Air Quality Assessment, Emissions Inventory and Source Apportionment Studies for Kanpur City

(Final Report)

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Executive Summary

Pollution control strategies for attainment of particulate standards must be able to provide convincing evidence that (a) the relative importance of emission sources is understood and that (b) the control programmes proposed are cost-effective and can be adopted by the community with confidence. To specifically address these issues, Central Pollution Control Board, New Delhi has sponsored this project to the Indian Institute of Technology Kanpur for the city of Kanpur. The project has the following specific components:

- identify and inventorize emission sources (industry, traffic, power plants, local power generation, small scale industries etc.) in Kanpur city;
- measure baseline air pollutants and air toxic levels at different parts of Kanpur, which includes "hot spots" on kerbside as well ;
- 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 thereof;
- apply receptor and dispersion modeling for PM_{10} levels in ambient air to arrive at source apportionments; and
- Prioritization of Management/Control Options and prepare action plan for the city.

The overall framework of the study is presented in Figure 1.

Air Quality Monitoring

The air quality sampling stations have been categorized based on the predominant land-use pattern (Table 1 and Figure 2). Ambient air was characterized for SPM, $PM_{10,}$ $PM_{2.5}$, SO_2, NO_2, CO, OC, EC, Ions, Elements, VOCs (benzene, ethyl benzene, ortho-xylene, para-xylene, meta-xylene, aldehyde, NMHC, HCHO, PAHs and molecular markers. The air quality sampling was conducted for three seasons: summer, post monsoon and winter. Figure 3 (PM levels), Figure 4 (NO_2-SO_2), Figure 5 (a) (EC-OC), Figure 5(b) (CO), Figure 6 (a) (PAHs), Figure 6(b) (Relative Compositions of PM_{10} and $PM_{2.5}$ at Kerbside- Winter), Figure 6 (c) (composition of PM_{10} for ions, carbons and elements) and Figures 6(d) and (e) (molecular markers pentatriacontane and hopanes**)** show summary results of air quality monitoring. Table 2 presents average summary PM levels along with its main constituents (and EC/OC ratio) of PM_{10} for summer, post monsoon and winter seasons. The following broad conclusions can be drawn from the monitoring results..

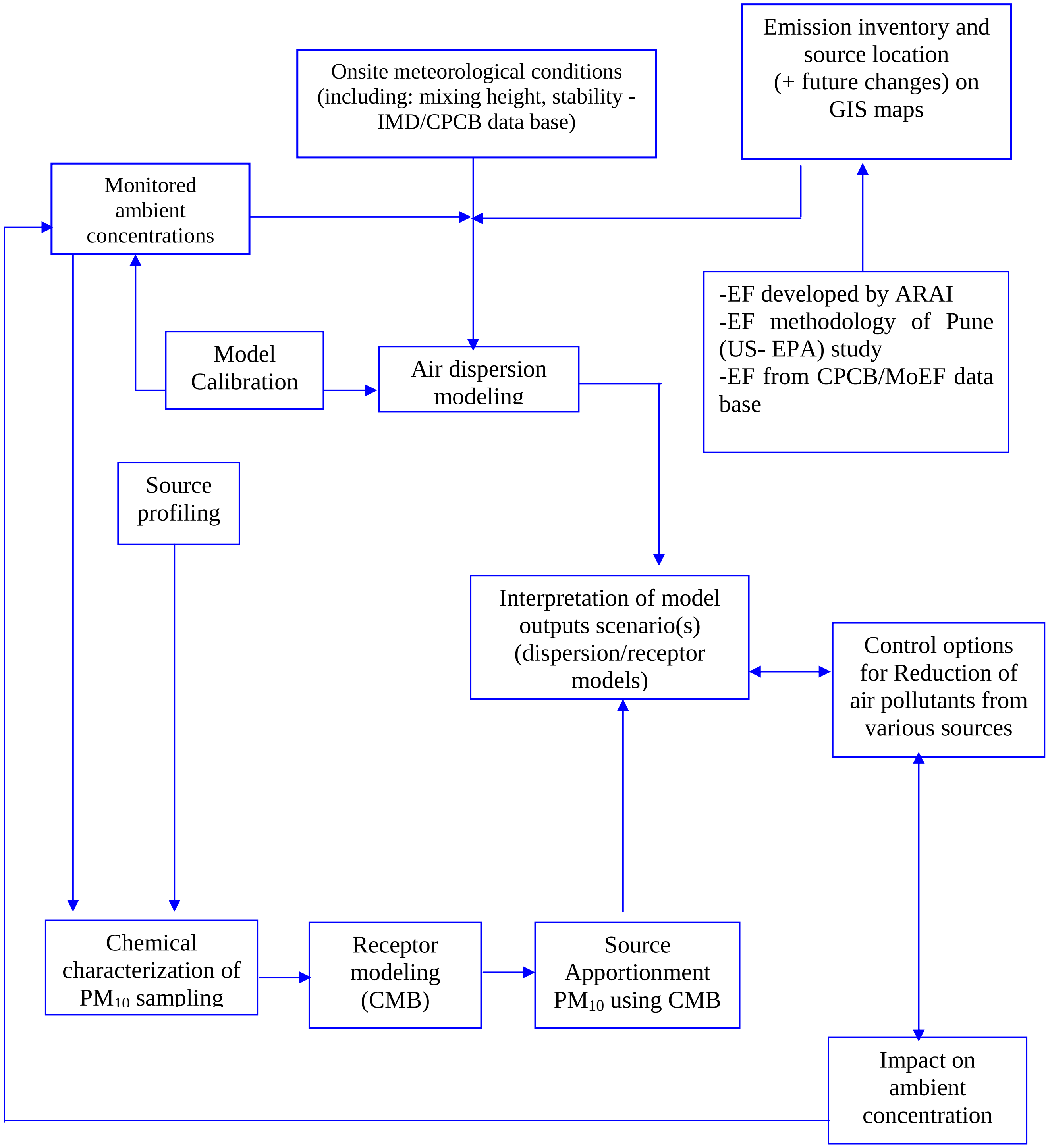


Figure 1: Overall Framework of Study

- Particulate pollution is the main concern in the city where levels of SPM, PM_{10} and $PM_{2.5}$ levels are 2.5- 3.5 times higher than the acceptable levels (Fig. 3 and Table 2).
- PM levels at all sites in all three seasons exceeded the air quality standards for PM_{10} and SPM.
- OC (organic carbon) levels are always much higher (2 - 4.5 times) than EC levels. The ratio of EC/OC is variable from one location to another, indicating that sources, those contribute to particulate pollution, are variable (Table 2).
- EC and OC almost account for 30 percent of $PM_{2.5}$, which is quite high and reflects as to how badly the city is affected because of combustion and /or fuel related emissions which account for most respiratory problems (Fig. 6(c)).

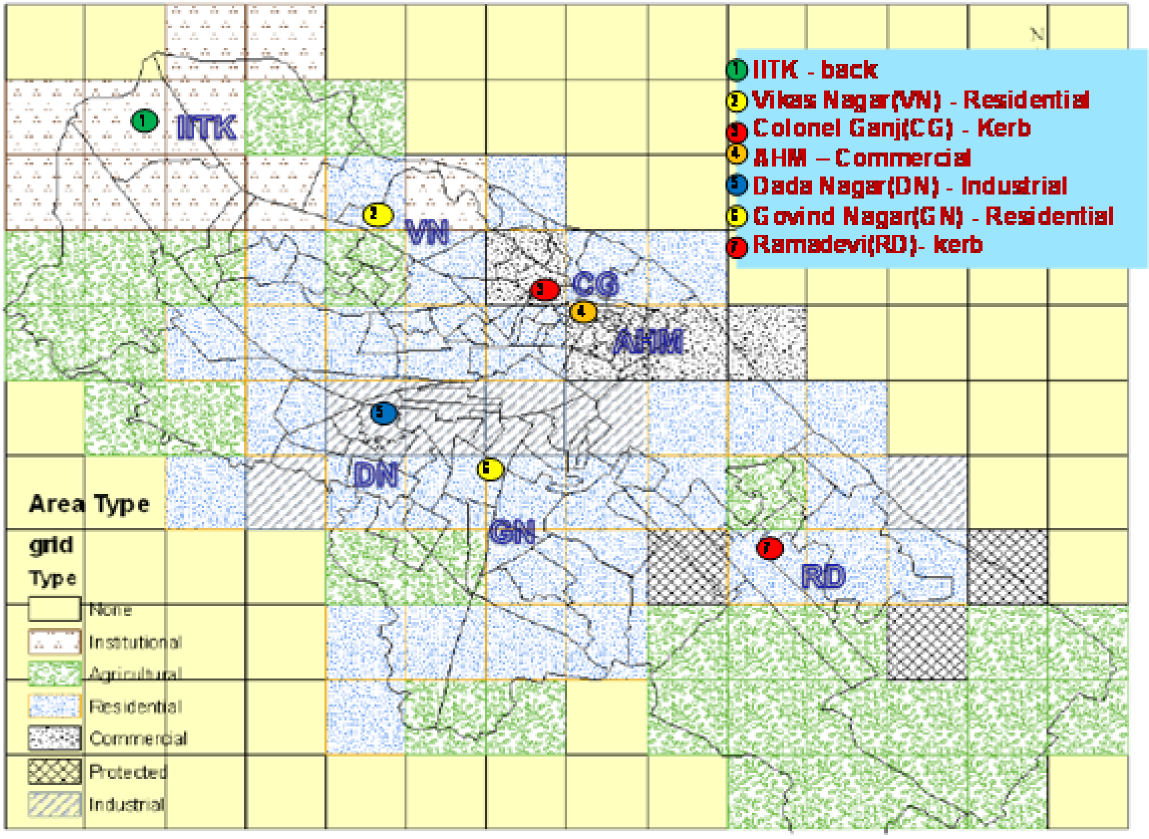


Figure 2: The Location of the Sampling Sites

Table 1 Sampling Sites and their Descriptions

S. No.	Sampling Location	Site Code	Description of the site	Type of sources based on land use
1.	IIT Kanpur (IITK)	S1	Background area	Domestic cooking, light vehicles
2.	Vikash nagar (VN)	S2	Commercial cum residential area	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
3.	Govind nagar (GN)	S3	Residential area	Domestic cooking, vehicles, road dust
4.	Dada nagar (DN)	S4	Industrial area	Industries, Domestic cooking, DG sets, vehicles, road dust, garbage burning
5.	Colonel ganj (CG)	S5	Kerb site	Vehicles, Domestic cooking, DG sets, road dust, garbage burning
6.	A.H.M. Hospital (AHM)	S6	Commercial area	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
7.	Ramadevi Square (RD)	S7	Traffic site, away from kerb	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants

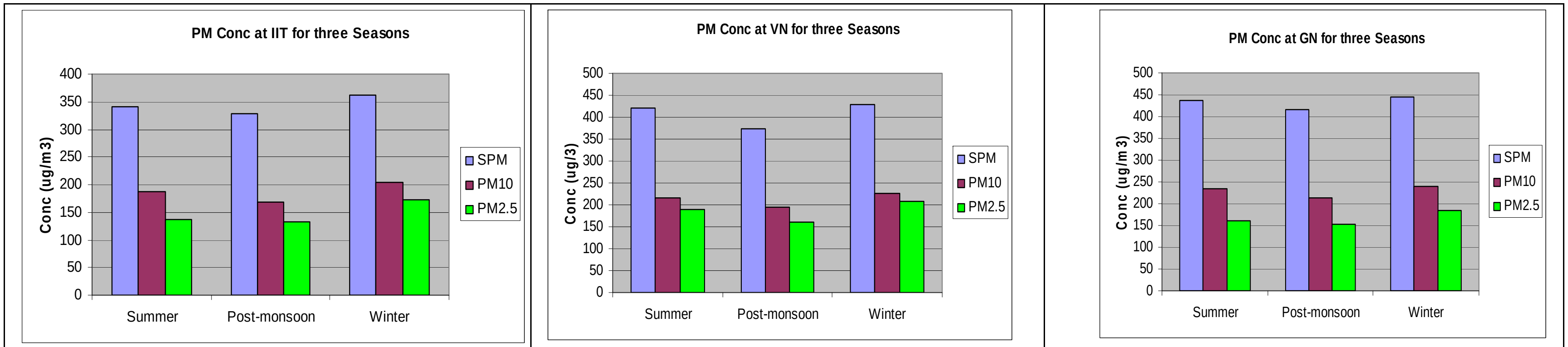
- EC to OC ratio increases at traffic, kerb and industrial sites. Higher EC/OC ratio can again be attributed to freshly contributed diesel combustion at the sites and indicating these to be the hot spots for particulate pollution (Table 2). EC/OC ratios are the smallest in the winter at all locations for the reason that volatile and semi-volatile organic compounds will absorb/condense on these particles due to low temperatures. This interpretation is corroborated by the fact that EC levels in winter have gone up, and at the same time, and EC/OC ratio is the lowest in the winter (Table 2).

- Elemental and ion analysis show abundance of soil constituents (e.g. Si, Fe, Ca, Na). This clearly suggests that there could be significant sources of particulate pollution from soil, and road dust.
- There are significant quantities of SO_4, NO_3, and NH_4 even at the background upwind direction (Table 2). It signifies long-range transport of particles in the city.
- Roadside (CJ) and commercial sites (AHM) are heavily influenced by the traffic related emissions and are the real hot spots in terms fine particles; See high EC/OC ratio (Table 2).
- It can be concluded here that NH_4^+, NO_3^-, SO_4^{2-} and OC are mostly formed in the fine mode; whereas, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- are found in coarse as well as fine mode (Fig. 6(b)).
- Industrial area was found to be the worst for all pollutants (Figures. 3,4,5; Table 2).
- Maximum CO concentration is observed during the peak hours of the day (both in morning as well as evening). Standard of 2 mg/m^3 is exceeded during the peak hours at the kerbside (Fig. 5(b)).
- Post-monsoon air quality was better than summer and winter for all air quality parameters. However, winter season was the worst from air quality point of view (Table 2).
- The following molecular markers were present in the ambient air: hentriacontane, tritriacontane, pentatriacontane, octadecanamide, levoglucosan, stigmasterol, hopanes and PAHs. The presence of these markers suggests that possibly the following sources are also contributing to PM_{10}: vegetative detritus, cigarette smoke, tyre wear debris, gasoline, diesel, fuel oil Gasoline, biomass (cow dung), biomass burning (hardwood, softwood) (Figures 6(a)-(d)).
- BaP (PAH) levels exceed proposed CPCB 24-hour standard of 5 ng/m^3 at four locations GN(Resi), DN (Ind), SG (kerbside), AHM (commercial) Figure 6(a).
- OC, K, Ca, NH_4, SO_4 are found to be higher, in a relative sense, in $PM_{2.5}$ compared to PM_{10} indicating that OC and secondary particles are generally present in fine mode Figure 6(b).

Emission Inventory

An extensive primary emission survey was undertaken at seven grids in the area of 2×2 km (Table 1). Survey results were projected for other areas based on road length, population, and land-use of the areas. The overall results of emission inventory exercise are shown in Figure 7. The following conclusions can be drawn from emission inventory estimates.

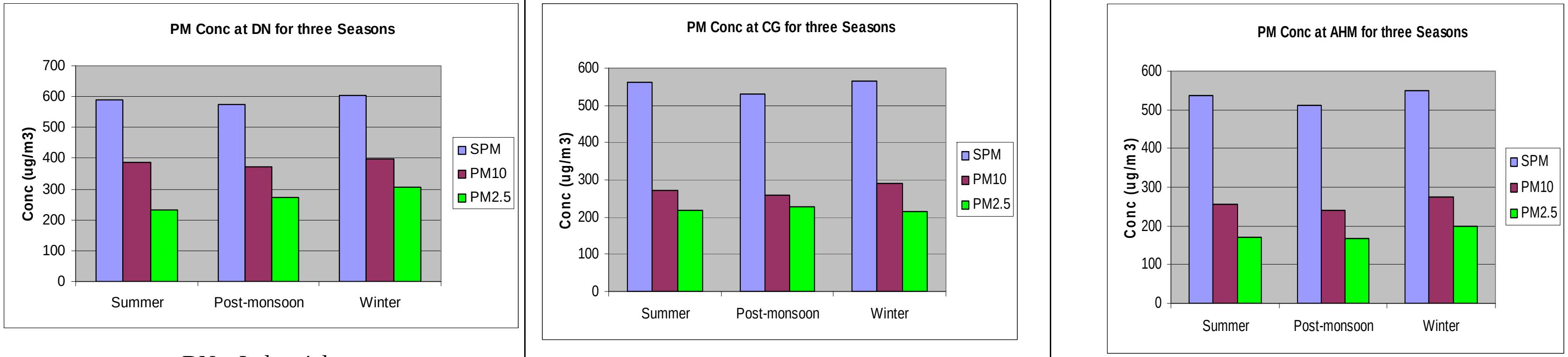
- The total PM_{10} emission load in the city is estimated as 10 t/d. There are several important sources of PM_{10} in the city including industrial point sources (26%), industry area source (7 %), vehicles (21%), domestic fuel burning (19%) paved and unpaved road (15%), garbage burning (5%) and rest others. The estimated emission suggests that there are many important sources and a composite emission abatement including most of the sources will be required to attain the desired air quality.
- NOx emissions are even higher than PM_{10} emission ~ 22.5 t/d. Nearly 50% of emissions are attributed to vehicles that occur at ground level, probably making it the most important pollutant in coming time. Vehicle sources are followed by industrial point and area sources (42%), DG sets (5%) and domestic sources and rest others (3%).
- SO_2 emissions are relatively low at 4.2 t/d. Industrial sources account for nearly 60 percent of total emission. It appears there may not be any need to control SO_2 but SO_2 is known to contribute to secondary particles (sulfates). Control of SO_2 from industrial sources, if necessary, can improve air quality both for SO_2 and particulates.
- Estimated CO emission is about 50 t/d. Nearly 60% emission of CO is from vehicles, followed by domestic sources 16% and about 5% from garbage burning. Vehicles could be the main target for controlling CO for improving air quality with respect to CO.
- Spatial variations in emission quantity suggest that for PM_{10}, CO and NOx, it is the central down town area of the city where emissions are the highest. It suggests that air quality will be worst in the central part of city for all the pollutants with the exception of SO_2 which has highest emission in the industrial areas.



IITK – Background

VN – Residential

GN - Residential

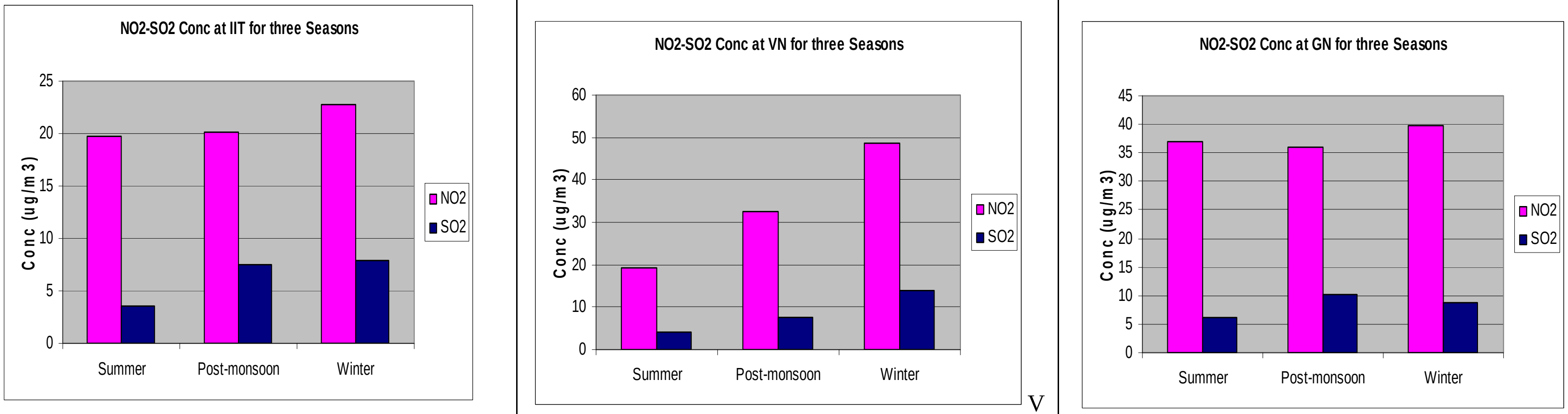


DN – Industrial

CG – Kerbsite

AHM- Commercial

Figure 3: PM Levels in Various Seasons



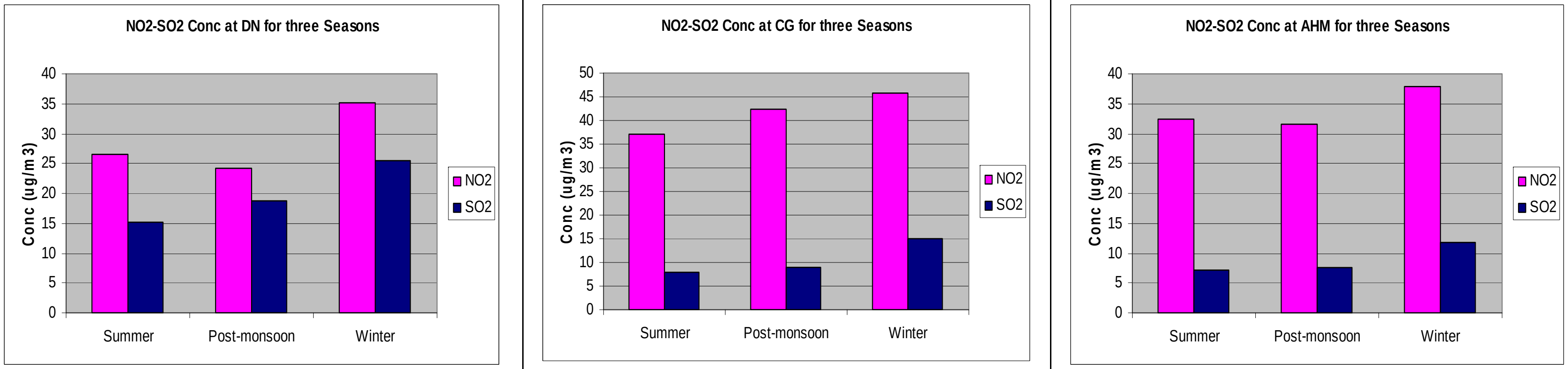
V

G

ITK – Background

VN – Residential

GN - Residential

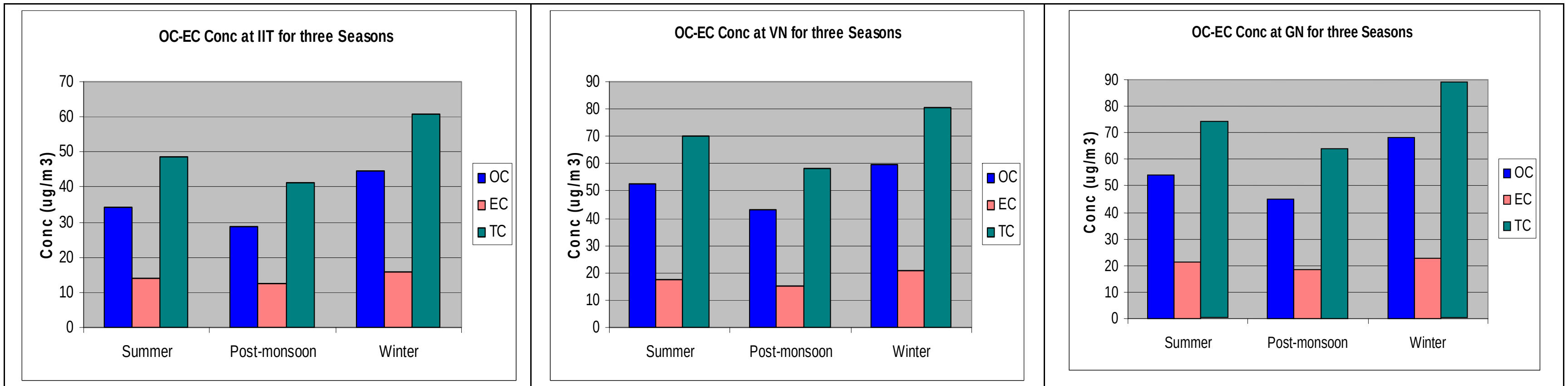


DN – Industrial

CG – Kerbsite

AHM- Commercial

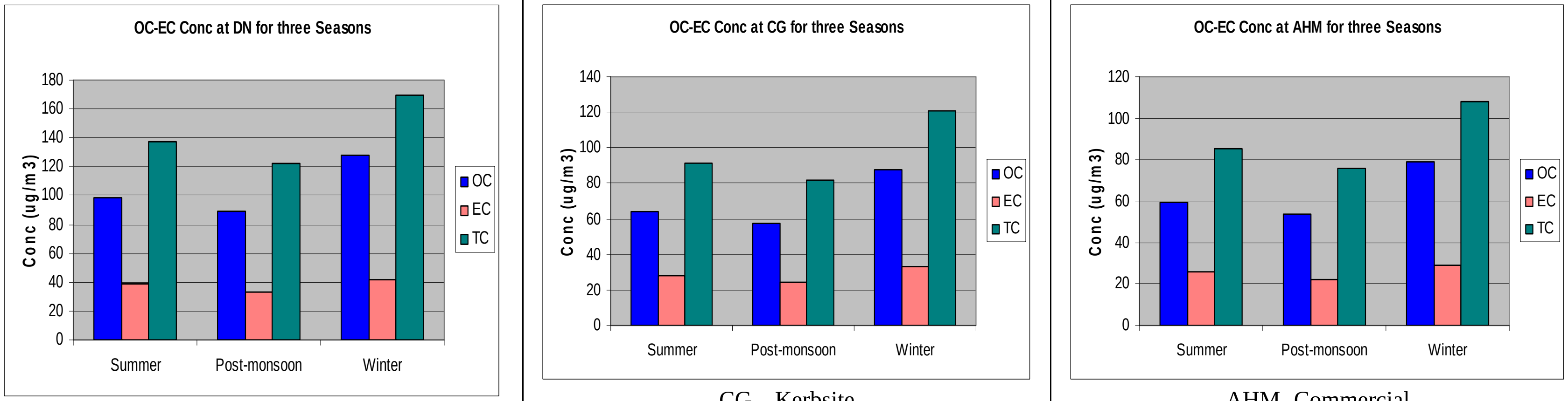
Figure 4: NO_2- SO_2 Levels in Various Seasons



IITK – Background

VN – Residential

GN - Residential



DN – Industrial

CG – Kerbsite

AHM- Commercial

Figure 5 (a): EC-OC Levels in Various Seasons

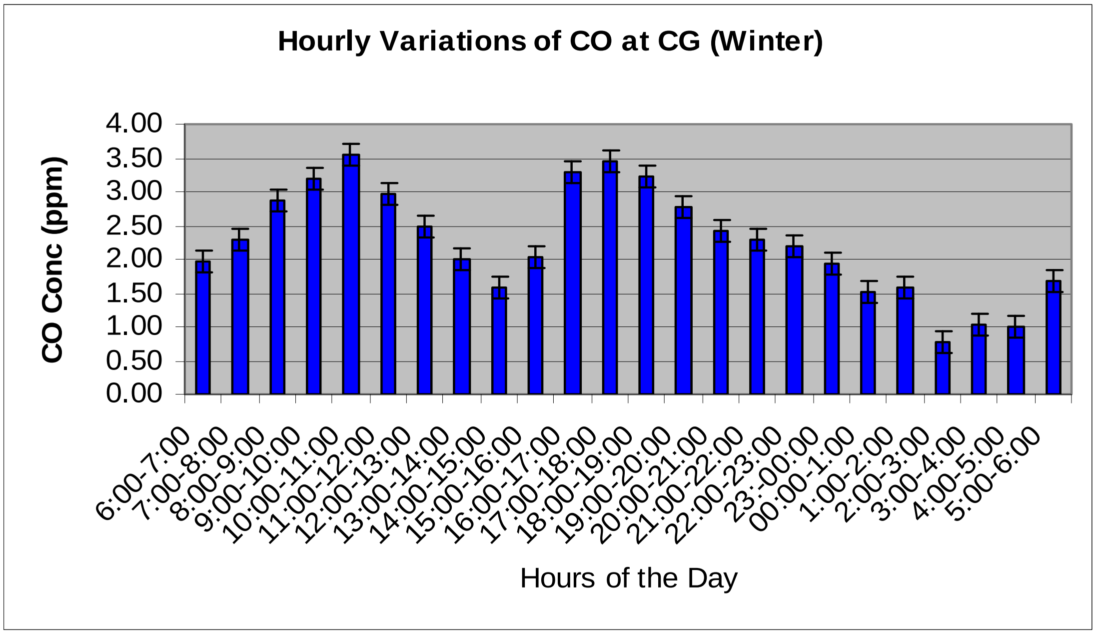


Figure 5 (b): Diurnal Variations of CO at Kerbside

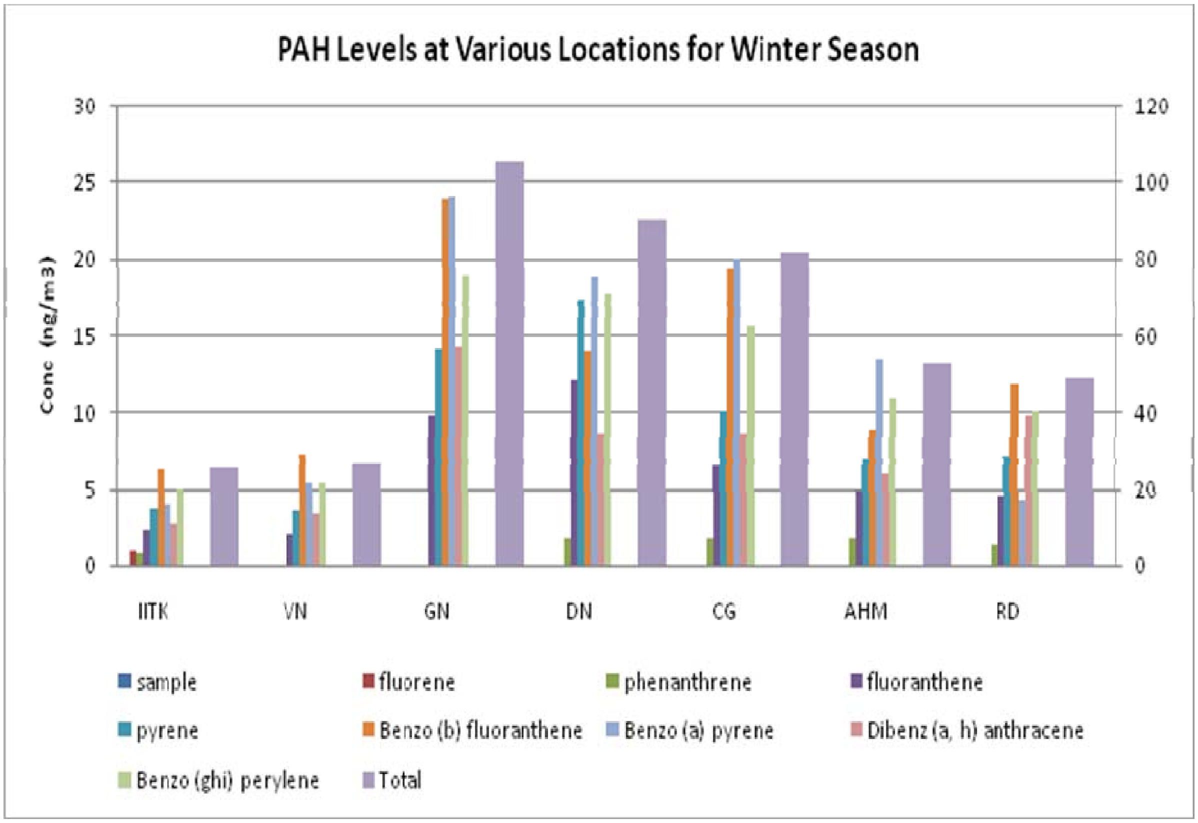


Figure 6(a): PAH Levels Winter; CPCB Proposed 24-hr Standard for BaP (5 ng/m^3) exceed at four locations, GN (res), CG (kerbside), AHM (commercial), DN(ind)

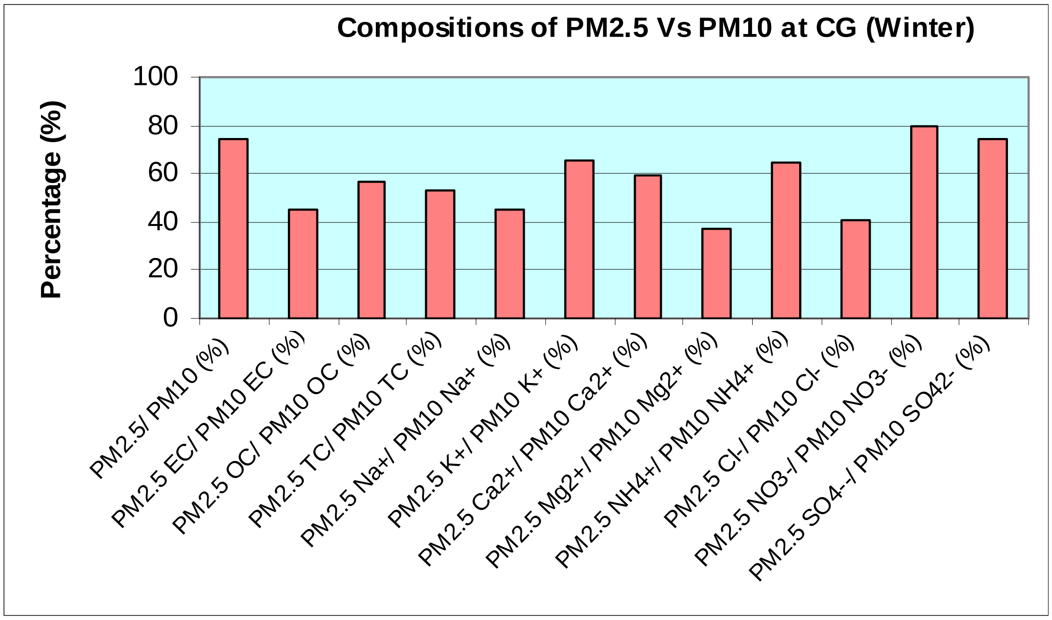


Figure 6(b): Relative Compositions of PM_{10} and $PM_{2.5}$ at Kerbside (Winter)

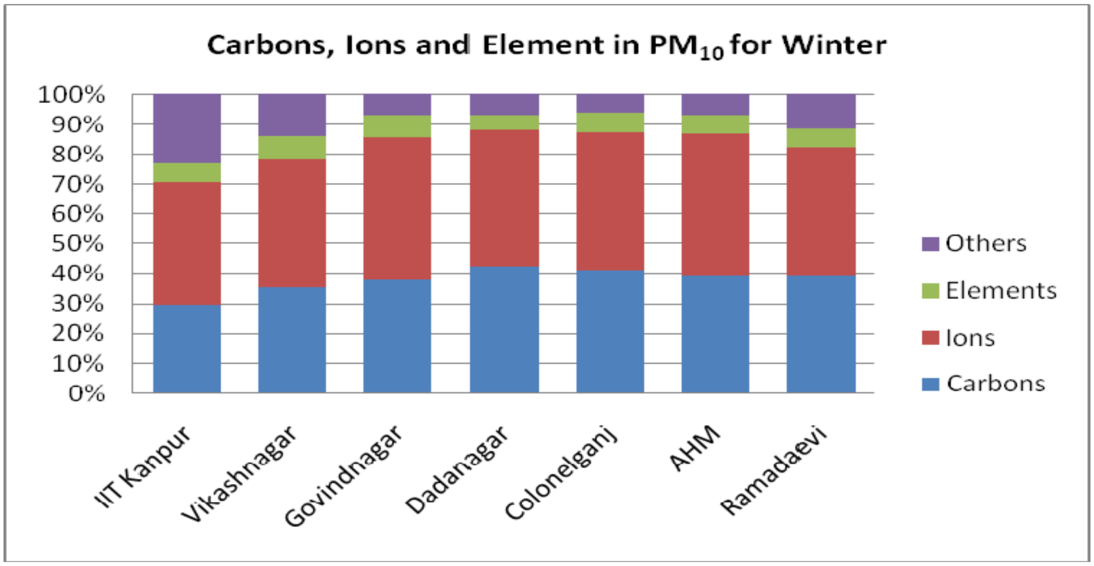


Figure 6(c): Percentage Composition of Carbons, Ions and Element in PM_{10} (Winter)

Figure 6(d): Pentatriacontane Concentarion Season Variation

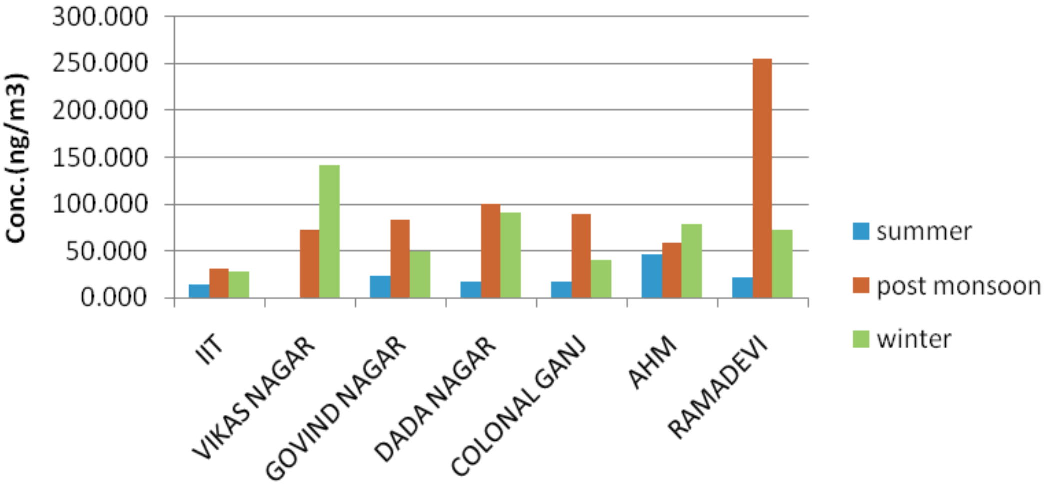


Figure 6(e): Hopanes Concentarions Season Variation

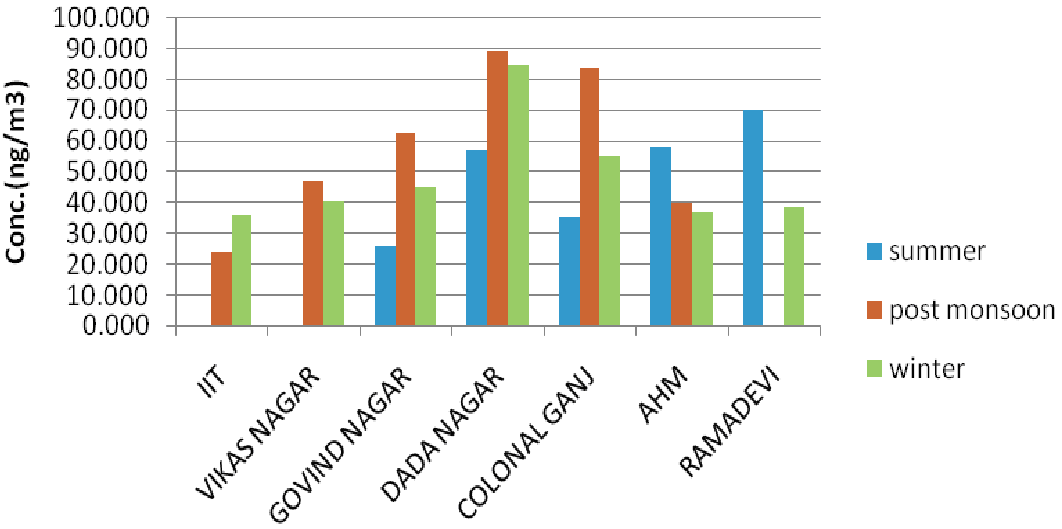


Table 2 : Summary of Pollution Parameters, Particulate Composition

Site (land-use)	SPM	PM_{10}	PM2.5	NO2	SO2	OC	EC	TC	EC/OC	NH4+	NO3-	SO42-
IITK (Back'd) Sum'r	341	187	136	19	3	34	14	49	0.41	13	7	28
Post-monsoon	329	169	132	20	7	28	12	41	0.43	11	6	24
Winter	362	205	172	23	8	45	16	61	0.36	15	9	32
VN (Res.) Summer	422	216	190	19	4	52	17	70	0.34	14	8	34
Post-monsoon	372	194	161	32	7	43	15	58	0.35	13	8	32
Winter	429	226	207	49	14	60	21	81	0.35	19	11	41
GN (Res.) Summer	436	234	159	36	6	53	21	74	0.40	18	12	42
Post-monsoon	416	212	153	36	10	45	18	63	0.41	17	16	33
Winter	445	240	185	40	9	68	23	91	0.33	19	16	48
DN (Ind.) Summer	590	387	232	26	15	98	38	138	0.39	27	27	59
Post-monsoon	576	370	272	24	18	88	33	122	0.38	24	37	51
Winter	603	396	305	35	25	128	42	169	0.33	32	34	66
CJ (Kerb) Summer	561	272	218	37	7	63	27	91	0.44	21	31	29
Post-monsoon	531	259	225	42	9	57	24	81	0.43	20	30	23
Winter	564	292	216	46	15	88	33	121	0.38	23	37	34
AHM(Comm) Sum'r	536	255	171	32	7	59	25	85	0.43	21	30	41
Post-monsoon	511	238	169	31	7	53	22	76	0.41	24	32	35
Winter	550	276	198	38	12	79	29	108	0.37	26	36	41
RD (Traffic) Sum'r	506	190	170	29	12	43	17	61	0.40	11	13	20
Post-monsoon	508	221	197	35	14	48	19	67	0.40	17	22	29
Winter	515	234	207	39	17	69	23	92	0.33	18	24	29

Unit μg/m^3 (except for EC/OC ratio)

Air Quality Modeling

Receptor modeling using CMB8.2 at seven locations (Table 1) and dispersion modeling using ISCST3 for the entire city were undertaken. The results of receptor modeling for PM_{10} are shown in Figure 8 and for $PM_{2.5}$ in Figure 9. The results of dispersion modeling for critical winter season for PM_{10} and NO_2 are shown in Figures 10 and 11.

Receptor Modeling

- There are two consistent sources contributing to PM_{10} – vehicular and secondary inorganic particles. Vehicular source contribution is in a narrow range of 10 - 25 % at all locations in all seasons. However, the contribution tends to be higher in winter season compared to the summer and post-monsoon seasons. The consistency of vehicular source contribution is even more at three locations Colonelganj (kerbside), AHM (commercial) and Ramadevi (traffic). At these same locations, secondary particles are also consistent in a narrow range of 15 - 30 % of total particle mass (Figure 8).
- Open burning is another important source that contributes very high levels of PM_{10} but its contribution fluctuates in a wide range of 0 - 65 %. What is noteworthy is the fact that this source contributes the most in the winter season. It is understandable that the open garbage burning is not an every day affair; rather it is a function of collected amount of waste and thus justifies the variability. Winter season is particularly critical source for open burning (garbage, plastic, refuse, leaves agricultural residue etc.) (Figure 8).
- Road dust was expected to be major contributing source, however, its contribution is only limited to 5 - 10 percent as per the receptor modelling.
- A few locations, especially, the commercial areas (AHM) show significant contribution of 5 - 25 % to PM_{10} from DG sets; this source is prominent in summer season when power failure is frequent (Figure 8).
- Coal combustion related contribution is prominent in industrial area (10 - 30 %) followed by commercial and kerbside locations. It is to be noted that the kerbside and commercial sites are not free of population and have many restaurants and railway station within around 2.5 - 3 km from these sampling sites, where coal is frequently used.

- Wood burning is also important source that contributes to PM_{10} but it is mostly limited to outskirt of the city (e.g. at IITK and Vikasnagar)
- In general, sources identified by factor analysis match with those obtained from CMB 8.2 modeling. However, the CMB modeling did not find road dust to be as important as identified by the factor analysis as a contributor to PM_{10} .
- Range of source contribution to $PM_{2.5}$ is: open burning (7 – 23 %), road dust (3 – 6 %), coal (0 – 13 %), vehicles (28 – 37 %) and secondary particles (15 -30 %) (Figure 9).
- Contribution by vehicles is larger in $PM_{2.5}$ (28 – 37 %) compared to what it was in PM_{10} (10 – 25 %) (Figure 9).

Dispersion Modeling

- For PM_{10}, the industrial site (Dadanagar) showed the highest concentration and the industries appear to contribute a significant pollution at this site (~ 40 percent).
- There are three prominent and probably equally important sources of PM_{10} (vehicles, road dust and domestic fuel burning) that contribute to about 80 percent of PM_{10} at all sampling sites (except for the industrial location).
- For NO_2, 50-70 percent contribution is from vehicles at all sampling sites. It is only at industrial area (i.e. Dadanagar), where contribution of industries is seen and on a few occasions, the point source (power plant) also contributes to NO_2 at this site. At the kerbsite and commercial site almost entire NO_2 is from vehicles.
- Overall city specific modelling results follow the meteorology and emissions in each grid and there are clear hotspots. These hotspots vary depending on the season. PM_{10} hotspot in summer is in the industrial area and in winter season there are two equally important hotspots - industrial area and city centre (Figures 10 and 11).
- NO_2 levels show two consistent hotspots where concentrations can really be very high: (i) industrial area and (ii) the city centre. It is seen that emission are also high in these two areas (Figure 11).
- Model performance was found adequate (R-square 0.88 – 0.44 for observed and predicted values). Observed levels are generally higher than predicted

levels both for PM_{10} and NO_2. For PM_{10}, there is a significant part as background level.

Dispersion Modelling for 2007, 2012 and 2017 BAU (Business As Usual) Scenario

For 10 critical grids (showing consistently high pollution levels), air pollution contributions from various sources for 2007, and projected emissions in 2012 and 2017 in respect of PM_{10} and NO_2, were estimated using ISCST3 modelling tool (Figure 12). It is clearly seen that if no action is taken air quality standards for NO_2 (in addition to PM_{10}) will also exceed in 2012 and 2017 almost in all critical grids.

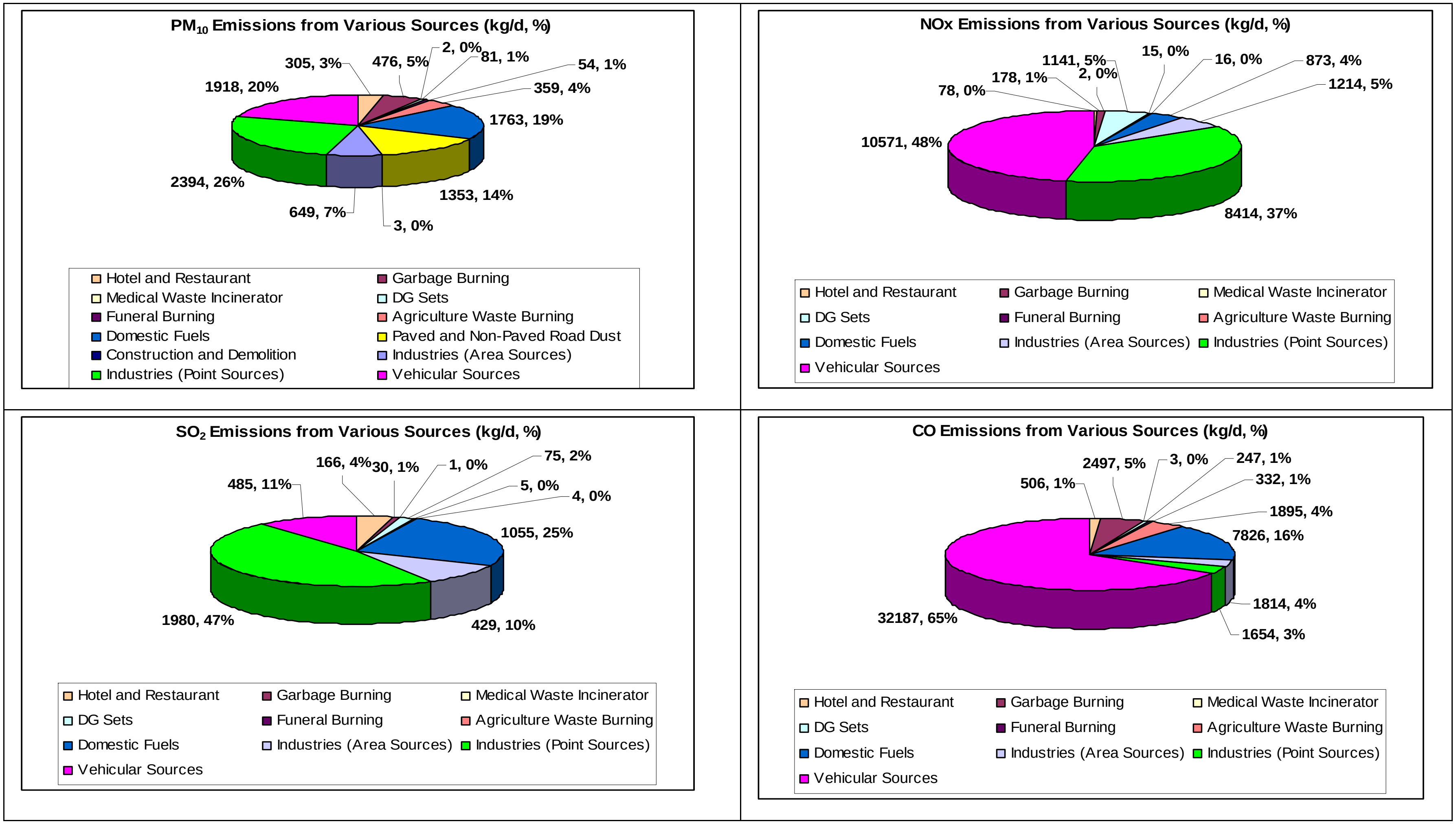


Figure 7: Overall Emission Inventory of PM_{10}, NOx, SO_2 and CO

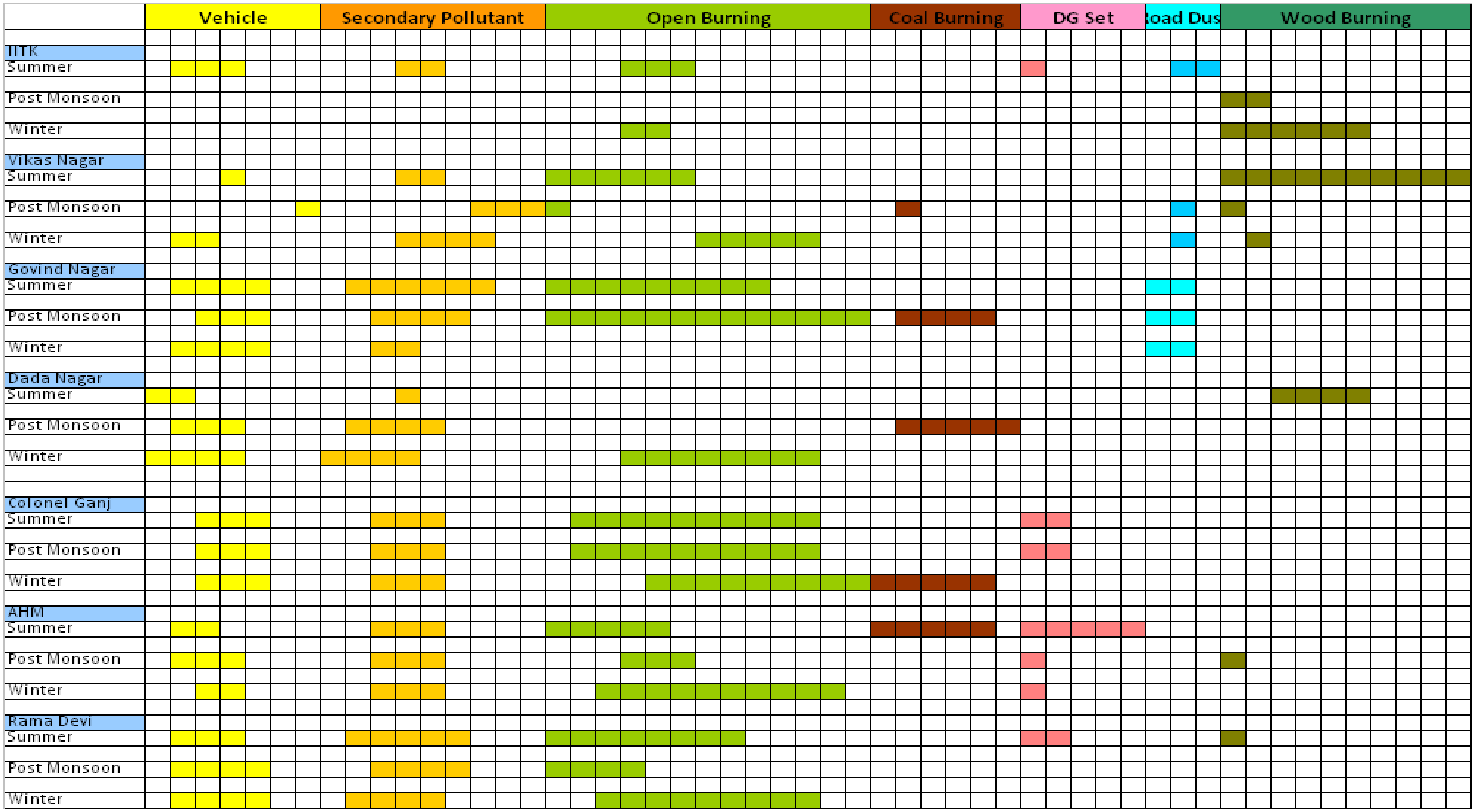


Figure 8: Percent range of Contribution of each Source to PM_{10} at Sampling Location in three Seasons (every square represents 5% contribution) based on CMB 8.2 Modelling

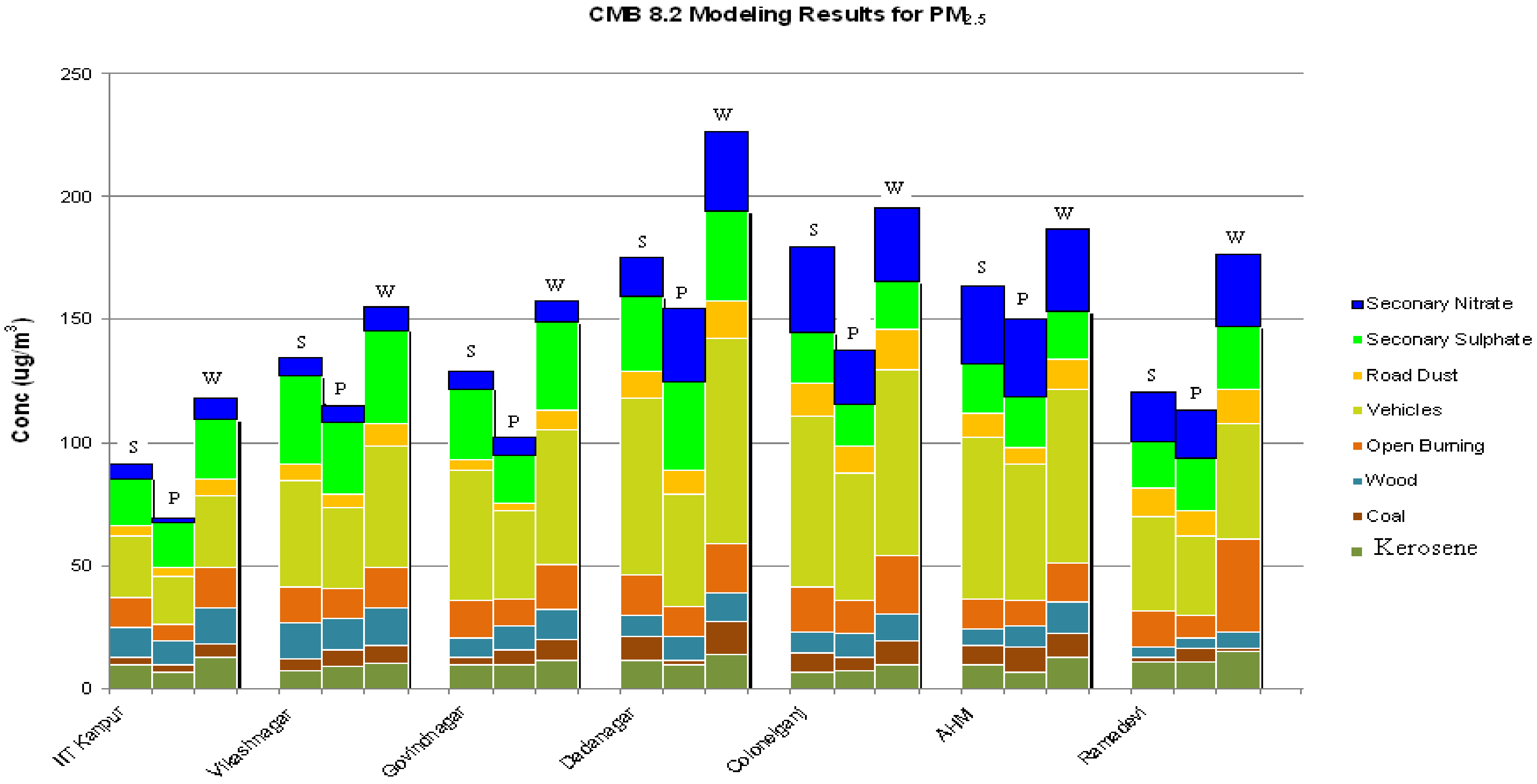
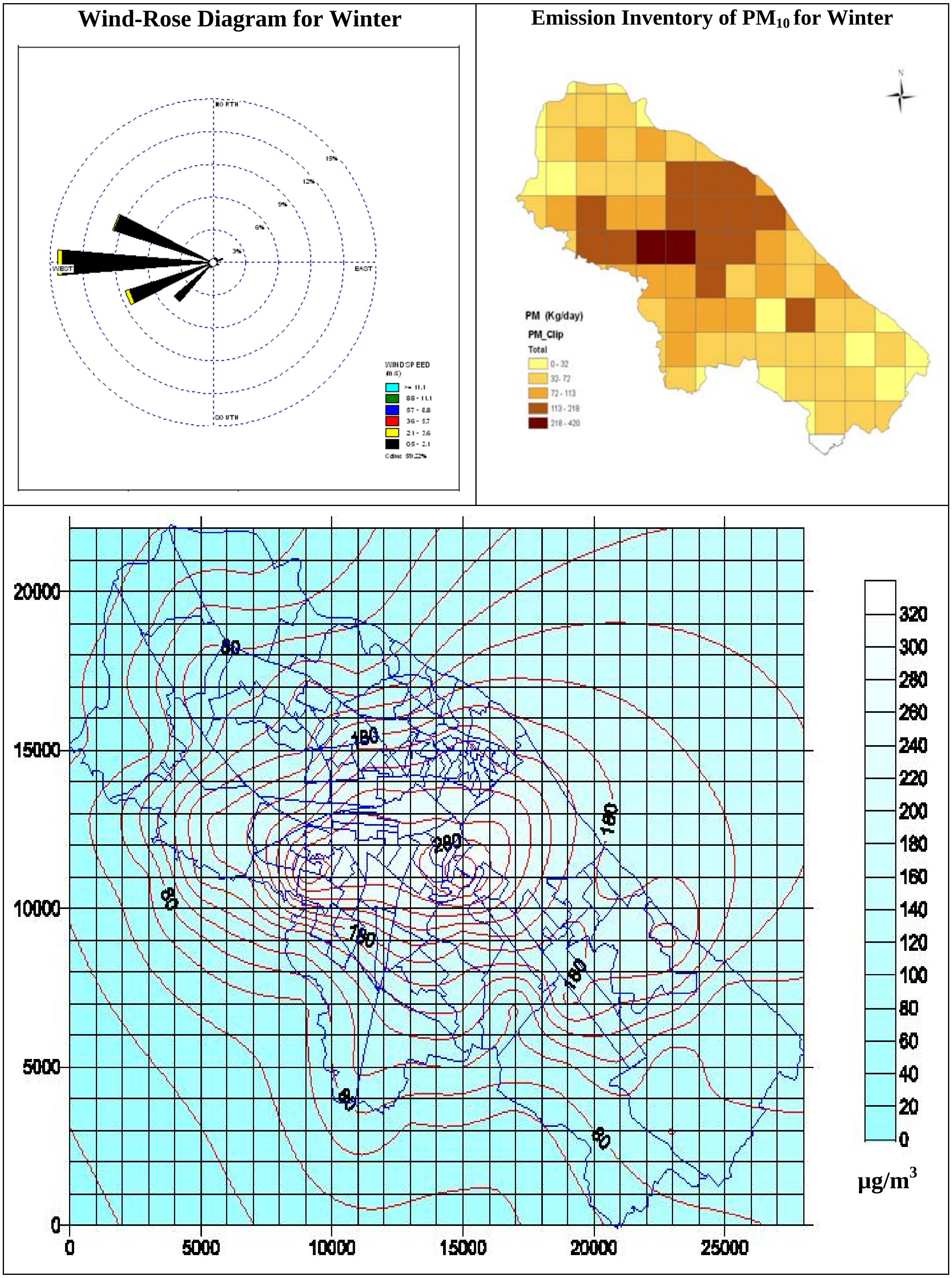
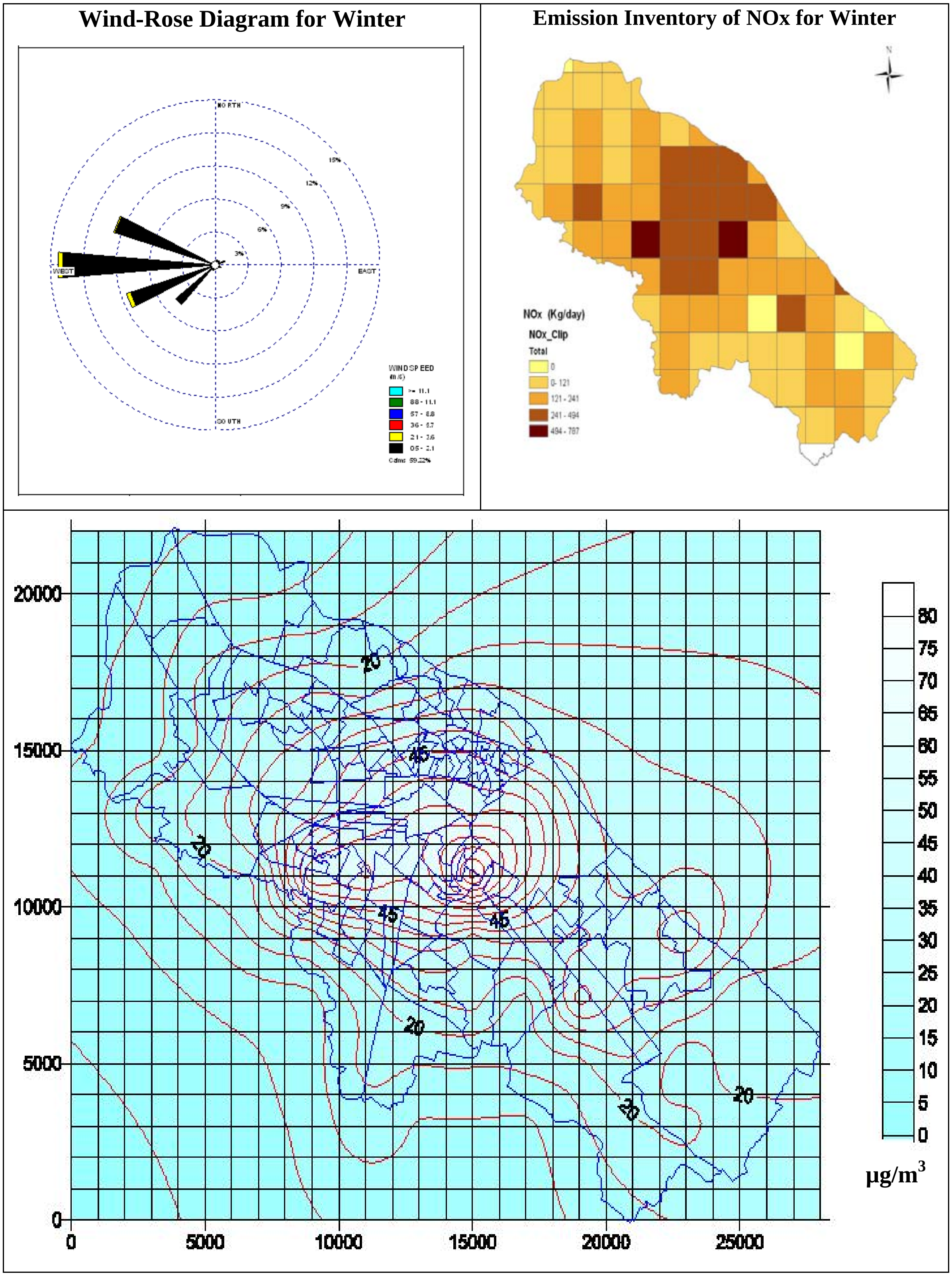


Figure 9: CMB Source Apportionment for $PM_{2.5}$


Wind-Rose Diagram for Winter

Emission Inventory of PM_{10} for Winter

Figure 10: PM_{10} Concentration Profiles for Winter 2007

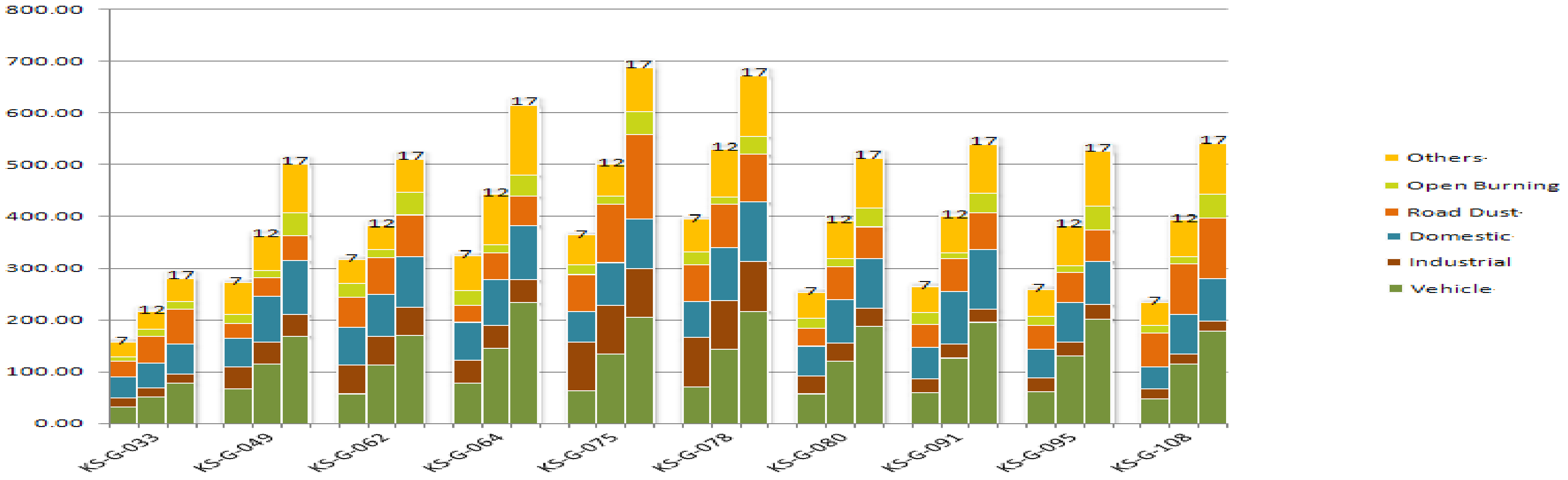


Wind-Rose Diagram for Winter

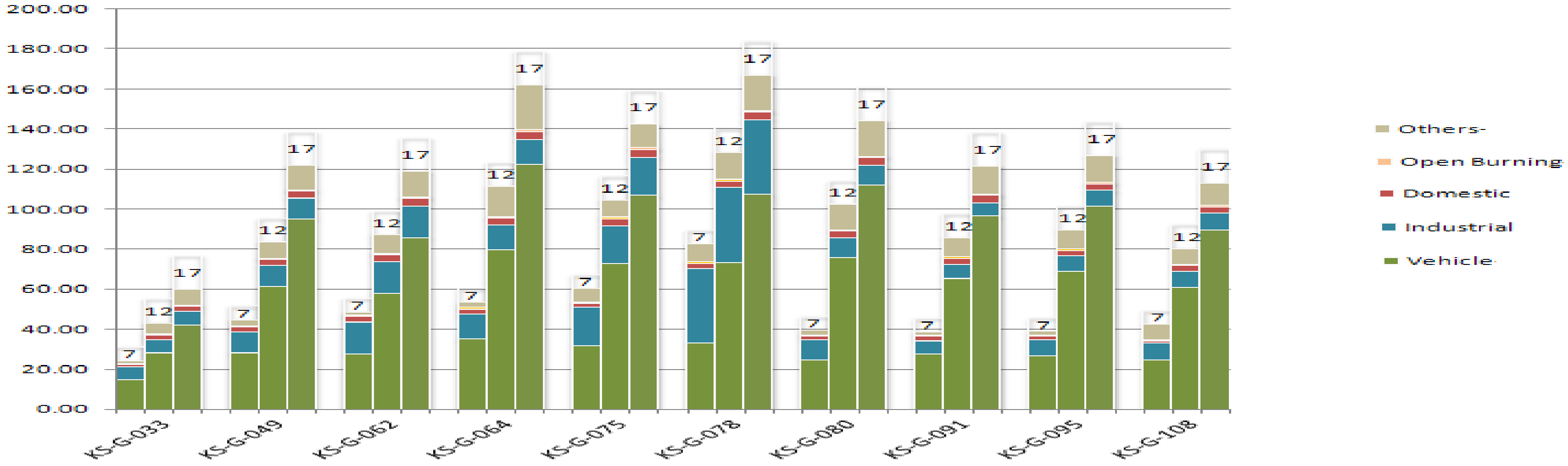
Emission Inventory of NOx for Winter

Figure 11: NOx Concentration Profiles for Winter 2007

Figure 12: Results of Dispersion Modelling in Critical Grids for BAU Scenario in 2007, 2012 and 2017 (Y-axis Conc. ug/m^3)



PM$_{10}$



NOx

Efficacy of Control Options and Scenario Development

Some 24 control options were considered and evaluated for their impact in terms of emission reduction and air quality improvements for PM_{10} and NO_2 using ISCST3 modelling. Table 3 presents ten most promising options those showed the significant average air quality improvements in all critical grids. Further, scenarios were developed as a combination of various control options to examine as to which control options, if implemented as a group, will give the best improvements in air quality (Table 3). It was found that Scenario- 3 (Table 4) produced the best results for air quality improvements for both PM_{10} and NO_2.

Table 3: Prominent Control Options and Potential PM_{10} Level Reduction (Average)

Option No	Description	% Reduction	
		2012	2017
Option-2	Implementation of BS – VI norms	-	8
Option-5	CNG/LPG to commercial Vehicles: Line Source	12	47
Option-10	Retro fitment of diesel particulate filter (DOC): Line Source	19	25
Option-11	Inspection/ maintenance of vehicles: Line Source	3	4
Option-12	Banning of 15 year old private vehicles: Line Source	26	21
Option-14	Changing of solid fuel to natural gas: Industrial Source	75	74
Option-15	Particulate control systems in industry: Industrial Source	99	99
Option-17	Domestic-Use of Natural Gas/LPG: Area source	33	50
Option-19	Adequate supply of grid power: Area Source	100	100
Option-21	Converting unpaved roads to paved roads: Line/Area source	16	29
Option-23	Sweeping and watering (mechanized) Line/Area Source	18	53
Option-24	Strict compliance to ban of open burning: Area Source	50	100

* The calculation is based on the results of emission inventory

Table 4: Scenarios with Combination of Control Options

S. No.	Scenario	Combinations of Control Options
1.	Scenario-1	(2+12+5+14+17+21+23+24) Control Option
2.	Scenario-2	(2+12+10+14+17+21+23+24) Control Option
3.	Scenario-3	(2+11+12+5+15+17+19+21+23+24) Control Option
4.	Scenario-4	(2+12+10) Control Option+(15+17+21+23+24) BAU

* Best scenario for air quality improvement

The air quality modelling was conducted for the years 2012 and 2017 with Scenario 3 being enforced to see the improvement in the air quality for PM_{10} (Figure 13) and NO_2 (Figure 14) for the entire city**.**

If no action is taken to reduce PM_{10} and NOx emissions, in 2012, entire city will totter under high air pollution when standards for PM_{10} will exceed over the entire city with very high concentration of over 500 $\mu g/m^3$ (max 24- hour) in 16 sq-km area. If no action is taken up to 2017 and city will have unbridled growth, not only the entire city will exceed the air quality standards, nearly 50 sq-km (nearly 1/5th of city) area may have air quality much above 500 $\mu g/m^3$ (max 24- hour) for PM_{10}. NOx standard will be met in the year 2012 with control options however about 1/5th of the area will still exceed air quality standard for NOx.

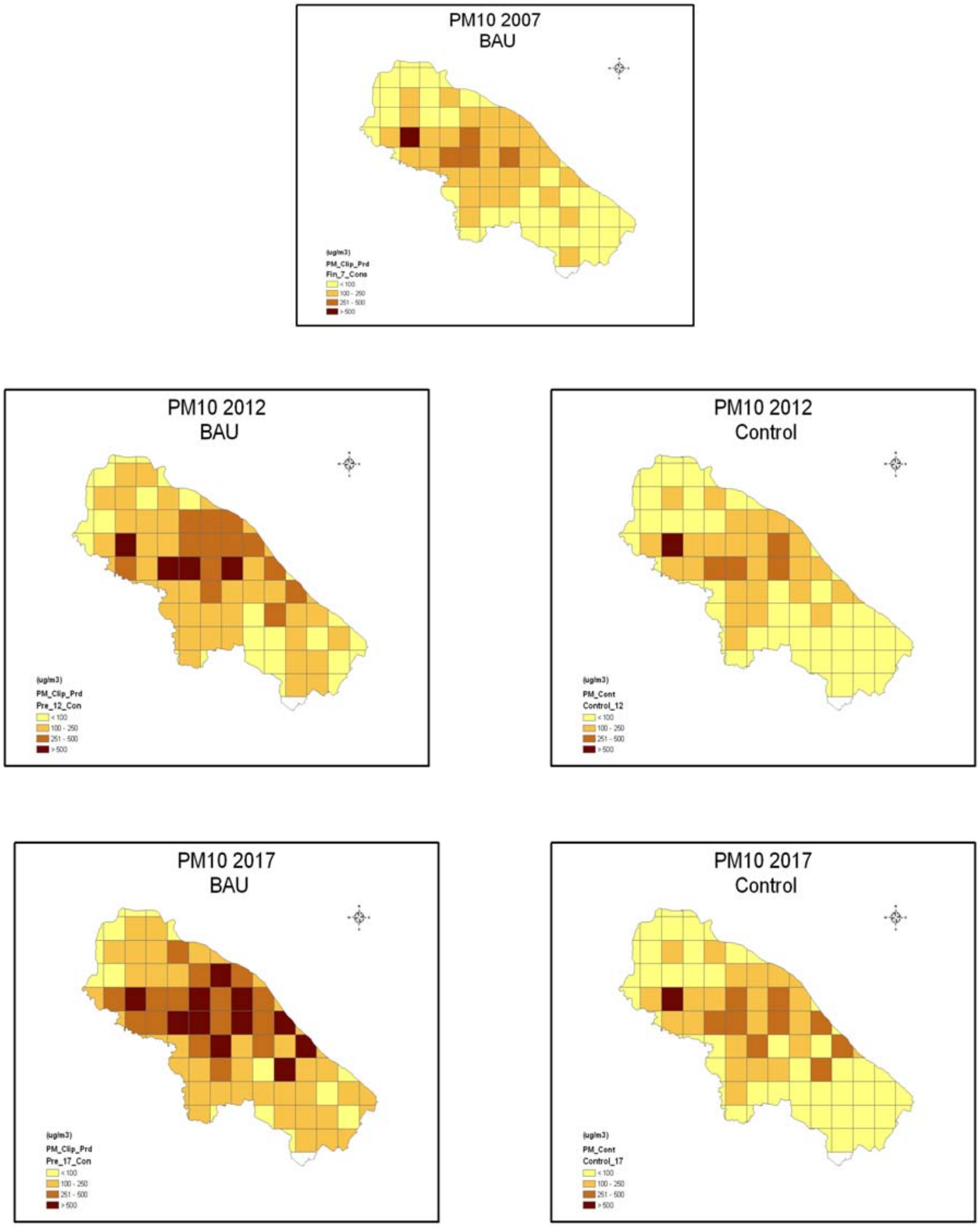


Figure 13: Modeling Results Daily Average of PM_{10} (for all grids) – For Best Scenario -3

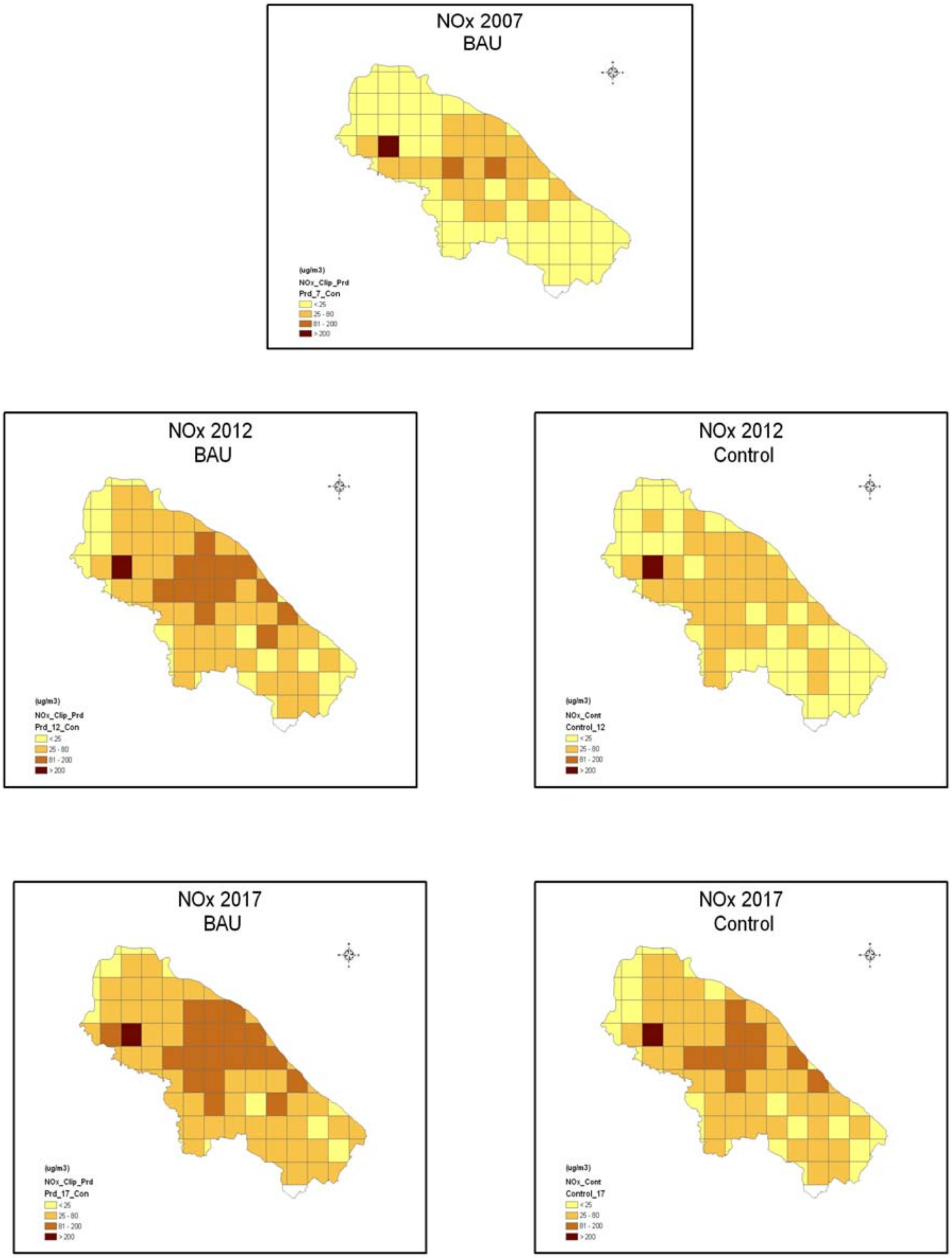


Figure 14: Modeling Results Daily Average of PM_{10} (for all grids) – For Best Scenario -3

Action Plan

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

- Implementation of BS – VI norms
- CNG/LPG to commercial Vehicles
- Improvement in Inspection and Maintenance of vehicles
- Banning of 15 year old private vehicles
- Particulate control systems in industry
- Domestic-Use of Natural Gas/LPG
- Converting unpaved roads to paved roads
- Sweeping and watering (mechanized)
- DG Sets: No Power cut
- Strict compliance to ban of open burning

By implementing the above options, air quality will improve dramatically but will fall short of achieving 24-hour air quality standards for PM_{10} in 1/4 th part of the city and by the year 2017, almost 2/3 area will still be below the desired air quality; this represents worst case scenario by considering that standard should be attained on each day. It is necessary that emissions in certain grids (area) should reduce to 40 percent of controlled emission of 2012 and 2017 (as recommended above). This will require additional efforts to reduce the emission. Vehicles, road dust and domestic cooking are the important sources both in 2012 and 2017. It may be noted that that if vehicular pollution is reduced further by 50 percent which can best be done by restricting entry of vehicles in critical areas by 50 percent of projected number of vehicles (e.g. by allowing odd number of vehicles the first day and the next day even number and the repeating the cycle). This needs to be done by in winter months (November to January) only. The reduction in vehicles will also reduce the road dust by 50 percent. In addition, there should be a total ban on any refuse or garbage burning from 2012.

The decision to restrict the public transport can put the general public to inconvenience. It is emphasized that a network of public transport in terms of metro or elevated railway needs to be planned. Further, construction of flyovers at all railway intersections (15 Nos.)

will help in about 20 percent time saving that will result in 20 percent lowering of vehicular emissions and corresponding improvements in air quality. The overall action plan that will ensure compliance with air quality standards both for PM_{10} (100 µg/m^3 – 24-hr average), $PM_{2.5}$ and NOx (80 µg/m^3) is presented below.

Action Plan

S. No.	Details	2008	2009	2010	2011	2012	2013 - 2017
1.	Adoption of BS – VI for all vehicles						**From 2015**
2.	Banning of 15 year old private vehicles and 10 year old commercial vehicles					🟥	🟥
3.	CNG/LPG for Commercial Vehicles	🟨	🟨	🟨	🟨	🟨	🟨
4.	Particulate control systems in all industry				🟪	🟪	🟪
5.	Inspection and Maintenance of vehicles			🟧	🟧	🟧	🟧
6.	LPG for Domestic Sources (50% by 2012)				🟦	🟦	
7.	LPG for Domestic Sources (75% by 2017)						🟦
8	Inspection and Maintenance of DG sets				🟦	🟦	
9.	Ban on DG sets (100% Grid power)						🟦
10.	Unpaved to paved roads (50% by 2012)				🟩	🟩	
11	Unpaved to paved roads (100% by 2017)						🟩
12	Sweeping and watering of Road				🟪	🟪	🟪
13	Ban on open burning (100%)					🟧	🟧
14	Restricted vehicle Movement ~ 50% only (in winter in polluted areas)					🟦	🟦
15	Mass Rapid Transport System			🟩	🟩	🟩	🟩
16	Construction of flyovers (15 Nos.)			🟧	🟧	🟧	🟧

Acknowledgments

This project on "Air Quality Assessment, Emissions Inventory and Source Apportionment Studies for Kanpur City" was sponsored by Central Pollution Control Board to IIT Kanpur. The project was quite vast in terms of activities including field sampling, data collection, laboratory analyses, computational work and interpretation of results. One needs support from several institutions and individuals at all levels for timely completion of the project. 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 in our effort.

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Chapter 1

Introduction

1.1 Background of the Study

Air pollution professionals responsible for the development of air particulate control strategies and other particles impact analysis programs, have long been faced with the basic need to understand the relative importance of specific source impacts within air-sheds. Pollution control agencies responsible for developing strategies for attainment of particulate standard must be able to provide convincing evidence that (a) the relative importance of emission sources is understood and that (b) the control programs proposed are cost effective and can be adopted by the community with confidence.

Until quite 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 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, 1981). These shortcomings are largely the result of difficulty in developing accurate 24-hour particulate emission inventories and meteorological database. Although traditional techniques using dispersion modeling 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 confounded by the predominance of non-ducted and widely distributed area (fugitive) sources and the lack of understanding of the sources of secondary aerosol, their formation and transport. The advent of receptor modeling and recent developments in the areas of trace element analysis now permit a much more detailed analysis of ambient aerosol samples. By providing detailed information on the sources of the total, fine and inhalable particles, receptor models can play a major role in developing strategies for controlling airborne particulate matter.

It is evident from the above discussions that a receptor modeling 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 is typically true for our urban cities. In order to apply receptor modeling to any city, 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 modeling can complement at each other for better interpretations and decision making and can be applied at tandem.

To effectively address the pollution problem in the city of Kanpur by identifying major air pollution sources and their contributions to ambient air pollution levels, studies including receptor and dispersion modeling are desirable for taking short and long-term control measures.

1.2 General Description of City

1.2.1 Demography

Kanpur, the largest industrial city in Uttar Pradesh mainly having cotton, jute leather and wool industries with a total area of 230 square kilometers, is located about 435 kilometers east of New Delhi. Kanpur is boarded by the river Ganges to the north and the river Pandu to the south. As per Kanpur census of 1991, the population was 19 lakh; and in 2001, the population rose to 25.67 lakhs (Kanpur city as well as rural area has population of about 40 lakhs in 2001). Kanpur is divided into six administrative zones, which are further sub-divided into 110 wards (election wards) (Tiwari, 2003). Per capita income in Kanpur city is about Rs. 850. Out of 25.67 lakh persons in Kanpur city, approximately more than 60% belong to lower to middle income group. Languages spoken in and around Kanpur include Hindi, English, Urdu and some Bengali and Punjabi. With the coordinates 26.4670° North and 80.3500° East, Kanpur is 80 km from Lucknow, the capital city of Uttar Pradesh and 126 meters above the mean sea level. It is surrounded by two main rivers of India, Ganges in the north-east and Yamuna in the south. The districts surrounding Kanpur are Hamirpur in the south, Unnao in the north-east, Farrukkhabad in the north and Etawah in the west.

1.2.2 Climate

Temperatures in cold weather drop to freezing sometimes reaching a minimum of -1 ^{0}C (Lowest -1 ^{0}C, 2004, 1968) with maximum at almost 12 to 14 ^{0}C. Kanpur experiences severe fog in December and January, resulting in massive traffic and travel delays. In summer (April-June) maximum temperatures spiral up to 47.5 ^{0}C and are accompanied by dust storm-cum-heat-waves. During the rainy season the relative humidity is generally high over 70%. Thereafter the humidity decreases and by summer, which is the driest part of the year, the relative humidities in the afternoons become less than 30%. The average annual rainfall in the district is 792 mm. About 85% of the annual normal rainfall is received during the south west monsoon months from June to September, August being the rainiest month. Winds are generally light and are mostly from directions between south-west and north-west. In May, the south-west monsoon season, winds on many days blows also from directions between north-east and south-east.

1.2.3 Emission Source Activities

The source activities for air pollution in the city of Kanpur 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/ kerosene generators are the most prevailing sources for air pollution in the city. For transport of men, mostly public transport (buses) and private diesel tempos fulfill the transport requirement for the city. The combustion of fuels like coal, kerosene, liquefied petroleum gas (LPG) and wood come under the source for domestic activities. As far as the industrial activities are concerned, the dominant source is the 200 MW Panki Thermal Power Plant. 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 evening) is a common practice; it can be an important contributor to air pollution. The road condition in the city is quite bad as roads are broken, poorly maintained and partially paved surfaces 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

Several studies have been conducted in terms of post graduate research and project work at Kanpur on ambient air quality study. Selective studies are discussed in this section of this report. A project on **“**Operation and Maintenance of Ambient Air Quality Monitoring Station, Vikash Nagar, Kanpur” (sponsored by Central Pollution Control Board (CPCB), Lucknow) has generated air quality data for last three years. The project work included regular air quality sampling and analysis of PM_{10} (particles of size less than 10 µm aerodynamic diameter), SO_2 and NO_2 at Vikash Nagar, Kanpur. On the basis of this project data, the ambient air quality of Kanpur can be summarized as follows:

While SO_2 and NO_2 levels have always been within the National Air Quality Standard, PM_{10} and TSPM levels have exceeded the air quality standard over 90 percent of time except for monsoon months when PM_{10} levels were within standard for 60 - 70 percent of time.

In general, nigh time TSPM and PM_{10} levels drop significantly in a statistical sense in all seasons reflecting the reduction in urban activities (emissions) in nighttime. In all seasons TSPM and PM_{10} correlate well (coefficient of correlation: 0.60-0.82) in all time slots and on 24-hourly basis. There was no correlation between PM_{10} and NO_2 (except for October and January months), it implies that most of the time NO_2 and PM_{10} come from different sources and not from combustion alone.

TSPM and PM_{10} levels have increased in pre-summer period (compared to winter months) due to high-speed winds prevalent in the months of March and April. However, there is a significant statistical difference in ratio of PM_{10} to TSPM for the months of March (0.52) and April (0.41). The pre-summer PM_{10}/TSPM ratio is smaller than the mean winter ratio of 0.55. This suggests that there is a higher contribution of large particles in pre-summer months (more so in the month of April) than in winter months.

PM_{10} and $PM_{2.5}$ levels are very high which range from (50-600 ug/m^3 for PM_{10}) and from (25-200 ug/m^3 for $PM_{2.5}$). There is an immediate need for controlling particulate pollution for improving the environment and public health. The results from these previous studies sampling and analysis for PM_{10} and NO_x from Vikash Nagar sampling site (for the year 2006-07) are shown in Figures 1.1 to 1.4.

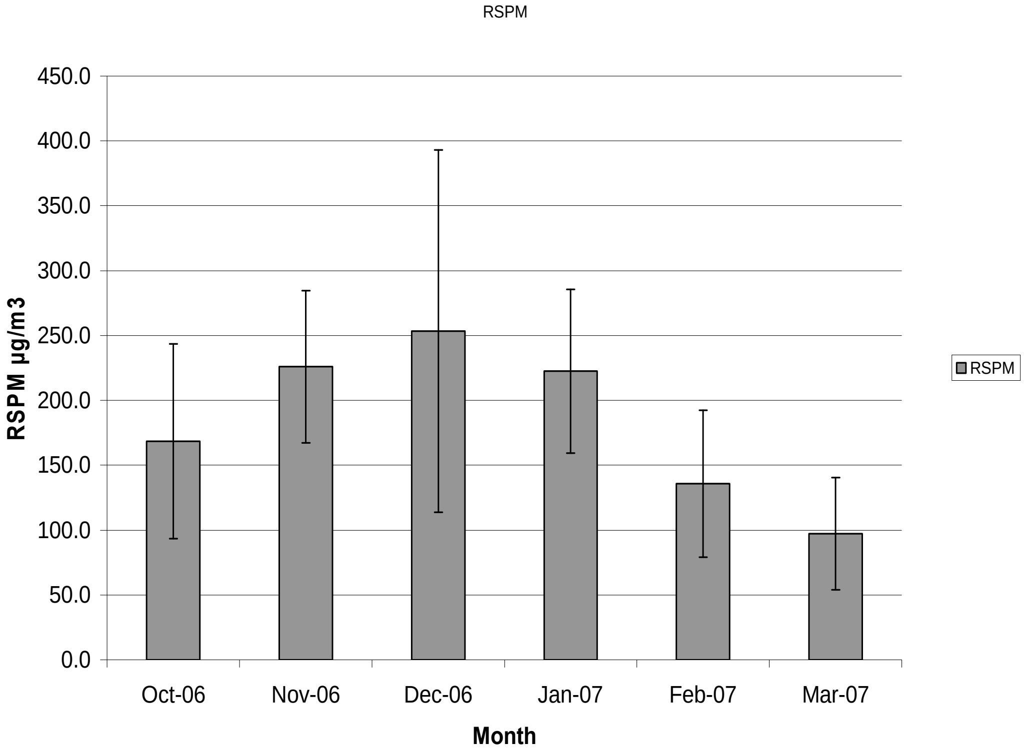


Figure 1.1: Monthly Variation in Concentration of PM_{10}

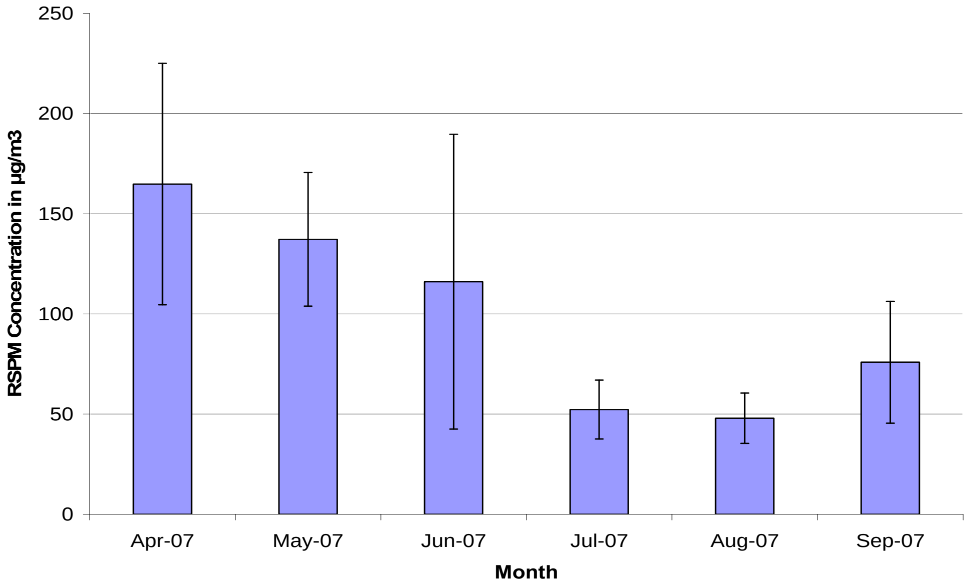


Figure 1.2: Monthly Variation in Concentration of PM_{10}

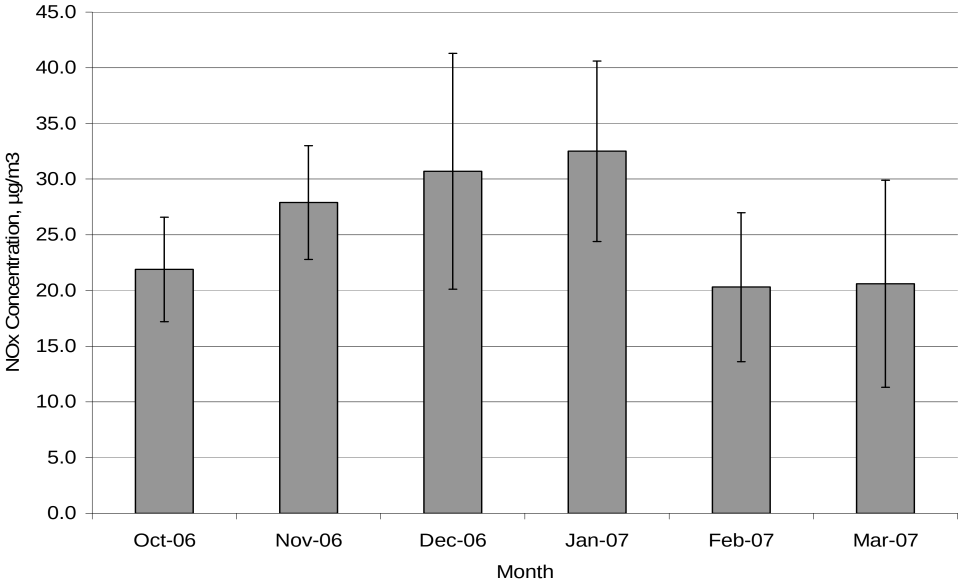


Figure 1.3: Monthly Variation in Concentration of NO_x

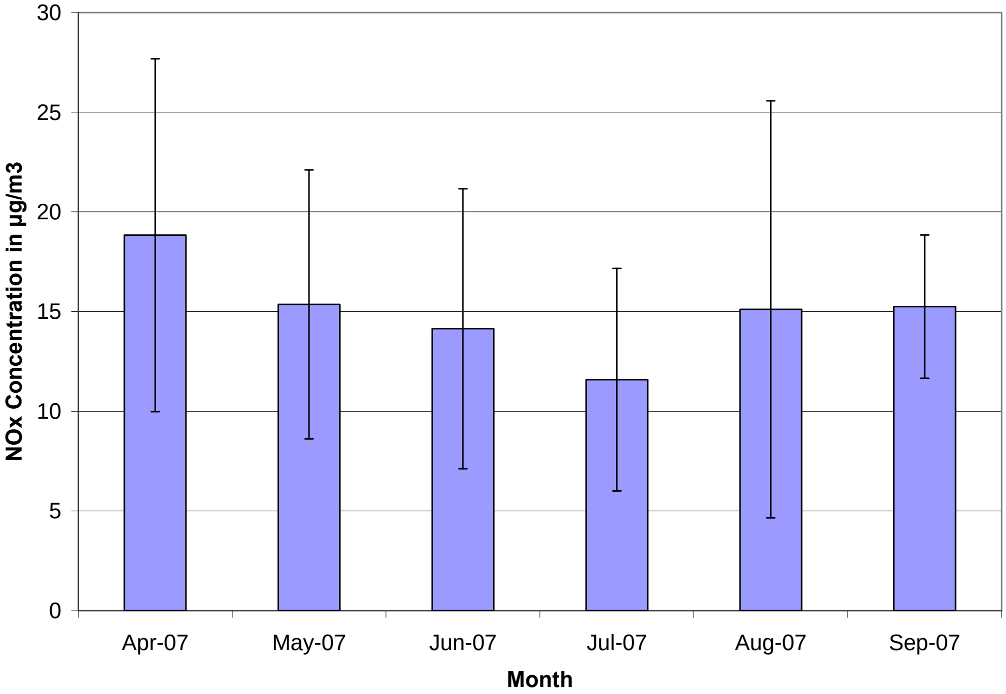


Figure 1.4: Monthly Variation in Concentration of NO_x

Air quality sampling was also done at other locations in Kanpur for PM_{10} and $PM_{2.5}$. The results from other locations Vikash Nagar (VN), Juhilal colony (JC) and IITK are shown in Figure 1.5 to 1.6 for the year 2002-03 (Sharma and Maloo, 2005).

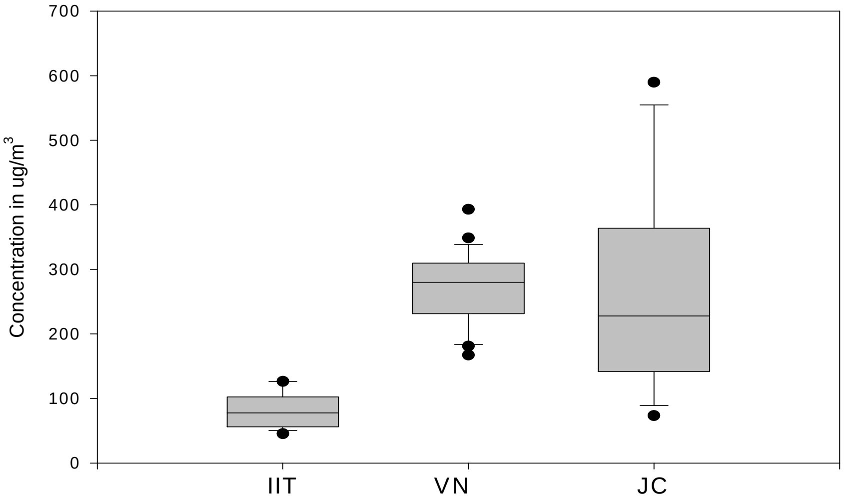


Figure 1.5: PM_{10} Levels in Kanpur

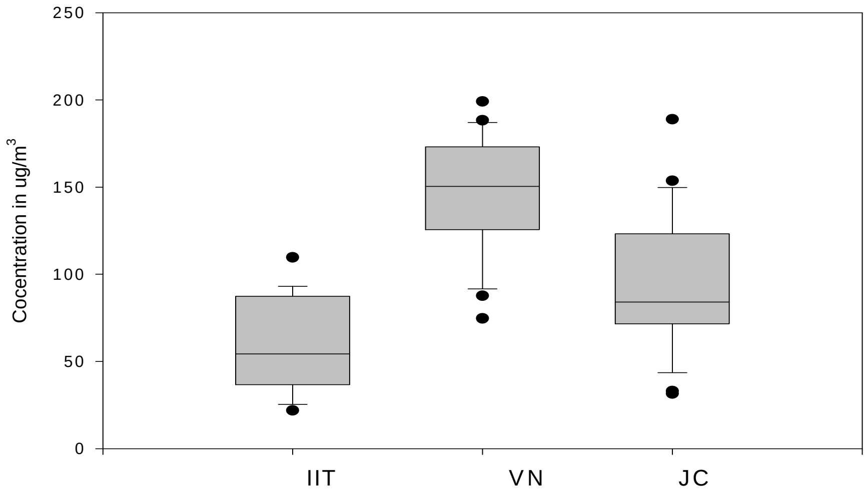


Figure 1.6: $PM_{2.5}$ Levels in Kanpur

The following conclusions can be drawn from these studies:

(i) PM_{10} and $PM_{2.5}$ levels are very high which range from (50-600 ug/m^3 for PM_{10}) and from (25-200 ug/m^3 for $PM_{2.5}$). There is an immediate need for controlling particulate pollution for improving the environment and public health.

(ii) PM_{10} and NOx levels do not correlate suggesting that PM_{10} may not be originating from the combustion sources alone.

(iii) TSPM and PM_{10} correlate well and may originate from the same source, which is also evident from high PM_{10} to TSPM ratio being in the range 0.6 – 0.8 during post-monsoon and winter periods and around 0.4 in summer and monsoon period.

(iv) In all months, night time PM_{10} and TSPM levels are lower than daytime levels. This can be attributed to the fact as the daytime activities are stopped and the levels drop in the nigh time after 10 pm.

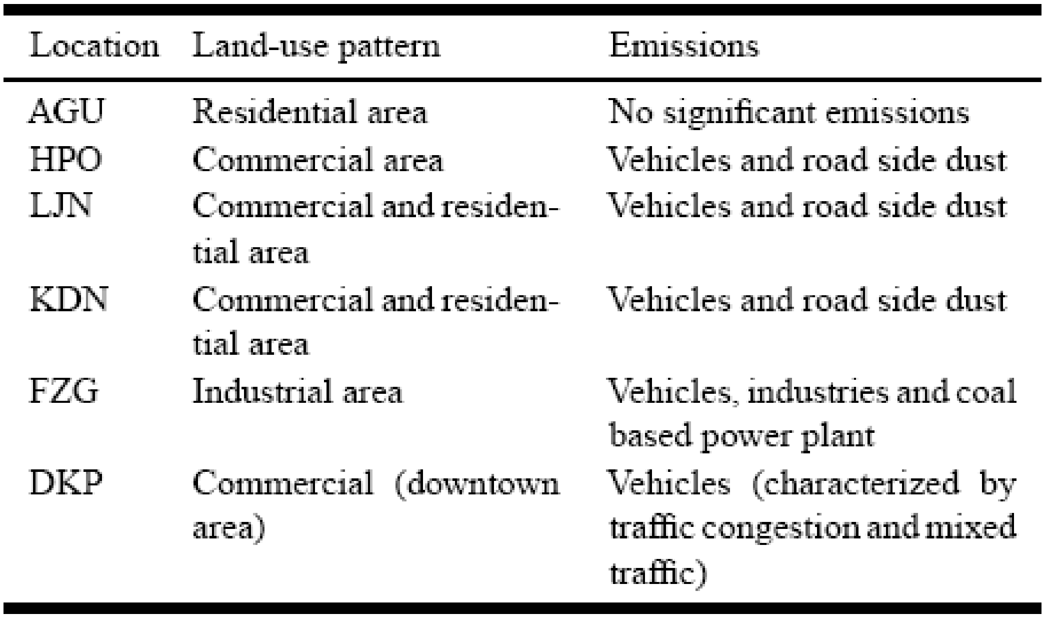
(v) As expected, NO_x levels are found to be higher in December and January months compared post monsoon and February and March months.

(vi) The December month showed worst air quality both for PM_{10} and $NO_{2.}$ It is by mid-January that air quality begins to improve.

(vii) The July month showed best air quality both for PM_{10} and $NO_{2.}$

A composite index of air quality has also been studied (Sharma et al. 2005). Over 90 percent contribution for the index has been reported to come from particulate matter. Table 1.1 and Figure 1.7 show the sampling locations with their description for which air quality index has been studied. Figure 1.8 shows the monthly variation of AQI at six locations. From this study, it can be concluded that air quality worsens (very poor to severe) in winter months and also during the early summer months (March, April, and part of May). These months are characterized by dusty winds resulting in high SPM. The air quality generally improves in monsoon and post-monsoon period (good to moderate) as rain washes out the pollutants.

Table 1.1: Monitoring Location at Kanpur



Location	Land-use pattern	Emissions
AGU	Residential area	No significant emissions
HPO	Commercial area	Vehicles and road side dust
LJN	Commercial and residential area	Vehicles and road side dust
KDN	Commercial and residential area	Vehicles and road side dust
FZG	Industrial area	Vehicles, industries and coal based power plant
DKP	Commercial (downtown area)	Vehicles (characterized by traffic congestion and mixed traffic)

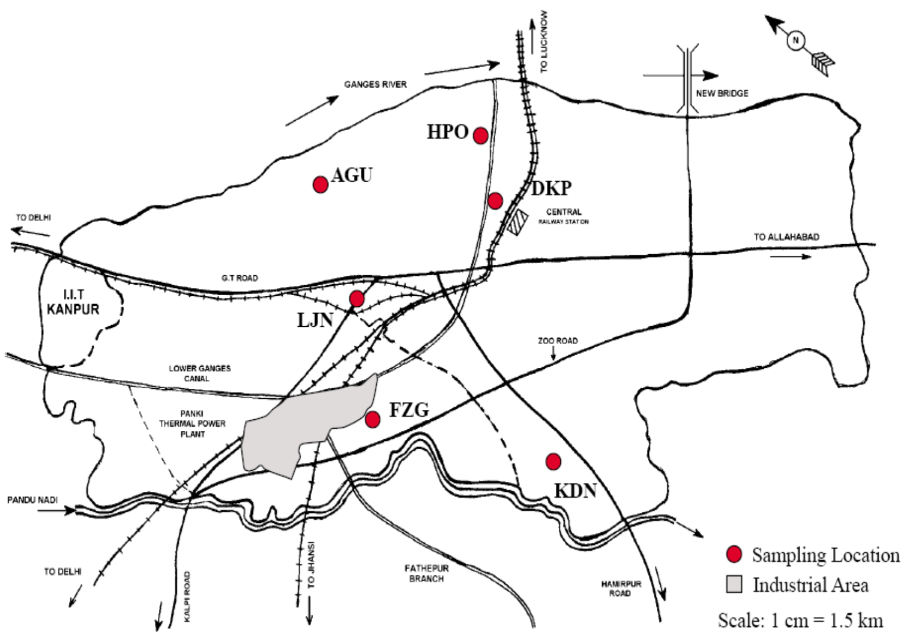


Figure 1.7: Sampling Locations in the City for Air Quality Index Study

In other study on lead pollution in ambient air (Sharma et al. 2005), high levels of lead in air and food products were reported in the city and estimated risk of lead toxicity for the population of Kanpur was also high. There are several studies from the study area (Sharma et al. 2003 and 2007) indicating high levels of sulfates and nitrates in the ambient particulate and confirming formation of secondary particles. Presence of ammonia was reported to be an important constituent for formation of secondary particles. The past studies related to air quality in the city of Kanpur can be briefed in terms of the literatures as given in the citations at the end of the chapter.

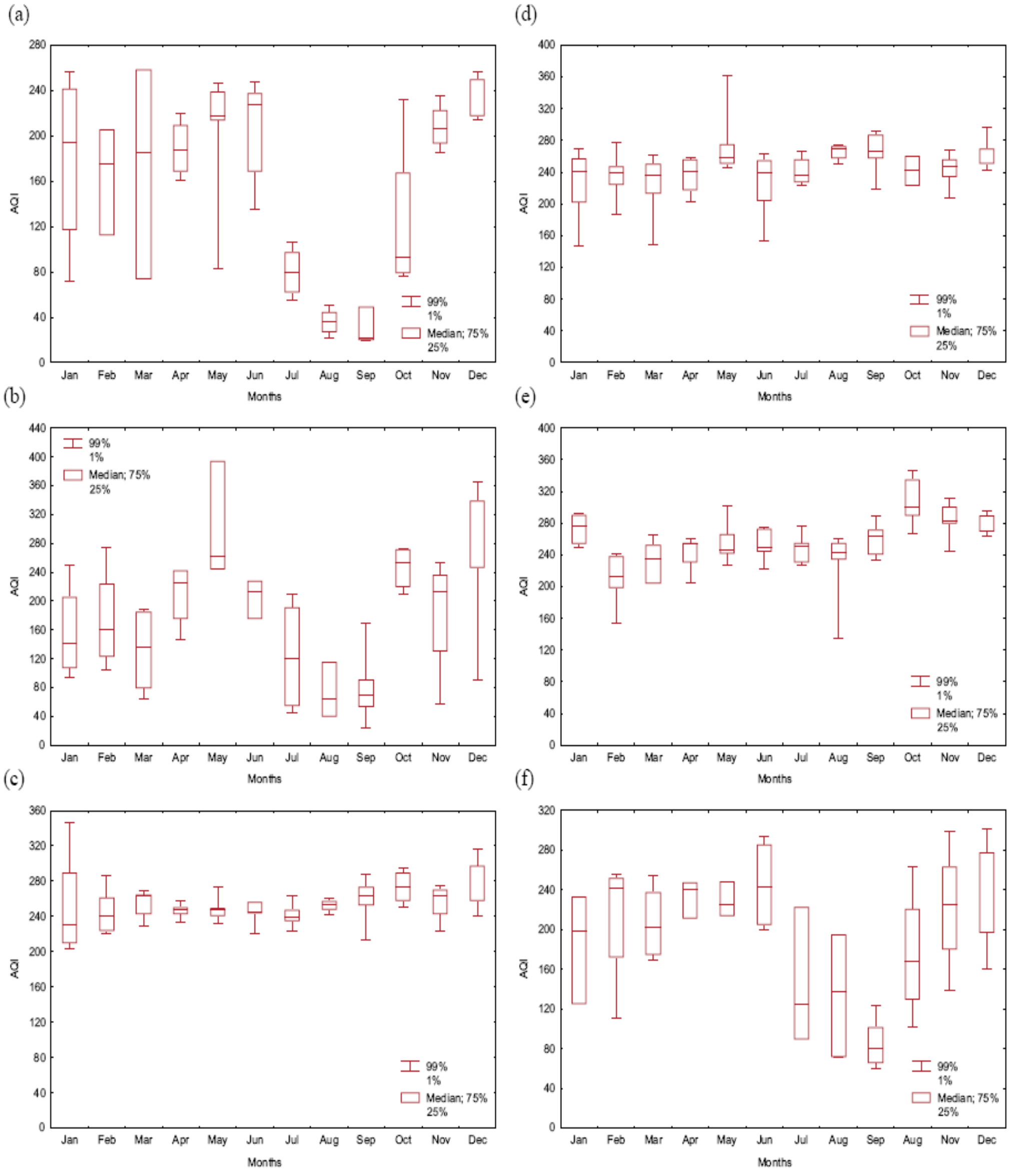


Figure 1.8: Monthly variation of AQI at different Air Quality Monitoring stations in the City of Kanpur, India: (a) AGU, (b) HPO, (c) DKP, (d) KDN, (e) FZG, (f) LJN (1998): An Index Value higher than 100 Shows Noncompliance of Air Quality Standards.

1.3.2 Need for the Study

Kanpur is an industrial town mainly having cotton, jute leather and wool industries. It has a population of about 2.57 million, out of which, approximately more than 60% belongs to lower to middle income groups. Being an industrial town a good percentage belongs to the labor class. It also happens to be one of the most polluted cities in the country (details later in text). Pollution, industry mainly cotton and lower socio-economic strata from a trio, which predispose to the respiratory diseases. Prevalence of respiratory ailments is on the rise. Diseases include tuberculosis, non-tuberculoses respiratory infections, amongst infants and children both related to poverty, non-infective diseases like bronchial asthma and chronic obstructive pulmonary diseases both related to pollution and industrial exposure. In addition to industrial and automobile pollution, due to large population being in economically lower strata, there is a significant emission from domestic cooking using cheap fuels like wood, coal, biomass etc., which are not common in other cities.

Previous investigations (IITK-NILU, 2005) show that Kanpur is the city having one of the highest particulate air pollution (Seasonal average $PM_{2.5}$ levels in urban area: 100-400 $\mu g/m^3$). It is also a city with large proportion of population in the lowest economic strata. Environmental health of this section of Kanpur's population has been shown to be deteriorated. Thus, even small improvements of the urban air quality here will lead to significant health benefits. Such improvements will be most effective if they are achieved in a scientific way.

To effectively address the pollution problem in the city of Kanpur by identifying major air pollution sources and their contributions to ambient air pollution levels, Central Pollution Control Board (CPCB) has sponsored a project, **"**Air Quality Assessment, Emissions Inventory and Source Apportionment Studies for Kanpur City**"** to IIT Kanpur. The project activities commenced in from April 2006. This document constitutes the final report of the project covering sampling, analysis, modeling and interpretation of results for all seasons, i.e. summer, post-monsoon and winter (April 2007 to January 2008).

1.4 Objectives and Scope of Work

The project aims to achieve the following objectives:

1. Identification and inventorization of emission sources (industry, traffic, power plants, local power generation, small scale industries etc.) in Kanpur city;
2. To measure baseline air pollutants and air toxic levels at different parts of Kanpur, which includes "hot spots" on kerbside as well;
3. To project emission inventories using mathematical models taking into account of vehicle population/ improvements in vehicle technology, fuel quality changes and other activities having impact on ambient air quality thereof;

4. Application of receptor modeling to PM_{10} levels in ambient air to arrive at source apportionments.
5. Application of ISCST3 modeling to assess the dispersion of PM_{10} and NO_x over some locations of the city from various sources at existing and future scenarios.
6. To assess some control options for reductions of air pollutants in the Kanpur city after studying the results from emission inventory, dispersion modeling, CMB modeling and factor analysis.

The overall scope for this study is summarized below:

1. Development of detailed emission inventory in the grid of 2×2 sq-km around the air quality monitoring stations for pollutants (such as: SO_2, NO_x, CO, SPM, PM_{10} and $PM_{2.5}$) are being established throughout the city of Kanpur.
2. Development of software for emission database and information/data retrieval system.
3. The study has been carried out by monitoring ambient air quality for thirty days continuously in each season (summer, post-monsoon and winter) at each identified location.
4. Air monitoring stations were installed at locations such as kerbside, residential, industrial, outskirts (reference), commercial and sensitive areas or downwind of city. There are 7 air monitoring stations in Kanpur city for the purpose of this study.
5. In each station 24 hrs average data were considered by monitoring ambient air quality for thirty days continuously in each season (summer, post-monsoon and winter) with total of 90 sampling days in a year. Monitoring of the pollutants such as: SO_2, NO_x, CO, formaldehyde, Ions, Elements, VOCs (benzene, ethyl benzene, ortho-xylene, para-xylene, meta-xylene, 1, 3-butadiene), NMHC, THC, PAHs, molecular markers, SPM, PM_{10} and $PM_{2.5}$ are being carried out. Continuous CO monitoring (online) has been done at least at one monitoring station (Colonelganj). O_3, NO_x and NH_3 were monitored continuously at one location, i.e. IIT Kanpur for one season.
6. Analyses of the above monitored parameters were done by the recommended methods.
7. Kerbside by definition is site with sample inlets within 1 m of the edge of a busy road and sampling heights are at 3 m elevation. If for reasons, 1 m of the road edge

is not possible, declare the site as roadside location, which has the definition of being a site with sample inlets between 1m of the kerbside of a busy road and the back of the pavement. Typical are within 5 m of the kerbside and the sampling height remains at 3 m elevation.

8. In order to get a wider cross section of vehicles in-use / on-road and the actual distance traveled by each sample vehicle, a systematic survey of vehicle population was undertaken in the city. Also, special emphasis was laid on the emission factors from vehicles of pre Euro / India 2000 as these form higher percentage in total vehicle population for assessing cost effective solutions.
9. Automotive Research Association of India (ARAI) developed emission factors for each representative vehicle considering vehicle technology, age, traffic and conditions including influence of fuel quality with or without tail pipe treatment are being used.
10. For all other sources, USEPA emission factors (AP-42) and the factors finalized by the CBCB expert committee are being used to estimate the emissions.
11. The actual meteorological data obtained from weather monitoring stations are being used for air quality modeling. Two permanent weather monitoring stations were installed on two of the locations throughout the year and also at the time of the sampling station, the weather monitoring were installed at that particular station.
12. The data were analyzed for preparation of Emission inventory (EI) in Kanpur using appropriate technique like IPIECA tool, IVE model or other equivalent technique being used by reputed organizations like CARB, US EPA , NILU etc.
13. Review of receptor modeling techniques and their applicability in Indian context (e.g. fingerprinting, chemical mass balance, Multivariate analysis). Adoption of the technique suitable for study area.
14. Source apportionment analyses are being carried out for the components of PM using receptor model. For these purpose, relevant details pertaining to the city were gathered. It was proposed to use USEPA CMB8.0 model or equivalent model to be used; a brief description of the model is given later in this report.
15. Further, by the way of application of suitable air dispersion models like ISCST3, the critical air pollutant levels (NOx, PM_{10} etc.) in ambient air were predicted under different scenarios on an attempt were made to validate the model based on actual measurements.

1.5 Approaches to the Study

The approach of the study is based on attainment of its objectives and scope, as explained in the section 1.4. The summary of the approach is presented in Figure 1.9. The overall approach to the study is broadly described as followed:

1.5.1 Selection of sampling Sites to Represent Urban Land Use

It was considered appropriate that seven sites in a city like Kanpur can represent typical land use patterns. It needs to be ensured that at all sites there is a free flow of air without any obstruction (e.g. buildings, trees etc.). In view of the safety of the stations, public buildings (institutions, police stations, hospitals, electric substations) could be better choices as sampling locations. Finalization of sites was done in consultation with CPCB, Delhi. The land uses that need to be covered include, background, commercial cum residential, residential, industrial, kerb site, commercial, and traffic site (away from kerb).

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 small emission sources like refuses burning, road dust, and coal/coke burnt by street vendors/small restaurants, riverbed dust to large units like foundries, 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. Therefore, the identification of particulate emission sources needs to be repeated in each season (winter, summer and post monsoon). 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

The next step was to either take the elemental and organic emission profiles from the literature or to develop the emission profile of identified sources for receptor modeling. It is proposed initially that emission profiles would be taken from the literature and if found that uncertainty source profile could be high, the actual source profile would be generated by taking samples and analyzing them for various metals, ions, carbon contents, PAHs and molecular markers. IIT Bombay and ARAI, Pune will provide the emission source profiles.

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 (www.epa.gov/scram001/cmb.htm). This model was able to provide contribution of each source in the particulate levels in ambient air that 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. The receptor modeling will also be conducted through statistical analysis using multivariate factor analysis.

1.5.5 Application of Dispersion Modeling

In addition to receptor modeling, dispersion modeling in the study area will also be undertaken. The meteorological data will be generated continuously at each of the monitoring locations on all days of sampling. The emission quantities coupled with predominant meteorological data of the city will be used in dispersion model in estimating the concentration of various pollutants and examining the contribution of each of the sources. Attempts will be made to validate the model as concurrent data on air quality generated on the field. It is proposed to apply USEPA regulatory model ISCST3 which could consider point and area sources including topographical features including lakes and other water bodies.

1.5.6 Emission Control Options: Analysis and Prioritization of Options

Develop future emission scenarios for 5-10 years (based on city development and growth) and account for options for line, area, and point Source control options & analyze the data in terms of air quality improvements. It is proposed that ISCST3 model will be able to provide impact and action matrix for 5 to 10 year scenario. The developed matrix can be used for prioritizing the list of management options for sources in a temporal framework leading to a city specific action plan.

1.6 Report Structure

The whole report is divided into eight chapters and annexure at the end. The brief descriptions of the chapters are as follows:

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 researches and project studies. The objectives, scope and approaches for the 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 three seasons, i.e. summer, post-monsoon and winter. 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 obtaining 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 factor analysis and in running CMB8.2 modeling for source apportionment study. The chapter also describes the results from the above approaches.

Chapter 5

This chapter enumerates the methodology used in conducting dispersion modeling (ISCST3 model). The chapter also describes the results form 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.

Chapter 7

This chapter 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

Chapter 8

This chapter highlights the important findings and issues from the study. The chapter also recommends the city specific action plan(s).

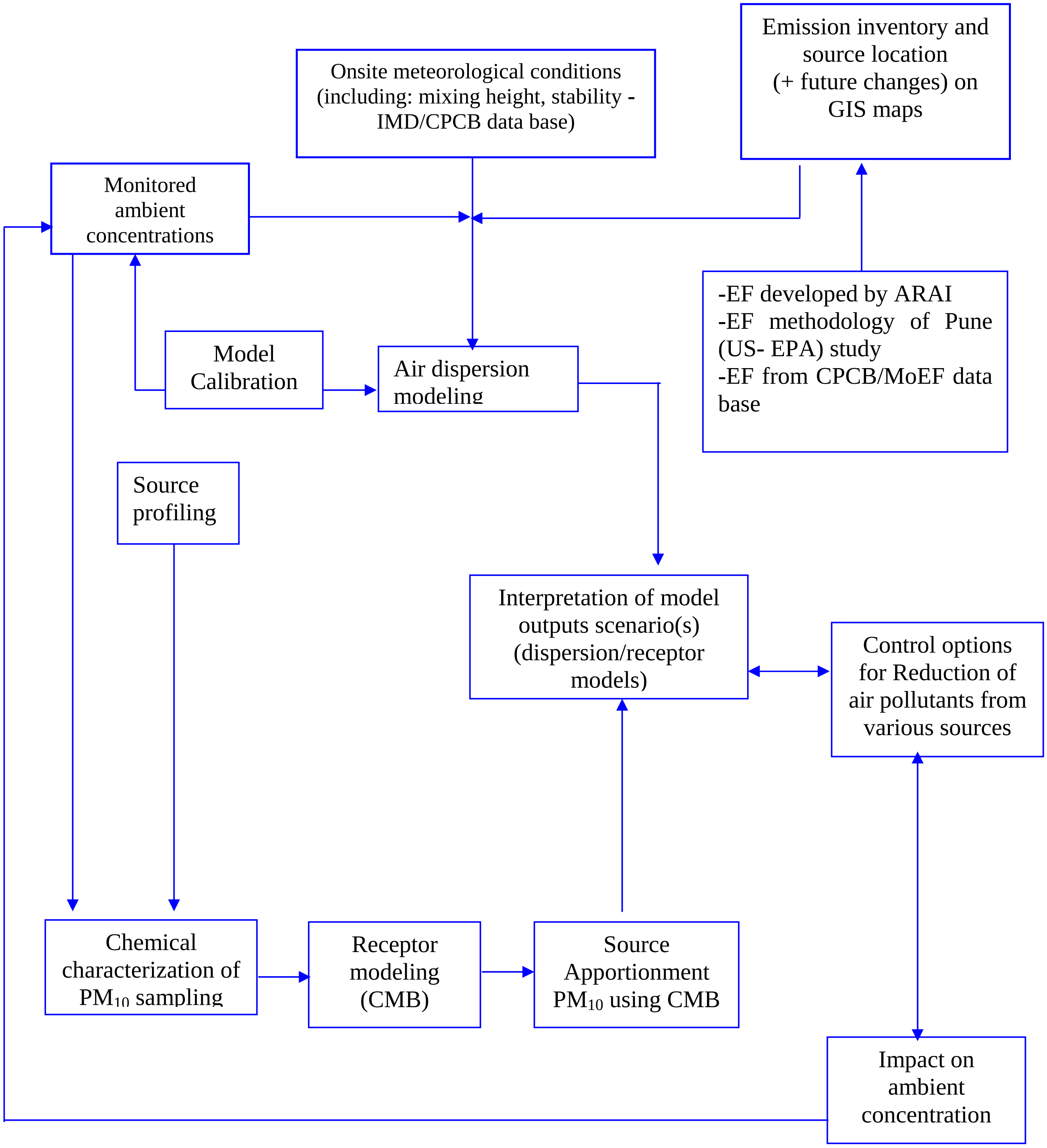


Figure 1.9: Study Framework for Approaches to the Study

1.7 References

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Chapter 2

Air Quality Status

2.1 Introduction

Several studies have been conducted in terms of post graduate research and project works at Kanpur on ambient air quality status. Selective studies are discussed in section 1.3. Pollution control strategies for attainment of particulate standards must be able to provide convincing evidence that (a) the relative importance of emission sources is understood and that (b) the control programmes proposed are cost-effective and can be adopted by the community with confidence. To specifically address these issues, Central Pollution Control Board, New Delhi has sponsored this project to the Indian Institute of Technology Kanpur for the city of Kanpur. This chapter presents and discusses the current status of air quality of Kanpur city from the sampling and chemical analysis results for three seasons carried out under the present project.

2.2 Methodology

Total seven sites were selected to cover various land-use patterns prevailing in the city. It was ensured that at all locations there was a free flow of air without any obstruction (e.g. buildings, trees etc.). In view of the safety of the stations, public buildings (institutions, police stations, hospitals, electric substations) were selected as sampling locations. A team from CPCB, Delhi had approved the sites. Table 2.1 describes the sampling sites with prevailing land-use and other features. Figure 2.1 shows the photographs of the sampling sites. Figure 2.2 shows locations of the sampling sites in a GIS based map. Overall land-use pattern of the city along with the surrounding area is shown in Figure 2.3.

Table 2.1: Description of Sampling Sites of Kanpur City

S. No.	Sampling Location	Site Code	Description of the site	Type of sources
1.	IIT Kanpur (IITK)	S1	Background area	Domestic cooking, light vehicles
2.	Vikash nagar (VN)	S2	Commercial cum residential area	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
3.	Govind nagar (GN)	S3	Residential area	Domestic cooking, vehicles, road dust
4.	Dada nagar (DN)	S4	Industrial area	Industries, Domestic cooking, DG sets, vehicles, road dust, garbage burning
5.	Colonel ganj (CG)	S5	Near to kerb site	Vehicles, Domestic cooking, DG sets, , road dust, garbage burning
6.	A.H.M. Hospital (AHM)	S6	Commercial area	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants
7.	Ramadevi Square (RD)	S7	Away from kerb site	Domestic cooking, DG sets, vehicles, road dust, garbage burning, restaurants

[At all locations, there was free flow of air without any obstructions (e.g. tree, building) within 10 m from the site. The sampling height (except kerb site station; height 1.5 m) varied between 3.5 to 6.0 m.]

Figure 2.1: Photographs Showing Sampling Sites

Figure 2.2: The Location of the Sampling Sites Selected in 2x2 Grid (GIS based)

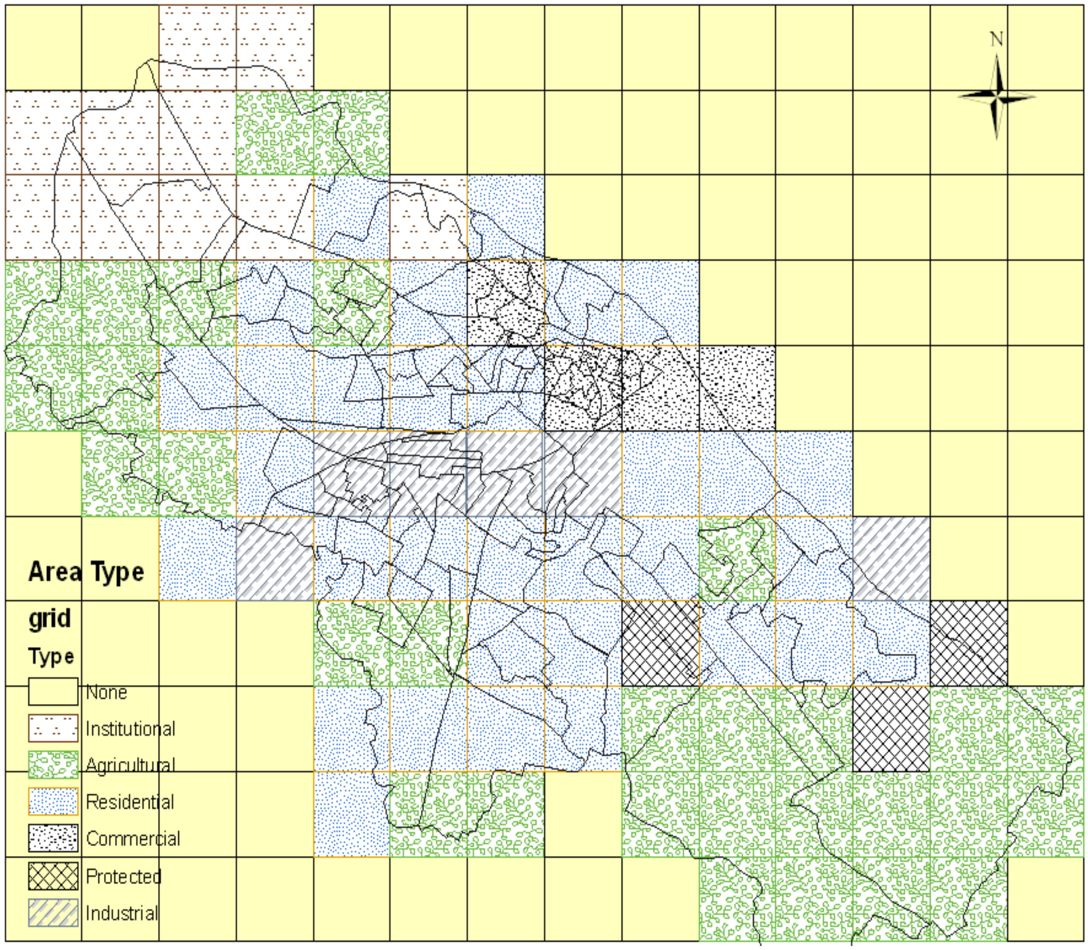


Figure 2.3: Grid Map of the City Showing Type of Land-use Pattern

The parameters for sampling and their monitoring methodologies including type of filter papers/chemicals and calibration protocols were prescribed by CPCB, Delhi (www.cpcb.nic.in). Every aspect related to sampling and analysis of parameters is based on the consignment with CPCB, New Delhi. The whole monitoring programme is divided into two groups, i.e. gaseous sampling and particulate matter sampling. Nitrogen dioxide (NO_2), sulphur dioxide (SO_2), formaldehyde (HCHO), volatile organic compounds (VOCs), nonmethane hydrocarbons are among the gaseous species. The major particulate matters (PM) sampled are suspended particulate matter (SPM), particulate matter of aerodynamic diameter of 10 µm (PM_{10}) and particulate matter of aerodynamic diameter of 2.5 µm ($PM_{2.5}$). The monitoring parameters for this study along with sampling and analytical methods are presented in Table 2.2.

Table 2.2: Details of Samplers/Analyzers and Methods

Sr. No.	Parameters	Sampler/Analyzer Type	Method
1.	SPM	Respirable Dust Sampler (RDS) (Filter + cyclonic collection)	Gravimetric
		High Volume Sampler (HVS)	Gravimetric
2.	PM_{10}	RDS	Gravimetric
		4-Channel Speciation Sampler (4-CSS)	Gravimetric
3.	$PM_{2.5}$	Pacwil/Westech	Gravimetric
4.	SO_2	Bubbler/Spectrophotometer	West and Gaek
5.	NO_2	Bubbler/Spectrophotometer	Jacob & Hochheiser modified
6.	CO	Continuous online analyzer	Non-dispersive infrared
7.	OC/EC	OC/EC Analyzer	Thermal Optical Reflectance
8.	Ions	Ion-Chromatograph	Ion-Chromatography
9.	Elements	ED-XRF Spectrophotometer	USEPA
10.	VOCs (benzene, ethyl benzene, ortho-xylene, para-xylene, meta-xylene, 1,3-butadiene)	Gas-Chromatograph	USEPA
11.	Formaldehyde	Bubbler/Spectrophotometer	Lodge, 1989
12.	NMHC	Gas-Chromatograph	FID analysis
13.	HC	Gas-Chromatograph	FID analysis
14.	PAHs	High performance liquid chromatography	Florescence /UV detector
15.	Molecular markers	Gas-Chromatograph-Mass Spectroscopy	Quantitative high temperature combustion

2.3 Quality Assurance and Quality Control (QA/QC)

At the time of sampling and analysis, the coding system has been adopted effectively to avoid the confusion. Separate codes for seasons, site locations, parameters, time slots are adopted. The persons working in the sampling sites and in the laboratory were aware of these coding system. Special training was given to the personnel working in the project prior to the commencement of the work. A suitable coding system was adopted to represent the results. The detailed results are given in the annexure following the coding system. The basis of the coded systems is explained as follows:

KSAISO2-01 **(2.1)**

In this code K- City code for Kanpur
S- Season of the sampling (S-Summer, P-Post-monsoon and W-Winter)
A- Month of result (say April etc.)
I- Sampling Location (say IIT Kanpur)
SO_2- Pollutant Parameter (say SO_2)
01- Sample code numbering

The sampling periods: summer season (April 2007 to June 2007), post-monsoon (October 2007 to November 2007), winter (December 2007 to January 2008). Due to continued monsoon and equipment problem, the post-monsoon samples were collected till early of part of December 2007 and the winter samples were collected till early part of February 2008. All efforts were made to complete 100% sampling. Tables 2.3 (2.3(a) to (g)); 2.4 (2.4(a) to (g)); 2.5 (2.5(a) to (g)) presents the details of sampling days for all pollutants sampled at all sampling locations. Percentage achievement for sampling of various pollutants are presented in Tables 2.6(a)-(c) for summer, post-monsoon and winter season. For parameters like SO_2, NO_x, SPM, PM_{10}, $PM_{2.5}$, HCHO, VOCs, NMHC and EC-OC, analyses were done regularly just after the sampling following the procedures of the standard operating procedures (SOPs). CO analyzer gave the online measurement data and it is averaged for every hour of the day. The analyses for elements, ions and PAHs were done immediately after the seasonal capture of the samples.

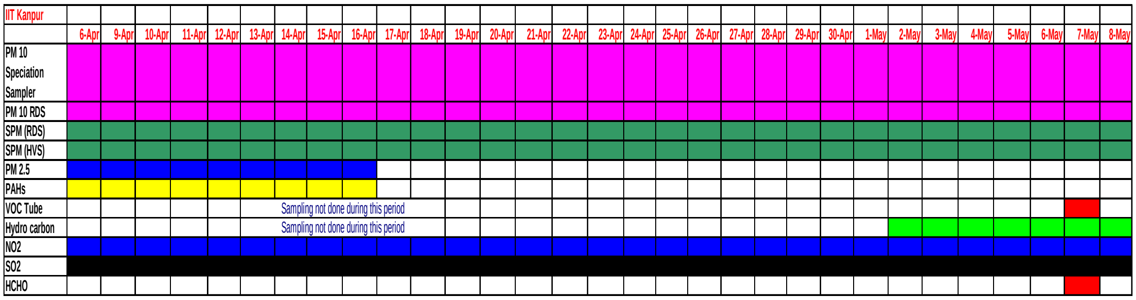
The calibrations for all samplers were done at regular intervals at the time of sampling. The results were also produced to the team of CPCB at their visit to the sampling sites. The calibrations of analyses of the pollutants were also done frequently and were cross-checked with known concentrations of the pollutants at the time of analyses. SOPs for field sampling of ambient and analysis for chemical characterization of particulate matter filter samples were prepared through inter-organizational cooperation between CPCB and IITK. The SOPs for all the samplers and instruments were prepared after consultation with the CPCB and these were produced in hard copies. Separate hard copies of different purposes were distributed among the personnel dealing with the specific work in our project for their reference. These SOPs are also given in the Annexure of this report.

Quality assurance and quality control (QA/QC) in entire project planning and implementation at all levels were designed in advance and hands on training were imparted to project team members before beginning of any sampling and analysis. The major features of QA/QC are briefly described here.

- Site selection: Sites were carefully selected to get representative samples of ambient air. In addition to sampling, selection of sampling sites was to cover various types of land-use pattern for the city.
- Standard operating procedures (SOPs) for entire project planning and implementation were developed, peer reviewed by CPCB experts and project personnel were trained in the field and in the laboratory by senior experts specifically to follow the SOPs. Whenever necessary the SOPs were adjusted to meet the field challenges.
- SOPs included type of equipment (with specifications), sampling and calibration methods with their frequency, height and distance of measurement from source.
- The SOPs for chemical analysis, included description of methods, standards to be used, laboratory and field blanks, internal and recovery standards, data base, screening of data, record keeping, traceability of calculations and standards.
- Field blanks for summer, post-monsoon and winter sampling were used to check the contamination in the handling of filter paper during sampling.

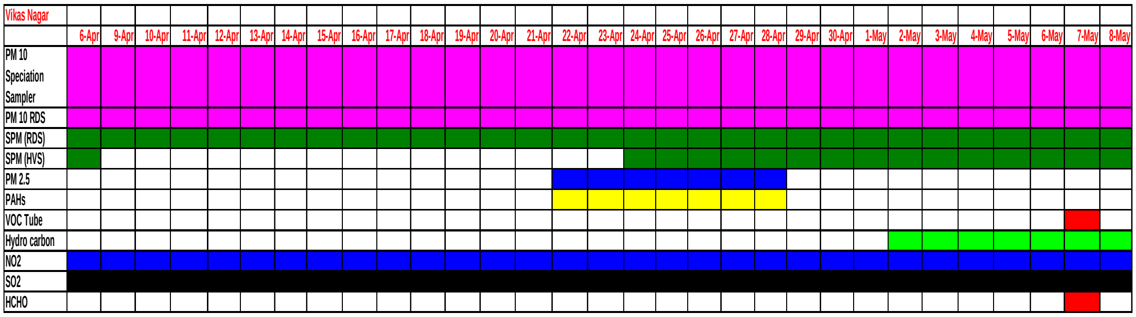
All efforts were made for achievement of 100 % completion of the analysis immediately after the sample collections.

Table 2.3(a): Sampling Days of Various Pollutants in Summer Season at IIT Kanpur



IIT Kanpur																															
	6-Apr	9-Apr	10-Apr	11-Apr	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
PM 10 RDS	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SPM (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (HVS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM 2.5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																						
PAHs	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																						
VOC Tube						Sampling not done during this period																								🟥	
Hydro carbon						Sampling not done during this period																			🟩	🟩	🟩	🟩	🟩	🟩	🟩
NO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SO2	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
HCHO																														🟥	

Table 2.3(b): Sampling Days of Various Pollutants in Summer Season at Vikashnagar



Vikas Nagar																															
	6-Apr	9-Apr	10-Apr	11-Apr	12-Apr	13-Apr	14-Apr	15-Apr	16-Apr	17-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr	1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
PM 10 RDS	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SPM (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (HVS)	🟩																🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
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PAHs															🟨	🟨	🟨	🟨	🟨	🟨	🟨										
VOC Tube																														🟥	
Hydro carbon																									🟩	🟩	🟩	🟩	🟩	🟩	🟩
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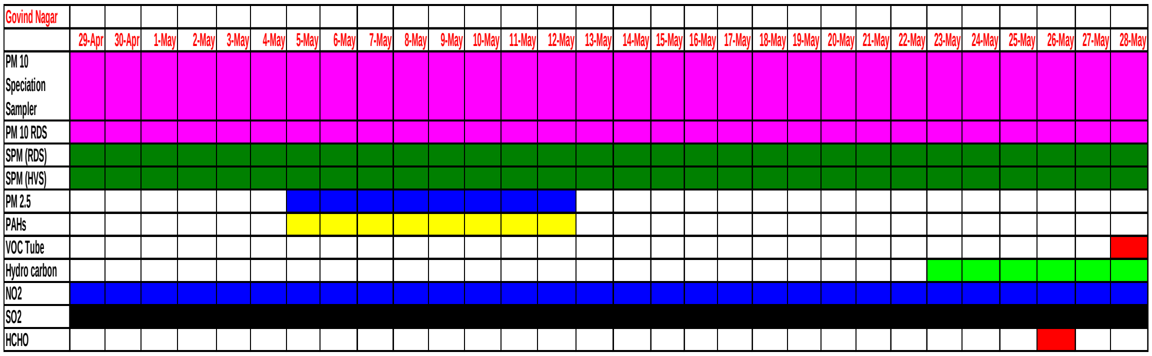
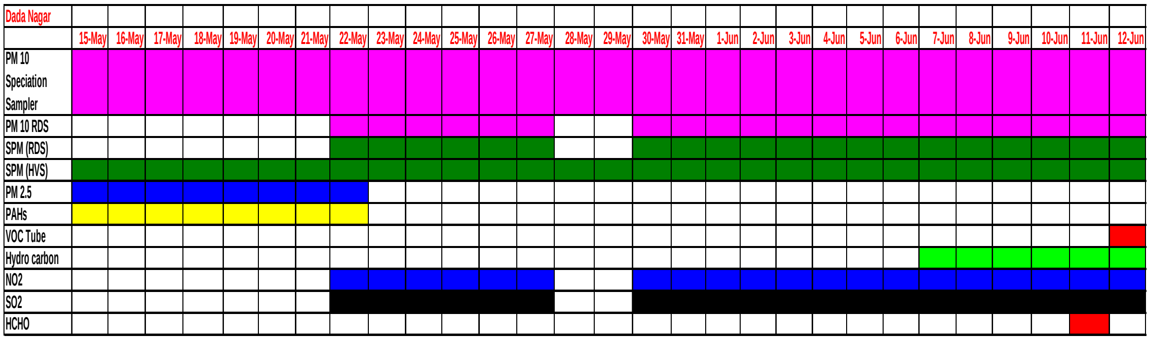
SO2	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
HCHO																														🟥	

Table 2.3(c): Sampling Days of Various Pollutants in Summer Season at Govindnagar



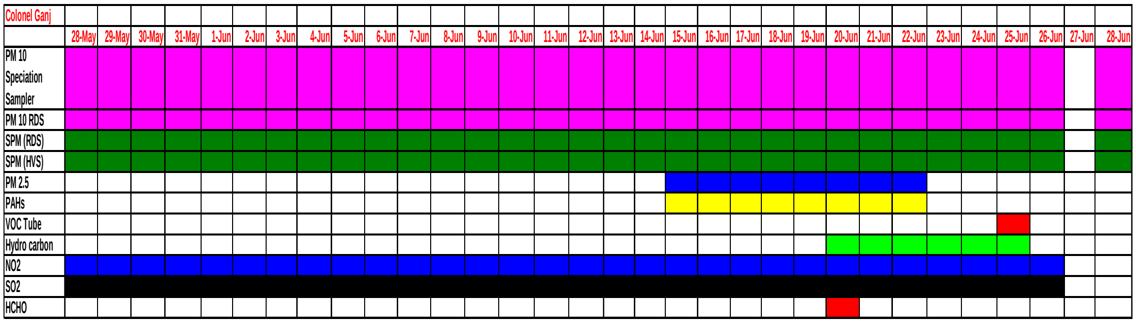
Govind Nagar																														
	29-Apr	30-Apr	1-May	2-May	3-May	4-May	5-May	6-May	7-May	8-May	9-May	10-May	11-May	12-May	13-May	14-May	15-May	16-May	17-May	18-May	19-May	20-May	21-May	22-May	23-May	24-May	25-May	26-May	27-May	28-May
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
PM 10 RDS	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SPM (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (HVS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM 2.5							🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																
PAHs							🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																
VOC Tube																														🟥
Hydro carbon																									🟩	🟩	🟩	🟩	🟩	🟩
NO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SO2	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
HCHO																												🟥		

Table 2.3(d): Sampling Days of Various Pollutants in Summer Season at Dadanagar



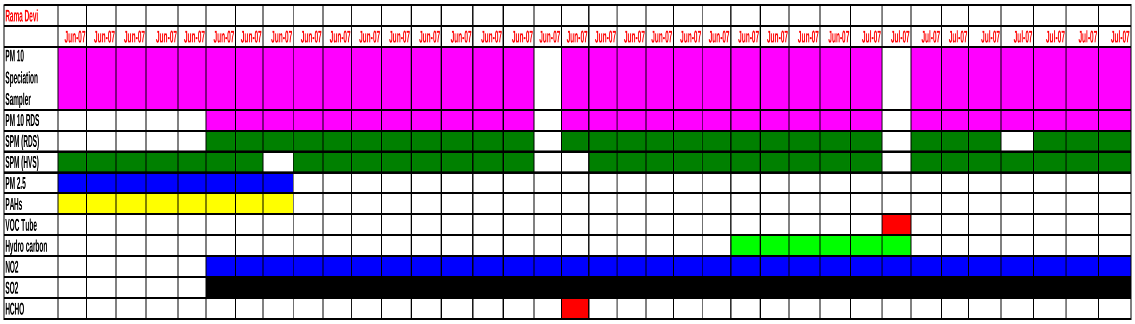
Dada Nagar																													
	15-May	16-May	17-May	18-May	19-May	20-May	21-May	22-May	23-May	24-May	25-May	26-May	27-May	28-May	29-May	30-May	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
PM 10 RDS								🟪	🟪	🟪	🟪	🟪	🟪			🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SPM (RDS)								🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (HVS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM 2.5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																					
PAHs	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																					
VOC Tube																													🟥
Hydro carbon																								🟩	🟩	🟩	🟩	🟩	🟩
NO2								🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SO2								⬛	⬛	⬛	⬛	⬛	⬛			⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
HCHO																												🟥	

Table 2.3(e): Sampling Days of Various Pollutants in Summer Season at Colonelganj



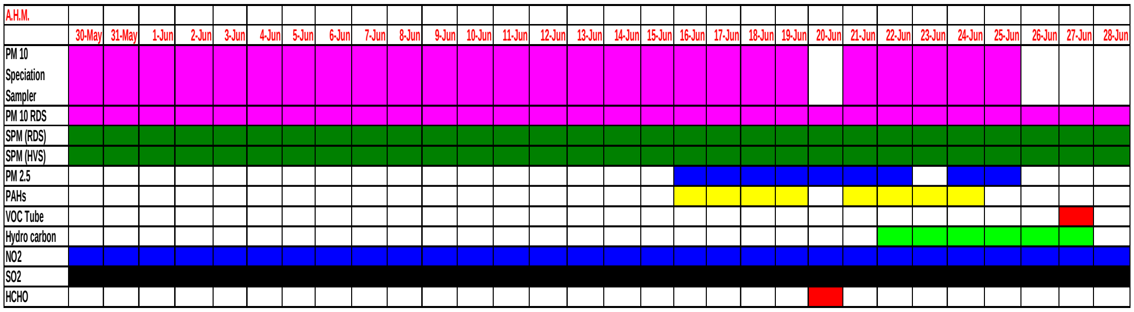
Colonel Ganj																																
	28-May	29-May	30-May	31-May	1-Jun	2-Jun	3-Jun	4-Jun	5-Jun	6-Jun	7-Jun	8-Jun	9-Jun	10-Jun	11-Jun	12-Jun	13-Jun	14-Jun	15-Jun	16-Jun	17-Jun	18-Jun	19-Jun	20-Jun	21-Jun	22-Jun	23-Jun	24-Jun	25-Jun	26-Jun	27-Jun	28-Jun
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪
PM 10 RDS	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪
SPM (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩
SPM (HVS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩
PM 2.5																			🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦						
PAHs																			🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨						
VOC Tube																													🟥			
Hydro carbon																								🟩	🟩	🟩	🟩	🟩	🟩			
NO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
SO2	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛		
HCHO																								🟥								

Table 2.3(f): Sampling Days of Various Pollutants in Summer Season at Ramadevi



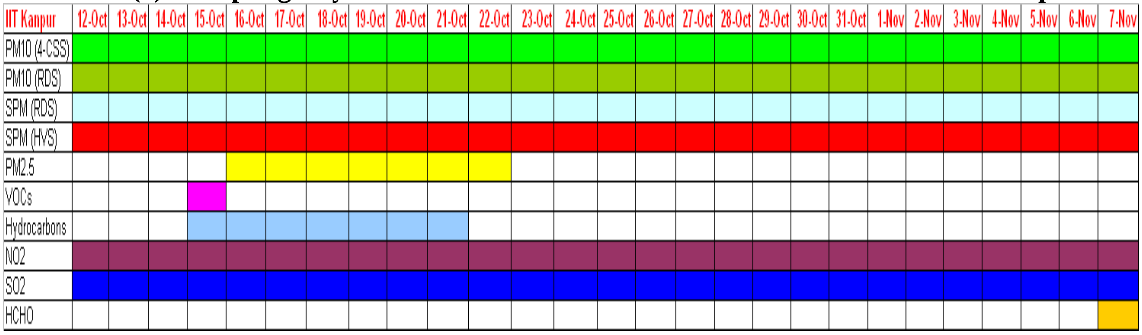
Rama Devi																																				
	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jun-07	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07	Jul-07
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪	🟪	🟪	🟪	🟪	🟪	🟪
PM 10 RDS						🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪	🟪	🟪	🟪	🟪	🟪	🟪
SPM (RDS)						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩		🟩	🟩	🟩
SPM (HVS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM 2.5	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																												
PAHs	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨																												
VOC Tube																													🟥							
Hydro carbon																								🟩	🟩	🟩	🟩	🟩	🟩							
NO2						🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SO2						⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
HCHO																		🟥																		

Table 2.3(g): Sampling Days of Various Pollutants in Summer Season at A.H.M.



A.H.M.																														
	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	20-Jun	21-Jun	22-Jun	23-Jun	24-Jun	25-Jun	26-Jun	27-Jun	28-Jun
PM 10 Speciation Sampler	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪		🟪	🟪	🟪	🟪	🟪			
PM 10 RDS	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SPM (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (HVS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM 2.5																		🟦	🟦	🟦	🟦	🟦	🟦	🟦		🟦	🟦			
PAHs																		🟨	🟨	🟨	🟨		🟨	🟨	🟨	🟨				
VOC Tube																													🟥	
Hydro carbon																								🟩	🟩	🟩	🟩	🟩	🟩	
NO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SO2	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛	⬛
HCHO																						🟥								

Table 2.4(a): Sampling Days of Various Pollutants in Post-monsoon Season at IIT Kanpur



IIT Kanpur	12-Oct	13-Oct	14-Oct	15-Oct	16-Oct	17-Oct	18-Oct	19-Oct	20-Oct	21-Oct	22-Oct	23-Oct	24-Oct	25-Oct	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct	31-Oct	1-Nov	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov
PM10 (4-CSS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM10 (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (RDS)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SPM (HVS)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
PM2.5					🟨	🟨	🟨	🟨	🟨	🟨	🟨																
VOCs				🟪																							
Hydrocarbons				🟦	🟦	🟦	🟦	🟦	🟦	🟦																	
NO2	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
HCHO																											🟧

Table 2.4(b): Sampling Days of Various Pollutants in Post-monsoon Season at Vikashnagar

VN	31-Oct	1-Nov	2-Nov	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	24-Nov	25-Nov
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■															
VOCs				■																						
Hydrocarbons				■	■	■	■	■	■	■																
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																										■

Table 2.4(c): Sampling Days of Various Pollutants in Post-monsoon Season at Govindnagar

GN	8-Oct	9-Oct	10-Oct	11-Oct	12-Oct	13-Oct	14-Oct	15-Oct	16-Oct	17-Oct	18-Oct	19-Oct	20-Oct	21-Oct	22-Oct	23-Oct	24-Oct	25-Oct	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct	31-Oct	1-Nov	2-Nov
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■															
VOCs				■																						
Hydrocarbons				■	■	■	■	■	■	■																
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																										■

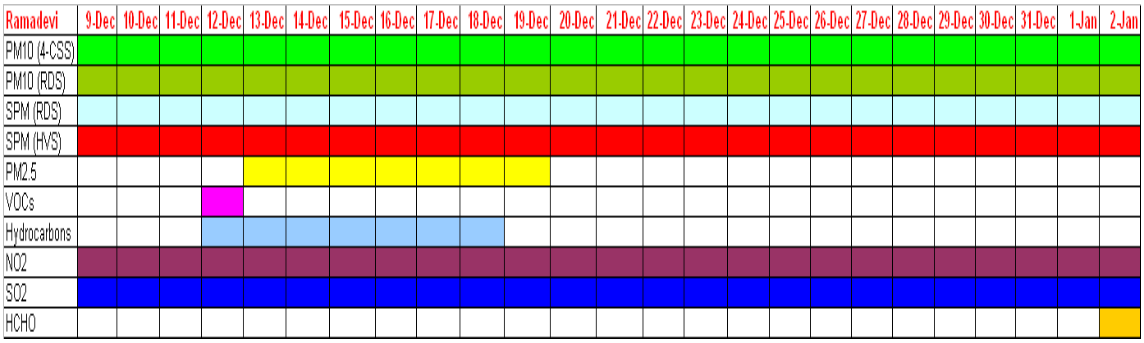
Table 2.4(d): Sampling Days of Various Pollutants in Post-monsoon Season at Dadanagar

DN	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	24-Nov	25-Nov	26-Nov	27-Nov	28-Nov	29-Nov	30-Nov	1-Dec	2-Dec	3-Dec
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■															
VOCs				■																						
Hydrocarbons				■	■	■	■	■	■	■																
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																										■

Table 2.4(e): Sampling Days of Various Pollutants in Post-monsoon Season at Colonelganj

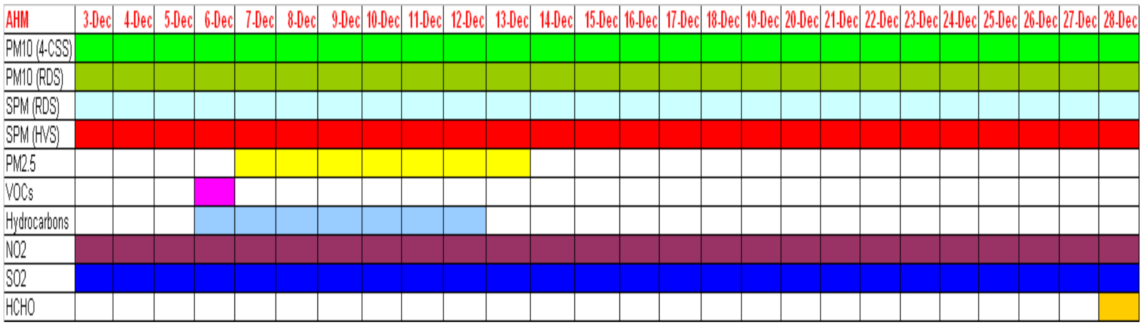
CG	16-Nov	17-Nov	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	23-Nov	24-Nov	25-Nov	26-Nov	27-Nov	28-Nov	29-Nov	30-Nov	1-Dec	2-Dec	3-Dec	4-Dec	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■															
VOCs				■																						
Hydrocarbons				■	■	■	■	■	■	■																
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																										■
CO	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2.4(f): Sampling Days of Various Pollutants in Post-monsoon Season at Ramadevi



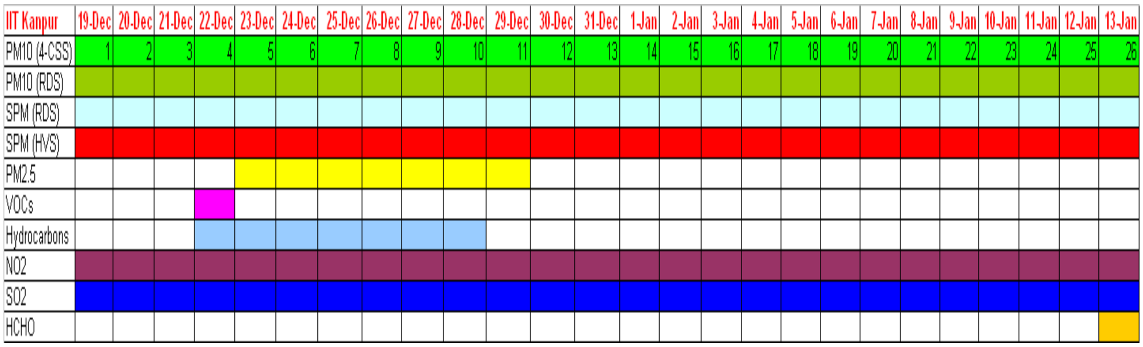
Ramadevi	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec	29-Dec	30-Dec	31-Dec	1-Jan	2-Jan
PM10 (4-CSS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM10 (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (RDS)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SPM (HVS)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
PM2.5					🟨	🟨	🟨	🟨	🟨	🟨	🟨														
VOCs				🟪																					
Hydrocarbons				🟦	🟦	🟦	🟦	🟦	🟦	🟦															
NO2	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
HCHO																									🟧

Table 2.4(g): Sampling Days of Various Pollutants in Post-monsoon Season at AHM



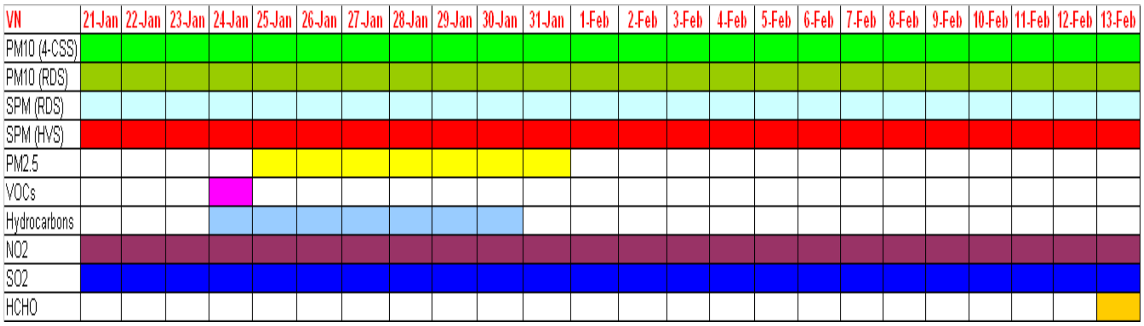
AHM	3-Dec	4-Dec	5-Dec	6-Dec	7-Dec	8-Dec	9-Dec	10-Dec	11-Dec	12-Dec	13-Dec	14-Dec	15-Dec	16-Dec	17-Dec	18-Dec	19-Dec	20-Dec	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec	26-Dec	27-Dec	28-Dec
PM10 (4-CSS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM10 (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (RDS)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SPM (HVS)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
PM2.5					🟨	🟨	🟨	🟨	🟨	🟨	🟨															
VOCs				🟪																						
Hydrocarbons				🟦	🟦	🟦	🟦	🟦	🟦	🟦																
NO2	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
HCHO																										🟧

Table 2.5(a): Sampling Days of Various Pollutants in Winter Season at IIT Kanpur



IIT Kanpur	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	5-Jan	6-Jan	7-Jan	8-Jan	9-Jan	10-Jan	11-Jan	12-Jan	13-Jan
PM10 (4-CSS)	🟩 1	🟩 2	🟩 3	🟩 4	🟩 5	🟩 6	🟩 7	🟩 8	🟩 9	🟩 10	🟩 11	🟩 12	🟩 13	🟩 14	🟩 15	🟩 16	🟩 17	🟩 18	🟩 19	🟩 20	🟩 21	🟩 22	🟩 23	🟩 24	🟩 25	🟩 26
PM10 (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (RDS)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SPM (HVS)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
PM2.5					🟨	🟨	🟨	🟨	🟨	🟨	🟨															
VOCs				🟪																						
Hydrocarbons				🟦	🟦	🟦	🟦	🟦	🟦	🟦																
NO2	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
HCHO																										🟧

Table 2.5(b): Sampling Days of Various Pollutants in Winter Season at Vikashnagar



VN	21-Jan	22-Jan	23-Jan	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 (4-CSS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM10 (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (RDS)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SPM (HVS)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
PM2.5					🟨	🟨	🟨	🟨	🟨	🟨	🟨													
VOCs				🟪																				
Hydrocarbons				🟦	🟦	🟦	🟦	🟦	🟦	🟦														
NO2	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
HCHO																								🟧

Table 2.5(c): Sampling Days of Various Pollutants in Winter Season at Govindnagar

GN	22-Jan	23-Jan	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	14-Feb
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■													
VOCs				■																				
Hydrocarbons				■	■	■	■	■	■	■														
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																								■

Table 2.5(d): Sampling Days of Various Pollutants in Winter Season at Dadanagar

DN	20-Jan	21-Jan	22-Jan	23-Jan	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
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■												
VOCs				■																			
Hydrocarbons				■	■	■	■	■	■	■													
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																							■

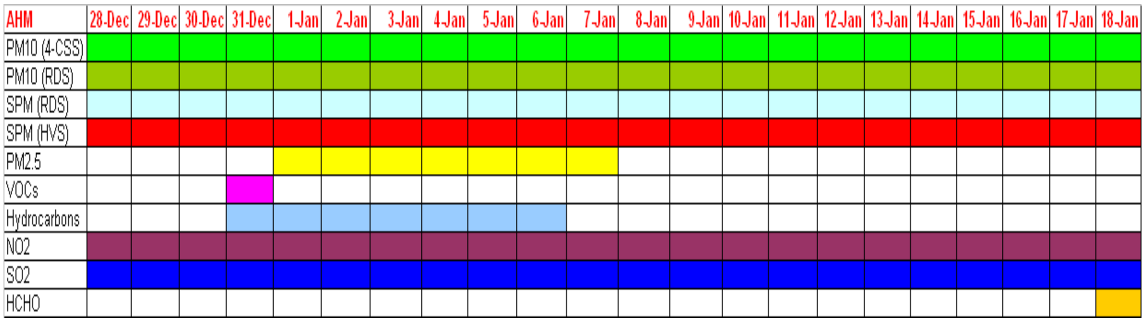
Table 2.5(e): Sampling Days of Various Pollutants in Winter Season at Colonelganj

CG	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	5-Jan	6-Jan	7-Jan
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■												
VOCs				■																			
Hydrocarbons				■	■	■	■	■	■	■													
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																							■

Table 2.5(f): Sampling Days of Various Pollutants in Winter Season at Ramadevi

Ramadevi	7-Jan	8-Jan	9-Jan	10-Jan	11-Jan	12-Jan	13-Jan	14-Jan	15-Jan	16-Jan	17-Jan	18-Jan	19-Jan	20-Jan	21-Jan	22-Jan	23-Jan	24-Jan	25-Jan	26-Jan	27-Jan	28-Jan
PM10 (4-CSS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM10 (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (RDS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SPM (HVS)	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
PM2.5					■	■	■	■	■	■	■											
VOCs				■																		
Hydrocarbons				■	■	■	■	■	■	■												
NO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
SO2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
HCHO																							■

Table 2.5(g): Sampling Days of Various Pollutants in Winter Season at AHM



AHM	28-Dec	29-Dec	30-Dec	31-Dec	1-Jan	2-Jan	3-Jan	4-Jan	5-Jan	6-Jan	7-Jan	8-Jan	9-Jan	10-Jan	11-Jan	12-Jan	13-Jan	14-Jan	15-Jan	16-Jan	17-Jan	18-Jan
PM10 (4-CSS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
PM10 (RDS)	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
SPM (RDS)	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
SPM (HVS)	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
PM2.5					🟨	🟨	🟨	🟨	🟨	🟨	🟨											
VOCs				🟪																		
Hydrocarbons				🟦	🟦	🟦	🟦	🟦	🟦	🟦												
NO2	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪	🟪
SO2	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
HCHO																						🟧

Table 2.6(a): Sampling Status (Percentage Achievement) at Various Sites in Summer

Sampling Status (Summer)															
Particulars		**IIT-K**	**%**	**VN**	**%**	**GN**	**%**	**DN**	**%**	**CG**	**%**	**AHM**	**%**	**RD**	**%**
PM10 (4-CSS)	TA	87	97	77	86	84	93	83	92	89	99	75	83	90	100
	TB	87	97	83	92	85	94	83	92	90	100	74	82	90	100
	Q	87	97	83	92	84	93	84	93	88	98	74	82	90	100
	TOTAL	**261**	**97**	**243**	**90**	**253**	**94**	**250**	**93**	**267**	**99**	**223**	**83**	**270**	**100**
PM10 (RDS)		87	97	88	98	84	93	58	64	88	98	84	93	69	77
SPM (RDS)		87	97	88	98	84	93	58	64	88	98	84	93	69	77
SPM (HVS)		87	97	86	96	84	93	82	91	88	98	85	94	81	90
$PM_{2.5}$		21	100	14	67	21	100	21	100	23	110	21	100	21	100
VOCs		21	100	21	100	21	100	21	100	21	100	21	100	21	100
HC		21	100	21	100	21	100	21	100	21	100	21	100	21	100
SO_2		173	96	185	103	166	92	159	88	174	97	147	82	130	72
NOx		173	96	185	103	166	92	159	88	174	97	147	82	130	72
HCHO		6	100	5	83	5	83	3	50	6	100	4	67	5	83
CO										24-hr	100				

Table 2.6(b): Sampling Status (Percentage Achievement) at all Sites in Post- monsoon

Sampling Status (Post-monsoon)															
Particulars		**IIT-K**	**%**	**VN**	**%**	**GN**		**DN**	**%**	**CG**	**%**	**AHM**	**%**	**RD**	**%**
PM10 (4-CSS)	TA	81	90	78	87	78	87	78	87	81	90	78	87	75	83
	Q	81	90	78	87	78	87	78	87	81	90	78	87	75	83
	TOTAL	**162**	**60**	**156**	**58**	**156**	**58**	**156**	**58**	**162**	**60**	**156**	**58**	**150**	**56**
PM10 (RDS)		81	90	78	87	78	87	78	87	81	90	78	87	75	83
SPM (RDS)		81	90	78	87	78	87	78	87	81	90	78	87	75	83
SPM (HVS)		81	90	78	87	78	87	78	87	81	90	78	87	75	83
$PM_{2.5}$		21	100	14	67	21	100	21	100	21	100	21	100	21	100
VOCs		21	100	21	100	21	100	21	100	21	100	21	100	21	100
HC		21	100	21	100	21	100	21	100	21	100	21	100	21	100
SO_2		162	90	156	87	156	87	156	87	162	90	156	87	162	90
NOx		162	90	156	87	156	87	156	87	162	90	156	87	162	90
HCHO		12	100	12	100	12	100	12	100	12	100	12	100	12	100
CO										24-hr	100				

Table 2.6(c): Sampling Status (Percentage Achievement) at Various Sites in Winter

Sampling Status (Winter)															
Particulars		**IIT-K**	**%**	**VN**	**%**	**GN**	**%**	**DN**	**%**	**CG**	**%**	**AHM**	**%**	**RD**	**%**
PM10 (4-CSS)	TA	78	87	72	80	72	80	69	77	69	77	66	73	66	73
	Q	78	87	72	80	72	80	69	77	69	77	66	73	66	73
	TOTAL	**156**	**58**	**144**	**53**	**144**	**53**	**138**	**51**	**138**	**51**	**132**	**49**	**132**	**49**
PM10 (RDS)		78	87	72	80	72	80	69	77	69	77	66	73	66	73
SPM (RDS)		78	87	72	80	72	80	69	77	69	77	66	73	66	73
SPM (HVS)		78	87	72	80	72	80	69	77	69	77	66	73	66	73
$PM_{2.5}$		21	100	14	67	21	100	21	100	21	100	21	100	21	100
VOCs		4	100	4	100	4	100	4	100	4	100	4	100	4	100
HC		21	100	21	100	21	100	21	100	21	100	21	100	21	100
SO_2		156	87	144	80	144	80	138	77	138	77	132	73	132	73
NOx		156	87	144	80	144	80	138	77	138	77	132	73	132	73
HCHO		12	100	12	100	12	100	12	100	12	100	12	100	12	100
CO										24-hr	100				

2.4 Monitoring Results

2.4.1 Summer Season

The duration of the sampling for summer season was from April 2007 to June 2007. This section presents the observational results of various pollutants at all sampling locations during this period of time.

