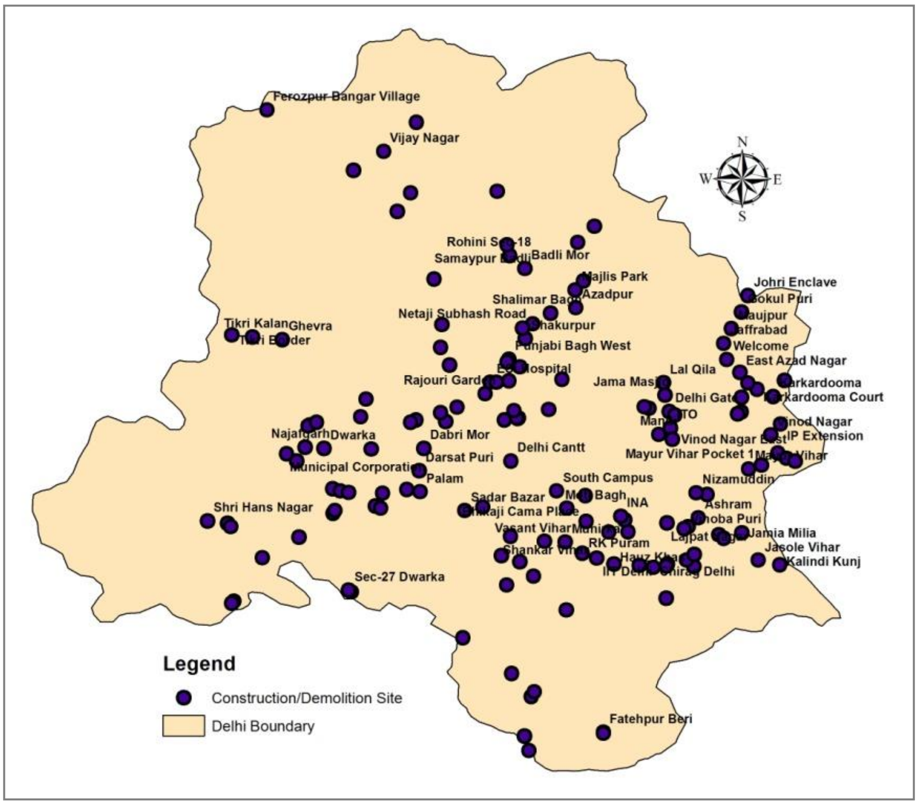


Figure 3.28: Construction/Demolition Sites

Total emission from construction and demolition activities is presented in Table 3.1. The spatially resolved map of construction and demolition activities is shown in Figures 3.29 to 3.30.

Table 3.1: Emission Load from Construction and Demolition activities (kg/day)

Category	**TSP**	**PM_{10}**	**$PM_{2.5}$**
Buildings	16281.72	4070.4301	1017.61
Roads and Flyover	4385.63	1096.4075	274.102
Totals	**20667.35**	**5166.8376**	**1291.71**

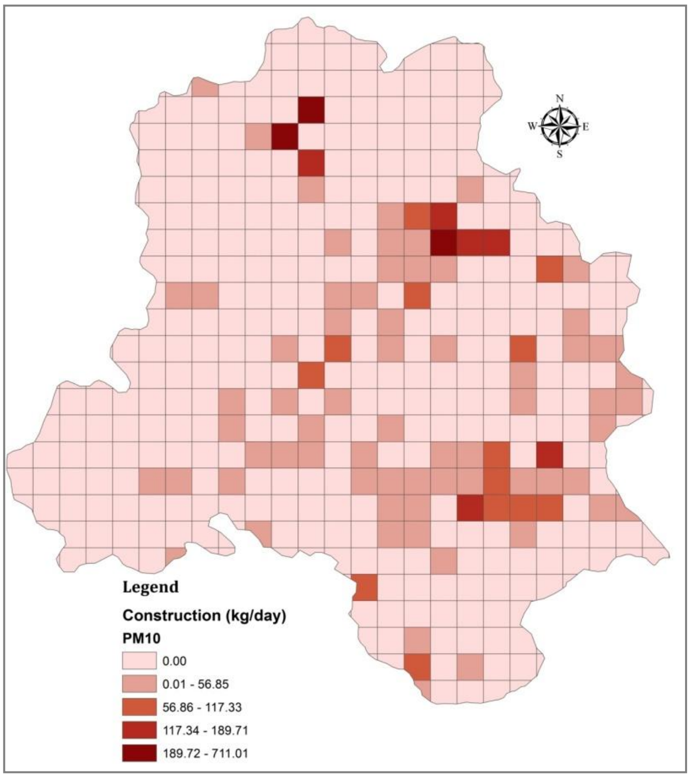


Figure 3.29: Spatial Distribution of PM_{10} Emissions from Construction/Demolition

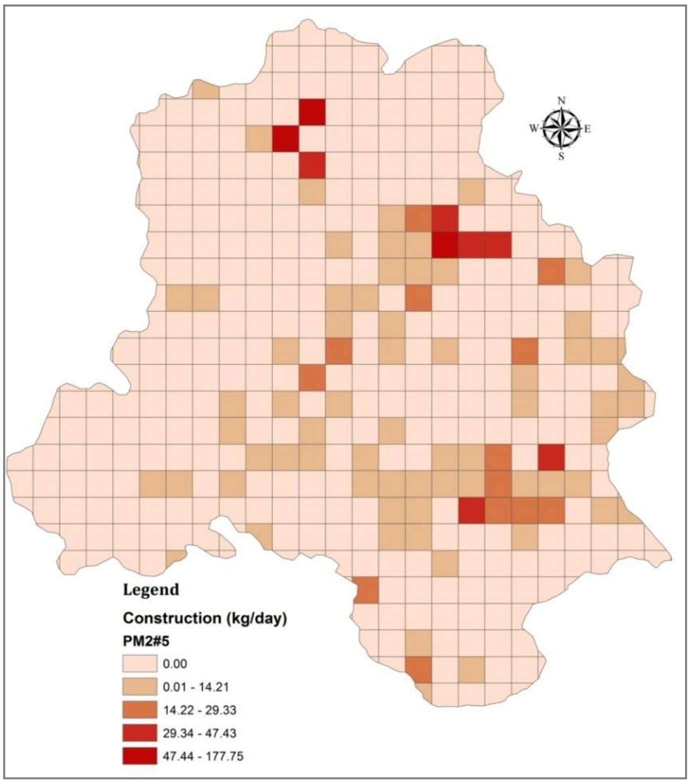


Figure 3.30: Spatial Distribution of $PM_{2.5}$ Emissions from Construction/Demolition

3.3.5Commercial and Industrial Diesel Generator Sets (DG sets)

DG sets are used as the source of power in shopping complexes and industries during the power-cut hours. From the results of the survey, it can be concluded that there is minimum of 2 hours/day power cut in the city, especially in summer. The DG set details were obtained from DPCC; the DG sets were located on the map.

The unit of the activity data is KWh power generation. The emissions from DG sets installed in commercial complexes, institutes and industries were estimated and then were summed up for each grid. The calculation is based on Eq (3.1), where ER, overall efficiency reduction was taken as zero. The CPCB (2011) emission factors were used for emission estimation. The total emissions from DG sets are presented in Figure 3.31. Spatial Distribution of Emissions from DG Sets is shown in Figures 3.32 to 3.36.

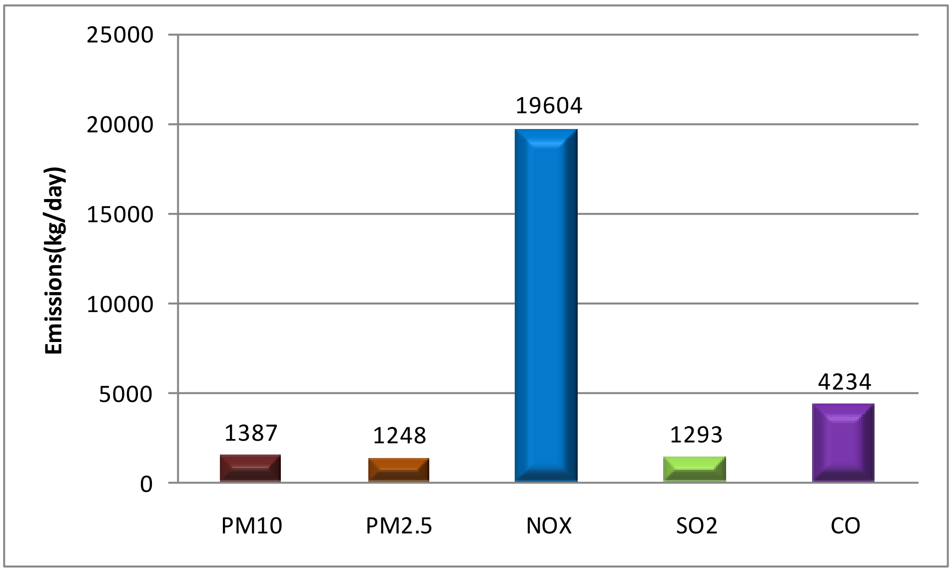


Figure 3.31: Emission Load (kg/day) from DG sets

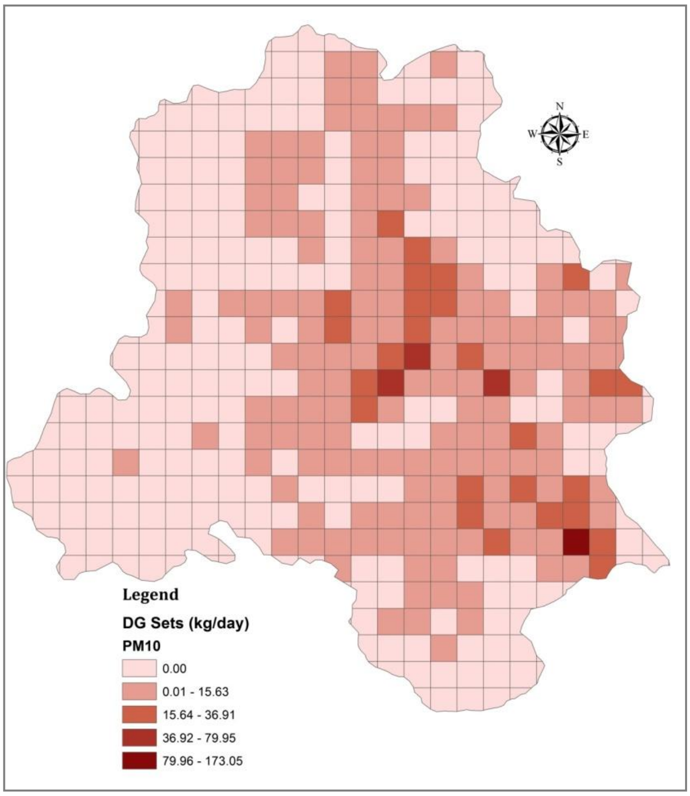


Figure 3.32: Spatial Distribution of PM_{10} Emissions from DG Sets

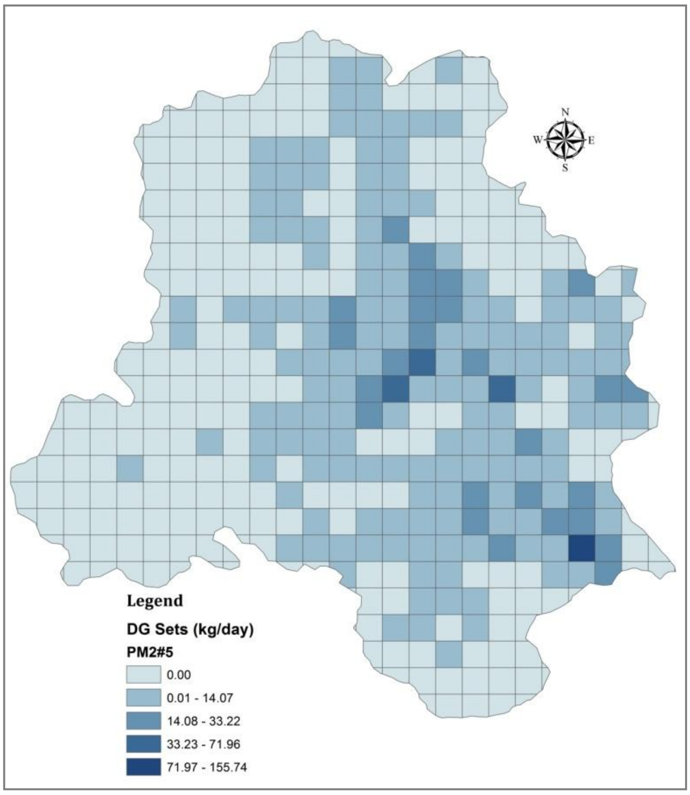


Figure 3.33: Spatial Distribution of $PM_{2.5}$ Emissions from DG Sets

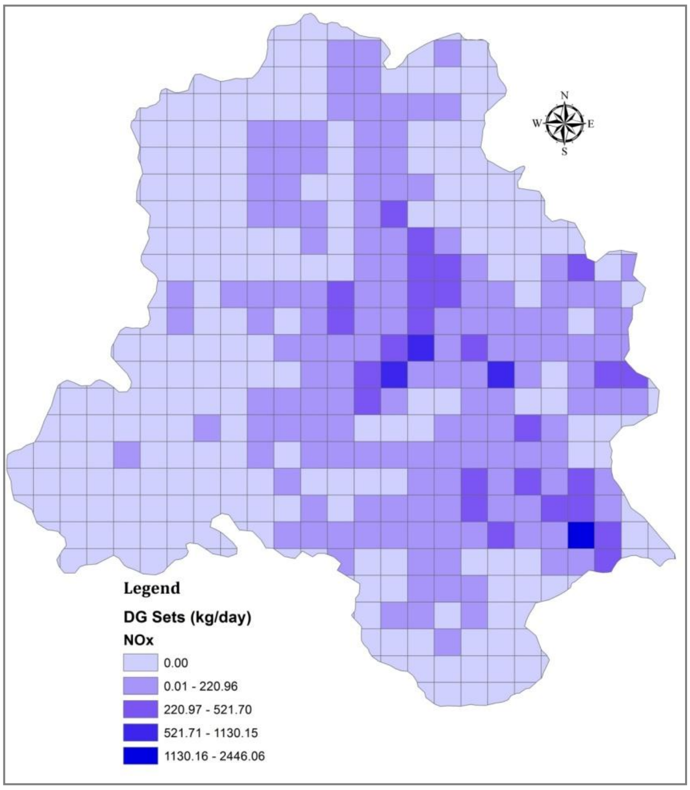


Figure 3.34: Spatial Distribution of NOx Emissions from DG Sets

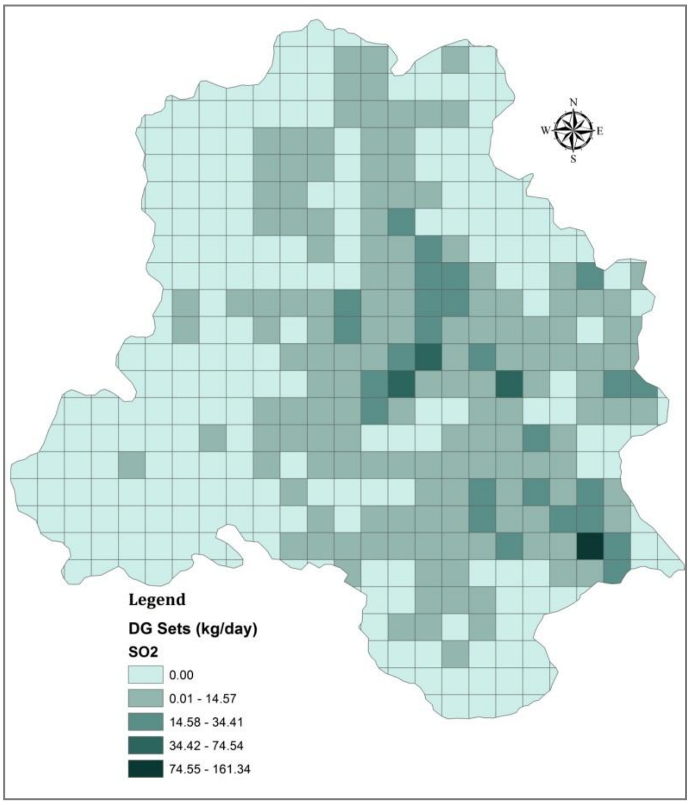


Figure 3.35: Spatial Distribution of SO_2 Emissions from DG Sets

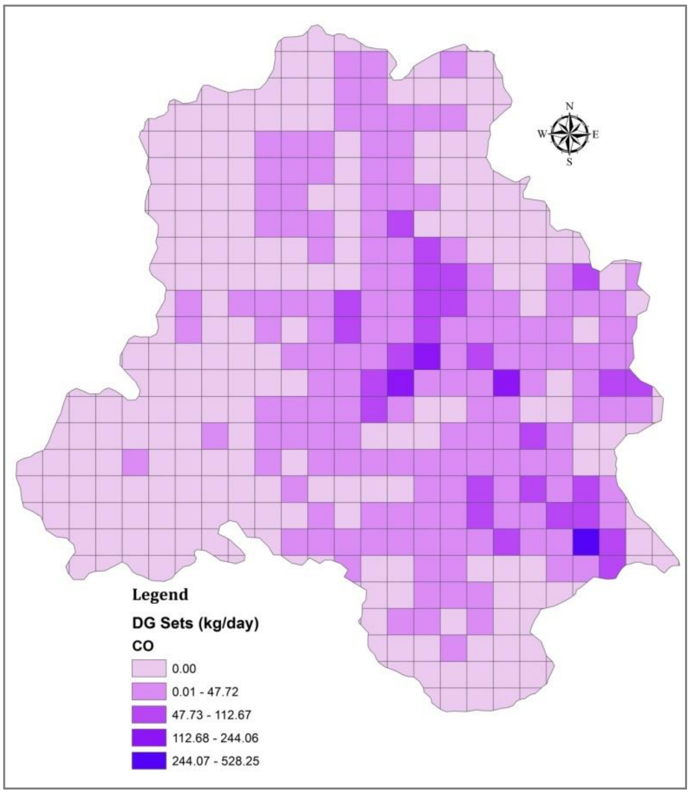


Figure 3.36: Spatial Distribution of CO Emissions from DG Sets

3.3.6 Cremation

There are 53 cremation sites in the city of Delhi, which operates in various zones of Municipal Corporation of Delhi. These cremation sites were located in the grids with the help of GIS (Figure 3.37). Specific information on number of dead bodies cremated in each cremation site was not available. The information pertaining to total number of deaths in Delhi was obtained from Directorate of Economics and Statistics handbook for the year 2014.

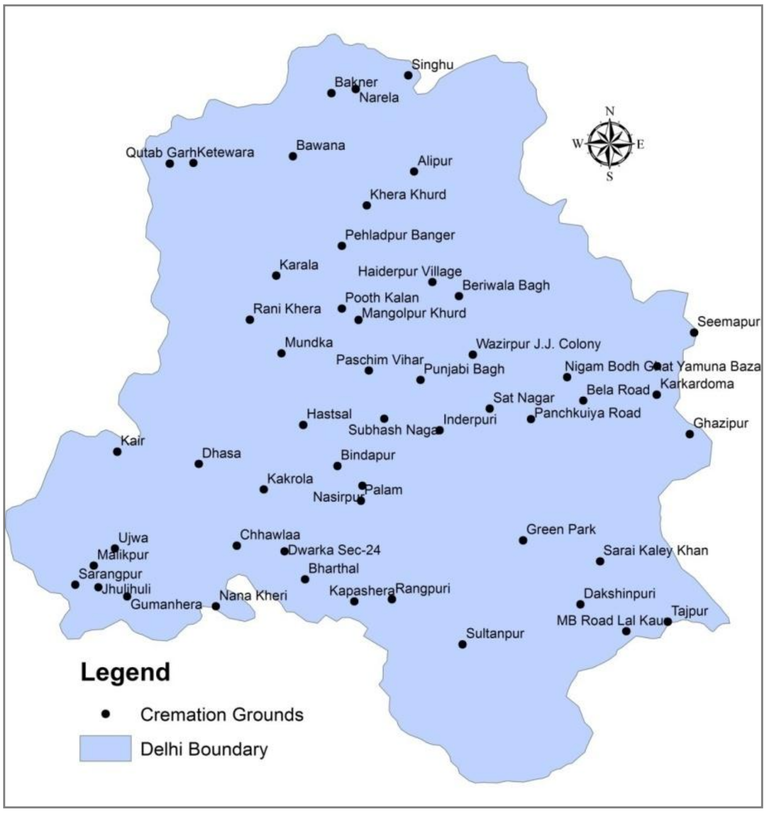


Figure 3.37: Cremation Sites in City of Delhi

The total number of registered death in 2014 for Hindus was 105336. The wood required for per body for the cremation is taken as 216 kg (Sharma, 2010). The emission factors for each pollutant for cremation were decided on the basis of CPCB (2011) recommended emission factors. The total emissions from cremation sites are presented in Figure 3.38. Spatial Distribution of PM_{10}, $PM_{2.5}$, NOx, SO_2, and CO emissions from cremation sites are presented in Figure 3.39.

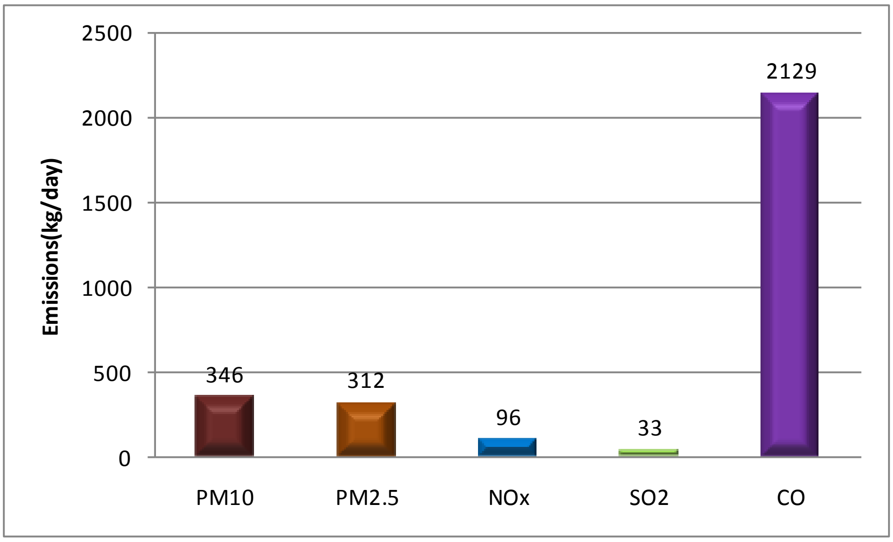


Figure 3.38: Emission Load from Cremation Sites

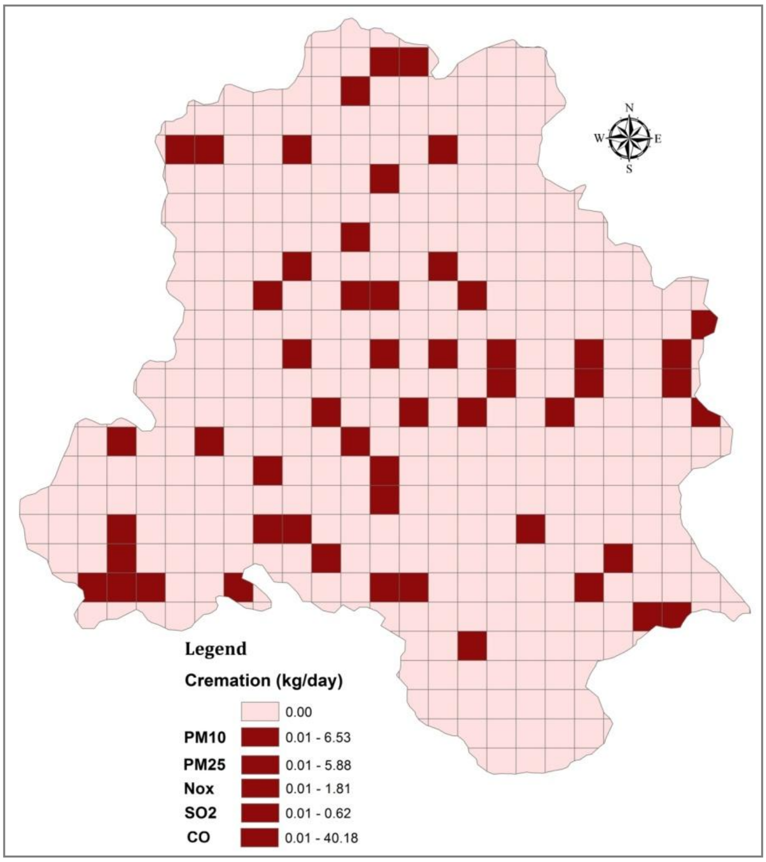


Figure 3.39: Spatial Distribution of PM_{10}, $PM_{2.5}$, NOx, SO_2, CO Emissions from Cremation Sites

3.3.7 Aircraft

Indira Gandhi International Airport (IATA: DEL, ICAO: VIDP) is the primary airport of the National Capital Region of Delhi, situated in south-west Delhi, 16 km New Delhi's city center. Total number of flight (arrival + departure) is approximately 800 per day at IGI 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 Delhi border. The estimated emission is presented in Figure 3.40. This emission is expected to be dispersing in upper part of atmosphere.

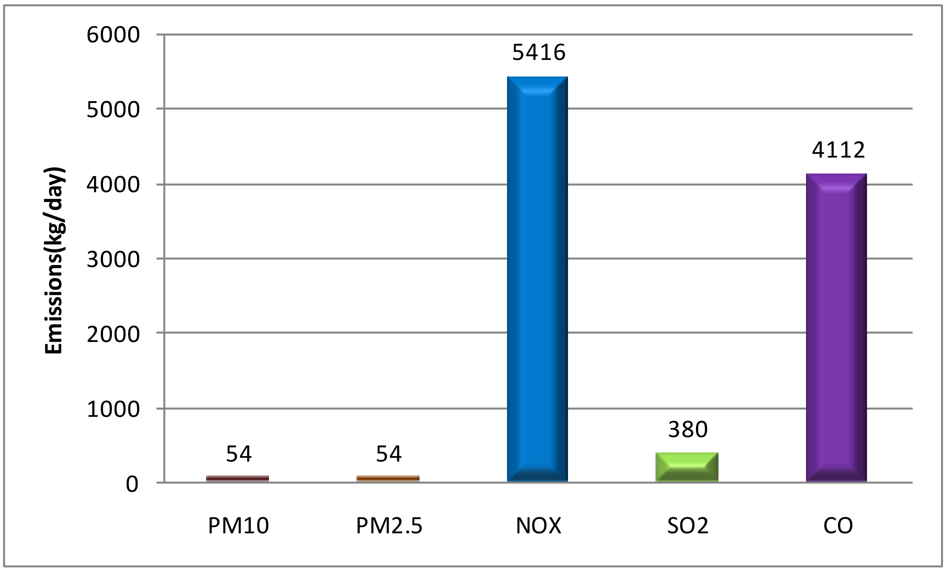


Figure 3.40: Emission Load from Aircraft

3.3.8 Bio-Medical Waste Incinerator and Boilers

There are 32 health care establishments relevant to air pollutant emissions in the city. These health care establishments are having 14 incinerators (12 (private) and 2 (CBWTF: Common Bio-medical Waste Treatment Facility) and rest have boilers. For each health care establishment activity data were taken from DPCC and emissions calculated using CPCB (2011) (Figure 3.41).

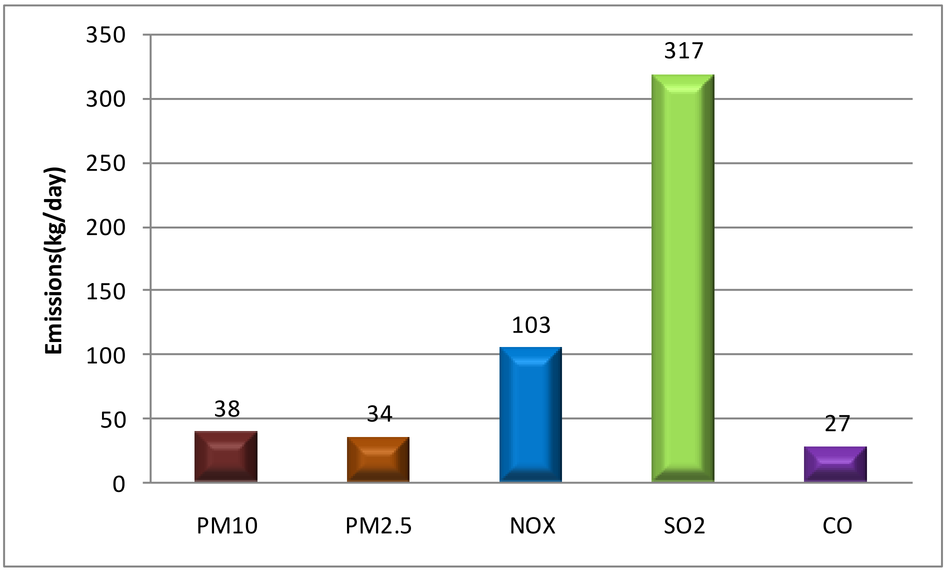


Figure 3.41: Emission Load from Health Care Establishment

3.3.9 Waste to Energy Plants (MSW)

There is only one waste to energy plant (Timarpur Okhla Waste Management Co Pvt Ltd) operating in the city of Delhi. This plant uses 225 ton/day of refuse to derive fuel to generate energy. The plant is equipped with bag house filter, so the controlled emission factor of AP-42 (USEPA, 2000) was used to calculate the controlled emissions. The plant emission is 6.9 kg/day of PM_{10}; 6.9 kg/day of $PM_{2.5}$; 62.33 kg/day of SO_2; 205.86 kg/day of NOx.

3.3.10 Agricultural Soil Dust

The total agricultural land (50500 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 agricultural soil dust is estimated to be 1353 kg/day. The $PM_{2.5}$ emission is negligible.

3.3.11 Ready Mix Concrete Batching

Concrete is a fixed mixture of water, cement, sand (fine aggregate) and coarse aggregate. Coarse aggregate consist of gravel, crushed stone or iron blast furnace slag. Cementitious materials, also called mineral admixtures or pozzolan minerals may be added to make the concrete mixtures more economical, reduce permeability, increase strength, or influence other concrete properties (USEPA, 2000).

During the study period massive construction activities were found in the study area which requires concrete batching. There were 60 DMRC locations where construction was under progress and it was assumed that there will be 40 concrete batching plants of 120 m^3/hr capacities operating for 16 hours. Several medium and small construction activities were also observed in the city (see section on construction and demolition). The AP-42 (USEPA, 2000) emission factors were used to calculate the emissions from concrete batching. The total PM_{10} and $PM_{2.5}$ emissions from these concrete mix plant estimated to be 14.37 ton/day and 3.5 ton/day respectively. It may be noted there are a few hundred concrete batching plants exist in NCR, which may contribute to air quality in Delhi but these have not been included in emission inventory of Delhi

3.3.10 Industries as Area Sources

There are 25 industrial areas in the city (Figure 3.42). All industries having stack height below 20 m have been considered as industrial area source. Majority of the industries is having small boilers and some cupola furnaces were also present. Most of the information on the industrial areas concerning fuel consumption, stack height, production capacity has been collected from DPCC. We had to make certain assumptions and made improvements in the database to make compatibility in fuel consumptions and size of the industry (production capacity), where no fuel consumption was given minimum consumption per hour of fuel has been considered. If type of fuel uses were not indicated then it was assumed that industry used HSD. Ash content in the coal was assumed to be 35% and ‘S’ content as 1.8% for LDO; 1% for HSD (https://www.iocl.com/).CPCB (2011) and AP-42 (USEPA, 2000) emission factors were used to calculate the emissions. Finally all the emission for each pollutant is summed up. Figure 3.43 presents the overall emissions from industries as area source. Table 3.2 presents emission from different industrial areas in the city of Delhi. Spatial Distribution of Emissions from Industries as Area Source is presented in Figures 3.44 from 3.48.

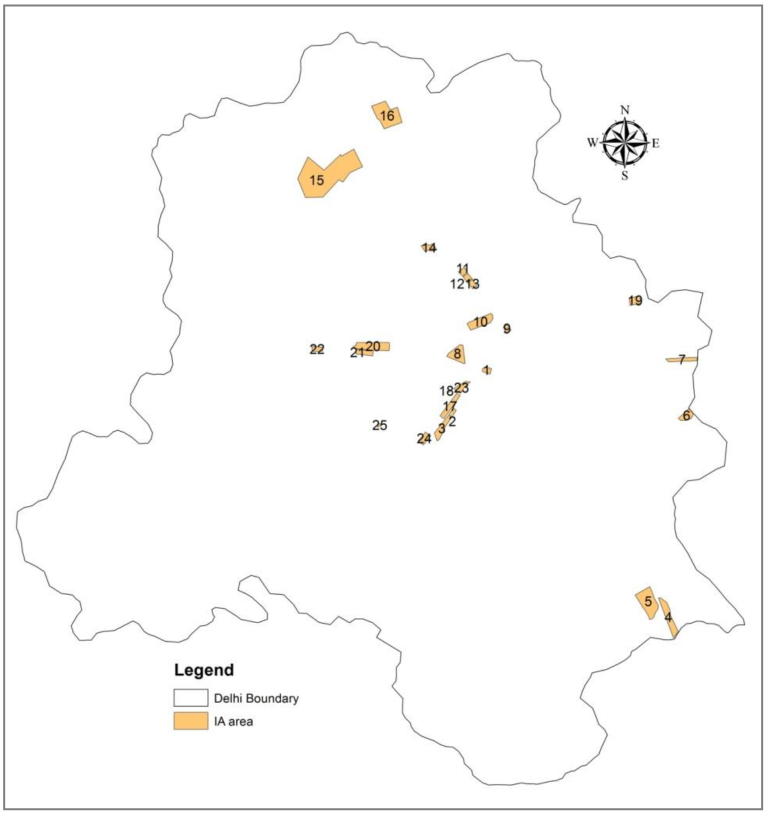


Figure 3.42: Location of Industrial Areas in Delhi

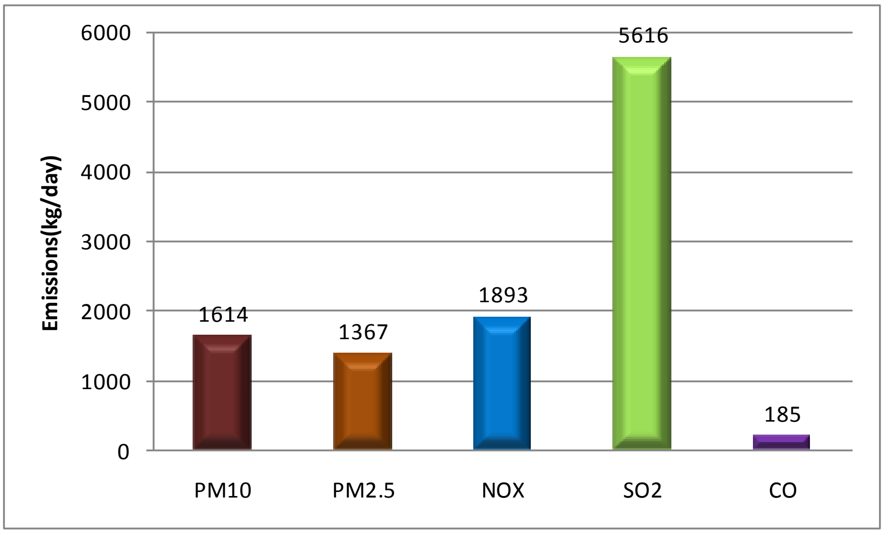


Figure 3.43: Emission Load from Industries as Area Source.

Table 3.2: Emission Load from Industries as Area Source (kg/day)

Code	Name	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO
1	ShahzadaBagh	0.98	0.88	12.43	4.36	0.40
2	Naraina Phase 2	1.76	1.58	22.21	7.78	0.71
3	Naraina phase 1	2.44	2.20	31.64	10.13	0.92
4	Mohan Cooperative	6.91	6.22	88.42	29.61	2.69
5	Okhla Industrial Area Phase 1	94.36	84.93	1239.10	373.38	34.48
6	Patparganj IA	8.98	8.08	116.48	36.89	3.35
7	Jhilmil	87.51	27.83	383.45	148.48	9.04
8	Lawrence Road	226.67	204.01	157.73	55.42	5.11
9	GT Karnal Road	8.44	7.60	107.40	36.95	4.27
10	Wazirpur	138.85	124.97	1785.47	587.02	53.59
11	SMA	7.61	6.85	96.37	33.67	3.43
12	SSI	5.73	5.16	75.28	22.69	2.06
13	Rajasthan Udyog	3.79	3.41	50.64	14.19	1.29
14	Badli	13.47	12.12	182.83	47.29	4.31
15	Bawana	431.30	388.35	211.85	102.05	24.95
16	Narela	468.66	401.98	162.77	78.72	5.82
17	Kirti Nagar	8.52	7.67	114.05	31.54	2.87
18	Moti Nagar	0.52	0.46	6.53	2.29	0.21
19	Friends Colony Shahdara	23.25	19.70	123.21	48.74	3.76
20	Mangolpuri	7.72	6.95	98.55	33.34	3.03
21	Udyog Nagar	6.37	5.73	80.62	28.24	2.57
22	Nangloi	1.10	1.00	13.84	5.12	1.10
23	Najafgarh Road	32.86	22.33	218.02	75.60	8.52
24	Mayapuri	26.08	16.06	228.75	76.64	6.28
25	Tilak Nagar	0.62	0.56	7.88	2.76	0.25
Total		**1614.50**	**1366.62**	**5615.52**	**1892.88**	**185.01**

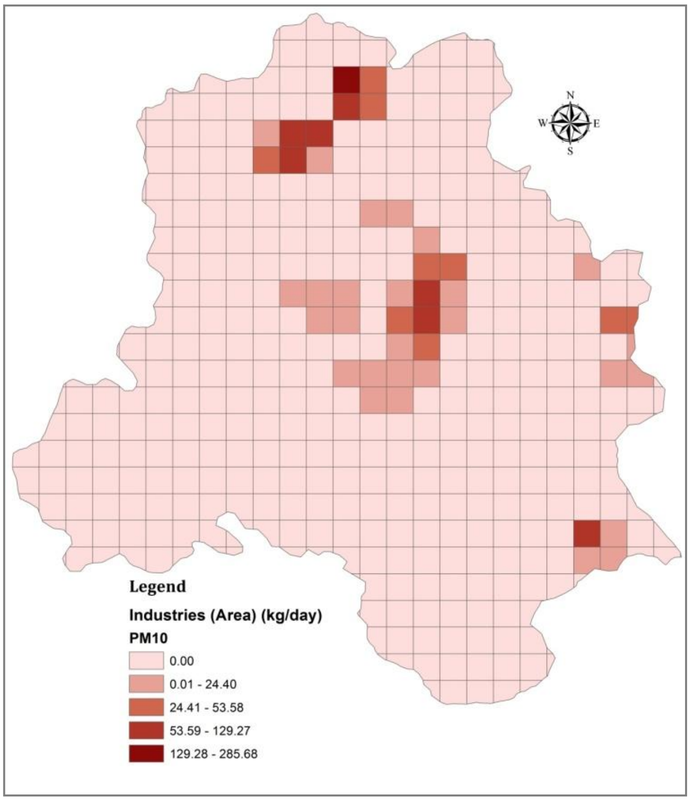


Figure 3.44: Spatial Distribution of PM_{10} Emissions from Industries as Area Source

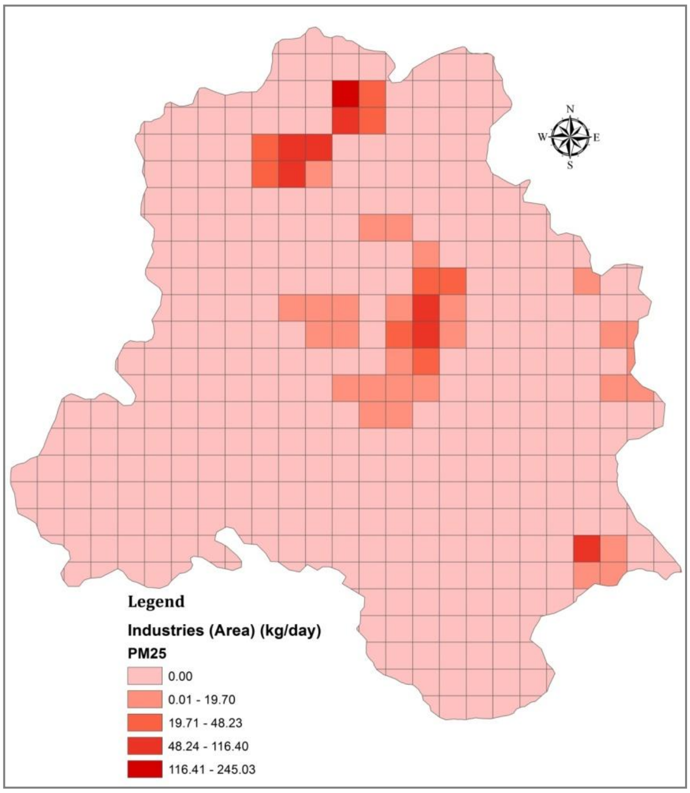


Figure 3.45: Spatial Distribution of $PM_{2.5}$ Emissions from Industries as Area Source

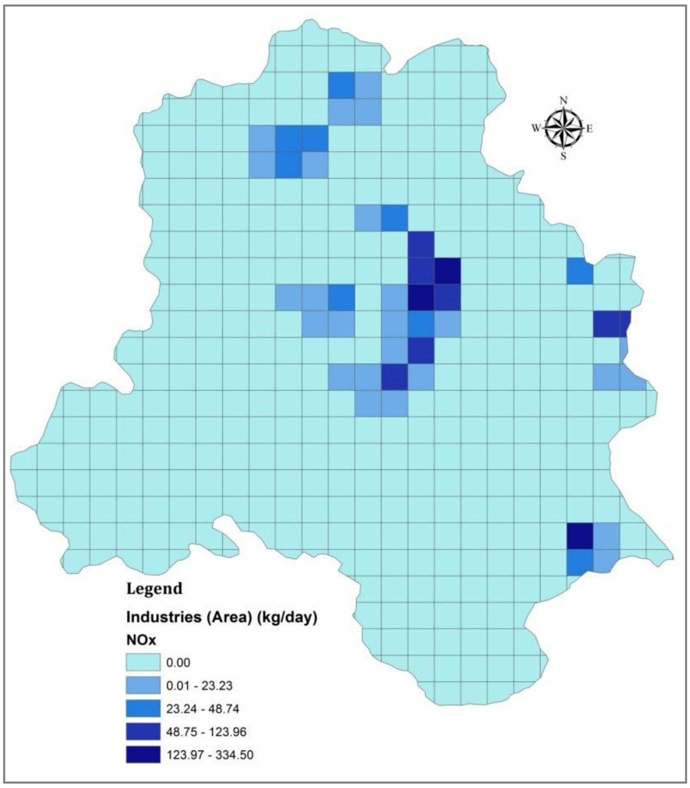


Figure 3.46: Spatial Distribution of NOx Emissions from Industries as Area Source

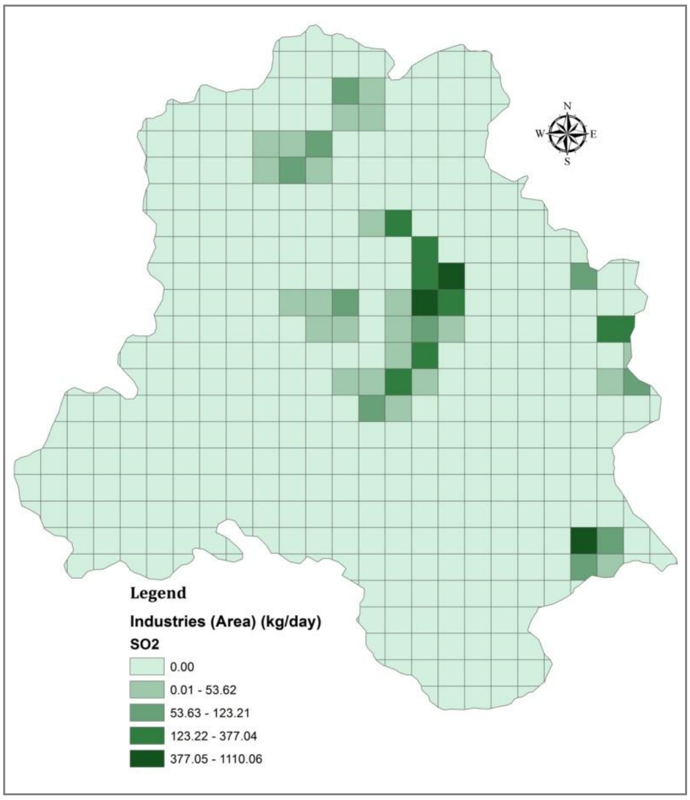


Figure 3.47: Spatial Distribution of SO_2 Emissions from Industries as Area Source

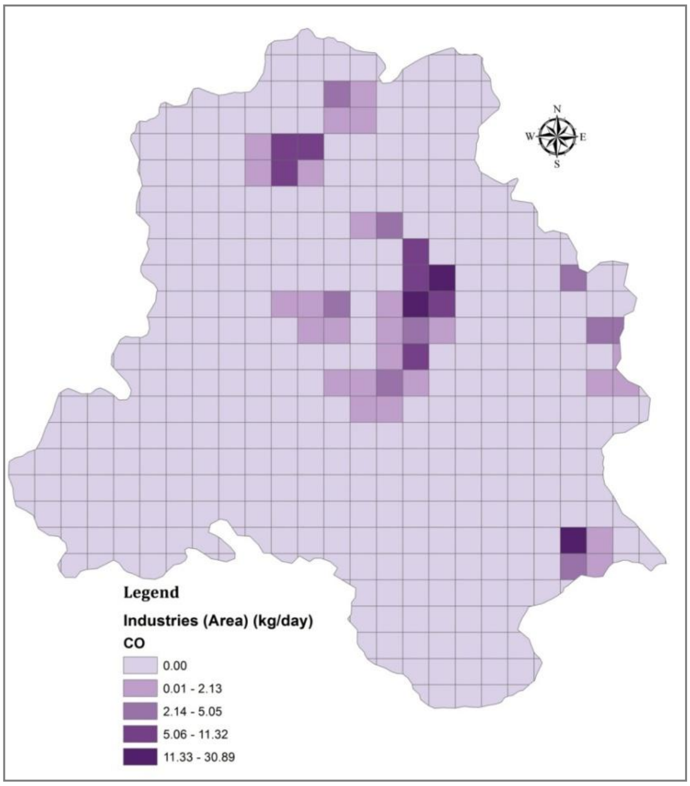


Figure 3.48: Spatial Distribution of CO Emissions from Industries as Area Source

3.3.11 Contribution of Emissions from Area Sources excluding Vehicles and large Industry (point source)

Summary of emissions from various are source categories discussed is presented in Table 3.3.

Table 3.3: Summary of Emission Load from Area Sources (kg/day)

Category	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO
Hotels/Restaurants	3493	1758	1105	2710	6179
Domestic	7381	6940	7682	1232	25401
Aircrafts	54	54	5416	380	4112
Industries as Area Source	1614	1367	1893	5616	185
DG Set	1387	1248	19604	1293	4234
MSW Burning	1968	1771	738	123	10332
Cremation	346	312	96	33	2129
Construction/Demolition	5167	1292	-	-	-
Concrete Batching	14370	3594	-	-	-
Medical Incinerators	38	34	103	317	27
Agricultural Soil Dust	1353	-	-	-	-
Total	**37171**	**18369**	**36637**	**11704**	**52598**

Figures 3.49 to 3.53 show the break-up of emissions of area sources for PM_{10}, $PM_{2.5}$, NOx, SO_2 and CO. The major contribution is from concrete batching, followed by domestic sector and construction and demolition activities for PM_{10} and $PM_{2.5}$. For NOx, the largest sources are DG sets (Figure 3.51).

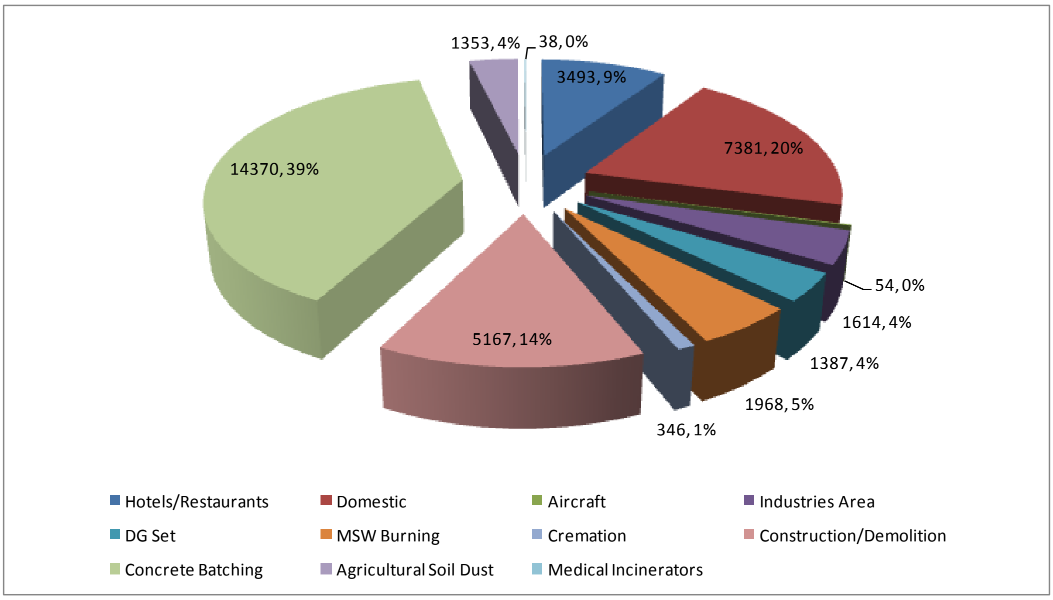


Figure 3.49: PM_{10} Emission Load for area sources (kg/day, %)

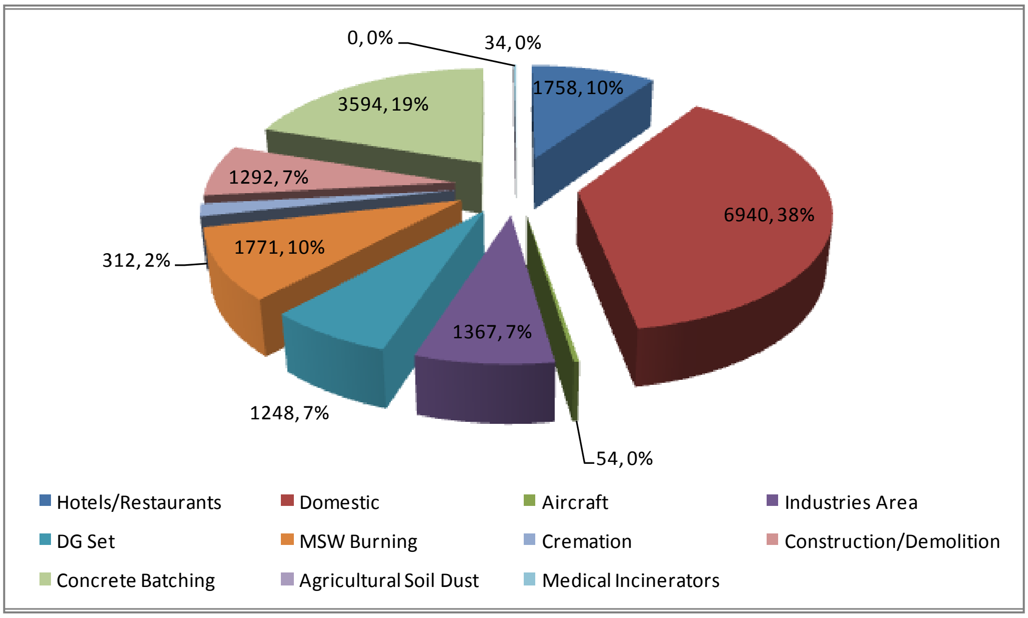


Figure 3.50: $PM_{2.5}$ Emission Load for area sources (kg/day, %)

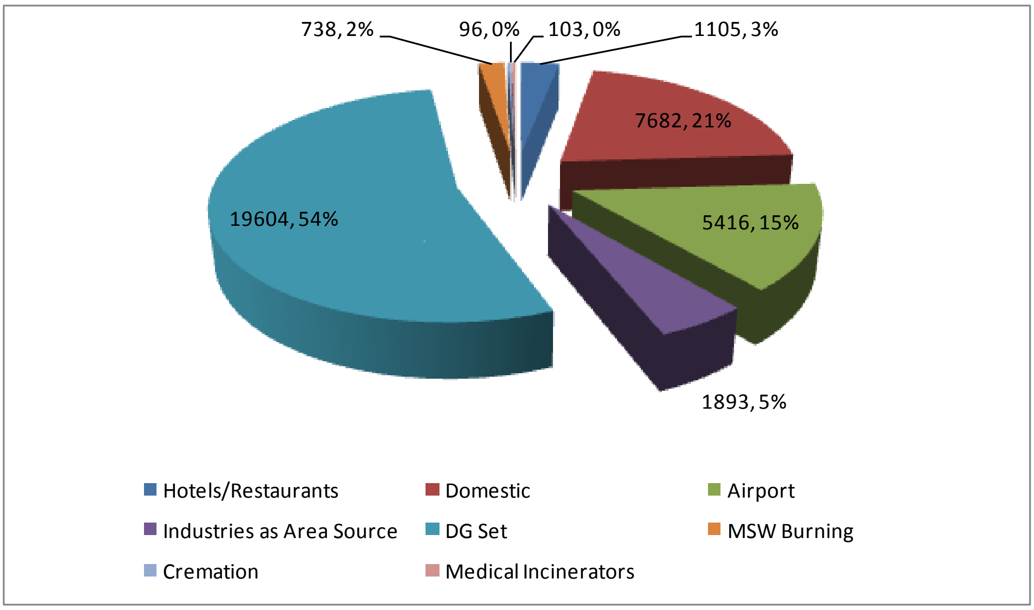


Figure 3.51: NOx Emission Load for area sources (kg/day, %)

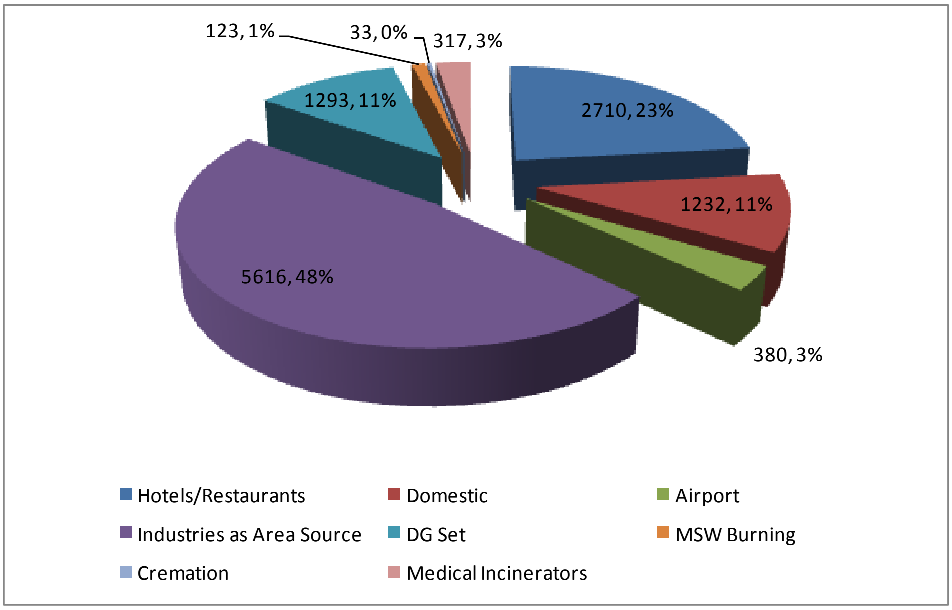


Figure 3.52: SO_2 Emission Load for area sources (kg/day, %)

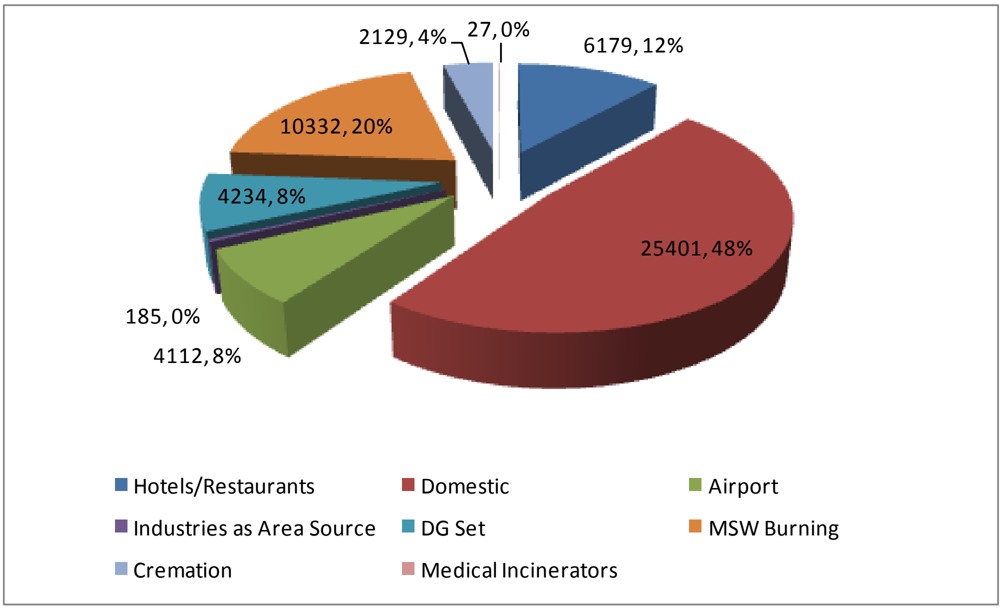


Figure 3.53: CO Emission Load for area sources (kg/day, %)

3.4 Point Sources

The industries having stack height of more than 20 m have been taken as point source. The information on stacks, fuel and its consumption was obtained from DPCC. The power plants information was taken from the annual report of Central Electricity Authority (CEA, 2012). The industries have been numbered and located on the map (Figure 3.54). 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 and power plant is given in Table 3.4 and Figure 3.55. Spatial Distribution of Emissions from Point Sources is presented in Figures 3.56 to 3.60.

Table 3.4: Emission Load from Point Sources

Category	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO
Industries	196	144	225	458	12
Power Plants	13485	6431	161613	128304	11635

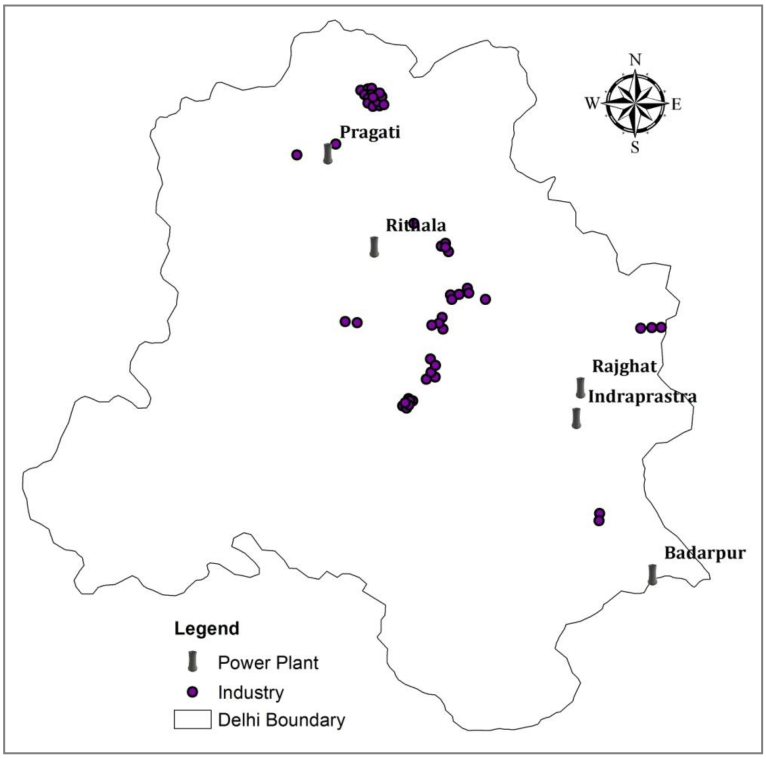


Figure 3.54: Locations of Points Sources in the City

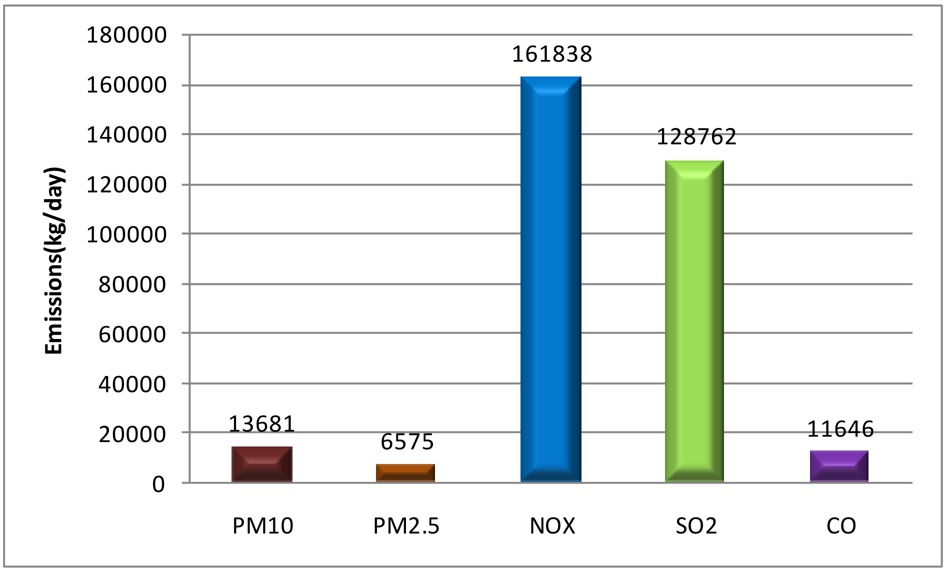


Figure 3.55: Emission Load from Point Sources

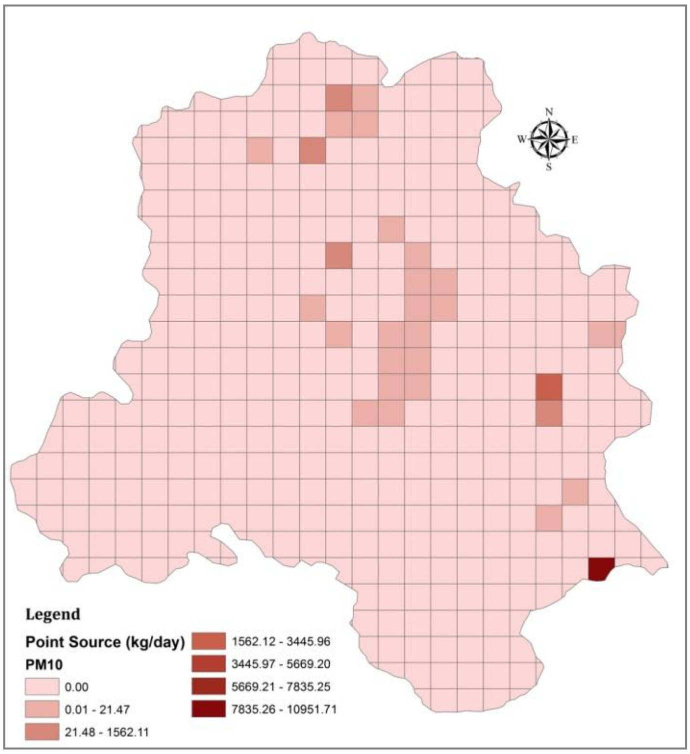


Figure 3.56: Spatial Distribution of PM_{10} Emissions from Point Sources

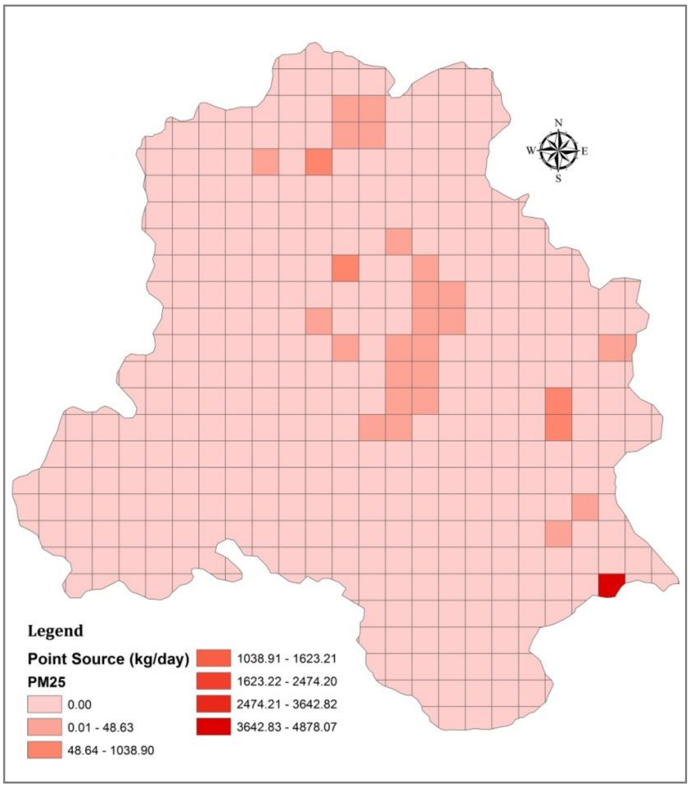


Figure 3.57: Spatial Distribution of $PM_{2.5}$ Emissions from Point Sources

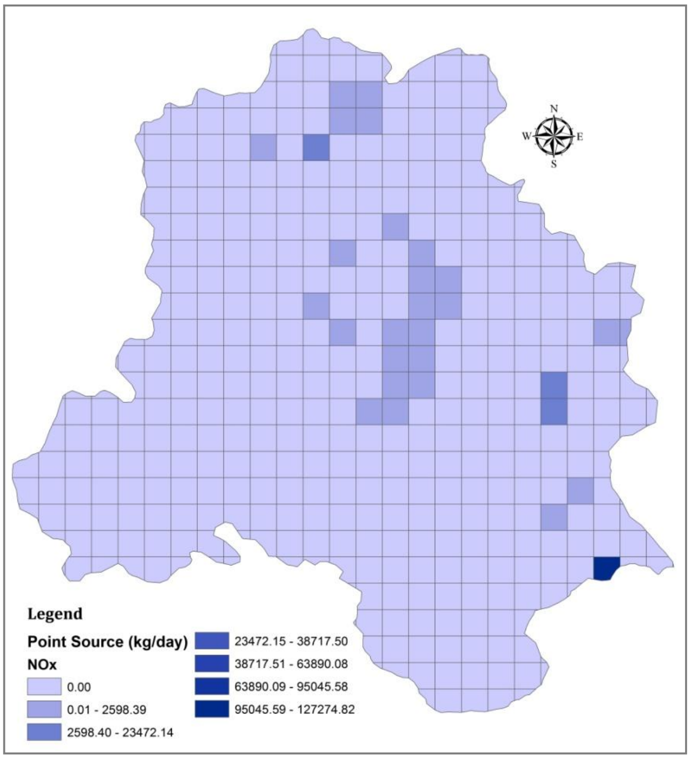


Figure 3.58: Spatial Distribution of NOx Emissions from Point Sources

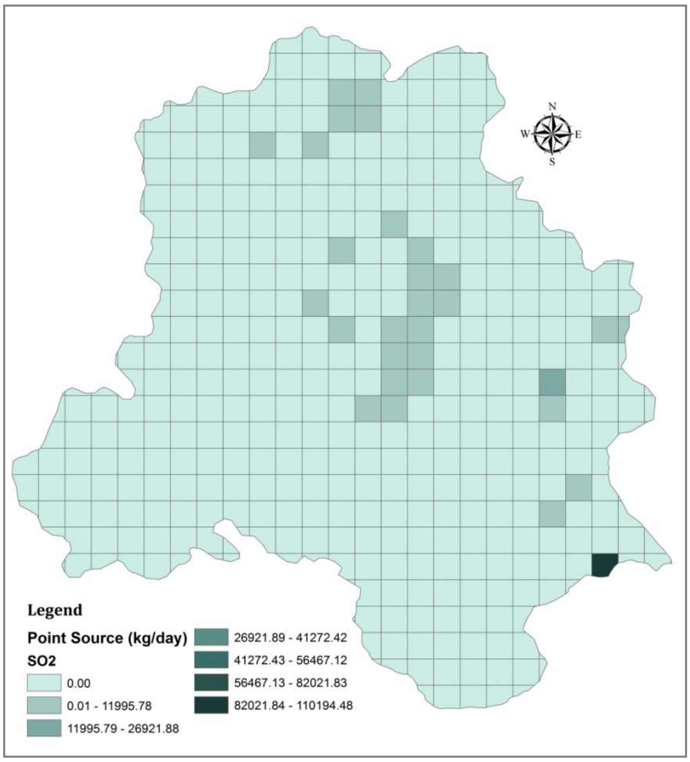


Figure 3.59: Spatial Distribution of SO_2 Emissions from Point Sources

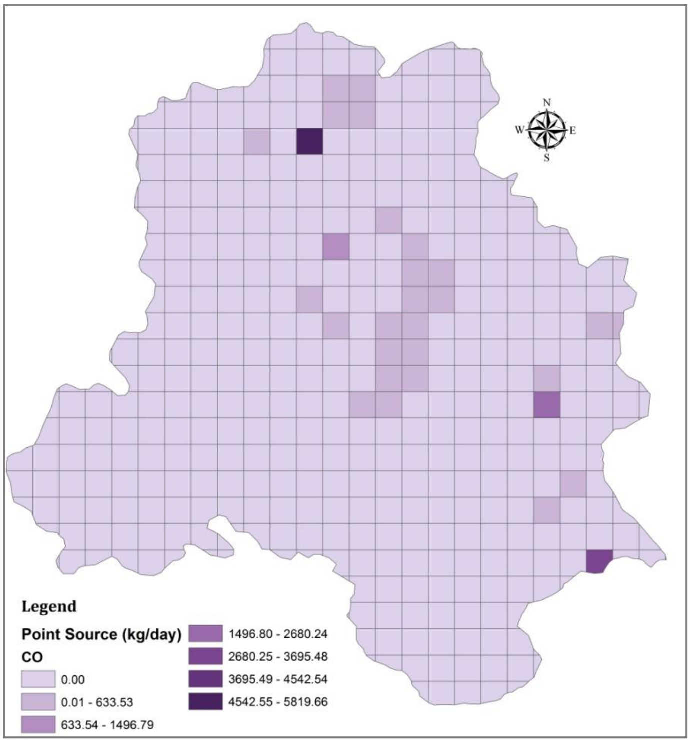


Figure 3.60: Spatial Distribution of CO Emissions from Point Sources

3.5 Vehicular - Line Sources

The average daily flow of vehicles in each hour for 2Ws, 3Ws, 4Ws, LCVs, Buses and Trucks at 64 locations were obtained from Central Road Research Institute (CRRI, 2015) (Figure 3.61). Traffic data were modeled to estimate the vehicle plying on road for the year 2013-14. From these 64 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.

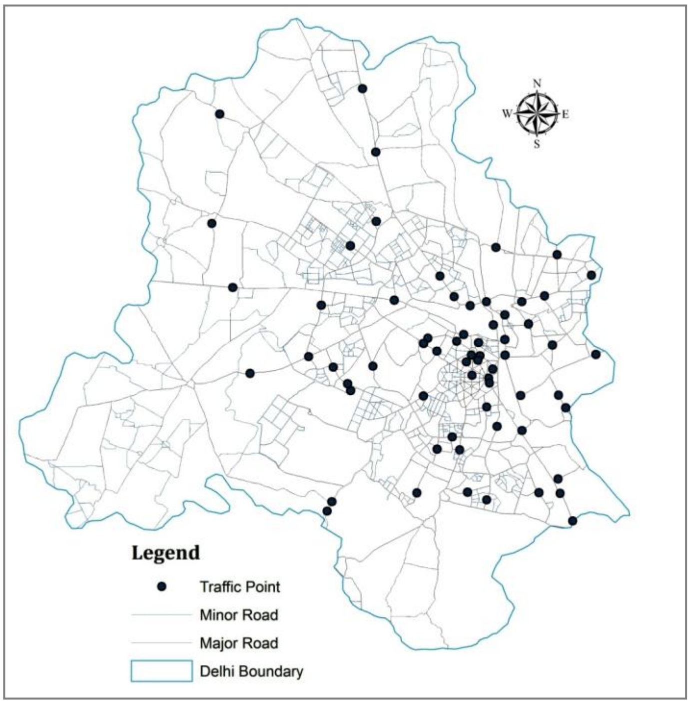


Figure 3.61: Traffic location considered for vehicle emission in the city of Delhi.

The emissions from railway locomotives are not taken into considerations, as the emissions are negligible in comparison with the vehicles and other sources. Most of the railway tracks in Delhi are of electric traction.

3.5.1 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 (Uttam Nagar, Janakpuri, Hauz Khas, Saket, Connaught Place, Dwarka, PVR Priya, Rajendra Nagar, Kirti Nagar, Barakhamba, Chandni Chowk, Karkardooma, NDLS Station, Laxmi Nagar, Preet Vihar, Pragati Maidan, Kashmere Gate, Khan Market, Anand Vihar, and Lajpat Nagar) in the city of Delhi. Out of total 5644 vehicles surveyed, the breakdown was: 1353 2-Ws; 455 3-Ws; 3836 4-Ws. During parking lot survey, 300 LCVs were surveyed and it was found out that all LCVs runs on CNG fuel and 99% LCVs are post 2005. All the city buses run on CNG and are of post 2000. The traffic flow from outside Delhi is also accounted in this inventory. The data from all (127) toll booth in the city were obtained and is presented in Table 3.5. Approximately 25% percent of 4-Ws use diesel, 11% uses CNG and the remaining 64% use gasoline. 3-Ws use compressed natural gas (CNG) and all 2-Ws use gasoline. ARAI (2011) and CPCB (2011) emission factors were used to calculate the emissions. Figures 3.62 to 3.64 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.

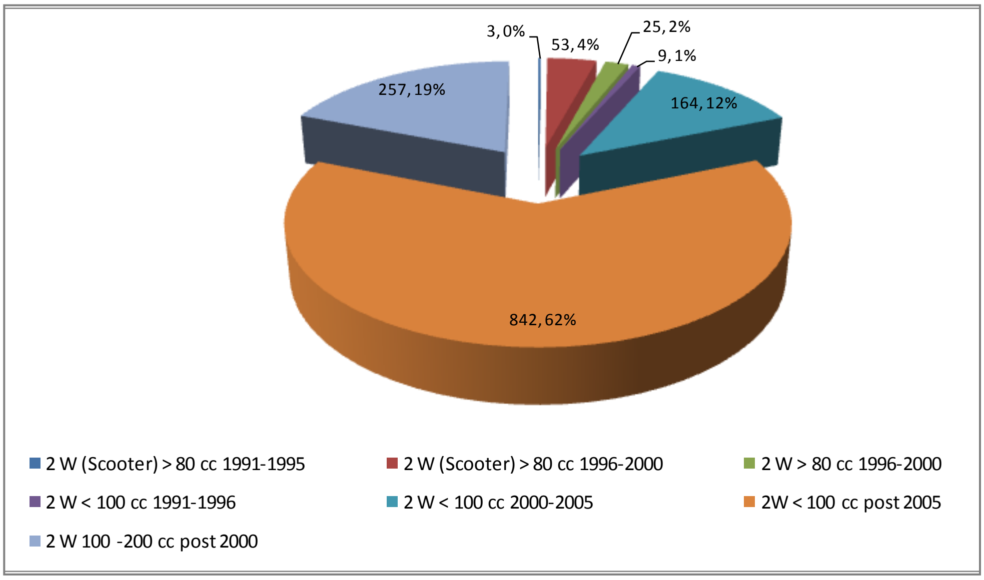


Figure 3.62: Distribution of 2-Ws in study area (parking lot survey)

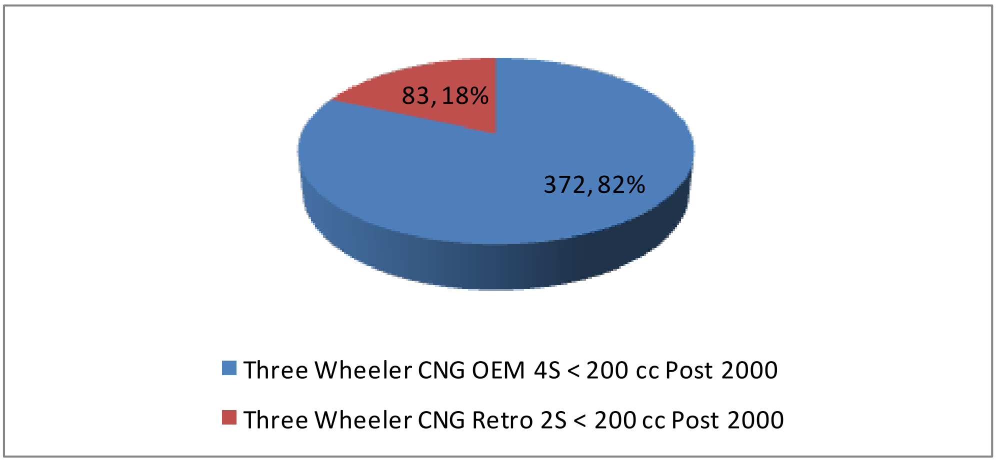


Figure 3.63: Distribution of 3-Ws in study area (parking lot survey)

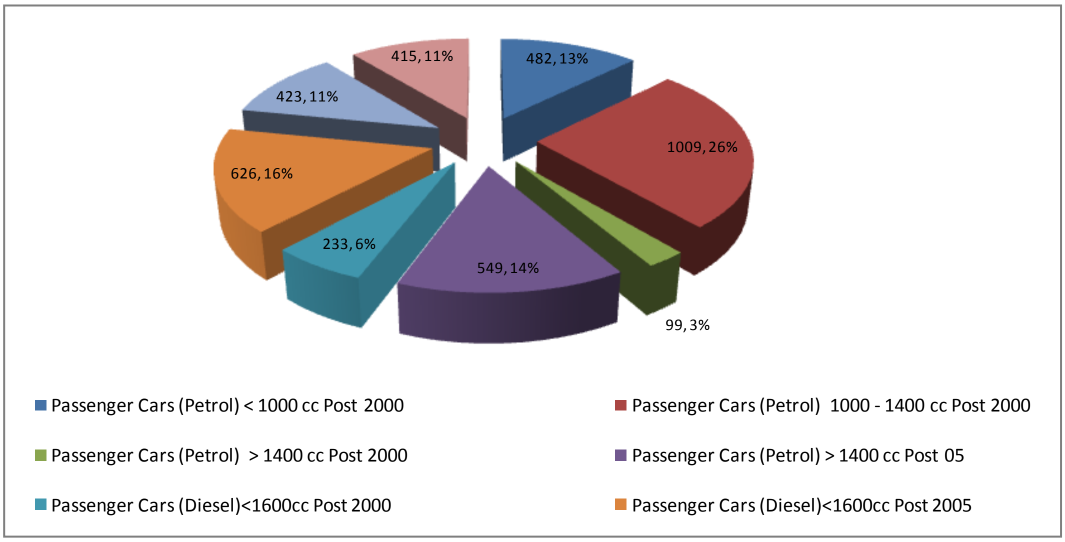


Figure 3.64: Distribution of 4-Ws in study area (parking lot survey)

Table 3.5: Data of Vehicles at Entry Points of Delhi (average per day)

S.No.	Name of Toll	CAT-1	CAT-2	CAT-3	CAT-4	CAT-5	TOTAL
1	Shahdra 1st	635	928	258	304	77	2202
2	Shahdra 2nd	1775	1882	385	690	144	4876
3	Mandooli Main	762	948	297	724	180	2911
4	Mandooli 2nd	12	1	0	0	0	13
5	Loni Main	337	308	375	120	23	1163
6	Loni 2nd	34	16	0	0	0	50
7	Seema Puri 1st	253	161	130	51	16	611
8	Seema Puri 2nd	99	6	0	0	0	105
9	Seema Puri 3rd	139	60	8	10	0	217
10	Chander Nagar	515	216	34	29	5	799
11	Surya Nagar	154	1	0	0	0	155
12	Sonia Vihar	189	148	121	24	3	485
13	Jhilmil	0	0	0	0	0	0
14	Ramprastha	0	17	0	0	0	17
15	Wazirabad	61	120	397	38	3	619
16	Indirapuri	19	10	2	0	0	31
17	Jauhripur 1st	37	40	8	4	0	89
18	Jauhripur 2nd	19	13	0	0	0	32
19	Sewadham 1st	262	75	29	56	14	436
20	Sewadham 2nd		0	0	0	0	0
21	Karawal Nagar	95	90	10	7	0	202
22	Dharamkanta	8	3	1	1	0	13
23	Amit Nagar	15	1	0	0	0	16

S.No.	Name of Toll	CAT-1	CAT-2	CAT-3	CAT-4	CAT-5	TOTAL
24	Shahdara 3rd		0	0	0	0	0
25	Ghazipur Main	4936	1182	259	400	228	7005
26	Old Ghazipur	719	1435	317	551	395	3417
27	Mohan Nagar	537	2282	114	90	18	3041
28	New Kondli	537	507	35	36	6	1121
29	Old Kondli	281	33	2	0	0	316
30	Vasundra 1st	363	110	8	4	2	487
31	Vasundra 2nd	169	41	0	0	0	210
32	Ashok Nagar 1st	232	16	11	4	0	263
33	Ashok Nagar 2nd	25	2	0	0	0	27
34	Between 1st	37	2	0	0	0	39
35	Between 2nd	76	5	0	0	0	81
36	Sabji Mandi	82	10	0	0	0	92
37	Sabji Mandi 2nd	310	19	0	0	0	329
38	Nagarjun	17	0	0	0	0	17
39	Nahar Naks	116	25	0	0	0	141
40	Nahar Naks 2nd	0	0	0	0	0	0
41	Nahar Naks 3rd	0	0	0	0	0	0
42	Mayur Vihar Ph Iii	33	6	0	0	0	39
43	Noida Major	3451	1086	280	282	83	5182
44	Mayur Vihar Cng	41	0	0	0	0	41
45	Cprf	48	0	0	0	0	48
46	Badarpur Main	31	0	0	0	0	31
47	Tuglagabad	516	17	16	10	2	561
48	Prahladpur	1041	269	259	148	23	1740
49	Surajkund	256	127	45	61	47	536
50	Kalindikunj	3628	1924	722	1016	874	8164
51	Jaitpura 1st	71	0	0	0	0	71
52	Jaitpura 2nd	13	1	0	0	0	14
53	Jaitpura 3rd	62	3	3	0	0	68
54	Jaitpura 4th	48	2	1	0	0	51
55	Ballabhgarh	20	2	4	0	0	26
56	Sector 37 1st	11	1	0	0	0	12
57	Sector 37 2nd	4	0	0	0	0	4
58	Sector 37 3rd	9	0	0	0	0	9
59	Sector 37 4th	42	6	3	0	0	51
60	Sector 37 5th	29	0	0	0	0	29
61	Lakkarpur	127	9	6	2	0	144

S.No.	Name of Toll	CAT-1	CAT-2	CAT-3	CAT-4	CAT-5	TOTAL
62	Durga Builder	358	30	8	9	0	405
63	Kapashera	1942	462	193	225	81	2903
64	Ayanagar	4029	332	117	296	126	4900
65	Old Bijwasan	349	43	14	21	7	434
66	New Bijwasan	456	64	21	29	11	581
67	Palam Vihar	656	83	24	26	8	797
68	Bajghera Main	638	158	57	59	17	929
69	Bajghera 2nd	9	1	0	0	0	10
70	Bajghera 3rd	39	4	1	1	0	45
71	Jhatikra	246	68	7	17	1	339
72	Nanakheri 1st	14	3	0	0	0	17
73	Nanakheri 2nd	3	1	0	0	0	4
74	Mandi More	107	53	10	16	3	189
75	Banswara	152	54	30	12	3	251
76	Kapashera B/P	8	0	0	0	0	8
77	Palam B/P	4	0	0	0	0	4
78	Kapashera Cng	6	3	0	0	0	9
79	Kgt Main	4969	4008	1419	1422	528	12346
80	Jaunti 1st	273	211	76	82	29	671
81	Jaunti 2nd	307	242	85	99	27	760
82	Punjab Khore 1st	281	209	79	75	29	673
83	Punjab Khore 2nd	246	214	78	66	21	625
84	Kutubgarh 1st	272	197	73	72	23	637
85	Kutubgarh 2nd	294	212	74	83	29	692
86	Kutubgarh 3rd	31	45	32	13	0	121
87	Mungeshpur	31	27	26	0	0	84
88	Auchandi 1st	70	31	26	52	9	188
89	Auchandi 2nd	9	2	2	0	0	13
90	Harewali	7	1	0	0	0	8
91	Revli 2nd	67	23	7	0	0	97
92	Lampur	111	76	57	122	20	386
93	Bananer	11	3	1	0	0	15
94	Safia Bad	163	78	19	43	10	313
95	Saboli Road	62	20	3	2	0	87
96	Tt Post	255	126	11	11	3	406
97	Kundali 1st	18	11	3	16	2	50
98	Kundali 2nd	235	291	111	160	37	834
99	Singhu School	37	15	4	10	0	66

S.No.	Name of Toll	CAT-1	CAT-2	CAT-3	CAT-4	CAT-5	TOTAL
100	Singhu Gaon	77	8	3	0	0	88
101	Janti Khurd	5	5	4	2	0	16
102	Zero Palla	18	10	0	0	0	28
103	Tajpur	4	2	2	0	0	8
104	Tikri	2957	1778	439	1091	439	6704
105	Jharoda 1st	893	318	64	139	43	1457
106	Jharoda 2nd	9	3	0	15	0	27
107	Dhansa	174	238	44	343	45	844
108	Dorala 1st	201	171	23	107	34	536
109	Dorala 2nd	17	11	5	5	3	41
110	Dorala 3rd	3	0	3	0	0	6
111	Nizampur 1st	118	47	27	33	1	226
112	Nizampur 2nd	117	38	91	6	0	252
113	Bakargarh	43	98	16	41	0	198
114	Badshah Ghalimpur	5	5	0	2	0	12
115	Badshah Ghalimpur 2nd	10	2	0	0	0	12
116	Surakhpur	28	2	0	0	0	30
117	Devarkhana	3	1	0	0	0	4
118	Mundelkalan 1st	25	29	3	5	0	62
119	Mundelkalan 2nd	9	5	1	0	0	15
120	Kairnaka 1st	14	4	1	0	0	19
121	Kairnaka 2nd	2	4	0	0	0	6
122	Chornaka	62	18	4	0	0	84
123	Isapur	2	2	0	0	0	4
124	Head Office	0	0	0	0	0	0
125	Dnd Toll	4051	703	139	277	111	5281
126	Bftc(Badarpur Toll)	6563	2507	1152	1709	663	12594
127	Rajokari	19171	4613	1468	4001	2533	31786
Total		**74684**	**32189**	**10297**	**15477**	**7039**	**139686**

Cat 1: Taxi, Tempo, Tata407 and other commercial vehicles, **Cat 2**: Bus, Nissan, Canter and other commercial vehicles, **Cat 3**: six wheel truck, Cat 4: 10 wheel truck, **Cat 5**: 14 wheel truck.

The emission from vehicles is shown in Figure 3.65. Emission contribution of each vehicle type in city of Delhi is presented in Figures 3.66 to 3.70. In the category of 4W cars, it is estimated that in PM emission, petrol cars contributes about 22% and rest 78% is contributed by diesel cars; contribution of CNG cars is negligible. The spatial distribution of emissions from vehicles is presented in Figures 3.71 to 3.75.

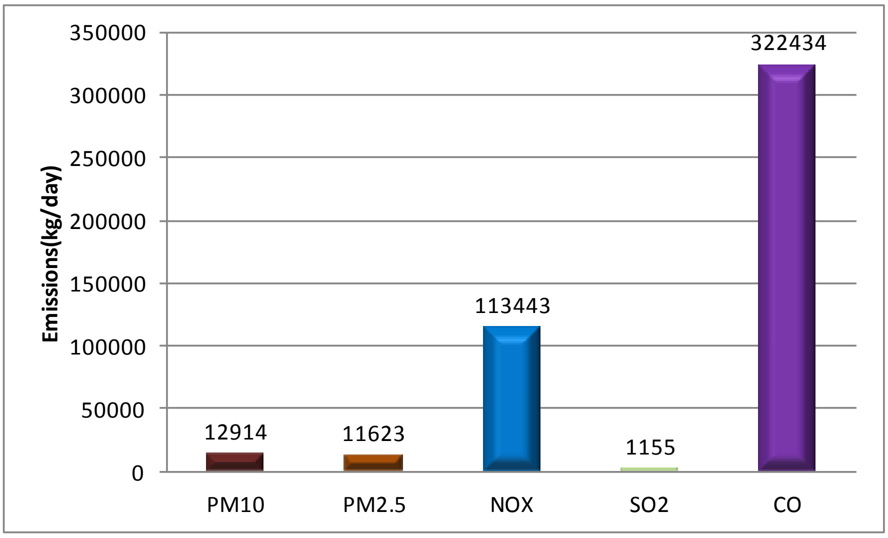


Figure 3.65: Emission Load from Vehicles (kg/day)

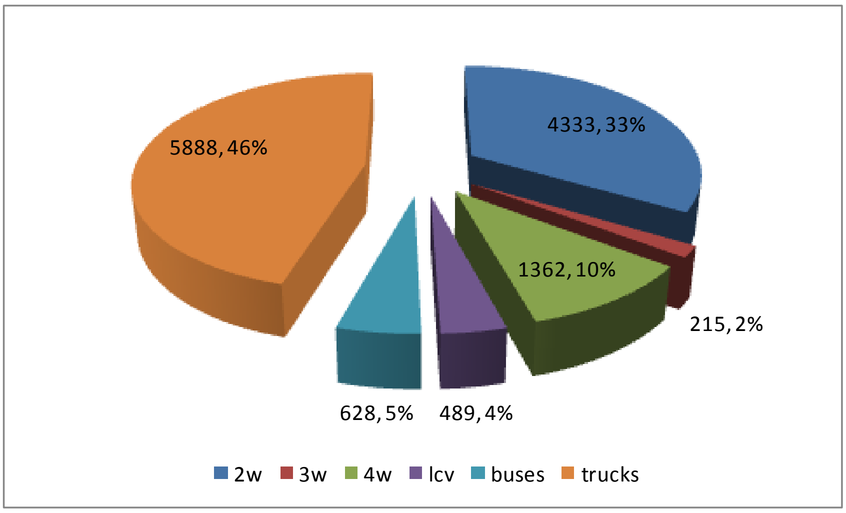


Figure 3.66: PM_{10} Emission Load contribution of each vehicle type in city of Delhi

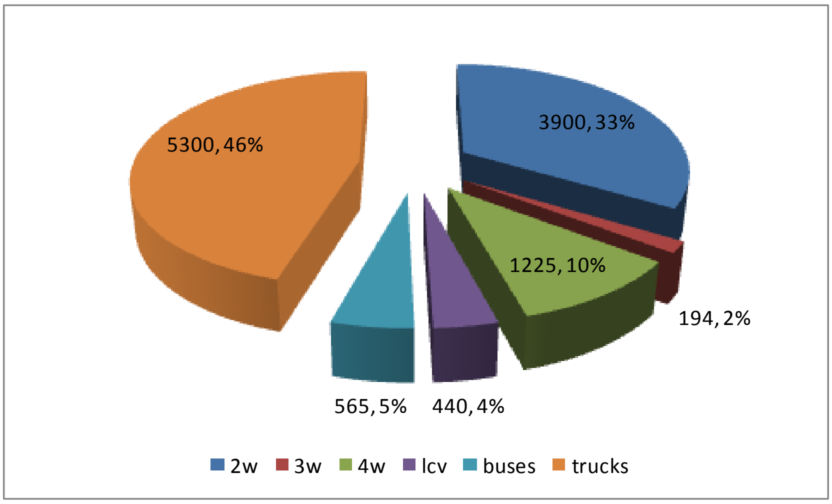


Figure 3.67: $PM_{2.5}$ Emission Load contribution of each vehicle type in city of Delhi

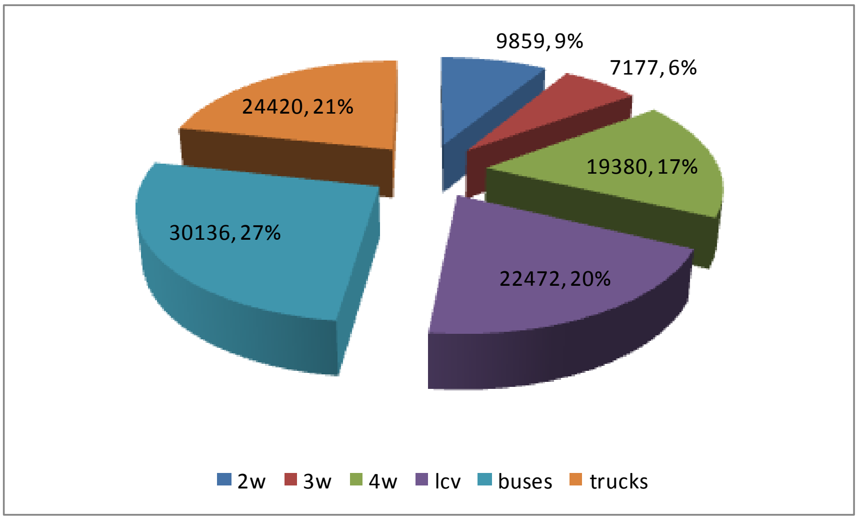


Figure 3.68: NOx Emission Load contribution of each vehicle type in city of Delhi

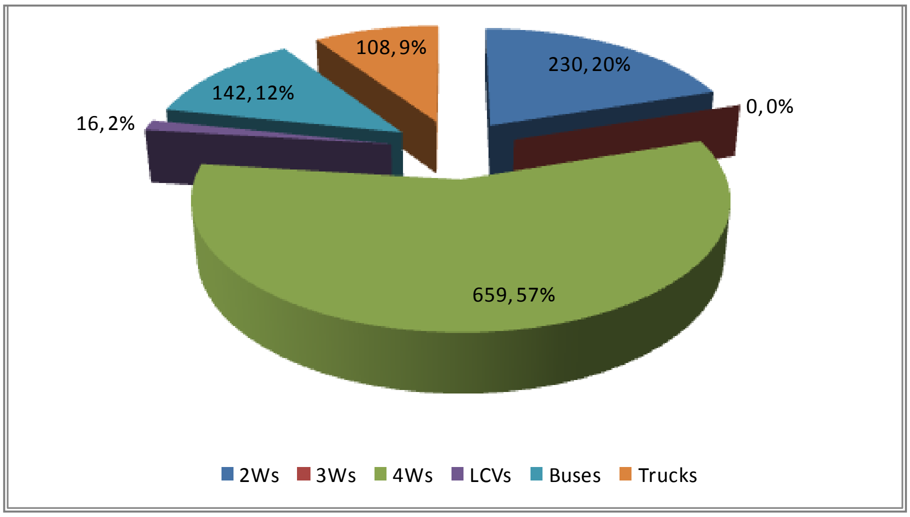


Figure 3.69: SO_2 Emission Load contribution of each vehicle type in city of Delhi

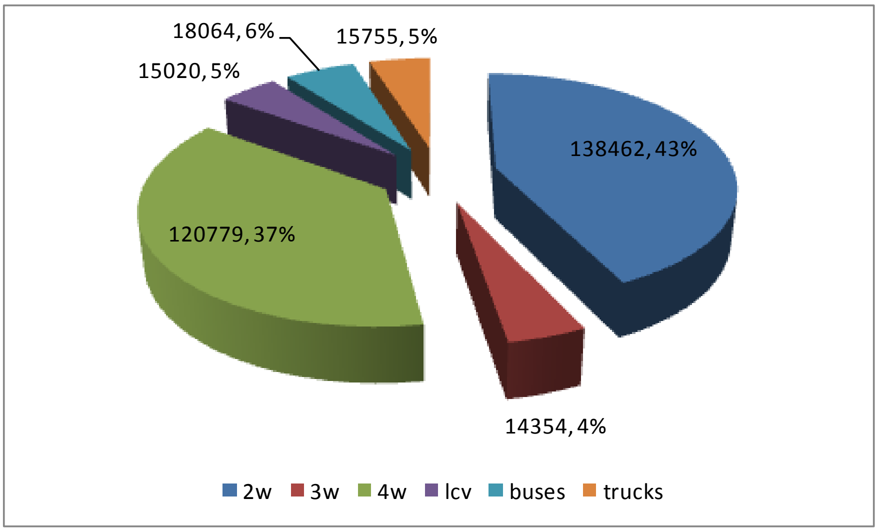


Figure 3.70: CO Emission Load contribution of each vehicle type in city of Delhi

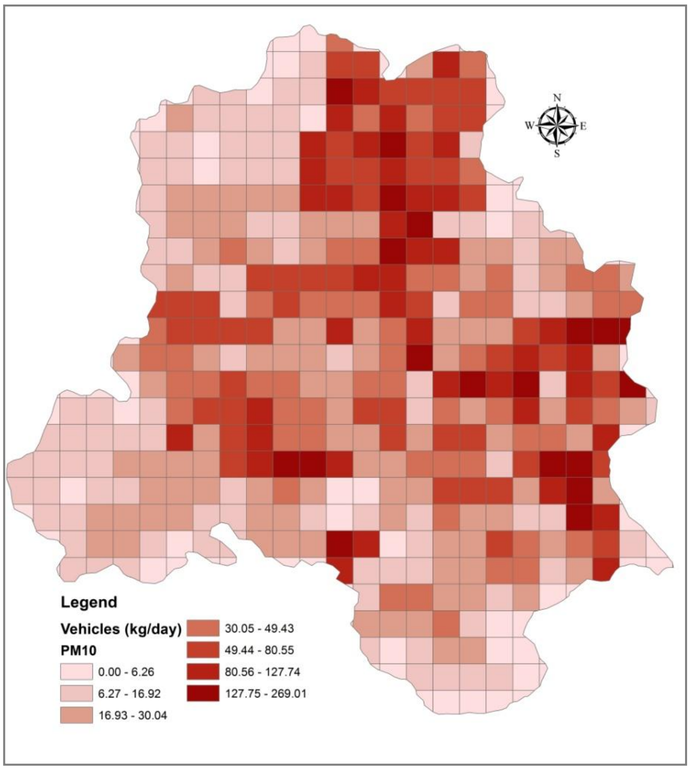


Figure 3.71: Spatial Distribution of PM_{10} Emissions from Vehicles

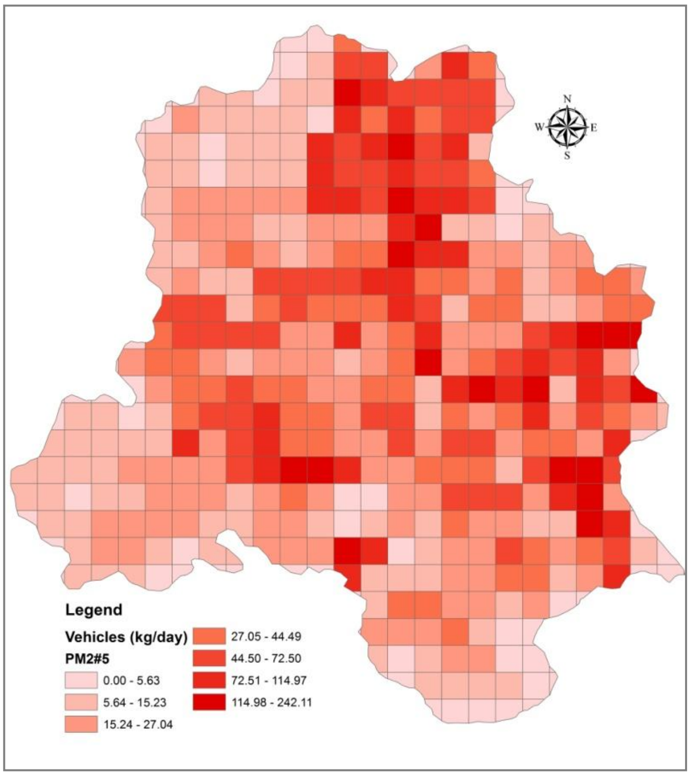


Figure 3.72: Spatial Distribution of $PM_{2.5}$ Emissions from Vehicles

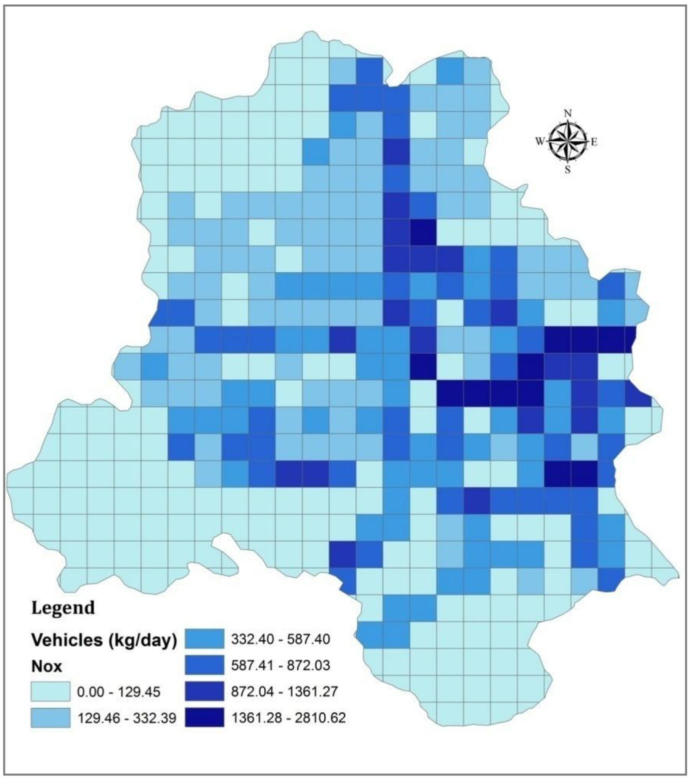


Figure 3.73: Spatial Distribution of NOx Emissions from Vehicles

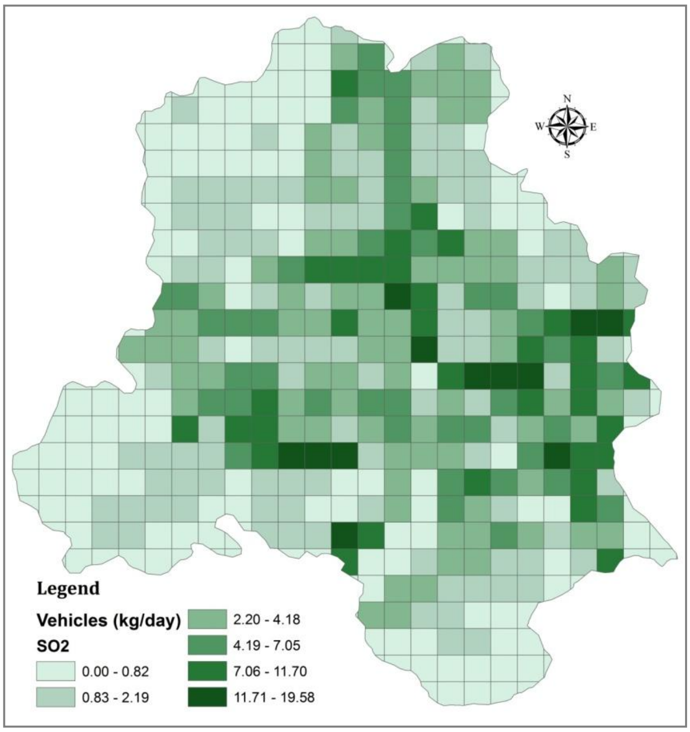


Figure 3.74: Spatial Distribution of SO_2 Emissions from Vehicles

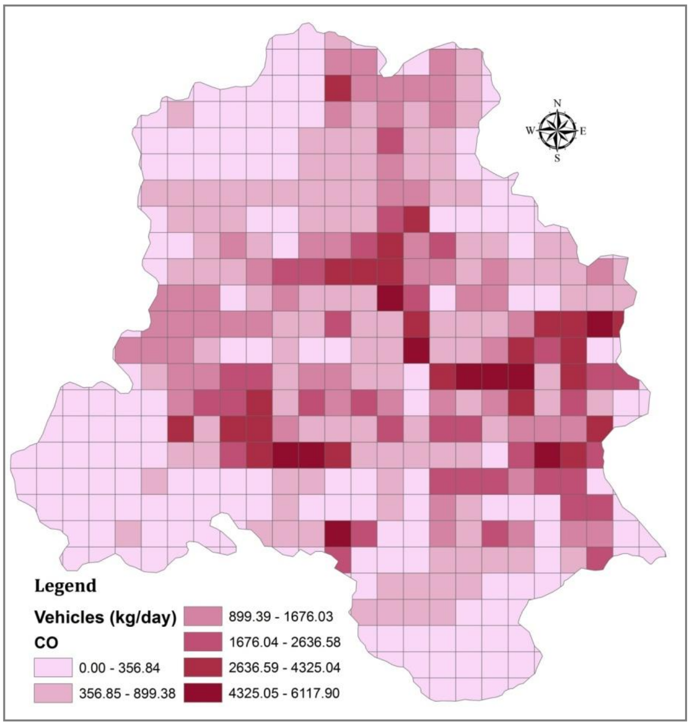


Figure 3.75: Spatial Distribution of CO Emissions from Vehicles

3.5.3 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:

$$E = k\,(sL)^{0.91} \times (W)^{1.02} \tag{3.5}$$

Where

E: particulate emission factor (same units as "k")
sL: silt load (g m^{-2})
W: mean weight of the vehicle fleet (Tons)
k: constant (function of particle size) in g VKT^{-1}(Vehicle Kilometer Travel) (e.g. k = 0.62 for PM_{10}).

The silt loads (sL) samples from 16 locations were collected (Figure 3.76). Then mean weight of the vehicle fleet (W) was estimated by giving the weightage to the percentage of vehicles of all types with their weight. Then emission rate (g VKT^{-1}) was calculated based on Eq(3.5). 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(3.5). The PM_{10} and $PM_{2.5}$ emission from road dust is 79626 kg/day and 22165 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 3.77 to 3.78.