2.4.1.1 Particulate Matters (SPM, RSPM, PM_{10} and $PM_{2.5}$)

Daily average concentrations observed for SPM, RSPM, PM_{10} and $PM_{2.5}$ are shown graphically in this section during summer season. Figures 2.4(a), 2.4(b), 2.4(c), 2.4 (d), 2.4 (e), 2.4 (f) and 2.4 (g) show the daily variations of the PM concentrations of sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The figures show well understood trends of the particulate matter concentrations. $PM_{2.5}$ concentration also shows a good agreement with SPM and PM_{10} concentrations.

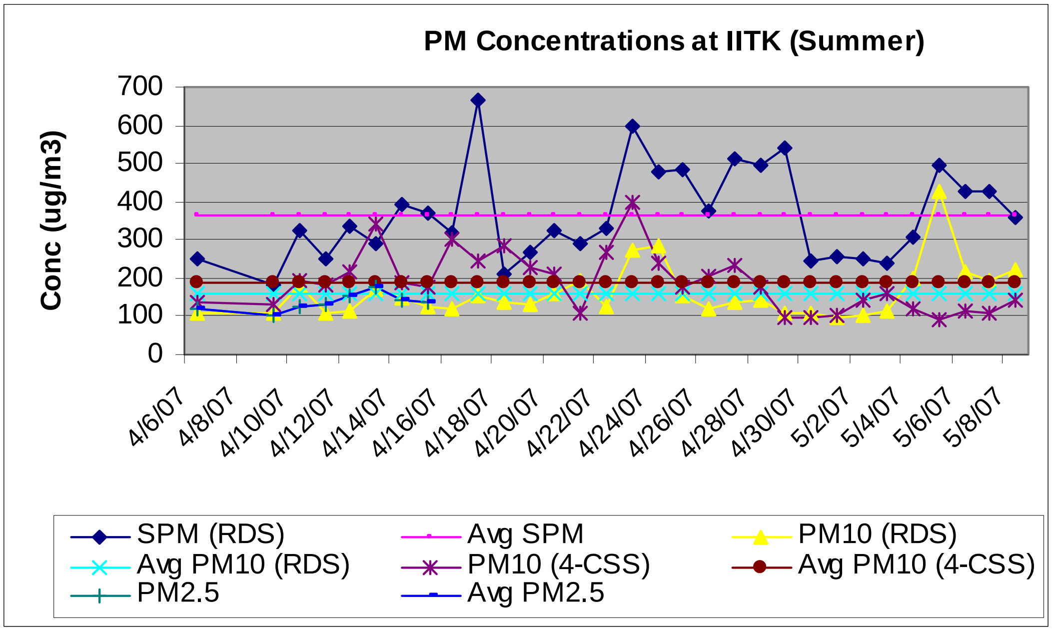


Figure 2.4(a): Observed PM Concentrations at IIT Kanpur Site for Summer Season

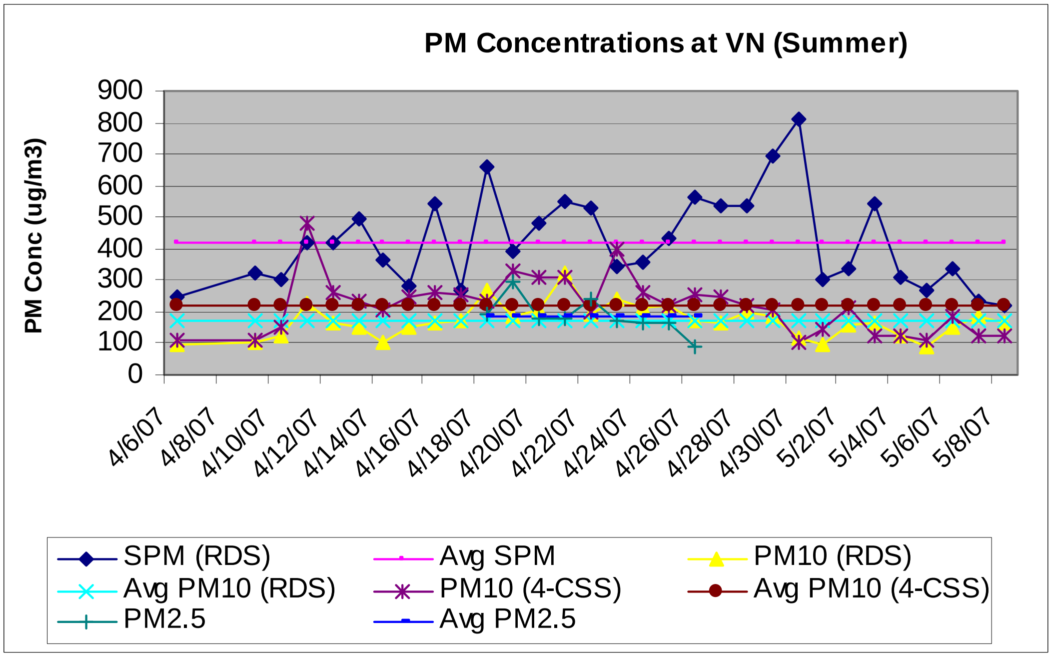


Figure 2.4(b): Observed PM Concentrations at Vikashnagar Site for Summer Season

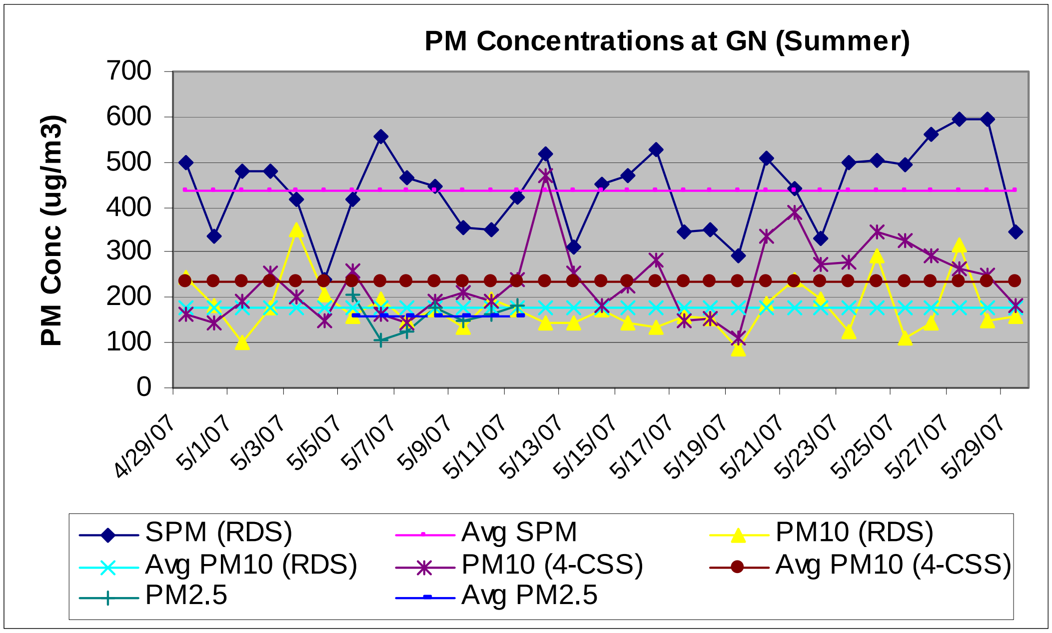


Figure 2.4(c): Observed PM Concentrations at Govindnagar Site for Summer Season

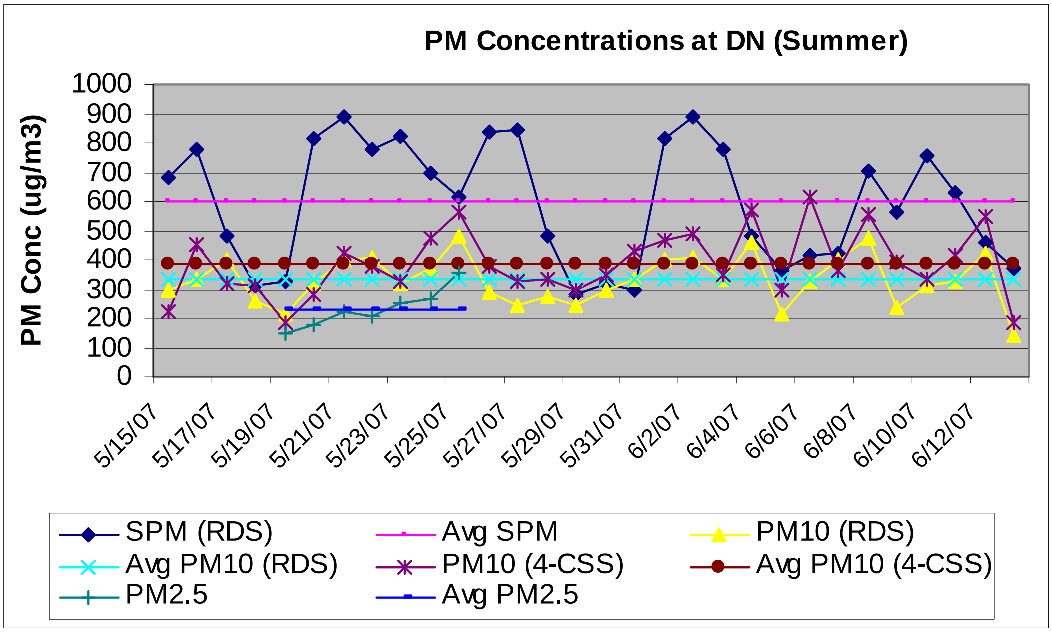


Figure 2.4(d): Observed PM Concentrations at Dadanagar Site for Summer Season

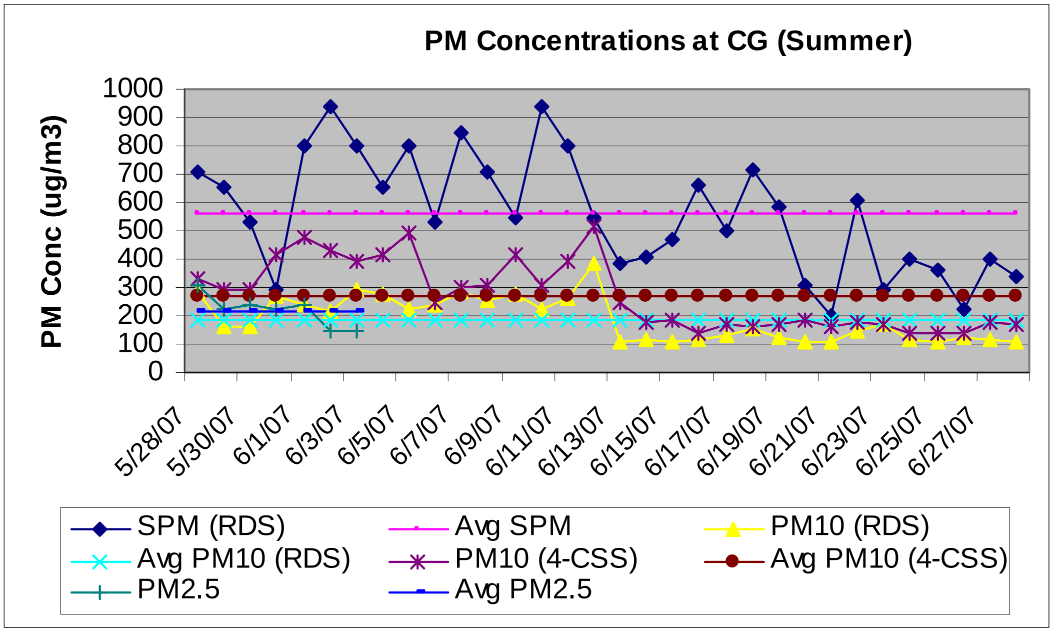


Figure 2.4(e): Observed PM Concentrations at Colonelganj Site for Summer Season

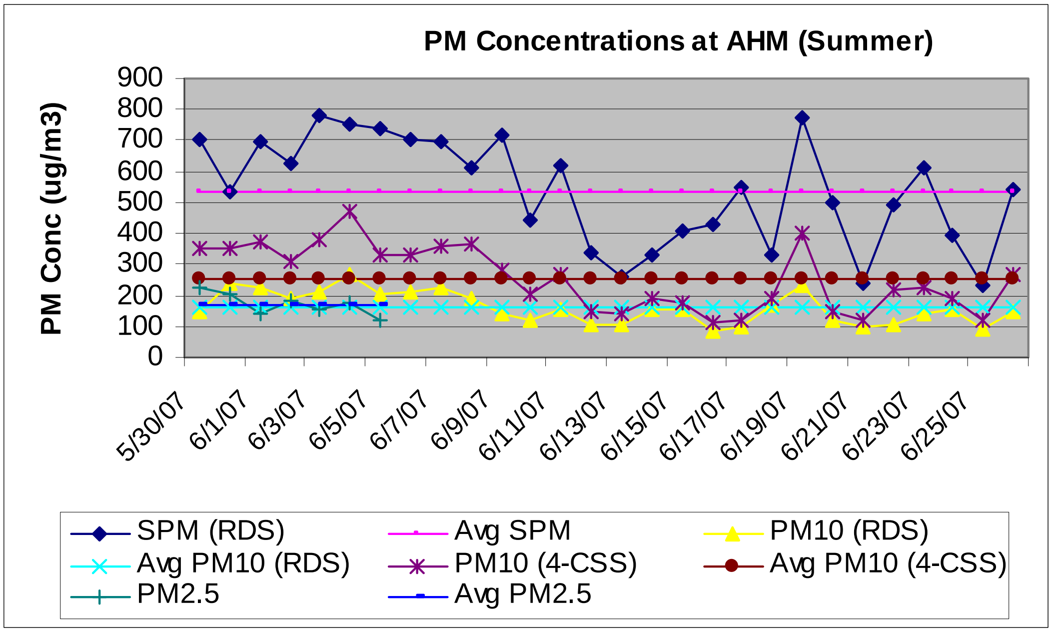


Figure 2.4(f): Observed PM Concentrations at AHM Site for Summer Season

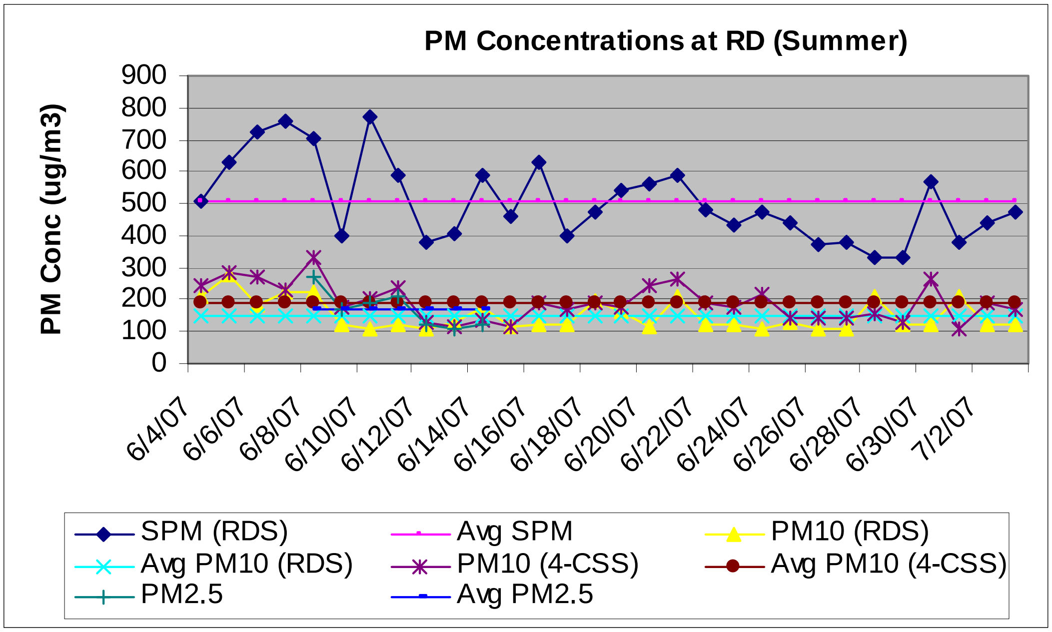


Figure 2.4(g): Observed PM Concentrations at Ramadevi Site for Summer Season

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

This section presents the daily average concentrations of NO_2 and SO_2 observed in summer season. Figures 2.5(a), 2.5(b), 2.5(c), 2.5(d), 2.5(e), 2.5(f) and 2.5 (g) show the daily variations of the SO_2 and NO_2 concentrations of sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. It can be concluded that low concentration of SO_2 was observed; may be due to introduction of low sulphur content in the diesel fuels; and NO_2 concentration is well below the permissible limits.

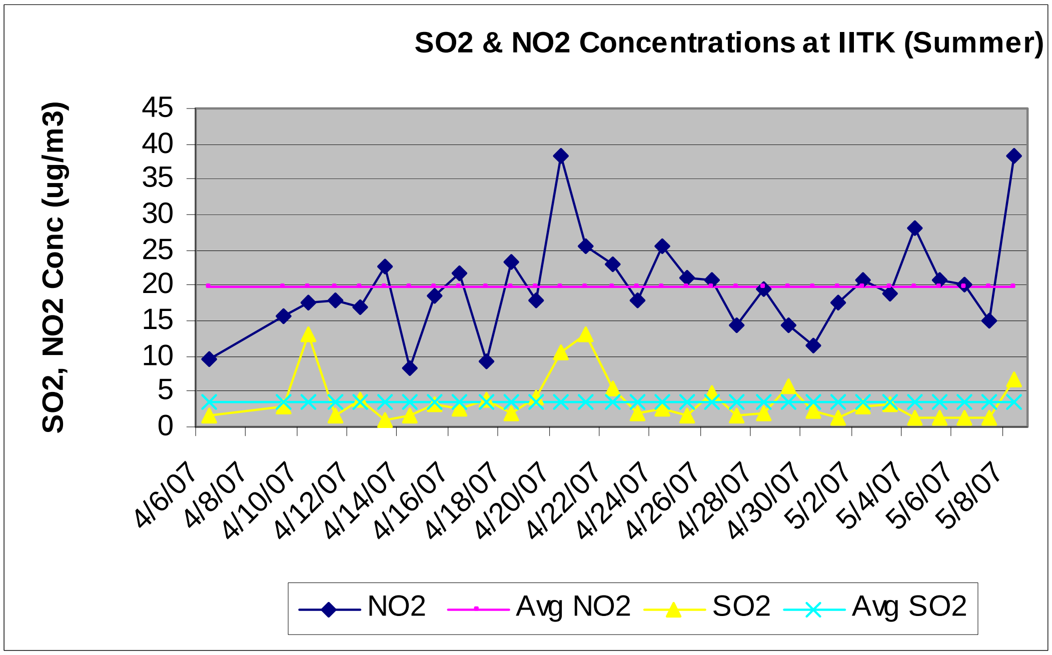


Figure 2.5(a): Observed SO_2 and NO_2 Concentrations at IIT Kanpur Site for Summer Season

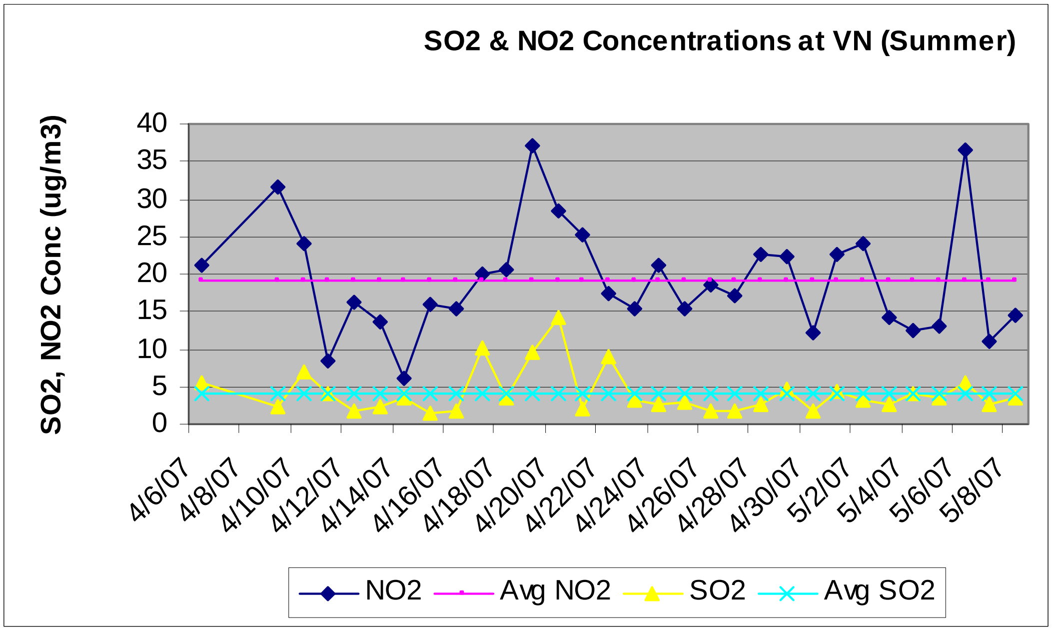


Figure 2.5(b): Observed SO_2 and NO_2 Concentrations at Vikashnagar Site for Summer Season

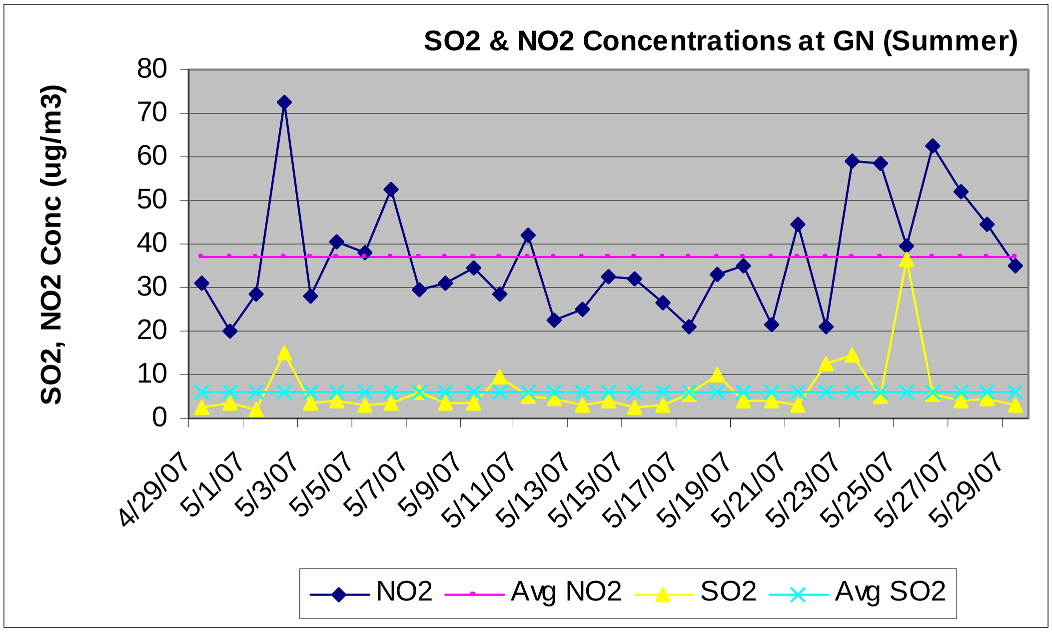


Figure 2.5(c): Observed SO_2 and NO_2 Concentrations at Govindnagar Site for Summer Season

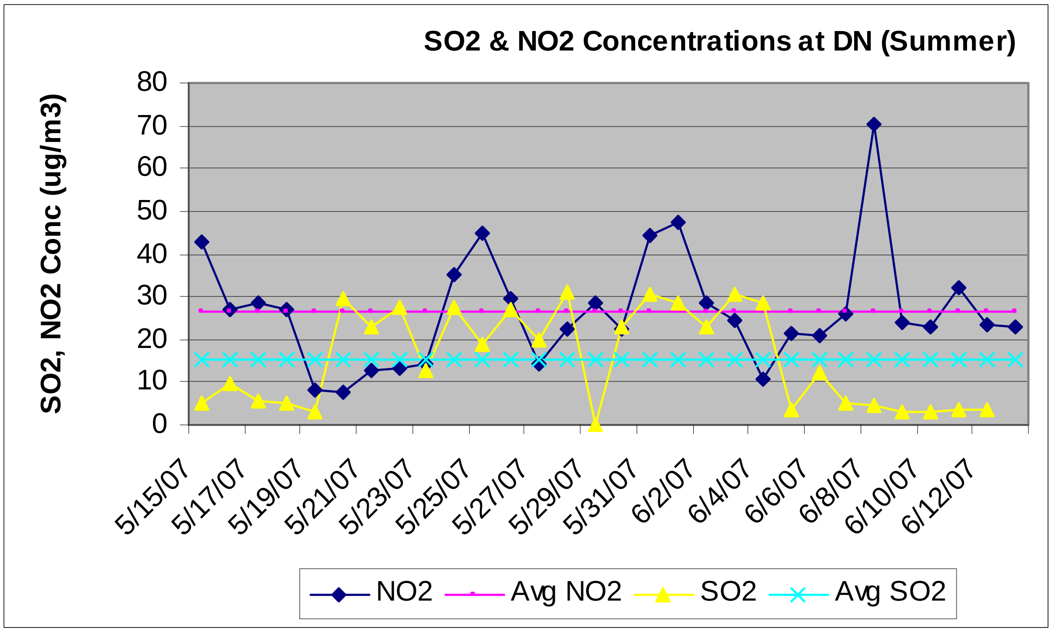


Figure 2.5(d): Observed SO_2 and NO_2 Concentrations at Dadanagar Site for Summer Season

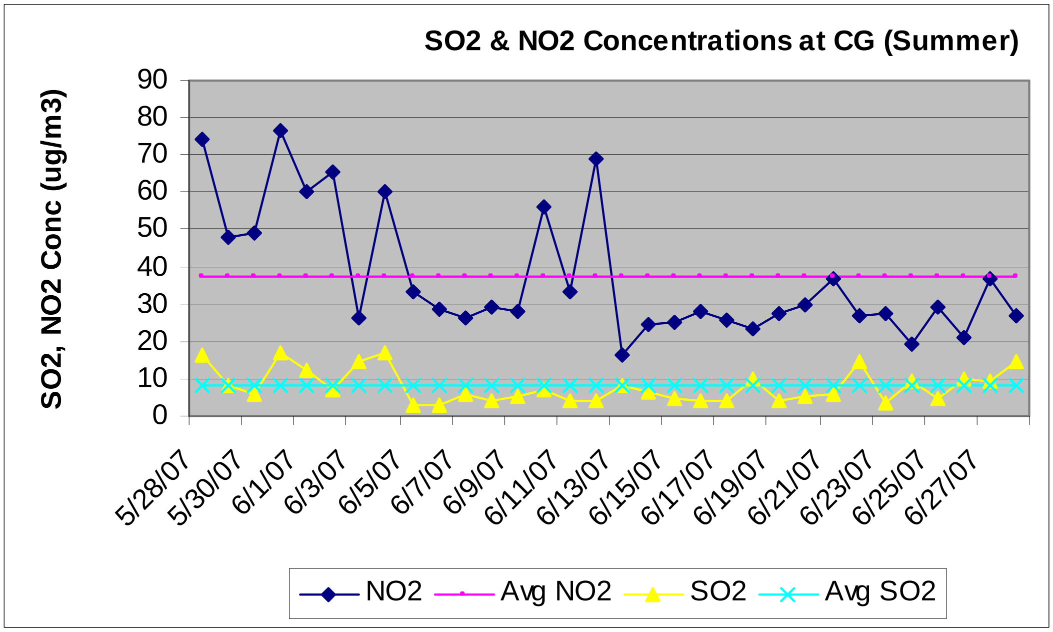


Figure 2.5(e): Observed SO_2 and NO_2 Concentrations at Colonelganj Site for Summer Season

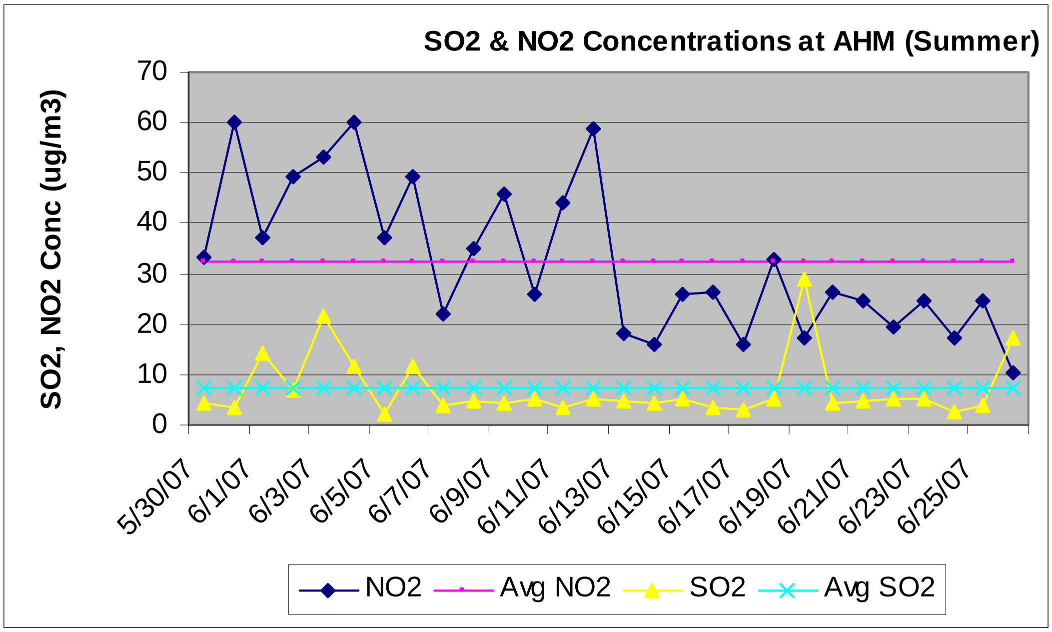


Figure 2.5(f): Observed SO_2 and NO_2 Concentrations at AHM Site for Summer Season

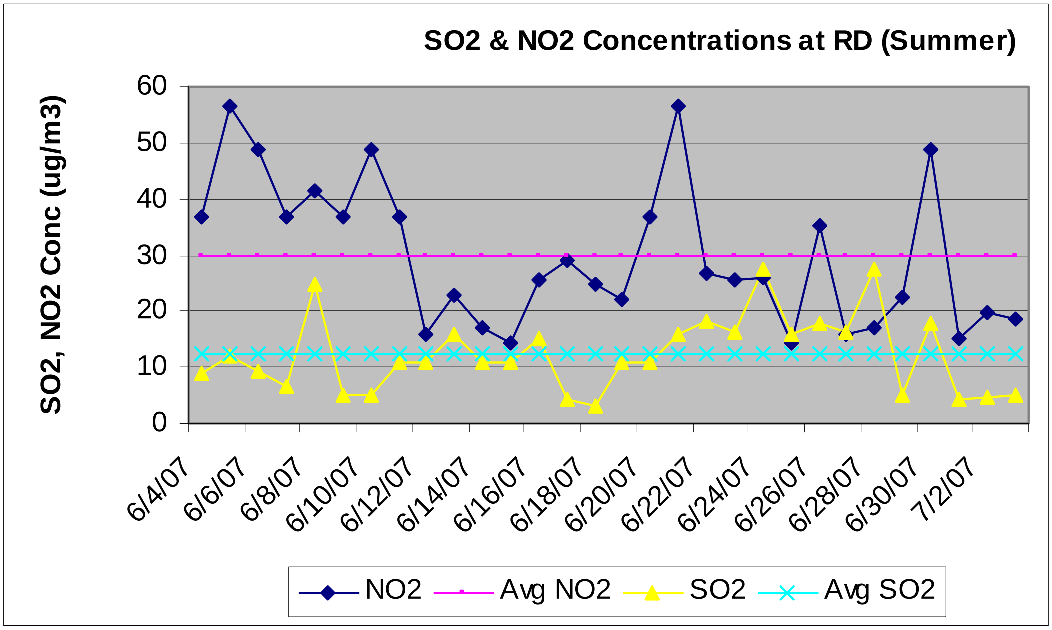


Figure 2.5(g): Observed SO_2 and NO_2 Concentrations at Ramadevi Site for Summer Season

2.4.1.3 Volatile Organic Compounds (VOCs) and Nonmethane Hydrocarbons (NMHC)

This section shows graphically the observed daily average concentrations of VOCs, NMHC along with benzene, toluene, ethyl benzene, m, p-xylene and o-xylene also for summer season. Figures 2.6(a), 2.6(b), 2.6(c), 2.6(d), 2.6(e), 2.6(f) and 2.6(g) show the variations of daily average concentrations of VOCs and NMHC for sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. It can be concluded that the dominant species of VOCs in Kanpur is toluene followed by benzene. The higher concentrations of VOCs are observed at sampling locations nearby traffic junctions and industrial activities.

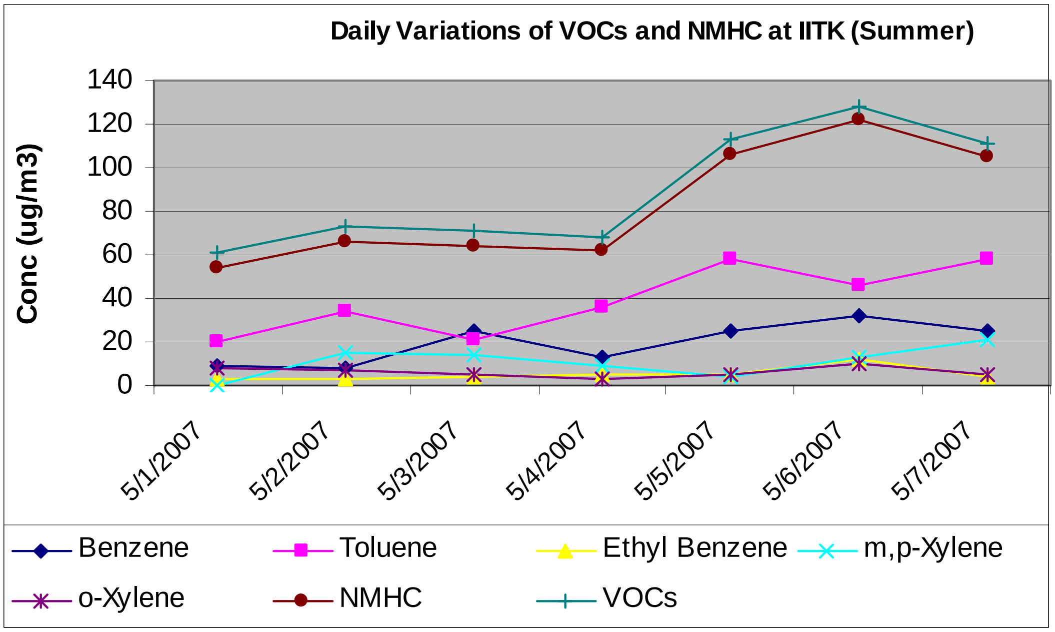


Figure 2.6(a): Observed VOC$_S$ and NMHC Concentrations at IIT Kanpur Site for Summer Season

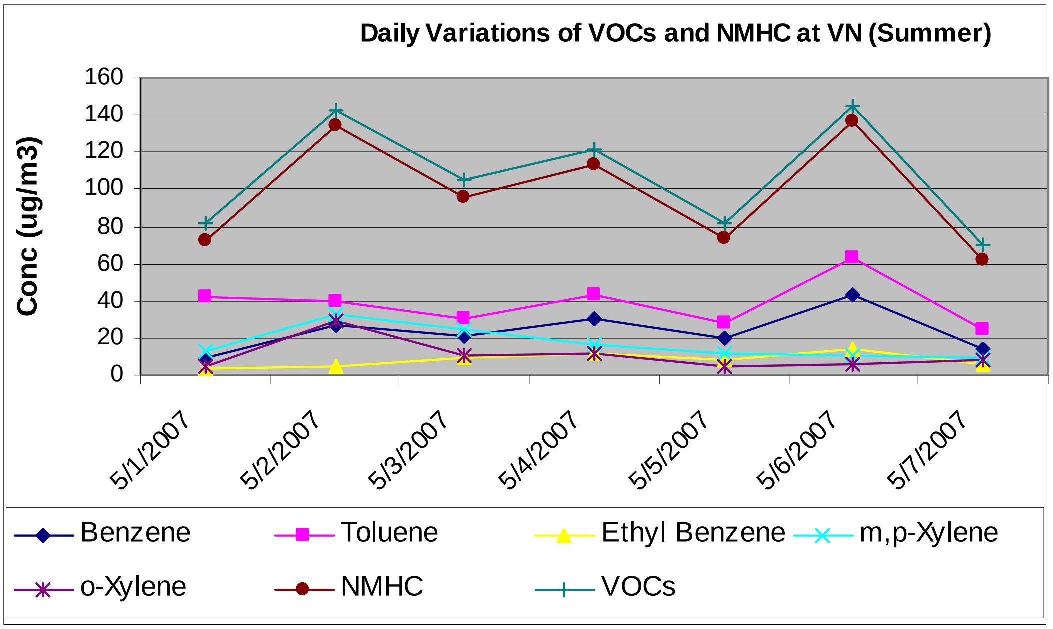


Figure 2.6(b): Observed VOC$_S$ and NMHC Concentrations at Vikashnagar Site for Summer Season

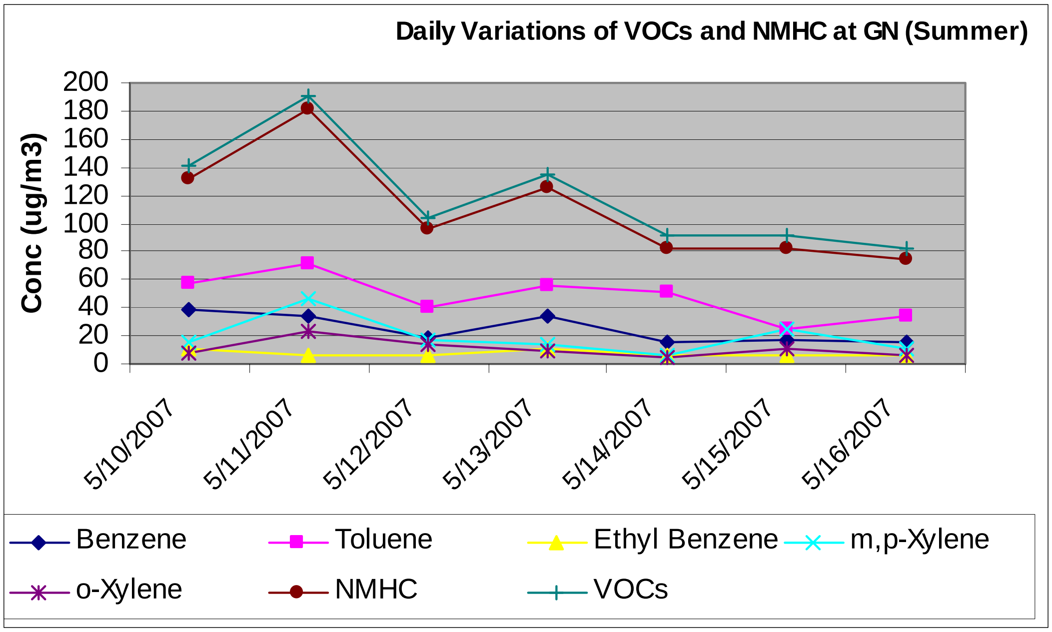


Figure 2.6(c): Observed VOC$_S$ and NMHC Concentrations at Govindnagar Site for Summer Season

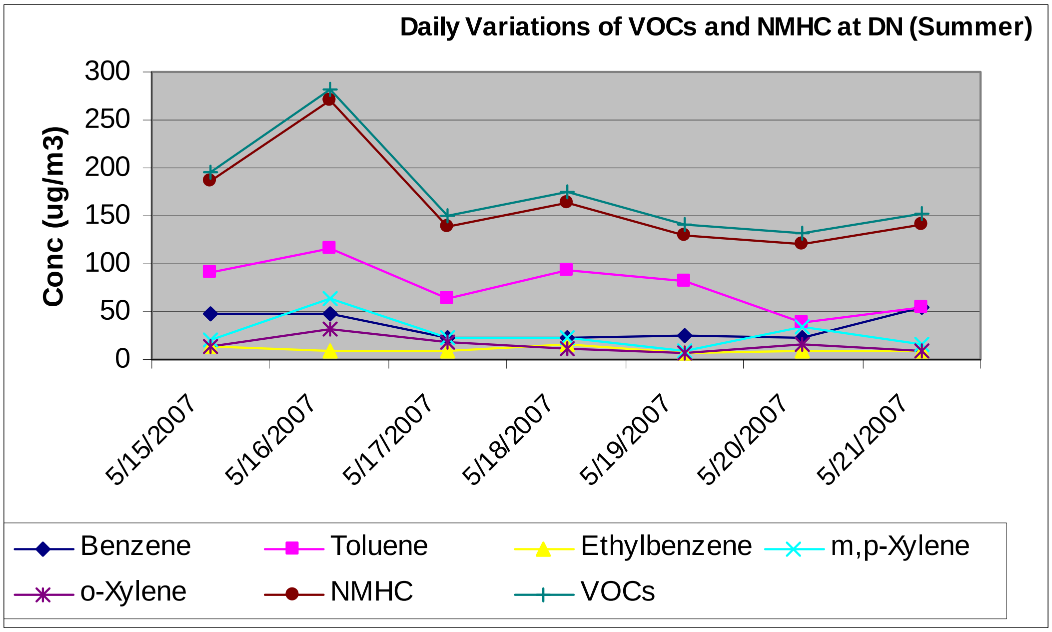


Figure 2.6(d): Observed VOC$_S$ and NMHC Concentrations at Dadanagar Site for Summer Season

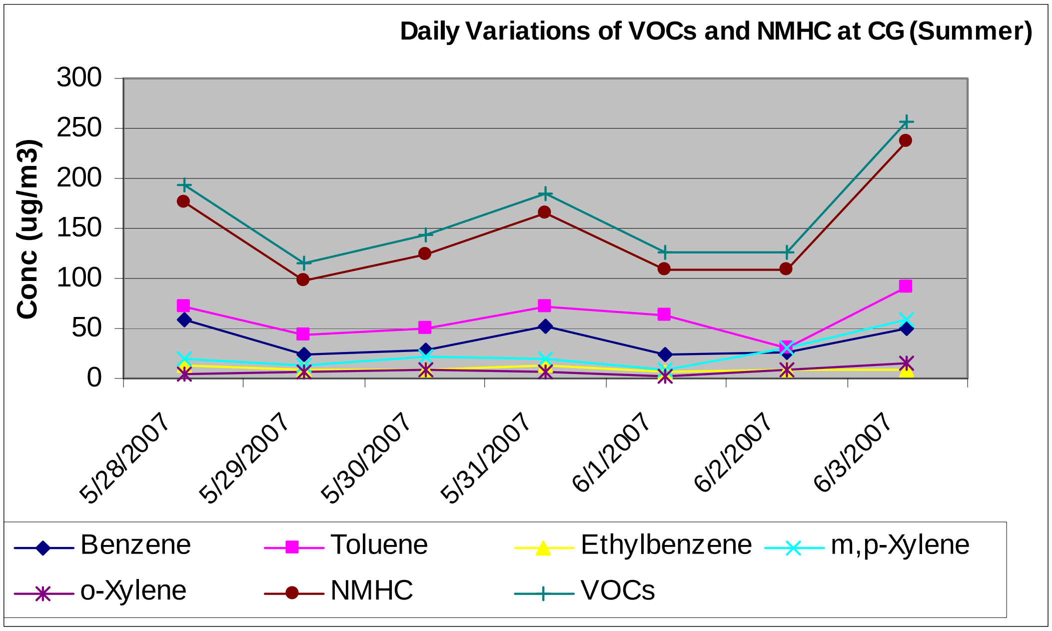


Figure 2.6(e): Observed VOC$_S$ and NMHC Concentrations at Colonelganj Site for Summer Season

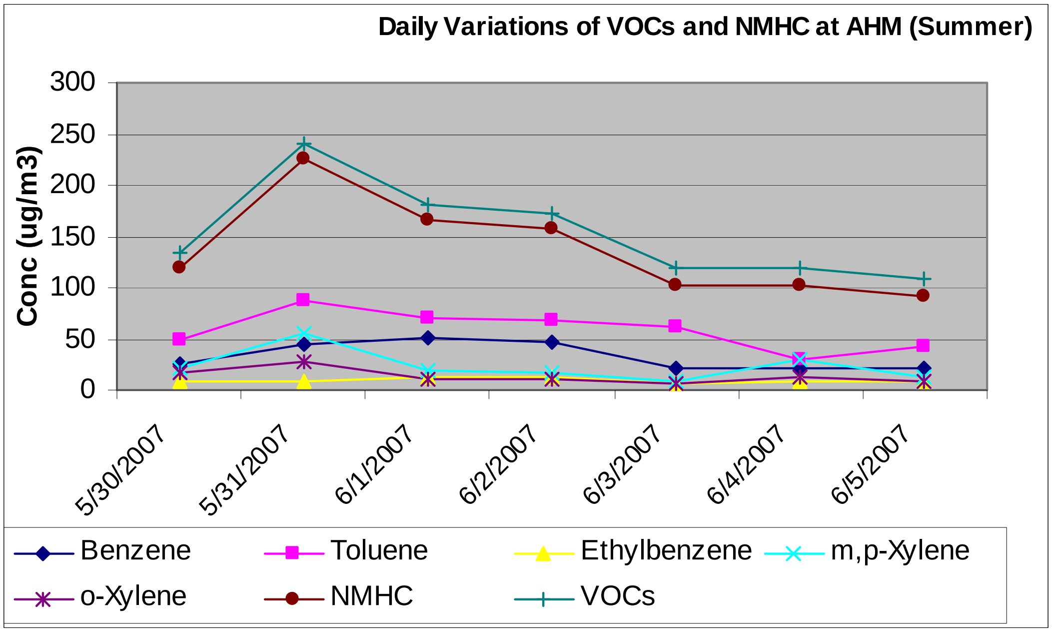


Figure 2.6(f): Observed VOC$_S$ and NMHC Concentrations at AHM Site for Summer Season

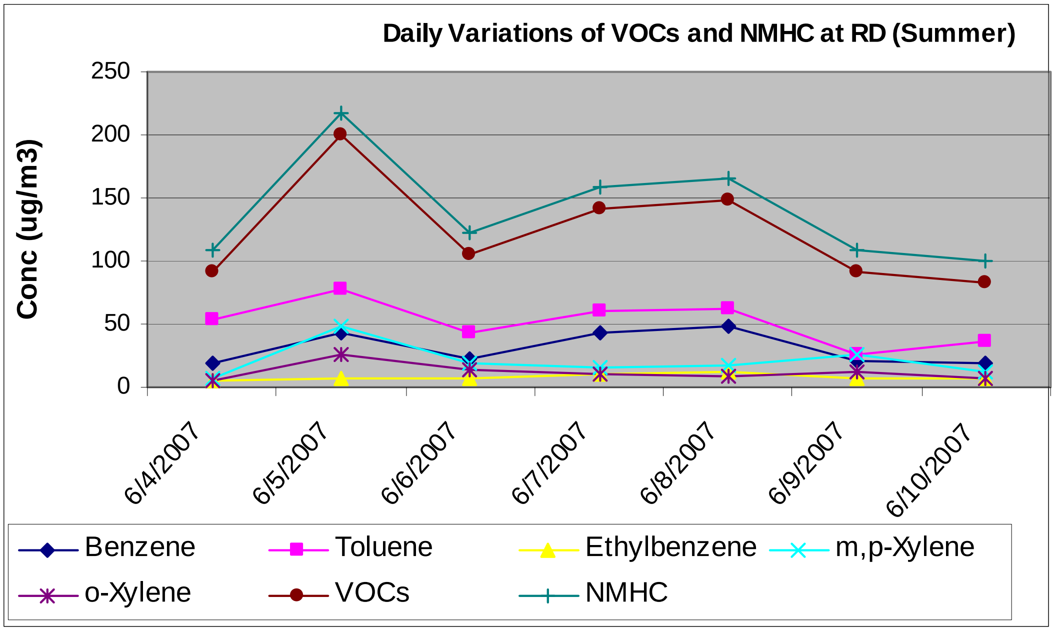


Figure 2.6(g): Observed VOC$_S$ and NMHC Concentrations at Ramadevi Site for Summer Season

2.4.1.4 Formaldehyde (HCHO)

This section shows the average concentrations of HCHO observed during different hours of the day for summer season. Figure 2.7 shows the observed concentration of the formaldehyde during different hours of the day for all sampling sites. From this figure it can be concluded that the maximum concentration is observed during the peak hours of the day. The maximum values are observed at sites nearby traffic junctions.

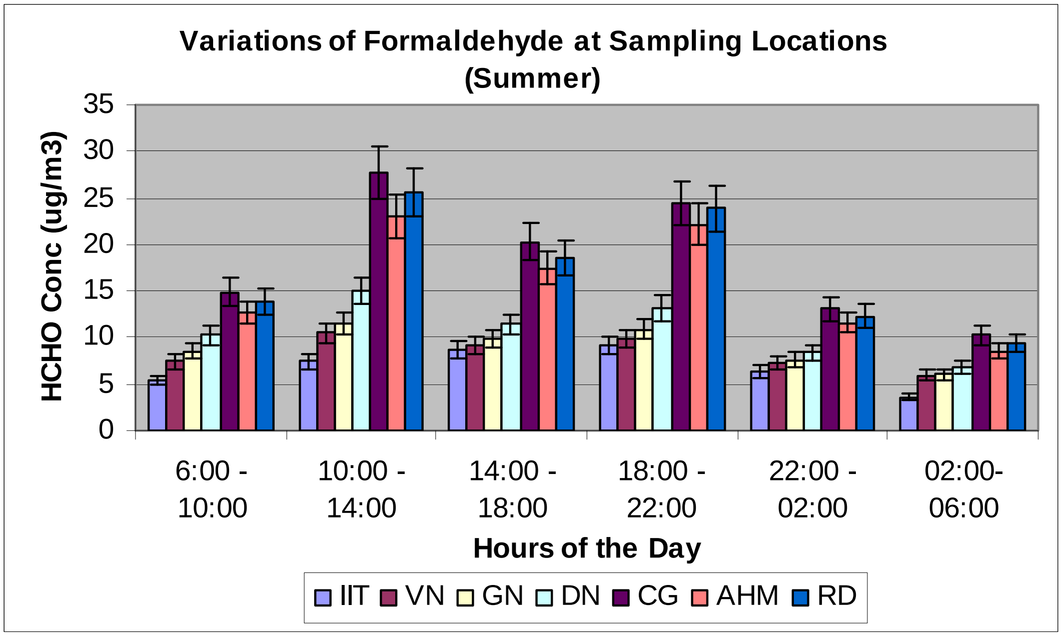


Figure 2.7: Observed HCHO Concentrations at all Sampling Sites for Summer Season

2.4.1.5 Carbon monoxide (CO)

This section presents the daily and hourly average concentrations CO observed at Colonelganj site (kerbside) for summer season. Figures 2.8(a) and 2.8(b) show the observed CO concentration on different day of the month and hours of the day respectively. From these figures it can be concluded that the maximum concentration is observed during the peak hours of the day (both in morning as well as evening).

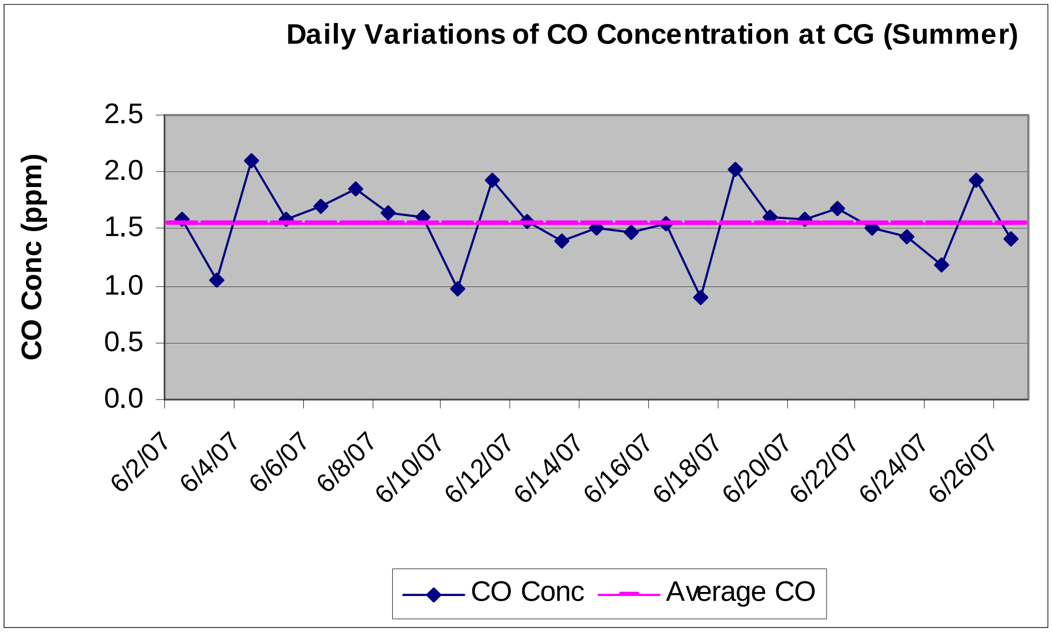


Figure 2.8(a): Observed CO Concentration (Daily Variations) at Colonelganj Site for Summer Season

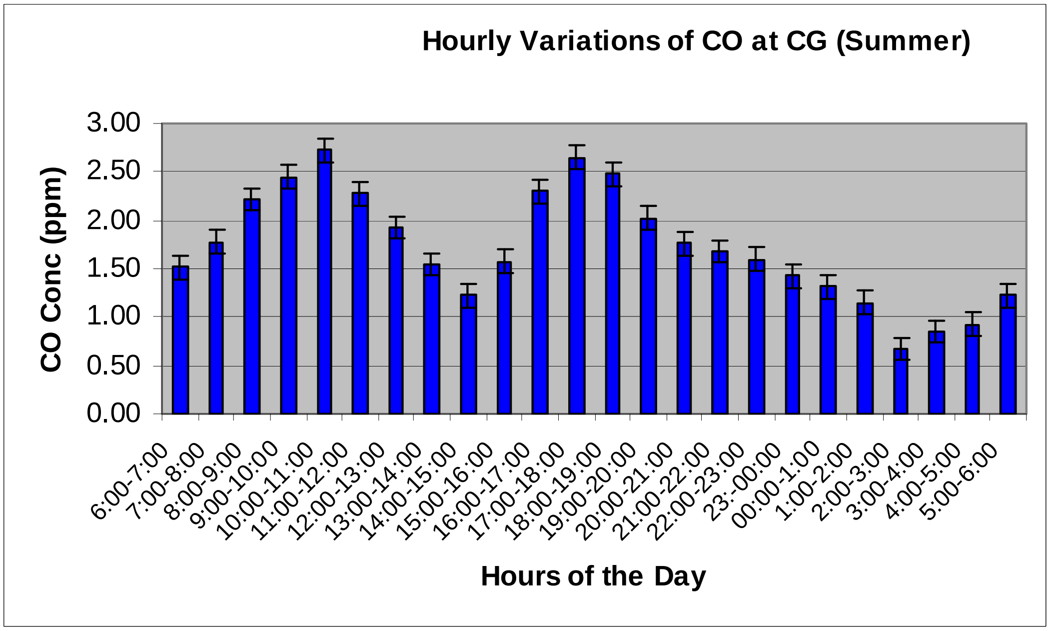


Figure 2.8(b): Observed CO Concentration (Hourly Variations) at Colonelganj Site for Summer Season

2.4.1.6 Polycyclic Aromatic Hydrocarbons (PAHs)

This section reveals the average concentrations of PAHs with some specific markers observed at all sampling locations of the city for summer season. Figure 2.9 shows the observed concentration of some markers of PAHs at all sampling locations. The compounds analyzed are fluorene, phenathrene, fluorathene, pyrene, benzo(a) anthracene, benzo(b) fluoranthene, benzo (a) pyrene, dibenzo(a,h) anthracene and benzo(ghi) perylene. From this figure it can be concluded that the maximum concentration is observed at Dadanagar site (industrial site).

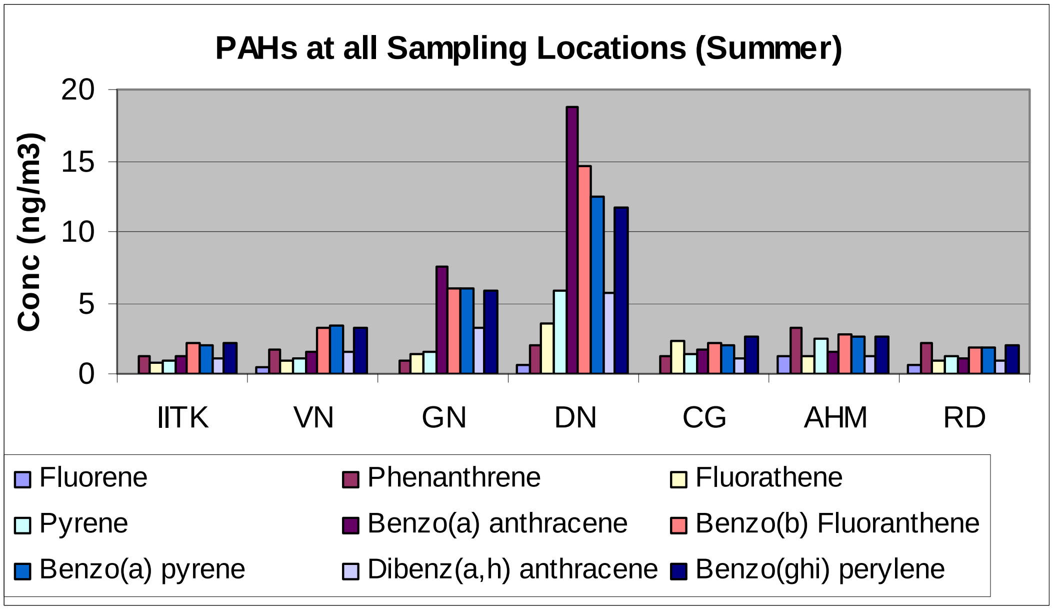


Figure 2.9: Observed PAHs Concentrations at all Sampling Sites for Summer Season

2.4.1.7 Brief Presentation of the Experimental Results and their Correlations (along with PM_{10} and $PM_{2.5}$Chemical Speciation)

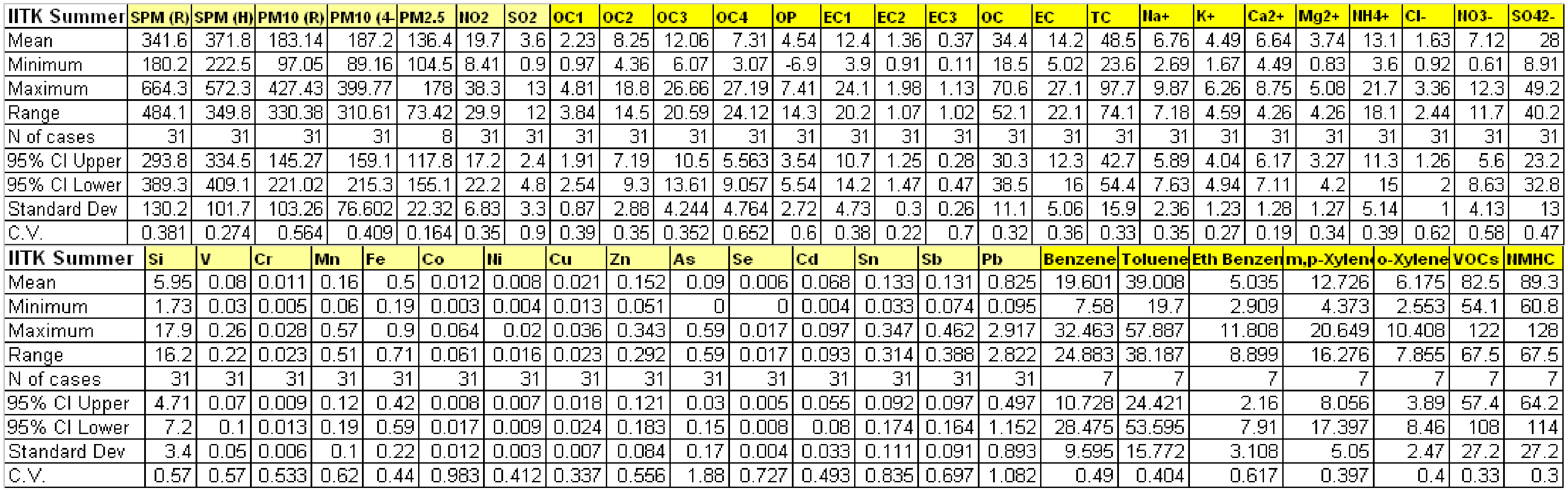
A brief of the experimental results for all parameters during the summer season are presented statistically in tabular form in this section. Tables 2.7(a), 2.7(b), 2.7(c), 2.7(d), 2.7(e), 2.7(f) and 2.7(g) present the concentrations of SPM (from RDS), SPM (from HVS), PM_{10} (from RDS), PM_{10} (from 4-CSS), $PM_{2.5}$, NO_2, SO_2, OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Sn, Sb, Pb, benzene, toluene, ethyl benzene, m,p-xylene, o-xylene, VOCs and NMHC at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The results presented for elements, ions and carbon concentrations are from the PM_{10} chemical speciation. These tables contains the average, minimum, maximum, range, number of data points (24-hr average), range, 95% upper and lower confidence limits, standard deviation and coefficient of variance for all the parameters as mentioned above.

Tables 2.8(a), 2.8(b), 2.8(c), 2.8(d), 2.8(e), 2.8(f) and 2.8(g) present the correlation matrices among the four dust parameters, i.e. SPM, RSPM, PM_{10}, $PM_{2.5}$ at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during summer season. It can be concluded from these tables that PM_{10} is maintaining a good correlation with SPM and similar trend for $PM_{2.5}$ with PM_{10} for most of the cases.

Tables 2.9(a), 2.9(b), 2.9(c), 2.9(d), 2.9(e), 2.9(f) and 2.9(g) present the correlation matrices among the major species of PM_{10}, i.e. NH_4^+, NO_3^-, SO_4^{2-}, EC, OC, TC and with NO_2 and SO_2 at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during summer season. It can be concluded from these tables that NH_4^+ is maintaining a good correlation with NO_3^-, SO_4^{2-} and similar trend for EC with OC; and these species maintain a good correlation with PM_{10} overally. As SO_2 concentration is low for most of the sites, so it is difficult to draw any correlation of it with others. NO_2 is also maintaining a good correlation with NO_3^-.

A brief of the experimental results related to $PM_{2.5}$ chemical speciation of some major parameters are presented in Tables 2.10(a), 2.10(b), 2.10(c), 2.10(d), 2.10(e), 2.10(f) and 2.10(g) for the sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during summer season. The major species presented are OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. These tables contains the average, minimum, maximum, range, number of data points (24-hr average), range, 95% upper and lower confidence limits, standard deviation and coefficient for all the parameters as mentioned above.

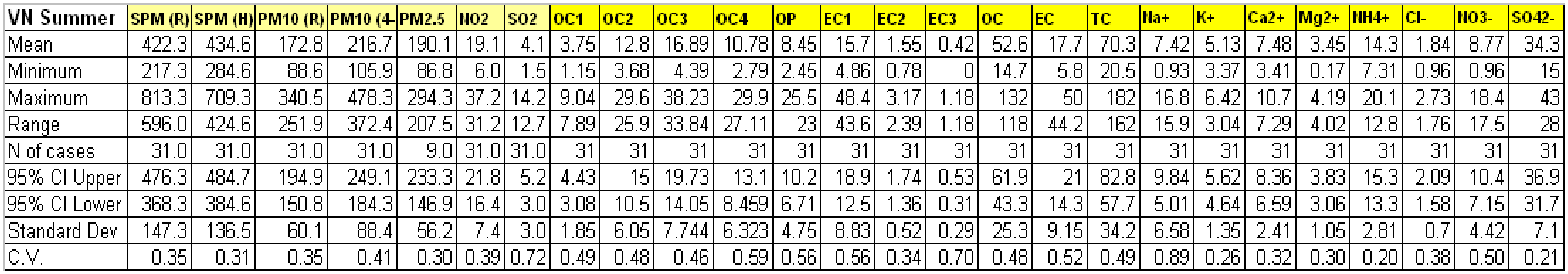
Table 2.7(a): Experimental Results with PM_{10} Chemical Speciation of IIT Kanpur Site for Summer Season



IITK Summer	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	341.6	371.8	183.14	187.2	136.4	19.7	3.6	2.23	8.25	12.06	7.31	4.54	12.4	1.36	0.37	34.4	14.2	48.5	6.76	4.49	6.64	3.74	13.1	1.63	7.12	28
Minimum	180.2	222.5	97.05	89.16	104.5	8.41	0.9	0.97	4.36	6.07	3.07	-6.9	3.9	0.91	0.11	18.5	5.02	23.6	2.69	1.67	4.49	0.83	3.6	0.92	0.61	8.91
Maximum	664.3	572.3	427.43	399.77	178	38.3	13	4.81	18.8	26.66	27.19	7.41	24.1	1.98	1.13	70.6	27.1	97.7	9.87	6.26	8.75	5.08	21.7	3.36	12.3	49.2
Range	484.1	349.8	330.38	310.61	73.42	29.9	12	3.84	14.5	20.59	24.12	14.3	20.2	1.07	1.02	52.1	22.1	74.1	7.18	4.59	4.26	4.26	18.1	2.44	11.7	40.2
N of cases	31	31	31	31	8	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
95% CI Upper	293.8	334.5	145.27	159.1	117.8	17.2	2.4	1.91	7.19	10.5	5.563	3.54	10.7	1.25	0.28	30.3	12.3	42.7	5.89	4.04	6.17	3.27	11.3	1.26	5.6	23.2
95% CI Lower	389.3	409.1	221.02	215.3	155.1	22.2	4.8	2.54	9.3	13.61	9.057	5.54	14.2	1.47	0.47	38.5	16	54.4	7.63	4.94	7.11	4.2	15	2	8.63	32.8
Standard Dev	130.2	101.7	103.26	76.602	22.32	6.83	3.3	0.87	2.88	4.244	4.764	2.72	4.73	0.3	0.26	11.1	5.06	15.9	2.36	1.23	1.28	1.27	5.14	1	4.13	13
C.V.	0.381	0.274	0.564	0.409	0.164	0.35	0.9	0.39	0.35	0.352	0.652	0.6	0.38	0.22	0.7	0.32	0.36	0.33	0.35	0.27	0.19	0.34	0.39	0.62	0.58	0.47

IITK Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC
Mean	5.95	0.08	0.011	0.16	0.5	0.012	0.008	0.021	0.152	0.09	0.006	0.068	0.133	0.131	0.825	19.601	39.008	5.035	12.726	6.175	82.5	89.3
Minimum	1.73	0.03	0.005	0.06	0.19	0.003	0.004	0.013	0.051	0	0	0.004	0.033	0.074	0.095	7.58	19.7	2.909	4.373	2.553	54.1	60.8
Maximum	17.9	0.26	0.028	0.57	0.9	0.064	0.02	0.036	0.343	0.59	0.017	0.097	0.347	0.462	2.917	32.463	57.887	11.808	20.649	10.408	122	128
Range	16.2	0.22	0.023	0.51	0.71	0.061	0.016	0.023	0.292	0.59	0.017	0.093	0.314	0.388	2.822	24.883	38.187	8.899	16.276	7.855	67.5	67.5
N of cases	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	7	7	7	7	7	7	7
95% CI Upper	4.71	0.07	0.009	0.12	0.42	0.008	0.007	0.018	0.121	0.03	0.005	0.055	0.092	0.097	0.497	10.728	24.421	2.16	8.056	3.89	57.4	64.2
95% CI Lower	7.2	0.1	0.013	0.19	0.59	0.017	0.009	0.024	0.183	0.15	0.008	0.08	0.174	0.164	1.152	28.475	53.595	7.91	17.397	8.46	108	114
Standard Dev	3.4	0.05	0.006	0.1	0.22	0.012	0.003	0.007	0.084	0.17	0.004	0.033	0.111	0.091	0.893	9.595	15.772	3.108	5.05	2.47	27.2	27.2
C.V.	0.57	0.57	0.533	0.62	0.44	0.983	0.412	0.337	0.556	1.88	0.727	0.493	0.835	0.697	1.082	0.49	0.404	0.617	0.397	0.4	0.33	0.3

Table 2.7(b): Experimental Results with PM_{10} Chemical Speciation of Vikashnagar Site for Summer Season



VN Summer	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	422.3	434.6	172.8	216.7	190.1	19.1	4.1	3.75	12.8	16.89	10.78	8.45	15.7	1.55	0.42	52.6	17.7	70.3	7.42	5.13	7.48	3.45	14.3	1.84	8.77	34.3
Minimum	217.3	284.6	88.6	105.9	86.8	6.0	1.5	1.15	3.68	4.39	2.79	2.45	4.86	0.78	0	14.7	5.8	20.5	0.93	3.37	3.41	0.17	7.31	0.96	0.96	15
Maximum	813.3	709.3	340.5	478.3	294.3	37.2	14.2	9.04	29.6	38.23	29.9	25.5	48.4	3.17	1.18	132	50	182	16.8	6.42	10.7	4.19	20.1	2.73	18.4	43
Range	596.0	424.6	251.9	372.4	207.5	31.2	12.7	7.89	25.9	33.84	27.11	23	43.6	2.39	1.18	118	44.2	162	15.9	3.04	7.29	4.02	12.8	1.76	17.5	28
N of cases	31.0	31.0	31.0	31.0	9.0	31.0	31.0	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
95% CI Upper	476.3	484.7	194.9	249.1	233.3	21.8	5.2	4.43	15	19.73	13.1	10.2	18.9	1.74	0.53	61.9	21	82.8	9.84	5.62	8.36	3.83	15.3	2.09	10.4	36.9
95% CI Lower	368.3	384.6	150.8	184.3	146.9	16.4	3.0	3.08	10.5	14.05	8.459	6.71	12.5	1.36	0.31	43.3	14.3	57.7	5.01	4.64	6.59	3.06	13.3	1.58	7.15	31.7
Standard Dev	147.3	136.5	60.1	88.4	56.2	7.4	3.0	1.85	6.05	7.744	6.323	4.75	8.83	0.52	0.29	25.3	9.15	34.2	6.58	1.35	2.41	1.05	2.81	0.7	4.42	7.1
C.V.	0.35	0.31	0.35	0.41	0.30	0.39	0.72	0.49	0.48	0.46	0.59	0.56	0.56	0.34	0.70	0.48	0.52	0.49	0.89	0.26	0.32	0.30	0.20	0.38	0.50	0.21

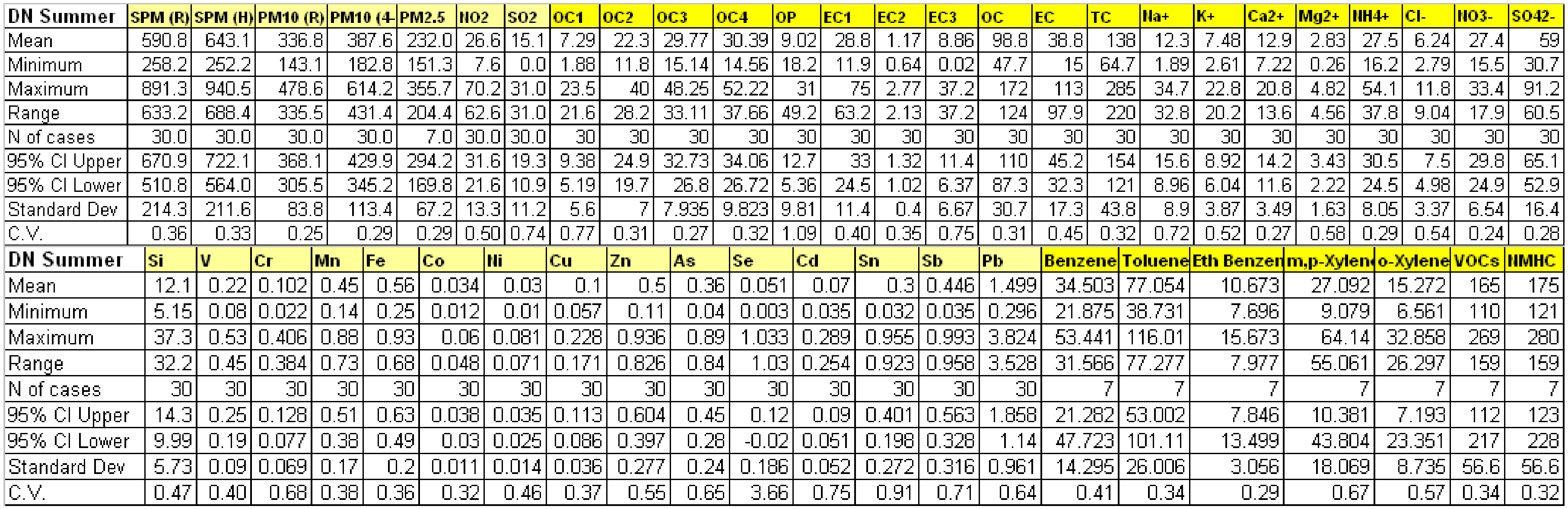
VN Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC
Mean	8.22	0.12	0.014	0.25	0.5	0.016	0.011	0.033	0.211	0.07	0.005	0.063	0.16	0.155	0.258	23.576	38.593	8.361	17.079	10.755	98.4	107
Minimum	2.89	0.04	0.004	0.08	0.01	0.005	0.003	0.015	0.056	0.01	0.002	0.053	0.034	0.118	0.042	9.287	24.025	4.033	9.433	4.665	61.7	70.1
Maximum	15.5	0.39	0.039	0.88	0.93	0.062	0.038	0.085	0.64	0.73	0.011	0.128	0.469	0.696	0.855	43.623	63.403	13.641	32.652	29.59	137	145
Range	12.6	0.36	0.035	0.79	0.92	0.057	0.035	0.07	0.584	0.72	0.009	0.075	0.435	0.578	0.813	34.336	39.378	9.608	23.219	24.925	75.2	75.2
N of cases	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	7	7	7	7	7	7	7
95% CI Upper	9.51	0.14	0.017	0.31	0.6	0.02	0.013	0.039	0.262	0.12	0.005	0.069	0.224	0.201	0.354	13.141	26.459	4.973	9.068	2.637	70.1	78.5
95% CI Lower	6.93	0.09	0.011	0.18	0.4	0.012	0.008	0.027	0.16	0.02	0.004	0.057	0.095	0.11	0.163	34.01	50.726	11.748	25.09	18.874	127	135
Standard Dev	3.52	0.07	0.009	0.18	0.28	0.011	0.008	0.016	0.138	0.15	0.002	0.015	0.176	0.125	0.26	11.283	13.119	3.663	8.662	8.778	30.5	30.5
C.V.	0.43	0.62	0.65	0.73	0.56	0.71	0.76	0.48	0.66	2.10	0.49	0.25	1.10	0.81	1.01	0.48	0.34	0.44	0.51	0.82	0.31	0.29

Table 2.7(c): Experimental Results with PM_{10} Chemical Speciation of Govindnagar Site for Summer Season

GN Summer	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	436.5	463.2	178.79	234.14	159.3	36.8	6.2	8.86	4.1	4.009	9.099	27	5.62	5.59	10.2	53.1	21.4	74.5	7.1	2.59	6.54	3.58	18.8	2.91	12.9	42.7
Minimum	237.4	342.2	86.23	110.7	105.3	20.1	2.2	1.96	1.14	0.13	4.86	4.05	0.1	2.39	5.57	26.1	13.4	41.6	2.64	0	5.07	0.75	6.43	0.63	2.28	5.41
Maximum	595.4	599.7	415.09	470.63	206.2	72.4	36	18.3	12.3	10.98	18.29	56.7	13.3	16.5	14.8	94.8	33.3	118	22	4.28	8.27	6	25.8	6.6	30.1	49
Range	358	257.5	328.86	359.93	100.9	52.4	34	16.3	11.2	10.85	13.43	52.7	13.2	14.1	9.26	68.7	19.9	76.2	19.3	4.28	3.2	5.25	19.4	5.97	27.8	43.6
N of cases	31	31	31	31	7	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31
95% CI Upper	402	436.7	154.36	204.26	126.9	31.9	3.9	7.57	3.29	3.211	7.746	22.7	4.51	4.52	9.33	46.2	19.8	66.6	5.18	2.29	6.14	2.8	17.2	2.12	9.78	39.6
95% CI Lower	471	489.7	203.21	264.03	191.6	41.8	8.6	10.2	4.92	4.807	10.45	31.2	6.72	6.66	11.1	59.9	23	82.3	9.03	2.89	6.94	4.37	20.4	3.71	16.1	45.8
Standard Dev	94.12	72.3	66.602	81.47	34.99	13.4	6.5	3.53	2.22	2.176	3.688	11.5	3.02	2.92	2.39	18.8	4.29	21.4	5.25	0.82	1.09	2.14	4.43	2.16	8.61	8.51
C.V.	0.216	0.156	0.373	0.348	0.22	0.37	1	0.4	0.54	0.543	0.405	0.43	0.54	0.52	0.23	0.35	0.2	0.29	0.74	0.32	0.17	0.6	0.24	0.74	0.67	0.2

GN Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC
Mean	8.54	0.11	0.025	0.22	0.45	0.014	0.011	0.043	0.315	0.1	0.006	0.074	0.156	0.19	0.732	24.645	47.859	7.623	19.352	10.909	110	119
Minimum	2.55	0.03	0.011	0.08	0.09	0.004	0.004	0.019	0.116	0.01	0.003	0	0	0.049	0.168	15.625	24.057	5.497	6.485	4.686	73.7	82.7
Maximum	35.4	0.39	0.058	0.75	0.93	0.058	0.035	0.1	0.808	0.83	0.02	0.21	0.467	0.405	1.953	38.172	72.054	11.195	45.815	23.47	181	190
Range	32.9	0.36	0.047	0.67	0.84	0.054	0.031	0.081	0.692	0.82	0.017	0.21	0.467	0.356	1.785	22.547	47.997	5.698	39.33	18.784	108	108
N of cases	31	31	31	31	31	31	31	31	31	31	31	31	31	31	31	7	7	7	7	7	7	7
95% CI Upper	5.95	0.08	0.02	0.17	0.36	0.01	0.008	0.035	0.245	0.04	0.005	0.051	0.099	0.138	0.52	15.202	32.921	5.605	7.415	5.138	75	84
95% CI Lower	11.1	0.14	0.029	0.28	0.54	0.018	0.014	0.051	0.384	0.17	0.008	0.097	0.212	0.241	0.945	34.088	62.798	9.642	31.289	16.679	146	155
Standard Dev	7.08	0.07	0.012	0.14	0.25	0.011	0.007	0.021	0.189	0.18	0.004	0.063	0.154	0.141	0.579	10.21	16.152	2.183	12.907	6.239	38.3	38.3
C.V.	0.83	0.65	0.474	0.64	0.55	0.751	0.676	0.488	0.601	1.79	0.675	0.841	0.988	0.742	0.791	0.41	0.34	0.29	0.67	0.57	0.35	0.32

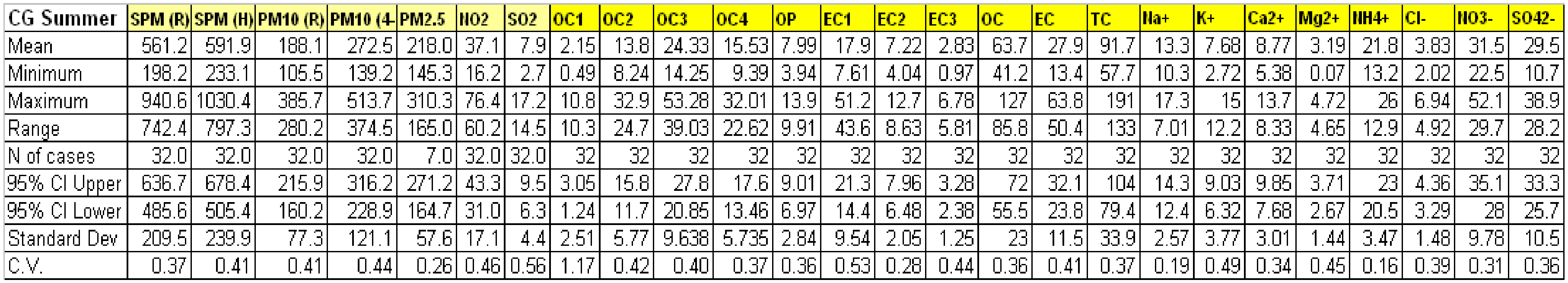
Table 2.7(d): Experimental Results with PM_{10} Chemical Speciation of Dadanagar Site for Summer Season



DN Summer	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	590.8	643.1	336.8	387.6	232.0	26.6	15.1	7.29	22.3	29.77	30.39	9.02	28.8	1.17	8.86	98.8	38.8	138	12.3	7.48	12.9	2.83	27.5	6.24	27.4	59
Minimum	258.2	252.2	143.1	182.8	151.3	7.6	0.0	1.88	11.8	15.14	14.56	18.2	11.9	0.64	0.02	47.7	15	64.7	1.89	2.61	7.22	0.26	16.2	2.79	15.5	30.7
Maximum	891.3	940.5	478.6	614.2	355.7	70.2	31.0	23.5	40	48.25	52.22	31	75	2.77	37.2	172	113	285	34.7	22.8	20.8	4.82	54.1	11.8	33.4	91.2
Range	633.2	688.4	335.5	431.4	204.4	62.6	31.0	21.6	28.2	33.11	37.66	49.2	63.2	2.13	37.2	124	97.9	220	32.8	20.2	13.6	4.56	37.8	9.04	17.9	60.5
N of cases	30.0	30.0	30.0	30.0	7.0	30.0	30.0	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
95% CI Upper	670.9	722.1	368.1	429.9	294.2	31.6	19.3	9.38	24.9	32.73	34.06	12.7	33	1.32	11.4	110	45.2	154	15.6	8.92	14.2	3.43	30.5	7.5	29.8	65.1
95% CI Lower	510.8	564.0	305.5	345.2	169.8	21.6	10.9	5.19	19.7	26.8	26.72	5.36	24.5	1.02	6.37	87.3	32.3	121	8.96	6.04	11.6	2.22	24.5	4.98	24.9	52.9
Standard Dev	214.3	211.6	83.8	113.4	67.2	13.3	11.2	5.6	7	7.935	9.823	9.81	11.4	0.4	6.67	30.7	17.3	43.8	8.9	3.87	3.49	1.63	8.05	3.37	6.54	16.4
C.V.	0.36	0.33	0.25	0.29	0.29	0.50	0.74	0.77	0.31	0.27	0.32	1.09	0.40	0.35	0.75	0.31	0.45	0.32	0.72	0.52	0.27	0.58	0.29	0.54	0.24	0.28

DN Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC
Mean	12.1	0.22	0.102	0.45	0.56	0.034	0.03	0.1	0.5	0.36	0.051	0.07	0.3	0.446	1.499	34.503	77.054	10.673	27.092	15.272	165	175
Minimum	5.15	0.08	0.022	0.14	0.25	0.012	0.01	0.057	0.11	0.04	0.003	0.035	0.032	0.035	0.296	21.875	38.731	7.696	9.079	6.561	110	121
Maximum	37.3	0.53	0.406	0.88	0.93	0.06	0.081	0.228	0.936	0.89	1.033	0.289	0.955	0.993	3.824	53.441	116.01	15.673	64.14	32.858	269	280
Range	32.2	0.45	0.384	0.73	0.68	0.048	0.071	0.171	0.826	0.84	1.03	0.254	0.923	0.958	3.528	31.566	77.277	7.977	55.061	26.297	159	159
N of cases	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	7	7	7	7	7	7	7
95% CI Upper	14.3	0.25	0.128	0.51	0.63	0.038	0.035	0.113	0.604	0.45	0.12	0.09	0.401	0.563	1.858	21.282	53.002	7.846	10.381	7.193	112	123
95% CI Lower	9.99	0.19	0.077	0.38	0.49	0.03	0.025	0.086	0.397	0.28	-0.02	0.051	0.198	0.328	1.14	47.723	101.11	13.499	43.804	23.351	217	228
Standard Dev	5.73	0.09	0.069	0.17	0.2	0.011	0.014	0.036	0.277	0.24	0.186	0.052	0.272	0.316	0.961	14.295	26.006	3.056	18.069	8.735	56.6	56.6
C.V.	0.47	0.40	0.68	0.38	0.36	0.32	0.46	0.37	0.55	0.65	3.66	0.75	0.91	0.71	0.64	0.41	0.34	0.29	0.67	0.57	0.34	0.32

Table 2.7(e): Experimental Results with PM_{10} Chemical Speciation of Coloneglganj Site for Summer Season



CG Summer	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	561.2	591.9	188.1	272.5	218.0	37.1	7.9	2.15	13.8	24.33	15.53	7.99	17.9	7.22	2.83	63.7	27.9	91.7	13.3	7.68	8.77	3.19	21.8	3.83	31.5	29.5
Minimum	198.2	233.1	105.5	139.2	145.3	16.2	2.7	0.49	8.24	14.25	9.39	3.94	7.61	4.04	0.97	41.2	13.4	57.7	10.3	2.72	5.38	0.07	13.2	2.02	22.5	10.7
Maximum	940.6	1030.4	385.7	513.7	310.3	76.4	17.2	10.8	32.9	53.28	32.01	13.9	51.2	12.7	6.78	127	63.8	191	17.3	15	13.7	4.72	26	6.94	52.1	38.9
Range	742.4	797.3	280.2	374.5	165.0	60.2	14.5	10.3	24.7	39.03	22.62	9.91	43.6	8.63	5.81	85.8	50.4	133	7.01	12.2	8.33	4.65	12.9	4.92	29.7	28.2
N of cases	32.0	32.0	32.0	32.0	7.0	32.0	32.0	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
95% CI Upper	636.7	678.4	215.9	316.2	271.2	43.3	9.5	3.05	15.8	27.8	17.6	9.01	21.3	7.96	3.28	72	32.1	104	14.3	9.03	9.85	3.71	23	4.36	35.1	33.3
95% CI Lower	485.6	505.4	160.2	228.9	164.7	31.0	6.3	1.24	11.7	20.85	13.46	6.97	14.4	6.48	2.38	55.5	23.8	79.4	12.4	6.32	7.68	2.67	20.5	3.29	28	25.7
Standard Dev	209.5	239.9	77.3	121.1	57.6	17.1	4.4	2.51	5.77	9.638	5.735	2.84	9.54	2.05	1.25	23	11.5	33.9	2.57	3.77	3.01	1.44	3.47	1.48	9.78	10.5
C.V.	0.37	0.41	0.41	0.44	0.26	0.46	0.56	1.17	0.42	0.40	0.37	0.36	0.53	0.28	0.44	0.36	0.41	0.37	0.19	0.49	0.34	0.45	0.16	0.39	0.31	0.36

CG Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	CO (ppm)
Mean	7.47	0.11	0.022	0.2	0.4	0.014	0.011	0.048	0.188	0.08	0.005	0.141	0.16	0.156	1.206	37.263	60.303	9.605	24.383	13.745	145	164	1.551
Minimum	1.47	0.04	0.007	0.07	0.01	0.004	0.004	0.029	0.091	0.01	0.002	0.038	0.028	0.036	0.132	23.625	30.312	6.927	8.171	5.905	96.7	115	0.9
Maximum	19.1	0.26	0.091	0.38	0.98	0.042	0.024	0.127	0.547	0.55	0.019	0.254	0.309	0.595	3.509	57.716	90.788	14.105	57.726	29.572	237	255	2.1
Range	17.6	0.22	0.084	0.31	0.97	0.038	0.02	0.098	0.456	0.54	0.017	0.216	0.281	0.559	3.377	34.091	60.476	7.178	49.555	23.667	140	140	1.2
N of cases	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32	7	7	7	7	7	7	7	25
95% CI Upper	9.09	0.13	0.029	0.24	0.5	0.017	0.013	0.055	0.225	0.13	0.006	0.169	0.204	0.212	1.599	22.985	41.481	7.062	9.343	6.474	98.7	117	1.427
95% CI Lower	5.84	0.09	0.016	0.16	0.31	0.01	0.009	0.04	0.15	0.03	0.004	0.113	0.115	0.1	0.814	51.541	79.126	12.149	39.423	21.015	192	210	1.675
Standard Dev	4.5	0.07	0.018	0.12	0.26	0.009	0.006	0.021	0.104	0.13	0.003	0.078	0.124	0.155	1.089	15.438	20.352	2.75	16.262	7.862	50.4	50.4	0.3
C.V.	0.60	0.60	0.80	0.57	0.63	0.67	0.54	0.44	0.55	1.63	0.71	0.55	0.77	0.99	0.90	0.41	0.34	0.29	0.67	0.57	0.35	0.31	0.19

Table 2.7(f): Experimental Results with PM_{10} Chemical Speciation of AHM Site for Summer Season

AHM Summe	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	536.7	511.9	160.2	255.1	171.7	32.5	7.2	1.89	12.4	22.94	15.3	7.06	17.6	6.31	1.97	59.6	25.8	85.4	6.17	5.21	7.95	2.5	21.5	3.55	30.2	41.1
Minimum	233.4	225.3	87.7	114.2	120.6	10.4	2.4	0.32	4.48	7.3	5.42	1.42	4.81	2.73	0.04	20.9	7.58	28.6	1.94	2.1	3.57	0.25	6.33	1.31	8.24	16.2
Maximum	778.8	884.4	268.9	467.9	223.0	60.0	28.9	7.59	31.6	43.66	30.14	12.2	34.9	11.2	5.03	114	50.8	165	9.36	9.01	13.3	10.4	40.2	5.11	49.3	64.8
Range	545.4	659.1	181.2	353.7	102.4	49.6	26.5	7.27	27.1	36.36	24.72	10.8	30.1	8.48	4.99	92.9	43.2	136	7.42	6.91	9.75	10.2	33.9	3.8	41	48.7
N of cases	28.0	28.0	28.0	28.0	7.0	28.0	28.0	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
95% CI Upper	603.8	596.5	180.1	295.2	204.9	38.2	9.7	2.38	14.6	26.57	17.53	8.2	20.9	7.07	2.41	67.8	30.1	97.5	7.09	6.08	9.34	3.2	25.7	3.91	34.7	47.9
95% CI Lower	469.7	427.2	140.4	215.0	138.4	26.8	4.8	1.39	10.2	19.3	13.07	5.93	14.3	5.54	1.53	51.3	21.6	73.4	5.25	4.34	6.56	1.8	17.3	3.18	25.7	34.3
Standard Dev	173.0	218.2	51.2	103.4	35.9	14.8	6.3	1.28	5.6	9.377	5.748	2.94	8.54	1.98	1.13	21.3	10.9	31.1	2.36	2.24	3.59	1.8	10.9	0.95	11.6	17.6
C.V.	0.32	0.43	0.32	0.41	0.21	0.45	0.87	0.68	0.45	0.41	0.38	0.42	0.49	0.31	0.58	0.36	0.42	0.36	0.38	0.43	0.45	0.72	0.51	0.27	0.39	0.43

AHM Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC
Mean	6.8	0.09	0.015	0.18	0.36	0.013	0.011	0.052	0.196	0.07	0.005	0.188	0.12	0.154	1.171	33.019	58.293	9.285	23.57	13.287	137	153
Minimum	1.61	0.02	0.003	0.05	0.02	0.004	0.006	0.013	0.041	0.02	0.003	0.046	0.038	0.068	0.108	20.934	29.301	6.696	7.898	5.708	91.6	108
Maximum	17.4	0.23	0.039	0.41	0.99	0.037	0.028	0.187	0.538	0.35	0.017	0.309	0.202	0.33	3.626	51.143	87.762	13.635	55.802	28.586	225	241
Range	15.8	0.21	0.036	0.36	0.97	0.033	0.022	0.174	0.497	0.34	0.014	0.263	0.164	0.262	3.518	30.209	58.461	6.939	47.904	22.878	133	133
N of cases	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	7	7	7	7	7	7	7
95% CI Upper	8.62	0.12	0.019	0.22	0.46	0.016	0.014	0.068	0.246	0.1	0.006	0.232	0.142	0.192	1.601	20.367	40.098	6.826	9.031	6.258	93.3	109
95% CI Lower	4.98	0.07	0.012	0.13	0.26	0.01	0.009	0.037	0.146	0.04	0.004	0.145	0.097	0.116	0.742	45.671	76.488	11.744	38.109	20.315	182	197
Standard Dev	4.69	0.06	0.009	0.11	0.25	0.009	0.006	0.04	0.129	0.08	0.003	0.111	0.058	0.098	1.107	13.68	19.674	2.659	15.72	7.599	47.7	47.7
C.V.	0.69	0.66	0.60	0.64	0.70	0.68	0.54	0.77	0.66	1.10	0.62	0.59	0.49	0.64	0.95	0.41	0.34	0.29	0.67	0.57	0.35	0.31

Table 2.7(g): Experimental Results with PM_{10} Chemical Speciation of Ramadevi Site for Summer Season

RD Summer	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-
Mean	506.9	521.5	151.7	190.2	170.1	29.7	12.3	1.28	9.17	17.25	10.67	5.35	9.43	6.36	1.68	43.7	17.5	61.2	5.95	2.76	7.61	3.33	11.5	2.91	13.9	20.5
Minimum	330.2	252.5	105.3	108.5	107.6	14.2	3.2	0.53	5.47	0.65	6.63	2.58	2.07	3.34	0.63	29.7	8.69	38.7	0.14	1.56	3.82	2.43	3.85	0.52	0.61	4.08
Maximum	773.0	834.7	279.6	334.4	273.7	56.4	27.4	3.35	16.3	34.03	18.32	22.3	23.6	28	6.1	71.1	36.1	102	17.6	5.54	13.3	4.69	25.3	15.1	29.9	89.7
Range	442.8	582.2	174.3	225.9	166.1	42.3	24.2	2.82	10.8	33.38	11.69	19.8	21.5	24.6	5.47	41.4	27.5	63.5	17.4	3.98	9.51	2.26	21.4	14.5	29.3	85.6
N of cases	30.0	30.0	30.0	30.0	7.0	30.0	30.0	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
95% CI Upper	553.9	579.8	169.5	211.8	225.1	34.5	14.8	1.49	10.1	19.5	11.68	6.7	11	7.95	2.05	47.6	19.8	66.8	7.8	3.03	9.15	3.75	13.3	3.94	16.5	26.4
95% CI Lower	459.9	463.2	133.8	168.5	115.2	24.9	9.7	1.06	8.29	15.01	9.666	3.99	7.83	4.76	1.31	39.8	15.1	55.6	4.11	2.49	6.07	2.91	9.63	1.88	11.4	14.6
Standard Dev	125.8	156.2	47.8	58.0	59.4	12.8	6.8	0.57	2.38	6.021	2.696	3.62	4.28	4.28	0.99	10.4	6.22	15	4.94	0.72	4.12	1.13	4.98	2.77	6.77	15.7
C.V.	0.25	0.30	0.32	0.31	0.35	0.43	0.55	0.45	0.26	0.35	0.25	0.68	0.45	0.67	0.59	0.24	0.36	0.24	0.83	0.26	0.54	0.34	0.43	0.95	0.49	0.77

RD Summer	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC
Mean	6.11	0.08	0.024	0.42	0.47	0.011	0.008	0.03	0.198	0.04	0.004	0.151	0.106	0.118	0.848	34.606	56.953	9.072	23.028	12.981	137	154
Minimum	1.24	0.02	0.007	0	0.16	0.004	0.004	0.016	0.077	0.01	0.002	0.039	0.038	0.039	0.114	21.94	28.628	6.542	7.717	5.577	91	108
Maximum	16.3	0.21	0.072	0.97	0.98	0.032	0.015	0.056	0.641	0.19	0.009	0.326	0.164	0.176	3.874	53.601	85.745	13.322	54.519	27.929	223	240
Range	15	0.18	0.065	0.97	0.81	0.028	0.011	0.04	0.564	0.17	0.007	0.287	0.126	0.137	3.76	31.661	57.117	6.78	46.802	22.352	132	132
N of cases	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	7	7	7	7	7	7	7
95% CI Upper	7.4	0.09	0.03	0.53	0.56	0.013	0.009	0.034	0.253	0.06	0.005	0.191	0.124	0.138	1.219	21.346	39.176	6.67	8.824	6.114	92.8	110
95% CI Lower	4.81	0.06	0.018	0.31	0.38	0.008	0.007	0.026	0.143	0.03	0.003	0.11	0.088	0.098	0.477	47.866	74.73	11.474	37.233	19.848	180	198
Standard Dev	3.46	0.05	0.017	0.31	0.24	0.006	0.003	0.01	0.148	0.04	0.002	0.109	0.049	0.054	0.993	14.338	19.222	2.598	15.359	7.425	47.4	47.4
C.V.	0.57	0.60	0.68	0.73	0.50	0.58	0.42	0.34	0.75	0.95	0.45	0.73	0.46	0.46	1.17	0.41	0.34	0.29	0.67	0.57	0.35	0.31

Table 2.8: Correlation Matrices of Four Dust Parameters for Summer Season at all Sampling Sites

(a) IIT Kanpur Site

IIT(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.432	1		
PM_{10}	0.468	0.621	1	
$PM_{2.5}$	0.485	0.447	0.927	1

(b) Vikashnagar Site

VN(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.771	1		
PM_{10}	0.832	0.876	1	
$PM_{2.5}$	0.612	0.812	0.845	1

(c) Govindnagar Site

GN(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.624	1		
PM_{10}	0.482	0.181	1	
$PM_{2.5}$	0.572	0.154	0.852	1

(d) Dadanagar Site

DN(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.466	1		
PM_{10}	0.522	0.929	1	
$PM_{2.5}$	0.339	0.784	0.907	1

(e) Colonelganj Site

CG(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.634	1		
PM_{10}	0.504	0.314	1	
$PM_{2.5}$	0.36	0.194	0.885	1

(f) AHM Site

AHM(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.323	1		
PM_{10}	0.554	0.865	1	
$PM_{2.5}$	0.292	0.61	0.725	1

(g) Ramadevi Site

RD(S)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.413	1		
PM_{10}	0.674	0.584	1	
$PM_{2.5}$	0.671	0.516	0.992	1

Table 2.9: Correlation Matrices of Chemical Species for Summer Season at all Sampling Sites

(a) IIT Kanpur Site

IIT(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.079	1							
SO_2	0.071	0.383	1						
NH_4^+	0.439	0.073	0.104	1					
SO_4^{2-}	0.344	0.041	0.008	0.942	1				
NO_3^-	0.226	0.256	0.033	0.871	0.873	1			
EC	0.33	0.024	0.096	-0.087	-0.021	-0.089	1		
OC	0.425	0.061	0.148	-0.023	0.012	-0.049	0.912	1	
TC	0.403	0.035	0.135	-0.043	0.002	-0.063	0.958	0.991	1

(b) Vikashnagar Site

VN(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.151	1							
SO_2	0.024	0.432	1						
NH_4^+	0.522	0.032	0.318	1					
SO_4^{2-}	0.473	0.036	0.16	0.893	1				
NO_3^-	0.365	0.275	0.277	0.677	0.168	1			
EC	0.449	0.514	0.122	-0.047	-0.15	-0.106	1		
OC	0.594	0.482	0.114	-0.054	-0.175	-0.063	0.961	1	
TC	0.56	0.494	0.117	-0.052	-0.17	-0.075	0.979	0.997	1

(c) Govindnagar Site

GN(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.208	1							
SO_2	0.191	0.227	1						
NH_4^+	0.641	0.12	0.133	1					
SO_4^{2-}	0.547	0.211	0.243	0.711	1				
NO_3^-	0.447	0.293	0.037	0.72	0.216	1			
EC	0.014	0.351	0.269	-0.06	0.21	-0.191	1		
OC	0.59	0.371	0.233	-0.31	0.21	-0.564	0.534	1	
TC	0.515	0.396	0.259	-0.284	0.227	-0.534	0.67	0.986	1

(d) Dadanagar Site

DN(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.168	1							
SO_2	0.163	0.001	1						
NH_4^+	0.593	0.044	0.138	1					
SO_4^{2-}	0.325	0.075	0.13	0.781	1				
NO_3^-	0.221	0.259	0.164	0.646	0.196	1			
EC	0.069	0.236	0.163	-0.176	0.142	-0.322	1		
OC	0.195	0.412	0.084	-0.226	0.012	-0.106	0.672	1	
TC	0.166	0.383	0.119	-0.226	0.059	-0.191	0.842	0.965	1

Table 2.9: Correlation Matrices of Chemical Species for Summer Season at all Sampling Sites

(e) Colonelganj Site

CG(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.159	1							
SO_2	0.649	0.394	1						
NH_4^+	0.651	0.017	0.007	1					
SO_4^{2-}	0.521	0.216	0.083	0.609	1				
NO_3^-	0.366	0.344	0.004	0.845	0.27	1			
EC	0.601	0.083	0.532	-0.195	-0.051	-0.034	1		
OC	0.58	0.201	0.535	-0.104	-0.085	-0.013	0.918	1	
TC	0.598	0.165	0.544	-0.137	-0.075	-0.02	0.963	0.991	1

(f) AHM Site

AHM(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.522	1							
SO_2	0.48	0.046	1						
NH_4^+	0.541	0.195	0.281	1					
SO_4^{2-}	0.493	0.068	0.292	0.766	1				
NO_3^-	0.516	0.449	-0.194	0.832	0.679	1			
EC	0.348	0.005	0.387	0.066	0.271	0.147	1		
OC	0.311	0.048	0.4	0.102	0.305	0.142	0.859	1	
TC	0.334	0.031	0.409	0.093	0.304	0.149	0.937	0.984	1

(g) Ramadevi Site

RD(S)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.201	1							
SO_2	0.812	0.024	1						
NH_4^+	0.581	0.015	0.308	1					
SO_4^{2-}	0.408	0.04	0.024	0.717	1				
NO_3^-	0.465	0.323	-0.172	0.647	0.689	1			
EC	0.177	0.031	0.247	0.216	-0.278	-0.141	1		
OC	0.578	0.059	0.561	-0.036	-0.178	-0.145	0.592	1	
TC	0.476	0.054	0.493	0.065	-0.24	-0.16	0.828	0.942	1

Table 2.10(a): Experimental Results of $PM_{2.5}$ Chemical Speciation of IIT Kanpur Site for Summer Season

IIT (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	104.5	0.62	2.78	3.87	2.1	-4.4	1.66	0.39	0.06	11.8	2.13	14	1.076	1.33	2.472	0.371	2.18	0.37	0.46	6.413
Maximum	178	3.07	12	17	17.3	4.15	10.26	0.81	0.48	45	11.5	56.53	3.947	5.01	4.815	2.286	12.4	1.35	9.22	35.39
Range	73.42	2.45	9.22	13.13	15.2	8.55	8.6	0.42	0.42	33.2	9.41	42.53	2.871	3.67	2.343	1.915	10.2	0.98	8.77	28.98
Arithmetic Mean	136.4	1.35	5.56	7.996	6.2	1.47	5.328	0.53	0.209	22.6	6.06	28.64	2.645	3.47	3.616	1.636	7.43	0.65	5.22	19.44
95.0% Lower CI	117.8	0.65	2.85	4.03	1.46	-0.7	2.479	0.38	0.064	12	2.96	15.09	1.804	2.57	2.981	1.101	4.49	0.3	2.45	10.89
95.0% Upper CI	155.1	2.05	8.26	11.96	10.9	3.6	8.176	0.67	0.354	33.1	9.17	42.18	3.485	4.36	4.25	2.172	10.4	1	7.99	27.99
S.D.	22.32	0.84	3.24	4.744	5.67	2.55	3.407	0.17	0.174	12.6	3.71	16.2	1.006	1.07	0.759	0.641	3.51	0.42	3.31	10.23
C.V.	0.164	0.62	0.58	0.593	0.91	1.74	0.64	0.33	0.831	0.56	0.61	0.566	0.38	0.31	0.21	0.392	0.47	0.64	0.64	0.526

Table 2.10(b): Experimental Results of $PM_{2.5}$ Chemical Speciation of Vikashnagar Site for Summer Season

VN (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	86.8	1.4	4.51	6.45	3.72	3.07	3.82	0.44	0.01	19.9	4.28	24.19	0.389	2.53	2.088	1.16	9.41	0.4	1.04	25.15
Maximum	294.3	2.27	15.6	17.53	16.6	6.25	12.17	0.99	0.39	58	13.3	71.33	7.049	4.81	5.552	1.761	14.9	1.15	10.2	40.17
Range	207.5	0.87	11.1	11.08	12.9	3.18	8.35	0.55	0.38	38.1	9.02	47.14	6.66	2.28	3.464	0.601	5.53	0.74	9.14	15.02
Arithmetic Mean	190.1	1.85	9	11.54	8.7	5.24	7.351	0.78	0.218	36.3	8.35	44.68	2.523	3.72	4.148	1.546	13.1	0.84	6.66	35.11
95.0% Lower CI	146.9	1.62	6.71	9.236	5.96	4.46	5.502	0.63	0.135	28.5	6.4	35.07	0.212	2.84	3.063	1.346	11.5	0.58	4.58	30.52
95.0% Upper CI	233.3	2.09	11.3	13.85	11.4	6.02	9.2	0.93	0.3	44.1	10.3	54.28	4.834	4.61	5.234	1.745	14.7	1.1	8.73	39.69
S.D.	56.21	0.3	2.97	3.001	3.56	1.01	2.406	0.2	0.108	10.2	2.55	12.5	3.006	1.15	1.412	0.26	2.07	0.34	2.7	5.969
C.V.	0.296	0.16	0.33	0.26	0.41	0.19	0.327	0.25	0.494	0.28	0.31	0.28	1.191	0.31	0.34	0.168	0.16	0.4	0.41	0.17

Table 2.10(c): Experimental Results of $PM_{2.5}$ Chemical Speciation of Govindnagar Site for Summer Season

GN (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	105.3	3.17	1.49	1.44	3.22	11.4	1.59	1.67	3.19	21.5	8.05	31.96	1.108	1.77	2.865	0.316	4.63	0.26	1.82	4.06
Maximum	206.2	5.45	5.41	3.54	8.39	20.5	5.08	5	5.32	41.1	11.5	50.28	4.446	2.15	4.385	2.522	17.1	2.77	24.1	35.52
Range	100.9	2.28	3.92	2.1	5.17	9.05	3.49	3.33	2.13	19.6	3.47	18.32	3.338	0.38	1.52	2.206	12.4	2.51	22.2	31.46
Arithmetic Mean	159.3	4.5	2.59	2.256	5.06	15.1	2.557	2.85	4.394	29.5	9.8	39.27	2.447	1.93	3.479	1.542	13.2	1.29	9.78	29.78
95.0% Lower CI	126.9	3.72	1.36	1.648	3.32	11.5	1.423	1.87	3.716	23	8.76	33.01	1.306	1.77	2.845	0.567	8.83	0.29	2.1	19.19
95.0% Upper CI	191.6	5.28	3.81	2.863	6.81	18.6	3.691	3.83	5.073	36	10.8	45.53	3.588	2.08	4.113	2.517	17.7	2.29	17.5	40.38
S.D.	34.99	0.85	1.33	0.657	1.89	3.87	1.226	1.06	0.734	7.05	1.13	6.766	1.233	0.17	0.686	1.055	4.78	1.08	8.3	11.45
C.V.	0.22	0.19	0.51	0.291	0.37	0.26	0.48	0.37	0.167	0.24	0.12	0.172	0.504	0.09	0.197	0.684	0.36	0.84	0.85	0.384

Table 2.10(d): Experimental Results of $PM_{2.5}$ Chemical Speciation of Dadanagar Site for Summer Season

DN (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	151.3	1.53	7.73	8.7	10.6	1.88	7.53	0.21	1.7	31.4	9.75	41.09	0.897	4.74	5.008	0.096	9.1	1.48	11	19.03
Maximum	355.7	3.9	10.7	16.07	14	9.65	13.69	0.9	3.92	50.9	18	68.85	10.45	9.31	8.008	1.41	30.3	4.35	19.4	49.17
Range	204.4	2.37	2.98	7.37	3.38	7.77	6.16	0.69	2.22	19.5	8.21	27.76	9.549	4.56	3	1.314	21.2	2.87	8.38	30.13
Arithmetic Mean	232	3.16	9.49	12.38	12.4	6.13	10.88	0.42	2.787	43.6	14.1	57.67	6.324	6.03	7.214	0.669	18.4	3.64	17	38.93
95.0% Lower CI	169.8	2.4	8.34	9.887	11.4	3.78	8.999	0.21	2.068	37.3	11.6	49.37	3.489	4.59	6	0.187	12.7	2.63	13.9	30.33
95.0% Upper CI	294.2	3.91	10.6	14.87	13.5	8.47	12.76	0.64	3.507	49.8	16.6	65.98	9.159	7.46	8.427	1.152	24.2	4.66	20.1	47.54
S.D.	67.23	0.81	1.24	2.694	1.16	2.54	2.031	0.23	0.778	6.76	2.71	8.976	3.065	1.55	1.312	0.522	6.23	1.1	3.35	9.305
C.V.	0.29	0.26	0.13	0.218	0.09	0.42	0.187	0.54	0.279	0.16	0.19	0.156	0.485	0.26	0.182	0.78	0.34	0.3	0.2	0.239

Table 2.10(e): Experimental Results of $PM_{2.5}$ Chemical Speciation of Colonelganj Site for Summer Season

CG (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	145.3	0.74	4.93	8.64	7.83	3.93	5.4	2.65	0.98	26.6	9.03	37.46	4.943	1.93	2.798	0.026	13.4	0.97	19.1	12.74
Maximum	310.3	1.45	14.4	28.74	16.7	7.47	23.3	3.75	2	68.5	29	97.53	8.305	10.6	7.129	1.701	20	3.33	44.3	30.73
Range	165	0.71	9.51	20.1	8.82	3.54	17.9	1.1	1.02	41.9	20	60.07	3.362	8.7	4.331	1.675	6.62	2.36	25.2	17.99
Arithmetic Mean	218	1	8.75	15.56	11	5.55	11.71	3.17	1.4	41.8	16.3	58.1	6.522	5.61	4.443	0.992	17.4	1.82	27.2	24.3
95.0% Lower CI	164.7	0.77	5.33	8.939	7.65	4.36	5.725	2.79	1.07	28.5	9.79	38.48	5.29	2.91	2.92	0.414	15.5	1.15	18.7	16.75
95.0% Upper CI	271.2	1.24	12.2	22.18	14.3	6.75	17.69	3.56	1.73	55.2	22.8	77.72	7.753	8.31	5.966	1.57	19.3	2.49	35.6	31.85
S.D.	57.59	0.26	3.7	7.156	3.57	1.29	6.468	0.42	0.357	14.4	7.02	21.22	1.331	2.92	1.647	0.625	2.03	0.72	9.14	8.162
C.V.	0.264	0.26	0.42	0.46	0.33	0.23	0.552	0.13	0.255	0.35	0.43	0.365	0.204	0.52	0.371	0.63	0.12	0.4	0.34	0.336

Table 2.10(f): Experimental Results of $PM_{2.5}$ Chemical Speciation of AHM Site for Summer Season

AHM (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	120.6	0.6	5.11	8.93	7.36	3.05	5.91	2.45	0.67	26.9	9.68	37.65	1.526	2.55	2.334	0.648	14.6	1.06	12.2	13.37
Maximum	223	1.01	8.07	20.63	11.4	6.64	9.56	3.14	1.21	43.6	13.7	57.32	4.29	3.56	5.034	1.561	21.4	1.56	23.8	40.23
Range	102.4	0.41	2.96	11.7	4.05	3.59	3.65	0.69	0.54	16.7	4.02	19.67	2.764	1.01	2.7	0.913	6.71	0.5	11.6	26.86
Arithmetic Mean	171.7	0.86	6.07	12.38	8.68	4.62	7.64	2.81	0.98	32.6	11.4	44.04	2.509	3.27	3.43	0.991	16.4	1.44	21.9	19.26
95.0% Lower CI	138.4	0.74	5.11	8.85	7.36	3.43	6.177	2.53	0.778	27.2	9.88	37.23	1.359	2.81	2.533	0.613	14	1.27	18	10.2
95.0% Upper CI	204.9	0.99	7.03	15.9	10	5.8	9.103	3.09	1.182	38	13	50.85	3.659	3.72	4.326	1.37	18.8	1.61	25.9	28.33
S.D.	35.95	0.13	1.04	3.812	1.43	1.28	1.582	0.31	0.218	5.85	1.68	7.364	1.243	0.49	0.969	0.409	2.59	0.18	4.3	9.799
C.V.	0.209	0.15	0.17	0.308	0.17	0.28	0.207	0.11	0.223	0.18	0.15	0.167	0.495	0.15	0.283	0.413	0.16	0.13	0.2	0.509

Table 2.10(g): Experimental Results of $PM_{2.5}$ Chemical Speciation of Ramadevi Site for Summer Season

RD (Summer)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	107.6	0.51	5.35	7.04	5.62	2.21	4.46	3.02	0.38	21.1	7.98	30.53	0.059	1.21	2.492	0.899	10.2	0.28	6.71	9.172
Maximum	273.7	1.18	7.97	15.06	9.44	5.58	8.66	3.71	1.19	36.8	13.1	49.89	3.331	2.12	6.927	1.735	16.7	1.47	26.3	25.87
Range	166.1	0.67	2.62	8.02	3.82	3.37	4.2	0.69	0.81	15.7	5.11	19.36	3.272	0.92	4.435	0.836	6.48	1.2	19.6	16.7
Arithmetic Mean	170.1	0.89	6.14	11.18	7.09	3.63	5.859	3.44	0.923	28.9	10.2	39.16	1.75	1.94	3.759	1.138	11.8	0.91	16.9	18.99
95.0% Lower CI	115.2	0.68	5.31	8.217	5.83	2.55	4.446	3.19	0.666	23.2	8.53	32.08	0.337	1.62	1.758	0.761	9.63	0.4	10	12.51
95.0% Upper CI	225.1	1.1	6.96	14.15	8.36	4.71	7.271	3.7	1.179	34.6	11.9	46.23	3.163	2.26	5.761	1.515	14	1.41	23.7	25.47
S.D.	59.4	0.23	0.9	3.208	1.37	1.17	1.528	0.28	0.277	6.18	1.83	7.648	1.528	0.35	2.164	0.408	2.38	0.55	7.39	7.004
C.V.	0.349	0.26	0.15	0.287	0.19	0.32	0.261	0.08	0.301	0.21	0.18	0.195	0.873	0.18	0.576	0.359	0.2	0.6	0.44	0.369

2.4.1.7 Comparisons of PM_{10} and $PM_{2.5}$ Compositions

This section presents some important observations from the experimental findings related to fine particles and coarse particle concentrations. Table 2.11 presents a comparison between $PM_{2.5}$ and PM_{10} with respect to their compositions for the major chemical species from all sampling sites during summer season. The chemical species considered for the comparisons are EC, OC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. It can be concluded here that NH_4^+, NO_3^-, SO_4^{2-} and OC are formed in the fine mode; whereas, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- are formed in coarse as well as fine mode.

The above results are also shown graphically for all sampling sites of the city for better understanding. Figures 2.10(a), 2.10(b), 2.10(c), 2.10(d), 2.10(e), 2.10(f) and 2.10(g) show the compositional comparison of $PM_{2.5}$ Vs PM_{10} for major chemical species at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during summer season.

Table 2.11: Ratios of Chemical Species of $PM_{2.5}$ and PM_{10} for all Sites of Summer Season

Summer Site	IIT Kanpur	Vikash nagar	Govind nagar	Dada nagar	Colonel ganj	AHM	Ramadevi
$PM_{2.5}$ (ug/m3)	136.4	190.1	159.3	232.0	218.0	171.7	170.1
PM_{10} (ug/m3)	187.1	216.7	234.1	387.6	272.6	255.1	190.2
$PM_{2.5}$/ PM_{10} (%)	72.9	87.7	68.0	59.9	80.0	67.3	89.4
$PM_{2.5}$ EC/ PM_{10} EC (%)	43.0	47.5	45.8	36.3	58.4	44.2	58.3
$PM_{2.5}$ OC/ PM_{10} OC (%)	65.7	69.0	55.6	44.1	65.6	54.7	66.1
$PM_{2.5}$ TC/ PM_{10} TC (%)	59.0	63.6	52.8	41.8	63.4	51.6	64.1
$PM_{2.5}$ Na^+/ PM_{10} Na^+ (%)	41.9	33.8	33.8	51.2	48.9	40.3	30.5
$PM_{2.5}$ K^+/ PM_{10} K^+ (%)	77.8	72.5	73.1	80.0	72.7	63.5	67.9
$PM_{2.5}$ Ca^{2+}/ PM_{10} Ca^{2+} (%)	54.5	56.0	53.8	55.8	50.0	43.0	50.0
$PM_{2.5}$ Mg^{2+}/ PM_{10} Mg^{2+} (%)	43.2	44.1	41.7	25.0	30.9	39.6	33.3
$PM_{2.5}$ NH_4^+/ PM_{10} NH_4^+ (%)	56.5	91.6	70.2	66.9	79.8	76.3	97.5
$PM_{2.5}$ Cl^-/ PM_{10} Cl^- (%)	40.6	46.7	44.8	58.1	47.4	38.9	31.0
$PM_{2.5}$ NO_3^-/ PM_{10} NO_3^- (%)	73.2	76.1	76.0	61.7	86.0	73.0	82.7
$PM_{2.5}$ SO_4^{2-}/ PM_{10} $SO4^{2-}$ (%)	69.3	97.7	69.8	65.9	82.4	71.5	92.7

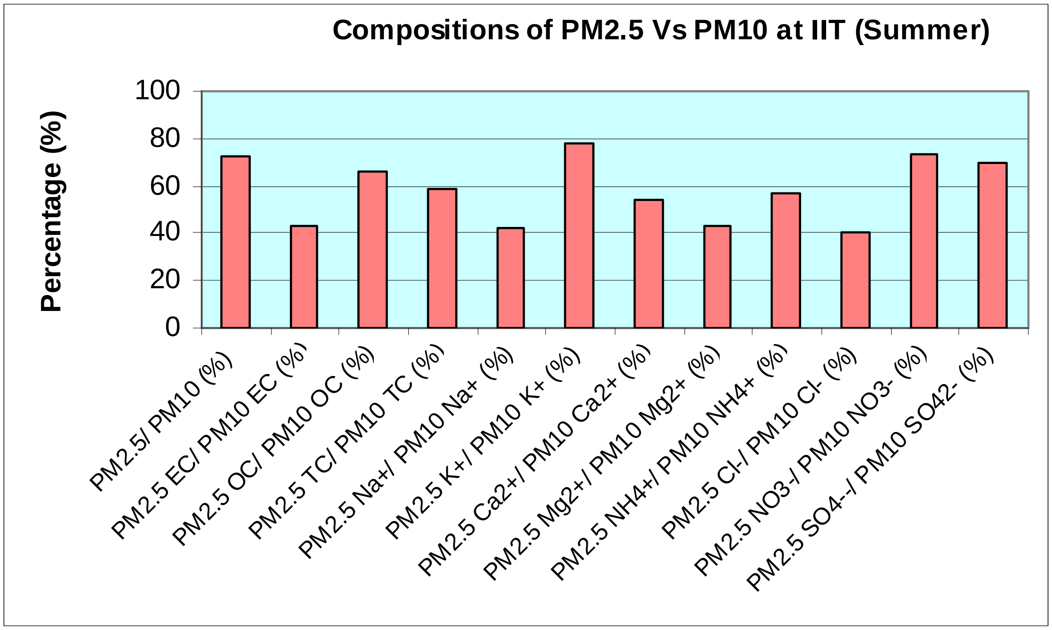


Figure 2.10(a): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at IIT Kanpur Site for Summer Season

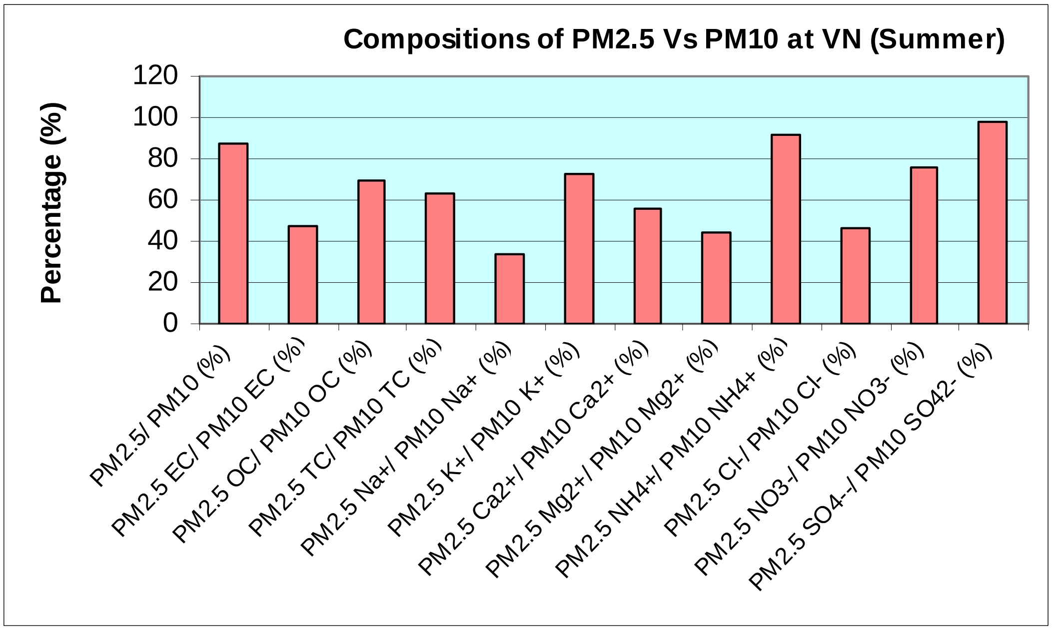


Figure 2.10(b): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Vikashnagar Site for Summer Season

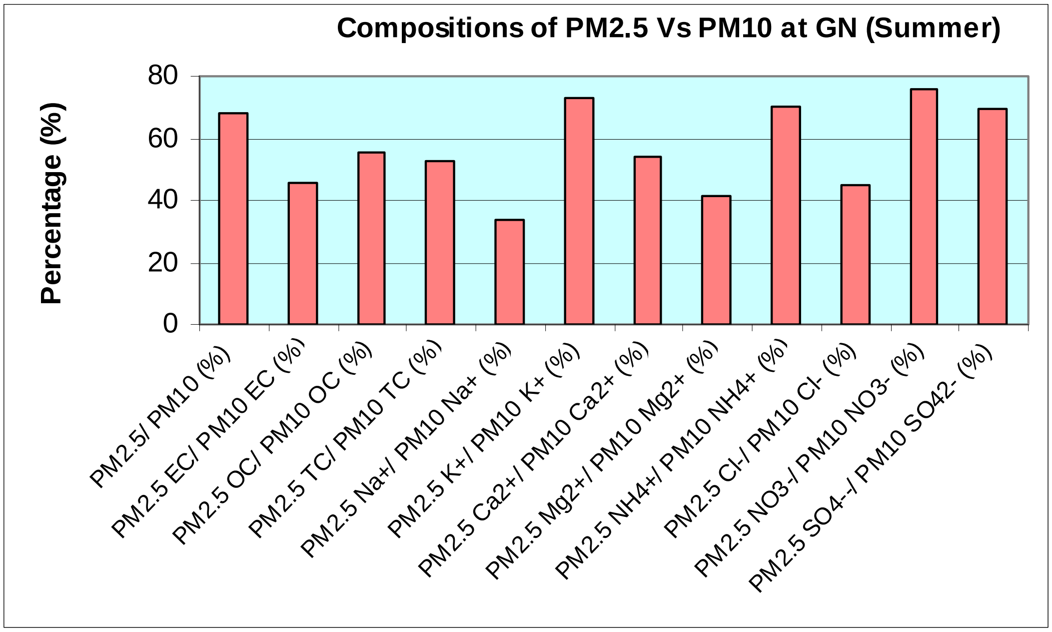


Figure 2.10(c): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Govindnagar Site for Summer Season

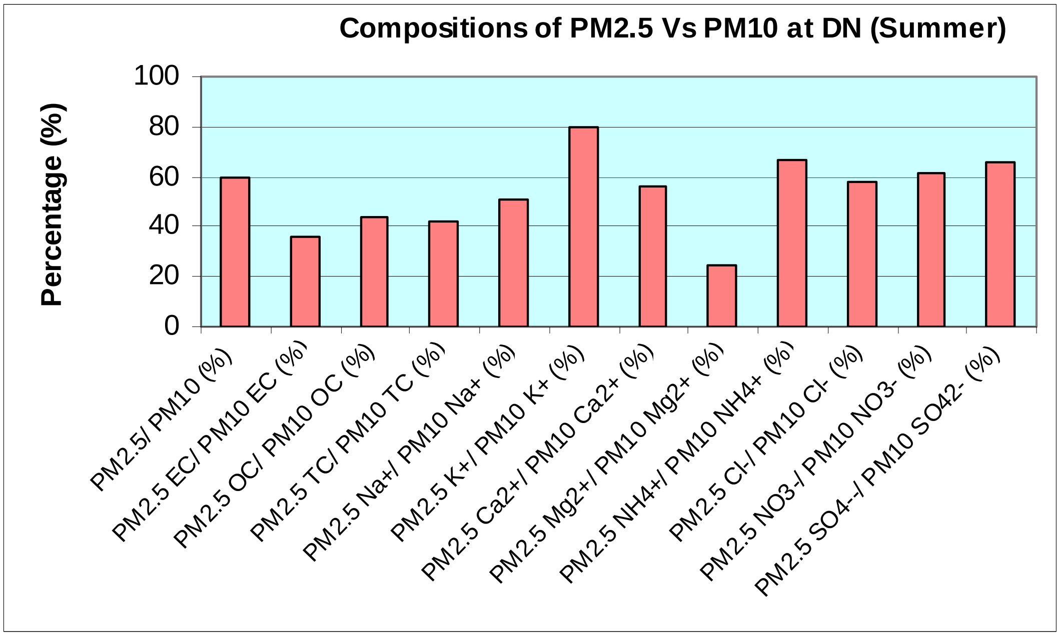


Figure 2.10(d): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Dadanagar Site for Summer Season

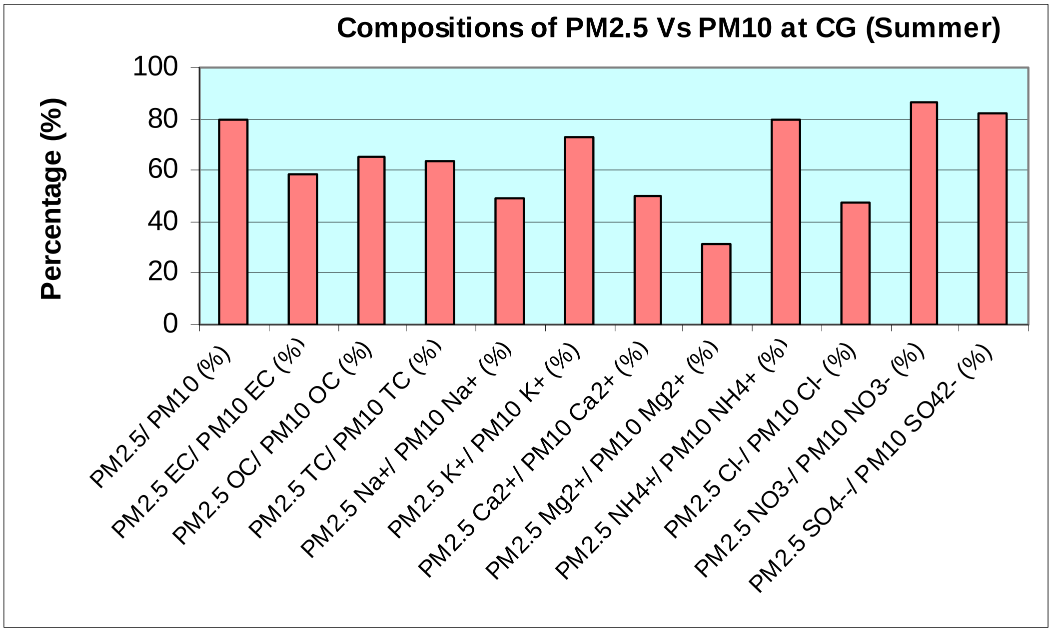


Figure 2.10(e): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Colonelganj Site for Summer Season

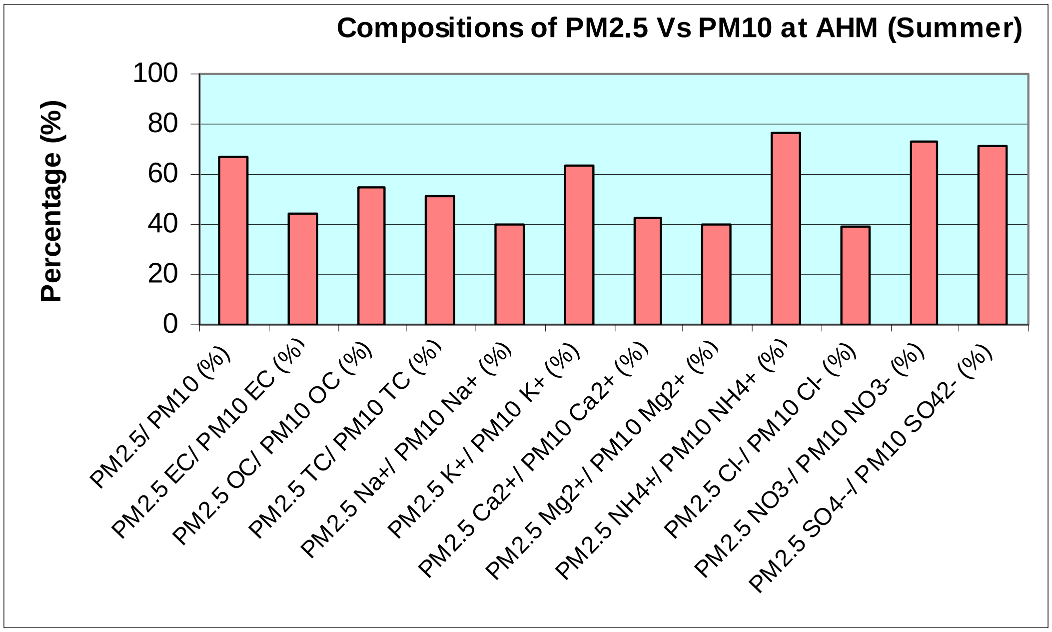


Figure 2.10(f): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at AHM Site for Summer Season

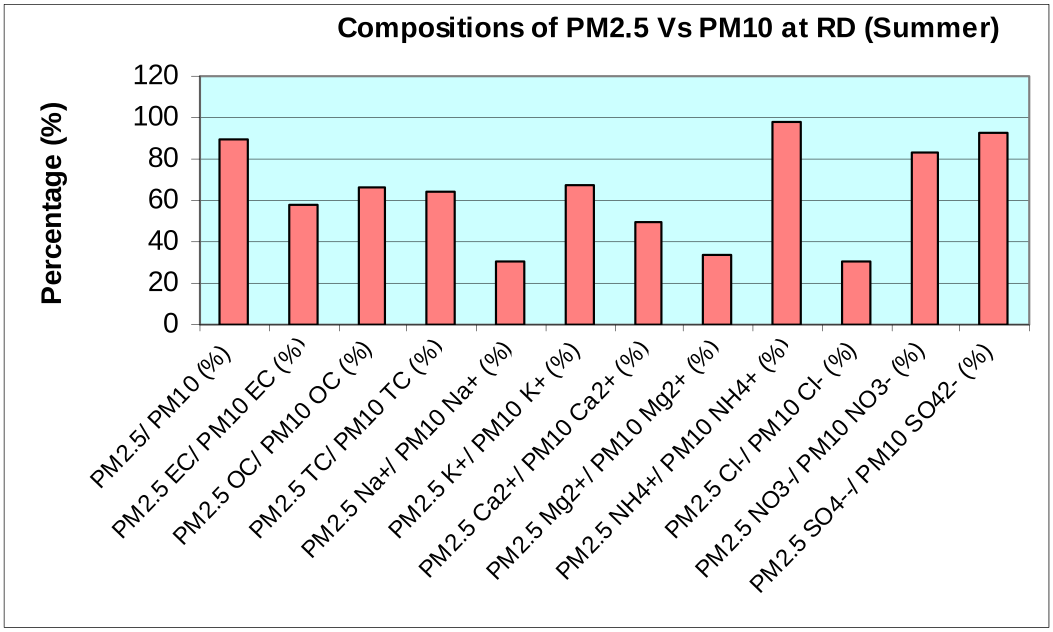


Figure 2.10(g): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Ramadevi Site for Summer Season

2.4.2 Post-monsoon Season

The duration of the sampling for post-monsoon season was from October 2007 and November 2007. But due to machinery problem, the sampling was done till early of the December 2007 at two sites. This section presents the observational results of various pollutants at all sampling locations during this period of time.

2.4.2.1 Particulate Matters (SPM, RSPM, PM_{10} and $PM_{2.5}$)

Daily average concentrations observed for SPM, RSPM, PM_{10} and $PM_{2.5}$ are shown graphically in this section during post-monsoon season. Figures 2.11(a), 2.11(b), 2.11(c), 2.11(d), 2.11(e), 2.11(f) and 2.11(g) show the daily variations of the PM concentrations of sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The figures show well understood trends of the particulate matter concentrations. $PM_{2.5}$ concentration also shows a good agreement with SPM and PM_{10} concentrations.

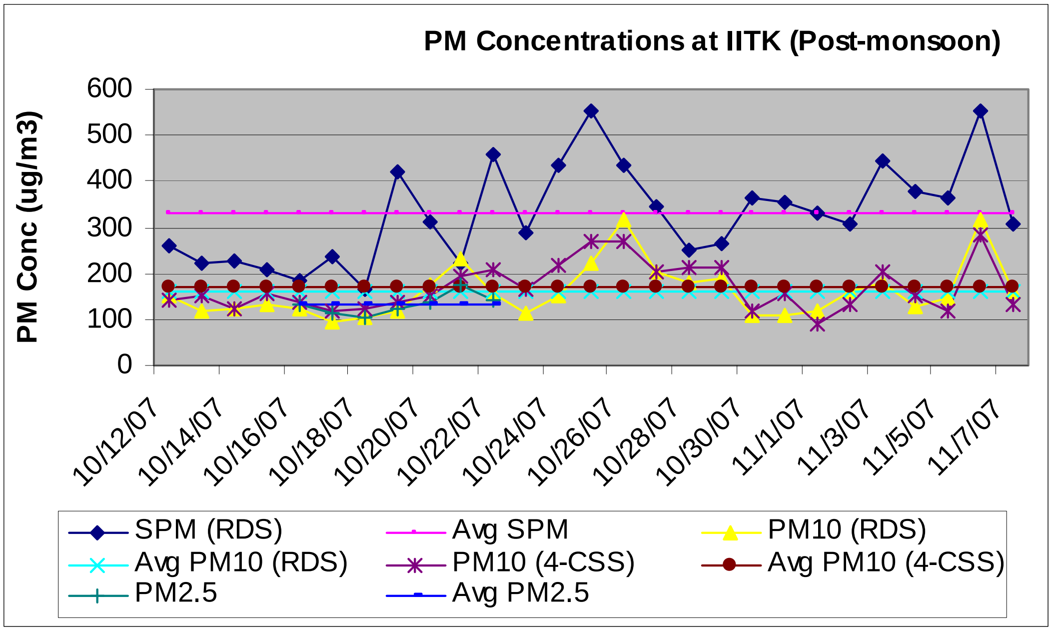


Figure 2.11(a): Observed PM Concentrations at IIT Kanpur Site for Post-monsoon Season

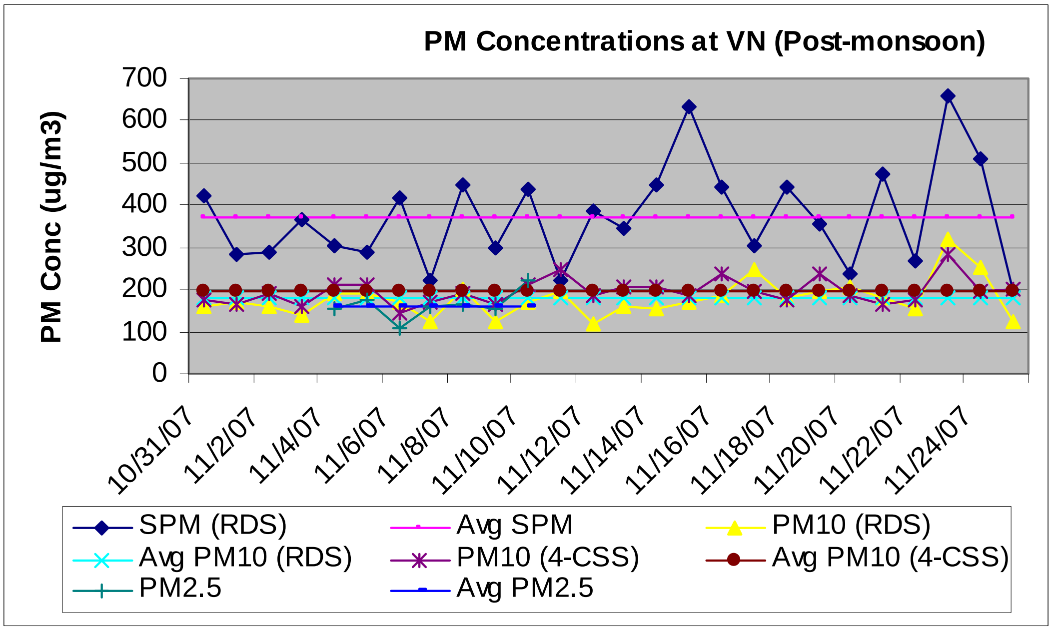


Figure 2.11(b): Observed PM Concentrations at Vikashnagar Site for Post-monsoon Season

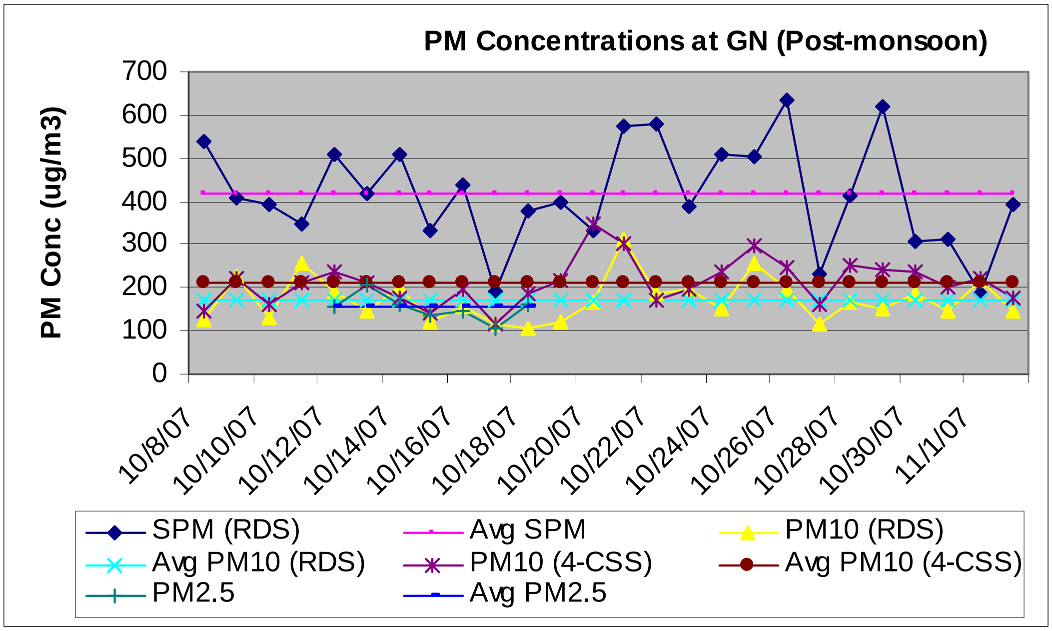


Figure 2.11(c): Observed PM Concentrations at Govindnagar Site for Post-monsoon Season

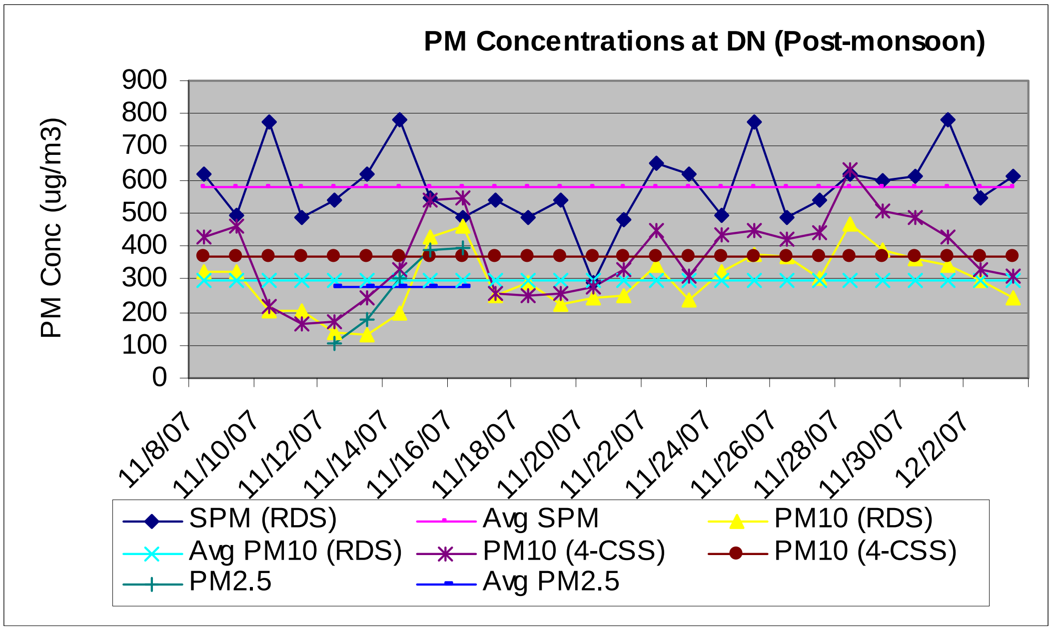


Figure 2.11(d): Observed PM Concentrations at Dadanagar Site for Post-monsoon Season

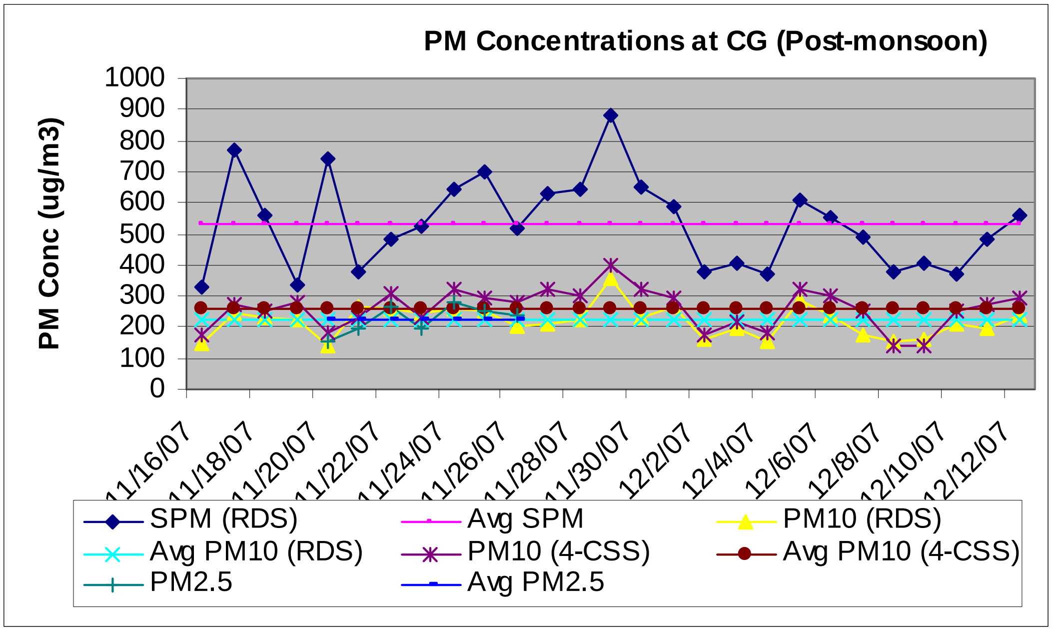


Figure 2.11(e): Observed PM Concentrations at Colonelganj Site for Post-monsoon Season

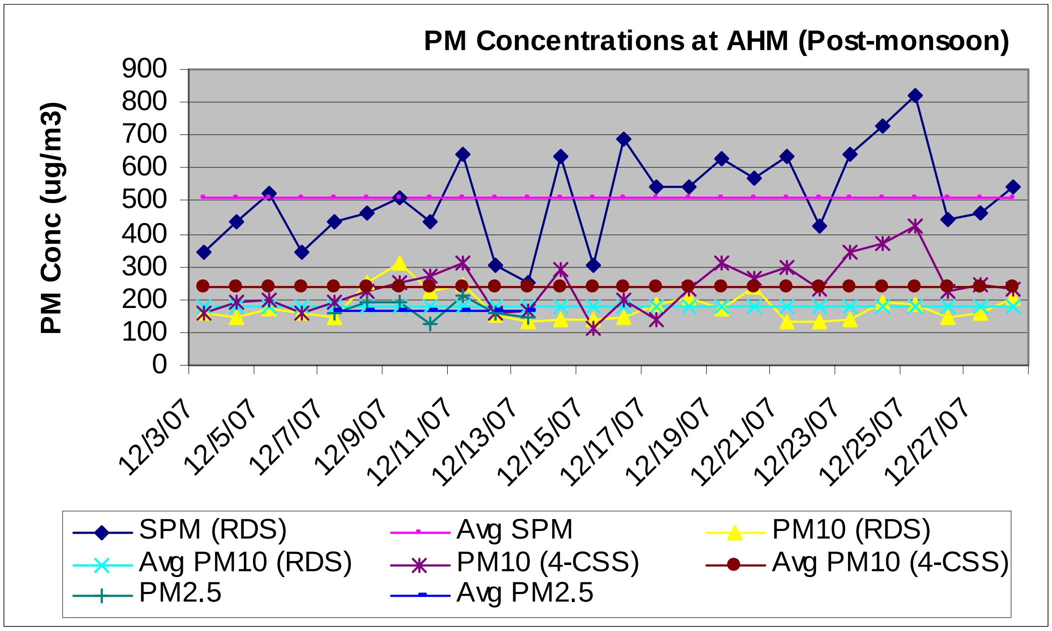


Figure 2.11(f): Observed PM Concentrations at AHM Site for Post-monsoon Season

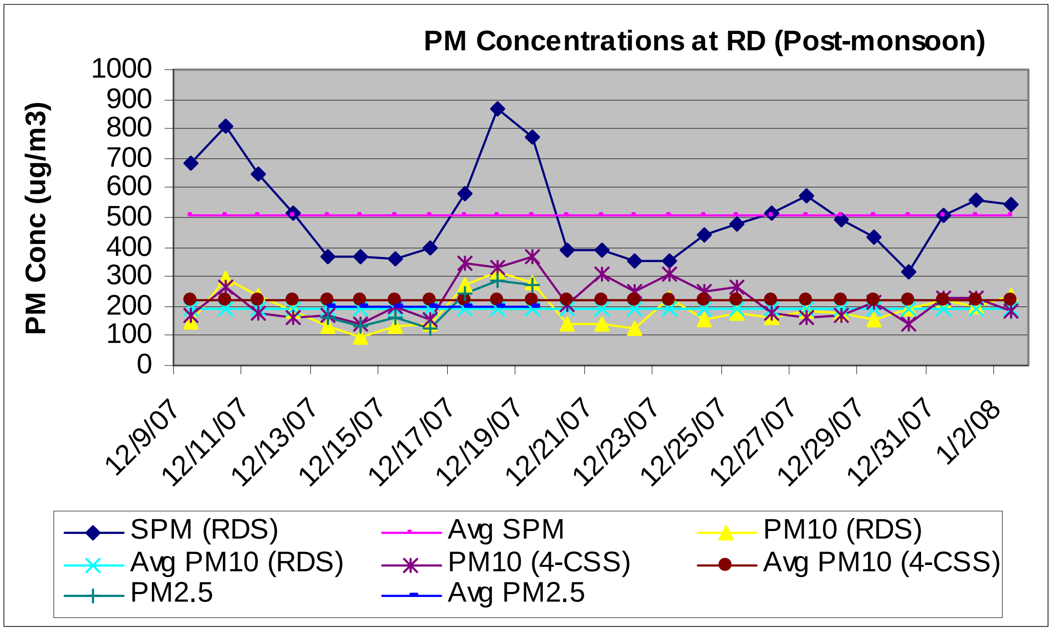


Figure 2.11(g): Observed PM Concentrations at Ramadevi Site for Post-monsoon Season

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

This section reveals the daily average concentrations of NO_2 and SO_2 observed in a graphical way for post-monsoon season. Figures 2.12(a), 2.12(b), 2.12(c), 2.12(d), 2.12(e), 2.12(f) and 2.12(g) show the daily variations of the SO_2 and NO_2 concentrations of sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. It can be concluded that low concentration of SO_2 was observed; may be due to introduction of low sulphur content in the diesel fuels; and NO_2 concentration is below the permissible limits.