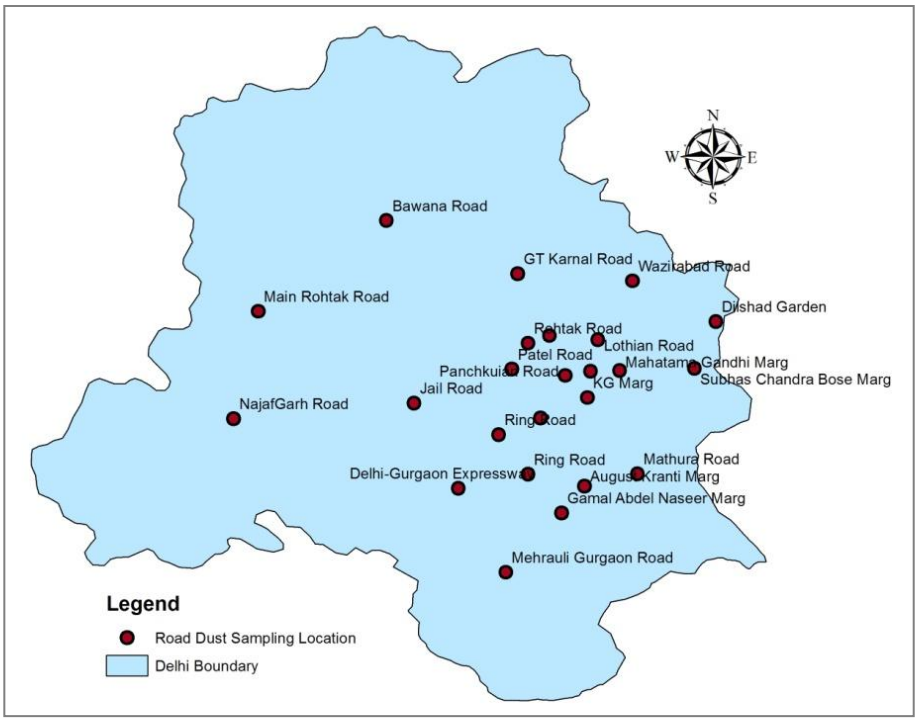


Figure 3.76: Road Dust Sampling Location

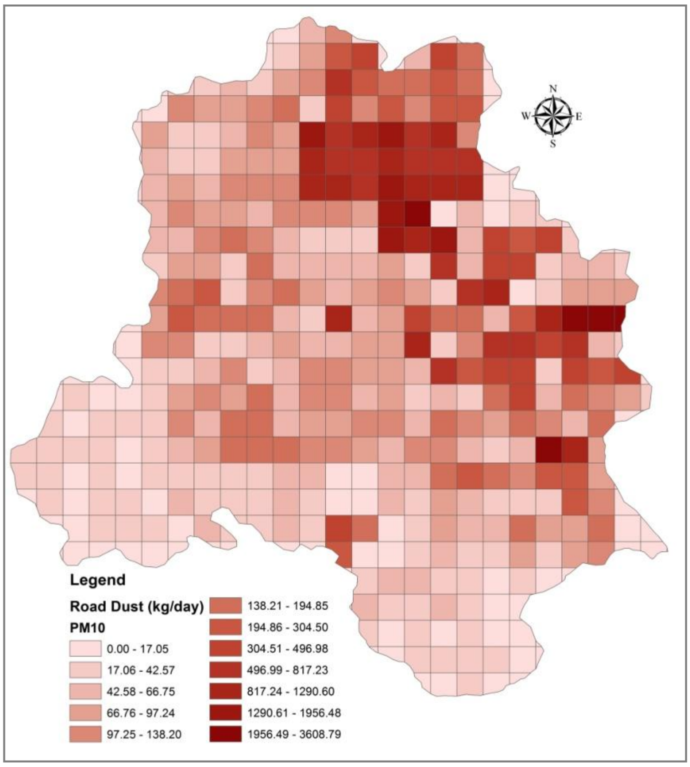


Figure 3.77: Spatial Distribution of PM_{10} Emissions from Road Dust Re-suspension

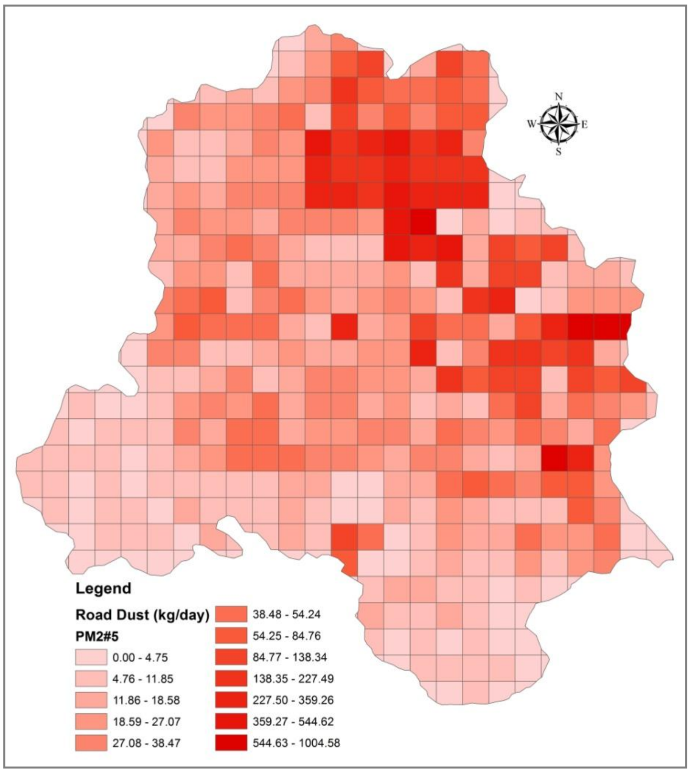


Figure 3.78: Spatial Distribution of $PM_{2.5}$ Emissions from Road Dust Re-suspension

3.6 City Level Emission Inventory

The overall baseline emission inventory for the entire city is presented in Table 3.7 (period: November 2013 – June 2014). The pollutant wise contribution is shown in Figures 3.79 to 3.83. Spatial Distribution of pollutant Emissions from all sources is presented in figures from 3.84 to 88.

The total PM_{10} emission load in the city is estimated to be 143 t/d. The top four contributors to PM_{10} emissions are road dust (56%), concrete batching (10%), industrial point sources (10%) and vehicles (9%); these are based on annual emissions. Seasonal and daily emissions could be highly variable. For example, fugitive road and soil dust re-suspension from ash pond and emission from concrete batching will be significantly lower in winter than summer months. 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.

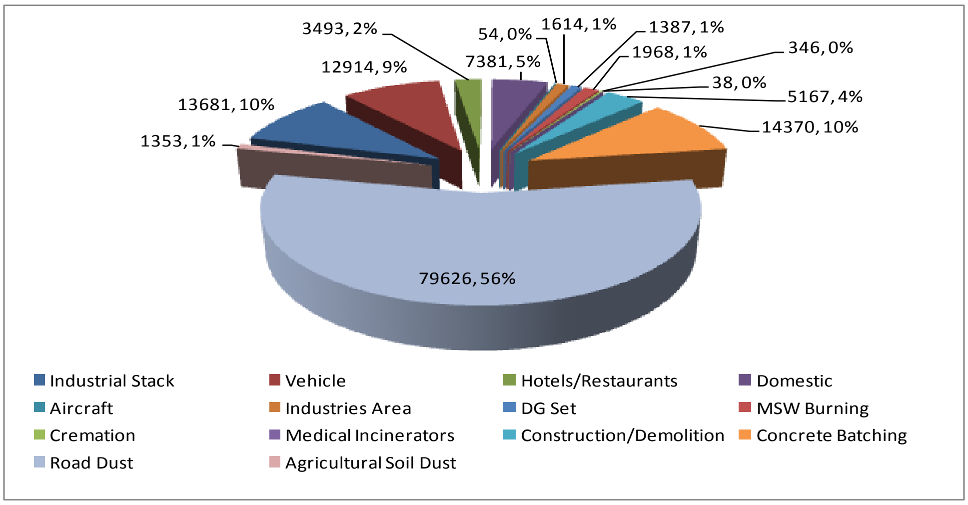


Figure 3.79: PM_{10} Emission Load of Different Sources in the City Of Delhi

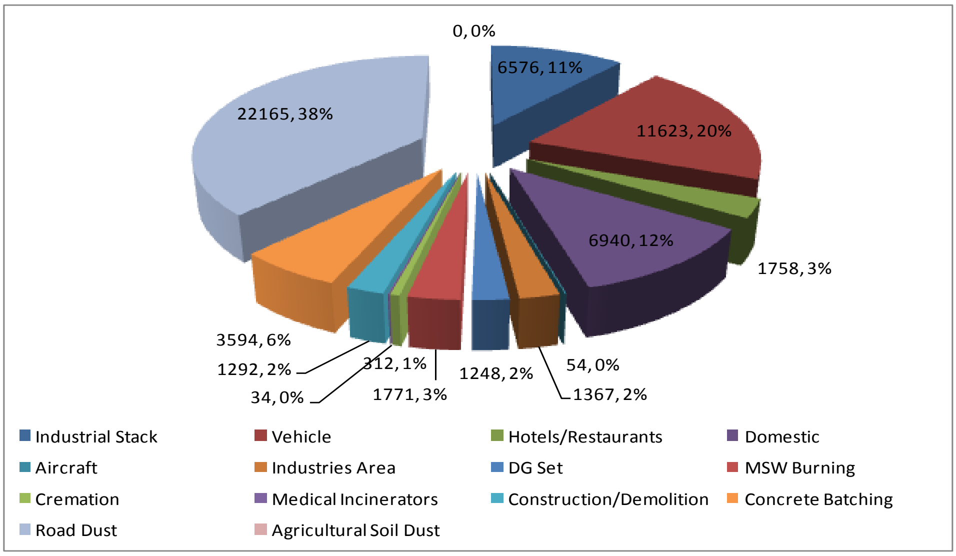


Figure 3.80: $PM_{2.5}$ Emission Load of Different Sources in the City Of Delhi

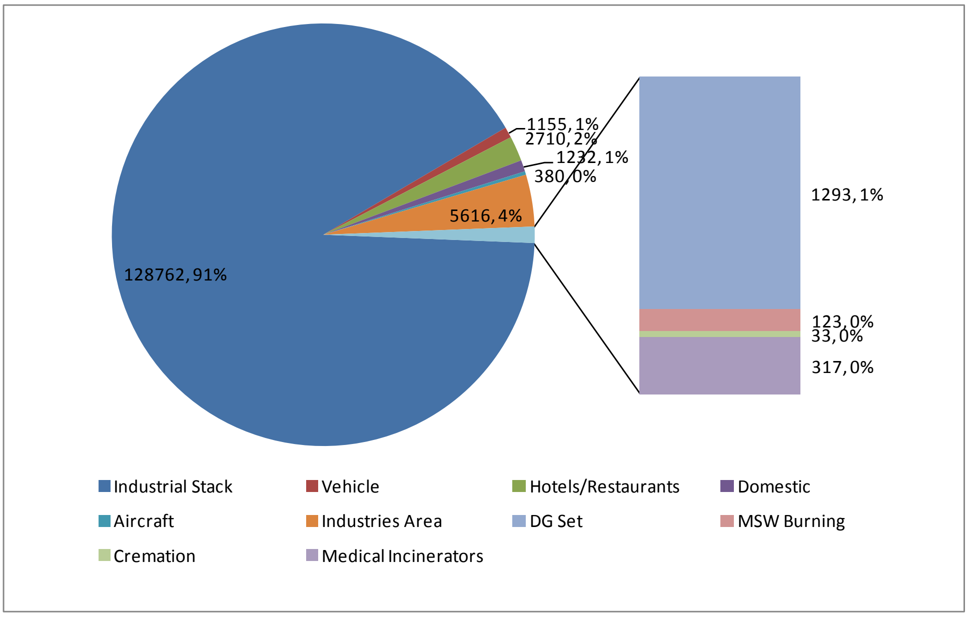


Figure 3.81: SO_2 Emission Load of Different Sources in the City Of Delhi

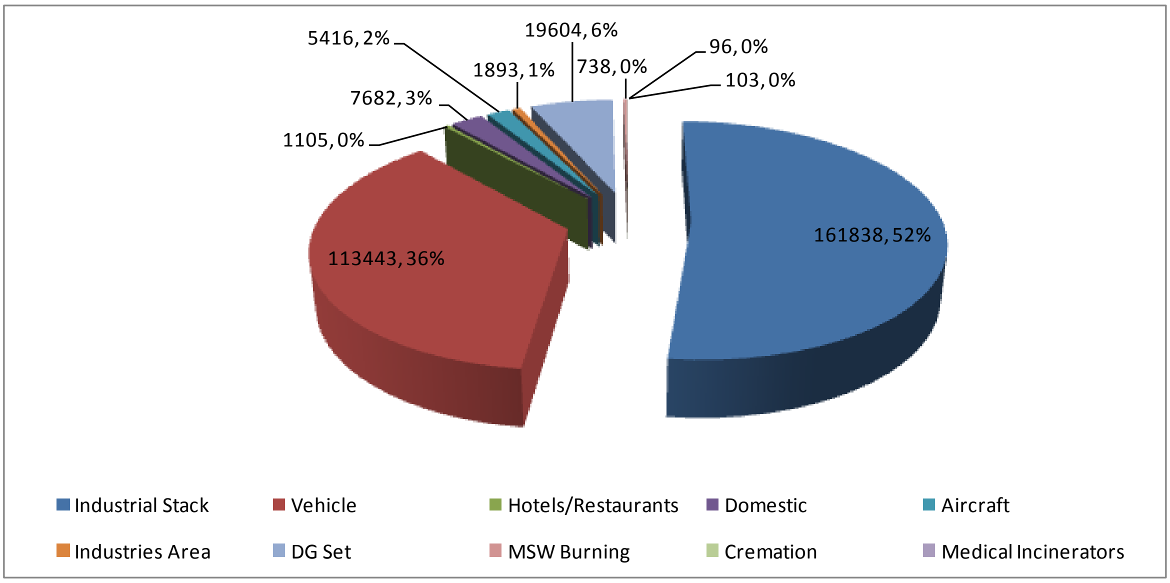


Figure 3.82: NOx Emission Load of Different Sources in the City Of Delhi

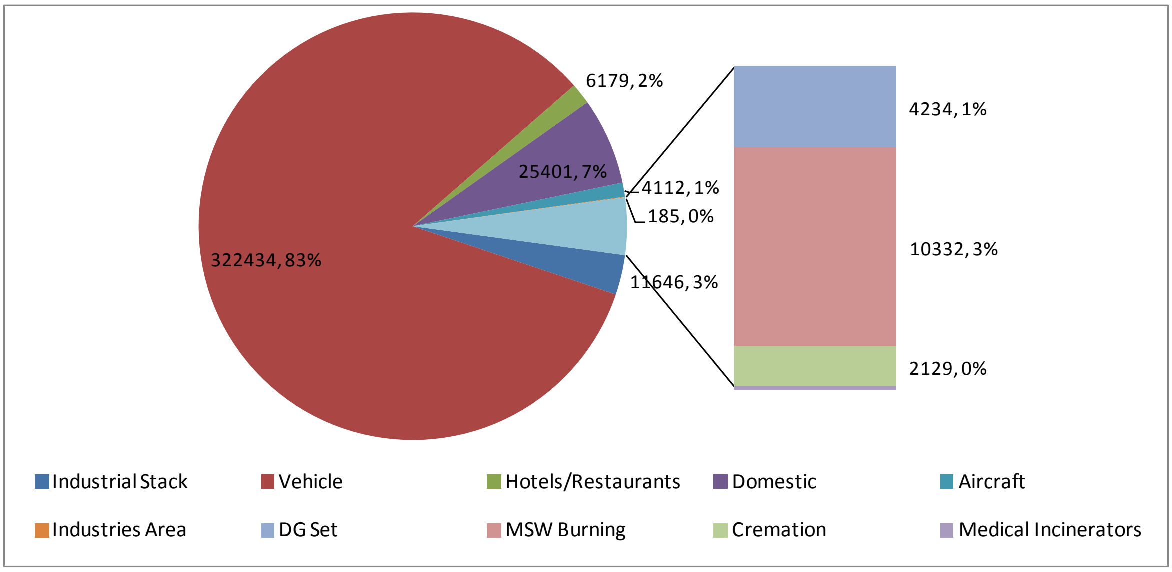


Figure 3.83: CO Emission Load Contribution of Different Sources in the City Of Delhi

$PM_{2.5}$ emission load in the city is estimated to be 59 t/d. The top four contributors to $PM_{2.5}$ emissions are road dust (38 %), vehicles (20 %), domestic fuel burning (12 %) and industrial point sources (11%); these are based on annual emissions. Seasonal and daily emissions could be highly variable.

NOx emissions are even higher than PM_{10} emission ~ 312 t/d. Nearly 52 % of emissions are attributed to industrial point source (largely from power plants) followed by vehicular emissions (36%) that occur at ground level, probably making it the most important emission. DG sets contributes 6% to NOx emission and is followed by Aircraft emission (2%). NOx apart from being a pollutant itself, it is important component in 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 141 t/d. Industrial point sources account for above 90 percent of total emission; most of the emissions are from power plants. It appears there may be a need to control SO_2 from power plants. SO_2 is known to contribute to secondary particles (sulfates).

Estimated CO emission is about 387 t/d. Nearly 83 % emission of CO is from vehicles, followed by domestic sources 7 %, MSW burning 3% and about 3 % from industrial point source. 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 down town area, north and east of the city show higher emissions than other parts.

Table 3.6: Overall Baseline Emission Inventory for the Delhi City (kg/day)

Category	**PM_{10}**	**$PM_{2.5}$**	**NOx**	**SO_2**	**CO**
Industrial Stack	13681	6576	161838	128762	11646
Vehicle	12914	11623	113443	1155	322434
Road Dust	79626	22165	0	0	0
Hotels/Restaurants	3493	1758	1105	2710	6179
Domestic	7381	6940	7682	1232	25401
Aircraft	54	54	5416	380	4112
Industries Area	1614	1367	1893	5616	185
DG Set	1387	1248	19604	1293	4234
MSW Burning	1968	1771	738	123	10332
Cremation	346	312	96	33	2129
Construction/Demolition	5167	1292	0	0	0
Concrete Batching	14370	3594			
Agricultural Soil Dust	1353	0	0	0	0
Medical Incinerators	38	34	103	317	27
Total	**143392**	**58733**	**311918**	**141621**	**386678**

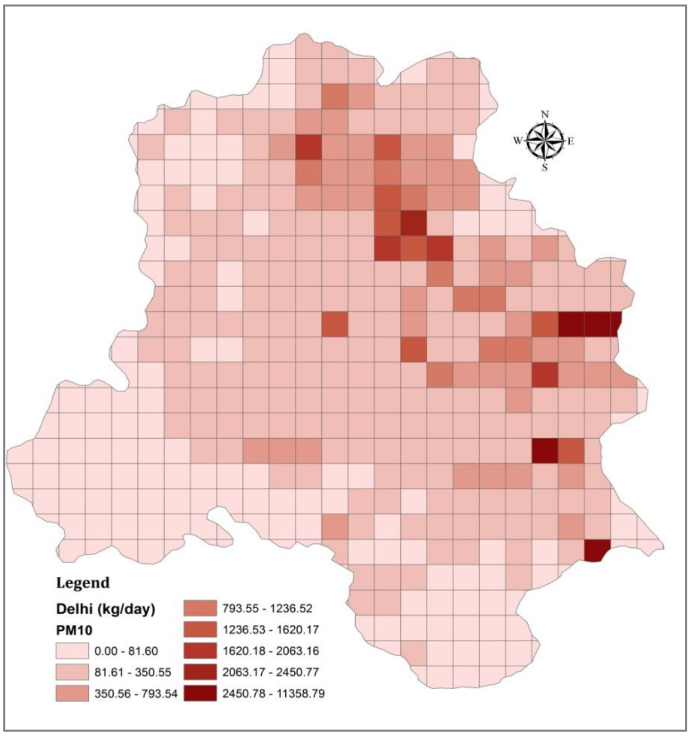


Figure 3.84: Spatial Distribution of PM_{10} Emissions in the City of Delhi

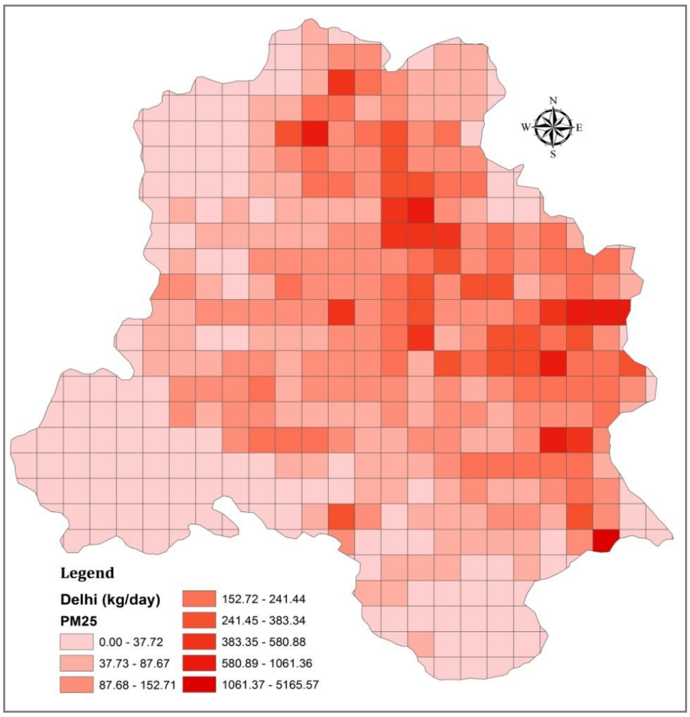


Figure 3.85: Spatial Distribution of $PM_{2.5}$ Emissions in the City of Delhi

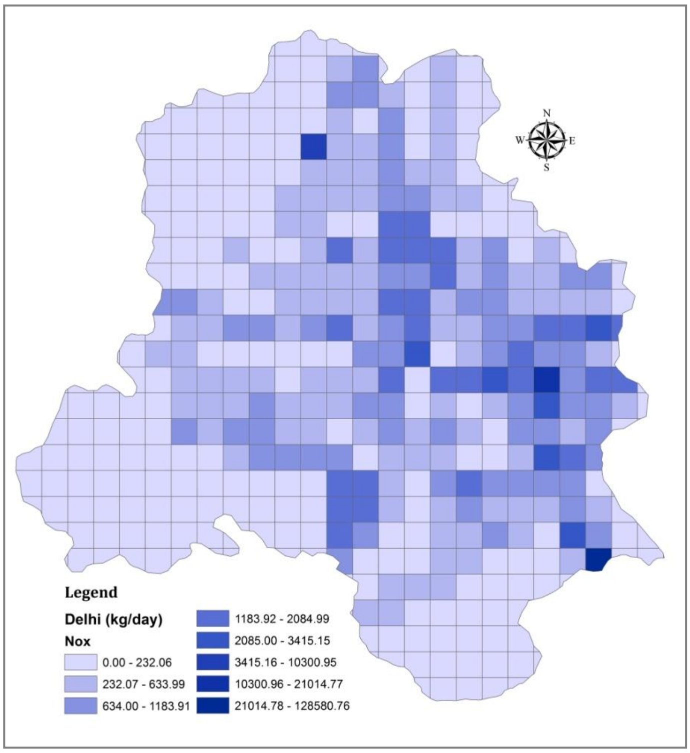


Figure 3.86: Spatial Distribution of NOx Emissions in the City of Delhi

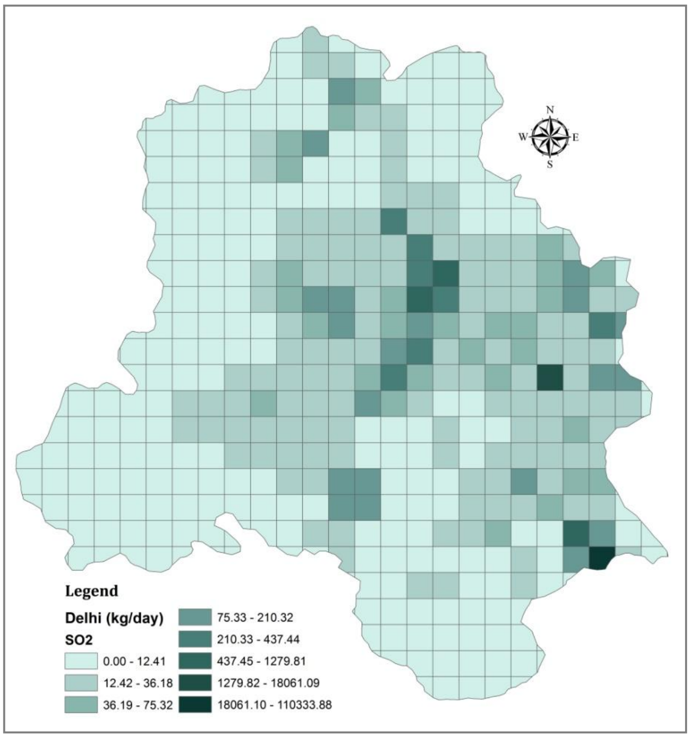


Figure 3.87: Spatial Distribution of SO_2 Emissions in the City of Delhi

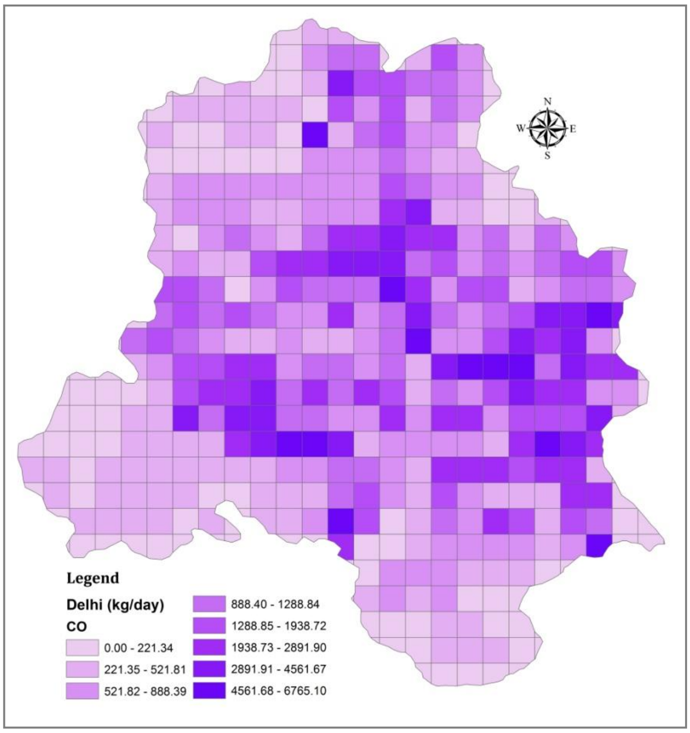


Figure 3.88: Spatial Distribution of CO Emissions in the City of Delhi

Chapter 4

Receptor Modeling and Source Apportionment

4.1 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).

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

Since for $PM_{2.5}$, Indian or Delhi 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 Delhi’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 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 Delhi could impact air quality in Delhi.

4.3 CMB Modeling Results and interpretation

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

4.3.1 Delhi Technical University, Rohini (RHN)

4.3.1.1 Winter Season RHN [sampling period: November 03- November 23, 2013]

At this site, three days, November 3-5, which indicated impact of Diwali fire crackers are not included and dealt separately.

PM_{10} (winter)

The average PM_{10} concentration was 593 µg/m^3. Figure 4.1 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at RHN. Table 4.1 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing to PM_{10} was biomass burning (174 µg/m^3 ~ 28%) followed by vehicular emissions (116 µg/m^3 ~ 19%). The other major sources are secondary particles, (105 µg/m^3 ~ 17%), solid waste burning (74 µg/m^3 ~ 12%), coal and flyash (10%) and soil and road dust (11%). Contribution of the industrial emission was estimated at less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 428 µg/m^3 (i.e. about 0.70 of PM_{10}). Figure 4.2 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at RHN. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (137 µg/m^3 ~ 34%) followed by vehicular emission (96 µg/m^3 ~ 24%). Other sources are secondary particle formation (81 µg/m^3 ~ 20%), solid waste burning (48 µg/m^3 ~ 12%) and coal and flyash (5%).

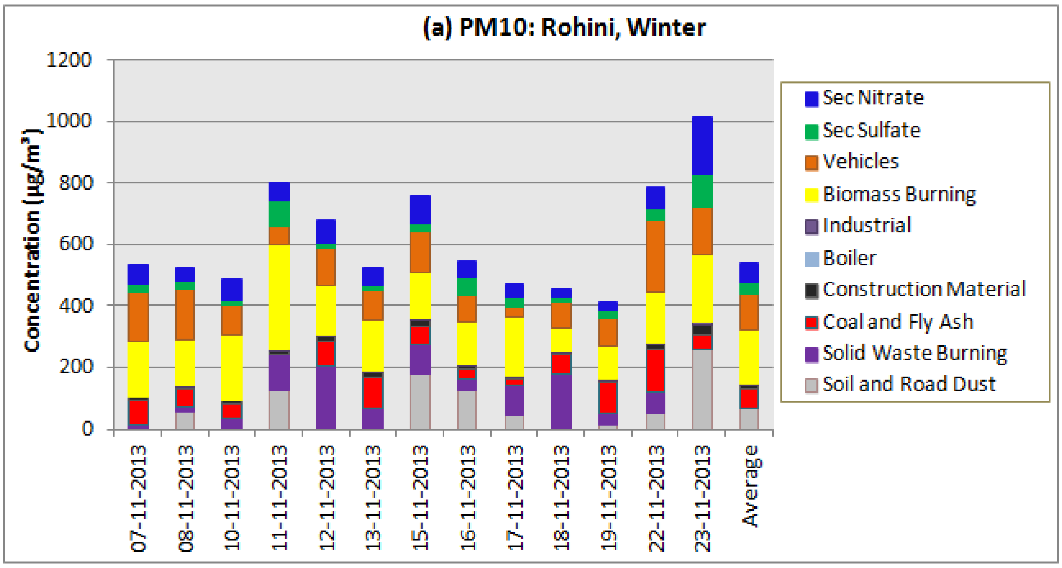
HYSPLIT back trajectories (Figure 4.3) indicate that wind is flowing from NW and sometimes from West direction. Wind mass as it travels over Punjab, Haryana and parts of Rajasthan states before entering in Delhi. Winds can pick up the pollutants on the way especially from large sources (e.g. crop residue burning (CRB)) and tall emitting sources but these contributions have not been quantifies.

Inferences

- The biomass burning has major contribution (29% for PM_{10} and 35% for $PM_{2.5}$%) to the PM at RHN. Biomass burning is prohibited in Delhi and not a common practice at a large scale. In all likelihood the biomass PM is contributed from CRB prevalent in Punjab and Haryana during this time of the year. The back trajectory analyses (Figure 4.3) also suggest that the CRB and other biomass emissions may be transported to Delhi from the states of Punjab and Haryana.

- Vehicles contribute significantly to PM_{10} and $PM_{2.5}$ (29% for PM_{10} and 35% for $PM_{2.5}$%).
- The secondary particles contribute to PM_{10} (16%) and $PM_{2.5}$ (19%). 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 NW wind is expected to transport SO_2 and transformed sulfates emitted from large power plants and refineries situated in the upwind of Delhi.
- The MSW burning contribution has surprised. The recent study by Nagpure et al. (2015) has estimated 190 to 246 tons/day of MSW burning (~2−3% of MSW generated; 8390 tons/day). It is myth that MSW is not burned in Delhi. 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.

The flyash contribution reduced to 5% from 11% in PM_{10} and similarly the road and soil dust emission reduced to 2% in $PM_{2.5}$ compared to 11 % 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}.



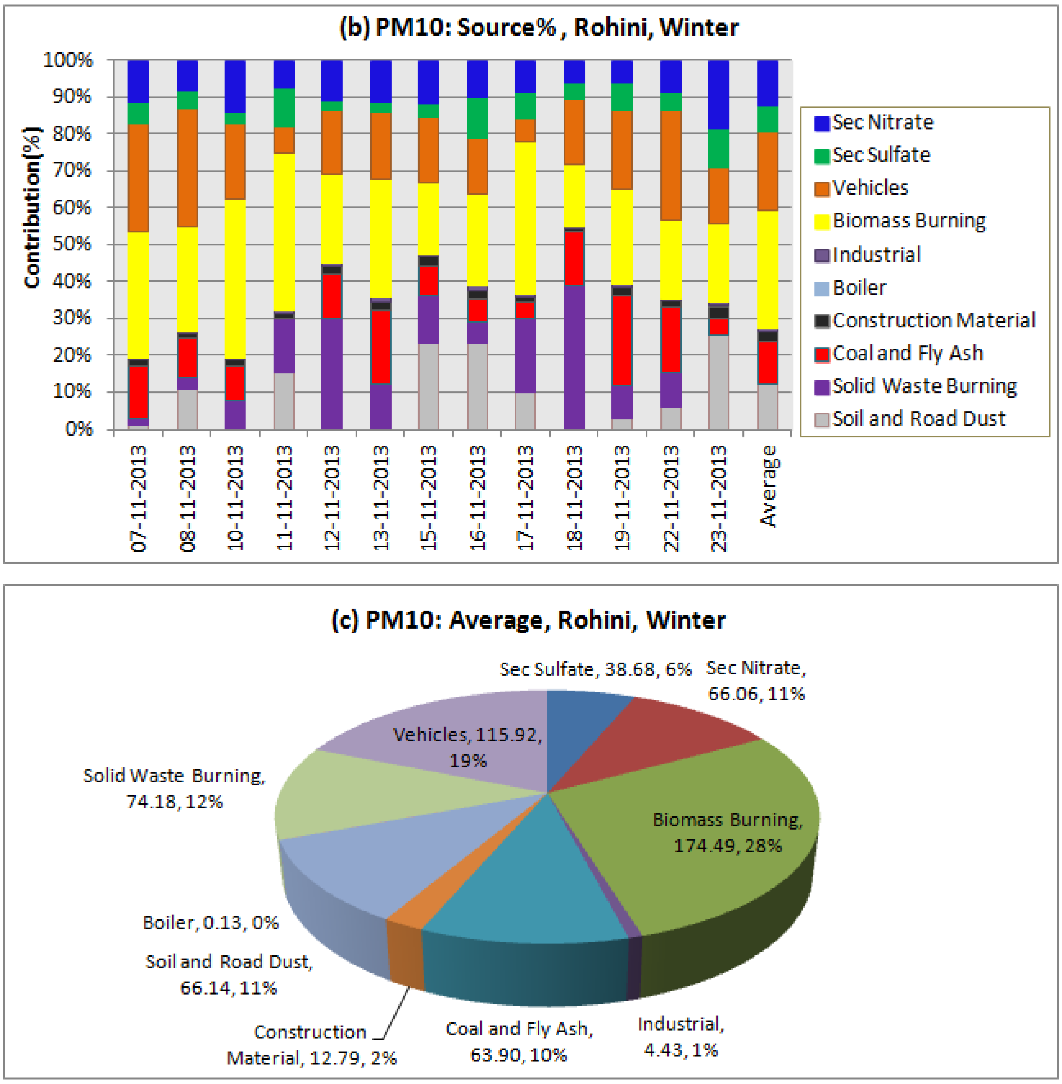
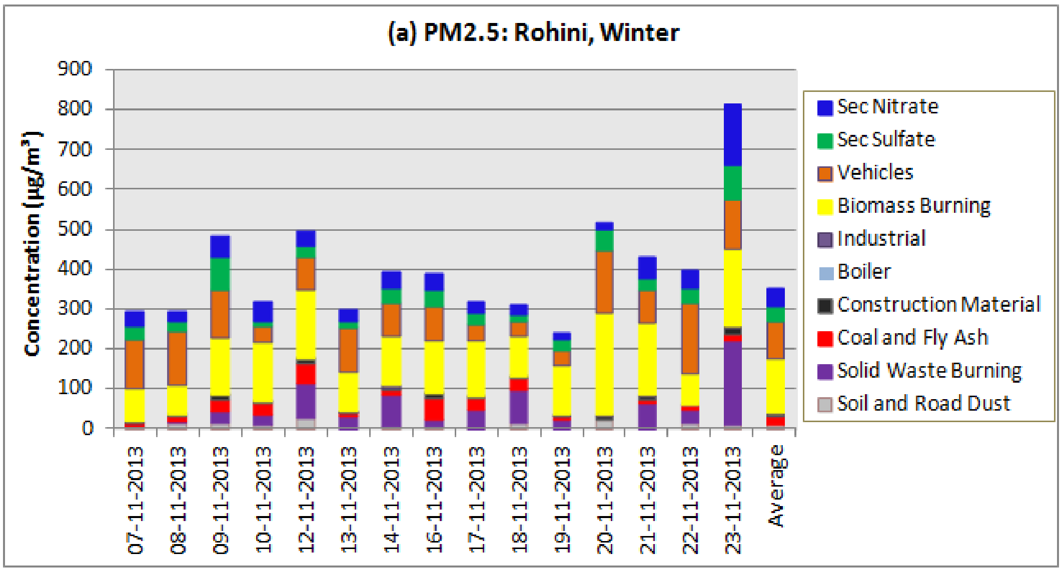


Figure 4.1: CMB Modeling for PM_{10} at RHN for Winter Season, 2013-14



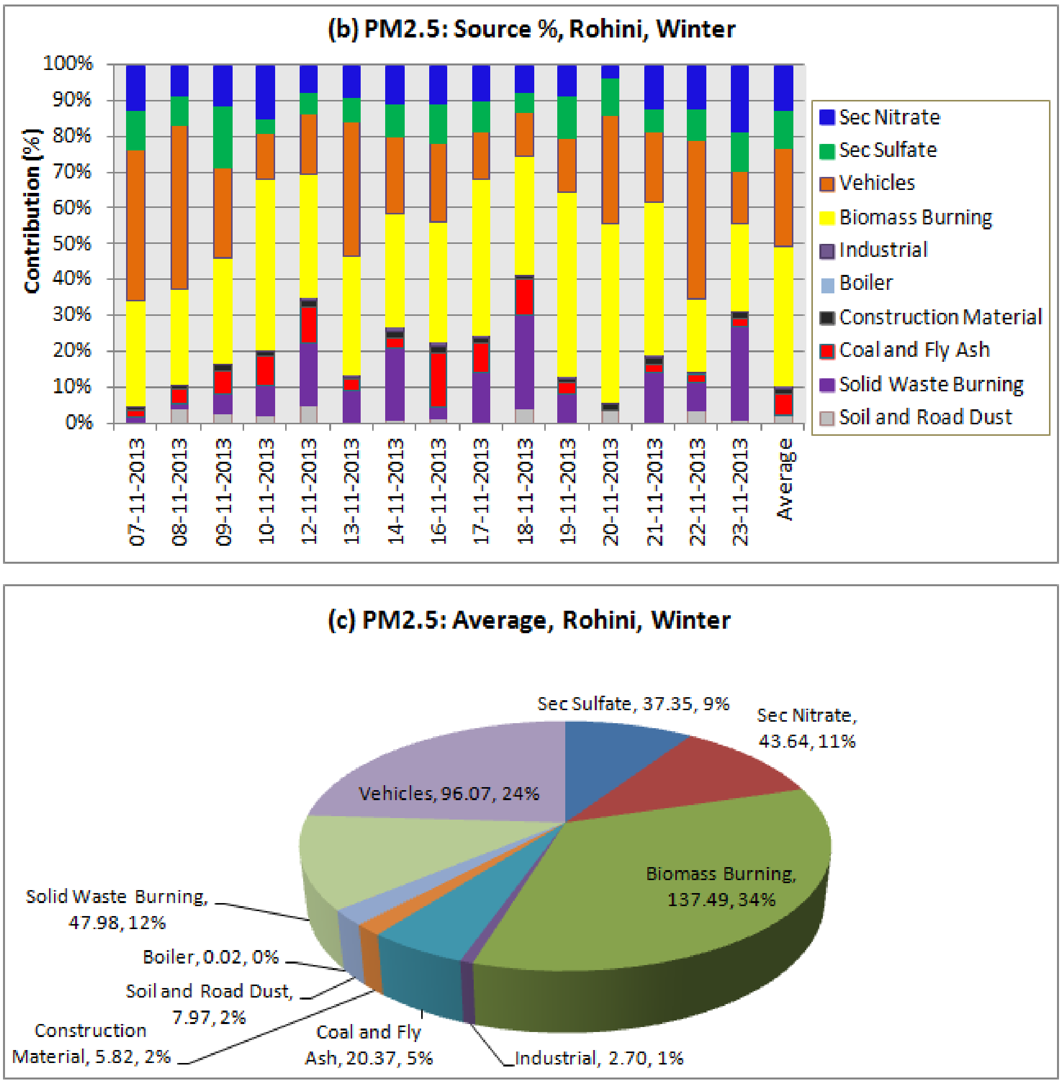


Figure 4.2: CMB Modeling for $PM_{2.5}$ at RHN for Winter Season, 2013-14

Table 4.1: Statistical Summary: RHN, Winter Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	592.56	616.71	104.97	0.67	428.45	399.41	92.82	0.66
StdDev	185.43	177.64	8.75	0.07	119.09	142.16	14.57	0.04
CoV	0.31	0.29	0.08	0.10	0.28	0.36	0.16	0.06
Maximum	1043.39	1015.34	123.90	0.75	733.83	813.54	122.10	0.71
Minimum	362.54	413.60	94.10	0.53	261.34	241.52	78.30	0.57

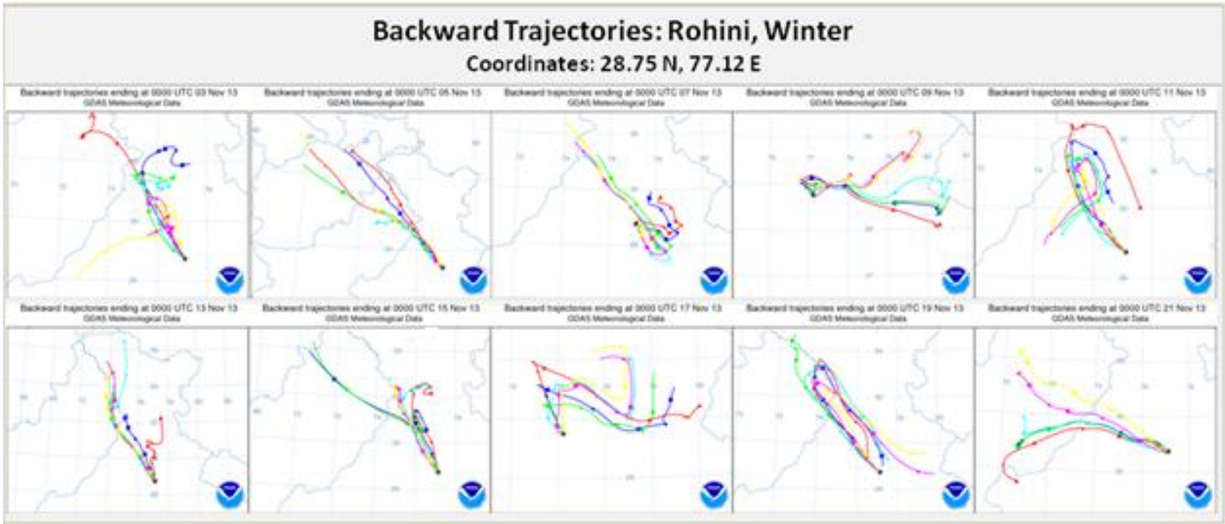


Figure 4.3: Backward trajectories at RHN for Winter Season

4.3.1.2 Summer Season RHN: [sampling period: April 04 – April 23, 2014]

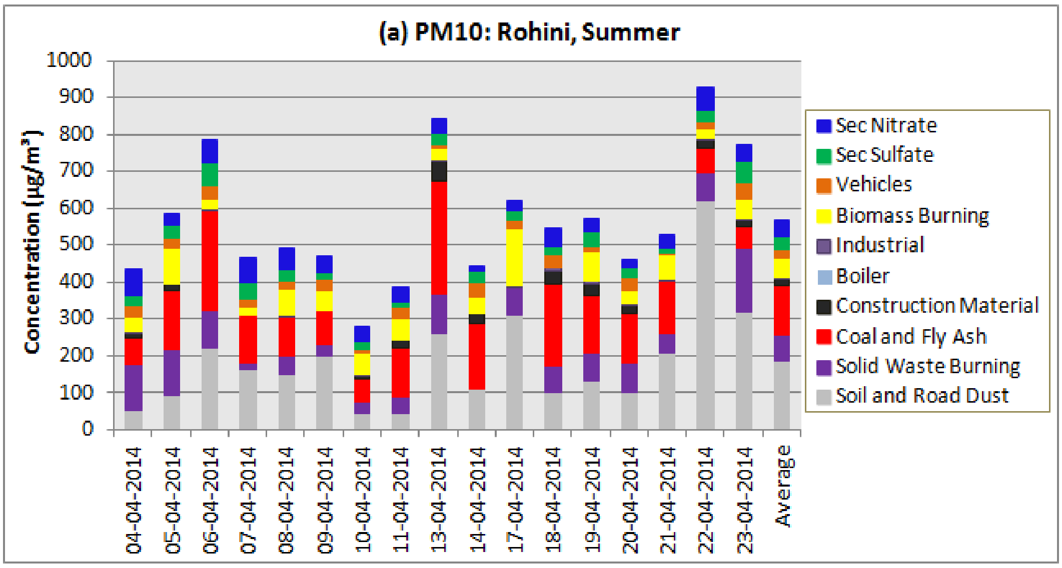
PM_{10} (summer)

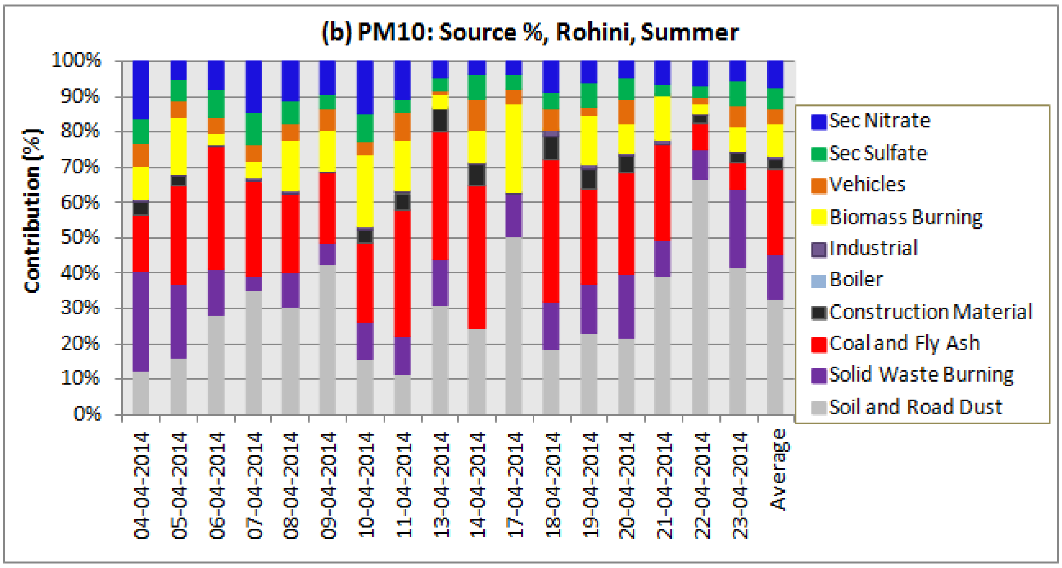
The average PM_{10} concentration was 545µg/m^3. Figure 4.4 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at RHN. Table 4.2 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (183 µg/m^3 ~ 33%) followed by coal and fly ash (134 µg/m^3 ~ 24%) in PM_{10}. Other significant sources are secondary particle formation (76 µg/m^3 ~ 14%), solid waste burning (73 µg/m^3 ~ 13%), biomass burning (9%), and vehicular emission (4%) in PM_{10}. Contribution of the industrial emission was estimated less than 1 % in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 337 µg/m^3; the $PM_{2.5}/PM_{10}$ ratio is about 0.6. Figure 4.5 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at RHN. It is observed that the major source contributing in $PM_{2.5}$ was soil and road dust (80 µg/m^3 ~ 24%) followed by biomass burning (64 µg/m^3 ~ 19%). Other major sources are coal and fly ash (60 µg/m^3 ~ 18%), secondary particle formation (55 µg/m^3 ~ 17%), solid waste burning (11%) and vehicular emission (7%). Contribution of the industrial emission was estimated less than 1 % in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.6) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from tall emitting sources.





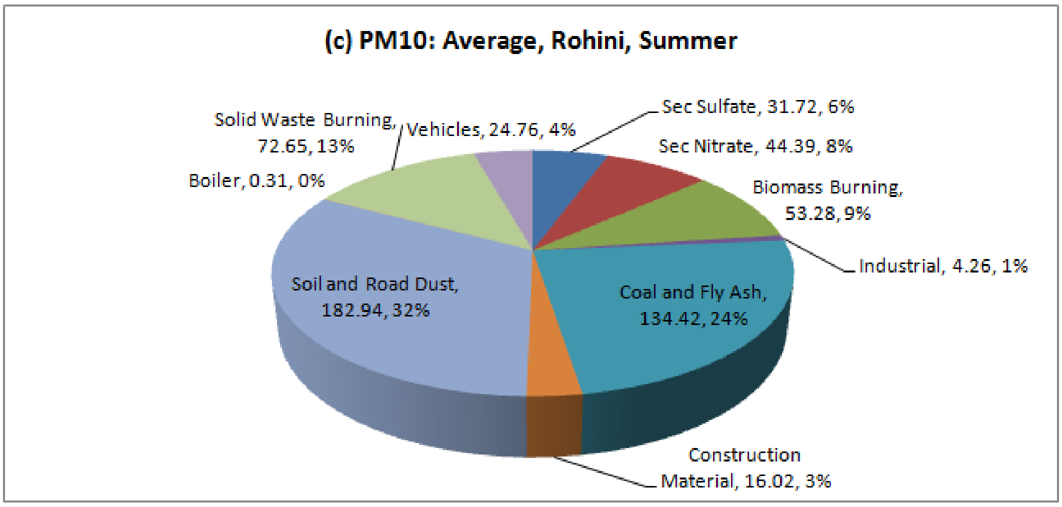


Figure 4.4: CMB Modeling for PM_{10} at RHN for Summer Season, 2014

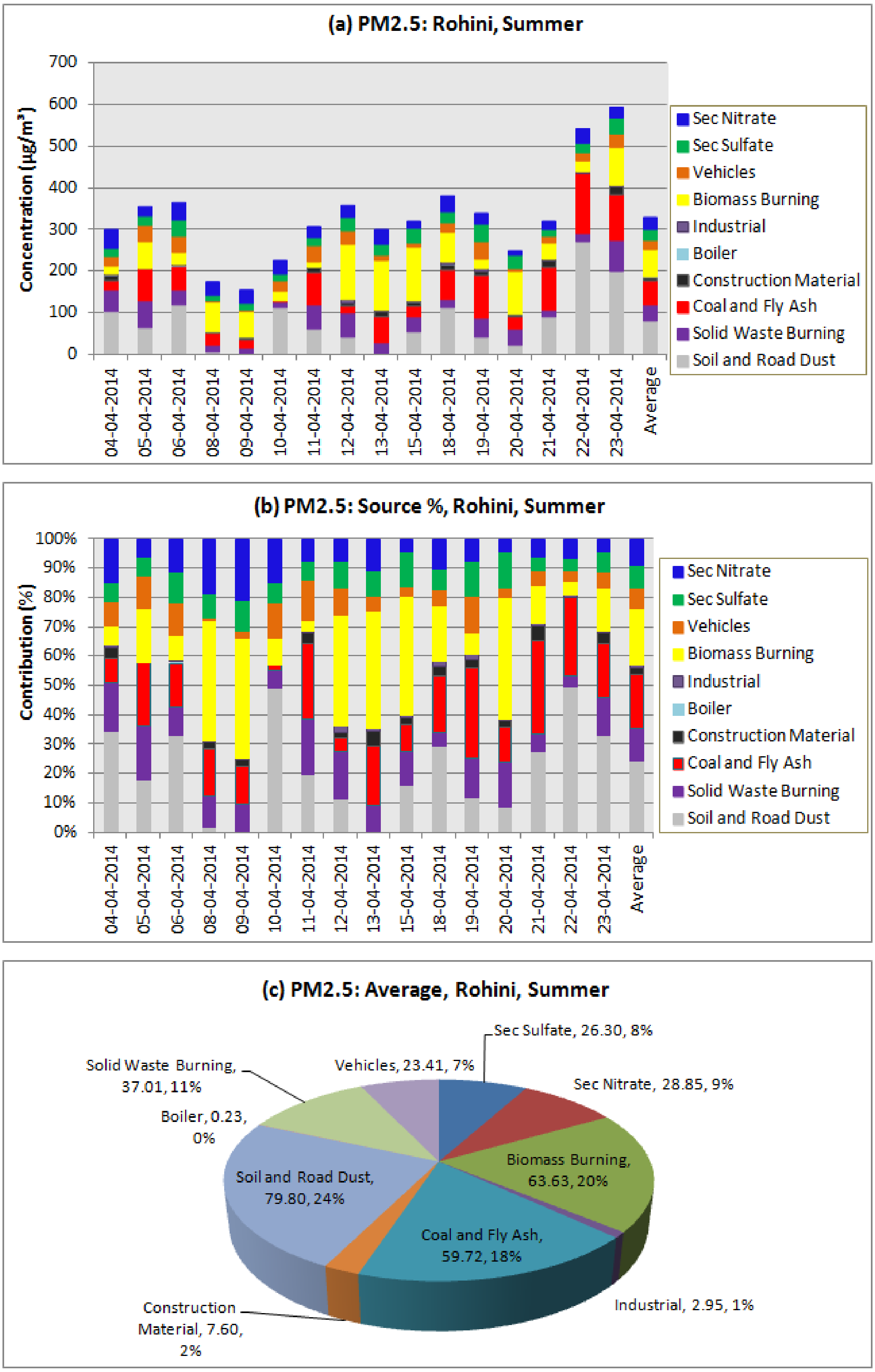


Figure 4.5: CMB Modeling for $PM_{2.5}$ at RHN for Summer Season, 2014

Table 4.2: Statistical Summary: RHN, Summer Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	544.71	562.23	104.24	0.67	337.16	329.52	97.98	0.68
StdDev	178.82	177.20	10.87	0.06	114.34	114.61	12.43	0.05
CoV	0.33	0.32	0.10	0.09	0.34	0.35	0.13	0.08
Maximum	927.90	928.68	123.80	0.77	598.44	595.52	122.60	0.77
Minimum	274.78	279.63	75.10	0.58	169.54	154.83	71.70	0.60

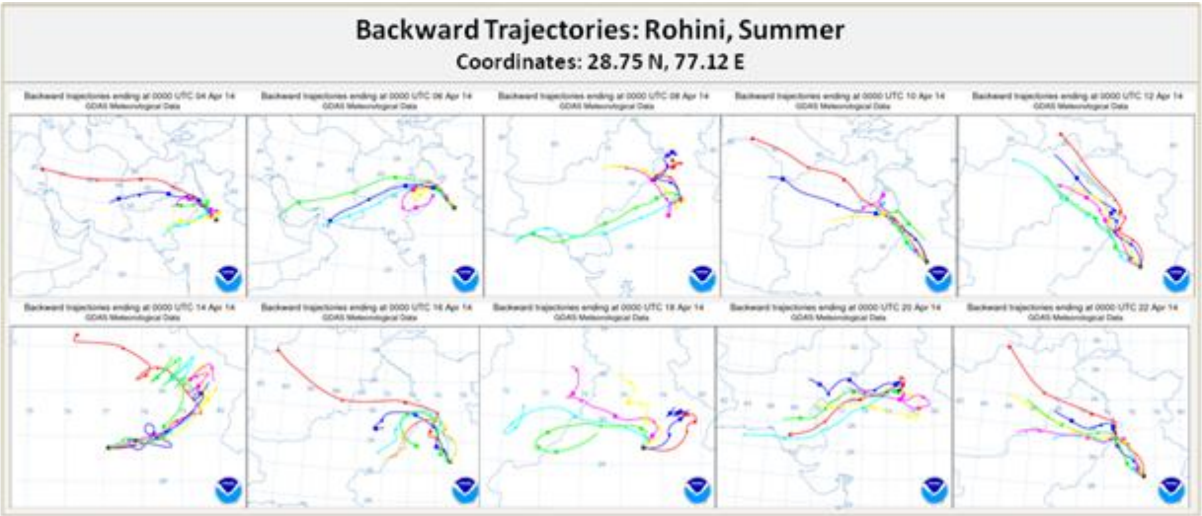


Figure 4.6: Backward trajectories at RHN for Summer Season

Inferences

The major sources contributing to PM_{10} and $PM_{2.5}$ have dramatically changed. Coal flyash, road and soil dust 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 fly ash and 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 fly and road/soil dust resuspension.

4.3.2 Envirotech, Okhla (OKH)

4.3.2.1 Winter Season [sampling period: November 03- November 23, 2013]

At this site, three days, November 3-5, 2013, which indicated impact of Diwali fire crackers are not included here and dealt separately.

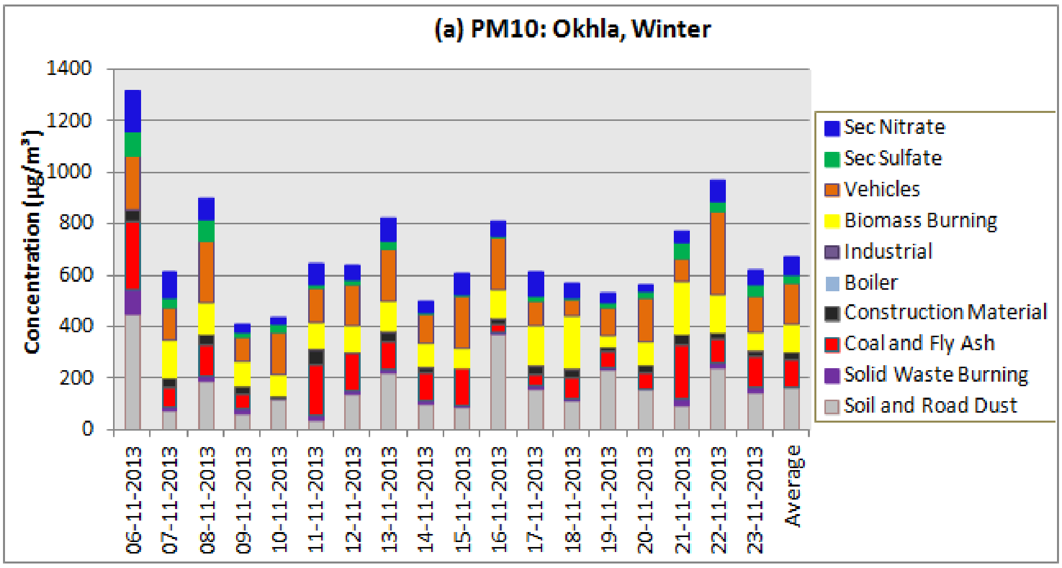
PM_{10} (winter)

The average PM_{10} concentration was 697µg/m^3. Figure 4.7 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at OKH. Table 4.3 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (164 µg/m^3 ~ 24%) followed by vehicular emission (158 µg/m^3 ~ 23%) in PM_{10}. The other major sources are biomass burning (109 µg/m^3 ~ 16%), coal and flyash (108 µg/m^3 ~ 16%), secondary particle formation (14%), construction material (4%) and Solid waste burning (2.2%) in PM_{10}. Contribution of the industrial emission was estimated less than 1% in PM_{10}.

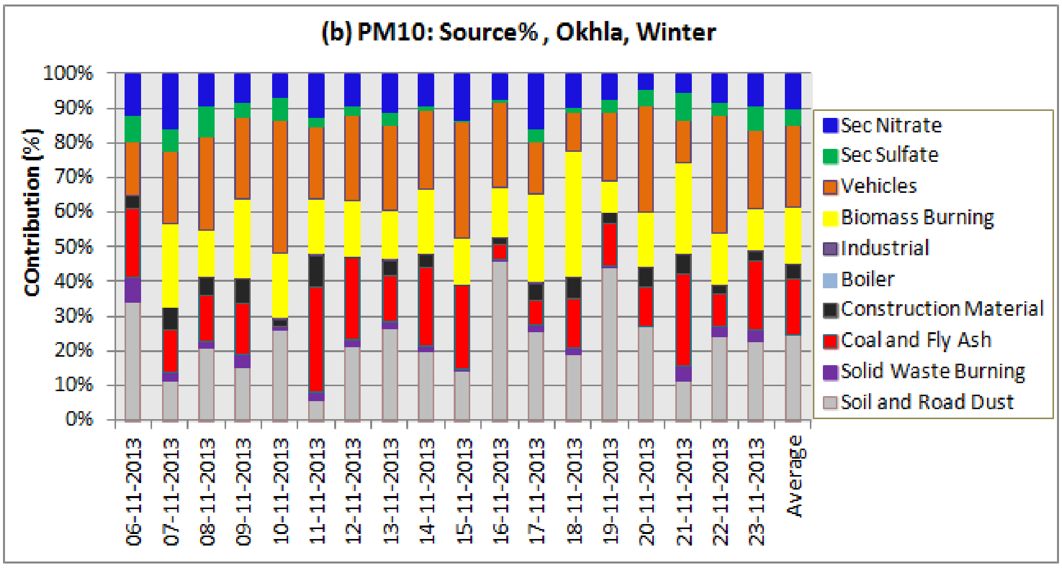
$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 412 µg/m^3. Figure 4.8 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at OKH. It is observed that the major source contributing in $PM_{2.5}$ was vehicular emission (109 µg/m^3 ~ 29%) followed by biomass burning (108 µg/m^3 ~ 29%). Other predominant sources are secondary particle formation (76 µg/m^3 ~ 20%), coal and fly ash (39 µg/m^3 ~ 10%), soil and road dust (7%) and solid waste burning (3%). Contribution of the industrial emission was estimated less than 1% in $PM_{2.5}$.

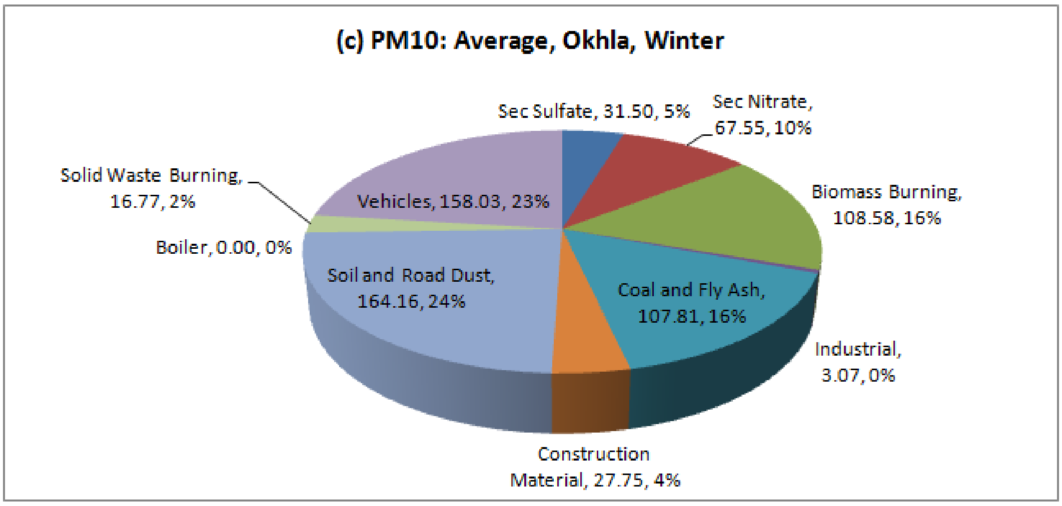
HYSPLIT back trajectories (Figure 4.9) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana States before entering in Delhi. These winds pick up the pollutants on the way especially from large (e.g. crop residue burning (CRB)) and tall emitting sources.



(a) PM10: Okhla, Winter



(b) PM10: Source% , Okhla, Winter



(c) PM10: Average, Okhla, Winter

Figure 4.7: CMB Modeling for PM_{10} at OKH for Winter Season, 2013-14

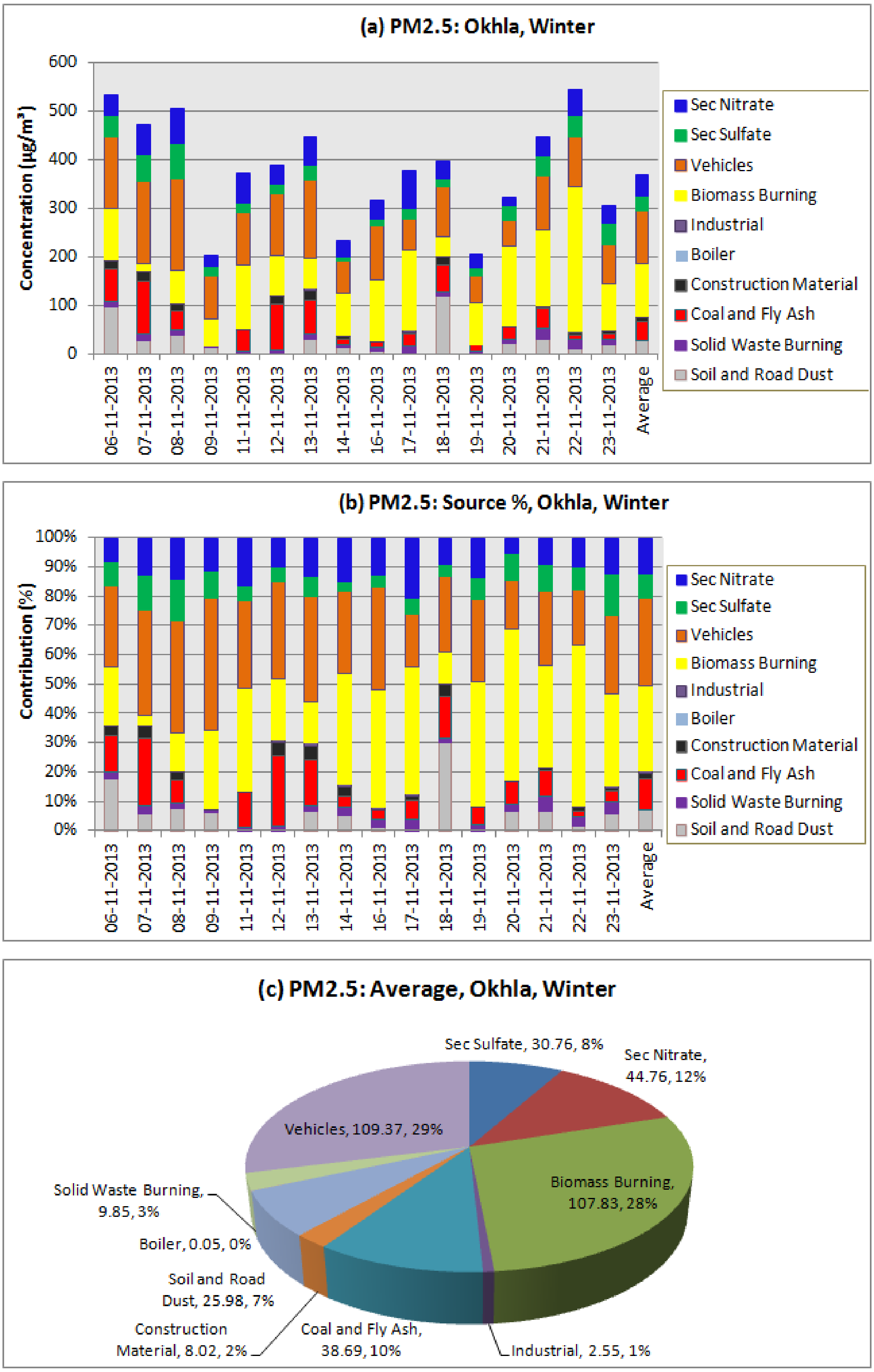


Figure 4.8: CMB Modeling for $PM_{2.5}$ at OKH for Winter Season, 2013-14

Table 4.3: Statistical Summary: OKH, Winter Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R²	Measured	Calculated	% Mass	R²
Average	696.86	685.21	98.27	0.75	412.40	377.87	91.69	0.74
StdDev	209.92	219.97	7.77	0.06	116.87	109.93	12.93	0.06
CoV	0.30	0.32	0.08	0.08	0.28	0.29	0.14	0.08
Maximum	1254.51	1320.92	111.10	0.84	681.65	542.56	114.50	0.82
Minimum	408.42	408.23	78.50	0.65	240.29	201.46	73.20	0.62

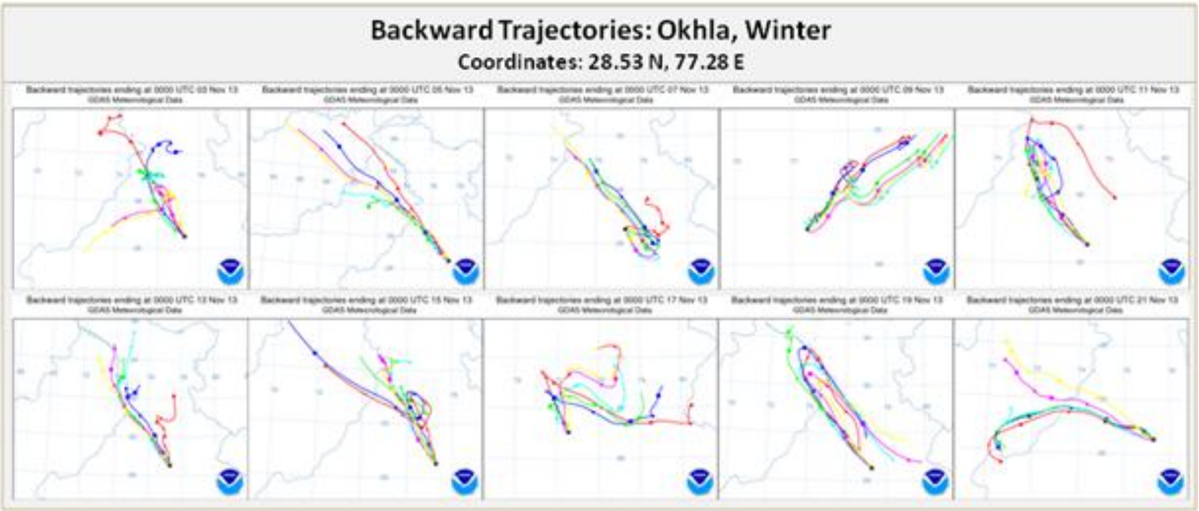


Figure 4.9: Backward trajectories at OKH for winter Season

Inferences

For PM_{10}, soil dust, road dust and vehicles contribute about equally at about 24 and 23 percent followed by biomass burning followed by biomass burning and coal and flyash. For $PM_{2.5}$, soil and road dust contributions reduces dramatically to about 7% (from 24% in PM_{10}) and vehicles and biomass burning contribution increases to about 29%.

4.3.2.2 Summer Season OKH [sampling period: April 04-24, 2014]

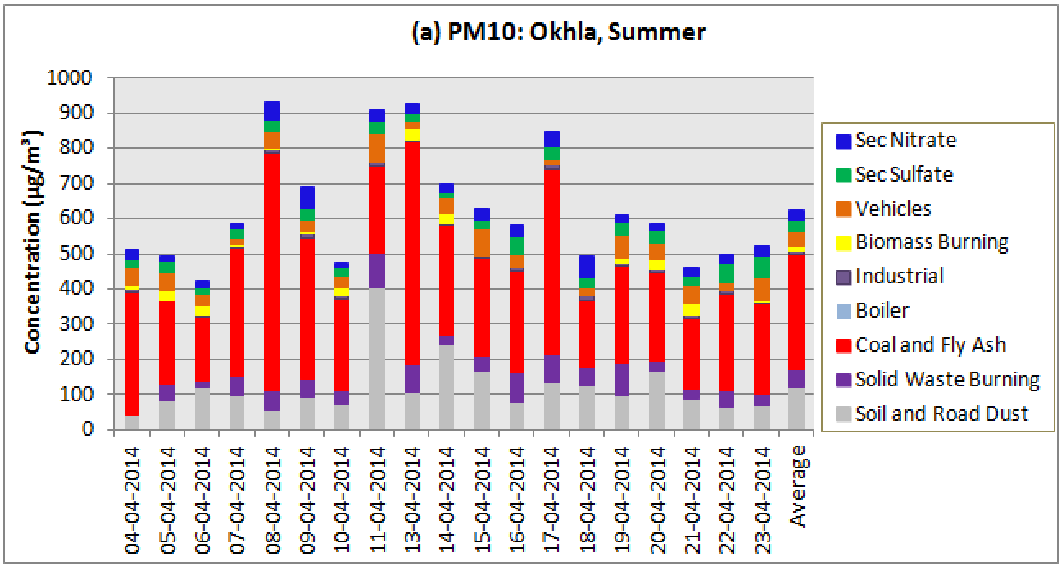
PM_{10} (summer)

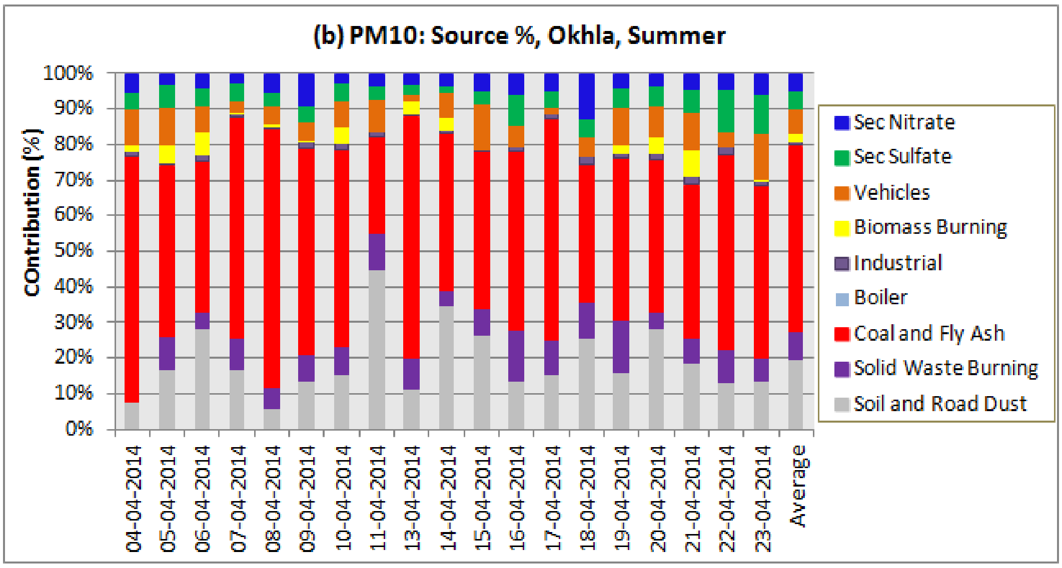
The average PM_{10} concentration was 632 µg/m^3. Figure 4.10 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at OKH. Table 4.4 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was coal and flyash (327 µg/m^3 ~ 50%) followed by soil and road dust (122 µg/m^3 ~ 19%) in PM_{10}. The other significant sources are secondary particle formation (63 µg/m^3 ~ 10%), solid waste burning (50 µg/m^3 ~ 8%), vehicular emission (7%) and biomass burning (2%). Contribution of the industrial emission was estimated less than 2% in PM$_{10}$.

PM$_{2.5}$ (summer)

The average PM$_{2.5}$ concentration was 410 µg/m^3; the ratio of PM$_{2.5}$/PM$_{10}$ is about 0.57. Figure 4.11 (a), (b), (c) represents PM$_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at OKH. It is observed that the major source contributing in PM$_{2.5}$ was soil and road dust (139 µg/m^3 ~ 36%) followed by coal and fly ash (110 µg/m^3 ~ 29%). Other significant sources are secondary particle formation (54 µg/m^3 ~ 14%), vehicular emission (31 µg/m^3 ~ 8%), solid waste burning (7%) and biomass burning (3%). Contribution of the industrial emission was estimated less than 2% in PM$_{2.5}$.

HYSPLIT back trajectories (Figure 4.12) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large (e.g. crop residue burning (CRB)) and tall emitting sources.





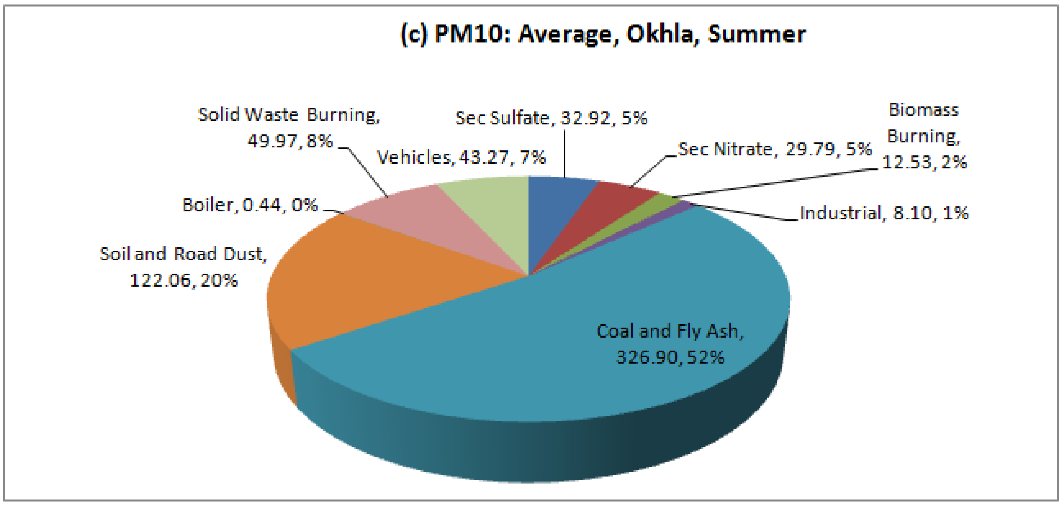
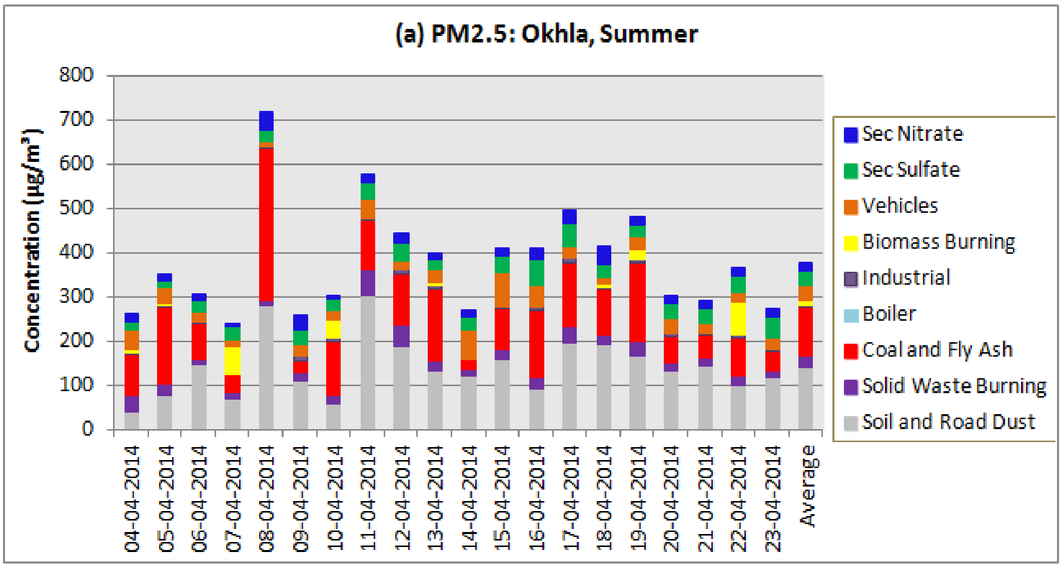


Figure 4.10: CMB Modeling for PM$_{10}$ at OKH for Summer Season, 2014



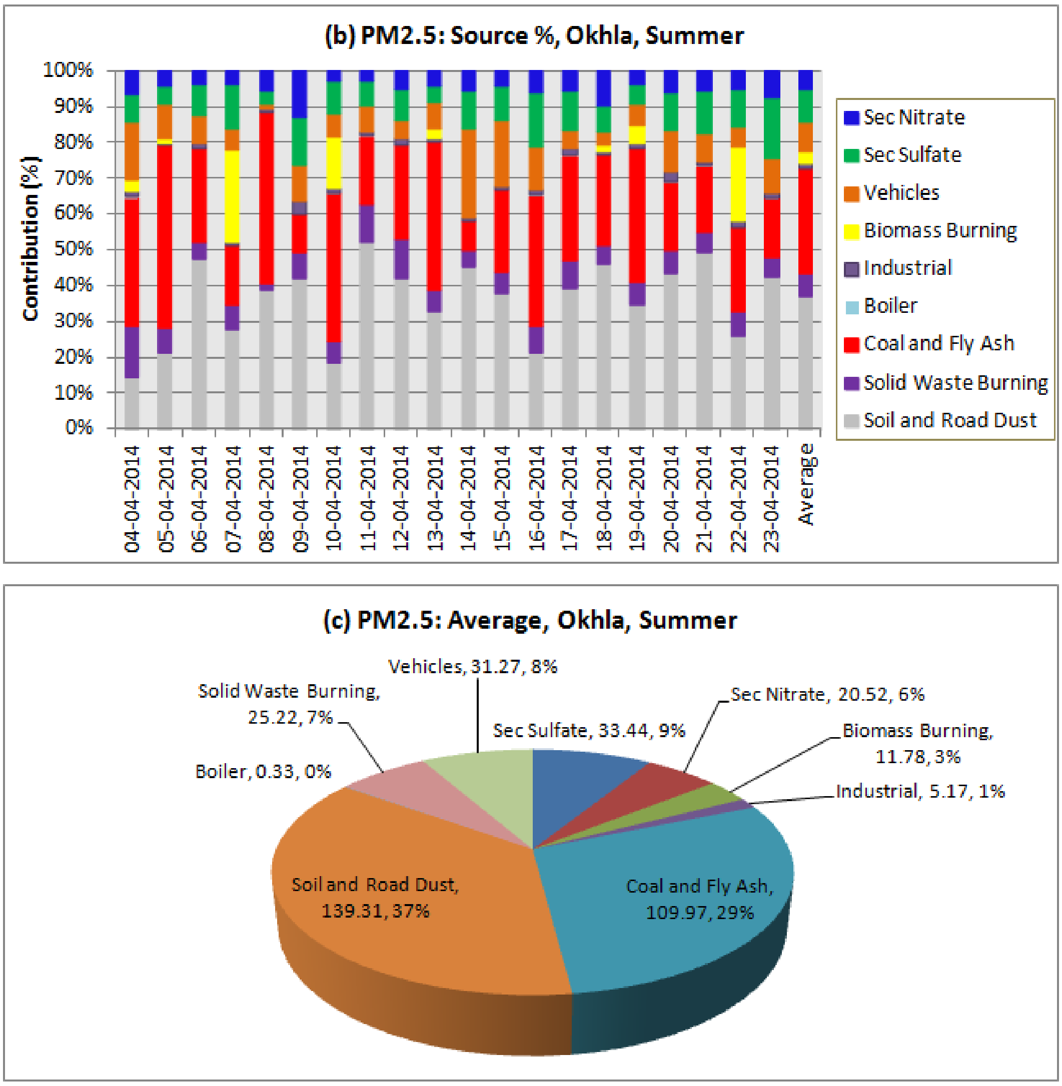


Figure 4.11: CMB Modeling for $PM_{2.5}$ at OKH for Summer Season, 2014

Table 4.4: Statistical Summary: OKH, Summer Season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	632.43	648.72	103.30	0.68	410.02	383.83	93.51	0.70
StdDev	170.45	168.00	8.92	0.06	119.36	126.62	12.07	0.05
CoV	0.27	0.26	0.09	0.08	0.29	0.33	0.13	0.07
Maximum	954.75	936.80	122.10	0.74	704.02	726.17	120.70	0.78
Minimum	373.84	456.45	86.50	0.51	232.02	240.79	70.20	0.61

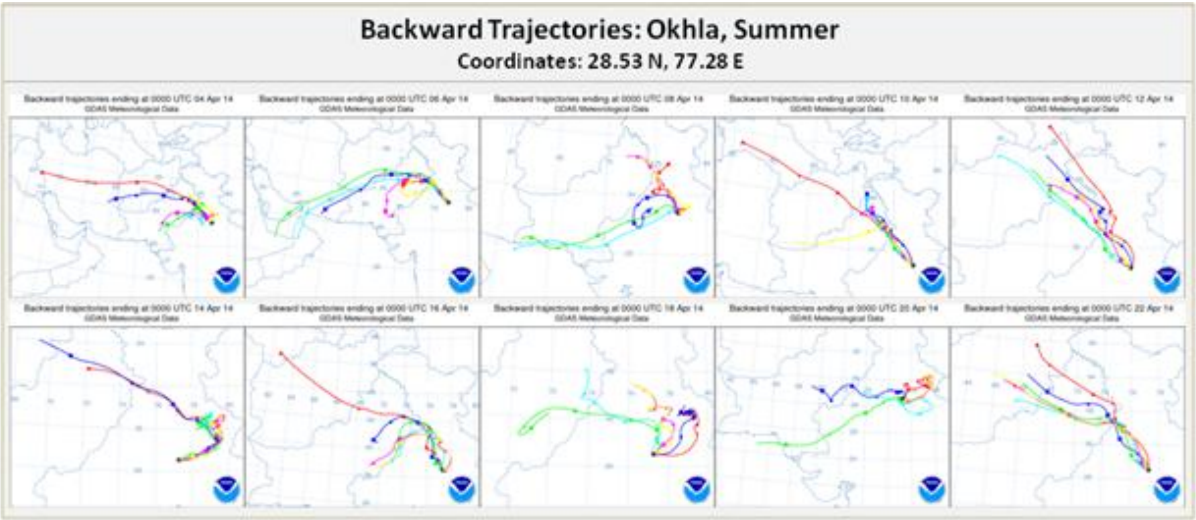


Figure 4.12: Backward trajectories at OKH for Summer Season

Inference

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 and tandoors were seen in ever by lane. Coal and fly ash is 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 $PM_{2.5}$.

4.3.3 DAV School, Dwarka (DWK)

4.3.3.1 Winter Season (DWK) [sampling period: December 02- December 22, 2013]

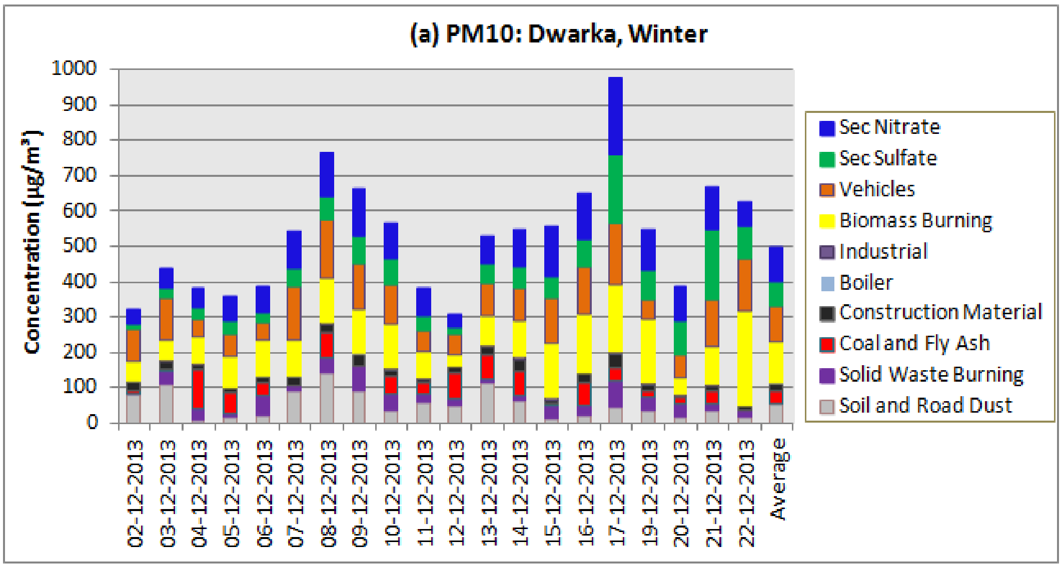
PM_{10} (winter)

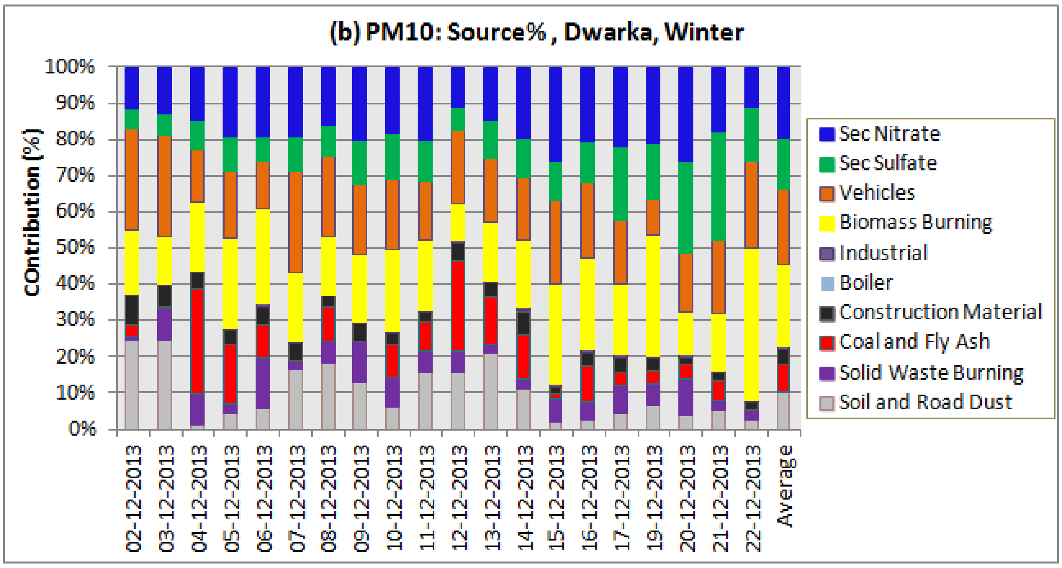
The average PM_{10} concentration was 544 µg/m^3. Figure 4.13 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DWK. Table 4.5 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was secondary particle formation (167 µg/m^3 ~ 32%) followed by biomass burning (113 µg/m^3 ~ 21%). The other significant contributing sources are vehicular emission (105 µg/m^3 ~ 20%), soil and road dust (52 µg/m^3 ~ 10%), coal and flyash (7%), solid waste burning (6%) and construction material (4%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 339 µg/m^3. Figure 4.14 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DWK. It is observed that the major source contributing in $PM_{2.5}$ was secondary particle formation (118 µg/m^3 ~ 38%) followed by biomass burning (92 µg/m^3 ~ 30%). Other major sources are vehicular emission (59 µg/m^3 ~ 19%), solid waste burning (15 µg/m^3 ~ 5%), and coal and fly ash (4%). Contributions of minor sources are soil and road dust (3%), construction material (2%). Contribution of the industrial emission was estimated to be less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.15) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.





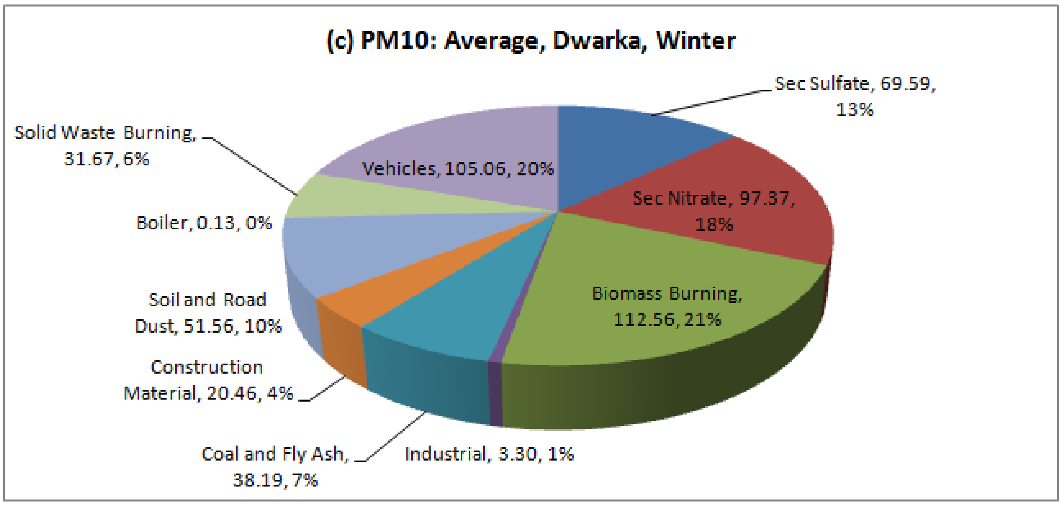
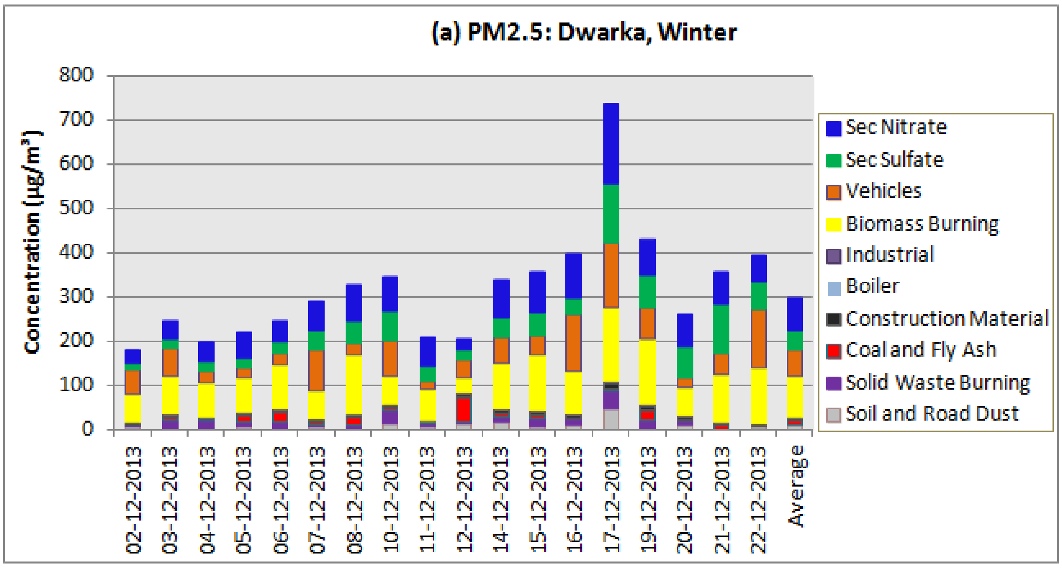


Figure 4.13: CMB Modeling for PM_{10} at DWK Winter Season, 2013-14



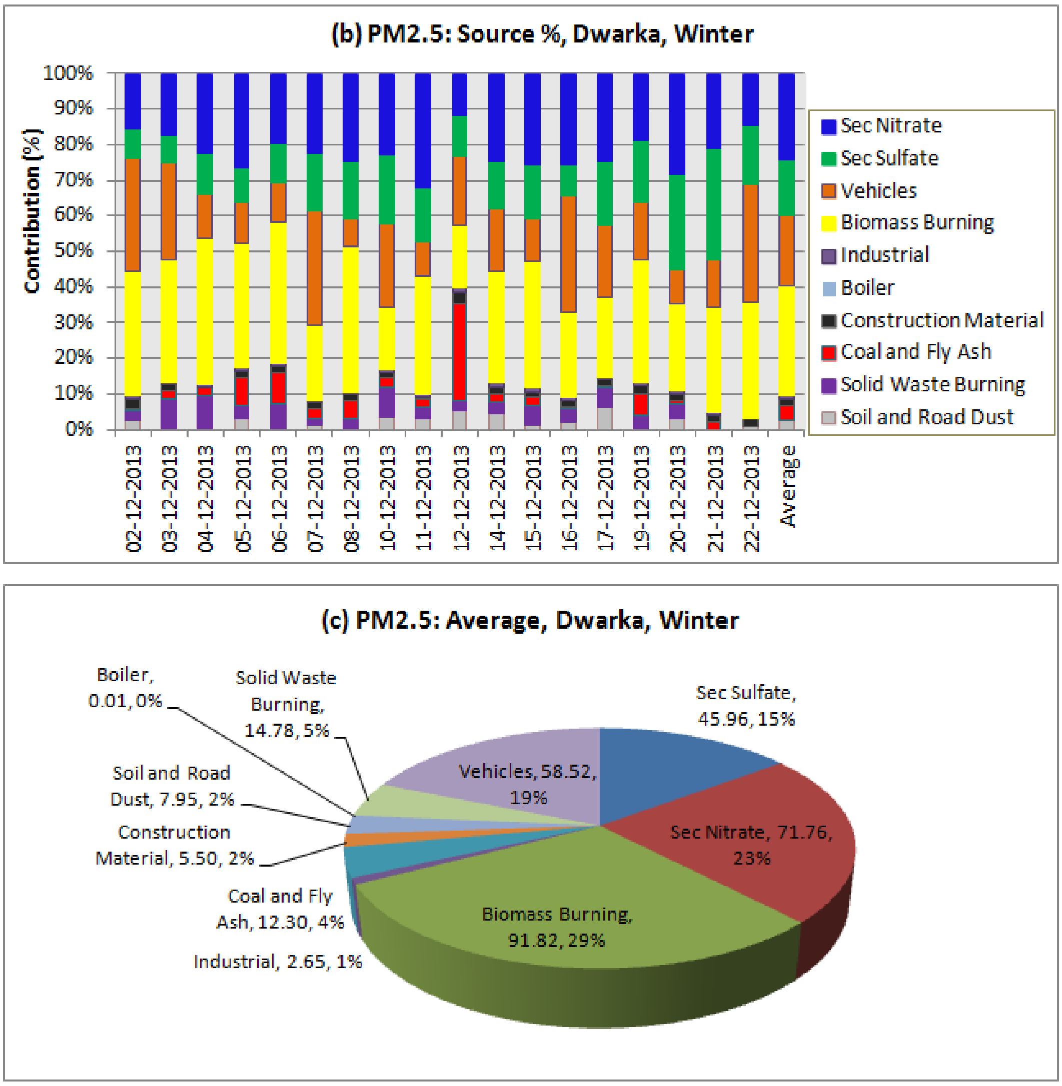


Figure 4.14: CMB Modeling for $PM_{2.5}$ at DWK, Winter Season, 2013-14

Table 4.5: Statistical Summary: DWK, Winter Season

	PM_{10}				**$PM_{2.5}$**			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	543.85	529.89	97.83	0.64	339.46	311.25	93.18	0.62
StdDev	174.49	168.36	7.70	0.05	156.92	137.13	12.47	0.05
CoV	0.32	0.32	0.08	0.07	0.46	0.44	0.13	0.08
Maximum	981.39	978.12	110.90	0.72	825.90	738.25	117.10	0.70
Minimum	321.00	305.63	85.60	0.51	202.27	177.42	77.90	0.54

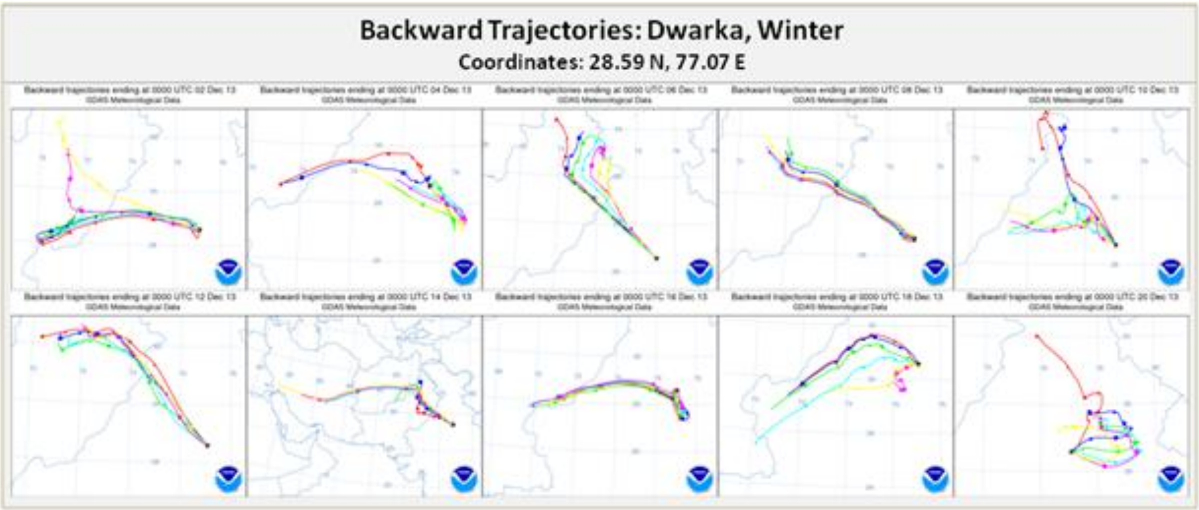


Figure 4.15: Backward trajectories at DWK for Winter Season

Inferences

Secondary PM (31-38%) and biomass burning (21-29%) are the major sources followed by vehicular contribution (~20%) – 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 $PM_{2.5}$.

4.3.3.2 Summer Season: [sampling period: May 01- May 24, 2014]

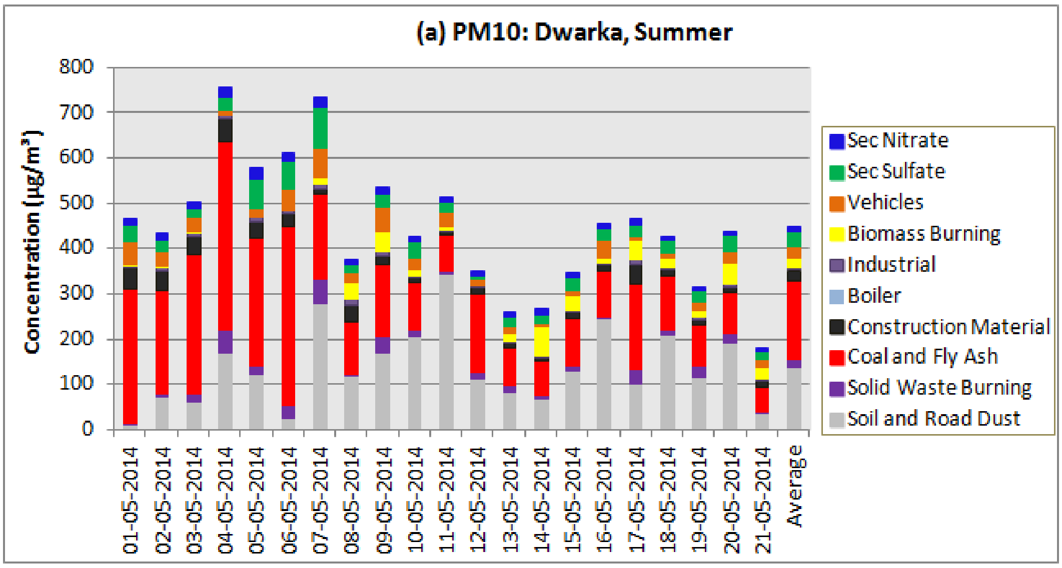
PM_{10} (summer)

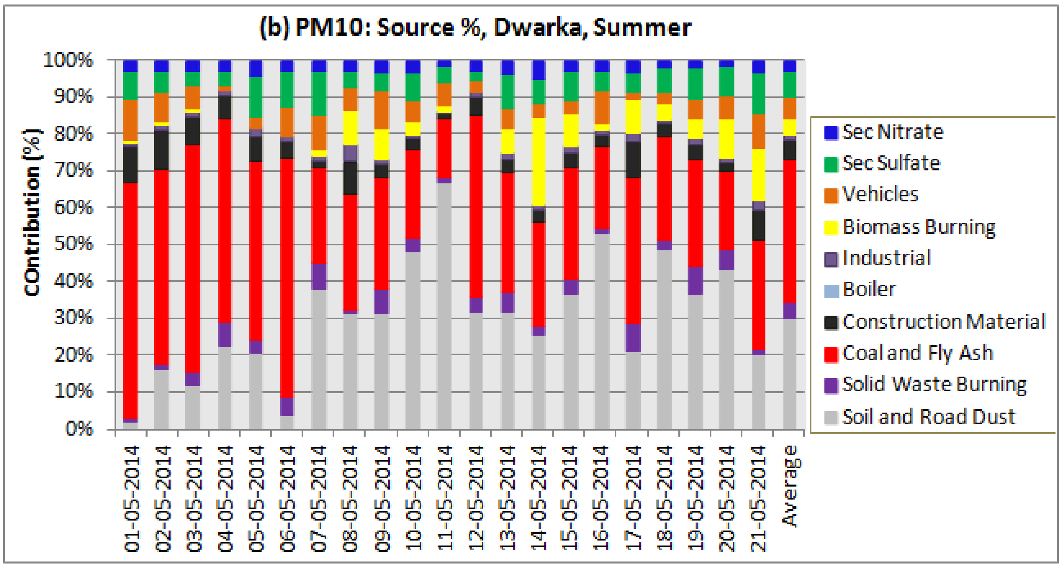
The average PM_{10} concentration was 458 µg/m^3. Figure 4.16 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DWK. Table 4.6 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was coal and flyash (174 µg/m^3 ~ 39%) followed by soil and road dust (135 µg/m^3 ~ 30%) in PM_{10}. The other significant sources are secondary particle formation (45 µg/m^3 ~ 10%), vehicular emission (27 µg/m^3 ~ 6%), construction material (5%), solid waste burning (4%) and biomass burning (4%). Contribution of the industrial emission was estimated less than 2% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 206 µg/m^3. Figure 4.17 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DWK. It is observed that the major source contributing in $PM_{2.5}$ was coal and flyash (69 µg/m^3 ~ 35%) followed by soil and road dust (52 µg/m^3 ~ 26%). Other significant sources are secondary particle formation (30 µg/m^3 ~ 15%), biomass burning (15 µg/m^3 ~ 7%), vehicular emission (6%), construction material (5%), solid waste burning (4%) and industrial emission (2%).

HYSPLIT back trajectories (Figure 4.18) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.