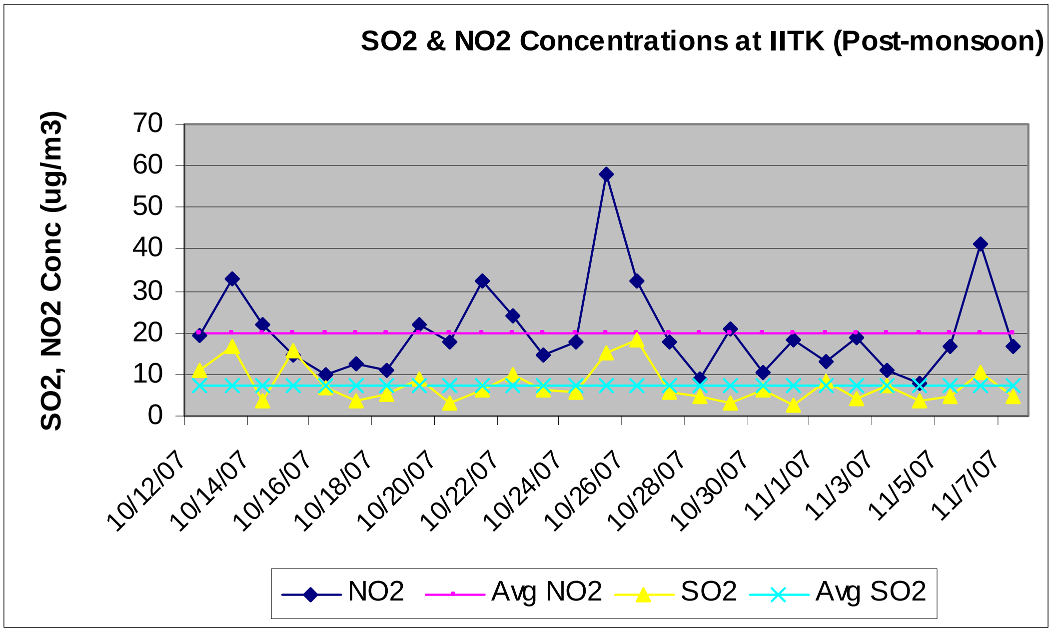


Figure 2.12(a): Observed SO_2 and NO_2 Concentrations at IIT Kanpur Site for Post-monsoon Season

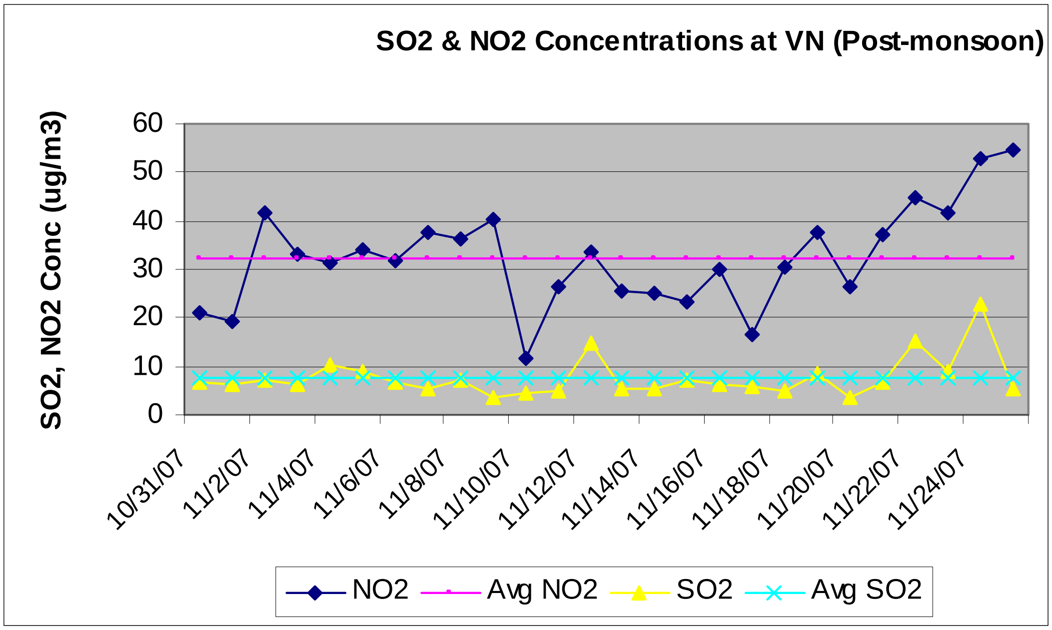


Figure 2.12(b): Observed SO_2 and NO_2 Concentrations at Vikashnagar Site Post-monsoon Season

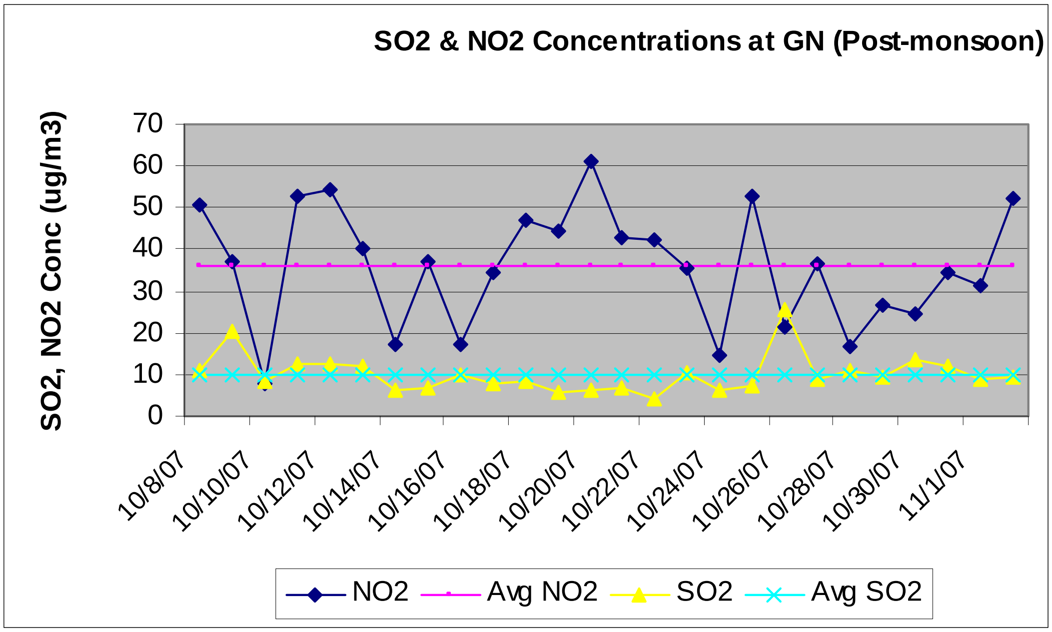


Figure 2.12(c): Observed SO_2 and NO_2 Concentrations at Govindnagar Site for Post-monsoon Season

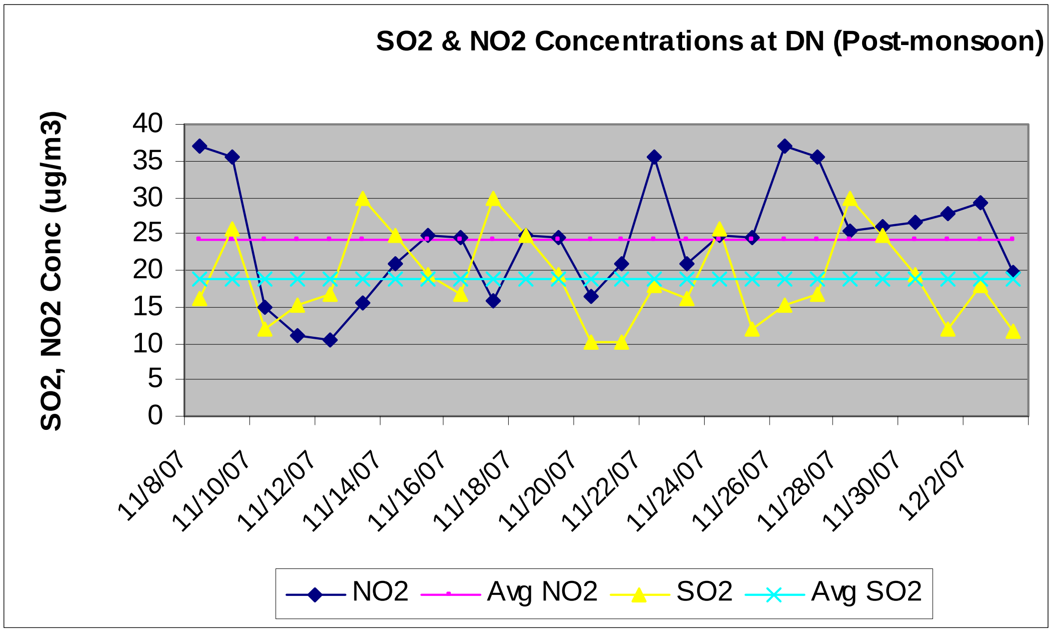


Figure 2.12(d): Observed SO_2 and NO_2 Concentrations at Dadanagar Site for Post-monsoon Season

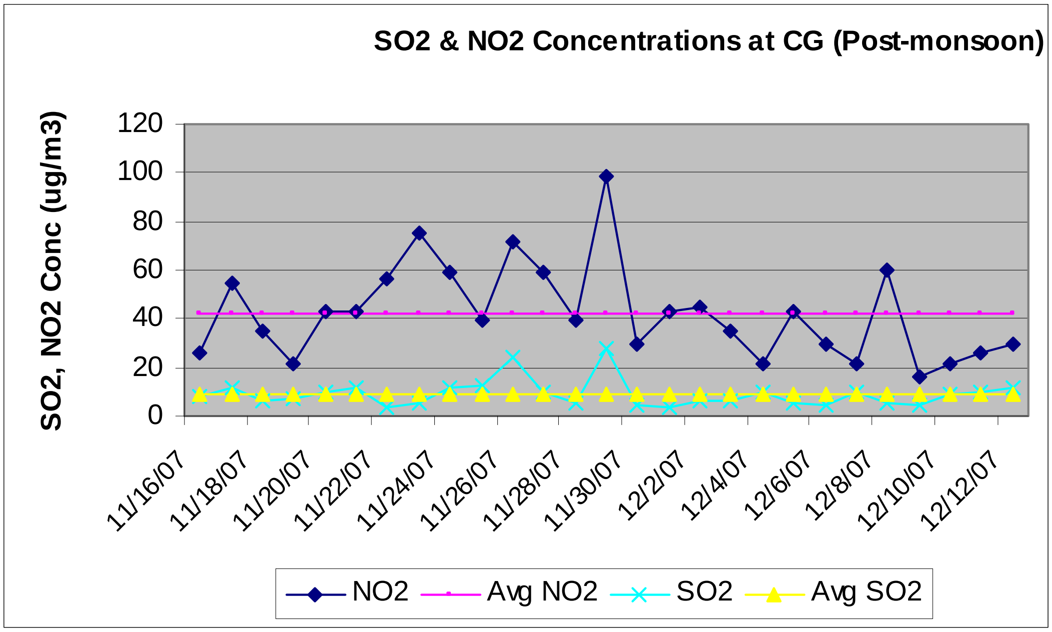


Figure 2.12(e): Observed SO_2 and NO_2 Concentrations at Colonelganj Site for Post-monsoon Season

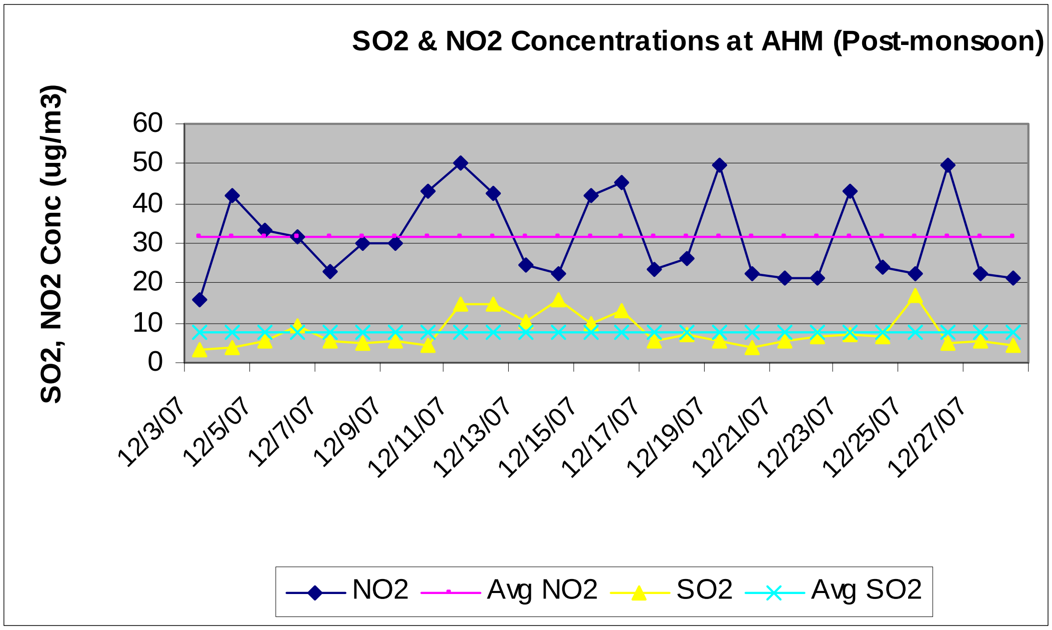


Figure 2.12(f): Observed SO_2 and NO_2 Concentrations at AHM Site for Post-monsoon Season

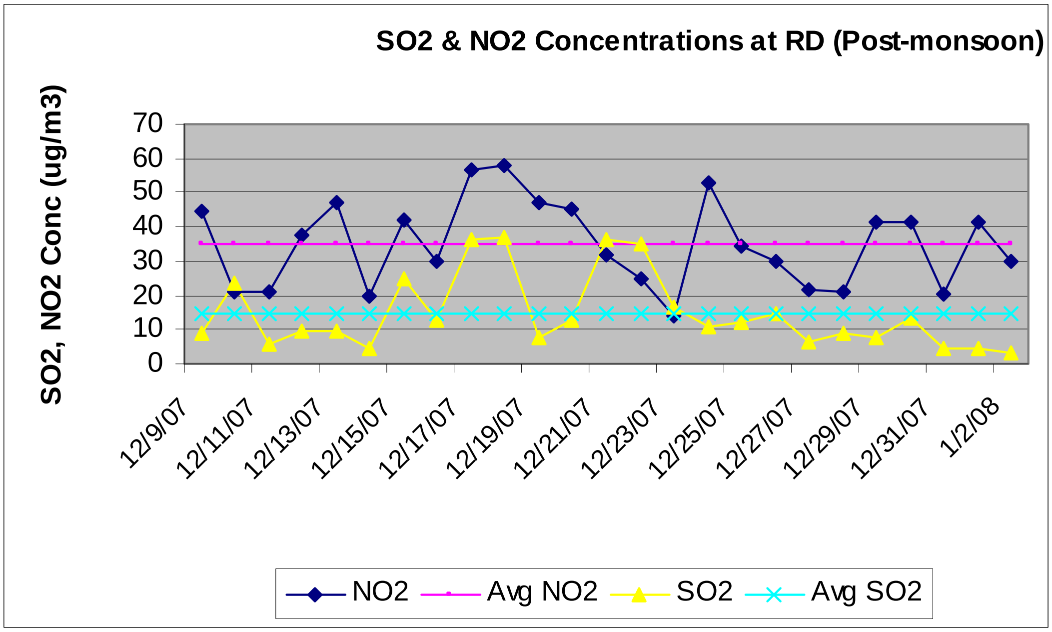


Figure 2.12(g): Observed SO_2 and NO_2 Concentrations at Ramadevi Site for Post-monsoon Season

2.4.2.3 Volatile Organic Compounds (VOCs) and Nonmethane Hydrocarbons (NMHC)

This section shows graphically the observed daily average concentrations of VOCs, NMHC along with benzene, toluene, ethyl benzene, m, p-xylene and o-xylene also for post-monsoon season. Figures 2.13(a), 2.13(b), 2.13(c), 2.13(d), 2.13(e), 2.13(f) and 2.13(g) show the variations of daily average concentrations of VOCs and NMHC for sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. It can be concluded that the dominant species of VOCs in Kanpur is toluene followed by benzene. The higher concentrations of VOCs are observed at sampling locations nearby traffic junctions and industrial activities.

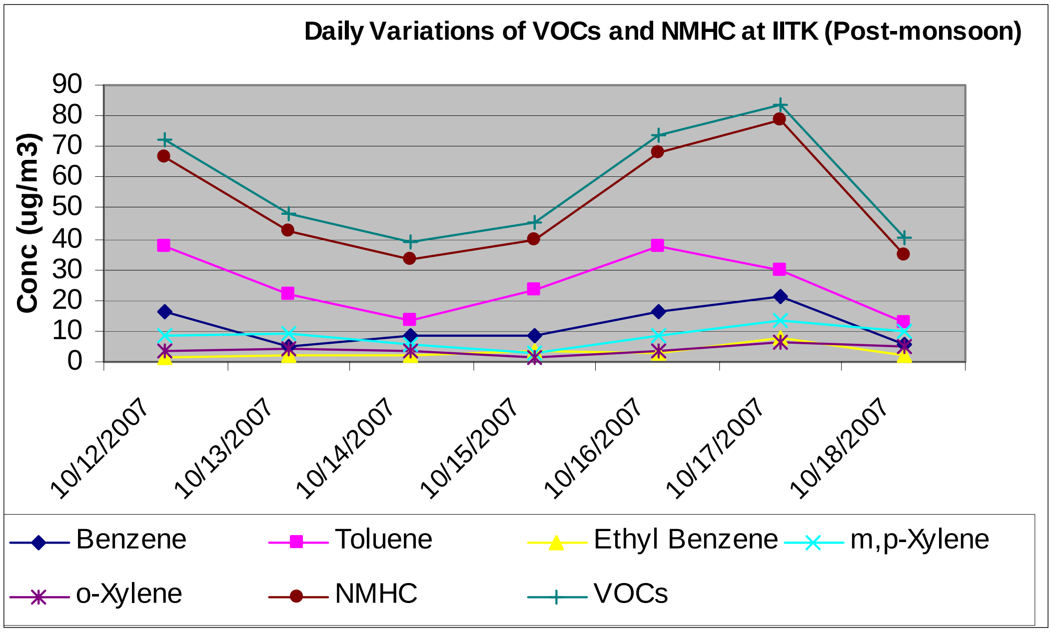


Figure 2.13(a): Observed VOC$_S$ and NMHC Concentrations at IIT Kanpur Site for Post-monsoon Season

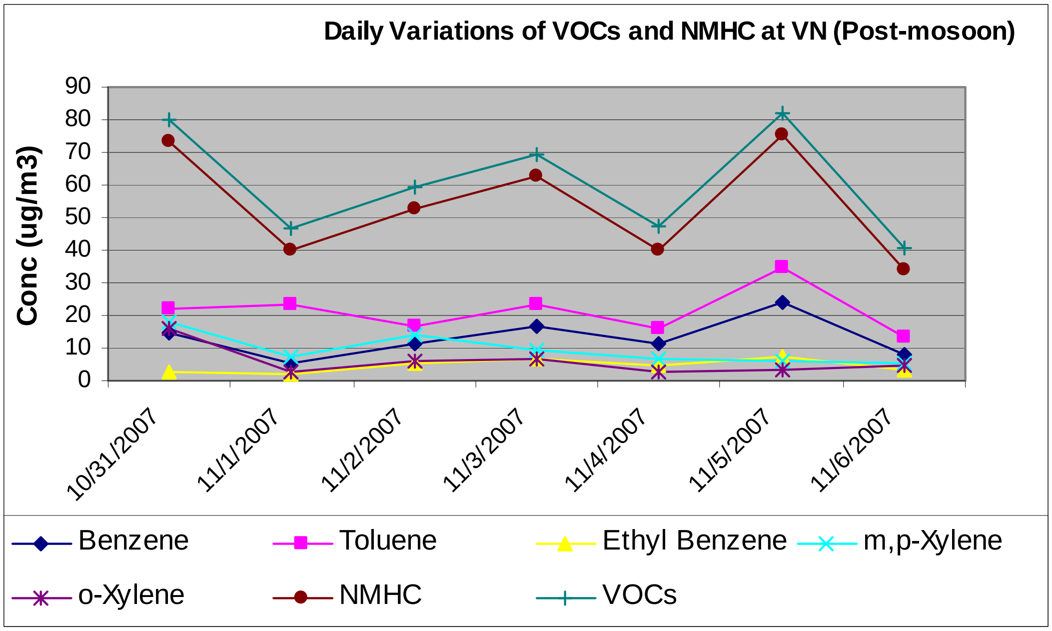


Figure 2.13(b): Observed VOC$_S$ and NMHC Concentrations at Vikashnagar Site for Post-monsoon Season

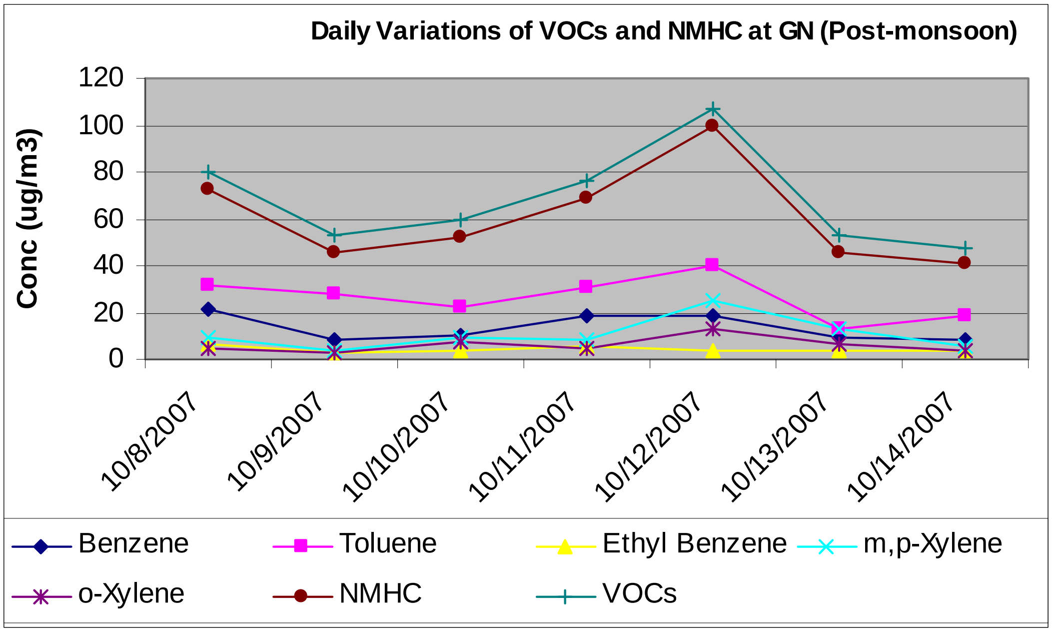


Figure 2.13(c): Observed VOC$_S$ and NMHC Concentrations at Govindnagar Site for Post-monsoon Season

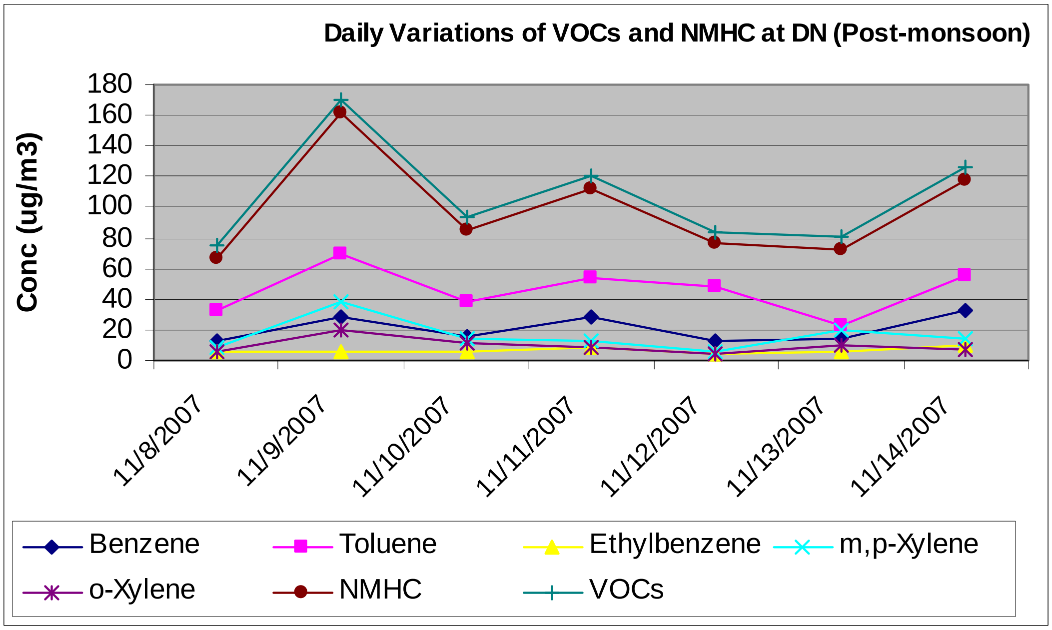


Figure 2.13(d): Observed VOC$_S$ and NMHC Concentrations Dadanagar Site for Post-monsoon Season

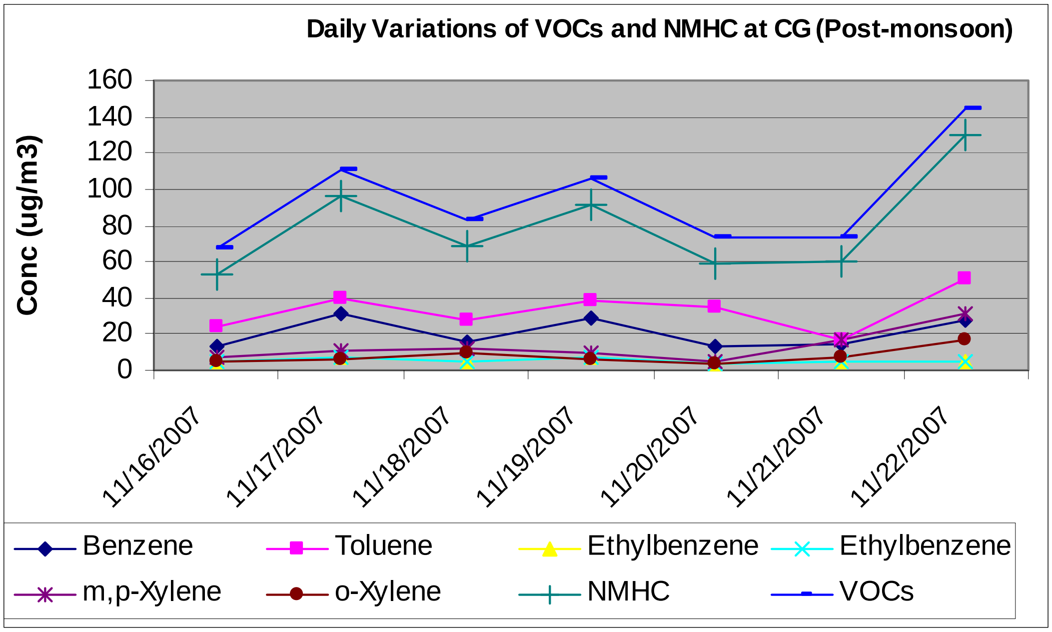


Figure 2.13(e): Observed VOC$_S$ and NMHC Concentrations at Colonelganj Site for Post-monsoon Season

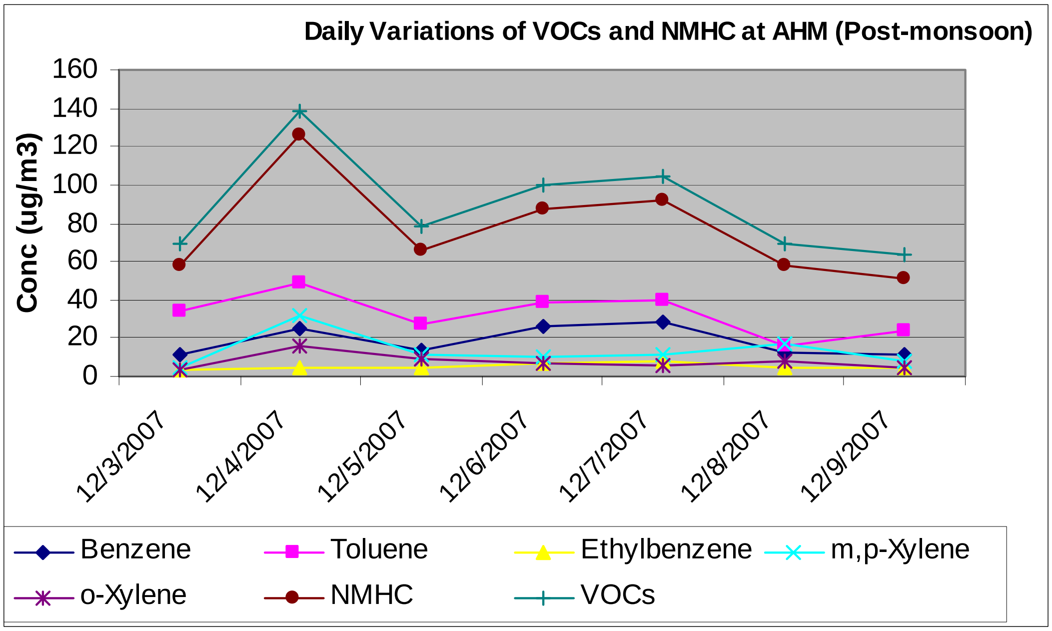


Figure 2.13(f): Observed VOC$_S$ and NMHC Concentrations at AHM Site for Post-monsoon Season

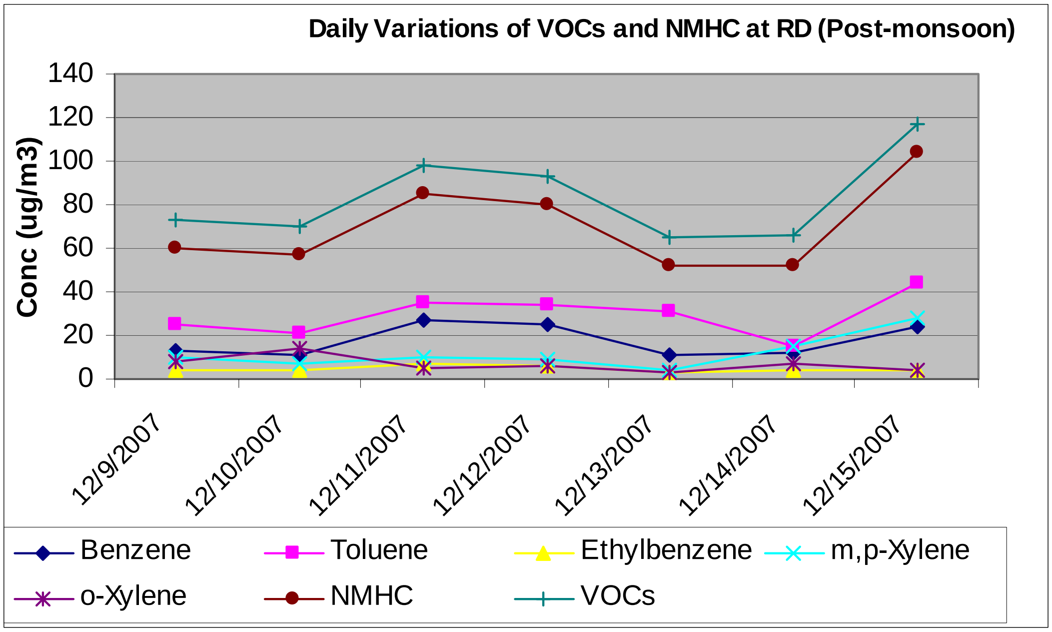


Figure 2.13(g): Observed VOC$_S$ and NMHC Concentrations at Ramadevi Site for Post-monsoon Season

2.4.2.4 Formaldehyde (HCHO)

This section shows the average concentrations of HCHO observed during different hours of the day for post-monsoon season. Figure 2.14 shows the observed concentration of the formaldehyde during different hours of the day for all sampling sites. From this figure it can be concluded that the maximum concentration is observed during the peak hours of the day. The maximum values are observed at sites nearby traffic junctions.

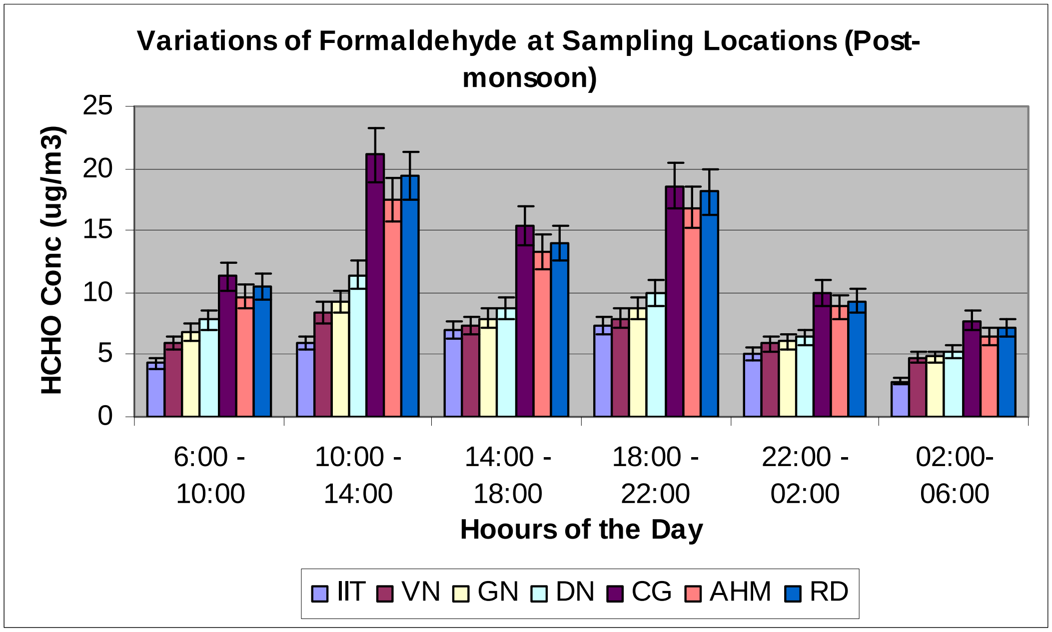


Figure 2.14: Observed HCHO Concentrations at all Sampling Sites for Post-monsoon Season

2.4.2.5 Carbon monoxide

This section presents the daily and hourly average concentrations CO observed at Colonelganj site (kerbside) for post-monsoon season. Figures 2.15(a) and 2.15(b) show the observed CO concentration on different day of the month and hours of the day respectively. From these figures it can be concluded that the maximum concentration is observed during the peak hours of the day (both in morning as well as evening).

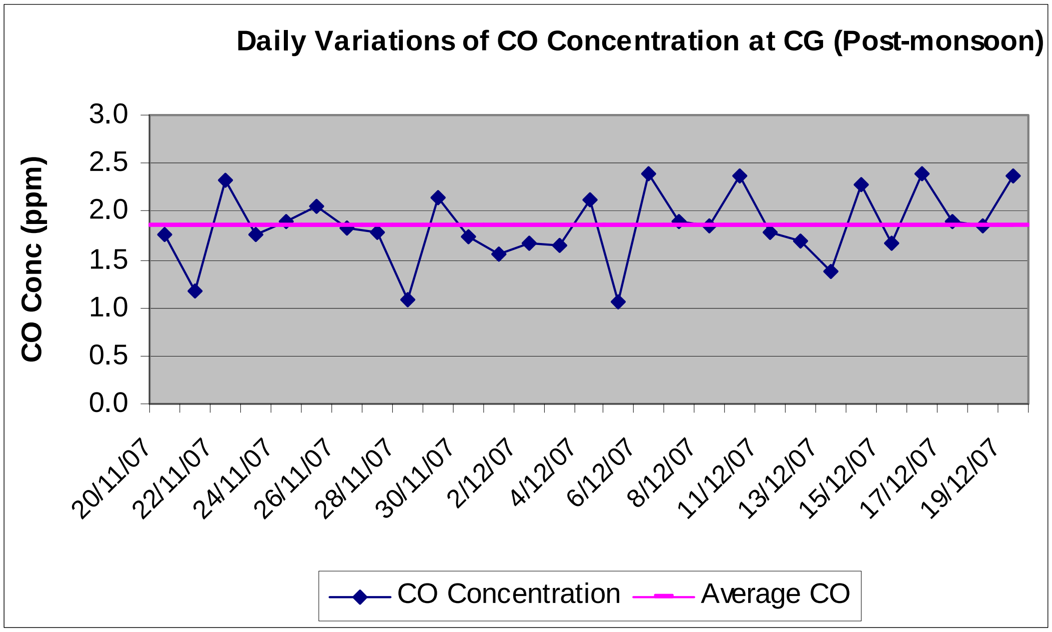


Figure 2.15(a): Observed CO Concentration (Daily Variations) at Colonelganj Site for Post-monsoon Season

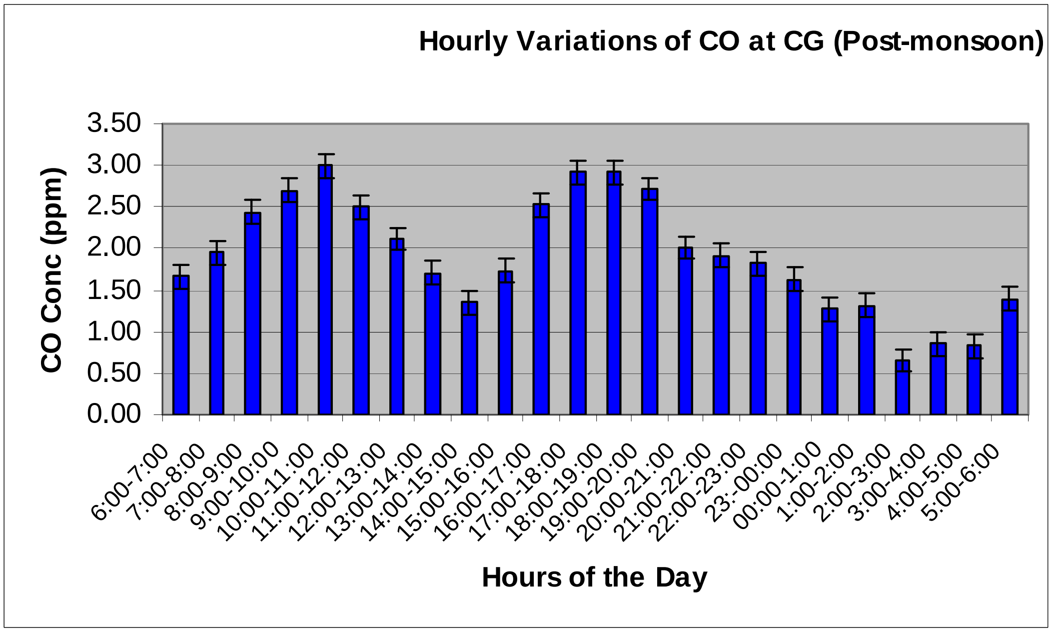


Figure 2.15(b): Observed CO Concentration (Hourly Variations) at Colonelganj Site for Post-monsoon Season

2.4.2.6 Polycyclic Aromatic Hydrocarbons (PAHs)

This section reveals the average concentrations of PAHs with some specific markers observed at all sampling locations of the city for post-monsoon season. Figure 2.16 shows the observed concentration of some markers of PAHs at all sampling locations. The compounds analyzed are fluorene, phenathrene, fluorathene, pyrene, benzo(a) anthracene, benzo(b) fluoranthene, benzo (a) pyrene, dibenzo(a,h) anthracene and benzo(ghi) perylene. From this figure it can be concluded that the maximum concentration is observed at Dadanagar site (industrial site) followed by Colonelganj and Ramadevi.

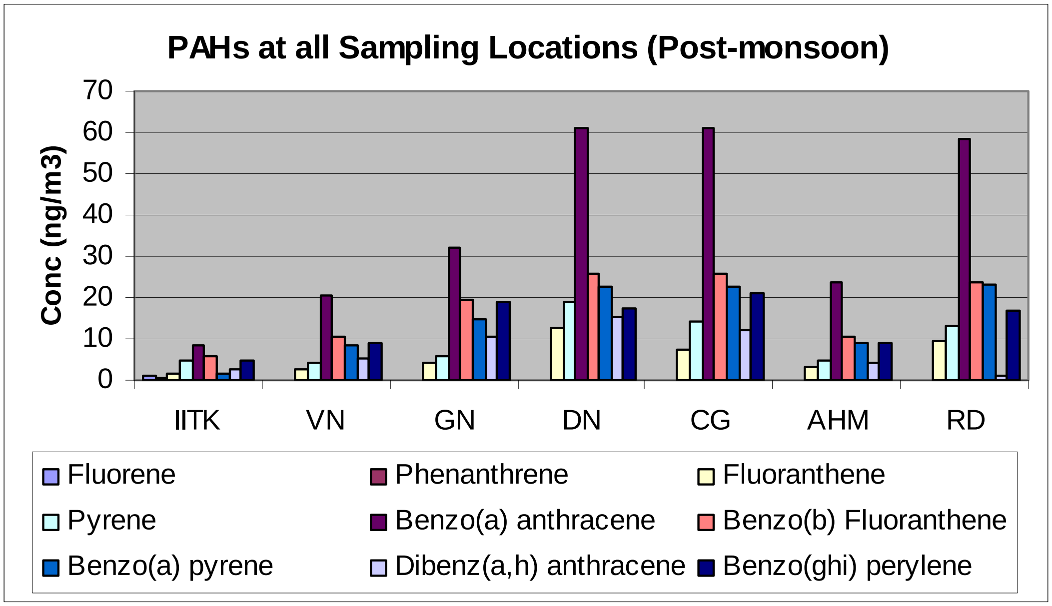


Figure 2.16: Observed PAHs Concentrations at all Sampling Sites for Post-monsoon Season

2.4.2.7 Brief Presentation of the Experimental Results and their Correlations (along with PM_{10} and $PM_{2.5}$Chemical Speciation)

A brief of the experimental results for all parameters during the post-monsoon season are presented statistically in tabular form in this section. Tables 2.12(a), 2.12(b), 2.12(c), 2.12(d), 2.12(e), 2.12(f) and 2.12(g) present the concentrations of SPM (from RDS), SPM (from HVS), PM_{10} (from RDS), PM_{10} (from 4-CSS), $PM_{2.5}$, NO_2, SO_2, OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Sn, Sb, Pb, P, S, Sc, Ti, Ga, Ge, Br, Rb, Sr, Y, Mo, Rh, Pd, Ag, Te, I, Cs, Ba, La, W, Au, benzene, toluene, ethyl benzene, m,p-xylene, o-xylene, VOCs and NMHC at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The results presented for elements, ions and carbon concentrations are from the PM_{10} chemical speciation. These tables contains the average, minimum, maximum, range, number of data points (24-hr average), range, 95% upper and lower confidence limits, standard deviation and coefficient of variance for all the parameters as mentioned above.

Tables 2.13(a), 2.13(b), 2.13(c), 2.13(d), 2.13(e), 2.13(f) and 2.13(g) present the correlation matrices among the four dust parameters, i.e. SPM, RSPM, PM_{10}, $PM_{2.5}$ at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during post-monsoon season. It can be concluded from these tables that PM_{10} is maintaining a good correlation with SPM and similar trend for $PM_{2.5}$ with PM_{10} for most of the cases.

Tables 2.14(a), 2.14(b), 2.14(c), 2.14(d), 2.14(e), 2.14(f) and 2.14(g) present the correlation matrices among the major species of PM_{10}, i.e. NH_4^+, NO_3^-, SO_4^{2-}, EC, OC, TC and with NO_2 and SO_2 at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during post-monsoon season. It can be concluded from these tables that NH_4^+ is maintaining a good correlation with NO_3^-, SO_4^{2-} and similar trend for EC with OC; and these species maintain a good correlation with PM_{10} overally. As SO_2 concentration is low for most of the sites, so it is difficult to draw any correlation of it with others. NO_2 is also maintaining a good correlation with NO_3^-.

A brief of the experimental results related to $PM_{2.5}$ chemical speciation of some major parameters are presented in Tables 2.15(a), 2.15(b), 2.15(c), 2.15(d), 2.15(e), 2.15(f) and 2.15(g) for the sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during post-monsoon season. The major species presented are OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. These tables contains the average, minimum, maximum, range, number of data points (24-hr average), range, 95% upper and lower confidence limits, standard deviation and coefficient for all the parameters as mentioned above.

Table 2.12(a): Experimental Results with PM$_{10}$ Chemical Speciation of IIT Kanpur Site for Post-monsoon Season

IITK Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	329.3	359.4	160.5	169.5	132.1	20.1	7.5	1.58	5.79	9.57	6.36	5.47	11.18	0.87	0.38	28.76	12.4	41.2	6.14	3.94	5.92	2.22	11.3	3.7	6.38	24.4	0.19	4.53	0.016	0.013	0.14	0.46
Minimum	164.1	202.1	92.7	91.5	104.4	7.9	2.8	0.45	2.07	3.21	2.01	1.67	3.36	0.34	0	9.43	3.82	13.3	2.42	1.5	4.04	0.5	3.24	2.08	0.55	8.02	0.07	0.96	0.002	0.003	0.04	0.16
Maximum	554.9	687.3	317.5	284.6	173.7	58.0	18.5	6.49	15.2	31.2	18.7	14	31.52	4.79	5.25	70.85	34.7	105	8.88	5.63	7.88	3.05	18.5	7.56	11.1	44.2	0.39	11.8	0.028	0.038	0.32	0.79
Range	390.8	485.2	224.7	193.1	69.2	50.0	15.7	6.04	13.1	28	16.7	12.4	28.16	4.45	5.25	61.42	30.9	92.1	6.46	4.13	3.84	2.55	15.2	5.49	10.5	36.2	0.32	10.9	0.026	0.035	0.27	0.63
N of cases	27.0	27.0	27.0	27.0	7.0	27.0	27.0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
95% CI Upper	371.1	403.8	183.3	189.8	153.3	24.5	9.2	2.05	6.79	11.9	7.72	6.69	13.38	1.21	0.77	34.36	15.1	49.4	6.99	4.37	6.37	2.54	13.1	4.59	7.87	29	0.22	5.67	0.018	0.016	0.17	0.53
95% CI Lower	287.4	315.0	137.6	149.1	110.9	15.7	5.7	1.11	4.79	7.29	5	4.25	8.975	0.53	-0	23.16	9.76	33	5.29	3.5	5.46	1.91	9.53	2.82	4.88	19.7	0.16	3.39	0.013	0.009	0.12	0.4
Standard Dev	105.8	112.3	57.7	51.4	23.0	11.1	4.4	1.19	2.53	5.78	3.44	3.08	5.562	0.85	0.99	14.15	6.74	20.8	2.15	1.1	1.14	0.8	4.55	2.24	3.78	11.9	0.08	2.87	0.007	0.009	0.06	0.16
C.V.	0.32	0.31	0.36	0.30	0.17	0.56	0.59	0.75	0.44	0.60	0.54	0.56	0.50	0.98	2.61	0.49	0.54	0.51	0.35	0.28	0.19	0.36	0.40	0.61	0.59	0.49	0.44	0.63	0.44	0.70	0.42	0.35

IITK Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzene	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.009	0.016	0.026	0.443	0.059	0.006	0.02	0.103	0.104	0.724	0.011	5.794	0.009	0.046	0.114	0.002	0.038	0.016	0.054	0.05	0.009	0.066	0.01	0.037	0.005	0.029	0.044	0.145	0.045	0.04	0.007	11.537	25.16	3.164	8.209	3.983	52.1	57.46
Minimum	0.002	0.005	0.008	0.13	0.002	0.003	0.007	0.005	0.002	0.039	0.011	2.564	0.009	0.019	0.003	0.001	0.004	0.006	0.008	0.011	0.008	0.02	0.005	0.005	0.004	0.01	0.002	0.04	0.012	0.013	0.002	4.889	12.706	1.739	2.821	1.647	33.4	38.8
Maximum	0.028	0.058	0.075	0.99	0.358	0.017	0.108	0.87	0.784	1.48	0.012	12.07	0.01	0.089	0.843	0.002	0.106	0.033	0.247	0.157	0.014	0.393	0.024	0.301	0.007	0.113	0.07	0.751	0.104	0.101	0.013	20.938	37.337	7.616	13.319	6.713	78.4	83.84
Range	0.026	0.053	0.067	0.86	0.356	0.014	0.101	0.865	0.782	1.441	0.001	9.509	0.001	0.07	0.84	0.001	0.102	0.027	0.239	0.146	0.006	0.373	0.019	0.296	0.003	0.103	0.068	0.711	0.092	0.088	0.011	16.05	24.631	5.878	10.498	5.066	45	45.05
N of cases	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	7	7	7	7	7	7	7
95% CI Upper	0.012	0.021	0.032	0.533	0.093	0.007	0.029	0.179	0.178	0.903	0.011	6.776	0.009	0.053	0.182	0.002	0.048	0.019	0.076	0.066	0.01	0.093	0.013	0.058	0.006	0.039	0.055	0.201	0.061	0.051	0.009	5.818	15.752	1.258	5.196	2.509	34.9	40.29
95% CI Lower	0.007	0.01	0.019	0.353	0.025	0.005	0.011	0.026	0.031	0.544	0.011	4.812	0.009	0.039	0.046	0.001	0.028	0.013	0.032	0.035	0.009	0.039	0.007	0.015	0.005	0.019	0.033	0.089	0.03	0.029	0.005	17.256	34.568	5.07	11.221	5.456	69.2	74.62
Standard Dev	0.006	0.014	0.017	0.228	0.086	0.003	0.022	0.194	0.186	0.454	0	2.482	0	0.018	0.172	0.001	0.025	0.008	0.056	0.039	0.002	0.069	0.007	0.055	0.001	0.026	0.028	0.141	0.039	0.028	0.005	6.184	10.173	2.061	3.257	1.593	18.6	18.56
C.V.	0.66	0.87	0.66	0.51	1.47	0.55	1.12	1.89	1.79	0.63	0.04	0.43	0.05	0.39	1.51	0.34	0.67	0.47	1.04	0.78	0.24	1.04	0.76	1.51	0.19	0.90	0.64	0.97	0.86	0.68	0.70	0.54	0.40	0.65	0.40	0.40	0.36	0.32

Table 2.12(b): Experimental Results with PM$_{10}$ Chemical Speciation of Vikashnagar Site for Post-monsoon Season

VN Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	372.6	392.4	178.4	194.9	161.4	32.4	7.7	4.36	9.87	12.1	7.47	9.52	14.48	0.45	0.19	43.34	15.1	58.5	5.99	4.81	7.15	3.27	13.9	2.6	8.49	32.2	0.17	15.5	0.034	0.025	0.33	0.5
Minimum	196.7	231.2	119.9	143.2	106.4	11.5	3.5	0.94	4.8	6.99	4.76	3.11	6.73	0.27	0.09	21.45	7.27	29.1	0.87	3.17	3.21	0.16	7.05	1.36	0.9	14.1	0	4.49	0.01	0.007	0.13	0.04
Maximum	657.0	680.0	319.8	283.3	221.0	54.5	22.9	13.8	21.7	21.8	11.1	23.5	32.45	0.75	0.37	89.01	33.6	121	15.8	6.03	10.1	3.94	19.4	3.84	17.3	40.4	0.31	58.5	0.069	0.054	0.53	0.98
Range	460.4	448.8	199.9	140.1	114.7	43.0	19.4	12.9	16.9	14.8	6.34	20.4	25.72	0.48	0.28	67.56	26.3	92.3	14.9	2.86	6.86	3.78	12.4	2.49	16.4	26.3	0.31	54	0.059	0.047	0.4	0.95
N of cases	26.0	26.0	26.0	26.0	7.0	26.0	26.0	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
95% CI Upper	420.5	442.1	196.4	207.2	192.7	36.6	9.4	5.71	11.6	13.6	8.2	11.8	17.17	0.5	0.21	50.74	17.9	68.6	8.32	5.31	8.08	3.7	15	3	10.3	35.1	0.21	20.9	0.04	0.029	0.37	0.63
95% CI Lower	324.6	342.6	160.4	182.5	130.2	28.3	6.0	3.01	8.12	10.6	6.74	7.29	11.8	0.4	0.16	35.95	12.4	48.3	3.66	4.31	6.22	2.84	12.7	2.2	6.68	29.3	0.14	10.1	0.029	0.021	0.29	0.37
Standard Dev	118.7	123.2	44.5	30.5	33.8	10.3	4.2	3.35	4.34	3.79	1.8	5.52	6.647	0.12	0.06	18.31	6.79	25.1	5.77	1.24	2.3	1.06	2.88	1	4.49	7.18	0.09	13.3	0.014	0.011	0.09	0.31
C.V.	0.32	0.31	0.25	0.16	0.21	0.32	0.54	0.77	0.44	0.31	0.24	0.58	0.46	0.27	0.33	0.42	0.45	0.43	0.96	0.26	0.32	0.32	0.21	0.39	0.53	0.22	0.53	0.86	0.42	0.42	0.29	0.62

VN Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzene	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.027	0.017	0.06	0.544	0.062	0.009	0.054	0.134	0.146	0.875	0.011	7.273	0.009	0.129	0.122	0.002	0.047	0.053	0.099	0.05	0.009	0.061	0.013	0.039	0.006	0.035	0.069	0.42	0.056	0.061	0.008	12.967	21.226	4.598	9.393	5.915	54.1	60.8
Minimum	0.007	0.008	0.022	0.101	0.004	0.003	0.044	0.031	0.106	0.011	0.011	3.197	0.009	0.055	0.022	0.001	0.012	0.011	0.051	0.015	0.008	0.035	0.005	0.026	0.004	0.01	0.06	0.022	0.012	0.013	0.002	5.108	13.214	2.218	5.188	2.566	33.9	40.64
Maximum	0.056	0.026	0.121	0.88	0.343	0.018	0.16	0.422	0.626	1.974	0.012	11.99	0.01	0.2	0.392	0.003	0.084	0.085	0.203	0.244	0.014	0.084	0.024	0.077	0.007	0.113	0.121	0.942	0.104	0.15	0.013	23.993	34.871	7.502	17.959	16.274	75.3	82.02
Range	0.049	0.018	0.099	0.779	0.339	0.015	0.116	0.391	0.52	1.963	0.001	8.794	0.001	0.145	0.37	0.002	0.072	0.074	0.152	0.229	0.006	0.049	0.019	0.051	0.003	0.103	0.061	0.92	0.092	0.137	0.011	18.885	21.658	5.284	12.77	13.709	41.4	41.38
N of cases	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	7	7	7	7	7	7	7
95% CI Upper	0.032	0.019	0.068	0.626	0.09	0.01	0.065	0.195	0.195	1.123	0.012	8.135	0.009	0.143	0.157	0.002	0.055	0.06	0.116	0.069	0.01	0.069	0.016	0.043	0.006	0.045	0.074	0.514	0.072	0.074	0.01	7.228	14.553	2.735	4.987	1.45	38.6	45.26
95% CI Lower	0.023	0.015	0.052	0.463	0.033	0.007	0.043	0.073	0.096	0.627	0.011	6.412	0.009	0.115	0.087	0.001	0.04	0.045	0.082	0.031	0.008	0.053	0.009	0.034	0.005	0.024	0.064	0.325	0.04	0.049	0.006	18.706	27.899	6.462	13.8	10.38	69.6	76.33
Standard Dev	0.011	0.005	0.021	0.201	0.07	0.004	0.027	0.151	0.122	0.613	0.001	2.134	0	0.035	0.086	0.001	0.019	0.018	0.042	0.046	0.002	0.02	0.008	0.011	0.001	0.026	0.013	0.233	0.041	0.031	0.005	6.206	7.215	2.015	4.764	4.828	16.8	16.8
C.V.	0.42	0.29	0.35	0.37	1.14	0.48	0.51	1.12	0.84	0.70	0.04	0.29	0.05	0.27	0.71	0.45	0.40	0.34	0.43	0.92	0.23	0.33	0.64	0.28	0.21	0.75	0.20	0.56	0.72	0.50	0.66	0.48	0.34	0.44	0.51	0.82	0.31	0.28

Table 2.12(c): Experimental Results with PM_{10} Chemical Speciation of Govindnagar Site for Post-monsoon Season

GN Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	416.6	453.8	172.9	212.0	153.7	36.0	10.1	4.02	10.7	12.9	8.34	9.15	17.59	0.64	0.38	45.07	18.6	63.7	6.44	4.45	8.02	3.05	17.4	3.3	16.8	33.5	0.35	8.73	0.044	0.053	0.46	0.63
Minimum	185.1	191.0	106.3	114.3	108.0	7.9	4.3	0.27	1.38	1.97	1.05	0.83	2.51	0.25	0.05	5.66	2.8	8.46	2.37	2.73	1.62	0.75	5.79	0.93	4.21	15.4	0.06	0	0.004	0.009	0.08	0.13
Maximum	636.5	733.6	314.2	346.4	204.5	61.0	25.6	19.1	40.1	38	18.8	39.1	70.82	1.38	1.99	155.2	72.9	228	19.8	8.31	17.2	6	23.3	10.6	33.1	64.3	1.08	21.3	0.271	0.115	1.13	0.98
Range	451.4	542.6	207.8	232.1	96.6	53.1	21.2	18.9	38.7	36.1	17.8	38.3	68.31	1.13	1.94	149.5	70.1	220	17.4	5.58	15.6	5.25	17.5	9.67	28.8	49	1.02	21.3	0.267	0.106	1.06	0.85
N of cases	26.0	26.0	26.0	26.0	7.0	26.0	26.0	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
95% CI Upper	465.9	501.7	193.7	233.1	180.8	41.7	11.9	5.75	14.1	16.1	9.96	13.1	23.27	0.76	0.53	58.47	24.4	82.4	8.45	5.03	10.1	3.91	19.1	4.62	19.9	40.3	0.44	11	0.065	0.064	0.57	0.74
95% CI Lower	367.3	405.8	152.1	190.8	126.6	30.2	8.2	2.3	7.3	9.61	6.71	5.22	11.91	0.53	0.22	31.66	12.8	44.9	4.42	3.88	5.97	2.18	15.8	1.98	13.6	26.6	0.27	6.46	0.024	0.041	0.34	0.52
Standard Dev	122.1	118.7	51.4	52.4	29.3	14.2	4.5	4.27	8.37	8.09	4.03	9.73	14.06	0.29	0.38	33.18	14.4	46.4	4.98	1.42	5.08	2.15	4.04	3.26	7.75	17	0.22	5.63	0.051	0.028	0.29	0.27
C.V.	0.29	0.26	0.30	0.25	0.19	0.40	0.45	1.06	0.78	0.63	0.48	1.06	0.80	0.45	1.02	0.74	0.78	0.73	0.77	0.32	0.63	0.70	0.23	0.99	0.46	0.51	0.62	0.65	1.16	0.54	0.65	0.44

GN Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzene	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.029	0.028	0.094	0.471	0.261	0.009	0.123	0.307	0.182	0.671	0.016	6.548	0.009	0.123	0.178	0.002	0.063	0.034	0.089	0.134	0.011	0.066	0.013	0.044	0.006	0.035	0.073	0.308	0.08	0.077	0.009	13.555	26.323	4.193	10.643	6	60.7	67.98
Minimum	0.005	0.005	0.015	0.075	0.002	0.004	0.063	0.056	0.027	0.005	0.011	2.024	0.009	0.025	0.03	0.001	0.013	0.008	0.028	0.012	0.008	0.033	0.005	0.026	0.004	0.01	0.06	0.06	0.012	0.013	0.002	8.594	13.231	3.024	3.567	2.577	40.5	47.78
Maximum	0.092	0.064	0.303	0.985	0.942	0.022	0.369	0.945	0.469	1.295	0.045	11.83	0.01	0.409	0.866	0.003	0.141	0.084	0.27	0.63	0.029	0.111	0.024	0.089	0.007	0.113	0.186	0.907	0.125	0.15	0.014	20.994	39.63	6.157	25.198	12.908	99.8	107
Range	0.087	0.059	0.288	0.91	0.94	0.018	0.306	0.889	0.442	1.29	0.034	9.802	0.001	0.384	0.836	0.002	0.128	0.076	0.242	0.618	0.021	0.078	0.019	0.063	0.003	0.103	0.126	0.847	0.113	0.137	0.012	12.401	26.399	3.133	21.631	10.331	59.3	59.25
N of cases	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	7	7	7	7	7	7	7
95% CI Upper	0.037	0.035	0.121	0.582	0.379	0.011	0.154	0.43	0.236	0.835	0.022	7.676	0.009	0.154	0.253	0.002	0.082	0.042	0.112	0.196	0.013	0.077	0.017	0.052	0.006	0.045	0.084	0.389	0.097	0.092	0.011	8.361	18.106	3.082	4.078	2.826	41.2	48.5
95% CI Lower	0.021	0.021	0.067	0.359	0.144	0.008	0.093	0.184	0.128	0.507	0.011	5.42	0.009	0.093	0.103	0.002	0.044	0.026	0.067	0.072	0.009	0.056	0.01	0.037	0.005	0.024	0.062	0.228	0.063	0.062	0.007	18.748	34.539	5.303	17.209	9.173	80.2	87.46
Standard Dev	0.019	0.017	0.066	0.277	0.291	0.004	0.076	0.305	0.134	0.406	0.012	2.793	0	0.076	0.185	0.001	0.047	0.02	0.056	0.152	0.005	0.026	0.008	0.019	0.001	0.026	0.026	0.199	0.043	0.037	0.005	5.616	8.884	1.201	7.099	3.432	21.1	21.07
C.V.	0.67	0.60	0.70	0.59	1.11	0.47	0.62	1.00	0.74	0.61	0.75	0.43	0.05	0.62	1.04	0.45	0.75	0.60	0.63	1.14	0.40	0.39	0.61	0.42	0.22	0.75	0.36	0.65	0.54	0.49	0.56	0.41	0.34	0.29	0.67	0.57	0.35	0.31

Table 2.12(d): Experimental Results with PM_{10} Chemical Speciation of Dadanagar Site for Post-monsoon Season

DN Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	576.5	612.9	295.9	370.8	272.8	24.2	18.8	5.03	23.3	26	25.1	9.41	19.41	8.56	5.42	88.83	33.4	122	10.9	6.49	13.8	2.7	24	8.72	37.1	51.8	0.33	3.87	0.089	0.176	0.39	0.52
Minimum	288.5	433.7	131.7	167.4	103.3	10.5	10.1	1.88	3.11	1.54	1.17	0.87	5.35	0.21	0.05	14.05	6.56	20.9	2.27	1.35	0.36	0.26	14.6	1.5	9.33	20.7	0.01	0.13	0.013	0.024	0.03	0.02
Maximum	782.4	834.3	467.7	629.2	391.3	37.0	29.8	11.1	84.5	79	64.1	24.6	33.61	22.9	31.8	208.2	62.1	270	26	14.9	35.1	4.82	33	28.8	58.9	63.6	0.69	9.51	0.505	0.59	0.95	0.93
Range	493.9	400.5	336.0	461.7	288.0	26.4	19.7	9.22	81.4	77.5	62.9	23.7	28.26	22.7	31.7	194.1	55.5	249	23.7	13.6	34.8	4.56	18.3	27.3	49.5	43	0.68	9.38	0.492	0.566	0.93	0.91
N of cases	26.0	26.0	26.0	26.0	5.0	26.0	26.0	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
95% CI Upper	622.8	662.9	332.3	420.7	432.4	27.3	21.3	6.1	31.2	36.2	32.6	11.9	22.49	11.2	8.04	109.2	39.6	147	14.6	8.37	18.1	3.35	26.3	12.8	44.5	56.8	0.41	4.76	0.127	0.227	0.49	0.63
95% CI Lower	530.2	562.8	259.5	321.0	113.2	21.1	16.3	3.97	15.4	15.9	17.5	6.91	16.34	5.91	2.8	68.5	27.2	97	7.23	4.61	9.43	2.05	21.8	4.63	29.6	46.7	0.24	2.98	0.052	0.126	0.28	0.42
Standard Dev	114.6	123.8	90.1	123.4	128.5	7.7	6.2	2.64	19.5	25.2	18.7	6.21	7.62	6.57	6.49	50.32	15.3	62.5	9.18	4.65	10.8	1.62	5.63	10.1	18.4	12.5	0.22	2.19	0.093	0.126	0.26	0.25
C.V.	0.20	0.20	0.31	0.33	0.47	0.32	0.33	0.52	0.84	0.97	0.75	0.66	0.39	0.77	1.20	0.57	0.46	0.51	0.84	0.72	0.78	0.60	0.23	1.16	0.50	0.24	0.67	0.57	1.04	0.71	0.67	0.48

DN Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.061	0.049	0.191	0.553	0.435	0.014	0.268	0.451	0.554	1.35	0.011	7.365	0.009	0.311	0.257	0.004	0.072	0.06	0.112	0.229	0.011	0.079	0.031	0.064	0.007	0.045	0.105	0.55	0.129	0.156	0.013	20.702	46.232	6.404	16.256	9.163	98.8	107
Minimum	0.009	0.013	0.05	0.082	0.018	0.003	0.064	0.064	0.053	0.078	0.011	0.358	0.009	0.009	0.007	0.001	0.011	0.018	0.033	0.014	0.008	0.035	0.005	0.03	0.004	0.01	0.06	0.182	0.012	0.042	0.002	13.125	23.239	4.618	5.447	3.936	66.2	74.46
Maximum	0.121	0.197	0.393	0.996	0.942	0.04	0.896	0.984	0.964	3.183	0.012	21.15	0.01	0.742	0.532	0.006	0.482	0.129	0.196	0.631	0.026	0.354	0.105	0.232	0.01	0.113	0.272	0.861	0.198	0.292	0.024	32.064	69.605	9.404	38.484	19.715	161	169.7
Range	0.112	0.184	0.343	0.914	0.924	0.037	0.832	0.92	0.911	3.105	0.001	20.8	0.001	0.733	0.525	0.005	0.471	0.111	0.163	0.617	0.018	0.319	0.1	0.202	0.006	0.103	0.212	0.679	0.186	0.25	0.022	18.94	46.366	4.786	33.037	15.778	95.2	95.24
N of cases	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	7	7	7	7	7	7	7
95% CI Upper	0.074	0.063	0.226	0.672	0.557	0.019	0.357	0.573	0.679	1.721	0.012	9.317	0.009	0.388	0.329	0.005	0.111	0.07	0.128	0.299	0.013	0.104	0.046	0.084	0.008	0.054	0.136	0.635	0.155	0.192	0.016	12.769	31.802	4.708	6.229	4.316	67.3	75.59
95% CI Lower	0.048	0.034	0.157	0.434	0.312	0.01	0.18	0.329	0.429	0.979	0.011	5.413	0.009	0.233	0.186	0.003	0.033	0.05	0.096	0.158	0.01	0.053	0.016	0.043	0.006	0.036	0.073	0.465	0.103	0.12	0.01	28.634	60.663	8.1	26.282	14.01	130	138.4
Standard Dev	0.032	0.036	0.085	0.295	0.303	0.011	0.219	0.302	0.31	0.919	0	4.833	0	0.192	0.177	0.002	0.097	0.025	0.039	0.175	0.004	0.063	0.038	0.05	0.002	0.023	0.077	0.211	0.064	0.089	0.007	8.577	15.603	1.834	10.842	5.241	34	33.97
C.V.	0.52	0.75	0.45	0.53	0.70	0.76	0.82	0.67	0.56	0.68	0.04	0.66	0.05	0.62	0.69	0.55	1.34	0.42	0.35	0.77	0.38	0.80	1.21	0.79	0.33	0.50	0.74	0.38	0.50	0.57	0.53	0.41	0.34	0.29	0.67	0.57	0.34	0.32

Table 2.12(e): Experimental Results with PM_{10} Chemical Speciation of Colonelganj Site for Post-monsoon Season

CG Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	531.8	559.8	220.4	259.9	225.9	42.3	9.0	6.99	14.2	15	6.43	14.8	23.8	0.56	0.25	57.33	24.6	81.9	12	6.78	7.23	2.62	20.4	4.91	30	23.5	0.14	5.29	0.017	0.024	0.2	0.43
Minimum	325.8	336.0	141.3	137.1	153.5	16.5	3.4	2.69	6.65	7.88	3.48	4.7	10.81	0.39	0.15	27.21	11.4	38.6	3.57	5.05	4.5	1.59	14.3	0.82	15.9	16.8	0.03	1.92	0.002	0.006	0.09	0.11
Maximum	884.4	771.5	357.7	400.2	278.1	98.1	27.3	12.1	21	23.5	10.6	27.4	38.53	0.95	0.4	83.99	39.7	124	17.6	14.1	12	4.84	23.4	10.4	39.6	36.9	0.45	11.9	0.035	0.121	0.48	0.98
Range	558.7	435.5	216.4	263.2	124.6	81.6	23.9	9.41	14.4	15.6	7.13	22.7	27.72	0.56	0.25	56.78	28.4	85.1	14	9.01	7.51	3.25	9.15	9.58	23.8	20.1	0.42	9.93	0.033	0.115	0.39	0.87
N of cases	27.0	27.0	27.0	27.0	7.0	27.0	27.0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
95% CI Upper	589.7	616.9	240.0	285.3	267.3	50.0	11.2	7.93	15.8	16.4	7.09	17.3	26.86	0.62	0.28	63.55	27.7	91.2	14.4	8.18	8.55	3.21	21.6	6.22	33.8	26.3	0.2	6.61	0.022	0.036	0.23	0.54
95% CI Lower	473.9	502.7	200.7	234.6	184.5	34.6	6.8	6.05	12.7	13.5	5.77	12.2	20.73	0.5	0.23	51.11	21.5	72.7	9.46	5.38	5.92	2.04	19.2	3.6	26.3	20.7	0.08	3.97	0.013	0.013	0.16	0.32
Standard Dev	146.3	144.4	49.7	64.1	44.8	19.5	5.6	2.38	3.92	3.56	1.67	6.39	7.75	0.15	0.06	15.72	7.88	23.4	6.29	3.54	3.32	1.47	3.11	3.32	9.54	7	0.15	3.33	0.011	0.029	0.09	0.28
C.V.	0.28	0.26	0.23	0.25	0.20	0.46	0.63	0.34	0.28	0.24	0.26	0.43	0.33	0.27	0.26	0.27	0.32	0.29	0.53	0.52	0.46	0.56	0.15	0.68	0.32	0.30	1.06	0.63	0.65	1.20	0.46	0.64

CG Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC	CO (ppm)
Mean	0.013	0.016	0.109	0.393	0.024	0.009	0.12	0.182	0.178	1.119	0.023	6.814	0.009	0.103	0.172	0.002	0.056	0.031	0.062	0.097	0.01	0.067	0.025	0.047	0.006	0.037	0.103	0.336	0.106	0.088	0.01	20.494	33.167	5.283	13.411	7.56	79.9	93.92	1.841
Minimum	0.003	0.005	0.039	0.15	0.003	0.003	0.034	0.071	0.04	0.375	0.012	3.221	0.009	0.034	0.051	0.001	0.021	0.011	0.021	0.013	0.008	0.035	0.005	0.027	0.004	0.01	0.06	0.136	0.012	0.013	0.002	12.994	16.671	3.81	4.494	3.248	53.2	67.22	1.06
Maximum	0.025	0.033	0.187	0.888	0.111	0.038	0.229	0.403	0.654	2.68	0.036	16.08	0.01	0.152	0.47	0.003	0.121	0.057	0.096	0.206	0.014	0.209	0.105	0.076	0.009	0.113	0.186	0.859	0.225	0.15	0.014	31.744	49.934	7.758	31.749	16.265	130	144.4	2.39
Range	0.022	0.028	0.148	0.738	0.108	0.035	0.195	0.332	0.614	2.305	0.024	12.86	0.001	0.118	0.419	0.002	0.1	0.046	0.075	0.193	0.006	0.174	0.1	0.049	0.005	0.103	0.126	0.723	0.213	0.137	0.012	18.75	33.262	3.948	27.256	13.017	77.1	77.14	1.33
N of cases	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	7	7	7	7	7	7	7	29
95% CI Upper	0.015	0.019	0.133	0.493	0.035	0.012	0.148	0.228	0.251	1.409	0.027	8.291	0.01	0.117	0.238	0.003	0.066	0.036	0.069	0.127	0.011	0.085	0.039	0.055	0.006	0.046	0.124	0.402	0.128	0.103	0.012	12.642	22.814	3.884	5.139	3.561	54.3	68.27	1.699
95% CI Lower	0.011	0.013	0.085	0.294	0.013	0.006	0.092	0.135	0.106	0.829	0.018	5.336	0.009	0.089	0.106	0.002	0.047	0.027	0.054	0.067	0.009	0.05	0.012	0.039	0.005	0.028	0.081	0.27	0.085	0.072	0.008	28.347	43.519	6.682	21.683	11.558	106	119.6	1.983
Standard Dev	0.005	0.007	0.06	0.252	0.028	0.008	0.071	0.117	0.183	0.733	0.012	3.735	0	0.035	0.167	0.001	0.024	0.011	0.02	0.075	0.003	0.044	0.035	0.02	0.002	0.022	0.055	0.167	0.054	0.039	0.005	8.491	11.194	1.513	8.944	4.324	27.7	27.73	0.374
C.V.	0.41	0.48	0.55	0.64	1.18	0.95	0.59	0.65	1.02	0.66	0.54	0.55	0.05	0.34	0.97	0.44	0.42	0.36	0.33	0.78	0.28	0.65	1.37	0.42	0.27	0.59	0.54	0.50	0.51	0.44	0.46	0.41	0.34	0.29	0.67	0.57	0.35	0.30	0.20

Table 2.12(f): Experimental Results with PM_{10} Chemical Speciation of AHM Site for Post-monsoon Season

AHM Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	511.48	524.54	177.07	238.84	169	31.6	7.66	5.13	11.2	16.3	10.3	11.1	20.86	0.69	0.61	53.94	22.2	76.1	7.69	5.52	5.55	2.59	24.3	4.79	32.3	35.3	0.08	2.58	0.014	0.014	0.08	0.37
Minimum	250.2	317.0	130.9	114.6	123.5	16.0	3.1	1.75	5.91	8.39	6.03	4.63	9.31	0.32	0.06	28.73	9.88	40.1	2.42	3.34	3.06	1.71	7.22	2.57	20	22.9	0	0.3	0.004	0.008	0.01	0.01
Maximum	823.2	987.8	309.7	423.4	209.3	50.3	17.0	10.5	17.6	30.4	16.7	21	33.63	1.15	4.47	81.52	34.4	110	12.8	10.3	10.4	10.4	45.9	8.77	44.8	69.5	0.32	6.65	0.04	0.029	0.26	0.81
Range	572.9	670.8	178.8	308.8	85.9	34.3	13.8	8.74	11.6	22	10.6	16.4	24.32	0.83	4.41	52.79	24.5	69.9	10.4	6.93	7.29	8.72	38.7	6.2	24.8	46.5	0.31	6.35	0.036	0.021	0.25	0.8
N of cases	26.0	26.0	26.0	26.0	7.0	26.0	26.0	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
95% CI Upper	568.9	588.5	195.5	269.2	196.8	36.0	9.3	6.12	12.5	18.2	11.4	12.8	23.67	0.78	0.99	59.77	25	84.7	9.52	6.3	6.69	3.32	29	5.75	36.9	42.4	0.12	3.56	0.018	0.016	0.11	0.51
95% CI Lower	454.0	460.6	158.6	208.5	140.3	27.2	6.0	4.15	9.87	14.4	9.12	9.37	18.06	0.59	0.23	48.11	19.3	67.6	5.85	4.75	4.42	1.86	19.6	3.83	27.7	28.3	0.03	1.6	0.01	0.011	0.04	0.23
Standard Dev	142.2	158.4	45.7	75.2	30.5	11.0	4.1	2.44	3.27	4.69	2.84	4.25	6.945	0.23	0.94	14.44	7.14	21.2	4.55	1.93	2.81	1.81	11.7	2.38	11.3	17.5	0.11	2.43	0.01	0.006	0.08	0.34
C.V.	0.28	0.30	0.26	0.32	0.18	0.35	0.54	0.48	0.29	0.29	0.28	0.38	0.33	0.34	1.55	0.27	0.32	0.28	0.59	0.35	0.51	0.70	0.48	0.50	0.35	0.49	1.38	0.94	0.73	0.45	1.07	0.93

AHM Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.016	0.011	0.053	0.359	0.026	0.009	0.169	0.15	0.144	0.578	0.011	6.251	0.009	0.103	0.168	0.002	0.051	0.023	0.077	0.066	0.009	0.067	0.02	0.049	0.006	0.038	0.089	0.21	0.098	0.086	0.009	18.491	32.644	5.2	13.2	7.44	77	89.06
Minimum	0.006	0.004	0.007	0.042	0.006	0.003	0.044	0.092	0.062	0.246	0.011	2.295	0.009	0.002	0.049	0.001	0.015	0.003	0.038	0.022	0.008	0.046	0.005	0.027	0.004	0.01	0.06	0.07	0.012	0.013	0.002	11.723	16.409	3.75	4.423	3.196	51.3	63.4
Maximum	0.027	0.024	0.151	0.796	0.168	0.022	0.294	0.273	0.297	1.189	0.012	14.25	0.01	0.241	0.446	0.003	0.151	0.044	0.161	0.264	0.014	0.278	0.105	0.076	0.009	0.113	0.186	0.69	0.225	0.15	0.014	28.64	49.147	7.636	31.249	16.008	126	138.1
Range	0.021	0.02	0.144	0.754	0.162	0.019	0.25	0.181	0.235	0.943	0.001	11.96	0.001	0.239	0.397	0.002	0.136	0.041	0.123	0.242	0.006	0.232	0.1	0.049	0.005	0.103	0.126	0.62	0.213	0.137	0.012	16.917	32.738	3.886	26.826	12.812	74.7	74.71
N of cases	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	7	7	7	7	7	7	7
95% CI Upper	0.019	0.013	0.07	0.461	0.041	0.012	0.212	0.181	0.18	0.721	0.011	7.409	0.01	0.143	0.232	0.002	0.065	0.028	0.088	0.092	0.01	0.088	0.031	0.058	0.006	0.047	0.107	0.257	0.121	0.102	0.011	11.405	22.455	3.823	5.058	3.504	52.3	64.36
95% CI Lower	0.014	0.009	0.037	0.257	0.011	0.006	0.126	0.119	0.109	0.434	0.011	5.092	0.009	0.063	0.103	0.001	0.038	0.018	0.066	0.041	0.008	0.046	0.009	0.041	0.005	0.029	0.072	0.162	0.075	0.071	0.007	25.576	42.833	6.577	21.341	11.376	102	113.8
Standard Dev	0.006	0.005	0.04	0.252	0.038	0.007	0.106	0.077	0.089	0.355	0	2.867	0.001	0.099	0.16	0.001	0.034	0.012	0.026	0.063	0.002	0.052	0.026	0.02	0.002	0.022	0.044	0.118	0.057	0.039	0.005	7.661	11.017	1.489	8.803	4.256	26.7	26.71
C.V.	0.35	0.43	0.74	0.70	1.47	0.80	0.63	0.52	0.61	0.62	0.04	0.46	0.05	0.96	0.95	0.46	0.66	0.54	0.34	0.94	0.23	0.77	1.32	0.41	0.28	0.57	0.50	0.57	0.58	0.45	0.56	0.41	0.34	0.29	0.67	0.57	0.35	0.30

Table 2.12(g): Experimental Results with PM_{10} Chemical Speciation of Ramadevi Site for Post-monsoon Season

RD Post-mon	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	508.2	530.5	188.6	221.1	197.2	35.0	14.7	5.05	10.5	15.2	10.4	7.14	18.26	0.9	0.36	48.33	19.5	67.8	5.29	3.28	4.88	3.11	17.3	4.87	22.1	29.2	0.29	8.47	0.029	0.04	0.29	0.42
Minimum	314.6	256.4	96.4	139.3	127.7	14.2	3.5	2.17	5.49	10.1	6.69	2.2	8.14	0.34	0.09	26.66	8.78	35.4	4.2	2.4	1.81	2.27	16.5	3.26	20.3	22.1	0.17	3.2	0.017	0.019	0.17	0.24
Maximum	870.6	784.5	313.9	367.1	284.5	57.7	36.7	10.4	20.6	30	20.8	15	37.84	1.42	0.69	94.79	39.7	134	6.94	4.6	20.9	4.38	17.8	7.28	24.9	39.9	0.88	28.5	0.072	0.087	0.68	0.9
Range	556.1	528.1	217.5	227.8	156.8	43.5	33.2	8.21	15.1	19.9	14.2	12.8	29.7	1.08	0.6	68.13	30.9	99.1	2.74	2.19	19.1	2.11	1.32	4.02	4.66	17.9	0.71	25.3	0.055	0.068	0.51	0.66
N of cases	25.0	25.0	25.0	25.0	7.0	25.0	25.0	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
95% CI Upper	571.0	577.5	212.2	249.0	258.7	40.2	19.2	6.05	12.1	17.6	11.8	8.41	21.45	1.01	0.43	55.39	22.8	78.2	5.86	3.73	6.51	3.55	17.6	5.7	23.1	32.9	0.37	10.7	0.036	0.048	0.35	0.52
95% CI Lower	445.5	483.4	164.9	193.3	135.8	29.8	10.2	4.05	8.89	12.9	8.95	5.87	15.07	0.78	0.29	41.27	16.2	57.5	4.73	2.83	3.25	2.68	17	4.04	21.2	25.5	0.21	6.23	0.021	0.032	0.24	0.33
Standard Dev	152.1	114.0	57.3	67.5	66.5	12.6	10.9	2.43	3.94	5.67	3.46	3.08	7.726	0.28	0.18	17.11	7.94	25	1.37	1.1	3.96	1.06	0.66	2.01	2.33	8.93	0.2	5.45	0.017	0.02	0.14	0.23
C.V.	0.30	0.22	0.30	0.31	0.34	0.36	0.74	0.48	0.38	0.37	0.33	0.43	0.42	0.31	0.49	0.35	0.41	0.37	0.26	0.33	0.81	0.34	0.04	0.41	0.11	0.31	0.70	0.64	0.61	0.50	0.48	0.55

RD Post-mon	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.016	0.019	0.073	0.382	0.09	0.011	0.142	0.13	0.104	0.759	0.022	6.036	0.009	0.124	0.126	0.002	0.041	0.039	0.086	0.053	0.012	0.06	0.015	0.041	0.006	0.036	0.068	0.228	0.054	0.078	0.008	19.725	32.463	5.171	13.126	7.399	77.9	90.99
Minimum	0.009	0.007	0.028	0.179	0.016	0.009	0.037	0.05	0.035	0.034	0.011	0.291	0.009	0.044	0.076	0.001	0.018	0.011	0.049	0.031	0.009	0.047	0.005	0.027	0.004	0.01	0.06	0.101	0.012	0.013	0.002	12.506	16.318	3.729	4.399	3.179	51.9	64.98
Maximum	0.047	0.046	0.165	0.938	0.323	0.018	0.31	0.395	0.159	2.354	0.055	17.12	0.01	0.277	0.161	0.003	0.075	0.091	0.178	0.147	0.014	0.131	0.105	0.076	0.009	0.113	0.121	0.498	0.104	0.15	0.014	30.552	48.874	7.593	31.076	15.92	127	140.2
Range	0.038	0.039	0.137	0.759	0.307	0.009	0.273	0.345	0.124	2.32	0.044	16.83	0.001	0.233	0.085	0.002	0.057	0.08	0.129	0.116	0.005	0.084	0.1	0.049	0.005	0.103	0.061	0.397	0.092	0.137	0.012	18.047	32.557	3.864	26.677	12.741	75.3	75.26
N of cases	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	7	7	7	7	7	7	7
95% CI Upper	0.02	0.024	0.088	0.475	0.127	0.013	0.185	0.162	0.124	1.043	0.03	7.403	0.01	0.148	0.142	0.002	0.049	0.048	0.101	0.066	0.013	0.068	0.023	0.048	0.006	0.046	0.074	0.272	0.071	0.095	0.01	12.167	22.33	3.802	5.03	3.485	52.9	66
95% CI Lower	0.013	0.014	0.058	0.29	0.054	0.01	0.1	0.099	0.084	0.476	0.014	4.668	0.009	0.101	0.11	0.002	0.033	0.03	0.072	0.04	0.011	0.053	0.007	0.034	0.005	0.027	0.063	0.184	0.038	0.062	0.006	27.284	42.596	6.54	21.223	11.313	103	116
Standard Dev	0.009	0.011	0.036	0.224	0.088	0.004	0.103	0.076	0.049	0.687	0.019	3.312	0	0.057	0.038	0.001	0.019	0.022	0.035	0.031	0.002	0.018	0.02	0.017	0.002	0.022	0.013	0.107	0.04	0.04	0.005	8.172	10.956	1.481	8.755	4.232	27	27.03
C.V.	0.57	0.60	0.49	0.59	0.97	0.32	0.72	0.58	0.47	0.91	0.88	0.55	0.05	0.46	0.30	0.44	0.45	0.57	0.40	0.58	0.20	0.30	1.35	0.41	0.28	0.62	0.19	0.47	0.75	0.52	0.63	0.41	0.34	0.29	0.67	0.57	0.35	0.30

Table 2.13: Correlation Matrices of Four Dust Parameters for Post-monsoon Season at all Sampling Sites

(a) IIT Kanpur Site

IIT (P)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.503	1		
PM_{10}	0.673	0.785	1	
$PM_{2.5}$	0.368	0.957	0.847	1

(b) Vikashnagar Site

VN (P)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.638	1		
PM_{10}	0.762	0.765	1	
$PM_{2.5}$	0.619	0.637	0.856	1

(c) Govindnagar Site

GN (P)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.827	1		
PM_{10}	0.845	0.778	1	
$PM_{2.5}$	0.764	0.522	0.837	1

(d) Dadanagar Site

DN (P)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.726	1		
PM_{10}	0.545	0.972	1	
$PM_{2.5}$	0.411	0.899	0.97	1

(e) Colonelganj Site

CG (P)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.664	1		
PM_{10}	0.475	0.819	1	
$PM_{2.5}$	0.375	0.719	0.897	1

(f) AHM Site

AHM (P)	SPM	RSPM	PM10	PM2.5
SPM	1			
RSPM	0.873	1		
PM_{10}	0.904	0.847	1	
$PM_{2.5}$	0.871	0.794	0.758	1

(g) Ramadevi Site

RD (P)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.947	1		
PM_{10}	0.884	0.956	1	
$PM_{2.5}$	0.953	0.968	0.967	1

Table 2.14: Correlation Matrices of Chemical Species for Post-monsoon Season at all Sampling Sites

(a) IIT Kanpur Site

IIT (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.512	1							
SO_2	0.487	0.509	1						
NH_4^+	0.556	0.173	0.147	1					
SO_4^{2-}	0.597	0.199	0.193	0.944	1				
NO_3^-	0.419	0.314	0.244	0.863	0.871	1			
EC	0.267	-0.036	-0.013	0.143	0.132	0.02	1		
OC	0.257	-0.01	0.012	0.171	0.156	0.064	0.976	1	
TC	0.206	-0.019	0.004	0.163	0.149	0.05	0.989	0.997	1

(b) Vikashnagar Site

VN (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.058	1							
SO_2	0.029	0.493	1						
NH_4^+	0.638	0.077	0.099	1					
SO_4^{2-}	0.507	0.129	0.092	0.894	1				
NO_3^-	0.444	0.347	0.17	0.498	0.487	1			
EC	0.368	0.275	0.501	0.064	0.097	-0.468	1		
OC	0.307	0.233	0.511	0.068	0.097	-0.454	0.991	1	
TC	0.497	0.245	0.509	0.067	0.097	-0.459	0.995	0.999	1

(c) Govindnagar Site

GN (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.288	1							
SO_2	0.211	0.125	1						
NH_4^+	0.862	0.036	0.119	1					
SO_4^{2-}	0.719	0.005	0.275	0.725	1				
NO_3^-	0.673	0.392	0.235	0.449	0.805	1			
EC	0.485	0.043	0.122	0.012	-0.016	-0.036	1		
OC	0.584	0.058	0.17	-0.017	-0.083	-0.043	0.881	1	
TC	0.422	0.029	0.159	-0.009	-0.065	-0.042	0.941	0.989	1

(d) Dadanagar Site

DN (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.176	1							
SO_2	0.647	0.03	1						
NH_4^+	0.626	0.018	0.038	1					
SO_4^{2-}	0.505	0.128	0.037	0.765	1				
NO_3^-	0.499	0.471	0.235	0.416	0.368	1			
EC	0.326	-0.217	0.288	-0.294	-0.039	-0.173	1		
OC	0.564	-0.207	0.41	-0.234	0.052	0.035	0.739	1	
TC	0.529	-0.22	0.401	-0.26	0.032	-0.014	0.84	0.986	1

Table 2.14: Correlation Matrices of Chemical Species for Post-monsoon Season at all Sampling Sites

(e) Colonelganj Site

CG (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.367	1							
SO_2	0.375	0.547	1						
NH_4^+	0.712	0.148	0.231	1					
SO_4^{2-}	0.741	0.145	0.19	0.464	1				
NO_3^-	0.631	0.411	0.009	0.652	0.773	1			
EC	0.484	-0.207	0.392	0.063	-0.107	-0.066	1		
OC	0.353	0.036	0.367	0.095	-0.075	-0.052	0.971	1	
TC	0.431	0.024	0.378	0.085	-0.086	-0.057	0.987	0.997	1

(f) AHM Site

AHM (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.207	1							
SO_2	0.007	0.174	1						
NH_4^+	0.635	0.336	0.105	1					
SO_4^{2-}	0.511	0.081	0.091	0.509	1				
NO_3^-	0.728	0.321	0.114	0.682	0.637	1			
EC	0.316	-0.165	0.204	-0.045	0.102	0.043	1		
OC	0.499	-0.244	0.324	0.062	0.002	0.087	0.916	1	
TC	0.473	-0.222	0.289	0.028	0.036	0.074	0.962	0.991	1

(g) Ramadevi Site

RD (P)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.576	1							
SO_2	0.316	0.269	1						
NH_4^+	0.585	0.102	0.19	1					
SO_4^{2-}	0.485	0.102	0.19	0.609	1				
NO_3^-	0.585	0.402	0.19	0.582	0.873	1			
EC	0.307	-0.067	0.286	-0.194	0.194	0.194	1		
OC	0.347	-0.017	0.32	-0.154	0.154	0.154	0.99	1	
TC	0.335	-0.032	0.31	-0.167	0.167	0.167	0.995	0.999	1

Table 2.15(a): Experimental Results of $PM_{2.5}$ Chemical Speciation of IIT Kanpur Site for Post-monsoon Season

IIT (Post-mon)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	104.4	0.34	1.55	2.41	1.51	1.25	1.68	0.22	0.01	7.07	1.91	8.98	0.969	1.201	2.224	0.223	2.477	0.831	0.411	5.772
Maximum	173.7	1.1	4.48	6.05	3.96	3.98	5.08	0.46	0.1	19.57	5.6	25.17	3.552	4.504	4.333	1.372	11.68	3.026	8.299	31.85
Range	69.24	0.76	2.93	3.64	2.45	2.73	3.4	0.24	0.09	12.5	3.69	16.19	2.583	3.303	2.109	1.149	9.204	2.195	7.888	26.08
Arithmetic Mean	132.1	0.76	3.15	4.341	3.247	2.519	3.593	0.323	0.064	14.01	3.981	18	2.386	3.16	3.3	1.007	7.567	1.508	5.075	18.53
95.0% Lower CI	110.9	0.531	2.29	3.239	2.512	1.52	2.497	0.235	0.035	10.32	2.805	13.15	1.482	2.207	2.631	0.63	4.352	0.583	2.295	9.805
95.0% Upper CI	153.3	0.989	4	5.444	3.982	3.517	4.688	0.411	0.094	17.7	5.157	22.84	3.289	4.113	3.97	1.384	10.78	2.433	7.854	27.25
S.D.	22.97	0.248	0.92	1.192	0.795	1.08	1.184	0.096	0.032	3.989	1.272	5.239	0.977	1.03	0.724	0.408	3.477	1	3.005	9.429
C.V.	0.174	0.326	0.29	0.275	0.245	0.429	0.33	0.296	0.499	0.285	0.319	0.291	0.41	0.326	0.219	0.405	0.459	0.663	0.592	0.509

Table 2.15(b): Experimental Results of $PM_{2.5}$ Chemical Speciation of Vikashnagar Site for Post-monsoon Season

VN (Post-mon)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	106.4	0.72	3.19	4.63	3.35	2.06	3.36	0.13	0.06	14.22	3.56	17.78	0.525	2.706	3.159	0.067	6.614	0.755	3.913	12.67
Maximum	221	2.61	6.87	9.18	5.66	7.89	8.08	0.25	0.1	30.75	8.42	39.17	6.626	4.525	5.332	1.655	11.26	1.614	12.75	29.9
Range	114.7	1.89	3.68	4.55	2.31	5.83	4.72	0.12	0.04	16.53	4.86	21.39	6.101	1.819	2.173	1.588	4.645	0.859	8.839	17.23
Arithmetic Mean	161.4	1.574	5.14	6.953	4.466	4.641	5.31	0.2	0.077	22.78	5.583	28.36	2.172	3.633	4.589	1.348	8.431	1.233	6.64	23.64
95.0% Lower CI	130.2	0.96	3.91	5.38	3.767	2.749	3.794	0.158	0.062	17.12	4.013	21.17	0.056	2.837	3.696	0.79	6.91	0.836	3.549	17.95
95.0% Upper CI	192.7	2.189	6.38	8.526	5.164	6.534	6.826	0.242	0.092	28.43	7.152	35.54	4.288	4.429	5.482	1.905	9.952	1.631	9.731	29.34
S.D.	33.79	0.664	1.34	1.701	0.755	2.046	1.64	0.046	0.016	6.114	1.697	7.77	2.288	0.861	0.966	0.603	1.645	0.43	3.342	6.156
C.V.	0.209	0.422	0.26	0.245	0.169	0.441	0.309	0.229	0.208	0.268	0.304	0.274	1.054	0.237	0.21	0.447	0.195	0.348	0.503	0.26

Table 2.15(c): Experimental Results of $PM_{2.5}$ Chemical Speciation of Govindnagar Site for Post-monsoon Season

GN (Post-mon)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	108	0.21	1.09	1.56	0.83	0.66	1.38	0.14	0.03	4.47	1.54	6.01	0.997	2.818	0.859	0.474	3.473	0.389	3.367	11.51
Maximum	204.5	1.91	6.04	7.72	6.5	7.91	9.42	0.38	0.47	26.65	9.81	36.46	3.473	6.231	7.174	2.522	13.96	4.449	24.26	41.84
Range	96.59	1.7	4.95	6.16	5.67	7.25	8.04	0.24	0.44	22.18	8.27	30.45	2.476	3.413	6.315	2.048	10.48	4.06	20.89	30.33
Arithmetic Mean	153.7	0.883	3.28	4.276	3.414	2.487	4.4	0.224	0.147	14.34	4.771	19.11	1.773	3.306	3.508	1.272	9.896	1.113	10.4	18.97
95.0% Lower CI	126.6	0.287	1.64	2.278	1.543	0.085	1.492	0.148	0.009	6.39	1.798	8.209	0.988	2.113	0.934	0.349	6.524	-0.26	3.612	9.464
95.0% Upper CI	180.8	1.479	4.92	6.273	5.285	4.889	7.308	0.3	0.285	22.28	7.745	30.01	2.558	4.499	6.081	2.195	13.27	2.482	17.19	28.47
S.D.	29.29	0.644	1.77	2.16	2.023	2.597	3.145	0.082	0.149	8.593	3.215	11.79	0.849	1.29	2.783	0.998	3.646	1.48	7.342	10.28
C.V.	0.191	0.73	0.54	0.505	0.593	1.044	0.715	0.366	1.014	0.599	0.674	0.617	0.479	0.39	0.793	0.785	0.368	1.329	0.706	0.542

Table 2.15(d): Experimental Results of $PM_{2.5}$ Chemical Speciation of Dadanagar Site for Post-monsoon Season

DN (Post-mon)	$PM_{2.5}$	OC_1	OC_2	OC_3	OC_4	OP	EC_1	EC_2	EC_3	OC	EC	TC	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Minimum	103.3	1.59	2.7	1.91	0.96	0.72	3.48	0.14	0.03	11.52	4.27	15.98	0.978	0.973	5.636	0.442	17.69	0.643	16.9	26.49
Maximum	391.3	3.52	10.8	27.34	40.62	7.96	10.82	8.05	8.85	89.15	24.64	113.8	1.964	2.941	7.832	1.41	21.84	1.029	48.86	46.49
Range	288	1.93	8.09	25.43	39.66	7.24	7.34	7.91	8.82	77.63	20.37	97.81	0.986	1.968	2.196	0.968	4.144	0.386	31.96	20
Arithmetic Mean	272.8	2.35	5.83	7.858	13.35	4.622	6.456	3.742	2.712	34.01	12.91	46.92	1.372	1.76	6.514	0.636	19.88	0.797	27.17	36.01
95.0% Lower CI	113.2	1.432	1.21	-5.7	-8.25	0.315	2.137	-0.586	-1.87	-6.15	1.166	-3.88	0.702	0.422	5.021	0.098	17.96	0.535	8.861	23.97
95.0% Upper CI	432.4	3.268	10.5	21.42	34.95	8.929	10.78	8.07	7.297	74.18	24.65	97.72	2.043	3.099	8.008	1.173	21.79	1.06	45.48	48.05
S.D.	128.5	0.739	3.72	10.92	17.39	3.468	3.478	3.485	3.692	32.35	9.456	40.91	0.54	1.078	1.203	0.433	1.54	0.211	14.74	9.696
C.V.	0.471	0.315	0.64	1.39	1.303	0.75	0.539	0.931	1.362	0.951	0.733	0.872	0.394	0.612	0.185	0.681	0.077	0.265	0.543	0.269

Table 2.15(e): Experimental Results of $PM_{2.5}$ Chemical Speciation of Colonelganj Site for Post-monsoon Season

CG (Post-mon)	$PM_{2.5}$	OC_1	OC_2	OC_3	OC_4	OP	EC_1	EC_2	EC_3	OC	EC	TC	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Minimum	153.5	2.42	6.89	7.8	2.44	7.25	9.64	0.24	0.09	28.28	9.97	38.25	1.716	3.584	2.338	0.571	13.71	0.393	13.5	13.28
Maximum	278.1	6.33	11	9.85	4.23	14.35	16.51	0.31	0.16	43.72	16.88	60.6	8.427	3.724	6.244	1.742	20.71	2.539	29.48	17.82
Range	124.6	3.91	4.11	2.05	1.79	7.1	6.87	0.07	0.07	15.44	6.91	22.35	6.711	0.14	3.906	1.171	6.997	2.146	15.98	4.543
Arithmetic Mean	225.9	4.451	9.06	8.956	3.183	10.46	13.06	0.27	0.123	36.1	13.46	49.56	5.551	3.644	4.012	1.073	18.65	1.619	22.63	15.87
95.0% Lower CI	184.5	3.251	7.49	8.342	2.614	7.729	10.58	0.24	0.102	30.54	10.97	41.54	2.233	3.575	2.081	0.494	16.4	0.558	14.73	13.63
95.0% Upper CI	267.3	5.652	10.6	9.569	3.752	13.18	15.55	0.3	0.144	41.66	15.95	57.57	8.868	3.713	5.943	1.652	20.89	2.68	30.53	18.12
S.D.	44.78	1.298	1.69	0.663	0.616	2.948	2.69	0.033	0.023	6.013	2.693	8.665	3.587	0.075	2.088	0.626	2.424	1.147	8.542	2.428
C.V.	0.198	0.292	0.19	0.074	0.193	0.282	0.206	0.121	0.186	0.167	0.2	0.175	0.646	0.021	0.52	0.583	0.13	0.708	0.377	0.153

Table 2.15(f): Experimental Results of $PM_{2.5}$ Chemical Speciation of AHM Site for Post-monsoon Season

AHM (Post-mon)	$PM_{2.5}$	OC_1	OC_2	OC_3	OC_4	OP	EC_1	EC_2	EC_3	OC	EC	TC	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Minimum	123.5	1.75	4.31	5.41	3.04	4.64	7.18	0.14	0.05	20.39	7.59	28.23	1.115	2.336	1.561	0.648	13.91	1.182	12.5	13.22
Maximum	209.3	4.38	6.88	9.11	5.38	9.41	12.81	0.28	0.13	34.16	13.11	47	5.895	4.989	5.278	1.561	20.28	4.033	28.05	40.03
Range	85.85	2.63	2.57	3.7	2.34	4.77	5.63	0.14	0.08	13.77	5.52	18.77	4.78	2.653	3.717	0.913	6.378	2.851	15.55	26.81
Arithmetic Mean	168.6	2.774	5.39	7.446	4.361	6.706	9.627	0.227	0.09	26.67	9.946	36.62	2.44	4.287	3.443	0.991	15.54	2.564	23.28	22.09
95.0% Lower CI	140.3	1.843	4.4	6.316	3.676	4.581	7.2	0.184	0.064	21.48	7.527	29.08	0.815	3.435	1.982	0.613	13.27	1.504	17.56	10.69
95.0% Upper CI	196.8	3.706	6.38	8.576	5.047	8.83	12.06	0.27	0.116	31.86	12.37	44.16	4.065	5.139	4.904	1.37	17.82	3.624	29.01	33.49
S.D.	30.51	1.007	1.07	1.222	0.741	2.297	2.625	0.047	0.028	5.611	2.615	8.151	1.757	0.922	1.58	0.409	2.459	1.146	6.192	12.33
C.V.	0.181	0.363	0.2	0.164	0.17	0.343	0.273	0.206	0.308	0.21	0.263	0.223	0.72	0.215	0.459	0.413	0.158	0.447	0.266	0.558

Table 2.15(g): Experimental Results of $PM_{2.5}$ Chemical Speciation of Ramadevi Site for Post-monsoon Season

RD (Post-mon)	**$PM_{2.5}$**	**OC_1**	**OC_2**	**OC_3**	**OC_4**	**OP**	**EC_1**	**EC_2**	**EC_3**	**OC**	**EC**	**TC**	**Na^+**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**NH_4^+**	**Cl^-**	**NO_3^-**	**SO_4^{2-}**
Minimum	127.7	1.49	3.87	5.6	4.11	1.17	5.25	0.24	0.04	17.39	5.63	23.03	1.847	1.683	1.412	0.839	11.06	1.534	7.224	7.003
Maximum	284.5	4.06	8.92	13.5	8.29	6.27	13.42	0.59	0.28	41.05	14.23	55.27	3.053	3.218	3.436	1.619	11.95	3.423	21.18	30.76
Range	156.8	2.57	5.05	7.9	4.18	5.1	8.17	0.35	0.24	23.66	8.6	32.24	1.206	1.535	2.024	0.78	0.885	1.889	13.96	23.76
Arithmetic Mean	197.2	2.374	5.36	7.884	5.553	3.841	7.494	0.433	0.18	25.02	8.11	33.13	2.192	2.122	2.114	1.062	11.69	2.074	16.93	19.51
95.0% Lower CI	135.8	1.329	3.44	5.066	3.931	2.435	4.513	0.333	0.099	16.79	5.033	21.84	1.647	1.429	1.387	0.71	11.3	1.221	12.61	11.63
95.0% Upper CI	258.7	3.419	7.29	10.7	7.174	5.248	10.48	0.533	0.261	33.25	11.19	44.42	2.736	2.814	2.84	1.414	12.09	2.926	21.24	27.38
S.D.	66.46	1.13	2.08	3.048	1.753	1.521	3.224	0.108	0.088	8.898	3.327	12.21	0.588	0.749	0.785	0.381	0.432	0.922	4.667	8.511
C.V.	0.337	0.476	0.39	0.387	0.316	0.396	0.43	0.25	0.487	0.356	0.41	0.368	0.269	0.353	0.372	0.358	0.037	0.444	0.276	0.436

2.4.2.8 Comparisons of PM_{10} and $PM_{2.5}$ Compositions

This section gives some important information coming from the experimental findings related to fine and coarse particles. Table 2.16 presents a comparison between $PM_{2.5}$ Vs PM_{10} with respect to their compositions for the major chemical species of all sampling sites during post-monsoon season. The chemical species considered for the comparisons are EC, OC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. It can be concluded here that NH_4^+, NO_3^-, SO_4^{2-} and OC are formed in the fine mode; whereas, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- are formed in coarse as well as fine mode.

The above results are also shown graphically for all sampling sites of the city for better feeling. Figures 2.17(a), 2.17(b), 2.17(c), 2.17(d), 2.17(e), 2.17(f) and 2.17(g) show the compositional comparison of $PM_{2.5}$ Vs PM_{10} for major chemical species at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during post-monsoon season.

Table 2.16: Ratios of Chemical Species of $PM_{2.5}$ and PM_{10} for all Sites of Post-monsoon Season

Post-monsoon **Site**	**IIT Kanpur**	**Vikash nagar**	**Govind nagar**	**Dada nagar**	**Colonel ganj**	**AHM**	**Ramadevi**
$PM_{2.5}$ (ug/m^3)	132.1	161.4	153.7	272.8	225.9	169	197.2
PM_{10} (ug/m^3)	169.5	194.9	212	370.8	259.9	238.8	221.1
$PM_{2.5}$/ PM_{10} (%)	77.9	82.8	72.5	73.6	86.9	70.8	89.2
$PM_{2.5}$ EC/ PM_{10} EC (%)	31.5	37.1	25.8	38.6	54.9	44.6	41.5
$PM_{2.5}$ OC/ PM_{10} OC (%)	48.6	52.7	31.7	38.3	63.0	49.5	51.8
$PM_{2.5}$ TC/ PM_{10} TC (%)	43.7	48.5	30.0	38.4	60.6	48.1	48.8
$PM_{2.5}$ Na^+/ PM_{10} Na^+ (%)	39.3	37.3	28.1	12.8	46.7	31.2	41.5
$PM_{2.5}$ K^+/ PM_{10} K^+ (%)	82.1	75.0	75.0	27.7	52.9	78.2	63.6
$PM_{2.5}$ Ca^{2+}/ PM_{10} Ca^{2+} (%)	55.9	63.9	43.8	47.1	55.6	60.7	42.9
$PM_{2.5}$ Mg^{2+}/ PM_{10} Mg^{2+} (%)	45.5	42.4	41.9	22.2	42.3	38.5	35.5
$PM_{2.5}$ NH_4^+/ PM_{10} NH_4^+ (%)	67.3	60.4	56.9	82.9	91.2	63.8	67.6
$PM_{2.5}$ Cl^-/ PM_{10} Cl^- (%)	40.5	46.2	33.3	9.2	32.7	54.2	42.9
$PM_{2.5}$ NO_3^-/ PM_{10} NO_3^- (%)	79.7	77.6	61.9	73.3	75.3	72.1	73.8
$PM_{2.5}$ SO_4^{2-}/ PM_{10} $SO4^{2-}$ (%)	75.8	73.3	56.4	69.5	67.7	62.6	66.8

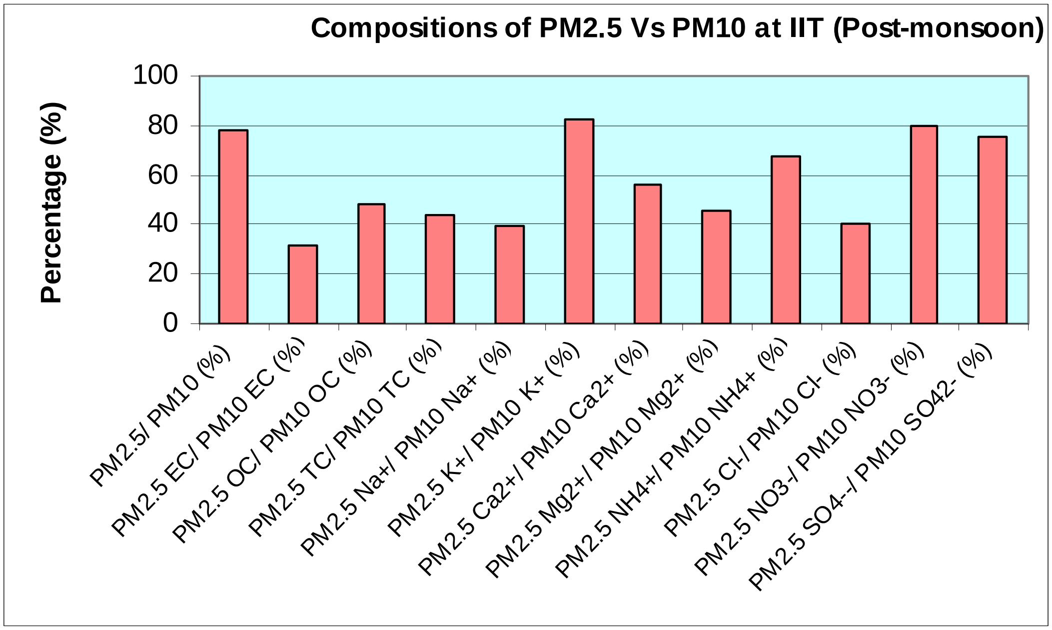


Figure 2.17(a): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at IIT Kanpur Site for Post-monsoon Season

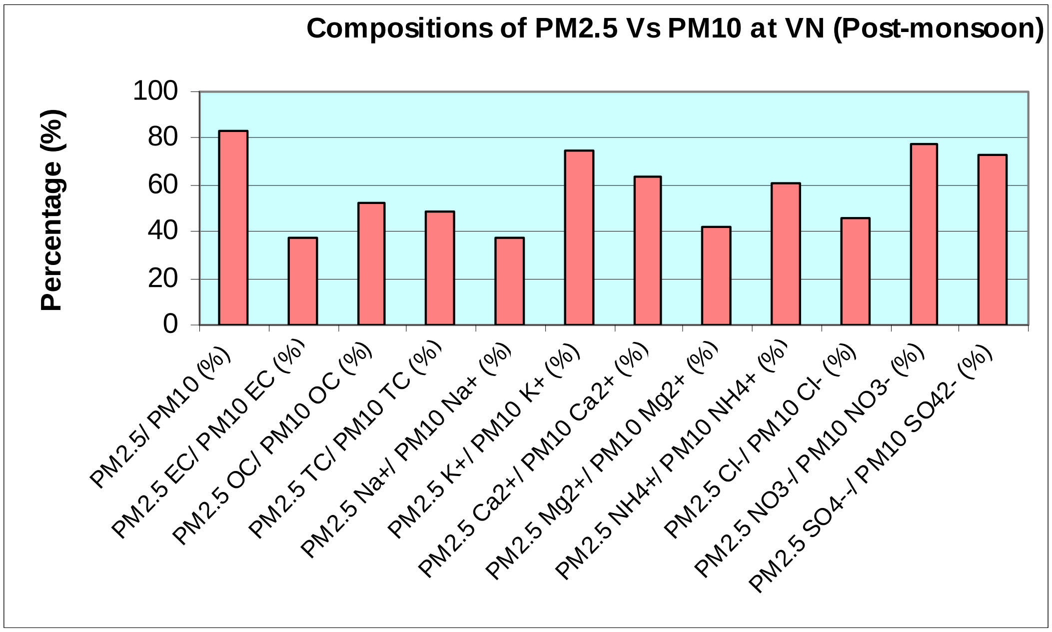


Figure 2.17(b): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Vikashnagar Site for Post-monsoon Season

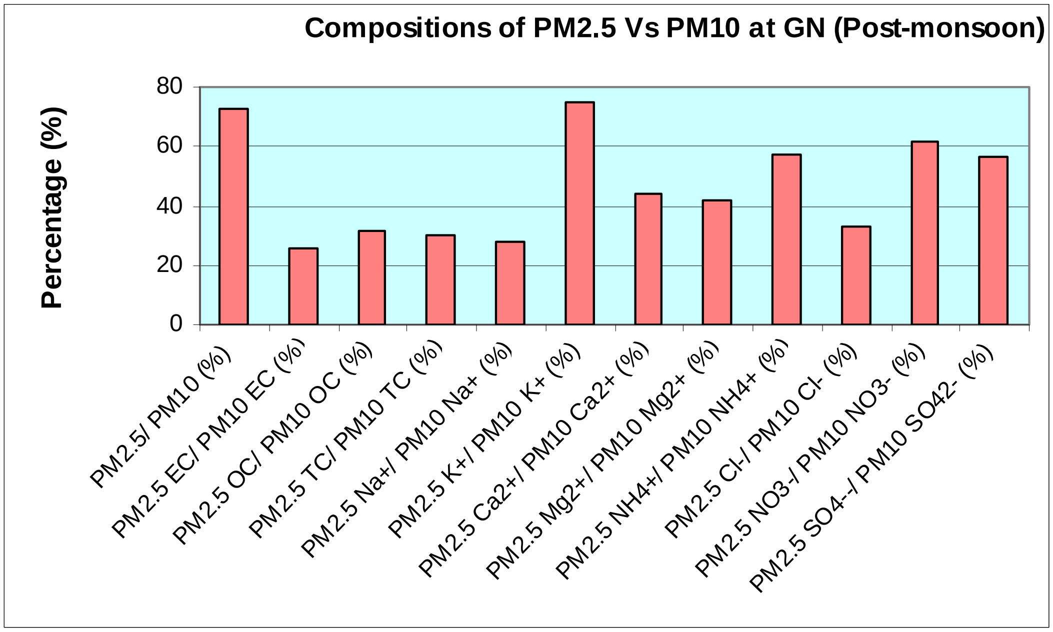


Figure 2.17(c): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Govindnagar Site for Post-monsoon Season

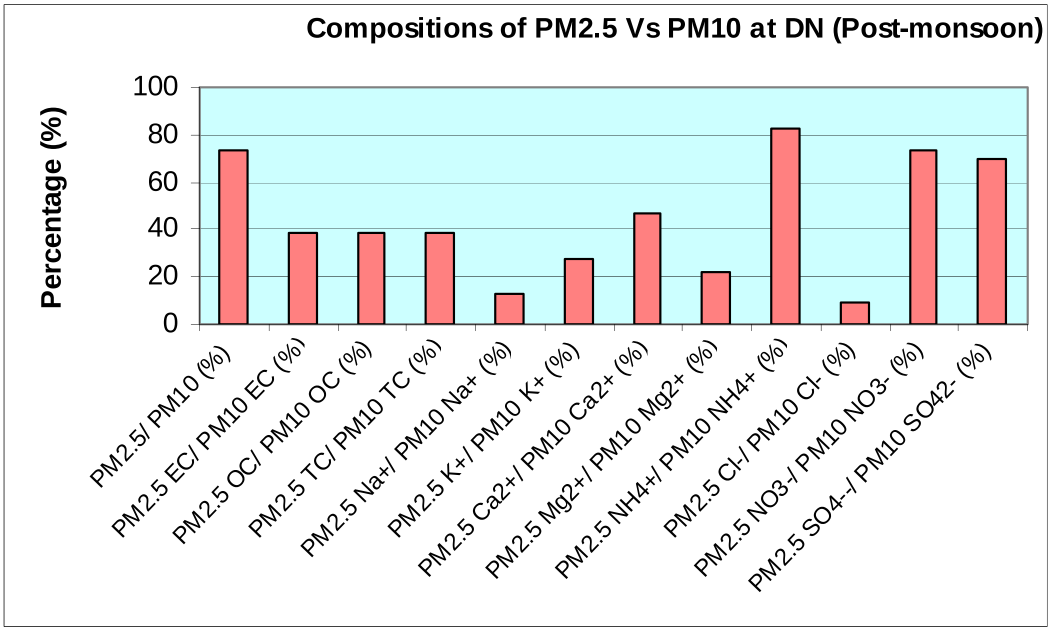


Figure 2.17(d): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Dadanagar Site for Post-monsoon Season

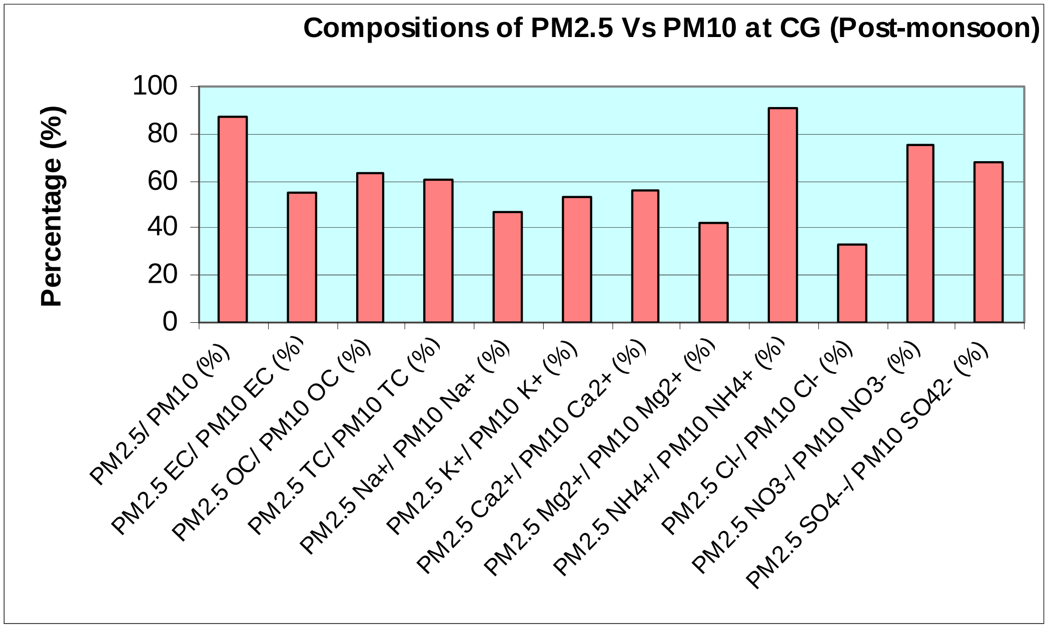


Figure 2.17(e): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Colonelganj Site for Post-monsoon Season

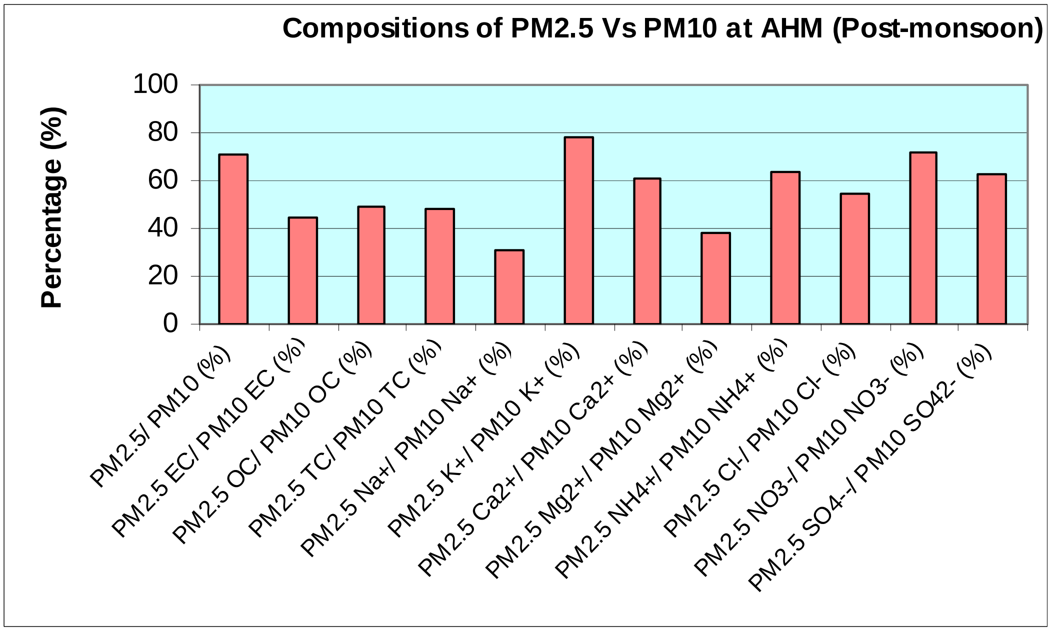


Figure 2.17(f): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at AHM Site for Post-monsoon Season

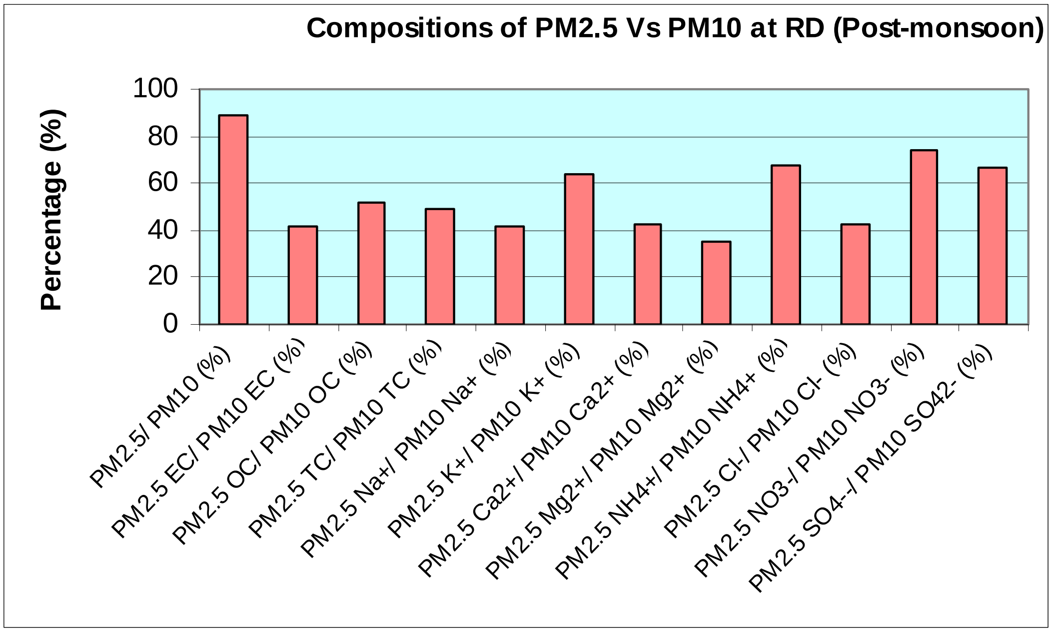


Figure 2.17(g): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Ramadevi Site for Post-monsoon Season

2.4.3 Winter Season

The duration of the sampling for winter season was from December 2007 and January 2008. But due to machinery problem, the sampling was done till early of the February 2008 at two sites. This section presents the observational results of various pollutants at all sampling locations during this period of time.

2.4.3.1 Particulate Matters (SPM, RSPM, PM_{10} and $PM_{2.5}$)

Daily average concentrations observed for SPM, RSPM, PM_{10} and $PM_{2.5}$ are shown graphically in this section during winter season. Figures 2.18(a), 2.18(b), 2.18(c), 2.18(d), 2.18(e), 2.18(f) and 2.18(g) show the daily variations of the PM concentrations of sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The figures show well understood trends of the particulate matter concentrations. $PM_{2.5}$ concentration also shows a good agreement with SPM and PM_{10} concentrations.

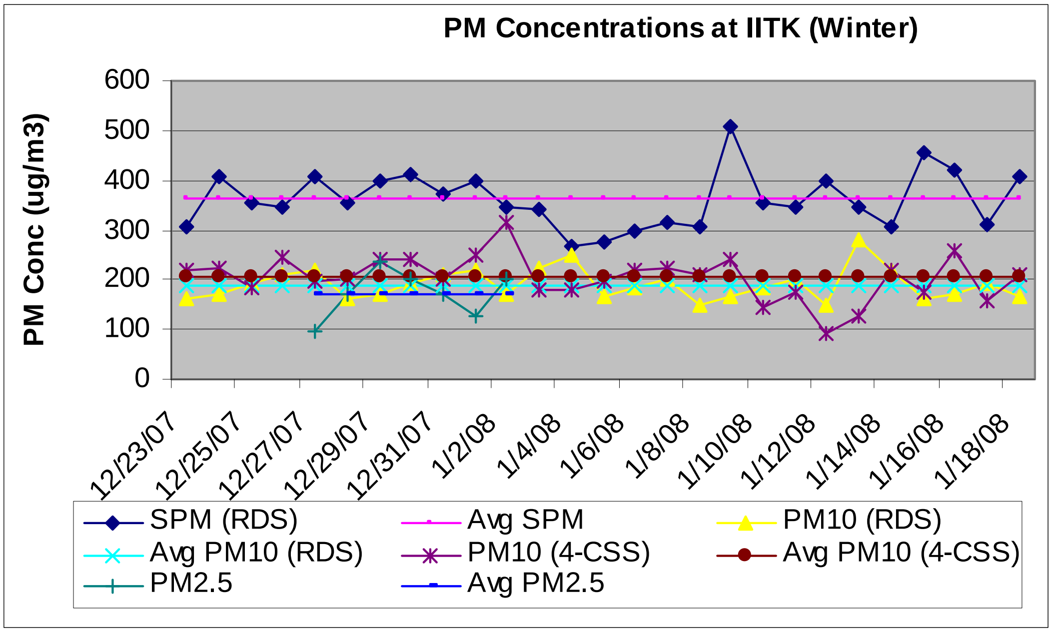


Figure 2.18(a): Observed PM Concentrations at IIT Kanpur Site for Winter Season

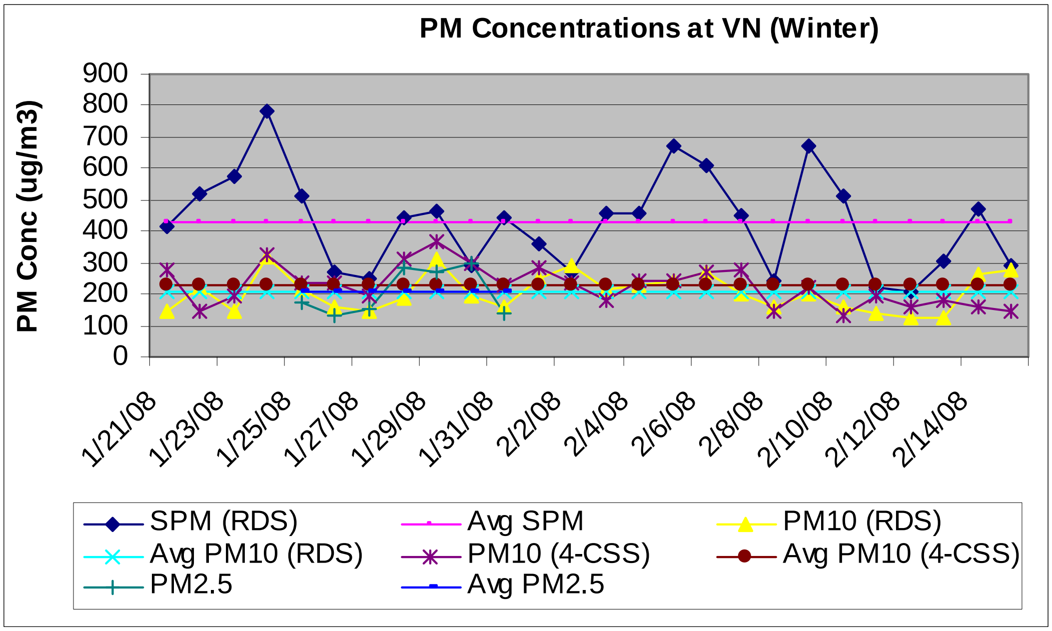


Figure 2.18(b): Observed PM Concentrations at Vikashnagar Site for Winter Season

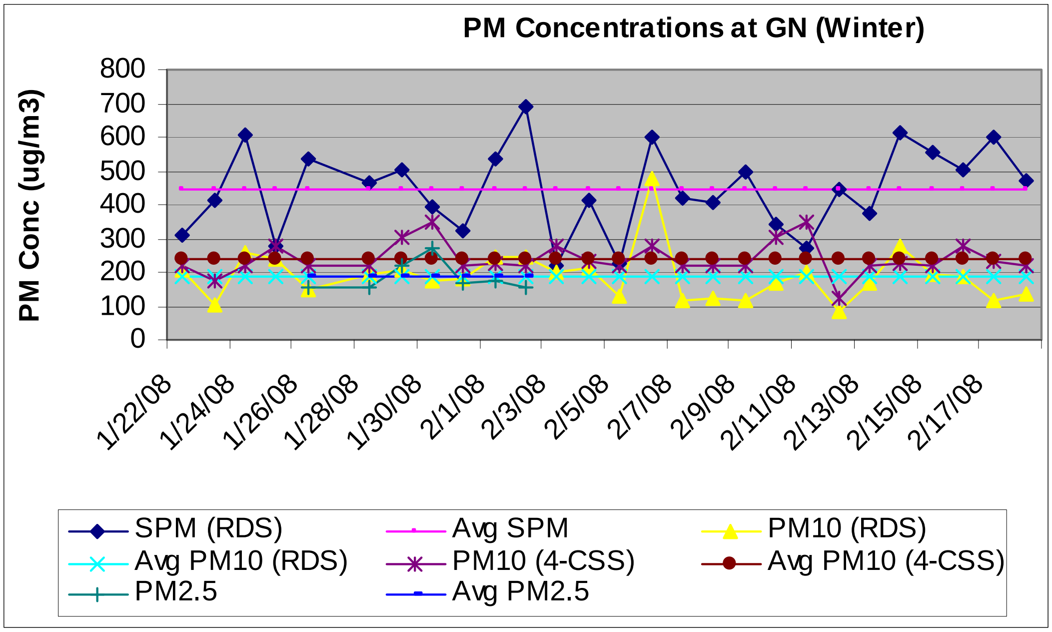


Figure 2.18(c): Observed PM Concentrations at Govindnagar Site for Winter Season

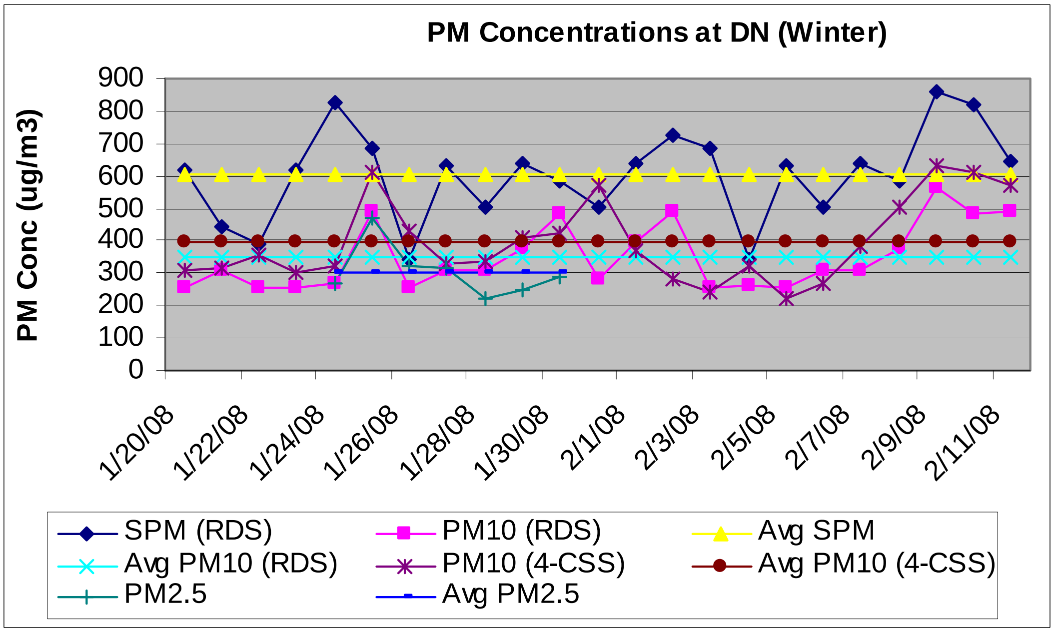


Figure 2.18(d): Observed PM Concentrations at Dadanagar Site for Winter Season

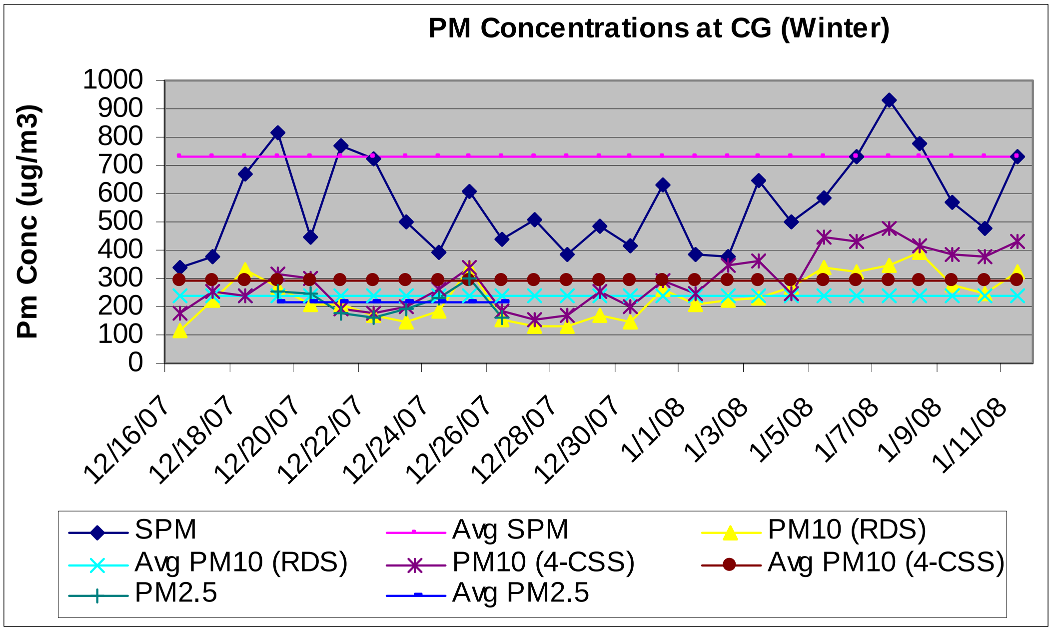


Figure 2.18(e): Observed PM Concentrations at Colonelganj Site for Winter Season

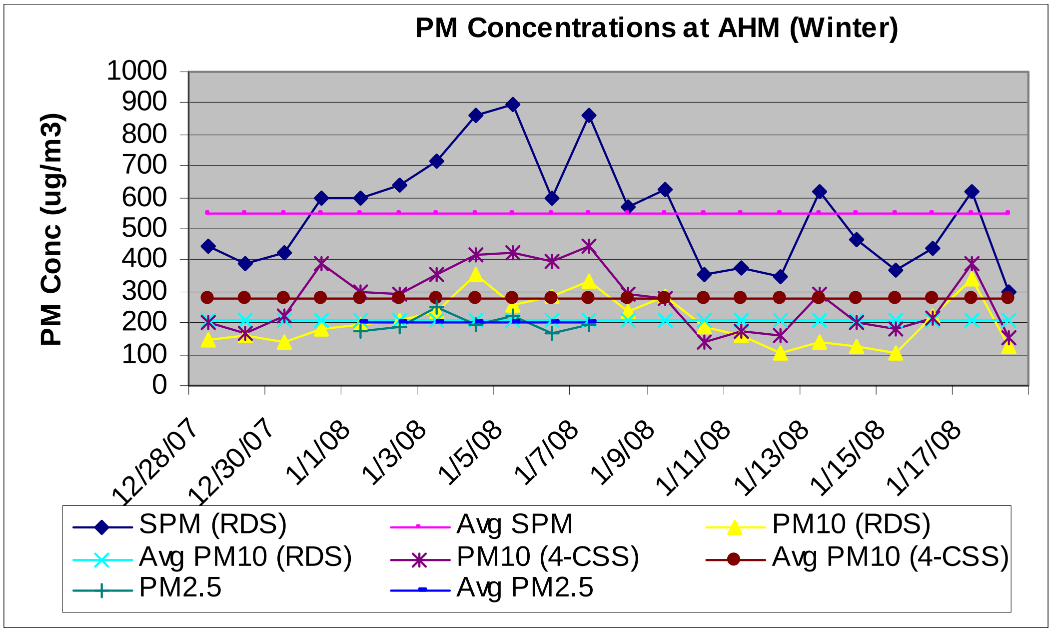


Figure 2.18(f): Observed PM Concentrations at AHM Site for Winter Season

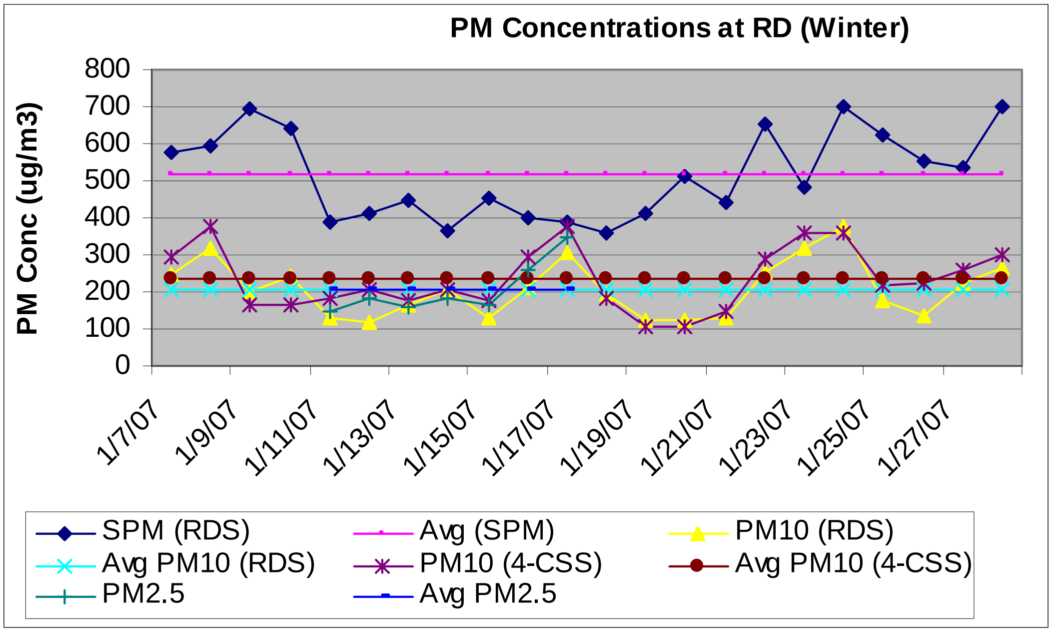


Figure 2.18(g): Observed PM Concentrations at IIT Kanpur Site for Winter Season

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

This section reveals the daily average concentrations of NO_2 and SO_2 observed in a graphical way for winter season. Figures 2.19(a), 2.19(b), 2.19(c), 2.19(d), 2.19(e), 2.19(f) and 2.19(g) show the daily variations of the SO_2 and NO_2 concentrations of sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. It can be concluded that low concentration of SO_2 was observed; may be due to introduction of low sulphur content in the diesel fuels; and NO_2 concentration is below the permissible limits.

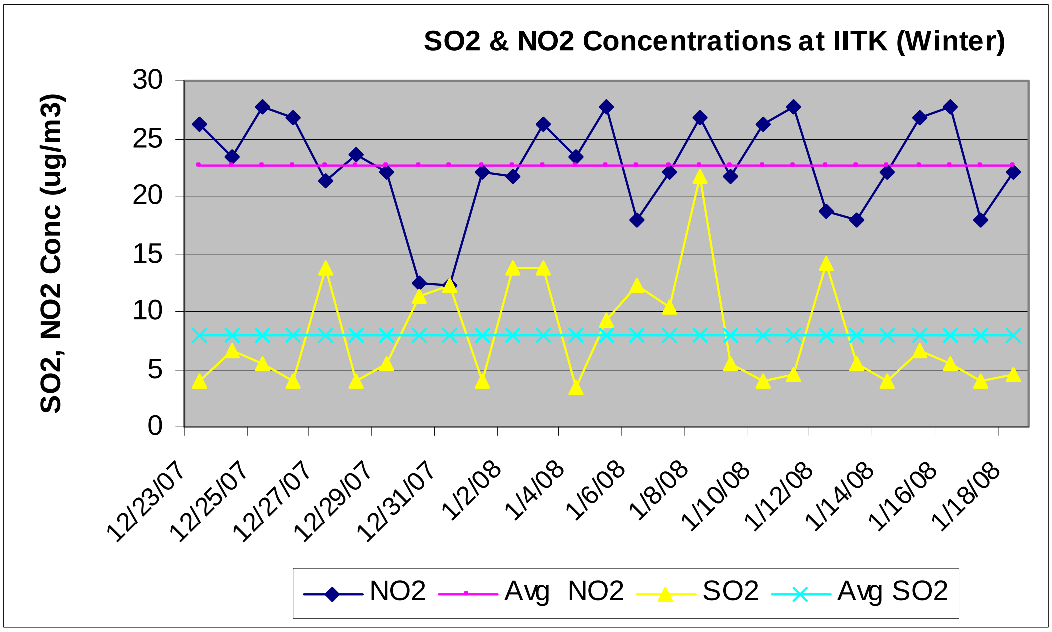


Figure 2.19(a): Observed SO_2 and NO_2 Concentrations at IIT Kanpur Site for Winter Season

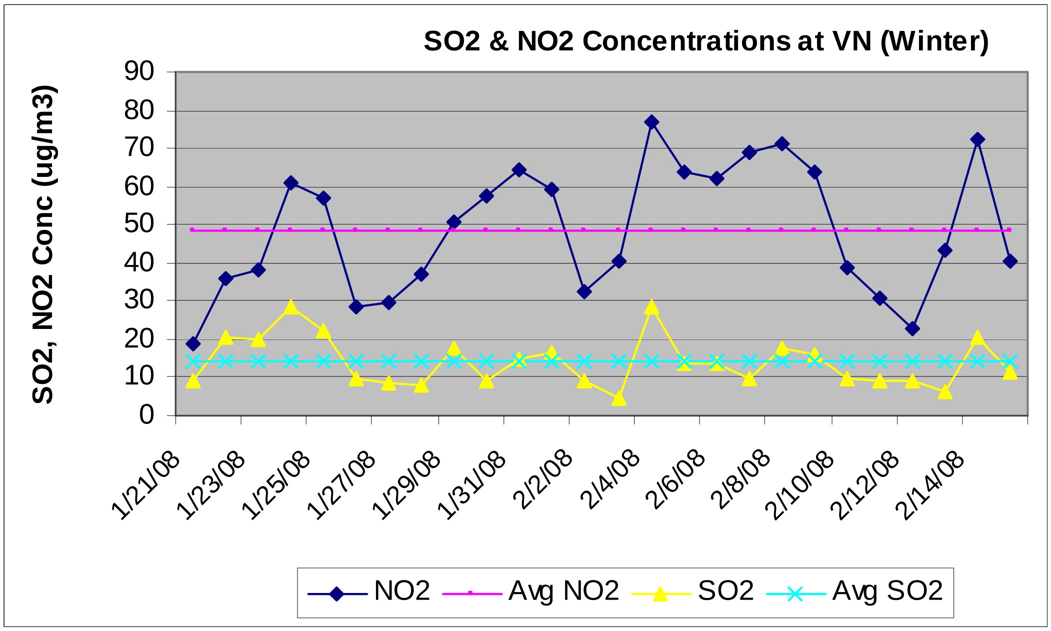


Figure 2.19(b): Observed SO_2 and NO_2 Concentrations at Vikashnagar Site for Winter Season

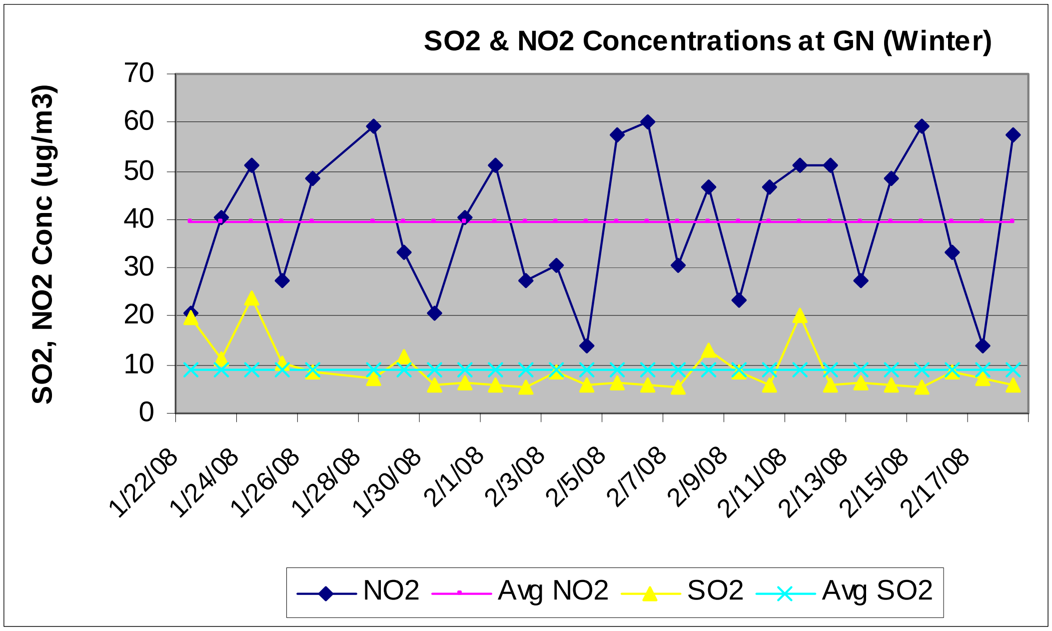


Figure 2.19(c): Observed SO_2 and NO_2 Concentrations at Govindnagar Site for Winter Season

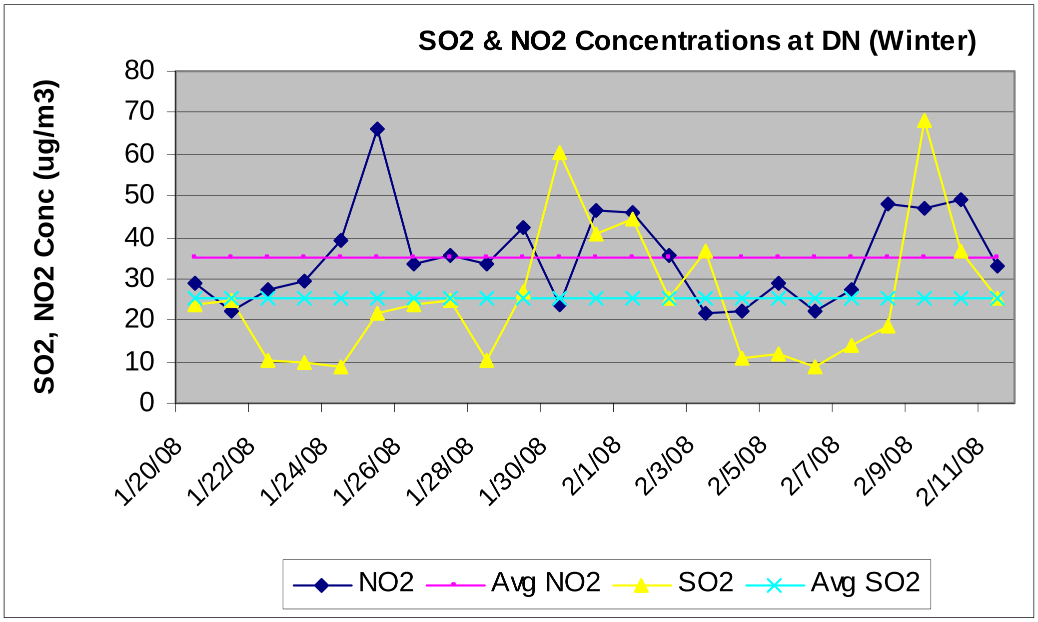


Figure 2.19(d): Observed SO_2 and NO_2 Concentrations at Dadanagar Site for Winter Season

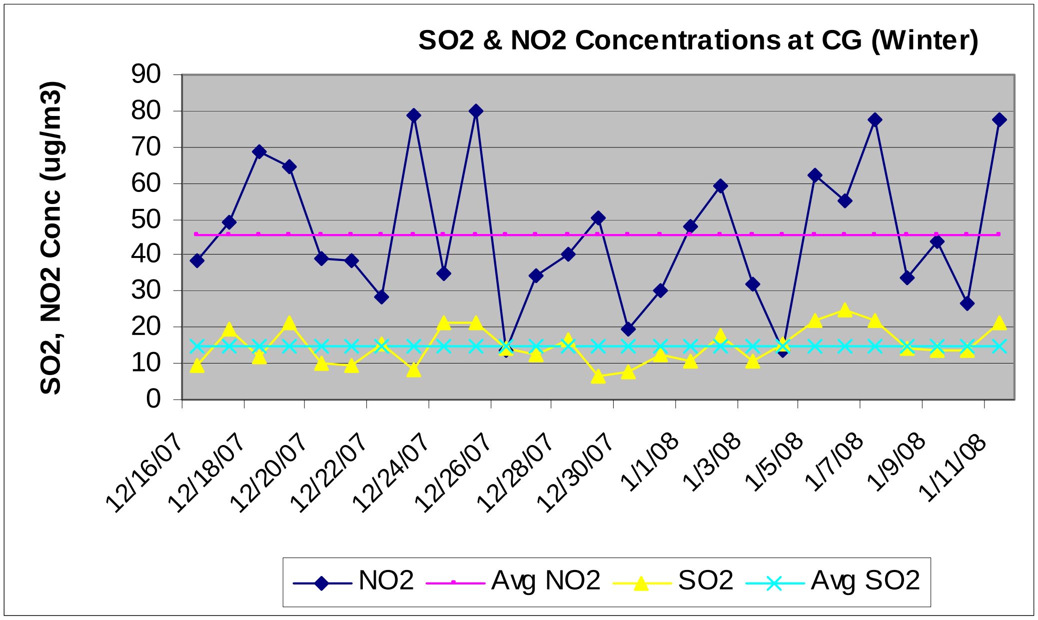


Figure 2.19(e): Observed SO_2 and NO_2 Concentrations at Colonelganj Site for Winter Season

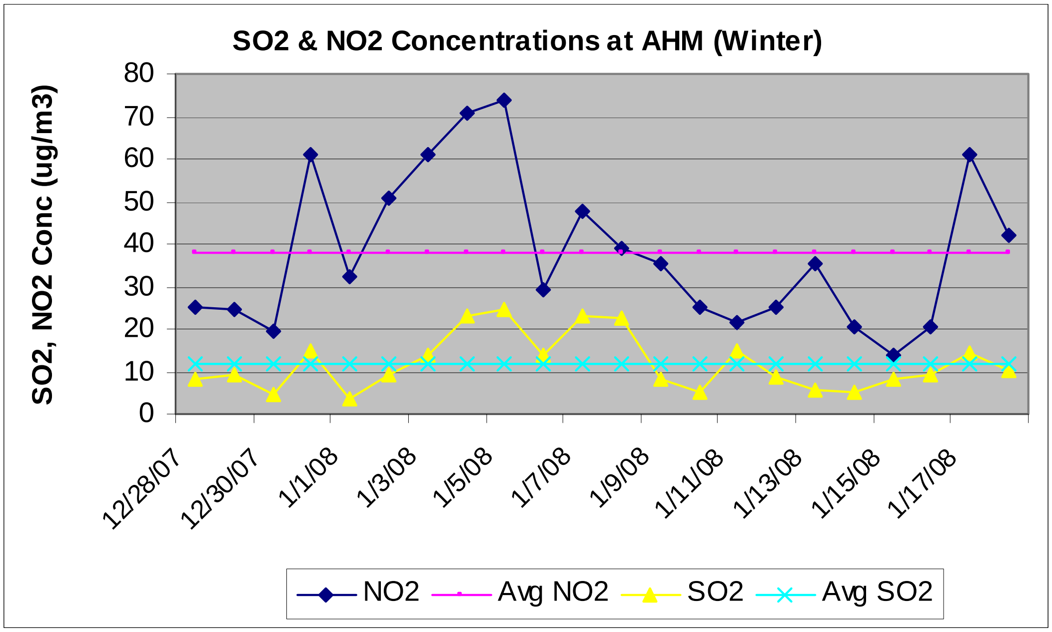


Figure 2.19(f): Observed SO_2 and NO_2 Concentrations at AHM Site for Winter Season

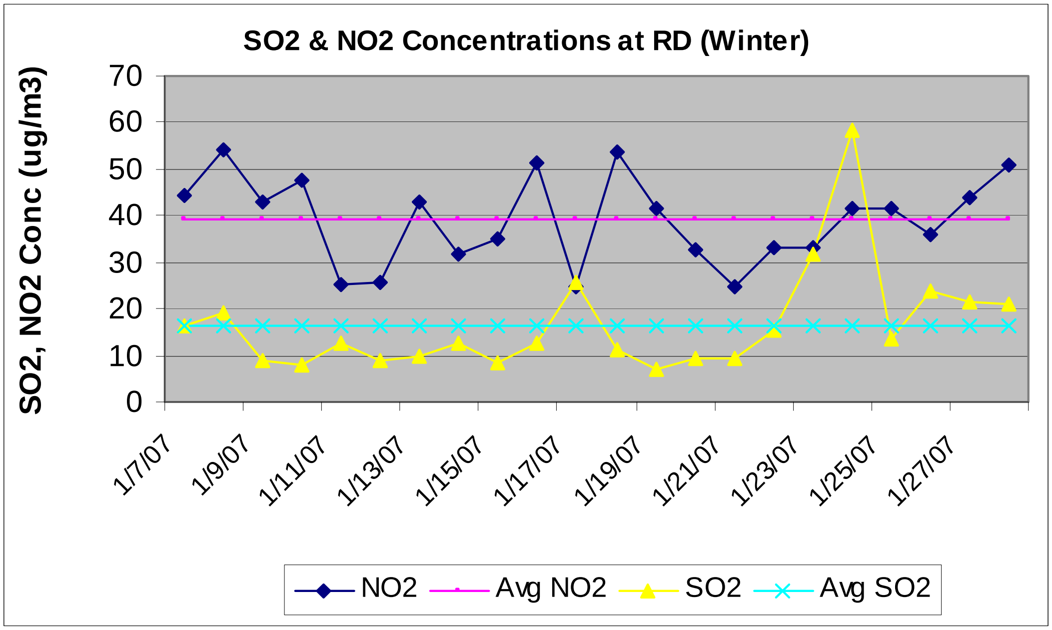


Figure 2.19(g): Observed SO_2 and NO_2 Concentrations at Ramadevi Site for Winter Season

2.4.3.3 Volatile Organic Compounds (VOCs) and Nonmethane Hydrocarbons (NMHC)

This section shows graphically the observed daily average concentrations of VOCs, NMHC along with benzene, toluene, ethyl benzene, m, p-xylene and o-xylene also for winter season. Figures 2.20(a), 2.20(b), 2.20(c), 2.20(d), 2.20(e), 2.20(f) and 2.20(g) show the variations of daily average concentrations of VOCs and NMHC for sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. It can be concluded that the dominant species of VOCs in Kanpur is toluene followed by benzene. The higher concentrations of VOCs are observed at sampling locations nearby traffic junctions and industrial activities.

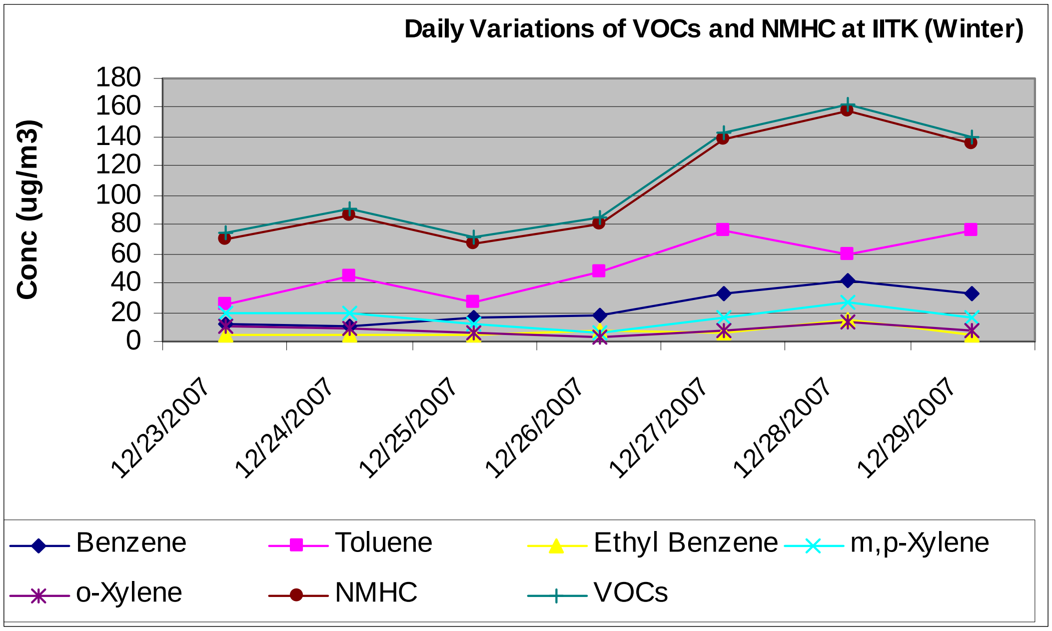


Figure 2.20(a): Observed VOC$_S$ and NMHC Concentrations at IIT Kanpur Site for Winter Season

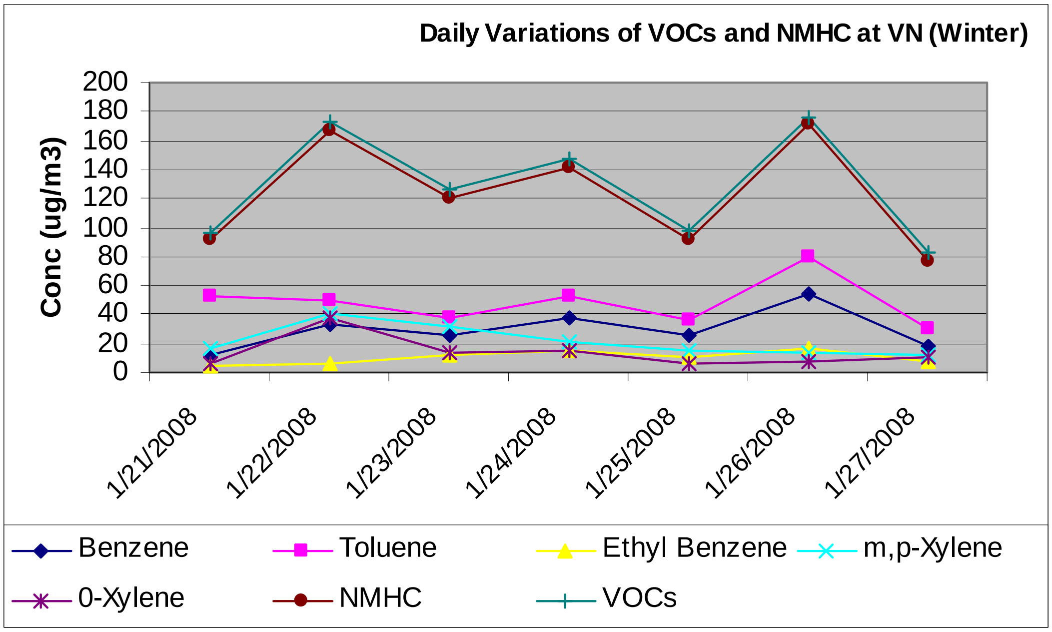


Figure 2.20(b): Observed VOC$_S$ and NMHC Concentrations at Vikashnagar Site for Winter Season

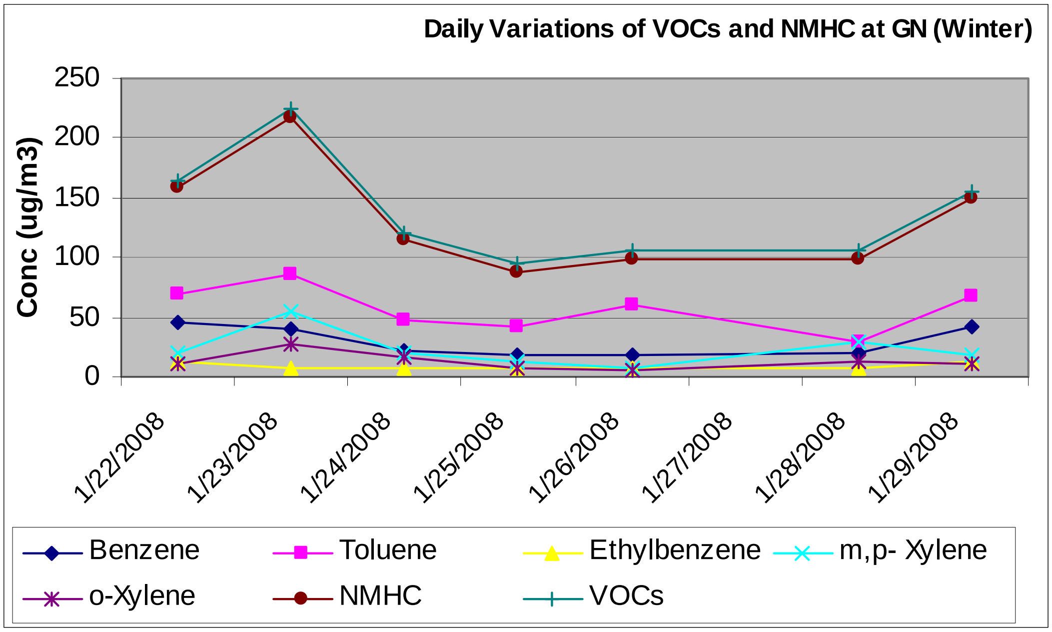


Figure 2.20(c): Observed VOC$_S$ and NMHC Concentrations at Govindnagar Site for Winter Season

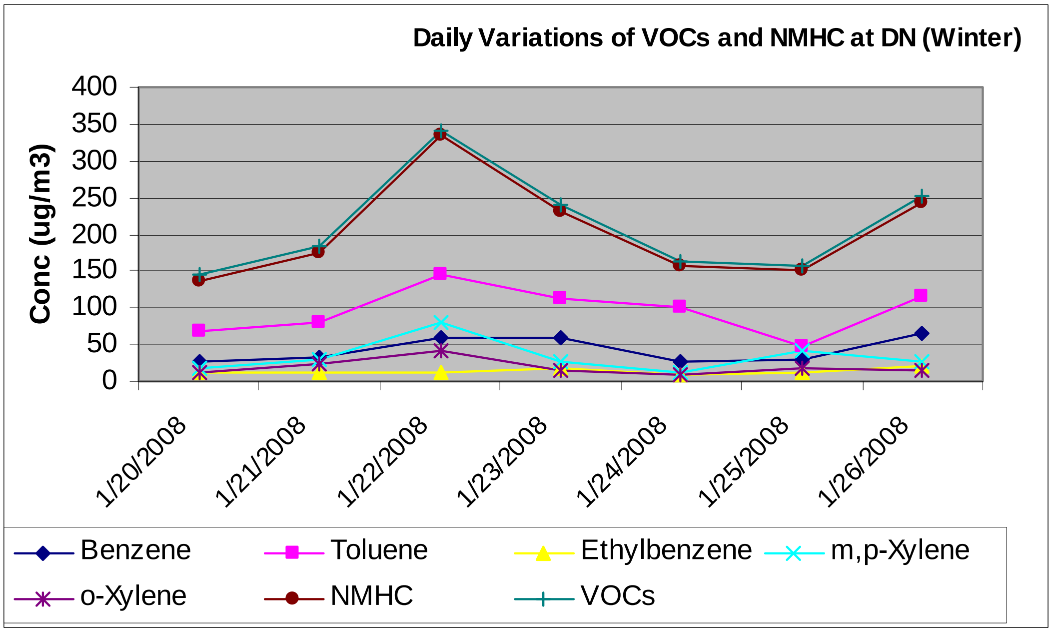


Figure 2.20(d): Observed VOC$_S$ and NMHC Concentrations at Dadanagar Site for Winter Season

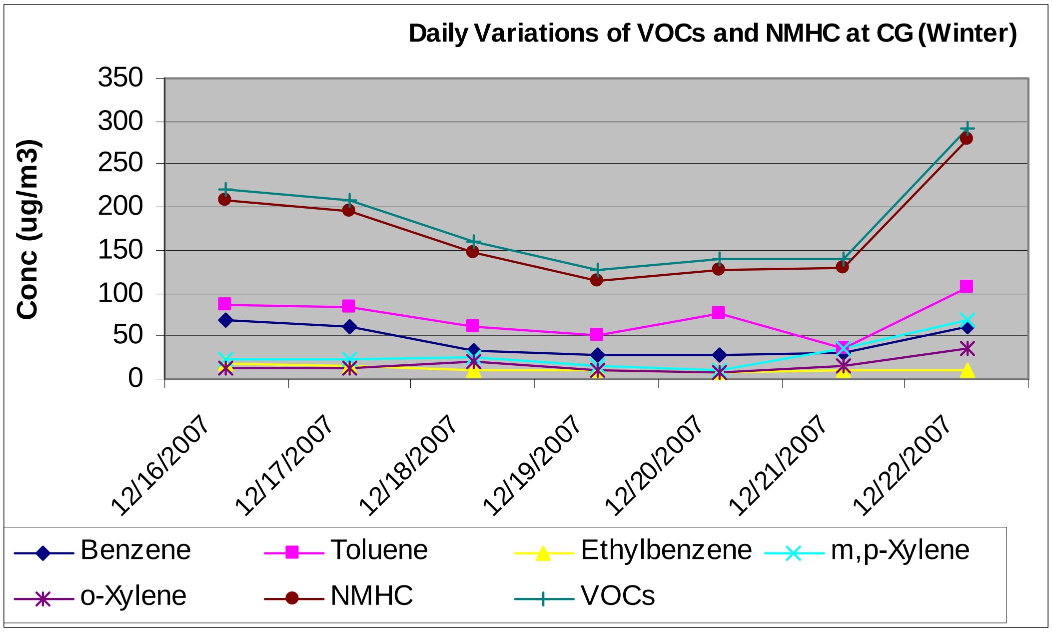


Figure 2.20(e): Observed VOC$_S$ and NMHC Concentrations at Colonelganj Site for Winter Season

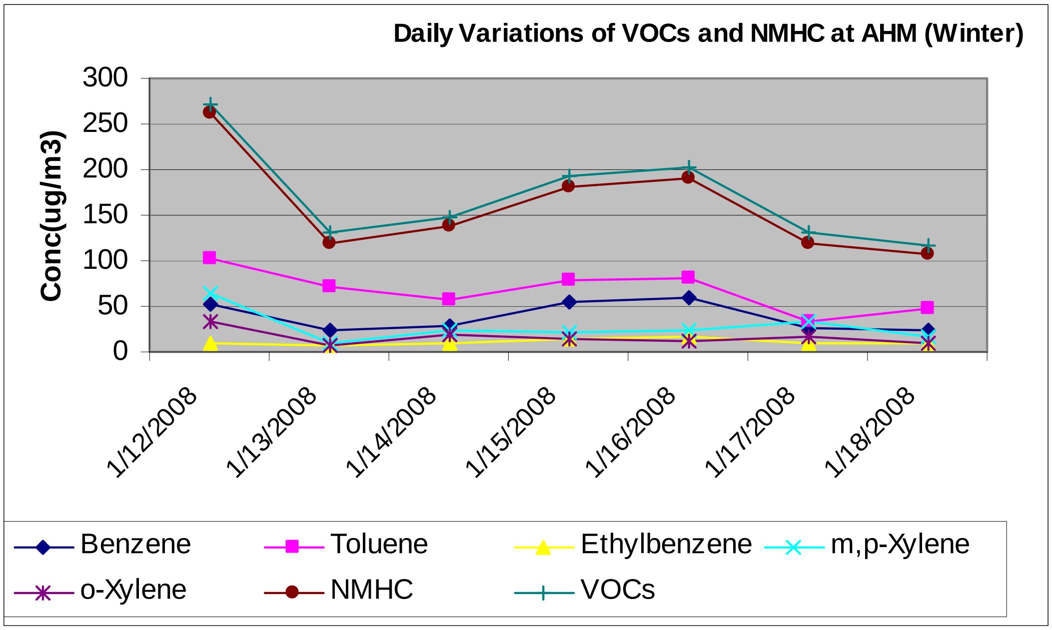


Figure 2.20(f): Observed VOC$_S$ and NMHC Concentrations at AHM Site for Winter Season

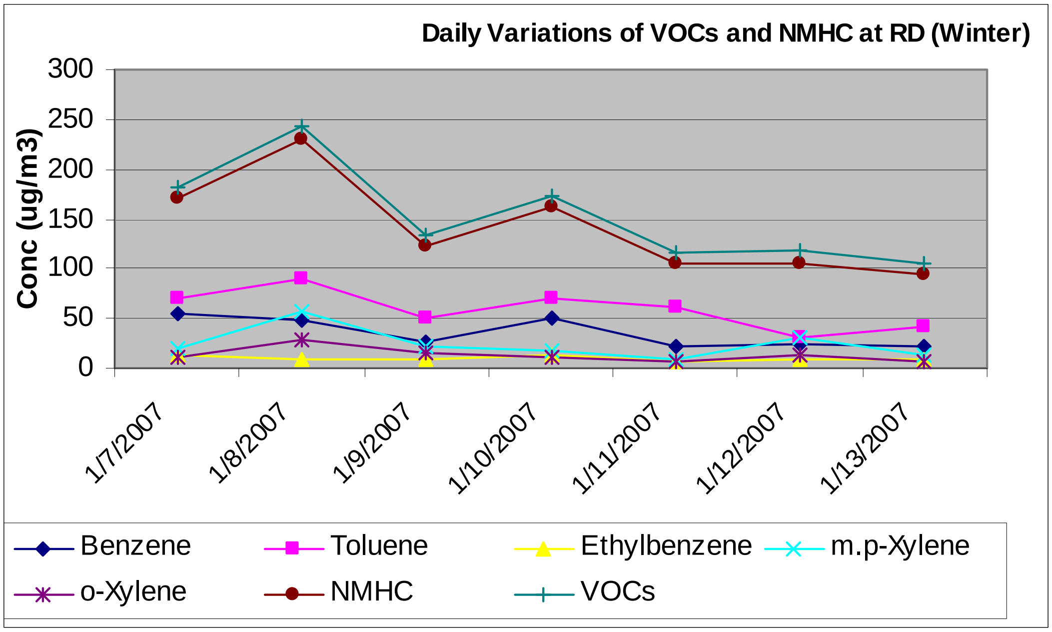


Figure 2.20(g): Observed VOC$_S$ and NMHC Concentrations at Ramadevi Site for Winter Season

2.4.3.4 Formaldehyde (HCHO)

This section shows the average concentrations of HCHO observed during different hours of the day for winter season. Figure 2.21 shows the observed concentration of the formaldehyde during different hours of the day for all sampling sites. From this figure it can be concluded that the maximum concentration is observed during the peak hours of the day. The maximum values are observed at sites nearby traffic junctions.