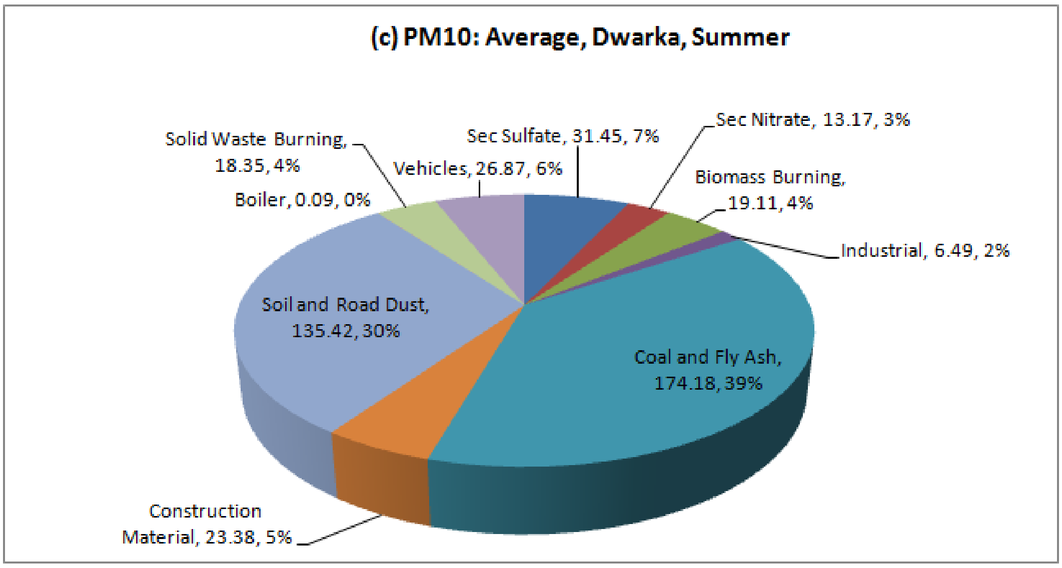
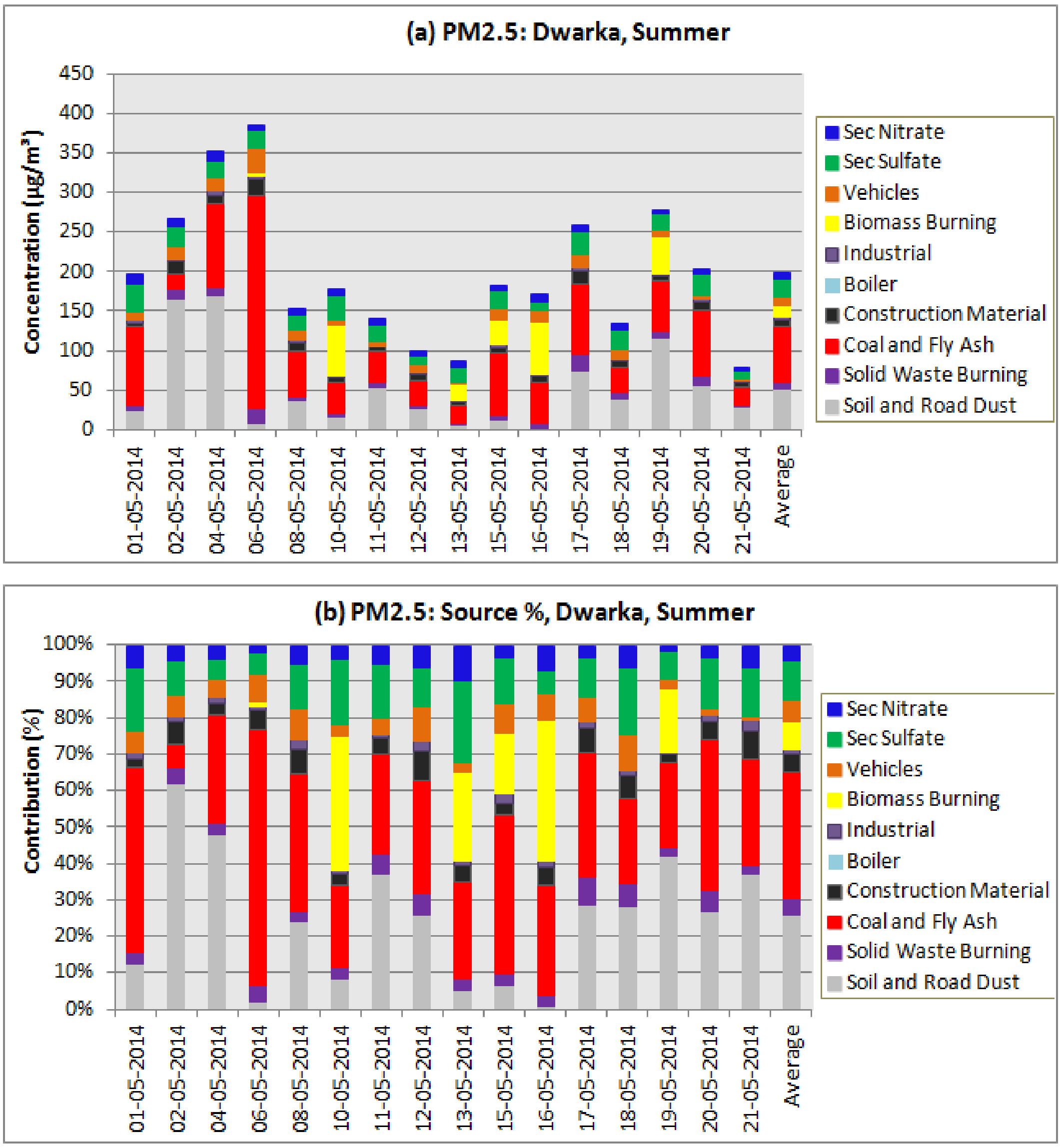


Figure 4.16: CMB Modeling for PM_{10} at DWK for Summer Season, 2014



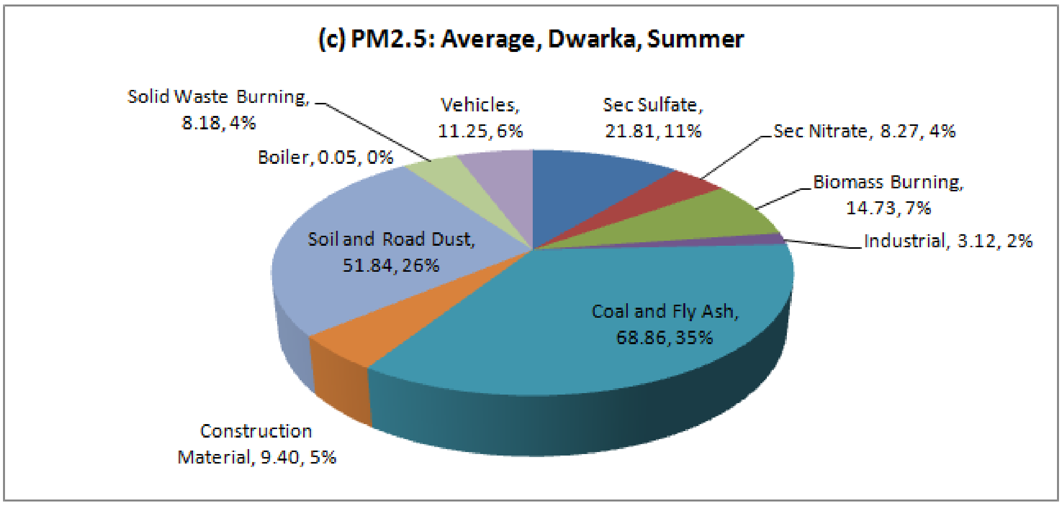


Figure 4.17: CMB Modeling for $PM_{2.5}$ at DWK for Summer Season, 2014

Table 4.6: Statistical Summary: DWK, Summer Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	457.63	448.51	98.21	0.68	205.62	197.50	96.03	0.68
StdDev	137.91	144.92	11.43	0.06	82.88	89.83	14.30	0.06
CoV	0.30	0.32	0.12	0.09	0.40	0.45	0.15	0.08
Maximum	722.94	756.02	116.20	0.76	356.06	385.38	124.00	0.77
Minimum	163.25	178.70	81.20	0.52	78.69	78.18	69.30	0.57

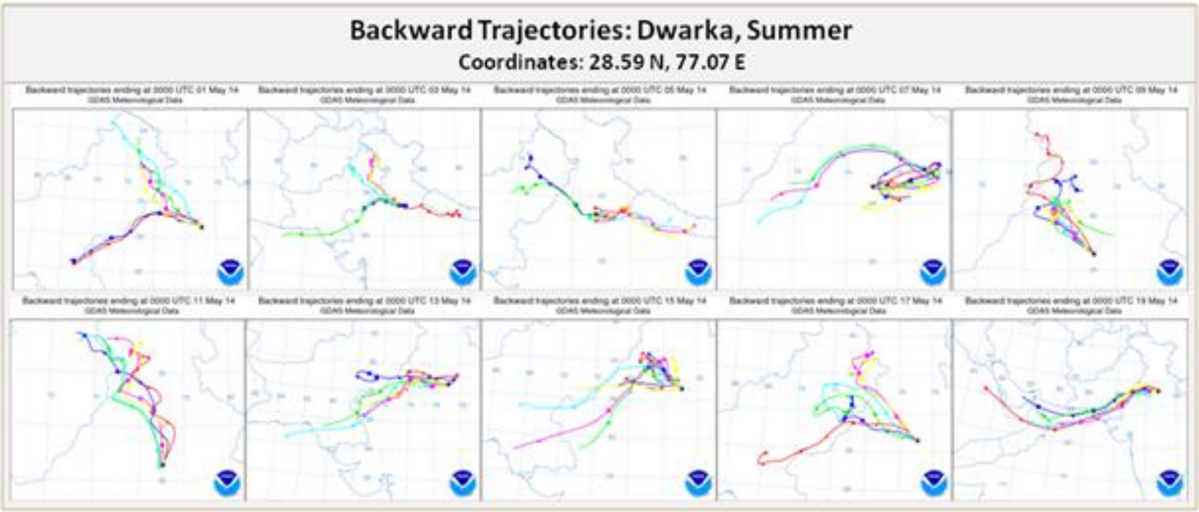


Figure 4.18: Backward trajectories at DWK for Summer Season

Inference

Coal and flyash, road and soil dusts are the major contributors in summer both for PM_{10} and $PM_{2.5}$, at the same time road side dust is prominent both in PM_{10} and $PM_{2.5}$.There was low vehicular density at this site. The station was located at a school point which had play round and it is possible that this site may represent the soil dust emitted from playground of the school.

4.3.4 Indian Spinal Injuries Centre, Vasantkunj (VKJ)

4.3.4.1 Winter Season [sampling period: December 15, 2013 - January 04, 2014]

PM_{10} (winter)

The average PM_{10} concentration was 555 µg/m^3. Figure 4.19 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKJ. Table 4.7 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was secondary particle (163 µg/m^3 ~ 32%) followed by vehicular emission (119 µg/m^3 ~ 24%). The other significant contributing sources are biomass burning (92 µg/m^3 ~ 18%), coal and flyash (43 µg/m^3 ~ 9%), soil and road dust (8%), solid waste burning (6%) and construction material (2.5%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 301µg/m^3; $PM_{2.5}$/PM_{10} ratio was 0.54. Figure 4.20 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKJ. It is observed that the major source contributing in $PM_{2.5}$ was secondary particle formation (92 µg/m^3 ~ 34%) followed by biomass burning (80 µg/m^3 ~ 29%). Other major sources are vehicular emission (76 µg/m^3 ~ 28%) and solid waste burning (13 µg/m^3 ~ 5%). The minor source are coal and flyash (1.5%), soil and road dust (1.3%), construction material (<1%) and industrial emission (<1%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.21) show that wind is not stable in any particular direction and wind mass travel over to neighboring states (i.e Haryana, Uttar Pradesh and Rajasthan) before entering into Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.

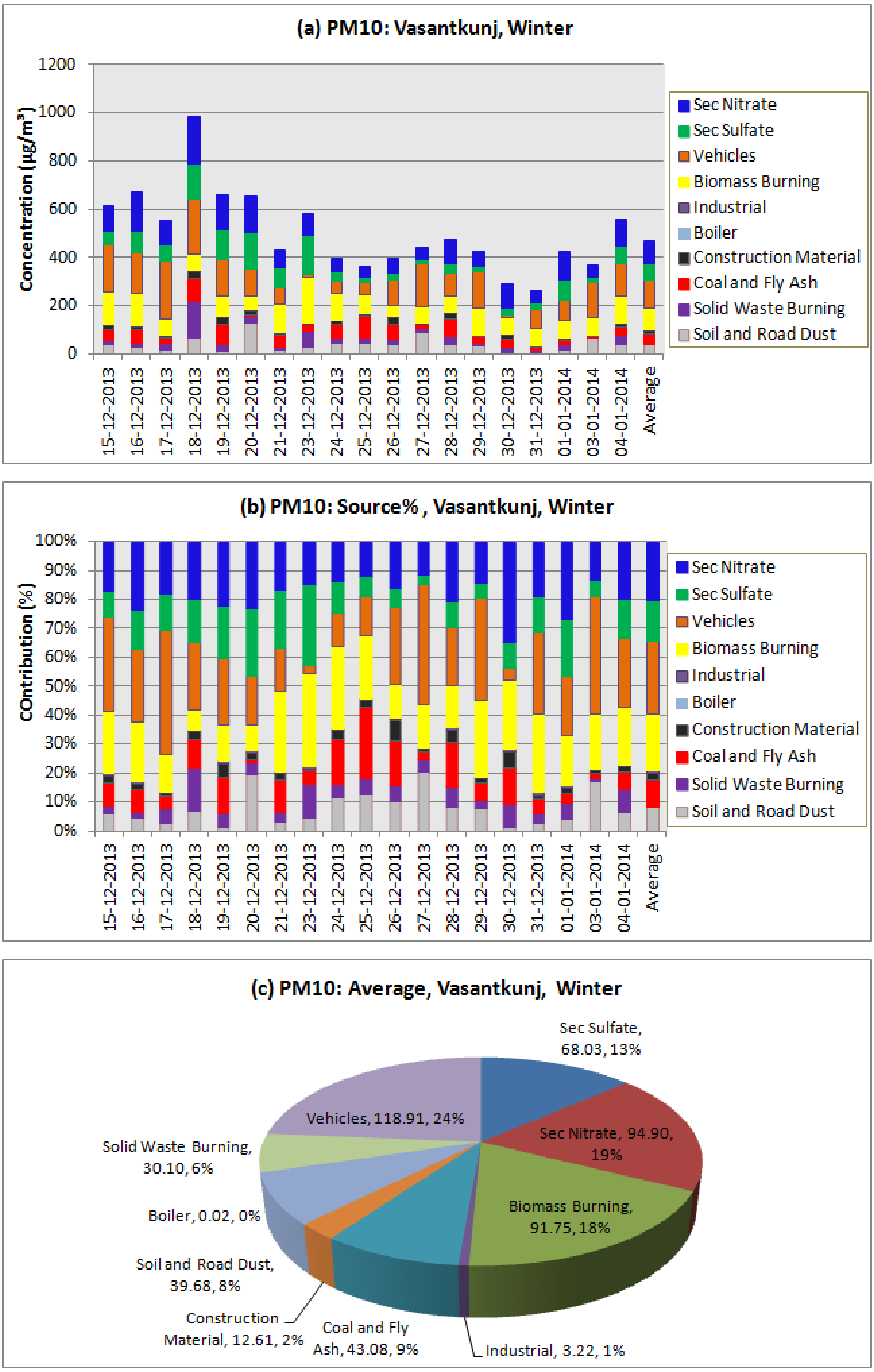
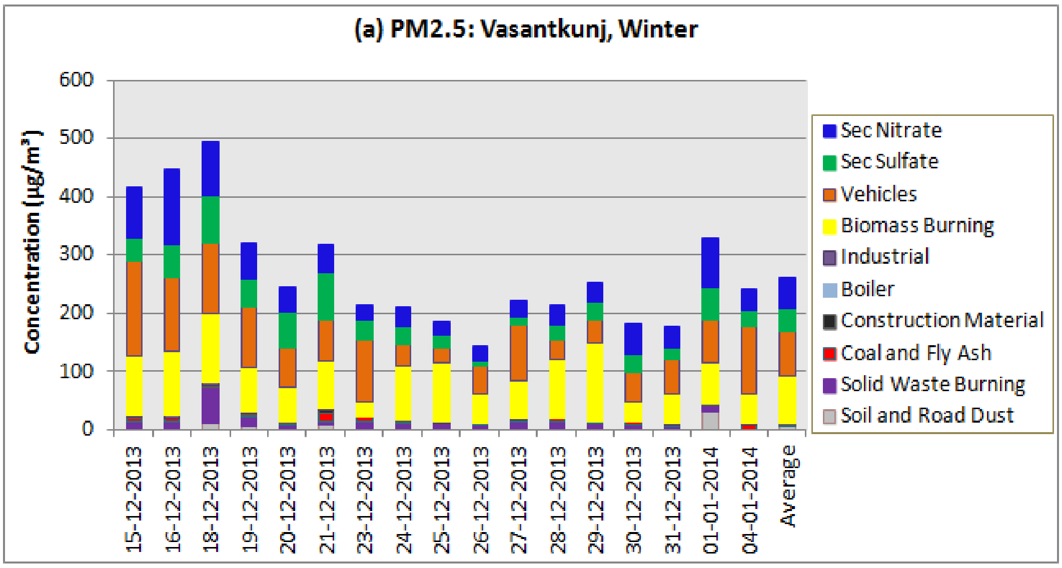
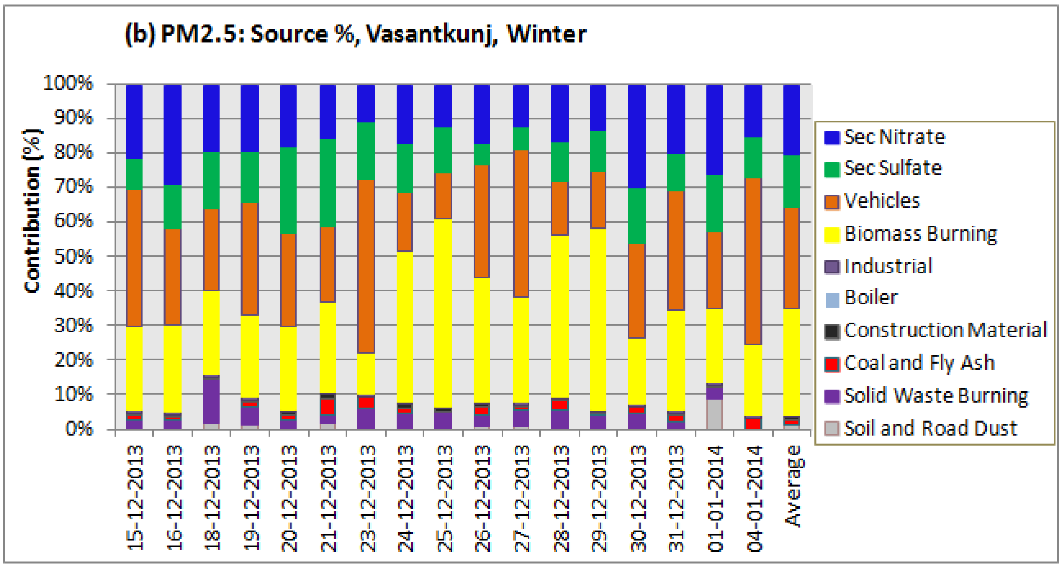


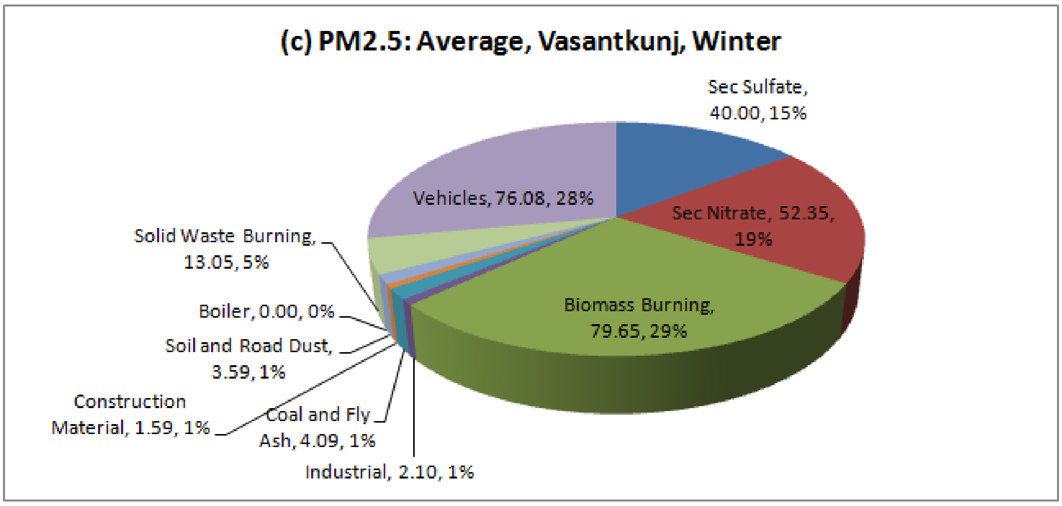
Figure 4.19: CMB Modeling for PM_{10} at VKJ for Winter Season, 2013-14



(a) PM2.5: Vasantkunj, Winter



(b) PM2.5: Source %, Vasantkunj, Winter



(c) PM2.5: Average, Vasantkunj, Winter

Figure 4.20: CMB Modeling for PM$_{2.5}$ at VKJ for Winter Season, 2013-14

Table 4.7: Statistical Summary: VKJ, Winter Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	555.38	502.31	91.86	0.69	300.79	272.47	89.14	0.69
StdDev	188.78	169.40	13.24	0.06	88.70	104.80	12.54	0.05
CoV	0.34	0.34	0.14	0.09	0.29	0.38	0.14	0.07
Maximum	959.63	985.69	118.40	0.76	472.56	495.03	112.40	0.78
Minimum	254.04	264.40	71.50	0.51	180.89	141.14	70.70	0.58

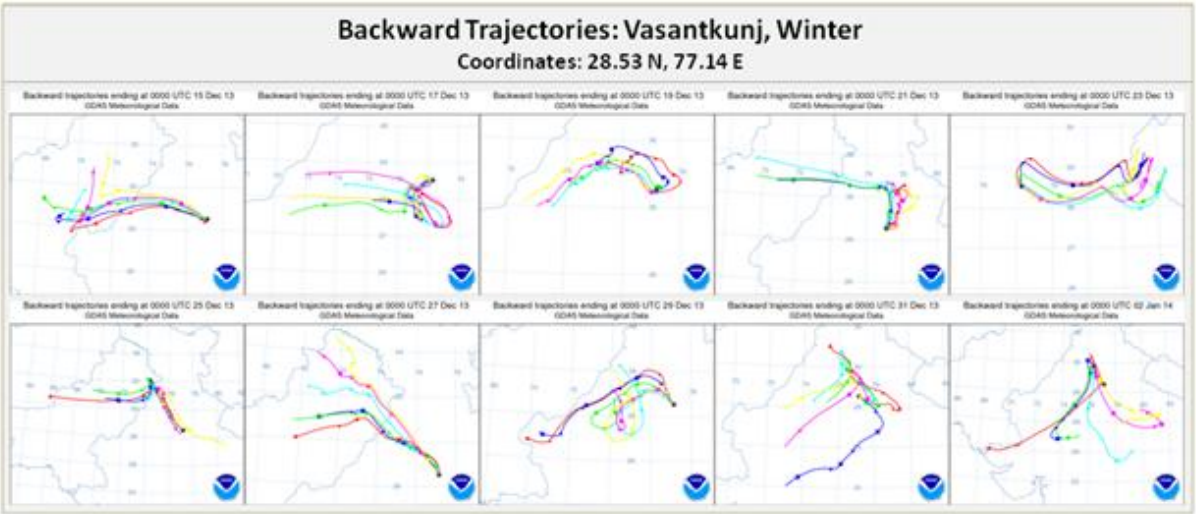


Figure 4.21: Backward trajectories at VKJ for Winter Season

Inference

It is to be noted that at VKJ, secondary particles contribute about 32-33%, vehicles28-24% and biomass burning 29-18% for $PM_{2.5}$ and PM_{10}. It signifies that there is need to control emissions of precursor gases (SO_2 and NO_x) both from outside and inside of Delhi.

4.3.4.2 Summer Season: [sampling period: April 29 - May 19, 2014]

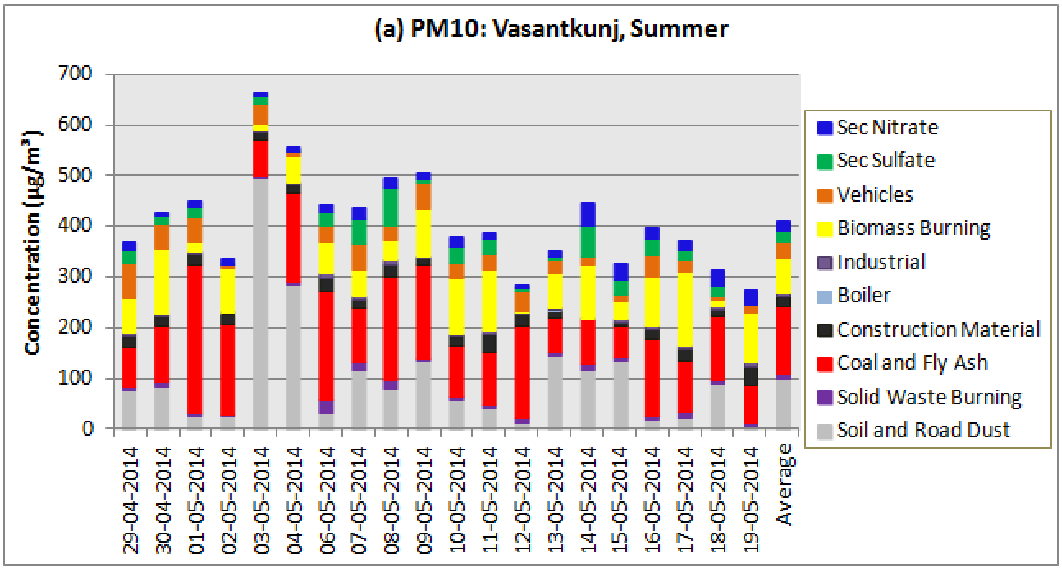
PM_{10} (summer)

The average PM_{10} concentration was 410 µg/m^3. Figure 4.22 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKJ. Table 4.8 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was coal and flyash (133 µg/m^3 ~ 33%) followed by soil and road dust (98 µg/m^3 ~ 24%) in PM_{10}. The other major sources are biomass burning (71 µg/m^3 ~ 17%), secondary particle formation (42 µg/m^3 ~ 10%), vehicular emission (8%), construction material (5%), solid waste burning (2%) and industrial emission (1%) in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 252 µg/m^3; $PM_{2.5}/PM_{10}$ ratio was 0.6. Figure 4.23 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at VKJ. It is observed that the major source contributing in $PM_{2.5}$ was biomass burning (65 µg/m^3 ~ 27%) followed by coal and flyash (58 µg/m^3 ~ 24%). Other major sources are Soil and road dust (52 µg/m^3 ~ 21%), secondary particle formation soil (31 µg/m^3 ~ 13%), vehicular emission (9%), solid waste burning (3%). Other minor sources are construction material (2%) and industrial emission (1%).

HYSPLIT back trajectories (Figure 4.24) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.



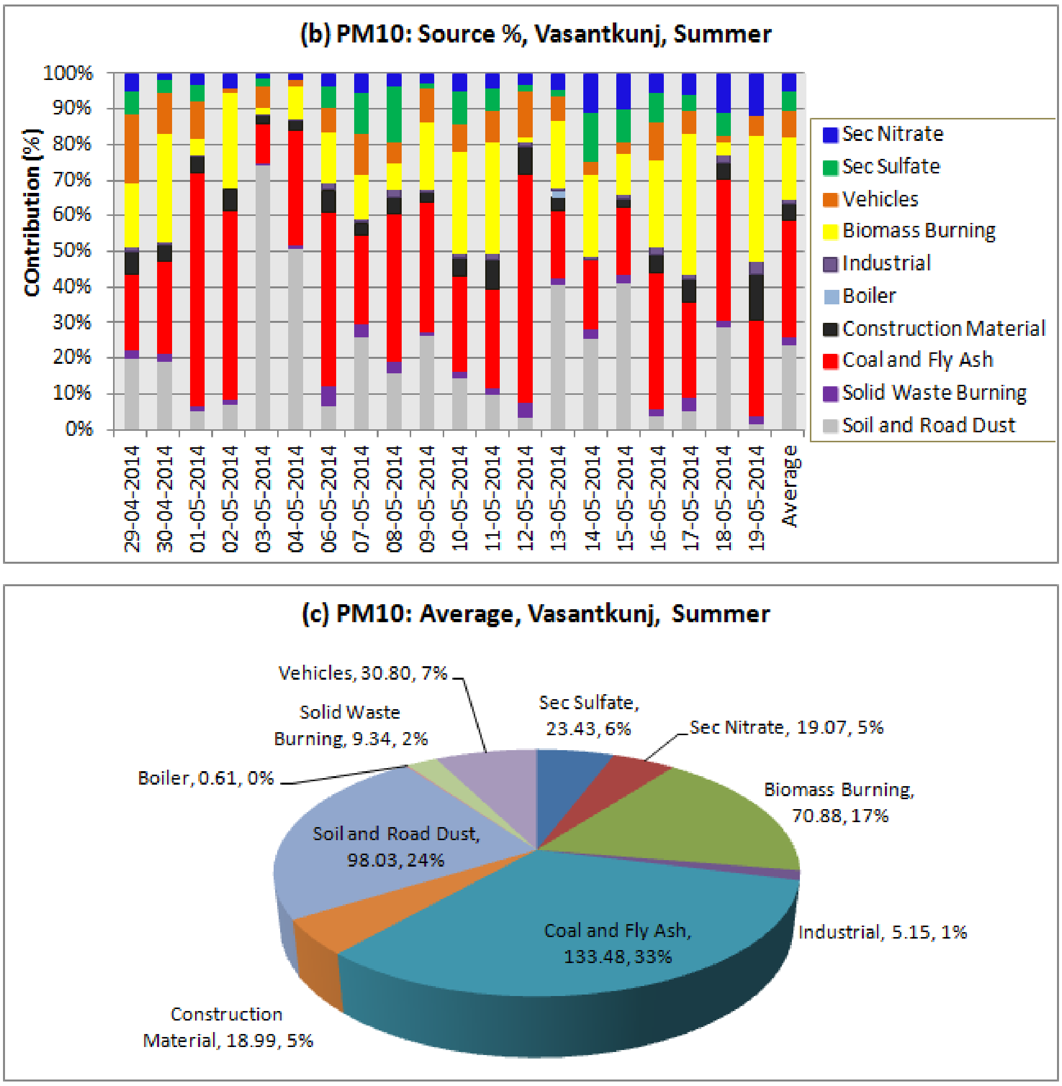
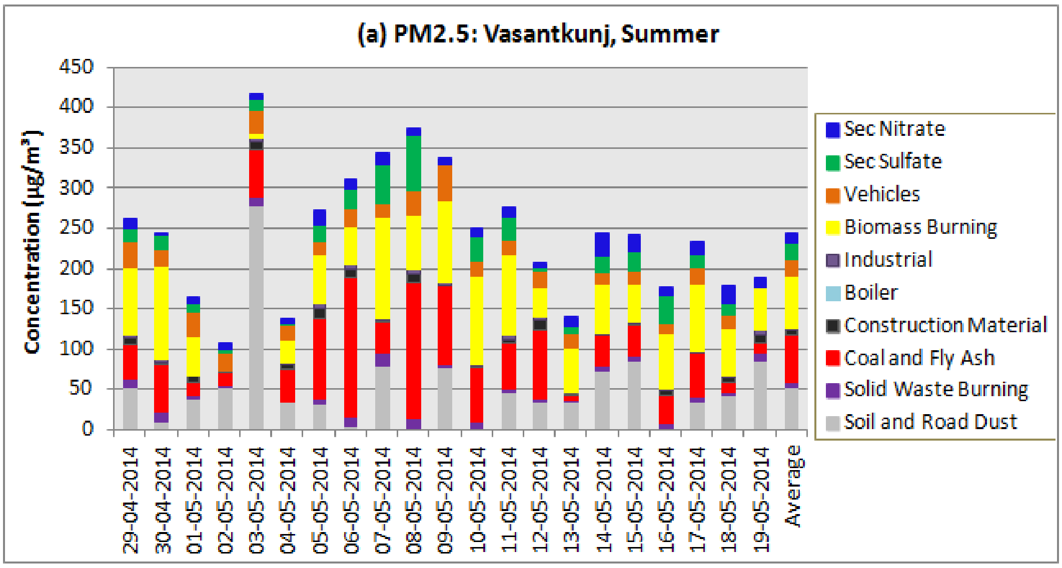


Figure 4.22: CMB Modeling for PM_{10} at VKJ for Summer Season, 2014



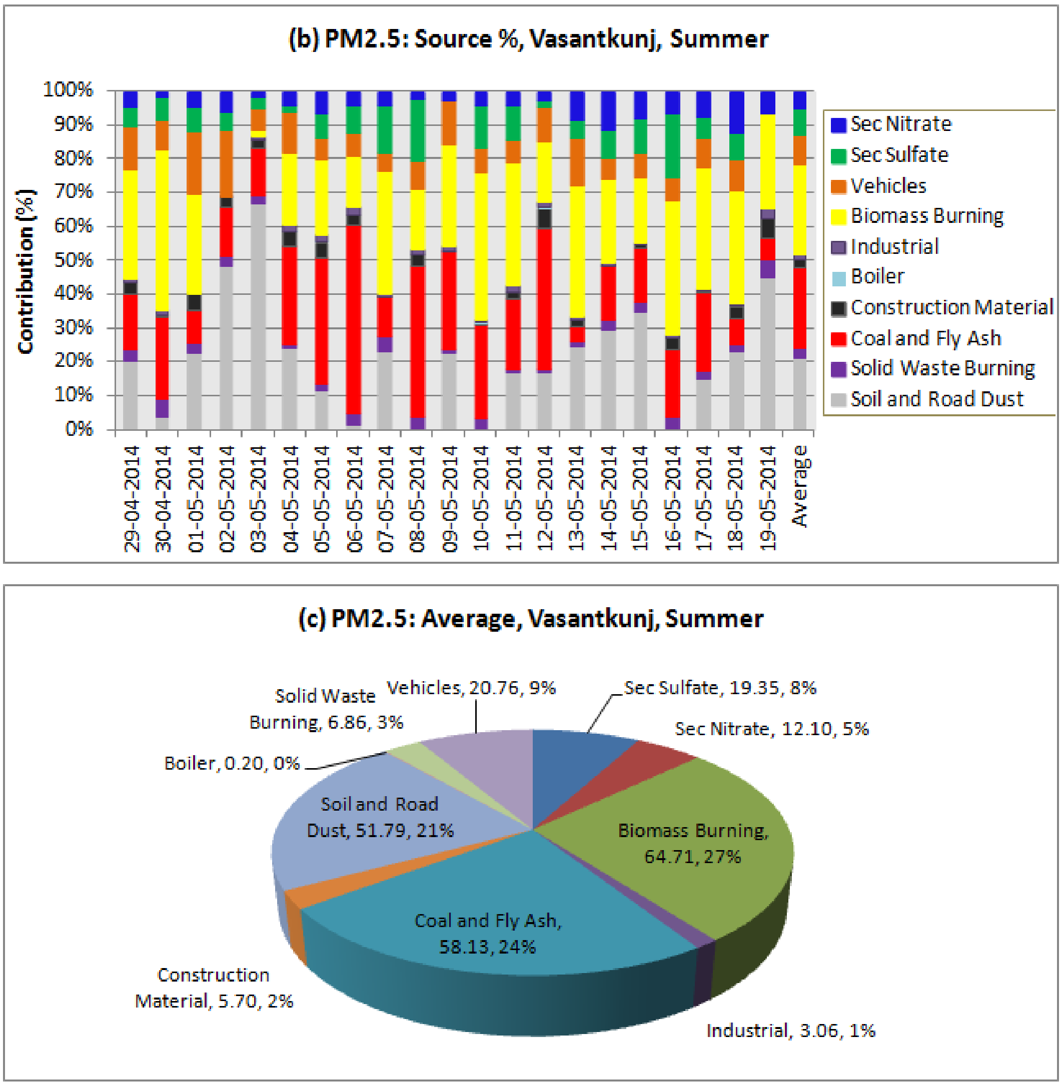


Figure 4.23: CMB Modeling for $PM_{2.5}$ at VKJ for Summer Season, 2014

Table 4.8: Statistical Summary: VKJ, Summer Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	413.20	409.78	100.03	0.64	252.14	242.67	95.52	0.66
StdDev	90.15	94.78	14.59	0.06	70.72	81.49	11.69	0.05
CoV	0.22	0.23	0.15	0.09	0.28	0.34	0.12	0.08
Maximum	644.79	663.89	123.80	0.75	356.69	416.89	121.90	0.81
Minimum	274.77	274.64	69.20	0.50	120.47	106.16	77.50	0.58

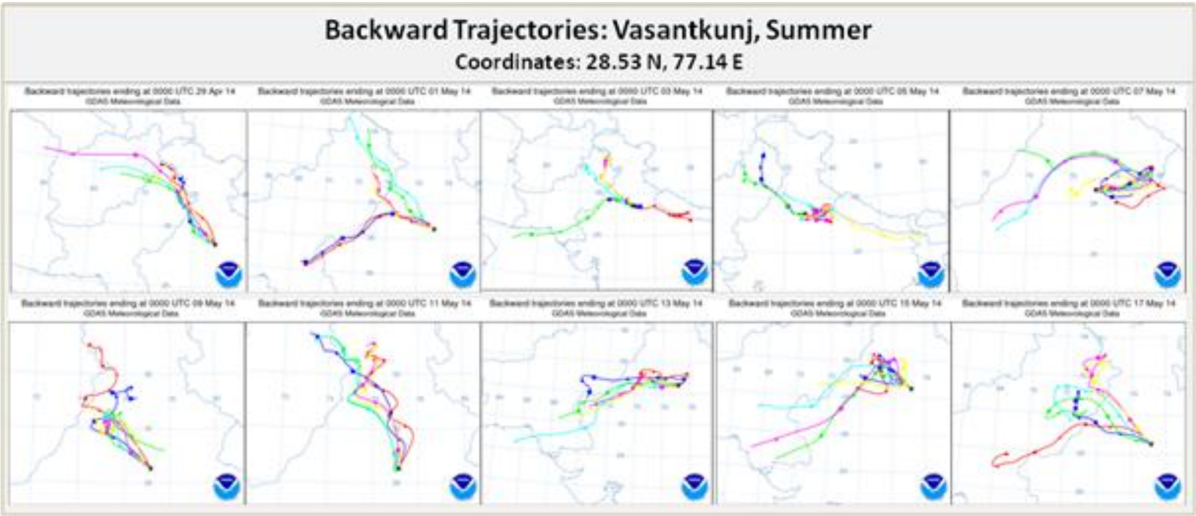


Figure 4.24: Backward trajectories at VKJ for Summer Season

Inference

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

4.3.5 Arwachin International School, Dilshad Garden (DSG)

4.3.5.1 Winter Season [sampling period: January 24 - Febuary 13, 2014]

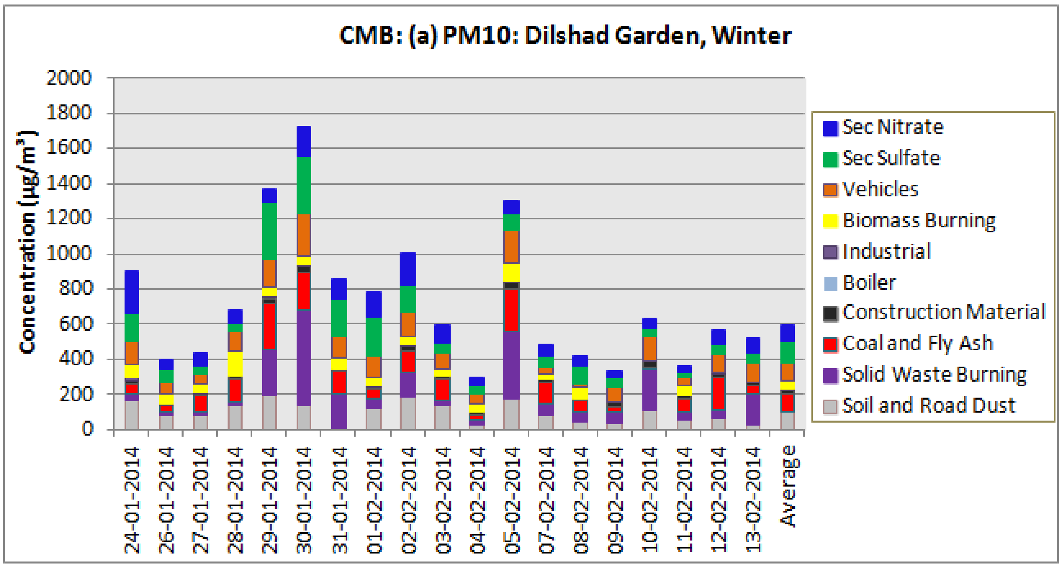
PM_{10} (winter)

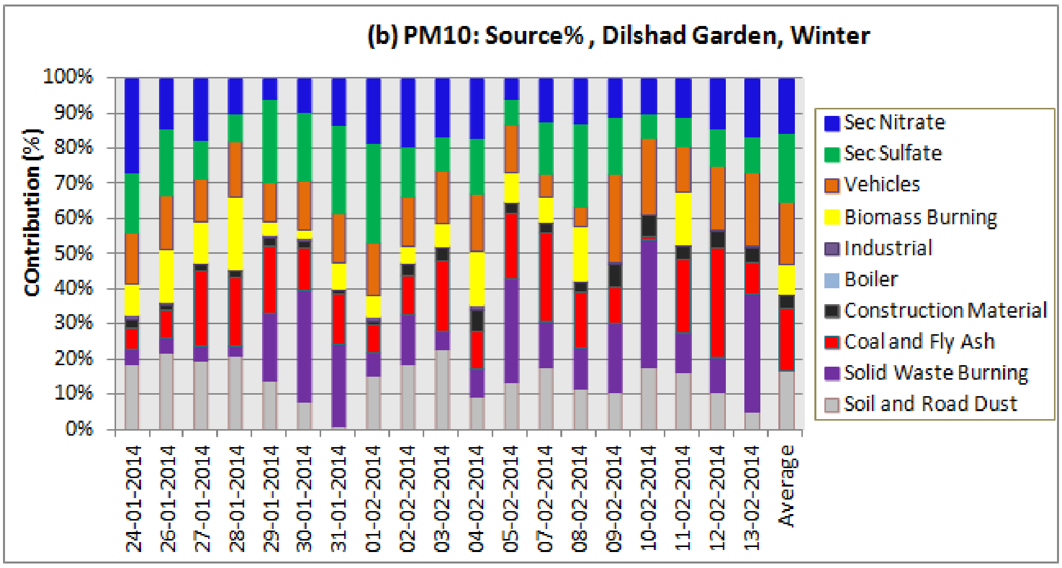
The average PM_{10} concentration was 688 µg/m^3. Figure 4.25 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DSG. Table 4.9 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was secondary particle formation (210 µg/m^3 ~ 29%) followed by solid waste burning (127 µg/m^3 ~ 18%). The other major contributing sources are coal and flyash (106 µg/m^3~ 15%), vehicular emission (104 µg/m^3 ~ 14%), soil and road dust (14%), biomass burning (7%) and construction material (3%).Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (winter)

The average $PM_{2.5}$ concentration was 425 µg/m^3; ratio of $PM_{2.5}/PM_{10}$ is about 0.58. Figure 4.26 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DSG. It is observed that the major source contributing in $PM_{2.5}$ was secondary particle formation (143 $\mu g/m^3$ ~ 39%) followed by vehicular emission (88$\mu g/m^3$ ~ 24%). Other major sources are solid waste burning (54 $\mu g/m^3$ ~ 15%), biomass burning (43 $\mu g/m^3$ ~ 12%), coal and flyash (4%) and soil and road dust (4%). The minor source are construction material (2%) and industrial emission (<1%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.27) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.





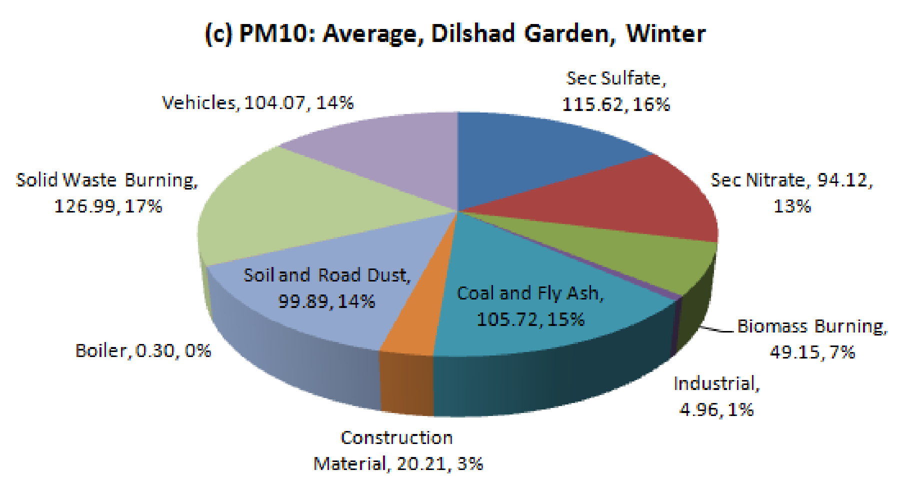
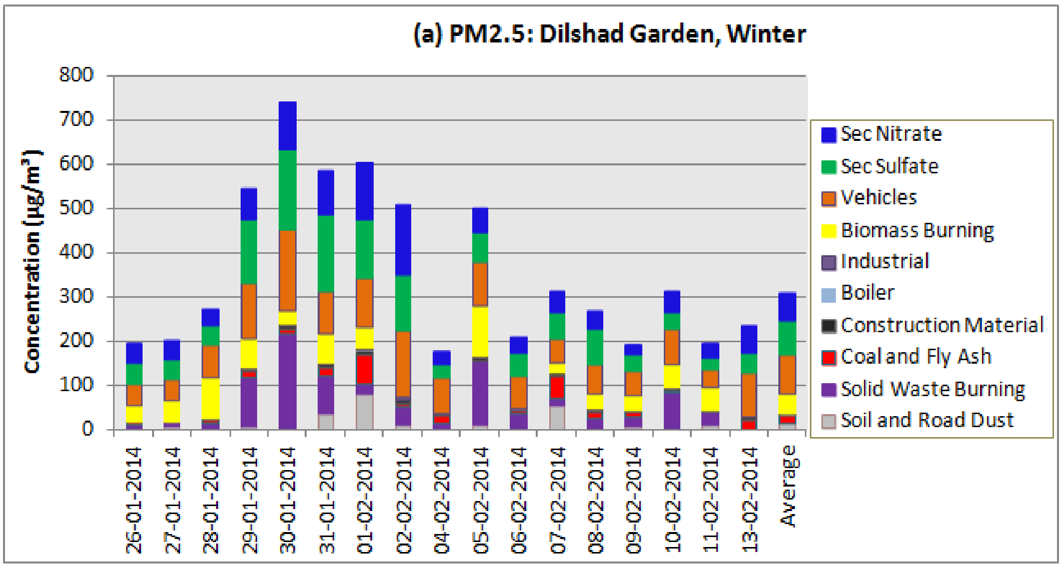
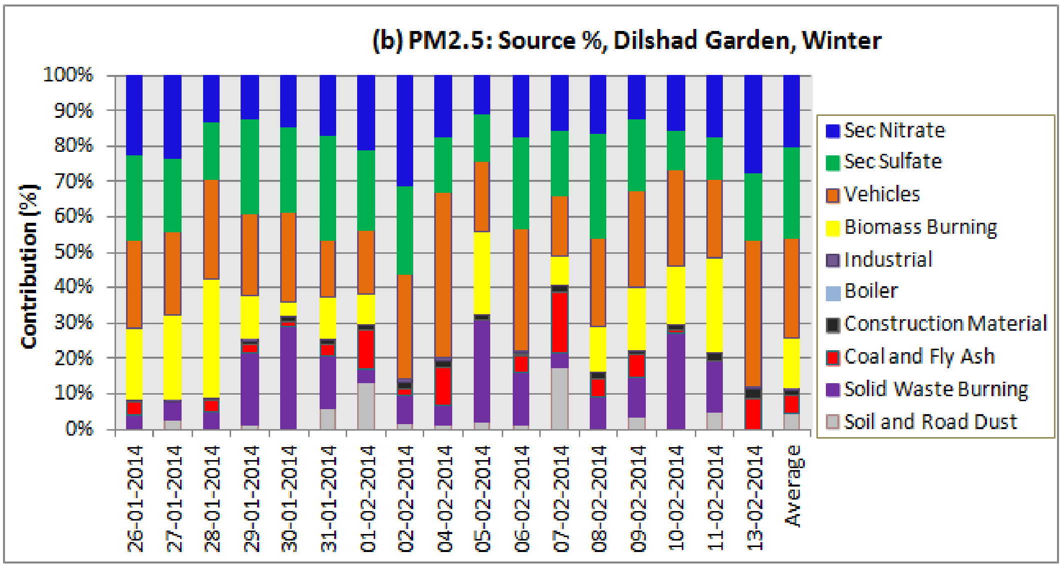


Figure 4.25: CMB Modeling for PM$_{10}$ at DSG for Winter Season, 2013-14





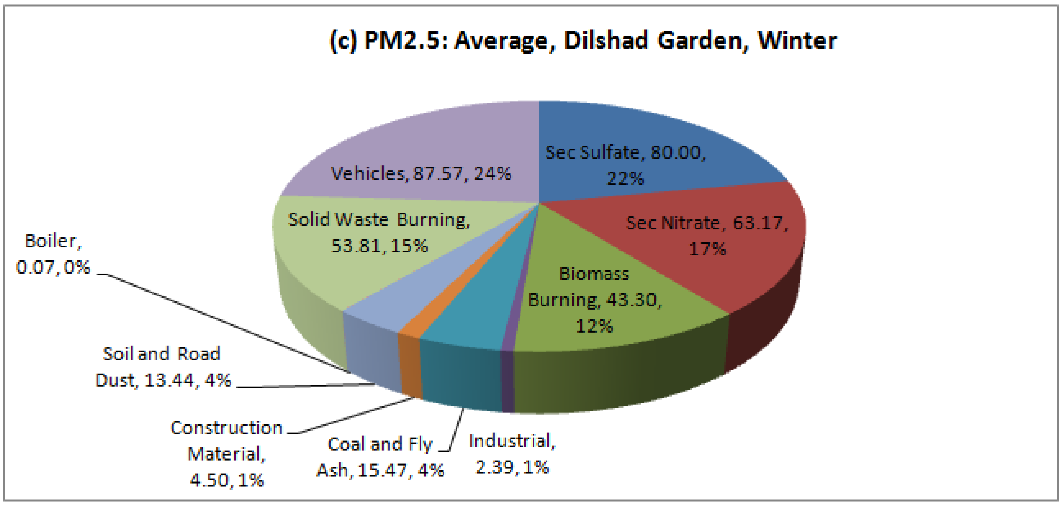


Figure 4.26: CMB Modeling for $PM_{2.5}$ at DSG for Winter Season, 2013-14

Table 4.9: Statistical Summary: DSG, Winter Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	687.58	721.03	104.14	0.70	425.49	363.72	88.19	0.68
StdDev	334.96	393.70	13.25	0.05	224.96	186.60	13.10	0.05
CoV	0.49	0.55	0.13	0.08	0.53	0.51	0.15	0.08
Maximum	1418.94	1726.25	124.20	0.77	757.90	742.66	110.90	0.77
Minimum	280.14	300.53	81.00	0.56	157.60	174.73	70.00	0.59

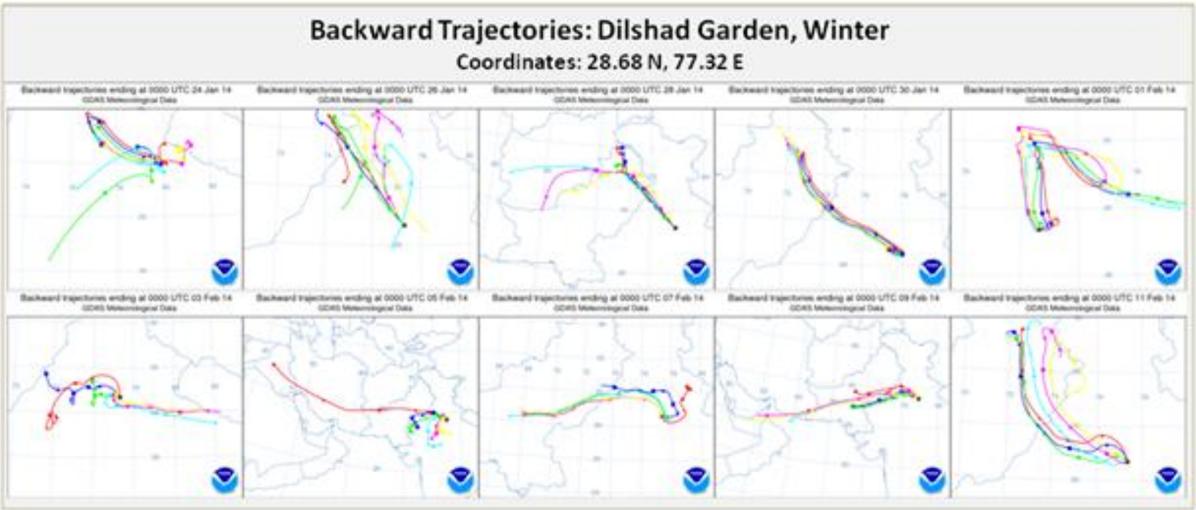


Figure 4.27: Backward trajectories at DSG for Winter Season

Inference

Contributions of secondary particles are consistent high 29% and 39% for PM_{10} and $PM_{2.5}$ followed by vehicles at 14 and 24%. Solid waste burning appears to be wide spread and consistently contributing to both PM_{10} and $PM_{2.5}$.

4.3.5.2 Summer Season [sampling period: May 26, 2014 - June 14, 2014]

PM_{10} (summer)

The average PM_{10} concentration was 531 µg/m^3. Figure 4.28 (a), (b), (c) shows PM_{10} concentration contribution of sources, percent contribution of sources and summary of sources (average over about 20 days) at DSG. Table 4.10 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was soil and road dust (185 µg/m^3 ~ 34%) followed by coal and flyash (145 µg/m^3 ~ 27%). The other major contributing sources are solid waste burning (54 µg/m^3 ~ 10%), secondary particle formation (46 µg/m^3 ~ 9%), biomass burning (8%), vehicular emission (7%) and construction material (4%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 276 µg/m^3. Figure 4.29 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at DSG. It is observed that the major source contributing in $PM_{2.5}$ was soil and road dust (74 µg/m^3 ~ 28%) followed by coal and flyash (56 µg/m^3 ~ 21%). Other major sources are secondary particle formation (38 µg/m^3 ~ 14%), biomass burning (37 µg/m^3 ~ 14%), solid waste burning (9%), vehicular emission (9%) and construction material (3%). Contribution of the industrial emission was estimated less than 1% in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.30) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.

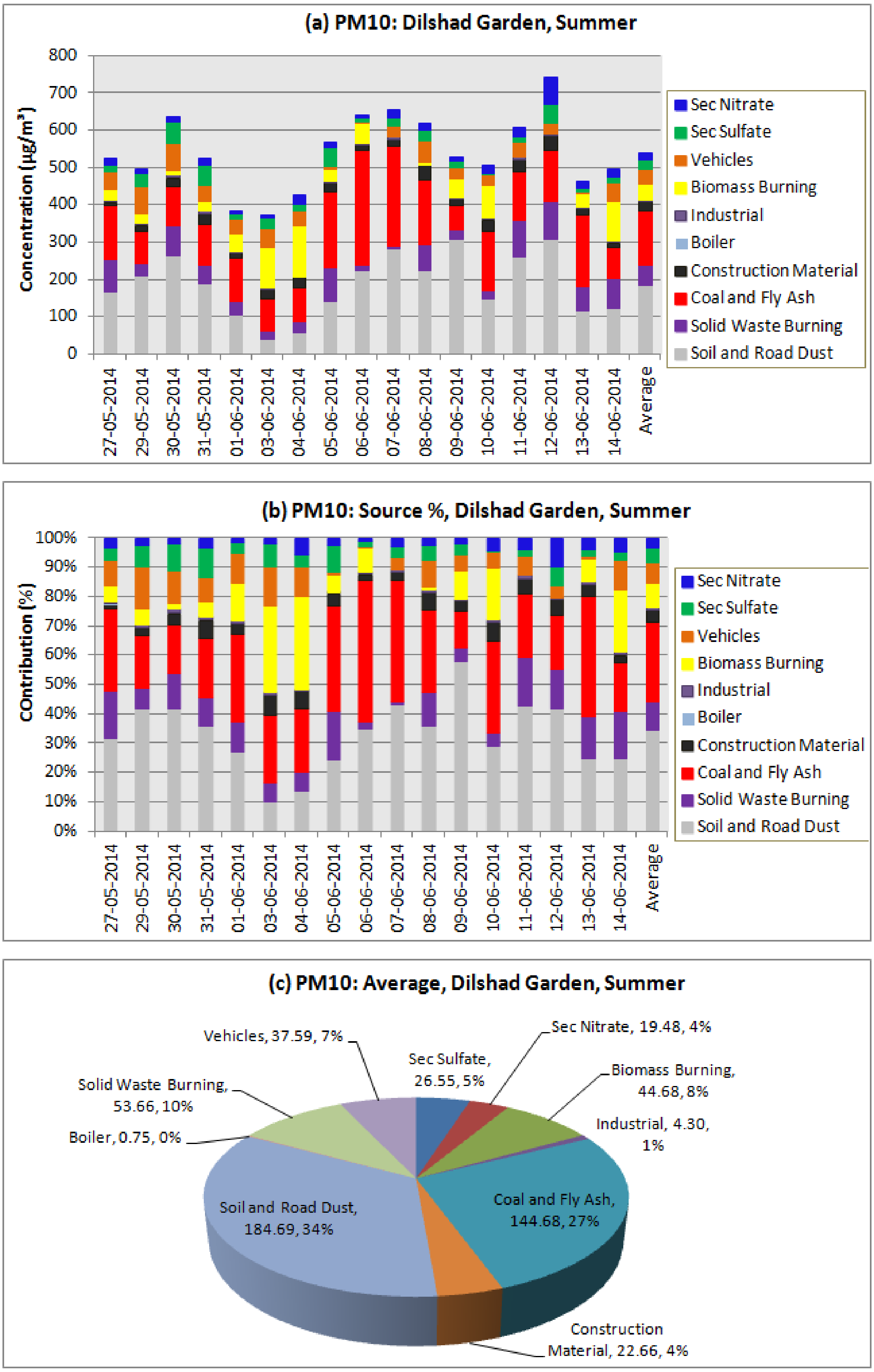
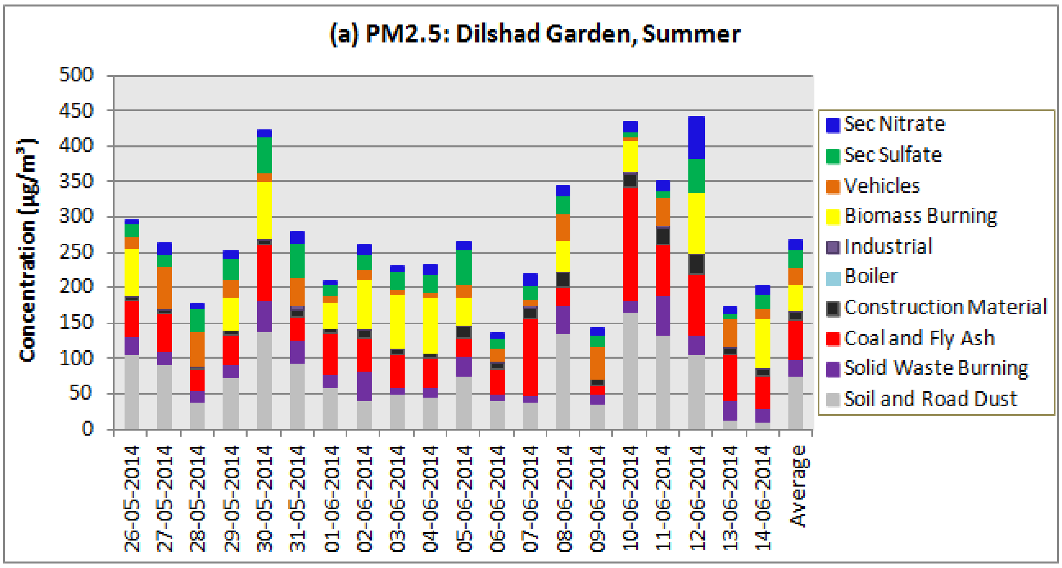
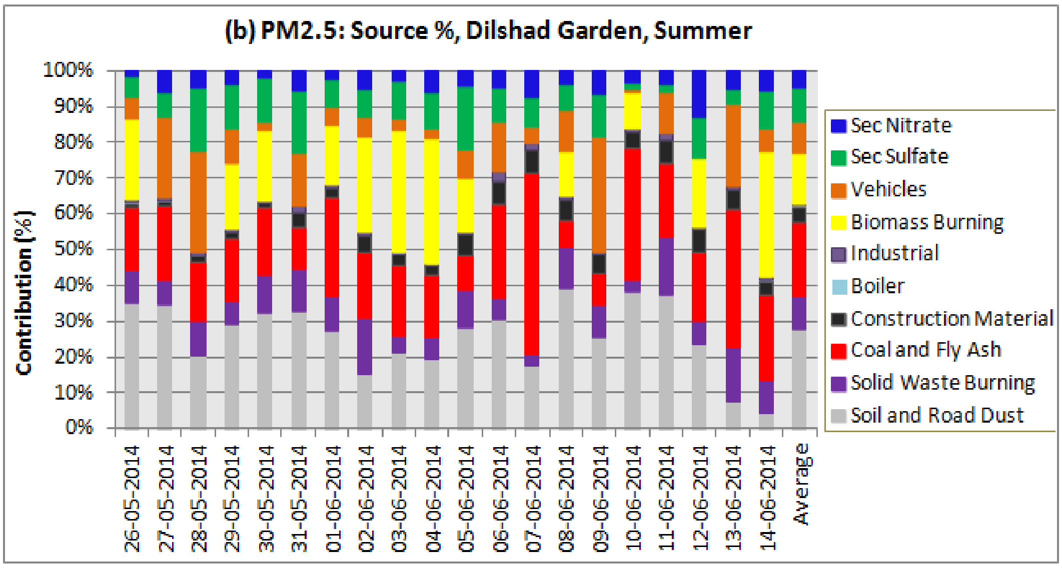


Figure 4.28: CMB Modeling for PM_{10} at DSG for Summer Season, 2014


(a) PM2.5: Dilshad Garden, Summer


(b) PM2.5: Source %, Dilshad Garden, Summer

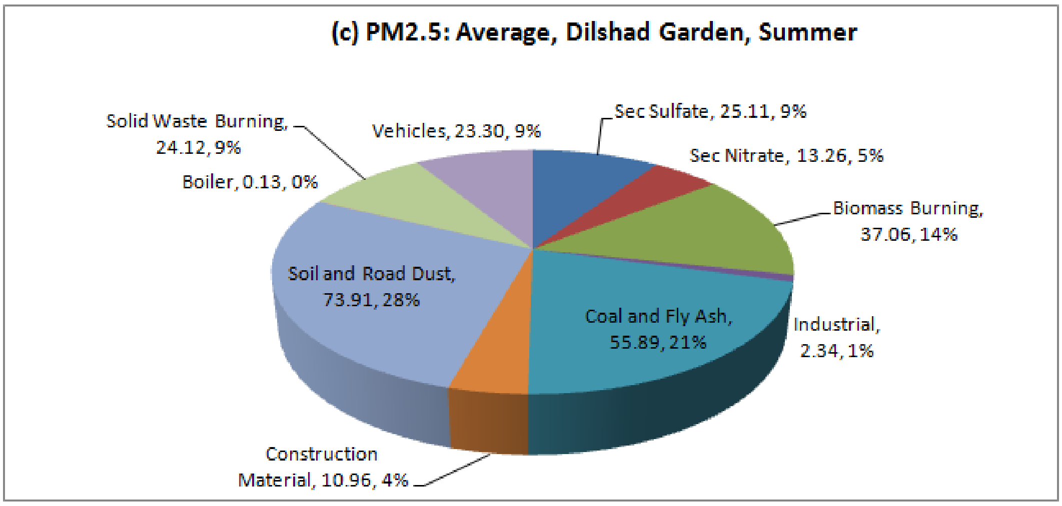

(c) PM2.5: Average, Dilshad Garden, Summer

Figure 4.29: CMB Modeling for $PM_{2.5}$ at DSG for Summer Season, 2014

Table 4.10: Statistical Summary: DSG, Summer Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R²	Measured	Calculated	% Mass	R²
Average	531.00	539.05	102.21	0.67	276.15	266.09	97.76	0.71
StdDev	98.24	100.13	11.79	0.06	104.44	91.54	8.84	0.05
CoV	0.19	0.19	0.12	0.09	0.38	0.34	0.09	0.07
Maximum	680.28	739.25	123.60	0.77	467.37	441.38	118.60	0.79
Minimum	348.67	371.26	77.80	0.56	140.28	134.25	77.10	0.63

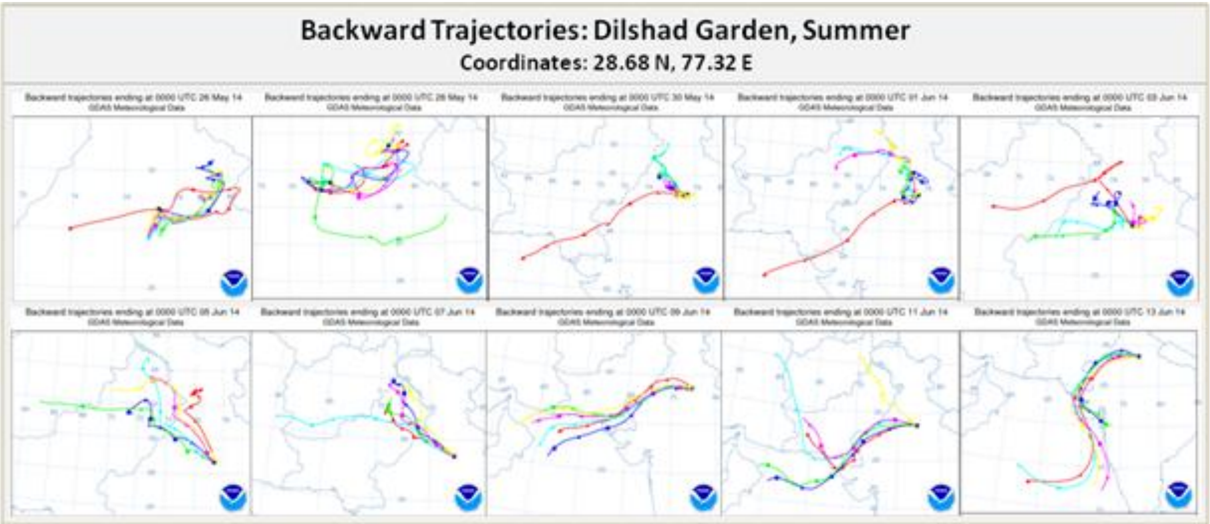


Figure 4.30: Backward trajectories at DSG for Summer Season

Inference

In summer both PM_{10} and $PM_{2.5}$ by soil and road dust, coal and flyash, biomass burning and solid waste burning are the major sources which requires control in fugitive sources.

4.3.6 DTEA School, Pusa Road (PUS)

4.3.6.1 Winter Season [sampling period: January 30, 2014 - February 22, 2014]

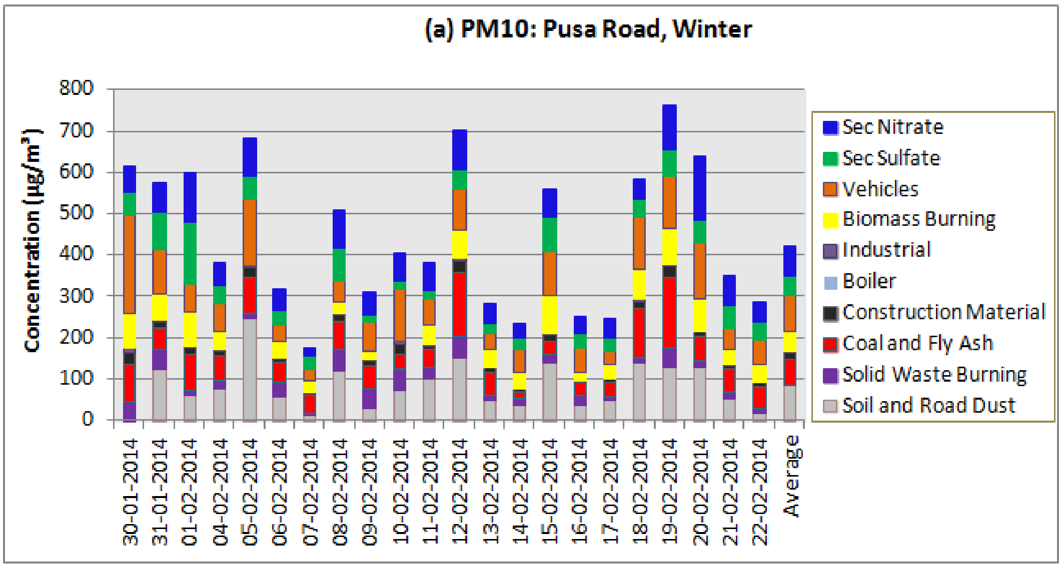
PM_{10} (winter)

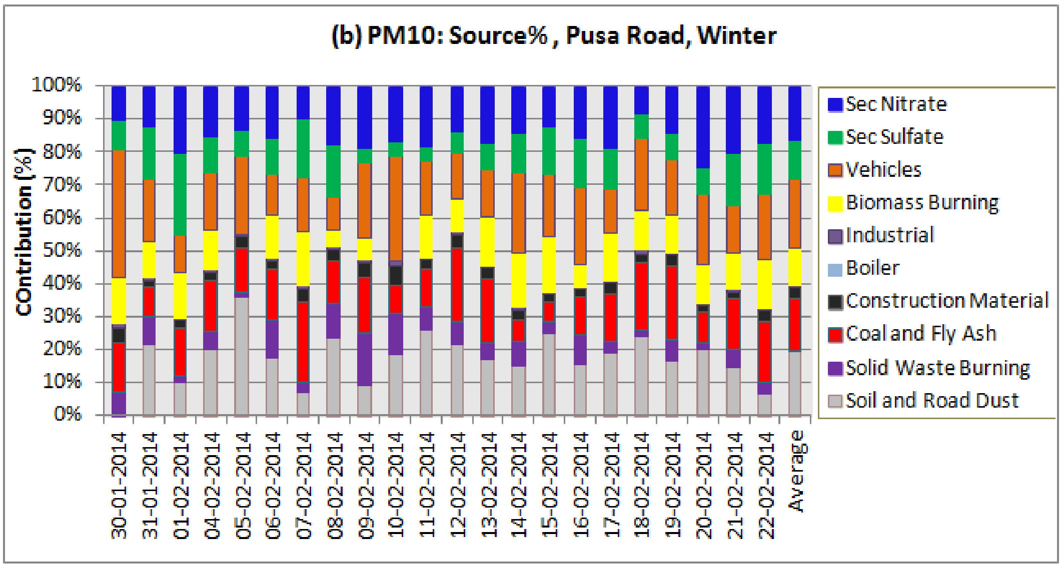
The average PM_{10} concentration was 473 µg/m^3. Figure 4.31 (a), (b) and (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at PUS. Table 4.11 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was secondary particle formation (119 µg/m^3 ~ 26%) followed by vehicular emission (87 µg/m^3 ~ 19%). The other major contributing sources are soil and road dust (83 µg/m^3 ~ 19%), coal and fly ash (66 µg/m^3 ~ 15%), biomass burning (11%), solid waste burning (6%) and construction material (3%). Contribution of the industrial emission was estimated less than 1% in PM$_{10}$.

PM$_{2.5}$ (winter)

The average PM$_{2.5}$ concentration was 272 µg/m^3. Figure 4.32 (a), (b), (c) represents PM$_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at PUS. It is observed that the major source contributing in PM$_{2.5}$ was secondary particle formation (76 µg/m^3 ~ 32%) followed by vehicular emission (65µg/m^3 ~ 28%). Other major sources are biomass burning (47 µg/m^3 ~ 20%), soil and road dust (25 µg/m^3 ~ 11%), and solid waste burning (5%). The minor sources are construction material (2%), coal and flyash (1.3%) and industrial emission (1.2%) in PM$_{2.5}$.

HYSPLIT back trajectories (Figure 4.33) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.


(a) PM10: Pusa Road, Winter



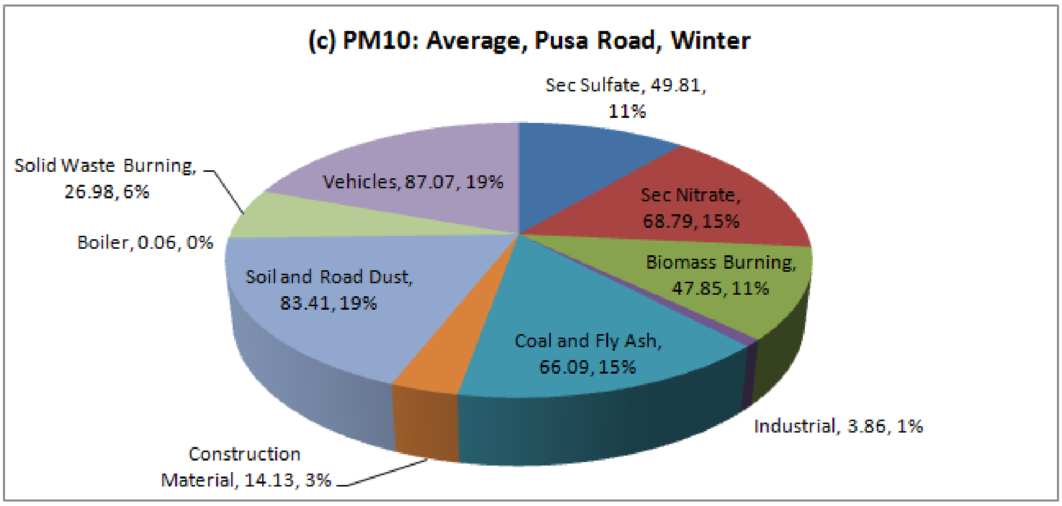
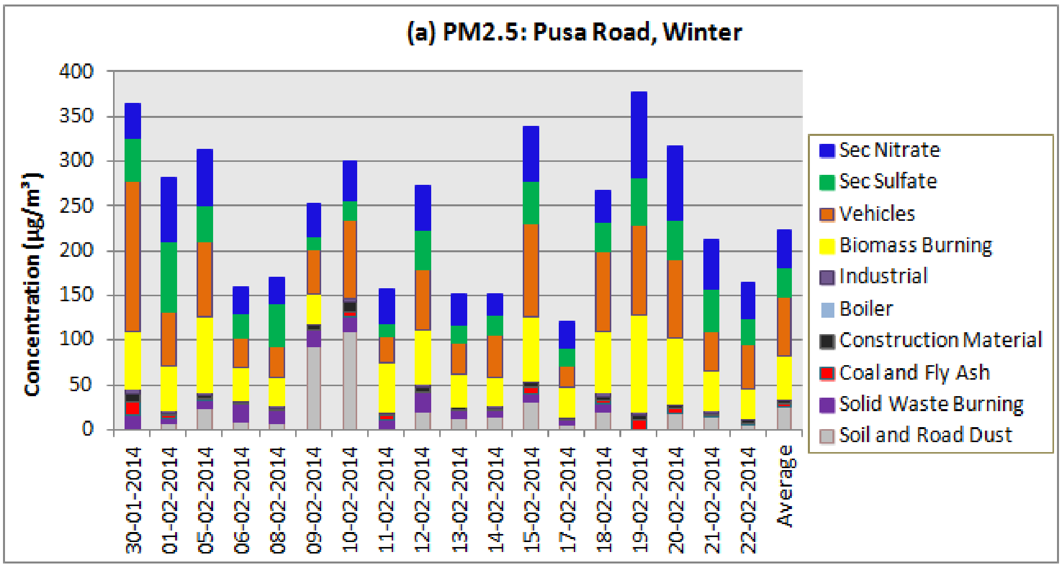
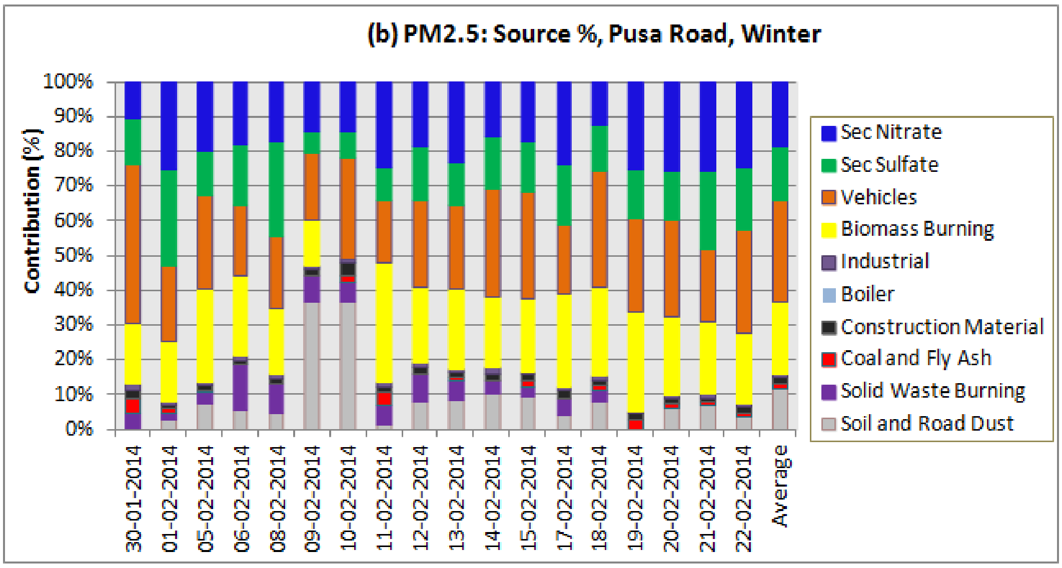


Figure 4.31: CMB Modeling for PM_{10} at PUS for Winter Season, 2013-14





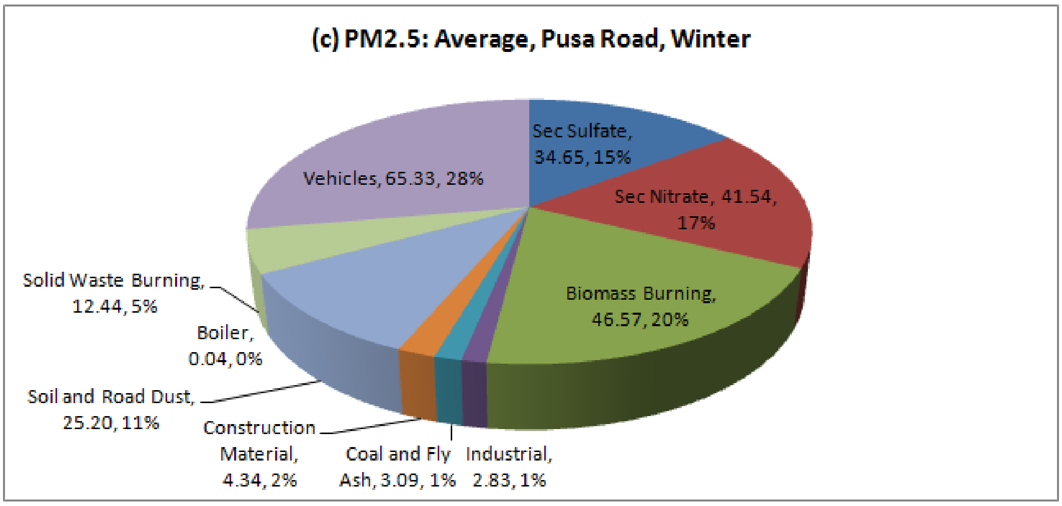


Figure 4.32: CMB Modeling for $PM_{2.5}$ at PUS for Winter Season, 2013-14

Table 4.11: Statistical Summary: PUS, Winter Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	472.79	448.05	95.37	0.71	272.02	236.04	85.62	0.67
StdDev	184.79	177.97	11.77	0.03	73.37	80.95	11.48	0.03
CoV	0.39	0.40	0.12	0.05	0.27	0.34	0.13	0.04
Maximum	757.22	761.72	121.40	0.77	368.26	364.41	109.30	0.71
Minimum	171.93	174.14	70.00	0.65	142.11	121.54	71.10	0.60

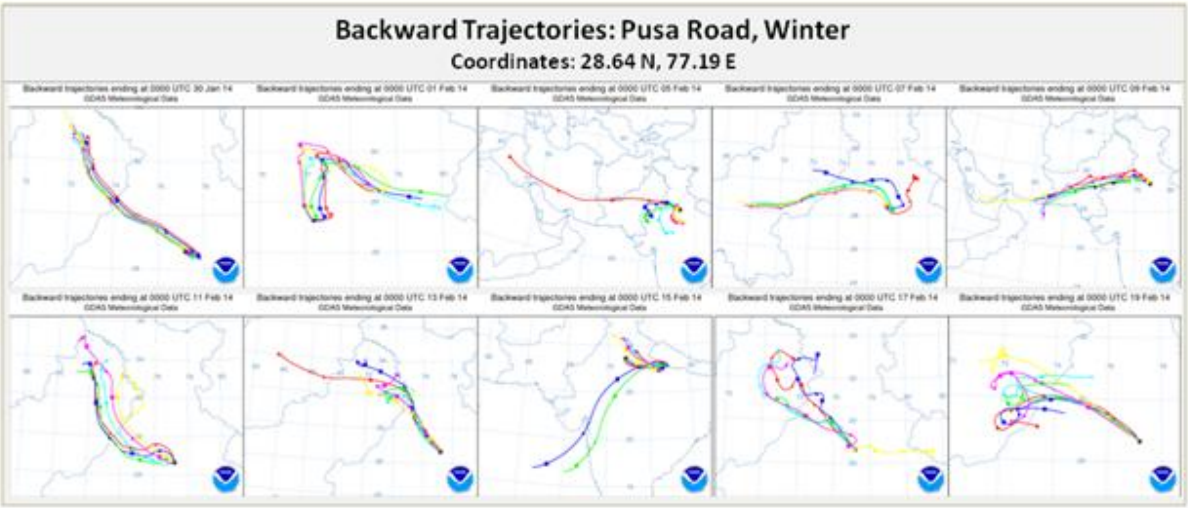


Figure 4.33: Backward trajectories at PUS for Winter Season

Inference

Contributions of secondary particles are consistent high 26% and 32% for PM_{10} and $PM_{2.5}$ followed by vehicles at 19 and 28%. Soil and road dust contributes 19% and 11% to PM_{10} and $PM_{2.5}$ Biomass burning contributes about 20% to $PM_{2.5}$. This site is also consistent with other site for winter season when contribution of secondary particles is very high.

4.3.6.1 Summer Season PUS [sampling period: May 25, 2014 - June 16, 2014]

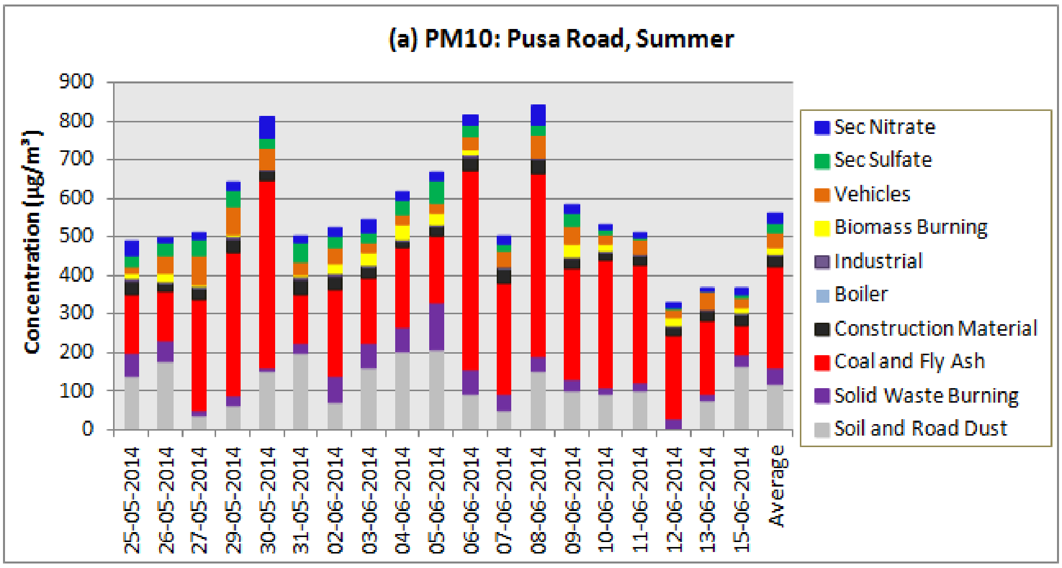
PM_{10} (summer)

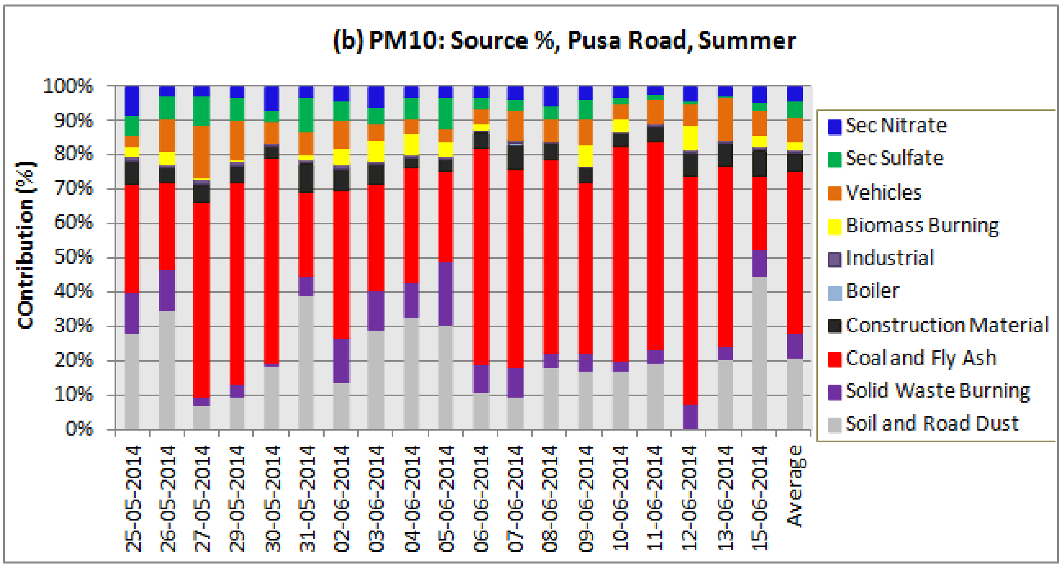
The average PM_{10} concentration was 553 µg/m^3. Figure 4.34 (a), (b), (c) represents PM_{10} contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at PUS .Table 4.12 presents summary of performance and acceptability of CMB model. It is observed that the major PM_{10} source contributing was coal and flyash (265 µg/m^3 ~ 47%) followed by soil and road dust (116 µg/m^3 ~ 21%). The other significant contributing sources are secondary particle formation (50 µg/m^3 ~ 9%), solid waste burning (42 µg/m^3 ~ 7%), vehicular emission (7%), construction material (5%) and biomass burning (3%). Contribution of the industrial emission was estimated less than 1% in PM_{10}.

$PM_{2.5}$ (summer)

The average $PM_{2.5}$ concentration was 269 µg/m^3. Figure 4.35 (a), (b), (c) represents $PM_{2.5}$ contribution of sources in terms of concentration, percent contribution of sources and overall contribution (average over about 20 days) in terms of concentration and percentage respectively at PUS. It is observed that the major source contributing in $PM_{2.5}$ was coal and fly ash (83 µg/m^3 ~ 32%) followed by soil and road dust (80 µg/m^3 ~ 29%). Other major sources are secondary particle formation (41 µg/m^3 ~ 16%), and vehicular emission (33 µg/m^3 ~ 13%), solid waste burning (8%), biomass burning (5%) and construction material (3%). The minor source is industrial emission (1%) in $PM_{2.5}$.

HYSPLIT back trajectories (Figure 4.36) show that most of the time wind is from NW and wind mass travels over Punjab and Haryana states before entering in Delhi. These winds pick up the pollutants on the way especially from large and tall emitting sources.


(a) PM10: Pusa Road, Summer


(b) PM10: Source %, Pusa Road, Summer

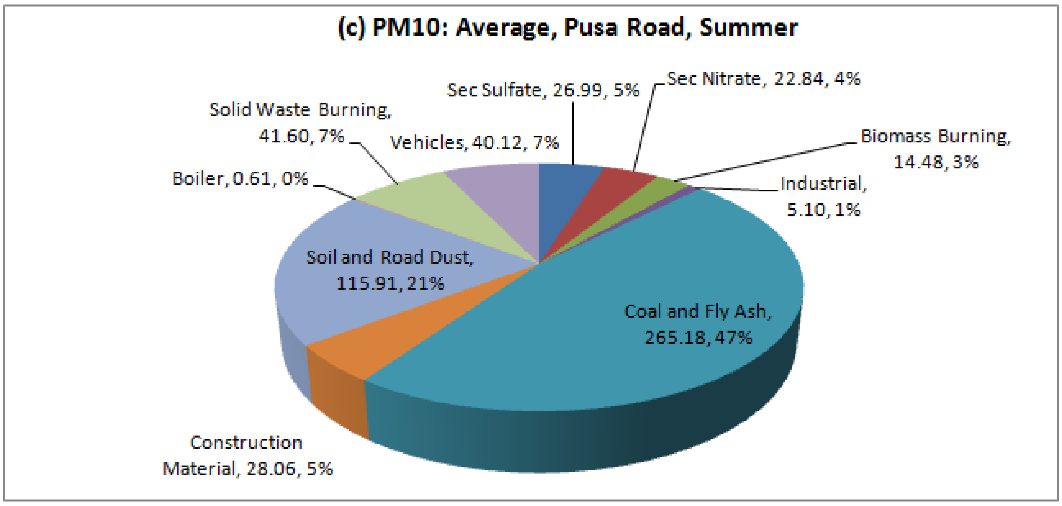
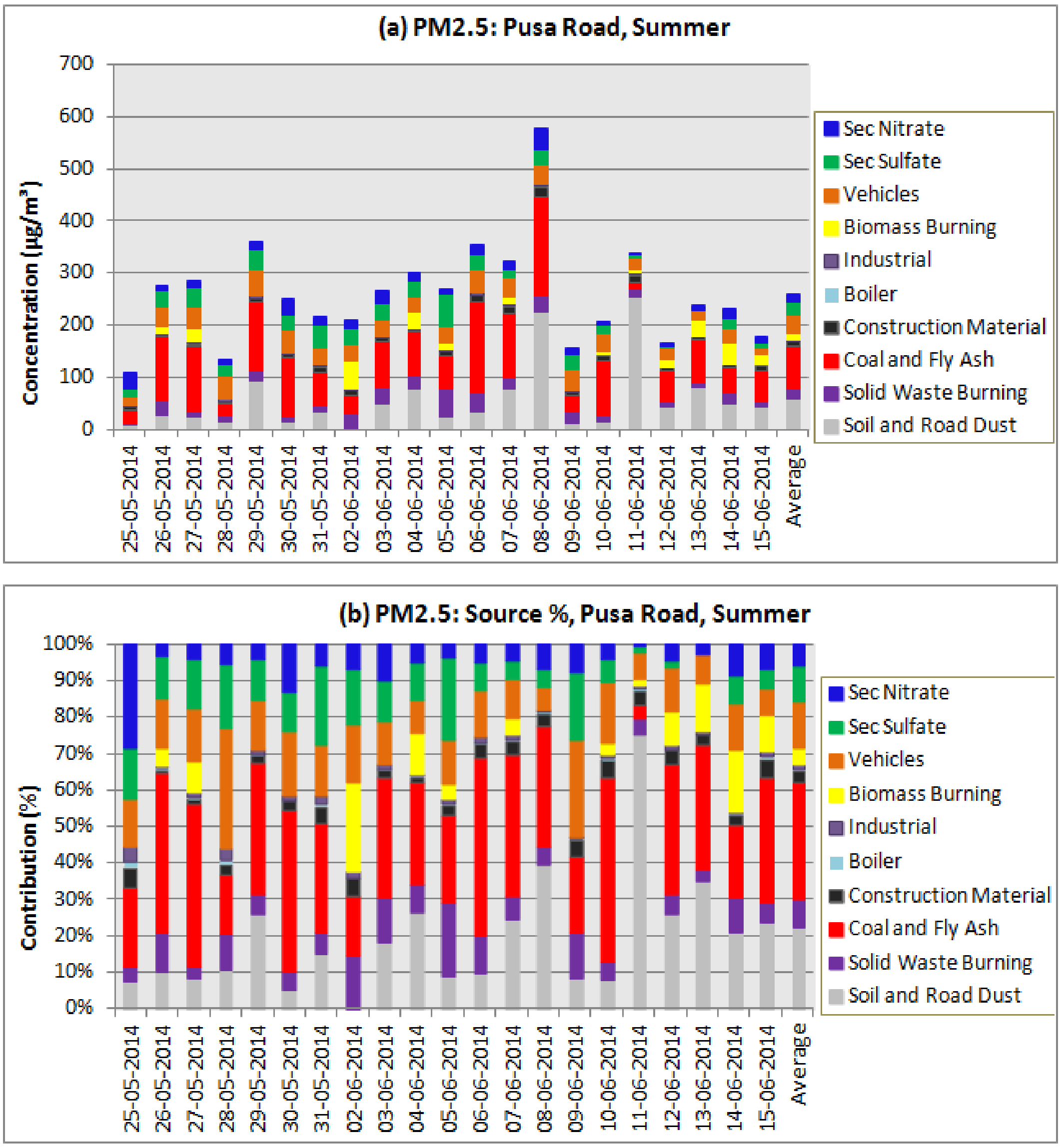


Figure 4.34: CMB Modeling for PM_{10} at PUS for Summer Season, 2014



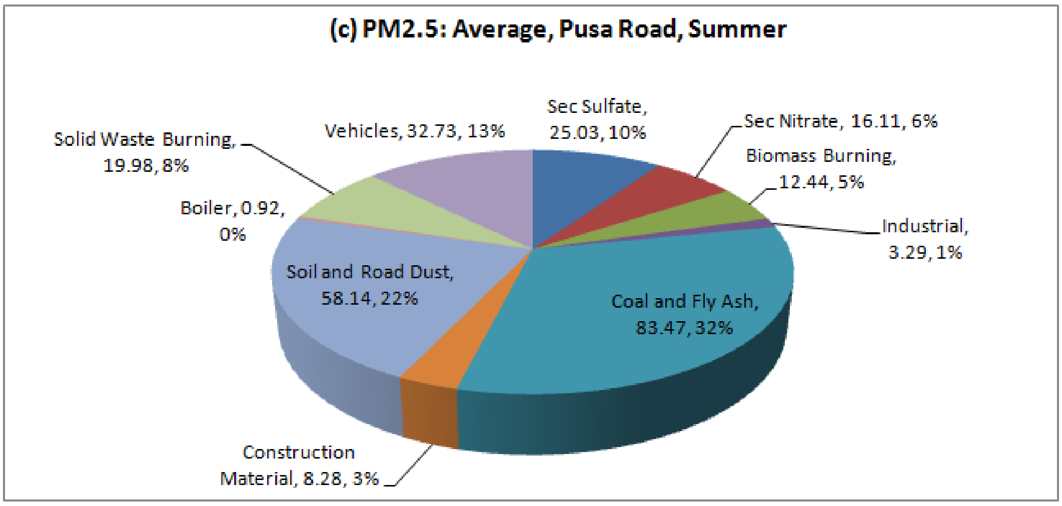


Figure 4.35: CMB Modeling for $PM_{2.5}$ at PUS for Summer Season, 2014

Table 4.12: Statistical Summary: PUS, Summer Season

	PM_{10}				$PM_{2.5}$			
Parameter	Measured	Calculated	% Mass	R^2	Measured	Calculated	% Mass	R^2
Average	552.53	560.90	101.71	0.70	268.75	260.40	97.90	0.68
StdDev	122.95	145.64	13.06	0.06	104.93	101.54	10.03	0.05
CoV	0.22	0.26	0.13	0.08	0.39	0.39	0.10	0.07
Maximum	771.91	841.47	121.00	0.80	577.81	577.57	114.80	0.75
Minimum	336.65	329.72	73.40	0.58	116.49	109.40	80.50	0.58

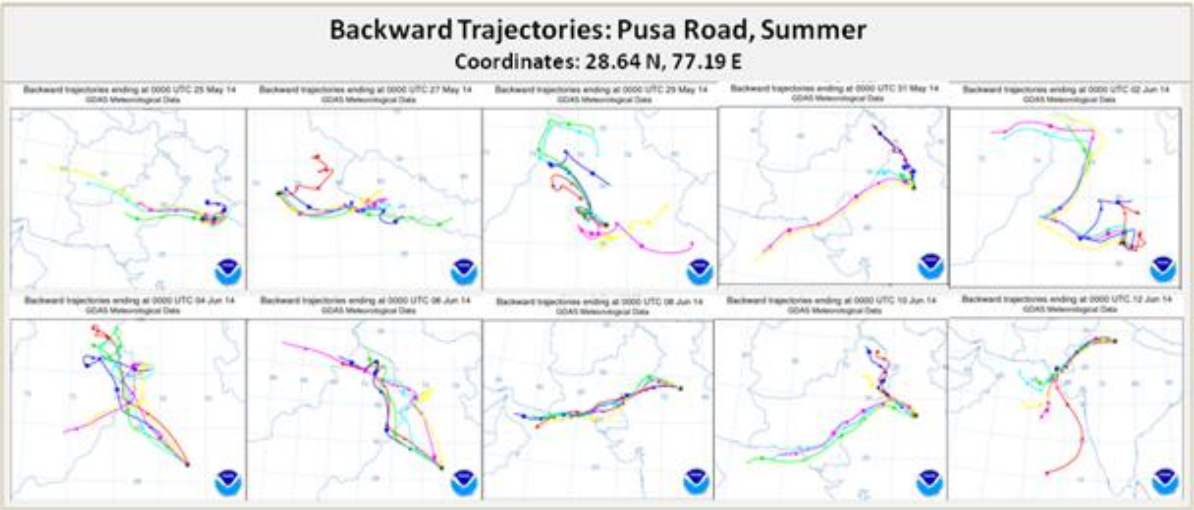


Figure 4.36: Backward trajectories at PUS for Winter Season

4.4 Break-up Vehicular Contribution: Fuel-wise

As stated in the beginning of this chapter, due to colinearity in source profiles of vehicular fuels, CMB modeling could not resolve the contribution of vehicle fuels separately. The results of CMB modeling for vehicular contribution was distributed to fuel specific contributions based on emission inventory of $PM_{2.5}$ from gasoline, diesel and CNG specific to the grid where measurements were done. The vehicle fuel specific contributions to $PM_{2.5}$ for summer and winter seasons are given in Figure 4.37 ((a) concentration); (b) percentage)). Except for RHN site, major contribution is from diesel vehicles – at RNH diesel vehicle contribution is only 20 percent. While OKH, VKJ, DSG show 70-95% diesel contribution and at PUS and DWK, diesel contribution is about 60 percent. CNG contributes a very small (2 to 8 percent) amount of $PM_{2.5}$ compared to gasoline and diesel fuels.

4.5 Long range transport and contribution

HYSPLIT back trajectories show that most of the time wind is from NW and sometimes from west. Wind mass as it travels over Punjab, Haryana and parts of Rajasthan states before entering in Delhi may pick up the pollutants on the way especially from large sources (e.g. crop residue burning (CRB)) and tall emitting sources; however these contributions have not been quantifies. Ghosh et al. (2015) have made some assessment of the emissions upstream of Delhi and their contribution in Delhi.

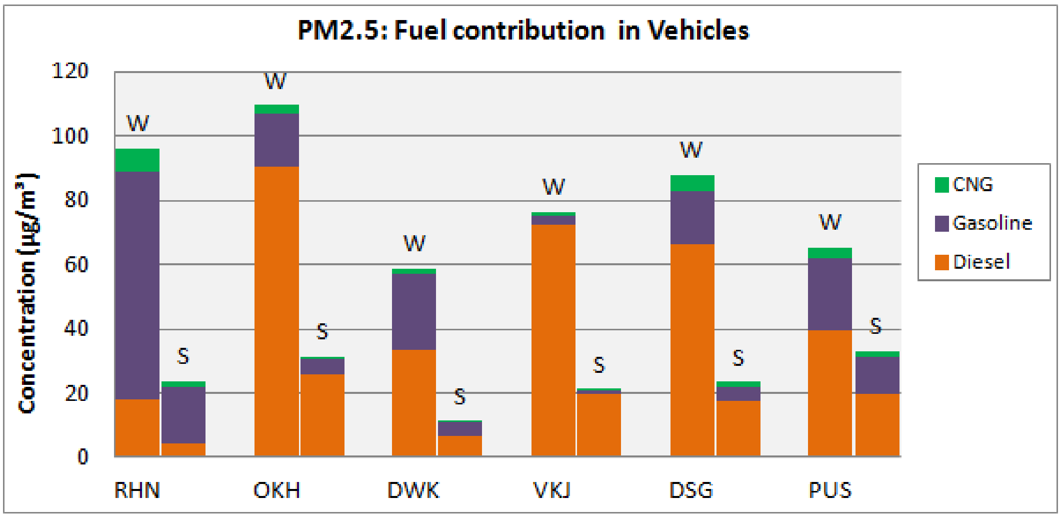
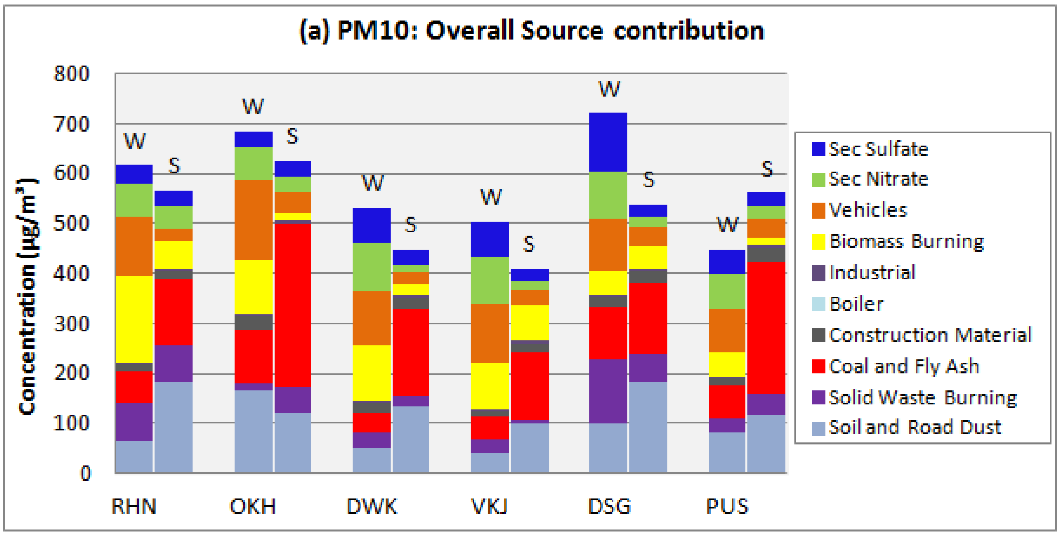


Figure 4.37: Contribution of Fuels in Vehicular Emission

4.6. Overall Summary and Source Apportionment at a Glance

The overall summary of CMB modeling results is shown in Figure 4.38 and Figure 4.39. Tables 4.13-4.16 proved summary with overall statistics. The mail highlights of CMB results are summarized below.

- Ranges of source contributions to PM_{10} are: secondary particle formation (8 – 32 %), biomass burning (2 – 28 %), coal and flyash (7 – 50 %), soil and road dust (8 - 34 %), vehicles (4 - 24%), solid waste burning (2 – 18 %) and construction material (2 - 5 %).
- Ranges of source contributions to $PM_{2.5}$ are : secondary particle formation (13 – 39 %), biomass burning (3 – 35%), coal and flyash (1 – 35 %), soil and road dust (1 – 36 %), vehicles (6 – 29 %), solid waste burning (3 – 15 %) and construction material (0.6 – 5 %).
- Contribution of secondary particles, biomass burning and vehicles are higher during winter season compared to summer season both in $PM_{2.5}$ and PM_{10}.
- Contribution by coal and flyash is higher during summer season (PM_{10}: 24 – 50 % and $PM_{2.5}$: 18– 35 %) compared to winter season (PM_{10}: 7 to 15 % and $PM_{2.5}$: 1 - 10%).
- Contribution by soil and road dust is higher during summer season (PM_{10}: 19 – 34 % and $PM_{2.5}$: 21 – 36%) compared to winter season (PM_{10}: 8 –24 %and $PM_{2.5}$:1 – 11 %).