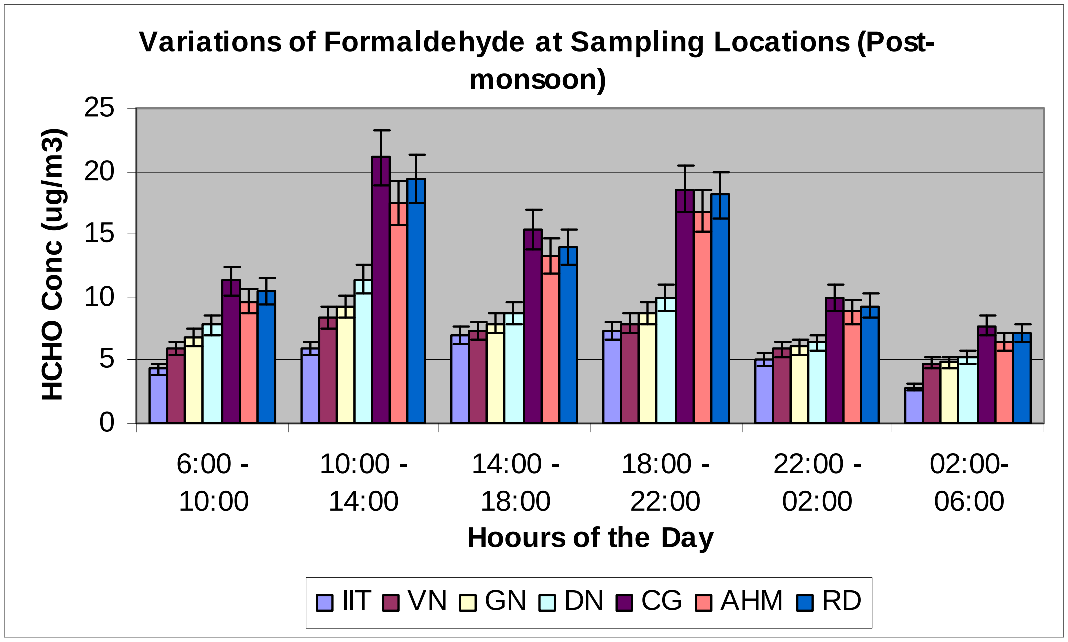


Figure 2.21: Observed HCHO Concentrations at all Sampling Sites for Winter Season

2.4.3.5 Carbon monoxide (CO)

This section presents the daily and hourly average concentrations CO observed at Colonelganj site (kerbside) for winter season. Figures 2.22(a) and 2.22(b) show the observed CO concentration on different day of the month and hours of the day respectively. From these figures it can be concluded that the maximum concentration is observed during the peak hours of the day (both in morning as well as evening).

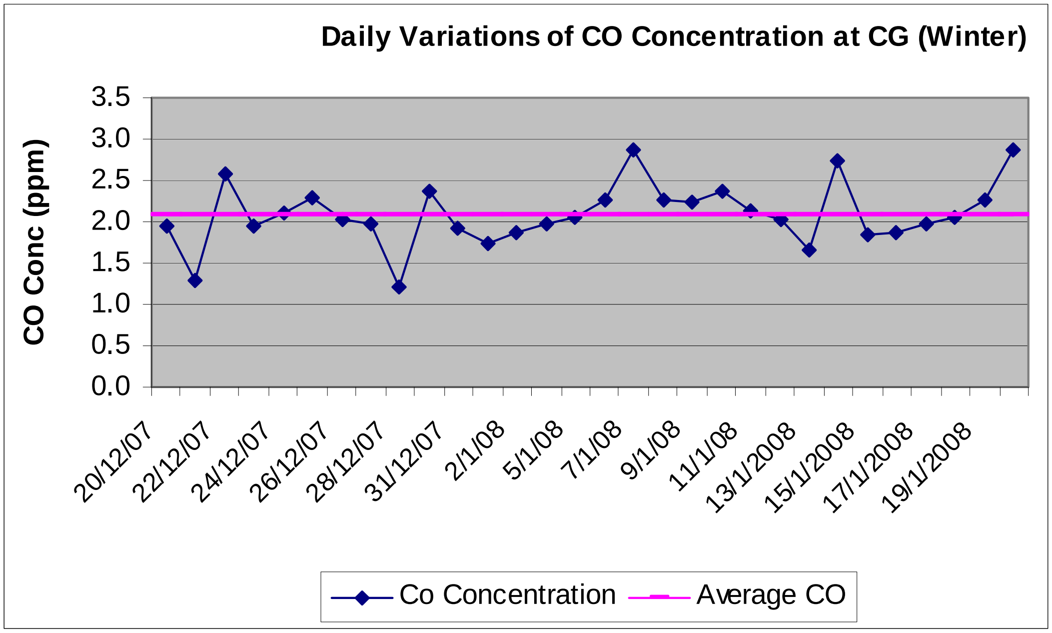


Figure 2.22(a): Observed CO Concentration (Daily Variations) at Colonelganj Site for Winter Season

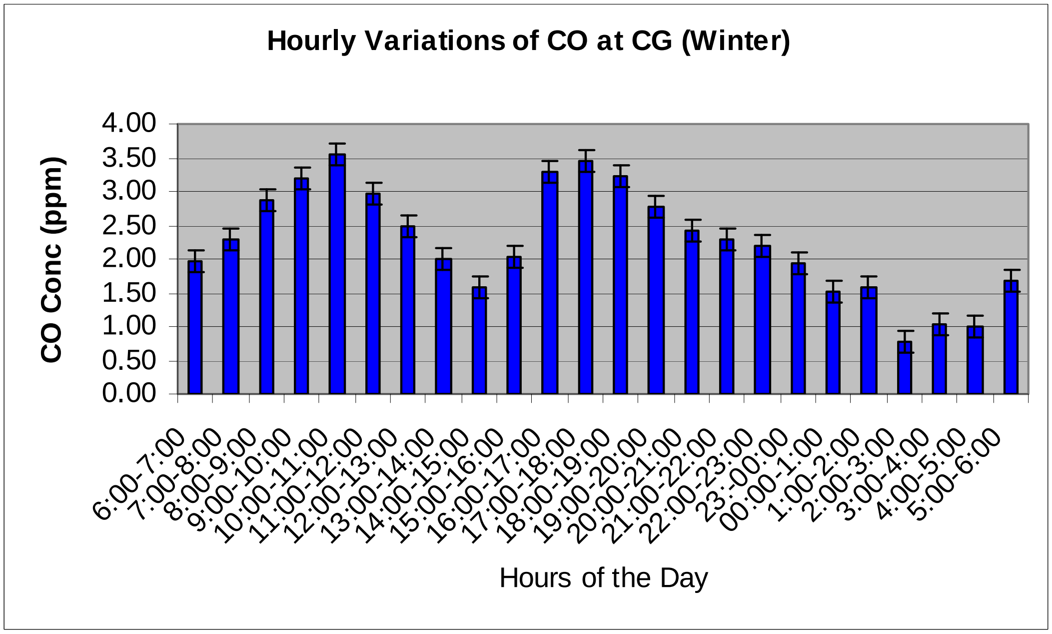


Figure 2.22(b): Observed CO Concentration (Hourly Variations) at Colonelganj Site for Winter Season

2.4.3.6 Polycyclic Aromatic Hydrocarbons (PAHs)

This section reveals the average concentrations of PAHs with some specific markers observed at all sampling locations of the city for winter season. Figure 2.23 shows the observed concentration of some markers of PAHs at all sampling locations. The compounds analyzed are fluorene, phenathrene, fluorathene, pyrene, benzo(a) anthracene, benzo(b) fluoranthene, benzo (a) pyrene, dibenzo(a,h) anthracene and benzo(ghi) perylene. From this figure it can be concluded that the maximum concentration is observed at Dadanagar site (industrial site) followed by Colonelganj and Ramadevi.

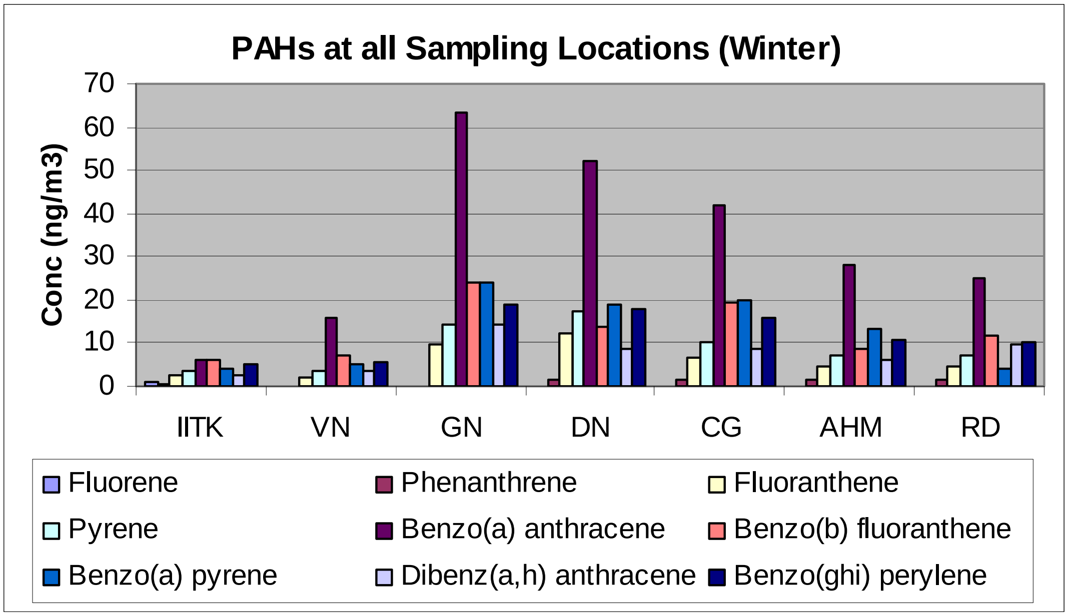


Figure 2.23: Observed PAHs Concentrations at all Sampling Sites for Winter Season

2.4.3.7 Brief Presentation of the Experimental Results and their Correlations (along with PM_{10} and $PM_{2.5}$Chemical Speciation)

A brief of the experimental results for all parameters during the winter season are presented statistically in tabular form in this section. Tables 2.17(a), 2.17(b), 2.17(c), 2.17(d), 2.17(e), 2.17(f) and 2.17(g) present the concentrations of SPM (from RDS), SPM (from HVS), PM_{10} (from RDS), PM_{10} (from 4-CSS), $PM_{2.5}$, NO_2, SO_2, OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Sn, Sb, Pb, P, S, Sc, Ti, Ga, Ge, Br, Rb, Sr, Y, Mo, Rh, Pd, Ag, Te, I, Cs, Ba, La, W, Au, benzene, toluene, ethyl benzene, m,p-xylene, o-xylene, VOCs and NMHC at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The results presented for elements, ions and carbon concentrations are from the PM_{10} chemical speciation. These tables contains the average, minimum, maximum, range, number of data points (24-hr average), range, 95% upper and lower confidence limits, standard deviation and coefficient of variance for all the parameters as mentioned above.

Tables 2.18(a), 2.18(b), 2.18(c), 2.18(d), 2.18(e), 2.18(f) and 2.18(g) present the correlation matrices among the four dust parameters, i.e. SPM, RSPM, PM_{10}, $PM_{2.5}$ at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during winter season. It can be concluded from these tables that PM_{10} is maintaining a good correlation with SPM and similar trend for $PM_{2.5}$ with PM_{10} for most of the cases.

Tables 2.19(a), 2.19(b), 2.19(c), 2.19(d), 2.19(e), 2.19(f) and 2.19(g) present the correlation matrices among the major species of PM_{10}, i.e. NH_4^+, NO_3^-, SO_4^{2-}, EC, OC, TC and with NO_2 and SO_2 at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during winter season. It can be concluded from these tables that NH_4^+ is maintaining a good correlation with NO_3^-, SO_4^{2-} and similar trend for EC with OC; and these species maintain a good correlation with PM_{10} overally. As SO_2 concentration is low for most of the sites, so it is difficult to draw any correlation of it with others. NO_2 is also maintaining a good correlation with NO_3^-.

A brief of the experimental results related to $PM_{2.5}$ chemical speciation of some major parameters are presented in Tables 2.20(a), 2.20(b), 2.20(c), 2.20(d), 2.20(e), 2.20(f) and 2.20(g) for the sampling sites at IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during winter season. The major species presented are OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. These tables contains the average, minimum, maximum, range, number of data points (24-hr average), range, 95% upper and lower confidence limits, standard deviation and coefficient for all the parameters as mentioned above.

Table 2.17(a): Experimental Results with PM_{10} Chemical Speciation of IIT Kanpur Site for Winter Season

IITK Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	361.6	382.5	190.1	204.7	172.1	22.7	7.9	5.2	10.1	13.71	8.54	7.25	14.94	0.74	0.33	44.7	16	60.8	8.18	5.25	6.57	2.97	15.1	4.94	8.5	32.47	0.131	3.05	0.017	0.009	0.12	0.402
Minimum	268.8	305.1	147.0	90.0	96.6	12.3	3.3	1.11	4.61	8.3	4.29	2.16	4.85	0.44	0.12	21.3	5.78	29.3	3.23	2	4.49	0.66	4.32	2.77	0.73	10.69	0.068	2.49	0.01	0.003	0.079	0.321
Maximum	506.4	506.4	280.5	313.4	235.9	27.7	21.8	16.5	26.2	22.08	13.9	13.9	29.63	1.17	0.61	75.8	31.2	103	11.8	7.51	8.75	4.06	24.6	10.1	14.8	58.98	0.208	4.57	0.026	0.033	0.279	0.598
Range	237.6	201.4	133.5	223.4	139.3	15.4	18.4	15.3	21.5	13.78	9.59	11.7	24.78	0.73	0.49	54.5	25.4	73.6	8.61	5.51	4.26	3.4	20.3	7.32	14	48.29	0.14	2.08	0.016	0.03	0.2	0.277
N of cases	27.0	27.0	27.0	27.0	7.0	27.0	27.0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
95% CI Upper	383.8	402.8	202.5	222.5	215.5	24.4	9.8	6.75	11.9	15.31	9.49	8.65	17.74	0.81	0.37	50.8	18.9	69.2	9.32	5.83	7.07	3.39	17.5	6.12	10.5	38.72	0.148	3.27	0.018	0.012	0.139	0.432
95% CI Lower	339.4	362.2	177.7	187.0	128.8	21.0	6.0	3.65	8.22	12.11	7.59	5.86	12.13	0.67	0.28	38.7	13.1	52.3	7.05	4.67	6.07	2.54	12.7	3.75	6.51	26.22	0.114	2.83	0.015	0.005	0.101	0.372
Standard Dev	56.1	51.3	31.4	44.9	46.9	4.3	4.7	3.92	4.64	4.042	2.4	3.52	7.093	0.17	0.12	15.3	7.22	21.5	2.86	1.47	1.27	1.07	6.06	2.99	5.04	15.8	0.042	0.57	0.004	0.008	0.048	0.075
C.V.	0.16	0.13	0.17	0.22	0.27	0.19	0.60	0.75	0.46	0.30	0.28	0.49	0.48	0.24	0.35	0.34	0.45	0.35	0.35	0.28	0.19	0.36	0.40	0.61	0.59	0.49	0.32	0.19	0.26	0.90	0.41	0.19

IITK Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.009	0.011	0.078	0.481	0.018	0.009	0.041	0.092	0.15	0.907	0.011	6.365	0.009	0.053	0.131	0.002	0.064	0.013	0.038	0.036	0.009	0.05	0.01	0.043	0.005	0.032	0.057	0.11	0.048	0.048	0.007	23.253	50.71	6.417	16.545	8.027	105	109.3
Minimum	0.004	0.007	0.014	0.209	0.002	0.004	0.007	0.004	0.082	0.109	0.009	1.944	0.009	0.038	0.003	0.001	0.036	0.007	0.023	0.015	0.008	0.034	0.005	0.036	0.004	0.01	0.007	0.071	0.012	0.013	0.002	9.853	25.609	3.782	5.685	3.319	67.3	71.69
Maximum	0.022	0.024	0.245	0.927	0.212	0.018	0.108	0.783	0.508	2.825	0.013	14.19	0.01	0.073	0.969	0.003	0.253	0.02	0.059	0.058	0.014	0.077	0.024	0.083	0.007	0.113	0.093	0.163	0.104	0.15	0.013	42.201	75.253	15.351	26.844	13.53	158.1	162.5
Range	0.018	0.017	0.231	0.718	0.21	0.014	0.101	0.779	0.426	2.716	0.004	12.25	0.001	0.035	0.966	0.002	0.217	0.013	0.036	0.043	0.006	0.043	0.019	0.047	0.003	0.103	0.086	0.092	0.092	0.137	0.011	32.348	49.644	11.569	21.159	10.211	90.79	90.79
N of cases	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	7	7	7	7	7	7	7
95% CI Upper	0.011	0.012	0.102	0.565	0.034	0.01	0.056	0.161	0.192	1.247	0.012	7.543	0.01	0.057	0.21	0.002	0.08	0.015	0.042	0.044	0.01	0.056	0.013	0.05	0.006	0.043	0.071	0.121	0.064	0.06	0.009	11.726	31.748	2.604	10.473	5.057	70.32	74.71
95% CI Lower	0.008	0.009	0.054	0.397	0.002	0.008	0.025	0.023	0.108	0.567	0.011	5.186	0.009	0.049	0.053	0.001	0.048	0.012	0.034	0.028	0.008	0.043	0.007	0.037	0.005	0.022	0.044	0.1	0.033	0.036	0.005	34.78	69.673	10.231	22.616	10.997	139.6	144
Standard Dev	0.004	0.003	0.061	0.212	0.04	0.003	0.038	0.174	0.106	0.859	0.001	2.978	0	0.01	0.198	0.001	0.041	0.003	0.01	0.02	0.002	0.016	0.007	0.017	0.001	0.026	0.034	0.027	0.04	0.03	0.005	12.464	20.504	4.123	6.565	3.212	37.44	37.44
C.V.	0.46	0.30	0.78	0.44	2.19	0.32	0.94	1.89	0.71	0.95	0.11	0.47	0.05	0.19	1.51	0.44	0.63	0.25	0.27	0.55	0.25	0.32	0.70	0.39	0.21	0.79	0.59	0.24	0.82	0.64	0.70	0.54	0.40	0.64	0.40	0.40	0.36	0.34

Table 2.17(b): Experimental Results with PM_{10} Chemical Speciation of Vikashnagar Site for Winter Season

VN Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	429.3	448.9	205.5	226.4	207.5	48.7	14.0	8.34	15.8	18.59	10.3	6.93	19.38	1.09	0.39	59.9	20.9	80.8	7.65	5.53	6.09	4.18	18.5	3.32	10.8	41.11	0.074	5.3	0.009	0.006	0.057	0.18
Minimum	209.7	177.6	122.0	134.9	134.6	18.9	4.8	3.19	7.72	7.91	5.05	2.82	6.02	0.56	0	27	6.92	33.9	1.11	3.64	2.73	0.2	9.4	1.73	1.15	17.96	0	1.24	0.002	0.005	0.016	0.055
Maximum	780.9	666.1	320.5	364.7	299.5	77.0	28.7	25.3	29.2	30.74	15.6	12.4	36.05	2.28	2.04	111	37.7	147	20.1	6.93	8.56	5.03	25.9	4.91	22.1	51.58	0.199	11.2	0.022	0.009	0.124	0.415
Range	571.2	488.5	198.6	229.8	164.9	58.1	23.9	22.2	21.5	22.83	10.5	9.57	30.03	1.72	2.04	84.2	30.7	113	19	3.29	5.84	4.83	16.5	3.18	20.9	33.62	0.199	9.92	0.02	0.004	0.108	0.36
N of cases	26.0	26.0	26.0	26.0	7.0	26.0	26.0	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26
95% CI Upper	491.4	501.0	229.2	251.4	274.7	55.5	16.6	10.6	18.5	21.61	11.8	8.25	23.44	1.24	0.56	70.1	25.1	95.1	10.6	6.1	6.88	4.72	20	3.83	13.2	44.82	0.095	6.6	0.012	0.007	0.072	0.229
95% CI Lower	367.2	396.7	181.9	201.3	140.2	41.8	11.4	6.11	13.1	15.56	8.82	5.6	15.33	0.93	0.21	49.7	16.6	66.4	4.67	4.95	5.3	3.63	16.9	2.8	8.53	37.41	0.053	4	0.007	0.006	0.041	0.132
Standard Dev	153.7	129.1	58.5	62.0	72.7	16.9	6.5	5.53	6.65	7.491	3.64	3.28	10.04	0.38	0.44	25.2	10.6	35.5	7.37	1.42	1.96	1.35	3.84	1.28	5.73	9.167	0.051	3.21	0.006	0.001	0.039	0.12
C.V.	0.36	0.29	0.29	0.27	0.35	0.35	0.46	0.66	0.42	0.40	0.35	0.47	0.52	0.35	1.15	0.42	0.51	0.44	0.96	0.26	0.32	0.32	0.21	0.39	0.53	0.22	0.69	0.61	0.68	0.23	0.69	0.66

VN Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.008	0.007	0.013	0.23	0.009	0.01	0.064	0.164	0.154	1.302	0.012	8.252	0.009	0.131	0.14	0.002	0.061	0.015	0.06	0.034	0.01	0.049	0.013	0.045	0.006	0.04	0.076	0.209	0.06	0.065	0.008	29.47	48.241	10.451	21.349	13.444	123	128.4
Minimum	0.004	0.004	0.008	0.058	0.003	0.003	0.052	0.038	0.112	0.22	0.011	3.116	0.009	0.032	0.025	0.001	0.025	0.004	0.019	0.014	0.008	0.034	0.005	0.026	0.004	0.01	0.06	0.075	0.012	0.013	0.002	11.608	30.031	5.042	11.792	5.831	77.14	82.58
Maximum	0.015	0.022	0.03	0.919	0.038	0.017	0.192	0.516	0.661	3.762	0.015	21.7	0.01	0.233	0.45	0.003	0.104	0.023	0.129	0.071	0.014	0.089	0.024	0.077	0.007	0.113	0.121	0.392	0.125	0.15	0.013	54.529	79.253	17.051	40.815	36.987	171.2	176.6
Range	0.011	0.018	0.022	0.861	0.035	0.014	0.14	0.478	0.549	3.542	0.004	18.59	0.001	0.201	0.425	0.002	0.079	0.019	0.11	0.057	0.006	0.055	0.019	0.051	0.003	0.103	0.061	0.317	0.113	0.137	0.011	42.921	49.222	12.009	29.024	31.156	94.06	94.06
N of cases	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	7	7	7	7	7	7	7
95% CI Upper	0.01	0.009	0.016	0.316	0.013	0.012	0.077	0.238	0.206	1.779	0.013	9.942	0.01	0.157	0.18	0.002	0.072	0.018	0.077	0.045	0.01	0.054	0.017	0.052	0.006	0.05	0.085	0.264	0.077	0.079	0.01	16.426	33.074	6.217	11.334	3.296	87.64	93.08
95% CI Lower	0.006	0.006	0.011	0.144	0.005	0.008	0.051	0.09	0.101	0.824	0.012	6.562	0.009	0.105	0.1	0.002	0.051	0.013	0.044	0.023	0.009	0.045	0.01	0.038	0.005	0.03	0.068	0.154	0.043	0.051	0.006	42.513	63.407	14.685	31.363	23.592	158.3	163.7
Standard Dev	0.005	0.004	0.006	0.213	0.009	0.004	0.033	0.184	0.129	1.182	0.002	4.184	0	0.064	0.099	0.001	0.025	0.005	0.04	0.028	0.002	0.011	0.008	0.017	0.001	0.025	0.021	0.136	0.042	0.034	0.005	14.104	16.399	4.578	10.828	10.972	38.18	38.19
C.V.	0.63	0.54	0.42	0.93	1.08	0.45	0.51	1.12	0.84	0.91	0.13	0.51	0.05	0.49	0.71	0.51	0.41	0.35	0.67	0.82	0.24	0.22	0.61	0.39	0.22	0.63	0.28	0.65	0.71	0.53	0.66	0.48	0.34	0.44	0.51	0.82	0.31	0.30

Table 2.17(c): Experimental Results with PM_{10} Chemical Speciation of Govindnagar Site for Winter Season

GN Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	444.6	467.4	189.2	239.8	185.2	39.7	8.9	10	15.8	25.78	13.5	3.08	20.24	1.41	1.13	68.2	22.8	91	8.73	4.77	7.57	4.19	19.2	5.08	16.1	48.54	0.208	6	0.024	0.029	0.199	0.495
Minimum	217.1	228.3	86.4	121.6	153.5	14.1	5.2	2.56	4.17	6.57	2.51	0	3.43	0.33	0.04	16.6	4	20.6	3.17	0	5.84	0.87	6.43	1.08	2.62	6.225	0	0	0.008	0.008	0.035	0
Maximum	688.0	758.6	480.6	349.2	268.9	60.3	23.6	26.8	31.2	38.96	19.3	14.1	40.06	14.6	12.1	130	58.5	172	26.4	7.88	9.51	6.9	25.8	11.4	34.6	56.31	0.787	28.1	0.117	0.167	0.776	0.966
Range	470.9	530.3	394.3	227.6	115.4	46.2	18.5	24.2	27	32.39	16.8	14.1	36.63	14.2	12	113	54.5	151	23.2	7.88	3.68	6.04	19.4	10.3	32	50.09	0.787	28.1	0.109	0.159	0.741	0.966
N of cases	27.0	27.0	27.0	27.0	7.0	27.0	27.0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
95% CI Upper	494.8	520.4	219.8	259.2	225.2	45.5	10.8	12.2	18	28.47	14.7	4.97	23.43	2.54	2.17	77.1	27.1	103	11.3	5.41	8.06	5.18	21	6.54	19.9	52.64	0.288	8.74	0.033	0.044	0.271	0.599
95% CI Lower	394.4	414.4	158.5	220.5	145.3	33.9	6.9	7.85	13.7	23.08	12.2	1.19	17.05	0.29	0.08	59.3	18.5	78.8	6.14	4.13	7.08	3.21	17.5	3.62	12.2	44.43	0.127	3.27	0.015	0.014	0.127	0.391
Standard Dev	126.9	134.1	77.4	48.9	43.2	14.7	4.9	5.5	5.47	6.818	3.17	4.78	8.063	2.84	2.64	22.4	10.9	30.8	6.56	1.61	1.23	2.49	4.46	3.69	9.72	10.38	0.203	6.92	0.022	0.039	0.182	0.263
C.V.	0.29	0.29	0.41	0.20	0.23	0.37	0.56	0.55	0.35	0.27	0.24	1.55	0.40	2.01	2.34	0.33	0.48	0.34	0.75	0.34	0.16	0.60	0.23	0.73	0.61	0.21	0.98	1.15	0.92	1.34	0.92	0.53

GN Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.015	0.018	0.054	0.396	0.055	0.012	0.146	0.126	0.338	0.869	0.011	7.477	0.009	0.13	0.205	0.002	0.082	0.027	0.07	0.057	0.011	0.054	0.014	0.048	0.006	0.042	0.081	0.268	0.093	0.082	0.009	29.574	57.431	9.148	23.222	13.09	132.5	138.4
Minimum	0.006	0.005	0.02	0.093	0.005	0.004	0.076	0.05	0.062	0.286	0.011	2.98	0.009	0.015	0.034	0.001	0.012	0.007	0.028	0.016	0.008	0.054	0.005	0.026	0.004	0.01	0.06	0.112	0.012	0.013	0.002	18.75	28.868	6.597	7.782	5.624	88.39	94.29
Maximum	0.058	0.057	0.191	0.959	0.275	0.035	0.443	0.248	1.039	1.967	0.012	13.44	0.01	0.242	0.996	0.003	0.653	0.093	0.175	0.089	0.014	0.055	0.024	0.089	0.007	0.113	0.173	0.582	0.135	0.15	0.014	45.806	86.465	13.434	54.977	28.164	217.7	223.6
Range	0.052	0.052	0.171	0.866	0.27	0.031	0.367	0.198	0.977	1.681	0.001	10.46	0.001	0.227	0.962	0.002	0.641	0.086	0.147	0.073	0.006	0.001	0.019	0.063	0.003	0.103	0.113	0.47	0.123	0.137	0.012	27.056	57.597	6.837	47.196	22.54	129.3	129.3
N of cases	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	7	7	7	7	7	7	7
95% CI Upper	0.021	0.024	0.07	0.503	0.084	0.017	0.181	0.154	0.468	1.079	0.012	8.615	0.009	0.154	0.288	0.002	0.132	0.034	0.086	0.068	0.012	0.054	0.018	0.057	0.006	0.051	0.093	0.324	0.109	0.097	0.011	18.242	39.505	6.725	8.898	6.166	89.96	95.86
95% CI Lower	0.01	0.013	0.037	0.289	0.025	0.008	0.11	0.098	0.207	0.658	0.011	6.34	0.009	0.106	0.122	0.002	0.032	0.019	0.054	0.045	0.01	0.054	0.011	0.04	0.005	0.032	0.07	0.213	0.076	0.067	0.007	40.905	75.358	11.571	37.546	20.015	175	180.9
Standard Dev	0.013	0.013	0.042	0.271	0.074	0.012	0.09	0.07	0.329	0.533	0.001	2.875	0	0.061	0.209	0.001	0.127	0.019	0.04	0.029	0.003	0	0.009	0.021	0.001	0.024	0.029	0.14	0.042	0.039	0.005	12.252	19.383	2.62	15.488	7.487	45.96	45.96
C.V.	0.86	0.73	0.79	0.68	1.36	0.94	0.62	0.56	0.97	0.61	0.04	0.39	0.05	0.47	1.02	0.40	1.55	0.70	0.57	0.52	0.27	0.01	0.60	0.44	0.22	0.57	0.36	0.52	0.45	0.47	0.55	0.41	0.34	0.29	0.67	0.57	0.35	0.33

Table 2.17(d): Experimental Results with PM_{10} Chemical Speciation of Dadanagar Site for Winter Season

DN Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	602.6	626.8	349.8	396.3	304.8	35.1	25.5	25.7	26.3	40.89	21.1	13.6	39.85	1.08	0.94	128	41.9	169	14.2	9.5	10.9	3.29	31.5	9.19	34	66.25	0.2	4.95	0.037	0.063	0.252	0.595
Minimum	344.9	371.1	252.8	220.7	220.3	21.5	8.6	7.85	14.8	27.58	15	0	17.1	0.4	0.19	65.8	17.7	85	2.27	3.13	5.77	0.31	19.5	4.1	19.1	42.37	0.095	1.43	0.014	0.02	0.145	0.31
Maximum	856.7	780.8	566.7	630.6	471.3	65.9	67.9	76.8	44.8	53.71	52.7	59.3	66.56	7.62	10.3	221	68.7	290	40.7	27.4	19.3	5.79	44	17	40.1	70.25	0.415	8.67	0.062	0.203	0.555	0.877
Range	511.8	409.7	313.8	409.9	251.0	44.5	59.4	69	30.1	26.13	37.7	59.3	49.46	7.22	10.1	155	51	205	38.4	24.3	13.5	5.48	24.5	12.9	21	27.88	0.32	7.24	0.048	0.183	0.41	0.567
N of cases	23.0	23.0	23.0	23.0	7.0	23.0	23.0	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23
95% CI Upper	663.3	673.7	393.5	451.3	380.6	40.0	32.4	34.7	30.2	43.84	24.4	21.4	46.25	1.71	1.82	147	48.2	193	18.3	11.5	12.2	4.12	34.8	11.3	37.4	68.71	0.241	5.66	0.044	0.082	0.307	0.67
95% CI Lower	541.9	579.9	306.1	341.3	229.1	30.2	18.5	16.7	22.4	37.94	17.7	5.75	33.44	0.46	0.05	108	35.5	146	10.1	7.47	9.64	2.46	28.1	7.12	30.7	63.8	0.159	4.24	0.03	0.044	0.197	0.519
Standard Dev	140.3	108.5	101.2	127.2	81.9	11.4	16.1	20.7	9.07	6.822	7.8	18.1	14.81	1.44	2.04	44.5	14.7	54.8	9.44	4.7	2.92	1.92	7.7	4.78	7.82	5.678	0.095	1.64	0.016	0.044	0.127	0.175
C.V.	0.23	0.17	0.29	0.32	0.27	0.32	0.63	0.81	0.35	0.17	0.37	1.33	0.37	1.33	2.18	0.35	0.35	0.32	0.67	0.49	0.27	0.58	0.25	0.52	0.23	0.09	0.48	0.33	0.43	0.70	0.50	0.29

DN Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.015	0.035	0.064	0.572	0.229	0.005	0.31	0.281	0.534	1.578	0.011	8.444	0.009	0.325	0.323	0.007	0.089	0.02	0.037	0.107	0.012	0.055	0.038	0.073	0.007	0.048	0.128	0.303	0.123	0.165	0.013	42.783	95.547	13.234	33.595	18.937	204.1	211.5
Minimum	0.003	0.017	0.026	0.009	0.014	0.003	0.071	0.055	0.033	0.309	0.011	0.737	0.009	0.102	0.008	0.002	0.012	0.007	0.016	0.013	0.008	0.037	0.005	0.014	0.004	0.01	0.06	0.093	0.012	0.042	0.002	27.125	48.027	9.544	11.257	8.135	136.8	144.2
Maximum	0.03	0.182	0.113	0.986	0.909	0.018	0.985	0.761	0.984	3.569	0.012	15.82	0.01	0.581	0.611	0.014	0.564	0.038	0.06	0.344	0.014	0.076	0.105	0.097	0.01	0.113	0.364	0.612	0.198	0.292	0.024	66.266	143.85	19.434	79.534	40.744	333.7	341
Range	0.027	0.165	0.087	0.977	0.895	0.015	0.914	0.706	0.951	3.26	0.001	15.09	0.001	0.479	0.603	0.012	0.552	0.031	0.044	0.331	0.006	0.039	0.1	0.083	0.006	0.103	0.304	0.519	0.186	0.25	0.022	39.142	95.822	9.89	68.277	32.608	196.8	196.8
N of cases	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	23	7	7	7	7	7	7	7
95% CI Upper	0.018	0.053	0.074	0.693	0.333	0.007	0.419	0.371	0.68	1.964	0.012	10.38	0.01	0.383	0.409	0.01	0.141	0.025	0.042	0.146	0.013	0.061	0.056	0.084	0.008	0.058	0.17	0.395	0.151	0.204	0.016	26.39	65.723	9.729	12.873	8.92	139.2	146.6
95% CI Lower	0.011	0.018	0.053	0.452	0.124	0.004	0.201	0.19	0.387	1.193	0.011	6.507	0.009	0.266	0.237	0.005	0.037	0.015	0.032	0.069	0.011	0.05	0.02	0.061	0.006	0.037	0.087	0.212	0.095	0.126	0.01	59.176	125.37	16.739	54.317	28.955	269	276.4
Standard Dev	0.008	0.04	0.025	0.279	0.241	0.004	0.253	0.21	0.339	0.892	0	4.48	0	0.135	0.199	0.006	0.12	0.012	0.011	0.089	0.003	0.012	0.042	0.027	0.002	0.024	0.095	0.211	0.065	0.091	0.007	17.725	32.247	3.79	22.406	10.831	70.2	70.2
C.V.	0.54	1.13	0.39	0.49	1.06	0.73	0.82	0.75	0.64	0.57	0.04	0.53	0.05	0.42	0.62	0.76	1.35	0.60	0.29	0.83	0.22	0.22	1.10	0.37	0.34	0.50	0.74	0.70	0.53	0.55	0.51	0.41	0.34	0.29	0.67	0.57	0.34	0.33

Table 2.17(e): Experimental Results with PM_{10} Chemical Speciation of Colonelganj Site for Winter Season

CG Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	563.9	578.9	236.1	291.5	215.6	45.8	15.0	14.4	23.2	26.25	13.1	10.7	31.8	0.99	0.34	87.7	33.1	121	14.3	7.51	9.81	3.15	22.5	5.89	36.6	34.15	0.208	6.31	0.018	0.032	0.186	0.592
Minimum	339.3	366.6	113.1	152.2	160.3	13.4	6.7	2.6	8.63	12.11	8.97	3.64	9.19	0.56	0.05	36.5	10.2	46.7	4.29	5.59	3.78	1.91	14.9	0.98	19.4	24.4	0	3.45	0.012	0.007	0.106	0.414
Maximum	928.3	917.9	389.9	476.5	302.8	79.9	25.1	29.4	50	67.42	27.1	19.2	62.24	3.1	0.56	184	63.5	242	21.1	15.6	22.7	5.81	29.5	12.5	48.3	53.64	0.683	12.1	0.048	0.134	0.758	0.905
Range	589.0	551.3	276.8	324.3	142.4	66.6	18.4	26.8	41.4	55.31	18.1	15.6	53.05	2.54	0.51	148	53.3	195	16.8	9.98	18.9	3.9	14.6	11.5	29	29.24	0.683	8.62	0.036	0.127	0.652	0.491
N of cases	27.0	27.0	27.0	27.0	8.0	27.0	27.0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27
95% CI Upper	628.0	645.4	267.2	330.3	258.1	53.6	17.0	17.5	27.5	30.86	14.9	12.5	37.77	1.18	0.39	102	39.2	141	17.3	9.06	13.2	3.85	24.4	7.47	41.2	38.17	0.271	7.13	0.021	0.044	0.237	0.648
95% CI Lower	499.8	512.4	205.0	252.7	173.2	38.0	12.9	11.4	18.8	21.63	11.4	9.02	25.82	0.8	0.29	73.4	27	101	11.4	5.95	6.42	2.45	20.6	4.32	32	30.12	0.145	5.5	0.014	0.02	0.135	0.536
Standard Dev	162.0	168.0	78.7	98.1	50.7	19.8	5.2	7.67	11.1	11.66	4.4	4.35	15.11	0.48	0.13	36.2	15.4	51.2	7.54	3.92	8.56	1.77	4.85	3.98	11.6	10.17	0.16	2.06	0.009	0.031	0.128	0.141
C.V.	0.29	0.29	0.33	0.34	0.24	0.43	0.35	0.53	0.48	0.44	0.34	0.41	0.48	0.48	0.38	0.41	0.47	0.42	0.53	0.52	0.87	0.56	0.22	0.68	0.32	0.30	0.77	0.33	0.49	0.96	0.69	0.24

CG Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC	CO (ppm)
Mean	0.015	0.024	0.124	0.448	0.041	0.009	0.147	0.197	0.195	1.561	0.011	7.734	0.009	0.107	0.198	0.002	0.072	0.024	0.053	0.043	0.009	0.057	0.03	0.058	0.006	0.046	0.111	0.235	0.11	0.095	0.01	43.97	71.158	11.334	28.772	16.219	171.5	184	2.088
Minimum	0.004	0.007	0.034	0.245	0.004	0.005	0.041	0.047	0.044	0.011	0.011	0.39	0.009	0.051	0.059	0.001	0.025	0.013	0.032	0.005	0.008	0.036	0.005	0.018	0.004	0.01	0.06	0.062	0.012	0.013	0.002	27.877	35.768	8.174	9.641	6.968	114.2	126.7	1.2
Maximum	0.037	0.213	1.043	0.923	0.285	0.025	0.279	0.494	0.714	3.694	0.012	23.59	0.01	0.177	0.54	0.003	0.176	0.053	0.13	0.12	0.014	0.163	0.105	0.237	0.009	0.113	0.264	0.625	0.225	0.15	0.014	68.105	107.13	16.644	68.117	34.895	279.7	292.2	2.87
Range	0.033	0.206	1.009	0.678	0.281	0.02	0.238	0.447	0.67	3.683	0.001	23.2	0.001	0.126	0.481	0.002	0.151	0.04	0.098	0.115	0.006	0.127	0.1	0.219	0.005	0.103	0.204	0.563	0.213	0.137	0.012	40.228	71.363	8.471	58.476	27.927	165.5	165.5	1.67
N of cases	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	7	7	7	7	7	7	7	30
95% CI Upper	0.018	0.039	0.205	0.543	0.066	0.011	0.181	0.252	0.273	1.99	0.012	9.913	0.01	0.123	0.274	0.002	0.087	0.027	0.061	0.057	0.01	0.067	0.044	0.083	0.006	0.053	0.139	0.296	0.133	0.111	0.012	27.122	48.947	8.333	11.025	7.639	116.4	129	1.946
95% CI Lower	0.012	0.009	0.042	0.352	0.016	0.007	0.113	0.141	0.116	1.132	0.011	5.555	0.009	0.092	0.122	0.002	0.057	0.02	0.044	0.029	0.009	0.047	0.015	0.032	0.005	0.038	0.083	0.173	0.088	0.079	0.008	60.818	93.368	14.336	46.52	24.798	226.5	239	2.231
Standard Dev	0.008	0.039	0.206	0.242	0.064	0.006	0.086	0.141	0.199	1.084	0	5.509	0.001	0.04	0.192	0.001	0.039	0.008	0.021	0.034	0.002	0.025	0.037	0.066	0.002	0.019	0.071	0.155	0.057	0.04	0.005	18.217	24.016	3.246	19.19	9.277	59.5	59.5	0.382
C.V.	0.55	1.62	1.67	0.54	1.55	0.65	0.59	0.72	1.02	0.70	0.04	0.71	0.05	0.37	0.97	0.44	0.54	0.34	0.39	0.80	0.23	0.44	1.26	1.14	0.27	0.41	0.63	0.66	0.52	0.42	0.50	0.41	0.34	0.29	0.67	0.57	0.35	0.32	0.18

Table 2.17(f): Experimental Results with PM_{10} Chemical Speciation of AHM Site for Winter Season

AHM Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	550.0	562.5	205.4	276.0	198.0	38.0	11.8	7.38	18.8	28.13	15.1	9.26	27.82	1.14	0.35	78.7	29.3	108	9.45	5.16	6.01	2.87	25.6	5.24	36.2	40.72	0.176	5.47	0.023	0.021	0.186	0.584
Minimum	297.6	354.4	102.0	142.0	165.1	13.9	3.6	1.56	7.97	11.58	7.35	0.65	9.86	0.63	0	31.9	10.7	42.6	2.99	3.06	3.37	1.88	17	2.69	22	25.24	0.016	1.57	0.01	0.006	0.068	0.237
Maximum	893.8	867.2	353.6	444.3	247.1	74.1	24.8	18.2	40.3	69.37	38.7	24.6	60.47	2.68	0.66	168	62.2	221	15.8	9.41	11.4	11.5	50.2	9.19	49.3	76.44	0.363	27.6	0.077	0.113	0.726	2.497
Range	596.3	512.8	251.6	302.3	82.0	60.2	21.2	16.7	32.3	57.79	31.3	23.9	50.61	2.05	0.66	136	51.6	179	12.8	6.35	8.02	9.59	33.2	6.49	27.3	51.2	0.347	26.1	0.067	0.107	0.658	2.26
N of cases	22.0	22.0	22.0	22.0	7.0	22.0	22.0	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
95% CI Upper	627.7	634.7	239.4	320.2	224.4	46.0	14.7	9.55	23.4	35.17	18.2	12.2	34.83	1.36	0.44	97	36.5	133	11.9	5.96	7.34	3.81	30.5	6.39	41.8	49.75	0.216	7.85	0.031	0.032	0.257	0.789
95% CI Lower	472.3	490.3	171.4	231.8	171.6	30.0	8.9	5.21	14.2	21.1	12	6.3	20.8	0.92	0.27	60.4	22.1	82.6	7.03	4.37	4.67	1.92	20.7	4.09	30.6	31.69	0.137	3.09	0.016	0.01	0.115	0.38
Standard Dev	175.2	162.9	76.7	99.7	28.5	18.1	6.5	4.9	10.4	15.87	7	6.68	15.82	0.5	0.19	41.3	16.3	57.3	5.47	1.79	3.01	2.13	11.1	2.59	12.6	20.36	0.089	5.36	0.018	0.025	0.16	0.461
C.V.	0.32	0.29	0.37	0.36	0.14	0.48	0.55	0.66	0.55	0.56	0.46	0.72	0.57	0.43	0.55	0.53	0.56	0.53	0.58	0.35	0.50	0.74	0.43	0.49	0.35	0.50	0.51	0.98	0.77	1.17	0.86	0.79

AHM Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.012	0.015	0.092	0.708	0.072	0.019	0.182	0.185	0.16	0.64	0.011	7.437	0.009	0.119	0.171	0.002	0.065	0.018	0.054	0.037	0.011	0.053	0.025	0.057	0.006	0.044	0.103	0.147	0.103	0.084	0.009	38.302	67.62	10.771	27.342	15.412	159.4	170.3
Minimum	0.006	0.008	0.022	0.202	0.005	0.01	0.051	0.042	0.065	0.26	0.011	1.676	0.009	0.029	0.056	0.001	0.016	0.008	0.037	0.017	0.008	0.037	0.005	0.027	0.004	0.01	0.06	0.07	0.012	0.013	0.002	24.283	33.989	7.767	9.162	6.621	106.3	117.1
Maximum	0.025	0.068	0.523	4.464	0.774	0.04	0.34	0.406	0.314	1.255	0.012	14.97	0.01	0.291	0.513	0.003	0.193	0.045	0.133	0.089	0.031	0.146	0.105	0.096	0.009	0.113	0.186	0.208	0.225	0.15	0.014	59.325	101.8	15.817	64.73	33.16	261	271.8
Range	0.019	0.06	0.501	4.262	0.769	0.03	0.289	0.364	0.249	0.995	0.001	13.3	0.001	0.262	0.457	0.002	0.177	0.037	0.096	0.072	0.023	0.109	0.1	0.069	0.005	0.103	0.126	0.138	0.213	0.137	0.012	35.042	67.815	8.049	55.568	26.539	154.7	154.7
N of cases	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	7	7	7	7	7	7	7
95% CI Upper	0.015	0.021	0.14	1.097	0.147	0.025	0.234	0.246	0.204	0.815	0.012	8.787	0.01	0.162	0.247	0.002	0.084	0.022	0.064	0.049	0.014	0.065	0.04	0.068	0.007	0.053	0.125	0.168	0.132	0.101	0.011	23.626	46.513	7.919	10.477	7.26	108.3	119.1
95% CI Lower	0.009	0.009	0.044	0.319	-0.002	0.014	0.13	0.125	0.116	0.465	0.011	6.088	0.009	0.076	0.096	0.002	0.046	0.014	0.045	0.026	0.009	0.041	0.011	0.045	0.005	0.035	0.081	0.127	0.075	0.067	0.007	52.978	88.726	13.623	44.207	23.565	210.6	221.4
Standard Dev	0.006	0.013	0.109	0.877	0.169	0.013	0.118	0.137	0.099	0.395	0	3.044	0.001	0.097	0.17	0.001	0.044	0.008	0.022	0.026	0.005	0.027	0.033	0.025	0.002	0.02	0.05	0.046	0.063	0.038	0.005	15.869	22.822	3.084	18.236	8.815	55.32	55.32
C.V.	0.49	0.85	1.18	1.24	2.33	0.68	0.65	0.74	0.62	0.62	0.04	0.41	0.05	0.82	1.00	0.44	0.67	0.45	0.40	0.69	0.46	0.51	1.31	0.44	0.28	0.46	0.48	0.31	0.61	0.46	0.55	0.41	0.34	0.29	0.67	0.57	0.35	0.33

Table 2.17(g): Experimental Results with PM_{10} Chemical Speciation of Ramadevi Site for Winter Season

RD Winter	SPM (R)	SPM (H)	PM10 (R)	PM10 (4	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Al	Si	V	Cr	Mn	Fe
Mean	514.9	536.6	208.2	234.2	207.0	39.0	16.6	6.23	16.4	22.27	14.7	9.08	20.97	1.54	0.38	68.7	22.9	91.6	8.78	3.63	9.11	3.69	17.8	5.4	24.4	28.53	0.116	4.11	0.015	0.024	0.141	0.472
Minimum	360.0	368.1	116.7	105.9	148.8	24.7	7.1	1.97	6.95	12.05	8.36	2.14	8.53	0.72	0.2	31.5	9.67	41.1	6.93	2.65	5.27	2.67	5.54	3.59	22.3	21.43	0.04	1.8	0.008	0.01	0.091	0.295
Maximum	700.4	692.0	373.7	376.7	345.1	54.2	58.2	18.1	33.2	52.9	31.3	15.4	42.4	2.68	0.76	139	45.7	185	11.4	5.06	14.7	5.16	36.4	8.01	27.4	38.77	0.316	9.83	0.032	0.092	0.361	0.743
Range	340.4	323.9	257.0	270.8	196.4	29.4	51.1	16.2	26.2	40.85	22.9	13.2	33.87	1.96	0.56	107	36	143	4.52	2.41	9.38	2.49	30.9	4.42	5.12	17.34	0.276	8.04	0.024	0.082	0.27	0.448
N of cases	22.0	22.0	22.0	22.0	7.0	22.0	22.0	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22
95% CI Upper	566.6	576.8	241.6	271.8	273.0	43.2	21.6	7.93	19.2	26.36	17	11	24.73	1.81	0.44	80.1	26.9	107	9.79	4.17	11.2	4.24	20.9	6.39	25.5	32.4	0.155	4.85	0.018	0.033	0.169	0.542
95% CI Lower	463.2	496.3	174.9	196.7	141.0	34.8	11.5	4.52	13.6	18.18	12.5	7.16	17.21	1.27	0.32	57.3	18.9	76.5	7.77	3.09	7.02	3.13	14.7	4.41	23.2	24.66	0.077	3.37	0.012	0.015	0.113	0.403
Standard Dev	116.7	90.8	75.1	84.7	71.4	9.4	11.4	3.85	6.26	9.224	5.16	4.32	8.482	0.61	0.13	25.7	9.05	33.9	2.28	1.21	4.72	1.25	7	2.23	2.58	8.726	0.088	1.67	0.007	0.02	0.063	0.156
C.V.	0.23	0.17	0.36	0.36	0.35	0.24	0.69	0.62	0.38	0.41	0.35	0.48	0.41	0.40	0.35	0.37	0.40	0.37	0.26	0.33	0.52	0.34	0.39	0.41	0.11	0.31	0.76	0.41	0.47	0.82	0.45	0.33

RD Winter	Co	Ni	Cu	Zn	As	Se	Cd	Sn	Sb	Pb	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Benzene	Toluene	Eth Benzen	m,p-Xylene	o-Xylene	VOCs	NMHC
Mean	0.01	0.012	0.044	0.36	0.018	0.007	0.178	0.132	0.136	1.056	0.018	6.086	0.009	0.137	0.148	0.002	0.055	0.023	0.063	0.027	0.01	0.054	0.016	0.048	0.006	0.046	0.076	0.144	0.061	0.084	0.008	39.797	65.496	10.433	26.483	14.928	157.1	168.9
Minimum	0.005	0.008	0.018	0.116	0.004	0.004	0.046	0.041	0.047	0.365	0.006	1.023	0.009	0.066	0.088	0.001	0.033	0.008	0.037	0.013	0.009	0.048	0.005	0.027	0.004	0.01	0.06	0.086	0.012	0.013	0.002	25.231	32.922	7.523	8.874	6.413	104.7	116.4
Maximum	0.023	0.023	0.094	0.97	0.083	0.017	0.392	0.165	0.212	2.405	0.051	16.87	0.01	0.283	0.186	0.003	0.119	0.065	0.123	0.043	0.014	0.106	0.105	0.076	0.009	0.113	0.173	0.318	0.125	0.15	0.014	61.641	98.606	15.32	62.697	32.118	256.5	268.2
Range	0.018	0.015	0.076	0.854	0.079	0.013	0.346	0.124	0.165	2.04	0.045	15.85	0.001	0.217	0.098	0.002	0.086	0.057	0.086	0.03	0.005	0.058	0.1	0.049	0.005	0.103	0.113	0.232	0.113	0.137	0.012	36.41	65.685	7.797	53.823	25.705	151.8	151.8
N of cases	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	7	7	7	7	7	7	7
95% CI Upper	0.012	0.014	0.054	0.471	0.028	0.008	0.234	0.153	0.165	1.333	0.027	7.849	0.01	0.161	0.167	0.002	0.065	0.028	0.073	0.032	0.011	0.061	0.026	0.057	0.006	0.055	0.088	0.168	0.079	0.101	0.01	24.548	45.052	7.67	10.148	7.032	106.7	118.4
95% CI Lower	0.008	0.01	0.034	0.248	0.008	0.005	0.121	0.111	0.107	0.779	0.009	4.323	0.009	0.112	0.129	0.001	0.045	0.019	0.054	0.023	0.009	0.048	0.007	0.04	0.005	0.036	0.064	0.119	0.042	0.067	0.006	55.046	85.939	13.195	42.818	22.825	207.6	219.3
Standard Dev	0.005	0.004	0.022	0.251	0.023	0.003	0.128	0.048	0.065	0.625	0.021	3.975	0.001	0.055	0.043	0.001	0.023	0.011	0.021	0.01	0.002	0.015	0.021	0.02	0.001	0.021	0.028	0.055	0.042	0.038	0.005	16.488	22.105	2.987	17.663	8.538	54.53	54.53
C.V.	0.45	0.35	0.51	0.70	1.29	0.50	0.72	0.36	0.48	0.59	1.12	0.65	0.05	0.40	0.29	0.47	0.42	0.46	0.34	0.36	0.21	0.27	1.30	0.42	0.25	0.47	0.36	0.38	0.69	0.46	0.65	0.41	0.34	0.29	0.67	0.57	0.35	0.32

Table 2.18: Correlation Matrices of Four Dust Parameters for Winter Season at all Sampling Sites

(a) IIT Kanpur Site

IIT (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.705	1		
PM_{10}	0.524	0.523	1	
$PM_{2.5}$	0.459	0.839	0.624	1

(b) Vikashnagar Site

VN (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.733	1		
PM_{10}	0.667	0.801	1	
$PM_{2.5}$	0.562	0.633	0.959	1

(c) Govindnagar Site

GN (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.897	1		
PM_{10}	0.516	0.692	1	
$PM_{2.5}$	0.616	0.401	0.984	1

(d) Dadanagar Site

DN (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.621	1		
PM_{10}	0.529	0.797	1	
$PM_{2.5}$	0.518	0.686	0.855	1

(e) Colonelganj Site

CG (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.793	1		
PM_{10}	0.544	0.884	1	
$PM_{2.5}$	0.427	0.857	0.971	1

(f) AHM Site

AHM (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.646	1		
PM_{10}	0.788	0.861	1	
$PM_{2.5}$	0.707	0.531	0.607	1

(g) Ramadevi Site

RD (W)	SPM	RSPM	PM_{10}	$PM_{2.5}$
SPM	1			
RSPM	0.746	1		
PM_{10}	0.642	0.892	1	
$PM_{2.5}$	0.466	0.899	0.995	1

Table 2.19: Correlation Matrices of Chemical Species for Winter Season at all Sampling Sites

(a) IIT Kanpur Site

IIT (W)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.015	1							
SO_2	0.051	0.219	1						
NH_4^+	0.558	0.018	0.117	1					
SO_4^{2-}	0.574	0.018	0.063	0.942	1				
NO_3^-	0.445	0.367	0.026	0.897	0.887	1			
EC	0.487	0.267	0.084	0.139	0.154	0.106	1		
OC	0.556	0.245	0.064	-0.247	-0.186	-0.246	0.787	1	
TC	0.503	0.264	0.074	-0.13	-0.081	-0.14	0.898	0.978	1

(b) Vikashnagar Site

VN (W)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.157	1							
SO_2	0.213	0.569	1						
NH_4^+	0.719	0.319	0.024	1					
SO_4^{2-}	0.631	0.268	0.111	0.894	1				
NO_3^-	0.528	0.603	0.092	0.498	0.387	1			
EC	0.537	0.223	-0.189	-0.056	-0.033	0.226	1		
OC	0.513	0.21	-0.253	0.032	0.055	0.288	0.97	1	
TC	0.621	0.215	-0.236	0.006	0.029	0.272	0.985	0.997	1

(c) Govindnagar Site

GN (W)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.168	1							
SO_2	0.163	0.001	1						
NH_4^+	0.693	0.044	0.138	1					
SO_4^{2-}	0.725	0.075	0.213	0.781	1				
NO_3^-	0.621	0.559	0.164	0.546	0.496	1			
EC	0.569	0.236	0.163	-0.176	0.142	-0.322	1		
OC	0.495	0.412	0.084	-0.226	0.012	-0.106	0.672	1	
TC	0.566	0.383	0.119	-0.226	0.059	-0.191	0.842	0.965	1

(d) Dadanagar Site

DN (W)	PM_{10}	NO_2	SO_2	NH_4^+	SO_4^{2-}	NO_3^-	EC	OC	TC
PM_{10}	1								
NO_2	0.501	1							
SO_2	0.724	0.261	1						
NH_4^+	0.696	0.369	0.183	1					
SO_4^{2-}	0.594	0.215	0.197	0.767	1				
NO_3^-	0.679	0.393	0.078	0.741	0.405	1			
EC	0.451	0.412	0.508	-0.197	0.265	-0.214	1		
OC	0.709	0.484	0.463	-0.18	0.346	0.029	0.617	1	
TC	0.697	0.504	0.512	-0.199	0.352	-0.034	0.769	0.977	1

Table 2.19: Correlation Matrices of Chemical Species for Winter Season at all Sampling Sites

(e) Colonelganj Site

CG (W)	PM$_{10}$	NO$_2$	SO$_2$	NH$_4^+$	SO$_4^{2-}$	NO$_3^-$	EC	OC	TC
PM$_{10}$	1								
NO$_2$	0.569	1							
SO$_2$	0.425	0.406	1						
NH$_4^+$	0.553	0.107	0.029	1					
SO$_4^{2-}$	0.428	0.147	0.243	0.584	1				
NO$_3^-$	0.401	0.431	0.318	0.832	0.773	1			
EC	0.807	0.45	0.313	0.052	0.092	0.075	1		
OC	0.798	0.467	0.393	0.07	0.01	-0.071	0.956	1	
TC	0.808	0.466	0.373	0.034	0.035	-0.028	0.978	0.996	1

(f) AHM Site

AHM (W)	PM$_{10}$	NO$_2$	SO$_2$	NH$_4^+$	SO$_4^{2-}$	NO$_3^-$	EC	OC	TC
PM$_{10}$	1								
NO$_2$	0.668	1							
SO$_2$	0.786	0.684	1						
NH$_4^+$	0.639	0.122	0.23	1					
SO$_4^{2-}$	0.602	0.007	0.312	0.546	1				
NO$_3^-$	0.771	0.497	0.058	0.677	0.659	1			
EC	0.766	0.51	0.7	-0.099	-0.033	0.121	1		
OC	0.737	0.443	0.639	-0.146	-0.019	0.186	0.972	1	
TC	0.749	0.464	0.66	-0.133	-0.023	0.169	0.985	0.998	1

(g) Ramadevi Site

RD (W)	PM$_{10}$	NO$_2$	SO$_2$	NH$_4^+$	SO$_4^{2-}$	NO$_3^-$	EC	OC	TC
PM$_{10}$	1								
NO$_2$	0.71	1							
SO$_2$	0.16	0.024	1						
NH$_4^+$	0.619	0.346	0.009	1					
SO$_4^{2-}$	0.644	0.127	0.015	0.638	1				
NO$_3^-$	0.744	0.527	0.015	0.838	0.642	1			
EC	0.521	-0.004	-0.263	-0.209	0.13	0.13	1		
OC	0.432	-0.012	-0.355	-0.132	0.178	0.178	0.886	1	
TC	0.501	-0.01	-0.338	-0.156	0.169	0.169	0.936	0.992	1

Table 2.20(a): Experimental Results of PM$_{2.5}$ Chemical Speciation of IIT Kanpur Site for Winter Season

IIT (Winter)	**PM$_{2.5}$**	**OC$_1$**	**OC$_2$**	**OC$_3$**	**OC$_4$**	**OP**	**EC$_1$**	**EC$_2$**	**EC$_3$**	**OC**	**EC**	**TC**	**Na$^+$**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**NH$_4^+$**	**Cl$^-$**	**NO$_3^-$**	**SO$_4^{2-}$**
Minimum	96.6	1.82	4.96	7.62	5.23	3	3.41	0.29	0.09	22.71	3.95	28.39	1.292	1.601	2.472	0.297	4.02	1.11	0.657	7.695
Maximum	235.9	9.73	6.71	11.73	7.51	8.89	7	0.58	0.27	35.42	7.49	42.15	4.736	6.005	4.815	1.829	18.96	4.03	13.28	42.47
Range	139.3	7.91	1.75	4.11	2.28	5.89	3.59	0.29	0.18	12.71	3.54	13.76	3.444	4.404	2.343	1.532	14.94	2.93	12.62	34.77
Arithmetic Mean	172.1	3.516	6.144	9.529	5.953	5.913	5.619	0.42	0.179	31.05	6.214	37.27	3.181	4.213	3.667	1.343	12.28	2.01	8.119	24.7
95.0% Lower CI	128.8	0.938	5.486	8.198	5.227	3.72	4.565	0.32	0.126	27.08	5.13	33.14	1.976	2.943	2.923	0.839	7.063	0.78	3.672	13.07
95.0% Upper CI	215.5	6.093	6.803	10.86	6.679	8.106	6.672	0.52	0.231	35.03	7.299	41.4	4.386	5.483	4.411	1.846	17.5	3.24	12.57	36.33
S.D.	46.88	2.787	0.712	1.439	0.785	2.371	1.139	0.108	0.057	4.293	1.173	4.465	1.303	1.373	0.804	0.544	5.644	1.33	4.809	12.57
C.V.	0.272	0.793	0.116	0.151	0.132	0.401	0.203	0.258	0.317	0.138	0.189	0.12	0.41	0.326	0.219	0.405	0.46	0.66	0.592	0.509

Table 2.20(b): Experimental Results of PM$_{2.5}$ Chemical Speciation of Vikashnagar Site for Winter Season

VN (Winter)	**PM$_{2.5}$**	**OC$_1$**	**OC$_2$**	**OC$_3$**	**OC$_4$**	**OP**	**EC$_1$**	**EC$_2$**	**EC$_3$**	**OC**	**EC**	**TC**	**Na$^+$**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**NH$_4^+$**	**Cl$^-$**	**NO$_3^-$**	**SO$_4^{2-}$**
Minimum	134.6	2.86	7.17	8.93	5.42	3	5.82	0.41	0.06	27.38	6.44	33.82	0.67	3.109	2.689	0.085	12.35	0.96	5.994	19.41
Maximum	299.5	10.42	13.64	15.08	8.66	6.18	12.63	0.77	0.86	50.42	13.95	63.74	8.459	5.199	4.538	2.113	21.02	2.06	19.54	45.8
Range	164.9	7.56	6.47	6.15	3.24	3.18	6.81	0.36	0.8	23.04	7.51	29.92	7.789	2.09	1.849	2.028	8.67	1.1	13.54	26.4
Arithmetic Mean	207.5	6.409	11.09	12.48	7.294	4.761	10.42	0.507	0.28	42.04	11.2	53.24	2.773	4.174	3.906	1.72	15.74	1.57	10.17	36.22
95.0% Lower CI	140.2	3.929	8.948	10.34	6.356	3.58	7.903	0.39	0.031	34.42	8.507	43.08	0.071	3.26	3.146	1.009	12.9	1.07	5.436	27.5
95.0% Upper CI	274.7	8.888	13.23	14.63	8.233	5.943	12.93	0.624	0.529	49.66	13.9	63.41	5.474	5.089	4.665	2.432	18.58	2.08	14.91	44.94
S.D.	72.73	2.681	2.314	2.318	1.015	1.278	2.717	0.127	0.269	8.238	2.917	10.99	2.921	0.989	0.821	0.77	3.07	0.55	5.12	9.43
C.V.	0.351	0.418	0.209	0.186	0.139	0.268	0.261	0.25	0.962	0.196	0.26	0.206	1.054	0.237	0.21	0.447	0.195	0.35	0.503	0.26

Table 2.20(c): Experimental Results of PM$_{2.5}$ Chemical Speciation of Govindnagar Site for Winter Season

GN (Winter)	**PM$_{2.5}$**	**OC$_1$**	**OC$_2$**	**OC$_3$**	**OC$_4$**	**OP**	**EC$_1$**	**EC$_2$**	**EC$_3$**	**OC**	**EC**	**TC**	**Na$^+$**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**NH$_4^+$**	**Cl$^-$**	**NO$_3^-$**	**SO$_4^{2-}$**
Minimum	153.5	2.52	7.23	9.02	6.65	0	5.96	0.23	0.08	28.5	6.43	34.93	1.329	1.017	3.295	0.547	5.209	0.45	2.304	5.136
Maximum	268.9	9.21	12.13	19.52	9.49	5.91	13.68	6.25	5.17	48.42	25.1	68.57	4.631	5.91	5.043	2.9	20.93	4.78	26.08	46.46
Range	115.4	6.69	4.9	10.5	2.84	5.91	7.72	6.02	5.09	19.92	18.67	33.64	3.302	4.893	1.748	2.353	15.72	4.33	23.78	41.32
Arithmetic Mean	185.2	6.009	9.131	13.95	7.969	1.441	8.891	1.51	1.376	38.51	11.78	50.28	2.364	3.503	3.852	2.089	14.85	1.55	11.78	37.31
95.0% Lower CI	145.3	4.087	7.581	11.06	7.038	-0.65	6.098	-0.582	-0.54	32.2	5.743	39.7	1.317	2.179	3.244	1.106	9.786	0.19	3.149	23.76
95.0% Upper CI	225.2	7.93	10.68	16.85	8.899	3.529	11.68	3.602	3.289	44.81	17.81	60.87	3.411	4.827	4.461	3.073	19.9	2.92	20.42	50.86
S.D.	43.16	2.078	1.676	3.125	1.006	2.257	3.02	2.262	2.068	6.82	6.525	11.45	1.132	1.432	0.658	1.063	5.47	1.47	9.337	14.65
C.V.	0.233	0.346	0.184	0.224	0.126	1.566	0.34	1.498	1.504	0.177	0.554	0.228	0.479	0.409	0.171	0.509	0.368	0.95	0.792	0.393

Table 2.20(d): Experimental Results of $PM_{2.5}$ Chemical Speciation of Dadanagar Site for Winter Season

DN (Winter)	$PM_{2.5}$	OC_1	OC_2	OC_3	OC_4	OP	EC_1	EC_2	EC_3	OC	EC	TC	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Minimum	220.3	5.42	9.29	16.75	7.81	1.01	8.38	0.18	0.1	42.43	8.65	51.08	1.076	5.693	4.006	0.115	13.65	2.13	18.92	24.09
Maximum	471.3	37.8	22.06	24.67	12.64	29.18	25.96	0.48	0.36	108.7	26.8	135.5	12.54	11.17	6.407	1.692	29.12	6.26	33.29	54.09
Range	251	32.38	12.77	7.92	4.83	28.17	17.58	0.3	0.26	66.23	18.15	84.39	11.46	5.476	2.401	1.577	15.47	4.13	14.37	30
Arithmetic Mean	304.8	16.57	14.75	20.94	9.843	8.359	16.82	0.321	0.216	70.47	17.35	87.82	7.588	7.23	5.771	0.803	25.14	5.24	29.06	45.9
95.0% Lower CI	229.1	5.54	10.26	18.54	8.37	-0.74	11.71	0.239	0.143	48.15	12.11	61.62	4.187	5.51	4.801	0.224	20.32	3.78	23.75	34.85
95.0% Upper CI	380.6	27.61	19.25	23.34	11.32	17.46	21.92	0.404	0.288	92.79	22.59	114	10.99	8.95	6.742	1.382	29.96	6.71	34.37	56.96
S.D.	81.92	11.93	4.86	2.595	1.593	9.836	5.519	0.089	0.078	24.13	5.67	28.32	3.678	1.86	1.05	0.626	5.213	1.58	5.746	11.95
C.V.	0.269	0.72	0.329	0.124	0.162	1.177	0.328	0.278	0.364	0.342	0.327	0.323	0.485	0.257	0.182	0.78	0.207	0.3	0.198	0.26

Table 2.20(e): Experimental Results of $PM_{2.5}$ Chemical Speciation of Colonelganj Site for Winter Season

CG (Winter)	$PM_{2.5}$	OC_1	OC_2	OC_3	OC_4	OP	EC_1	EC_2	EC_3	OC	EC	TC	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Minimum	160.3	1.79	5.94	8.34	6.18	2.89	5.34	0.43	0.15	25.15	5.93	31.07	2.059	3.97	1.964	0.686	10.14	0.47	16.45	19.28
Maximum	302.8	12.05	22.94	21.95	12.17	9.87	24	0.8	0.32	78.91	25.13	104	10.11	11.06	11.8	2.091	20.06	5.99	41.06	42.38
Range	142.4	10.26	17	13.61	5.99	6.98	18.66	0.37	0.17	53.76	19.2	72.96	8.054	7.088	9.833	1.405	9.923	5.52	24.62	23.1
Arithmetic Mean	215.6	6.55	12.72	15.04	8.421	6.807	14.04	0.515	0.222	49.54	14.78	64.31	6.524	4.914	5.801	1.233	14.5	2.45	29.26	25.46
95.0% Lower CI	173.2	3.489	8.143	11.33	6.898	4.861	9.107	0.413	0.173	35.15	9.717	44.89	3.176	2.838	1.637	0.638	11.27	0.85	20.27	19.13
95.0% Upper CI	258.1	9.611	17.3	18.75	9.945	8.754	18.98	0.617	0.272	63.92	19.85	83.74	9.872	6.991	9.966	1.829	17.73	4.05	38.25	31.8
S.D.	50.75	3.662	5.478	4.438	1.822	2.329	5.903	0.121	0.06	17.21	6.057	23.23	4.005	2.484	4.981	0.712	3.864	1.92	10.75	7.574
C.V.	0.235	0.559	0.431	0.295	0.216	0.342	0.42	0.236	0.268	0.347	0.41	0.361	0.614	0.505	0.859	0.578	0.267	0.78	0.367	0.297

Table 2.20(f): Experimental Results of $PM_{2.5}$ Chemical Speciation of AHM Site for Winter Season

AHM (Winter)	$PM_{2.5}$	OC_1	OC_2	OC_3	OC_4	OP	EC_1	EC_2	EC_3	OC	EC	TC	Na^+	K^+	Ca^{2+}	Mg^{2+}	NH_4^+	Cl^-	NO_3^-	SO_4^{2-}
Minimum	165.1	2.93	6.55	9.76	5.15	2.76	8.81	0.24	0.08	28.1	9.13	37.23	1.374	2.141	1.718	0.713	11.71	1.24	13.75	14.54
Maximum	247.1	7.3	16.12	27.75	8.78	9.83	20.56	0.91	0.22	63.46	21.15	84.61	7.262	4.574	5.806	1.717	17.08	4.23	30.85	44.03
Range	82	4.37	9.57	17.99	3.63	7.07	11.75	0.67	0.14	35.36	12.02	47.38	5.888	2.433	4.088	1.004	5.37	2.99	17.1	29.49
Arithmetic Mean	198	4.699	10.51	15.83	6.567	6.527	13.73	0.447	0.166	44.13	14.34	58.47	3.006	3.93	3.788	1.091	13.09	2.69	25.61	24.3
95.0% Lower CI	171.6	3.285	7.401	10.24	5.389	4.408	9.892	0.242	0.12	32.58	10.43	43.07	1.004	3.148	2.181	0.674	11.18	1.58	19.31	11.76
95.0% Upper CI	224.4	6.112	13.61	21.42	7.745	8.646	17.58	0.652	0.212	55.69	18.25	73.88	5.008	4.711	5.395	1.507	15	3.8	31.91	36.84
S.D.	28.53	1.529	3.358	6.044	1.274	2.292	4.154	0.222	0.05	12.49	4.231	16.66	2.164	0.845	1.738	0.45	2.07	1.2	6.812	13.56
C.V.	0.144	0.325	0.32	0.382	0.194	0.351	0.302	0.496	0.301	0.283	0.295	0.285	0.72	0.215	0.459	0.413	0.158	0.45	0.266	0.558

Table 2.20(g): Experimental Results of PM$_{2.5}$ Chemical Speciation of Ramadevi Site for Winter Season

RD (Winter)	**PM$_{2.5}$**	**OC$_1$**	**OC$_2$**	**OC$_3$**	**OC$_4$**	**OP**	**EC$_1$**	**EC$_2$**	**EC$_3$**	**OC**	**EC**	**TC**	**Na$^+$**	**K$^+$**	**Ca^{2+}**	**Mg^{2+}**	**NH$_4^+$**	**Cl$^-$**	**NO$_3^-$**	**SO$_4^{2-}$**
Minimum	148.8	2.11	7.49	10.29	7.04	3.46	4.89	0.42	0.12	32.18	5.54	41.91	3.048	1.851	2.741	0.989	13.58	1.69	10.74	19.8
Maximum	345.1	6.43	13.71	16.72	15.56	9.75	13.77	1.06	0.21	57.36	14.32	69.42	5.037	3.54	7.62	1.908	22.19	3.77	27.96	35.83
Range	196.4	4.32	6.22	6.43	8.52	6.29	8.88	0.64	0.09	25.18	8.78	27.51	1.989	1.689	4.879	0.919	8.613	2.08	17.22	16.02
Arithmetic Mean	207	3.311	10.01	13.19	9.297	5.841	10.36	0.686	0.173	41.65	11.22	52.87	3.616	2.334	4.135	1.252	15.73	2.28	22.51	24.38
95.0% Lower CI	141	1.758	7.667	10.81	6.678	3.596	7.499	0.495	0.145	32.38	8.349	42.04	2.719	1.571	1.933	0.837	12.81	1.34	17.2	17.15
95.0% Upper CI	273	4.865	12.35	15.57	11.92	8.087	13.21	0.876	0.2	50.92	14.08	63.7	4.514	3.096	6.337	1.666	18.65	3.22	27.83	31.61
S.D.	71.36	1.679	2.533	2.574	2.831	2.428	3.089	0.206	0.03	10.02	3.1	11.71	0.971	0.824	2.381	0.448	3.159	1.01	5.748	7.818
C.V.	0.345	0.507	0.253	0.195	0.305	0.416	0.298	0.301	0.173	0.241	0.276	0.222	0.268	0.353	0.576	0.358	0.201	0.44	0.255	0.321

2.4.3.8 Comparisons of PM_{10} and $PM_{2.5}$ Compositions

This section gives some important information coming from the experimental findings related to fine particles and coarse particle. Table 2.21 presents a comparison between $PM_{2.5}$ Vs PM_{10} with respect to their compositions for the major chemical species of all sampling sites during winter season. The chemical species considered for the comparisons are EC, OC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^- and SO_4^{2-}. It can be concluded here that NH_4^+, NO_3^-, SO_4^{2-} and OC are formed in the fine mode; whereas, EC, Na^+, K^+, Ca^{2+}, Mg^{2+}, and Cl^- are formed in coarse as well as fine mode.

The above results are also shown graphically for all sampling sites of the city for better feeling. Figures 2.24(a), 2.24(b), 2.24(c), 2.24(d), 2.24(e), 2.24(f) and 2.24(g) show the compositional comparison of $PM_{2.5}$ Vs PM_{10} for major chemical species at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively during winter season.

Table 2.21: Ratios of Chemical Species of $PM_{2.5}$ and PM_{10} for all Sites of Post-monsoon Season

Winter	**IIT Kanpur**	**Vikash nagar**	**Govind nagar**	**Dada nagar**	**Colonel ganj**	**AHM**	**Ramadevi**
Site							
$PM_{2.5}$ (ug/m^3)	172.1	207.5	185.2	304.8	215.6	198	207
PM_{10} (ug/m^3)	204.7	226.4	239.8	396.3	291.5	276	234.2
$PM_{2.5}$/ PM_{10} (%)	84.1	91.7	77.2	76.9	74.0	71.7	88.4
$PM_{2.5}$ EC/ PM_{10} EC (%)	38.8	53.6	51.8	27.2	44.7	48.8	49.3
$PM_{2.5}$ OC/ PM_{10} OC (%)	69.6	70.1	56.5	55.1	56.4	56.0	60.7
$PM_{2.5}$ TC/ PM_{10} TC (%)	61.3	65.8	55.3	52.0	53.1	54.2	57.8
$PM_{2.5}$ Na^+/ PM_{10} Na^+ (%)	39.0	36.4	27.6	53.5	45.5	31.6	40.9
$PM_{2.5}$ K^+/ PM_{10} K^+ (%)	79.2	76.4	72.9	75.8	65.3	75.0	41.1
$PM_{2.5}$ Ca^{2+}/ PM_{10} Ca^{2+} (%)	56.1	63.9	51.3	53.2	59.2	63.3	45.1
$PM_{2.5}$ Mg^{2+}/ PM_{10} Mg^{2+} (%)	44.8	40.5	50.0	24.2	37.5	37.9	35.1
$PM_{2.5}$ NH_4^+/ PM_{10} NH_4^+ (%)	81.5	84.9	77.6	79.7	64.4	51.2	88.2
$PM_{2.5}$ Cl^-/ PM_{10} Cl^- (%)	40.8	48.5	31.4	56.5	40.7	51.9	42.6
$PM_{2.5}$ NO_3^-/ PM_{10} NO_3^- (%)	95.3	94.4	73.3	85.6	80.1	70.7	92.2
$PM_{2.5}$ SO_4^{2-}/ PM_{10} $SO4^{2-}$ (%)	76.0	88.1	76.9	69.2	74.6	59.7	85.6

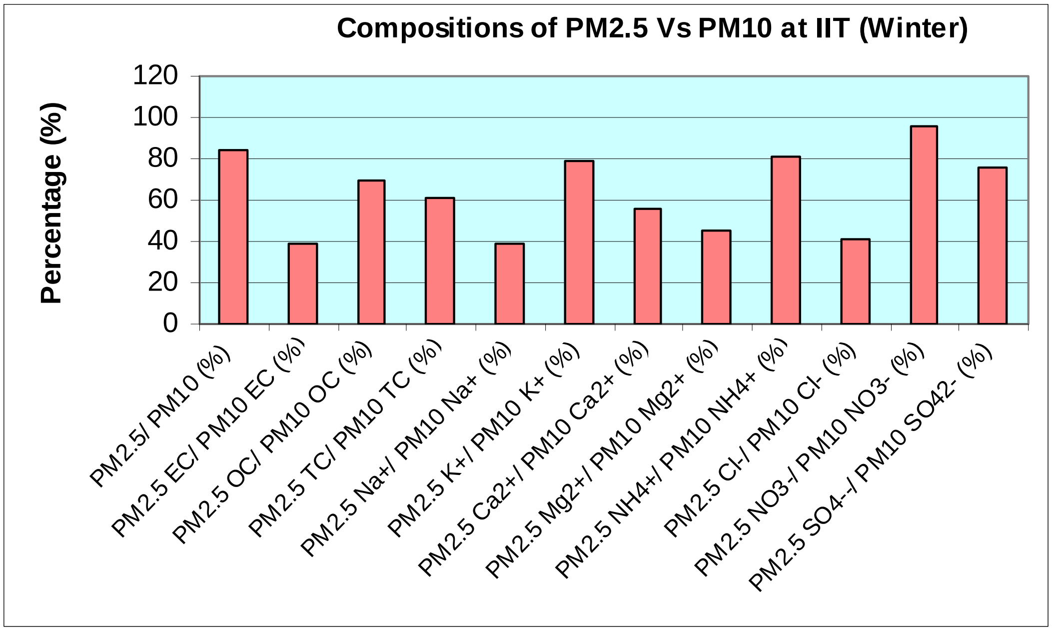


Figure 2.24(a): Compositional Comparison of PM$_{2.5}$ Vs PM$_{10}$ at IIT Kanpur Site for Winter Season

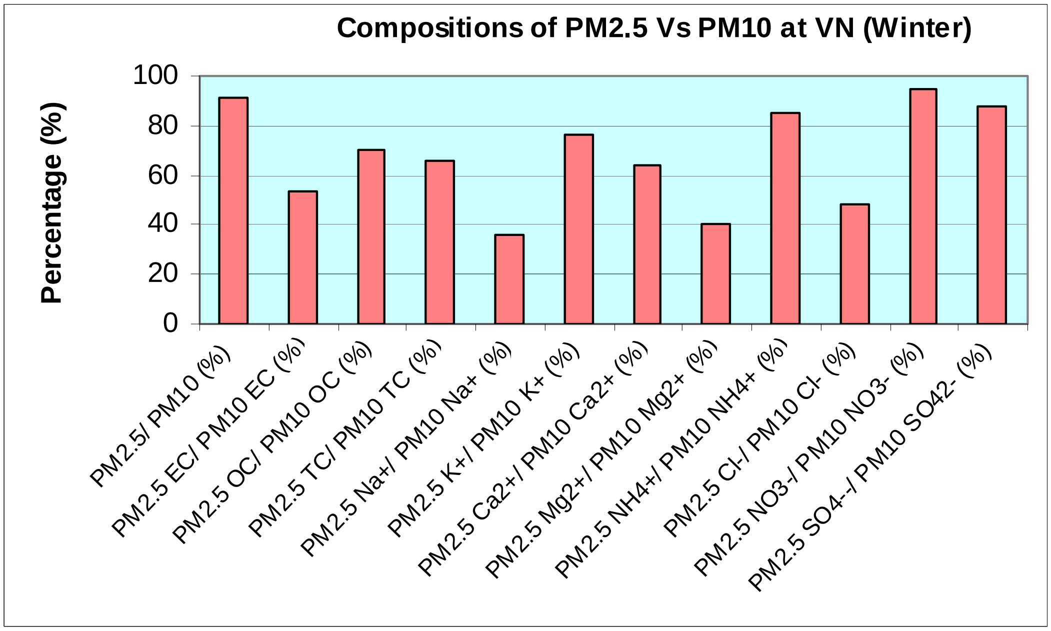


Figure 2.24(b): Compositional Comparison of PM$_{2.5}$ Vs PM$_{10}$ at Vikashnagar Site for Winter Season

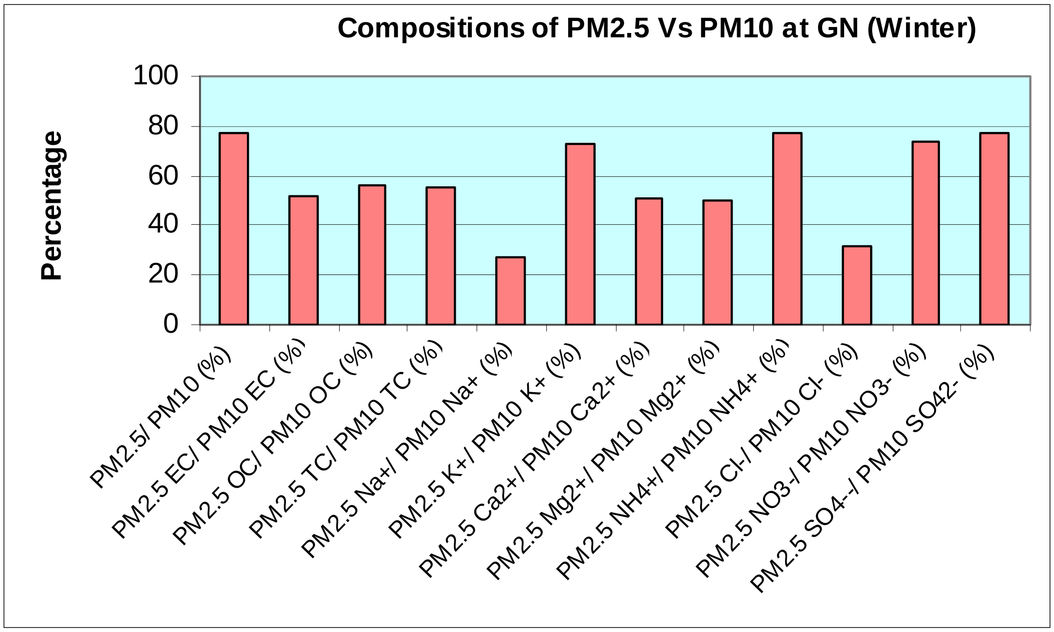


Figure 2.24(c): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Govindnagar Site for Winter Season

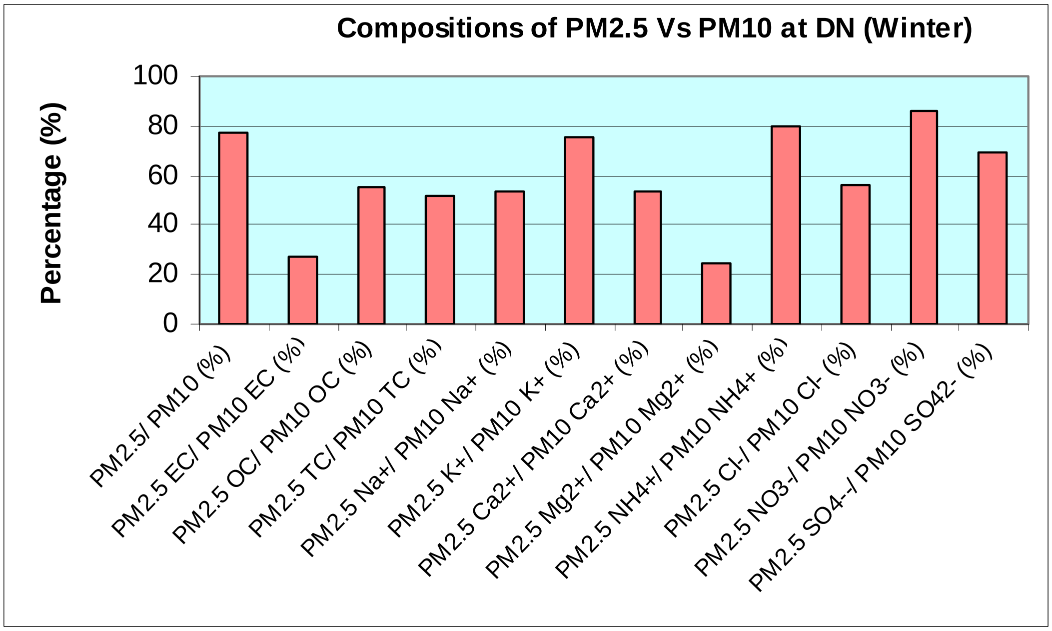


Figure 2.24(d): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Dadanagar Site for Winter Season

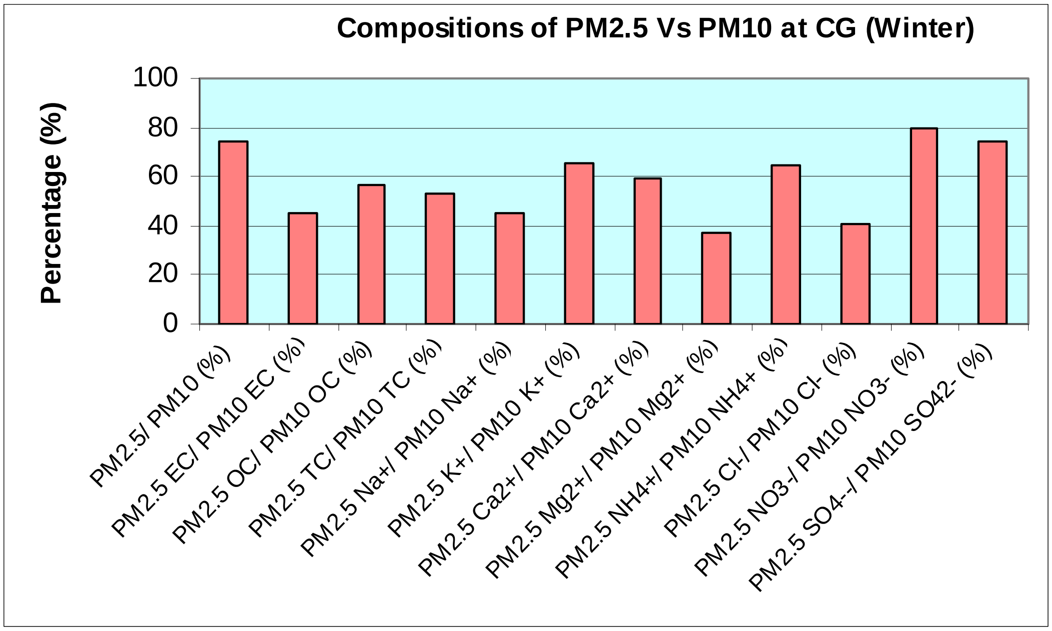


Figure 2.24(e): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Colonelganj Site for Winter Season

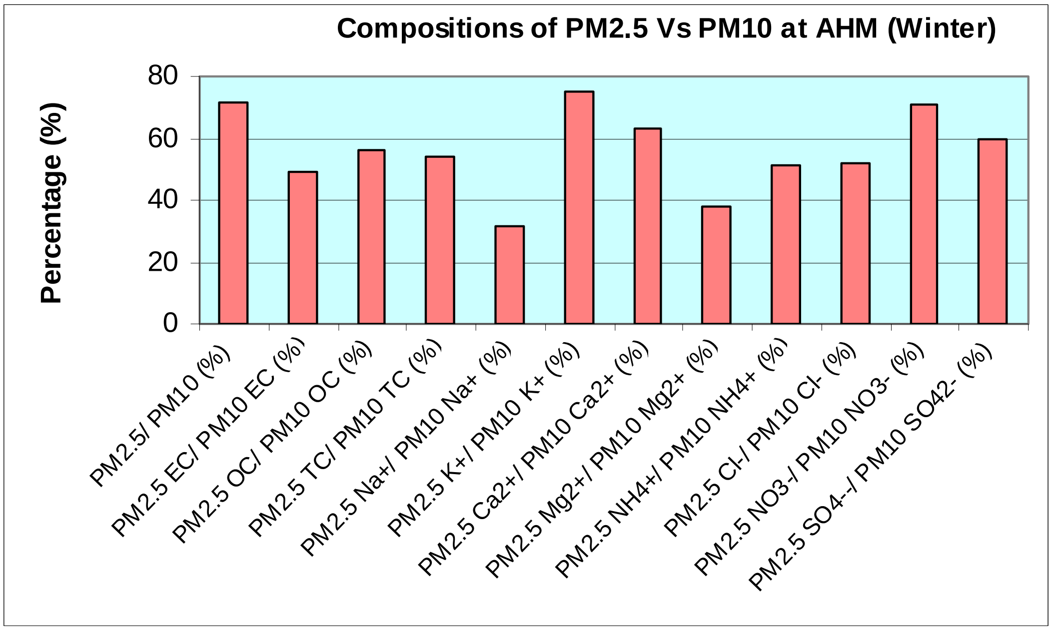


Figure 2.24(f): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at AHM Site for Winter Season

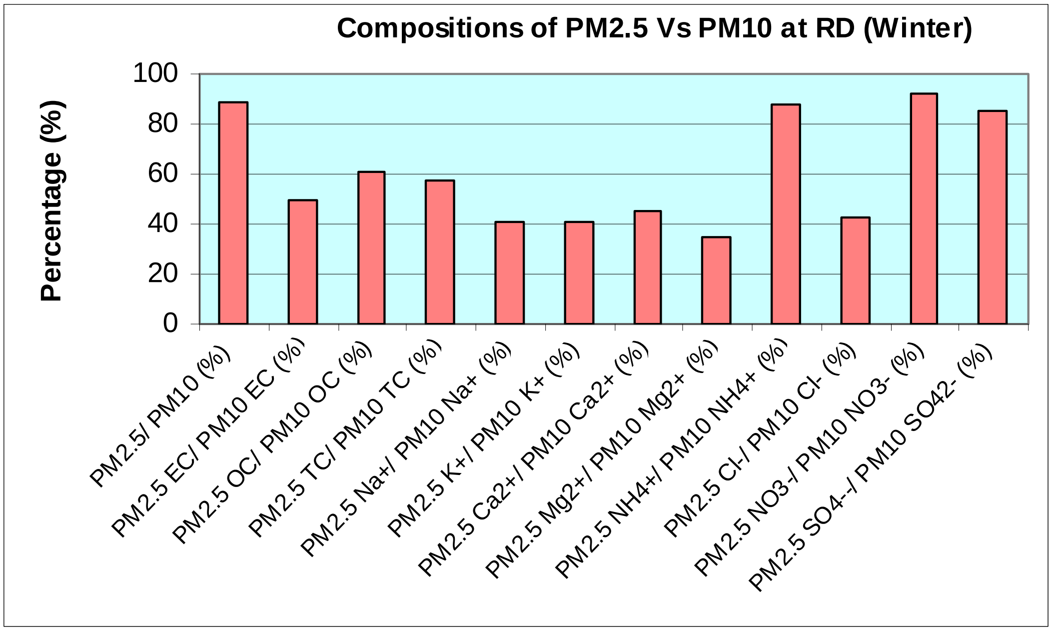


Figure 2.24(g): Compositional Comparison of $PM_{2.5}$ Vs PM_{10} at Ramadevi Site for Winter Season

2.5 Season–wise Comparisons of the Experimental Outcomes

A brief of the average experimental results for all parameters during all three seasons are presented in tabular as well as graphical forms in this section. Tables 2.22(a), 2.22(b), 2.22(c), 2.22(d), 2.22(e), 2.22(f) and 2.22(g) present the seasonal comparisons of average concentrations of SPM (from RDS), SPM (from HVS), PM_{10} (from RDS), PM_{10} (from 4-CSS), $PM_{2.5}$, NO_2, SO_2, OC_1, OC_2, OC_3, OC_4, OP, EC_1, EC_2, EC_3, OC, EC, TC, Na^+, K^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, NO_3^-, SO_4^{2-}, Si, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Cd, Sn, Sb, Pb, P, S, Sc, Ti, Ga, Ge, Br, Rb, Sr, Y, Mo, Rh, Pd, Ag, Te, I, Cs, Ba, La, W, Au, benzene, toluene, ethyl benzene, m,p-xylene, o-xylene, VOCs and NMHC at sampling sites of IIT Kanpur, Vikashnagar, Govindnagar, Dadanagar, Colonelganj, AHM and Ramadevi respectively. The results presented for elements, ions and carbon concentrations are from the PM_{10} chemical speciation.

2.5.1 IIT Kanpur Site

This section shows season-wise comparisons of observed concentrations of some important parameters at IIT Kanpur site. Figure 2.25(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at IIT Kanpur site. Figure 2.25(b) compares the results of NO_2 and SO_2 for all three seasons at IIT Kanpur site. Figure 2.25(c) compares the results of OC, EC and TC for all three seasons at IIT Kanpur site. Figure 2.25(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at IIT Kanpur site. Figure 2.25(e) compares the results of VOCs, and NMHC for all three seasons at IIT Kanpur site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

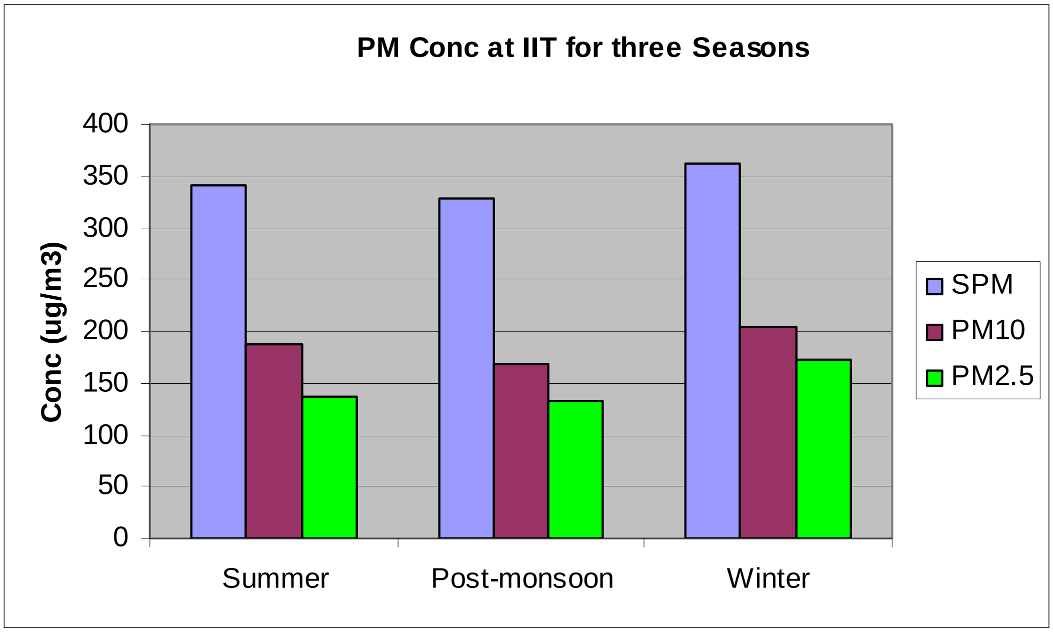


Figure 2.25(a): Seasonal Comparison of Observed PM Concentrations at IIT Kanpur Site

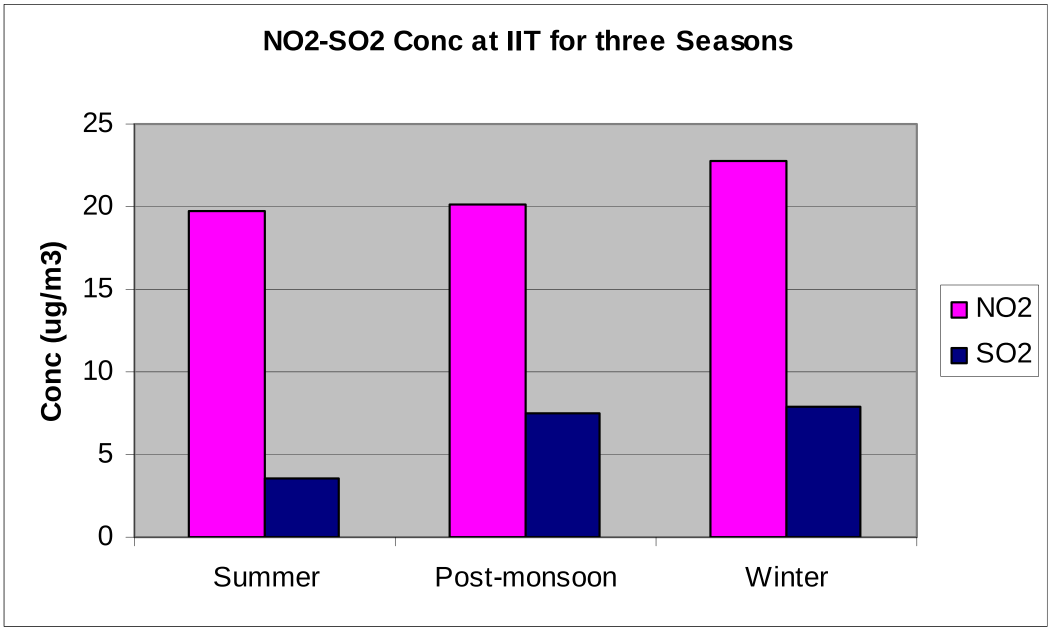


Figure 2.25(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at IIT Kanpur Site

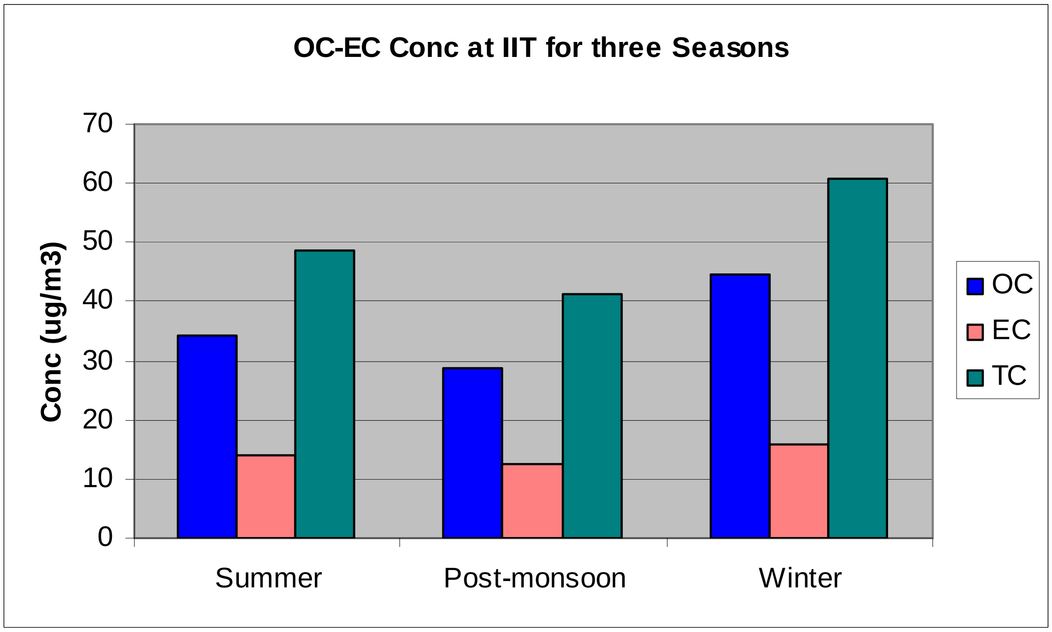


Figure 2.25(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at IIT Kanpur Site

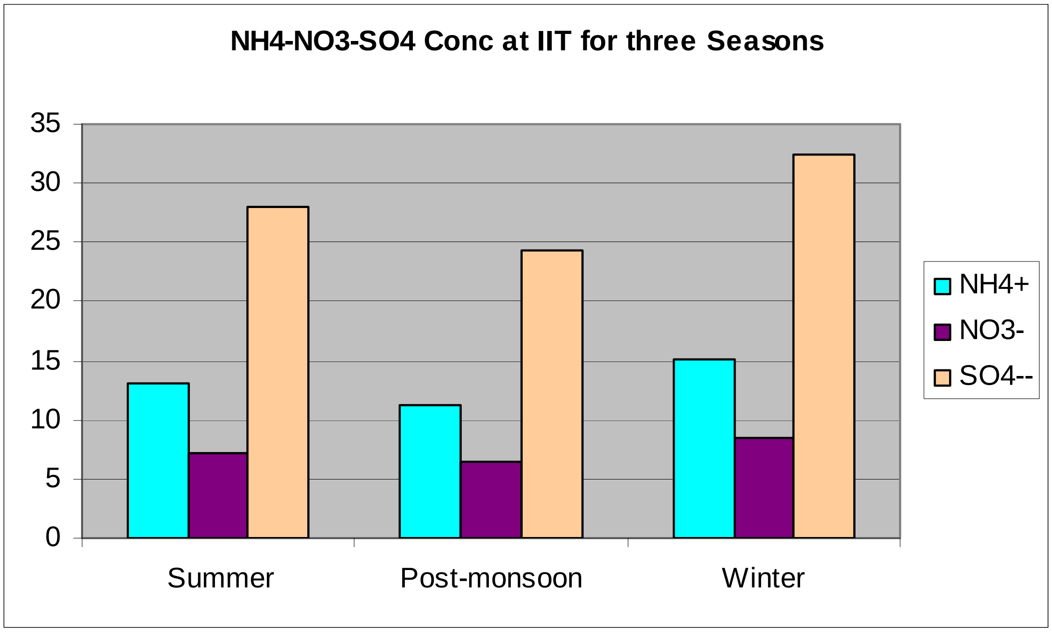


Figure 2.25(d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^{2-} Concentrations at IIT Kanpur Site

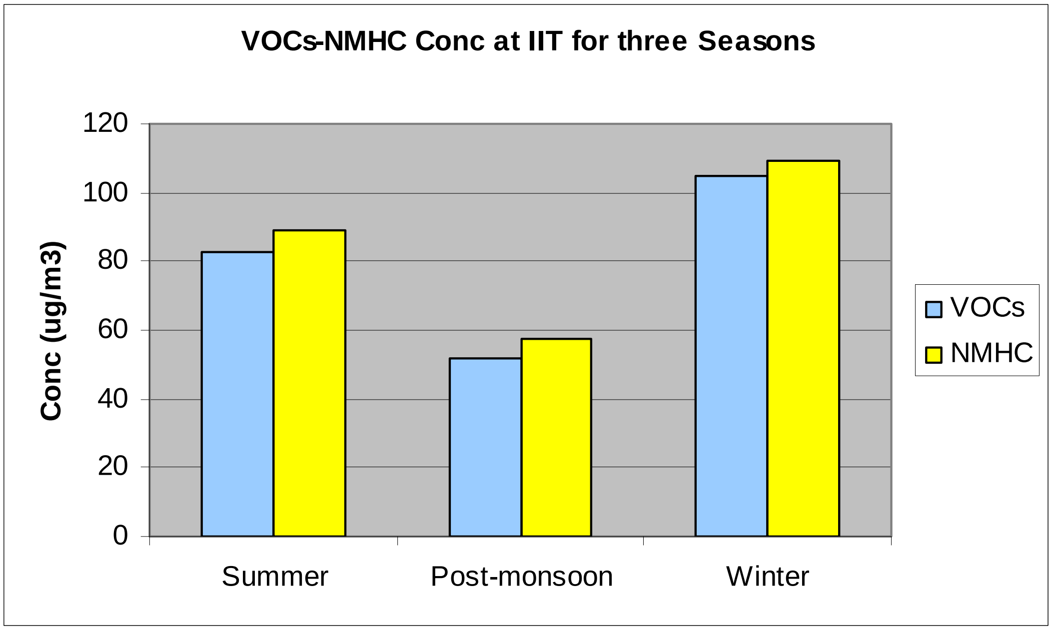


Figure 2.25(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at IIT Kanpur Site

2.5.2 Vikashnagar Site

This section shows season-wise comparisons of observed concentrations of some important parameters at Vikashnagar site. Figure 2.26(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at Vikashnagar site. Figure 2.26(b) compares the results of NO_2 and SO_2 for all three seasons at Vikashnagar site. Figure 2.26(c) compares the results of OC, EC and TC for all three seasons at Vikashnagar site. Figure 2.26(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at Vikashnagar. Figure 2.26(e) compares the results of VOCs, and NMHC for all three seasons at Vikashnagar site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

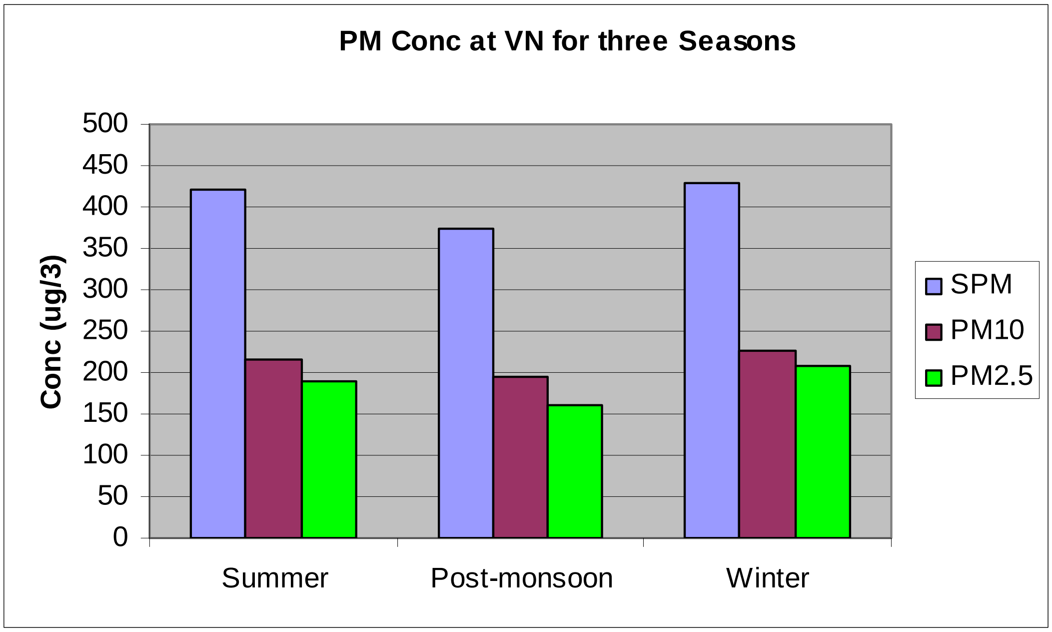


Figure 2.26(a): Seasonal Comparison of Observed PM Concentrations at Vikashnagar Site

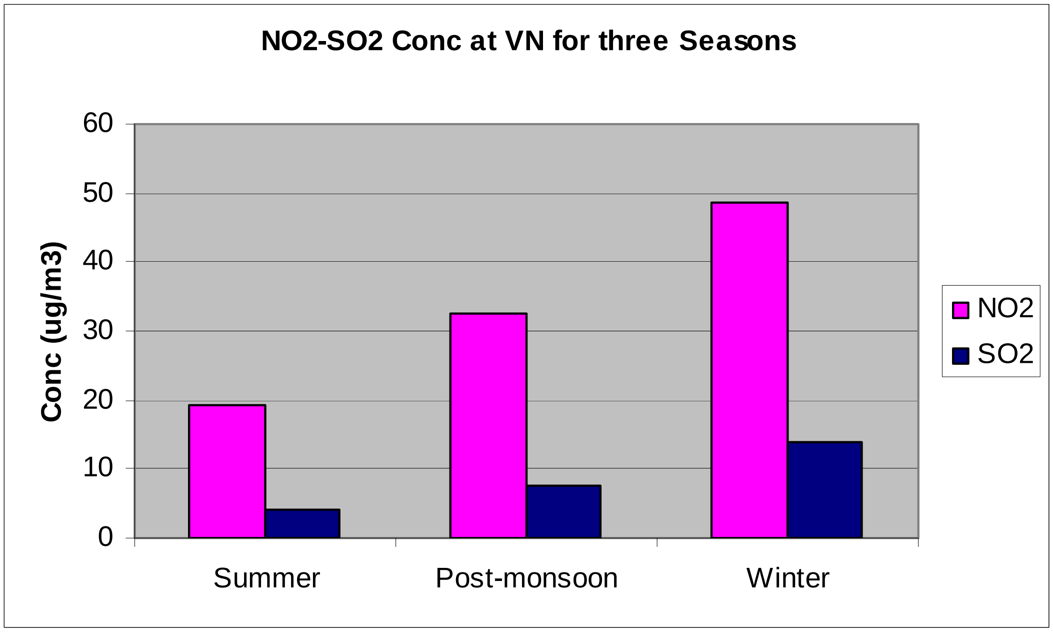


Figure 2.26(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at Vikashnagar Site

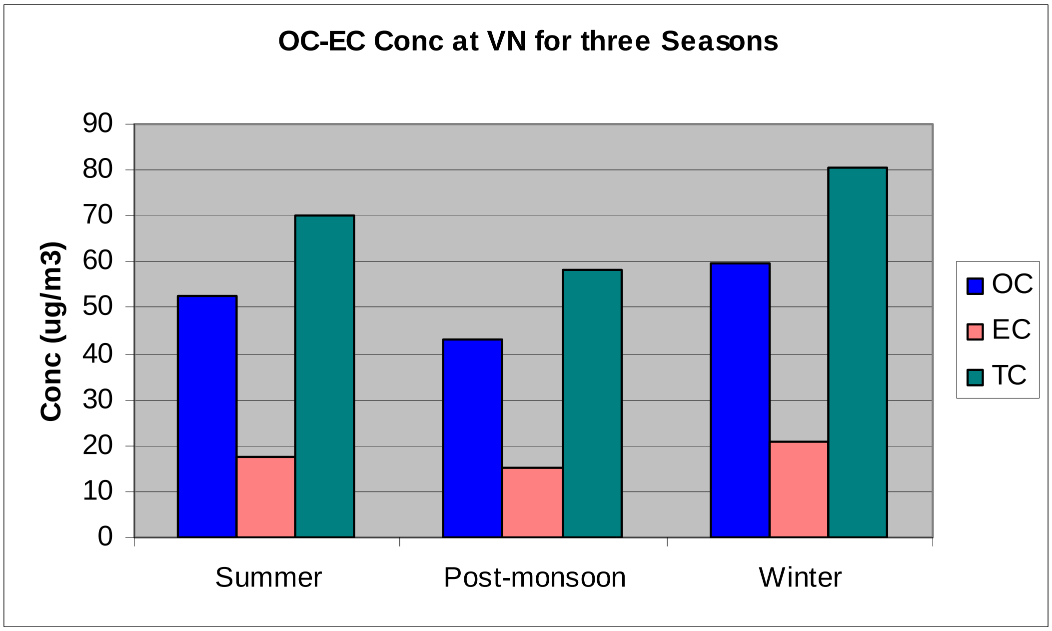


Figure 2.26(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at Vikashnagar Site

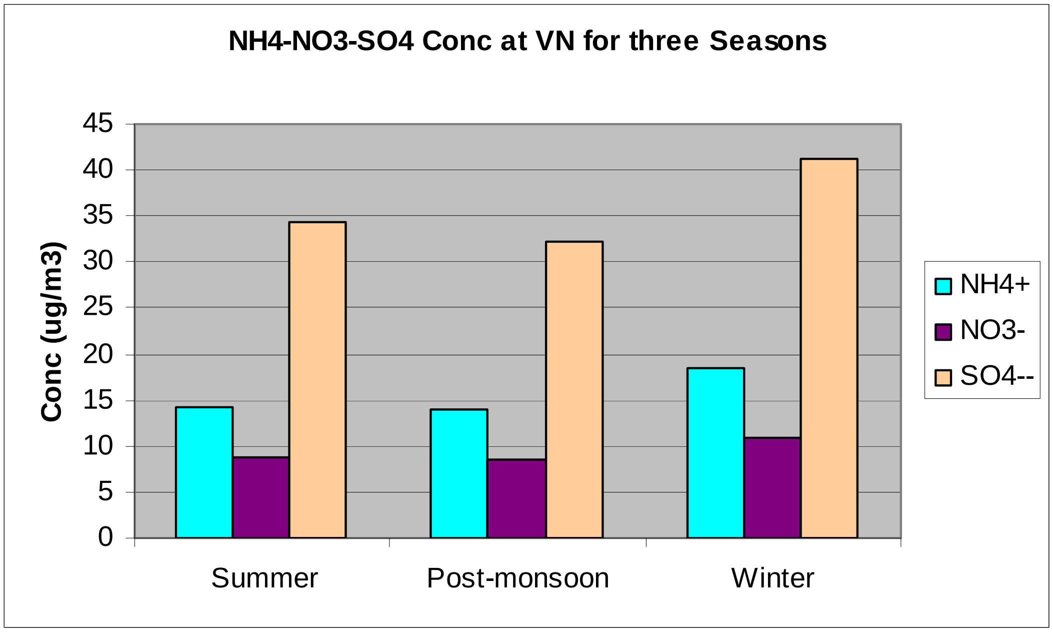


Figure 2.26(d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^{2-} Concentrations at Vikashnagar Site

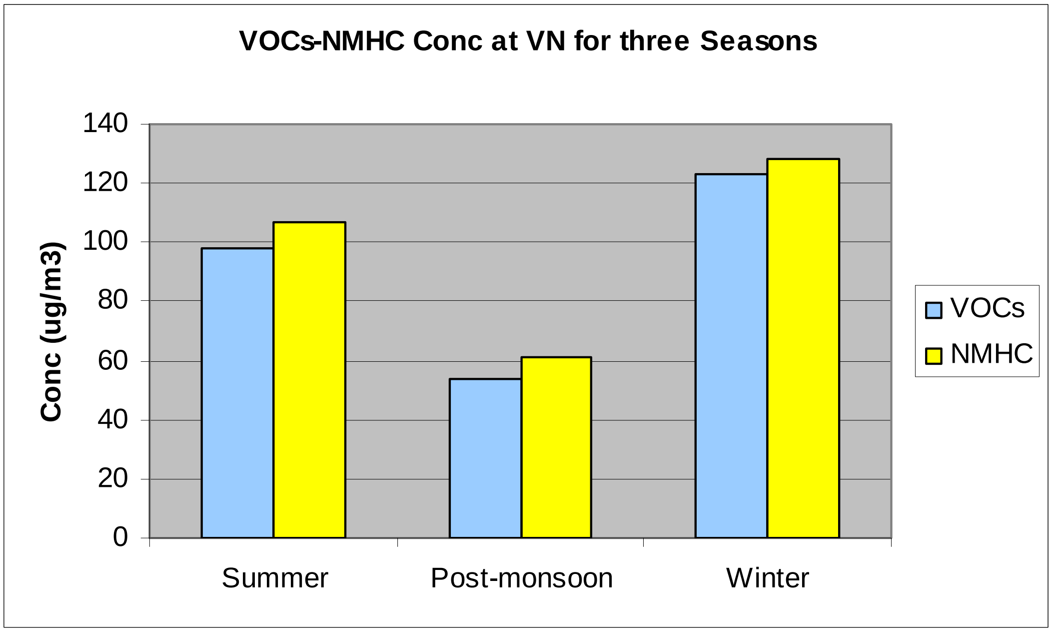


Figure 2.26(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at Vikashnagar Site

2.5.3 Govindnagar Site

This section shows season-wise comparisons of observed concentrations of some important parameters at Govindnagar site. Figure 2.27(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at Govindnagar site. Figure 2.27(b) compares the results of NO_2 and SO_2 for all three seasons at Govindnagar site. Figure 2.27(c) compares the results of OC, EC and TC for all three seasons at Govindnagar site. Figure 2.27(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at Govindnagar. Figure 2.27(e) compares the results of VOCs, and NMHC for all three seasons at Govindnagar site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

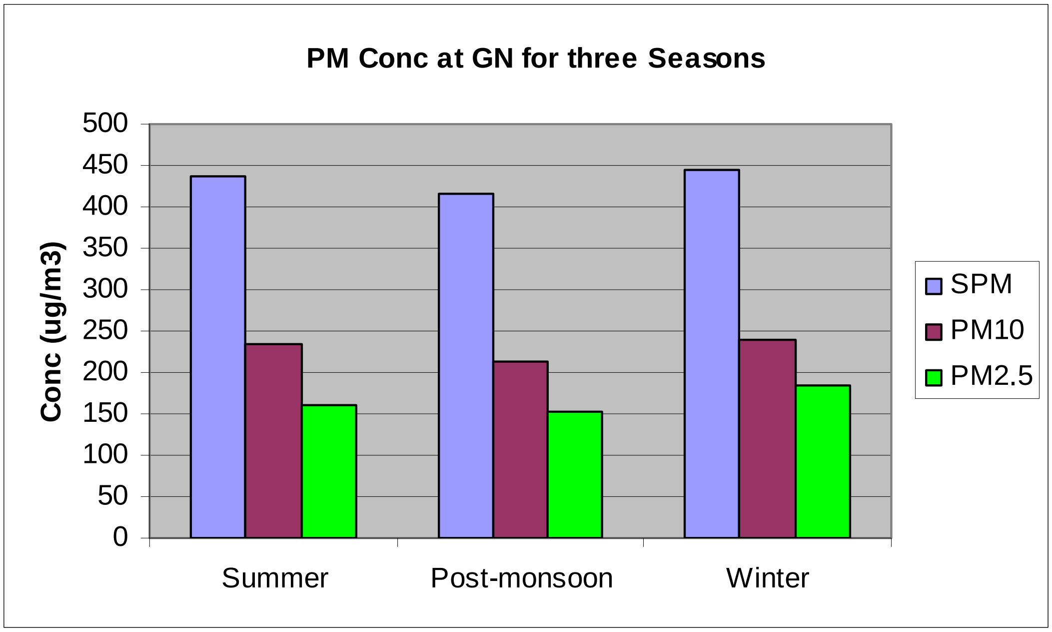


Figure 2.27(a): Seasonal Comparison of Observed PM Concentrations at Govindnagar Site

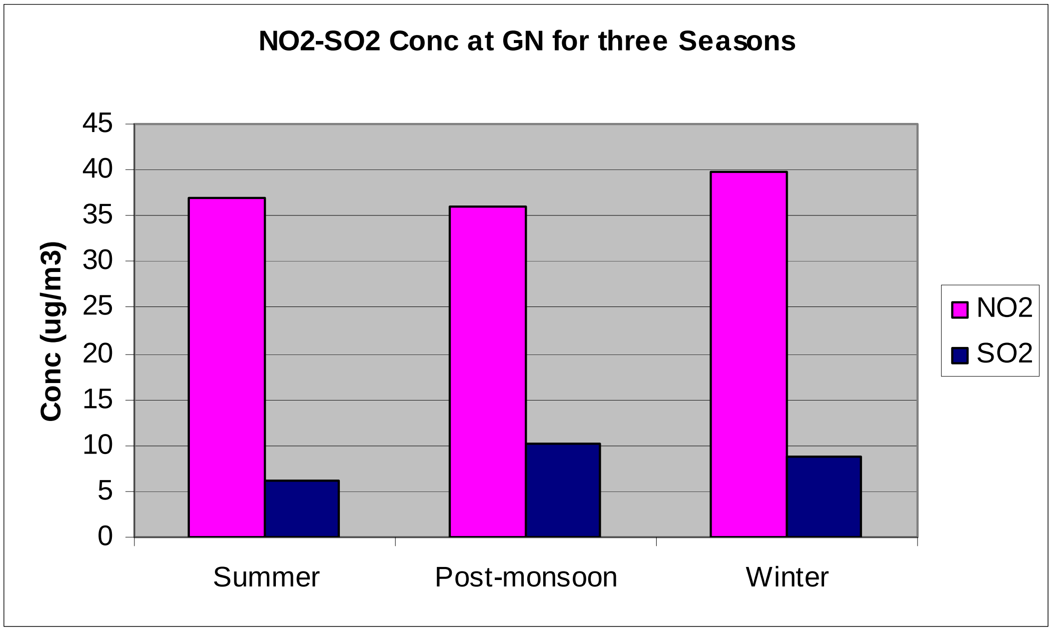


Figure 2.27(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at Govindnagar Site

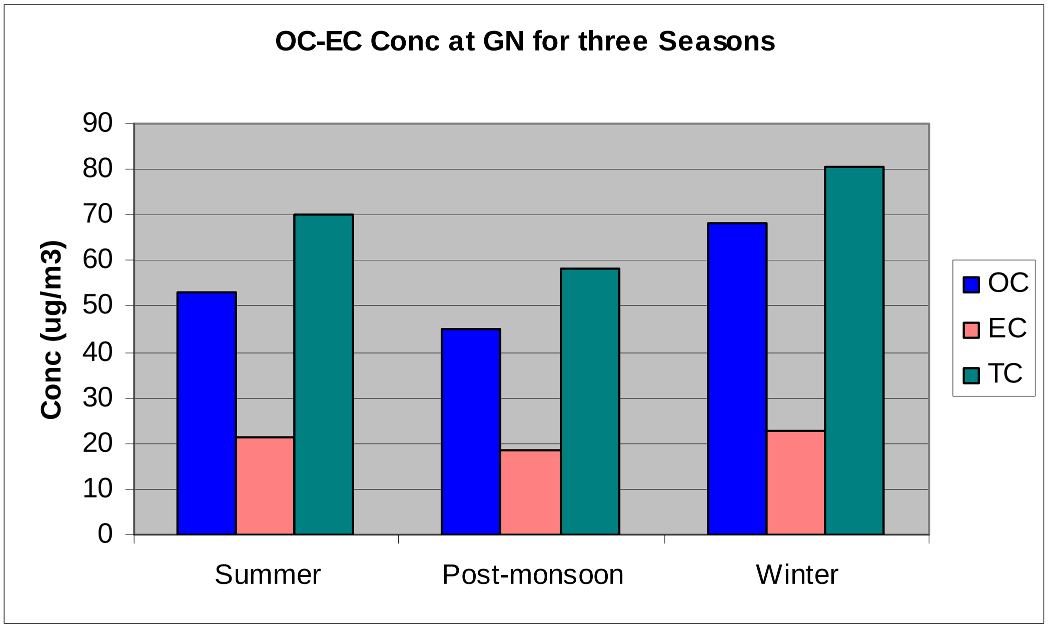


Figure 2.27(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at Govindnagar Site

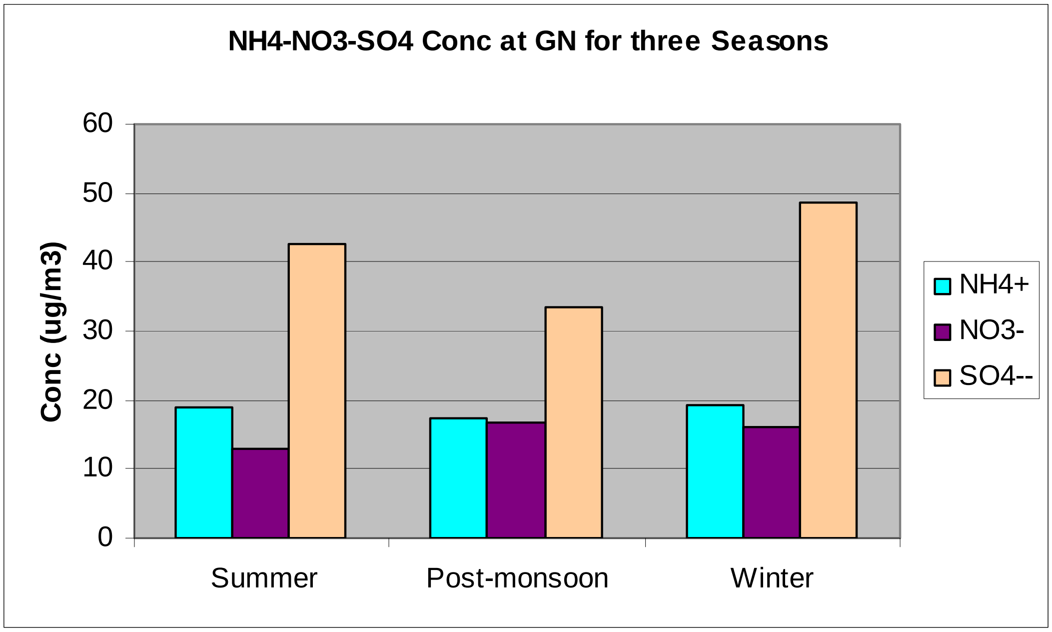


Figure 2.27(d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^{2-} Concentrations at Govindnagar Site

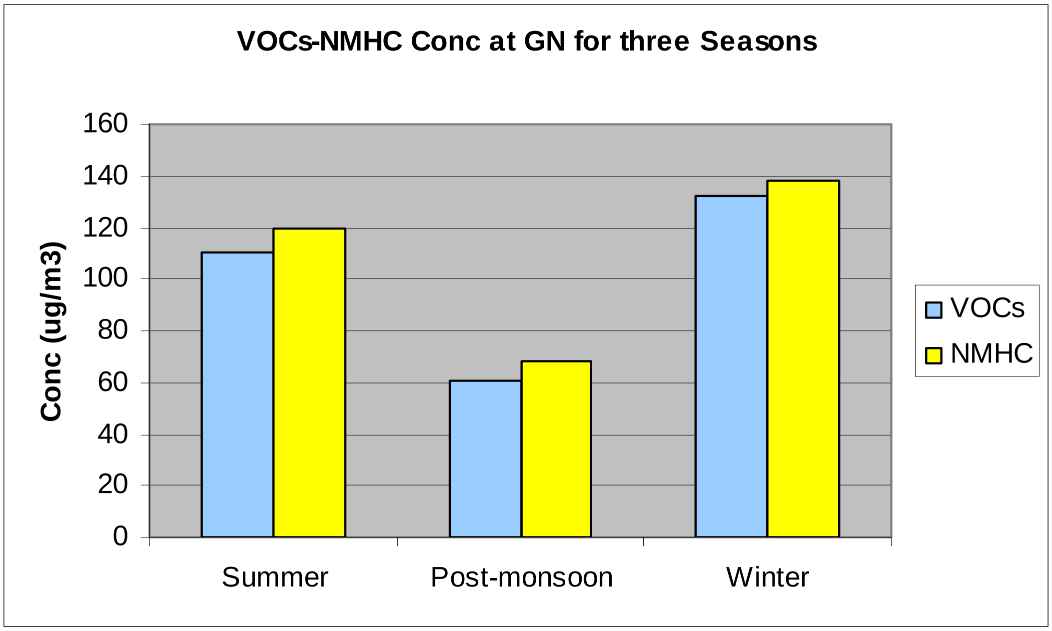


Figure 2.27(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at Govindnagar Site

2.5.4 Dadanagar Site

This section shows season-wise comparisons of observed concentrations of some important parameters at Dadanagar site. Figure 2.28(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at Dadanagar site. Figure 2.28(b) compares the results of NO_2 and SO_2 for all three seasons at Dadanagar site. Figure 2.28(c) compares the results of OC, EC and TC for all three seasons at Dadanagar site. Figure 2.28(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at Dadanagar. Figure 2.28(e) compares the results of VOCs, and NMHC for all three seasons at Dadanagar site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

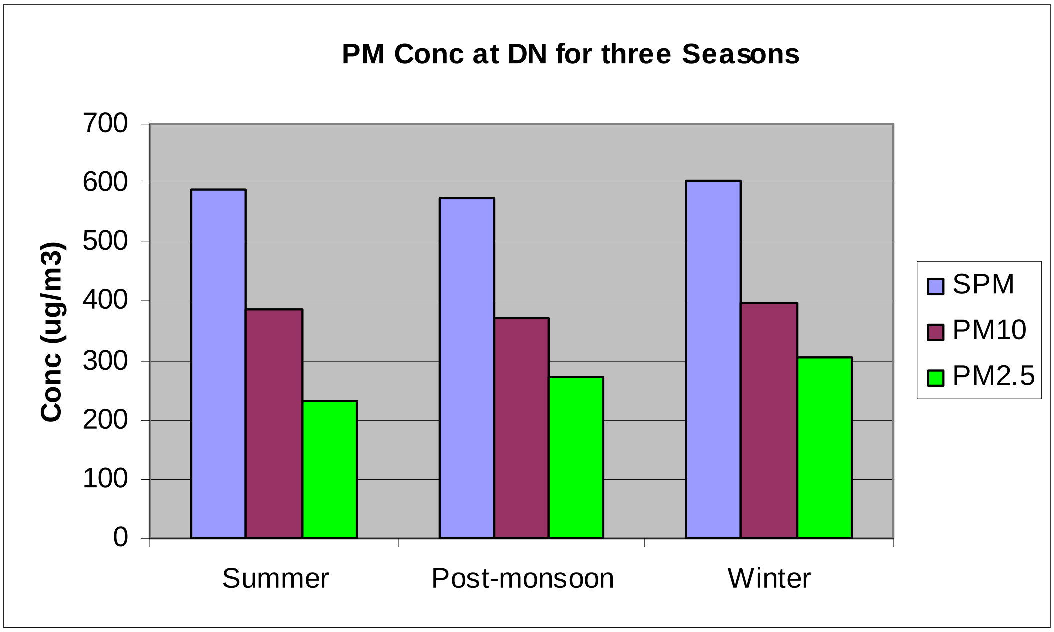


Figure 2.28(a): Seasonal Comparison of Observed PM Concentrations at Dadanagar Site

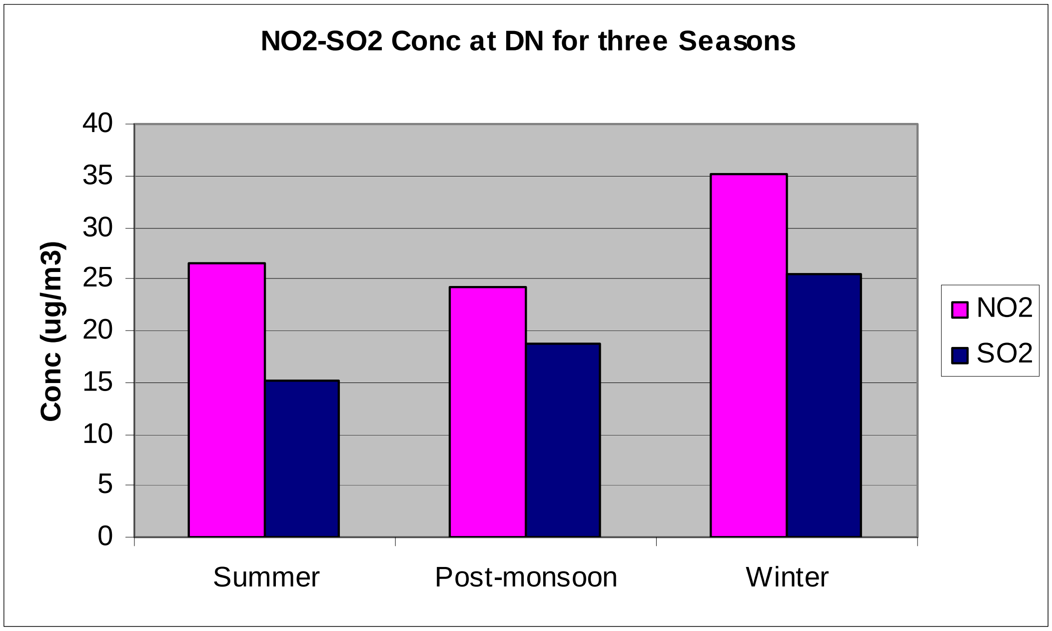


Figure 2.28(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at Dadanagar Site

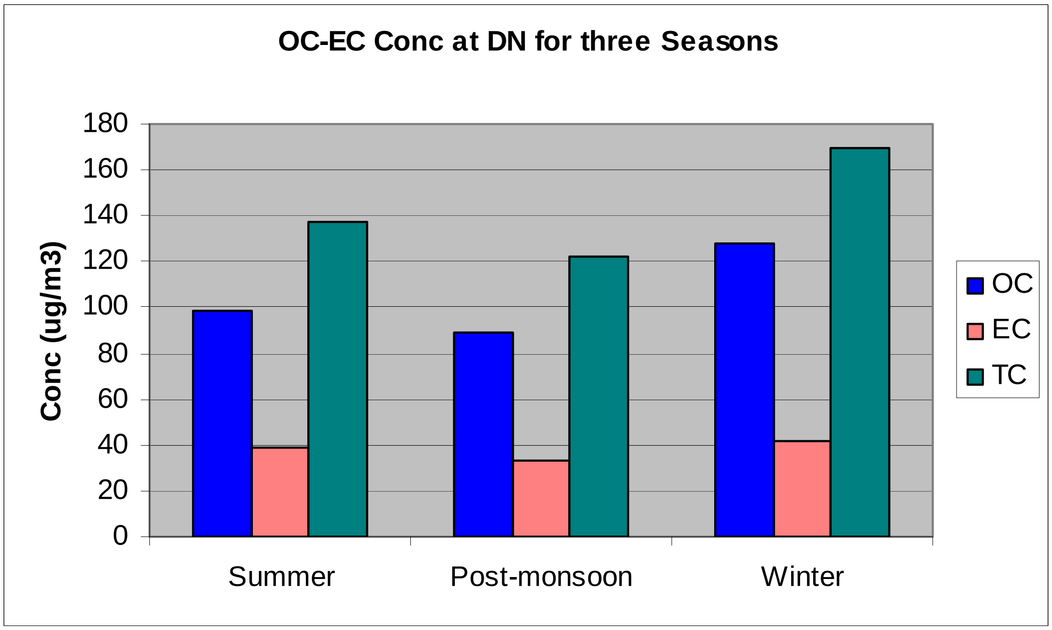


Figure 2.28(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at Dadanagar Site

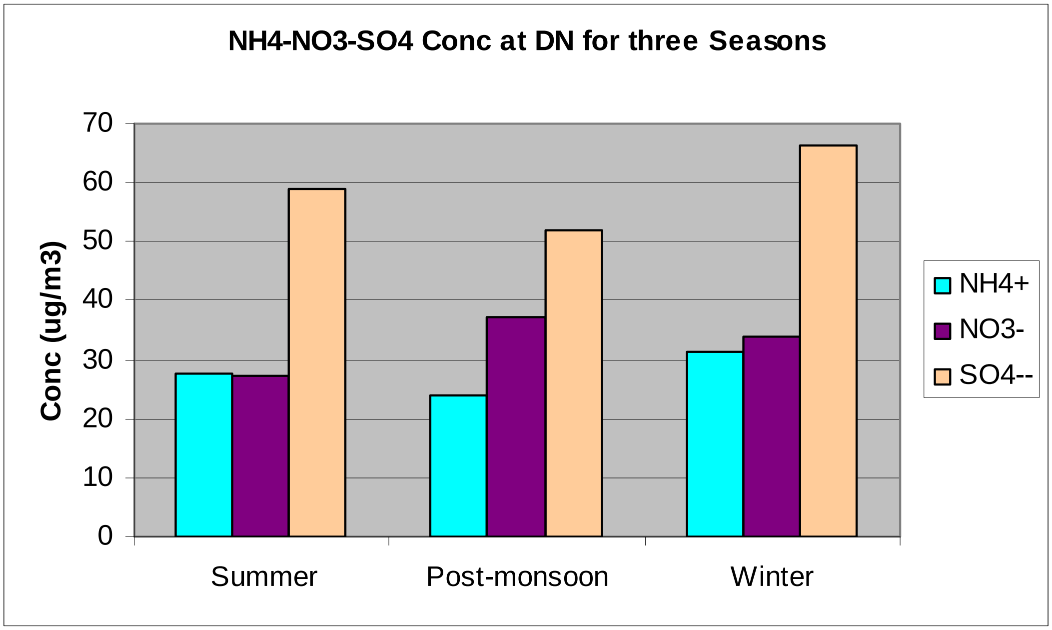


Figure 2.28 (d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^{2-} Concentrations at Dadanagar Site

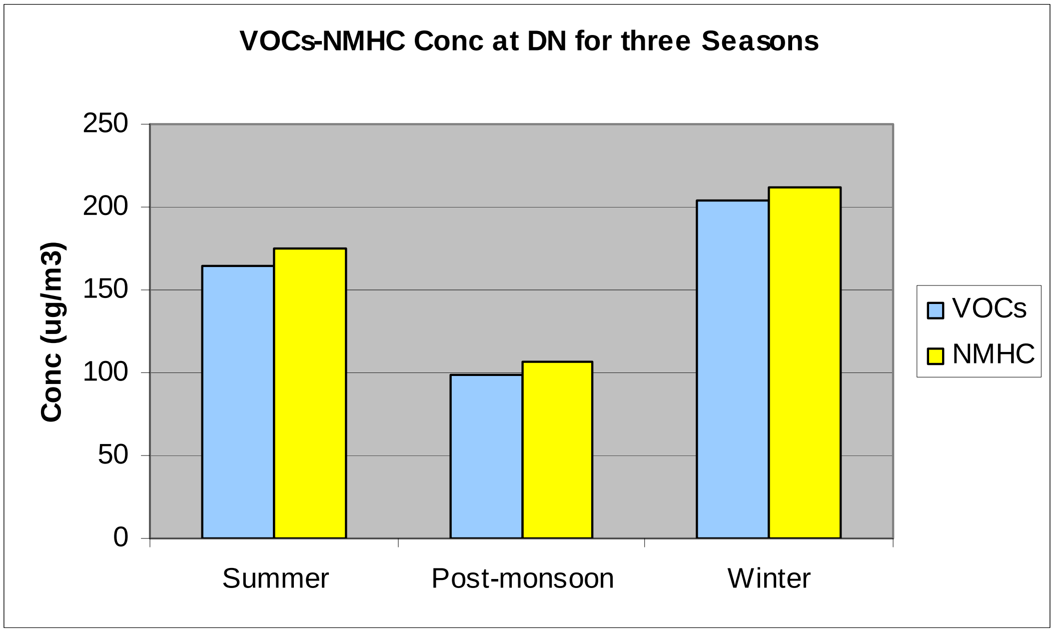


Figure 2.28(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at Dadanagar Site

2.5.5 Colonelganj Site

This section shows season-wise comparisons of observed concentrations of some important parameters at Colonelganj site. Figure 2.29(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at Colonelganj site. Figure 2.29(b) compares the results of NO_2 and SO_2 for all three seasons at Colonelganj site. Figure 2.29(c) compares the results of OC, EC and TC for all three seasons at Colonelganj site. Figure 2.29(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at Colonelganj site. Figure 2.29(e) compares the results of VOCs, and NMHC for all three seasons at Colonelganj site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

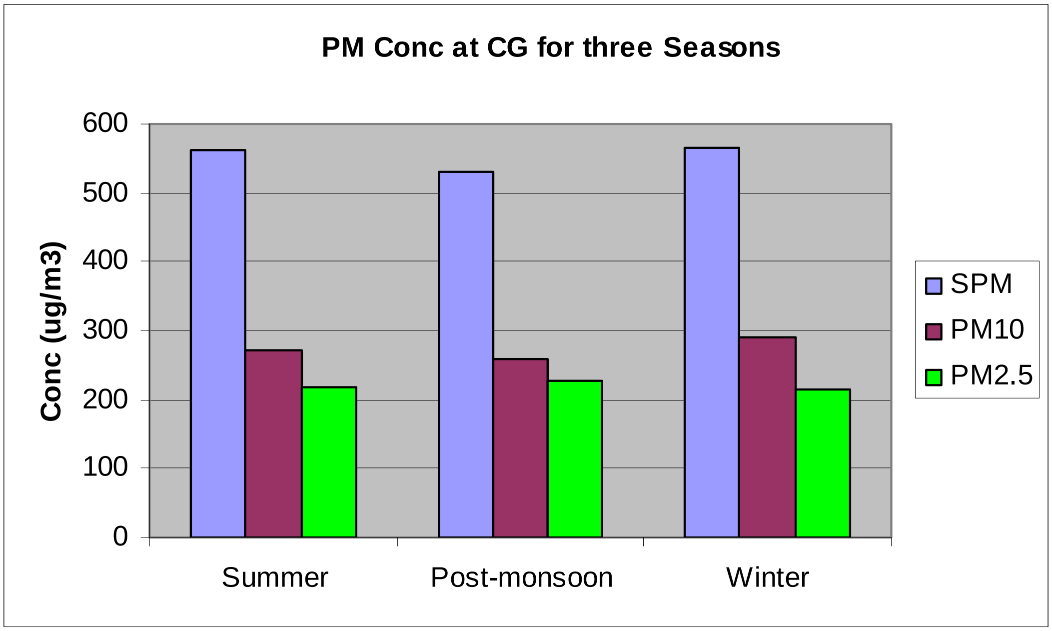


Figure 2.29(a): Seasonal Comparison of Observed PM Concentrations at Colonelganj Site

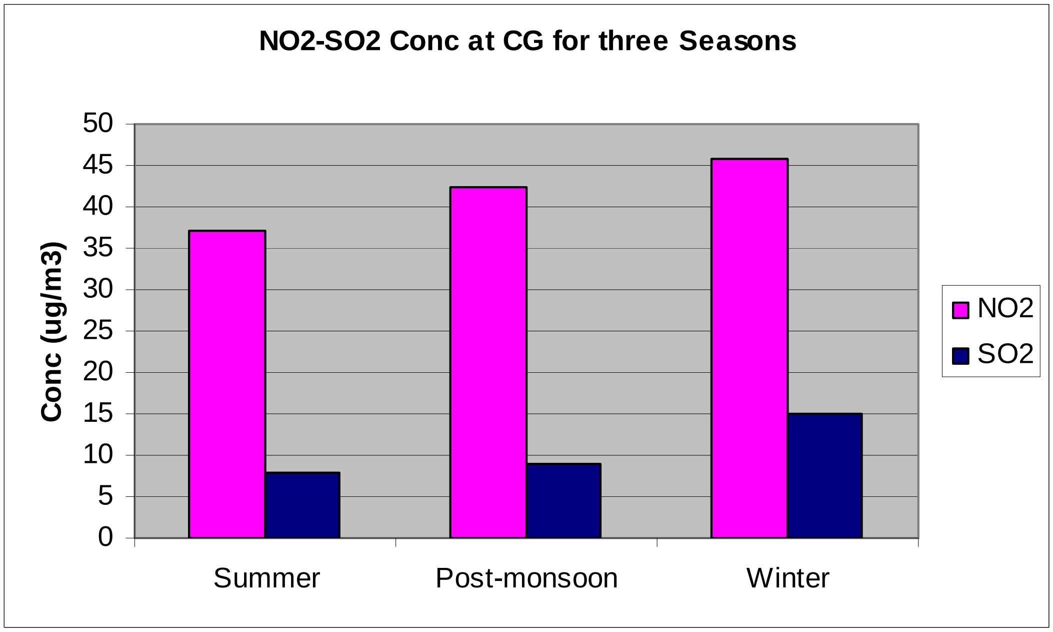


Figure 2.29(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at Colonelganj Site

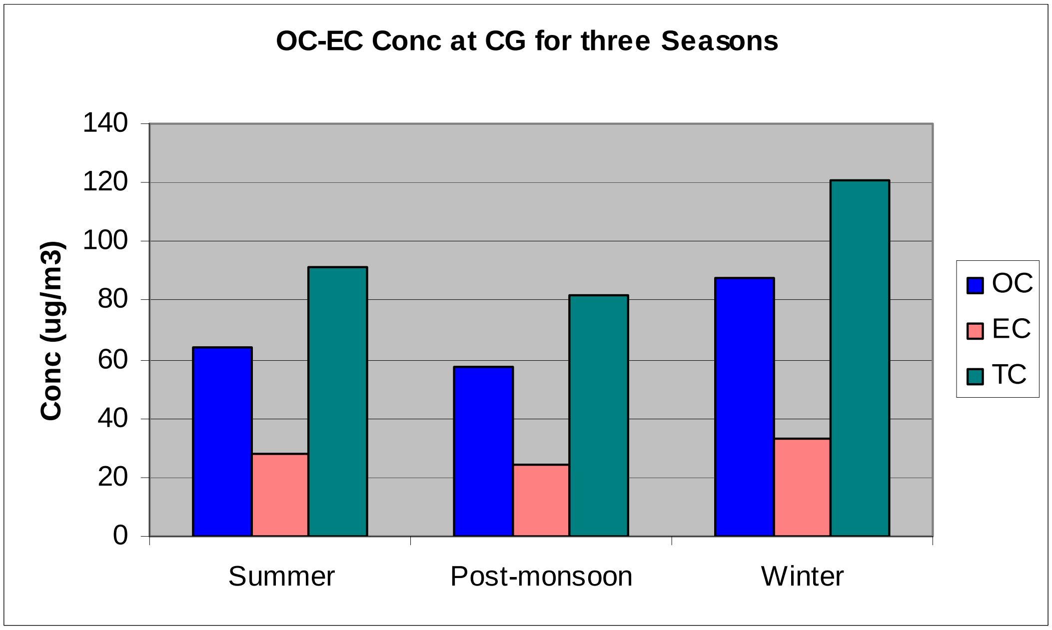


Figure 2.29(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at Colonelganj Site

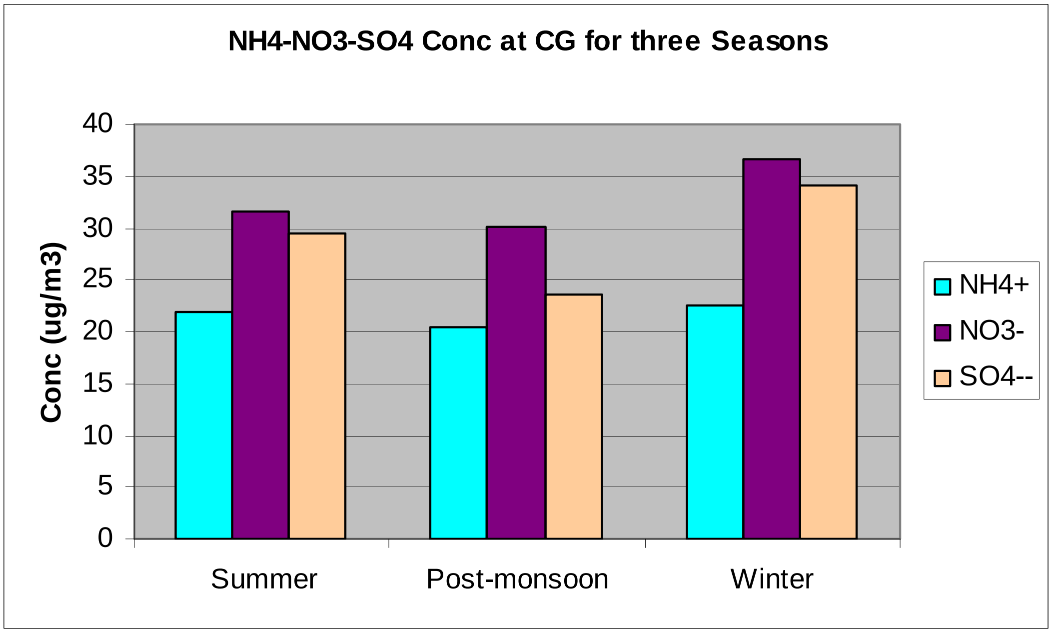


Figure 2.29(d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^{2-} Concentrations at Colonelganj Site

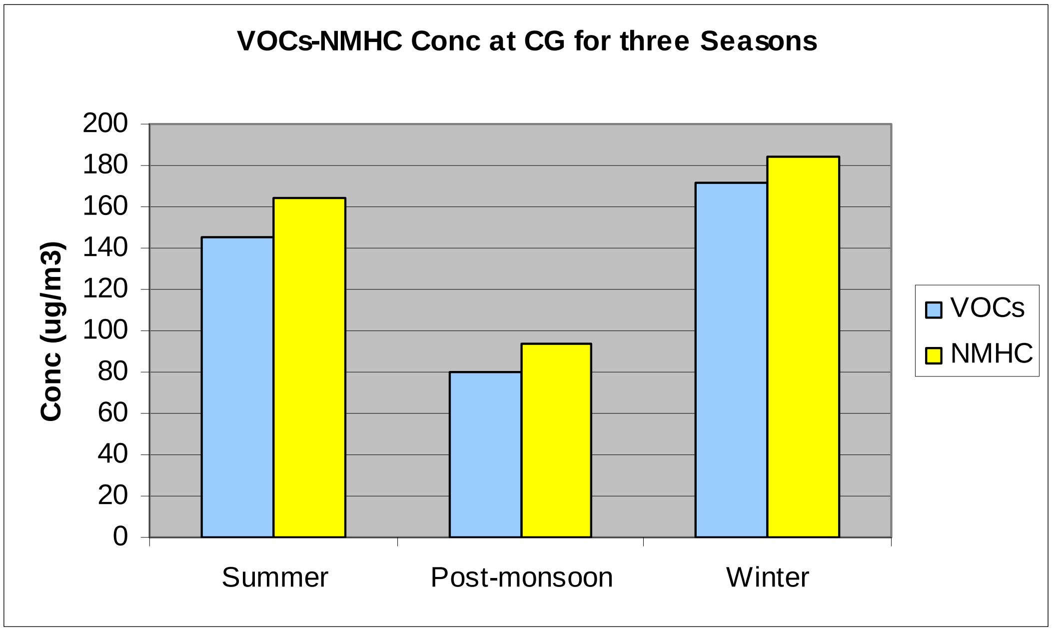


Figure 2.29(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at Colonelganj Site

2.5.6 AHM Site

This section shows season-wise comparisons of observed concentrations of some important parameters at AHM site. Figure 2.30(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at AHM site. Figure 2.30(b) compares the results of NO_2 and SO_2 for all three seasons at AHM site. Figure 2.30(c) compares the results of OC, EC and TC for all three seasons at AHM site. Figure 2.30(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at AHM site. Figure 2.30(e) compares the results of VOCs, and NMHC for all three seasons at Colonelganj site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

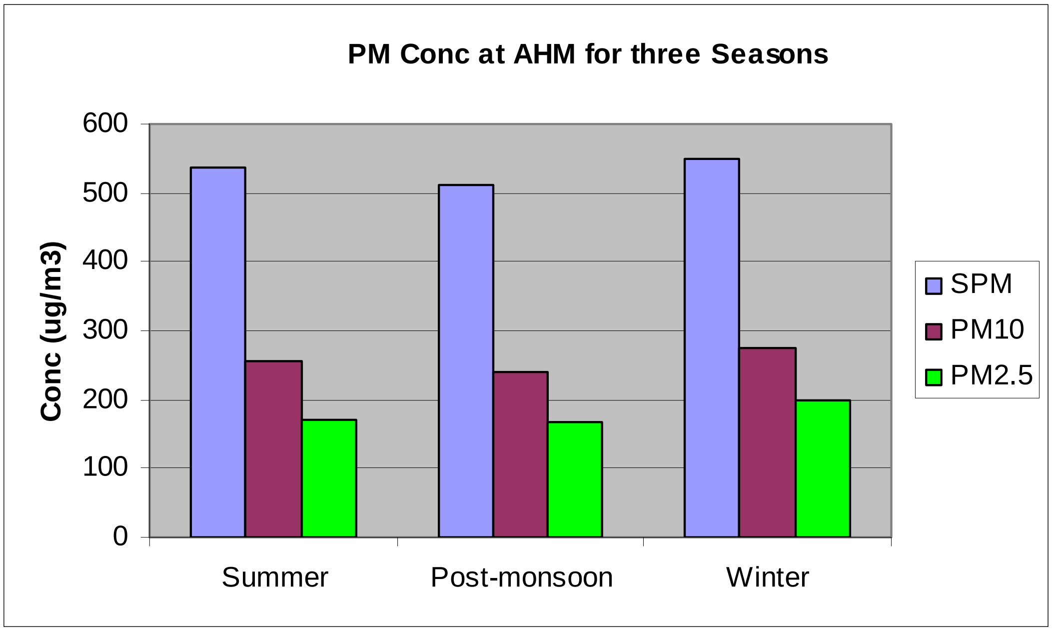


Figure 2.30(a): Seasonal Comparison of Observed PM Concentrations at AHM Site

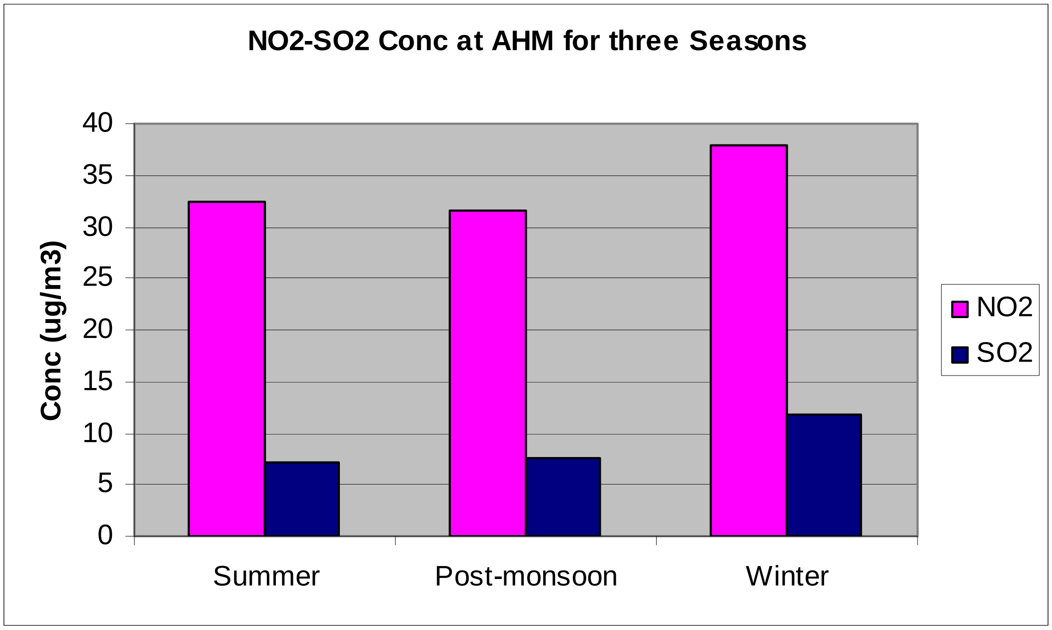


Figure 2.30(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at AHM Site

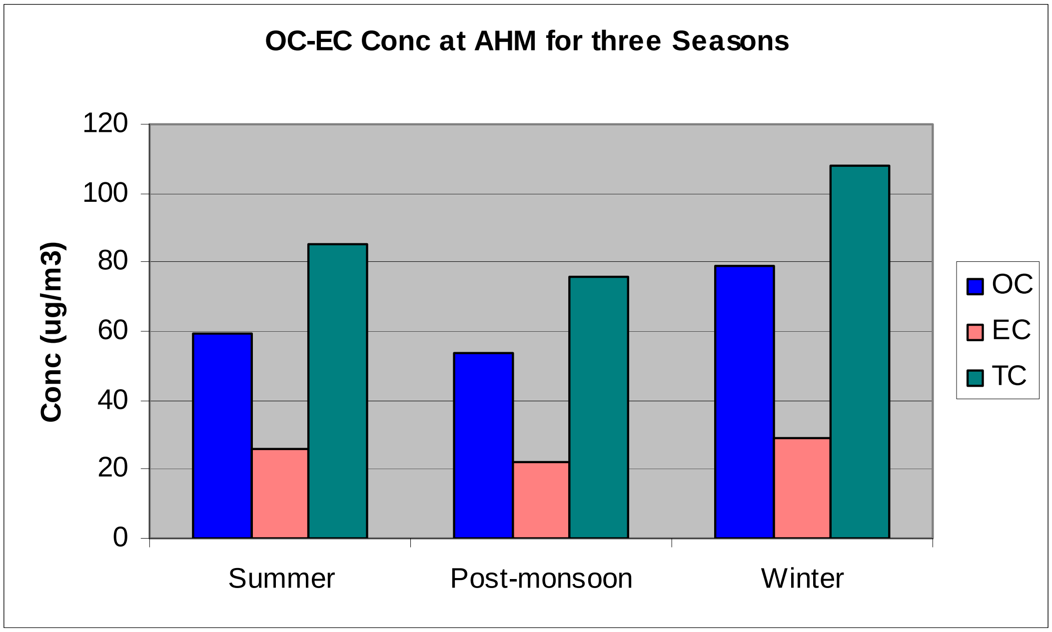


Figure 2.30(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at AHM Site

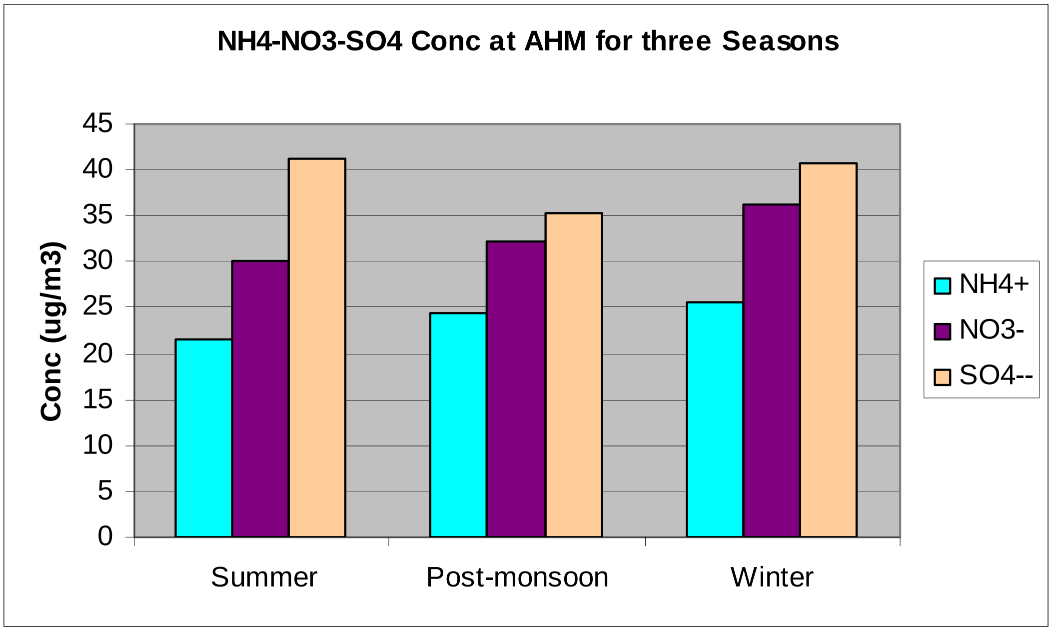


Figure 2.30(d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^{2-} Concentrations at AHM Site

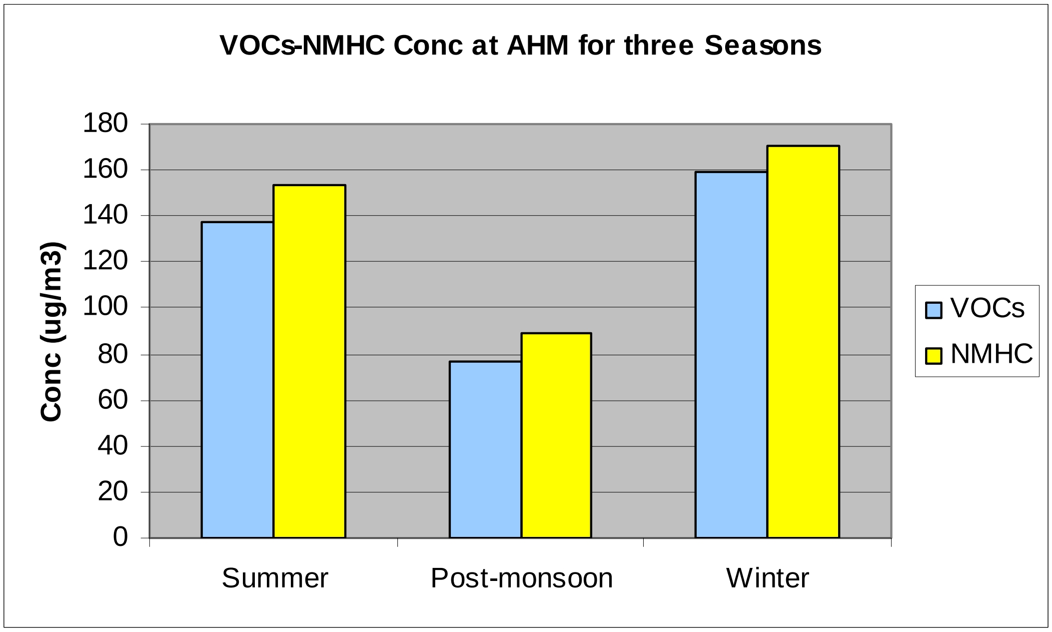


Figure 2.30(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at AHM Site

2.5.7 Ramadevi Site

This section shows season-wise comparisons of observed concentrations of some important parameters at Ramadevi site. Figure 2.31(a) compares the results of SPM, PM_{10} and $PM_{2.5}$ for all three seasons at Ramadevi site. Figure 2.31(b) compares the results of NO_2 and SO_2 for all three seasons at Ramadevi site. Figure 2.31(c) compares the results of OC, EC and TC for all three seasons at Ramadevi site. Figure 2.31(d) compares the results of NH_4^+, NO_3^- and SO_4^{2-} for all three seasons at Ramadevi site. Figure 2.31(e) compares the results of VOCs, and NMHC for all three seasons at Colonelganj site. It has been observed that the concentrations of these pollutants are higher in winter in comparison to summer and post-monsoon. The reasons are: (i) higher emission activities; (ii) lower dispersion of air in the atmosphere due to more calm conditions; (iii) the meteorological conditions in winter favors more particle formations in fine mode; (iv) due to lower quantity of hydroxyl radicals for degradation of VOCs in the atmosphere.

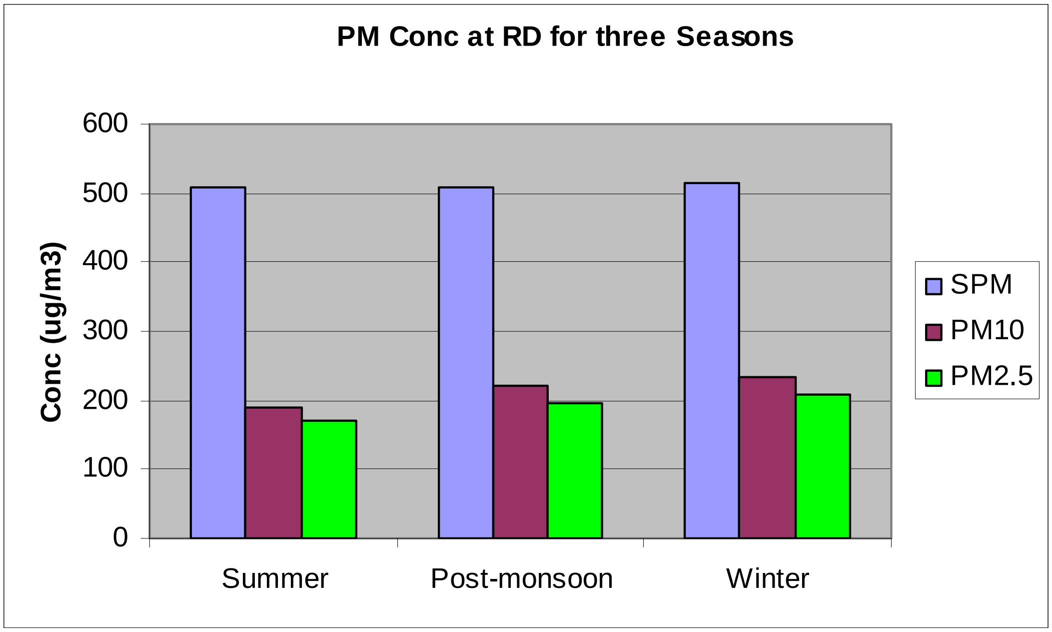


Figure 2.31(a): Seasonal Comparison of Observed PM Concentrations at Ramadevi Site

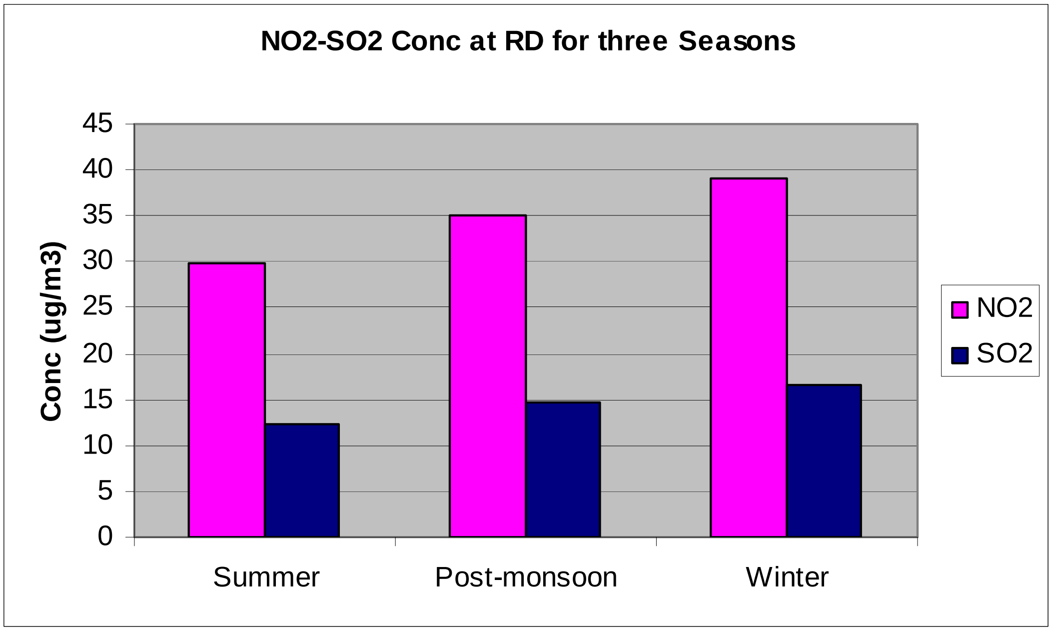


Figure 2.31(b): Seasonal Comparison of Observed NO_2 and SO_2 Concentrations at Ramadevi Site

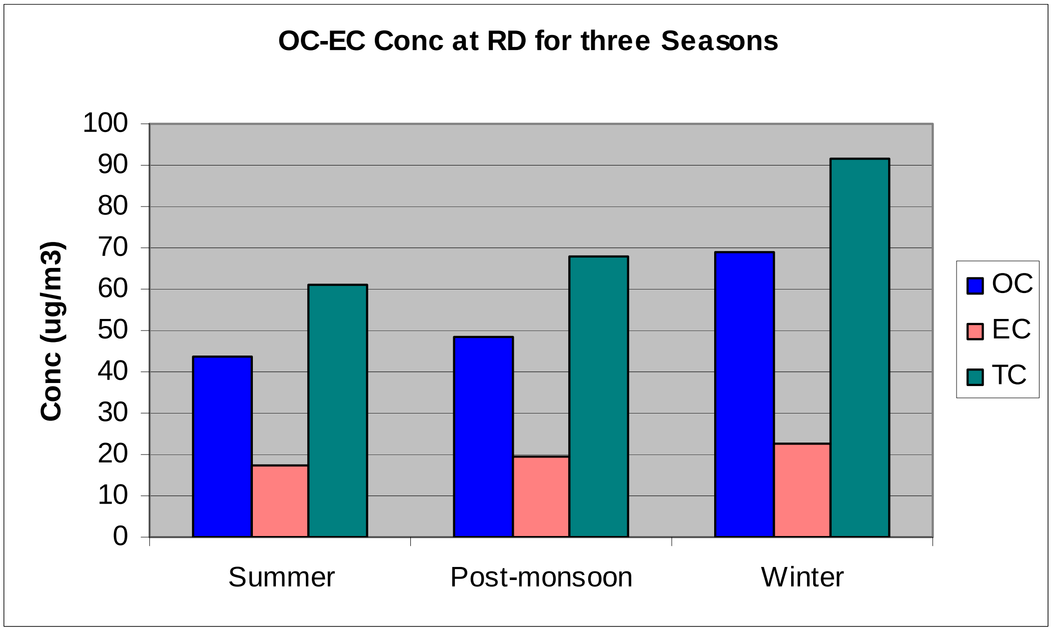


Figure 2.31(c): Seasonal Comparison of Observed OC, EC and TC Concentrations at Ramadevi Site

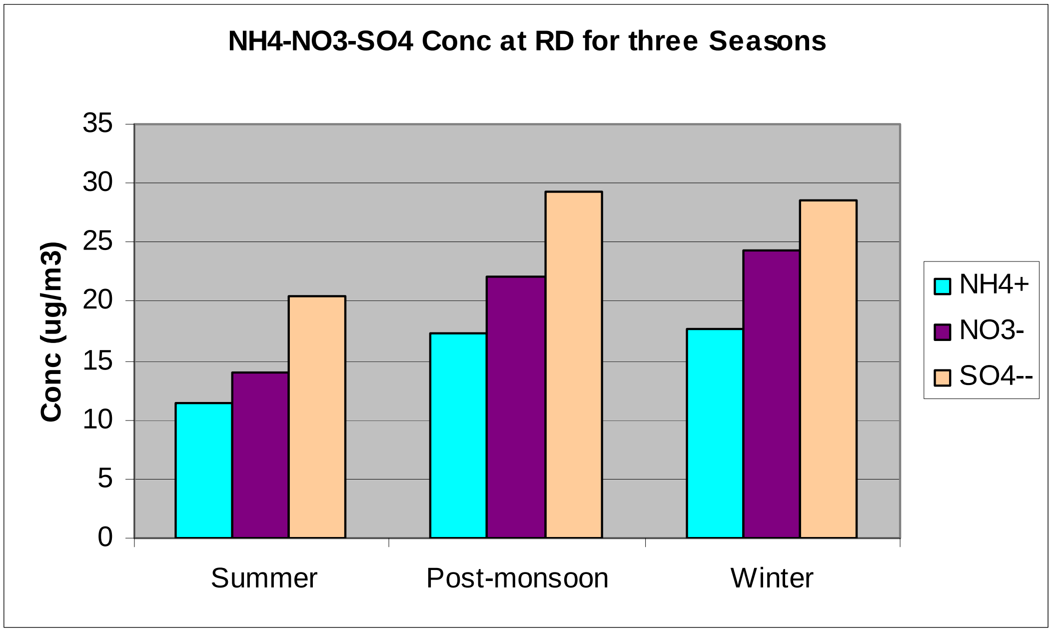


Figure 2.31(d): Seasonal Comparison of Observed NH_4^+, NO_3^- and SO_4^2 Concentrations at Ramadevi Site

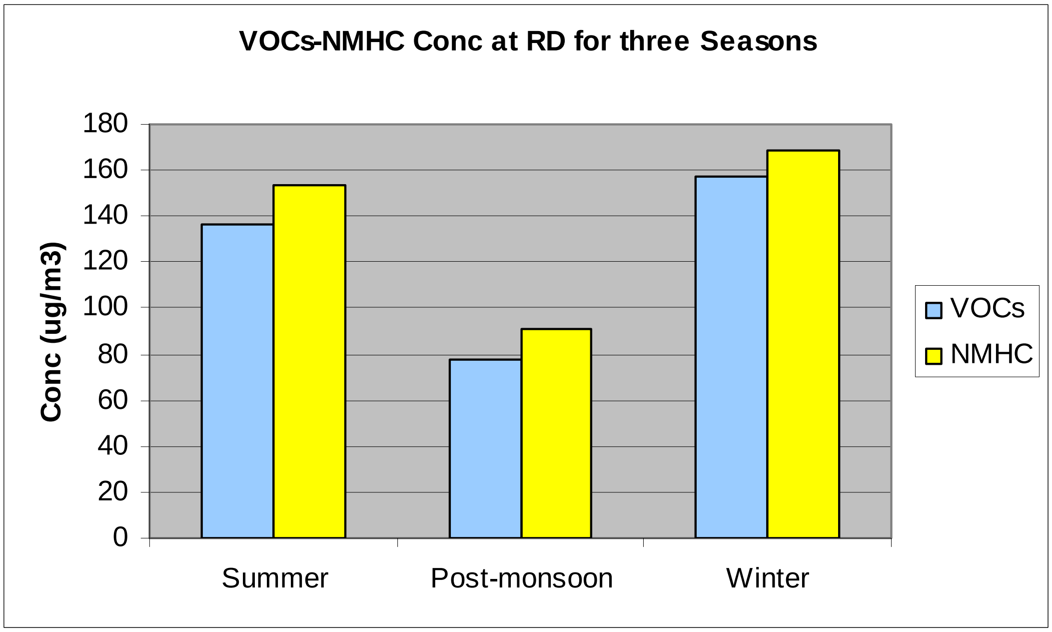


Figure 2.31(e): Seasonal Comparison of Observed VOCs and NMHC Concentrations at Ramadevi Site

Table 2.22(a): Seasonal Comparisons of Experimental Results with PM$_{10}$ Chemical Speciation at IIT Kanpur Site

IIT Kanpur	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	341.6	371.8	183.14	187.2	136.4	19.7	3.6	2.23	8.25	12.06	7.31	4.54	12.4	1.36	0.37	34.4	14.2	48.5	6.76	4.49	6.64	3.74	13.1	1.63	7.12	28	5.95	0.08	0.011	0.16	0.5	0.012	0.008	0.021	0.152	0.09	0.006	0.068
Post-monsoon	329.3	359.4	160.5	169.5	132.1	20.1	7.5	1.58	5.79	9.573	6.357	5.47	11.2	0.87	0.38	28.8	12.4	41.2	6.14	3.94	5.92	2.22	11.3	3.7	6.38	24.4	4.53	0.02	0.013	0.14	0.46	0.009	0.016	0.026	0.443	0.06	0.006	0.02
Winter	361.6	382.5	190.1	204.7	172.1	22.7	7.9	5.2	10.1	13.71	8.539	7.25	14.9	0.74	0.33	44.7	16	60.8	8.18	5.25	6.57	2.97	15.1	4.94	8.5	32.5	3.05	0.02	0.009	0.12	0.4	0.009	0.011	0.078	0.481	0.02	0.009	0.041

IIT Kanpur	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.133	0.131	0.825	19.601	39.008	5.035	12.726	6.175	82.5	89.3																						
Post-monsoon	0.103	0.104	0.724	11.537	25.16	3.164	8.209	3.983	52.1	57.5	0.01	5.794	0.009	0.046	0.114	0.002	0.038	0.016	0.054	0.05	0.009	0.066	0.01	0.037	0.005	0.029	0.044	0.145	0.045	0.04	0.007	0.189
Winter	0.092	0.15	0.907	23.253	50.71	6.417	16.545	8.027	105	109	0.01	6.365	0.009	0.053	0.131	0.002	0.064	0.013	0.038	0.036	0.009	0.05	0.01	0.043	0.005	0.032	0.057	0.11	0.048	0.048	0.007	0.131

Table 2.22(b): Seasonal Comparisons of Experimental Results with PM$_{10}$ Chemical Speciation at Vikashnagar Site

Vikashnagar	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	422.3	434.6	172.8	216.7	190.1	19.1	4.1	3.75	12.8	16.89	10.78	8.45	15.7	1.55	0.42	52.6	17.7	70.3	7.42	5.13	7.48	3.45	14.3	1.84	8.77	34.3	8.22	0.12	0.014	0.25	0.5	0.016	0.011	0.033	0.211	0.07	0.005	0.063
Post-monsoon	372.6	392.4	178.4	194.9	161.4	32.4	7.7	4.36	9.87	12.11	7.472	9.52	14.5	0.45	0.19	43.3	15.1	58.5	5.99	4.81	7.15	3.27	13.9	2.6	8.49	32.2	15.5	0.03	0.025	0.33	0.5	0.027	0.017	0.06	0.544	0.06	0.009	0.054
Winter	429.3	448.9	205.5	226.4	207.5	48.7	14.0	8.34	15.8	18.59	10.29	6.93	19.4	1.09	0.39	59.9	20.9	80.8	7.65	5.53	6.09	4.18	18.5	3.32	10.8	41.1	5.3	0.01	0.006	0.06	0.18	0.008	0.007	0.013	0.23	0.01	0.01	0.064

Vikashnagar	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.16	0.155	0.258	23.576	38.593	8.361	17.079	10.755	98.4	107																						
Post-monsoon	0.134	0.146	0.875	12.967	21.226	4.598	9.393	5.915	54.1	60.8	0.01	7.273	0.009	0.129	0.122	0.002	0.047	0.053	0.099	0.05	0.009	0.061	0.013	0.039	0.006	0.035	0.069	0.42	0.056	0.061	0.008	0.173
Winter	0.164	0.154	1.302	29.47	48.241	10.451	21.349	13.444	123	128	0.01	8.252	0.009	0.131	0.14	0.002	0.061	0.015	0.06	0.034	0.01	0.049	0.013	0.045	0.006	0.04	0.076	0.209	0.06	0.065	0.008	0.074

Table 2.22(c): Seasonal Comparisons of Experimental Results with PM$_{10}$ Chemical Speciation at Govindnagar Site

Govindnagar	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	436.5	463.2	178.79	234.14	159.3	36.8	6.2	8.86	4.1	4.009	9.099	27	5.62	5.59	10.2	53.1	21.4	74.5	7.1	2.59	6.54	3.58	18.8	2.91	12.9	42.7	8.54	0.11	0.025	0.22	0.45	0.014	0.011	0.043	0.315	0.1	0.006	0.074
Post-monsoon	416.6	453.8	172.9	212.0	153.7	36.0	10.1	4.02	10.7	12.87	8.338	9.15	17.6	0.64	0.38	45.1	18.6	63.7	6.44	4.45	8.02	3.05	17.4	3.3	16.8	33.5	8.73	0.04	0.053	0.46	0.63	0.029	0.028	0.094	0.471	0.26	0.009	0.123
Winter	444.6	467.4	189.2	239.8	185.2	39.7	8.9	10	15.8	25.78	13.48	3.08	20.2	1.41	1.13	68.2	22.8	91	8.73	4.77	7.57	4.19	19.2	5.08	16.1	48.5	6	0.02	0.029	0.2	0.5	0.015	0.018	0.054	0.396	0.06	0.012	0.146

Govindnagar	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.156	0.19	0.732	24.645	47.859	7.623	19.352	10.909	110	119																						
Post-monsoon	0.307	0.182	0.671	13.555	26.323	4.193	10.643	6	60.7	68	0.02	6.548	0.009	0.123	0.178	0.002	0.063	0.034	0.089	0.134	0.011	0.066	0.013	0.044	0.006	0.035	0.073	0.308	0.08	0.077	0.009	0.354
Winter	0.126	0.338	0.869	29.574	57.431	9.148	23.222	13.09	132	138	0.01	7.477	0.009	0.13	0.205	0.002	0.082	0.027	0.07	0.057	0.011	0.054	0.014	0.048	0.006	0.042	0.081	0.268	0.093	0.082	0.009	0.208

Table 2.22(d): Seasonal Comparisons of Experimental Results with PM$_{10}$ Chemical Speciation at Dadanagar Site

Dadanagar	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	590.8	643.1	336.8	387.6	232.0	26.6	15.1	7.29	22.3	29.77	30.39	9.02	28.8	1.17	8.86	98.8	38.8	138	12.3	7.48	12.9	2.83	27.5	6.24	27.4	59	12.1	0.22	0.102	0.45	0.56	0.034	0.03	0.1	0.5	0.36	0.051	0.07
Post-monsoon	576.5	612.9	295.9	370.8	272.8	24.2	18.8	5.03	23.3	26.02	25.06	9.41	19.4	8.56	5.42	88.8	33.4	122	10.9	6.49	13.8	2.7	24	8.72	37.1	51.8	3.87	0.09	0.176	0.39	0.52	0.061	0.049	0.191	0.553	0.44	0.014	0.268
Winter	602.6	626.8	349.8	396.3	304.8	35.1	25.5	25.7	26.3	40.89	21.08	13.6	39.8	1.08	0.94	128	41.9	169	14.2	9.5	10.9	3.29	31.5	9.19	34	66.3	4.95	0.04	0.063	0.25	0.6	0.015	0.035	0.064	0.572	0.23	0.005	0.31

Dadanagar	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.3	0.446	1.499	34.503	77.054	10.673	27.092	15.272	165	175																						
Post-monsoon	0.451	0.554	1.35	20.702	46.232	6.404	16.256	9.163	98.8	107	0.01	7.365	0.009	0.311	0.257	0.004	0.072	0.06	0.112	0.229	0.011	0.079	0.031	0.064	0.007	0.045	0.105	0.55	0.129	0.156	0.013	0.326
Winter	0.281	0.534	1.578	42.783	95.547	13.234	33.595	18.937	204	211	0.01	8.444	0.009	0.325	0.323	0.007	0.089	0.02	0.037	0.107	0.012	0.055	0.038	0.073	0.007	0.048	0.128	0.303	0.123	0.165	0.013	0.2

Table 2.22(e): Seasonal Comparisons of Experimental Results with PM$_{10}$ Chemical Speciation at Colonelganj Site

Colonelganj	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	561.2	591.9	188.1	272.5	218.0	37.1	7.9	2.15	13.8	24.33	15.53	7.99	17.9	7.22	2.83	63.7	27.9	91.7	13.3	7.68	8.77	3.19	21.8	3.83	31.5	29.5	7.47	0.11	0.022	0.2	0.4	0.014	0.011	0.048	0.188	0.08	0.005	0.141
Post-monsoon	531.8	559.8	220.4	259.9	225.9	42.3	9.0	6.99	14.2	14.95	6.427	14.8	23.8	0.56	0.25	57.3	24.6	81.9	12	6.78	7.23	2.62	20.4	4.91	30	23.5	5.29	0.02	0.024	0.2	0.43	0.013	0.016	0.109	0.393	0.02	0.009	0.12
Winter	563.9	578.9	236.1	291.5	215.6	45.8	15.0	14.4	23.2	26.25	13.13	10.7	31.8	0.99	0.34	87.7	33.1	121	14.3	7.51	9.81	3.15	22.5	5.89	36.6	34.1	6.31	0.02	0.032	0.19	0.59	0.015	0.024	0.124	0.448	0.04	0.009	0.147

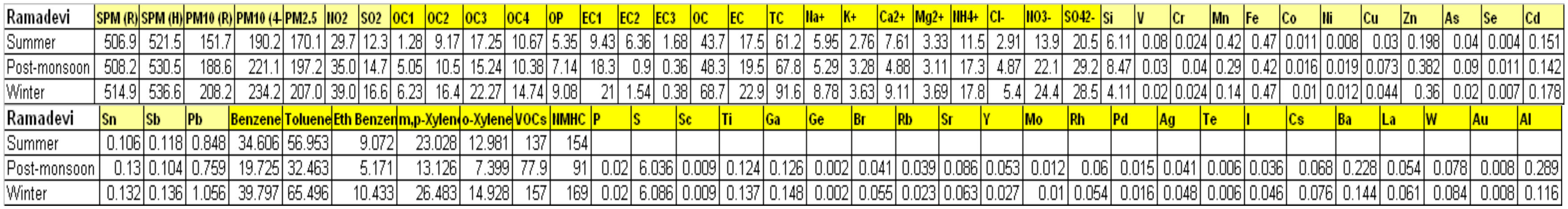
Colonelganj	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.16	0.156	1.206	37.263	60.303	9.605	24.383	13.745	145	164																						
Post-monsoon	0.182	0.178	1.119	20.494	33.167	5.283	13.411	7.56	79.9	93.9	0.02	6.814	0.009	0.103	0.172	0.002	0.056	0.031	0.062	0.097	0.01	0.067	0.025	0.047	0.006	0.037	0.103	0.336	0.106	0.088	0.01	0.144
Winter	0.197	0.195	1.561	43.97	71.158	11.334	28.772	16.219	171	184	0.01	7.734	0.009	0.107	0.198	0.002	0.072	0.024	0.053	0.043	0.009	0.057	0.03	0.058	0.006	0.046	0.111	0.235	0.11	0.095	0.01	0.208

Table 2.22(f): Seasonal Comparisons of Experimental Results with PM$_{10}$ Chemical Speciation at AHM Site

AHM	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	536.7	511.9	160.2	255.1	171.7	32.5	7.2	1.89	12.4	22.94	15.3	7.06	17.6	6.31	1.97	59.6	25.8	85.4	6.17	5.21	7.95	2.5	21.5	3.55	30.2	41.1	6.8	0.09	0.015	0.18	0.36	0.013	0.011	0.052	0.196	0.07	0.005	0.188
Post-monsoon	511.5	524.5	177.07	238.84	168.6	31.6	7.7	5.13	11.2	16.26	10.27	11.1	20.9	0.69	0.61	53.9	22.2	76.1	7.69	5.52	5.55	2.59	24.3	4.79	32.3	35.3	2.58	0.01	0.014	0.08	0.37	0.016	0.011	0.053	0.359	0.03	0.009	0.169
Winter	550.0	562.5	205.4	276.0	198.0	38.0	11.8	7.38	18.8	28.13	15.09	9.26	27.8	1.14	0.35	78.7	29.3	108	9.45	5.16	6.01	2.87	25.6	5.24	36.2	40.7	5.47	0.02	0.021	0.19	0.58	0.012	0.015	0.092	0.708	0.07	0.019	0.182

AHM	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.12	0.154	1.171	33.019	58.293	9.285	23.57	13.287	137	153																						
Post-monsoon	0.15	0.144	0.578	18.491	32.644	5.2	13.2	7.44	77	89.1	0.01	6.251	0.009	0.103	0.168	0.002	0.051	0.023	0.077	0.066	0.009	0.067	0.02	0.049	0.006	0.038	0.089	0.21	0.098	0.086	0.009	0.077
Winter	0.185	0.16	0.64	38.302	67.62	10.771	27.342	15.412	159	170	0.01	7.437	0.009	0.119	0.171	0.002	0.065	0.018	0.054	0.037	0.011	0.053	0.025	0.057	0.006	0.044	0.103	0.147	0.103	0.084	0.009	0.176

Table 2.22(g): Seasonal Comparisons of Experimental Results with PM_{10} Chemical Speciation at Ramadevi Site



Ramadevi	SPM (R)	SPM (H)	PM10 (R)	PM10 (4-	PM2.5	NO2	SO2	OC1	OC2	OC3	OC4	OP	EC1	EC2	EC3	OC	EC	TC	Na+	K+	Ca2+	Mg2+	NH4+	Cl-	NO3-	SO42-	Si	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Cd
Summer	506.9	521.5	151.7	190.2	170.1	29.7	12.3	1.28	9.17	17.25	10.67	5.35	9.43	6.36	1.68	43.7	17.5	61.2	5.95	2.76	7.61	3.33	11.5	2.91	13.9	20.5	6.11	0.08	0.024	0.42	0.47	0.011	0.008	0.03	0.198	0.04	0.004	0.151
Post-monsoon	508.2	530.5	188.6	221.1	197.2	35.0	14.7	5.05	10.5	15.24	10.38	7.14	18.3	0.9	0.36	48.3	19.5	67.8	5.29	3.28	4.88	3.11	17.3	4.87	22.1	29.2	8.47	0.03	0.04	0.29	0.42	0.016	0.019	0.073	0.382	0.09	0.011	0.142
Winter	514.9	536.6	208.2	234.2	207.0	39.0	16.6	6.23	16.4	22.27	14.74	9.08	21	1.54	0.38	68.7	22.9	91.6	8.78	3.63	9.11	3.69	17.8	5.4	24.4	28.5	4.11	0.02	0.024	0.14	0.47	0.01	0.012	0.044	0.36	0.02	0.007	0.178

Ramadevi	Sn	Sb	Pb	Benzene	Toluene	Eth Benzen	m,p-Xylen	o-Xylene	VOCs	NMHC	P	S	Sc	Ti	Ga	Ge	Br	Rb	Sr	Y	Mo	Rh	Pd	Ag	Te	I	Cs	Ba	La	W	Au	Al
Summer	0.106	0.118	0.848	34.606	56.953	9.072	23.028	12.981	137	154																						
Post-monsoon	0.13	0.104	0.759	19.725	32.463	5.171	13.126	7.399	77.9	91	0.02	6.036	0.009	0.124	0.126	0.002	0.041	0.039	0.086	0.053	0.012	0.06	0.015	0.041	0.006	0.036	0.068	0.228	0.054	0.078	0.008	0.289
Winter	0.132	0.136	1.056	39.797	65.496	10.433	26.483	14.928	157	169	0.02	6.086	0.009	0.137	0.148	0.002	0.055	0.023	0.063	0.027	0.01	0.054	0.016	0.048	0.006	0.046	0.076	0.144	0.061	0.084	0.008	0.116

Table 2.23: Molecular Markers and their Sources

Molecule Type	Molecular Marker	Major Urban Sources
Alkanes	n- Hentriacontane n-Tritriacontane n- Pentatriacontane	Vegetative detritus, Cigarette smoke Tyre wear debris Tyre wear debris
Hopanes	22, 29, 30 –Trisnorneohopane 17α(H), 21β(H)-29Norhopane 17α(H), 21β(H) Norhopane	Gasoline, diesel, fuel oil Gasoline, diesel, fuel oil Gasoline, diesel, fuel oil
Alkanoic acid	Hexadecanamide Octadecanamide	Biomass (Cow dung) Biomass (Cow dung)
Others	Stigmasterol Levoglucosan	Biomass burning Hardwood, Softwood

2.6 Molecular Markers

Organic molecular markers are individual compounds or groups of related compounds (homologous compounds such as n-alkanes, n-alkanoic acids, hopanes and steranes), which at a molecular level comprise the chemical profile or "fingerprint" for specific emission source types. An individual molecular marker or groups of marker compounds is linked quantitatively to major emission sources of urban fine particles. The molecular-level technology used in the current study matches chemical fingerprints of the PM samples collected to emission sources.

2.6.1 Methodology for Extraction

Three methods are prominently used for extraction of molecular markers for analysis under GC-MS, i.e. soxhlet extraction, methylation, silylation. These methods are explained as follows:

Soxhlet Extraction

Soxhlet extraction is a well-established particulate matter extraction method to remove the solvent-soluble organic components of the particles. The analysis of organic molecular markers on deposited on filter paper requires at least 600 μg organic carbon (OC) in sample, therefore normal practice is to club the required number of exposed filter papers to have sufficient mass (about 1000 μg OC) to represent the whole monitoring period. Prior to analysis, sample filters are extracted by soxhlet extraction in 200 ml of a 1:1 methylene chloride: acetone mixture for a period of 16 hours (6-8 cycle/hour). The combination of non polar (methylene chloride) and polar (acetone) solvents is an efficient technique proven by preliminary analysis and is used widely. The extracts are evaporated to 5 ml by using a Kuderna-Danish and then concentrated to 3 ml by a stream of pure nitrogen gas purging. The advantage of the Kuderna-Danish apparatus evaporation is that it gives higher recovery than any other techniques. The glass soxhlet extraction apparatus should be cleaned and rinsed with acetone. Only teflon-coated and solvent-cleaned forceps should be used to handle filters during the extraction process.

Methylation

Derivatization methods are an integral part of a number of chemical analysis practiced in medical, pharmaceutical and food science. In general, analytical derivatization is employed for two reasons: to permit analysis of compounds with inadequate volatility or stability; to improve chromatographic behavior or detectability.

Methylation is a derivatization step for alkanoic acid molecular marker. Final extract is derivatized by adding freshly prepared diazomethane in at least 100-fold excess to convert organic acids to their methyl derivatives. The conversion reaction is complete in seconds, and provides the equivalent methyl ester. The apparatus used for this process is diazomethane generator.

Silylation

Silylation is the most widely used derivatization technique. Nearly all functional groups which present a problem in gas chromatographic separation (hydroxyl, carboxylic acid, amine, thiol, phosphate) can be derivatized by silylation reagents. The derivatives are generally less polar, more volatile and thermally stable. Moreover, silylation enables the GC-MS analysis of many compounds. The trimethylsilyl (TMS) group is the most popular and versatile silyl group for these purposes and a variety of trimethylsilylating agents with different properties have been developed. Silylation is done by adding 300µl *N,O*-bis(trimethylsilyl) trifluoroacetamide (BSTFA) plus 1% trimethylchlorosilane (TMCS) .

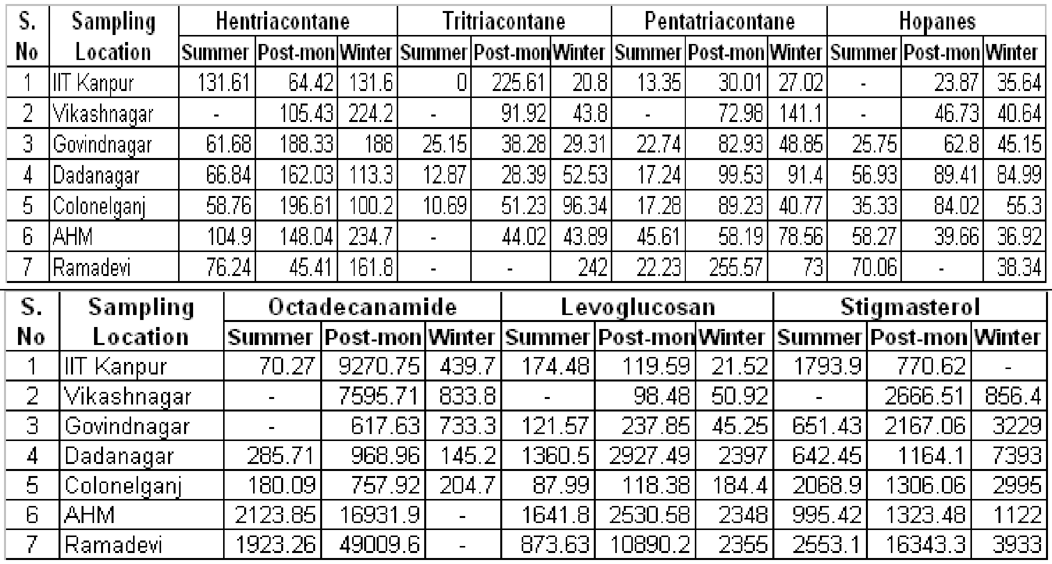
2.6.2 Methodology for GC-MS Analysis

Gas chromatograph-mass spectrometry (GC-MS) was performed using fused silica capillary column coated with DB-5 (30 m, 0.25 mm ID) and carrier gas of He. The carrier gas flow was 29 ml/min. The injection volume was 2µl. The GC analytical method is recommended for 60.5 minutes. The initial column temperature during injection was 50°C, which was held for 3 minutes at 50°C (isothermal). This was followed by a temperature ramp of 20°C/min up to 150°C, with another isothermal hold for 3 minutes. The next ramp was at 4°C/min till 280°C is reached followed by a final isothermal hold of 17 minutes.

2.6.3 Results

Concentrations of various markers for all three seasons at different sampling locations are shown Table 2.24. Graphical presentations for the respective markers related to Table 2.4 are shown from Figure 2.32(a) to 2.32(g).

Table 2.24: Results of Molecular Markers at Sampling Locations for all Seasons (ng/m^3)



S. No	Sampling Location	Hentriacontane			Tritriacontane			Pentatriacontane			Hopanes		
		Summer	Post-mon	Winter	Summer	Post-mon	Winter	Summer	Post-mon	Winter	Summer	Post-mon	Winter
1	IIT Kanpur	131.61	64.42	131.6	0	225.61	20.8	13.35	30.01	27.02	-	23.87	35.64
2	Vikashnagar	-	105.43	224.2	-	91.92	43.8	-	72.98	141.1	-	46.73	40.64
3	Govindnagar	61.68	188.33	188	25.15	38.28	29.31	22.74	82.93	48.85	25.75	62.8	45.15
4	Dadanagar	66.84	162.03	113.3	12.87	28.39	52.53	17.24	99.53	91.4	56.93	89.41	84.99
5	Colonelganj	58.76	196.61	100.2	10.69	51.23	96.34	17.28	89.23	40.77	35.33	84.02	55.3
6	AHM	104.9	148.04	234.7	-	44.02	43.89	45.61	58.19	78.56	58.27	39.66	36.92
7	Ramadevi	76.24	45.41	161.8	-	-	242	22.23	255.57	73	70.06	-	38.34

S. No	Sampling Location	Octadecanamide			Levoglucosan			Stigmasterol		
		Summer	Post-mon	Winter	Summer	Post-mon	Winter	Summer	Post-mon	Winter
1	IIT Kanpur	70.27	9270.75	439.7	174.48	119.59	21.52	1793.9	770.62	-
2	Vikashnagar	-	7595.71	833.8	-	98.48	50.92	-	2666.51	856.4
3	Govindnagar	-	617.63	733.3	121.57	237.85	45.25	651.43	2167.06	3229
4	Dadanagar	285.71	968.96	145.2	1360.5	2927.49	2397	642.45	1164.1	7393
5	Colonelganj	180.09	757.92	204.7	87.99	118.38	184.4	2068.9	1306.06	2995
6	AHM	2123.85	16931.9	-	1641.8	2530.58	2348	995.42	1323.48	1122
7	Ramadevi	1923.26	49009.6	-	873.63	10890.2	2355	2553.1	16343.3	3933

Figure 2.32(a): Hentriacontane Concentarion at all Locations for all Seasons

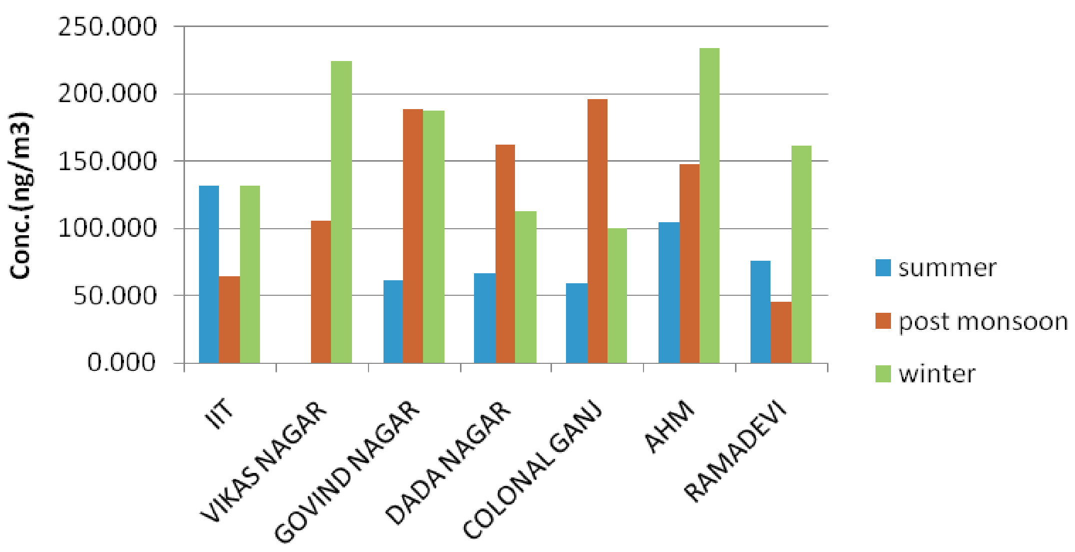


Figure 2.32(b): Tritriacontane Concentarion at all Locations for all Seasons

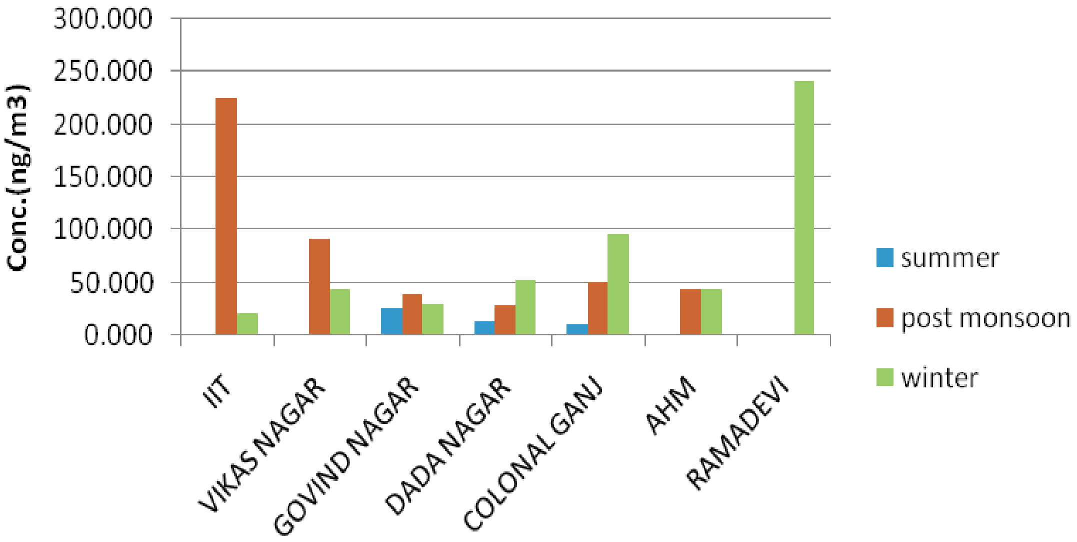


Figure 2.32(c): Pentatriacontane Concentarion at all Locations for all Seasons

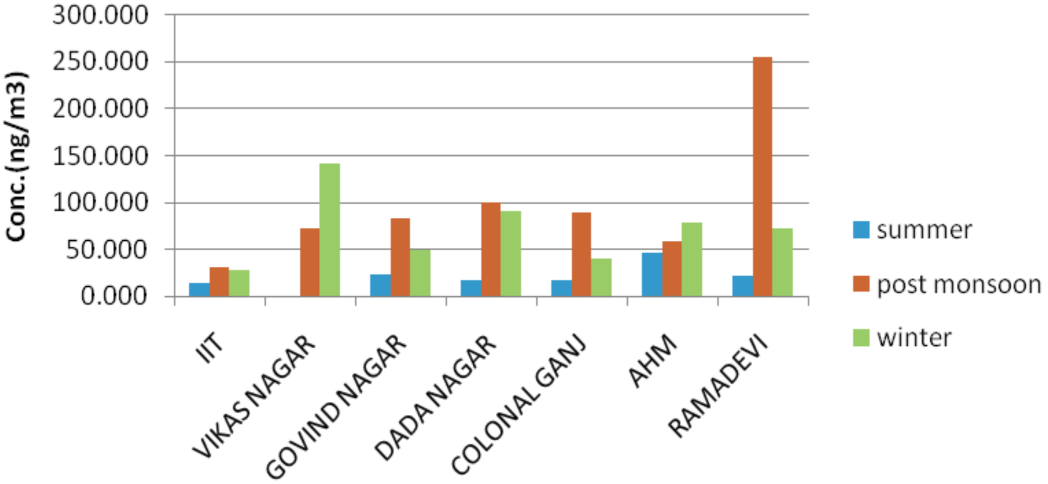


Figure 2.32(d): Hopanes Concentarions at all Locations for all Seasons

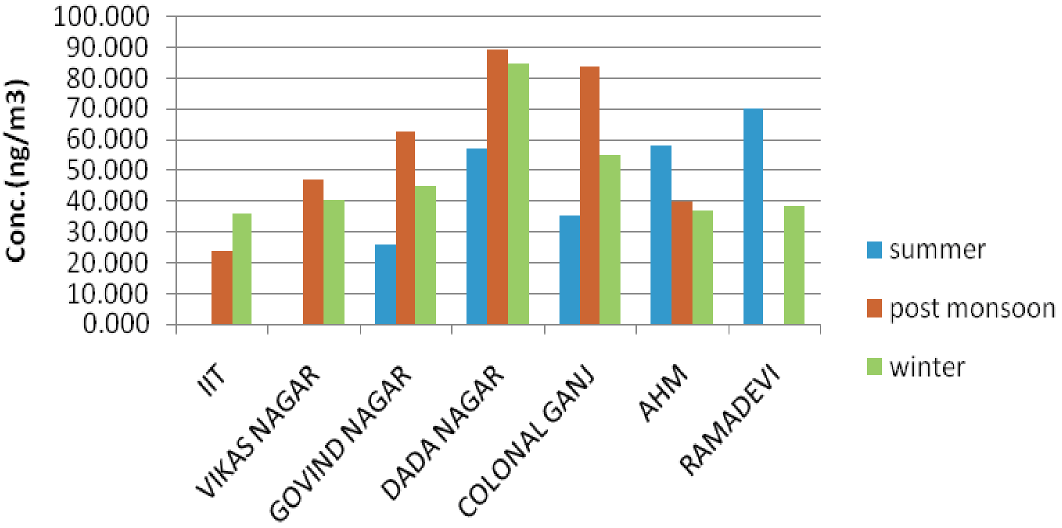


Figure 2.32(e): Octadecanamide Concentarions at all Locations for all Seasons

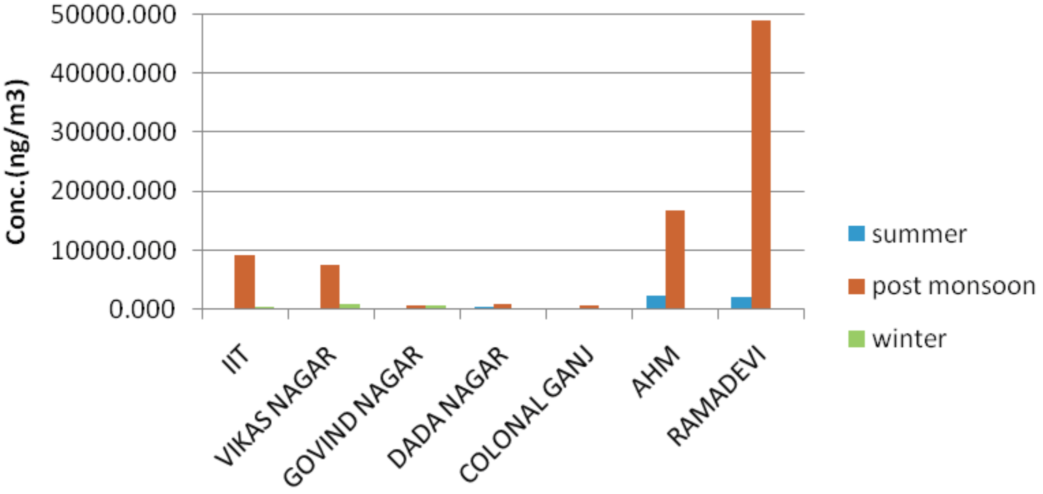


Figure 2.32(f): Levoglucosan Concentarions at all Locations for all Seasons

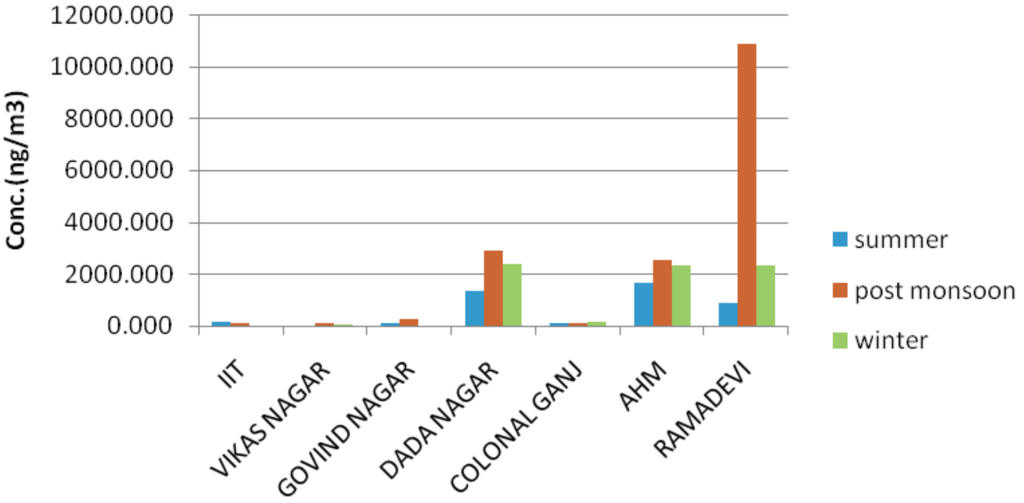
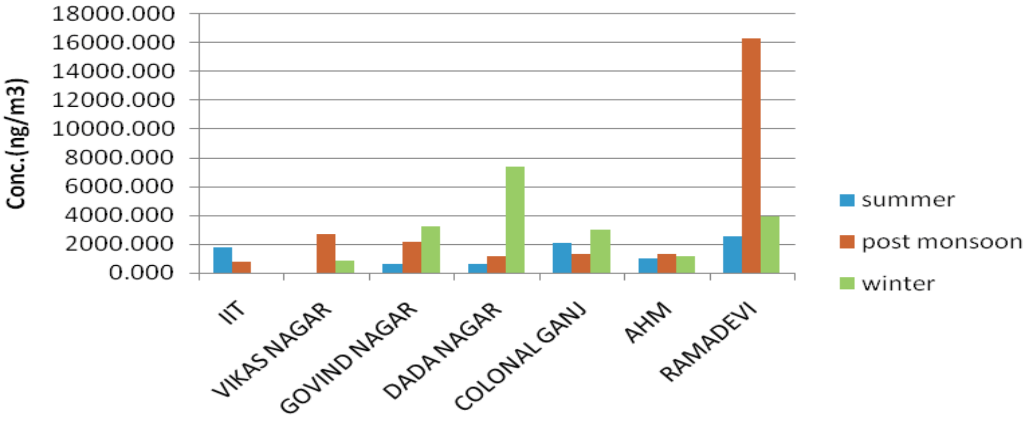


Figure 2.32(g): Stigmasterol Concentarions at all Locations for all Seasons



2.7 Conclusions

- Particulate pollution is the main concern in the city where levels of SPM, PM_{10} and $PM_{2.5}$ are 2.5- 3.5 times higher than the acceptable levels.
- OC (organic carbon) levels are always much higher 2-4.5 times than EC levels. The ratio of EC/OC is variable from one location to another, indicating that sources, those contribute to particulate pollution are variable.
- While SPM levels show dramatic diurnal variation at all locations (being lower in night time), such a variation for PM_{10} and $PM_{2.5}$ is not apparent. Therefore, SPM levels will have significant contribution related to daily urban activities which may not be from combustion related sources.
- EC and OC almost account for 30 percent of $PM_{2.5}$, which is quite high and reflects as how badly is the city affected because of combustion and /or fuel related emissions which account for most respiratory problems.
- EC to OC ratio increase at traffic, kerb and industrial sites. Higher EC/OC ratio can again be attributed to diesel combustion at the sites and indicating these to be the hot spots for particulate pollution.
- NO_2 levels are found to be stabilized across all locations at about 20-25 $\mu g/m^3$.
- Elemental and ion analysis show abundance of soil constituents (e.g. Si, Fe, Ca, Na and NH_4^+, SO_4^{2-} and NO_3^- ions). This clearly suggests that there could be significant sources of particulate pollution from soil, road dust and presence of secondary particles.
- HCHO levels clearly correlated with traffic emissions.
- Industrial area shows significantly high fraction of coarse fraction ($PM_{10-2.5}$), which is quite characteristic of industrial emissions.
- Kerb and traffic sites show high fraction of $PM_{2.5}$ ($PM_{2.5}/PM_{10}$ ratio as 0.78 and 0.92).
- Roadside locations are thus heavily influenced by the traffic related emissions and are the real hot spots in terms fine particles.
- As an urban background, $PM_{2.5}$ is nearly 65 percent of PM_{10}.

- CO levels were generally within air quality standards but levels clearly correlated with diurnal traffic pattern.
- VOC levels were the highest at the kerbsite followed by industrial site.
- The following molecular markers were present in the ambient air: hentriacontane, tritriacontane, pentatriacontane, octadecanamide, levoglucosan, stigmasterol and PAHs. The presence of these markers suggests that possibly the following sources are also contributing to PM_{10}: vegetative detritus, cigarette smoke, tyre wear debris, gasoline, diesel, fuel oil Gasoline, biomass (cow dung), biomass burning (hardwood, softwood).

Chapter 3

Emission Inventory

3.1 Introduction

An emission inventory is a quantitative detailed compilation of pollutants emitted into the atmosphere of a given community. It is an itemized list of emission estimates for sources of air pollution in a given area for a specified time period. Present and future year inventories are critical components of air quality planning and modeling. 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. An emission inventory should be able to provide:

- A reliable estimate of total emissions of different pollutants;
- Their spatial and temporal distribution;
- The evolution in time of emissions and their distributions;
- Identification and characterization of main sources in urban areas;
- Tracking progress towards National Ambient Air Quality Standards (NAAQS) attainments and emission reduction; and
- Serve as the basis for modelling of predicted pollutant concentrations in ambient air;

Emission inventories are developed for a variety of purposes. Inventories of natural and anthropogenic emissions are used

- by scientists as inputs to air quality models,
- by policy makers to develop strategies and policies or track progress of standards,
- by facilities and regulatory agencies to establish compliance records with allowable emission rates.

Several studies have been conducted in terms of post-graduate research and project works at Kanpur on emission inventory at city levels for various air pollutants as reported in the Chapter 1.

3.2 Methodology

The entire city was divided into 85 grids of 2 km x 2 km. Each grid was assigned a land use pattern based on the land use map from CPCB. The grid systems with the locations of the sampling sites, from where, the activity data were collected after a thorough survey is shown in Figure 3.1. Overall land-use pattern of the city along with the surrounding area is shown in Figure 3.2.

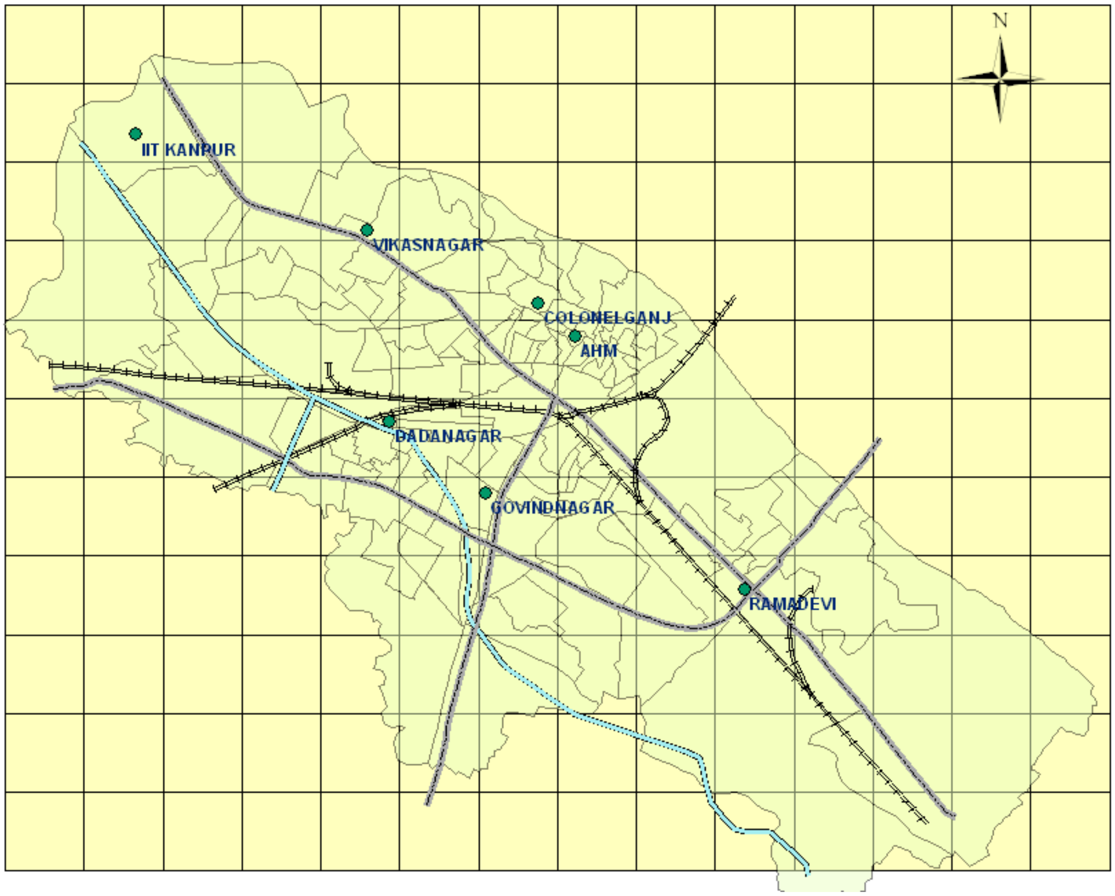


Figure 3.1: Grid Map of the City with Locations of Detailed Emission Survey

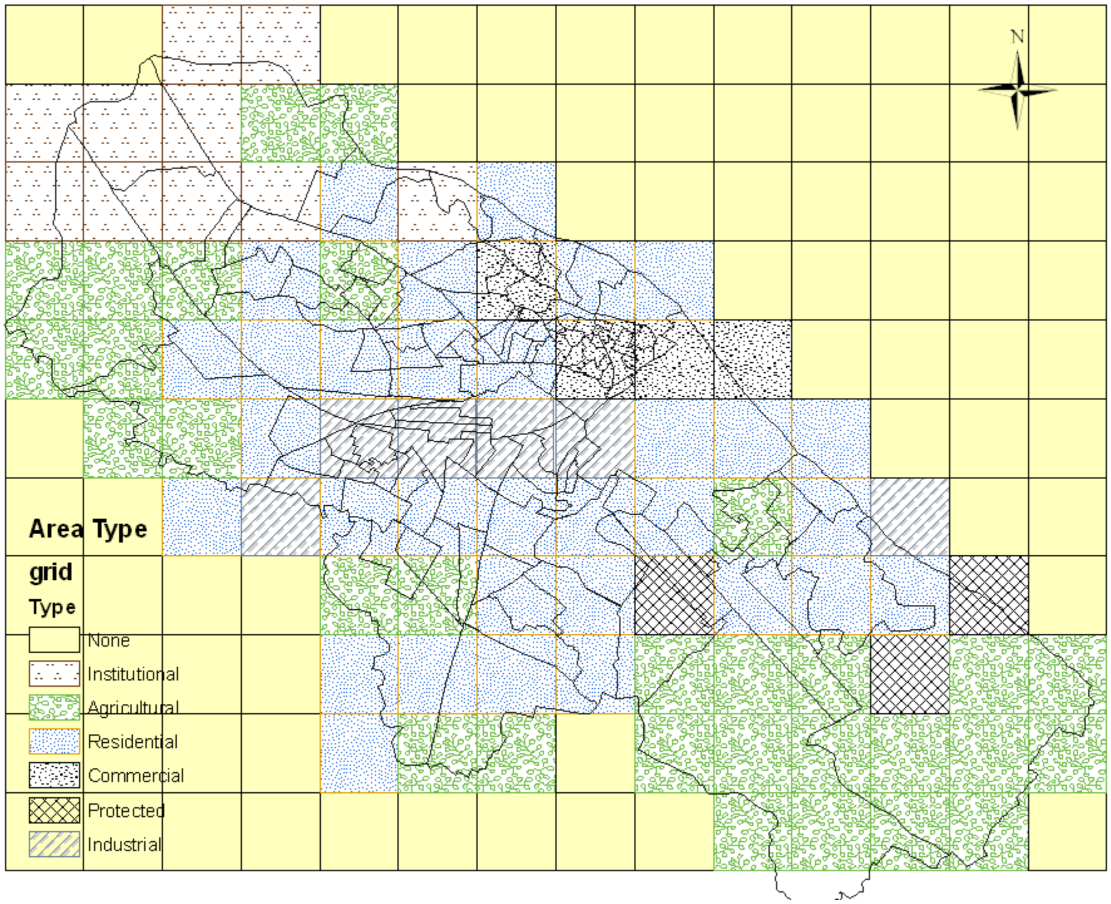


Figure 3.2: Grid Map of the City with Land-use Pattern

At the time of development of the emission inventory for the city, a suitable coding system has been adopted effectively to avoid the confusion and to present the results. The map with grid identity numbers is shown in Figure 3.3. The detailed results are given in the annexure following the coding system. The basis of the coded systems is explained as follows:

$$\textbf{KAISO2-01} \qquad \textbf{(3.1)}$$

In this code K- City code for Kanpur
A- Classified Source (say Area etc.)
I- Type of Source (say Industry)
SO_2- Pollutant Parameter (say SO_2)
01- Grid Identity number

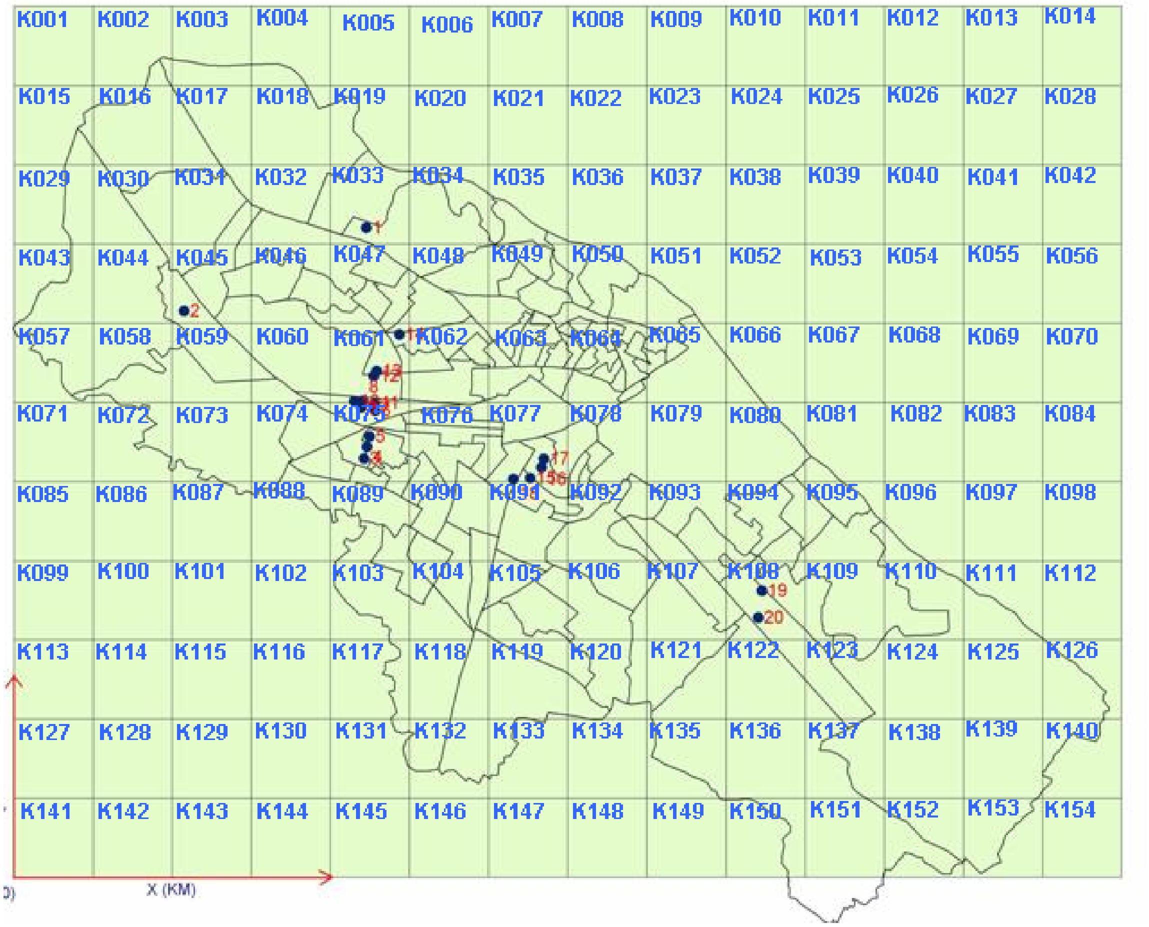


Figure 3.3: Grid Map of the City Showing Grid Identity Numbers

The interior boundaries in the map (Fig 3.3) show the ward boundaries. After obtaining the area of the wards, the population density is calculated from the population data supplied by Kanpur Nagar Nigam. All these exercises were done with Geo Informatics System (GIS).

Population Density (person/m^2)=Population of Ward (person) / Ward Area (m^2) (3.2)

For the wards for which population data were not available, the density of neighboring similar wards was assigned. The detailed tables are given in Annexure. For calculating grid population the wards falling inside that grid were noted and the overlapping area for each ward was noted. Then a weighted mean (with respect to area of ward falling in the grid) was taken to find grid population.

Grid population = $\sum_{i=1}^{N}$ (intersected ward area X density of ward) (3.3)

Where, N= no. of wards lying in that grid

Thus the population for each grid was determined. The team members had gathered demographic data about the percentage of people belonging to each of the classes: upper, middle and lower economic strata for the seven grids where sampling was done. The demographic of other grids were extrapolated from these values. The codes for the classes of people assigned as: M= Middle class; H= High class; P=Poor class.

The entire city of Kanpur was divided into 6 landuse types and every grid was assigned with a particular landuse pattern. The landuse patterns adopted for the whole city are (1) residential; (2) commercial; (3) institutional; (4) industrial; (5) agricultural; and (0) protected.

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 weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (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 (i.e., a population average).

The general equation for emissions estimation is:

$$E = A \times EF \times (1 - ER/100) \quad (3.4)$$

Where:

E = Emissions;

A = Activity rate;

EF = Emission factor, and

ER = Overall emission reduction efficiency, %

3.3 Area Sources

3.3.1 Bakery

Description

The details of the bakery were collected from each of seven grids where sampling was done. The details of the bakeries were collected from the State Pollution Control Board (SPCB), Kanpur. The data collected at the time of survey and from the SPCB, Kanpur include capacity of the bakery and daily fuel consumption. The maximum capacity of the bakery at Kanpur was reported to be 2.0 T/day. These activities are having no significant stacks with prominent heights. The type of fuel used for the manufacturing is kerosene in Kanpur for most of the bakeries. There are about 10 bakeries in Kanpur.

Assumptions

The assumptions are based on the survey by our team. In most of the cases, it has been explored that there is no control options practiced in these industries. So, the emissions of various parameters such as SO_2, NOx, PM_{10} and CO were calculated from the activity data with having no emission reduction facility.

Emission Estimations

The fuel consumption values for each bakery were found out by multiplying the capacity of the bakery with the fuel required for the unit rate of production. The unit of the activity data is kg of fuel/day consumed for each bakery. The level of confidence for these data is good for the locations, where surveys were conducted by the team (seven grids of Kanpur). The emissions from bakery w.r.t. various pollutants were estimated from Eq (3.4).

3.3.2 Hotel and Restaurants

Description

The team in the seven grids collected the details of the hotels and restaurants including the small halwai. The fuel consumption data for these works were collected for LPG, coal and wood. The maximum numbers of these activities were found in the commercial areas and some in industrial, institutional and residential zones as well. Some limited surveys were also conducted in agricultural zone. The data for other grids (excluding the seven sampling grids) were extrapolated from the survey results of seven grids of sampling site. The data were collected separately for restaurants and halwai. Data on fuel consumptions were also collected from open eat-outs.

Assumptions

In most of the cases, it was found that there was no control devices installed at these activities. So, the emissions of various parameters such as SO_2, NOx, PM_{10} and CO were calculated from the activity data with having no emission reduction.

Emission Estimations

The fuel consumptions for these activities are LPG, coal and wood. After successful survey, the fuel consumption for each fuel type was estimated for each grid. A well-defined database was developed for calculation of the emission with the help of software. The details of the database are also provided in the annexure. The level of confidence for these data is good for the locations, where surveys were conducted place by our team (seven grids of Kanpur). The emission w.r.t. various pollutants from these activities were estimated from each fuel type and then were summed up. The calculation is based on Eq (3.4), where ER, overall efficiency reduction was taken as 0. The details of the data-base are attached in the annexure. The emission factors for each fuel type for these activities were used basis of CPCB recommended emission factors.

3.3.3 Domestic Sector

Description

The emission estimates for household activities are based on the demographic data of the city. The classes, high, medium and low (based on economic strata) of a particular grid were identified in terms of population fraction. With help of a GIS software, the grid-wise population was found by following the intersection method as explained in section 3.2. IIT Kanpur team members surveyed seven grids of concern and produced the survey results in terms of the % age of these three classes of people in that grid. They also produced the consumption of fuel per day for all classes of people in that grid. The population of these three classes and fuel consumption other than seven grids are extrapolated from the data of these seven grids. The types of fuel used for household cooking in the city are wood, coal, kerosene and LPG.

Assumptions

Based on the survey, the assumption for the consumptions of the fuel for domestic purpose are: higher and middle class people hardly use kerosene, wood and coal. The poor class people in the city use coal, wood and kerosene (in different fractions). Poor class people also use LPG at some localities. Emissions of various pollutants such as SO_2, NOx, PM_{10} and CO were calculated from the activity data with having no emission reduction.

Emission Estimations

The fuel consumptions for these activities are LPG, coal, wood, and kerosene. After successful survey, the fuel consumption for each type of fuel was estimated based on the activity data (kg/person/day for each class) multiplied by population of that particular class and then finally summing up the obtained results. A well-defined database was developed for calculation of the emission with the help of software. The database with details is given in the annexure. The unit of the activity data is kg of fuel/person/day consumed for each class of the people. The level of confidence for these data is good for the locations, where surveys were undertaken the team (seven grids of Kanpur). The emission w.r.t. various pollutants from these activities were estimated from each fuel type belonging to specific class of the people and then were summed up. The calculation is based on Eq (3.4), where ER, overall efficiency reduction was taken as 0. The emission factors for each fuel type for these activities were as per the recommendation of CPCB, New Delhi.

3.3.4 Open Burning

Description

Open burning activities are broadly classified into: refuse and biomass burning. The tyre burning activities are hardly found in the city. On the basis of survey data, the emissions from tyre burning are assumed to be 5% of the refuse burning. So, 5% excess emissions are accounted in the refuse burning. As far as the refuse burning is concerned, the solid waste generation depends on the nature of the locality in that region, i.e. for example, if the area is having more commercial activities, the there will be more garbage generation. A detailed survey was done in seven grids of the city for the garbage collection points in the street. The results of survey sheets from the garbage collection points provided the data related to garbage generated in that particular locality. One simple example for this survey is explained as follows:

The area of survey is one of the streets in the Juhilal Colony of Kanpur. Number of garbage collection points=1 , the area of that collection point is 1.0 m^2, height is 0.3 m, volume of one point=1.0*0.3= 0.3 m^3. Dry density of garbage is taken as 800 kg/m^3. The mass of garbage at that street=800*0.3=240 kg. Total population of that street=200; per capita generation of garbage in that street=240000/200=1200 g/person. This is a four-day generation result. Therefore, garbage generation=300 g/person/day. Several surveys had been undertaken in the seven grids to ascertain the garbage collection. Finally the data for other grids, apart from these seven grids, were extrapolated from the data of the seven grids.

For biomass burning, surveys had been undertaken in some localities of the agricultural areas. It was observed that the agricultural wastes (biomass) are generated from the area of agricultural land-use. Generally, 70% of the agricultural land-use area is used for cultivation. Estimation for generation of biomass; taking 2 quintals/acre=200 kg/acre= 50 $tonns/km^2$; 70% of the agricultural waste subjected to burning and these burning takes place thrice in a year; duration of burning is up to 3 months in three seasons. Based on these data, the biomass burnt per day was estimated for each grid.

Assumptions

Based on the survey, the assumptions for garbage generation is more in higher class people in comparison to middle and lower class people; 25% of the garbage are collected and out of which, only 30% is combustible; and for agricultural waste about 70% of the biomass are subjected for burning. It was explored that these burning takes place in open area. So, the emissions of various parameters such as SO_2, NOx, PM_{10} and CO were calculated from the activity data with having no emission reduction.

Emission Estimations

Garbage generation was estimated based on the activity data (kg/person/day) multiplied by population of that particular grid. Then with help of the data-base made and the assumptions, emissions of various pollutants were calculated. The detailed database is provided in the annexure. The unit of the activity data is kg of combustible garbage/person/day. The level of confidence for these data is good for the locations, where surveys were undertaken by our team (seven grids of Kanpur). The emission w.r.t. various pollutants from these activities were estimated for all grids by extrapolating from these seven grids data. The calculation is based on Eq (3.4), where ER, overall efficiency reduction was taken as 0.

3.3.5 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:

$$E = k\,(sL/2)^{0.65}\,(W/3)^{1.5} \quad \underline{\hspace{2cm}} \quad (3.5)$$

Where
E: emission rate of size specific PM (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 = 4.6 for PM_{10}).

A post-graduate study had been done at IIT Kanpur for finding the fugitive road dust in Kanpur (Bhasker, 2004). In this study, he found the silt load at different locations of the city by suitable experimental methods. The value of silt loads (sL) at various locations were taken from this study. 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). A detailed data-base was developed for these calculations, the samples of which are provided in the annexure with all relevant values for all grids.

3.3.6 Construction / Demolition/ Alteration

A detailed survey had been performed by our IIT Kanpur team members for construction and demolition activities in seven grids. Number of buildings, roads and flyovers under construction were surveyed in seven locations. Then areas under construction activities were calculated on the basis of survey data. Finally the emissions were found out by using Eq (3.4). The unit of the activity data is m^2, i.e. area of these activities. The details of calculations are attached in the annexure.

3.3.7 Commercial and Industrial Diesel Generator Sets (DG sets)

Description

Due to crisis of power in Kanpur, 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 6 hours/day power cut in the city. That is why the DG sets activities are among the prominent sources contributing to the emissions. IIT Kanpur team members surveyed seven grids of concern and produced the survey results in terms of KWh consumption in each of the commercial complexes, institutes, and industries. After the survey, the total power requirement was summed up for each grid. Then the data for other grids were extrapolated from the data of these seven grids. After a thorough survey for the residential area, it can be concluded that residential houses hardly use DG sets to meet the electricity needs, instead they use battery-operated inverters.

Assumptions

Based on the survey, the assumption for the use of DG sets for other grids are calculated depending on the landuse pattern of the grids and the residential houses hardly use DG sets. It was explored that there is no control options practiced at these activities. So, the emissions of various parameters such as SO_2, NOx, PM_{10} and CO were calculated from the activity data with having no emission reduction.

Emission Estimations

The fuel consumptions for these activities are mostly diesel. The unit of the activity data is KWh power consumption for each grid of the city (from DG sets). The level of confidence for these data is good for the locations, where surveys were undertaken by our team (seven grids of Kanpur). The emission w.r.t. various pollutants from these activities were estimated for these three areas, i.e. commercial complexes, institutes and industries and then were summed up for each grid. The calculation is based on Eq (3.4), where ER, overall efficiency reduction was taken as 0. The emission factors for each pollutant for these activities were decided on the basis of CPCB recommendations.

3.3.8 Funeral Burning Emissions

There are eleven ghats in the city of Kanpur on the bank of river Ganga, where funeral burning takes place. The primary data were collected in terms of the number of dead bodies are subjected to burning at every ghat. IIT Kanpur team had surveyed these ghats and produced the data of the wood consumption per body. Then these ghats were located in the grids with the help of GIS mapping system. A well defined database was developed for estimation of emissions from these activities. The unit of activity data is kg of wood/each body. The level of confidence of these data is high as information was collected in person. The detailed database of emission from this source is provided in the annexure. In Kanpur, the practice for crematoria is hardly found. The emission factors for each pollutant for these activities were decided on the basis of CPCB recommended emission factors.

3.3.9 Medical Waste Incinerators Emissions

There are three numbers of medical waste incinerators in the city. The primary data were collected in terms of frequency of incinerator, weight of waste burning at each slot. Then the data were produced kg of waste per day for each incinerator. A data base was developed for compilation of all these data, which is provided in the annexure also. The emission factors for each pollutant for these activities were decided on the basis of CPCB recommended emission factors.

3.3.10 Graphical Representation of Emissions from Area Sources other than Vehicles and Industries

3.3.10.1 Domestic Sector

Figures 3.4 to 3.7 presents emission load of PM_{10}, NO_x, SO_2 and CO in the city of Kanpur from use of domestic fuel burning. Coal produce a significant pollution load, 822 kg/day, nearly 47 percent of total PM_{10} from domestic sector, although coal is used by only a small fraction of population, PM emissions are quite high from coal burning. NOx emissions are highest from LPG uses followed by coal and kerosene. Figure 3.8 shows the overall emissions of all the pollutants from the domestic sector.

Figure 3.4: PM_{10} Emission from Domestic Sources (kg/d, %)

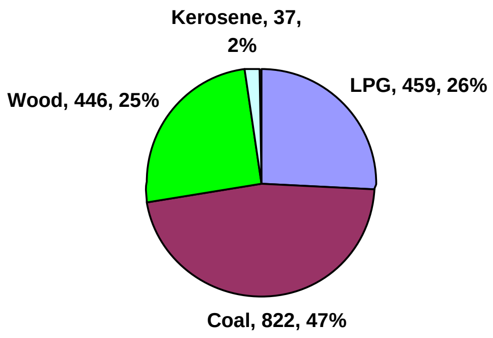


Figure 3.5: NOx Emission from Domestic Sources (kg/d, %)

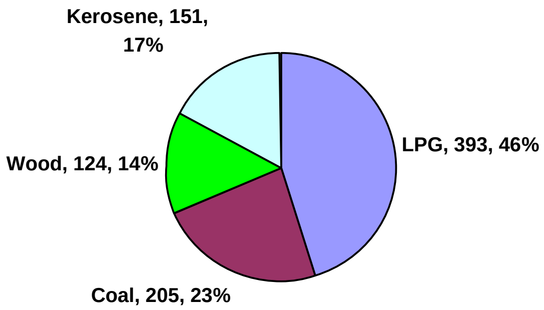


Figure 3.6: SO_2 Emission from Domestic Sources (kg/d, %)

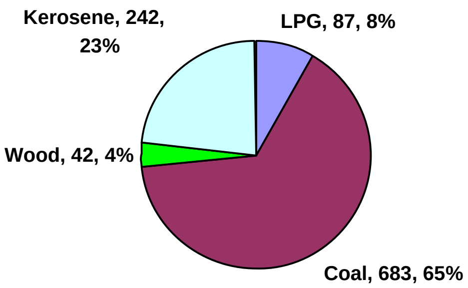


Figure 3.7: CO Emission from Domestic Sources (kg/d, %)

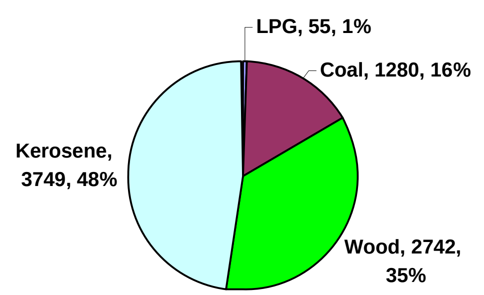
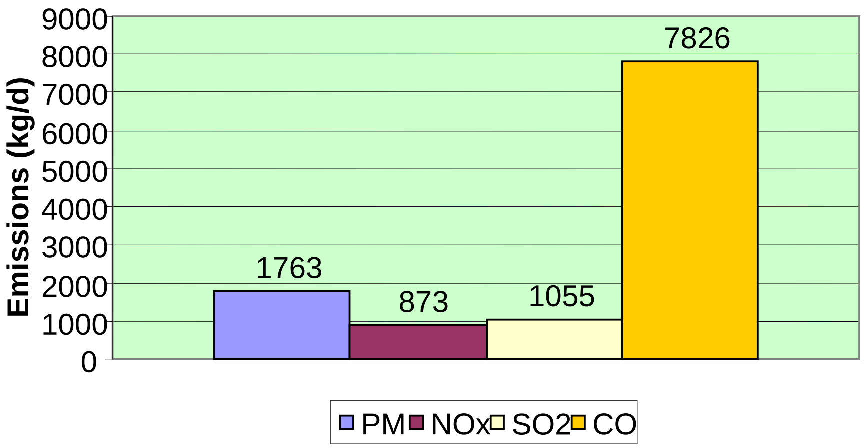


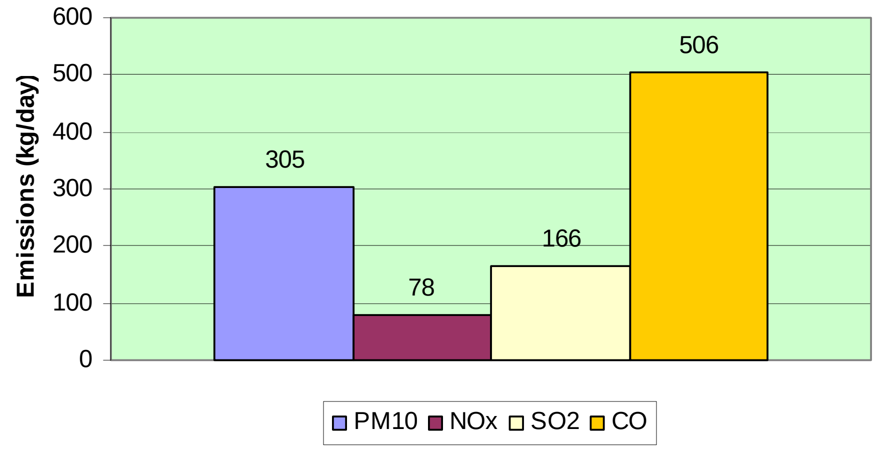
Figure 3.8: Overall Emissions from Domestic Sources



3.3.10.2 Hotel and Restaurants

Figure 3.9 shows the overall emissions of all the pollutants from the hotels and restaurants in the city. The emission of PM_{10} from hotels and restaurants (~305 kg/d) may appear high but most eat outs, halwais and small hotels and restaurants they use coal for cooking and this leads to higher particulate pollution.

Figure 3.9: Emissions from Hotel and Restaurants



3.3.10.3 Open Burning

Figures 3.10 and 3.11 show the overall emissions of all the pollutants from garbage and biomass burning (including agriculture waste burning). Both PM_{10} and CO are the major pollutants from these two sources.

Figure 3.10: Emissions from Garbage Burning

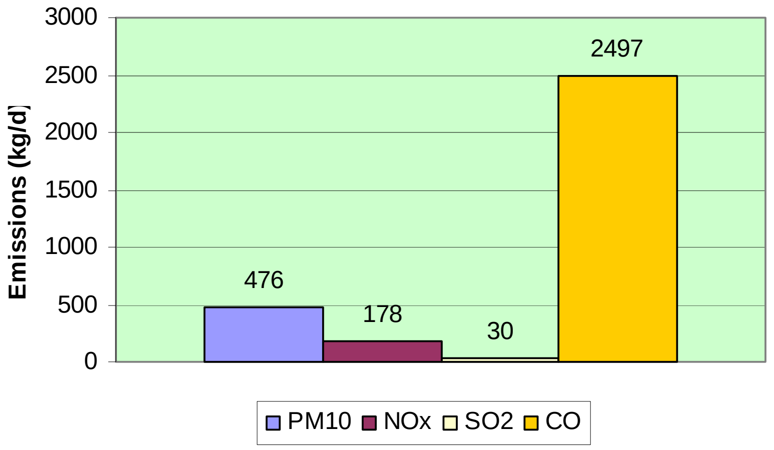
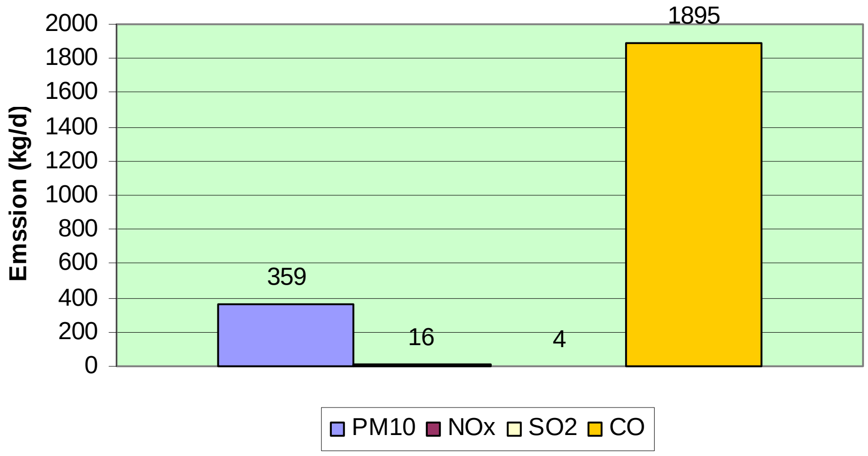


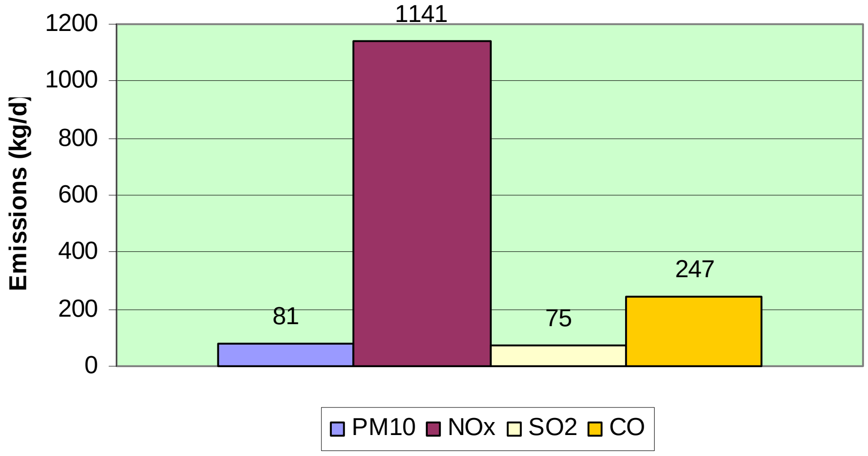
Figure 3.11: Emissions from Agricultural Waste Burning



3.3.10.4 Commercial and Industrial Diesel Generators

Figure 3.12 show the overall emissions of all the pollutants from DG sets used in the city to cater fro the shortage in power supply. NOx emission (1141 kg/d) from this source stands out, which even much more than emission of CO.

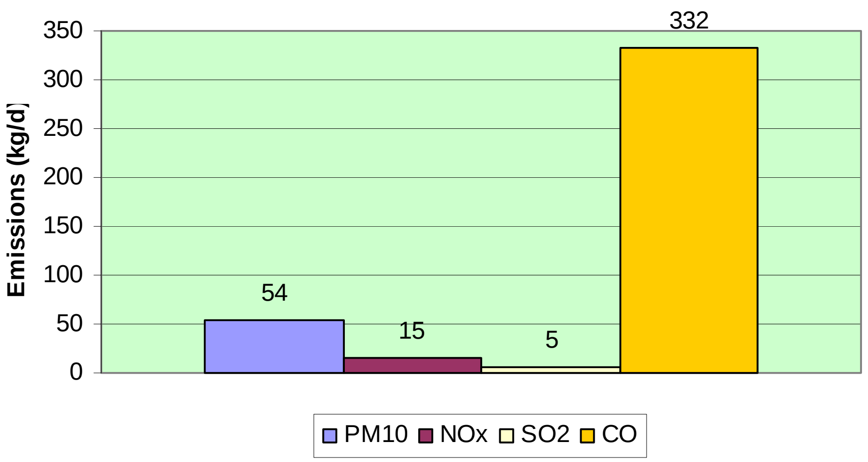
Figure 3.12: Emissions from DG Sets



3.3.10.5 Funeral Wood Burning

Figure 3.13 shows the overall emissions of all the pollutants burning of dead bodies. Since wood is used for this operation, CO emissions are very high from this source.

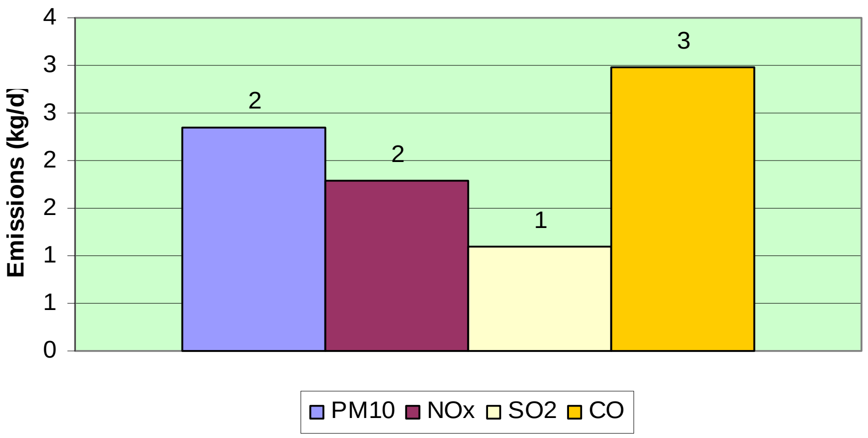
Figure 3.13: Emissions from Funeral Burning



3.3.10.6 Medical Waste Incinerators

Figure 3.14 shows the overall emissions of all the pollutants from medical waste incinerators. This source is not important as quantity of waste is less and incinerator is not used everyday.

Figure 3.14: Emissions from Medical Waste Incinerator



3.3.11 Contribution of Emissions from Area Sources other than Vehicles and Industries

Summary of emissions from various source categories discussed so far is presented in Table 3.1.

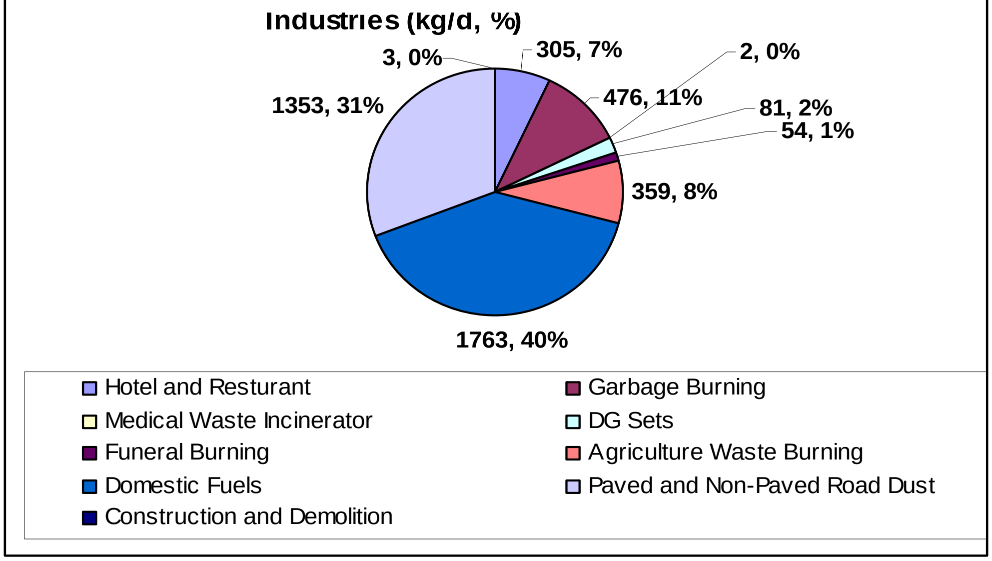
Table 3.1: Summary of Emissions from Area Sources

Source	Emissions of Pollutants (kg/d)			
	PM_{10}	NOx	SO_2	CO
Hotel and Restaurant	305	78	166	506
Garbage Burning	476	178	30	2497
Medical Waste Incinerator	2	2	1	3
DG Sets	81	1141	75	247
Funeral wood Burning	54	15	5	332
Agriculture Waste Burning	359	16	4	1895
Domestic Fuels	1763	873	1055	7826
Paved and Non-Paved Road Dust	1353	-	-	-
Construction and Demolition	3	-	-	-
Total	4396	2303	1336	13306

3.3.11.1 Particulate Matter of Size Less than 10 µm diameter (PM_{10})

The overall scenario of PM_{10} emission for area sources is shown in Fig. 3.15. The major source of PM_{10} amongst area sources are domestic cooking, road dust, garbage and agricultural waste burning.

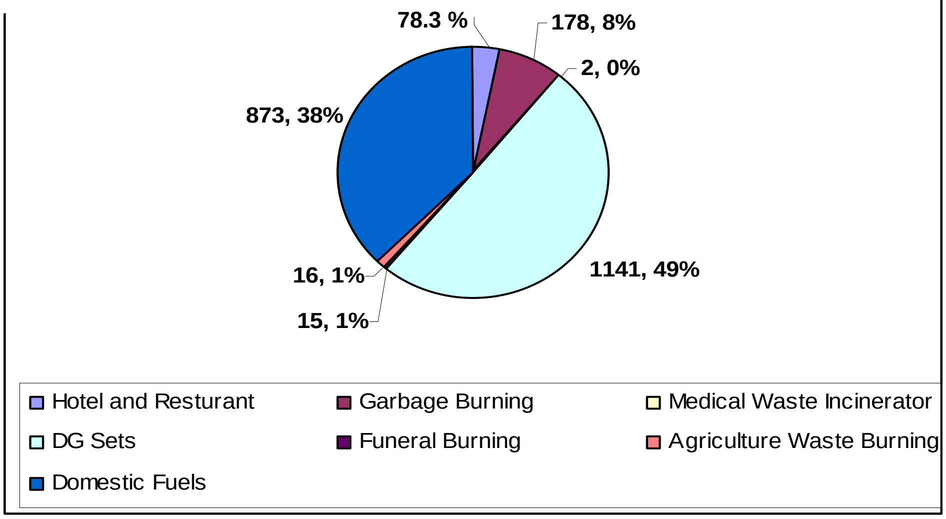
Figure 3.15: PM_{10} from Area Sources other than Vehicles and Industries (kg/d, %)



3.3.11.2 Nitrogen Oxides (NO_x)

The overall scenario of NO_x emission for area sources is shown in Fig. 3.16. The major source of NO_x amongst area sources are DG sets and domestic cooking.

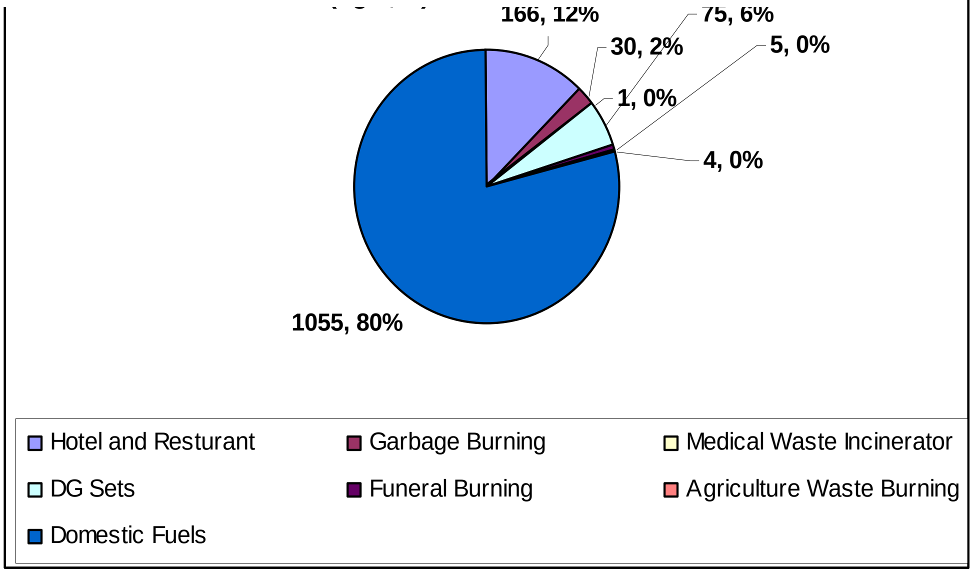
Figure 3.16: NO_x from Area Sources other than Vehicles and Industries (kg/d, %)



3.3.11.3 Sulphur Dioxide (SO_2)

The overall scenario of SO_2 emission for area sources is shown in Fig. 3.17. The major source of SO_2 from area sources are domestic cooking, and hotels and restaurants, mostly using coal.

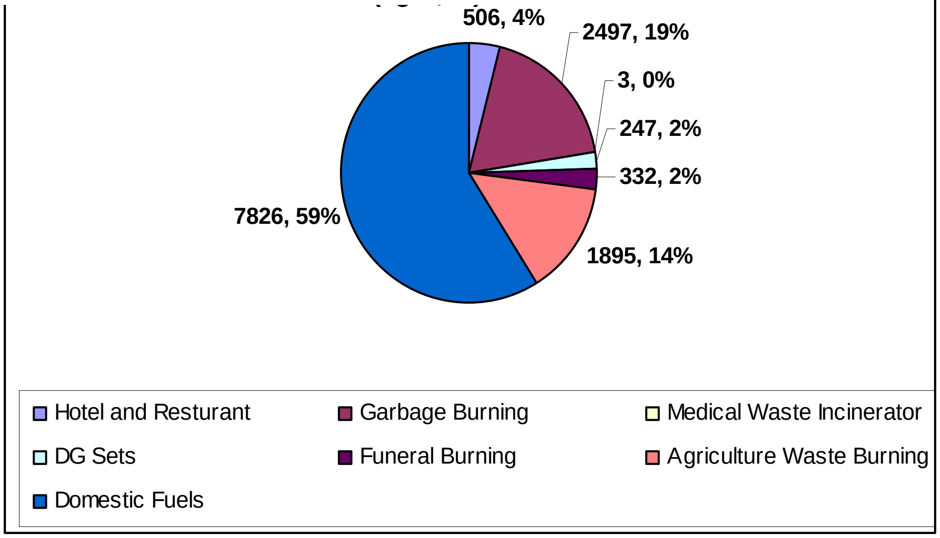
Figure 3.17: SO_2 from Area Sources other than Vehicles and Industries (kg/d, %)



3.3.11.4 Carbon Monoxide (CO)

The overall scenario of CO emission for area sources is shown in Fig. 3.18. The major source of CO from area sources are domestic cooking, and garbage burning.

Figure 3.18: CO from Area Sources other than Vehicles and Industries (kg/d, %)



3.3.12 Industries as Area Sources

Description

There are certain pockets in the city which have industries. There is major industrial area in south-west part of city, Dada Nagar / Fazalgang and Panki industrial areas and there are certain pockets in the city having industries (Fig. 3.2). All industries having stack height below 25 m have been clubbed as the industrial area source. Most of the industries had small boilers and some cupola furnaces were also present. Chemical industries including tanneries were also included in the emission inventory.

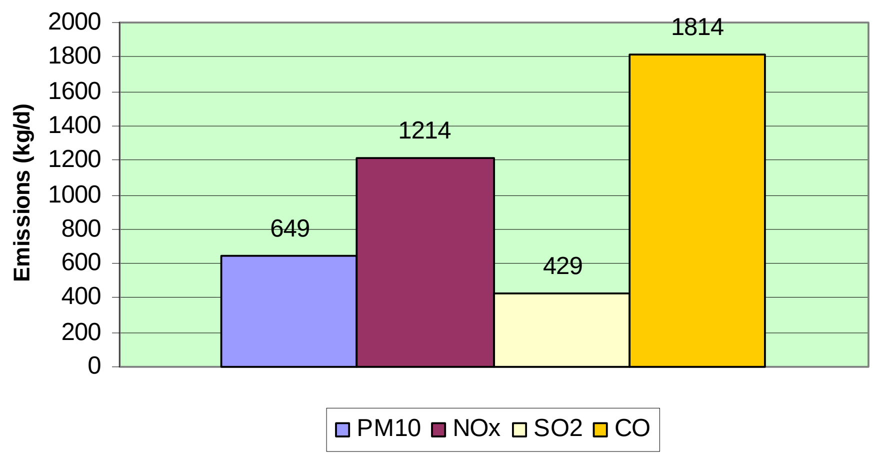
Assumptions

Most of the information on the industrial areas concerning fuel consumption, stack height, production capacity have been collected from the files of State Pollution Control Board, Kanpur. Some surveys were also made to check the industries physically and to get the on the spot information. Cooperation from the industry was less than desired. 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). If type of oil uses were not indicated then it was assumed that industry used furnace oil. Ash content is the coal was assumed to be 40% and ‘S’ content as 0.5%.

Emission Estimations

Figure 3.19 show emissions from small industries in Kanpur city. As expected, NO_x and CO emissions were high followed by PM_{10} emissions.

Figure 3.19: Emissions from Industries as Area Sources (Stack height< 25.0 m)



Tables 3.2 to 3.5 show emissions of PM_{10}, NO_x, SO_2 and CO from industries taken as area sources. It can be seen that most common fuel in the industry are coal and the furnace oil. It can also be seen that industries are located in certain grids only. This category of the industry is having stack height <25 m.

Table 3.2: PM_{10} Emission from Industries (Stack Height < 25 m)

		Industrial Fuel Consumtion (kg/d or L/d)						Emission of PM (kg/d)						Total
S.No.	**Grid No.**	**Wood**	**LPG**	**Coal**	**Diesel**	**Fuel Oil**	**Kerosene**	**Wood**	**LPG**	**Coal**	**Diesel**	**Fuel Oil**	**Kerosene**	**(kg/d)**
1	**KSIE-G-048**	0	0	1640	118	300	50	0	0	32.8	0.523	0.612	0.0975	34
2	**KSIE-G-059**	500	0	1510	527	500	50	7.65	0	30.2	2.335	1.02	0.0975	41
5	**KSIE-G-075**	7500	192	5125	3366	600	250	115	0.4	103	14.91	1.224	0.4875	234
6	**KSIE-G-076**	0	50	9485	3395	150	150	0	0.1	190	15.04	0.306	0.2925	205
7	**KSIE-G-077**	10	0	1020	1793	0	50	0.15	0	20.4	7.943	0	0.0975	29
8	**KSIE-G-078**	500	0	950	6755	500	150	7.65	0	19	29.92	1.02	0.2925	58
9	**KSIE-G-091**	0	0	0	200	0	50	0	0	0	0.886	0	0.0975	1
10	**KSIE-G-096**	0	0	1557	1726	150	50	0	0	31.1	7.646	0.306	0.0975	39
11	**KSIE-G-108**	0	0	0	1375	335	100	0	0	0	6.091	0.6834	0.195	7

Table 3.3: NOx emission from Industries (Stack Height < 25 m)

		Industrial Fuel Consumtion (kg/d or L/d)						Emission of NOx (kg/d)						Total
S.No.	**Grid No.**	**Wood**	**LPG**	**Coal**	**Diesel**	**Fuel Oil**	**Kerosene**	**Wood**	**LPG**	**Coal**	**Diesel**	**Fuel Oil**	**Kerosene**	**(kg/d)**
1	**KSIE-G-048**	0	0	1640	118	300	50	0	0	6.54	6.726	1.98	0.125	15
2	**KSIE-G-059**	500	0	1510	527	500	50	0.7	0	6.02	30.04	3.3	0.125	40
5	**KSIE-G-075**	7500	192	5125	3366	600	250	10.5	0.3	20.4	191.9	3.96	0.625	228
6	**KSIE-G-076**	0	50	9485	3395	150	150	0	0.1	37.8	193.5	0.99	0.375	233
7	**KSIE-G-077**	10	0	1020	1793	0	50	0.01	0	4.07	102.2	0	0.125	106
8	**KSIE-G-078**	500	0	950	6755	500	150	0.7	0	3.79	385	3.3	0.375	393
9	**KSIE-G-091**	0	0	0	200	0	50	0	0	0	11.4	0	0.125	12
10	**KSIE-G-096**	0	0	1557	1726	150	50	0	0	6.21	98.38	0.99	0.125	106
11	**KSIE-G-108**	0	0	0	1375	335	100	0	0	0	78.38	2.211	0.25	81

Table 3.4: SO_2 Emission from Industries (Stack Height < 25 m)

		Industrial Fuel Consumtion (kg/d or L/d)						Emission of SO2(kg/d)						Total
S.No.	**Grid No.**	**Wood**	**LPG**	**Coal**	**Diesel**	**Fuel Oil**	**Kerosene**	**Wood**	**LPG**	**Coal**	**Diesel**	**Fuel Oil**	**Kerosene**	**(kg/d)**
1	**KSIE-G-048**	0	0	1640	118	300	50	0	0	21.8	0.421	8.478	0.2	31
2	**KSIE-G-059**	500	0	1510	527	500	50	0.1	0	20.1	1.881	14.13	0.2	36
5	**KSIE-G-075**	7500	192	5125	3366	600	250	1.5	0.1	68.2	12.02	16.956	1	100
6	**KSIE-G-076**	0	50	9485	3395	150	150	0	0	126	12.12	4.239	0.6	143
7	**KSIE-G-077**	10	0	1020	1793	0	50	0	0	13.6	6.401	0	0.2	20
8	**KSIE-G-078**	500	0	950	6755	500	150	0.1	0	12.6	24.12	14.13	0.6	52
9	**KSIE-G-091**	0	0	0	200	0	50	0	0	0	0.714	0	0.2	1
10	**KSIE-G-096**	0	0	1557	1726	150	50	0	0	20.7	6.162	4.239	0.2	31
11	**KSIE-G-108**	0	0	0	1375	335	100	0	0	0	4.909	9.4671	0.4	15

Table 3.5: CO emission from Industries (Stack Height < 25 m)

S.No.	Grid No.	Industrial Fuel Consumtion (kg/d or L/d)						Emission of CO (kg/d)						Total (kg/d)
		Wood	LPG	Coal	Diesel	Fuel Oil	Kerosene	Wood	LPG	Coal	Diesel	Fuel Oil	Kerosene	
1	**KSIE-G-048**	0	0	1640	118	300	50	0	0	40.9	1.451	0.18	3.1	46
2	**KSIE-G-059**	500	0	1510	527	500	50	57.7	0	37.6	6.482	0.3	3.1	105
5	**KSIE-G-075**	7500	192	5125	3366	600	250	866	0	128	41.4	0.36	15.5	1051
6	**KSIE-G-076**	0	50	9485	3395	150	150	0	0	236	41.76	0.09	9.3	288
7	**KSIE-G-077**	10	0	1020	1793	0	50	1.15	0	25.4	22.05	0	3.1	52
8	**KSIE-G-078**	500	0	950	6755	500	150	57.7	0	23.7	83.09	0.3	9.3	174
9	**KSIE-G-091**	0	0	0	200	0	50	0	0	0	2.46	0	3.1	6
10	**KSIE-G-096**	0	0	1557	1726	150	50	0	0	38.8	21.23	0.09	3.1	63
11	**KSIE-G-108**	0	0	0	1375	335	100	0	0	0	16.91	0.201	6.2	23

3.4 Point Sources

The industries having stack height of more than 25 m have been taken as medium to large scale industries and these industries have been taken as point source. The longitude and latitude of these industries were determined through field survey using GPS (Fig 3.20) and information on stack and emission details were either obtained from survey or from the records of SPCB Kanpur. The industries have been numbered and located on the map (Fig 3.20) and details of these industries are given in Table 3.6. The types of the industry includes power plant, textiles, chemical, iron and steel and rice mills. The major emission is from a coal-based power plant (of 2*110 MW capacity), Panki Power Station.

Point Sources [mainly industries categories them under SSI, MSI, LSI]
Approach/Methodology for different categories of Industries (with data sources)
Total Emission Estimation for(0.5 x 0.5)
Uncertainties or limitations of estimations
Percentage Distribution of Pollutants from Industrial Sources
Data Constraints / Assumptions
Give industry category wise information as per local inventory

Figure 3.21 and Table 3.6 show emissions from point sources and it can be seen that emissions from the industrial sources are very high for all pollutants, maximum being NO_x (8414 kg/d). The power plant have ESPs having efficiency of 99% PM removal therefore

PM emissions are much smaller than NOx, which is not controlled in any of the industry. The grid-wise emission of pollutants from large industry is given in Table 3.7.

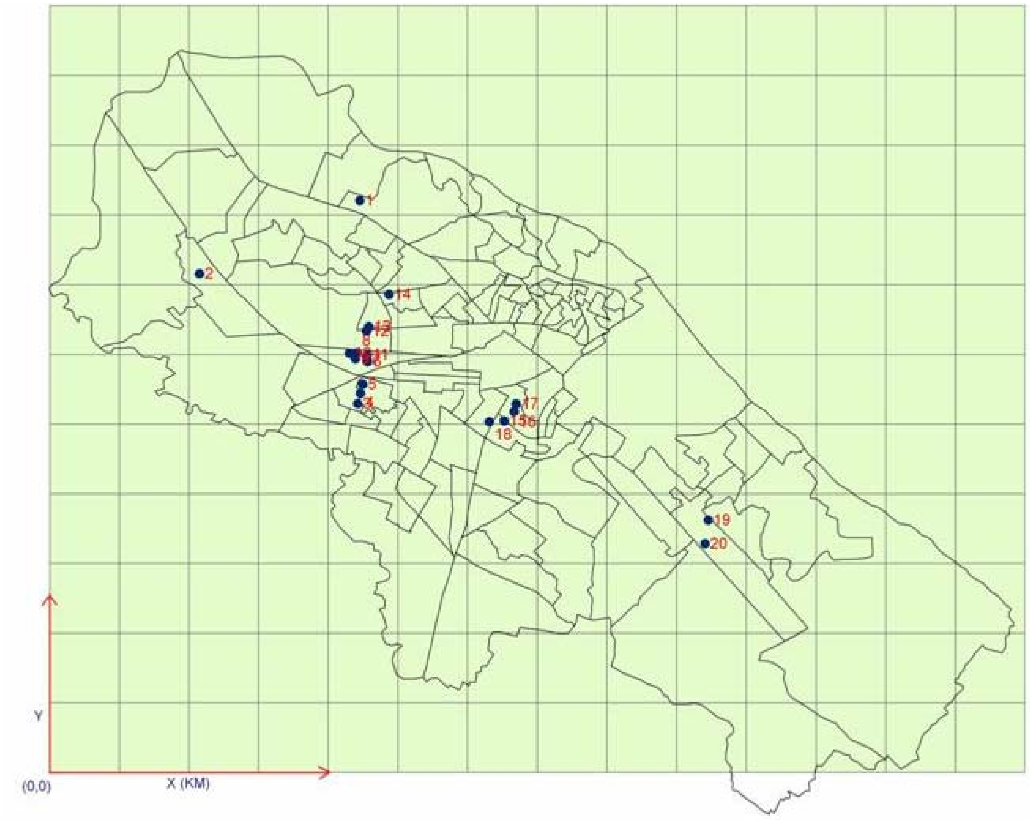


Figure 3.20: Locations of Points Sources in the City

Figure 3.21: Emissions from Industries as Point Sources (Stack height> 25.0 m)

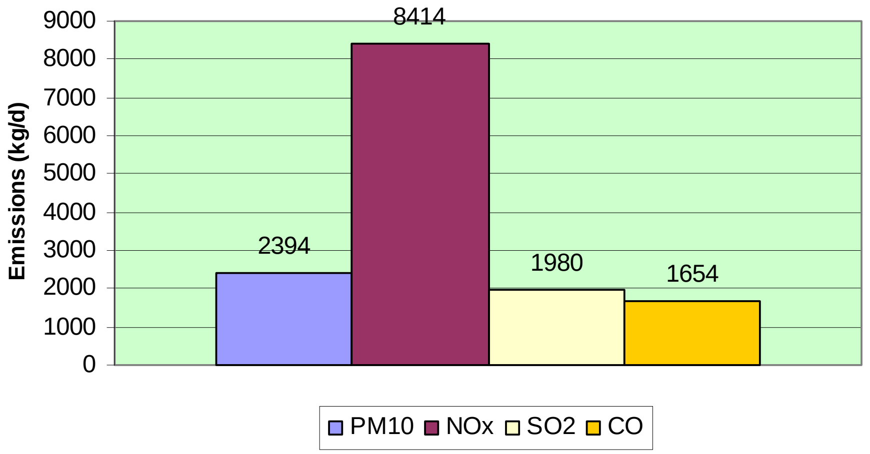


Table 3.6: Details of Point Sources (for Location of Source, Refer Fig 3.20)

S. No.	Grid No.	Particular of Industry	Capacity	Fuel Consumpti	Stack Height (m)	Lattitude (N)	Longitude (E)	PM (Kg/d)	NOx (Kg/d)	SO2 (Kg/d)	CO (Kg/d)
1	G048	Rice Mill	48 T/d	640 Kg/d coal	30 m	26029'40.18"	80017'11.45"	0.736	2.5536	0.608	15.936
3	G059	Thermal Power Plant	2*110 MW	2030 T/d coal	120 m	26°28'31.08"	80°14'25.878"	2334.5	8099.7	1928.5	507.5
4	G075	Iron and Steel Industry	31.59 T/d	2.2 T/d coal	30 m	26°26'30.26"	80°17'10.073"	2.53	8.778	2.09	54.78
5	G075	Textile Industry	7 T/d	700 L/d diesel	60 m	26°26'40.24"	80°17'13.043"	3.101	39.9	2.499	8.61
6	G075	Rice Mill	150 T/d	2 T/d coal	35 m	26°26'48.34"	80°17'15.035"	2.3	7.98	1.9	49.8
7	G076	Iron and Steel Industry	20 T/d	20 L/d diesel & 18 T/d coal	25 m	26°27'10.66"	80°17'20.076"	20.7886	72.96	17.1714	448.446
8	G076	Iron and Steel Industry	50 T/d	4.5 T/d coal	30 m	26°27'11.628"	80°17'20.016"	5.175	17.955	4.275	112.05
9	G076	Iron and Steel Industry	28 T/d	3 T/d Coal	25 m	26°27'18.762"	80°17'9.732"	3.45	11.97	2.85	74.7
10	G076	Oil Industry	2 T/d	2 T/d coal	25 m	26°27'12.56"	80°17'07.662"	2.3	7.98	1.9	49.8
11	G076	Textile Industry	5 T/d	1 T/d coal	55 m	26°27'17.95"	80°17'1.87"	1.15	3.99	0.95	24.9
12	G076	Rice Mill	25 T/d	375 kg/d coal	30 m	26°27'16.44"	80°17'20.35"	0.43125	1.49625	0.35625	9.3375
13	G077	Textile Industry	5.5 T/d	1 T/d coal	60 m	26°27'38.632"	80°17'19.481"	1.15	3.99	0.95	24.9
14	G077	Leather Industry	5 T/d	960 L/d diesel	35 m	26°27'42.745"	80°17'21.312"	4.2528	54.72	3.4272	11.808
15	G078	Iron and Steel Industry	11 T/d	10 L/d diesel & 1 T/d coal	25 m	26°28'12.745"	80°17'42.131"	1.1943	4.56	0.9857	25.023
16	G096	Oil Industry	7.5 T/d	750 L/d diesel	30 m	26°26'15.542"	80°19'42.236"	0.8625	42.75	2.6775	9.225
17	G096	Rice Mill	36 T/d	480 kg/d coal	35 m	26°26'24.356"	80°19'52.423"	0.552	1.9152	0.456	11.952
18	G096	Leather Industry	5 T/d	5 T/d Coal	35 m	26°26'31.256"	80°19'54.581"	5.75	19.95	4.75	124.5
19	G096	Rubber Industry	10 T/d	2 T/d coal	30 m	26°26'14.334"	80°19'27.184"	2.3	7.98	1.9	49.8
20	G108	Textile Industry	12 T/d	1.2 T/d coal	80 m	26024'43.152"	80023'14.361"	1.38	4.788	1.14	29.88
21	G108	Rice Mill	35 T/d	425 kg/d coal	35 m	26024'21.285"	80023'11.186"	0.48875	1.69575	0.40375	10.5825

Table 3.7: Grid-wise Emission from Point Sources

S.No.	Grid No.	Total Emissions from Point Sources (kg/d)			
		PM (Kg/d)	NOx (Kg/d)	SO2 (Kg/d)	CO (Kg/d)
1	KSIE-G-048	0.736	2.5536	0.608	15.936
2	KSIE-G-059	2334.5	8099.7	1928.5	507.5
3	KSIE-G-075	7.931	56.658	6.489	113.19
4	KSIE-G-076	33.29485	112.36125	27.50265	719.2335
5	KSIE-G-077	5.4028	58.71	4.3772	36.708
6	KSIE-G-078	1.1943	4.56	0.9857	25.023
7	KSIE-G-096	9.4645	72.5952	9.7835	195.477
8	KSIE-G-108	1.86875	6.48375	1.54375	40.4625
	Total	**2394**	**8414**	**1980**	**1654**

3.5 Line Sources

Figures 3.22 to 3.26 show average daily pattern of flow of vehicles in each hour for 2-W, 3-W, 4-W, LCV and HDV. While 2-W, 3-W and 4-W show similar patterns that more number of vehicles in the central part of the city Rawatpur, Bada Chaurah and Colonelganj and a larger flow of HDVs on the highways, especially the GT Road (IITK, Ramadevi). The flow patter also shoe morning and evening peaks, these peaks are however not so sharp in city suggesting that vehicle flow is nearly uniform all though the day.

Figure 3.22: Patterns of 2W Vehicles at some Important Traffic Junctions

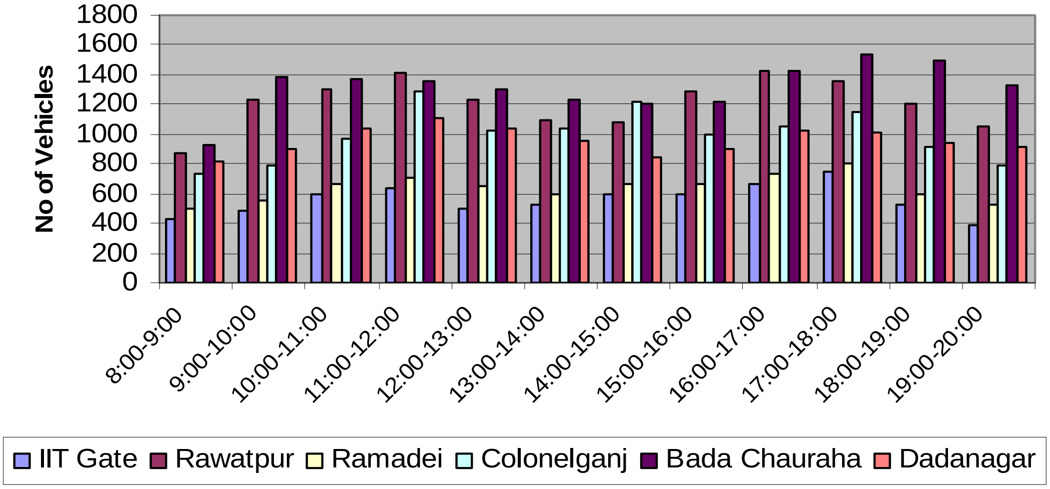


Figure 3.23: Patterns of 3W (Auto and Tempoes) Vehicles at some Important Traffic Junctions

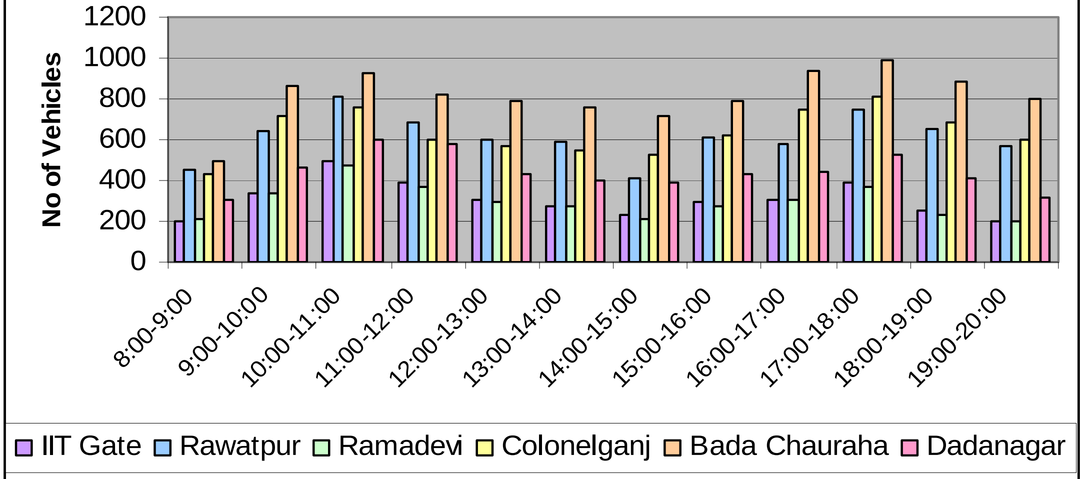


Figure 3.24: **Patterns of 4W (Passenger Cars and Jeeps) Vehicles at some Important Traffic Junctions**

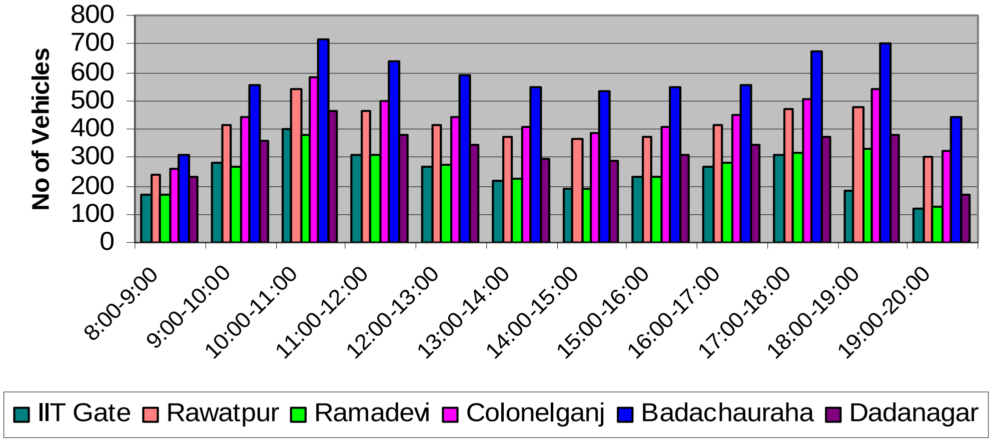


Figure 3.25: **Patterns of LCV Vehicles at some Important Traffic Junctions**

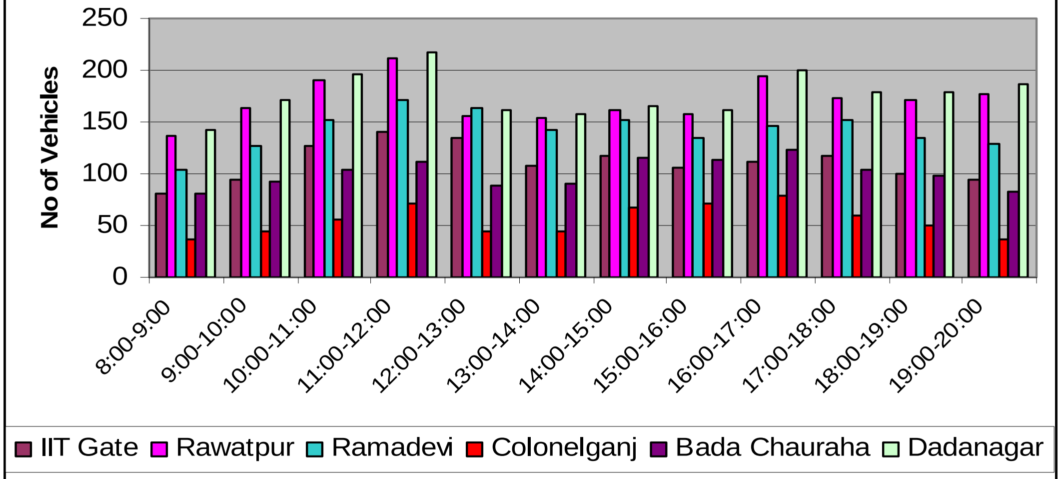


Figure 3.26: Patterns of HDV (Buses and Trucks) Vehicles at some Important Traffic Junctions

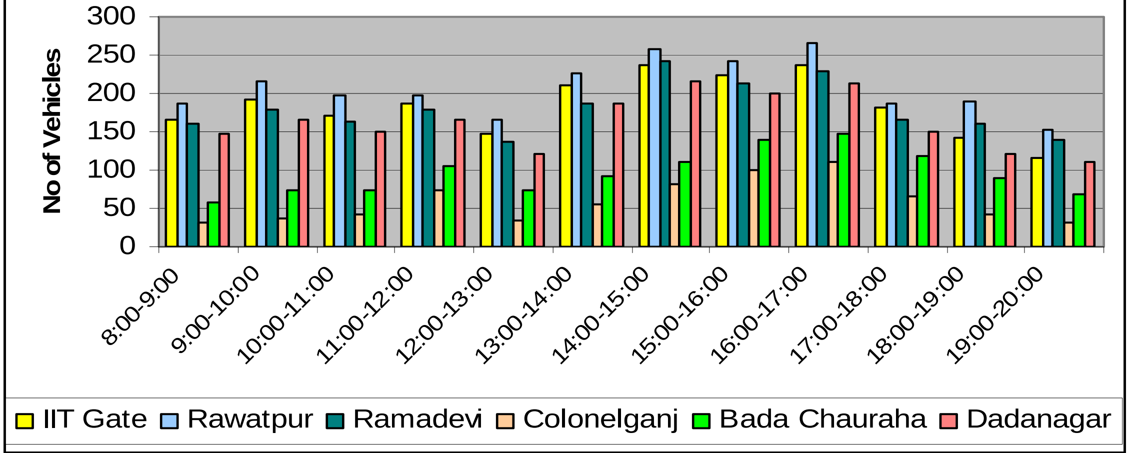
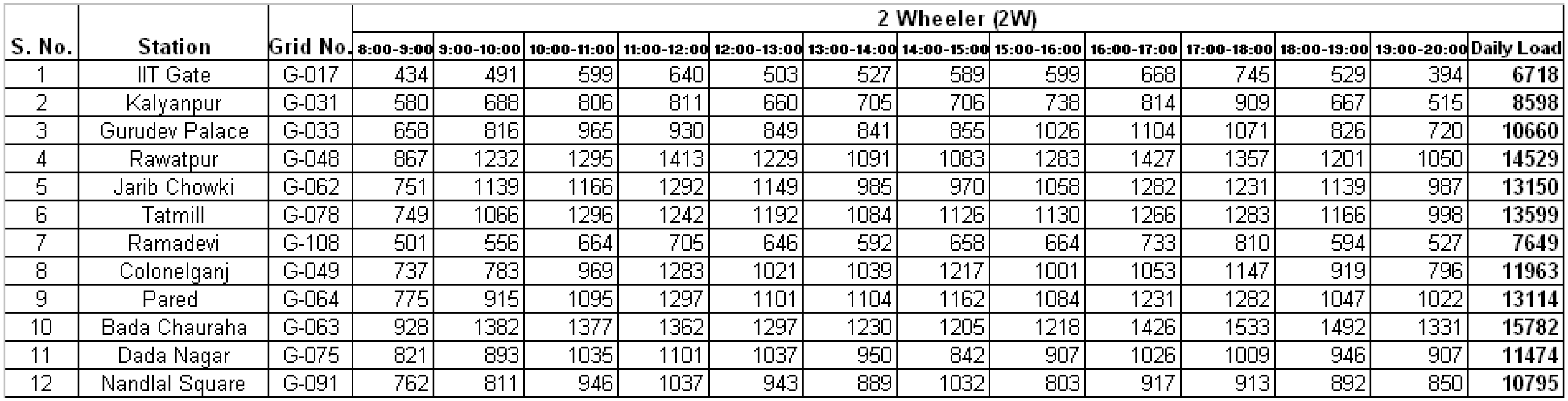


Table 3.8 shows traffic census data at important locations in the city for 2-W, 3-W, 4-W, LCV and HDV (Bus and Trucks).

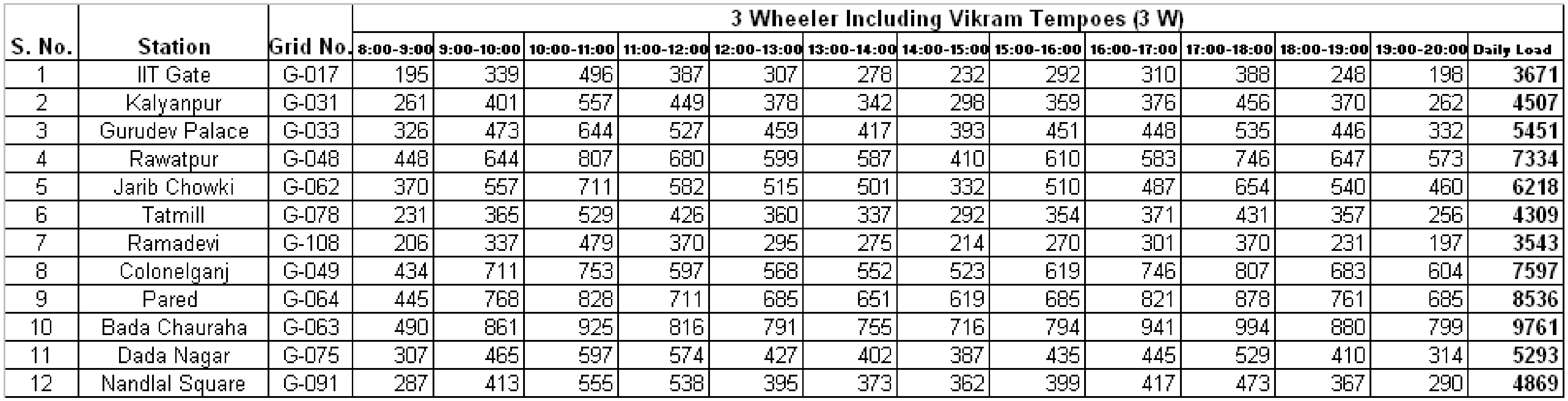
Total road length was estimated in each grid for major and minor roads by digitizing all the roads and then by superimposing the grids on the road map. A GIS software was used to accomplish this (i.e. road length in each grid) and therefore, exact road length was obtained from each grid. As the next step, information on traffic flow from traffic counts was translated into the vehicles on the roads in each grid. Wherever feasible, either traffic flow was taken directly from the traffic data, and for interior grids, traffic from medium rods going the highways was taken to flow in the interior part of the city. Based on road length and number of vehicles on the road, total vehicle kilometer travel (VKT) was estimated for each grid. This information on VKT for each grid is presented in Table 3.9 for each vehicle category.

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 Kanpur are of electric traction. When the diesel locomotives were taken into considerations, the total vehicle kilometer traveled per day is 400 km. The emission of PM_{10} from these VKT is 50 kg/day, which is negligible quaintly w.r.t. other sources.

Table 3.8: Traffic Census Data for various Vehicle Categories



S. No.	Station	Grid No.	2 Wheeler (2W)												
			8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	Daily Load
1	IIT Gate	G-017	434	491	599	640	503	527	589	599	668	745	529	394	**6718**
2	Kalyanpur	G-031	580	688	806	811	660	705	706	738	814	909	667	515	**8598**
3	Gurudev Palace	G-033	658	816	965	930	849	841	855	1026	1104	1071	826	720	**10660**
4	Rawatpur	G-048	867	1232	1295	1413	1229	1091	1083	1283	1427	1357	1201	1050	**14529**
5	Jarib Chowki	G-062	751	1139	1166	1292	1149	985	970	1058	1282	1231	1139	987	**13150**
6	Tatmill	G-078	749	1066	1296	1242	1192	1084	1126	1130	1266	1283	1166	998	**13599**
7	Ramadevi	G-108	501	556	664	705	646	592	658	664	733	810	594	527	**7649**
8	Colonelganj	G-049	737	783	969	1283	1021	1039	1217	1001	1053	1147	919	796	**11963**
9	Pared	G-064	775	915	1095	1297	1101	1104	1162	1084	1231	1282	1047	1022	**13114**
10	Bada Chauraha	G-063	928	1382	1377	1362	1297	1230	1205	1218	1426	1533	1492	1331	**15782**
11	Dada Nagar	G-075	821	893	1035	1101	1037	950	842	907	1026	1009	946	907	**11474**
12	Nandlal Square	G-091	762	811	946	1037	943	889	1032	803	917	913	892	850	**10795**



S. No.	Station	Grid No.	3 Wheeler Including Vikram Tempoes (3 W)												
			8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	Daily Load
1	IIT Gate	G-017	195	339	496	387	307	278	232	292	310	388	248	198	**3671**
2	Kalyanpur	G-031	261	401	557	449	378	342	298	359	376	456	370	262	**4507**
3	Gurudev Palace	G-033	326	473	644	527	459	417	393	451	448	535	446	332	**5451**
4	Rawatpur	G-048	448	644	807	680	599	587	410	610	583	746	647	573	**7334**
5	Jarib Chowki	G-062	370	557	711	582	515	501	332	510	487	654	540	460	**6218**
6	Tatmill	G-078	231	365	529	426	360	337	292	354	371	431	357	256	**4309**
7	Ramadevi	G-108	206	337	479	370	295	275	214	270	301	370	231	197	**3543**
8	Colonelganj	G-049	434	711	753	597	568	552	523	619	746	807	683	604	**7597**
9	Pared	G-064	445	768	828	711	685	651	619	685	821	878	761	685	**8536**
10	Bada Chauraha	G-063	490	861	925	816	791	755	716	794	941	994	880	799	**9761**
11	Dada Nagar	G-075	307	465	597	574	427	402	387	435	445	529	410	314	**5293**
12	Nandlal Square	G-091	287	413	555	538	395	373	362	399	417	473	367	290	**4869**

(Table 3.8. contd…)

S. No.	Station	Grid No.	4 Wheeler Passenger Cars and Jeep (4 W)												
			8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	Daily Load
1	IIT Gate	G-017	168	280	400	311	269	218	190	231	264	309	186	122	**2948**
2	Kalyanpur	G-031	190	309	423	335	298	243	217	252	295	335	347	137	**3381**
3	Gurudev Palace	G-033	215	342	454	369	329	277	283	282	326	369	380	166	**3792**
4	Rawatpur	G-048	239	415	542	463	412	373	368	372	413	471	477	304	**4849**
5	Jarib Chowki	G-062	228	385	495	400	372	334	348	343	373	445	488	295	**4506**
6	Tatmill	G-078	185	300	412	320	287	235	205	237	290	326	330	134	**3262**
7	Ramadevi	G-108	170	264	382	308	277	224	191	233	278	313	329	127	**3097**
8	Colonelganj	G-049	257	445	584	495	445	406	387	406	446	503	537	321	**5231**
9	Pared	G-064	267	481	640	550	501	463	446	465	480	558	590	380	**5819**
10	Bada Chauraha	G-063	308	556	719	638	589	550	534	547	555	672	699	441	**6809**
11	Dada Nagar	G-075	231	358	465	382	347	296	291	308	347	369	380	166	**3942**
12	Nandlal Square	G-091	215	341	449	373	324	280	277	293	328	347	363	151	**3738**

S. No.	Station	Grid No.	Light Commercial Vehicles (LCV)												
			8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	Daily Load
1	IIT Gate	G-017	80	95	126	140	134	107	116	106	112	116	100	95	**1327**
2	Kalyanpur	G-031	98	118	148	166	157	136	140	125	136	140	122	124	**1609**
3	Gurudev Palace	G-033	122	140	169	191	134	134	136	130	169	149	148	151	**1774**
4	Rawatpur	G-048	136	164	191	212	156	155	161	157	194	174	172	176	**2048**
5	Jarib Chowki	G-062	152	149	176	236	172	169	178	172	211	190	187	193	**2185**
6	Tatmill	G-078	164	172	194	253	196	187	197	194	235	211	211	221	**2436**
7	Ramadevi	G-108	103	127	152	172	164	143	152	134	145	151	134	128	**1708**
8	Colonelganj	G-049	37	44	56	70	44	45	68	71	79	59	50	37	**662**
9	Pared	G-064	56	67	76	89	67	68	94	91	104	82	76	70	**940**
10	Bada Chauraha	G-063	82	92	103	112	89	90	115	113	124	103	98	83	**1204**
11	Dada Nagar	G-075	142	172	196	217	161	158	166	161	200	179	179	187	**2117**
12	Nandlal Square	G-091	113	150	174	197	151	143	139	132	182	154	162	155	**1852**

(Table 3.8. contd…)

S. No.	Station	Grid No.	Bus/Truck												
			8:00-9:00	9:00-10:00	10:00-11:00	11:00-12:00	12:00-13:00	13:00-14:00	14:00-15:00	15:00-16:00	16:00-17:00	17:00-18:00	18:00-19:00	19:00-20:00	Daily Load
1	IIT Gate	G-017	166	191	172	186	147	209	238	224	238	181	142	116	**2209**
2	Kalyanpur	G-031	172	199	179	183	147	207	248	225	246	174	170	139	**2289**
3	Gurudev Palace	G-033	174	204	140	186	155	212	252	229	255	181	178	148	**2314**
4	Rawatpur	G-048	186	215	196	198	165	226	257	243	267	186	190	153	**2482**
5	Jarib Chowki	G-062	178	203	204	217	179	238	246	238	277	198	204	165	**2547**
6	Tatmill	G-078	192	231	228	225	194	256	283	270	290	216	218	179	**2783**
7	Ramadevi	G-108	161	179	163	178	138	186	242	212	229	166	160	139	**2153**
8	Colonelganj	G-049	31	36	41	73	34	55	83	100	110	66	43	31	**702**
9	Pared	G-064	42	51	56	88	46	69	99	116	127	94	68	43	**897**
10	Bada Chauraha	G-063	59	73	74	105	73	92	111	139	147	118	90	69	**1149**
11	Dada Nagar	G-075	147	166	151	165	121	186	215	199	213	151	121	111	**1945**
12	Nandlal Square	G-091	120	138	133	146	105	172	196	185	189	120	98	90	**1689**

Table 3.9: Vehicle Kilometer Traveled (VKT) per day (for each vehicle)

S. No.	Code with Grid Id	Road Length (kms)		Vehicle Kilometers Traveled (VKT) Estimation				
		Major	Minor	2W	3W (Auto & Tempoes)	4W (Cars & Jeeps)	LCV	Buses & Trucks
1	K-G-003	0.15		3.30	2.74	2.57	2.20	2.20
2	K-G-004		0.77	2.77	1.94	1.94	1.38	1.38
3	K-G-015			2.68	1.87	1.87	1.34	1.34
4	K-G-016		2.71	3.71	2.59	2.59	1.85	1.85
5	K-G-017	2.34	2.03	4.67	4.46	4.00	3.86	3.86
6	K-G-018	1.93	2.10	4.45	4.10	3.71	3.48	3.48
7	K-G-019			2.77	1.94	1.94	1.38	1.38
8	K-G-029		0.68	2.68	1.87	1.87	1.34	1.34
9	K-G-030		3.38	4.38	3.07	3.07	2.19	2.19
10	K-G-031	2.62	4.08	6.91	6.17	5.65	5.16	5.16
11	K-G-032	2.16	0.01	3.52	3.57	3.14	3.17	3.17
12	K-G-033	1.04	4.67	6.40	5.01	4.80	3.88	3.88
13	K-G-034		4.24	5.24	3.67	3.67	2.62	2.62
14	K-G-035		7.45	8.45	5.91	5.91	4.22	4.22
15	K-G-043			3.68	2.57	2.57	1.84	1.84
16	K-G-044			4.38	3.07	3.07	2.19	2.19
17	K-G-045	2.34	1.66	5.29	4.90	4.43	4.17	4.17
18	K-G-046		2.92	5.92	4.14	4.14	2.96	2.96
19	K-G-047	1.23	4.98	8.84	6.81	6.57	5.22	5.22
20	K-G-048	2.08	8.22	10.68	8.53	8.12	6.69	6.69
21	K-G-049		18.69	19.69	13.78	13.78	9.84	9.84
22	K-G-050	0.43	11.99	13.64	10.02	9.83	7.42	7.42
23	K-G-051	0.69	1.80	5.50	4.35	4.15	3.39	3.39
24	K-G-057	1.11	1.31	4.09	3.43	3.21	2.76	2.76
25	K-G-058	5.47	0.11	6.94	7.64	6.55	7.02	7.02
26	K-G-059	2.82	6.40	9.37	8.00	7.44	6.52	6.52
27	K-G-060	1.96	4.20	6.58	5.61	5.21	4.57	4.57
28	K-G-061	1.99	3.25	5.64	4.96	4.57	4.11	4.11
29	K-G-062	2.59	8.62	11.43	9.33	8.81	7.40	7.40
30	K-G-063	4.75	12.39	16.71	14.12	13.17	11.44	11.44
31	K-G-064	3.59	13.18	16.69	13.52	12.80	10.68	10.68
32	K-G-065		14.09	15.09	10.57	10.57	7.55	7.55
33	K-G-066		0.76	3.76	2.63	2.63	1.88	1.88
34	K-G-072	0.81		2.78	2.51	2.29	2.11	2.11
35	K-G-073	2.17	2.70	6.22	5.46	5.02	4.52	4.52
36	K-G-074	2.03	4.58	7.00	5.94	5.53	4.82	4.82
37	K-G-075	9.62		11.43	12.91	10.98	11.97	11.97
38	K-G-076		10.20	11.20	7.84	7.84	5.60	5.60
39	K-G-077	2.48	6.52	9.26	7.75	7.25	6.24	6.24
40	K-G-078	2.73	8.27	11.18	9.22	8.67	7.36	7.36
41	K-G-079	0.11	12.21	13.77	10.06	9.89	7.42	7.42
42	K-G-080		5.82	6.82	4.77	4.77	3.41	3.41
43	K-G-081	0.91	0.61	3.24	2.74	2.55	2.21	2.21
44	K-G-087	0.39		2.63	2.30	2.12	1.90	1.90
45	K-G-088	0.18		2.65	2.30	2.13	1.90	1.90
46	K-G-089	2.10	2.81	7.27	6.16	5.74	5.00	5.00
47	K-G-090	2.27	11.01	13.60	10.68	10.22	8.28	8.28
48	K-G-091	2.91	10.29	13.32	10.81	10.23	8.55	8.55
49	K-G-092		6.55	7.55	5.29	5.29	3.78	3.78
50	K-G-093	2.70	2.19	8.08	7.03	6.49	5.80	5.80
51	K-G-094	0.79	5.28	7.11	5.58	5.34	4.32	4.32
52	K-G-095	2.05	6.91	9.35	7.59	7.18	6.01	6.01
53	K-G-096		1.05	3.05	2.14	2.14	1.53	1.53
54	K-G-103			3.62	2.53	2.53	1.81	1.81
55	K-G-104	1.87	1.62	6.93	5.81	5.43	4.68	4.68
56	K-G-105	1.67	8.19	10.36	8.10	7.77	6.26	6.26
57	K-G-106	2.15	3.66	8.16	6.81	6.38	5.48	5.48
58	K-G-107	2.07	5.90					
59	K-G-108	4.73	3.44	9.74	9.23	8.29	7.94	7.94
60	K-G-109	0.37	0.79	6.61	5.23	4.99	4.07	4.07
61	K-G-110		5.67	6.67	4.67	4.67	3.33	3.33
62	K-G-111		4.73					
63	K-G-117			3.20	2.69	2.51	2.17	2.17
64	K-G-118	2.06	0.99	7.43	6.25	5.84	5.05	5.05
65	K-G-119		3.46	5.46	3.82	3.82	2.73	2.73
66	K-G-120		3.70	5.70	3.99	3.99	2.85	2.85
67	K-G-121		3.07	6.07	4.25	4.25	3.03	3.03
68	K-G-122		3.37	5.37	3.76	3.76	2.69	2.69
69	K-G-123	2.58	2.68	7.48	6.56	6.04	5.42	5.42
70	K-G-124		9.61					
71	K-G-125		8.20	9.20	6.44	6.44	4.60	4.60
72	K-G-126		0.74	4.74	3.32	3.32	2.37	2.37
73	K-G-131			3.05	2.14	2.14	1.53	1.53
74	K-G-132	2.07	1.66	7.11	6.03	5.62	4.90	4.90
75	K-G-133		1.10	3.10	2.17	2.17	1.55	1.55
76	K-G-135		1.91	3.91	2.73	2.73	1.95	1.95
77	K-G-136	0.52	4.55	6.12	4.70	4.54	3.59	3.59
78	K-G-137	0.10	7.50	9.08	6.77	6.61	5.07	5.07
79	K-G-138	2.49	3.29	6.03	5.49	5.00	4.64	4.64
80	K-G-139		0.68	3.68	2.58	2.58	1.84	1.84
81	K-G-140	0.52		3.62	2.95	2.79	2.34	2.34
82	K-G-150		0.96	3.96	2.77	2.77	1.98	1.98
83	K-G-151		4.02	5.66	4.44	4.25	3.43	3.43
84	K-G-152	0.56	0.04	4.82	4.68	4.17	4.07	4.07
85	K-G-153	0.03		3.70	3.06	2.88	2.45	2.45

3.6 **Parking Lane Survey**

Figs. 3.27 to 3.31 present parking lane survey results (for 2W, 3W, 4W, LCV and HDV) 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 3.27: **Parking Lane Survey Results for 2W (Nos, %)**

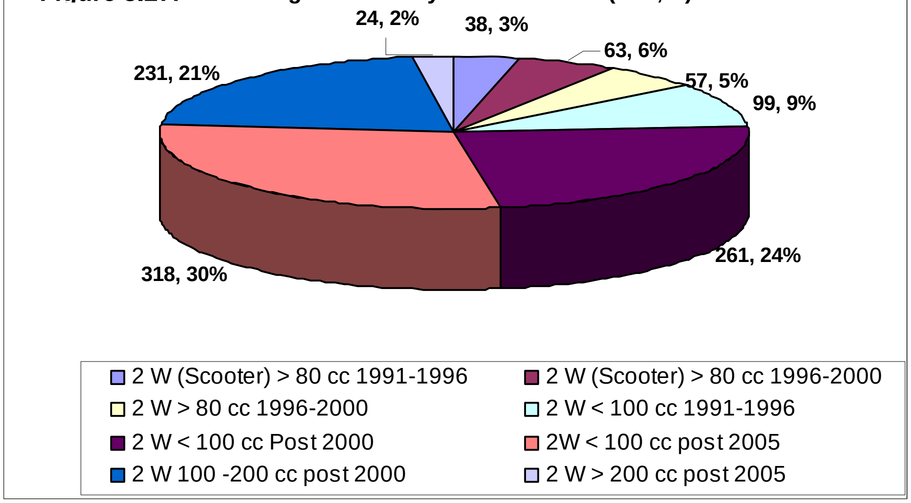


Figure 3.28: **Parking Lane Survey Results for 3W Auto and Tempos(Nos, %)**

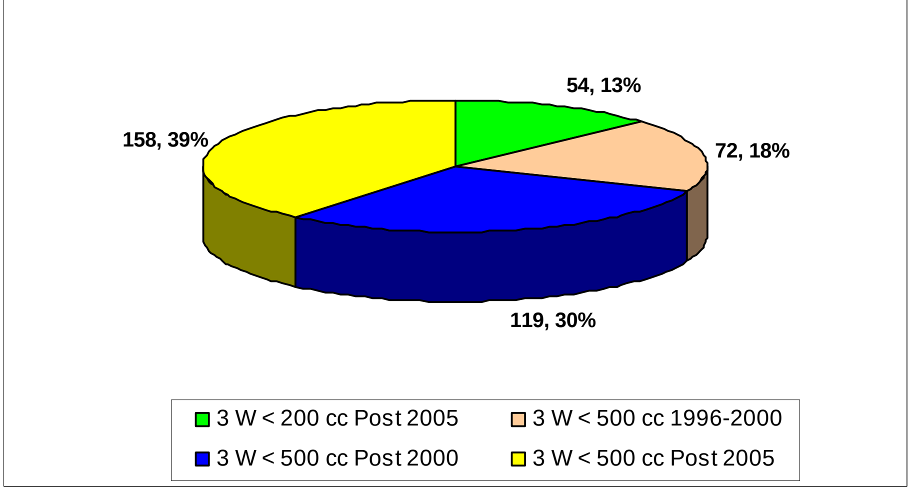


Figure 3.29: Parking Lane Survey Results for 4W Passenger Cars and Jeeps (Nos, %)

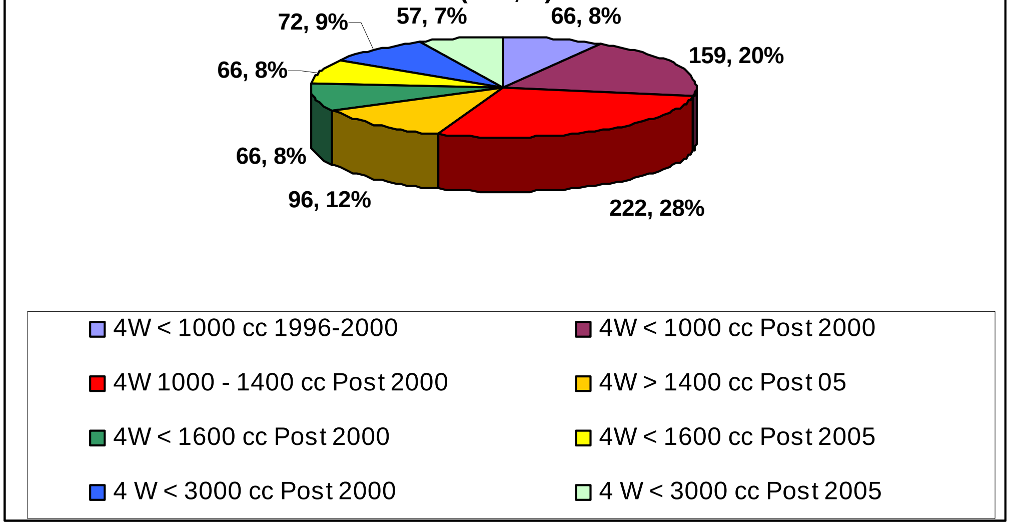


Figure 3.30: Parking Lane Survey Results for Light Commercial Vehicles (Nos, %)

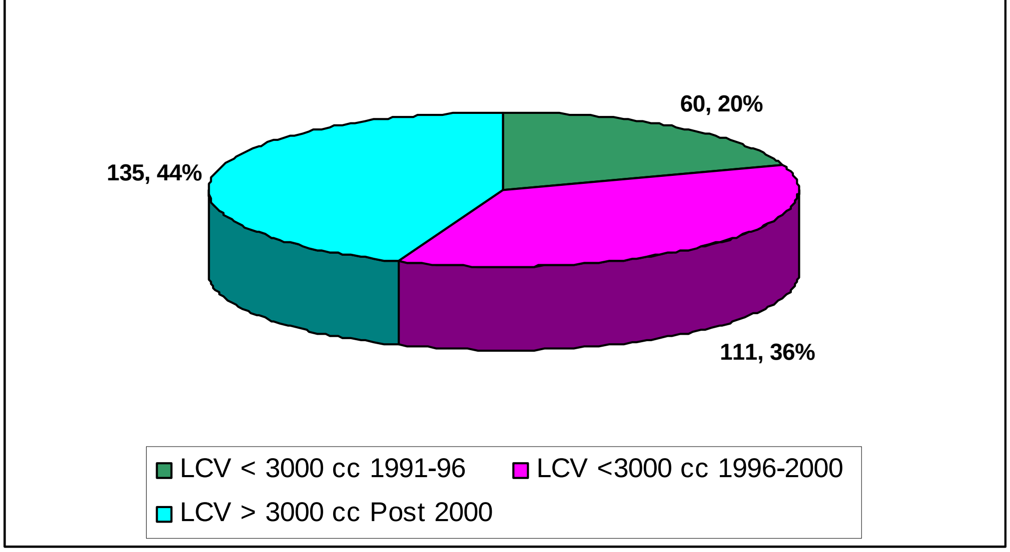
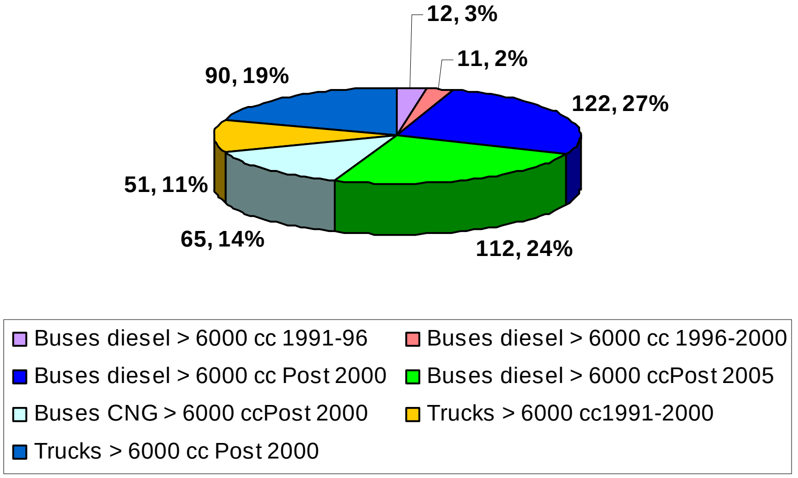


Figure 3.31: Parking Lane Survey Results for Buses and Trucks (Nos, %)



3.7 Emission Factor

The composite emission factors based on parking lane survey indicating fraction of various vehicle categories on the road have been worked out (Table 3.11).

Table 3.10: Composite Emission Factors based on Fraction of Vehicles on road

S. No.	Particulars of the Traffic	Final Emission Factor (gm/km/vehicle)				
		CO	HC	NO_x	CO_2	PM_{10}
1	Two Wheeler (2 W)	2.13	0.94	0.29	24.70	0.02
2	Three Wheeler and Tempos (3 W)	2.72	0.32	0.64	137.99	0.28
3	Passenger Cars and Jeeps (4 W)	1.82	0.28	0.50	154.25	0.07
4	Light Commercial Vehicles (LCV)	3.30	1.51	2.43	362.10	0.64
5	Heavy Duty vehicles (Buses/Trucks)	8.41	1.13	9.47	718.38	0.82

For estimating SO_2 emissions from vehicles, the following assumptions have been made. Average kilometer run per litre of diesel is taken as: 10 km (for 3W); 7 km (for LCV and 5 km (for Buses/Trucks). Sulfur content is in diesel is taken as =500 ppm (wt/wt). Total VKT from various vehicle categories is shown in Fig. 3.32. 2W produce highest VKT, nearly 6000000 km a day. Table 3.12 shows overall emissions from various vehicle types and pollutants.

Table 3.11: Overall Emissions from various Vehicle type and Pollutants

S. No	Particulars	Emissions (kg/day)					Total
		2W	3W Auto & Tempos	4W Passenger Cars & Jeeps	LCV	Buses & Trucks	
1	PM_{10}	115	753	130	372	547	1918
2	NO_x	1920	1725	940	1406	4581	10571
3	SO_2	-	269	-	83	133	485
4	CO	13960	7324	3381	1913	5609	32187

Figures 3.33-3.36 show emission of PM_{10}, NO_x, SO_2 and CO from various vehicle categories in the city. Although VKT is maximum by 2W, buses and trucks, 3W and LCV contribute maximum PM_{10} emissions because of diesel uses. However CO emission is highest from 2W. Fig 3.37 shows overall emissions from various vehicle types and pollutants.

Figure 3.32: Vehicle-wise Total VKT

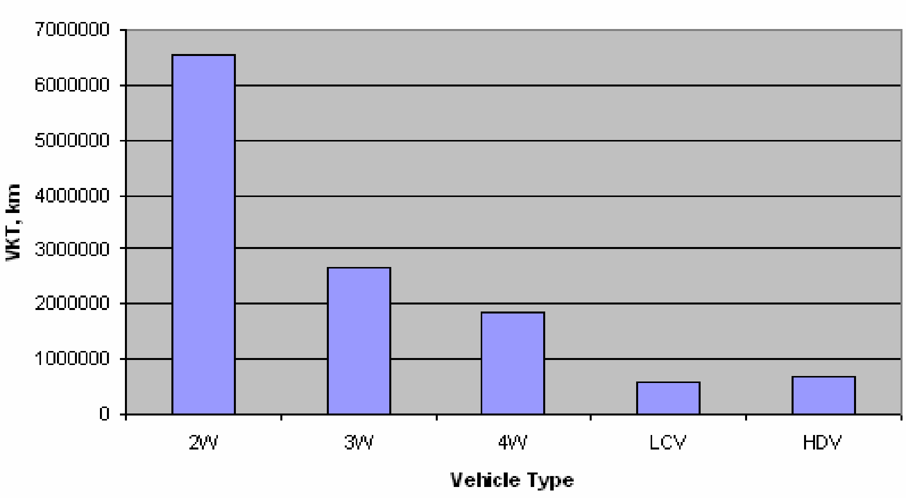


Figure 3.33: PM_{10} Emissions from Vehicles (Vehicle Category, kg/d, %)

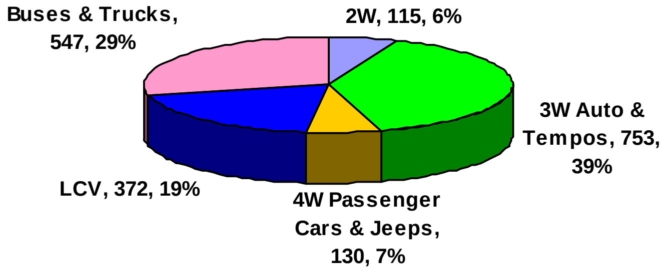


Figure 3.34: NO_x Emissions from Vehicles (Vehicle Category, kg/d, %)

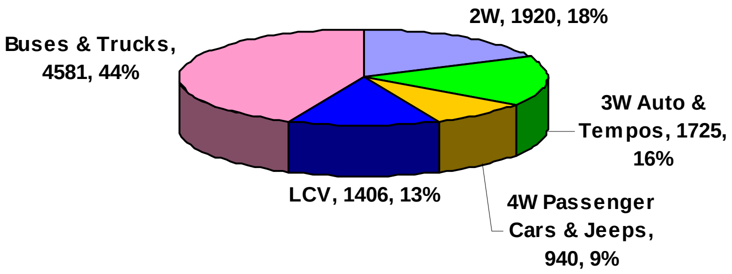


Figure 3.35: SO_2 Emissions from Vehicles (Vehicle Category, kg/d, %)

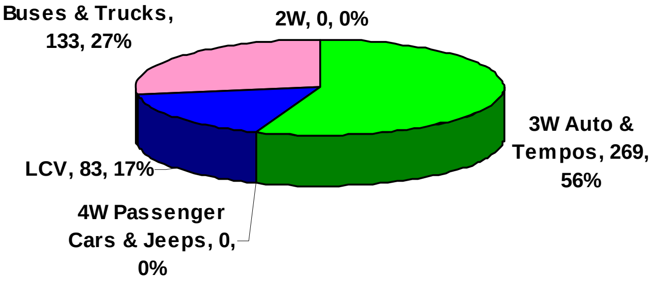


Figure 3.36: CO Emissions from Vehicles (Vehicle Category, kg/d, %)

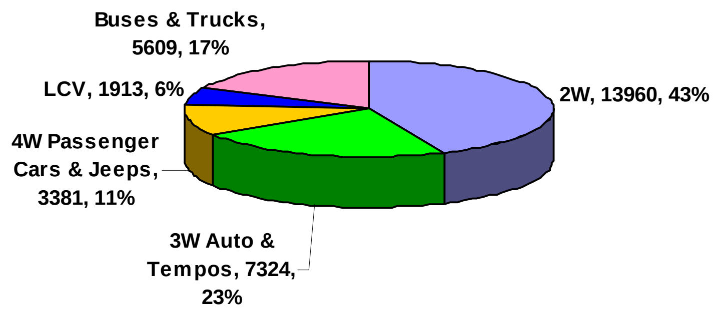
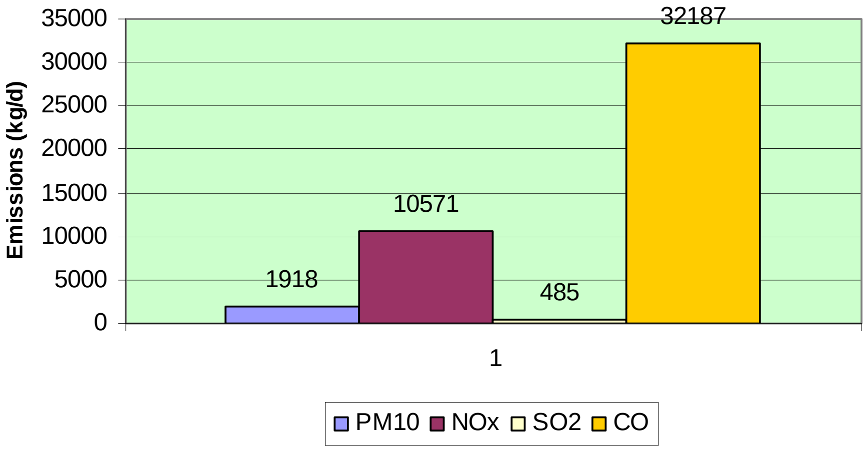


Figure 3.37: Emissions from Vehicles



3.8 City Level Inventory

Methodology

Emission inventory for the entire city for industrial and vehicular pollution was developed based on (i) industrial emission data from SPCB Kanpur, (ii) extrapolation of traffic data from traffic counts from 13 traffic intersections. The road length in each grid was accurately known through digitized road map and determining the road length in each grid. Information on type of vehicle (engine capacity and year of manufacturing) was gathered from parking lot surveys and this information will be fairly accurate as the data are from primary on the field surveys.