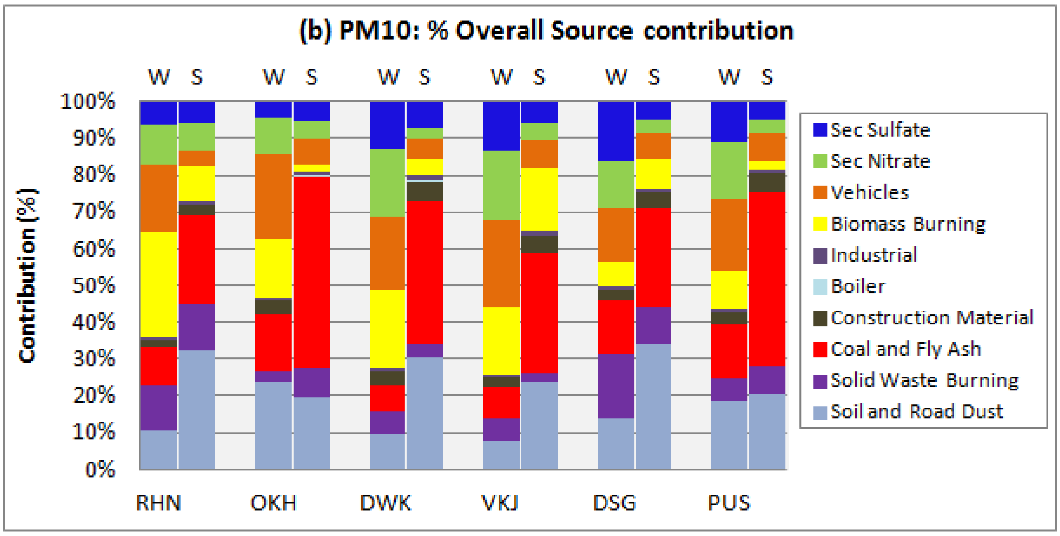
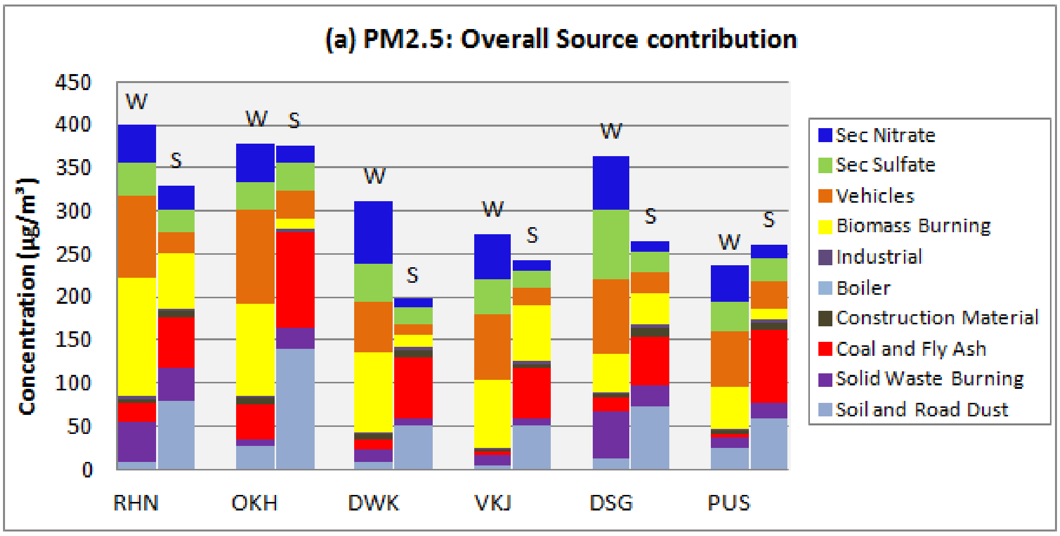


Figure 4.38: Overall Results of CMB Modeling for PM_{10}



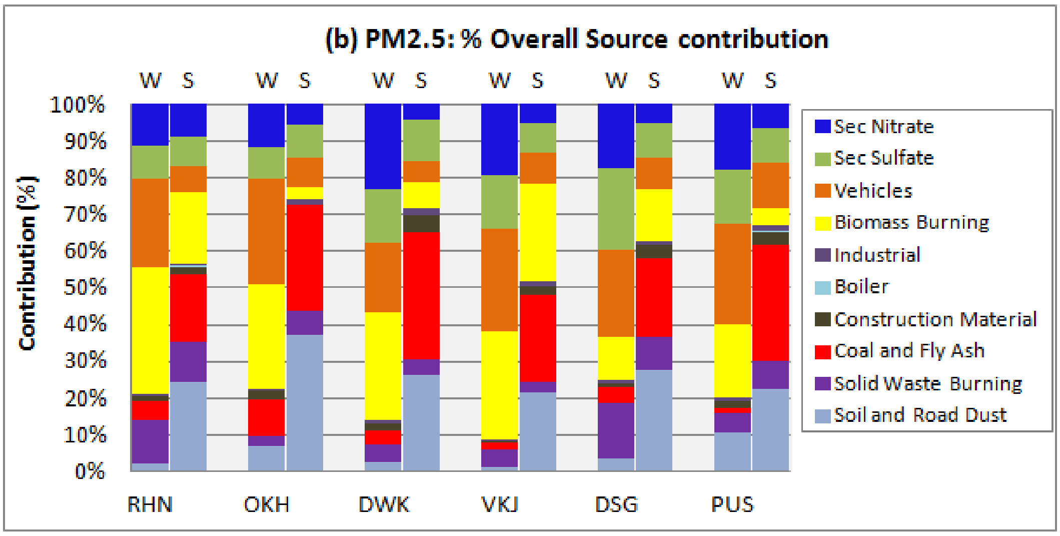


Figure 4.39: Overall Results of CMB Modeling for $PM_{2.5}$

Table 4.13: Statistical Summary of the Source Apportionment in PM$_{10}$ for Winter Season (Concentration in µg/m^3)

Site location	Parameter	Measured PM$_{10}$	Calculated PM$_{10}$	% Mass	R²	% Source Contribution									
						Sec Sulfate	Sec Nitrate	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	Average	592.56	616.71	104.97	0.67	6.01	10.21	28.91	0.69	11.20	1.98	9.12	0.02	12.76	19.10
	StdDev	185.43	177.64	8.75	0.07	3.05	3.39	9.04	0.27	6.92	0.61	9.86	0.03	11.21	7.86
	CoV	0.31	0.29	0.08	0.10	0.51	0.33	0.31	0.39	0.62	0.31	1.08	1.72	0.88	0.41
	Maximum	1043.39	1015.34	123.90	0.75	10.88	18.39	43.32	1.06	24.68	3.16	25.62	0.09	38.99	32.15
	Minimum	362.54	413.60	94.10	0.53	2.66	5.82	17.04	0.31	0.00	1.04	0.00	0.00	0.00	6.52
OKH	Average	696.86	685.21	98.27	0.75	4.35	9.73	17.11	0.47	15.50	4.13	23.13	0.00	2.16	23.42
	StdDev	209.92	219.97	7.77	0.06	2.52	3.20	7.81	0.18	7.95	2.38	10.45	0.00	1.64	7.39
	CoV	0.30	0.32	0.08	0.08	0.58	0.33	0.46	0.37	0.51	0.58	0.45	0.00	0.76	0.32
	Maximum	1254.51	1320.92	111.10	0.84	9.04	15.77	36.13	0.94	30.22	8.99	45.76	0.00	7.01	38.06
	Minimum	408.42	408.23	78.50	0.65	0.32	4.27	0.00	0.22	0.00	0.00	5.57	0.00	0.19	11.37
DWK	Average	543.85	529.89	97.83	0.64	12.31	18.04	20.82	0.65	8.16	3.99	10.24	0.03	6.00	19.77
	StdDev	174.49	168.36	7.70	0.05	6.35	4.34	7.56	0.20	8.10	1.62	7.82	0.05	3.41	4.93
	CoV	0.32	0.32	0.08	0.07	0.52	0.24	0.36	0.32	0.99	0.41	0.76	1.91	0.57	0.25
	Maximum	981.39	978.12	110.90	0.72	29.97	26.01	42.13	1.07	29.18	8.07	24.67	0.17	13.96	28.27
	Minimum	321.00	305.63	85.60	0.51	5.38	11.19	10.00	0.35	0.00	1.58	1.08	0.00	1.16	10.18
VKJ	Average	555.38	502.31	91.86	0.69	12.69	18.74	19.46	0.64	8.89	2.56	8.03	0.00	5.44	23.55
	StdDev	188.78	169.40	13.24	0.06	6.68	5.79	7.14	0.19	6.03	1.78	5.90	0.01	3.40	11.61
	CoV	0.34	0.34	0.14	0.09	0.53	0.31	0.37	0.29	0.68	0.70	0.73	3.04	0.63	0.49
	Maximum	959.63	985.69	118.40	0.76	28.23	34.94	32.19	1.16	24.73	7.11	20.56	0.05	15.15	43.00
	Minimum	254.04	264.40	71.50	0.51	3.54	11.20	7.01	0.44	1.03	0.54	1.58	0.00	0.67	2.58
DSG	Average	687.58	721.03	104.14	0.70	15.30	13.80	7.81	0.67	14.87	3.16	14.39	0.03	15.15	14.82
	StdDev	334.96	393.70	13.25	0.05	6.59	4.96	6.29	0.32	7.44	1.71	5.91	0.08	11.00	4.67
	CoV	0.49	0.55	0.13	0.08	0.43	0.36	0.81	0.47	0.50	0.54	0.41	3.05	0.73	0.31
	Maximum	1418.94	1726.25	124.20	0.77	28.42	26.65	20.78	1.46	31.44	6.58	22.78	0.34	36.64	25.21
	Minimum	280.14	300.53	81.00	0.56	7.30	5.76	0.00	0.27	1.06	0.79	0.80	0.00	2.56	5.31
PUS	Average	472.79	448.05	95.37	0.71	11.39	15.56	11.11	0.88	14.69	3.19	17.61	0.01	6.35	19.20
	StdDev	184.79	177.97	11.77	0.03	5.13	3.81	4.77	0.30	5.09	0.97	7.79	0.02	3.81	6.66
	CoV	0.39	0.40	0.12	0.05	0.45	0.25	0.43	0.34	0.35	0.31	0.44	2.02	0.60	0.35
	Maximum	757.22	761.72	121.40	0.77	25.27	24.39	16.66	1.70	24.22	6.00	36.03	0.08	16.07	38.50
	Minimum	171.93	174.14	70.00	0.65	4.45	8.33	0.00	0.53	6.23	1.66	0.09	0.00	1.78	10.15

Table 4.14: Statistical Summary of the Source Apportionment in PM_{10} for Summer Season (Concentration in µg/m^3)

Site location	Parameter	Measured PM_{10}	Calculated PM_{10}	% Mass	R²	% Source Contribution									
						Sec Sulfate	Sec Nitrate	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	Average	544.71	562.23	104.24	0.67	5.81	8.53	10.46	0.78	24.89	2.93	29.77	0.06	12.74	4.76
	StdDev	178.82	177.20	10.87	0.06	1.88	4.01	6.78	0.40	12.00	2.56	14.76	0.12	6.85	2.43
	CoV	0.33	0.32	0.10	0.09	0.32	0.47	0.65	0.51	0.48	0.87	0.50	2.05	0.54	0.51
	Maximum	927.90	928.68	123.80	0.77	9.18	16.32	25.08	1.68	40.28	6.76	66.57	0.48	28.54	8.83
	Minimum	274.78	279.63	75.10	0.58	2.90	3.81	0.10	0.21	0.00	0.00	12.00	0.00	0.00	0.25
OKH	Average	632.43	648.72	103.30	0.68	5.41	4.64	2.18	1.31	49.66	-	18.59	0.06	7.58	7.04
	StdDev	170.45	168.00	8.92	0.06	2.49	2.29	2.48	0.53	11.92	-	9.28	0.09	3.24	3.33
	CoV	0.27	0.26	0.09	0.08	0.46	0.49	1.14	0.40	0.24	-	0.50	1.43	0.43	0.47
	Maximum	954.75	936.80	122.10	0.74	11.52	12.01	7.33	2.31	73.58	-	44.52	0.27	14.06	12.74
	Minimum	373.84	456.45	86.50	0.51	1.86	2.29	0.00	0.49	27.08	-	5.86	0.00	0.00	1.65
DWK	Average	457.63	448.51	98.21	0.68	7.02	2.99	5.36	1.53	37.37	5.27	30.63	0.02	3.83	5.97
	StdDev	137.91	144.92	11.43	0.06	2.64	0.82	5.98	0.86	15.11	2.83	16.16	0.05	2.31	2.75
	CoV	0.30	0.32	0.12	0.09	0.38	0.27	1.12	0.56	0.40	0.54	0.53	1.91	0.60	0.46
	Maximum	722.94	756.02	116.20	0.76	12.14	5.19	23.74	4.59	64.88	10.44	66.83	0.15	7.77	10.99
	Minimum	163.25	178.70	81.20	0.52	2.70	1.63	0.00	0.50	16.14	1.23	1.86	0.00	0.56	1.57
VKJ	Average	413.20	409.78	100.03	0.64	5.65	5.05	18.17	1.33	33.32	4.97	21.40	0.17	2.34	7.60
	StdDev	90.15	94.78	14.59	0.06	4.54	3.20	11.60	0.77	15.05	2.75	18.77	0.37	1.20	4.43
	CoV	0.22	0.23	0.15	0.09	0.80	0.63	0.64	0.58	0.45	0.55	0.88	2.22	0.51	0.58
	Maximum	644.79	663.89	123.80	0.75	15.70	11.60	39.50	3.51	65.36	12.78	74.24	1.68	5.53	19.18
	Minimum	274.77	274.64	69.20	0.50	0.00	1.20	1.19	0.28	10.73	0.00	1.85	0.00	0.84	1.51
DSG	Average	531.00	539.05	102.21	0.67	4.90	3.51	9.59	0.81	26.65	4.24	32.96	0.14	9.90	7.30
	StdDev	98.24	100.13	11.79	0.06	2.89	2.03	9.91	0.31	10.21	1.69	11.82	0.17	5.22	4.22
	CoV	0.19	0.19	0.12	0.09	0.59	0.58	1.03	0.39	0.38	0.40	0.36	1.18	0.53	0.58
	Maximum	680.28	739.25	123.60	0.77	10.00	9.80	31.58	1.43	48.53	6.50	57.85	0.61	16.69	14.10
	Minimum	348.67	371.26	77.80	0.56	0.41	1.11	0.00	0.27	12.66	1.29	9.91	0.00	0.87	0.67
PUS	Average	552.53	560.90	101.71	0.70	4.67	3.99	2.74	0.94	46.40	5.25	21.02	0.13	7.50	7.37
	StdDev	122.95	145.64	13.06	0.06	2.86	1.66	2.48	0.28	15.65	1.59	11.92	0.12	4.45	3.12
	CoV	0.22	0.26	0.13	0.08	0.61	0.42	0.90	0.30	0.34	0.30	0.57	0.94	0.59	0.42
	Maximum	771.91	841.47	121.00	0.80	10.06	8.23	6.92	1.37	66.12	7.97	44.86	0.41	18.64	15.56
	Minimum	336.65	329.72	73.40	0.58	0.53	2.38	0.00	0.36	21.52	2.77	0.00	0.00	1.16	3.62

Table 4.15: Statistical Summary of the Source Apportionment in $PM_{2.5}$ for Winter Season (Concentration in $\mu g/m^3$)

Site location	Parameter	Measured $PM_{2.5}$	Calculated $PM_{2.5}$	% Mass	R²	% Source Contribution									
						Sec Sulfate	Sec Nitrate	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	Average	428.45	399.41	92.82	0.66	9.07	10.47	35.34	0.66	5.35	1.34	1.91	0.01	10.90	24.94
	StdDev	119.09	142.16	14.57	0.04	3.31	3.53	9.60	0.26	4.13	0.62	1.80	0.01	8.56	12.06
	CoV	0.28	0.36	0.16	0.06	0.36	0.34	0.27	0.39	0.77	0.46	0.94	1.74	0.79	0.48
	Maximum	733.83	813.54	122.10	0.71	17.42	18.47	51.16	1.32	14.79	2.24	5.14	0.03	26.28	45.95
	Minimum	261.34	241.52	78.30	0.57	4.12	3.22	20.06	0.24	0.00	0.00	0.00	0.00	0.00	12.64
OKH	Average	412.40	377.87	91.69	0.74	7.91	12.03	29.86	0.69	9.45	1.90	6.36	0.01	2.53	29.26
	StdDev	116.87	109.93	12.93	0.06	3.35	3.59	15.19	0.24	7.10	1.79	7.73	0.03	1.13	7.78
	CoV	0.28	0.29	0.14	0.08	0.42	0.30	0.51	0.34	0.75	0.94	1.22	3.02	0.45	0.27
	Maximum	681.65	542.56	114.50	0.82	14.33	20.37	54.78	1.22	24.34	4.60	30.07	0.11	5.04	45.13
	Minimum	240.29	201.46	73.20	0.62	3.38	5.36	3.02	0.38	0.00	0.00	0.00	0.00	0.51	16.75
DWK	Average	339.46	311.25	93.18	0.62	14.10	22.66	30.52	0.88	4.68	1.76	2.25	0.00	4.76	18.39
	StdDev	156.92	137.13	12.47	0.05	4.97	5.03	8.01	0.26	6.52	0.79	1.99	0.01	2.31	8.70
	CoV	0.46	0.44	0.13	0.08	0.35	0.22	0.26	0.30	1.39	0.45	0.88	2.39	0.49	0.47
	Maximum	825.90	738.25	117.10	0.70	26.80	31.83	40.71	1.32	27.08	3.60	6.15	0.03	9.67	33.03
	Minimum	202.27	177.42	77.90	0.54	7.89	11.97	17.45	0.43	0.32	0.00	0.00	0.00	1.97	8.01
VKJ	Average	300.79	272.47	89.14	0.69	14.28	18.44	30.79	0.75	1.63	0.60	1.09	0.00	4.49	27.92
	StdDev	88.70	104.80	12.54	0.05	5.54	5.65	12.53	0.17	1.24	0.37	2.19	0.00	2.49	10.58
	CoV	0.29	0.38	0.14	0.07	0.39	0.31	0.41	0.23	0.76	0.61	2.01	0.00	0.55	0.38
	Maximum	472.56	495.03	112.40	0.78	25.75	29.73	54.50	1.12	4.53	1.40	8.80	0.00	12.67	50.78
	Minimum	180.89	141.14	70.70	0.58	6.27	10.89	11.64	0.50	0.00	0.03	0.00	0.00	2.23	13.33
DSG	Average	425.49	363.72	88.19	0.68	21.02	17.39	13.43	0.65	4.50	1.22	3.35	0.02	12.75	25.68
	StdDev	224.96	186.60	13.10	0.05	5.95	5.15	10.10	0.19	4.78	0.60	5.00	0.04	9.07	7.43
	CoV	0.53	0.51	0.15	0.08	0.28	0.30	0.75	0.30	1.06	0.49	1.49	2.42	0.71	0.29
	Maximum	757.90	742.66	110.90	0.77	29.83	31.39	33.23	0.98	17.17	2.21	17.34	0.11	28.94	46.80
	Minimum	157.60	174.73	70.00	0.59	11.51	11.07	0.00	0.34	0.00	0.00	0.00	0.00	3.61	16.26
PUS	Average	272.02	236.04	85.62	0.67	15.03	18.31	20.75	1.20	1.12	1.79	9.96	0.01	5.67	26.15
	StdDev	73.37	80.95	11.48	0.03	6.39	4.63	7.93	0.36	1.36	0.68	11.65	0.04	2.86	7.56
	CoV	0.27	0.34	0.13	0.04	0.42	0.25	0.38	0.30	1.21	0.38	1.17	2.71	0.50	0.29
	Maximum	368.26	364.41	109.30	0.71	28.12	25.18	34.75	1.91	4.12	3.62	36.71	0.14	13.10	45.92
	Minimum	142.11	121.54	71.10	0.60	5.81	10.74	0.00	0.65	0.00	0.73	0.00	0.00	2.13	17.85

Table 4.16: Statistical Summary of the Source Apportionment in $PM_{2.5}$ for Summer Season (Concentration in µg/m^3)

Site location	Parameter	Measured $PM_{2.5}$	Calculated $PM_{2.5}$	% Mass	R^2	% Source Contribution									
						Sec Sulfate	Sec Nitrate	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	Average	337.16	329.52	97.98	0.68	8.33	9.82	21.64	0.85	17.17	2.36	21.42	0.07	11.36	6.98
	StdDev	114.34	114.61	12.43	0.05	2.68	5.16	15.55	0.63	8.96	1.64	15.87	0.18	4.87	4.09
	CoV	0.34	0.35	0.13	0.08	0.32	0.53	0.72	0.75	0.52	0.69	0.74	2.78	0.43	0.59
	Maximum	598.44	595.52	122.60	0.77	12.76	20.95	41.32	2.39	32.07	5.11	49.38	0.73	18.86	13.76
	Minimum	169.54	154.83	71.70	0.60	4.16	4.15	3.75	0.08	2.00	0.00	0.00	0.00	3.95	1.31
OKH	Average	410.02	383.83	93.51	0.70	9.35	5.54	3.68	1.40	27.06	-	35.65	0.09	6.70	8.96
	StdDev	119.36	126.62	12.07	0.05	3.53	2.37	7.40	0.72	11.83	-	10.68	0.12	2.59	5.47
	CoV	0.29	0.33	0.13	0.07	0.38	0.43	2.01	0.51	0.44	-	0.30	1.33	0.39	0.61
	Maximum	704.02	726.17	120.70	0.78	17.04	13.10	25.33	3.43	49.99	-	50.74	0.39	14.01	24.14
	Minimum	232.02	240.79	70.20	0.61	3.59	2.73	0.00	0.68	7.94	-	14.49	0.00	1.71	1.60
DWK	Average	205.62	197.50	96.03	0.68	12.45	4.85	8.43	1.72	32.93	5.02	24.83	0.02	4.12	5.64
	StdDev	82.88	89.83	14.30	0.06	4.92	2.09	13.84	0.82	14.16	1.73	17.85	0.04	1.61	2.75
	CoV	0.40	0.45	0.15	0.08	0.39	0.43	1.64	0.48	0.43	0.35	0.72	2.44	0.39	0.49
	Maximum	356.06	385.38	124.00	0.77	22.10	9.85	38.30	3.10	69.83	7.94	61.81	0.14	7.53	9.96
	Minimum	78.69	78.18	69.30	0.57	5.56	1.44	0.00	0.38	6.54	2.52	0.69	0.00	2.45	1.06
VKJ	Average	252.14	242.67	95.52	0.66	7.62	5.43	27.24	1.23	22.37	2.55	21.50	0.09	2.78	9.20
	StdDev	70.72	81.49	11.69	0.05	5.22	2.95	12.49	0.68	13.54	1.87	17.13	0.14	1.25	4.50
	CoV	0.28	0.34	0.12	0.08	0.69	0.54	0.46	0.56	0.61	0.73	0.80	1.57	0.45	0.49
	Maximum	356.69	416.89	121.90	0.81	19.09	12.45	47.51	3.10	55.74	5.79	66.88	0.54	5.33	19.78
	Minimum	120.47	106.16	77.50	0.58	0.00	1.62	0.00	0.19	4.50	0.00	0.00	0.00	0.98	0.06
DSG	Average	276.15	266.09	97.76	0.71	9.80	4.93	13.24	0.94	21.28	4.11	26.12	0.05	9.09	10.44
	StdDev	104.44	91.54	8.84	0.05	4.61	2.49	12.86	0.65	10.63	1.89	9.85	0.12	3.78	9.19
	CoV	0.38	0.34	0.09	0.07	0.47	0.51	0.97	0.69	0.50	0.46	0.38	2.23	0.42	0.88
	Maximum	467.37	441.38	118.60	0.79	18.13	13.15	34.70	2.80	50.55	6.43	39.23	0.40	15.87	32.08
	Minimum	140.28	134.25	77.10	0.63	1.83	1.55	0.00	0.32	7.00	1.23	4.39	0.00	3.31	0.00
PUS	Average	268.75	260.40	97.90	0.68	10.36	6.93	5.24	1.42	31.14	3.35	19.56	0.41	7.85	13.74
	StdDev	104.93	101.54	10.03	0.05	6.41	5.69	6.70	0.84	12.06	1.36	16.39	0.43	4.32	6.19
	CoV	0.39	0.39	0.10	0.07	0.62	0.82	1.28	0.59	0.39	0.41	0.84	1.06	0.55	0.45
	Maximum	577.81	577.57	114.80	0.75	22.64	28.76	24.15	3.86	50.33	5.71	75.14	1.75	19.90	32.66
	Minimum	116.49	109.40	80.50	0.58	0.00	0.81	0.00	0.40	3.84	0.71	0.26	0.00	2.90	6.34

Table 4.17(a): Concentration Apportionment: Winter PM_{10} (Concentration in $\mu g/m^3$)

Site location	Measured PM10	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	593	105	174	4	64	13	66	0	74	116
OKH	697	99	109	3	108	28	164	0	17	158
DWK	544	167	113	3	38	20	52	0	32	105
VKJ	555	163	92	3	43	13	40	0	30	119
DSG	688	210	49	5	106	20	100	0	127	104
PUS	473	119	48	4	66	14	83	0	27	87
Overall	592	144	97	4	71	18	84	0	51	115
Std	87	43.39	47.14	0.76	29.97	5.95	44.75	0.11	42.12	23.94

Table 4.18(b): Concentration Apportionment: Winter $PM_{2.5}$ (Concentration in $\mu g/m^3$)

Site location	Measured PM2.5	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	428	81	137	3	20	6	8	0	48	96
OKH	412	76	108	3	39	8	26	0	10	109
DWK	339	118	92	3	12	5	8	0	15	59
VKJ	301	92	80	2	4	2	4	0	13	76
DSG	425	143	43	2	15	4	13	0	54	88
PUS	272	76	47	3	3	4	25	0	12	65
Overall	363	98	84	3	16	5	14	0	25	82
Std	68	27.31	36.24	0.26	13.08	2.12	9.49	0.02	19.96	19.20

Table 4.19(a): Percentage Apportionment: Winter PM$_{10}$ (Concentration in µg/m^3)

Site location	Measured PM10	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	593	16.99	28.29	0.72	10.36	2.07	10.72	0.02	12.03	18.80
OKH	697	14.46	15.85	0.45	15.73	4.05	23.96	0.00	2.45	23.06
DWK	544	31.51	21.24	0.62	7.21	3.86	9.73	0.02	5.98	19.83
VKJ	555	32.44	18.27	0.64	8.58	2.51	7.90	0.00	5.99	23.67
DSG	688	29.09	6.82	0.69	14.66	2.80	13.85	0.04	17.61	14.43
PUS	473	26.47	10.68	0.86	14.75	3.15	18.62	0.01	6.02	19.43
Overall	592	24.61	16.68	0.65	12.13	3.08	14.41	0.02	8.75	19.67
Std	87	7.64	7.64	0.14	3.63	0.77	6.11	0.02	5.49	3.33

Table 4.20(b): Percentage Apportionment: Winter PM$_{2.5}$ (Concentration in µg/m^3)

Site location	Measured PM2.5	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	428	20.28	34.42	0.68	5.10	1.46	1.99	0.01	12.01	24.05
OKH	412	19.99	28.54	0.67	10.24	2.12	6.88	0.01	2.61	28.94
DWK	339	37.82	29.50	0.85	3.95	1.77	2.56	0.00	4.75	18.80
VKJ	301	33.89	29.23	0.77	1.50	0.58	1.32	0.00	4.79	27.92
DSG	425	39.36	11.90	0.66	4.25	1.24	3.70	0.02	14.80	24.08
PUS	272	32.28	19.73	1.20	1.31	1.84	10.68	0.02	5.27	27.68
Overall	363	29.88	25.84	0.78	4.79	1.52	4.29	0.01	7.75	25.14
Std	68	8.51	8.21	0.21	3.25	0.55	3.60	0.01	4.84	3.77

Table 4.21(a): Concentration Apportionment: Summer PM_{10} (Concentration in $\mu g/m^3$)

Site location	Measure PM10	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	545	76	53	4	134	16	183	0	73	25
OKH	632	63	13	8	327		122	0	50	43
DWK	458	45	19	6	174	23	135	0	18	27
VKJ	413	42	71	5	133	19	98	1	9	31
DSG	531	46	45	4	145	23	185	1	54	38
PUS	553	50	14	5	265	28	116	1	42	40
Overall	522	54	36	6	196	22	140	0	41	34
Std	77	13.16	24.04	1.48	80.91	4.58	36.13	0.24	23.49	7.52

Table 4.22(b): Concentration Apportionment: Summer $PM_{2.5}$ (Concentration in $\mu g/m^3$)

Site location	Measure PM2.5	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	337	55	64	3	60	8	80	0	37	23
OKH	410	54	12	5	110		115	0	25	31
DWK	206	30	15	3	69	9	52	0	8	11
VKJ	252	31	65	3	58	6	52	0	7	21
DSG	276	38	37	2	56	11	74	0	24	23
PUS	269	41	12	3	83	8	58	1	20	33
Overall	292	42	34	3	73	8	72	0	20	24
Std	72	10.80	25.14	0.96	20.90	1.97	33.21	0.31	11.36	7.78

Table 4.23(a): Percentage Apportionment: Summer PM$_{10}$ (Concentration in µg/m^3)

Site location	Measure PM10	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	545	13.54	9.48	0.76	23.91	2.85	32.54	0.06	12.92	4.40
OKH	632	9.67	1.93	1.25	50.39		18.82	0.07	7.70	6.67
DWK	458	9.95	4.26	1.45	38.84	5.21	30.19	0.02	4.09	5.99
VKJ	413	10.37	17.30	1.26	32.57	4.63	23.92	0.15	2.28	7.52
DSG	531	8.54	8.29	0.80	26.84	4.20	34.26	0.14	9.95	6.97
PUS	553	8.88	2.58	0.91	47.28	5.00	20.67	0.11	7.42	7.15
Overall	522	10.15	6.78	1.05	37.20	4.13	26.48	0.09	7.75	6.42
Std	77	1.79	5.76	0.28	10.79	0.94	6.48	0.05	3.85	1.13

Table 4.24(b): Percentage Apportionment: Summer PM$_{2.5}$ (Concentration in µg/m^3)

Site location	Measure PM2.5	Sec Particle	Biomass Burning	Industrial	Coal and Fly Ash	Construction Material	Soil and Road Dust	Boiler	Solid Waste Burning	Vehicles
RHN	337	16.74	19.31	0.90	18.12	2.31	24.22	0.07	11.23	7.11
OKH	410	14.06	3.07	1.35	28.65		34.29	0.09	6.57	8.15
DWK	206	15.23	7.46	1.58	34.86	4.76	26.25	0.02	4.14	5.70
VKJ	252	12.96	26.67	1.26	23.95	2.35	21.34	0.08	2.83	8.56
DSG	276	14.42	13.93	0.88	21.00	4.12	27.78	0.05	9.07	8.76
PUS	269	15.80	4.78	1.26	32.06	3.18	22.33	0.35	7.67	12.57
Overall	292	14.89	12.16	1.19	25.95	3.00	27.07	0.11	7.23	8.50
Std	72	1.34	9.20	0.27	6.52	1.08	5.42	0.12	3.11	2.30

4.7 Interpretations and Inferences

Based on the CMB modeling results (Figure 4.39 and 4.40) and their critical analyses, the following inferences and insights are drawn to establish quantified source-receptor impacts and to pave the path for preparation of action plan. Tables 4.17 to 4.20, 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: secondary particles (25 - 30%), vehicles (20 - 25%), biomass burning (17 – 26%), MSW burning (9 - 8%) and to a lesser extent soil and road dust. It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same.

  In the secondary nitrate particles, 50% contribution is attributed to emissions of NO_x within the urban area. Considering approximately 40% emission of NO_x is from vehicles, it is estimated that contribution of vehicles in secondary nitrates (to ambient air concentration) will be about 3% of total $PM_{2.5}$: this makes average vehicle contribution to $PM_{2.5}$ is about 28% in winter (Quazi, 2013).

  The summer sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$ to the ambient air level) include: coal and flyash (37 - 26%), soil and road dust (26 – 27%), secondary particles (10 - 15%), biomass burning (7 - 12%), vehicles (6 – 9%) and MSW burning (8 – 7%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.

- The two most consistent sources for PM_{10} and $PM_{2.5}$ in both the seasons are secondary particles 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 biomass burning followed by MSW burning. Soil and road dust and coal and flyash sources were consistent for PM_{10} but it was not true for $PM_{2.5}$.

- Consistent presence of secondary and vehicular PM_{10} and $PM_{2.5}$ across all sites and in two seasons, suggests these particles encompass entire Delhi region as a layer.
- Similar to the above point, in summer, consistent presence of soil and road dust and coal and flyash particles encompass entire Delhi region as a layer.
- Coal and flyash and road and soil dust in summer contribute 26-37% 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 flyash and 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 17% (for PM_{10}) 26% (for $PM_{2.5}$). Biomass burning is prohibited in Delhi and it is not a common practice at a large scale. The enhanced concentration of PM in October-November is possibly due to the effect of post-monsoon crop residue (CRB). It can be seen that the biomass contribution in PM_{10} in the month of November could be as high as 140 $\mu g/m^3$ and about 120 $\mu g/m^3$ for $PM_{2.5}$ (mean of contribution in entire winter season: 97 $\mu g/m^3$ and 86 $\mu g/m^3$) respectively. In all likelihood, the PM from biomass burning is contributed from CRB prevalent in Punjab and Haryana in winter. The back trajectory analyses suggest that the CRB and other biomass emissions may be transported to Delhi from the sources upwind of Delhi (in NW direction). There is an immediate need to control or find alternatives to completely eliminate CRB emissions to observe any significant improvement in air quality in Delhi. However, presence of sizeable biomass PM in December and January indicates to local sources present in Delhi and nearby areas.
- The contribution of MSW burning may surprise many persons. The recent study by Nagpure et al. (2015) has estimated 190 to 246 tons/day of MSW burning (∼2−3% of MSW generated; 8390 tons/day). It is a myth that MSW is not burned in Delhi. 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.

Directions for PM control

- Secondary particles

  What are the sources of secondary particles, the major contributors to Delhi'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. The NW wind is expected to transport SO_2 and transformed into sulfates emitted from large power plants and refineries situated in the upwind of Delhi. 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 5.

- Biomass burning

  CRB should be minimized if not completely stopped. Possibly it could be scheduled towards early September. All biomass burning in in Delhi 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 30 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. However, two large power plants in city are also important sources of flyash. Probably the major part is resuspension of fly ash from flyash ponds (in use or abandoned) which are not maintained properly and become dry in summer. 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 can contribute about 26% to PM_{10} and $PM_{2.5}$. The silt load on some of the Delhi'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 5.

Chapter 5

Dispersion Modeling for Existing Scenario

5.1 Introduction

USEPA's AERMOD model (described later) was run for PM_{10}, $PM_{2.5}$ and NOx to understand the impact of emissions occurring within Delhi on the ambient air at multiple locations. Centre of every grid cell (described in Chapter 3) and six sampling sites were the assigned receptors. This modeling exercise was performed for two seasons (winter and summer) and the model was calibrated for better predictions. Local meteorological data generated through WRF (Weather Research and Forecasting) model (described later) were used for the dispersion modeling and inputs emission inventory (EI) were taken from EI developed in Chapter 3. The model was first validated against the 20 day measurements carried out at six sites in each season. A Validated model ensures that physical and chemical description of atmospheric process are duly accounted and model can be used for assessing the impact and examining efficacy of pollution control action in terms of air quality improvements.

5.2 Meteorological Data

Hourly wind speed, wind direction, temperature, pressure, cloud cover (opaque), precipitation, global horizontal radiation and relative humidity for the period of October 1, 2013 - Jun 30, 2014 were generated from WRF (Weather Research and Forecasting) model at a height of 10 meter from the ground level. This generated data is validated with IMD observed information (Aryanagar, Delhi) and the results are presented in Figures 5.1 and 5.2. Windrose as summary of meteorological data are shown for the six air quality sampling sites for the period of October 1, 2013 - Jun 30, 2014 in Figure 5.1.

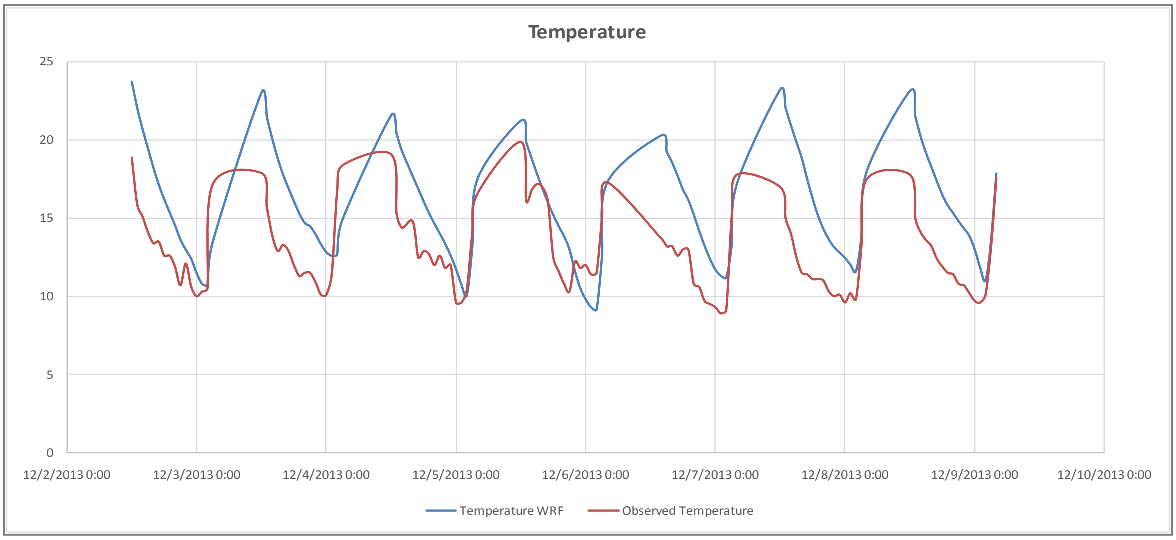


Figure 5.1: Temperature Validation of WRF generated values with IMD values

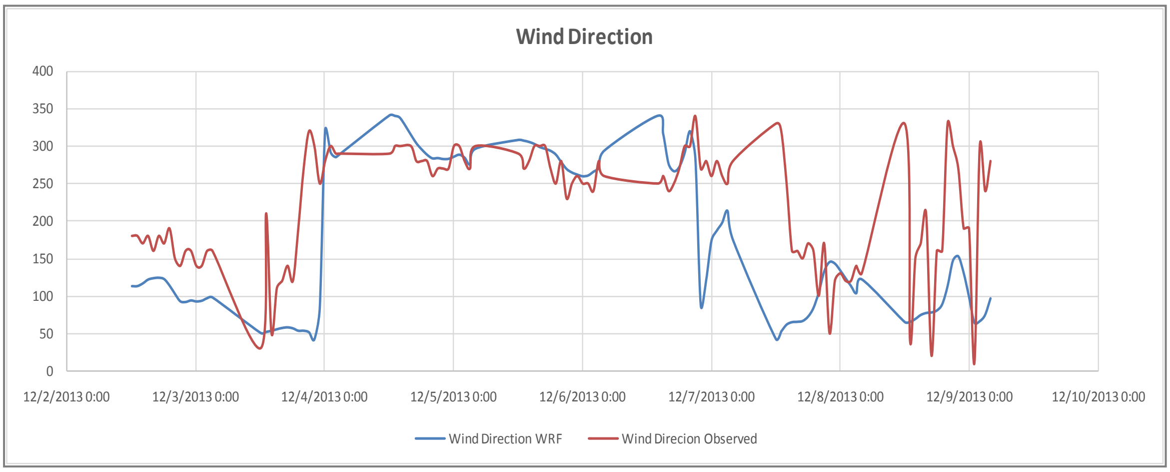
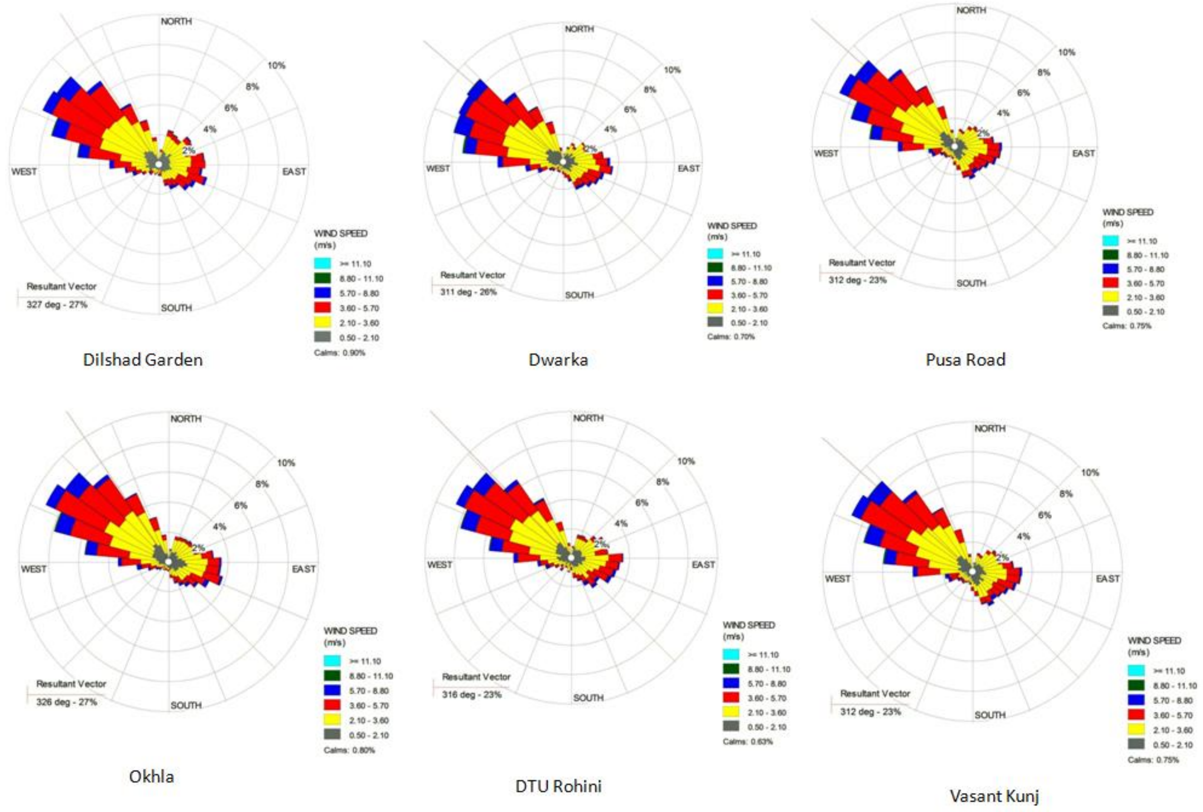


Figure 5.2: Wind Direction Validation of WRF generated values with IMD values.



Dilshad Garden Dwarka Pusa Road

Okhla DTU Rohini Vasant Kunj

Figure 5.3: Wind Rose Diagram at Six Air Quality Sampling Locations.

As expected the meteorology does not change much from one location to another. The most of the time the wind is from NW, NNW and WNN in a narrow channel. However, some wind is from SE, SSE, and ESE. The wind direction suggests that most of the pollutants will come from NW sector and some also from SE sector. The average wind speed is 3 m/s. Although not shown here, the wind speed in winter can be less than 1 m/s causing calm conditions and resulting in poor dispersion.

AERMOD

American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) is a dispersion model having the ability to characterize the planetary boundary layer (PBL) through both surface and mixed layer scaling.

AERMOD Modeling System – It is a steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain (USEPA AERMOD manual). The major components of AERMOD are:

1) AERMET – a meteorological preprocessor

2) AERMAP – a terrain data preprocessor
3) AERMOD – a dispersion model

The AERMIC meteorological preprocessor (AERMET) provides AERMOD with the meteorological information it needs to characterize the PBL. The AERMIC terrain preprocessor (AERMAP) both characterize the terrain, and generates receptor grids for the dispersion model (AERMOD). AERMET uses meteorological data and surface characteristics to calculate boundary layer parameters (e.g. mixing height, friction velocity, etc.) needed by AERMOD. This data, whether measured off-site or on-site, must be representative of the meteorology in the modeling domain.

AERMAP uses gridded terrain data for the modeling area to calculate a representative terrain-influence height associated with each receptor site. The features of the AERMOD model are: i) concept of plume penetration, ii) estimation of dispersion coefficients, iii) estimation of plume rise, iv) concentrations predictions in convective layer, v) concentration predictions in stable layer, vi) handling of downwash, and vii) treatment of simple terrain and complex terrain.

5.2 Model Performance

Model performance has been examined for seasonal averages (winter and summer) of PM_{10}, $PM_{2.5}$ and NOx. The performance of model was shown for PM_{10} (Figure 5.4 to 5.9) and $PM_{2.5}$ (Figure 10 to 15). A linear relationship is clearly seen between observed and computed levels of PM_{10} and $PM_{2.5}$ in winter months for each day of measurement. It can be concluded that in terms of R-square value, model performance is adequate (R-square 0.53 – 0.88). The model performance for daily observation was not satisfactory for summer months, especially because of unaccounted for windborne dust which has no well-defined source. The overall conclusion is that observed PM_{10} and $PM_{2.5}$ levels are generally higher than predicted levels for both PM_{10}, and $PM_{2.5}$. For NO_2 the observed values are higher than predicted value at four sites, and vice versa for two locations. For PM_{10} and $PM_{2.5}$, there is significant part as background level (which may be coming from outside the political boundary of Delhi or from missing sources (anthropogenic or non-anthropogenic)). It may be seen in chapter 4 that the secondary particles contribute 16 % to PM_{10} and 19% to $PM_{2.5}$ concentration. The results suggest that the model is performing satisfactorily in predicting concentrations and can be used for development of strategies.