The emission from domestic sector largely depends on population in the grid. To be able to assess this emission quantity, ward population, which is known fairly accurately was used. The ward boundaries were first digitized and it was determined that area of various wards that was in the grid. Based on the area of the ward falling in the grid and then multiplying the area with population density, population in the grid was obtained. The population in each grid was divided in three economic classes (high, medium and low). Population of these three classes and fuel consumption other than seven grids are extrapolated from the data of these seven grids. The types of fuel used for household cooking in the city are wood, coal, kerosene (mostly for low economic strata) and LPG.

Primary data on medical waste incinerator, funeral wood burning and construction and demolition activities were obtained in person, therefore this information must be fairly accurate. Rest of the emissions for the entire city (grid-wise) calculated based on land-use pattern. Suppose, X-grid is commercial then primary data from the commercial grid (recall the seven grids, out which one was commercial) was used to extrapolate the emissions in the X-grid.

For paved and unpaved roads information on silt load in terms of gm/m^2 was taken from the previous studies. This information coupled with number of vehicles, kilometer run was used to estimate this sources. Since all information is from primary source, it is expected to be an accurate inventory.

The overall baseline emission inventory for the entire city is presented in Table 3.13

Table 3.12: Baseline Inventory from various Sources, (year 2007)

S. No.	Source	PM_{10}		NOx		SO_2		CO	
		kg/d	%	kg/d	%	kg/d	%	Kg/d	%
1	Hotel and Restaurant	305	3.26	78	0.35	166	3.93	506	1.03
2	Garbage Burning	476	5.08	178	0.79	30	0.70	2497	5.10
3	Medical Waste Incinerator	2	0.03	2	0.01	1	0.03	3	0.01
4	DG Sets	81	0.86	1141	5.07	75	1.78	247	0.50
5	Funeral wood Burning	54	0.58	15	0.07	5	0.12	332	0.68
6	Agriculture Waste Burning	359	3.84	16	0.07	4	0.09	1895	3.87
7	Domestic Fuels	1763	18.84	873	3.88	1055	24.93	7826	15.99
8	Industries (Area Sources)	649	6.94	1214	5.40	429	10.15	1814	3.71
9	Industries (Point Sources)	2394	25.59	8414	37.39	1980	46.80	1654	3.38
10	Vehicular Sources	1918	20.49	10571	46.98	485	11.47	32187	65.74
11	Paved and Non-Paved Road Dust	1353	14.46	-	-	-	-	-	-
12	Construction and Demolition	3	0.03	-	-	-	-	-	-
TOTAL		9357	100	22503	100	4231	100	48960	100

Figures 3.38 to 3.41 show the overall emission inventory of PM_{10}, NOx, SO_2 and CO.

Figure 3.38: PM_{10} Emissions from Various Sources (kg/d, %)

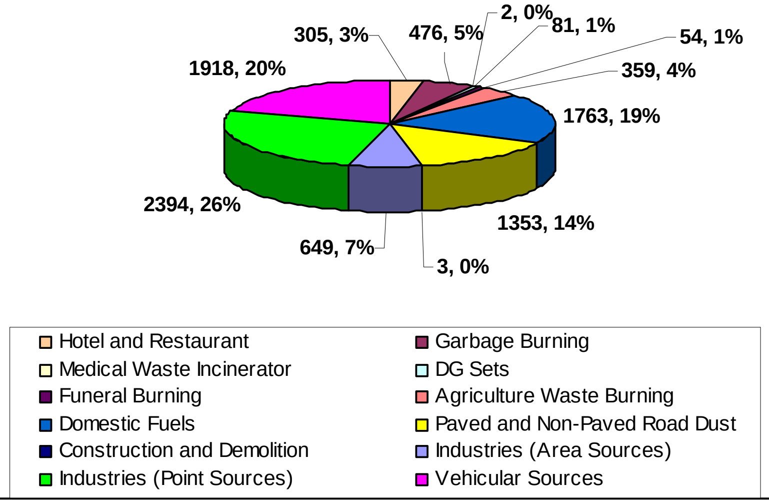


Figure 3.39: NOx Emissions from Various Sources (kg/d, %)

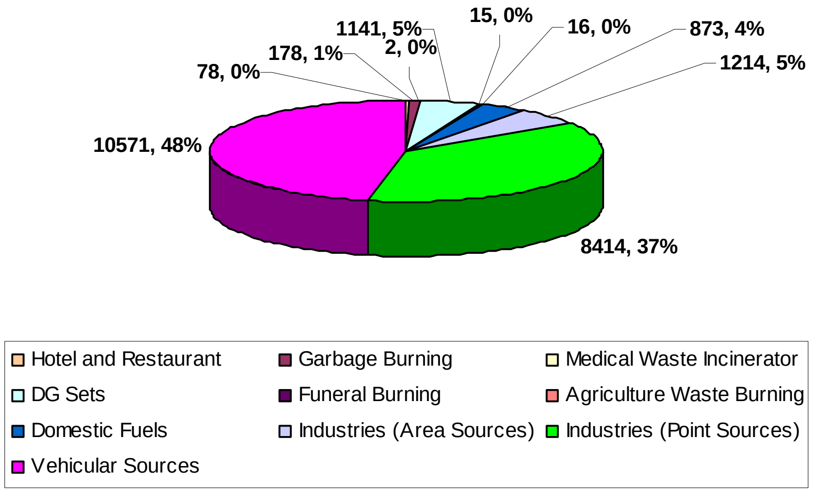


Figure 3.40: SO_2 Emissions from Various Sources (kg/d, %)

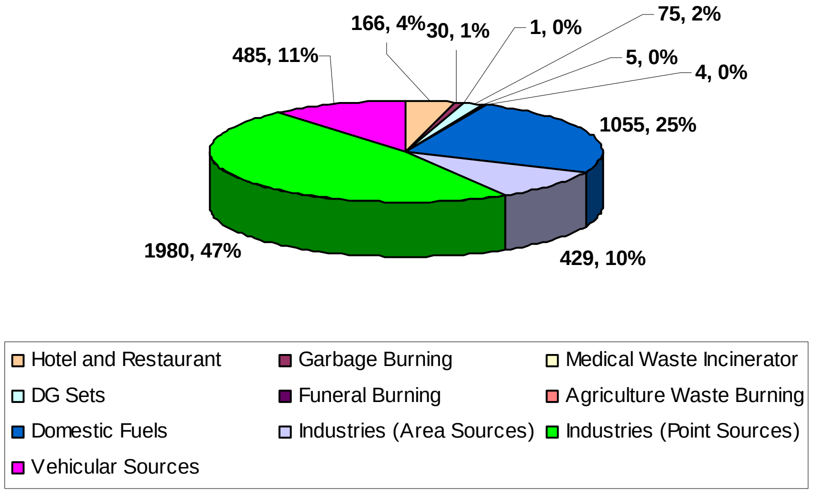
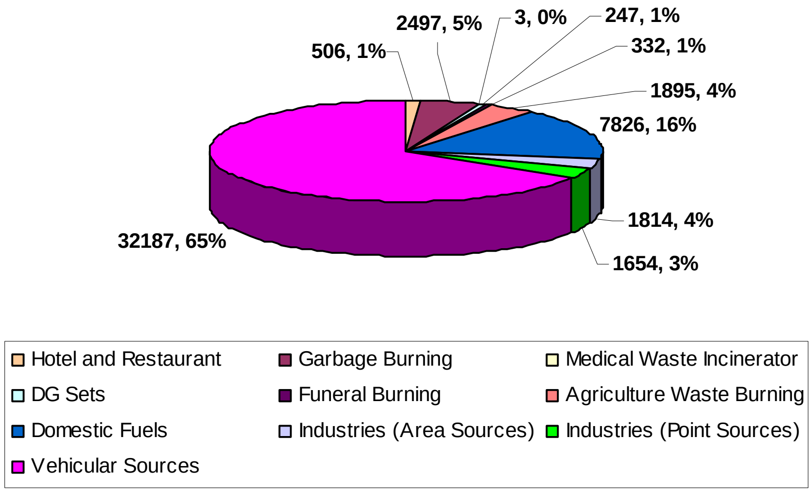


Figure 3.41: CO Emissions from Various Sources (kg/d, %)



Figures 3.42 to 3.45 show emission spatial grid-wise emission inventory for PM_{10}, NOx, SO_2 and CO.

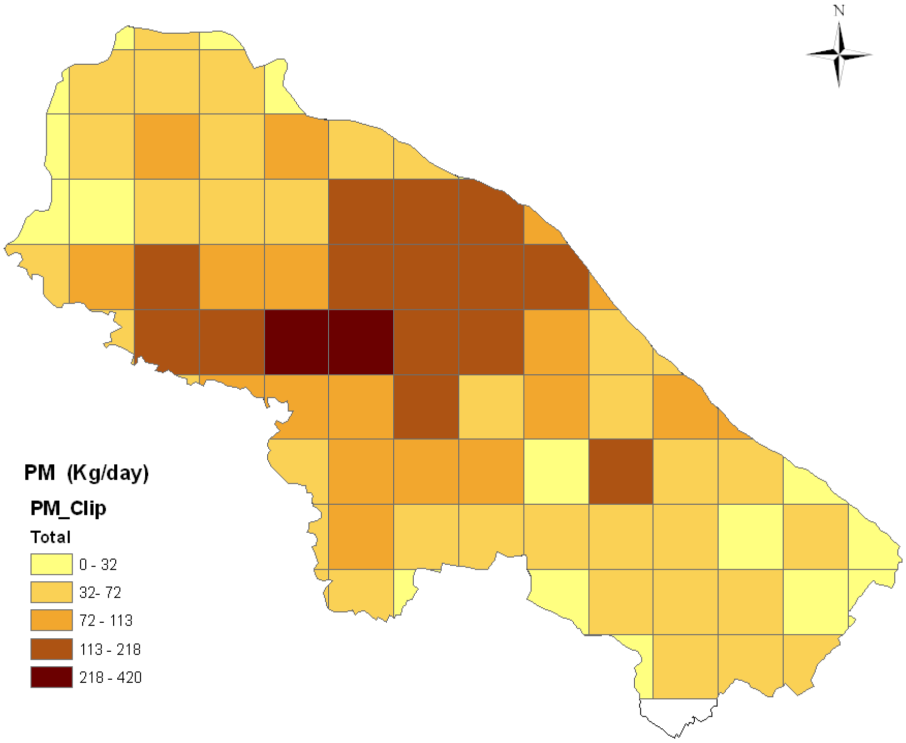


Figure 3.42: Spatial GRID-wise Emission Inventory for PM_{10}

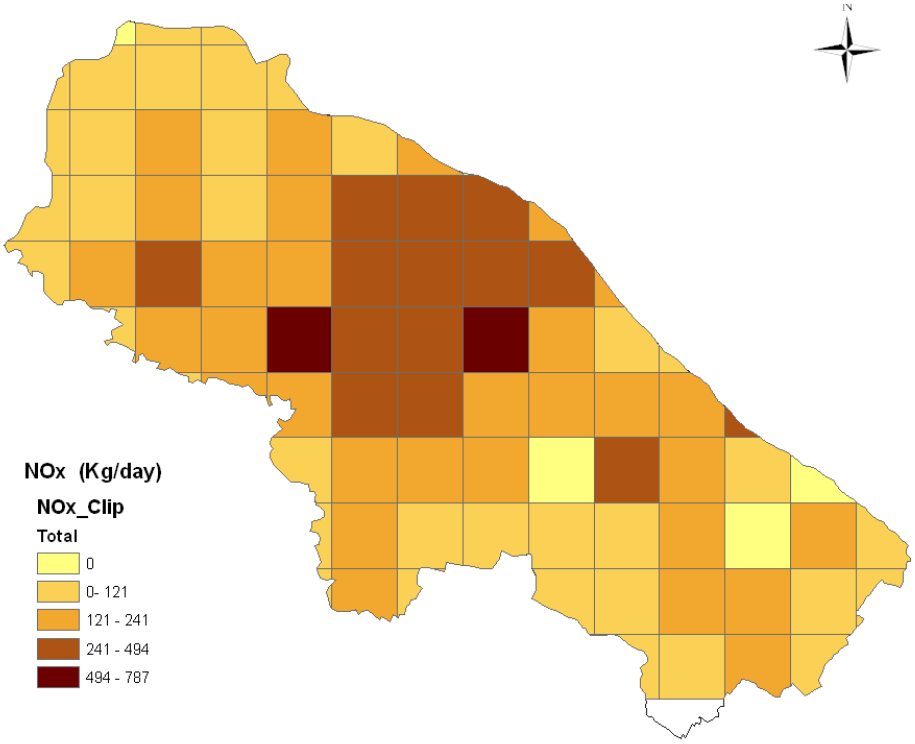


Figure 3.43: Spatial GRID-wise Emission Inventory for NO_x

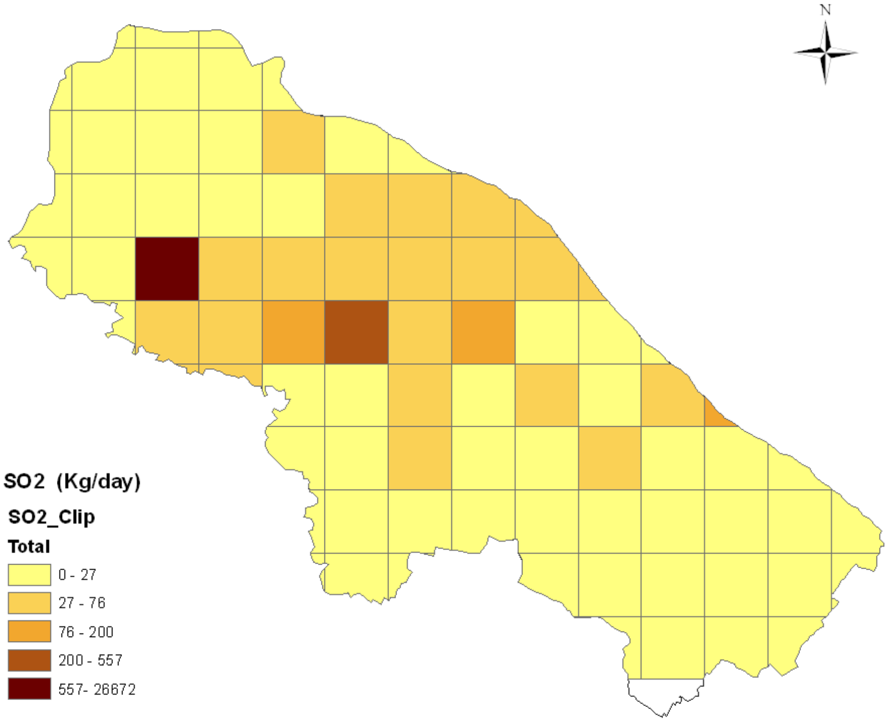


Figure 3.44: Spatial GRID-wise Emission Inventory for SO_2

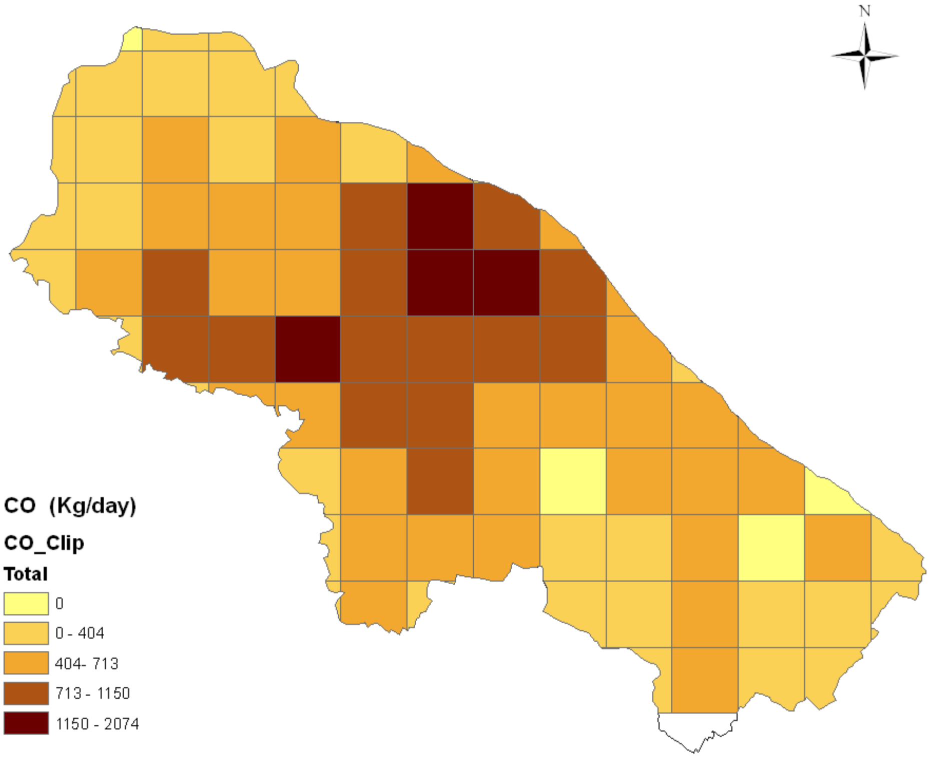


Figure 3.45: Spatial GRID-wise Emission Inventory for CO

3.9 Emission Inventory QA/QC

The emission inventory carried in this project is high quality. In seven grids, selected for extensive primary survey represents typical land use pattern in the city. The major challenge in quality of inventory is as to how to extrapolate the information to the other areas of the city.

Emission inventory for the entire city for **industrial and vehicular pollution** was developed based on (i) industrial emission data from SPCB Kanpur, (ii) extrapolation of traffic data from traffic counts from 13 traffic intersections. The road length in each grid was accurately known through digitized road map and determining the road length in each grid. Information on type of vehicle (engine capacity and year of manufacturing) was gathered from parking lot surveys and this information will be fairly accurate as the data are from primary on the field surveys. Since industrial data from SPCB is as good as primary survey, the data quality is very high. For certain industries, physical checks and stack height measurements were also done.

The emission from **domestic sector** largely depends on population in the grid. To be able to assess this emission quantity, ward population, which is known fairly accurately was used. The population in each grid was divided in three economic classes (high, medium and low). Population of these three classes and fuel consumption other than seven grids are extrapolated from the data of these seven grids. The types of fuel used for household cooking in the city are wood, coal, kerosene (mostly for low economic strata) and LPG. Some checks were made in a few grids (other than seven main grids) to have information on use of LPG, coal, kerosene and wood. Therefore this important source is accurately assessed.

Primary data on **medical waste incinerator, funeral wood burning and construction and demolition activities** were obtained in person, therefore this information must be fairly accurate.

For **paved and unpaved roads** information on silt load in terms of gm/m^2 was taken from the previous studies. This information coupled with number of vehicles, kilometer run was used to estimate these sources. Since all information is from primary source, it is expected to be an accurate inventory.

For **agricultural waste burning**, the grids were identified based on the land-use pattern. It was assumed that 70% of the area is under cultivation and about 200 kg of waste is burnt per acre of the land.

Rest of the emissions for the entire city (grid-wise) was calculated based on land-use pattern. Suppose, X-grid is commercial then primary data from the commercial grid (recall the seven grids, out which one was commercial) was used to extrapolate the emissions in the X-grid. The accuracy of these sources is not as good as other sources (described above), however, these categories of sources account for only about 10 percent of total PM10 emission. Therefore, it can be stated that emission inventory carried out in this project is of high quality. It may be stated that inherent uncertainty in emission factors will be reflected in emission inventory, as for many sources, typical of Indian urban environment may not be available. Under the circumstances, the developed inventory is of high quality as it has used mostly primary information; GIS software which can accurately delineates the areas to render accurate information on populations and road lengths, which are valuable for two important sources.

3.10 Conclusions

- The total PM_{10} emission load in the city is estimated as about 10 t/d. There are several important sources of PM_{10} in the city including industrial point sources (26%) industry, vehicles (21%), domestic fuel burning (19%) paved and unpaved road (15%), garbage burning (5%) and rest other sources. 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.
- NO_x emissions are even higher than PM_{10} emission ~ 22.5 t/d. Nearly 50% emissions are attributed to vehicles that occurs at ground level, probably making it the most important pollutant in coming time. Vehicle sources are followed by industrial point and are sources (42%) and DG sets (5%) and domestic sources (4%) and rest others. NO_x apart from being pollutant itself, it is important component for formation of secondary particles (nitrates) and ozone. NO_x from vehicles and from industry are potential sources for controlling of NO_x emissions.
- SO_2 emissions are relatively low at 4.2 t/d. Industrial sources account for nearly 60 percent of total emission. It appears there may not be any need to control SO_2 but SO_2 is known to contribute to secondary particles (sulfates). Control of SO_2 from industrial sources, if necessary can improve air quality both for SO_2 and particulates.
- Estimated CO emission is about 50 t/d. Nearly 60% emission of CO is from vehicles, followed by domestic sources 16% and about 5% from garbage burning. 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}, CO and NO_x, it is the central down town area of the city where emissions are the highest. It suggests that air quality will be worst in the central part of city for all the pollutants with the exception of SO_2 which has highest emission in the industrial areas.

Chapter 4

Receptor Modeling & Source Apportionment

4.1 Receptor Modeling

The urban atmosphere is a highly complicated system composed of gaseous and particulate material with many possible sources such as dust, sea salt, forest fire, volcanoes, and wind blown soil etc. Relatively a new technique such as receptor modeling using source fingerprinting can be applied quantitatively to know the sources of origin of particles. Mathematical models are frequently used to identify and to adopt the source cutbacks of environmental pollutants. There are two types of modeling approaches to establish source receptor linkages:

1. Dispersion Modeling and
2. Receptor source Modeling.

Receptor model start 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. There are two generally recognized classes of receptor Models:

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

Both the modeling techniques have been attempted in this chapter to fully understand contribution of each source to ambient air PM_{10} concentration.

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. The CMB method assumes that aerosol 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,

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

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

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 developed by USEPA.

The software used for FA-MR, a receptor model technique, can be employed to apportion the sources for PM_{10} and it can indicate formation of secondary particles. One such technique of factor analysis is the principal component analysis (PCA). The objective of applying PCA is to derive a small number of components, which explain a maximum of the variance in the data. Initially, the PCA results in as many PCs as there are original variables. Usually, however, only a limited number of these uncorrelated PCs are required to explain virtually all of the variance in a data set of fifteen or more original (inter correlated) variables. In order for this reduction in the dimensionality to be useful, the newly obtained components (or factors) must have simple substantive interpretations. To be able to interpret the component in terms of physical meaning, loadings of variables on the component is estimated. Loading represents the degree and direction of relationship of the variables with a factor. The loadings measure, association of variables with factor and to what degree. They can be interpreted like correlation coefficients. The square of the loading multiplied by 100 equals the percent variation that a variable has common with a factor. By comparing the factor loadings for all factors and variables, those particular variables involved in an independent factor can be defined.

Varimax rotated PCA was employed to apportion sources of PM_{10} using a statistical package, SYSTAT. The PCA has been conducted using a conventional R analysis of elemental correlations about their means. Initially PC loadings were determined on the basis of measured variables of data set for each season.

4.2 Factor Analysis and Interpretation

Description of sites (Table 4.1) and source identification species and source number referred in this study are presented below (Table 4.2).

Table 4.1: Summary of Factor Analysis Results for all Sampling Locations

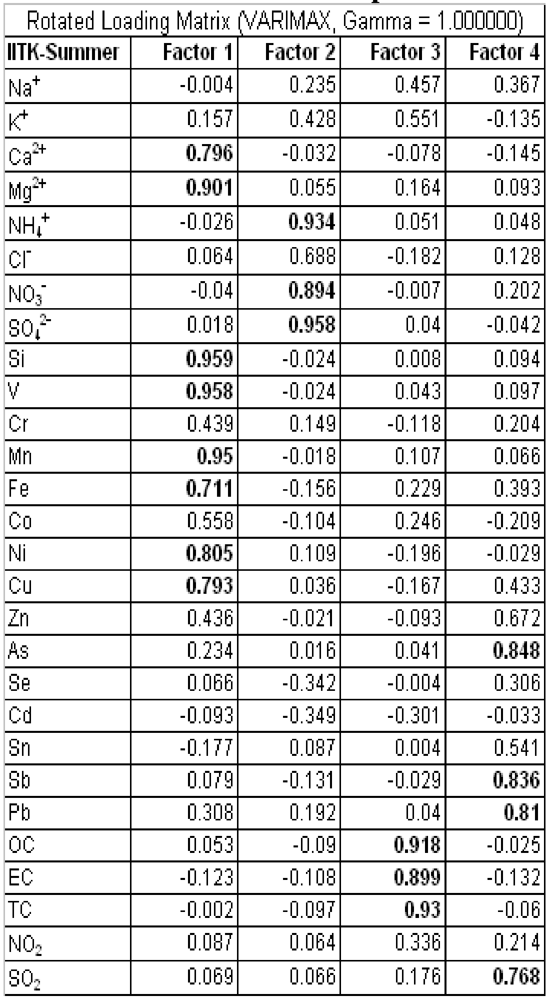
Site Description						
IITK	**Vikas Nagar**	**Govind Nagar**	**Dada Nagar**	**Colonel gang**	**AHM Hospital**	**Rama devi**
Background cum Institutional	**Residential cum Commercial**	**Residential**	**Industrial**	**Kerbside**	**Commercial**	**Traffic**

Table 4.2: Interpretation of Factor Loadings to PM_{10} during all three Seasons

Strong Loading	**Al, Ca, Fe, Mg**	**NH_4^+, NO_3^- SO_4^{-2}**	**EC and OC**	**As**	**V, Ni, Co**	**K**
Source	**Soil & road dust**	**Secondary particles**	**Combustion**	**Coal burning**	**Oil burning**	**Biomass burning**
Source Number	**1**	**2**	**3**	**4**	**5**	**6**

Results of factor analyses along with factor loading for seven sites and three seasons (summer, post-monsoon and winter) are presented in Tables 4.3 to 4.5. The loading of various species on the given factor can assist in tagging the factor to a source (Table 4.2).

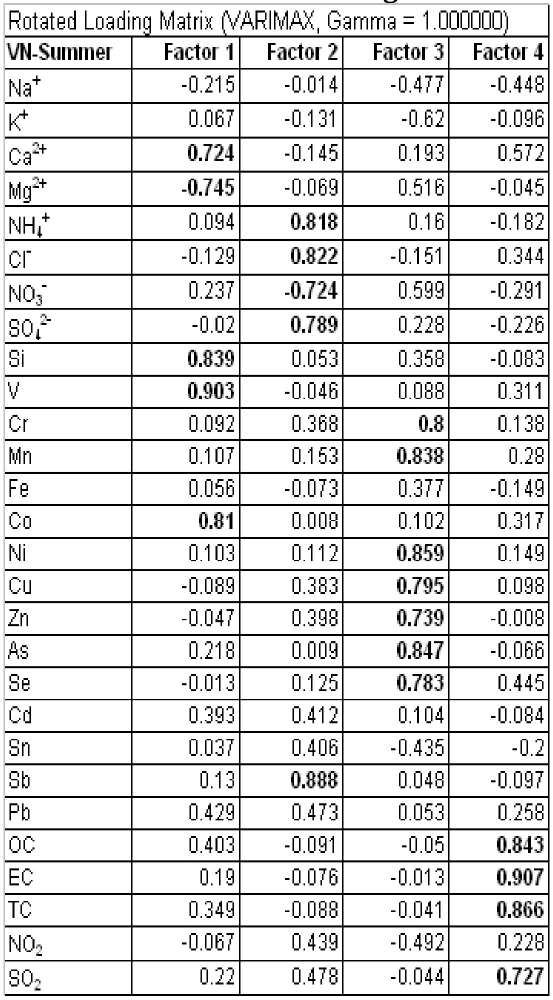
Table 4.3(a): Summer Factor Analysis Results at IIT Kanpur



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

IITK-Summer	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	-0.004	0.235	0.457	0.367
K^+	0.157	0.428	0.551	-0.135
Ca^{2+}	**0.796**	-0.032	-0.078	-0.145
Mg^{2+}	**0.901**	0.055	0.164	0.093
NH_4^+	-0.026	**0.934**	0.051	0.048
Cl^-	0.064	0.688	-0.182	0.128
NO_3^-	-0.04	**0.894**	-0.007	0.202
SO_4^{2-}	0.018	**0.958**	0.04	-0.042
Si	**0.959**	-0.024	0.008	0.094
V	**0.958**	-0.024	0.043	0.097
Cr	0.439	0.149	-0.118	0.204
Mn	**0.95**	-0.018	0.107	0.066
Fe	**0.711**	-0.156	0.229	0.393
Co	0.558	-0.104	0.246	-0.209
Ni	**0.805**	0.109	-0.196	-0.029
Cu	**0.793**	0.036	-0.167	0.433
Zn	0.436	-0.021	-0.093	0.672
As	0.234	0.016	0.041	**0.848**
Se	0.066	-0.342	-0.004	0.306
Cd	-0.093	-0.349	-0.301	-0.033
Sn	-0.177	0.087	0.004	0.541
Sb	0.079	-0.131	-0.029	**0.836**
Pb	0.308	0.192	0.04	**0.81**
OC	0.053	-0.09	**0.918**	-0.025
EC	-0.123	-0.108	**0.899**	-0.132
TC	-0.002	-0.097	**0.93**	-0.06
NO_2	0.087	0.064	0.336	0.214
SO_2	0.069	0.066	0.176	**0.768**

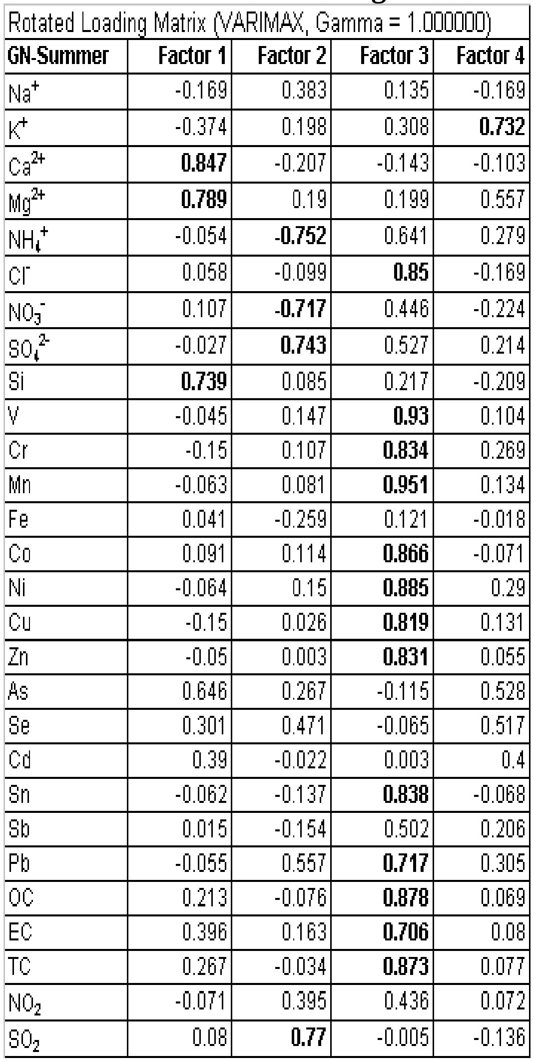
Table 4.3(b): Summer Factor Analysis Results at Vikashnagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

VN-Summer	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	-0.215	-0.014	-0.477	-0.448
K^+	0.067	-0.131	-0.62	-0.096
Ca^{2+}	**0.724**	-0.145	0.193	0.572
Mg^{2+}	**-0.745**	-0.069	0.516	-0.045
NH_4^+	0.094	**0.818**	0.16	-0.182
Cl^-	-0.129	**0.822**	-0.151	0.344
NO_3^-	0.237	**-0.724**	0.599	-0.291
SO_4^{2-}	-0.02	**0.789**	0.228	-0.226
Si	**0.839**	0.053	0.358	-0.083
V	**0.903**	-0.046	0.088	0.311
Cr	0.092	0.368	**0.8**	0.138
Mn	0.107	0.153	**0.838**	0.28
Fe	0.056	-0.073	0.377	-0.149
Co	**0.81**	0.008	0.102	0.317
Ni	0.103	0.112	**0.859**	0.149
Cu	-0.089	0.383	**0.795**	0.098
Zn	-0.047	0.398	**0.739**	-0.008
As	0.218	0.009	**0.847**	-0.066
Se	-0.013	0.125	**0.783**	0.445
Cd	0.393	0.412	0.104	-0.084
Sn	0.037	0.406	-0.435	-0.2
Sb	0.13	**0.888**	0.048	-0.097
Pb	0.429	0.473	0.053	0.258
OC	0.403	-0.091	-0.05	**0.843**
EC	0.19	-0.076	-0.013	**0.907**
TC	0.349	-0.088	-0.041	**0.866**
NO_2	-0.067	0.439	-0.492	0.228
SO_2	0.22	0.478	-0.044	**0.727**

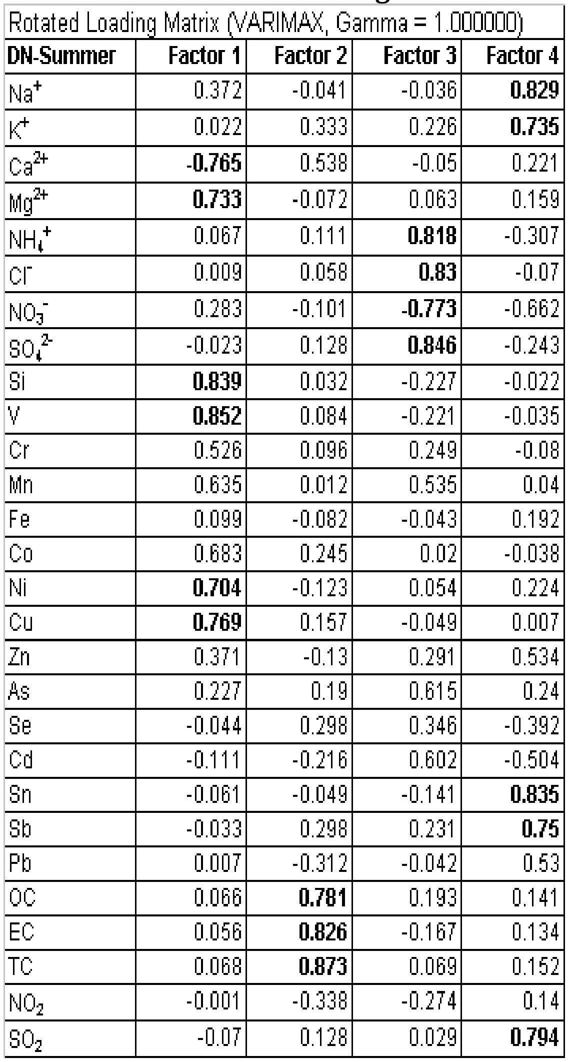
Table 4.3(c): Summer Factor Analysis Results at Govindnagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

GN-Summer	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	-0.169	0.383	0.135	-0.169
K^+	-0.374	0.198	0.308	**0.732**
Ca^{2+}	**0.847**	-0.207	-0.143	-0.103
Mg^{2+}	**0.789**	0.19	0.199	0.557
NH_4^+	-0.054	**-0.752**	0.641	0.279
Cl^-	0.058	-0.099	**0.85**	-0.169
NO_3^-	0.107	**-0.717**	0.446	-0.224
SO_4^{2-}	-0.027	**0.743**	0.527	0.214
Si	**0.739**	0.085	0.217	-0.209
V	-0.045	0.147	**0.93**	0.104
Cr	-0.15	0.107	**0.834**	0.269
Mn	-0.063	0.081	**0.951**	0.134
Fe	0.041	-0.259	0.121	-0.018
Co	0.091	0.114	**0.866**	-0.071
Ni	-0.064	0.15	**0.885**	0.29
Cu	-0.15	0.026	**0.819**	0.131
Zn	-0.05	0.003	**0.831**	0.055
As	0.646	0.267	-0.115	0.528
Se	0.301	0.471	-0.065	0.517
Cd	0.39	-0.022	0.003	0.4
Sn	-0.062	-0.137	**0.838**	-0.068
Sb	0.015	-0.154	0.502	0.206
Pb	-0.055	0.557	**0.717**	0.305
OC	0.213	-0.076	**0.878**	0.069
EC	0.396	0.163	**0.706**	0.08
TC	0.267	-0.034	**0.873**	0.077
NO_2	-0.071	0.395	0.436	0.072
SO_2	0.08	**0.77**	-0.005	-0.136

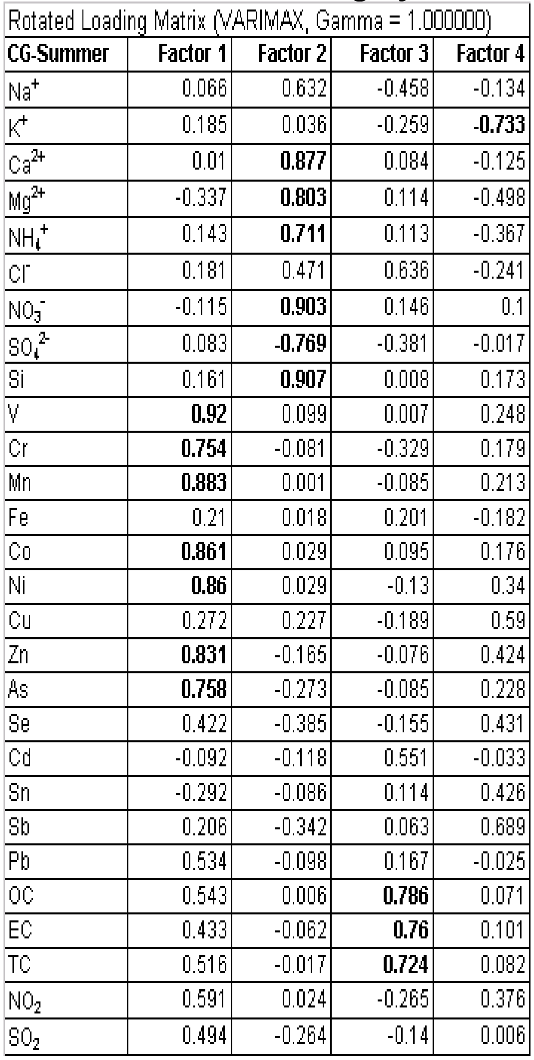
Table 4.3(d): Summer Factor Analysis Results at Dadanagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

DN-Summer	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	0.372	-0.041	-0.036	**0.829**
K^+	0.022	0.333	0.226	**0.735**
Ca^{2+}	**-0.765**	0.538	-0.05	0.221
Mg^{2+}	**0.733**	-0.072	0.063	0.159
NH_4^+	0.067	0.111	**0.818**	-0.307
Cl^-	0.009	0.058	**0.83**	-0.07
NO_3^-	0.283	-0.101	**-0.773**	-0.662
SO_4^{2-}	-0.023	0.128	**0.846**	-0.243
Si	**0.839**	0.032	-0.227	-0.022
V	**0.852**	0.084	-0.221	-0.035
Cr	0.526	0.096	0.249	-0.08
Mn	0.635	0.012	0.535	0.04
Fe	0.099	-0.082	-0.043	0.192
Co	0.683	0.245	0.02	-0.038
Ni	**0.704**	-0.123	0.054	0.224
Cu	**0.769**	0.157	-0.049	0.007
Zn	0.371	-0.13	0.291	0.534
As	0.227	0.19	0.615	0.24
Se	-0.044	0.298	0.346	-0.392
Cd	-0.111	-0.216	0.602	-0.504
Sn	-0.061	-0.049	-0.141	**0.835**
Sb	-0.033	0.298	0.231	**0.75**
Pb	0.007	-0.312	-0.042	0.53
OC	0.066	**0.781**	0.193	0.141
EC	0.056	**0.826**	-0.167	0.134
TC	0.068	**0.873**	0.069	0.152
NO_2	-0.001	-0.338	-0.274	0.14
SO_2	-0.07	0.128	0.029	**0.794**

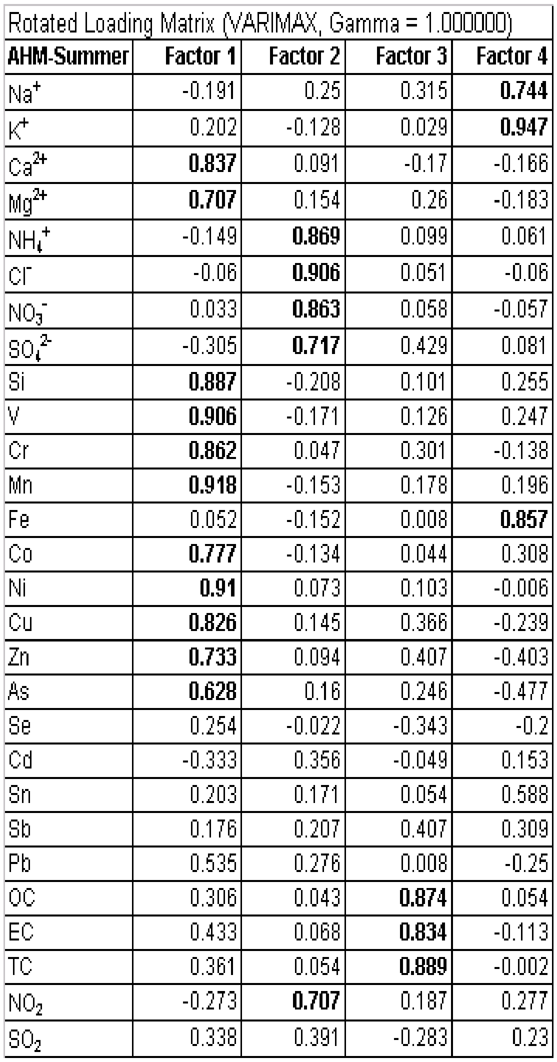
Table 4.3(e): Summer Factor Analysis Results at Colonelganj



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

CG-Summer	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	0.066	0.632	-0.458	-0.134
K^+	0.185	0.036	-0.259	**-0.733**
Ca^{2+}	0.01	**0.877**	0.084	-0.125
Mg^{2+}	-0.337	**0.803**	0.114	-0.498
NH_4^+	0.143	**0.711**	0.113	-0.367
Cl^-	0.181	0.471	0.636	-0.241
NO_3^-	-0.115	**0.903**	0.146	0.1
SO_4^{2-}	0.083	**-0.769**	-0.381	-0.017
Si	0.161	**0.907**	0.008	0.173
V	**0.92**	0.099	0.007	0.248
Cr	**0.754**	-0.081	-0.329	0.179
Mn	**0.883**	0.001	-0.085	0.213
Fe	0.21	0.018	0.201	-0.182
Co	**0.861**	0.029	0.095	0.176
Ni	**0.86**	0.029	-0.13	0.34
Cu	0.272	0.227	-0.189	0.59
Zn	**0.831**	-0.165	-0.076	0.424
As	**0.758**	-0.273	-0.085	0.228
Se	0.422	-0.385	-0.155	0.431
Cd	-0.092	-0.118	0.551	-0.033
Sn	-0.292	-0.086	0.114	0.426
Sb	0.206	-0.342	0.063	0.689
Pb	0.534	-0.098	0.167	-0.025
OC	0.543	0.006	**0.786**	0.071
EC	0.433	-0.062	**0.76**	0.101
TC	0.516	-0.017	**0.724**	0.082
NO_2	0.591	0.024	-0.265	0.376
SO_2	0.494	-0.264	-0.14	0.006

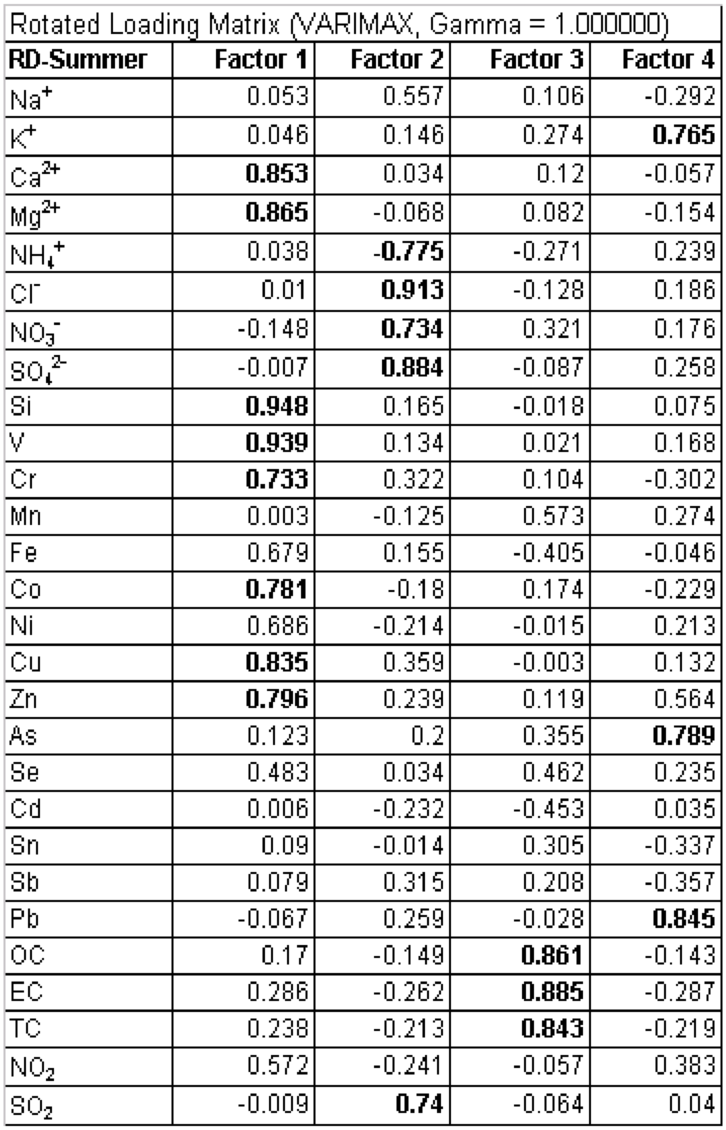
Table 4.3(f): Summer Factor Analysis Results at AHM



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

AHM-Summer	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	-0.191	0.25	0.315	**0.744**
K^+	0.202	-0.128	0.029	**0.947**
Ca^{2+}	**0.837**	0.091	-0.17	-0.166
Mg^{2+}	**0.707**	0.154	0.26	-0.183
NH_4^+	-0.149	**0.869**	0.099	0.061
Cl^-	-0.06	**0.906**	0.051	-0.06
NO_3^-	0.033	**0.863**	0.058	-0.057
SO_4^{2-}	-0.305	**0.717**	0.429	0.081
Si	**0.887**	-0.208	0.101	0.255
V	**0.906**	-0.171	0.126	0.247
Cr	**0.862**	0.047	0.301	-0.138
Mn	**0.918**	-0.153	0.178	0.196
Fe	0.052	-0.152	0.008	**0.857**
Co	**0.777**	-0.134	0.044	0.308
Ni	**0.91**	0.073	0.103	-0.006
Cu	**0.826**	0.145	0.366	-0.239
Zn	**0.733**	0.094	0.407	-0.403
As	**0.628**	0.16	0.246	-0.477
Se	0.254	-0.022	-0.343	-0.2
Cd	-0.333	0.356	-0.049	0.153
Sn	0.203	0.171	0.054	0.588
Sb	0.176	0.207	0.407	0.309
Pb	0.535	0.276	0.008	-0.25
OC	0.306	0.043	**0.874**	0.054
EC	0.433	0.068	**0.834**	-0.113
TC	0.361	0.054	**0.889**	-0.002
NO_2	-0.273	**0.707**	0.187	0.277
SO_2	0.338	0.391	-0.283	0.23

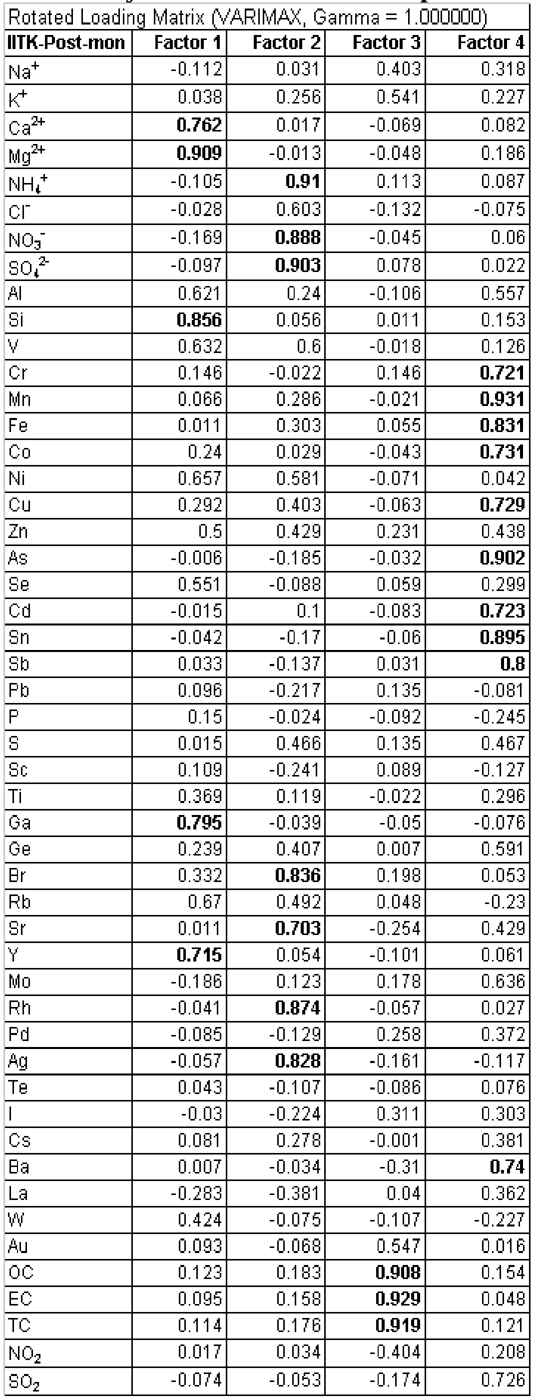
Table 4.3(g): Summer Factor Analysis Results at Ramadevi



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

RD-Summer	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	0.053	0.557	0.106	-0.292
K^+	0.046	0.146	0.274	**0.765**
Ca^{2+}	**0.853**	0.034	0.12	-0.057
Mg^{2+}	**0.865**	-0.068	0.082	-0.154
NH_4^+	0.038	**-0.775**	-0.271	0.239
Cl^-	0.01	**0.913**	-0.128	0.186
NO_3^-	-0.148	**0.734**	0.321	0.176
SO_4^{2-}	-0.007	**0.884**	-0.087	0.258
Si	**0.948**	0.165	-0.018	0.075
V	**0.939**	0.134	0.021	0.168
Cr	**0.733**	0.322	0.104	-0.302
Mn	0.003	-0.125	0.573	0.274
Fe	0.679	0.155	-0.405	-0.046
Co	**0.781**	-0.18	0.174	-0.229
Ni	0.686	-0.214	-0.015	0.213
Cu	**0.835**	0.359	-0.003	0.132
Zn	**0.796**	0.239	0.119	0.564
As	0.123	0.2	0.355	**0.789**
Se	0.483	0.034	0.462	0.235
Cd	0.006	-0.232	-0.453	0.035
Sn	0.09	-0.014	0.305	-0.337
Sb	0.079	0.315	0.208	-0.357
Pb	-0.067	0.259	-0.028	**0.845**
OC	0.17	-0.149	**0.861**	-0.143
EC	0.286	-0.262	**0.885**	-0.287
TC	0.238	-0.213	**0.843**	-0.219
NO_2	0.572	-0.241	-0.057	0.383
SO_2	-0.009	**0.74**	-0.064	0.04

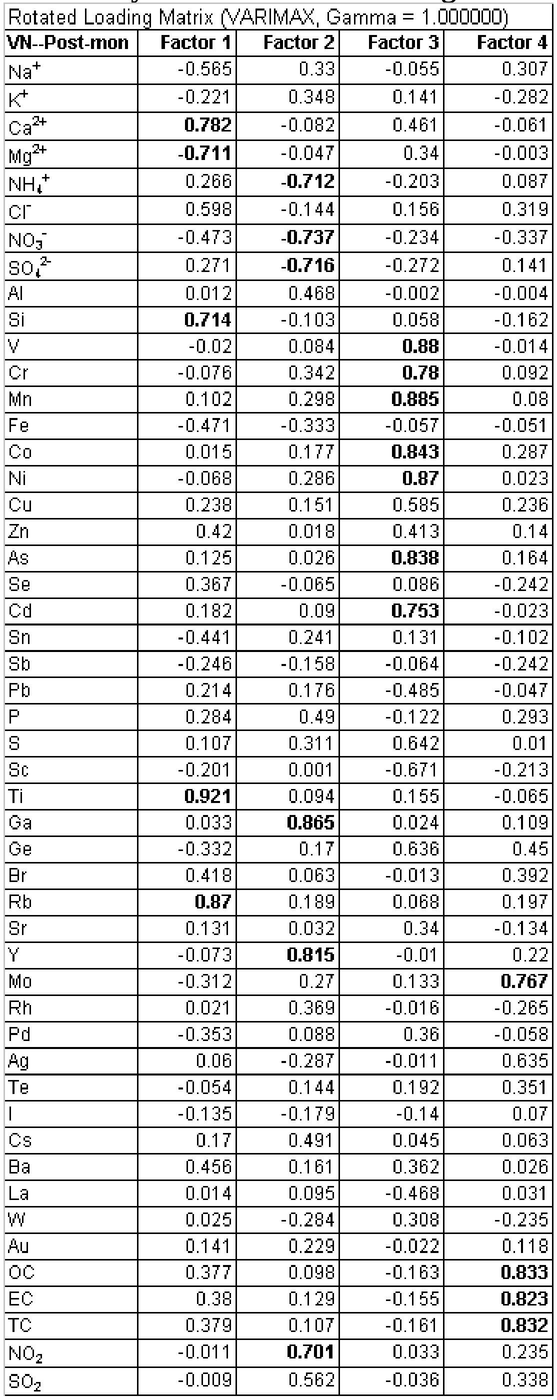
Table 4.4(a): Post-monsoon Factor Analysis Results at IIT Kanpur



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

IITK-Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	-0.112	0.031	0.403	0.318
K^+	0.038	0.256	0.541	0.227
Ca^{2+}	**0.762**	0.017	-0.069	0.082
Mg^{2+}	**0.909**	-0.013	-0.048	0.186
NH_4^+	-0.105	**0.91**	0.113	0.087
Cl^-	-0.028	0.603	-0.132	-0.075
NO_3^-	-0.169	**0.888**	-0.045	0.06
SO_4^{2-}	-0.097	**0.903**	0.078	0.022
Al	0.621	0.24	-0.106	0.557
Si	**0.856**	0.056	0.011	0.153
V	0.632	0.6	-0.018	0.126
Cr	0.146	-0.022	0.146	**0.721**
Mn	0.066	0.286	-0.021	**0.931**
Fe	0.011	0.303	0.055	**0.831**
Co	0.24	0.029	-0.043	**0.731**
Ni	0.657	0.581	-0.071	0.042
Cu	0.292	0.403	-0.063	**0.729**
Zn	0.5	0.429	0.231	0.438
As	-0.006	-0.185	-0.032	**0.902**
Se	0.551	-0.088	0.059	0.299
Cd	-0.015	0.1	-0.083	**0.723**
Sn	-0.042	-0.17	-0.06	**0.895**
Sb	0.033	-0.137	0.031	**0.8**
Pb	0.096	-0.217	0.135	-0.081
P	0.15	-0.024	-0.092	-0.245
S	0.015	0.466	0.135	0.467
Sc	0.109	-0.241	0.089	-0.127
Ti	0.369	0.119	-0.022	0.296
Ga	**0.795**	-0.039	-0.05	-0.076
Ge	0.239	0.407	0.007	0.591
Br	0.332	**0.836**	0.198	0.053
Rb	0.67	0.492	0.048	-0.23
Sr	0.011	**0.703**	-0.254	0.429
Y	**0.715**	0.054	-0.101	0.061
Mo	-0.186	0.123	0.178	0.636
Rh	-0.041	**0.874**	-0.057	0.027
Pd	-0.085	-0.129	0.258	0.372
Ag	-0.057	**0.828**	-0.161	-0.117
Te	0.043	-0.107	-0.086	0.076
I	-0.03	-0.224	0.311	0.303
Cs	0.081	0.278	-0.001	0.381
Ba	0.007	-0.034	-0.31	**0.74**
La	-0.283	-0.381	0.04	0.362
W	0.424	-0.075	-0.107	-0.227
Au	0.093	-0.068	0.547	0.016
OC	0.123	0.183	**0.908**	0.154
EC	0.095	0.158	**0.929**	0.048
TC	0.114	0.176	**0.919**	0.121
NO_2	0.017	0.034	-0.404	0.208
SO_2	-0.074	-0.053	-0.174	0.726

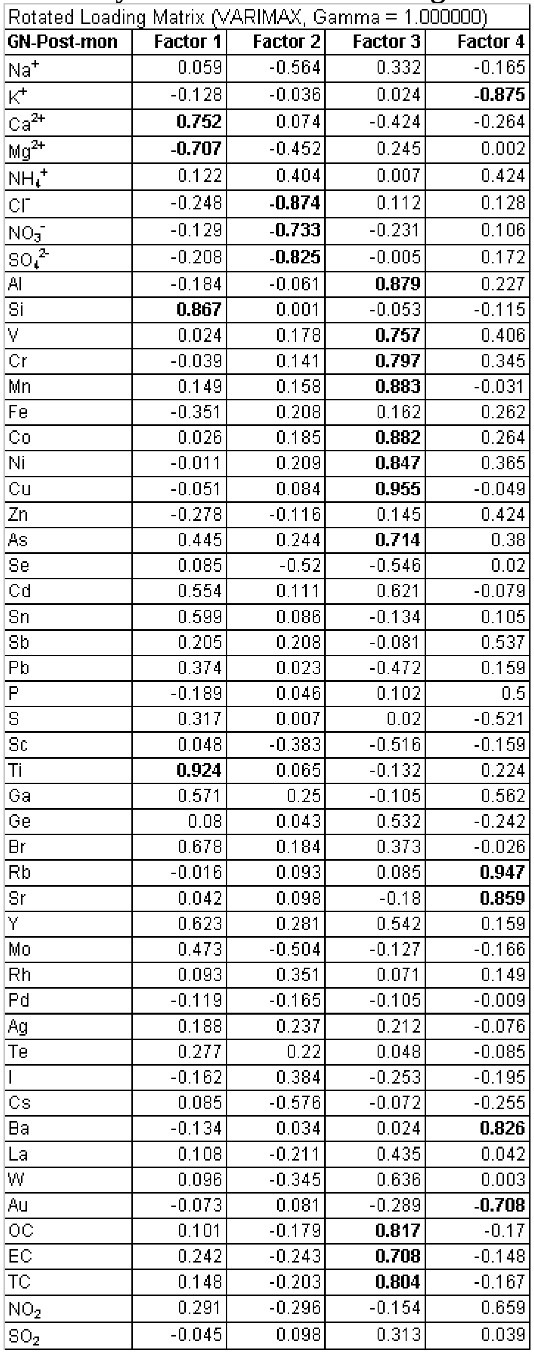
Table 4.4(b): Post-monsoon Factor Analysis Results at Vikashnagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

VN--Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	-0.565	0.33	-0.055	0.307
K^+	-0.221	0.348	0.141	-0.282
Ca^{2+}	**0.782**	-0.082	0.461	-0.061
Mg^{2+}	**-0.711**	-0.047	0.34	-0.003
NH_4^+	0.266	**-0.712**	-0.203	0.087
Cl^-	0.598	-0.144	0.156	0.319
NO_3^-	-0.473	**-0.737**	-0.234	-0.337
SO_4^{2-}	0.271	**-0.716**	-0.272	0.141
Al	0.012	0.468	-0.002	-0.004
Si	**0.714**	-0.103	0.058	-0.162
V	-0.02	0.084	**0.88**	-0.014
Cr	-0.076	0.342	**0.78**	0.092
Mn	0.102	0.298	**0.885**	0.08
Fe	-0.471	-0.333	-0.057	-0.051
Co	0.015	0.177	**0.843**	0.287
Ni	-0.068	0.286	**0.87**	0.023
Cu	0.238	0.151	0.585	0.236
Zn	0.42	0.018	0.413	0.14
As	0.125	0.026	**0.838**	0.164
Se	0.367	-0.065	0.086	-0.242
Cd	0.182	0.09	**0.753**	-0.023
Sn	-0.441	0.241	0.131	-0.102
Sb	-0.246	-0.158	-0.064	-0.242
Pb	0.214	0.176	-0.485	-0.047
P	0.284	0.49	-0.122	0.293
S	0.107	0.311	0.642	0.01
Sc	-0.201	0.001	-0.671	-0.213
Ti	**0.921**	0.094	0.155	-0.065
Ga	0.033	**0.865**	0.024	0.109
Ge	-0.332	0.17	0.636	0.45
Br	0.418	0.063	-0.013	0.392
Rb	**0.87**	0.189	0.068	0.197
Sr	0.131	0.032	0.34	-0.134
Y	-0.073	**0.815**	-0.01	0.22
Mo	-0.312	0.27	0.133	**0.767**
Rh	0.021	0.369	-0.016	-0.265
Pd	-0.353	0.088	0.36	-0.058
Ag	0.06	-0.287	-0.011	0.635
Te	-0.054	0.144	0.192	0.351
I	-0.135	-0.179	-0.14	0.07
Cs	0.17	0.491	0.045	0.063
Ba	0.456	0.161	0.362	0.026
La	0.014	0.095	-0.468	0.031
W	0.025	-0.284	0.308	-0.235
Au	0.141	0.229	-0.022	0.118
OC	0.377	0.098	-0.163	**0.833**
EC	0.38	0.129	-0.155	**0.823**
TC	0.379	0.107	-0.161	**0.832**
NO_2	-0.011	**0.701**	0.033	0.235
SO_2	-0.009	0.562	-0.036	0.338

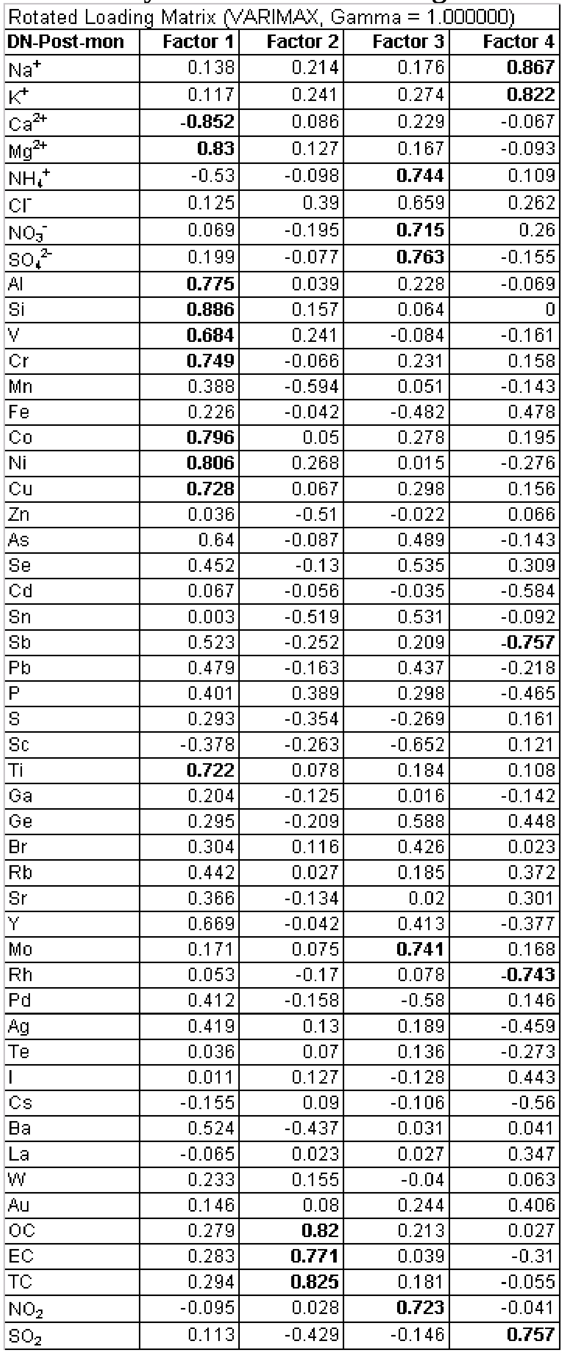
Table 4.4(c): Post-monsoon Factor Analysis Results at Govindnagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

GN-Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	0.059	-0.564	0.332	-0.165
K^+	-0.128	-0.036	0.024	**-0.875**
Ca^{2+}	**0.752**	0.074	-0.424	-0.264
Mg^{2+}	**-0.707**	-0.452	0.245	0.002
NH_4^+	0.122	0.404	0.007	0.424
Cl^-	-0.248	**-0.874**	0.112	0.128
NO_3^-	-0.129	**-0.733**	-0.231	0.106
SO_4^{2-}	-0.208	**-0.825**	-0.005	0.172
Al	-0.184	-0.061	**0.879**	0.227
Si	**0.867**	0.001	-0.053	-0.115
V	0.024	0.178	**0.757**	0.406
Cr	-0.039	0.141	**0.797**	0.345
Mn	0.149	0.158	**0.883**	-0.031
Fe	-0.351	0.208	0.162	0.262
Co	0.026	0.185	**0.882**	0.264
Ni	-0.011	0.209	**0.847**	0.365
Cu	-0.051	0.084	**0.955**	-0.049
Zn	-0.278	-0.116	0.145	0.424
As	0.445	0.244	**0.714**	0.38
Se	0.085	-0.52	-0.546	0.02
Cd	0.554	0.111	0.621	-0.079
Sn	0.599	0.086	-0.134	0.105
Sb	0.205	0.208	-0.081	0.537
Pb	0.374	0.023	-0.472	0.159
P	-0.189	0.046	0.102	0.5
S	0.317	0.007	0.02	-0.521
Sc	0.048	-0.383	-0.516	-0.159
Ti	**0.924**	0.065	-0.132	0.224
Ga	0.571	0.25	-0.105	0.562
Ge	0.08	0.043	0.532	-0.242
Br	0.678	0.184	0.373	-0.026
Rb	-0.016	0.093	0.085	**0.947**
Sr	0.042	0.098	-0.18	**0.859**
Y	0.623	0.281	0.542	0.159
Mo	0.473	-0.504	-0.127	-0.166
Rh	0.093	0.351	0.071	0.149
Pd	-0.119	-0.165	-0.105	-0.009
Ag	0.188	0.237	0.212	-0.076
Te	0.277	0.22	0.048	-0.085
I	-0.162	0.384	-0.253	-0.195
Cs	0.085	-0.576	-0.072	-0.255
Ba	-0.134	0.034	0.024	**0.826**
La	0.108	-0.211	0.435	0.042
W	0.096	-0.345	0.636	0.003
Au	-0.073	0.081	-0.289	**-0.708**
OC	0.101	-0.179	**0.817**	-0.17
EC	0.242	-0.243	**0.708**	-0.148
TC	0.148	-0.203	**0.804**	-0.167
NO_2	0.291	-0.296	-0.154	0.659
SO_2	-0.045	0.098	0.313	0.039

Table 4.4(d): Post-monsoon Factor Analysis Results at Dadanagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

DN-Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	0.138	0.214	0.176	**0.867**
K^+	0.117	0.241	0.274	**0.822**
Ca^{2+}	**-0.852**	0.086	0.229	-0.067
Mg^{2+}	**0.83**	0.127	0.167	-0.093
NH_4^+	-0.53	-0.098	**0.744**	0.109
Cl^-	0.125	0.39	0.659	0.262
NO_3^-	0.069	-0.195	**0.715**	0.26
SO_4^{2-}	0.199	-0.077	**0.763**	-0.155
Al	**0.775**	0.039	0.228	-0.069
Si	**0.886**	0.157	0.064	0
V	**0.684**	0.241	-0.084	-0.161
Cr	**0.749**	-0.066	0.231	0.158
Mn	0.388	-0.594	0.051	-0.143
Fe	0.226	-0.042	-0.482	0.478
Co	**0.796**	0.05	0.278	0.195
Ni	**0.806**	0.268	0.015	-0.276
Cu	**0.728**	0.067	0.298	0.156
Zn	0.036	-0.51	-0.022	0.066
As	0.64	-0.087	0.489	-0.143
Se	0.452	-0.13	0.535	0.309
Cd	0.067	-0.056	-0.035	-0.584
Sn	0.003	-0.519	0.531	-0.092
Sb	0.523	-0.252	0.209	**-0.757**
Pb	0.479	-0.163	0.437	-0.218
P	0.401	0.389	0.298	-0.465
S	0.293	-0.354	-0.269	0.161
Sc	-0.378	-0.263	-0.652	0.121
Ti	**0.722**	0.078	0.184	0.108
Ga	0.204	-0.125	0.016	-0.142
Ge	0.295	-0.209	0.588	0.448
Br	0.304	0.116	0.426	0.023
Rb	0.442	0.027	0.185	0.372
Sr	0.366	-0.134	0.02	0.301
Y	0.669	-0.042	0.413	-0.377
Mo	0.171	0.075	**0.741**	0.168
Rh	0.053	-0.17	0.078	**-0.743**
Pd	0.412	-0.158	-0.58	0.146
Ag	0.419	0.13	0.189	-0.459
Te	0.036	0.07	0.136	-0.273
I	0.011	0.127	-0.128	0.443
Cs	-0.155	0.09	-0.106	-0.56
Ba	0.524	-0.437	0.031	0.041
La	-0.065	0.023	0.027	0.347
W	0.233	0.155	-0.04	0.063
Au	0.146	0.08	0.244	0.406
OC	0.279	**0.82**	0.213	0.027
EC	0.283	**0.771**	0.039	-0.31
TC	0.294	**0.825**	0.181	-0.055
NO_2	-0.095	0.028	**0.723**	-0.041
SO_2	0.113	-0.429	-0.146	**0.757**

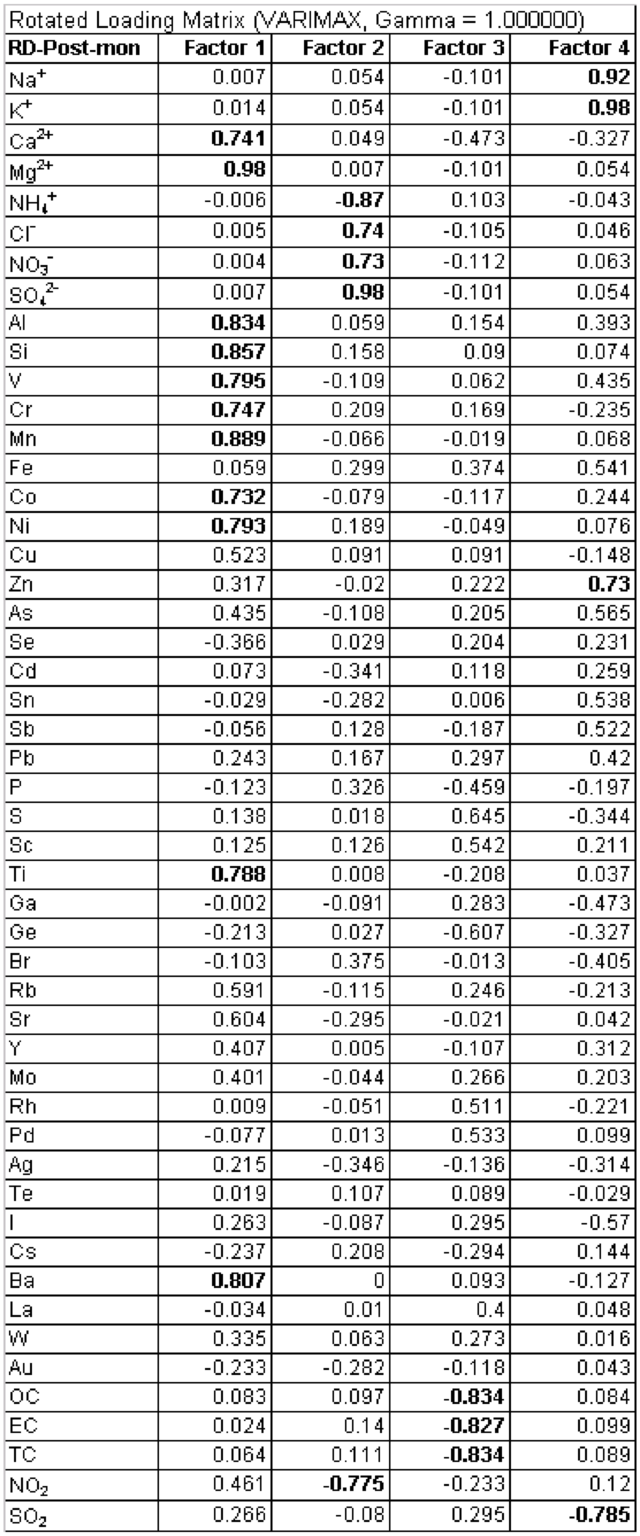
Table 4.4(e): Post-monsoon Factor Analysis Results at Colonelganj

Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)				
CG-Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	-0.199	-0.03	**0.893**	0.09
K^+	-0.053	-0.076	0.15	**0.833**
Ca^{2+}	0.054	**-0.938**	0.044	-0.083
Mg^{2+}	-0.128	**-0.954**	0.06	-0.07
NH_4^+	0.193	**0.795**	-0.431	-0.274
Cl^-	-0.089	0.637	**0.701**	0.009
NO_3^-	-0.077	**0.762**	0.103	0.047
SO_4^{2-}	-0.088	**0.756**	0.503	-0.017
Al	0.593	0.479	0.117	0.271
Si	0.296	0.662	0.058	0.355
V	**0.736**	0.117	0.181	0.462
Cr	0.357	0.376	0.075	0.616
Mn	0.572	0.319	0.054	0.654
Fe	0.616	0.153	-0.132	-0.151
Co	**0.809**	-0.008	0.048	0.438
Ni	0.505	0.138	0.145	0.494
Cu	**0.815**	0.179	-0.011	0.268
Zn	0.663	0.338	0.106	0.037
As	**0.84**	0.172	-0.103	0.028
Se	**0.731**	-0.008	-0.261	0.087
Cd	-0.127	0.116	0.222	0.144
Sn	-0.062	-0.265	0.181	-0.044
Sb	0.096	0.126	0.266	-0.393
Pb	**0.752**	0.019	0.011	0.147
P	-0.307	**-0.71**	-0.092	0.301
S	0.218	0.264	0.015	0.337
Sc	0.596	0.353	0.096	-0.165
Ti	0.088	0.083	0.402	0.578
Ga	-0.18	0.097	-0.394	0.111
Ge	-0.088	-0.133	-0.255	0.62
Br	0.1	0.542	-0.117	0.108
Rb	-0.018	0.268	0.291	0.667
Sr	0.498	0.155	0.25	0.484
Y	-0.122	-0.266	0.043	-0.121
Mo	-0.275	-0.59	-0.099	0.469
Rh	0.13	-0.131	0.172	0.417
Pd	-0.078	0.225	-0.156	0.329
Ag	-0.124	-0.056	-0.225	-0.248
Te	-0.22	-0.241	0.19	0.308
I	-0.244	0.416	0.124	0.015
Cs	-0.061	0.212	-0.007	0.005
Ba	0.363	0.219	0	0.376
La	-0.194	-0.261	-0.331	0.048
W	0.153	-0.046	-0.249	-0.175
Au	**-0.784**	0.126	-0.061	0.035
OC	-0.003	0.019	**0.89**	0.002
EC	-0.063	0.009	**0.873**	0.026
TC	-0.023	0.016	**0.89**	0.01
NO_2	0.125	0.625	-0.047	0
SO_2	0.205	0.235	-0.202	0.112

Table 4.4(f): Post-monsoon Factor Analysis Results at AHM

Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)				
AHM-Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	-0.168	-0.198	0.11	**-0.769**
K^+	0.069	-0.079	-0.224	**0.915**
Ca^{2+}	**0.799**	0.115	0.13	0.092
Mg^{2+}	**-0.722**	0.488	0.182	-0.355
NH_4^+	-0.404	**0.732**	0.019	-0.202
Cl^-	**0.72**	0.056	-0.45	0.109
NO_3^-	**0.78**	**0.785**	-0.391	0.206
SO_4^{2-}	**0.736**	-0.082	-0.403	0.038
Al	0.362	0.17	0.415	0.49
Si	**0.751**	0.237	0.356	0.36
V	0.57	0.246	0.306	0.488
Cr	**0.762**	0.369	0.36	0.138
Mn	0.577	0.291	0.353	0.463
Fe	**0.808**	0.103	0.119	0.205
Co	**-0.737**	-0.07	0.632	0.181
Ni	**0.728**	0.335	0.406	0.579
Cu	0.019	-0.001	0.541	0.615
Zn	**0.747**	0.138	0.278	0.604
As	-0.1	-0.074	-0.06	0.481
Se	-0.31	0.288	0.057	0.555
Cd	0.417	-0.156	0.105	-0.213
Sn	**-0.7**	0.577	0.044	0.097
Sb	-0.029	-0.077	-0.046	-0.343
Pb	-0.03	-0.078	-0.046	-0.342
P	-0.545	0.021	0.116	0.463
S	-0.057	0.117	0.071	0.29
Sc	**-0.796**	-0.041	0.049	-0.31
Ti	**0.823**	0.088	0.116	0.088
Ga	0.042	-0.238	-0.114	0.099
Ge	0.085	-0.293	-0.04	-0.035
Br	-0.102	0.01	**0.815**	0.323
Rb	0.148	-0.098	0.338	0.107
Sr	-0.144	0.079	-0.011	-0.008
Y	-0.115	-0.186	-0.064	-0.051
Mo	0.351	-0.206	-0.159	0.008
Rh	-0.44	0.306	0.106	0.267
Pd	-0.266	-0.284	-0.222	0.189
Ag	-0.031	0.061	0.53	0.017
Te	0.279	-0.126	-0.38	0.023
I	-0.174	0.208	-0.528	0.004
Cs	-0.225	0.471	0.191	-0.317
Ba	-0.246	0.07	-0.029	-0.306
La	0.286	0.137	-0.078	-0.253
W	-0.139	0.21	0.056	0.026
Au	0.125	0.388	-0.081	0.301
OC	0.22	-0.327	**-0.742**	0.632
EC	0.002	-0.312	**-0.757**	0.65
TC	0.151	-0.328	**-0.762**	0.65
NO_2	-0.143	**-0.768**	-0.492	-0.006
SO_2	-0.451	0.015	0.156	0.179

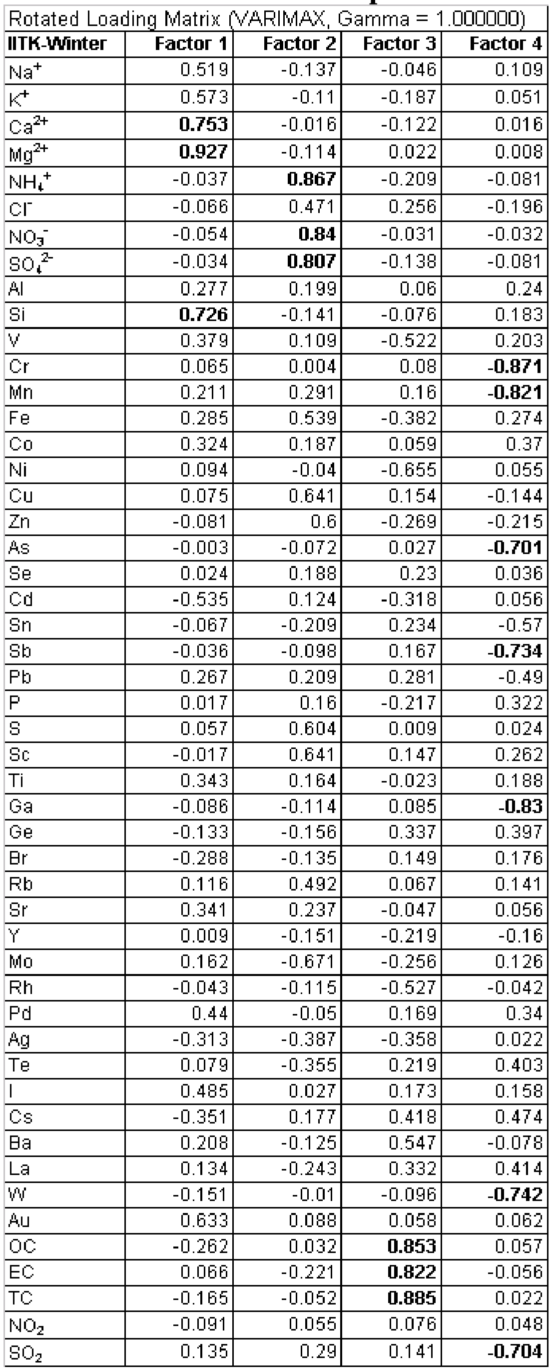
Table 4.4(g): Post-monsoon Factor Analysis Results at Ramadevi



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

RD-Post-mon	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	0.007	0.054	-0.101	**0.92**
K^+	0.014	0.054	-0.101	**0.98**
Ca^{2+}	**0.741**	0.049	-0.473	-0.327
Mg^{2+}	**0.98**	0.007	-0.101	0.054
NH_4^+	-0.006	**-0.87**	0.103	-0.043
Cl^-	0.005	**0.74**	-0.105	0.046
NO_3^-	0.004	**0.73**	-0.112	0.063
SO_4^{2-}	0.007	**0.98**	-0.101	0.054
Al	**0.834**	0.059	0.154	0.393
Si	**0.857**	0.158	0.09	0.074
V	**0.795**	-0.109	0.062	0.435
Cr	**0.747**	0.209	0.169	-0.235
Mn	**0.889**	-0.066	-0.019	0.068
Fe	0.059	0.299	0.374	0.541
Co	**0.732**	-0.079	-0.117	0.244
Ni	**0.793**	0.189	-0.049	0.076
Cu	0.523	0.091	0.091	-0.148
Zn	0.317	-0.02	0.222	**0.73**
As	0.435	-0.108	0.205	0.565
Se	-0.366	0.029	0.204	0.231
Cd	0.073	-0.341	0.118	0.259
Sn	-0.029	-0.282	0.006	0.538
Sb	-0.056	0.128	-0.187	0.522
Pb	0.243	0.167	0.297	0.42
P	-0.123	0.326	-0.459	-0.197
S	0.138	0.018	0.645	-0.344
Sc	0.125	0.126	0.542	0.211
Ti	**0.788**	0.008	-0.208	0.037
Ga	-0.002	-0.091	0.283	-0.473
Ge	-0.213	0.027	-0.607	-0.327
Br	-0.103	0.375	-0.013	-0.405
Rb	0.591	-0.115	0.246	-0.213
Sr	0.604	-0.295	-0.021	0.042
Y	0.407	0.005	-0.107	0.312
Mo	0.401	-0.044	0.266	0.203
Rh	0.009	-0.051	0.511	-0.221
Pd	-0.077	0.013	0.533	0.099
Ag	0.215	-0.346	-0.136	-0.314
Te	0.019	0.107	0.089	-0.029
I	0.263	-0.087	0.295	-0.57
Cs	-0.237	0.208	-0.294	0.144
Ba	**0.807**	0	0.093	-0.127
La	-0.034	0.01	0.4	0.048
W	0.335	0.063	0.273	0.016
Au	-0.233	-0.282	-0.118	0.043
OC	0.083	0.097	**-0.834**	0.084
EC	0.024	0.14	**-0.827**	0.099
TC	0.064	0.111	**-0.834**	0.089
NO_2	0.461	**-0.775**	-0.233	0.12
SO_2	0.266	-0.08	0.295	**-0.785**

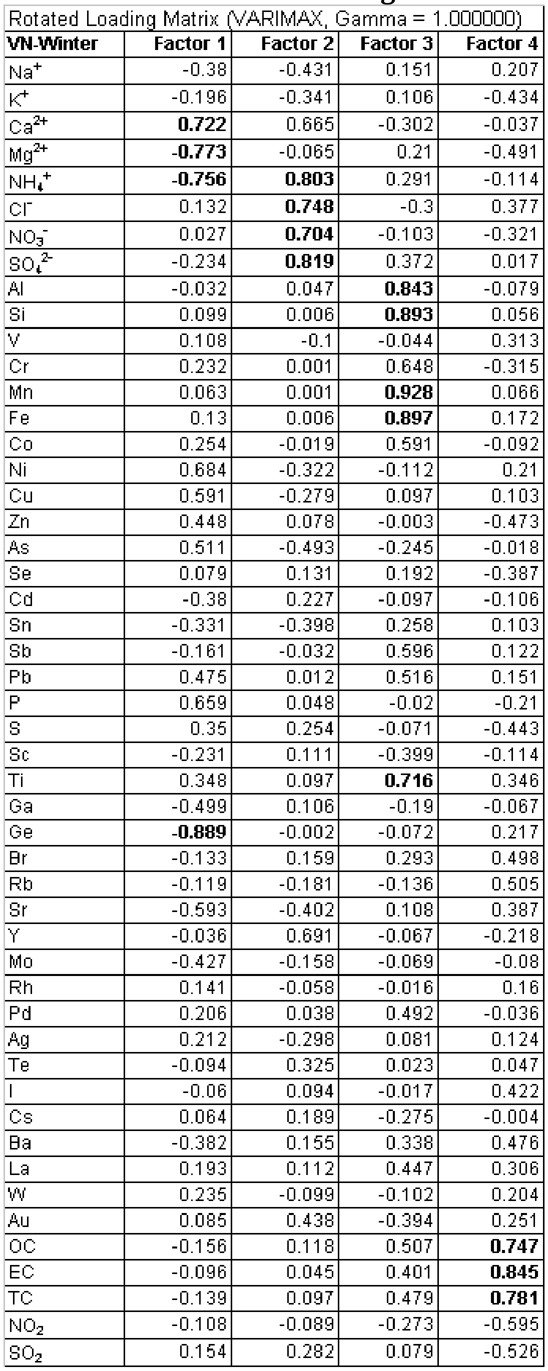
Table 4.5(a): Winter Factor Analysis Results at IITKanpur



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

IITK-Winter	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	0.519	-0.137	-0.046	0.109
K^+	0.573	-0.11	-0.187	0.051
Ca^{2+}	**0.753**	-0.016	-0.122	0.016
Mg^{2+}	**0.927**	-0.114	0.022	0.008
NH_4^+	-0.037	**0.867**	-0.209	-0.081
Cl^-	-0.066	0.471	0.256	-0.196
NO_3^-	-0.054	**0.84**	-0.031	-0.032
SO_4^{2-}	-0.034	**0.807**	-0.138	-0.081
Al	0.277	0.199	0.06	0.24
Si	**0.726**	-0.141	-0.076	0.183
V	0.379	0.109	-0.522	0.203
Cr	0.065	0.004	0.08	**-0.871**
Mn	0.211	0.291	0.16	**-0.821**
Fe	0.285	0.539	-0.382	0.274
Co	0.324	0.187	0.059	0.37
Ni	0.094	-0.04	-0.655	0.055
Cu	0.075	0.641	0.154	-0.144
Zn	-0.081	0.6	-0.269	-0.215
As	-0.003	-0.072	0.027	**-0.701**
Se	0.024	0.188	0.23	0.036
Cd	-0.535	0.124	-0.318	0.056
Sn	-0.067	-0.209	0.234	-0.57
Sb	-0.036	-0.098	0.167	**-0.734**
Pb	0.267	0.209	0.281	-0.49
P	0.017	0.16	-0.217	0.322
S	0.057	0.604	0.009	0.024
Sc	-0.017	0.641	0.147	0.262
Ti	0.343	0.164	-0.023	0.188
Ga	-0.086	-0.114	0.085	**-0.83**
Ge	-0.133	-0.156	0.337	0.397
Br	-0.288	-0.135	0.149	0.176
Rb	0.116	0.492	0.067	0.141
Sr	0.341	0.237	-0.047	0.056
Y	0.009	-0.151	-0.219	-0.16
Mo	0.162	-0.671	-0.256	0.126
Rh	-0.043	-0.115	-0.527	-0.042
Pd	0.44	-0.05	0.169	0.34
Ag	-0.313	-0.387	-0.358	0.022
Te	0.079	-0.355	0.219	0.403
I	0.485	0.027	0.173	0.158
Cs	-0.351	0.177	0.418	0.474
Ba	0.208	-0.125	0.547	-0.078
La	0.134	-0.243	0.332	0.414
W	-0.151	-0.01	-0.096	**-0.742**
Au	0.633	0.088	0.058	0.062
OC	-0.262	0.032	**0.853**	0.057
EC	0.066	-0.221	**0.822**	-0.056
TC	-0.165	-0.052	**0.885**	0.022
NO_2	-0.091	0.055	0.076	0.048
SO_2	0.135	0.29	0.141	**-0.704**

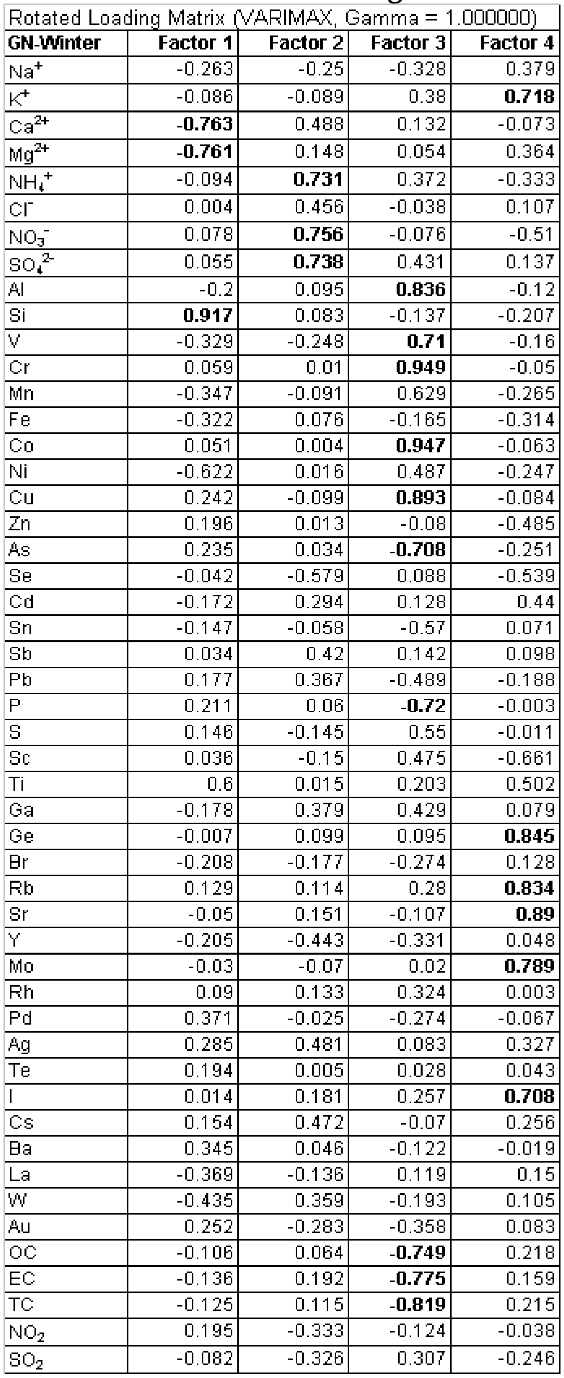
Table 4.5(b): Winter Factor Analysis Results at Vikashnagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

VN-Winter	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	-0.38	-0.431	0.151	0.207
K^+	-0.196	-0.341	0.106	-0.434
Ca^{2+}	**0.722**	0.665	-0.302	-0.037
Mg^{2+}	**-0.773**	-0.065	0.21	-0.491
NH_4^+	**-0.756**	**0.803**	0.291	-0.114
Cl^-	0.132	**0.748**	-0.3	0.377
NO_3^-	0.027	**0.704**	-0.103	-0.321
SO_4^{2-}	-0.234	**0.819**	0.372	0.017
Al	-0.032	0.047	**0.843**	-0.079
Si	0.099	0.006	**0.893**	0.056
V	0.108	-0.1	-0.044	0.313
Cr	0.232	0.001	0.648	-0.315
Mn	0.063	0.001	**0.928**	0.066
Fe	0.13	0.006	**0.897**	0.172
Co	0.254	-0.019	0.591	-0.092
Ni	0.684	-0.322	-0.112	0.21
Cu	0.591	-0.279	0.097	0.103
Zn	0.448	0.078	-0.003	-0.473
As	0.511	-0.493	-0.245	-0.018
Se	0.079	0.131	0.192	-0.387
Cd	-0.38	0.227	-0.097	-0.106
Sn	-0.331	-0.398	0.258	0.103
Sb	-0.161	-0.032	0.596	0.122
Pb	0.475	0.012	0.516	0.151
P	0.659	0.048	-0.02	-0.21
S	0.35	0.254	-0.071	-0.443
Sc	-0.231	0.111	-0.399	-0.114
Ti	0.348	0.097	**0.716**	0.346
Ga	-0.499	0.106	-0.19	-0.067
Ge	**-0.889**	-0.002	-0.072	0.217
Br	-0.133	0.159	0.293	0.498
Rb	-0.119	-0.181	-0.136	0.505
Sr	-0.593	-0.402	0.108	0.387
Y	-0.036	0.691	-0.067	-0.218
Mo	-0.427	-0.158	-0.069	-0.08
Rh	0.141	-0.058	-0.016	0.16
Pd	0.206	0.038	0.492	-0.036
Ag	0.212	-0.298	0.081	0.124
Te	-0.094	0.325	0.023	0.047
I	-0.06	0.094	-0.017	0.422
Cs	0.064	0.189	-0.275	-0.004
Ba	-0.382	0.155	0.338	0.476
La	0.193	0.112	0.447	0.306
W	0.235	-0.099	-0.102	0.204
Au	0.085	0.438	-0.394	0.251
OC	-0.156	0.118	0.507	**0.747**
EC	-0.096	0.045	0.401	**0.845**
TC	-0.139	0.097	0.479	**0.781**
NO_2	-0.108	-0.089	-0.273	-0.595
SO_2	0.154	0.282	0.079	-0.526

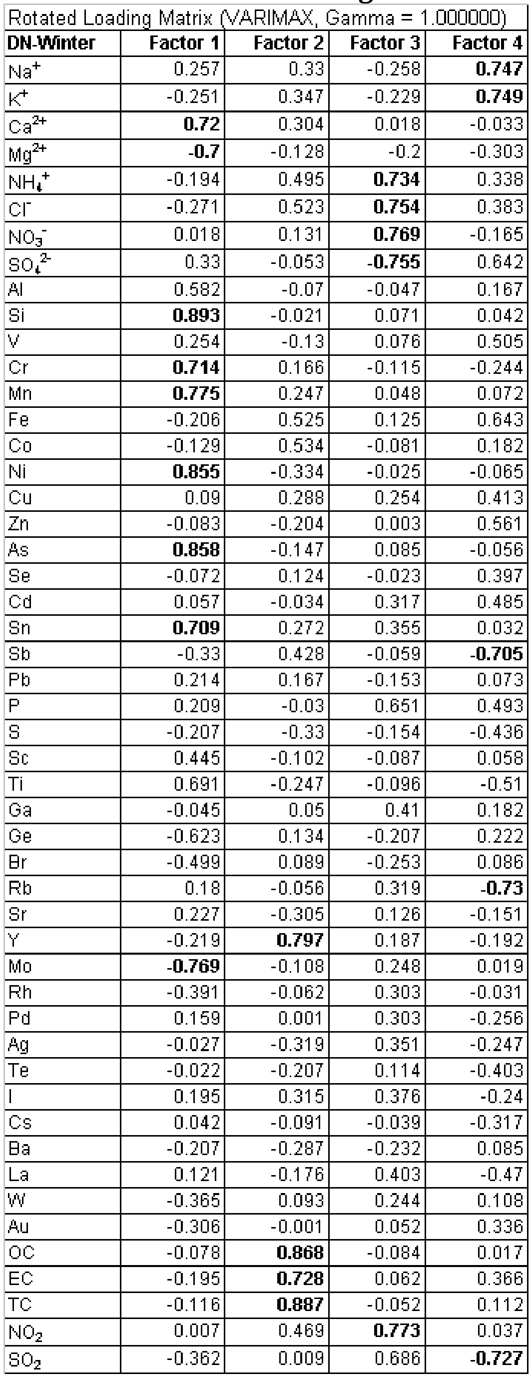
Table 4.5(c): Winter Factor Analysis Results at Govindnagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

GN-Winter	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	-0.263	-0.25	-0.328	0.379
K^+	-0.086	-0.089	0.38	**0.718**
Ca^{2+}	**-0.763**	0.488	0.132	-0.073
Mg^{2+}	**-0.761**	0.148	0.054	0.364
NH_4^+	-0.094	**0.731**	0.372	-0.333
Cl^-	0.004	0.456	-0.038	0.107
NO_3^-	0.078	**0.756**	-0.076	-0.51
SO_4^{2-}	0.055	**0.738**	0.431	0.137
Al	-0.2	0.095	**0.836**	-0.12
Si	**0.917**	0.083	-0.137	-0.207
V	-0.329	-0.248	**0.71**	-0.16
Cr	0.059	0.01	**0.949**	-0.05
Mn	-0.347	-0.091	0.629	-0.265
Fe	-0.322	0.076	-0.165	-0.314
Co	0.051	0.004	**0.947**	-0.063
Ni	-0.622	0.016	0.487	-0.247
Cu	0.242	-0.099	**0.893**	-0.084
Zn	0.196	0.013	-0.08	-0.485
As	0.235	0.034	**-0.708**	-0.251
Se	-0.042	-0.579	0.088	-0.539
Cd	-0.172	0.294	0.128	0.44
Sn	-0.147	-0.058	-0.57	0.071
Sb	0.034	0.42	0.142	0.098
Pb	0.177	0.367	-0.489	-0.188
P	0.211	0.06	**-0.72**	-0.003
S	0.146	-0.145	0.55	-0.011
Sc	0.036	-0.15	0.475	-0.661
Ti	0.6	0.015	0.203	0.502
Ga	-0.178	0.379	0.429	0.079
Ge	-0.007	0.099	0.095	**0.845**
Br	-0.208	-0.177	-0.274	0.128
Rb	0.129	0.114	0.28	**0.834**
Sr	-0.05	0.151	-0.107	**0.89**
Y	-0.205	-0.443	-0.331	0.048
Mo	-0.03	-0.07	0.02	**0.789**
Rh	0.09	0.133	0.324	0.003
Pd	0.371	-0.025	-0.274	-0.067
Ag	0.285	0.481	0.083	0.327
Te	0.194	0.005	0.028	0.043
I	0.014	0.181	0.257	**0.708**
Cs	0.154	0.472	-0.07	0.256
Ba	0.345	0.046	-0.122	-0.019
La	-0.369	-0.136	0.119	0.15
W	-0.435	0.359	-0.193	0.105
Au	0.252	-0.283	-0.358	0.083
OC	-0.106	0.064	**-0.749**	0.218
EC	-0.136	0.192	**-0.775**	0.159
TC	-0.125	0.115	**-0.819**	0.215
NO_2	0.195	-0.333	-0.124	-0.038
SO_2	-0.082	-0.326	0.307	-0.246

Table 4.5(d): Winter Factor Analysis Results at Dadanagar



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

DN-Winter	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	0.257	0.33	-0.258	**0.747**
K^+	-0.251	0.347	-0.229	**0.749**
Ca^{2+}	**0.72**	0.304	0.018	-0.033
Mg^{2+}	**-0.7**	-0.128	-0.2	-0.303
NH_4^+	-0.194	0.495	**0.734**	0.338
Cl^-	-0.271	0.523	**0.754**	0.383
NO_3^-	0.018	0.131	**0.769**	-0.165
SO_4^{2-}	0.33	-0.053	**-0.755**	0.642
Al	0.582	-0.07	-0.047	0.167
Si	**0.893**	-0.021	0.071	0.042
V	0.254	-0.13	0.076	0.505
Cr	**0.714**	0.166	-0.115	-0.244
Mn	**0.775**	0.247	0.048	0.072
Fe	-0.206	0.525	0.125	0.643
Co	-0.129	0.534	-0.081	0.182
Ni	**0.855**	-0.334	-0.025	-0.065
Cu	0.09	0.288	0.254	0.413
Zn	-0.083	-0.204	0.003	0.561
As	**0.858**	-0.147	0.085	-0.056
Se	-0.072	0.124	-0.023	0.397
Cd	0.057	-0.034	0.317	0.485
Sn	**0.709**	0.272	0.355	0.032
Sb	-0.33	0.428	-0.059	**-0.705**
Pb	0.214	0.167	-0.153	0.073
P	0.209	-0.03	0.651	0.493
S	-0.207	-0.33	-0.154	-0.436
Sc	0.445	-0.102	-0.087	0.058
Ti	0.691	-0.247	-0.096	-0.51
Ga	-0.045	0.05	0.41	0.182
Ge	-0.623	0.134	-0.207	0.222
Br	-0.499	0.089	-0.253	0.086
Rb	0.18	-0.056	0.319	**-0.73**
Sr	0.227	-0.305	0.126	-0.151
Y	-0.219	**0.797**	0.187	-0.192
Mo	**-0.769**	-0.108	0.248	0.019
Rh	-0.391	-0.062	0.303	-0.031
Pd	0.159	0.001	0.303	-0.256
Ag	-0.027	-0.319	0.351	-0.247
Te	-0.022	-0.207	0.114	-0.403
I	0.195	0.315	0.376	-0.24
Cs	0.042	-0.091	-0.039	-0.317
Ba	-0.207	-0.287	-0.232	0.085
La	0.121	-0.176	0.403	-0.47
W	-0.365	0.093	0.244	0.108
Au	-0.306	-0.001	0.052	0.336
OC	-0.078	**0.868**	-0.084	0.017
EC	-0.195	**0.728**	0.062	0.366
TC	-0.116	**0.887**	-0.052	0.112
NO_2	0.007	0.469	**0.773**	0.037
SO_2	-0.362	0.009	0.686	**-0.727**

Table 4.5(e): Winter Factor Analysis Results at Colonelganj

Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

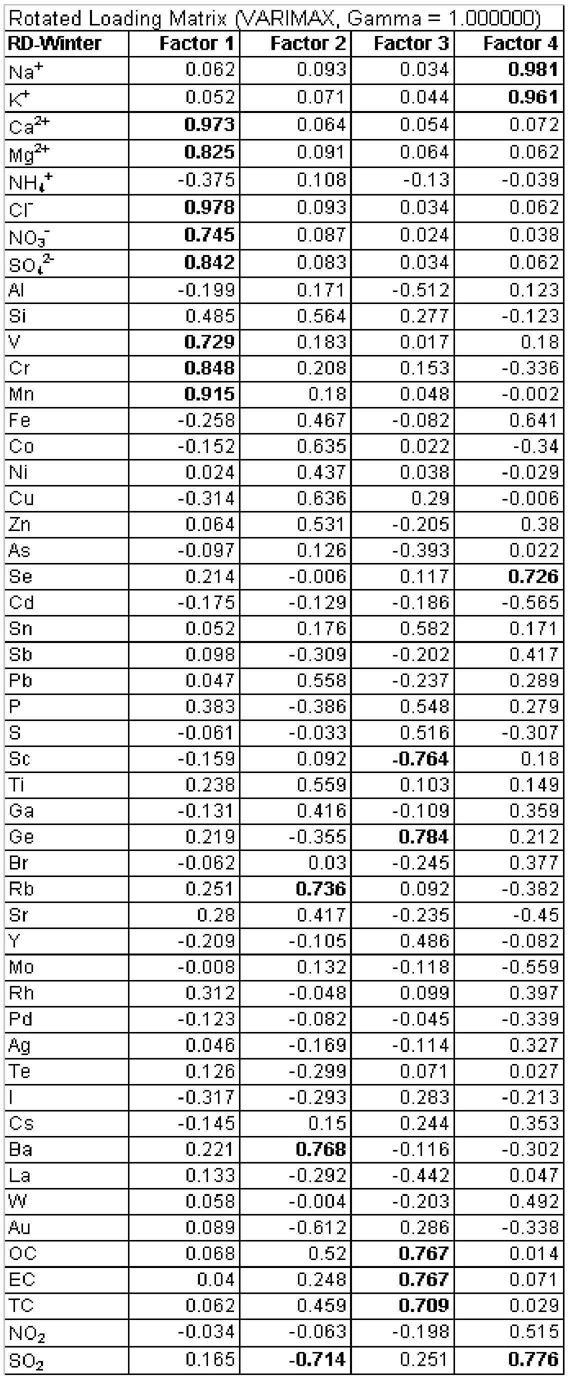
CG-Winter	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	0.1	**0.844**	-0.068	0.137
K^+	-0.154	0.266	0.153	**-0.727**
Ca^{2+}	-0.04	**-0.95**	0.008	0.106
Mg^{2+}	-0.039	**-0.95**	0.007	0.109
NH_4^+	-0.222	**-0.739**	-0.038	-0.008
Cl^-	-0.078	**0.774**	0.098	-0.487
NO_3^-	-0.01	**0.934**	0.039	-0.284
SO_4^{2-}	-0.115	**0.799**	0.127	-0.574
Al	**0.704**	0.143	-0.022	0
Si	0.646	0.142	0.49	0.324
V	**0.82**	0.121	0.034	-0.106
Cr	0.59	-0.067	0.191	0.3
Mn	**0.929**	-0.115	-0.058	0.14
Fe	0.072	0.401	-0.141	0.108
Co	**0.781**	0.04	0.188	0.455
Ni	**0.793**	-0.006	0.345	-0.168
Cu	0.566	0.162	0.184	-0.064
Zn	**0.732**	-0.141	-0.234	-0.452
As	**0.776**	0.093	0.163	-0.093
Se	**0.742**	0.01	-0.011	-0.073
Cd	-0.123	0.02	-0.115	-0.233
Sn	0.065	0.321	0.227	0.233
Sb	-0.071	0.191	-0.13	-0.239
Pb	0.449	-0.115	0.472	-0.132
P	-0.243	0.122	-0.275	0.075
S	**0.827**	-0.079	0.086	-0.091
Sc	-0.239	-0.037	-0.135	0.265
Ti	0.371	-0.138	0.056	0.64
Ga	0.103	-0.552	0.001	-0.086
Ge	0.131	0.076	-0.021	0.412
Br	0.58	-0.251	0.587	-0.021
Rb	**0.807**	-0.056	-0.138	0.233
Sr	0.584	0.088	-0.229	0.447
Y	0.276	-0.143	0.002	-0.698
Mo	0.561	0.042	0.114	0.093
Rh	0.698	-0.237	0.09	0.172
Pd	-0.257	-0.002	0.268	0.238
Ag	0.581	-0.049	-0.138	0.24
Te	0.539	0.049	0.316	0.152
I	0.066	0.189	-0.223	0.112
Cs	-0.111	0.384	-0.155	-0.077
Ba	0.506	-0.05	**0.713**	0.138
La	-0.185	-0.224	0.487	0.253
W	0.249	-0.18	-0.105	0.221
Au	-0.088	-0.046	0.115	**0.746**
OC	0.129	-0.099	**0.922**	-0.004
EC	0.236	0.039	**0.886**	-0.049
TC	0.163	-0.059	**0.92**	-0.018
NO_2	-0.138	0.409	0.511	0.031
SO_2	-0.028	0.208	0.62	0.213

Table 4.5(f): Winter Factor Analysis Results at AHM

Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

AHM-Winter	Factor 1	Factor 2	Factor 3	Factor 4
Na^+	-0.194	-0.649	-0.002	-0.395
K^+	0.152	0.641	-0.098	**0.719**
Ca^{2+}	**0.718**	0.357	-0.025	0.601
Mg^{2+}	**0.724**	0.037	-0.153	0.473
NH_4^+	-0.177	**-0.766**	-0.209	0.167
Cl^-	0.034	**0.726**	-0.013	-0.171
NO_3^-	0.174	**0.785**	0.01	0.052
SO_4^{2-}	-0.122	**0.75**	-0.011	-0.391
Al	-0.062	-0.658	0.098	0.529
Si	**0.983**	0.048	-0.113	-0.001
V	**0.803**	-0.358	0.097	0.091
Cr	**0.962**	-0.089	0.036	0.123
Mn	**0.969**	-0.112	0.09	0.031
Fe	**0.95**	0.212	-0.043	0.099
Co	0.424	0.404	0.375	-0.132
Ni	**-0.754**	0.37	0.236	0.113
Cu	**0.946**	0.134	0.004	0.134
Zn	**0.888**	0.237	-0.037	-0.071
As	0.615	-0.598	0.062	0.019
Se	-0.269	-0.023	-0.058	**-0.752**
Cd	-0.058	-0.221	0.367	0.109
Sn	0.192	-0.333	0.337	0.093
Sb	0.017	-0.015	0.112	0.491
Pb	0.017	-0.015	0.113	0.491
P	0.083	-0.211	0.664	-0.094
S	0.341	0.194	0.42	-0.119
Sc	0.332	-0.397	-0.091	-0.095
Ti	0.263	0.06	-0.553	-0.112
Ga	-0.232	0.086	0.061	-0.177
Ge	-0.432	0.294	-0.231	0.228
Br	**0.878**	-0.226	0.191	-0.209
Rb	**0.758**	0.283	0.218	-0.043
Sr	**0.783**	0.304	-0.074	-0.253
Y	-0.114	-0.016	-0.116	0.568
Mo	0.657	0.404	-0.346	0.128
Rh	0.669	0.351	-0.168	-0.169
Pd	-0.03	-0.167	0.441	0.336
Ag	-0.12	-0.247	0.006	0.063
Te	0.022	0.275	0.023	0.379
I	0.126	0.079	-0.11	-0.577
Cs	-0.024	-0.462	-0.068	-0.228
Ba	-0.238	-0.226	0.159	0.52
La	-0.341	0.269	0.301	0.331
W	0.169	-0.021	0.16	-0.368
Au	0.03	0.555	0.074	0.487
OC	0.028	0.277	**0.899**	0.142
EC	0.048	0.21	**0.925**	0.149
TC	0.034	0.259	**0.912**	0.145
NO_2	-0.002	**0.815**	0.011	-0.325
SO_2	-0.039	**0.737**	-0.326	-0.161

Table 4.5(g): Winter Factor Analysis Results at Ramadevi



Rotated Loading Matrix (VARIMAX, Gamma = 1.000000)

RD-Winter	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
Na^+	0.062	0.093	0.034	**0.981**
K^+	0.052	0.071	0.044	**0.961**
Ca^{2+}	**0.973**	0.064	0.054	0.072
Mg^{2+}	**0.825**	0.091	0.064	0.062
NH_4^+	-0.375	0.108	-0.13	-0.039
Cl^-	**0.978**	0.093	0.034	0.062
NO_3^-	**0.745**	0.087	0.024	0.038
SO_4^{2-}	**0.842**	0.083	0.034	0.062
Al	-0.199	0.171	-0.512	0.123
Si	0.485	0.564	0.277	-0.123
V	**0.729**	0.183	0.017	0.18
Cr	**0.848**	0.208	0.153	-0.336
Mn	**0.915**	0.18	0.048	-0.002
Fe	-0.258	0.467	-0.082	0.641
Co	-0.152	0.635	0.022	-0.34
Ni	0.024	0.437	0.038	-0.029
Cu	-0.314	0.636	0.29	-0.006
Zn	0.064	0.531	-0.205	0.38
As	-0.097	0.126	-0.393	0.022
Se	0.214	-0.006	0.117	**0.726**
Cd	-0.175	-0.129	-0.186	-0.565
Sn	0.052	0.176	0.582	0.171
Sb	0.098	-0.309	-0.202	0.417
Pb	0.047	0.558	-0.237	0.289
P	0.383	-0.386	0.548	0.279
S	-0.061	-0.033	0.516	-0.307
Sc	-0.159	0.092	**-0.764**	0.18
Ti	0.238	0.559	0.103	0.149
Ga	-0.131	0.416	-0.109	0.359
Ge	0.219	-0.355	**0.784**	0.212
Br	-0.062	0.03	-0.245	0.377
Rb	0.251	**0.736**	0.092	-0.382
Sr	0.28	0.417	-0.235	-0.45
Y	-0.209	-0.105	0.486	-0.082
Mo	-0.008	0.132	-0.118	-0.559
Rh	0.312	-0.048	0.099	0.397
Pd	-0.123	-0.082	-0.045	-0.339
Ag	0.046	-0.169	-0.114	0.327
Te	0.126	-0.299	0.071	0.027
I	-0.317	-0.293	0.283	-0.213
Cs	-0.145	0.15	0.244	0.353
Ba	0.221	**0.768**	-0.116	-0.302
La	0.133	-0.292	-0.442	0.047
W	0.058	-0.004	-0.203	0.492
Au	0.089	-0.612	0.286	-0.338
OC	0.068	0.52	**0.767**	0.014
EC	0.04	0.248	**0.767**	0.071
TC	0.062	0.459	**0.709**	0.029
NO_2	-0.034	-0.063	-0.198	0.515
SO_2	0.165	**-0.714**	0.251	**0.776**

Table 4.6: Indicative Sources at Sampling Sites in each Season

Sampling Site	IITK	VN	GN	DN	CG	AHM	RD
Land use	**Backg / Inst**	**Resi/ comm**	**Resid.**	**Ind**	**Kerb**	**Commr**	**Traffic**
Indicative Sources Number*							
Summer	**1, 2, 3, 4**	**1, 2, 4, 3**	**1, 2, 3, 6**	**5, 3, 2, 4**	**5, 1, 3**	**5, 2, 3, 6**	**5, 1, 3, 4**
Post-monsoon	**1, 2, 3, 4**	**1, 5, 3**	**1, 3, 6**	**1, 3, 2, 5**	**5, 1, 3, 7**	**5, 2, 3, 6**	**5, 1, 3, 7**
Winter	**1, 2, 3**	**2, 1, 3**	**1, 2, 4, 6**	**1, 3, 2, 6**	**1, 5, 2, 3**	**1, 2, 3, 6**	**1, 5, 3, 6**

***Source number details**

Source	Soil & road dust	Secondary particles	General Combustion	Coal burning	Oil burning	Biomass burning	Tyre wear
Source Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**

The following conclusions can be drawn from the factor analysis (Table 4.6)

- Soil and road dust is probably the most important source contributing to PM_{10} concentration in ambient air at all locations in all seasons.
- Presence of inorganic secondary particles (SO_4^{2+} , NO_3^-) definitely show formation of secondary particles as important source to PM_{10} levels at all locations in all seasons.
- Similar to secondary particles, combustion related sources are ubiquitously present at all sites
- Industrial, commercial, traffic and kerb sites show presence of oil burning (e.g. diesel or heavy oil) as a very prominent source.
- It is interesting to note that in winter season, biomass burning (including garbage) is prominent at almost all locations.
- At some locations (industrial and commercial), coal burning is identified as an important source. Most restaurants and hotels in commercial areas use coal as the basic fuel and the city has a 200 MW coal-based power plant.

4.3 CMB 8.2 Modeling and Analysis for PM_{10}

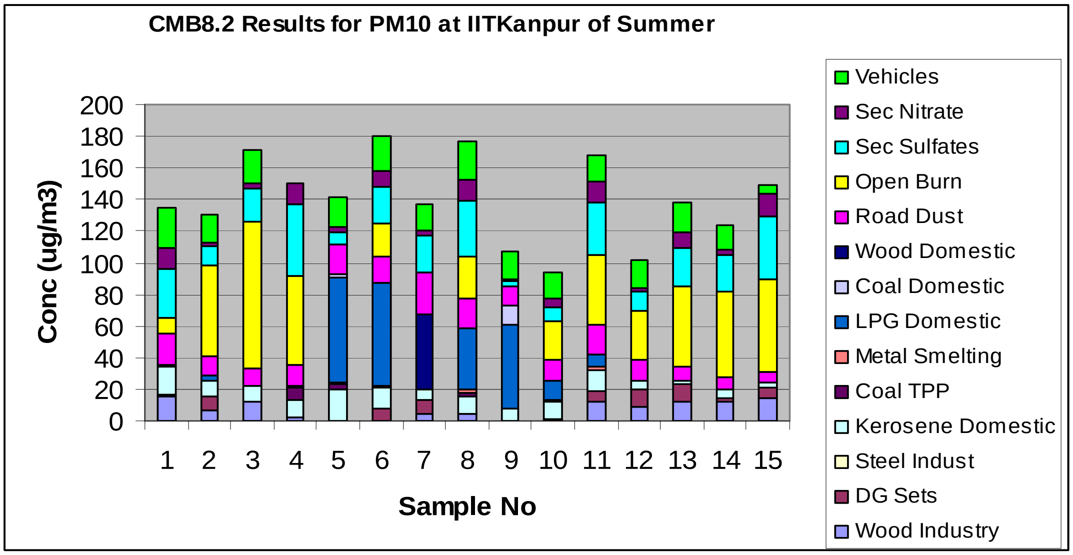
The PM_{10} monitoring data along with its chemical speciation results (described in Chapter 2) have been used in CMB 8.2 model. The source profile applicable to the prominent sources in Kanpur was developed by IIT Bombay for non-vehicular sources and ARAI, Pune developed the source profiles for vehicular sources. In this modeling exercise the molecular markers and PAHs (n-hentriacontane, n-triacontane, n-pentriacontane, octadecanamide, benzo(b) fluoranthene) were also used.

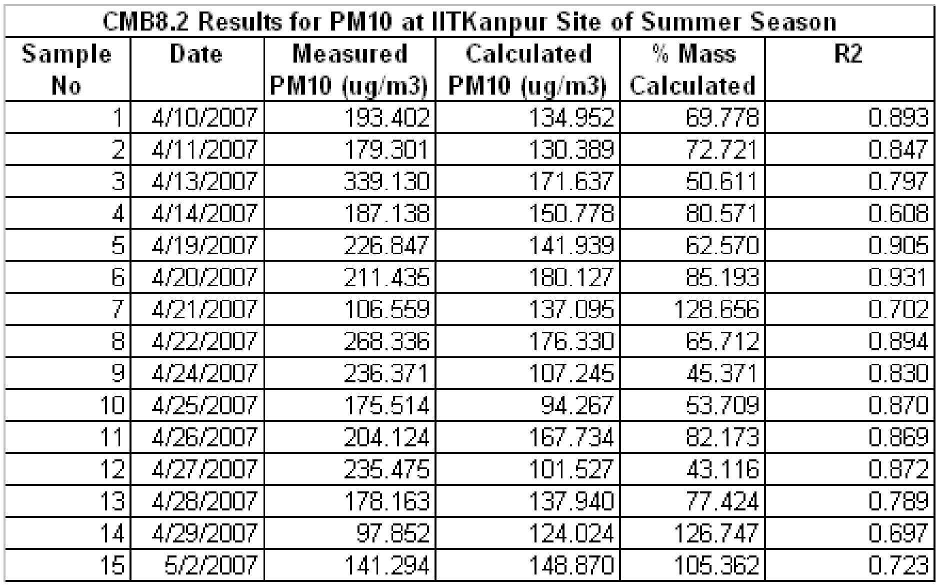
The CMB model was run for each location for each day of sampling (at the location) for three seasons. In all, over 600 model runs were made. The model results were analyzed in terms of R-square (model fitting) and model-computed percent mass (compared to the measured mass). It was found that only about 12-15 measurements at each site (off 25-28 measurements of each season) showed a reasonable R-square (> 0.70) and model-computed mass above 60 percent and were considered for further analysis and interpretations.

The results of CMB 8.2 for each location for each season are given in Figures 4.1 to 4.21. Along with each figure, a self-explanatory table is included to indicate the consistency and performance of the modeling exercise. It can be seen that receptor modeling has performed very well in terms of explanation of mass (or concentration) and R-square value which indicates linear association between observed PM_{10} concentration and model computed PM_{10} concentration on day to day basis.

It can be seen that there is a day-to-day variations in the prominent sources that contribute to PM_{10}. The sources which are most consistent in all seasons for all locations include vehicular source, formation of secondary particles and road dust emissions. To be able to make more generalized sense (location and season-wise), there is a need to prepare overall source-receptor linkages. Figure 4.22 presents the overall results of source-receptor impact relationship which can be utilized in drawing useful conclusions.

Figure 4.1: Results of CMB Modeling at IIT Kanpur for Summer Season

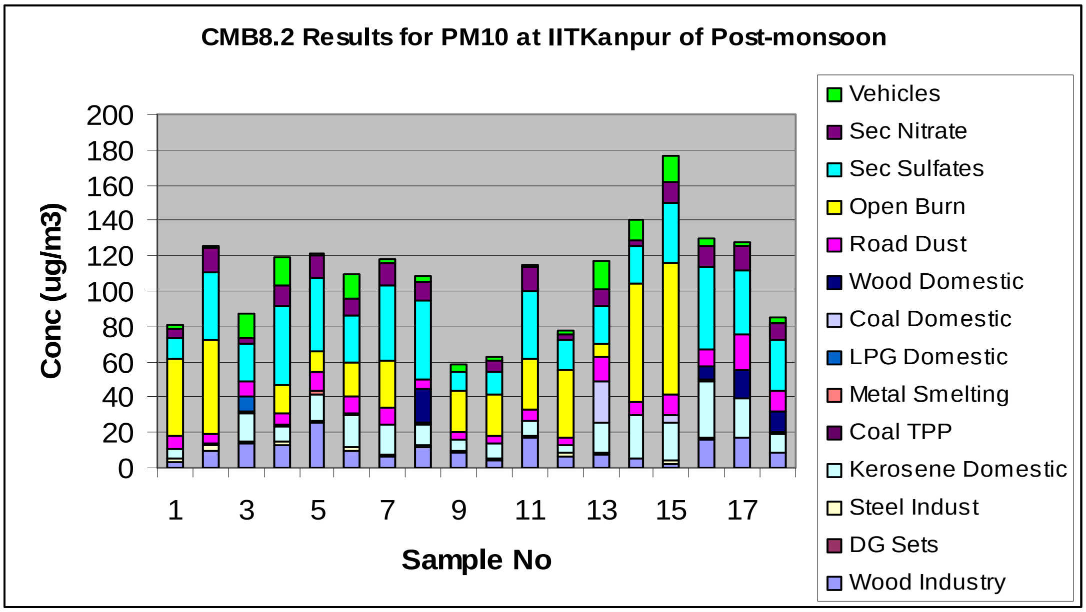


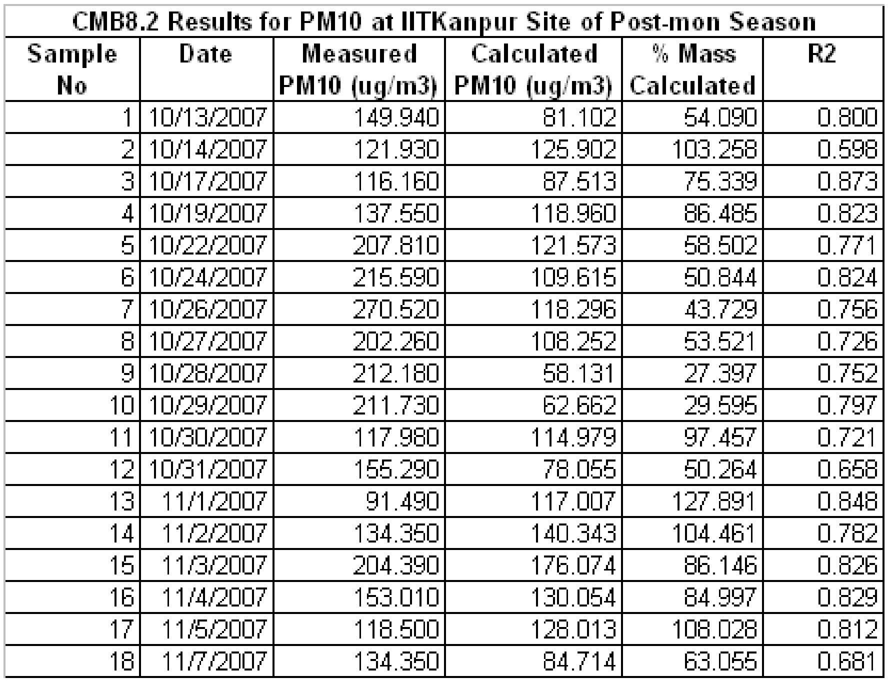


CMB8.2 Results for PM10 at IITKanpur Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	4/10/2007	193.402	134.952	69.778	0.893
2	4/11/2007	179.301	130.389	72.721	0.847
3	4/13/2007	339.130	171.637	50.611	0.797
4	4/14/2007	187.138	150.778	80.571	0.608
5	4/19/2007	226.847	141.939	62.570	0.905
6	4/20/2007	211.435	180.127	85.193	0.931
7	4/21/2007	106.559	137.095	128.656	0.702
8	4/22/2007	268.336	176.330	65.712	0.894
9	4/24/2007	236.371	107.245	45.371	0.830
10	4/25/2007	175.514	94.267	53.709	0.870
11	4/26/2007	204.124	167.734	82.173	0.869
12	4/27/2007	235.475	101.527	43.116	0.872
13	4/28/2007	178.163	137.940	77.424	0.789
14	4/29/2007	97.852	124.024	126.747	0.697
15	5/2/2007	141.294	148.870	105.362	0.723

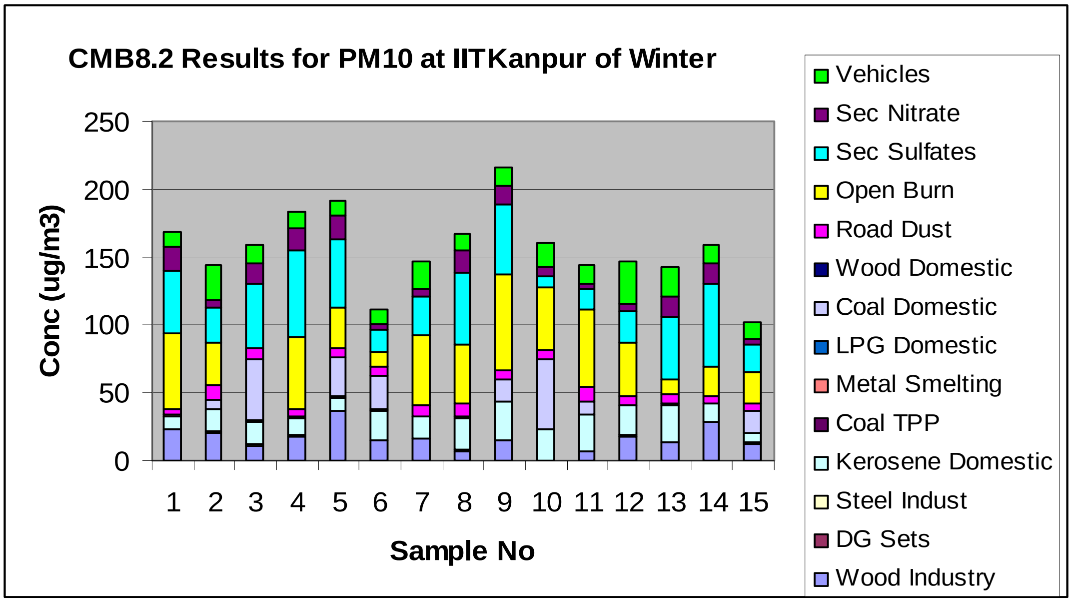
Figure 4.2: Results of CMB Modeling at IIT Kanpur for Post-monsoon Season

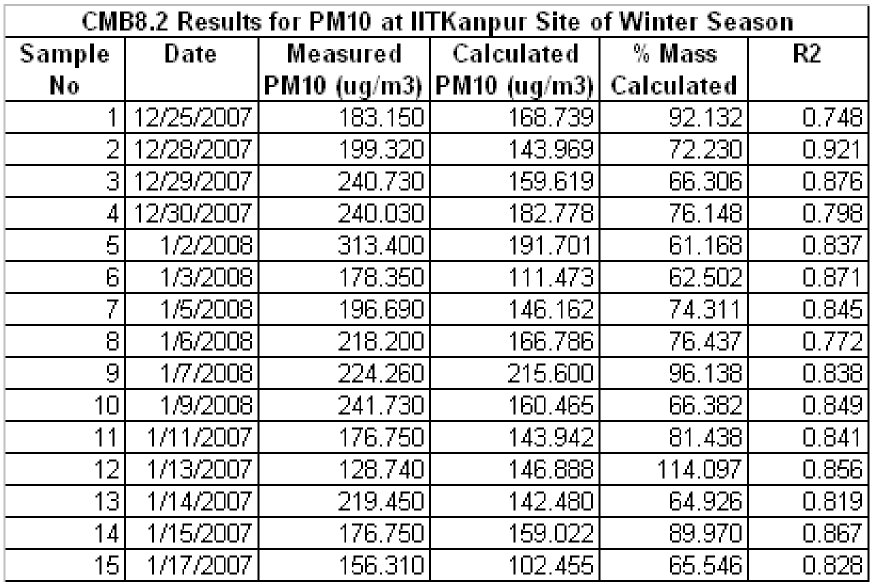




CMB8.2 Results for PM10 at IITKanpur Site of Post-mon Season					
Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	10/13/2007	149.940	81.102	54.090	0.800
2	10/14/2007	121.930	125.902	103.258	0.598
3	10/17/2007	116.160	87.513	75.339	0.873
4	10/19/2007	137.550	118.960	86.485	0.823
5	10/22/2007	207.810	121.573	58.502	0.771
6	10/24/2007	215.590	109.615	50.844	0.824
7	10/26/2007	270.520	118.296	43.729	0.756
8	10/27/2007	202.260	108.252	53.521	0.726
9	10/28/2007	212.180	58.131	27.397	0.752
10	10/29/2007	211.730	62.662	29.595	0.797
11	10/30/2007	117.980	114.979	97.457	0.721
12	10/31/2007	155.290	78.055	50.264	0.658
13	11/1/2007	91.490	117.007	127.891	0.848
14	11/2/2007	134.350	140.343	104.461	0.782
15	11/3/2007	204.390	176.074	86.146	0.826
16	11/4/2007	153.010	130.054	84.997	0.829
17	11/5/2007	118.500	128.013	108.028	0.812
18	11/7/2007	134.350	84.714	63.055	0.681

Figure 4.3: Results of CMB Modeling at IIT Kanpur for Winter Season

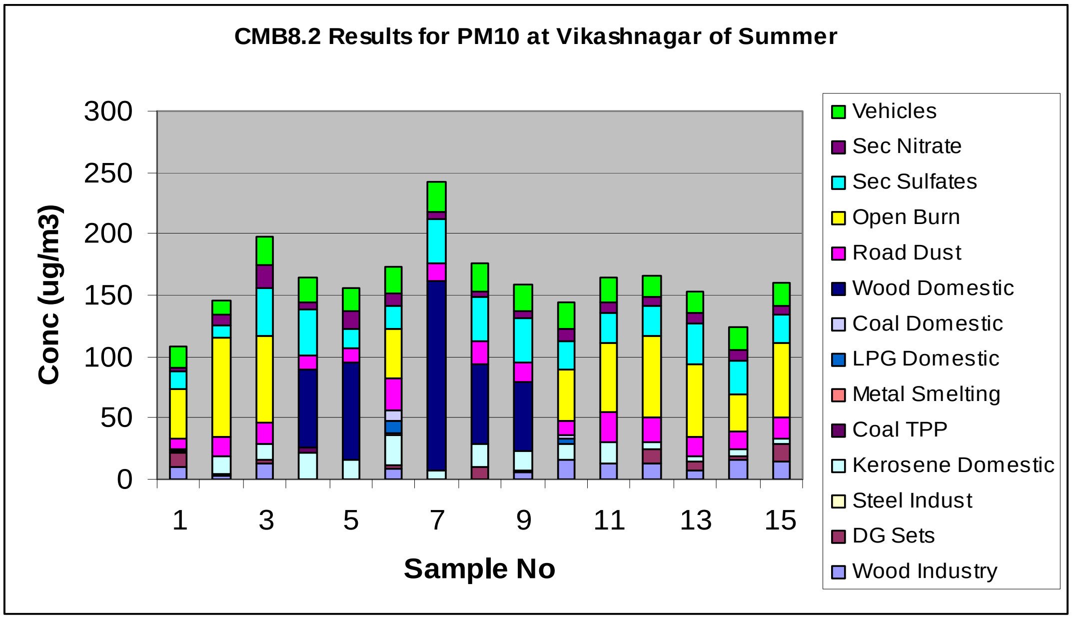


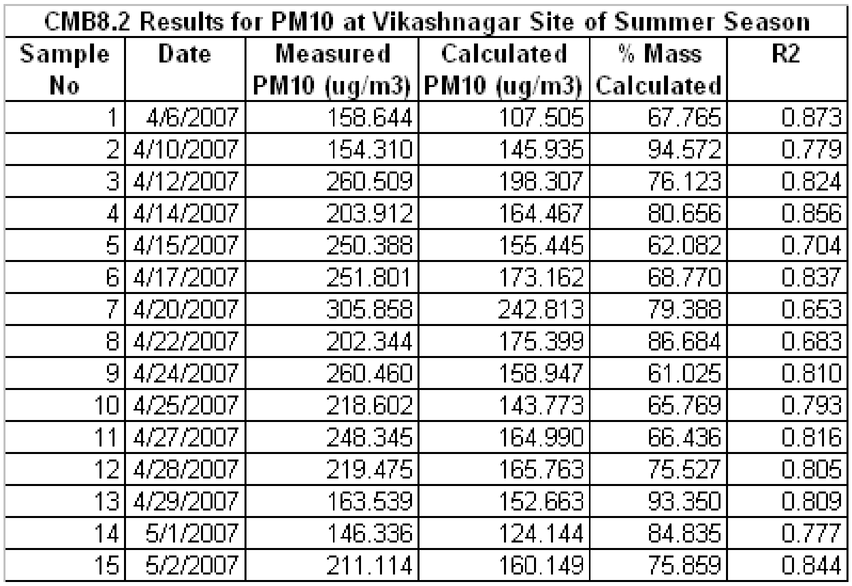


CMB8.2 Results for PM10 at IITKanpur Site of Winter Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	12/25/2007	183.150	168.739	92.132	0.748
2	12/28/2007	199.320	143.969	72.230	0.921
3	12/29/2007	240.730	159.619	66.306	0.876
4	12/30/2007	240.030	182.778	76.148	0.798
5	1/2/2008	313.400	191.701	61.168	0.837
6	1/3/2008	178.350	111.473	62.502	0.871
7	1/5/2008	196.690	146.162	74.311	0.845
8	1/6/2008	218.200	166.786	76.437	0.772
9	1/7/2008	224.260	215.600	96.138	0.838
10	1/9/2008	241.730	160.465	66.382	0.849
11	1/11/2007	176.750	143.942	81.438	0.841
12	1/13/2007	128.740	146.888	114.097	0.856
13	1/14/2007	219.450	142.480	64.926	0.819
14	1/15/2007	176.750	159.022	89.970	0.867
15	1/17/2007	156.310	102.455	65.546	0.828

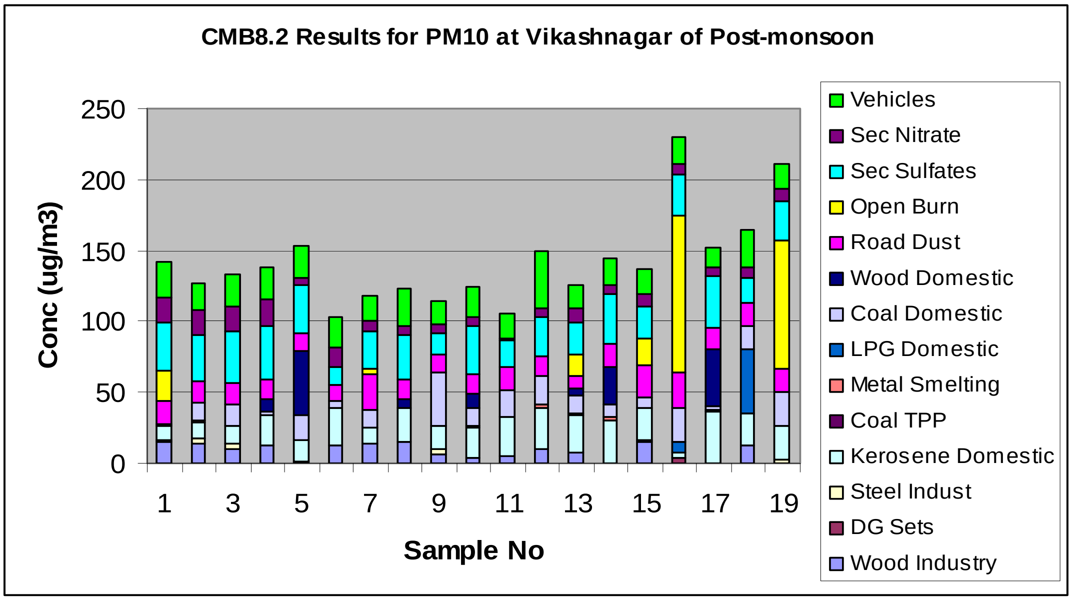
Figure 4.4: Results of CMB Modeling at Vikashnagar for Summer Season




CMB8.2 Results for PM10 at Vikashnagar Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	4/6/2007	158.644	107.505	67.765	0.873
2	4/10/2007	154.310	145.935	94.572	0.779
3	4/12/2007	260.509	198.307	76.123	0.824
4	4/14/2007	203.912	164.467	80.656	0.856
5	4/15/2007	250.388	155.445	62.082	0.704
6	4/17/2007	251.801	173.162	68.770	0.837
7	4/20/2007	305.858	242.813	79.388	0.653
8	4/22/2007	202.344	175.399	86.684	0.683
9	4/24/2007	260.460	158.947	61.025	0.810
10	4/25/2007	218.602	143.773	65.769	0.793
11	4/27/2007	248.345	164.990	66.436	0.816
12	4/28/2007	219.475	165.763	75.527	0.805
13	4/29/2007	163.539	152.663	93.350	0.809
14	5/1/2007	146.336	124.144	84.835	0.777
15	5/2/2007	211.114	160.149	75.859	0.844

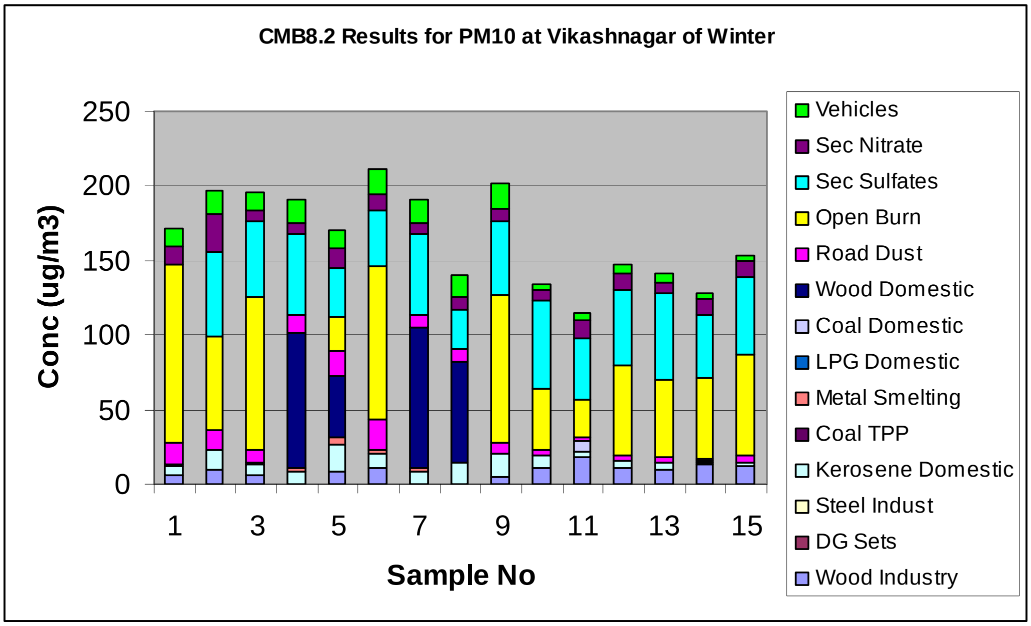
Figure 4.5: Results of CMB Modeling at Vikashnagar for Post-monsoon Season

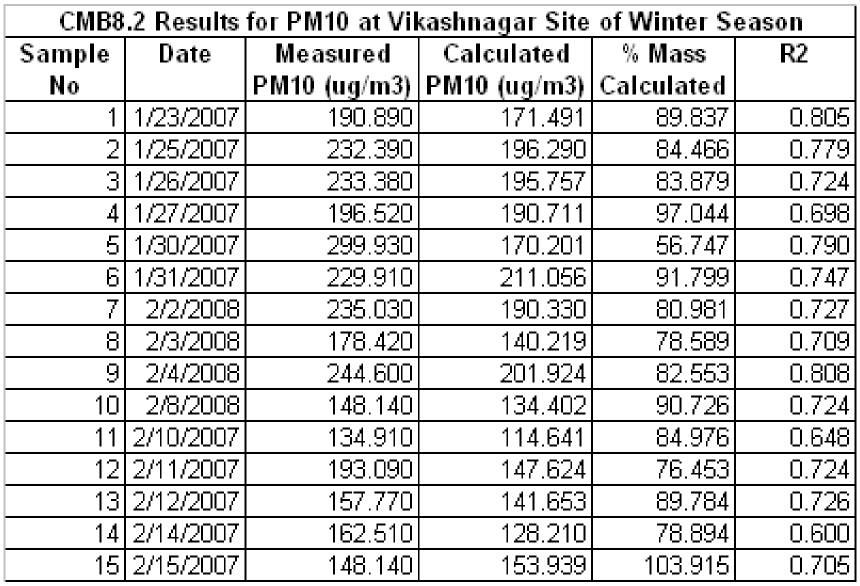


CMB8.2 Results for PM10 at Vikashnagar Site of Post-mon Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	10/31/2007	173.540	142.294	81.995	0.912
2	11/1/2007	165.440	127.478	77.054	0.863
3	11/3/2007	160.960	132.546	82.347	0.874
4	11/4/2007	208.630	137.571	65.940	0.826
5	11/6/2007	143.170	153.763	107.399	0.808
6	11/7/2007	171.050	102.545	59.950	0.712
7	11/10/2007	212.730	117.979	55.459	0.832
8	11/12/2007	184.990	123.480	66.749	0.813
9	11/13/2007	204.140	114.107	55.896	0.791
10	11/14/2007	203.550	124.263	61.048	0.806
11	11/15/2007	187.160	105.859	56.561	0.826
12	11/16/2007	234.770	148.921	63.433	0.795
13	11/17/2007	197.660	125.846	63.668	0.813
14	11/18/2007	174.080	144.280	82.881	0.819
15	11/20/2007	187.480	136.880	73.011	0.883
16	11/21/2007	166.710	230.168	138.065	0.802
17	11/22/2007	172.810	152.267	88.113	0.768
18	11/24/2007	197.430	164.596	83.369	0.833
19	11/25/2007	200.710	211.246	105.249	0.873

Figure 4.6: Results of CMB Modeling at Vikashnagar for Winter Season

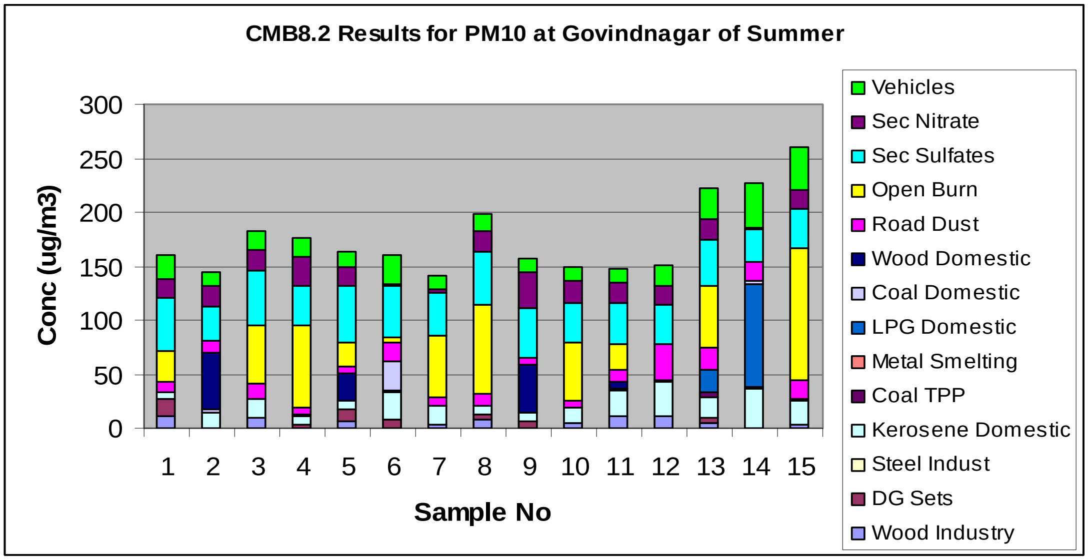


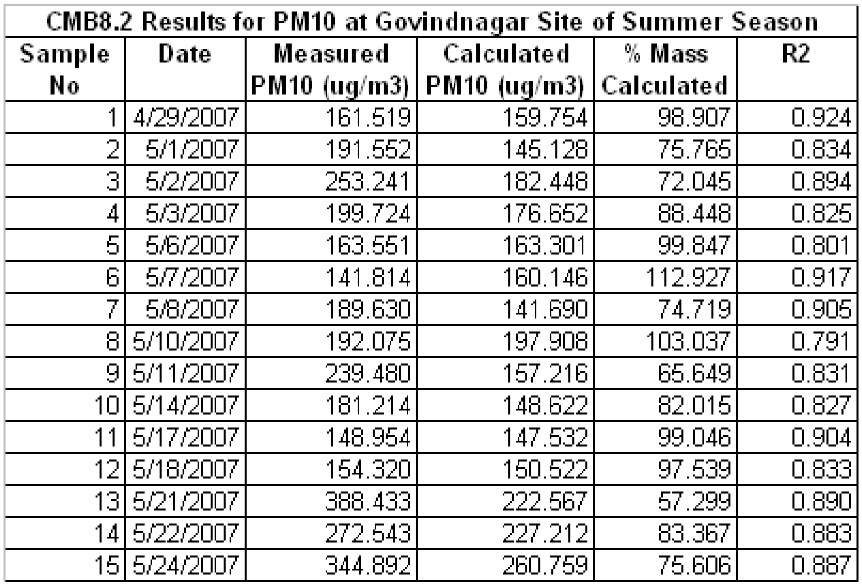


CMB8.2 Results for PM10 at Vikashnagar Site of Winter Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	1/23/2007	190.890	171.491	89.837	0.805
2	1/25/2007	232.390	196.290	84.466	0.779
3	1/26/2007	233.380	195.757	83.879	0.724
4	1/27/2007	196.520	190.711	97.044	0.698
5	1/30/2007	299.930	170.201	56.747	0.790
6	1/31/2007	229.910	211.056	91.799	0.747
7	2/2/2008	235.030	190.330	80.981	0.727
8	2/3/2008	178.420	140.219	78.589	0.709
9	2/4/2008	244.600	201.924	82.553	0.808
10	2/8/2008	148.140	134.402	90.726	0.724
11	2/10/2007	134.910	114.641	84.976	0.648
12	2/11/2007	193.090	147.624	76.453	0.724
13	2/12/2007	157.770	141.653	89.784	0.726
14	2/14/2007	162.510	128.210	78.894	0.600
15	2/15/2007	148.140	153.939	103.915	0.705

Figure 4.7: Results of CMB Modeling at Govindnagar for Summer Season

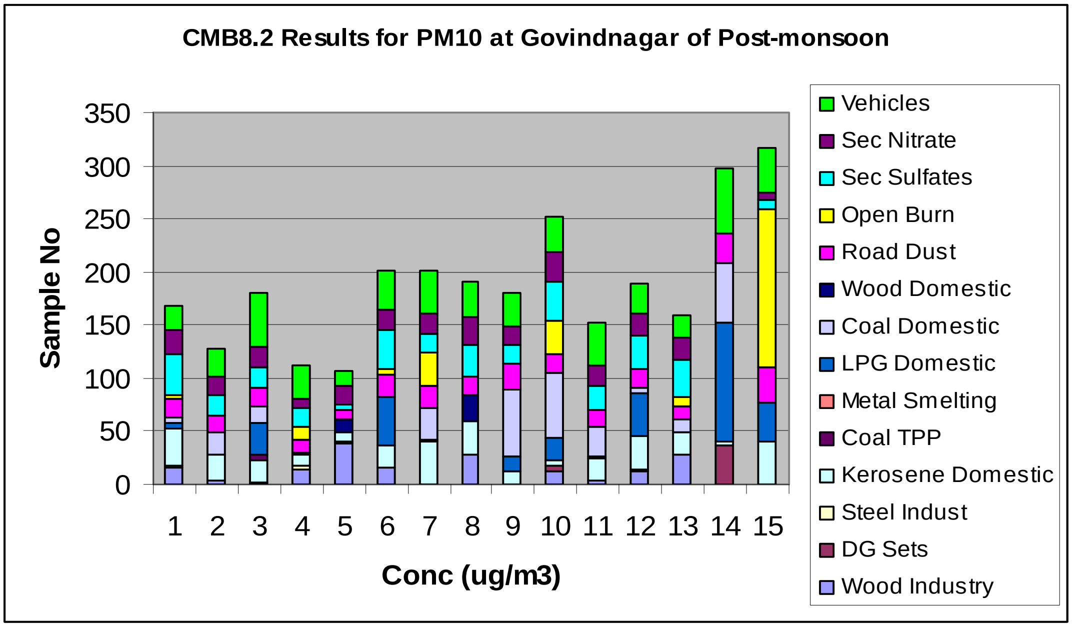


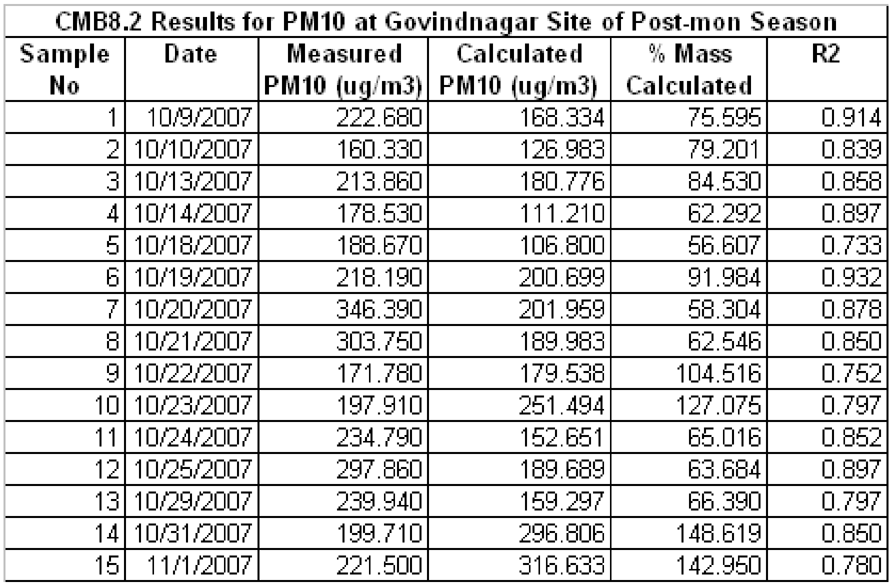


CMB8.2 Results for PM10 at Govindnagar Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	4/29/2007	161.519	159.754	98.907	0.924
2	5/1/2007	191.552	145.128	75.765	0.834
3	5/2/2007	253.241	182.448	72.045	0.894
4	5/3/2007	199.724	176.652	88.448	0.825
5	5/6/2007	163.551	163.301	99.847	0.801
6	5/7/2007	141.814	160.146	112.927	0.917
7	5/8/2007	189.630	141.690	74.719	0.905
8	5/10/2007	192.075	197.908	103.037	0.791
9	5/11/2007	239.480	157.216	65.649	0.831
10	5/14/2007	181.214	148.622	82.015	0.827
11	5/17/2007	148.954	147.532	99.046	0.904
12	5/18/2007	154.320	150.522	97.539	0.833
13	5/21/2007	388.433	222.567	57.299	0.890
14	5/22/2007	272.543	227.212	83.367	0.883
15	5/24/2007	344.892	260.759	75.606	0.887

Figure 4.8: Results of CMB Modeling at Govindnagar for Post-monsoon Season

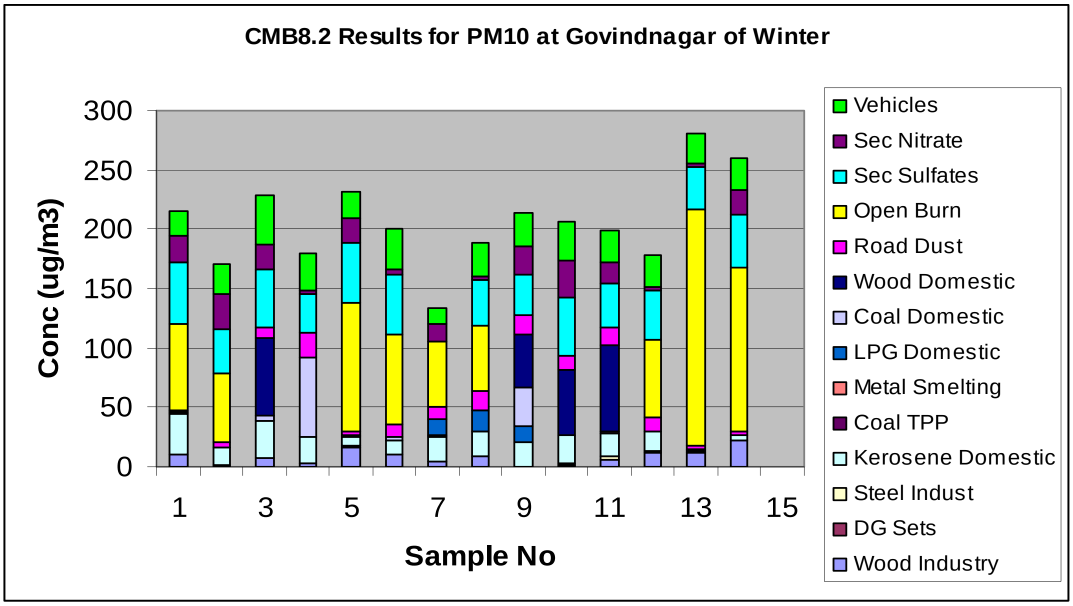


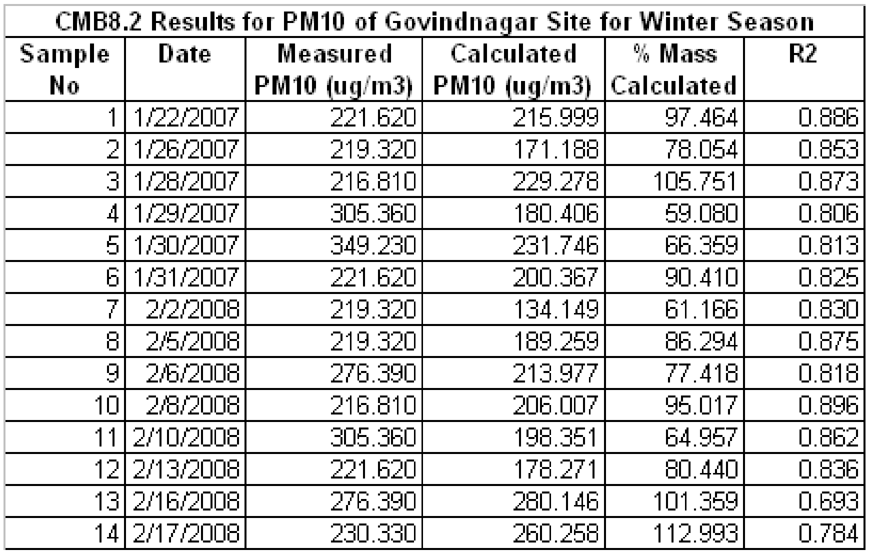


CMB8.2 Results for PM10 at Govindnagar Site of Post-mon Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	10/9/2007	222.680	168.334	75.595	0.914
2	10/10/2007	160.330	126.983	79.201	0.839
3	10/13/2007	213.860	180.776	84.530	0.858
4	10/14/2007	178.530	111.210	62.292	0.897
5	10/18/2007	188.670	106.800	56.607	0.733
6	10/19/2007	218.190	200.699	91.984	0.932
7	10/20/2007	346.390	201.959	58.304	0.878
8	10/21/2007	303.750	189.983	62.546	0.850
9	10/22/2007	171.780	179.538	104.516	0.752
10	10/23/2007	197.910	251.494	127.075	0.797
11	10/24/2007	234.790	152.651	65.016	0.852
12	10/25/2007	297.860	189.689	63.684	0.897
13	10/29/2007	239.940	159.297	66.390	0.797
14	10/31/2007	199.710	296.806	148.619	0.850
15	11/1/2007	221.500	316.633	142.950	0.780

Figure 4.9: Results of CMB Modeling at Govindnagar for Winter Season

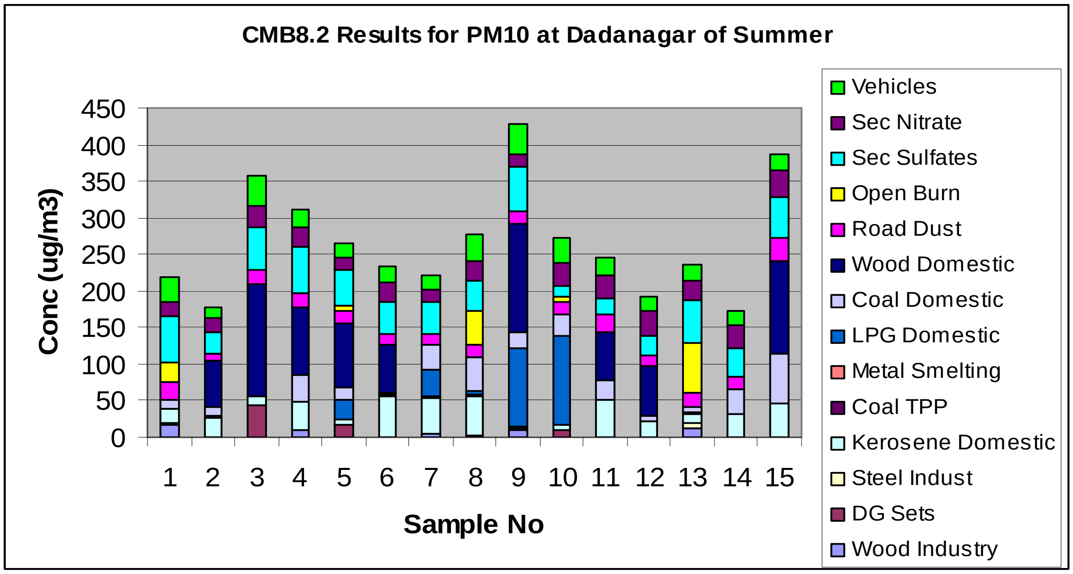


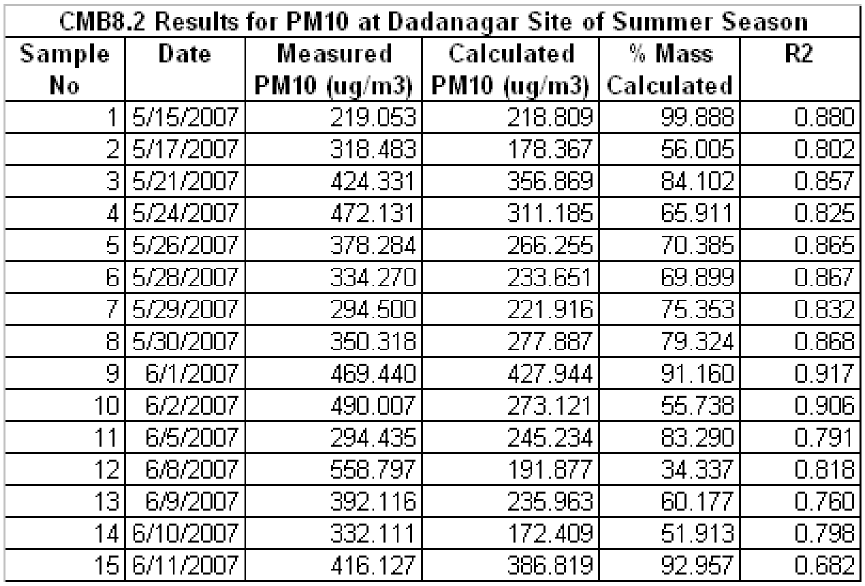


CMB8.2 Results for PM10 of Govindnagar Site for Winter Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	1/22/2007	221.620	215.999	97.464	0.886
2	1/26/2007	219.320	171.188	78.054	0.853
3	1/28/2007	216.810	229.278	105.751	0.873
4	1/29/2007	305.360	180.406	59.080	0.806
5	1/30/2007	349.230	231.746	66.359	0.813
6	1/31/2007	221.620	200.367	90.410	0.825
7	2/2/2008	219.320	134.149	61.166	0.830
8	2/5/2008	219.320	189.259	86.294	0.875
9	2/6/2008	276.390	213.977	77.418	0.818
10	2/8/2008	216.810	206.007	95.017	0.896
11	2/10/2008	305.360	198.351	64.957	0.862
12	2/13/2008	221.620	178.271	80.440	0.836
13	2/16/2008	276.390	280.146	101.359	0.693
14	2/17/2008	230.330	260.258	112.993	0.784

Figure 4.10: Results of CMB Modeling at Dadanagar for Summer Season

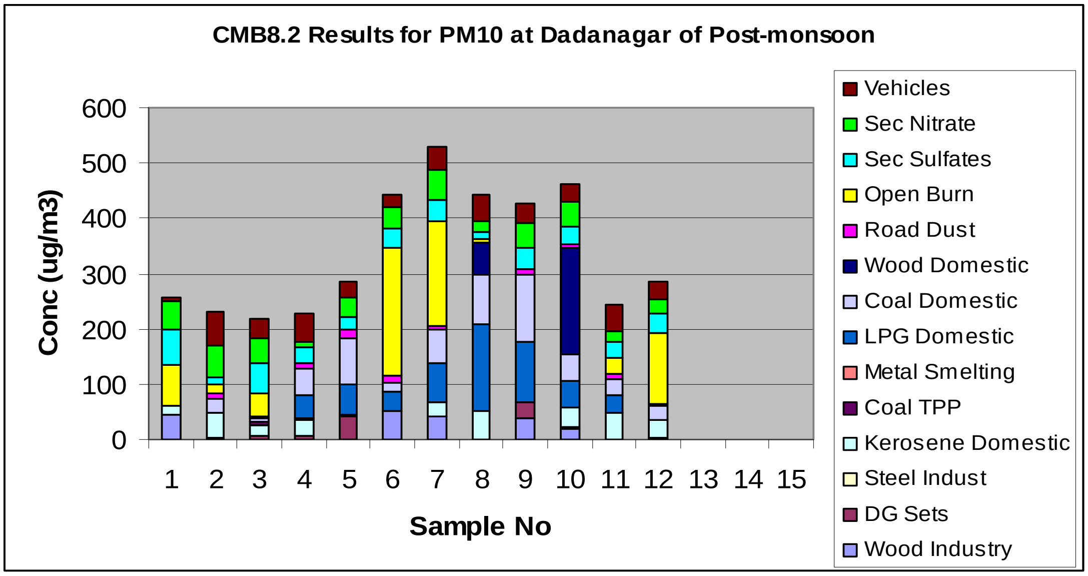




CMB8.2 Results for PM10 at Dadanagar Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	5/15/2007	219.053	218.809	99.888	0.880
2	5/17/2007	318.483	178.367	56.005	0.802
3	5/21/2007	424.331	356.869	84.102	0.857
4	5/24/2007	472.131	311.185	65.911	0.825
5	5/26/2007	378.284	266.255	70.385	0.865
6	5/28/2007	334.270	233.651	69.899	0.867
7	5/29/2007	294.500	221.916	75.353	0.832
8	5/30/2007	350.318	277.887	79.324	0.868
9	6/1/2007	469.440	427.944	91.160	0.917
10	6/2/2007	490.007	273.121	55.738	0.906
11	6/5/2007	294.435	245.234	83.290	0.791
12	6/8/2007	558.797	191.877	34.337	0.818
13	6/9/2007	392.116	235.963	60.177	0.760
14	6/10/2007	332.111	172.409	51.913	0.798
15	6/11/2007	416.127	386.819	92.957	0.682

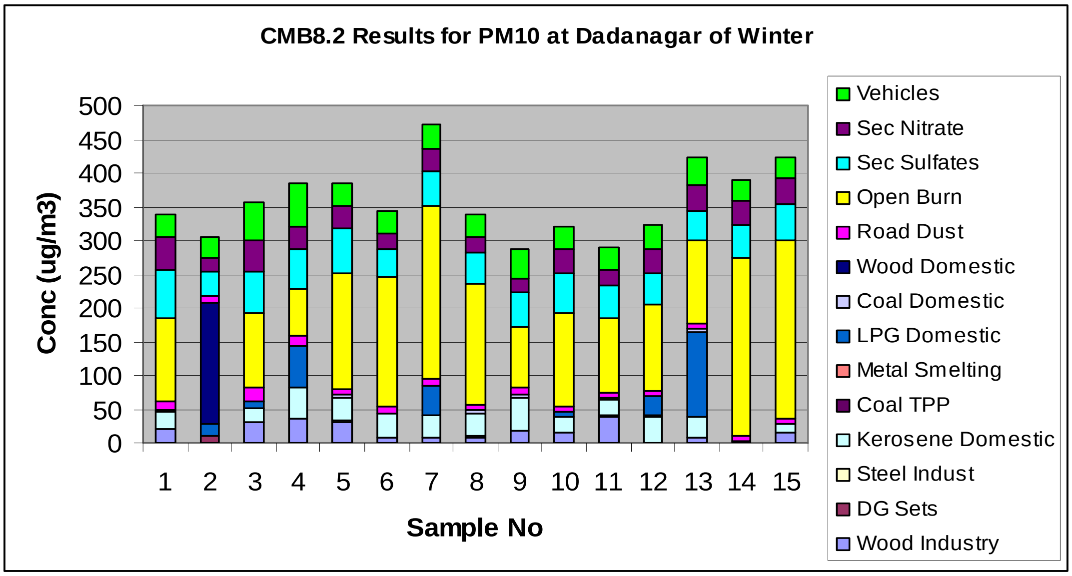
Figure 4.11: Results of CMB Modeling at Dadanagar for Post-monsoon Season

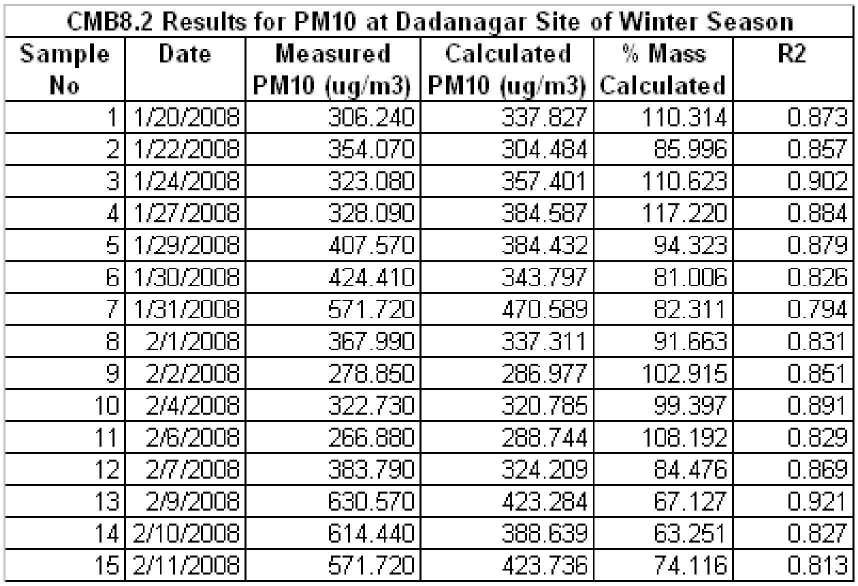


CMB8.2 Results for PM10 at Dadanagar Site of Post-mon Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	11/8/2007	424.160	258.163	60.864	0.688
2	11/11/2007	167.410	229.827	137.284	0.913
3	11/12/2007	167.890	219.590	130.794	0.846
4	11/18/2007	247.730	228.807	92.361	0.791
5	11/20/2007	279.180	286.170	102.504	0.712
6	11/24/2007	436.560	443.239	101.530	0.682
7	11/25/2007	445.940	528.736	118.567	0.874
8	11/26/2007	423.160	444.356	105.009	0.869
9	11/27/2007	441.720	427.945	96.882	0.873
10	11/28/2007	629.150	463.313	73.641	0.886
11	11/30/2007	486.340	242.816	49.927	0.880
12	12/3/2007	309.680	286.722	92.586	0.864

Figure 4.12: Results of CMB Modeling at Dadanagar for Winter Season

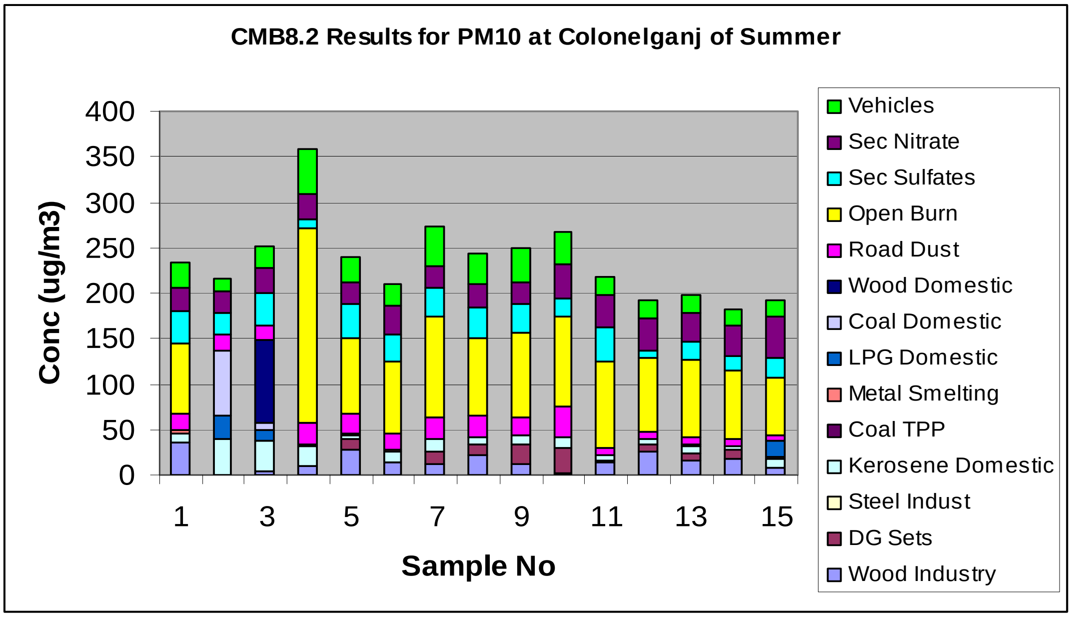


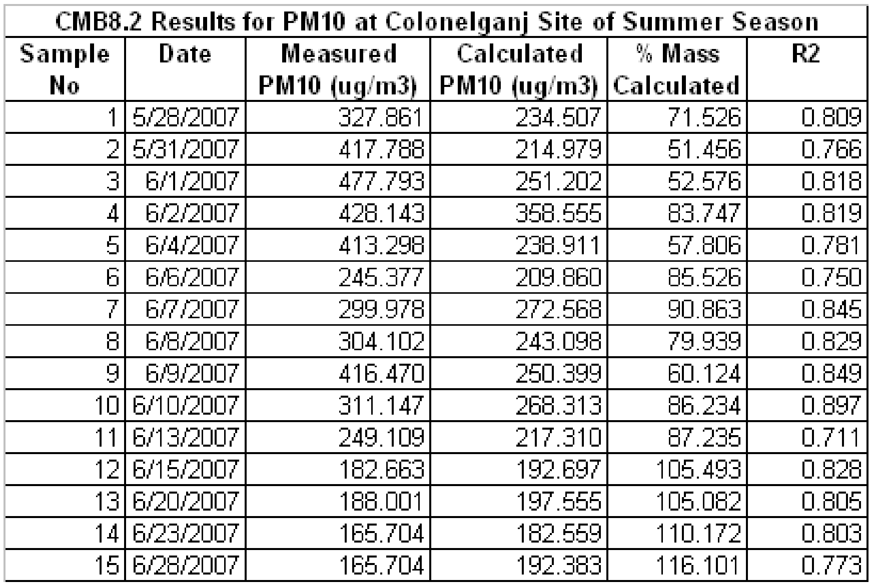


CMB8.2 Results for PM10 at Dadanagar Site of Winter Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	1/20/2008	306.240	337.827	110.314	0.873
2	1/22/2008	354.070	304.484	85.996	0.857
3	1/24/2008	323.080	357.401	110.623	0.902
4	1/27/2008	328.090	384.587	117.220	0.884
5	1/29/2008	407.570	384.432	94.323	0.879
6	1/30/2008	424.410	343.797	81.006	0.826
7	1/31/2008	571.720	470.589	82.311	0.794
8	2/1/2008	367.990	337.311	91.663	0.831
9	2/2/2008	278.850	286.977	102.915	0.851
10	2/4/2008	322.730	320.785	99.397	0.891
11	2/6/2008	266.880	288.744	108.192	0.829
12	2/7/2008	383.790	324.209	84.476	0.869
13	2/9/2008	630.570	423.284	67.127	0.921
14	2/10/2008	614.440	388.639	63.251	0.827
15	2/11/2008	571.720	423.736	74.116	0.813

Figure 4.13: Results of CMB Modeling at Colonelganj for Summer Season

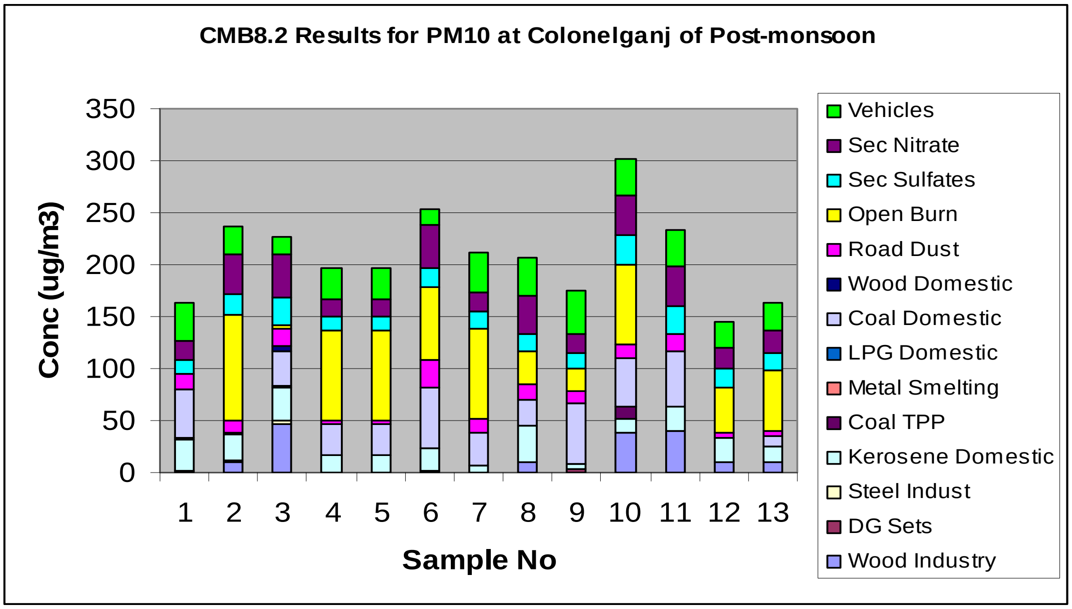


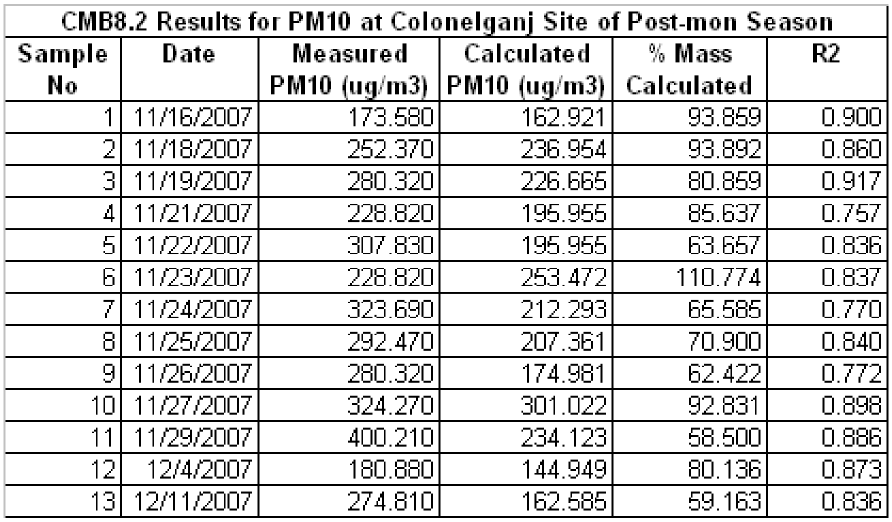


CMB8.2 Results for PM10 at Colonelganj Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	5/28/2007	327.861	234.507	71.526	0.809
2	5/31/2007	417.788	214.979	51.456	0.766
3	6/1/2007	477.793	251.202	52.576	0.818
4	6/2/2007	428.143	358.555	83.747	0.819
5	6/4/2007	413.298	238.911	57.806	0.781
6	6/6/2007	245.377	209.860	85.526	0.750
7	6/7/2007	299.978	272.568	90.863	0.845
8	6/8/2007	304.102	243.098	79.939	0.829
9	6/9/2007	416.470	250.399	60.124	0.849
10	6/10/2007	311.147	268.313	86.234	0.897
11	6/13/2007	249.109	217.310	87.235	0.711
12	6/15/2007	182.663	192.697	105.493	0.828
13	6/20/2007	188.001	197.555	105.082	0.805
14	6/23/2007	165.704	182.559	110.172	0.803
15	6/28/2007	165.704	192.383	116.101	0.773

Figure 4.14: Results of CMB Modeling at Colonelganj for Post-monsoon Season

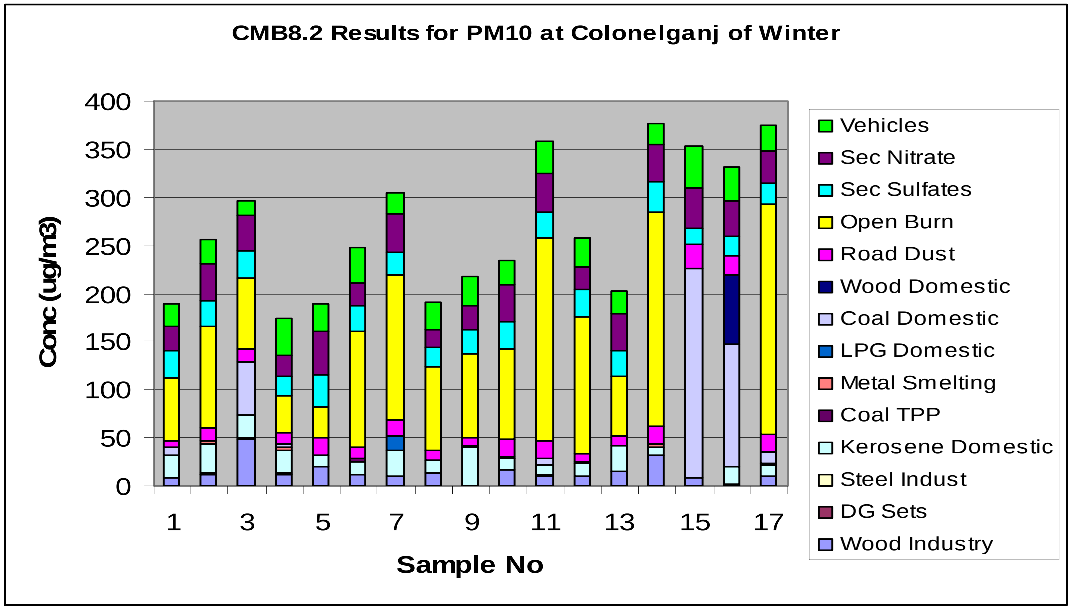


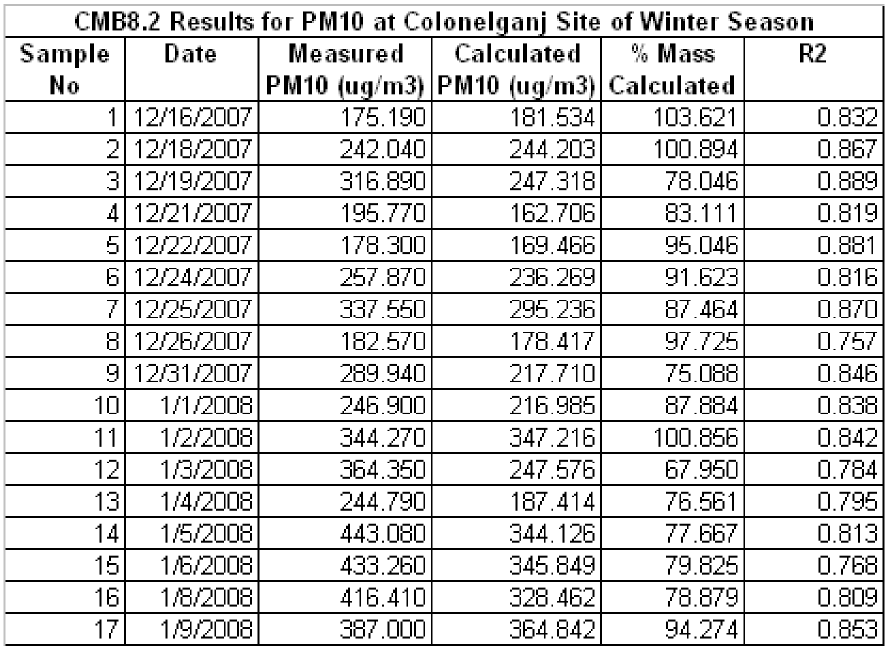


CMB8.2 Results for PM10 at Colonelganj Site of Post-mon Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	11/16/2007	173.580	162.921	93.859	0.900
2	11/18/2007	252.370	236.954	93.892	0.860
3	11/19/2007	280.320	226.665	80.859	0.917
4	11/21/2007	228.820	195.955	85.637	0.757
5	11/22/2007	307.830	195.955	63.657	0.836
6	11/23/2007	228.820	253.472	110.774	0.837
7	11/24/2007	323.690	212.293	65.585	0.770
8	11/25/2007	292.470	207.361	70.900	0.840
9	11/26/2007	280.320	174.981	62.422	0.772
10	11/27/2007	324.270	301.022	92.831	0.898
11	11/29/2007	400.210	234.123	58.500	0.886
12	12/4/2007	180.880	144.949	80.136	0.873
13	12/11/2007	274.810	162.585	59.163	0.836

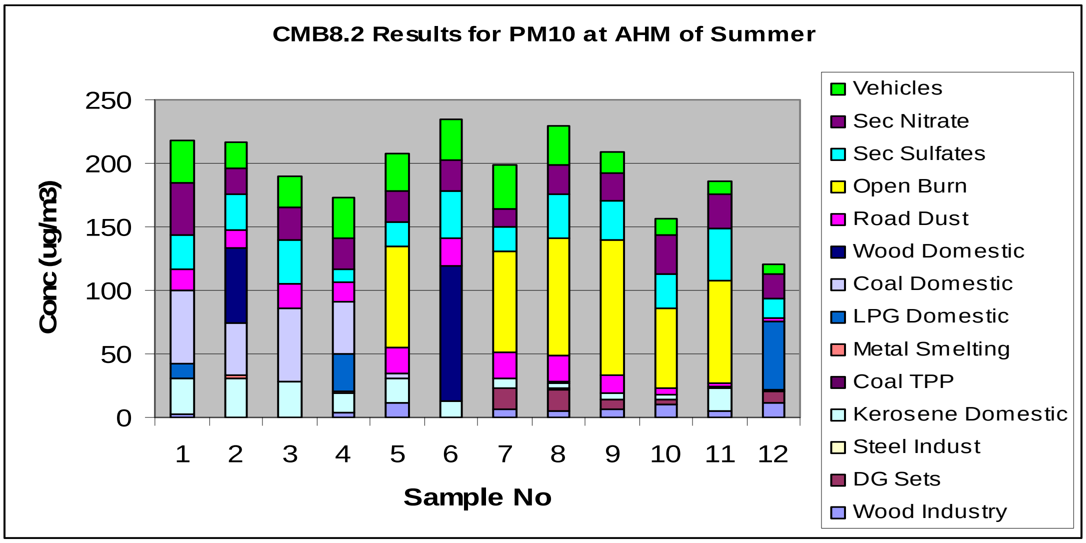
Figure 4.15: Results of CMB Modeling at Colonelganj for Winter Season

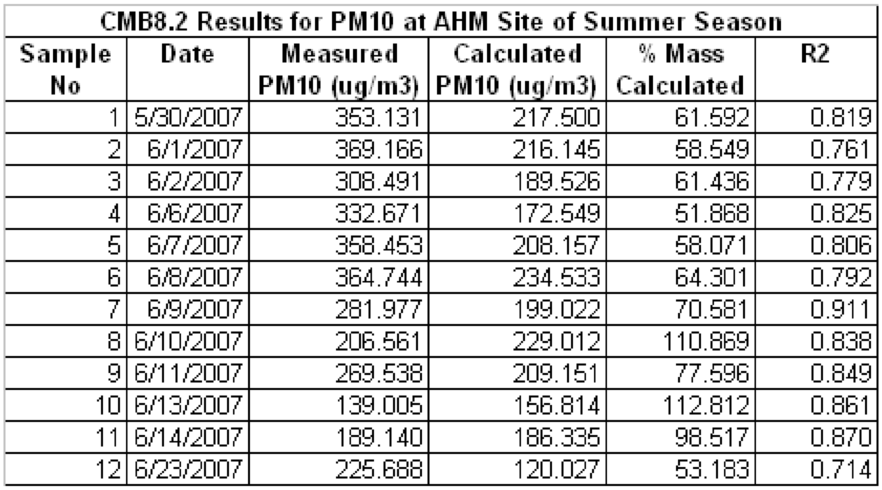




CMB8.2 Results for PM10 at Colonelganj Site of Winter Season					
Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	12/16/2007	175.190	181.534	103.621	0.832
2	12/18/2007	242.040	244.203	100.894	0.867
3	12/19/2007	316.890	247.318	78.046	0.889
4	12/21/2007	195.770	162.706	83.111	0.819
5	12/22/2007	178.300	169.466	95.046	0.881
6	12/24/2007	257.870	236.269	91.623	0.816
7	12/25/2007	337.550	295.236	87.464	0.870
8	12/26/2007	182.570	178.417	97.725	0.757
9	12/31/2007	289.940	217.710	75.088	0.846
10	1/1/2008	246.900	216.985	87.884	0.838
11	1/2/2008	344.270	347.216	100.856	0.842
12	1/3/2008	364.350	247.576	67.950	0.784
13	1/4/2008	244.790	187.414	76.561	0.795
14	1/5/2008	443.080	344.126	77.667	0.813
15	1/6/2008	433.260	345.849	79.825	0.768
16	1/8/2008	416.410	328.462	78.879	0.809
17	1/9/2008	387.000	364.842	94.274	0.853

Figure 4.16: Results of CMB Modeling at AHM for Summer Season

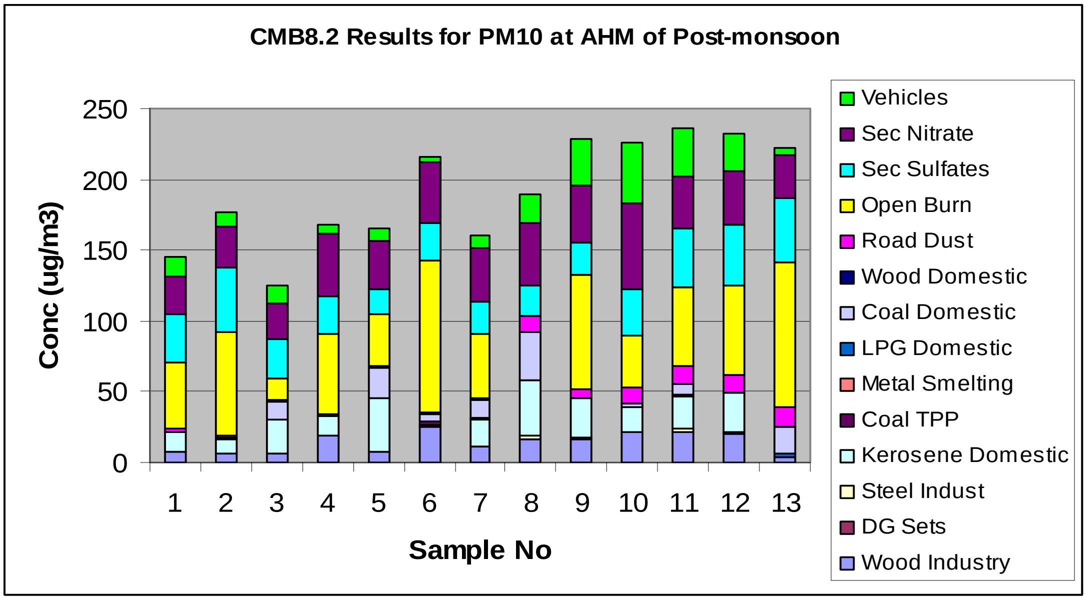


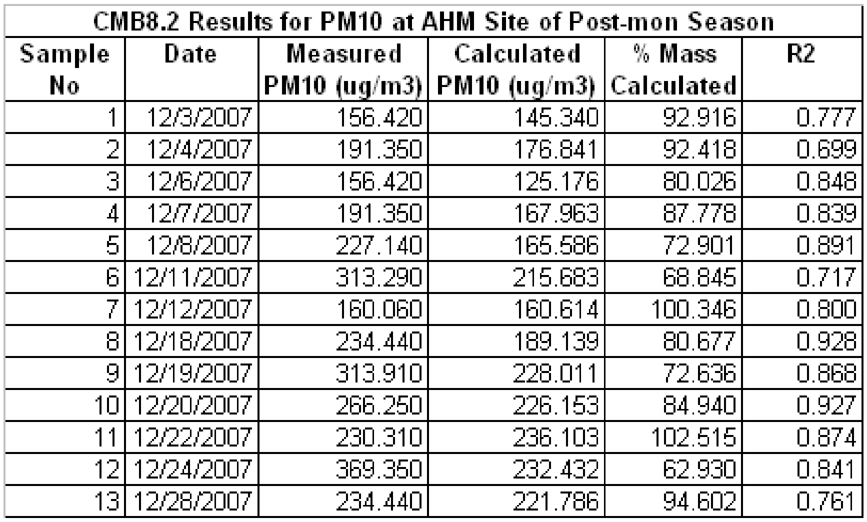


CMB8.2 Results for PM10 at AHM Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	5/30/2007	353.131	217.500	61.592	0.819
2	6/1/2007	369.166	216.145	58.549	0.761
3	6/2/2007	308.491	189.526	61.436	0.779
4	6/6/2007	332.671	172.549	51.868	0.825
5	6/7/2007	358.453	208.157	58.071	0.806
6	6/8/2007	364.744	234.533	64.301	0.792
7	6/9/2007	281.977	199.022	70.581	0.911
8	6/10/2007	206.561	229.012	110.869	0.838
9	6/11/2007	269.538	209.151	77.596	0.849
10	6/13/2007	139.005	156.814	112.812	0.861
11	6/14/2007	189.140	186.335	98.517	0.870
12	6/23/2007	225.688	120.027	53.183	0.714

Figure 4.17: Results of CMB Modeling at AHM for Post-monsoon Season

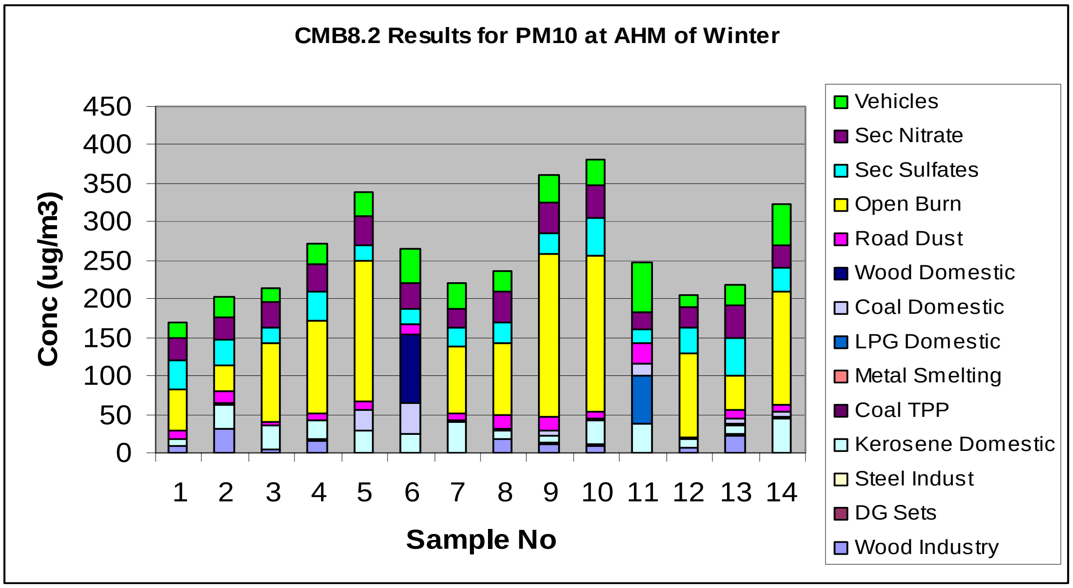


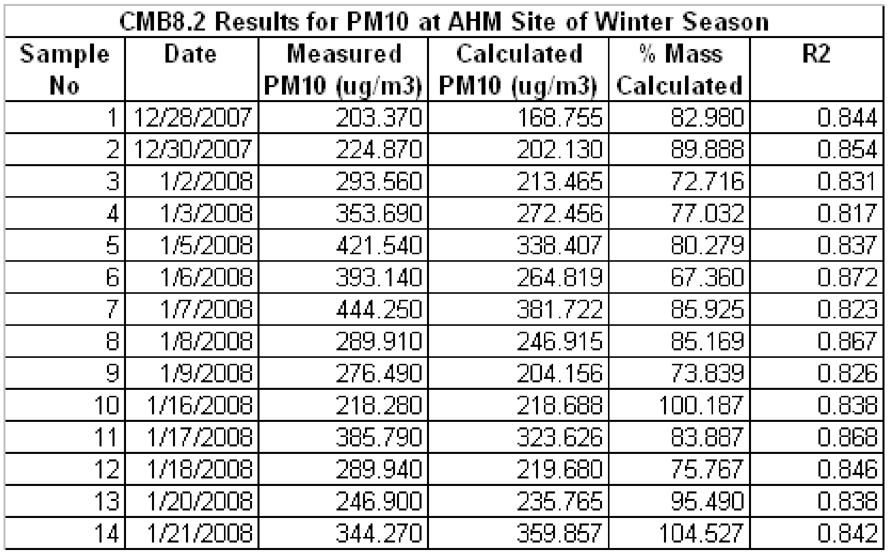


CMB8.2 Results for PM10 at AHM Site of Post-mon Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	12/3/2007	156.420	145.340	92.916	0.777
2	12/4/2007	191.350	176.841	92.418	0.699
3	12/6/2007	156.420	125.176	80.026	0.848
4	12/7/2007	191.350	167.963	87.778	0.839
5	12/8/2007	227.140	165.586	72.901	0.891
6	12/11/2007	313.290	215.683	68.845	0.717
7	12/12/2007	160.060	160.614	100.346	0.800
8	12/18/2007	234.440	189.139	80.677	0.928
9	12/19/2007	313.910	228.011	72.636	0.868
10	12/20/2007	266.250	226.153	84.940	0.927
11	12/22/2007	230.310	236.103	102.515	0.874
12	12/24/2007	369.350	232.432	62.930	0.841
13	12/28/2007	234.440	221.786	94.602	0.761

Figure 4.18: Results of CMB Modeling at AHM for Winter Season

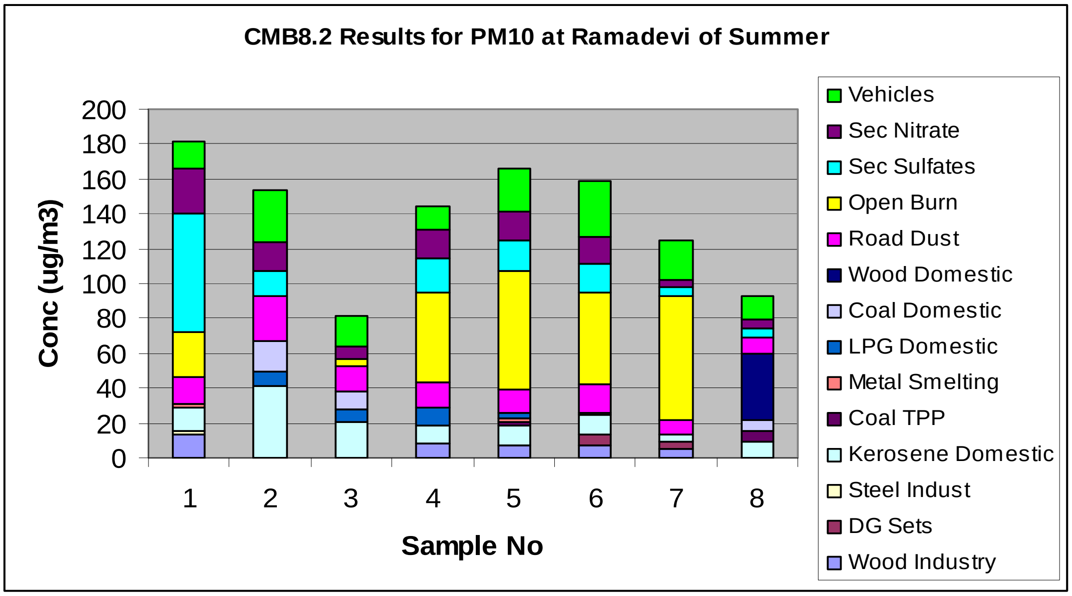


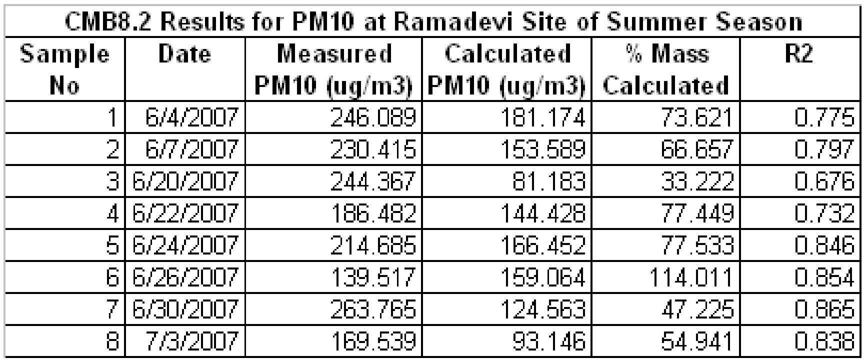


CMB8.2 Results for PM10 at AHM Site of Winter Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	12/28/2007	203.370	168.755	82.980	0.844
2	12/30/2007	224.870	202.130	89.888	0.854
3	1/2/2008	293.560	213.465	72.716	0.831
4	1/3/2008	353.690	272.456	77.032	0.817
5	1/5/2008	421.540	338.407	80.279	0.837
6	1/6/2008	393.140	264.819	67.360	0.872
7	1/7/2008	444.250	381.722	85.925	0.823
8	1/8/2008	289.910	246.915	85.169	0.867
9	1/9/2008	276.490	204.156	73.839	0.826
10	1/16/2008	218.280	218.688	100.187	0.838
11	1/17/2008	385.790	323.626	83.887	0.868
12	1/18/2008	289.940	219.680	75.767	0.846
13	1/20/2008	246.900	235.765	95.490	0.838
14	1/21/2008	344.270	359.857	104.527	0.842

Figure 4.19: Results of CMB Modeling at Ramadevi for Summer Season

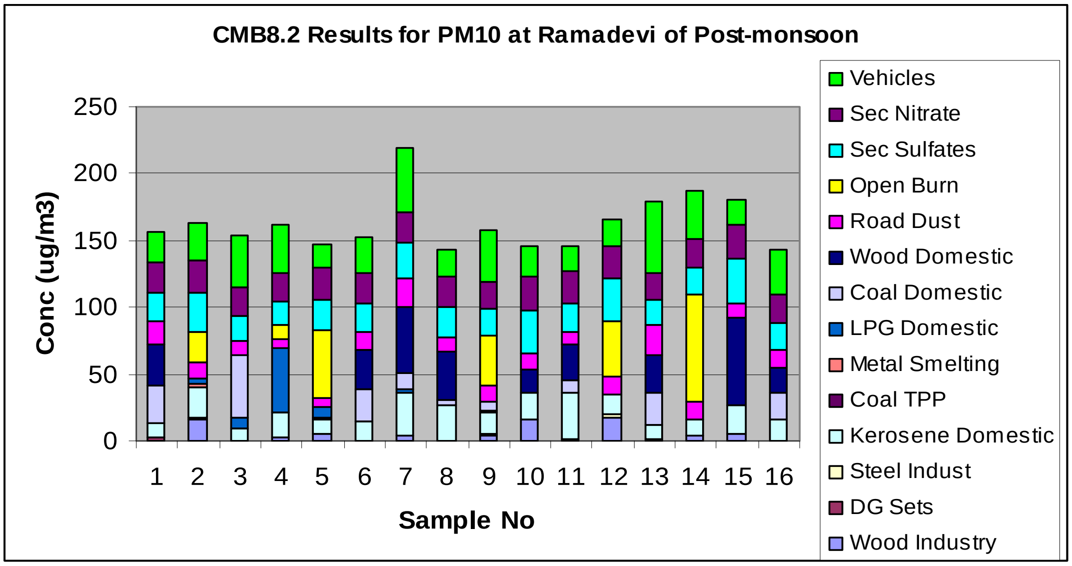


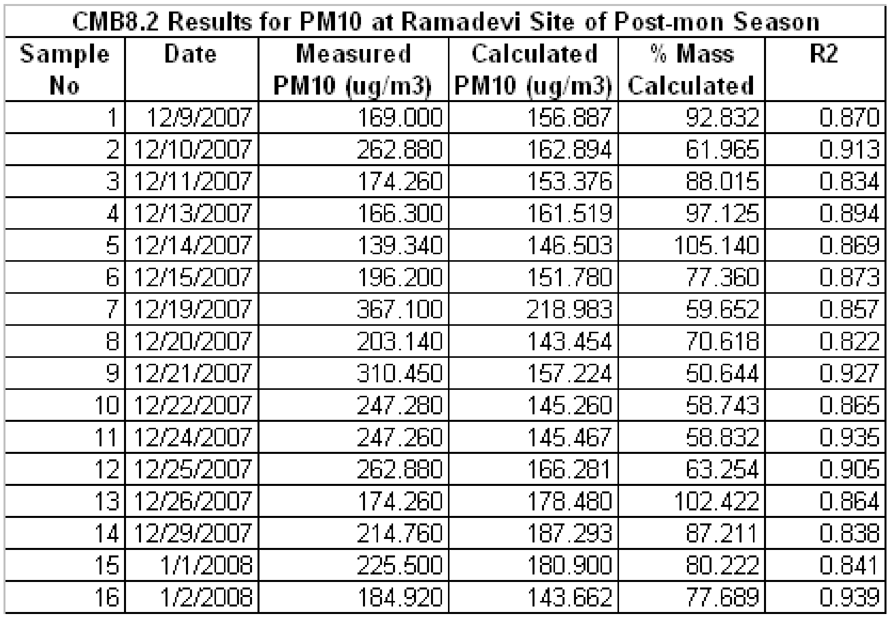


CMB8.2 Results for PM10 at Ramadevi Site of Summer Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	6/4/2007	246.089	181.174	73.621	0.775
2	6/7/2007	230.415	153.589	66.657	0.797
3	6/20/2007	244.367	81.183	33.222	0.676
4	6/22/2007	186.482	144.428	77.449	0.732
5	6/24/2007	214.685	166.452	77.533	0.846
6	6/26/2007	139.517	159.064	114.011	0.854
7	6/30/2007	263.765	124.563	47.225	0.865
8	7/3/2007	169.539	93.146	54.941	0.838

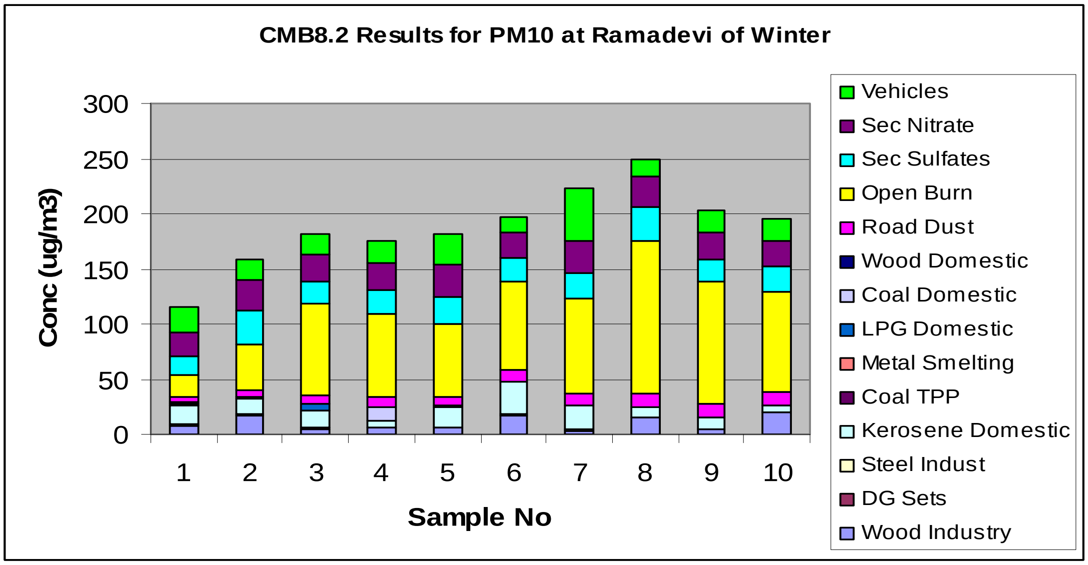
Figure 4.20: Results of CMB Modeling at Ramadevi for Post-monsoon Season

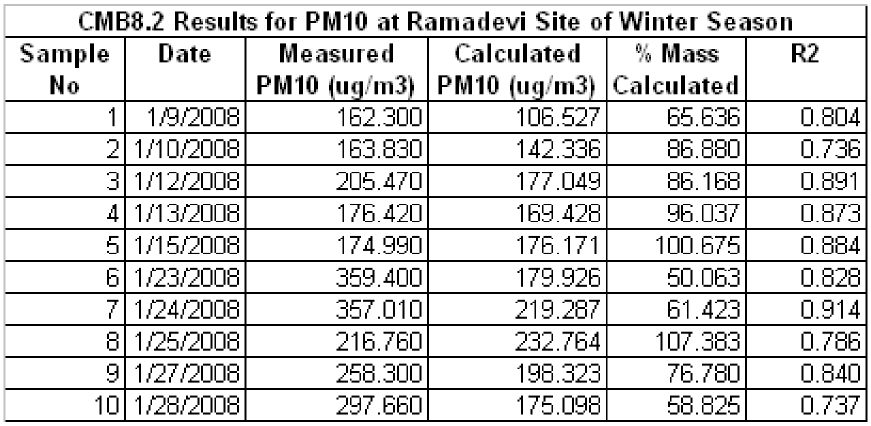




CMB8.2 Results for PM10 at Ramadevi Site of Post-mon Season					
Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	12/9/2007	169.000	156.887	92.832	0.870
2	12/10/2007	262.880	162.894	61.965	0.913
3	12/11/2007	174.260	153.376	88.015	0.834
4	12/13/2007	166.300	161.519	97.125	0.894
5	12/14/2007	139.340	146.503	105.140	0.869
6	12/15/2007	196.200	151.780	77.360	0.873
7	12/19/2007	367.100	218.983	59.652	0.857
8	12/20/2007	203.140	143.454	70.618	0.822
9	12/21/2007	310.450	157.224	50.644	0.927
10	12/22/2007	247.280	145.260	58.743	0.865
11	12/24/2007	247.260	145.467	58.832	0.935
12	12/25/2007	262.880	166.281	63.254	0.905
13	12/26/2007	174.260	178.480	102.422	0.864
14	12/29/2007	214.760	187.293	87.211	0.838
15	1/1/2008	225.500	180.900	80.222	0.841
16	1/2/2008	184.920	143.662	77.689	0.939

Figure 4.21: Results of CMB Modeling at Ramadevi for Winter Season





CMB8.2 Results for PM10 at Ramadevi Site of Winter Season

Sample No	Date	Measured PM10 (ug/m3)	Calculated PM10 (ug/m3)	% Mass Calculated	R2
1	1/9/2008	162.300	106.527	65.636	0.804
2	1/10/2008	163.830	142.336	86.880	0.736
3	1/12/2008	205.470	177.049	86.168	0.891
4	1/13/2008	176.420	169.428	96.037	0.873
5	1/15/2008	174.990	176.171	100.675	0.884
6	1/23/2008	359.400	179.926	50.063	0.828
7	1/24/2008	357.010	219.287	61.423	0.914
8	1/25/2008	216.760	232.764	107.383	0.786
9	1/27/2008	258.300	198.323	76.780	0.840
10	1/28/2008	297.660	175.098	58.825	0.737

4.4 CMB8.2 Modeling for $PM_{2.5}$

Figure 4.23 shows the results of CMB modeling for $PM_{2.5}$ source apportionment. A limited sampling was done for $PM_{2.5}$ and its composition (about 7 days sampling in each season at each locations). CMB model was run for all data set but it was found that generally on average three data points (i.e. three days) only produce a reasonable CMB modeling results (i.e. percent mass computed >= 65% and R-square >= 0.8) at each location for each season. A careful examination of Figure 4.23 concludes the following:

- Range of source contribution to $PM_{2.5}$ is: open burning (7- 23%), road dust (3 - 6%), coal (0- 13%) , vehicles (28-37%) and secondary particles (15-30%).
- Contribution by vehicles is larger in $PM_{2.5}$ (28-37%) compared to what it was in PM_{10} (10-25%).
- Contribution of secondary particles in PM_{10} and $PM_{2.5}$ are about the same (15-30 %).
- Winters is worst season followed by summer and monsoon season.
- Open burning contribution is much higher in winter months than in monsoon or winter months.

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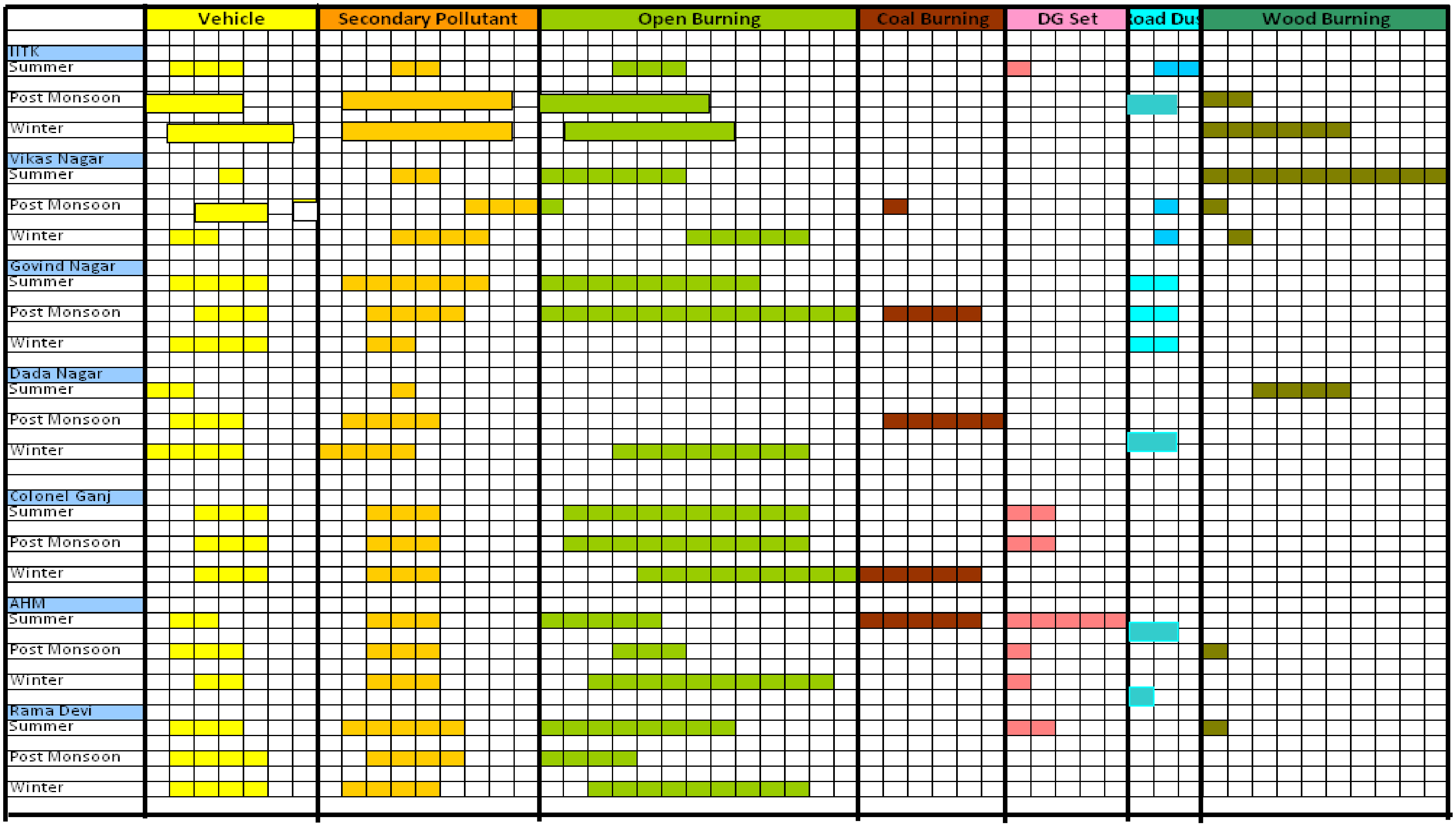
4.5 Conclusions

- There are two consistent sources contributing to PM_{10} – vehicular and secondary particle formation. Vehicular source contribution is in a narrow range of 10-25 % at all locations in all seasons. However, the contribution tends to be higher in winter season compared to summer and post-monsoon season. The consistency of vehicular source contribution is even more at three locations Colonelganj (kerbside), AHM (commercial) and Ramadevi (traffic). At these same locations, secondary particles are also consistent in the narrow range of 15-30 % of total particle mass.
- Open burning is another important source that contributes very high levels of PM_{10} but its contribution fluctuates in a wide range of 0-65 %. What is noteworthy is the fact that this source contributes the most in the winter season. It is understandable that the open garbage burning is not an every day affair; rather it is a function of

collected amount of waste. Winter season is particularly critical source for open burning (garbage, plastic, refuse, leaves agricultural residue etc.).

- Road dust was expected to be major contributing source, however, its contribution is only limited to 5-10 percent.
- A few locations, especially, the commercial areas (AHM) show significant contribution of 5-25 % to PM_{10} from DG sets; this source is prominent in summer season.
- Coal combustion related contribution is prominent in industrial area (10-30 %) followed by commercial and kerbside locations. It is to be noted that the kerbside and commercial sites are not free of population and have many restaurants and railways station within around 2.5-3 km from the this sampling site, where coal is frequently used.
- Wood burning is also important source that contributes to PM_{10} but it is mostly limited to outskirt of the city (e.g. at IITK and Vikasnagar)
- In general, sources identified by factor analysis match with those obtained from CMB 8.2 modelling. However, the CMB modeling did not find road dust to be as important as identified by the factor analysis as a contributor to PM_{10}.
- Range of source contribution to $PM_{2.5}$ is: open burning (7- 23%), road dust (3 - 6%), coal (0- 13%) , vehicles (28-37%) and secondary particles (15-30%).
- Contribution by vehicles is larger in $PM_{2.5}$ (28-37%) compared to what it was in PM_{10} (10-25%).

Figure 4.22: Percent range of Contribution of each Source to PM_{10} at Sampling Location in three Seasons (every square represents 5% contribution)



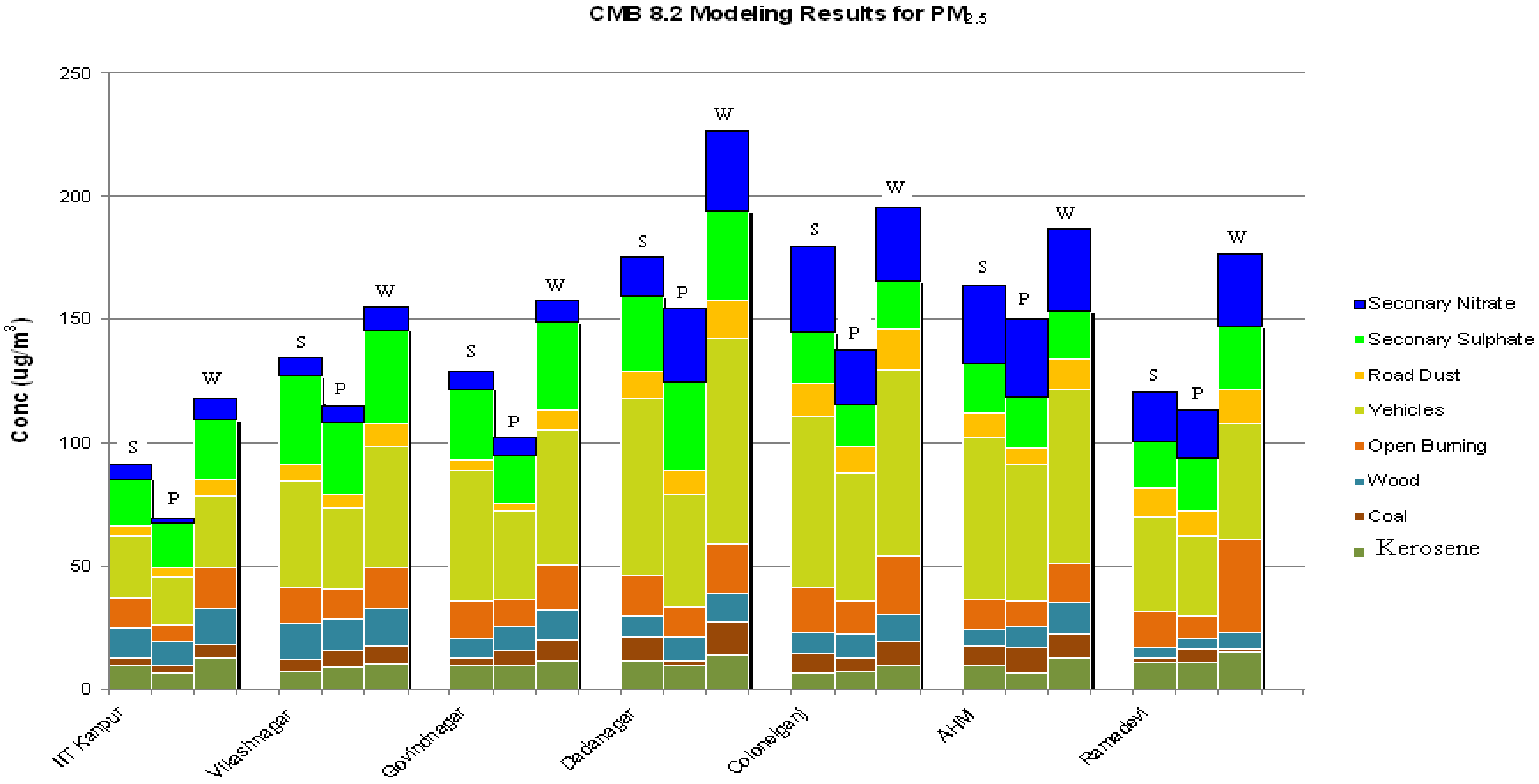


Figure 4.23: Overall Results of CMB8.2 Modeling for $PM_{2.5}$

Chapter 5

Dispersion Modeling for Existing Scenario

5.1 Methodology

USEPA's ISCST3 model was run for PM_{10} and NO_x for seven sampling sites and all other remaining grids as receptors by considering emission emanating from all the grids (presented in Chapter 3). This modeling exercise was repeated for each season and the model was also calibrated for better predictions. As far as possible, local meteorological data generated at the sampling sites were used in the modeling. However, it was not entirely possible to use the local meteorology. This also became necessary as sources from far location are unaffected by the local meteorology and there impact can best be evaluated by broad meteorology for the city, measured at a flat terrain with no disturbance around it.

The emission inventory of all the grids including those, which had sampling sites, was used. It may be noted that model was run for different days of the season (1-30 days) for each source separately to identify and interpret the impact of each sources on air quality level at the sampling site.

5.2 Modeling Results

5.2.1 Daily Modeling

Figures 5.1 to 5.7 present the predicted air quality at seven locations for PM_{10} and NO_x for summer season; lowest concentration was at background station followed by residential area, commercial area, traffic sites and the maximum concentration was at the industrial site.

As for PM_{10}, domestic, vehicular and road dust sources are the main contributors to the PM_{10} in ambient air. It may be noted that contribution of point source (e.g. large power plant) is the minimal. It may be noted that at the industrial area site (i.e. Dadanagar – Fig 5.4), the industries grouped as industrial source (area) contribute maximum PM_{10} to ambient air. At the kerb site, maximum contribution is from vehicles and followed by road-generated dust due to movement of vehicles (Fig 5.5).

As for NOx, 50-70 percent contribution is from vehicles at all sites (Fig. 5.1 to 5.7). It is only at industrial area (i.e. Dadanagar, Fig 5.4) where contribution of industries is seen and, on a few occasions, the point source (power plant) also contributes to NOx at this site. At the kerb site (Fig 5.5) and commercial site (Fig. 5.6), almost entire NOx is from vehicles,

The pattern of contribution of sources to PM_{10} and NOx in post monsoon and winter months (Figs 5.8 to 5.21) are similar to those described for summer season above, except for residential site, Vikashnagar. It was observed that at this site, the power plant is contributing significant PM_{10} and NOx on many days in post monsoon and winter (Figs 5.9 and 5.16). It may be noted that Vikashnagar location was the closest to the power plant (estimated aerial distance 4 km) and in these two seasons, most of the time wind is blowing from west and west of west-north making the Vikashnagar site to receive pollution from the power plant.

Figure 5.1: Results from ISCST3 Predictions for PM_{10} and NOx at IIT for Summer

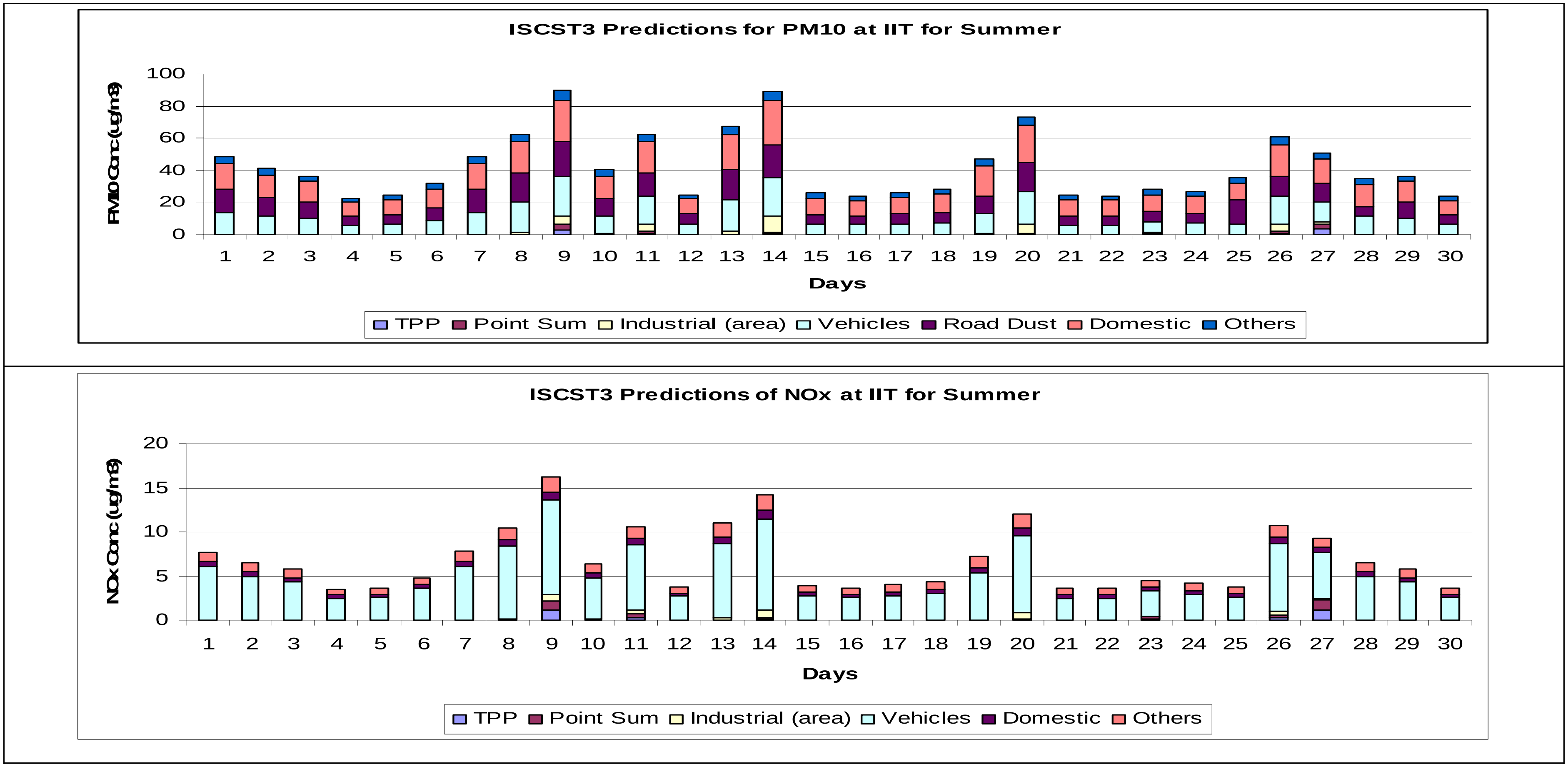


Figure 5.2: Results from ISCST3 Predictions for PM_{10} and NO_x at Vikashnagar for Summer

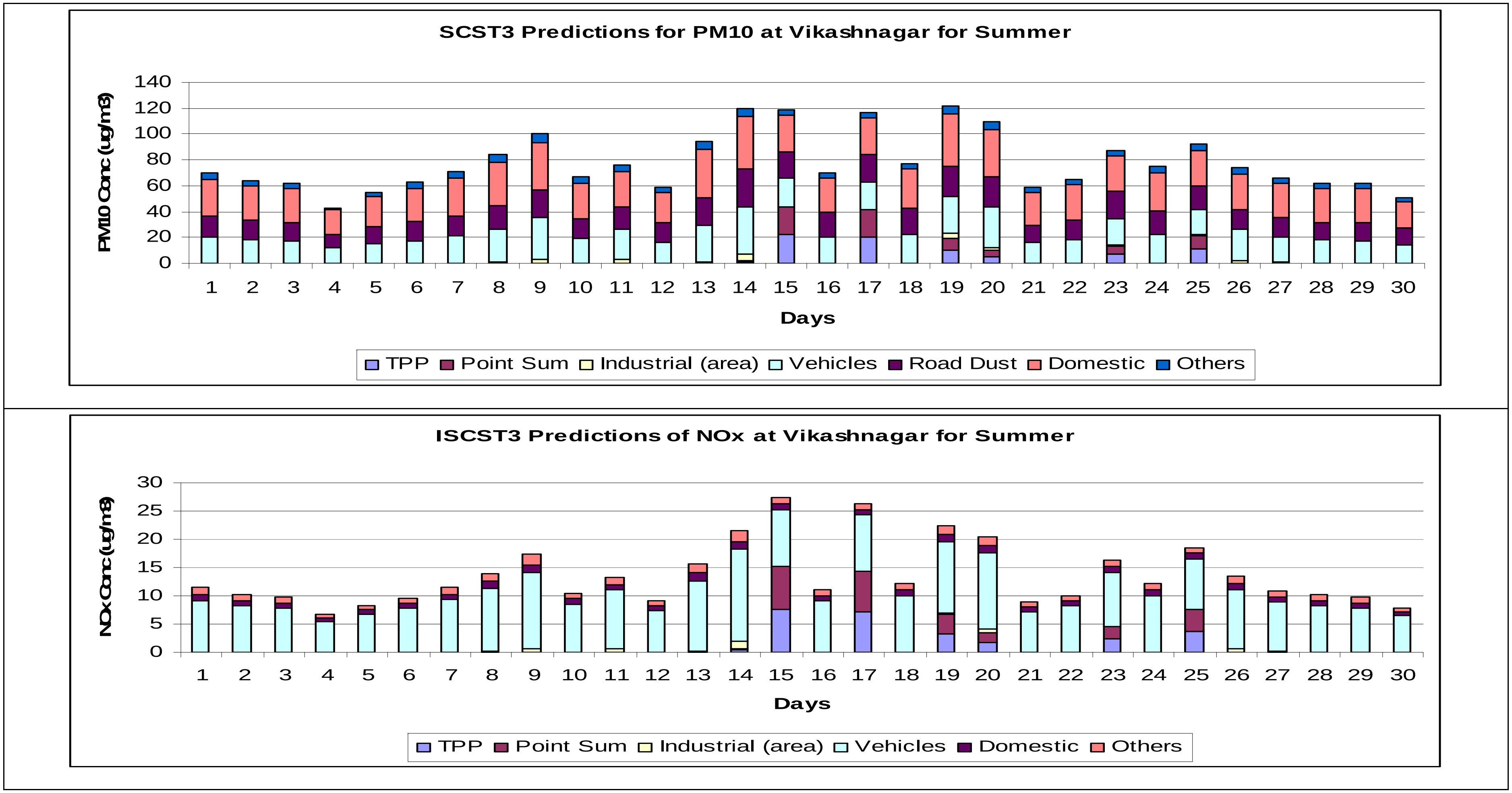


Figure 5.3: Results from ISCST3 Predictions for PM_{10} and NOx at Govindnagar for Summer

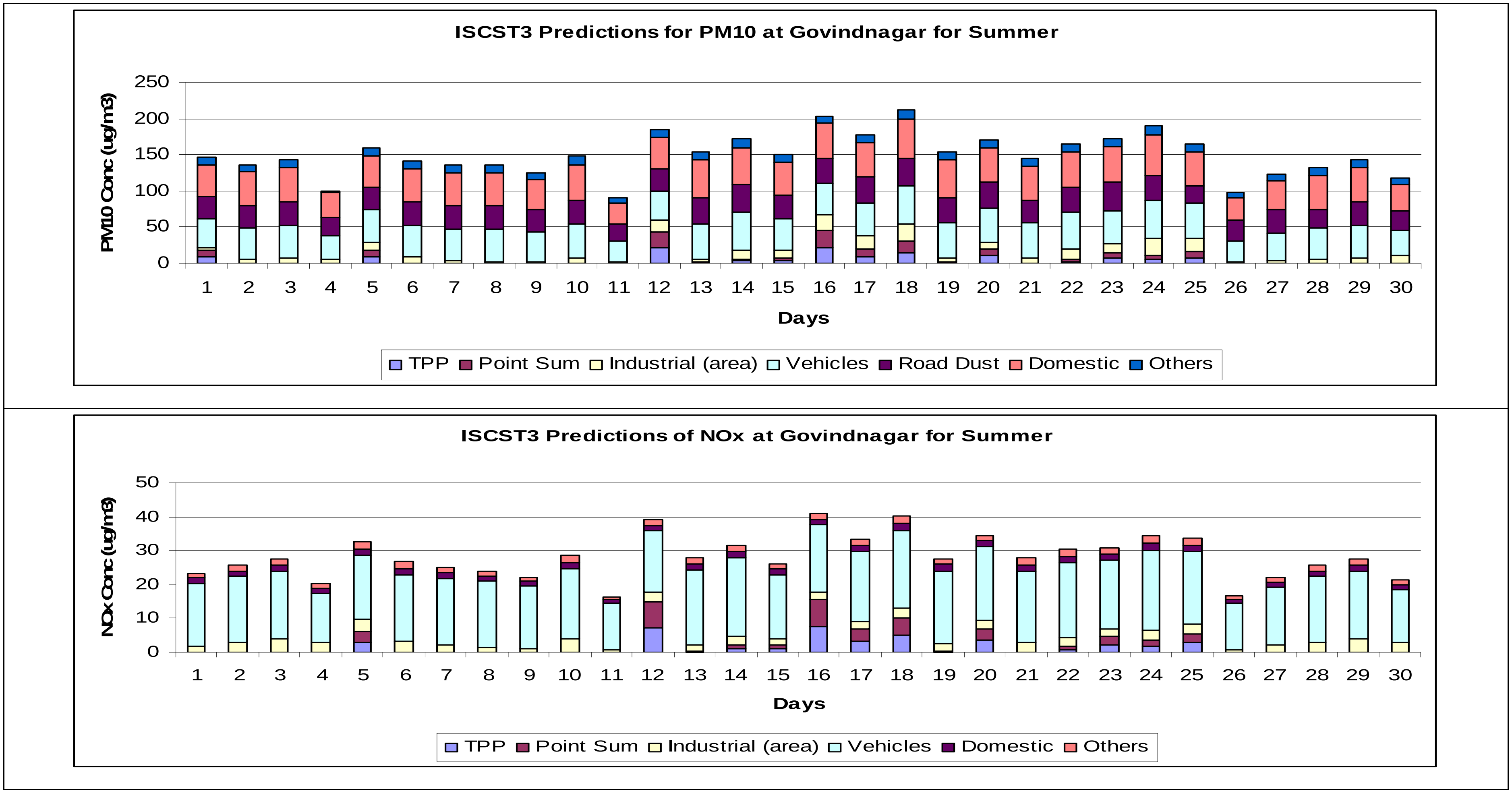


Figure 5.4: Results from ISCST3 Predictions for PM_{10} and NOx at Dadanagar for Summer

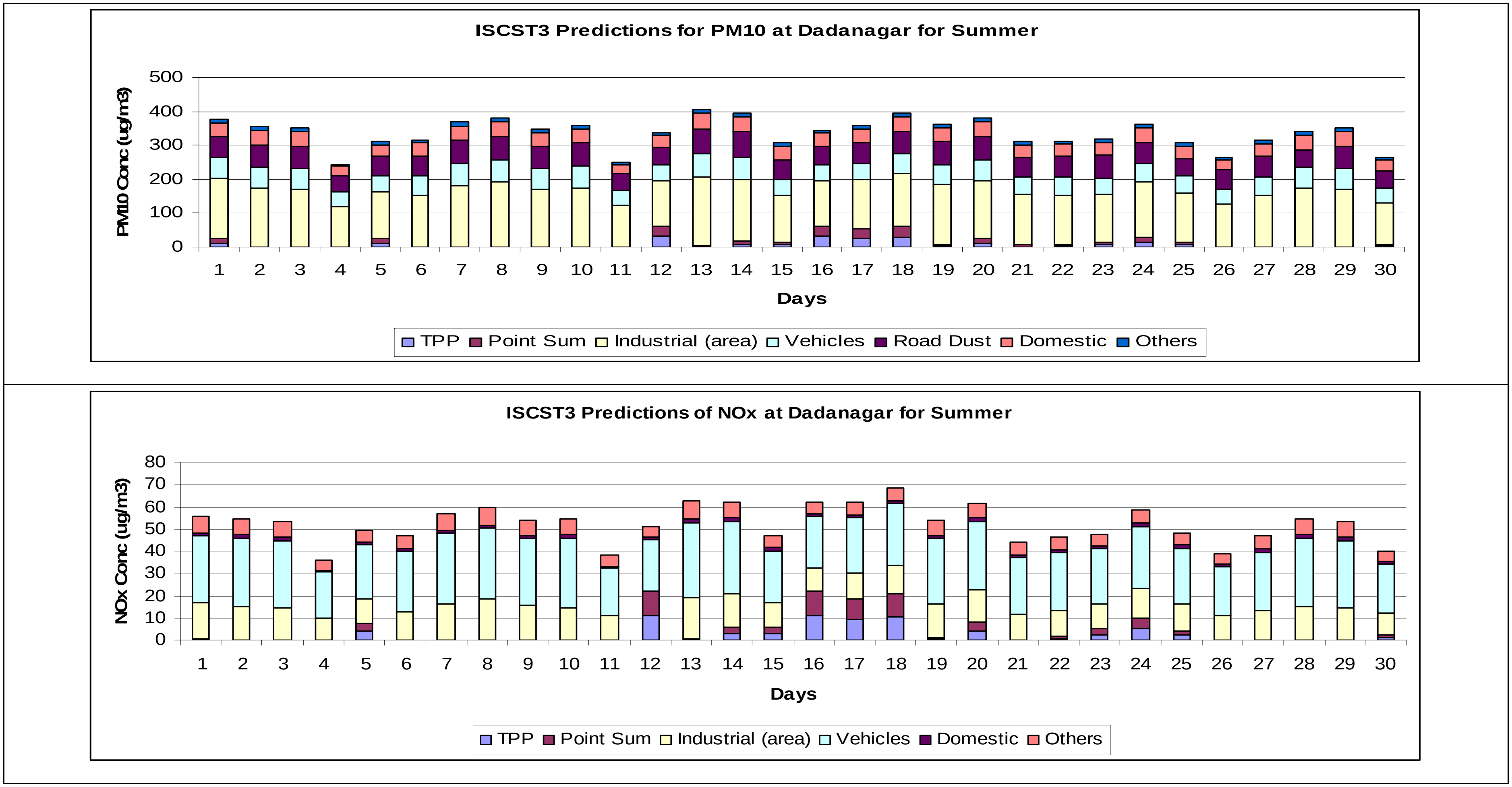


Figure 5.5: Results from ISCST3 Predictions for PM_{10} and NOx at Colonelganj for Summer

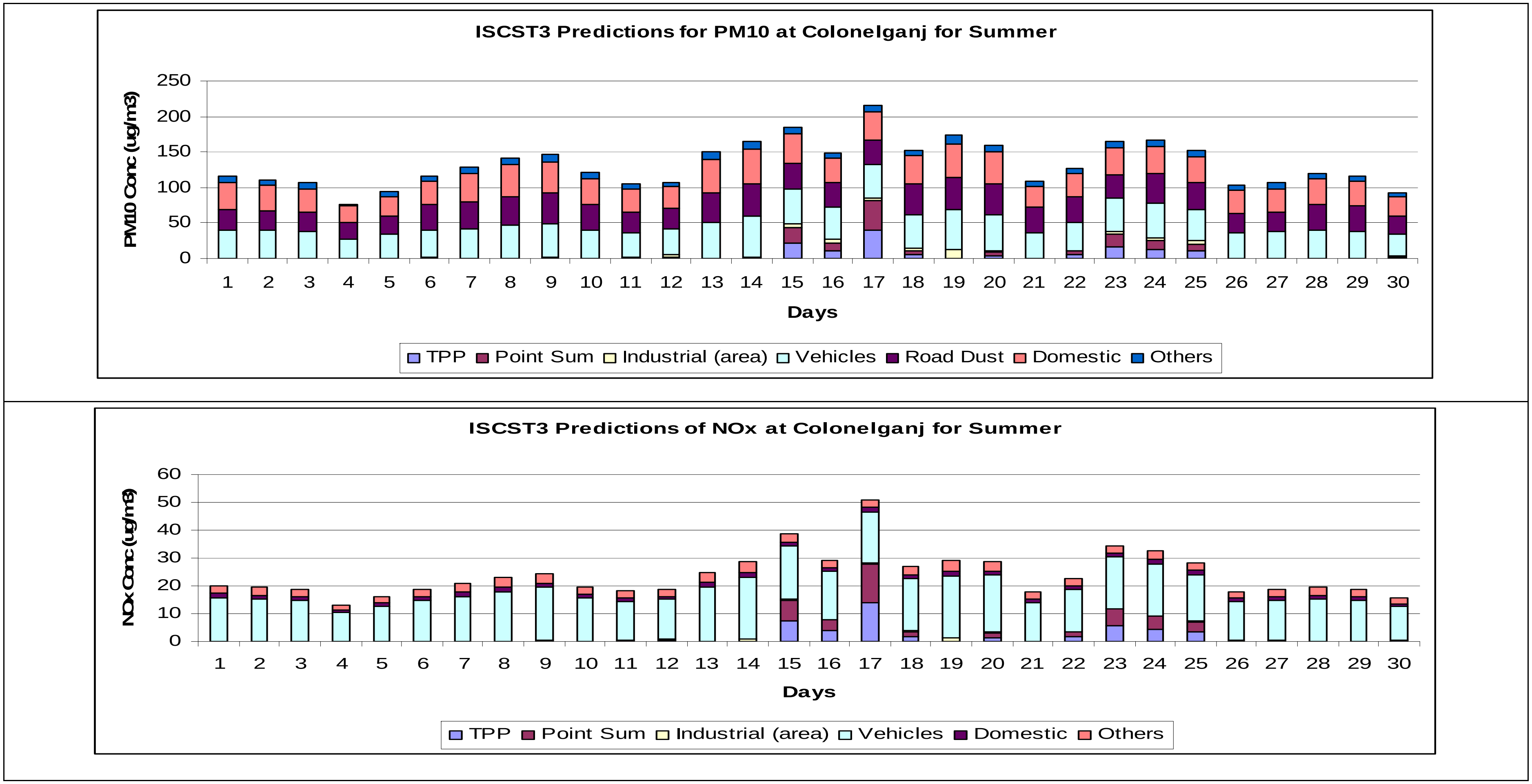


Figure 5.6: Results from ISCST3 Predictions for PM$_{10}$ and NOx at AHM for Summer

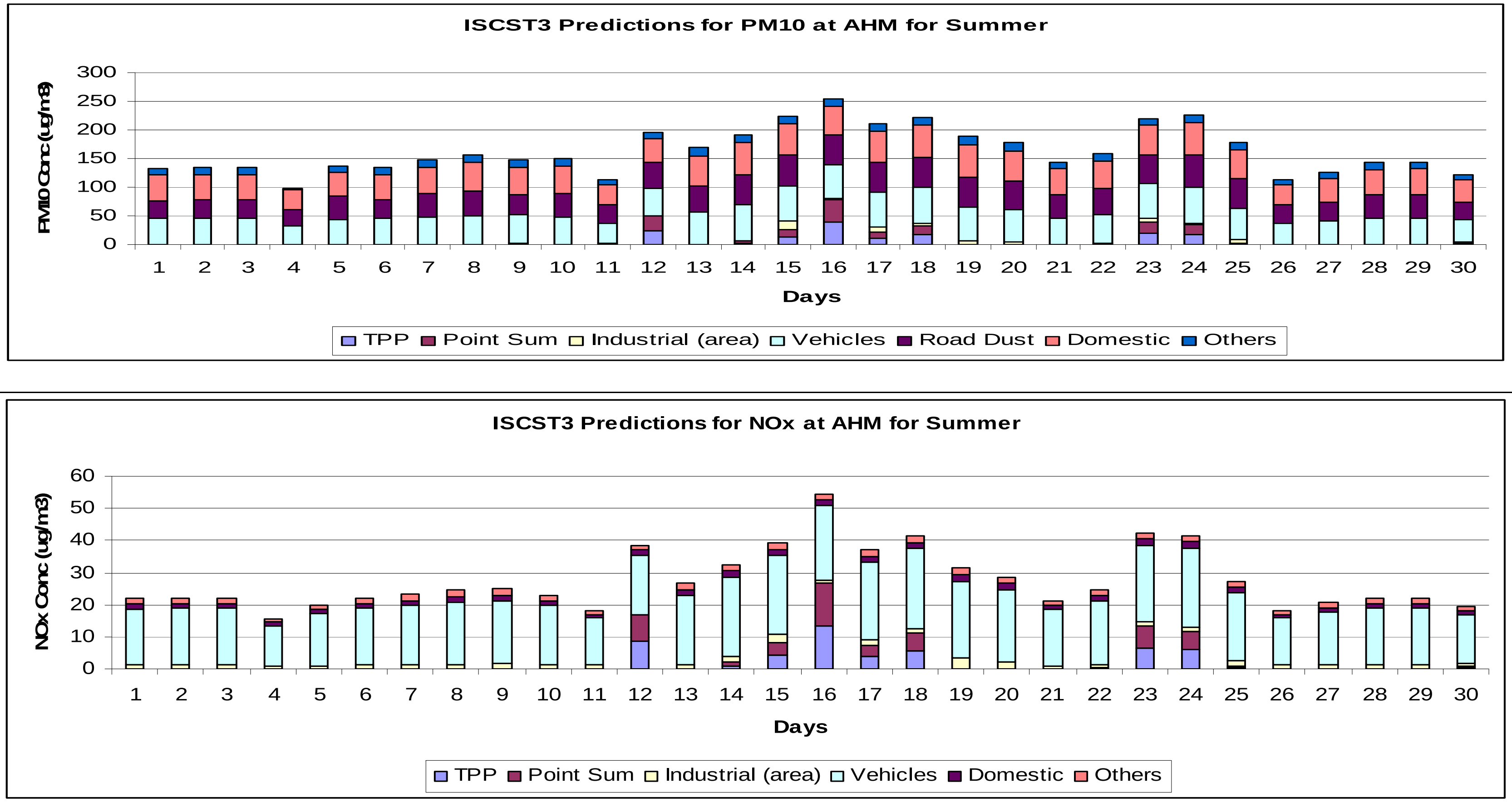


Figure 5.7: Results from ISCST3 Predictions for PM_{10} and NOx at Ramadevi for Summer

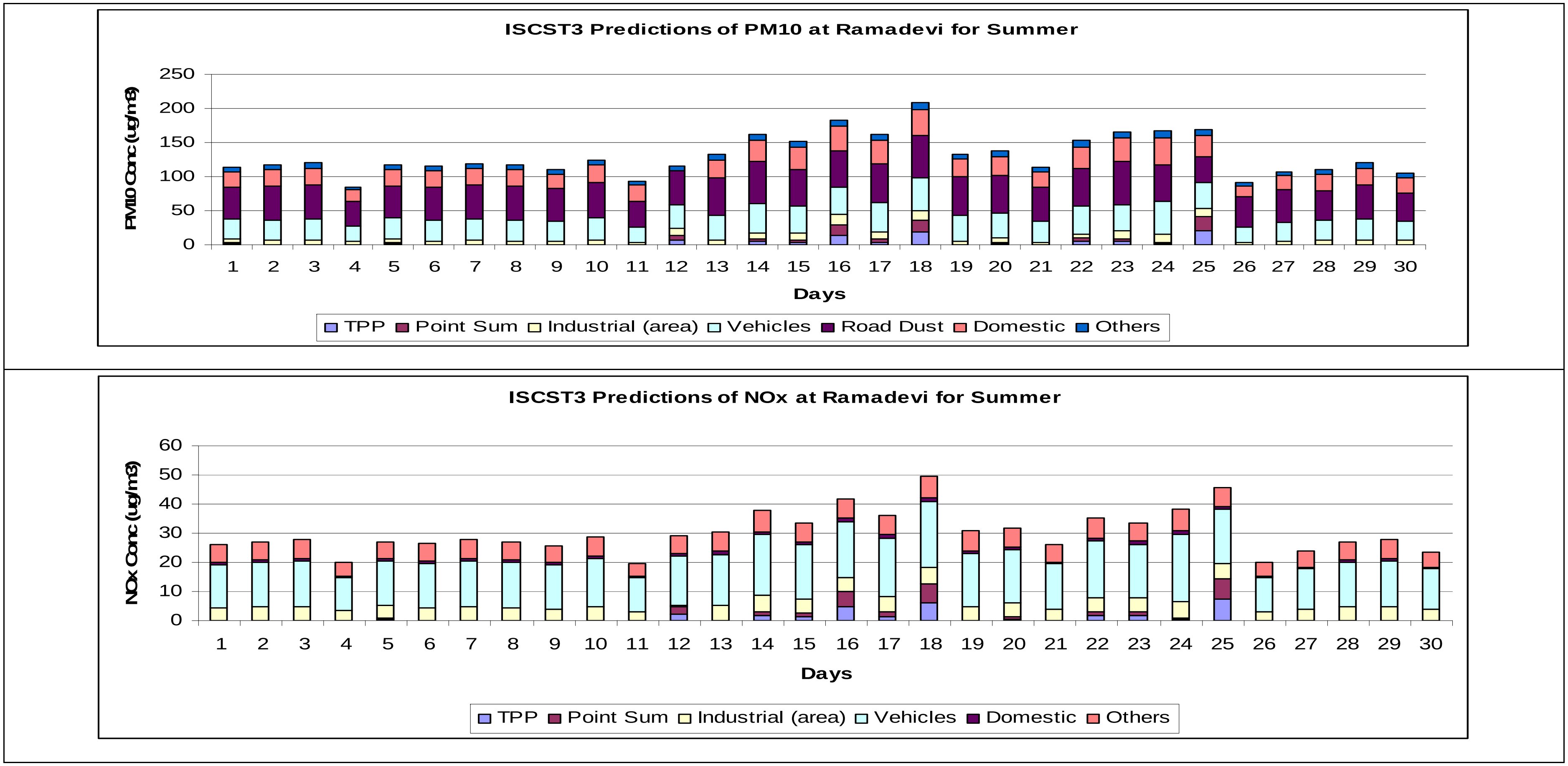


Figure 5.8: Results from ISCST3 Predictions for PM_{10} and NOx at IIT for Post-monsoon

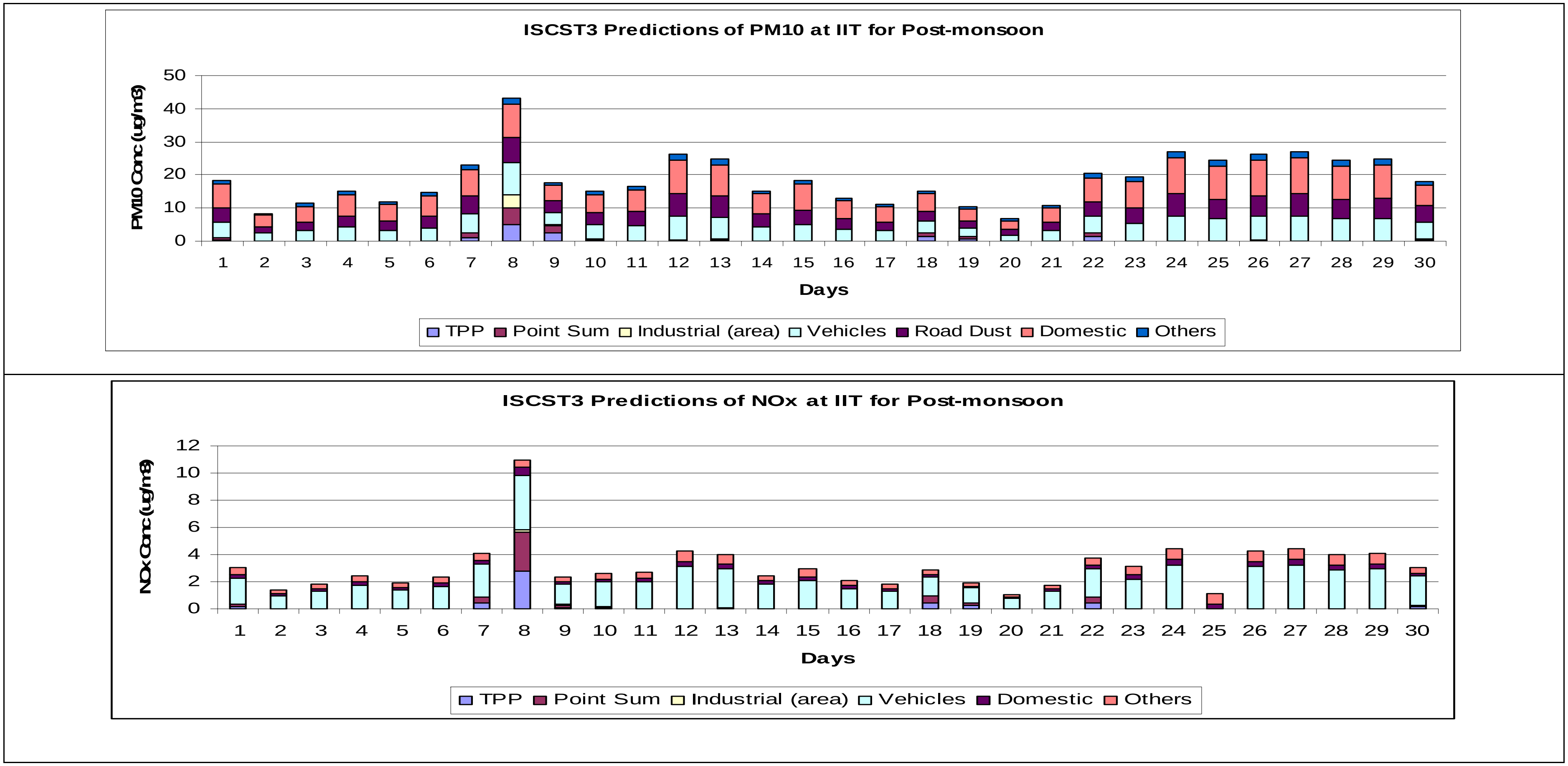


Figure 5.9: Results from ISCST3 Predictions for PM_{10} and NOx at Vikashnagar for Post-monsoon

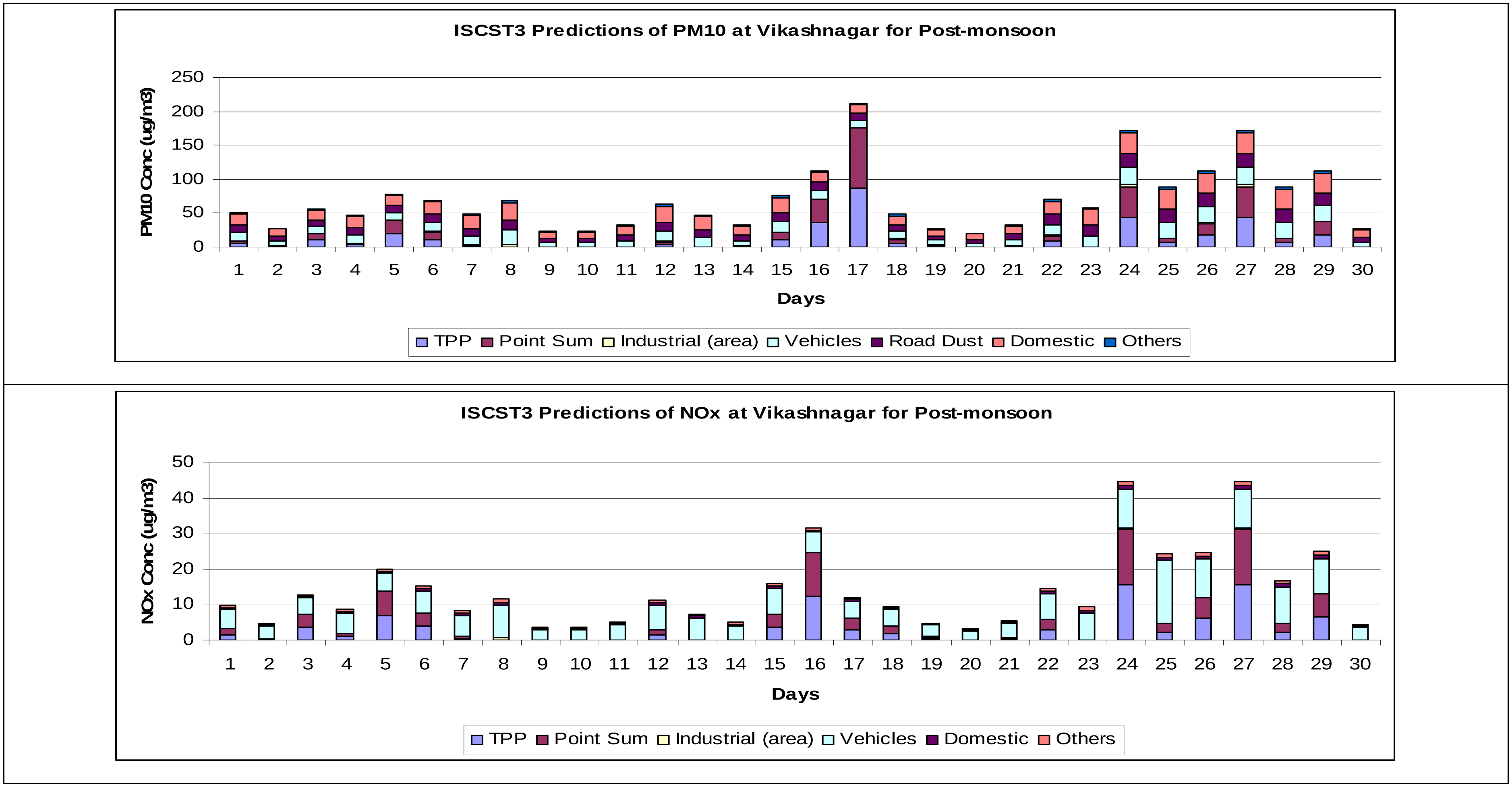


Figure 5.10: Results from ISCST3 Predictions for PM_{10} and NOx at Govindnagar for Post-monsoon

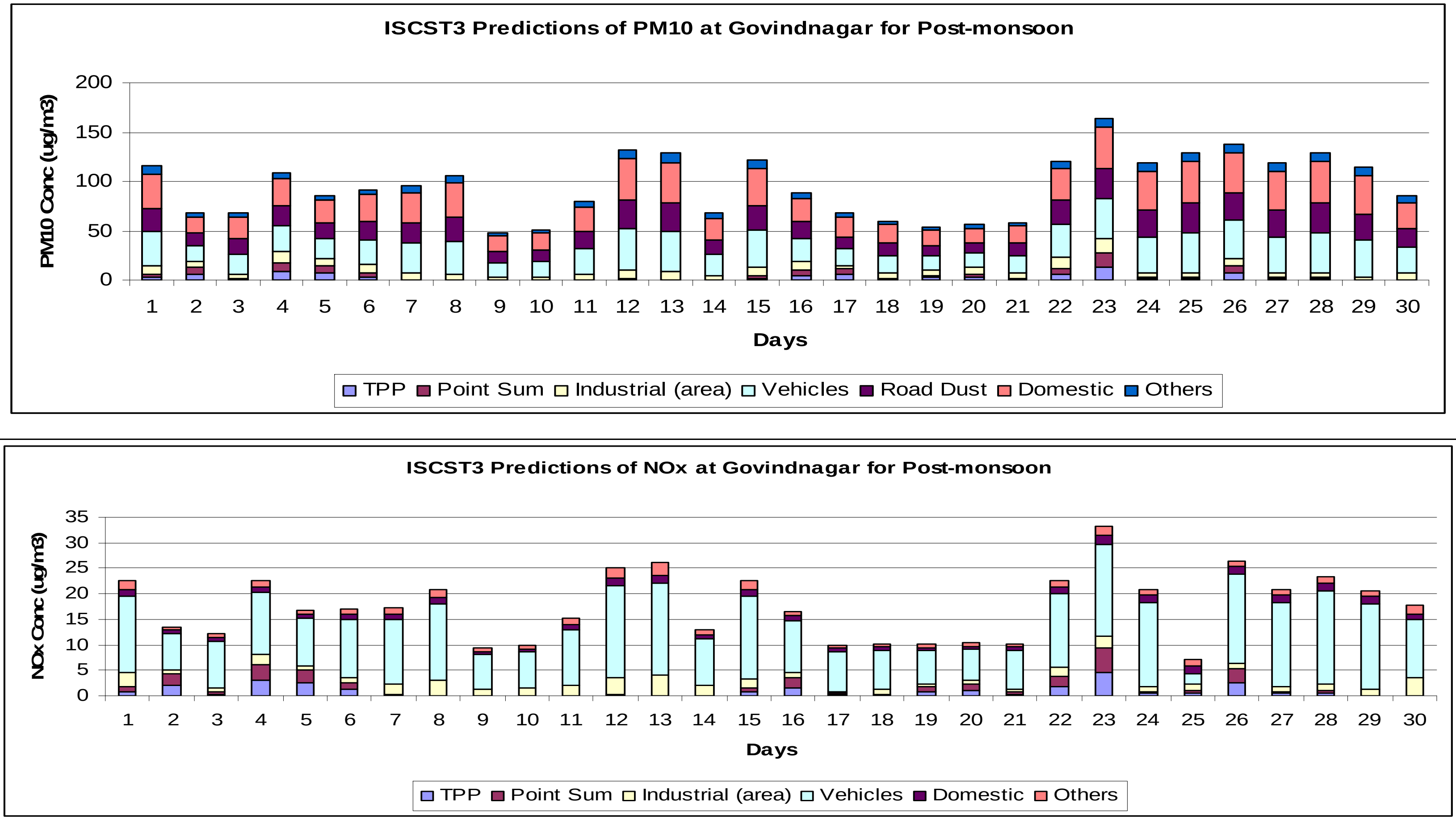
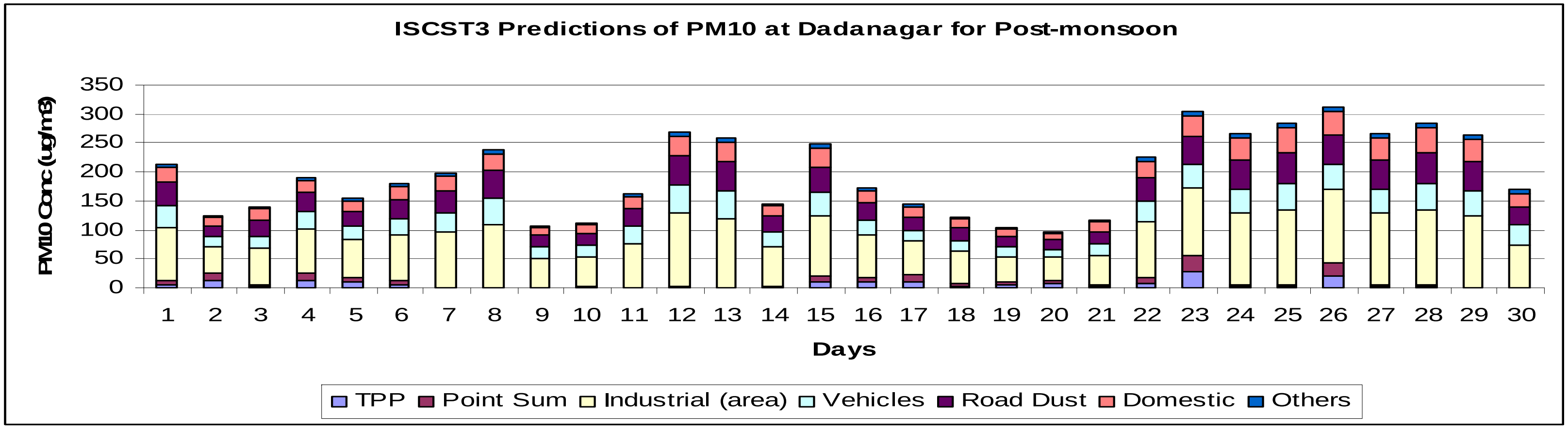


Figure 5.11: Results from ISCST3 Predictions for PM_{10} and NOx at Dadanagar for Post-monsoon



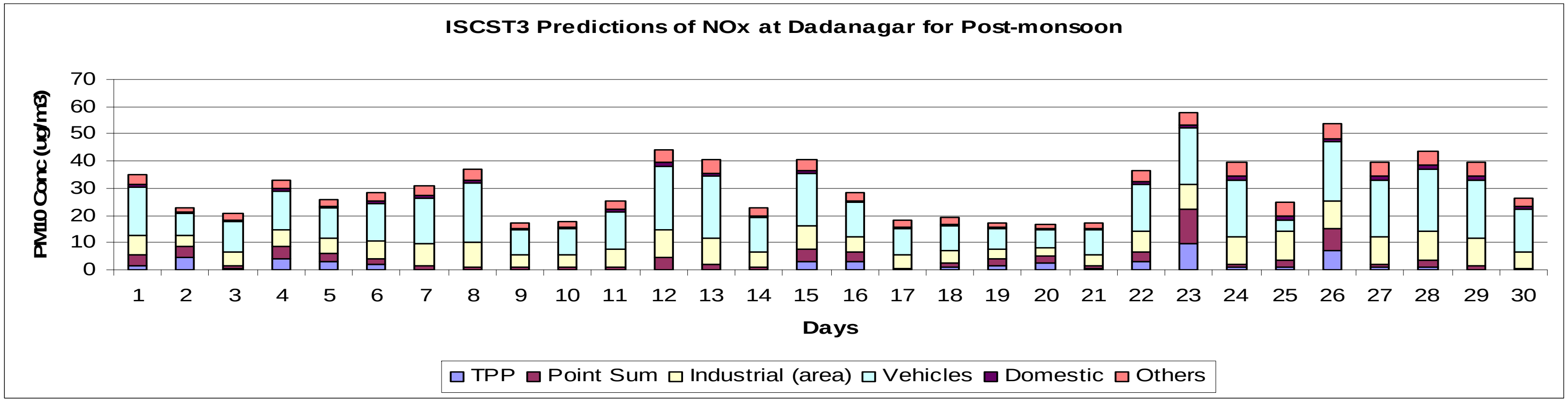


Figure 5.12: Results from ISCST3 Predictions for PM_{10} and NOx at Colonelganj for Post-monsoon

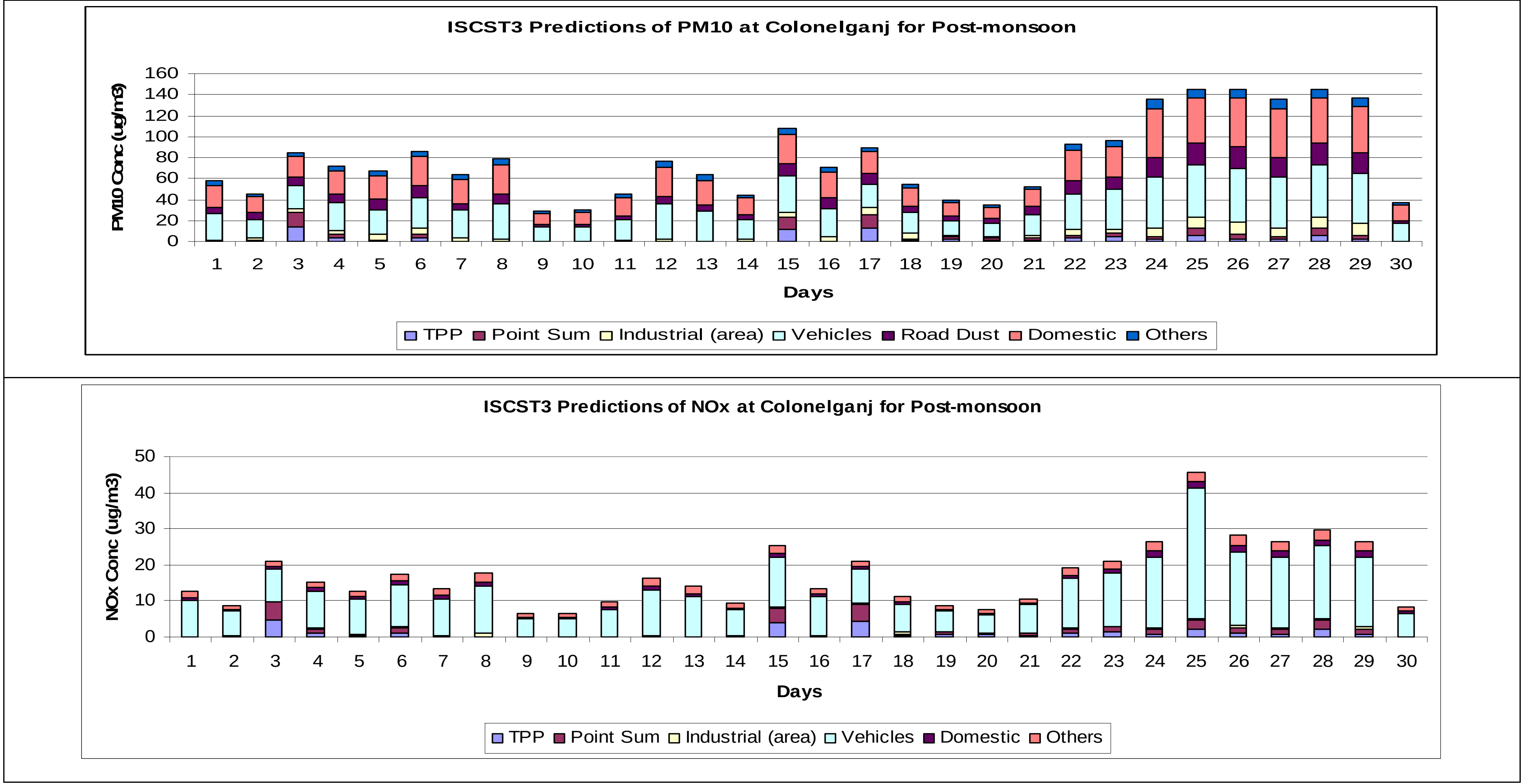


Figure 5.13: Results from ISCST3 Predictions for PM_{10} and NOx at AHM for Post-monsoon

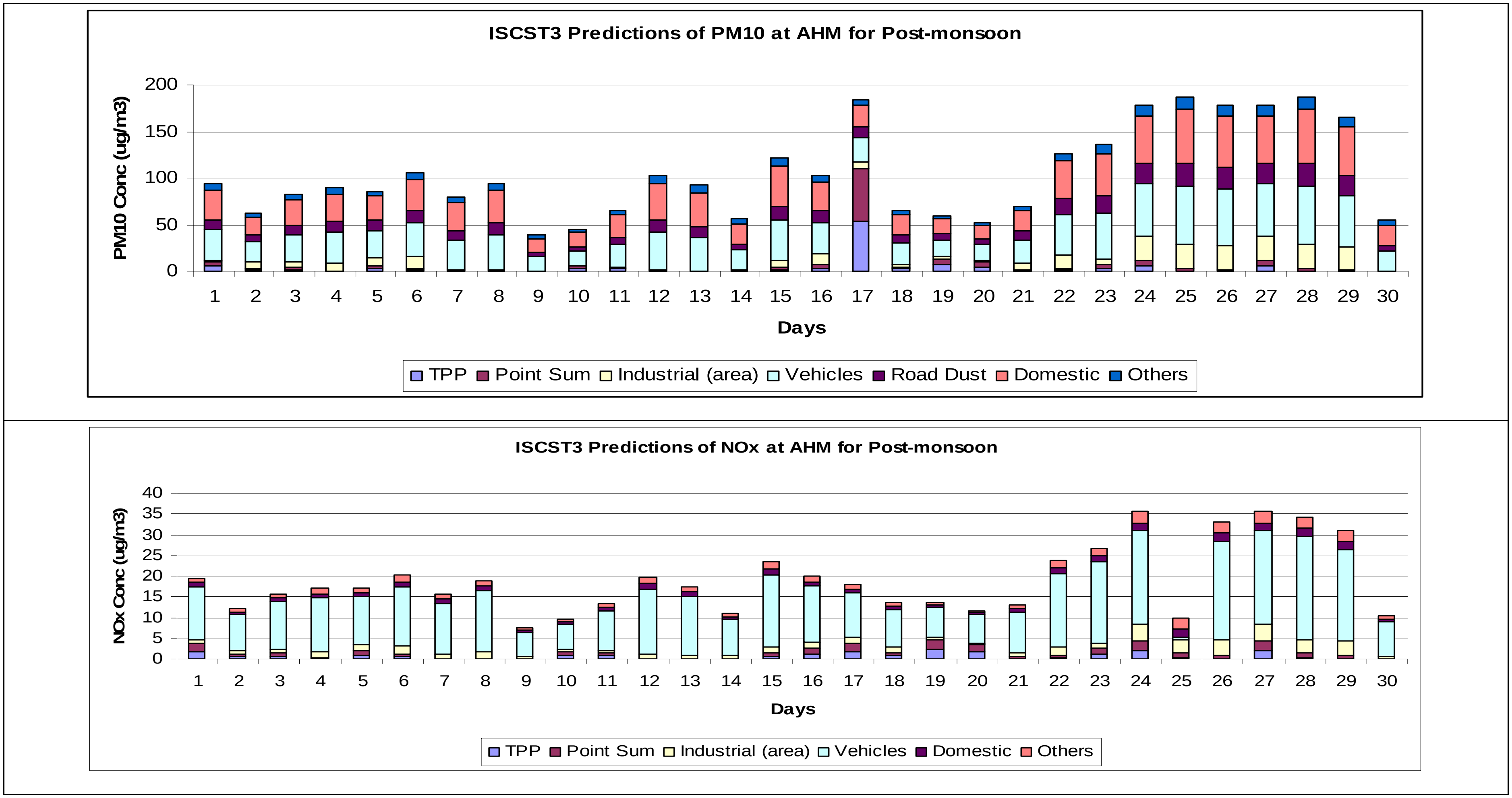


Figure 5.14: Results from ISCST3 Predictions for PM_{10} and NOx at Ramadevi for Post-monsoon

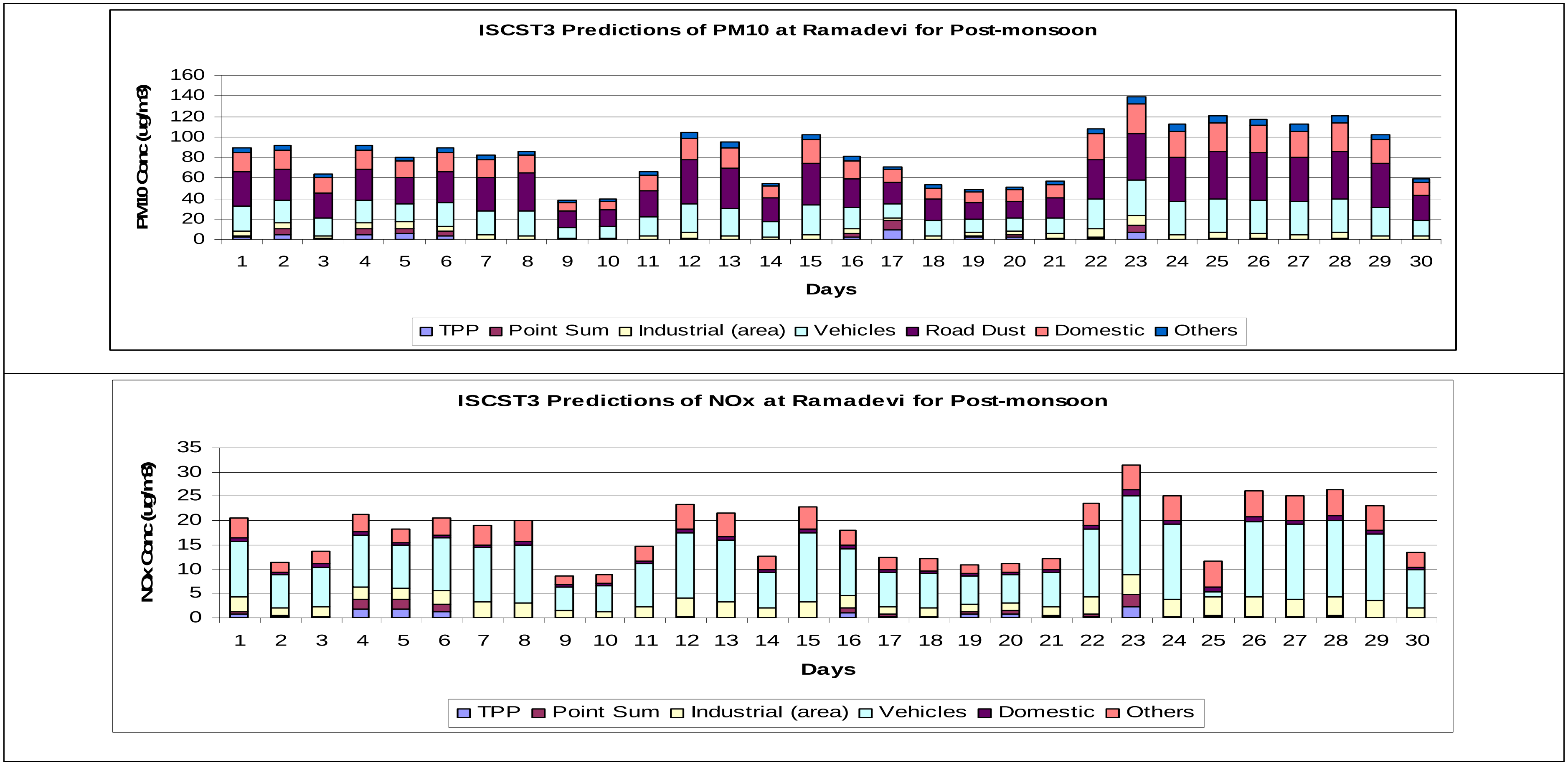


Figure 5.15: Results from ISCST3 Predictions for PM_{10} and NOx at IIT for Winter

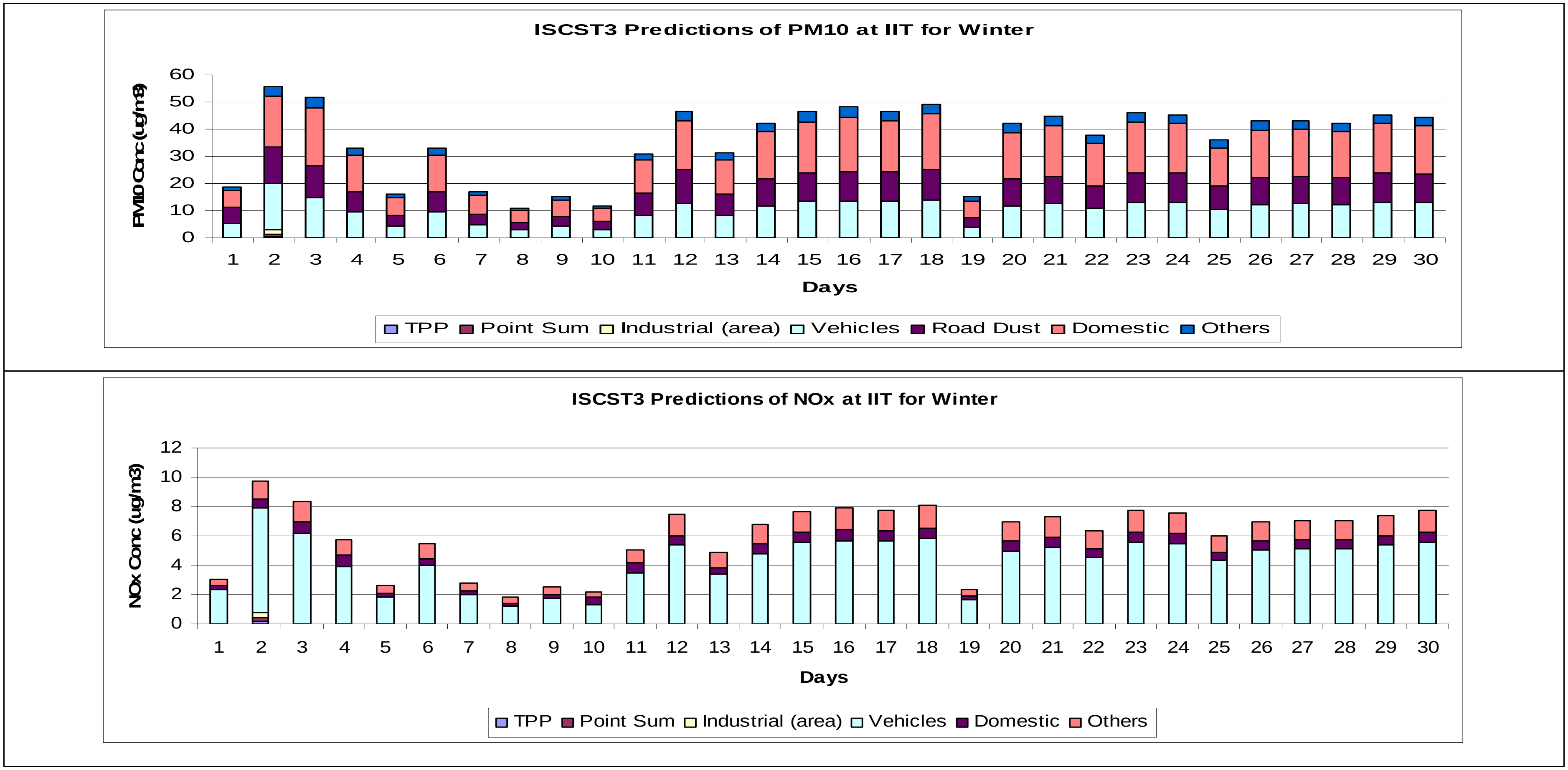


Figure 5.16: Results from ISCST3 Predictions for PM_{10} and NOx at Vikashnagar for Winter

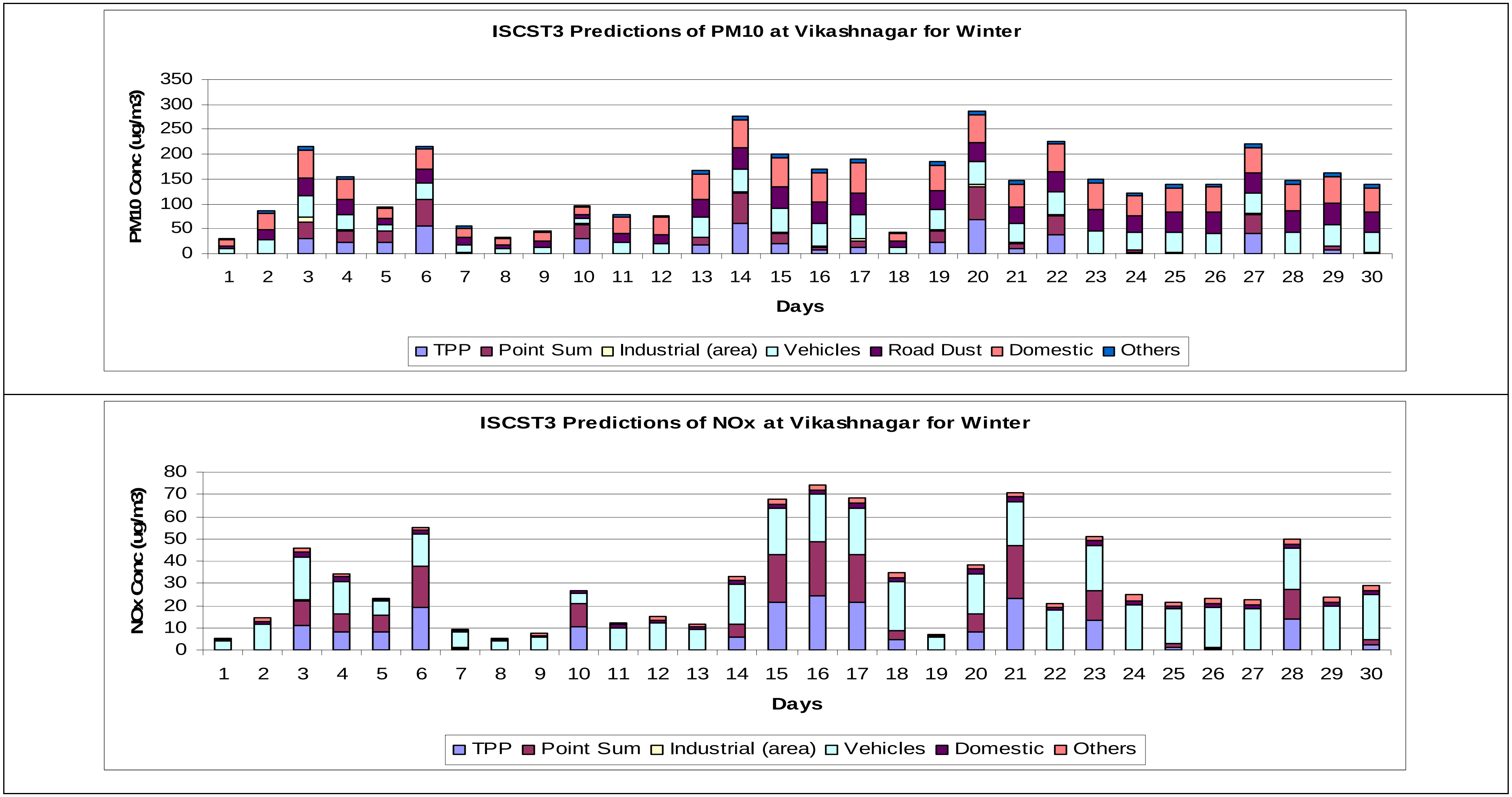


Figure 5.17: Results from ISCST3 Predictions for PM_{10} and NOx at Govindnagar for Winter

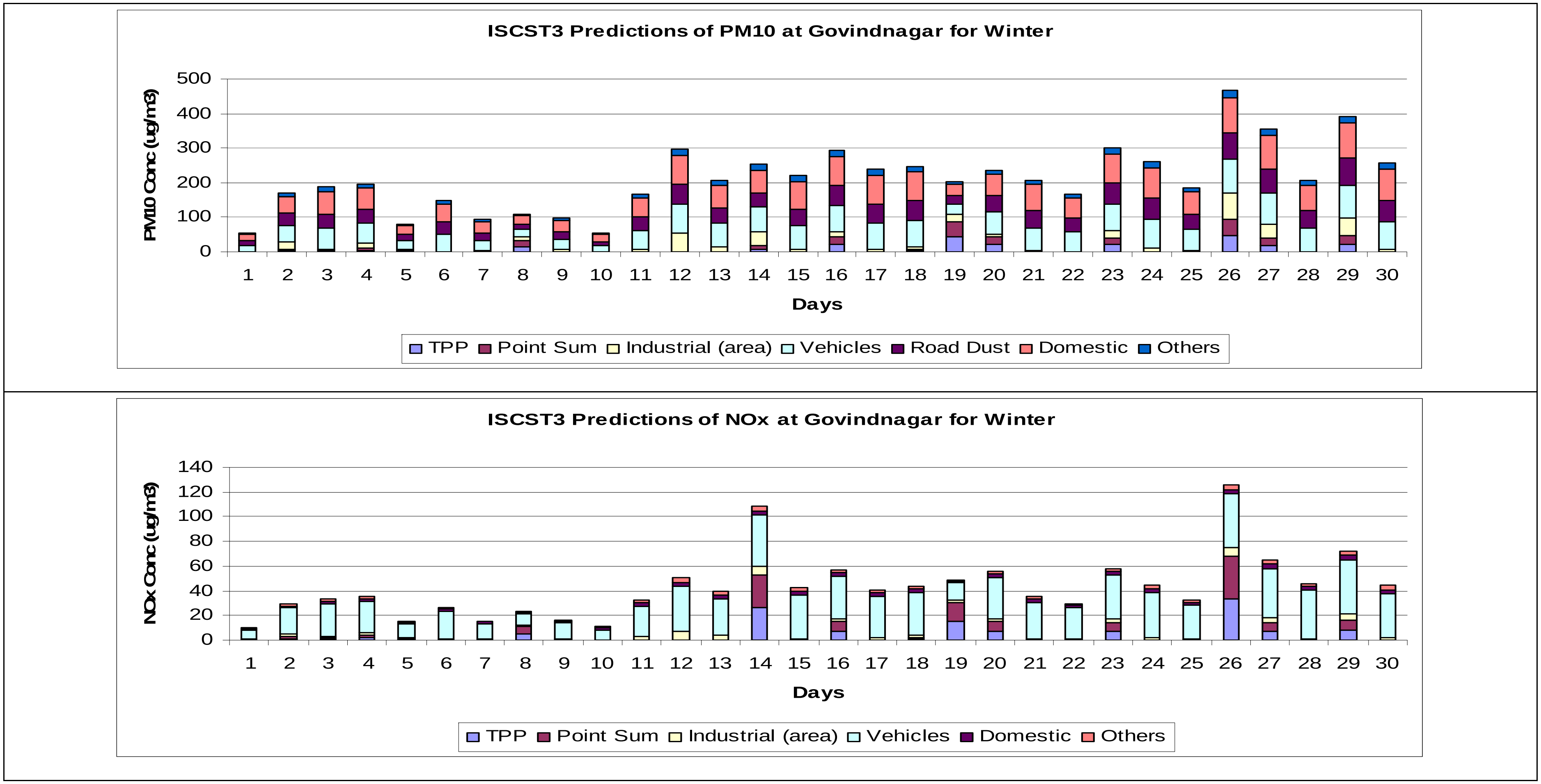


Figure 5.18: Results from ISCST3 Predictions for PM_{10} and NOx at Dadanagar for Winter

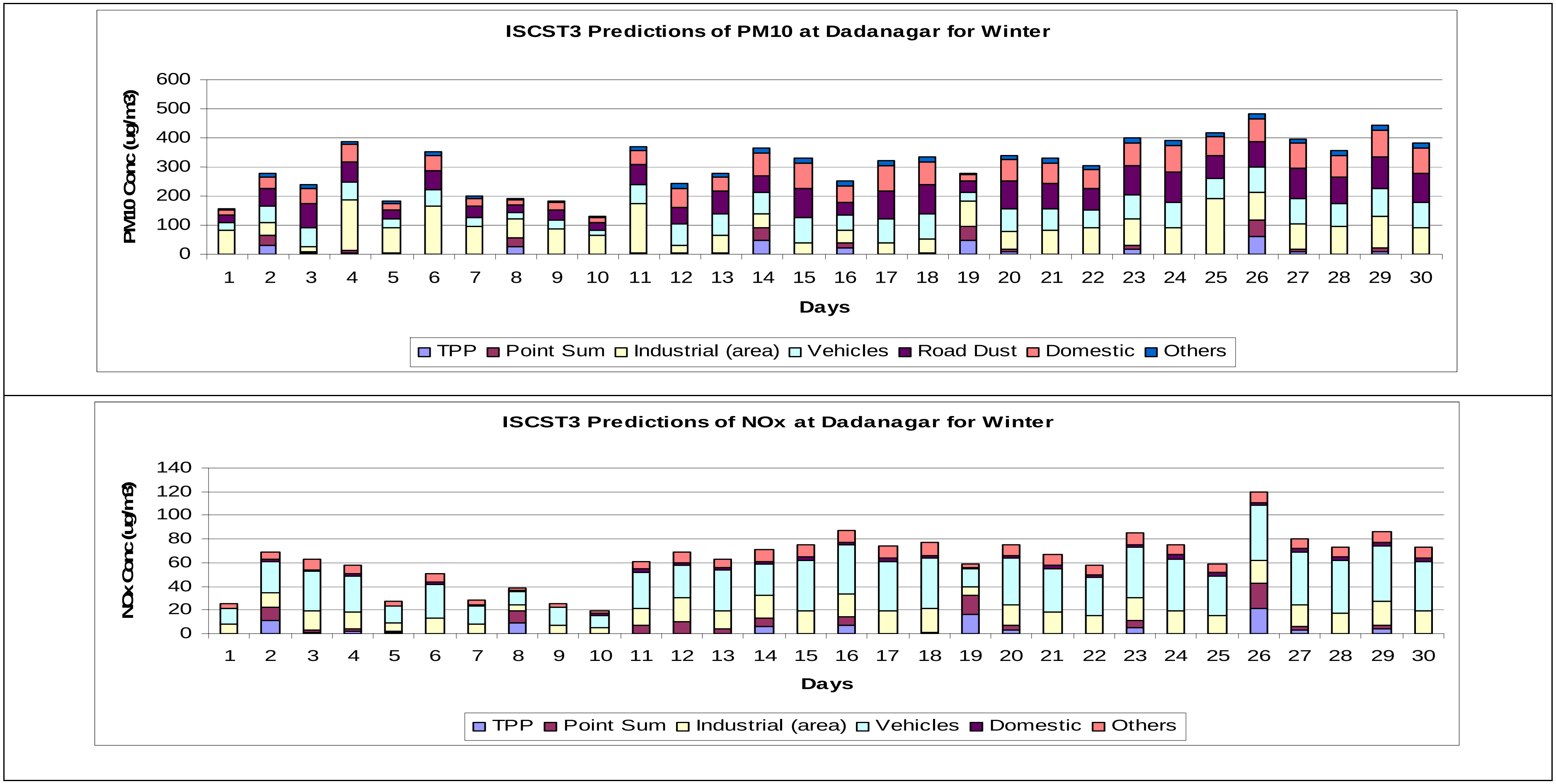


Figure 5.19: Results from ISCST3 Predictions for PM_{10} and NOx at Colonelganj for Winter

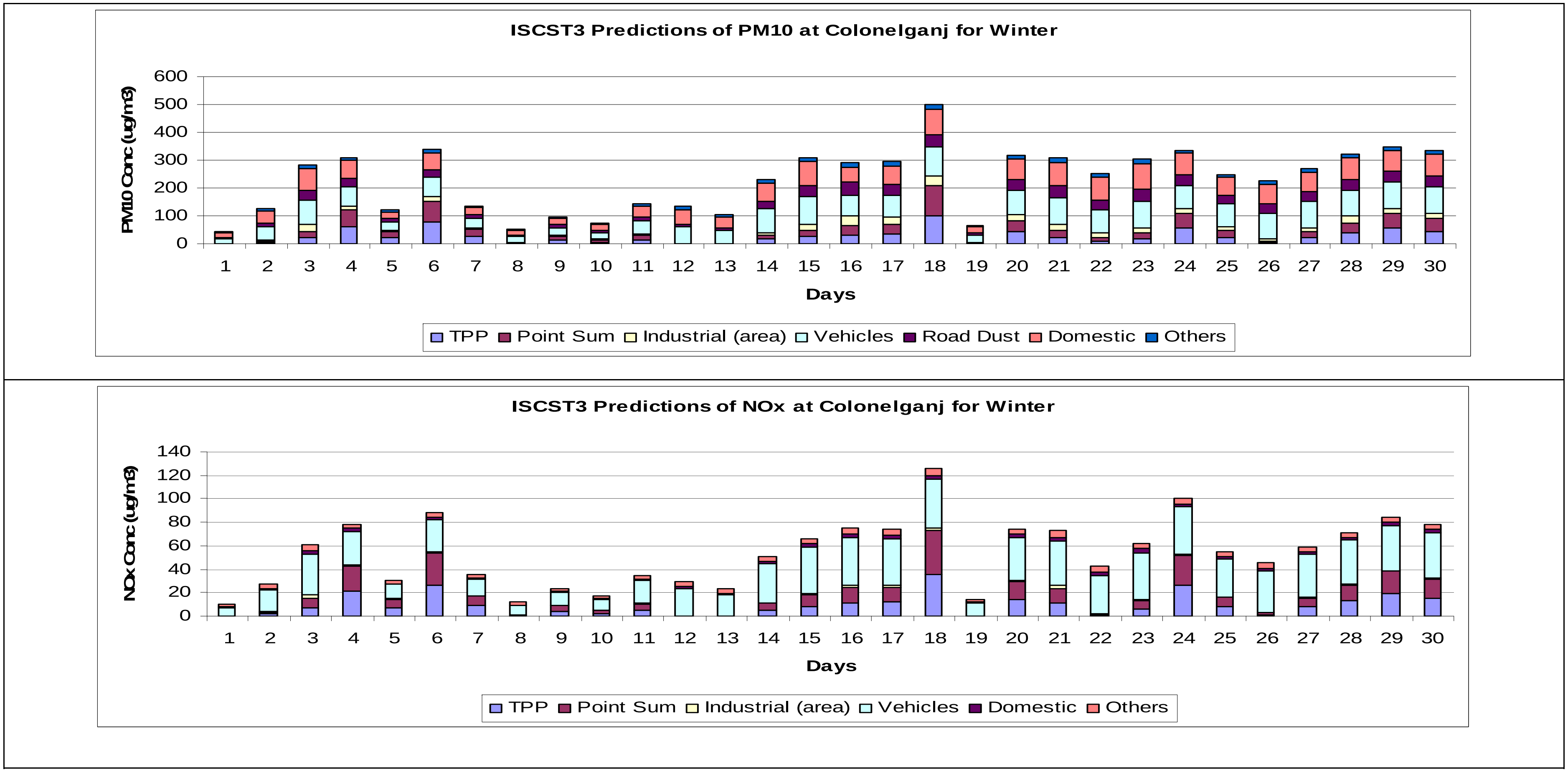


Figure 5.20: Results from ISCST3 Predictions for PM_{10} and NOx at AHM for Winter

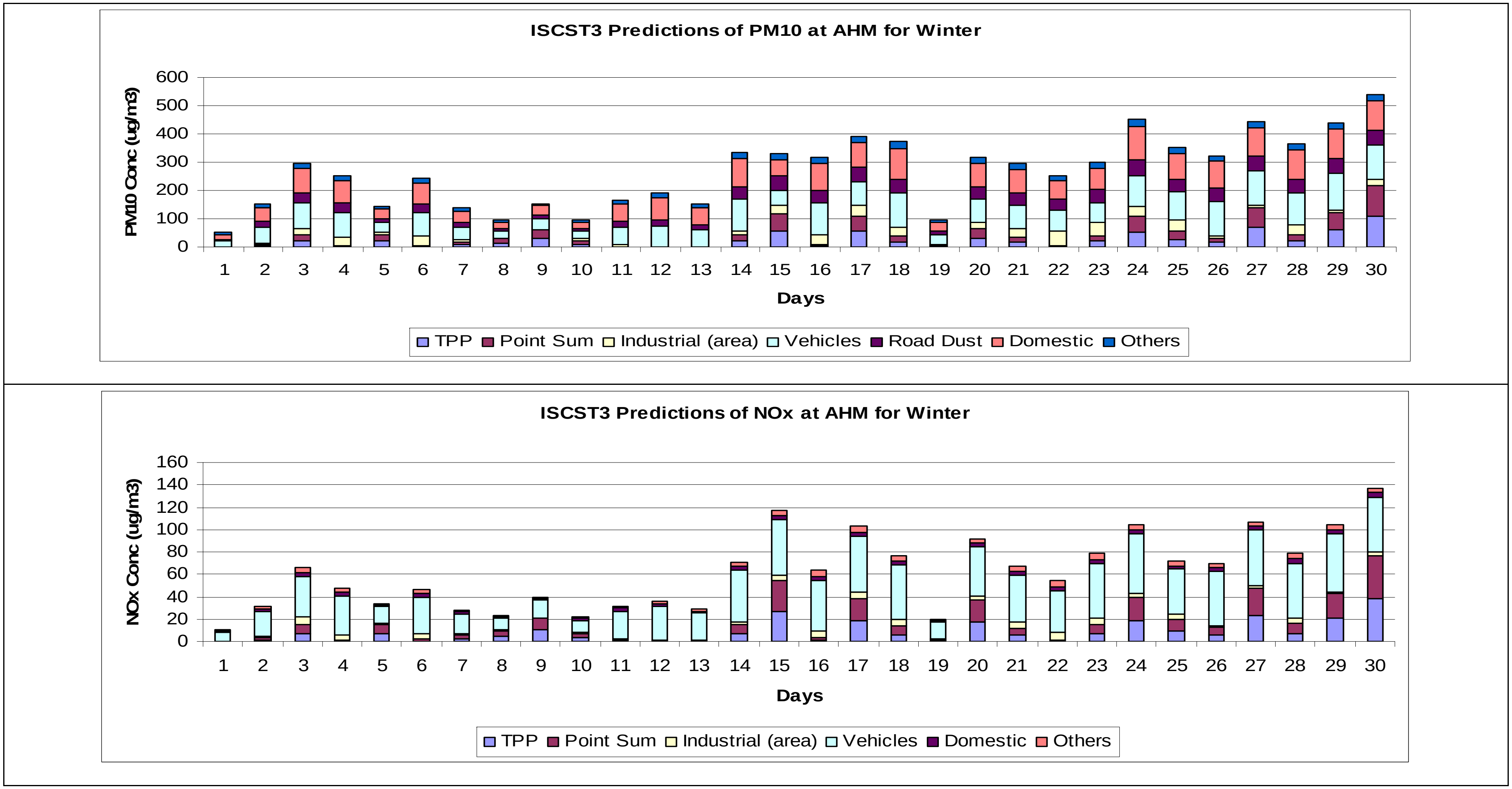
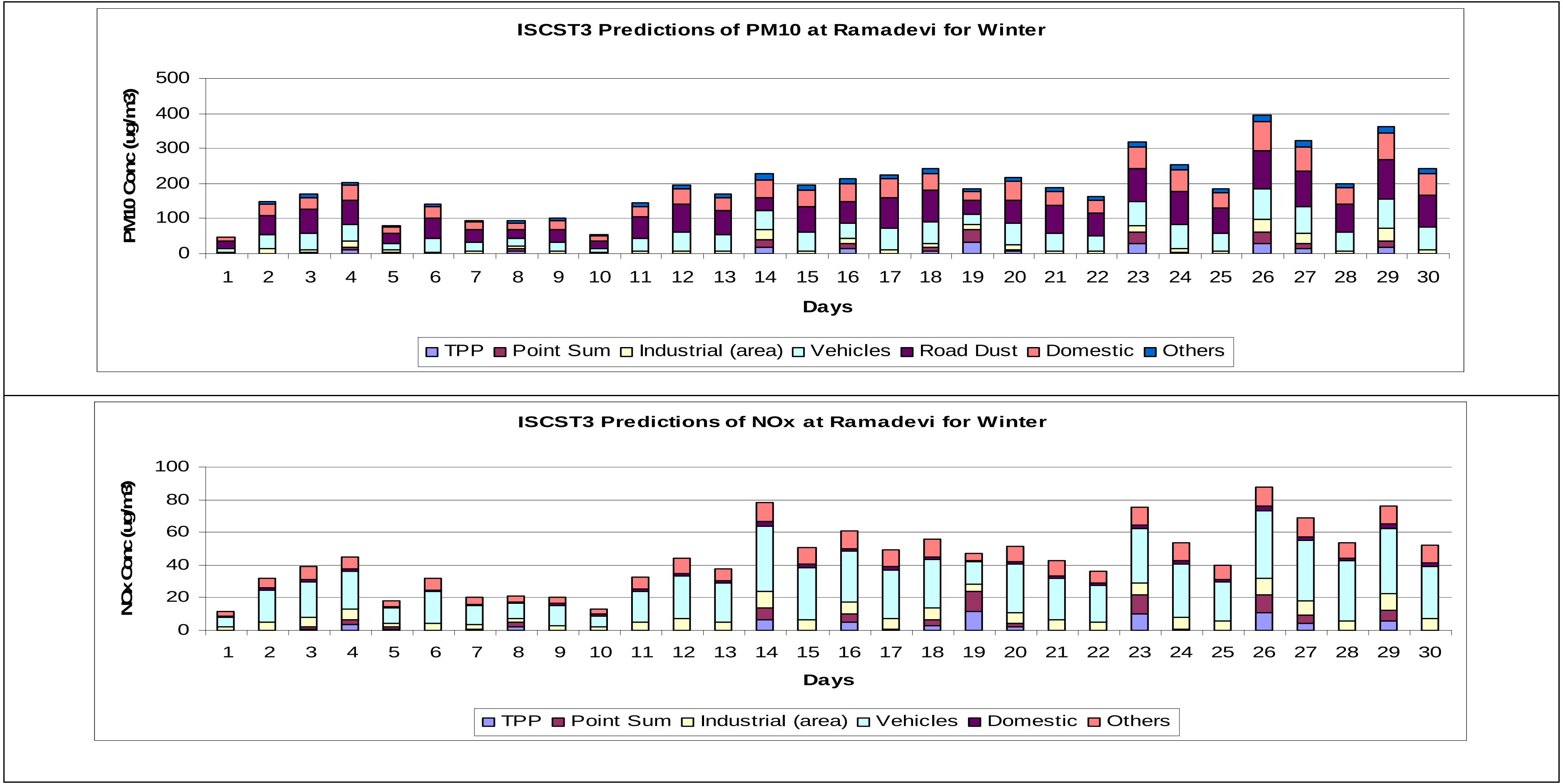


Figure 5.21: Results from ISCST3 Predictions for PM_{10} and NOx at Ramadevi for Winter



5.2.2 Season-wise Modeling

Figs 5.22 to 5.27 present contribution of various sources to PM_{10} and NOx at seven sampling sites in various seasons to understand season specific impact in a broad sense.

It is clearly seen that there are three prominent and probably equally important sources of PM_{10} (vehicles, road dust and domestic fuel burning) that contribute to about 80 percent PM_{10} at all sampling sites (except for the industrial location).

At the industrial site, PM_{10} contribution from cluster of industries (grouped as industrial area source) can be as high as 40-50 percent. The other observation includes that in post monsoon, levels were the lowest at all locations compared to the levels in summer and winter seasons.

The observations/patterns for NO_x levels at the sampling site are quite different compared to those found for PM_{10} (Figs. 5.23, 5.25 and 5.27). Contribution of vehicles to NO_x at all locations is very high ~ 50 to 70 percent (except for industrial site – Dadanagar). At Dadanagar, NO_x contribution from industries is estimated to be about 30-40 percent. The concentrations of NO_x are highest in winter season and lowest in post monsoon.

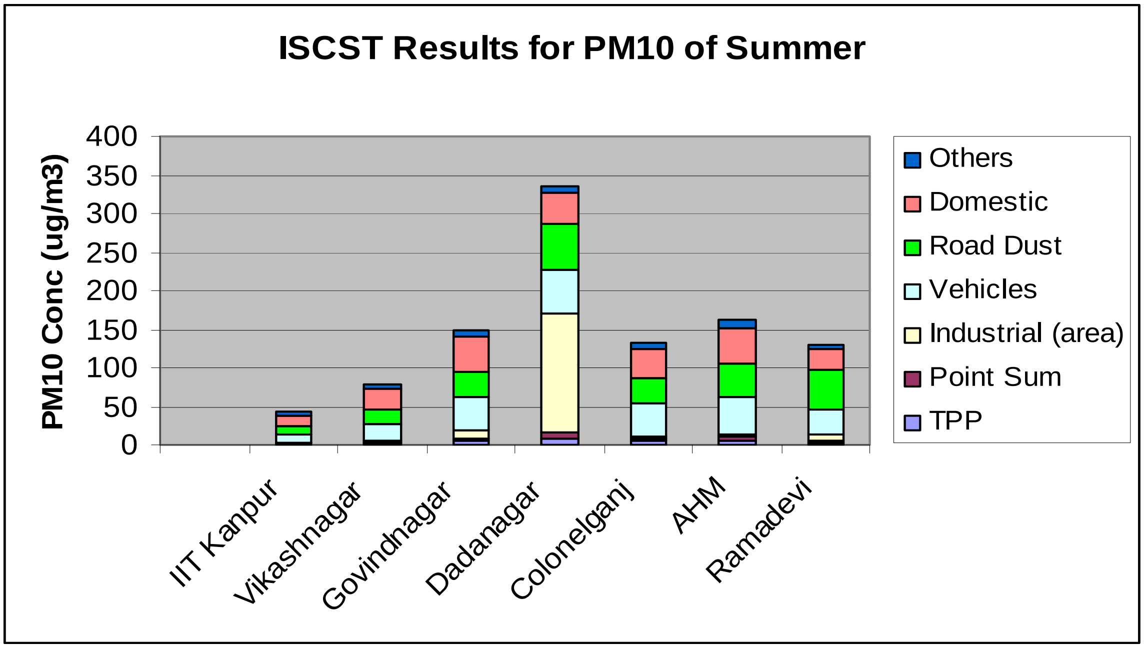


Figure 5.22: Results from ISCST3 Predictions for PM_{10} for Summer

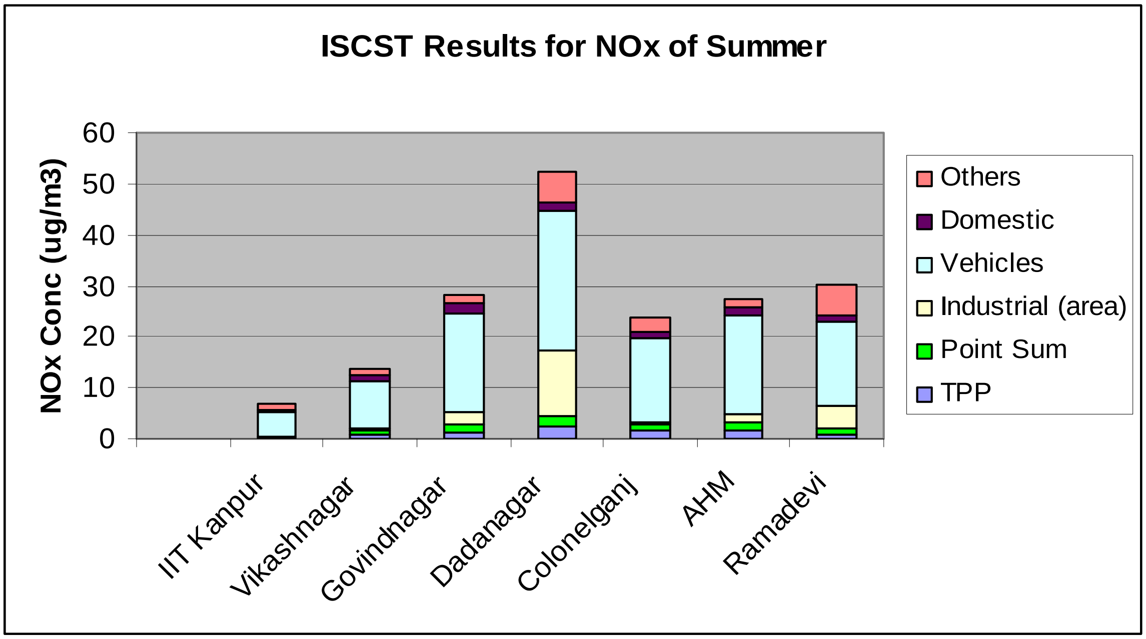


Figure 5.23: Results from ISCST3 Predictions for NOx for Summer

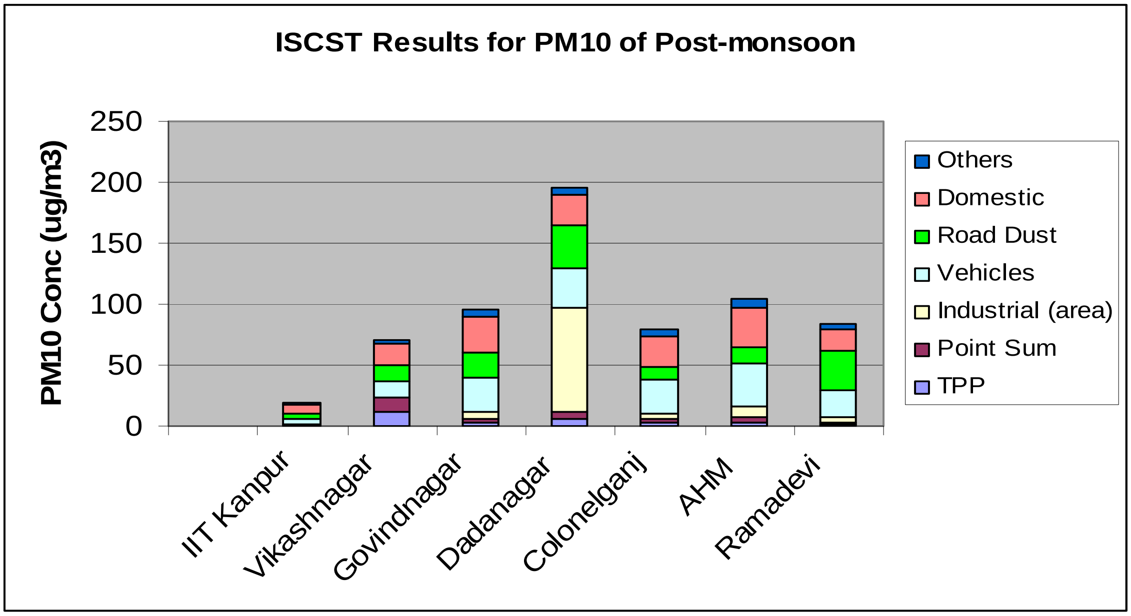


Figure 5.24: Results from ISCST3 Predictions for PM_{10} for Post-monsoon

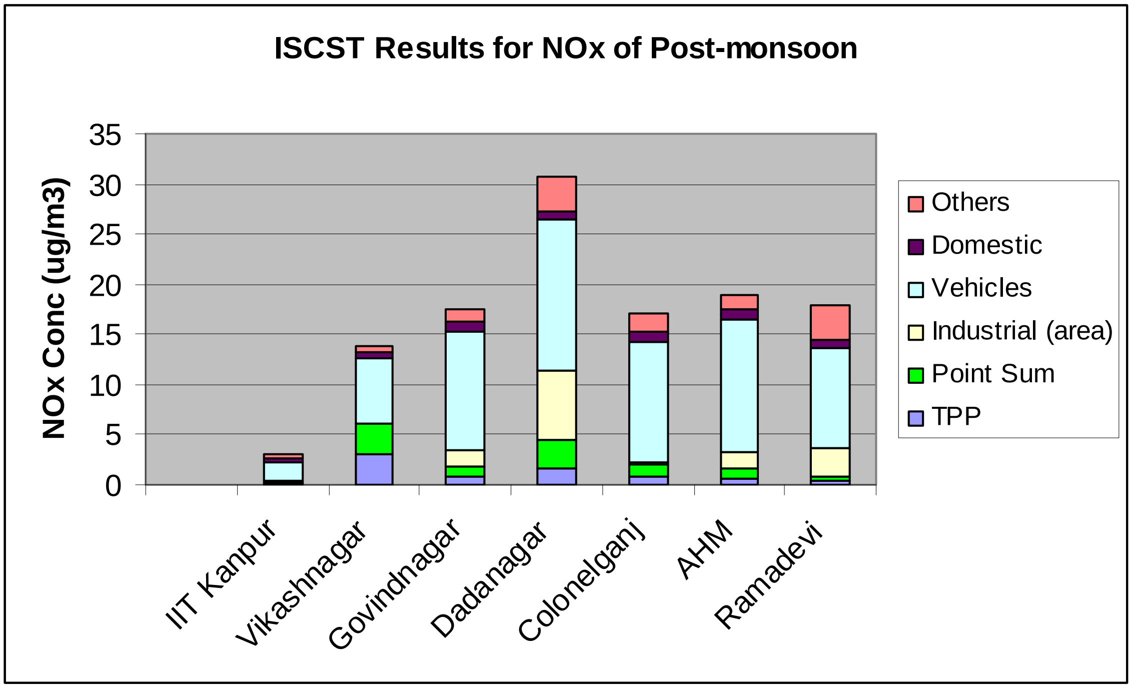


Figure 5.25: Results from ISCST3 Predictions for NOx for Post-monsoon

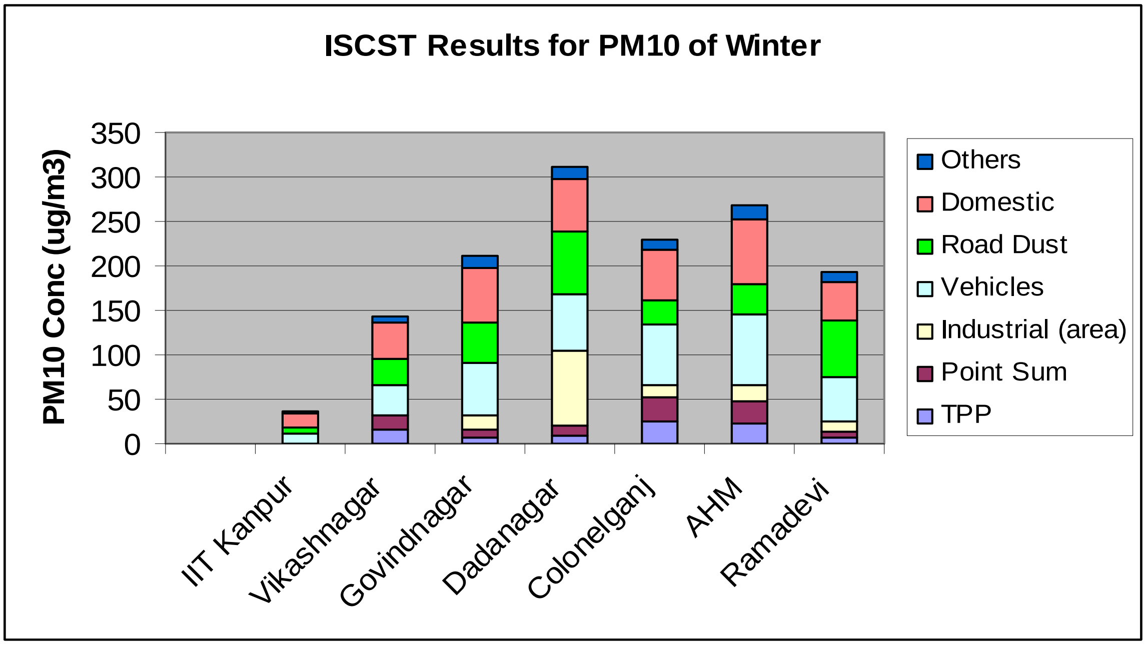


Figure 5.26: Results from ISCST3 Predictions for PM_{10} for Winter

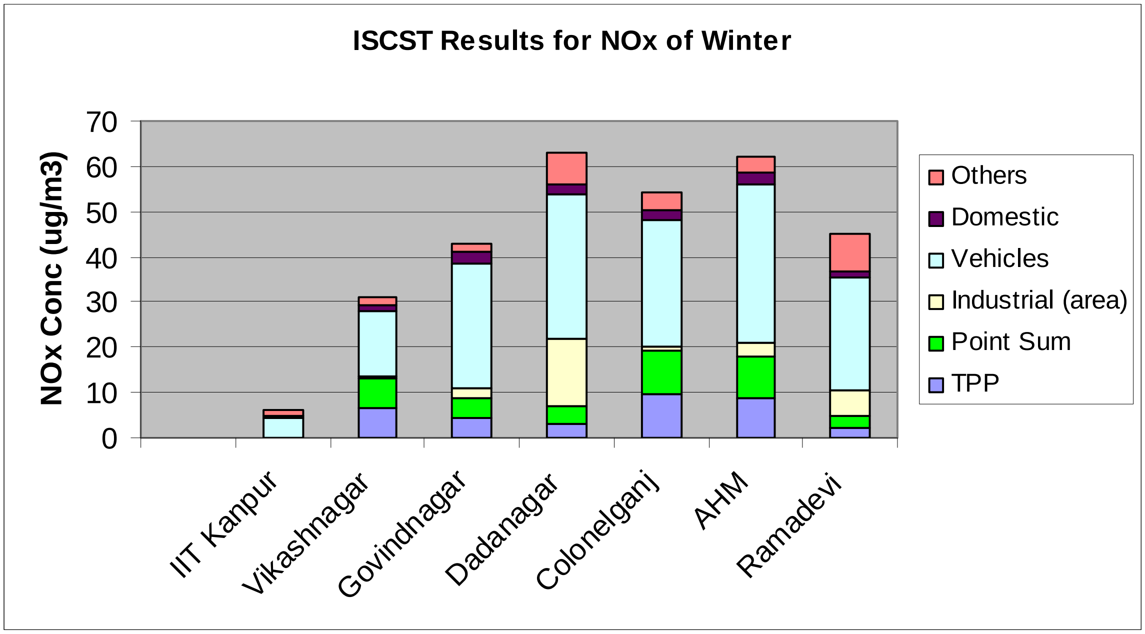
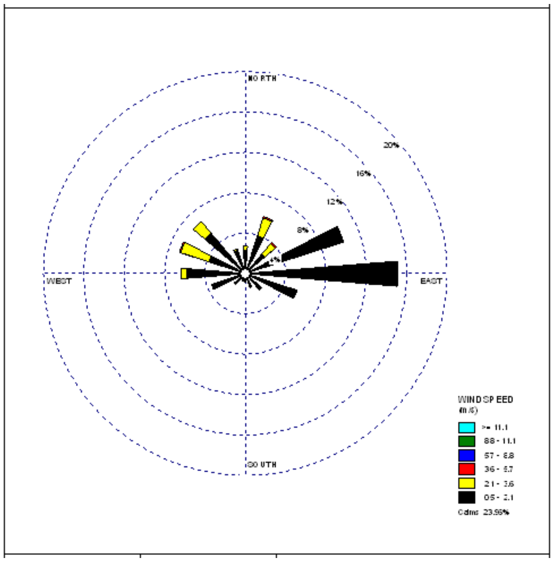


Figure 5.27: Results from ISCST3 Predictions for NO_x for Winter

5.2.3 City Level Modeling

Figures 5.28 to 5.33 show grid-wise emission inventories, wind roses and model computed air quality levels for PM_{10} and NO_x in three seasons.