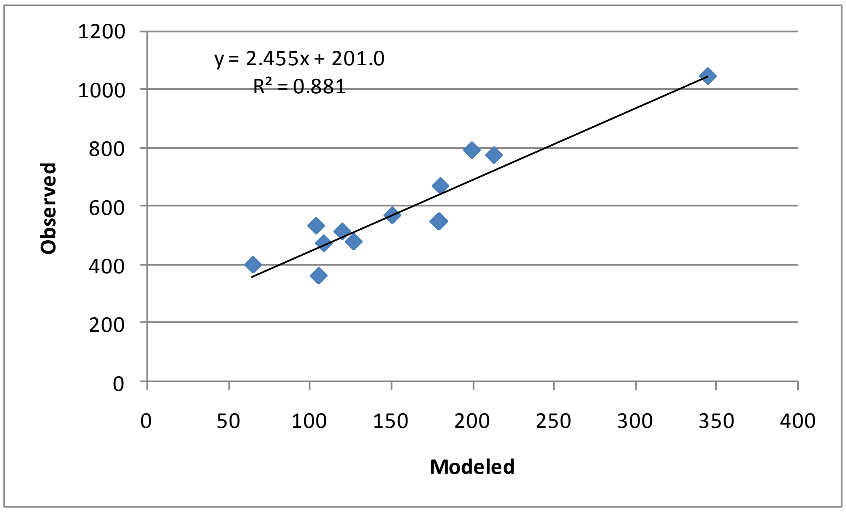


Figure 5.4: Observed vs computed PM_{10} (μg/m^3), Winter, RHN

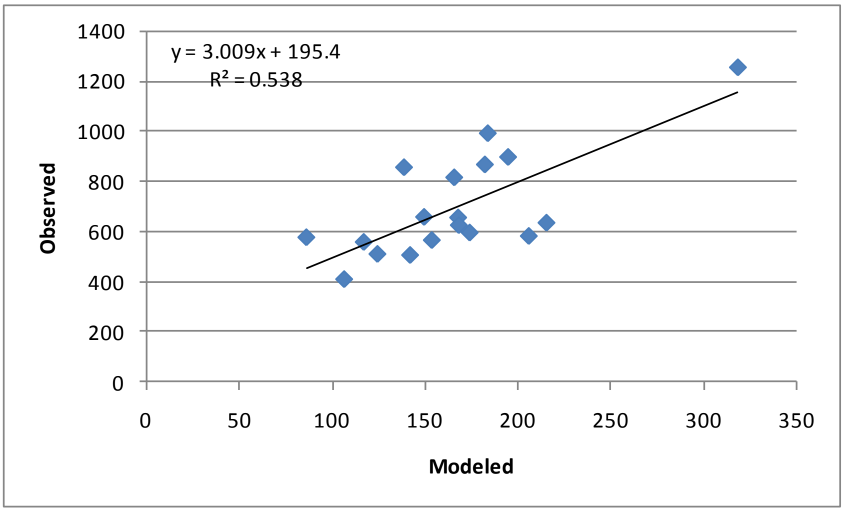


Figure 5.5: Observed vs Predicted of PM_{10} for Winter, OKH

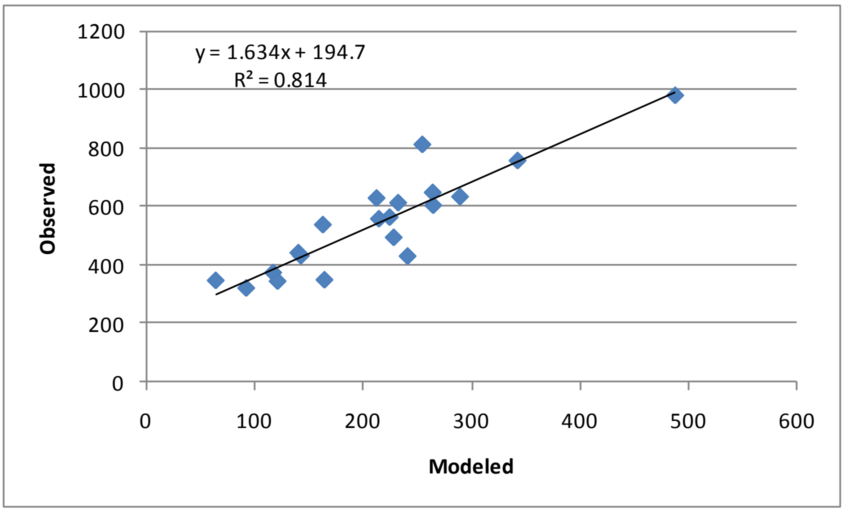


Figure 5.6: Observed vs Predicted of PM_{10} (μg/m^3), for Winter, DWK

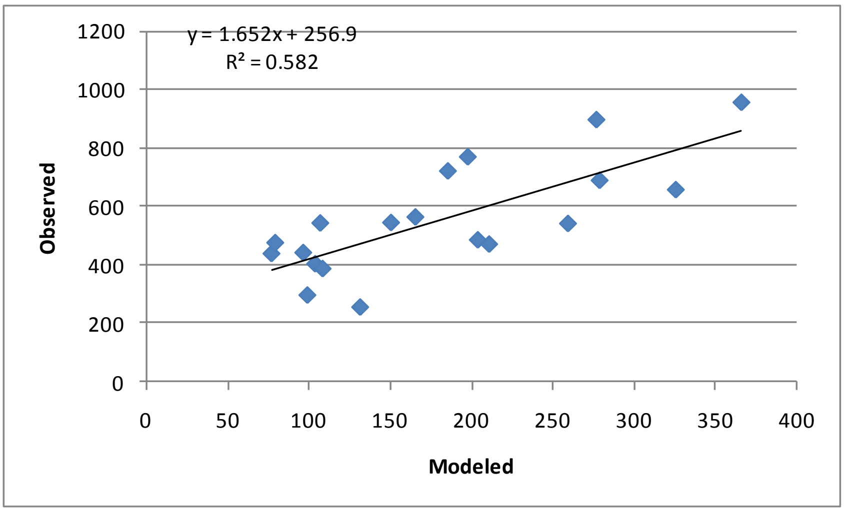


Figure 5.7: Observed vs Predicted of PM_{10} (μg/m^3), Winter, VKJ

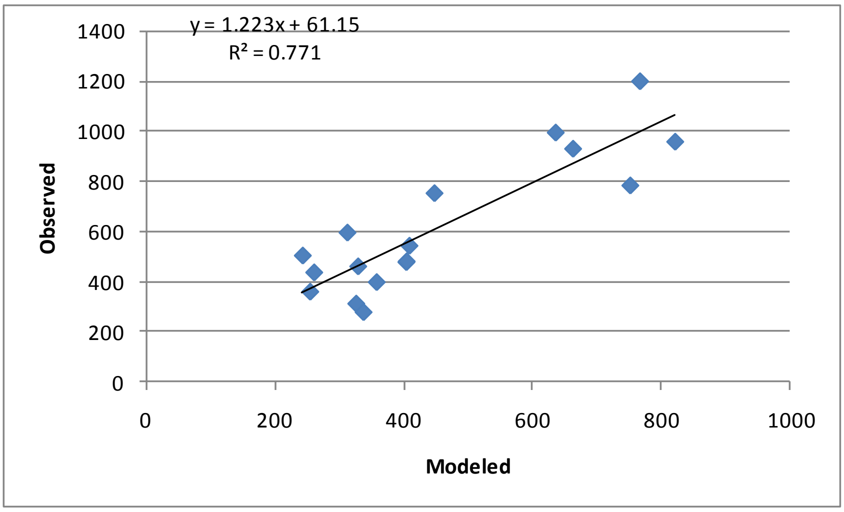


Figure 5.8: Observed vs Predicted of PM_{10} (μg/m^3), for Winter, DSG

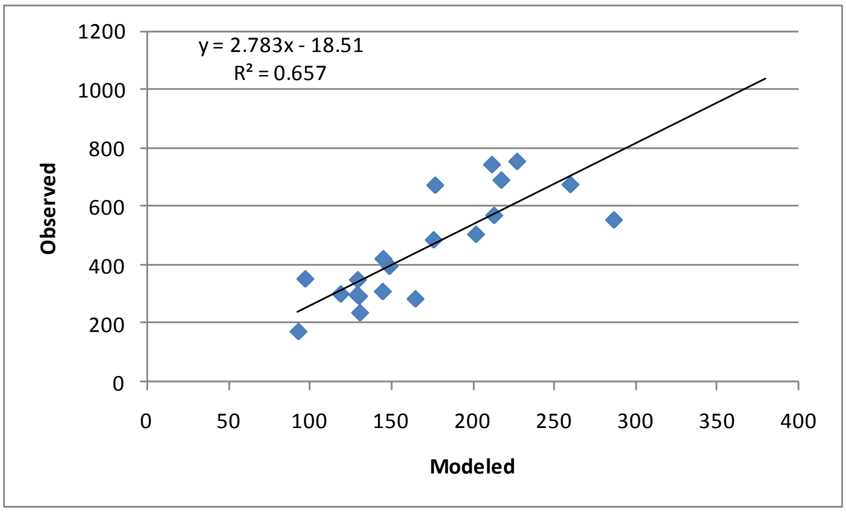


Figure 5.9: Observed vs Predicted of PM_{10} (μg/m^3), Winter, PUS

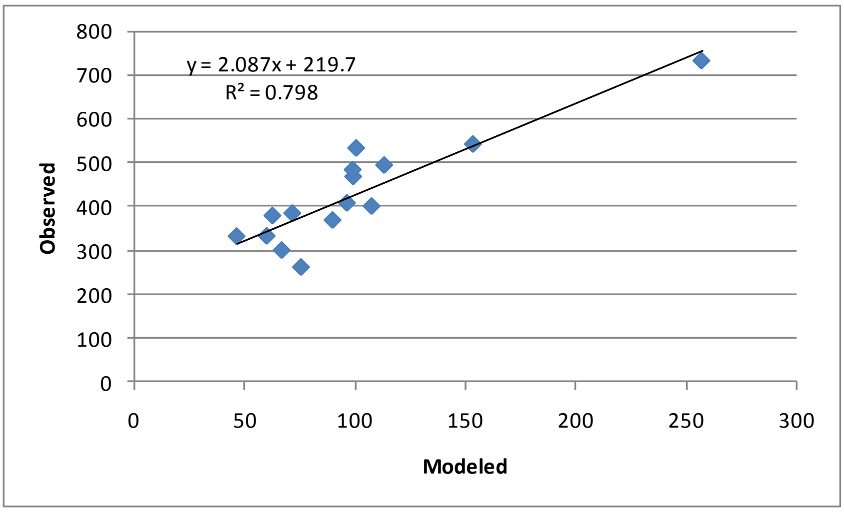


Figure 5.10: Observed vs Predicted of $PM_{2.5}$ ($\mu g/m^3$), Winter, RHN

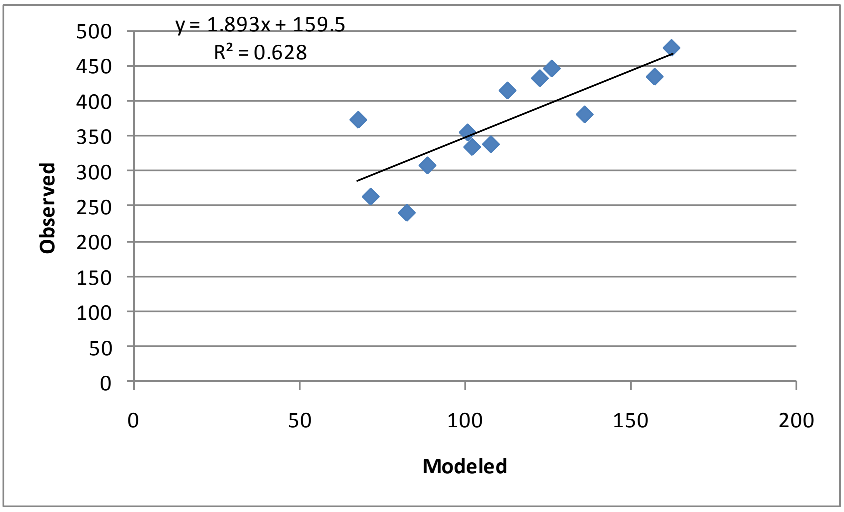


Figure 5.11: Observed vs Predicted of $PM_{2.5}$ ($\mu g/m^3$), Winter, OKH

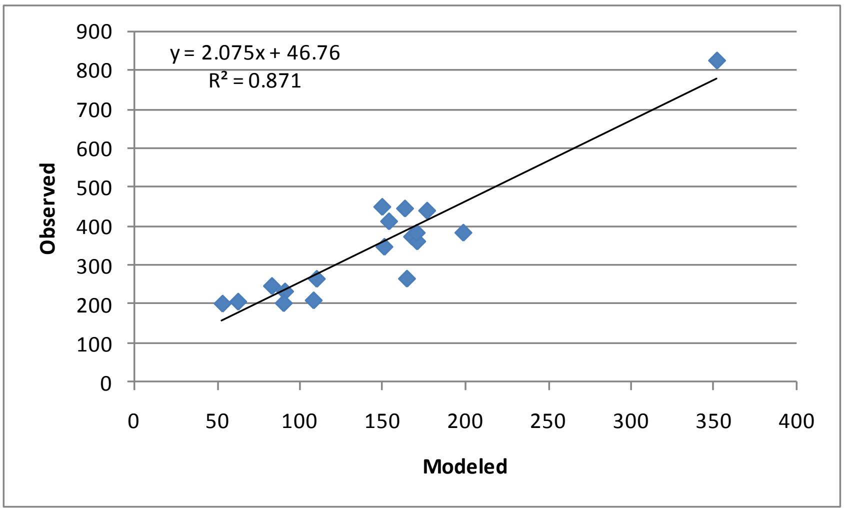


Figure 5.12: Observed vs Predicted of $PM_{2.5}$ ($\mu g/m^3$), Winter, DWK

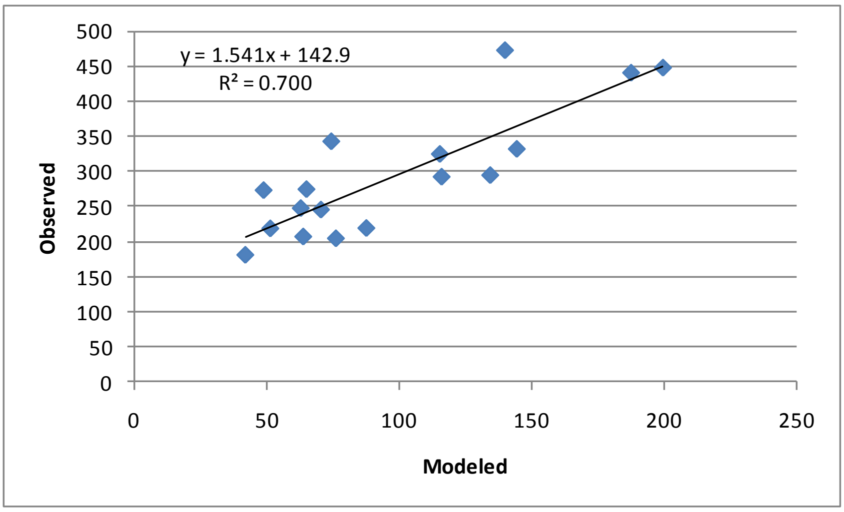


Figure 5.13: Observed vs Predicted of $PM_{2.5}$ (μg/m^3), Winter, VKJ

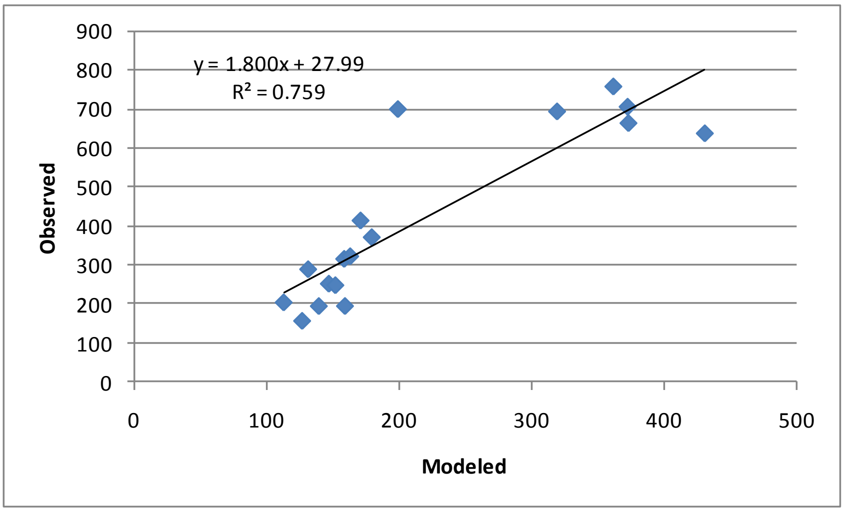


Figure 5.14: Observed vs Predicted of $PM_{2.5}$ (μg/m^3), Winter, DSG

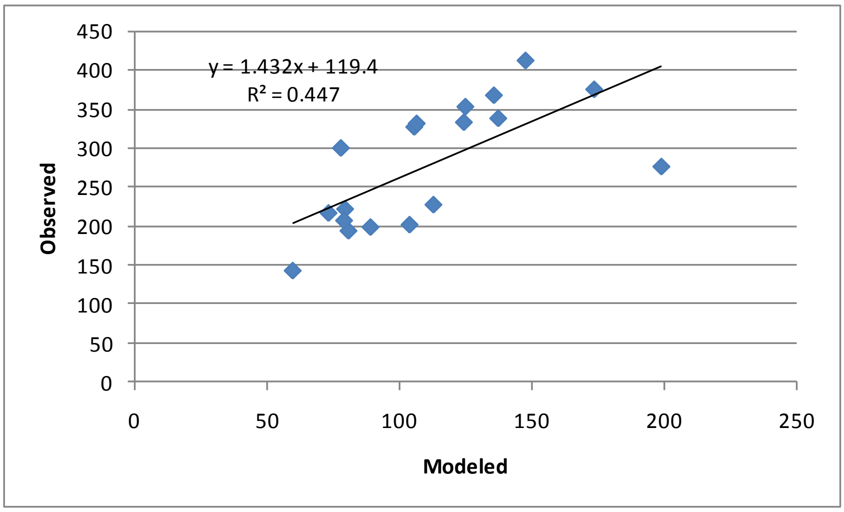


Figure 5.15: Observed vs Predicted of $PM_{2.5}$ (μg/m^3), Winter, PUS

Figure 5.16 and 5.17 show the highest 24-hr concentration isopleths for PM_{10} and $PM_{2.5}$ respectively. Although there are high pollution levels all around in Delhi, this analysis can be used for finding hotspots in the city. The hot spot for PM level point of view is Shahdara, East Delhi, Badarpur, Rithala and Badli Samerpur.

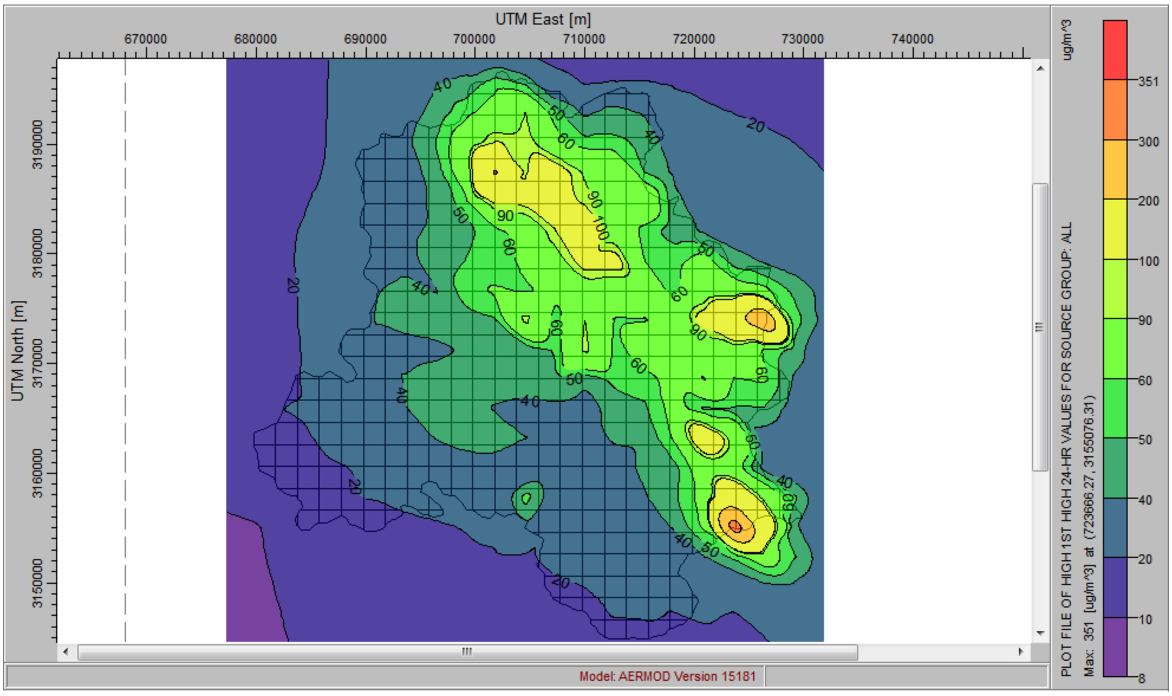


Figure 5.16: Isopleths of highest 24-hr values of PM_{10}

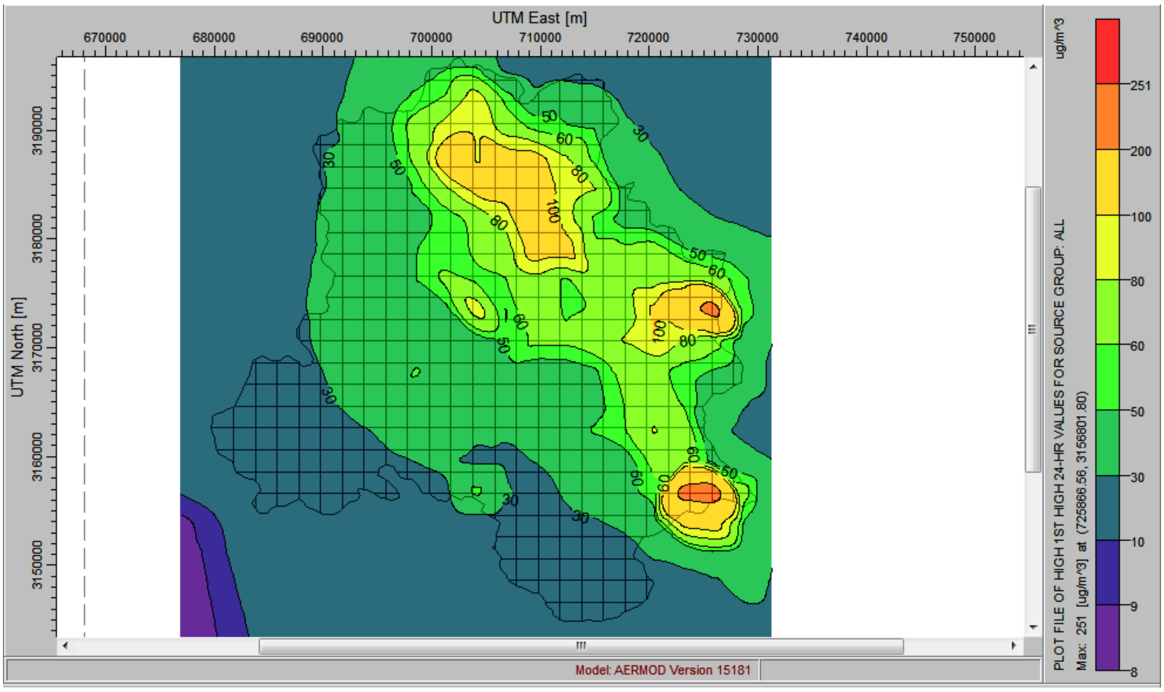


Figure 5.17: Isopleths of highest 24-hr values of $PM_{2.5}$

A liner relationship between observed and computed levels of PM_{10} and $PM_{2.5}$ in winter months with R-square 0.53 – 0.88 shows that model describe the physics of dispersion and captures the impact of emission quite well.

The observed concentrations are much higher 1.6 to 3.0 times for PM_{10} and 1.4 to 2.8 times for $PM_{2.5}$ than the model computed concentrations in terms of slope of the best fit lines (Figure 5.4 to 5.15). This although not a desirable situation but at the same time not uncommon that the models under predict (CPCB, 2010; Behera et al., 2011). The model under prediction suggests incomplete emission inventory and/or missing sources. Although all efforts we made to account for all sources, uncertainties both in activity data and emission factor exist. Since the model does not account formation of secondary particles, this provides a plausible reason for under prediction.

What is interesting to note is that the best fit lines have very high intercepts; 170 $\mu g/m^3$ and about 100 $\mu g/m^3$ for $PM_{2.5}$. Since model performance in terms linear association is established for observed and computed concentrations, the large intercept concentration can be attributed to the background pollution in Delhi that appears to be contributed from outside Delhi. In other words almost about one-third of pollution PM levels can be attributed to emissions from outside the Delhi. This analysis makes it clear that pollution control will have to focus both inside and outside Delhi for improvements in air quality not only in Delhi but the entire NCR. The pollution control options and their efficacies have been examined in Chapter 6.

Chapter 6

Control options, Analyses and Prioritization for Actions

6.1 Air Pollution Scenario in the City of Delhi

The city of Delhi has a complex urban environment with respect to air pollution and faces severe air pollution of PM_{10}, $PM_{2.5}$ and NO_2. There are several prominent sources within and outside Delhi contributing to PM_{10}, $PM_{2.5}$ and NO_2 in ambient air; these pollutants can be taken as surrogate of other pollutants also, as most of the pollutants coexist and have common sources. The Chapter 5 has focused on dispersion modeling and has revealed that there are significant emitting sources both inside and outside Delhi. In other words, an integrated pollution control approach in the region can only improve the air quality. Chapter 3 presents the emission inventory and Chapter 4 describes the contributions of sources to the ambient air concentrations. Based on the comprehensive source apportionment study, the sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality are different in summer and winter. The highlights of source apportionment study are presented below.

The winter sources (% contribution given in parenthesis for PM_{10} - $PM_{2.5}$) include: secondary particles (25 - 30%), vehicles (20 - 25%), biomass burning (17 – 26%), MSW burning (9 - 8%) and to a lesser extent soil and road dust. 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} - $PM_{2.5}$) include: coal and fly ash (37 - 26%), soil and road dust (26 – 27%), secondary particles (10 - 15%), biomass burning (7 - 12%), vehicles (6 – 9%) and MSW burning (8 – 7%). 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 Tables 6.1 and 6.2 for $PM_{2.5}$ and NO_2 respectively. The assessment of efficacies of control options and development of these tables are outcome of thorough modelling exercise and further analyses and interpretation to arrive at improvements in ground level air quality throughout the city. The description of control options is given below.

Table 6.1: Control Options, Emission Load and Reductions in $PM_{2.5}$

A. Immediate Actions (for details see sections 6.2.1 to 6.2.12)

Source	Option No.	Description Option	Existing $PM_{2.5}$ (kg/day)	Controlled $PM_{2.5}$ (kg/day)	Mean Modeled Concentration ($\mu g/m^3$) Averaging time: Oct-June		
					Existing $PM_{2.5}$	**Controlled $PM_{2.5}$**	**Percent Change**
Hotels/ Restaurants	1	Stop use of Coal	1758	675	3.60	0.70	80.56
Domestic Cooking	2	LPG to all	6940	4111	7.20	3.60	50.00
MSW Burning	3	Stop MSW burning: Improve collection and disposal (landfill and waste to energy plants)	1771	0	1.80	0.00	100.00
Construction and Demolition	4	Vertically cover the construction area with fine screens	1292	646	0.80	0.40	50.00
		Handling and Storage of Raw Material: completely cover the material					
		Water spray and wind breaker					
		Store the waste inside premises with proper cover					
Concrete Batching	5	Water Spray	3594	1797	2.00	1.20	40.00
		Wind Breaker					
		Bag Filter at Silos					
		Enclosures, Hoods, Curtains, Telescopic Chutes, Cover Transfer Points and Conveyer Belts					
Road Dust and Soil dust	6.1	Vacuum Sweeping of major roads (Four Times a Month)	22165	6649	36.00	10.80	70.00
		Carpeting of shoulders					
		Mechanical sweeping with water wash					
	6.2	Plant small shrubs, perennial forages, grass covers in open areas	--	--	--	--	--
	Sub Total (A)				**51.4**	**16.7**	**67.5**

Notes: (1) The above plan is also effective for control of PM_{10}. The expected reduction is about 67% in PM_{10}. (2) The model computed concentrations are 9-month average. Specific reduction in winter or summer can be estimated from source apportionment in chapter 4 (refer to Tables 4.17 to 4.20).

Table 6.2: Control Options, Emission Load and Reductions in $PM_{2.5}$ (Continued...)

B. Time-bound Actions (for details see sections 6.2.1 to 6.2.12)

Source	Option No.	Description Option	Existing $PM_{2.5}$ (kg/day)	Controlled $PM_{2.5}$ (kg/day)	Mean Modeled Concentration ($\mu g/m^3$) Averaging time: Oct-June		
					Existing $PM_{2.5}$	Controlled $PM_{2.5}$	Percent Change
Vehicles	7.1	Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws wef July 2017: New residential and commercial buildings to have charging facilities	11623	5808	33.2	16.6	50.0
	7.2	Retrofitment of Diesel Particulate Filter: wef July 2018					
	7.3	Implementation of BS – VI for all diesel vehicles including heavy duty vehicles (non-CNG buses and trucks) and LCVs (non-CNG): wef January 2019					
	7.4	Inspection/ Maintenance of Vehicles					
	7.5	Ultra Low Sulphur Fuel (<10 PPM); BS-VI compliant: wef January 2018					
	7.6	2-Ws with Multi Point Fuel Injection (MPFI) system or equivalent: wef January 2019	--	--	--	--	--
Industry and DG Sets	8.1	Reduce sulphur content in Industrial Fuel (LDO, HSD) to less than 500 PPM	1743	1220	3.93	2.751	30.00
	8.2	Minimize uses, uninterrupted power supply, Banning 2-KVA or smaller DG sets	--	--	--	--	--
Secondary Particles	9.1	De-SOx-ing at Power Plants within 300 km of Delhi	--	132438	38.5	3.9	90.0
	9.2	De-NOx-ing at Power Plants within 300 km of Delhi	--	153349	25.2	2.5	90.1
Secondary Organic Aerosols	10	Controlling Evaporative emissions: Vapour Recovery System at petrol pumps (Fuel unloading and dispensing)	--	--	40.1	8.0	80.0
Biomass Burning	11	Managing crop residue burning in Haryana, Punjab and other local biomass burning, Potential alternatives: energy production, biogas generation, commercial feedstock for cattle, composting, conversion in biochar, Raw material for industry: wef July 2016	--	--	84.0	8.4	90.0
Fly Ash	12	Wind Breaker, Water Spraying, plantation, reclamation	--	--	--	--	--
	Sub Total (B)				**224.9**	**42.2**	**81.3**
	Total (A+B)				**276.3**	**58.9**	**78.7**
Contribution in concentration from outside local sources**					**59**	**13.0**	**78.0**
Overall Total					**335.3**	**71.8**	**78.6**

Notes: (1) The above plan is also effective for control of PM_{10}. The expected reduction is about 81% in PM_{10}. (2) The model computed concentrations are 9-month average. Specific reduction in winter or summer can be estimated from source apportionment in chapter 4 (refer to Tables 4.17 to 4.20).

* Vehicle growth rate calculated for 2019. It is assumed 80% of the vehicles added per year will go out of vehicle fleet because of being 15 years (or more) old.

**Air quality standards cannot be achieved unless stringent measures are also taken at sources outside Delhi. It is recommended that the above actions are implemented in NCR, else 24-hr $PM_{2.5}$ levels are likely to exceed 110 $\mu g/m^3$.

Table 6.3: Control Options, Emission Load and Reductions in NOx

Source	Option Number	Description Option	Existing NO_2 (kg/day)	Controlled NO_2 (kg/day)	Percent Change
Hotels/Restaurants	1	Stop use of Coal	1103.0	502.5	54.4
Domestic Cooking	2	LPG to all	7682.0	7047.5	8.3
MSW Burning	3	Stop MSW burning: Improve collection and disposal (landfill and waste to energy plants)	738.0	0.0	100.0
Vehicles	4.1	Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws wef July 2017: New residential and commercial buildings to have charging facilities	113443.0	111264.0	1.9
	4.2	Implementation of BS – VI for all diesel vehicles including heavy duty vehicles (non-CNG buses and trucks) and LCVs (non-CNG): wef January 2019	119607.0	116558.3	2.5
	4.3	Inspection/ Maintenance of Vehicles	-	-	-
	4.4	Ultra Low Sulphur Fuel (<10 PPM); BS-VI compliant: wef January 2018	-	-	-
	4.5	2-Ws with Multi Point Fuel Injection (MPFI) system or equivalent: wef January 2019	-	-	-
Power Plants	5.1	De-NOx-ing at Power Plants within Delhi	161612.0	32322.4	80.0
Total			**--**	**--**	**34**

It is expected that with the implementation of control options, the overall NOx emission will reduce by 34%. This implies that average concentration of NOx will reduce to about 55 μg/m^3 and air quality standard of NOx will be achieved throughout the Delhi city.

6.2.1 Hotels/Restaurant

There are approximately 9000 Hotels/Restaurants in the city of Delhi, which use coal (mostly in tandoors). The PM emission in the form of flyash from this source is large (Chapter 3) 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. A careful examination shows that about 67 % reduction of PM_{10} (2142 kg/d) and $PM_{2.5}$ (1083 kg/d) emission from this source can be achieved by stopping uses of coal. It may be seen that coal and flyash is the largest contributing sources in summer and this action is expected to reduce ambient air concentration by 2.7 $\mu g/m^3$ and 2.9 $\mu g/m^3$ in PM_{10} and $PM_{2.5}$ respectively.

6.2.2 Domestic Sector

Although Delhi is kerosene free and 90% of the households use LPG for cooking, the remaining 10% uses wood, crop residue, cow dung, and coal for cooking (Census-India, 2012). The LPG should be made available to remaining 10% households to make the city 100% LPG-fueled. This action is expected to reduce 55% of PM_{10} (3270 kg/d), 50% of $PM_{2.5}$ (2829 kg/d) and 4% of NOx (635 kg/d) emissions from domestic sector. This reduction in emission will reduce the ambient air concentration by 4.4 $\mu g/m^3$ and 3.6 $\mu g/m^3$ in PM_{10} and $PM_{2.5}$ respectively.

6.2.3 Municipal Solid Waste (MSW) Burning

The MSW burning is wide spread in Delhi and NCR, more frequent in winter. A recent study by Nagpure et al. (2015) in Delhi has estimated 190 to 246 tons/day of MSW burning (∼2−3% of MSW generated; 8390 tons/day). The presence of chloride (see chapter 2) in the ambient air indicates that along with MSW, plastics and tyres burning could also be taking place in some areas. The estimated emissions are: 2000 kg/d of PM_{10} and about 1800 kg/d of $PM_{2.5}$. MSW burning contributes to nearly 10% of PM_{10} and $PM_{2.5}$ in ambient air (Chapter 4) in winters. Any form of garbage burning should be strictly stopped and monitored for its compliance. It will require development of infrastructure (including access to remote and congested areas) for effective collection of MSW and disposal at landfill site. The other viable option due to space constraint is to use Waste to Energy technology with effective flue gas control system to dispose of MSW. A complete ban on MSW burning can almost bring the emissions from this source to zero and one can see an improvement of 5-10 percent in air quality.

6.2.4 Construction and Demolition

The construction and demolition emission can be classified as temporary or short term. In city like Delhi which is high in urban agglomeration, these activities are frequent. It can be seen from Chapter 3 that this source is the third most contributor to area source emission in PM_{10} and importantly it is a consistent source all through the year. 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. 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 wind breakers
- vehicle cleaning and specific fixed wheel washing on leaving site and damping down of haul routes
- Actual construction area is covered by fine screen
- No storage (no matter how small) of construction material near road side (up to 10 m from the edge of road)

The suggested control measures will reduce the emission by 50%. This reduction in emission will reduce the ambient air concentration by 1.6 $\mu g/m^3$ (Sharma, 2010). This will also reduce the road dust and fly ash contribution to ambient air concentration.

6.2.5 Ready Mix Concrete Batching

The ready mix concrete is used for construction activities. In city like Delhi which is high in urban agglomeration, these activities are frequent. It can be seen from chapter 3 that this source is the third most contributor to total PM_{10} emission. As large amount of flyash generation is also expected from this source because pozzalan cement is used in the process has about 35 percent fly ash in it. The control measures include:

- Wet suppression (Figure 6.1)
- Wind speed reduction (Figure 6.2)
- The transfer of pozzalan cement and other material to silos is one of the major emission sources in the plant, and installation of fabric filter should be compulsory.

- Waste should be properly disposed. It should not be kept lying near the roads as it may contribute to road dust emission.
- Proper handling of raw material (loading, unloading, storage, etc).
- Vehicle cleaning and specific fixed wheel washing on leaving site and damping down of haul routes.
- All transfer points and conveyer belts should be covered
- Telescopic chute should be used for dropping the raw material

Figure 6.1: Dust Suppression System; Sprays are used to capture airborne dust

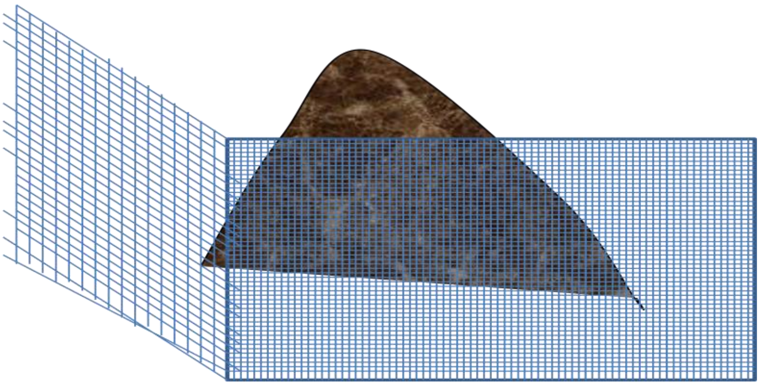


Figure 6.2: Windscreen for dust control from storage area

The introduction of fabric filter will reduce the emission by 96% emissions from the silo. This will also reduce the road dust and fly ash contribution to ambient air concentration.

6.2.6 Road Dust

It can be seen from chapters 3 and 4, that the road dust emission and its contribution to ambient air concentration is consistent and it is one of the largest sources of PM_{10} and $PM_{2.5}$ in summer. It was assumed that the observed silt load on road was the result of one month of accumulation. The following control measures are evaluated and suggested to reduce the dust emissions on major roads:

1. Mechanical sweeping with water wash: The road dust PM_{10} emission estimated is 79 ton/day and it depends on the season and moisture on the road. This emission will be maximum in summer and least in monsoon. Efficiency of mechanical sweeping has been reported as 55% (Amato et al., 2010). If the sweeping of the main roads is done twice a month, the road dust emission will be reduced by 23% and if the frequency is increased to four times in a month, then the road dust emission will be reduced by 52%. This reduction is likely to reduce the ambient air concentration of PM_{10} by 71 $\mu g/m^3$ in summer.
2. 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 emission at the end of the month will be 46 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% i.e. road dust emission at the end of the month will be 24 ton/day. This reduction is likely to reduce ambient air concentration of PM_{10} by 93 $\mu g/m^3$ in summer.
3. It is more important that condition of the roads is maintained properly and paved wall to wall. Broken roads are source of silt accumulation and particle generation.
4. Soil dust could be part of road dust also. It is recommended that open fields should be kept slightly wet and small shrubs are planted to prevent drift of dust in summer.

6.2.7 Vehicles

It can be seen from Chapters 3 and 4 that the vehicle emission and their contribution to ambient air concentration is the significant to PM_{10} and $PM_{2.5}$ both in winter and summer. In winter, on average vehicles can contribute 25% to $PM_{2.5}$ and at certain locations this contribution could be above 35%. In summer, vehicular contribution is masked by other prominent sources. There is a significant contribution of diesel vehicles (trucks, buses, LCVs an cars etc) to PM_{10}, $PM_{2.5}$ and NOx. Therefore, control measures have focused on advanced technological intervention for diesel vehicles.

1. Retro-fitment of Diesel Particulate Filter (DPF): These filters have PM emission reduction efficiency of 60-90%. If the diesel vehicle entering in the city has been equipped with DPF, there is a reduction of 40% emission. This reduction in emission will reduce the ambient air concentration by 10 $\mu g/m^3$.
2. Introduction of Electric/Hybrid Vehicles: If electrical and hybrid vehicles are introduced, it is assumed that by January 2017, 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws will be electric/hybrid vehicles. The percentage reduction in emission estimated to be 2.3 %. If we assume additional multiplier of 1.5 to electrical and hybrid vehicles of January 2017, the reduction in PM emission will be about 4.5% and net improvement in air quality by about 1-2 $\mu g/m^3$.
3. It is recommended that the sulphur content in diesel should be brought down to 10 ppm or less by end of 2018. This ultra-low sulphur fuel will reduce PM_{10} and $PM_{2.5}$ emissions from vehicles by about 6 percent.
4. If the above points (1,2,3) are implemented as scheduled, then there is an effective reduction of 51 percent of total vehicular emissions.
5. The effectiveness and usefulness of accelerated implementation of BS VI has been analysed. It is important to introduce BS VI as both PM and NO_x emissions are expected to reduce significantly. Introduction of BS VI will reduce PM_{10} and $PM_{2.5}$ emission by 2.4 $\mu g/m^3$ for the introduction year (2019). The reduction in NO_2 control will help in reducing secondary nitrates and will also prevent formation of ozone.
6. Introduction of 2-Ws with Multi Point Fuel Injection (MPFI) or simply referred to as Fuel Injection system: This option was not assessed but it can impart significant reduction in emission from 2-Ws. It is recommended to introduce this technology from January 2018.
7. Vehicular emission norms/standards are enforced for the new vehicles at the factory. PUC checks are the means to check emissions from on road vehicles. Emissions from in-use vehicles also depend on the maintenance and up keep of vehicles. There is a need to ensure that vehicles are properly maintained as per the recommendation of the manufacturer. In this regard, it is proposed 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.

8. For the long-term sustenance of the air quality, the vehicular population should stabilize to the level of number of vehicle at the end of 2019, as vehicular emission reduction in Tables 6.1 and 6.2 are up to December 2019.

6.2.8 Industries and Diesel Generator Sets

Industries

Several measures have been taken to control emissions in the industry (including relocation), especially in small and medium size industries. It is however recommended industries use light diesel oil (LDO) and high speed diesel (HSD) of sulphur content of 500 ppm or less in boilers or furnaces. Expected PM control will be about 15 to 30 % from this source and SO_2 emissions will become negligible. No new polluting industry should be allowed in Delhi.

Diesel Generator Sets

For Delhi and NCR, the sulphur content should be reduced to 500 ppm in HSD and LDO to be used in DG sets. A reduction of 15 to 30% of PM emission from this source is expected from present emission of about 1400 kg/d, if sulphur content is brought down to 500 ppm. It will have major impact on reduction of SO_2 and secondary particles. The DG sets should be properly maintained and regular inspection should be done. Emission limit prescribed by CPCB in Environment (Protection) (Third Amendment) Rules, 2013, should be strictly followed (MoEF, 2013).

All efforts should be made to minimize uses of DG sets and to strengthen regular power supply. Since small DG sets are used at the ground level and create nuisance and high pollution. It is recommended that all DG sets of size 2 KVA or less should not be allowed to operate; solar powered generation, storage and inverter should be promoted.

6.2.9 Secondary Particles: Control of SO_2 and NO_2 from Large point sources

What are the sources of secondary particles, the major and consistent contributors to Delhi’s PM? These particles 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. The prevalent wind from north-west and south-east can bring in the secondary sulfates and nitrates from large power plants and refineries almost from all sides in Delhi. However, contribution of NO_2 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. In Delhi, estimated contribution of secondary particles in $PM_{2.5}$ is 30% and requires strict controls. What is even more significant, controlling secondary particles through control of SO_2 and NO_x will benefit the entire NCR and just not Delhi.

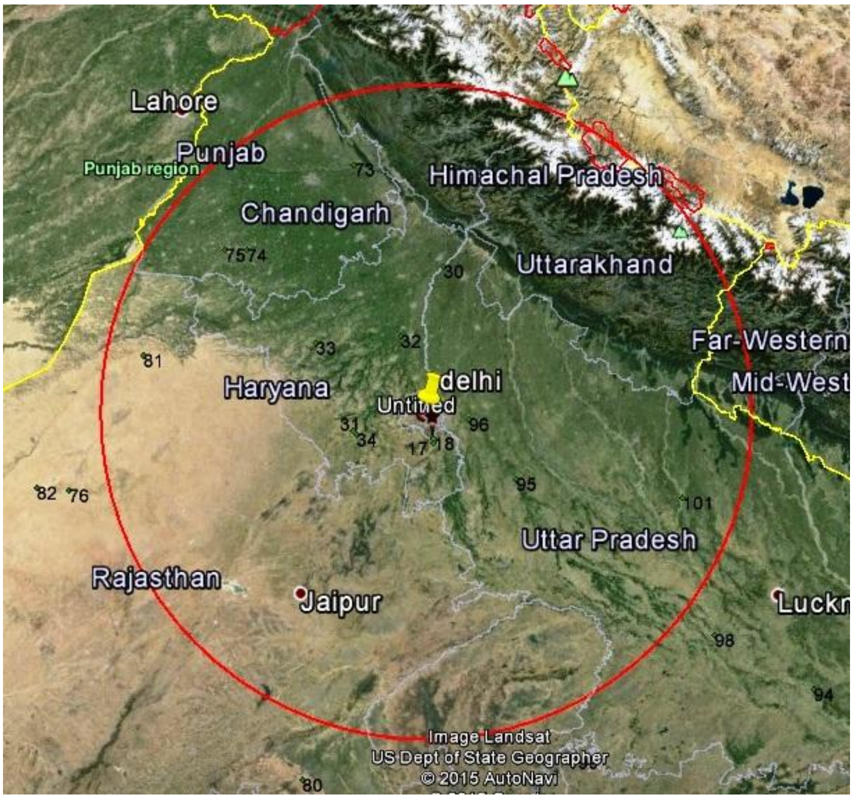


Figure 6.3: Locations of thermal power plants (Numerical number indicates TPPs)

There are 13 thermal power plants (TPPs) (Figure 6.3) with a total capacity of over 11000 MW within the radius of 300 km from Delhi, which are expected to contribute to secondary particles. Based on the study done by Quazi (2013), it was shown that power plants contribute nearly 80% of sulfates and 50% nitrates to the receptor concentration. A calculation assuming 90% reduction in SO_2 from these plants can reduce 72% of sulphates.

This will effectively reduce PM_{10} and $PM_{2.5}$ concentration by about 62 $\mu g/m^3$ and 35 $\mu g/m^3$ respectively. Similarly 90% reduction in NO_x can reduce the nitrates by 45%. This will effectively reduce PM_{10} and $PM_{2.5}$ concentration by about 37 $\mu g/m^3$ and 23 $\mu g/m^3$ respectively. It implies that control of SO_2 and NO_x from power plant can reduce PM_{10} concentration approximately by 99 $\mu g/m^3$ and for $PM_{2.5}$ the reduction could be about 57 $\mu g/m^3$.

SO_2 removal technologies include wet flue gas desulfurization (FGD), dry FGD utilizing a spray dryer absorber and dry adsorbent (lime and lime stone) injection. Most SO_2 removal processes are engineered oxidation systems which transforms calcium sulfite ($CaSO_3$) formed by the SO_2 removal process to calcium sulfate ($CaSO_4$: gypsum). In a De-NOx-ing (removal of NO_2) system, NO_2 is reduced by ammonia (NH_3) or urea to nitrogen and water. Based on economic considerations, a suitable reducing agent can be selected out of ammonia like materials. This process is called Selective Catalytic Reduction (SCR). SCR De-NOx-ing system consists of reactor, injection system and catalyst.

6.2.10 Secondary Organic Aerosols

The contribution of secondary organic aerosols (SOA) in Delhi has not been assesssed. However, Behera and Sharma (2010) have estimated that the SOA is about 17 percent of Total $PM_{2.5}$ in Kanpur, another city in Ganga basin. We have assumed 12% of PM_{10} is SOA based on $PM_{10}/PM_{2.5}$ ratio. This implies that emissions of VOCs (volatile organic compounds) need to be controlled both in and outside of Delhi, as SOA can be formed from VOC sources at far distance from the receptor. It is recommended that all petrol pumps in Delhi should install vapour recovery system to reduce VOC emissions both at the time of dispensing petrol/diesel but also at the time of filling of storage tank at the petrol pump. In addition, the VOC sources should be controlled in all industry producing, handling and using solvents in Delhi and NCR. It is also recommended that VOC free paints to be used in painting works.

6.2.11 Biomass Burning

India being an agrarian country produces a huge amount of crop residue annually, both on field and off-field, which is estimated to be about 500-550 million tons (Mt) (Indian Agricultural Research Institute, 2012). Rice crop contributes 36% of total crop residue whereas wheat contributes 22%. Traditionally, these residues are used for feeding cattle, composting, thatching roofs in rural areas, and fuel for domestic and industrial uses. Uttar Pradesh (60 Mt) is the largest generator of crop residue followed by Punjab (51 Mt) and Haryana (28 Mt). According to a study conducted by Pathak et al. (2010) and from the calculations based on IPCC coefficients, total crop residue burnt per year in the country is estimated to be over 90 million tones.

In Punjab and Haryana about 80% of rice residue was burned in situ; in Uttar Pradesh it was about 25%. In Punjab, Haryana and Uttar Pradesh, 23% of wheat and 25% of sugarcane trash is burnt in the field (Indian Agricultural Research Institute, 2012).

Combine harvesters are used for harvesting both rice and wheat crops, especially in Punjab, Haryana and Uttar Pradesh. About 80% of straw is left on the field on using combine harvesters, most of which end up being burnt. The time gap between harvest of rice crop and sowing of wheat crop in Punjab, Haryana, and Uttar Pradesh during October-November is typically 15-20 days. In this short time span, farmers prefer burning the straw in the field, which is quick, easy, and economical, rather than incorporating it for soil enrichment or harvesting it for any other use. Wheat straw being a highly valued cattle fodder is largely removed. Consequently, huge amount of paddy straw is burned on the open field during October-November. The practice is known as stubble burning. Though crop residue burning (CRB) is banned in these regions, practice still continues. At present, about 70-80 Mt of rice residue is disposed of through open field burning (Gadde et al., 2009; Badarinath et al., 2009, 2006). The thick cloud of smoke emitted causes atmospheric pollution and poor air quality at local, global and regional scale and poses serious threat to human health (Kaskaoutis, 2014). This emission of CRB can certainly impact air quality in Delhi and other cities in the Gangetic plane.

The CMB modelling (Chapter 4) has clearly identified biomass burning as an important contributor to Delhi's PM_{10} and $PM_{2.5}$. The data of Mayapuri air quality station, maintained by CPCB has been analysed and interpreted for 2005 to 2013. From the equation, concentration $C = k. (Q/(u.H))$, it can be seen that concentration is inversely proportional to mixing height (H) and wind speed (u). It is found that mixing height in Delhi during post-monsoon is about 800m and that during winter is about 500m (CPCB, 2002). Also, the wind speed is found to be the same during both the periods. At Mayapuri air quality station (Figure 6.4) which shows a sudden increase in PM_{10} concentration from the latter half of October to the first half of November, after which it drops gradually during winter. Therefore, from the above equation it can be concluded that emission rate (Q) during post monsoon (Oct – Nov) is greater than that during winter ($Q_{PoM}/Q_w > (H_{PoM} * u_{PoM})/(H_W * u_W)$), thus increased Q is attributed to CRB and peak in November is the impact of CRB in air quality of Delhi.

The enhanced concentration in October-November is possibly due to the effect of post-monsoon crop residue burning. It can be seen that the biomass contribution in PM_{10} in the month of November could be as high as 140 µg/m^3 and about 120 µg/m^3 for $PM_{2.5}$. There is an immediate need to control perhaps completely eliminate CRB emissions to see any effective improvement in air quality in Delhi.

A second peak is observed in the pre-monsoon season from second half of March to first half of May. It is plausible to assume that the pre-monsoonal rise in concentration is caused by the dust transport by North-Westerly and Westerly winds (Mishra and Shibata, 2012), with possible contribution from the crop residue burning during pre-monsoon season.

Alternatives to biomass burning

Alternatives to biomass burning include removal of the straw from the field and its use for other economic activities: energy production, biogas generation, commercial feedstock for cattle, composting, conversion in biochar, raw material for industry (John A., 2013).

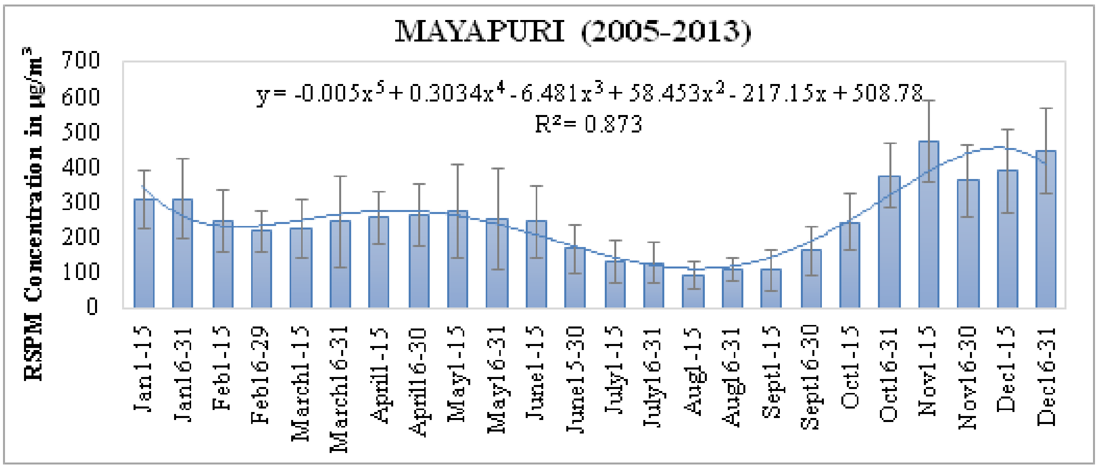


Figure 6.4: Seasonal Variation of PM_{10}

6.2.12 Fly Ash

This study has identified that fly ash is a major contributor especially to PM_{10} in summer. This implies that there is more windborne fly ash in the atmosphere. In the earlier discussions in this chapter, control at other sources (hotels/restaurants and rapid mix plants) were the analysed. In use or abandoned fly ash ponds are also contributing to PM pollution. There is a possibility of contribution of flyash from brick kilns operating outside Delhi. The following actions are proposed to reduce the fly ash emissions.

Preventing the wind from entraining the dust particles can be accomplished by keeping the wind from blowing over the material. This can be done by confinement or by wind control or by developing a dense green belt all around the ash pond.

Reduction in wind speed, and therefore reduction in emissions can be achieved using one or more of the many diverse forms of windscreen in addition to enclosing the dust area. Commercial windscreens are portable and can be placed in front, on top, or any desired position in respect to a source (Figure 6.2).

The most effective was to avoid fly ash getting airborne is to keep the entire pond moist and possibly maintained about 1mm of water layer over the entire fly ash pond.

6.3 Action Plan and Concluding Remarks

It appears that even with implementation of all control options (Table 6.1), the national air quality standards will not be achieved for PM_{10} (100 µg/m^3), and $PM_{2.5}$ (60 µg/m^3). With implementation of all control options in Delhi, expected mean PM_{10} concentration (including emissions from outside Delhi) is 198 µg/m^3 and for $PM_{2.5}$ it is 117 µg/m^3. It may be recalled from Chapter 5 that sources outside the Delhi (excluding secondary particles) contribute about 100 µg/m^3 of PM_{10} and 59 µg/m^3 of $PM_{2.5}$ in Delhi. As a next step towards attaining air quality standards, since the NCR is a contiguous area with similarities in emitting sources, it is proposed that the control options (developed for Delhi: Table 6.1) are implemented for the entire NCR. With the implementation of control options in Delhi as well as NCR, the overall air quality in Delhi will improve significantly and expected mean PM_{10} levels will be 120 µg/m^3 and $PM_{2.5}$ will be 72 µg/m^3. In addition to the above control options, some local efforts will be required to ensure that city of Delhi and NCR attain the air quality standards all through the year and possibly for many years to come.

The above analyses are based on air quality modelling results and calculations by simplifying some factors. The action plan will certainly be effective in a broad sense and air quality standard will be attained and health and aesthetic benefits will be enjoyed by all citizens in NCR including Delhi. The overall action plan that will ensure compliance with air quality standards for PM_{10} (100 µg/m^3), $PM_{2.5}$ (60 µg/m^3) and NO_2 (80 µg/m^3) is presented in Table 6.3.

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, dispersion modeling, identification of control options, their efficacies and action plan for attaining air quality standards. It was observed that NCR is a contiguous extension of activities similar to that of NCTD. The pollution levels in NCR were also similar to that of NCTD. It is expected the findings and action plan of this study are applicable for NCR and will bring air quality improvement in the entire region. In view of limited financial resources, it is suggested that no separate or repetitive study is required in NCR and Delhi for re-establishing source-receptor impacts; the focus should be on early implementation of action plan.

Table 6.4: Action Plan for NCT of Delhi

Source	Option No.	Description Option	2016	2017	2018	2019	2020-2023	Percent improvement in AQ
Hotels/ Restaurants	1	Stop use of Coal	🟥	🟥	🟥	🟥	🟥	80.56
Domestic Cooking	2	LPG to all	🟥	🟥	🟥	🟥	🟥	50.00
MSW Burning	3	Stop MSW burning: Improve collection and disposal (landfill and waste to energy plants)	🟪	🟪	🟪	🟪	🟪	100.00
Construction and Demolition	4	Vertically cover the construction area with fine screens	🟦	🟦	🟦	🟦	🟦	50.00
		Handling and Storage of Raw Material: completely cover the material						
		Water spray and wind breaker						
		Store the waste inside premises with proper cover						
Concrete Batching	5	Water Spray	🟫	🟫	🟫	🟫	🟫	40.00
		Wind Breaker						
		Bag Filter at Silos						
		Enclosures, Hoods, Curtains, Telescopic Chutes, Cover Transfer Points and Conveyer Belts						
Road Dust and Soil dust	6.1	Vacuum Sweeping of major roads (Four Times a Month)	🟦	🟦	🟦	🟦	🟦	70.00
		Carpeting of shoulders						
		Mechanical sweeping with water wash						
	6.2	plant small shrubs, perennial forages, grass covers in open areas	🟦	🟦	🟦	🟦	🟦	--
Vehicles	7.1	Electric/Hybrid Vehicles: 2% of 2-Ws, 10% of 3-Ws and 2% 4Ws wef July 2017: New residential and commercial buildings to have charging facilities		🟥	🟥	🟥	🟥	50.0
	7.2	Retrofitment of Diesel Particulate Filter: wef July 2018			🟥	🟥	🟥	
	7.3	Implementation of BS – VI for all diesel vehicles including heavy duty vehicles (non-CNG buses and trucks) and LCVs (non-CNG): wef January 2019				🟧	🟧	
	7.4	Inspection/ Maintenance of Vehicles	🟪	🟪	🟪	🟪	🟪	
	7.5	Ultra Low Sulphur Fuel (<10 PPM); BS-VI compliant: wef January 2018			🟦	🟦	🟦	

Source	**Option No.**	**Description Option**	**2016**	**2017**	**2018**	**2019**	**2020-2023**	**Percent improvement in AQ**
	7.6	2-Ws with Multi Point Fuel Injection (MPFI) system or equivalent: wef January 2019				🟥	🟥	
Industry and DG Sets	8.1	Reduce sulphur content in Industrial Fuel (LDO, HSD) to less than 500 PPM		🟦	🟦	🟦	🟦	30.00
	8.2	Minimize uses, uninterrupted power supply, Banning 2-KVA or smaller DG sets		🟦	🟦	🟦	🟦	--
Secondary Particles	9.1	De-SOx-ing at Power Plants within 300 km of Delhi			🟩	🟩	🟩	90.0
	9.2	De-NOx-ing at Power Plants within 300 km of Delhi			🟪	🟪	🟪	90.1
Secondary Organic Aerosols	10	Controlling Evaporative emissions: Vapour Recovery System at petrol pumps (Fuel unloading and dispensing)		🟦	🟦	🟦	🟦	80.0
Biomass Burning	11	Managing crop residue burning in Haryana, Punjab and other local biomass burning, Potential alternatives: energy production, biogas generation, commercial feedstock for cattle, composting, conversion in biochar, Raw material for industry: wef July 2016	🟥	🟥	🟥	🟥	🟥	90.0
Fly Ash	12	Wind Breaker, Water Spraying, plantation, reclamation		🟧	🟧	🟧	🟧	--

Notes: for implementation year 2016 may begin from July 2016

(1) The above plan is also effective for control of PM_{10}. The expected reduction is about 81% in PM_{10}. (2) The model computed concentrations are 9-month average. Specific reduction in winter or summer can be estimated from source apportionment in chapter 4 (refer to Tables 4.17 to 4.20).

* Vehicle growth rate calculated for 2019. It is assumed 80% of the vehicles added per year will go out of vehicle fleet because of being 15 years (or more) old.

**Air quality standards cannot be achieved unless stringent measures are also taken at sources outside Delhi. It is recommended that the above actions are implemented in NCR, else 24-hr $PM_{2.5}$ levels are likely to exceed 110 $\mu g/m^3$.

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