Wind-Rose Diagram for Summer



Emission Inventory of PM$_{10}$ for Summer

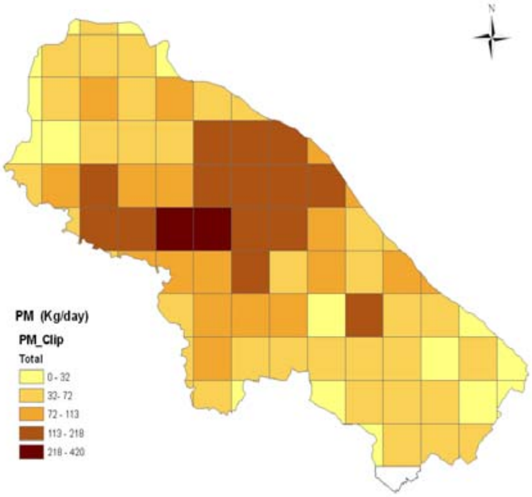
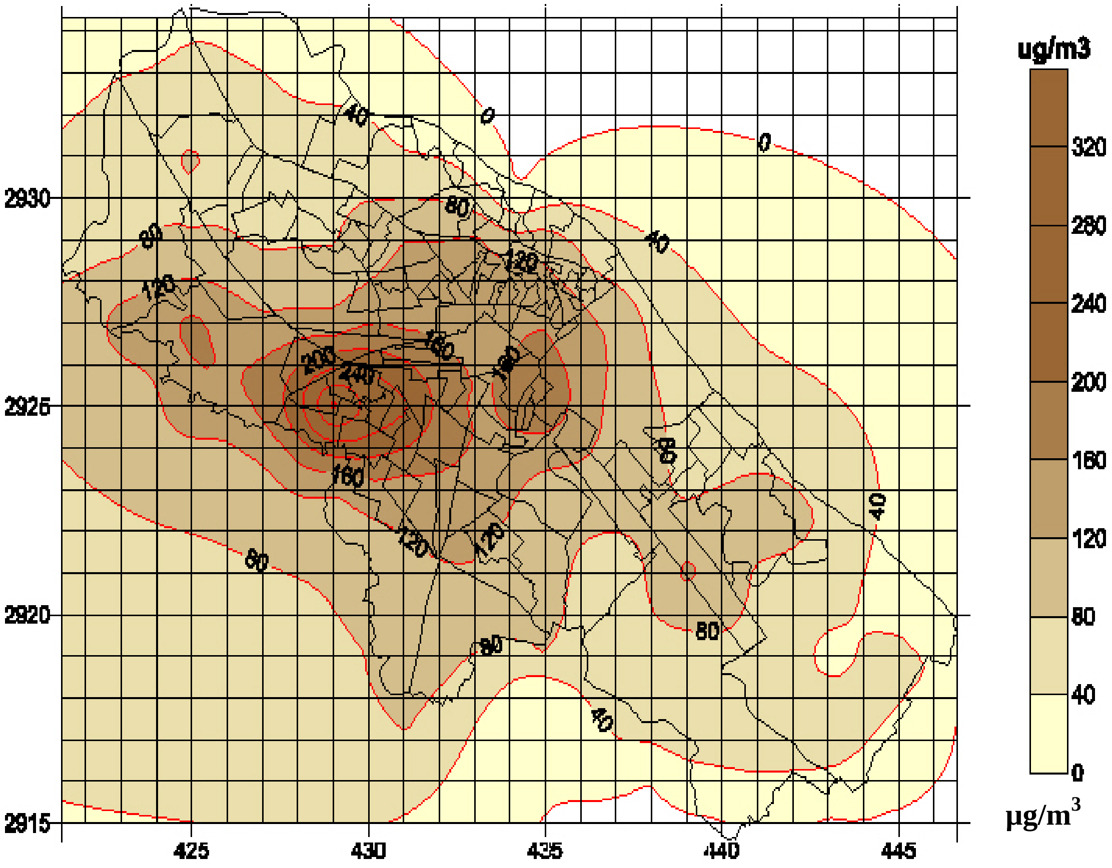
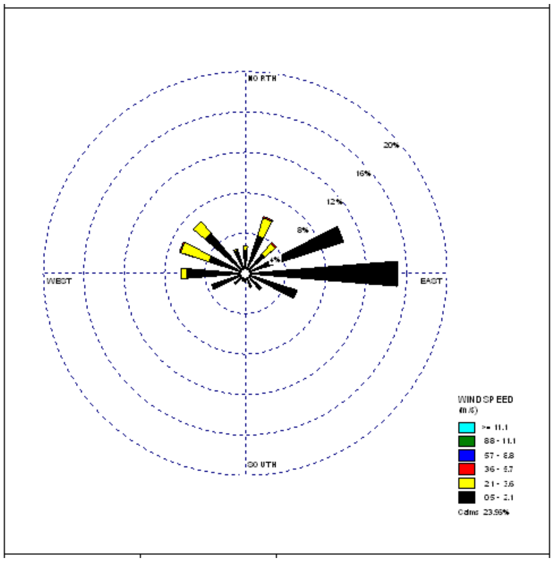


Figure 5.28 : PM$_{10}$ Concentration Profiles for Summer



Wind-Rose Diagram for Summer



Emission Inventory of NOx for Summer

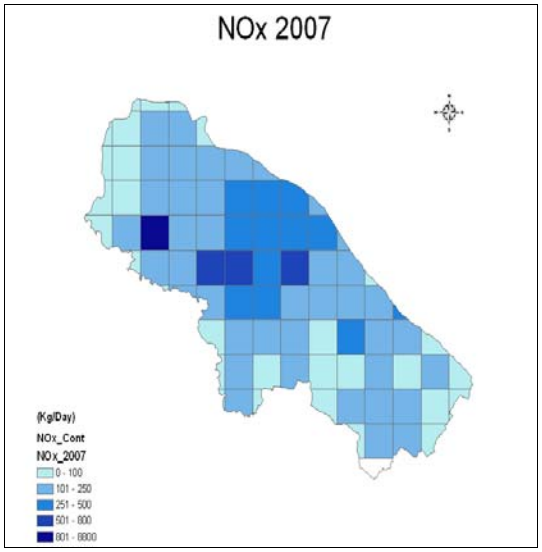
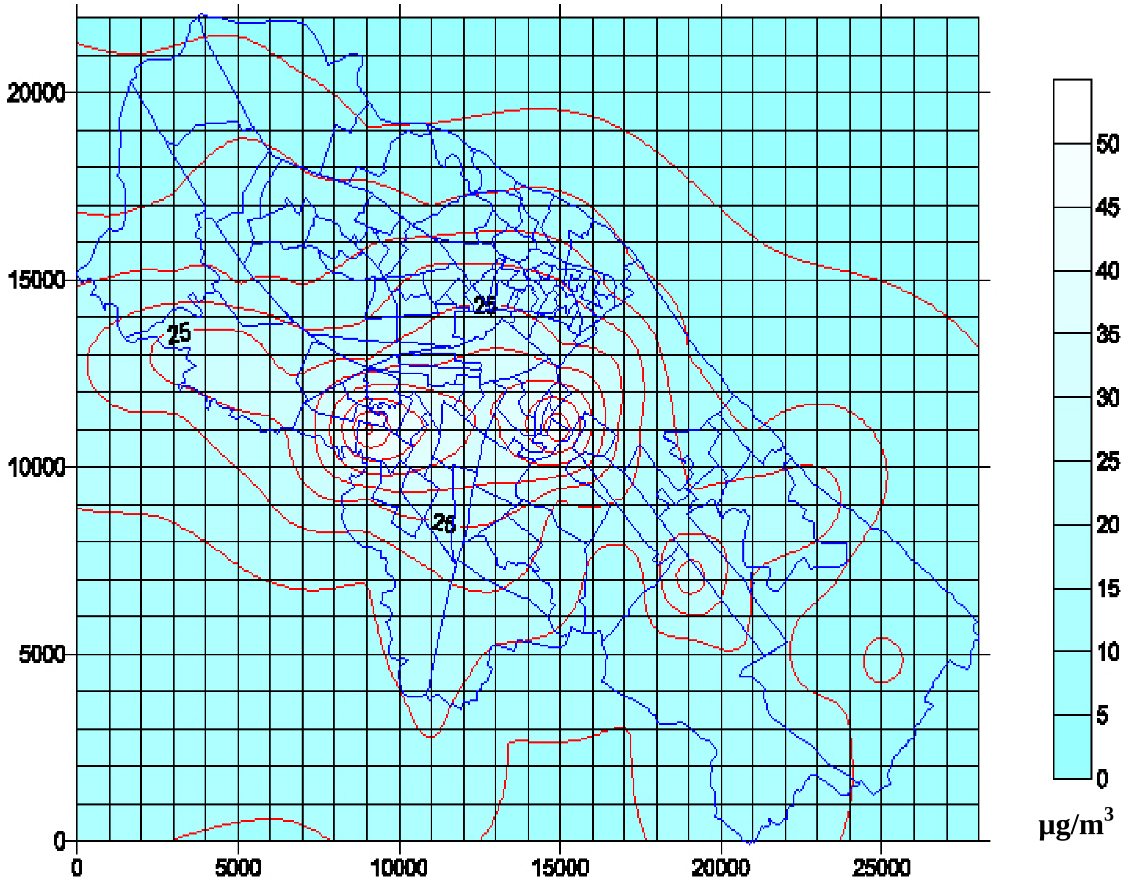
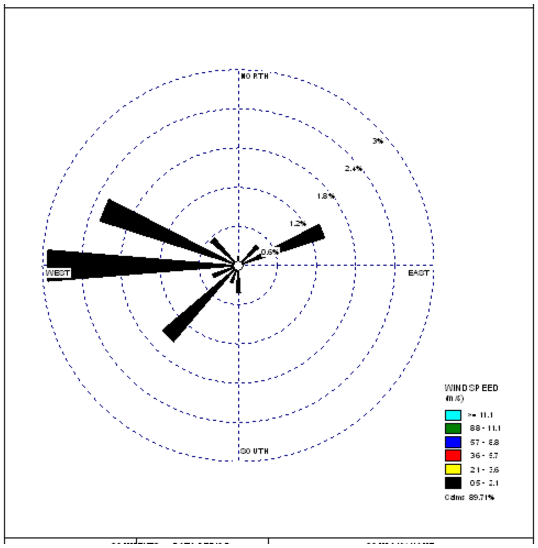


Figure 5.29: NOx Concentration Profiles for Summer



Wind-Rose Diagram for Post-monsoon



Emission Inventory of PM$_{10}$ for Post-monsoon

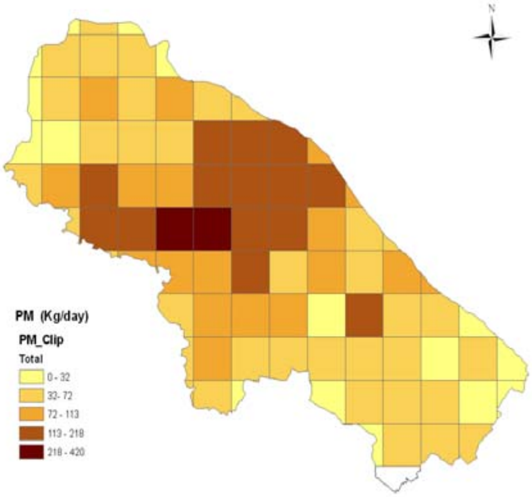
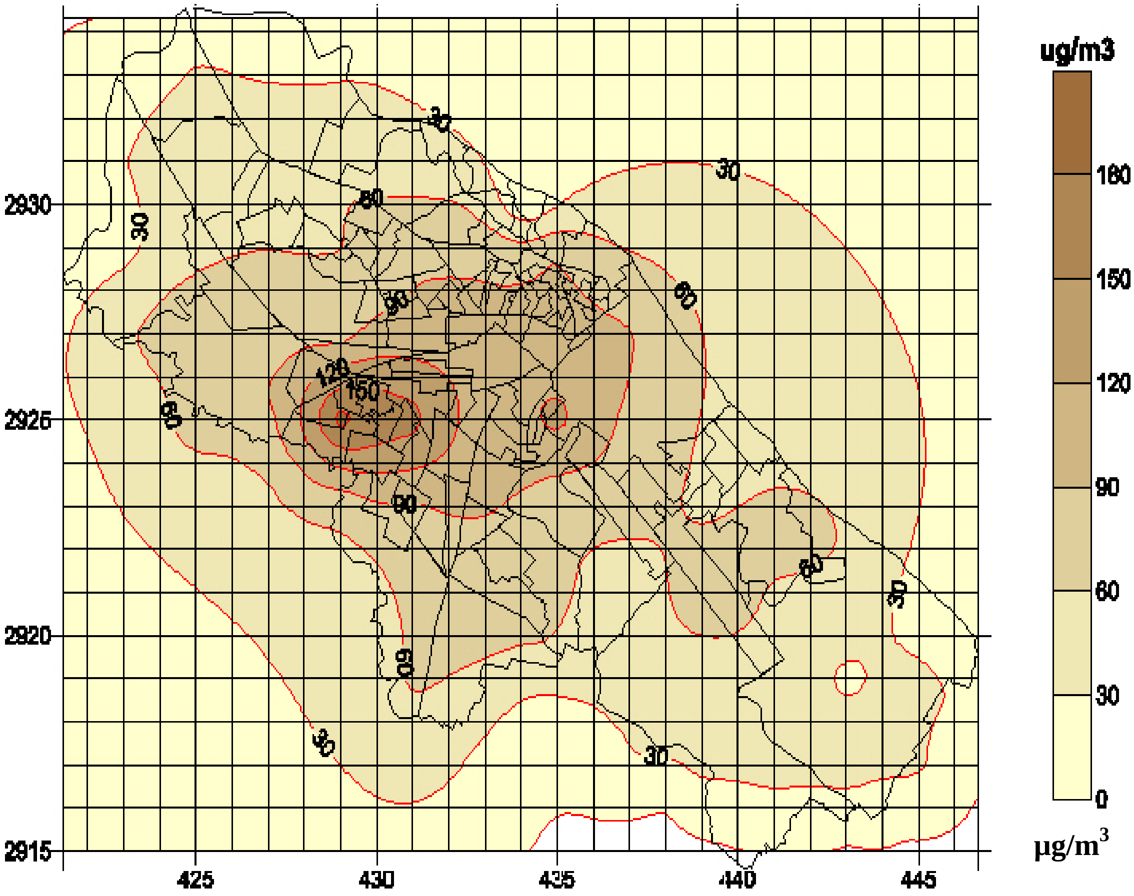
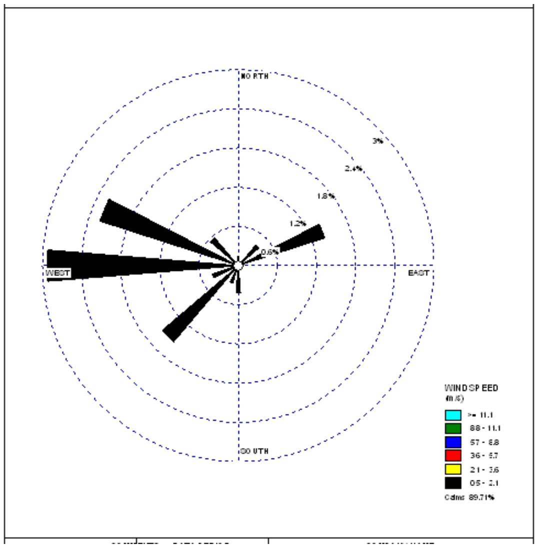


Figure 5.30 : PM$_{10}$ Concentration Profiles for Post-monsoon



Wind-Rose Diagram for Post-monsoon



Emission Inventory of NOx for Post-monsoon

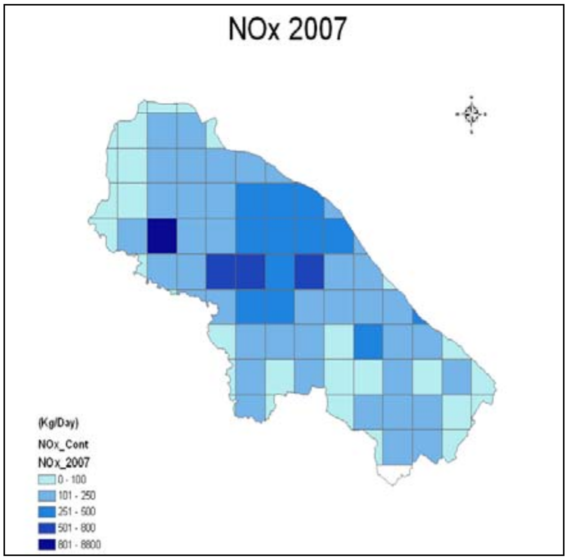
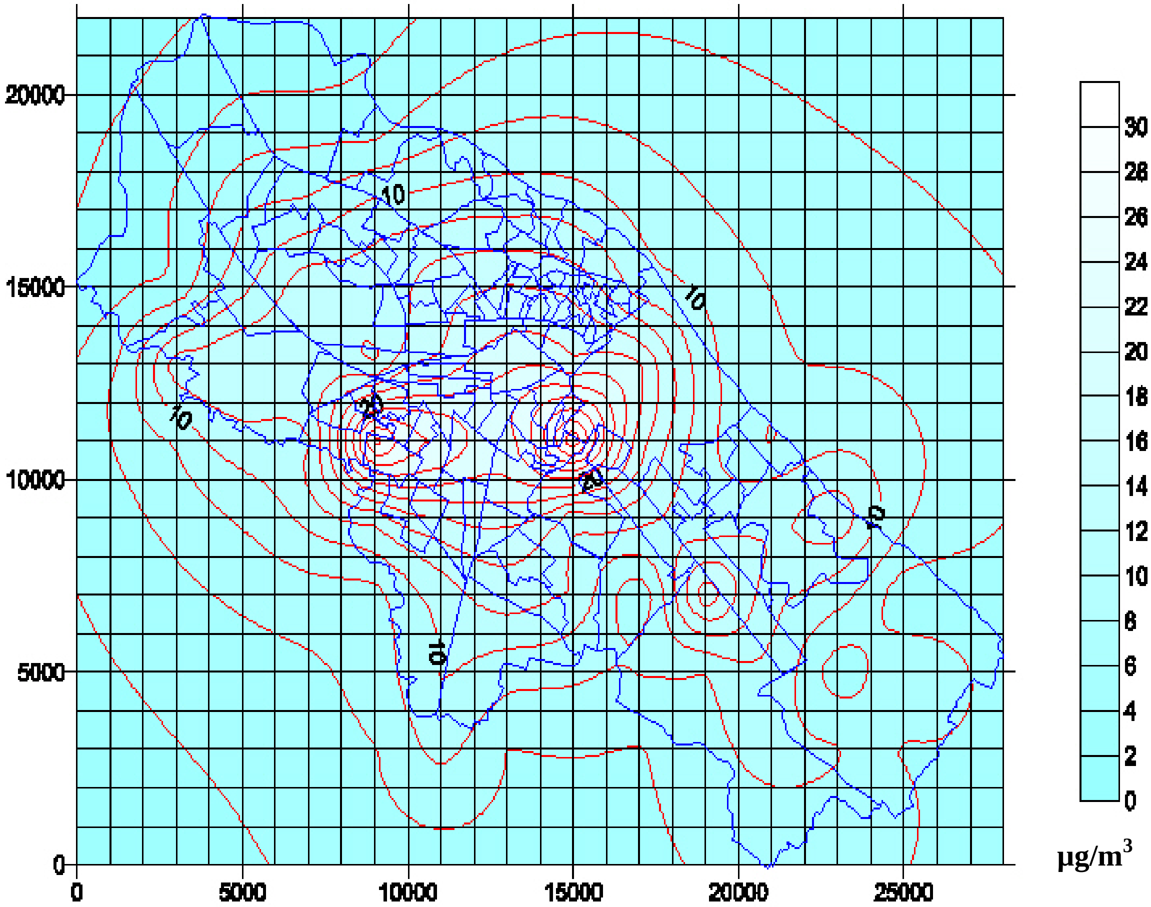
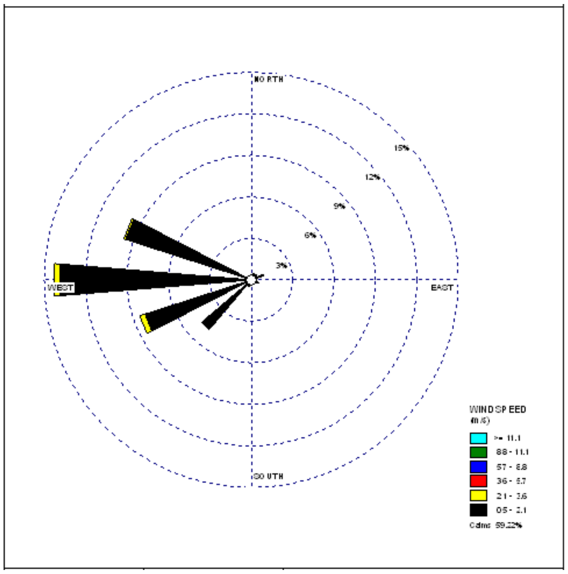


Figure 5.31 : NOx Concentration Profiles for Post-monsoon



Wind-Rose Diagram for Winter



Emission Inventory of PM_{10} for Winter

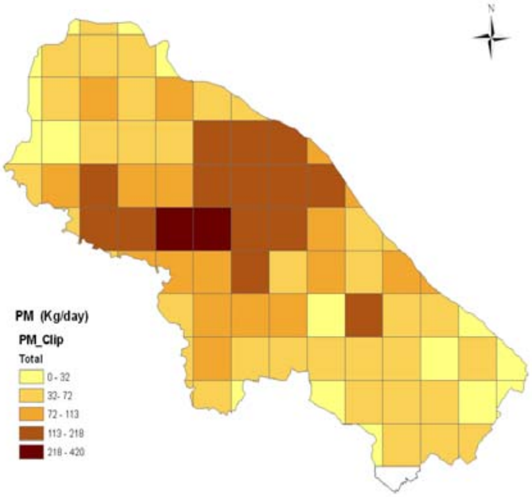
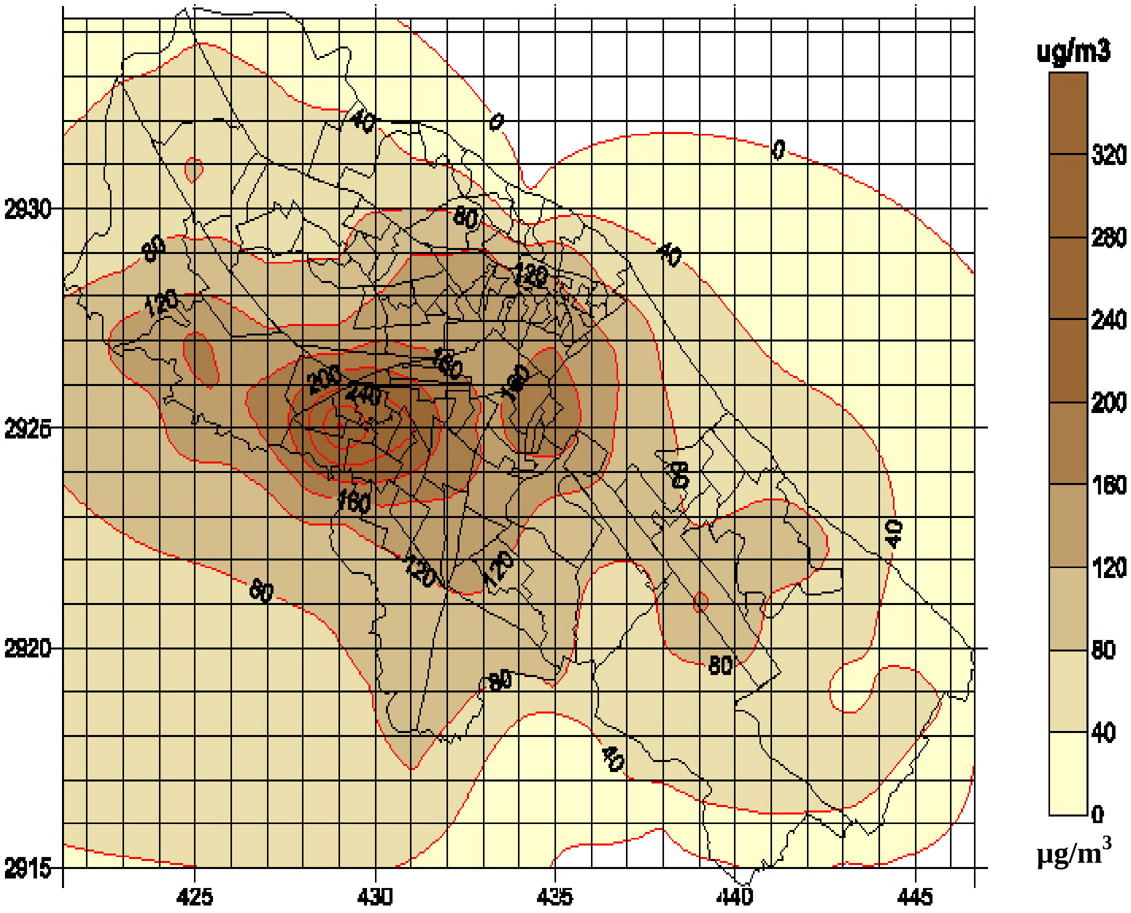
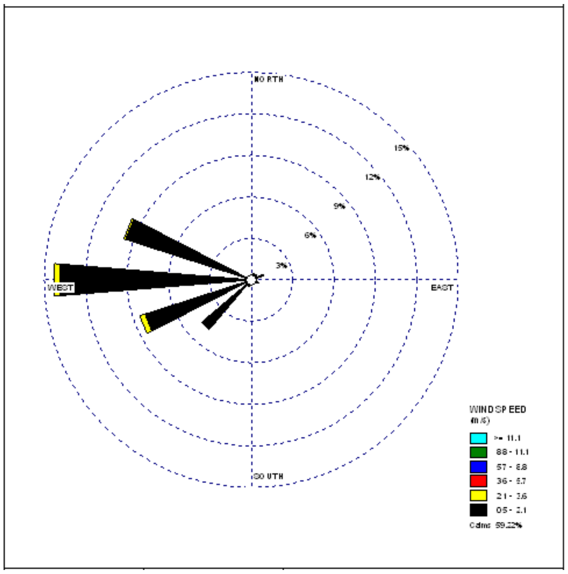


Figure 5.32: PM_{10} Concentration Profiles for Winter



Wind-Rose Diagram for Winter



Emission Inventory of NOx for Winter

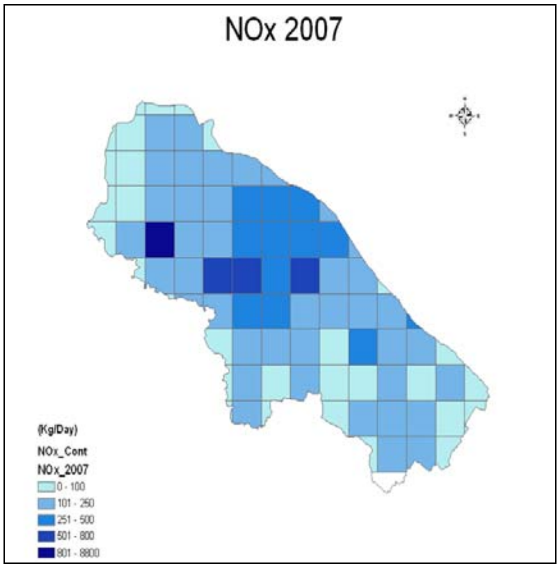
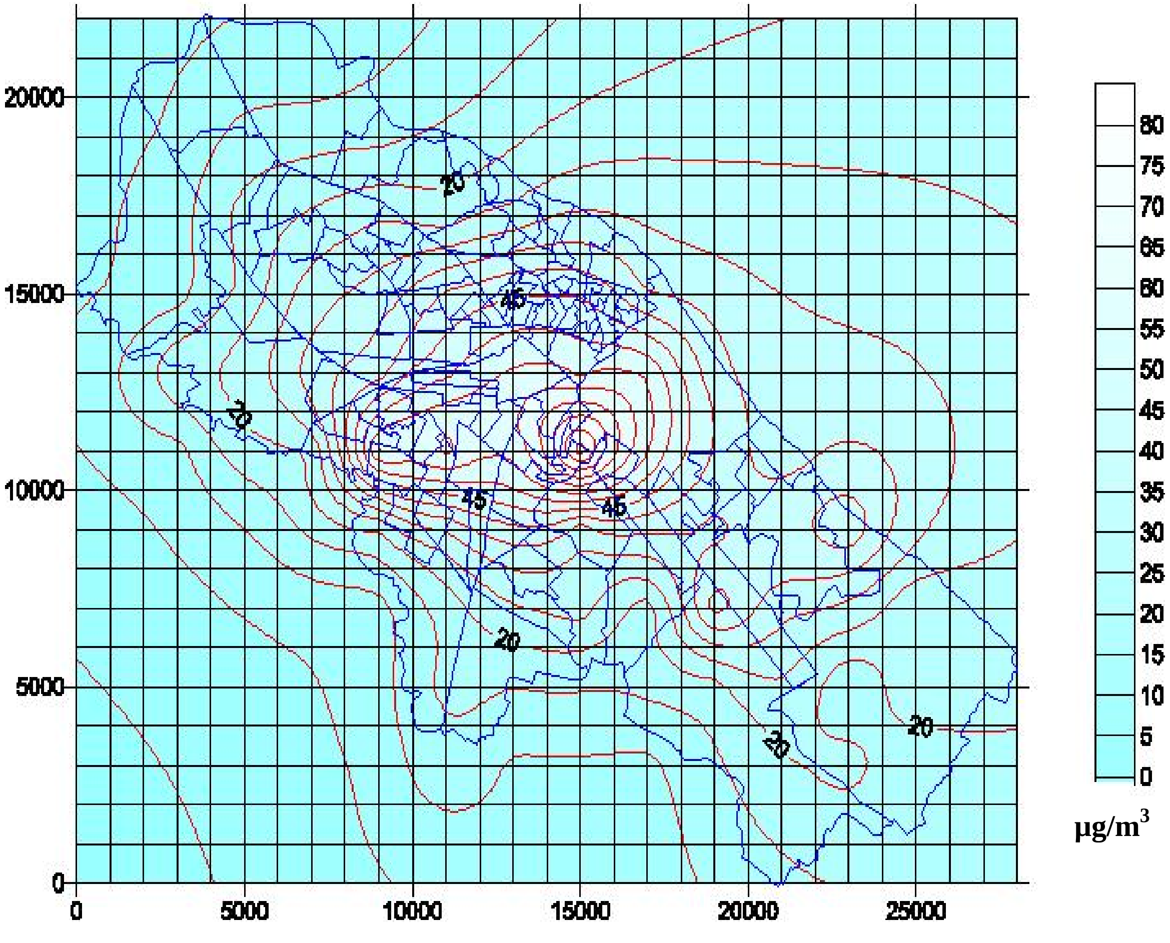


Figure 5.33: NOx Concentration Profiles for Winter



The overall city specific modeling results follow the meteorology and emissions in each grid. For PM_{10} and NOx, there are clear hotspots. These hotspots also vary depending on the season. It may be observed that PM_{10} hotspot in summer is in the industrial area (Fig 5.28) and in winter season, there are two equally important hotspots - industrial area and city center. This is due to very concentrated wind direction from west in winter. Wind direction in summer was quite diffused, as wind blew from many directions (Fig 5.32).

NOx shows consistent two hotspots, where concentrations can really be very high: (i) industrial area and (ii) the city center. It can be seen that emission are also high in these two areas. There is about 6-8 sq-km area, where air quality standards can be exceeded in respect of NOx. The city level modeling once again suggests that NOx air quality levels are largely contributed from vehicles.

Winter season results in high levels of NOx and PM_{10} for two reasons – (i) wind is consistently from one direction and (ii) mixing heights are low. In other seasons the wind direction fluctuations are more, as a result, it is not same area that is impacted every time. Therefore, winter season will produce worst air quality and focus should be developing strategies for improving air quality in winter.

5.3 Model Performance

Model performance has been examined for seasonal averages. Figure 5.34 to 5.39 present model performance for PM_{10} and NOx in three seasons. For each season, observed and predicted concentrations at each of locations have been plotted and R- square value has been determined. It can be concluded that in terms of R-square value, model performance is adequate (R-square 0.88 – 0.44). The overall conclusion is that observed PM_{10} levels are generally higher than predicted levels both for PM_{10} and NOx. For PM_{10}, there is significant part as background level. Models do not perform exactly but the given results suggest the model is doing a good job in predicting concentrations and can be used development of strategies.

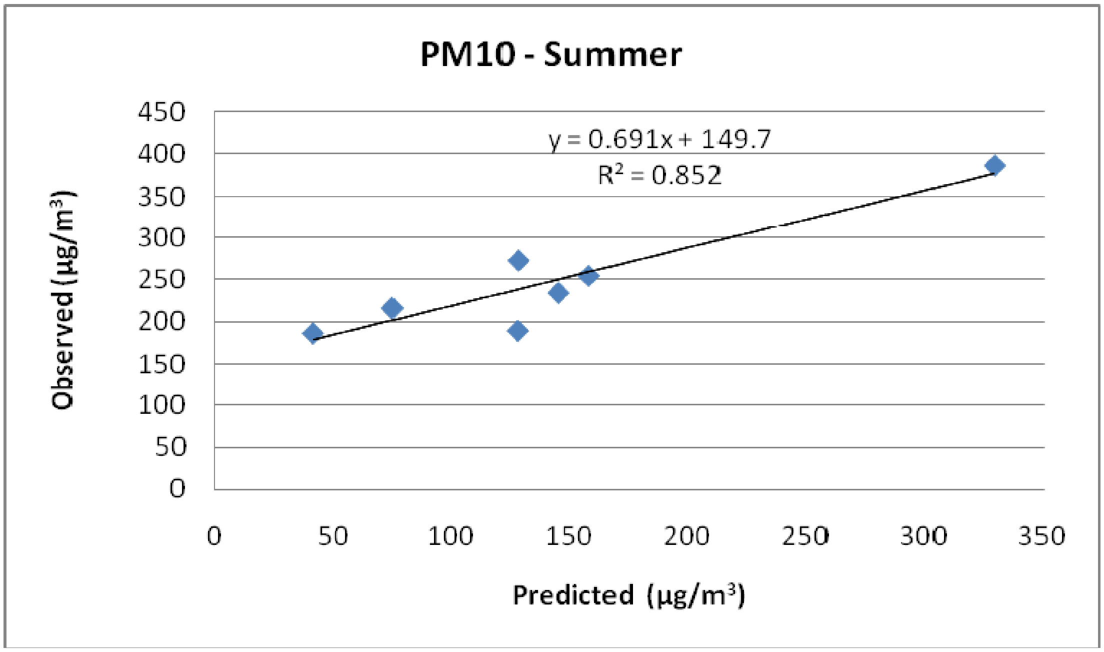


Figure 5.34: Observed vs Predicted of PM_{10} for Summer

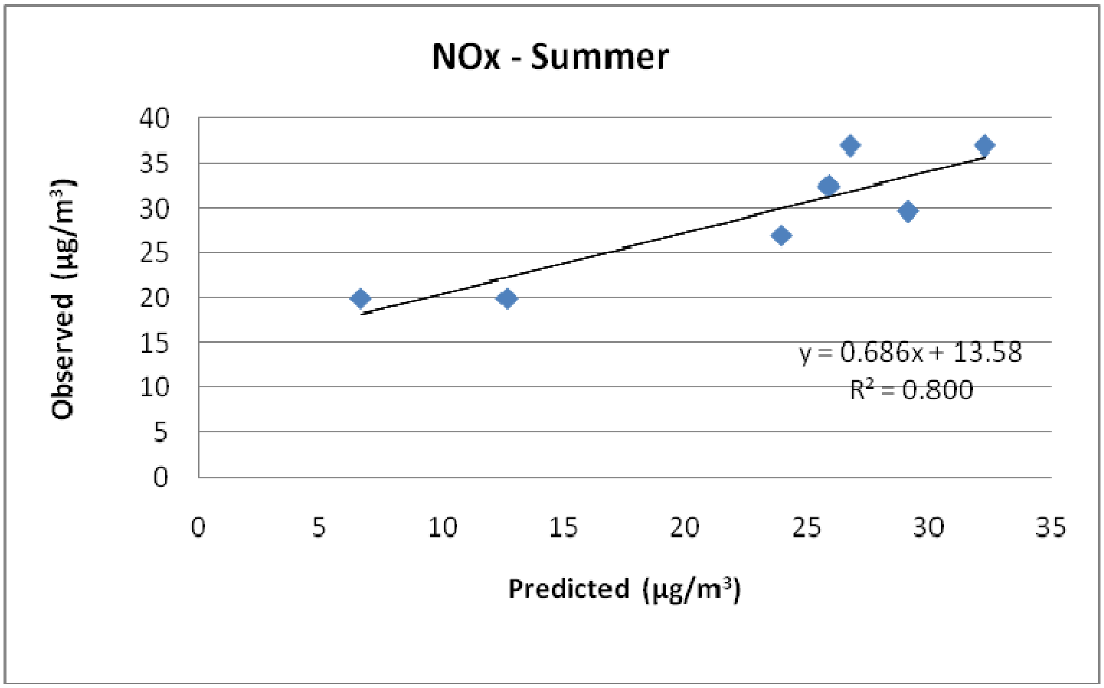


Figure 5.35: Observed vs Predicted of NOx for Summer

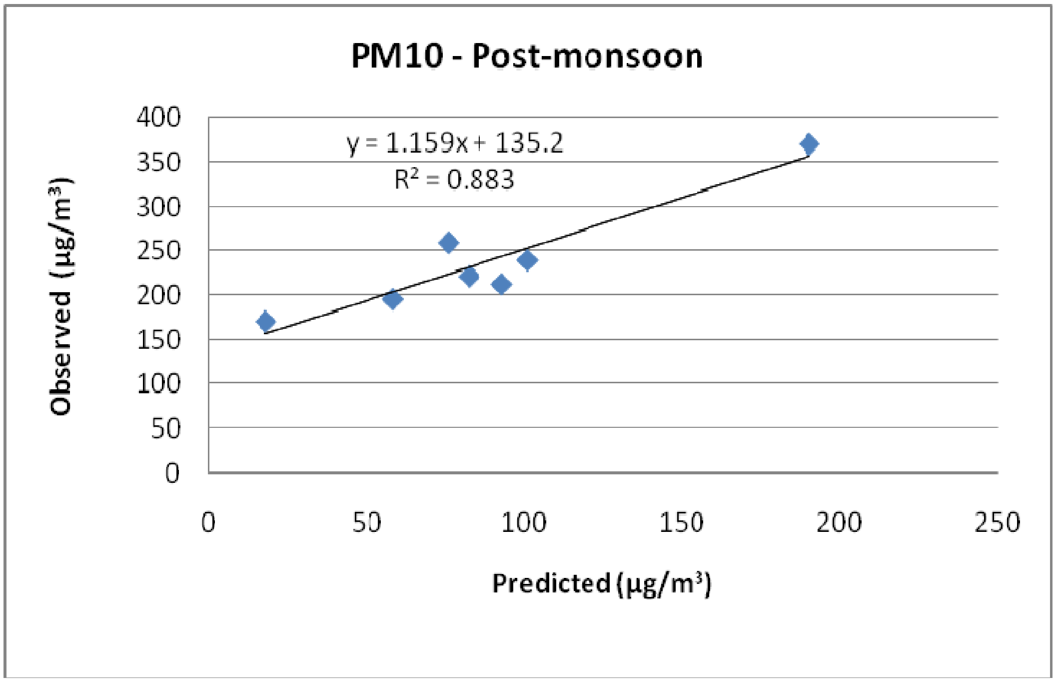


Figure 5.36: Observed vs Predicted of PM_{10} for Post-monsoon

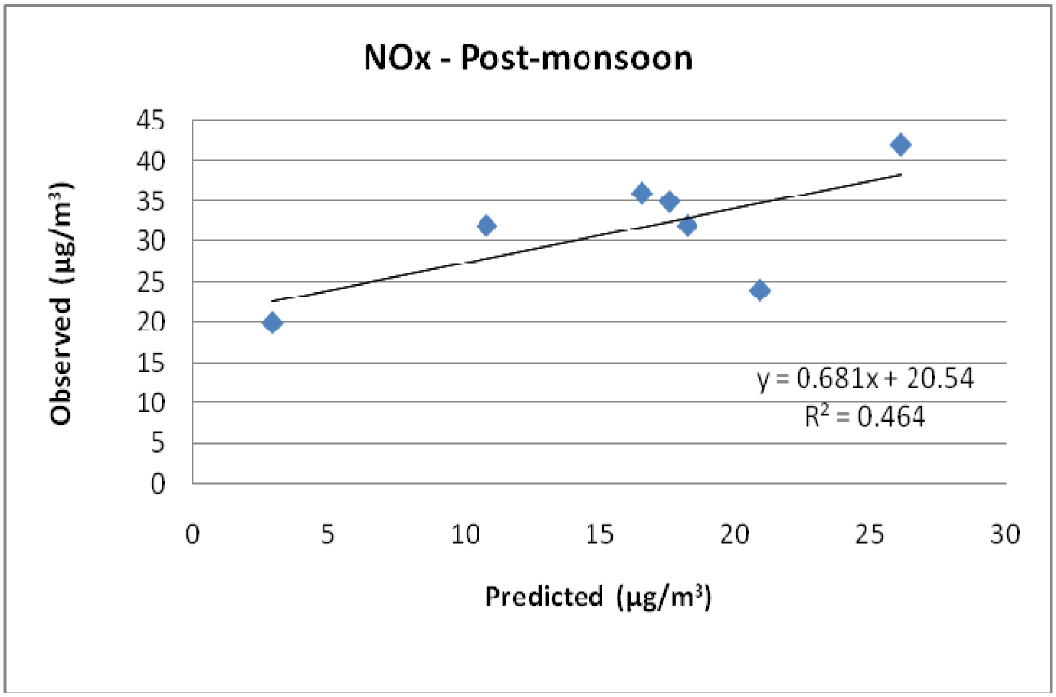


Figure 5.37: Observed vs Predicted of NOx for Post-monsoon

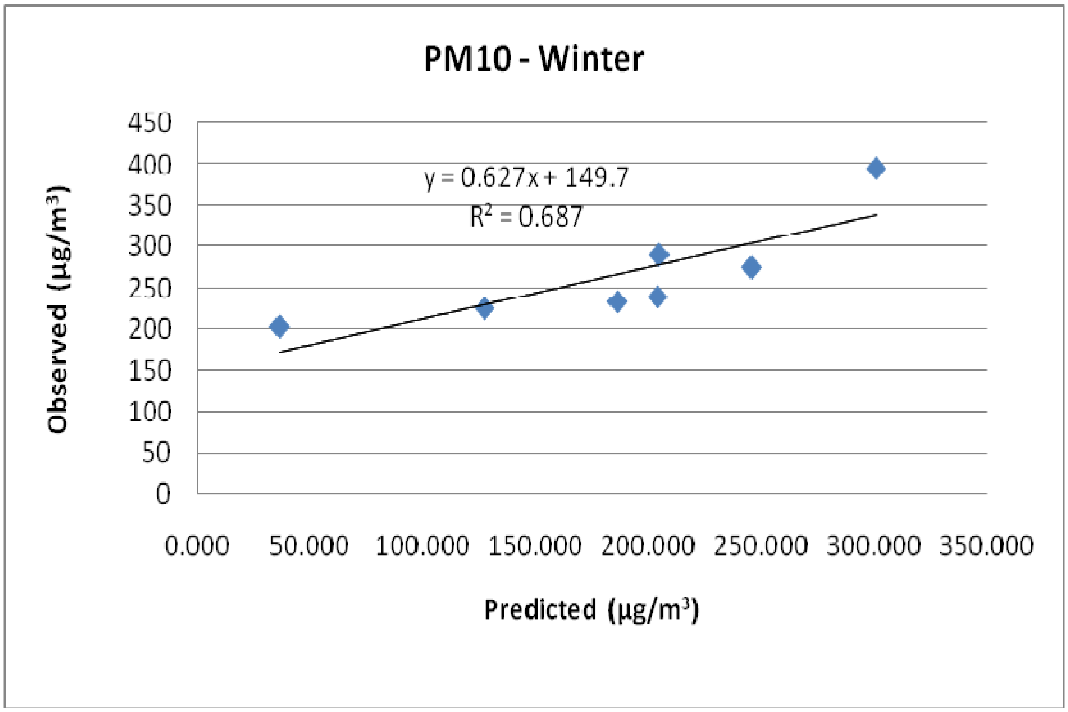


Figure 5.38: Observed vs Predicted of PM_{10} for Winter

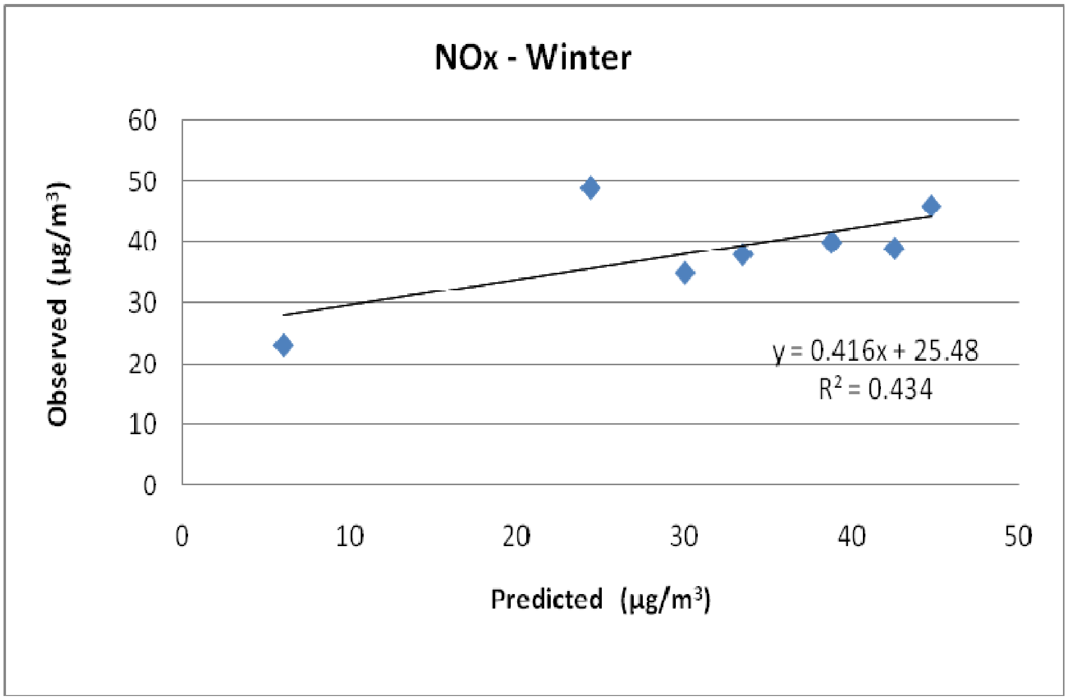


Figure 5.39: Observed vs Predicted of NO_x for Winter

5.4 Conclusions

The modeling results have been summarized in Figures 5.40 and 5.41. The following conclusions can be drawn from the modeling exercise.

- For PM_{10}, the industrial site (Dadanagar) showed the highest concentration and the industries appear to contribute a significant pollution at this site (~ 40 percent).
- There are three prominent and probably equally important sources of PM_{10} (vehicles, road dust and domestic fuel burning) that contribute to about 80 percent of PM_{10} at all sampling sites (except for the industrial location).
- Contribution of the largest sources (Panki power plant) is not significant probably due to very high emission release.
- For NO_x, 50-70 percent contribution is from vehicles at all sampling sites. It is only at industrial area (i.e. Dadanagar), where contribution of industries is seen and on a few occasions, the point source (power plant) also contributes to NO_x at this site. At the kerbsite and commercial site almost entire NO_x is from vehicles.
- Overall city specific modeling results follow the meteorology and emissions in each grid and there are clear hotspots. These hotspots vary depending on the season. PM_{10} hotspot in summer is in the industrial area and in winter season there are two equally important hotspots - industrial area and city center.
- NO_x levels show two consistent hotspots where concentrations can really be very high: (i) industrial area and (ii) the city center. It is seen that emission are also high in these two areas.
- Post monsoon season resulted in the lowest concentrations at all sampling sites. Winter was the worst season from air quality point of view. In addition to low mixing heights in winter, consistently wind being in the same direction results in high concentration in certain areas.
- Model performance was found adequate (R-square 0.88 – 0.44 for observed and predicted values). Observed levels are generally higher than predicted levels both for PM_{10} and NO_x. For PM_{10}, there is a significant part as background level.

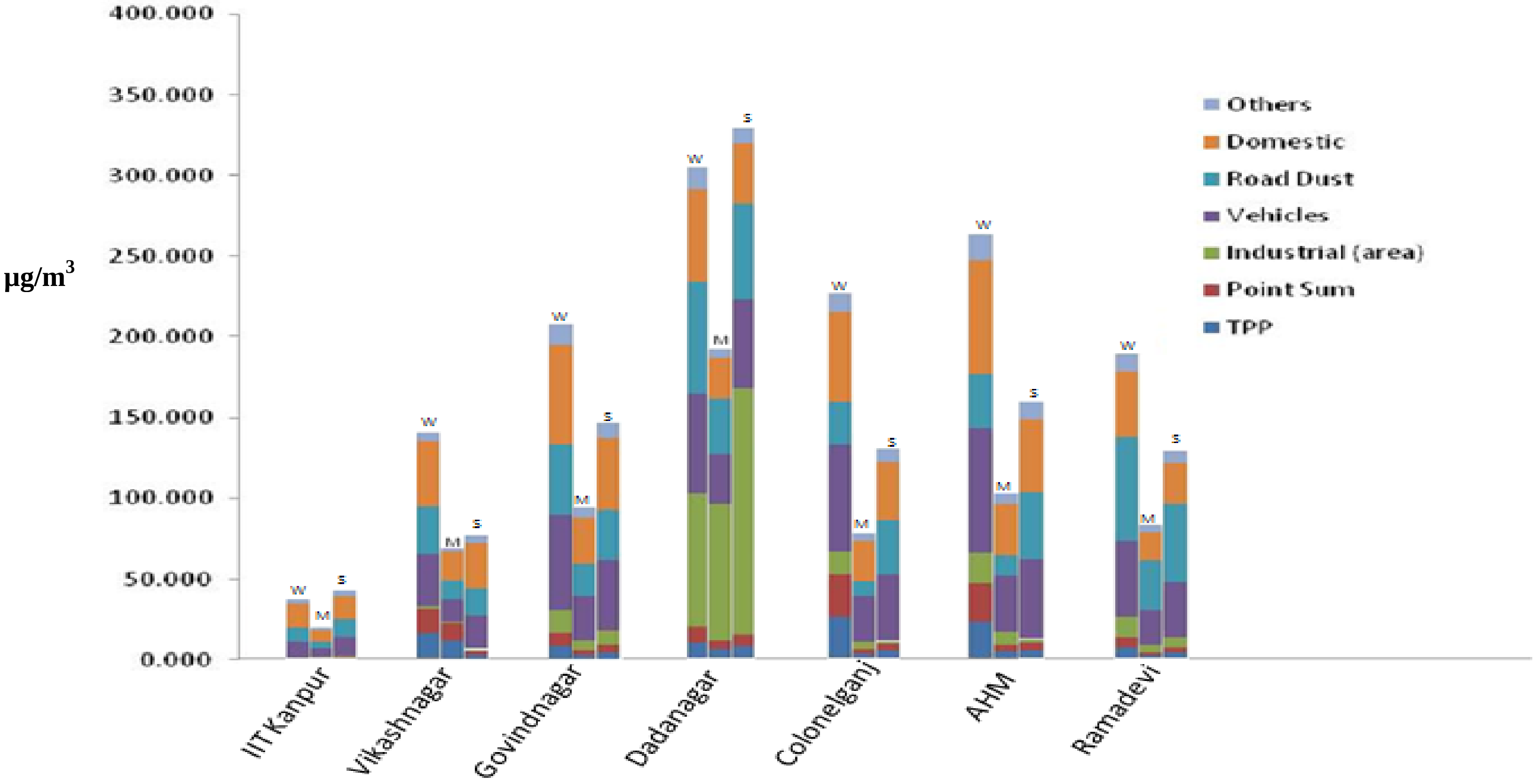


Figure 5.40: Location-wise Comparisons of ISCST3 Predictions for PM_{10}

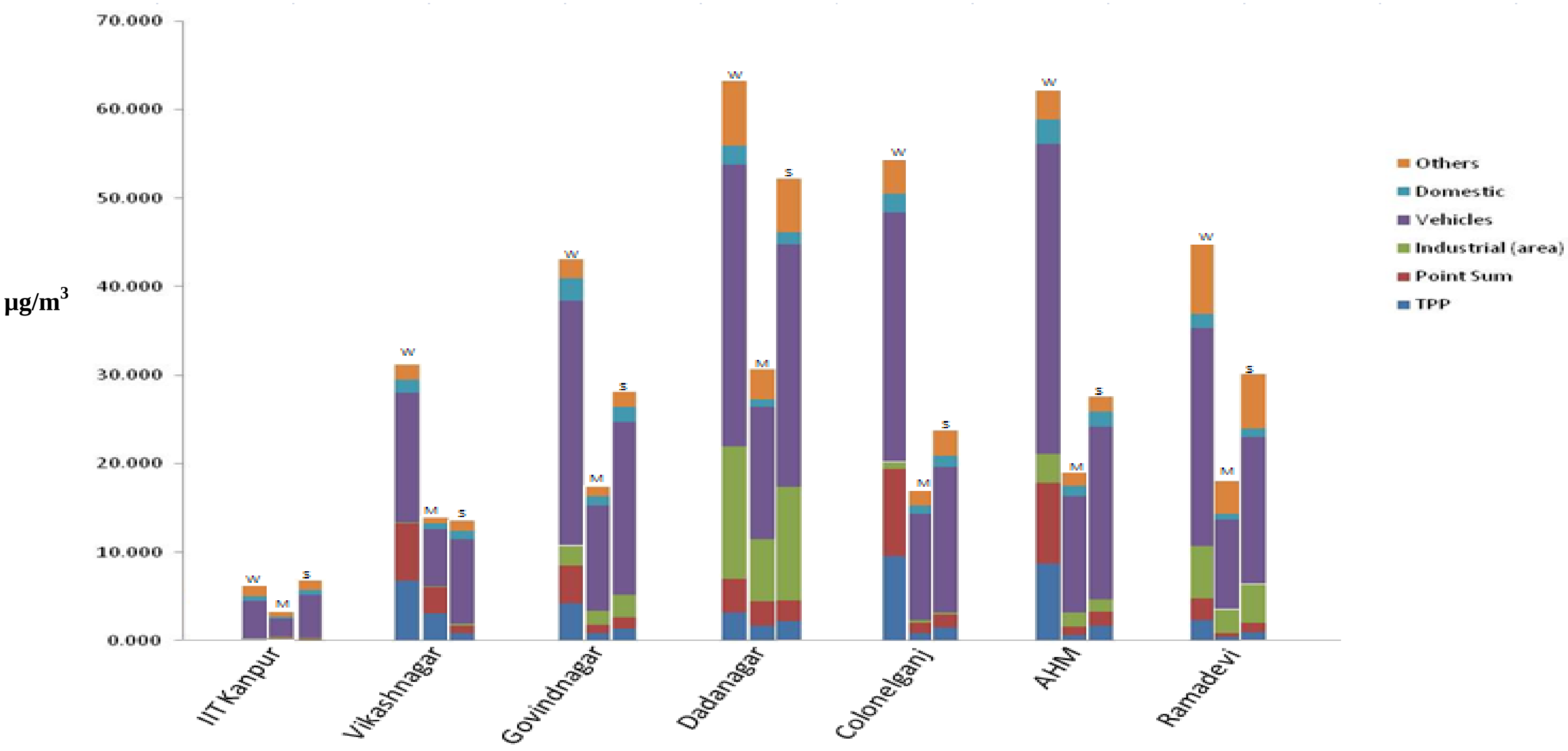


Figure 5.41: Location-wise Comparisons of ISCST3 Predictions for NOx

Chapter 6

Emission Control Options and Analysis

6.1 Summary of Prominent Sources

There are several prominent sources in Kanpur contributing to PM_{10} and NOx in ambient air. The Chapter 3 presented the emission inventory and Chapter 4 described contributions of each source identified in Chapter 3 to the ambient air pollution. The major PM_{10} sources include: vehicles, domestic fuel burning, road dust, industries as area sources and point sources (including 200 MW coal-based power plants) and other area sources including open garbage and agricultural waste burning and DG sets. The major sources of NOx are vehicles and industrial sources.

Contribution of pollutants to ambient air can be disproportionately high or low from the given source strength. For reasonable estimates of source contributions, one needs to resort to air quality models like ISCST3 of USEPA. The model can also assist in generating future air quality scenarios and in planning the air pollution control strategies.

6.2 Future Growth Scenario

There are three major sectors that have significant impact on emission and growth in these sectors can directly or indirectly influence the future emissions. These sectors are: vehicle, population and industry. In Kanpur city, vehicle and population are growing very rapidly whereas industrial growth in the urban area is negligible as there is no space available in the city. In fact all industrial growth in last 5 years has been in the areas which are 15-20 km away from the city.

Vehicle registration records for the last five years were obtained from the RTO, Kanpur and future (registered) number of vehicles in different categories was projected for the years 2012 and 2017. The estimated vehicular growth varies depending on vehicle category. The growth is as follows: 2-wheelers: 8%; 3-wheelers: 18%; 4-wheelers: 9%;

bus and trucks 16% and LCV: 16%. Similarly population growth was considered based census data of 1991 and 2001. Population is growing at 3.5 %, annually. It may be noted that population has both direct and indirect impact on emissions. While emission from domestic cooking can increase but this also lead to increased garbage burning, uses of DG sets, increase in restaurants and other urban activities.

On the basis of growth of vehicles and the population, projection of emission inventory has bee prepared for each of grid of the city (for grid details- see Chapter 3) for two years 2012 and 2017. The emission inventory results for these two projected years will be referred to as “Emission BAU 2012” and “Emission BAU 2017”.

6.3 Future Emission Inventory Scenario

Figures 6.1 and 6.2 show BAU emission inventory in each grid for year 2007, 2012 and 2017 for PM_{10} and NOx; one need to examine these figures in view of the legends given in the figures. It can be seen that the emissions increase dramatically in 2017 in each grid compared 2012. It can be seen that overall at city level, for the year 2012 compared to 2007, emission load for PM_{10} may increase by a factor of 1.5 and for the year 2017 compared to 2007, PM_{10} emission load may be up by a factor of 2.2 (Table 6.1). For example in 2007, 8 sq-km area had PM_{10} emission in the range 251-500 kg per day, the area with same emission increased to 12 sq-km in 2007 and in 2008 it increased to 20 sq-km. This increase is after accounting for the fact that beginning 2010, BS IV will be enforced for the new vehicles. The overall pattern or trend of emission inventory in each grid remains unchanged.

As for NOx emission, the increase in 2012 and 2017 is even more dramatic. It can be seen that overall at city level for the year 2012 compared to 2007, emission load for NOx may increase by a factor of 2.1 and for the year 2017 (compared to 2007), NOx emission load may be up by a factor of 3.1. This large increase in emission can be attributed to increase in number of vehicles that will happen in 2017.

In a broad sense, it is projected that ambient air pollution levels will increase by a factor of 2 and factor over 3 in the years 2012 and 2017 if no action is taken. The succeeding section proposes and examines various control options for the year 2012 and 2017.

6.4 Control Options and Modified Emission Inventory

There is a need to explore various options for controlling air pollutants to tackle increased emission in future. A list of control options that includes technological and management interventions is presented in Table 6.1 for PM_{10} and Table 6.2 for NOx.

The effectiveness of these options has also been examined in reducing the emissions at a city levels (Tables 6.1 and 6.2). Figures 6.3 to 6.6 show the effectiveness of control options for various source categories (line source, Industrial area sources and other area sources; details in Figures 6.3 to 6.6) for PM_{10}. For control of NOx emissions, some of the options may be common (as for PM_{10} e.g. adoption of BS V for vehicles) and/or some additional control options can be explored. Figures 6.7 to 6.9 show the effectiveness of control options for various source categories (line source, Industrial area sources and other area sources; details in Figures 6.7 to 6.9) for NOx. The emission inventory will get modified from BAU scenarios as control options are made effective.

Figure 6.1: PM_{10} Pollution Load over the City with BAU for (a) 2007 (b) 2012 (c) 2017

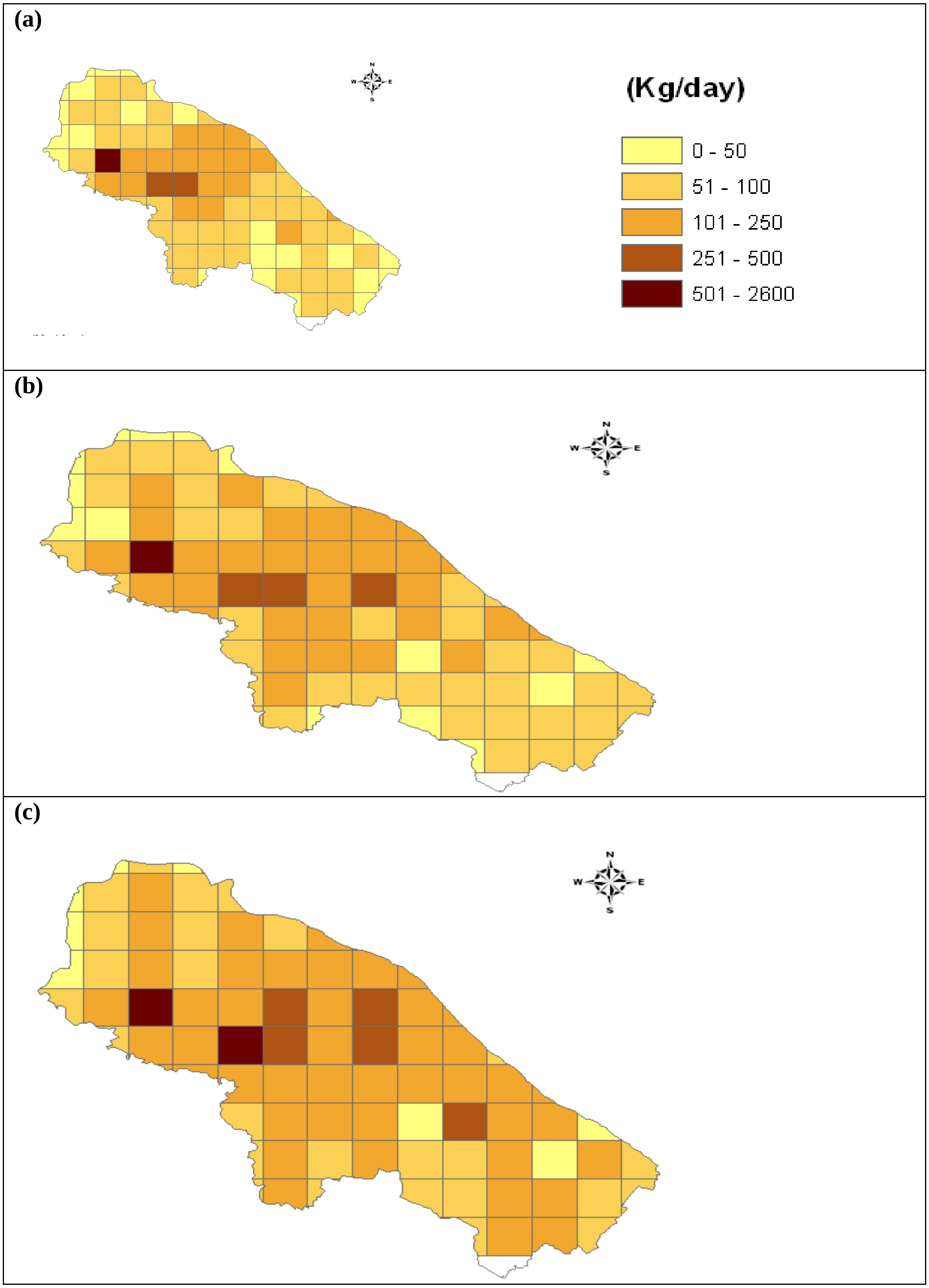


Figure 6.2: NO$_x$ Pollution Load over the City with BAU for (a) 2007 (b) 2012 (c) 2017

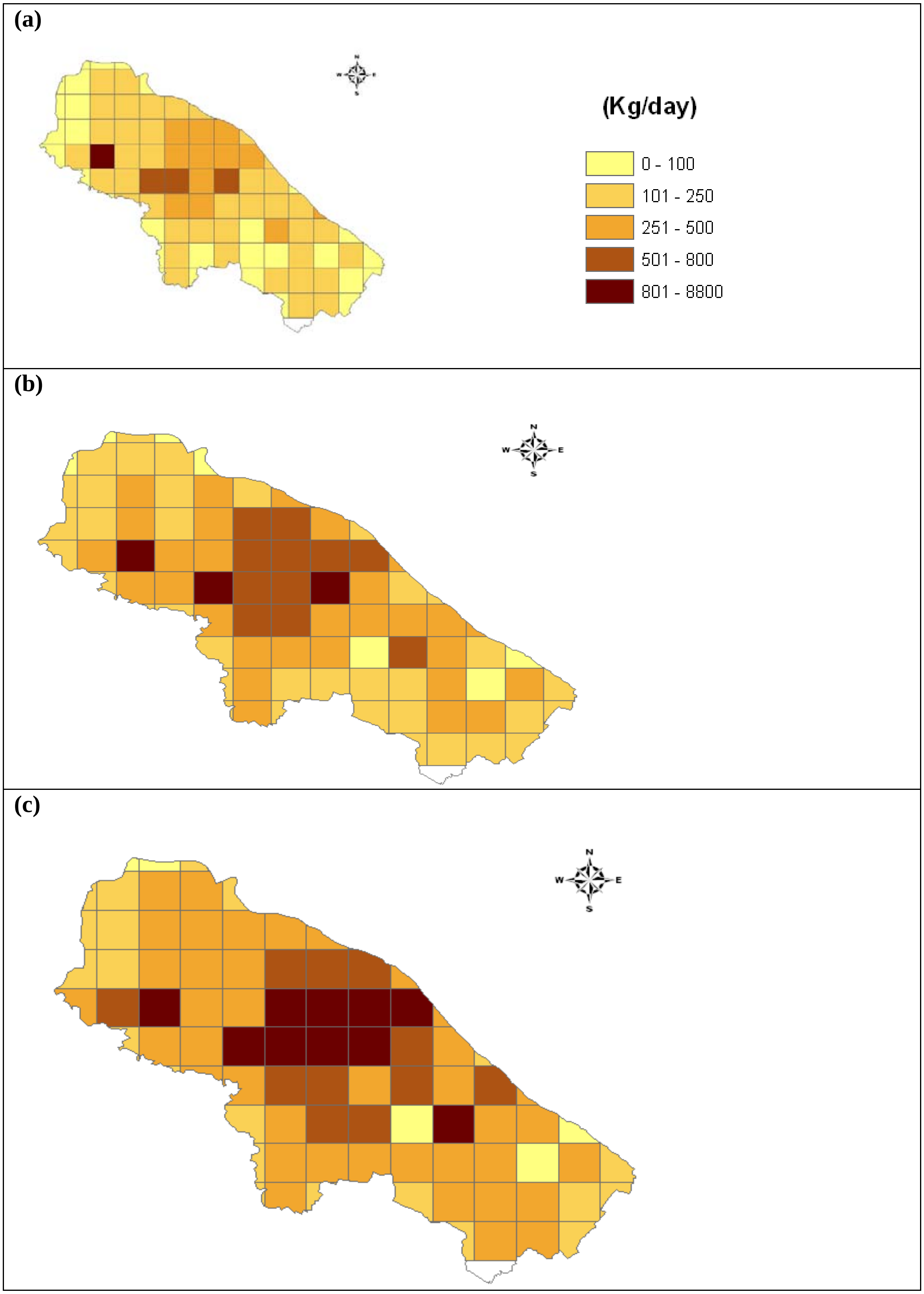


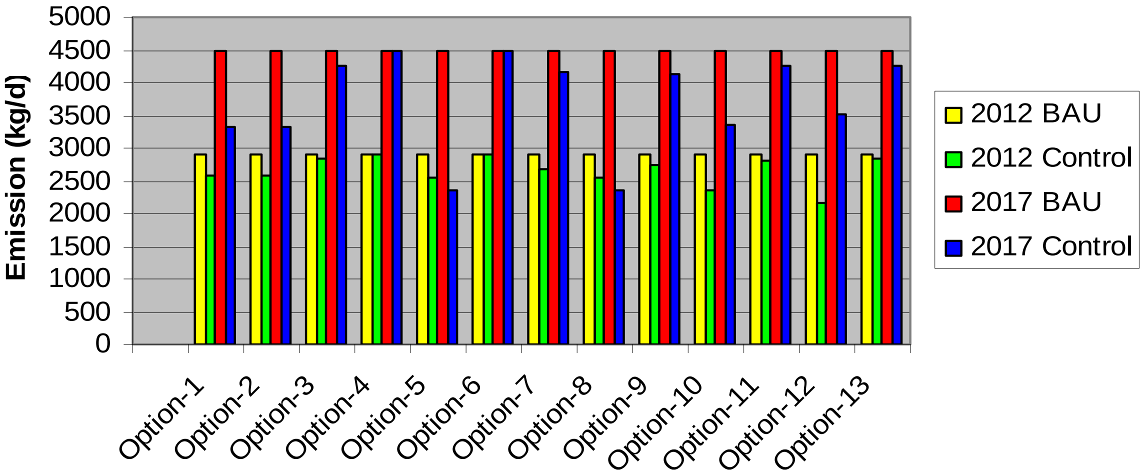
Table 6.1: Emission Loads (kg/day) and Percentage Reductions of PM_{10} for Kanpur City (Overall) with Control Options (Emission Inventory)

S. No	Option No.	Details of Control Option	2007 BAU (Base)	Scenario 2012			Scenario 2017		
				2012 BAU	2012 Control	% Reduction	2017 BAU	2017 Control	% Reduction
1	Option-1	Implementation of BS – V norms	1918	2918	2593	11.1	4475	3339	25.4
2	Option-2	Implementation of BS – VI norms	1918	2918	2918	0.0	4475	4108	8.2
3	Option-3	Electric vehicles	1918	2918	2852	2.3	4475	4256	4.9
4	Option-4	Hybrid vehicles	1918	2918	2918	0.0	4475	4475	0.0
5	Option-5	CNG/LPG to commercial	1918	2918	2555	12.4	4475	2368	47.1
6	Option-6	Ethanol blending (E10 – 10% blend)	1918	2918	2918	0.0	4475	4475	0.0
7	Option-7	Bio-diesel (B5/B10: 5 – 10% blend)	1918	2918	2689	7.9	4475	4149	7.3
8	Option-8	Hydrogen–CNG blend	1918	2918	2555	12.4	4475	2368	47.1
9	Option-9	Retro fitment of diesel oxidation catalyst	1918	2918	2739	6.1	4475	4118	8.0
10	Option-10	Retro fitment of diesel particulate filter	1918	2918	2362	19.0	4475	3364	24.8
11	Option-11	Inspection/ maintenance of vehicles	1918	2918	2812	3.6	4475	4264	4.7
12	Option-12	Banning of 15 year old private vehicles	1918	2918	2157	26.1	4475	3525	21.2
13	Option-13	Improvement of public transport	1918	2918	2828	3.1	4475	4247	5.1
14	Option-14	Industry fuel change	3043	3043	758	75.1	3043	783	74.3
15	Option-15	Particulate control system in industry	3043	3043	38	98.8	3043	38	98.8
16	Option-16	Shifting of air polluting industries	3043	3043	1522	50.0	3043	0	100.0
17	Option-17	Domestic-Use of Natural Gas/LPG	2068	2440	1641	32.7	2812	1417	49.6
18	Option-18	Inspection & Maintenance of large DG sets	81	95	81	15.0	110	93	15.0
19	Option-19	Adequate supply of grid power	81	95	0	100.0	110	0	100.0
20	Option-20	Better construction practices	3	3	2	50.0	4	2	50.0
21	Option-21	Converting unpaved roads to paved roads	1353	1880	1582	15.8	2406	1720	28.5
22	Option-22	Wall to wall paving (brick)	1353	1880	1776	5.5	2406	1702	29.2
23	Option-23	Sweeping and watering (mechanized)	1353	1880	1535	18.3	2406	1134	52.8
24	Option-24	Strict compliance to ban of open burning	835	921	460	50.0	1006	0	100.0

Table 6.2: Emission Loads (kg/day) and Percentage Reductions of NO_x for Kanpur City (Overall) with Control Options (Emission Inventory)

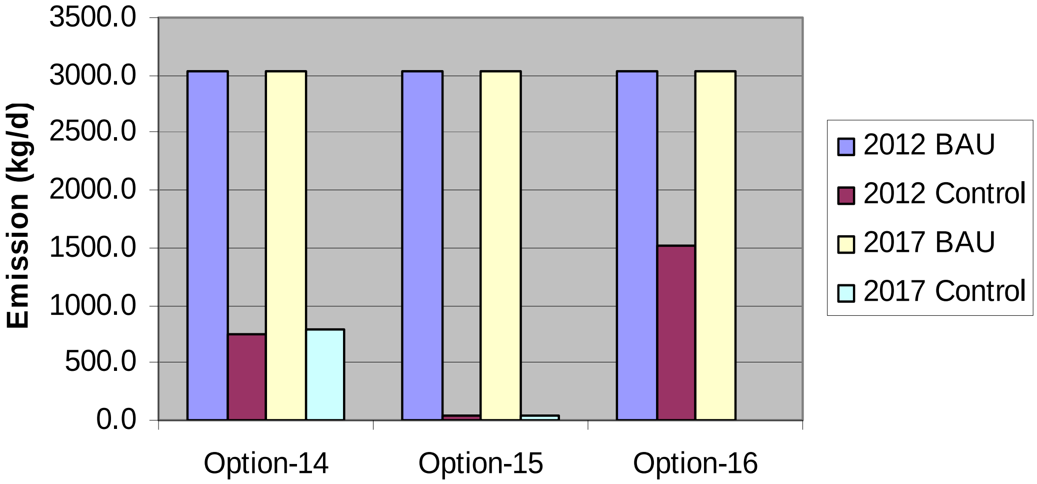
S. No.	Option No.	Details of Control Option	2007 BAU (Base)	Scenario 2012			Scenario 2017		
				2012 BAU	2012 Control	% Reduction	2017 BAU	2017 Control	% Reduction
1	Option-1	Implementation of BS – V norms	10571	21214	20560	3.1	31784	29502	7.2
2	Option-2	Implementation of BS – VI norms	10571	21214	21214	0.0	31784	29972	5.7
3	Option-3	Electric vehicles	10571	21214	20672	2.6	31784	30013	5.6
4	Option-4	Hybrid vehicles	10571	21214	21207	0.0	31784	31767	0.1
5	Option-5	CNG/LPG to commercial	10571	21214	18531	12.6	31784	29612	6.8
6	Option-6	Ethanol blending (E10 – 10% blend)	10571	21214	20405	3.8	31784	30681	3.5
7	Option-7	Bio-diesel (B5/B10: 5 – 10% blend)	10571	21214	21619	-1.9	31784	32335	-1.7
8	Option-8	Hydrogen–CNG blend	10571	21214	18531	12.6	31784	28092	11.6
9	Option-9	Retro fitment of diesel oxidation catalyst	10571	21214	21214	0.0	31784	31784	0.0
10	Option-10	Retro fitment of diesel particulate filter	10571	21214	21214	0.0	31784	31784	0.0
11	Option-11	Inspection/ maintenance of vehicles	10571	21214	20666	2.6	31784	30687	3.5
12	Option-12	Banning of 15 year old private vehicles	10571	21214	15680	26.1	31784	24866	21.8
13	Option-13	Improvement of public transport	10571	21214	20292	4.3	31784	29578	6.9
14	Option-14	Industry fuel change	9628	9628	5468.7	43.2	9628	5119	46.8
15	Option-15	Particulate control system in industry	9628	9628	9628	0.0	9628	9628	0.0
16	Option-16	Shifting of air polluting industries	9628	9628	4814	50.0	9628	0	100.0
17	Option-17	Domestic-Use of Natural Gas/LPG	951	1122	922	17.9	1294	936	27.7
18	Option-18	Inspection & Maintenance of large DG sets	1141	1347	1145	15.0	1552	1320	15.0
19	Option-19	Adequate supply of grid power	1141	1347	0	100.0	1552	0	100.0
20	Option-24	Strict compliance to ban of open burning	194	226	113	50.0	259	0	100.0

Figure 6.3: Effect of Control Option-Line Source for PM10 (Emission Inventory)



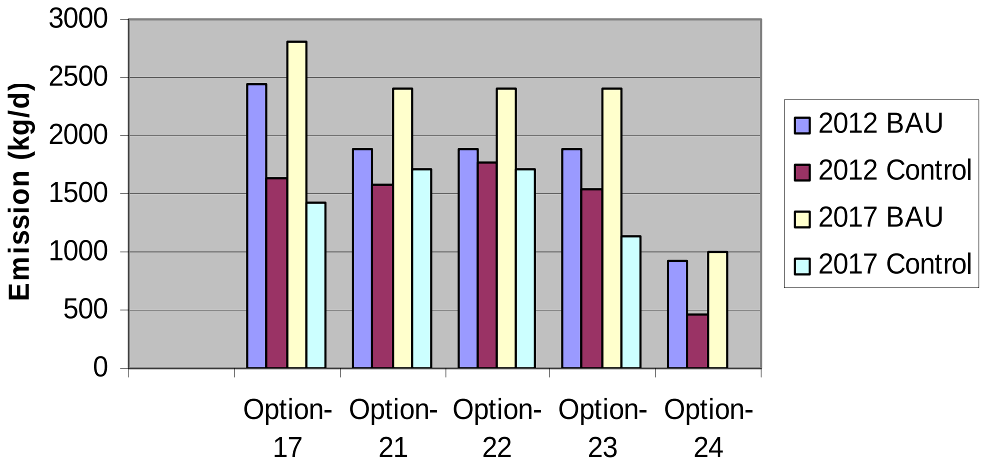
Opt-1: BS– V norms; Opt-2: BS– V norms; Opt-3: BS– Electric veh; Opt-4: Hybrid veh; Opt-5: CNG/LPG; Opt-6: Ethanol Blend; Opt-7: Biodiesel; Opt-8: Hydrogen-CNG blend; Opt-9: Retrofit DOC; Opt-10: Retrofit DPF; Opt-11: I/M of veh; Opt-12: Ban of 15yr old; Opt-13: Improvement of public transport.

Figure 6.4: Effect of Control Option- Industry for PM10 (Emission Inventory)



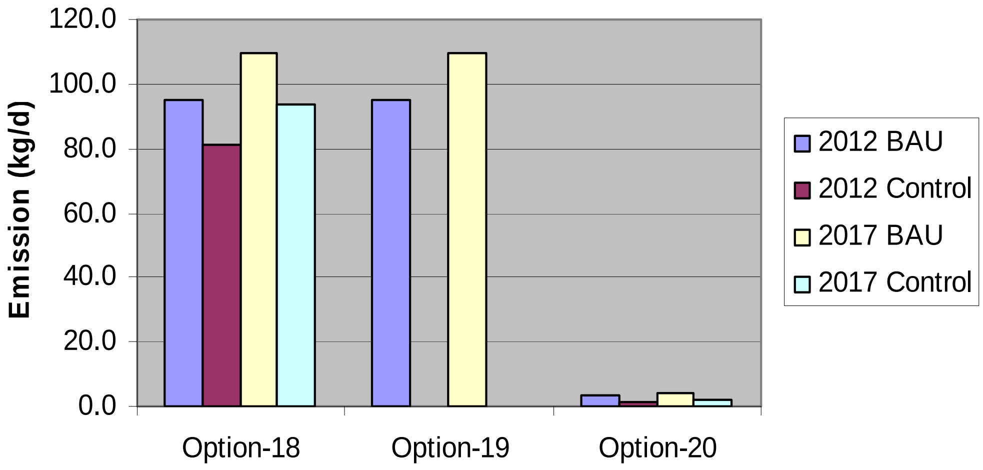
Opt 14: Ind fuel change; Opt 15: Ind particulate control system; Opt 16: Shift of ind

Figure 6.5: Effect of Control Option-Area Source-1 for PM10 (Emission Inventory)



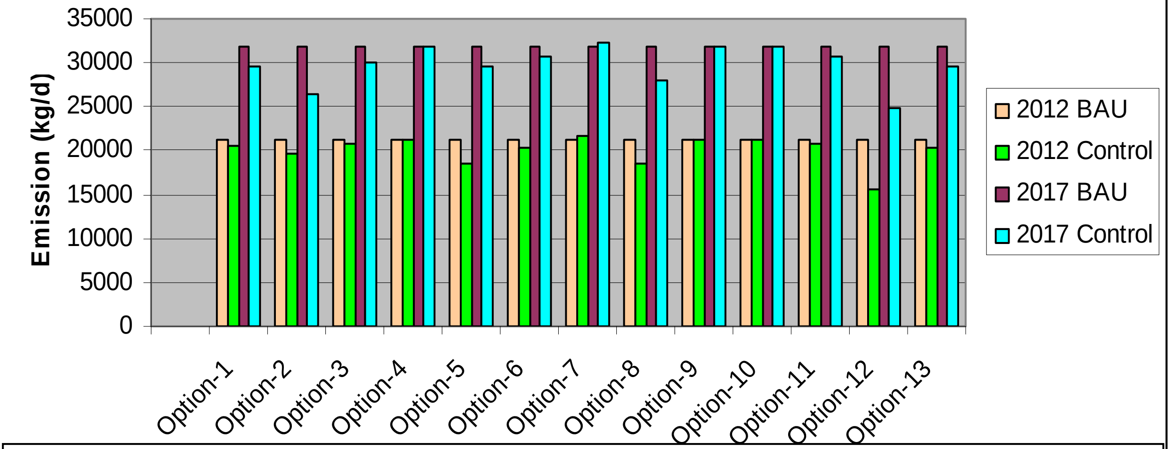
Area Source -1: Domestic, Road dust and open Burning
Opt 17: Change of domestic fuels; Opt 21: convert unpaved to paved road; Opt 22: Wall to wall paving; Opt 23: Sweeping & Watering; Opt 24: Compliance to ban of open burning.

Figure 6.6: Effect of Control Option-Area Source-2 for PM10 (Emission Inventory)



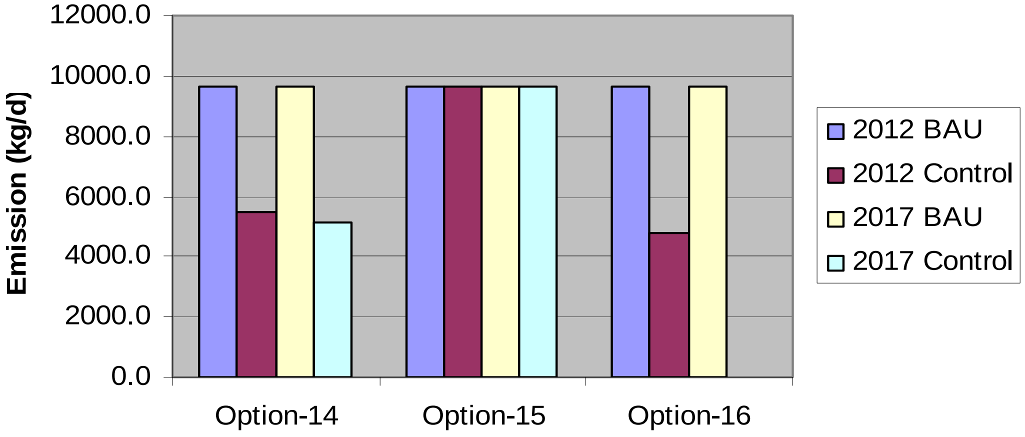
Area Source-2: Construction and DG sets
Opt 18: I/M of DG sets; Opt 19: Supply of grid power; Opt 20: Better construction practice;

Figure 6.7: Effect of Control Option-Line Source for NOx (Emission Inventory)



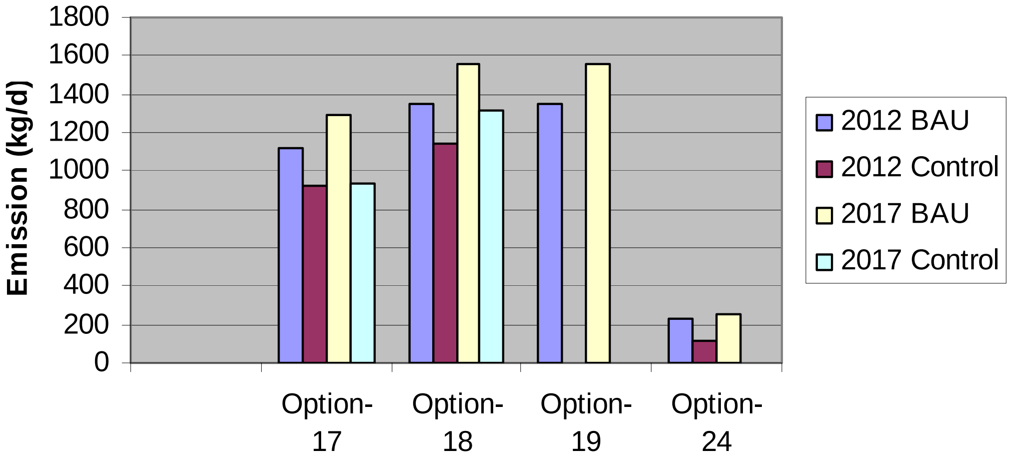
Opt-1: BS– V norms; Opt-2: BS– V norms; Opt-3: BS– Electric veh; Opt-4: Hybrid veh; Opt-5: CNG/LPG; Opt-6: Ethanol Blend; Opt-7: Biodiesel; Opt-8: Hydrogen-CNG blend; Opt-9: Retrofit DOC; Opt-10: Retrofit DPF; Opt-11: I/M of veh; Opt-12: Ban of 15yr old; Opt-13: Improvement of public transport.

Figure 6.8: Effect of Control Option-Industry for NOx (Emission Inventory)



Opt 14: Ind fuel change; Opt 15: Ind particulate control system; Opt 16: Shift of ind

Figure 6.9: **Effect of Control Option-Area Source for NOx (Emission Inventory)**



Opt 17: Change of domestic fuels; Opt 18: I/M of DG sets; Opt 19: Supply of grid power; Opt 24: Compliance to ban of open burning.

6.5 ISC Modeling Analysis: Efficacy of Various Control Options

ISC Modeling exercise was undertaken for winter time critical meteorology to examine efficacy of control options in terms of improvements in air quality vis-à-vis source emission reduction. For every control option for the specific source, the model was run twice with and without the control option for each source (keeping other sources as being absent). By this way, one could determine the impact of each control option for improving air quality from vehicles, industries and area sources. The model was run to pick up top 150 values (those exceeding the air quality standard) from 24 hrs x 30 days (720 values) of critical month. The grids showing top 150 values were identified as critical grids. The focus should be on improving the air quality in these grids with broad options and air quality in other grids will also improve concurrently along with critical grids. It may be noted that top 150 concentrations can fall in the same grids over and over again and it was found that it was generally 10 grids in which the maximum concentration will fall.

Tables 6.3 to 6.5 show contribution of a particular source category in BAU scenarios and then the improved air quality because of control options (in critical grids). The percent reduction columns in these tables and average improvement in air quality in the critical grids due to adoptions of the control options can assist in identifying the efficacy of a control option. Similar exercise was done to examine efficacy of control options for NOx (Tables 6.7 to 6.8).

Table 6.3: ISC Results for Line Source only: BAU and Control Options Efficacy for PM_{10}

			Control Option-1				Control Option-2				Control Option-3			
Critical Grid	**2012BAU Con (ug/m3)**	**2017BAU Con (ug/m3)**	**2012 C (ug/m3)**	**% Reduction**	**2017 C (ug/m3)**	**% Reduction**	**2012 C (ug/m3)**	**% Reduction**	**2017 C (ug/m3)**	**% Reduction**	**2012 C (ug/m3)**	**% Reduction**	**2017 C (ug/m3)**	**% Reduction**
K-G-033	51.04	79.40	44.86	12.11	58.80	25.94	0	0	72.02	9.29	48.39	5.20	75.27	5.20
K-G-049	115.97	169.45	99.63	14.09	125.50	25.94	0	0	160.48	5.29	113.37	2.24	158.96	6.19
K-G-062	113.57	170.52	96.45	15.08	126.29	25.94	0	0	160.24	6.03	111.03	2.24	159.97	6.19
K-G-064	146.44	234.09	128.70	12.11	191.87	18.04	0	0	220.06	5.99	140.27	4.21	221.92	5.20
K-G-075	133.39	206.00	113.28	15.08	152.57	25.94	0	0	200.47	2.68	130.41	2.24	193.25	6.19
K-G-078	142.99	217.56	125.67	12.11	161.13	25.94	0	0	200.98	7.62	135.56	5.20	206.25	5.20
K-G-080	120.50	187.27	104.72	13.10	138.69	25.94	0	0	168.69	9.92	108.29	10.14	175.68	6.19
K-G-091	127.27	195.24	109.34	14.09	160.02	18.04	0	0	182.67	6.44	120.65	5.20	183.16	6.19
K-G-095	129.60	202.26	112.62	13.10	165.78	18.04	0	0	187.8	7.15	116.46	10.14	189.75	6.19
K-G-108	115.66	178.08	101.65	12.11	145.96	18.04	0	0	150.13	15.70	110.79	4.21	168.82	5.20
Average	**119.64**	**183.99**	**103.69**	**13.33**	**142.66**	**22.46**	**0**	**0**	**133.55**	**7.61**	**113.52**	**5.12**	**173.30**	**5.81**

			Control Option-4				Control Option-5				Control Option-7			
Critical Grid	**2012BAU Con (ug/m3)**	**2017BAU Con (ug/m3)**	**2012 C (ug/m3)**	**% Reduction**	**2017 C (ug/m3)**	**% Reduction**	**2012 C (ug/m3)**	**% Reduction**	**2017 C (ug/m3)**	**% Reduction**	**2012 C (ug/m3)**	**% Reduction**	**2017 C (ug/m3)**	**% Reduction**
K-G-033	51.04	79.40	50.40	1.25	78.40	1.25	43.35	15.08	45.47	42.73	47.38	7.18	74.48	6.19
K-G-049	115.97	169.45	114.52	1.25	167.33	1.25	97.34	16.06	102.07	39.76	107.65	7.17	155.62	8.16
K-G-062	113.57	170.52	112.15	1.25	168.39	1.25	95.32	16.06	107.77	36.80	105.42	7.17	156.60	8.16
K-G-064	146.44	234.09	144.61	1.25	231.17	1.25	125.81	14.09	134.08	42.73	135.93	7.18	219.61	6.19
K-G-075	133.39	206.00	131.72	1.25	203.43	1.25	111.97	16.06	130.19	36.80	123.82	7.18	189.19	8.16
K-G-078	142.99	217.56	141.21	1.25	214.84	1.25	121.44	15.08	124.61	42.73	132.73	7.18	204.10	6.19
K-G-080	120.50	187.27	119.00	1.25	184.93	1.25	104.72	13.10	112.80	39.76	110.67	8.16	173.83	7.18
K-G-091	127.27	195.24	125.68	1.25	192.80	1.25	108.08	15.08	117.61	39.76	118.14	7.18	183.16	6.19
K-G-095	129.60	202.26	127.98	1.25	199.74	1.25	112.62	13.10	121.84	39.76	119.02	8.16	187.75	7.18
K-G-108	115.66	178.08	114.22	1.25	175.85	1.25	99.37	14.09	101.99	42.73	107.36	7.18	167.06	6.19
Average	**119.64**	**183.99**	**118.15**	**1.25**	**181.69**	**1.25**	**102.00**	**14.75**	**109.84**	**40.30**	**110.81**	**7.38**	**171.14**	**6.98**

Table 6.3: ISC Results for Line Source only: BAU and Control Options Efficacy for PM_{10}

Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-8				Control Option-9				Control Option-10			
			2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction
K-G-033	51.04	79.40	43.85	14.09	40.77	48.65	47.88	6.19	72.13	9.15	39.82	21.99	58.80	25.94
K-G-049	115.97	169.45	98.49	15.08	80.32	52.60	108.79	6.19	152.27	10.14	90.47	21.99	118.80	29.89
K-G-062	113.57	170.52	96.45	15.08	80.83	52.60	104.30	8.16	153.23	10.14	88.60	21.99	119.55	29.89
K-G-064	146.44	234.09	125.81	14.09	120.21	48.65	137.38	6.19	212.67	9.15	114.24	21.99	173.37	25.94
K-G-075	133.39	206.00	113.28	15.08	97.64	52.60	122.50	8.16	185.12	10.14	104.46	21.69	144.43	29.89
K-G-078	142.99	217.56	122.85	14.09	111.72	48.65	134.15	6.19	197.65	9.15	111.55	21.99	161.13	25.94
K-G-080	120.50	187.27	105.91	12.11	101.71	45.69	115.43	4.21	170.13	9.15	96.39	20.01	133.15	28.90
K-G-091	127.27	195.24	108.08	15.08	100.25	48.65	119.39	6.19	177.37	9.15	99.29	21.99	144.60	25.94
K-G-095	129.60	202.26	115.18	11.13	107.86	46.68	124.14	4.21	183.16	9.45	103.66	20.01	145.81	27.91
K-G-108	115.66	178.08	99.37	14.09	96.72	45.69	110.79	4.21	161.78	9.15	92.51	20.01	126.61	28.90
Average	**119.64**	**183.99**	**102.93**	**13.97**	**93.80**	**49.02**	**112.47**	**5.99**	**166.55**	**9.48**	**94.10**	**21.35**	**132.63**	**27.92**

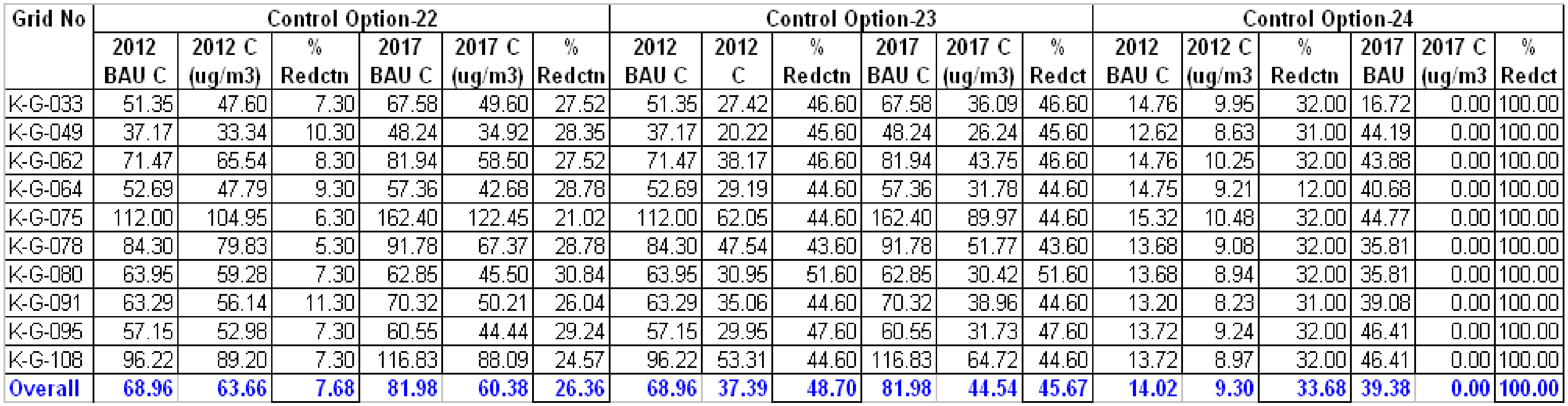
Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-11				Control Option-12				Control Option-13			
			2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction
K-G-033	51.04	79.40	48.39	5.20	75.27	5.20	31.00	39.27	60.37	23.96	48.39	5.20	76.05	4.21
K-G-049	115.97	169.45	112.23	3.22	160.64	5.20	84.86	26.83	129.35	23.67	109.94	5.20	157.12	7.27
K-G-062	113.57	170.52	109.90	3.22	161.65	5.20	83.10	26.83	130.16	23.67	107.66	5.20	162.32	4.81
K-G-064	146.44	234.09	138.82	5.20	221.92	5.20	111.06	24.16	178.00	23.96	140.27	4.21	224.23	4.21
K-G-075	133.39	206.00	130.72	2.00	193.25	6.19	97.61	26.83	157.25	23.67	126.46	5.20	197.53	4.11
K-G-078	142.99	217.56	135.56	5.20	206.25	5.20	86.84	39.27	165.43	23.96	135.56	5.20	208.39	4.21
K-G-080	120.50	187.27	115.43	4.21	173.83	7.18	84.96	29.49	145.17	22.48	115.43	4.21	175.68	6.19
K-G-091	127.27	195.24	120.65	5.20	185.08	5.20	93.13	26.83	148.45	23.96	120.65	5.20	187.01	4.21
K-G-095	129.60	202.26	124.14	4.21	189.75	6.19	91.38	29.49	156.99	22.38	125.42	3.23	189.75	6.19
K-G-108	115.66	178.08	111.93	3.22	165.30	7.17	70.24	39.27	138.04	22.48	110.79	4.21	167.06	6.19
Average	**119.64**	**183.99**	**114.78**	**4.07**	**173.29**	**5.81**	**83.42**	**30.28**	**140.92**	**23.41**	**114.06**	**4.67**	**174.51**	**5.15**

Table 6.4: ISC Results for Industrial Source only: BAU and Control Options Efficacy for PM_{10}

Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-14				Control Option-15				Control Option-16			
			2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction
K-G-033	16.88	16.88	3.71	78.00	8.27	51.00	0.17	99.00	0.17	99.00	8.27	51.00	8.27	51.00
K-G-049	40.77	40.77	8.97	78.00	13.05	68.00	0.41	99.00	0.41	99.00	19.98	51.00	19.98	51.00
K-G-062	54.83	54.83	12.06	78.00	26.86	51.00	0.55	99.00	0.55	99.00	26.86	51.00	26.86	51.00
K-G-064	43.64	43.64	14.40	67.00	13.96	68.00	0.87	98.00	0.87	98.00	21.38	51.00	21.38	51.00
K-G-075	94.53	94.53	20.80	78.00	27.41	71.00	0.95	99.00	0.95	99.00	46.32	51.00	46.32	51.00
K-G-078	94.64	94.64	31.23	67.00	30.29	68.00	1.89	98.00	1.89	98.00	46.37	51.00	46.37	51.00
K-G-080	34.64	34.64	9.70	72.00	11.08	68.00	0.35	99.00	0.35	99.00	16.97	51.00	16.97	51.00
K-G-091	25.18	25.18	5.54	78.00	11.08	56.00	0.50	98.00	0.50	98.00	12.34	51.00	12.34	51.00
K-G-095	28.14	28.14	6.19	78.00	12.38	56.00	0.56	98.00	0.56	98.00	13.79	51.00	13.79	51.00
K-G-108	18.89	18.89	4.16	78.00	8.31	56.00	0.38	98.00	0.38	98.00	9.26	51.00	9.26	51.00
Average	**45.21**	**45.21**	**11.68**	**74.18**	**16.27**	**64.01**	**0.66**	**98.53**	**0.66**	**98.53**	**22.15**	**51.00**	**22.15**	**51.00**

Table 6.5: ISC Results for Area Source only: BAU and Control Options Efficacy for PM_{10}

Critical Grid	Control Option-17						Control Option-21					
	2012 BAU C (ug/m3)	2012 C (ug/m3)	% Reduction	2017 BAU C (ug/m3)	2017 C (ug/m3)	% Reduction	2012 BAU C (ug/m3)	2012 C (ug/m3)	% Reduction	2017 BAU C (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	48.99	32.33	34.00	56.31	27.59	51.00	51.35	44.52	13.30	67.58	52.44	22.40
K-G-049	88.41	55.70	37.00	104.96	53.53	49.00	37.17	28.51	23.30	48.24	35.50	26.40
K-G-062	81.27	56.89	30.00	96.29	47.18	51.00	71.47	61.97	13.30	81.94	62.76	23.40
K-G-064	88.41	55.70	37.00	104.96	53.53	49.00	52.69	45.68	13.30	57.36	45.66	20.40
K-G-075	83.87	58.71	30.00	95.39	48.65	49.00	112.00	92.63	17.30	162.40	122.77	24.40
K-G-078	101.97	47.93	53.00	115.41	39.40	51.00	84.30	73.09	13.30	91.78	70.30	23.40
K-G-080	84.95	53.52	37.00	96.26	41.95	49.00	63.95	56.72	11.30	62.85	46.26	26.40
K-G-091	101.97	47.93	53.00	115.41	39.40	51.00	63.29	54.87	13.30	70.32	53.86	23.40
K-G-095	77.37	51.06	34.00	83.12	40.73	51.00	57.15	47.27	17.30	60.55	48.19	20.40
K-G-108	77.37	51.06	34.00	83.12	40.73	51.00	96.22	83.42	13.30	116.83	88.32	24.40
Average	**83.46**	**51.08**	**38.79**	**95.12**	**43.27**	**54.51**	**68.96**	**58.87**	**14.63**	**81.98**	**62.61**	**23.63**



Grid No	Control Option-22						Control Option-23						Control Option-24					
	2012 BAU C	2012 C (ug/m3)	% Redctn	2017 BAU C	2017 C (ug/m3)	% Redctn	2012 BAU C	2012 C	% Redctn	2017 BAU C	2017 C (ug/m3)	% Redct	2012 BAU C	2012 C (ug/m3	% Redctn	2017 BAU	2017 C (ug/m3	% Redct
K-G-033	51.35	47.60	7.30	67.58	49.60	27.52	51.35	27.42	46.60	67.58	36.09	46.60	14.76	9.95	32.00	16.72	0.00	100.00
K-G-049	37.17	33.34	10.30	48.24	34.92	28.35	37.17	20.22	45.60	48.24	26.24	45.60	12.62	8.63	31.00	44.19	0.00	100.00
K-G-062	71.47	65.54	8.30	81.94	58.50	27.52	71.47	38.17	46.60	81.94	43.75	46.60	14.76	10.25	32.00	43.88	0.00	100.00
K-G-064	52.69	47.79	9.30	57.36	42.68	28.78	52.69	29.19	44.60	57.36	31.78	44.60	14.75	9.21	12.00	40.68	0.00	100.00
K-G-075	112.00	104.95	6.30	162.40	122.45	21.02	112.00	62.05	44.60	162.40	89.97	44.60	15.32	10.48	32.00	44.77	0.00	100.00
K-G-078	84.30	79.83	5.30	91.78	67.37	28.78	84.30	47.54	43.60	91.78	51.77	43.60	13.68	9.08	32.00	35.81	0.00	100.00
K-G-080	63.95	59.28	7.30	62.85	45.50	30.84	63.95	30.95	51.60	62.85	30.42	51.60	13.68	8.94	32.00	35.81	0.00	100.00
K-G-091	63.29	56.14	11.30	70.32	50.21	26.04	63.29	35.06	44.60	70.32	38.96	44.60	13.20	8.23	31.00	39.08	0.00	100.00
K-G-095	57.15	52.98	7.30	60.55	44.44	29.24	57.15	29.95	47.60	60.55	31.73	47.60	13.72	9.24	32.00	46.41	0.00	100.00
K-G-108	96.22	89.20	7.30	116.83	88.09	24.57	96.22	53.31	44.60	116.83	64.72	44.60	13.72	8.97	32.00	46.41	0.00	100.00
Overall	**68.96**	**63.66**	**7.68**	**81.98**	**60.38**	**26.36**	**68.96**	**37.39**	**48.70**	**81.98**	**44.54**	**45.67**	**14.02**	**9.30**	**33.68**	**39.38**	**0.00**	**100.00**

Table 6.6: ISC Results for Line Source only: BAU and Control Options Efficacy for NOx

Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-1				Control Option-2				Control Option-3			
			2012 C (ug/m3)	% Reduc tion	2017 C (ug/m3)	% Reduc tion	2012 C (ug/m3)	% Reduc tion	2017 C (ug/m3)	% Reduc tion	2012 C (ug/m3)	% Reduc tion	2017 C (ug/m3)	% Reduc tion
K-G-033	28.19	42.24	24.68	12.45	35.38	16.24	0	0	38.21	9.54	27.46	2.60	39.66	6.10
K-G-049	61.30	95.11	59.13	3.55	85.06	10.56	0	0	89.7	5.69	59.71	2.60	89.59	5.80
K-G-062	58.14	85.80	54.91	5.55	79.80	6.99	0	0	83.53	2.65	55.69	4.20	80.65	6.00
K-G-064	79.54	122.36	70.12	11.85	106.10	13.29	0	0	114.87	6.12	76.20	4.20	113.79	7.01
K-G-075	72.71	106.85	69.58	4.30	95.32	10.80	0	0	100.18	6.24	69.65	4.20	102.47	4.10
K-G-078	73.49	107.40	62.51	14.94	101.20	5.77	0	0	96.35	10.29	71.72	2.40	102.78	4.30
K-G-080	75.92	111.97	74.00	2.53	110.48	1.33	0	0	105.96	5.37	72.73	4.20	105.84	5.47
K-G-091	65.58	96.54	58.68	10.53	86.34	10.56	0	0	90.9	5.84	63.88	2.60	90.74	6.00
K-G-095	68.72	101.48	64.66	5.91	90.76	10.56	0	0	93.82	7.55	67.48	1.80	95.73	5.67
K-G-108	60.72	89.60	59.74	1.63	76.32	14.82	0	0	82.58	7.83	59.27	2.40	84.55	5.63
Average	**64.43**	**95.93**	**59.80**	**7.19**	**86.68**	**9.65**	**0**	**0**	**80.41**	**6.71**	**62.38**	**3.18**	**90.58**	**5.58**

Table 6.6: ISC Results for Line Source only: BAU and Control Options Efficacy for NOx

Grid No	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-4				Control Option-5				Control Option-6				Control Option-7			
			2012 C (ug/m3)	% Redctn	2017 C (ug/m3)	% Redctn	2012 C (ug/m3)	% Redct	2017 C (ug/m3)	% Redct	2012 C (ug/m3)	% Redct	2017 C (ug/m3)	% Redctn	2012 C (ug/m3)	% Redct	2017 C (ug/m3	% Redct
K-G-033	28.19	42.24	27.88	1.10	41.31	2.20	26.02	7.70	39.32	6.90	26.17	7.17	41.14	2.60	28.36	-0.60	42.36	-0.30
K-G-049	61.30	95.11	60.63	1.10	93.01	2.20	56.58	7.70	92.35	2.90	59.73	2.56	90.26	5.10	61.36	-0.10	95.30	-0.20
K-G-062	58.14	85.80	57.96	0.30	83.99	2.10	51.45	11.50	83.31	2.90	54.85	5.65	80.48	6.20	58.19	-0.10	85.97	-0.20
K-G-064	79.54	122.36	79.46	0.10	119.79	2.10	71.35	10.30	118.81	2.90	75.14	5.53	116.12	5.10	80.01	-0.60	122.61	-0.20
K-G-075	72.71	106.85	72.56	0.20	104.61	2.10	64.35	11.50	100.44	6.00	69.45	4.48	100.01	6.40	73.14	-0.60	107.07	-0.20
K-G-078	73.49	107.40	73.27	0.30	105.14	2.10	65.92	10.30	104.28	2.90	69.89	4.89	104.60	2.60	73.93	-0.60	107.72	-0.30
K-G-080	75.92	111.97	75.69	0.30	109.62	2.10	69.31	8.70	103.80	7.30	71.31	6.07	105.03	6.20	76.07	-0.20	112.19	-0.20
K-G-091	65.58	96.54	65.52	0.10	94.51	2.10	59.88	8.70	89.87	6.90	62.27	5.05	90.55	6.20	65.71	-0.20	96.73	-0.20
K-G-095	68.72	101.48	68.65	0.10	99.35	2.10	61.64	10.30	96.71	4.70	64.46	6.20	95.19	6.20	68.86	-0.20	101.68	-0.20
K-G-108	60.72	89.60	60.60	0.20	87.72	2.10	55.44	8.70	87.00	2.90	59.60	1.85	83.87	6.40	61.09	-0.60	89.78	-0.20
Overall	**64.43**	**95.93**	**64.22**	**0.32**	**93.91**	**2.11**	**58.19**	**9.68**	**91.59**	**4.53**	**61.29**	**4.88**	**90.72**	**5.43**	**64.67**	**-0.38**	**96.14**	**-0.22**

Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-8				Control Option-9				Control Option-10			
			2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction
K-G-033	28.19	42.24	25.74	8.70	39.03	7.60	28.19	0.00	42.24	0.00	28.19	0.00	42.24	0.00
K-G-049	61.30	95.11	56.64	7.60	88.83	6.60	61.30	0.00	95.11	0.00	61.30	0.00	95.11	0.00
K-G-062	58.14	85.80	53.72	7.60	80.13	6.60	58.14	0.00	85.80	0.00	58.14	0.00	85.80	0.00
K-G-064	79.54	122.36	73.49	7.60	112.08	8.40	79.54	0.00	122.36	0.00	79.54	0.00	122.36	0.00
K-G-075	72.71	106.85	64.13	11.80	99.80	6.60	72.71	0.00	106.85	0.00	72.71	0.00	106.85	0.00
K-G-078	73.49	107.40	64.82	11.80	100.31	6.60	73.49	0.00	107.40	0.00	73.49	0.00	107.40	0.00
K-G-080	75.92	111.97	69.31	8.70	102.57	8.40	75.92	0.00	111.97	0.00	75.92	0.00	111.97	0.00
K-G-091	65.58	96.54	59.88	8.70	88.43	8.40	65.58	0.00	96.54	0.00	65.58	0.00	96.54	0.00
K-G-095	68.72	101.48	62.74	8.70	93.77	7.60	68.72	0.00	101.48	0.00	68.72	0.00	101.48	0.00
K-G-108	60.72	89.60	55.44	8.70	81.89	8.60	60.72	0.00	89.60	0.00	60.72	0.00	89.60	0.00
Average	**64.43**	**95.93**	**58.59**	**9.06**	**88.68**	**7.56**	**64.43**	**0.00**	**95.93**	**0.00**	**64.43**	**0.00**	**95.93**	**0.00**

Table 6.6: ISC Results for Line Source only: BAU and Control Options Efficacy for NOx

Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-11				Control Option-12				Control Option-13			
			2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction
K-G-033	28.19	42.24	26.98	4.30	40.59	3.90	20.81	26.20	33.66	20.30	26.02	7.70	37.63	10.90
K-G-049	61.30	95.11	58.67	4.30	91.40	3.90	47.51	22.50	75.80	20.30	56.58	7.70	79.99	15.90
K-G-062	58.14	85.80	55.64	4.30	83.74	2.40	45.06	22.50	66.58	22.40	55.17	5.10	72.15	15.90
K-G-064	79.54	122.36	72.06	9.40	117.59	3.90	58.70	26.20	97.52	20.30	73.41	7.70	109.03	10.90
K-G-075	72.71	106.85	69.58	4.30	104.82	1.90	0.51	99.30	82.92	22.40	69.44	4.50	89.86	15.90
K-G-078	73.49	107.40	70.33	4.30	103.21	3.90	56.95	22.50	85.60	20.30	67.83	7.70	95.69	10.90
K-G-080	75.92	111.97	72.65	4.30	107.60	3.90	56.03	26.20	84.76	24.30	71.29	6.10	99.77	10.90
K-G-091	65.58	96.54	59.42	9.40	94.22	2.40	50.83	22.50	76.94	20.30	62.24	5.10	81.19	15.90
K-G-095	68.72	101.48	65.70	4.40	98.13	3.30	50.58	26.40	78.04	23.10	64.24	6.51	88.77	12.52
K-G-108	60.72	89.60	55.01	9.40	86.11	3.90	44.45	26.80	67.83	24.30	57.57	5.20	79.83	10.90
Average	**64.43**	**95.93**	**60.60**	**5.94**	**92.74**	**3.33**	**43.14**	**33.04**	**74.96**	**21.86**	**60.38**	**6.29**	**83.39**	**13.07**

Table 6.7: ISC Results for Industrial Source only: BAU and Control Options Efficacy for NOx

Critical Grid	2012BAU Con (ug/m3)	2017BAU Con (ug/m3)	Control Option-14				Control Option-16			
			2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction	2012 C (ug/m3)	% Reduction	2017 C (ug/m3)	% Reduction
K-G-033	6.61	6.61	4.05	38.70	3.95	40.30	3.21	51.50	0.00	100.00
K-G-049	10.60	10.60	6.60	37.70	6.13	42.20	5.14	51.50	0.00	100.00
K-G-062	15.78	15.78	9.99	36.70	9.09	42.40	7.54	52.20	0.00	100.00
K-G-064	12.40	12.40	8.10	34.70	7.17	42.20	5.93	52.20	0.00	100.00
K-G-075	19.20	19.20	12.34	35.70	11.10	42.20	9.18	52.20	0.00	100.00
K-G-078	37.51	37.51	22.62	39.70	22.39	40.30	17.93	52.20	0.00	100.00
K-G-080	9.93	9.93	5.79	41.70	5.85	41.10	4.81	51.50	0.00	100.00
K-G-091	6.60	6.60	3.92	40.70	3.82	42.20	3.16	52.20	0.00	100.00
K-G-095	7.82	7.82	4.48	42.70	4.51	42.40	3.74	52.20	0.00	100.00
K-G-108	8.37	8.37	4.38	47.70	4.82	42.40	4.00	52.20	0.00	100.00
Average	**13.48**	**13.48**	**8.23**	**38.98**	**7.88**	**41.54**	**6.46**	**52.06**	**0.00**	**100.00**

Table 6.8: ISC Results for Area Source only: BAU and Control Options Efficacy for NOx

Critical Grid	Control Option-17						Control Option-24					
	2012 BAU (ug/m3)	**2012 C (ug/m3)**	**% Reduction**	**2017 BAU (ug/m3)**	**2017 C (ug/m3)**	**% Reduction**	**2012 BAU (ug/m3)**	**2012 C (ug/m3)**	**% Reduction**	**2017 BAU (ug/m3)**	**2017 C (ug/m3)**	**% Reduction**
K-G-033	2.24	1.83	18.40	2.51	1.84	26.50	0.61	0.37	38.95	0.72	0.00	100.00
K-G-049	2.88	2.37	17.91	3.31	2.42	26.80	0.61	0.37	38.95	0.72	0.00	100.00
K-G-062	3.34	2.75	17.51	3.79	2.78	26.50	0.68	0.35	48.25	0.80	0.00	100.00
K-G-064	3.52	2.88	18.26	4.13	2.96	28.30	0.77	0.35	54.83	0.88	0.00	100.00
K-G-075	3.47	2.78	20.02	3.86	2.83	26.80	0.73	0.37	49.39	0.87	0.00	100.00
K-G-078	3.09	2.53	18.09	3.56	2.55	28.40	0.70	0.29	58.36	0.80	0.00	100.00
K-G-080	3.44	2.83	17.82	3.98	2.92	26.50	0.57	0.31	45.48	0.66	0.00	100.00
K-G-091	3.19	2.67	16.51	3.67	2.63	28.30	0.67	0.34	49.62	0.77	0.00	100.00
K-G-095	2.80	2.29	18.31	3.20	2.29	28.30	0.72	0.36	50.10	0.84	0.00	100.00
K-G-108	2.85	2.34	17.67	3.28	2.35	28.30	0.58	0.28	51.14	0.68	0.00	100.00
Average	**3.08**	**2.53**	**18.06**	**3.53**	**2.56**	**27.48**	**0.66**	**0.34**	**48.84**	**0.77**	**0.00**	**100.00**

6.6 BAU Scenario for 2007, 2012 and 2017: Critical Grid Analysis

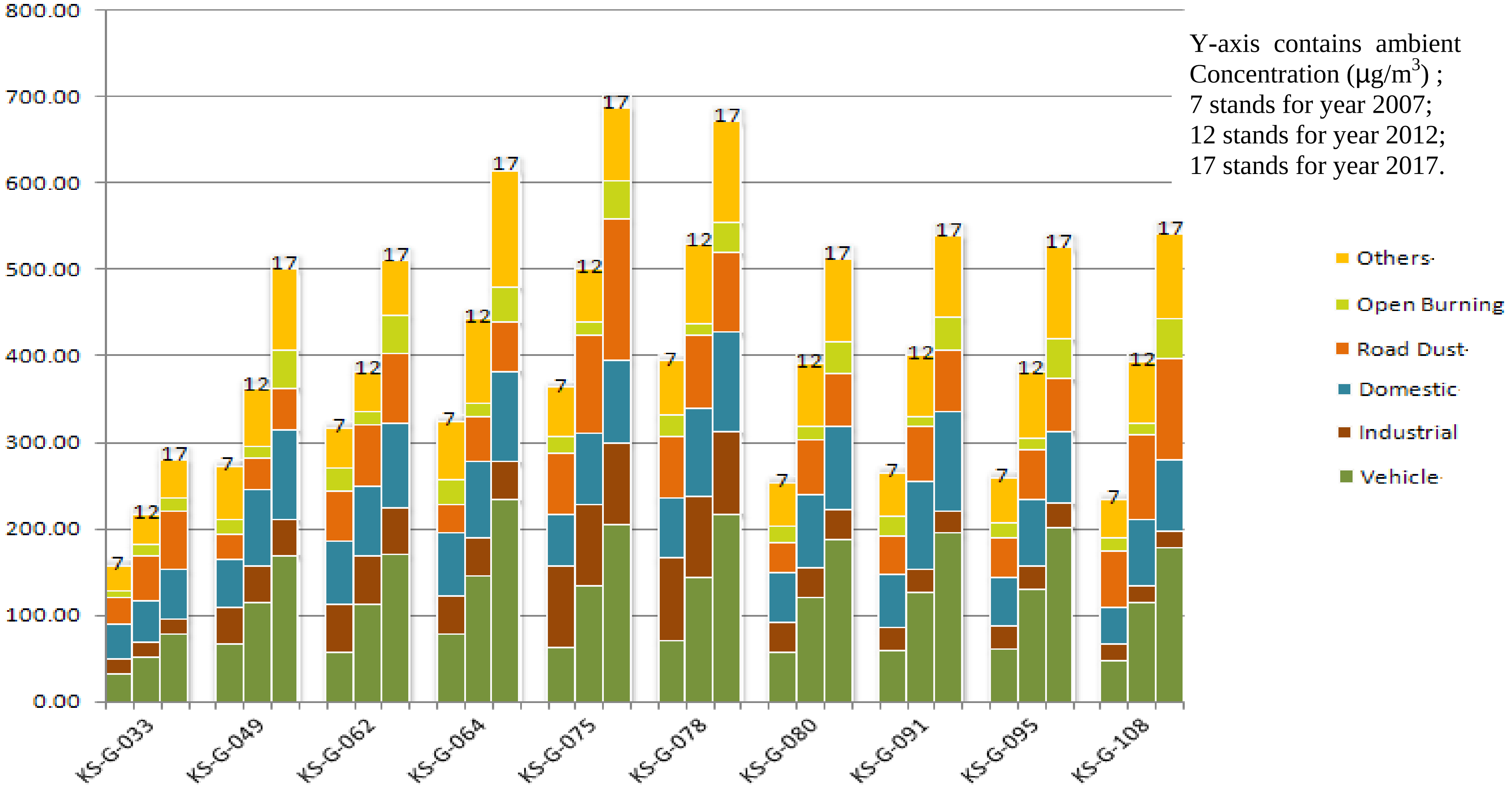
Figure 6.10 shows air quality BAU scenario for the years 2007, 2012 and 2017 for PM_{10} for critical grids (based on top 150 values in critical winter month). It may be seen that while air quality in 2007 may range in 150-350 ug/m^3 but it may increase to 200-500 ug/m^3 in 2012 and 300-700 ug/m^3 in 2017. Figure 6.10 also shows contribution of each source to air quality. It can be seen that vehicles contribute about 30 percent of ambient PM_{10} concentration and rest is contributed from industrial, domestic sources and soil dust.

Figure 6.11 shows improvements in air quality in each of the critical grid w.r.t. PM_{10} because of adoption of control options in line source, industrial source and other area sources including domestic cooking and road dust. Inferences can be drawn from Figure 6.11 that which control options improves air quality in all grids and just not few.

Figure 6.12 shows air quality BAU scenario for the years 2007, 2012 and 2017 for NOx for critical grids (based on top 150 values in critical winter month). It may be seen that while air quality in 2007 may range in 20-80 ug/m^3 but it may increase to 40-130 ug/m^3 in 2012 and 60-170 ug/m^3 in 2017. Figure 6.12 also shows contribution of each source to air quality w.r.t. NOx. It can be seen that vehicles contribute about 70 percent of ambient NOx concentration and rest is contributed from industrial, domestic sources and soil dust.

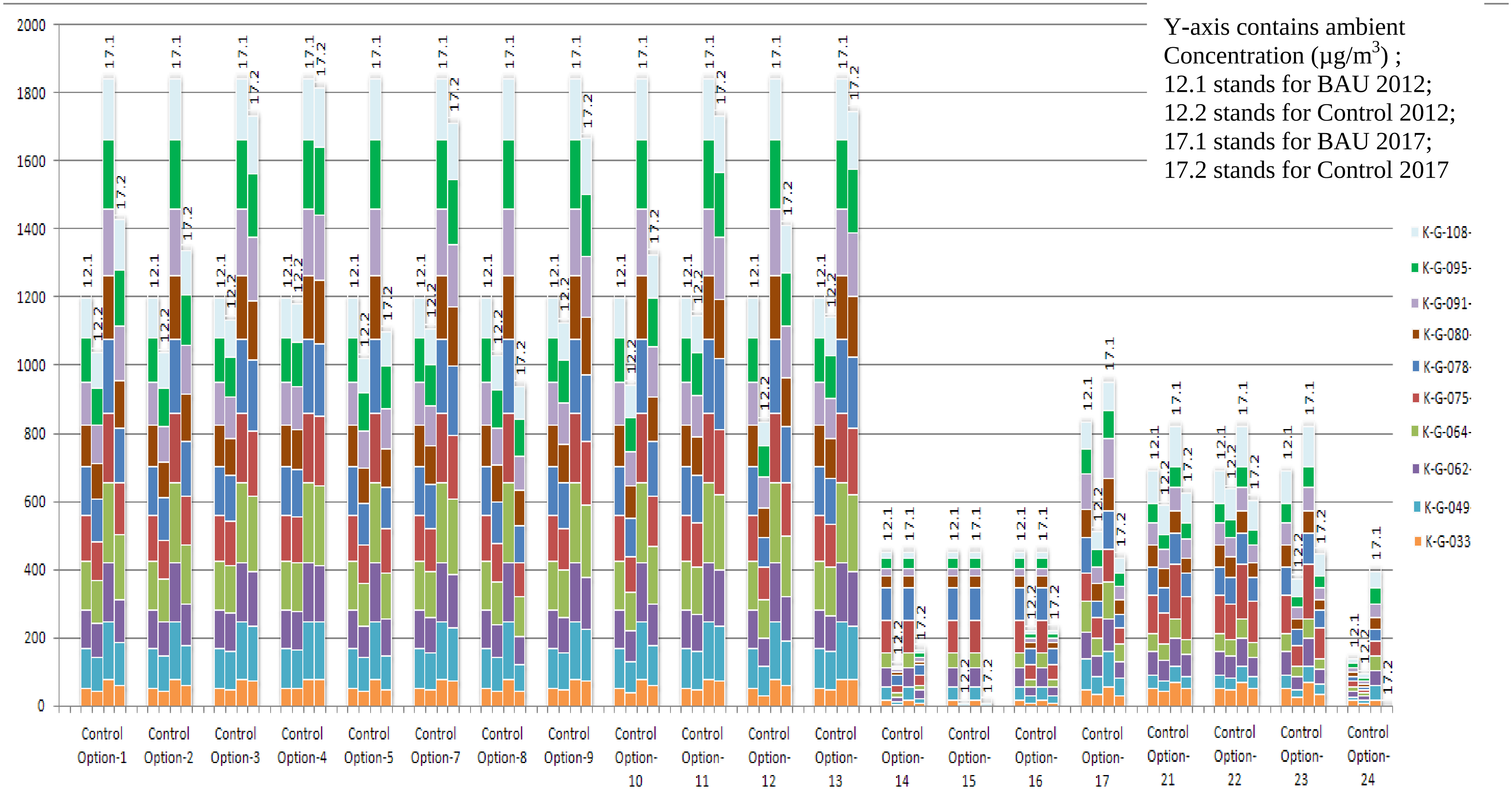
Figure 6.13 shows improvements in air quality in each of the critical grid because of adoption of control options in line source, industrial sources and other area sources including domestic cooking and road dust. This figure informs that which, control options improves air quality in all grids and just not few.

From emission inventory and ISC modeling exercises, it can be concluded that SO_2 concentration for BAU 2007, 2012 and 2017 are quite below the ambient air quality standards. So, after applying the any of the suitable control options, the standards for SO_2 will be met.



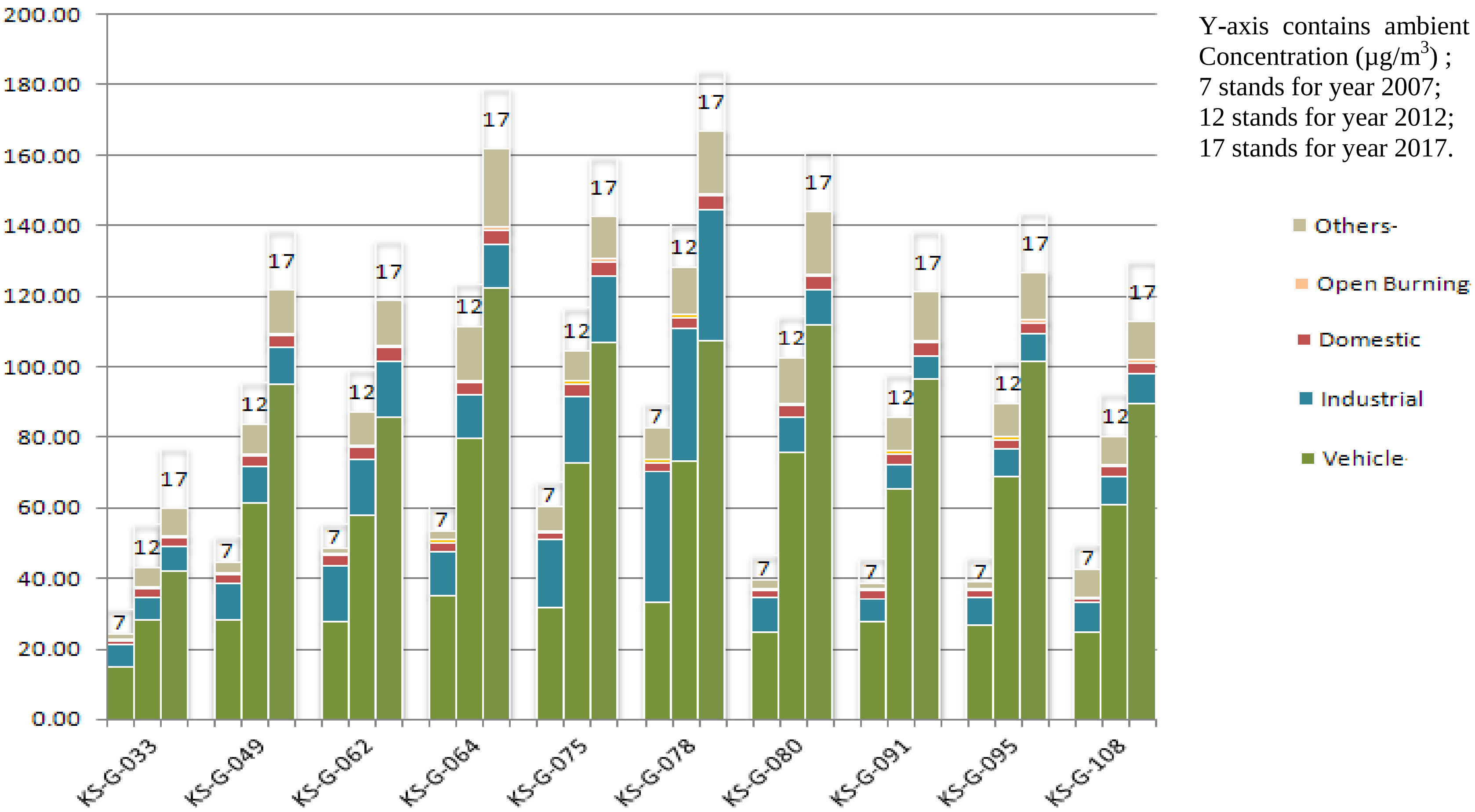
Y-axis contains ambient Concentration (µg/m^3) ;
7 stands for year 2007;
12 stands for year 2012;
17 stands for year 2017.

Figure 6.10: Modeled Concentrations for 2007, 2012 and 2017 BAU of PM$_{10}$ from Various Sources in Critical Grids



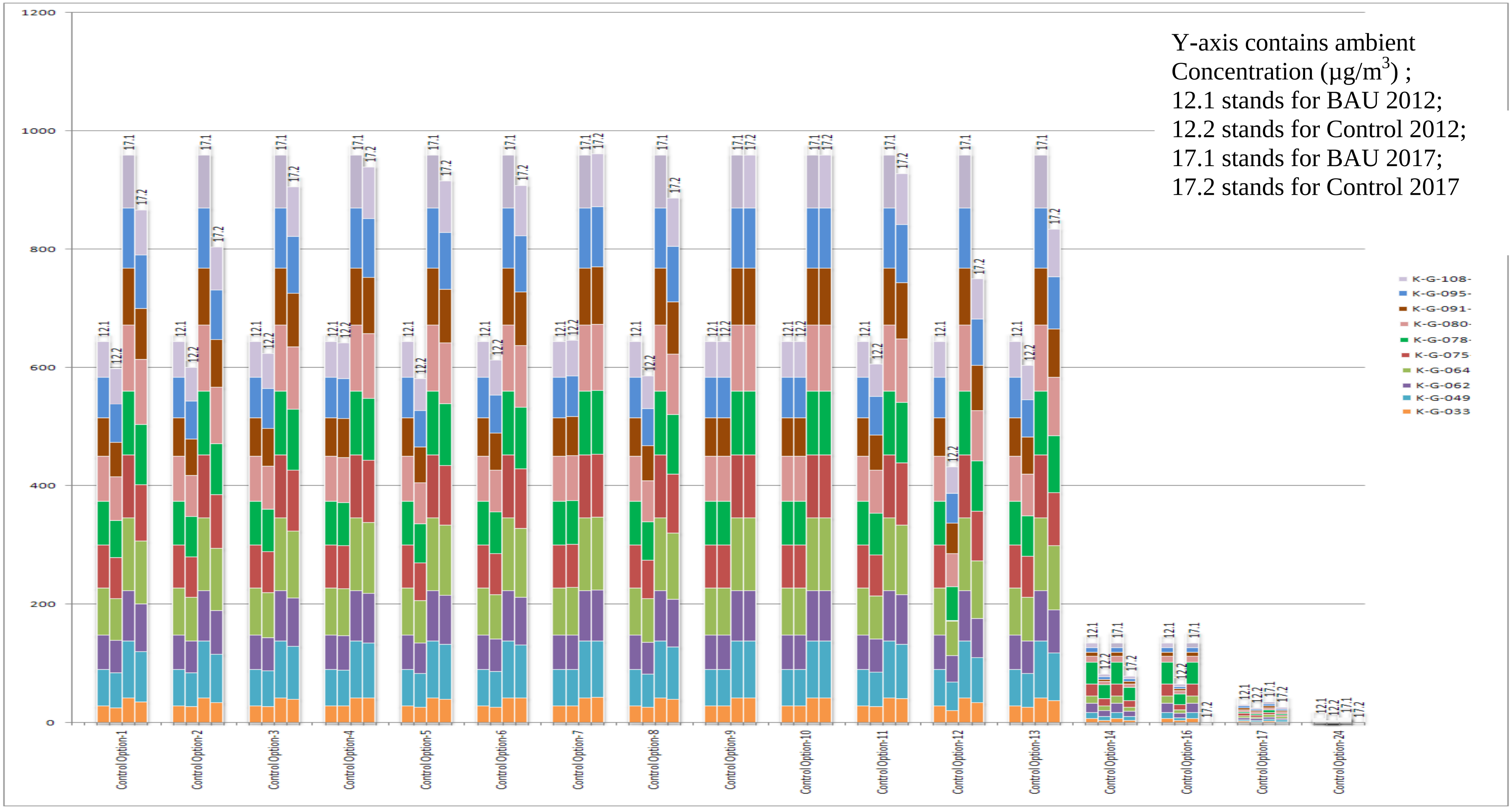
Y-axis contains ambient Concentration (µg/m^3) ;
12.1 stands for BAU 2012;
12.2 stands for Control 2012;
17.1 stands for BAU 2017;
17.2 stands for Control 2017

Figure 6.11: Concentration 2012 and 2017 BAU with Control Options of PM_{10} from Various Sources in Critical Grids



Y-axis contains ambient Concentration (µg/m^3) ;
7 stands for year 2007;
12 stands for year 2012;
17 stands for year 2017.

Figure 6.12: ISC Modeling Results for 2007, 2012 and 2017 BAU of NO$_x$ from Various Sources in Different Grids over the City



Y-axis contains ambient Concentration ($\mu g/m^3$) ;
12.1 stands for BAU 2012;
12.2 stands for Control 2012;
17.1 stands for BAU 2017;
17.2 stands for Control 2017

Figure 6.13: Comparisons 2012 and 2017 BAU with Control Options of NO_x from Various Sources in Different Grids over the City

6.7 Conclusions

The control options, individually or as a combination that may prove effective in improving the air quality is shown below (Table 6.9). The table below is the outcome of possible options that in combination should be applied to get the best possible improvements and this aspect and overall pollution control plan will be drawn again through ISC modeling and that has been attempted in Chapter 7.

Table 6.9: Prominent Control Options and Potential Air Quality Improvements for PM_{10}*

Option No	**Description**	**% Reduction**	
		2012	**2017**
Option-2	Implementation of BS – VI norms	-	8
Option-5	CNG/LPG to commercial Vehicles: Line Source	12	47
Option-10	Retro fitment of diesel particulate filter (DOC): Line Source	19	25
Option-11	Inspection/ maintenance of vehicles: Line Source	3	4
Option-12	Banning of 15 year old private vehicles: Line Source	26	21
Option-14	Changing of solid fuel to natural gas: Industrial Source	75	74
Option-15	Particulate control systems in industry: Industrial Source	99	99
Option-17	Domestic-Use of Natural Gas/LPG: Area source	33	50
Option-19	Adequate supply of grid power: Area Source	100	100
Option-21	Converting unpaved roads to paved roads: Line/Area source	16	29
Option-23	Sweeping and watering (mechanized) Line/Area Source	18	53
Option-24	Strict compliance to ban of open burning: Area Source	50	100

* The calculation is based on the results of emission inventory

Chapter 7

Prioritization of Management/Control Options

7.1 Dispersion Modeling for Years 2012 and 2017 for Selected Control Options

In Chapter 6, efficacy of various control options was examined and it was concluded that the following control options are best suited in terms of percent reduction from prominent sources. It can be seen that most the control options (certainly not all) can run concurrently. Some sources (e.g. adoption of BS V and VI) for vehicles can reduce both PM_{10} and NOx emissions.

Table 7.1: Details of the Control Options Selected

S. No.	Control Option	Details
1.	Option-2	Implementation of BS – VI norms
2.	Option-5	CNG/LPG to commercial Vehicles
3.	Option-10	Retro fitment of diesel particulate filter (DOC)
4.	Option-11	Inspection/ maintenance of vehicles
5.	Option-12	Banning of 15 year old private vehicles
6.	Option-14	Changing of solid fuel change to natural gas
7.	Option-15	Particulate control systems in industry
8.	Option-17	Domestic-Use of Natural Gas/LPG
9.	Option-19	Adequate supply of grid power
10.	Option-21	Converting unpaved roads to paved roads
11.	Option-23	Sweeping and watering (mechanized)
12.	Option-24	Strict compliance to ban of open burning

Table 7.2 presents the combination of control options (identified above) that could yield best reductions in emissions and improvements in air quality. These combinations have termed as Scenarios 1, 2, 3 and 4. Scenario 4 is only for line sources including (i) implementation of BS – VI norms (ii) retro-fitment of diesel particulate filter (iii) banning

of 15 year old private vehicles to examine if vehicles alone are taken as source reduction target, what is the expected improvements in air quality. The scenarios have been designed in such a way that they also account for best possible reduction in NO_x emissions and improvements in air quality.

Table7.2: Scenarios with Combination of Control Options

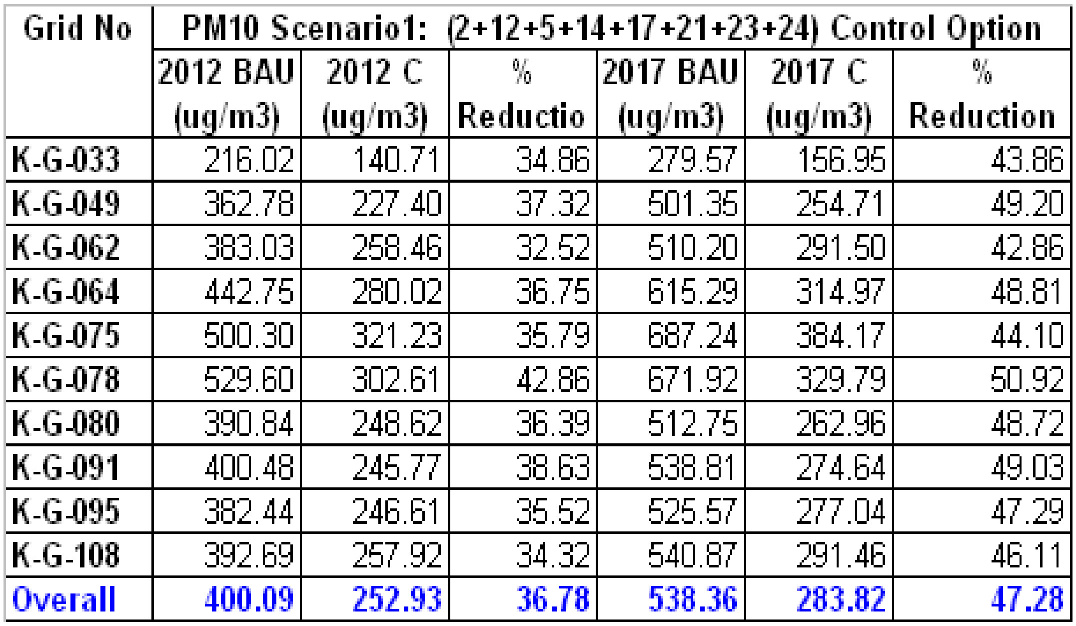
S. No.	Scenario	Combinations of Control Options
1.	Scenario-1	(2+12+5+14+17+21+23+24) Control Option
2.	Scenario-2	(2+12+10+14+17+21+23+24) Control Option
3.	Scenario-3	(2+11+12+5+15+17+19+21+23+24) Control Option
4.	Scenario-4	(2+12+10) Control Option+(15+17+21+23+24) BAU

7.2 Scenario Development

Table 7.3 (a) show the air quality improvements (i.e. reductions is air quality) in terms of PM_{10} for ten critical grids identified in Chapter 6. It can be seen that reductions in PM_{10} air concentrations are of the order 36% (in 2012) and 47% (in 2017), yet air quality standard of 150 ug/m^3 may not be met.

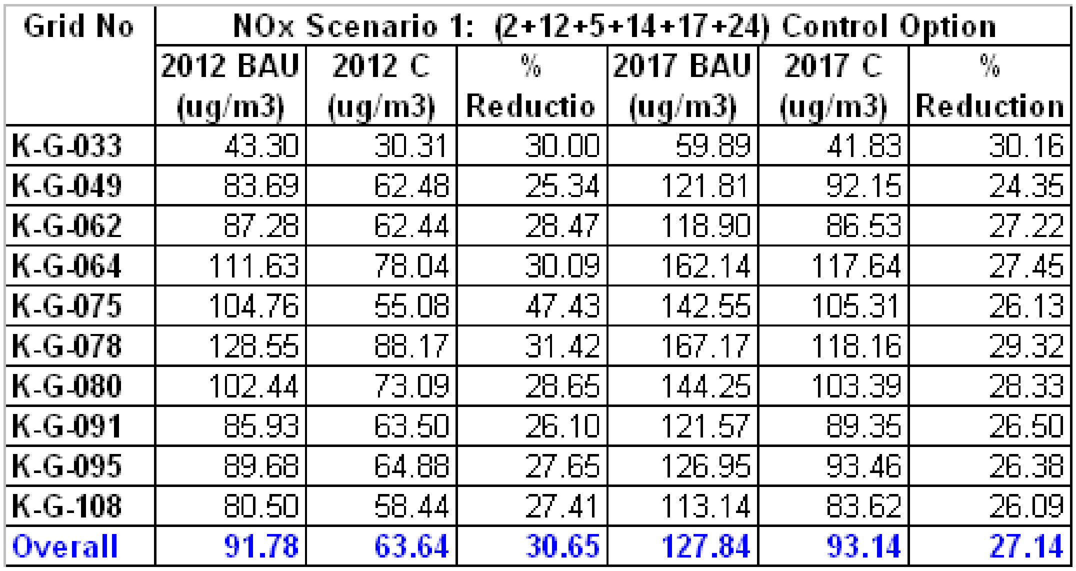
Table 7.3 (b) shows the air quality improvements (i.e. reductions is air quality) in terms of NOx for ten critical grids identified in Chapter 6. It can be seen that reductions in PM_{10} air concentrations are of the order 31% (in 2012) and 27% (in 2017), this means that air quality standard of 80 µg/m^3 will be met in 2012 but will marginally exceed in 2017.

Table7.3(a): Improvements in PM_{10} Levels (based on top 150 (24-hr) air concentrations): Scenario-1



Grid No	PM10 Scenario1: (2+12+5+14+17+21+23+24) Control Option					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	216.02	140.71	34.86	279.57	156.95	43.86
K-G-049	362.78	227.40	37.32	501.35	254.71	49.20
K-G-062	383.03	258.46	32.52	510.20	291.50	42.86
K-G-064	442.75	280.02	36.75	615.29	314.97	48.81
K-G-075	500.30	321.23	35.79	687.24	384.17	44.10
K-G-078	529.60	302.61	42.86	671.92	329.79	50.92
K-G-080	390.84	248.62	36.39	512.75	262.96	48.72
K-G-091	400.48	245.77	38.63	538.81	274.64	49.03
K-G-095	382.44	246.61	35.52	525.57	277.04	47.29
K-G-108	392.69	257.92	34.32	540.87	291.46	46.11
Overall	400.09	252.93	36.78	538.36	283.82	47.28

Table 7.3(b): Improvements in NOx Levels (based on top 150 (24-hr) air concentrations) Scenario-1



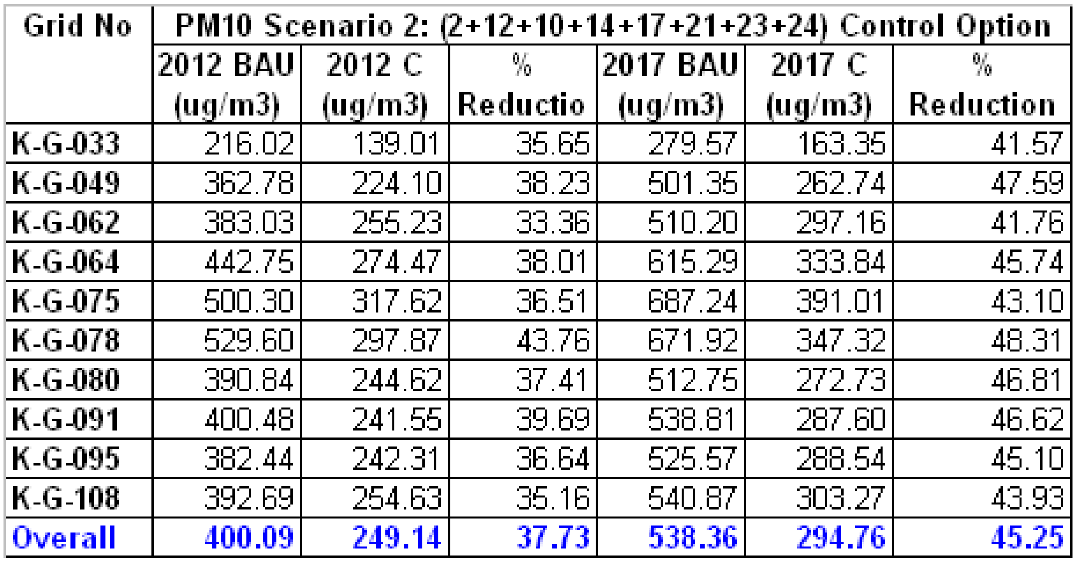
Grid No	NOx Scenario 1: (2+12+5+14+17+24) Control Option					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	43.30	30.31	30.00	59.89	41.83	30.16
K-G-049	83.69	62.48	25.34	121.81	92.15	24.35
K-G-062	87.28	62.44	28.47	118.90	86.53	27.22
K-G-064	111.63	78.04	30.09	162.14	117.64	27.45
K-G-075	104.76	55.08	47.43	142.55	105.31	26.13
K-G-078	128.55	88.17	31.42	167.17	118.16	29.32
K-G-080	102.44	73.09	28.65	144.25	103.39	28.33
K-G-091	85.93	63.50	26.10	121.57	89.35	26.50
K-G-095	89.68	64.88	27.65	126.95	93.46	26.38
K-G-108	80.50	58.44	27.41	113.14	83.62	26.09
Overall	91.78	63.64	30.65	127.84	93.14	27.14

Table 7.4 (a) show the air quality improvements (i.e. reductions is air quality) in terms of PM_{10} for ten critical grids identified in Chapter 6. It can be seen that reductions in PM_{10} air concentrations are of the order 37% (in 2012) and 45% (in 2017), yet air quality standard of 150 ug/m^3 may not be met.

Table 7.4 (b) shows the air quality improvements (i.e. reductions is air quality) in terms of NOx for ten critical grids identified in Chapter 6. It can be seen that reductions in PM_{10} air concentrations are of the order 28% (in 2012) and 26% (in 2017), this means that air quality standard of 80 ug/m^3 will be met in 2012 but will exceed in all other grids in 2017.

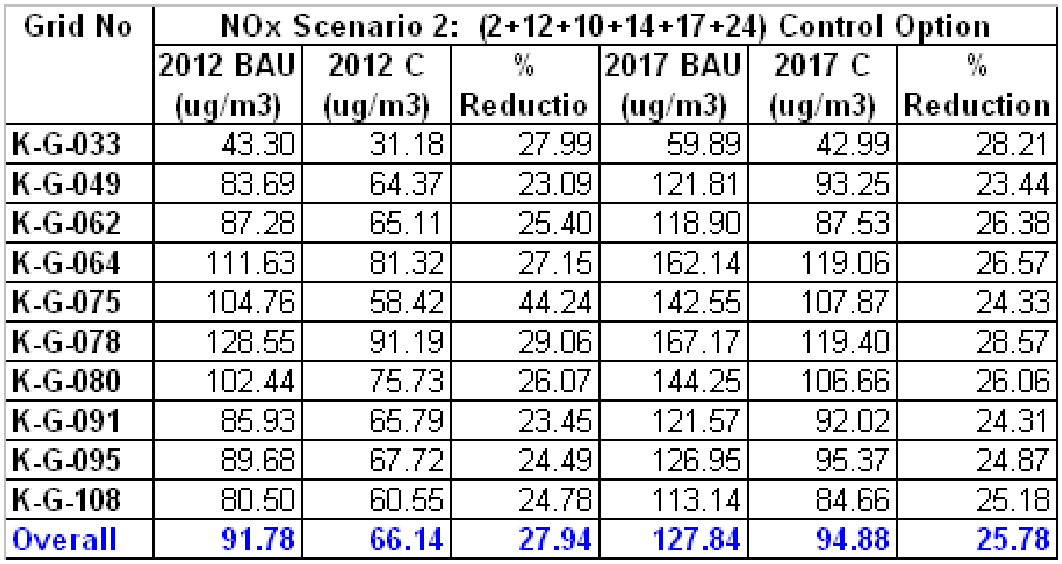
Similarly, Tables 7.5 (a) (for PM_{10}) and 7.5 (b) (for NOx) for scenario 3 and Tables 7.6 (a) (for PM_{10}) and 7.6 (b) (for NOx) for scenario 4, show percent reductions in emissions and improvements in air quality.

Table 7.4(a): Improvements in PM_{10} Levels (based on top 150 (24-hr) air concentrations): Scenario-2



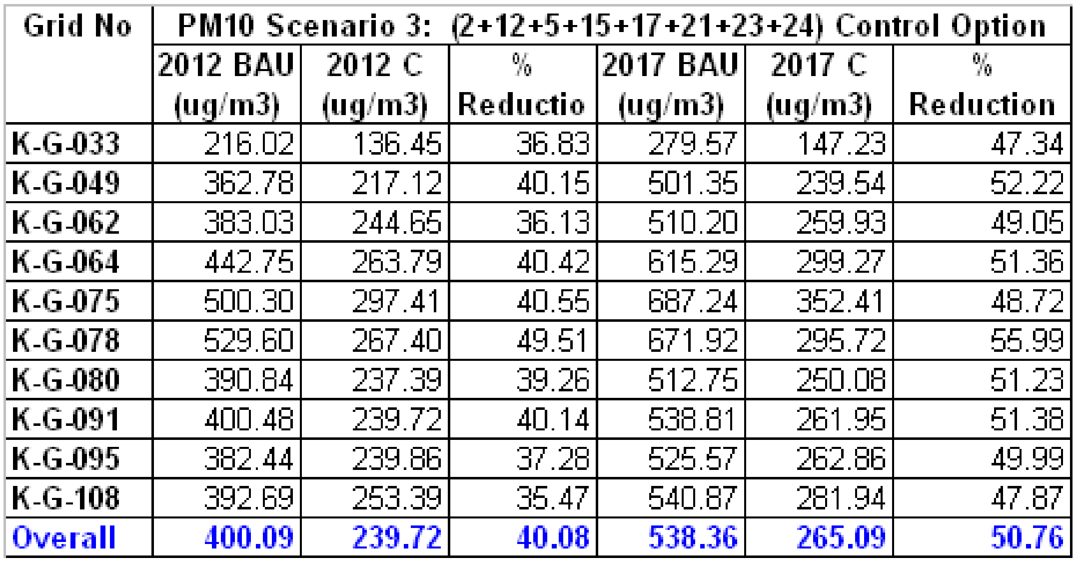
Grid No	PM10 Scenario 2: (2+12+10+14+17+21+23+24) Control Option					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	216.02	139.01	35.65	279.57	163.35	41.57
K-G-049	362.78	224.10	38.23	501.35	262.74	47.59
K-G-062	383.03	255.23	33.36	510.20	297.16	41.76
K-G-064	442.75	274.47	38.01	615.29	333.84	45.74
K-G-075	500.30	317.62	36.51	687.24	391.01	43.10
K-G-078	529.60	297.87	43.76	671.92	347.32	48.31
K-G-080	390.84	244.62	37.41	512.75	272.73	46.81
K-G-091	400.48	241.55	39.69	538.81	287.60	46.62
K-G-095	382.44	242.31	36.64	525.57	288.54	45.10
K-G-108	392.69	254.63	35.16	540.87	303.27	43.93
Overall	**400.09**	**249.14**	**37.73**	**538.36**	**294.76**	**45.25**

Table 7.4(b): Improvements in NOx Levels (based on top 150 (24-hr) air concentrations): Scenario-2



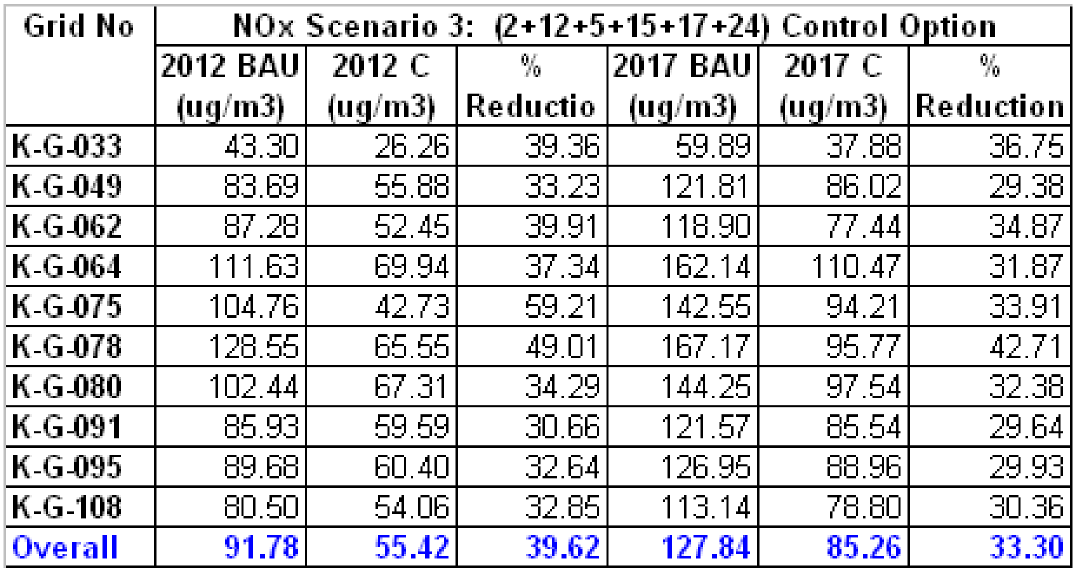
Grid No	NOx Scenario 2: (2+12+10+14+17+24) Control Option					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	43.30	31.18	27.99	59.89	42.99	28.21
K-G-049	83.69	64.37	23.09	121.81	93.25	23.44
K-G-062	87.28	65.11	25.40	118.90	87.53	26.38
K-G-064	111.63	81.32	27.15	162.14	119.06	26.57
K-G-075	104.76	58.42	44.24	142.55	107.87	24.33
K-G-078	128.55	91.19	29.06	167.17	119.40	28.57
K-G-080	102.44	75.73	26.07	144.25	106.66	26.06
K-G-091	85.93	65.79	23.45	121.57	92.02	24.31
K-G-095	89.68	67.72	24.49	126.95	95.37	24.87
K-G-108	80.50	60.55	24.78	113.14	84.66	25.18
Overall	**91.78**	**66.14**	**27.94**	**127.84**	**94.88**	**25.78**

Table 7.5(a): Improvements in PM_{10} Levels (based on top 150 (24-hr) air concentrations): Scenario-3



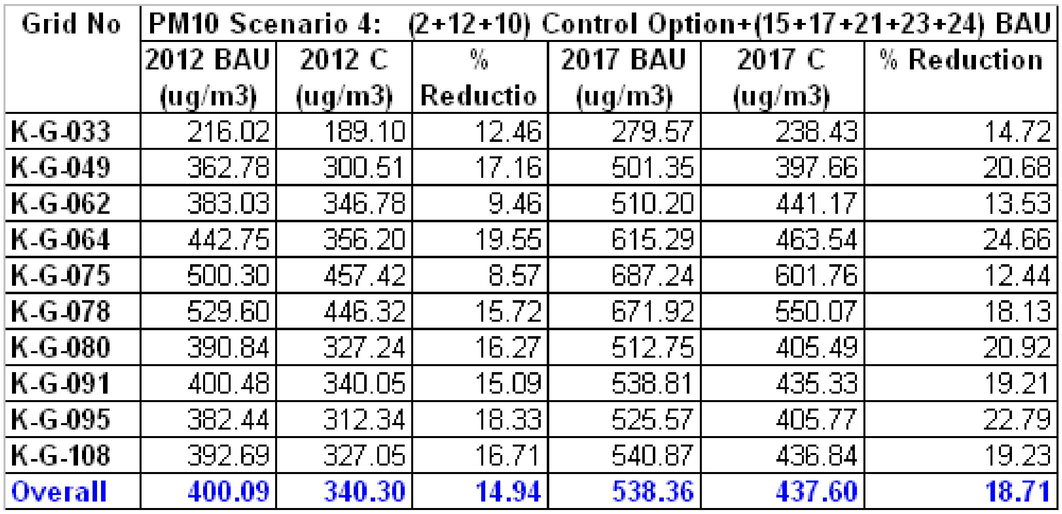
Grid No	PM10 Scenario 3: (2+12+5+15+17+21+23+24) Control Option					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	216.02	136.45	36.83	279.57	147.23	47.34
K-G-049	362.78	217.12	40.15	501.35	239.54	52.22
K-G-062	383.03	244.65	36.13	510.20	259.93	49.05
K-G-064	442.75	263.79	40.42	615.29	299.27	51.36
K-G-075	500.30	297.41	40.55	687.24	352.41	48.72
K-G-078	529.60	267.40	49.51	671.92	295.72	55.99
K-G-080	390.84	237.39	39.26	512.75	250.08	51.23
K-G-091	400.48	239.72	40.14	538.81	261.95	51.38
K-G-095	382.44	239.86	37.28	525.57	262.86	49.99
K-G-108	392.69	253.39	35.47	540.87	281.94	47.87
Overall	**400.09**	**239.72**	**40.08**	**538.36**	**265.09**	**50.76**

Table 7.5(b): Improvements in NOx Levels (based on top 150 (24-hr) air concentrations): Scenario-3



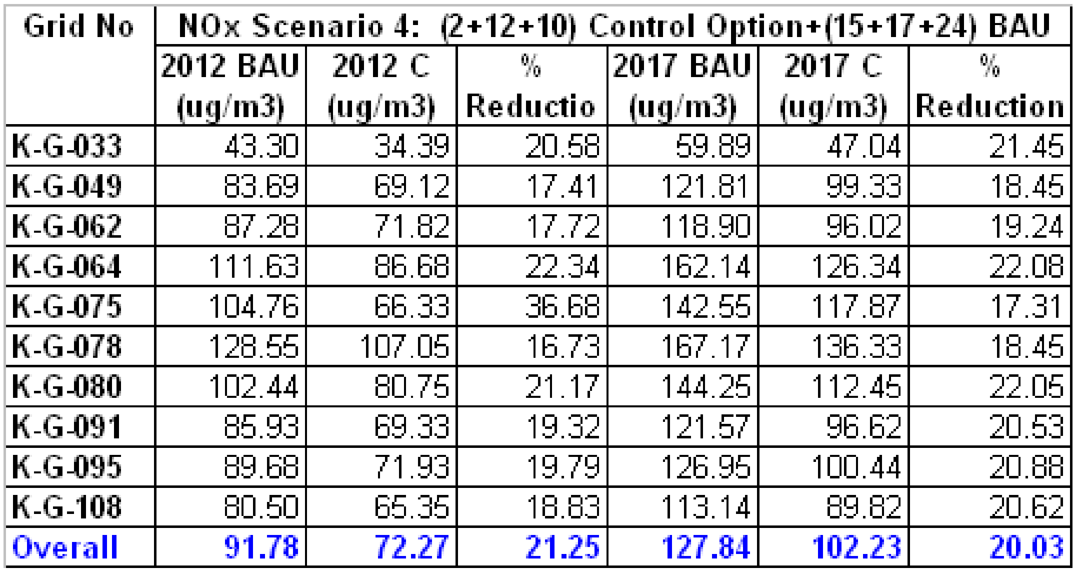
Grid No	NOx Scenario 3: (2+12+5+15+17+24) Control Option					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	43.30	26.26	39.36	59.89	37.88	36.75
K-G-049	83.69	55.88	33.23	121.81	86.02	29.38
K-G-062	87.28	52.45	39.91	118.90	77.44	34.87
K-G-064	111.63	69.94	37.34	162.14	110.47	31.87
K-G-075	104.76	42.73	59.21	142.55	94.21	33.91
K-G-078	128.55	65.55	49.01	167.17	95.77	42.71
K-G-080	102.44	67.31	34.29	144.25	97.54	32.38
K-G-091	85.93	59.59	30.66	121.57	85.54	29.64
K-G-095	89.68	60.40	32.64	126.95	88.96	29.93
K-G-108	80.50	54.06	32.85	113.14	78.80	30.36
Overall	**91.78**	**55.42**	**39.62**	**127.84**	**85.26**	**33.30**

Table 7.6(a): Improvements in PM_{10} Levels (based on top 150 (24-hr) air concentrations): Scenario-4



Grid No	PM10 Scenario 4: (2+12+10) Control Option+(15+17+21+23+24) BAU					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	216.02	189.10	12.46	279.57	238.43	14.72
K-G-049	362.78	300.51	17.16	501.35	397.66	20.68
K-G-062	383.03	346.78	9.46	510.20	441.17	13.53
K-G-064	442.75	356.20	19.55	615.29	463.54	24.66
K-G-075	500.30	457.42	8.57	687.24	601.76	12.44
K-G-078	529.60	446.32	15.72	671.92	550.07	18.13
K-G-080	390.84	327.24	16.27	512.75	405.49	20.92
K-G-091	400.48	340.05	15.09	538.81	435.33	19.21
K-G-095	382.44	312.34	18.33	525.57	405.77	22.79
K-G-108	392.69	327.05	16.71	540.87	436.84	19.23
Overall	**400.09**	**340.30**	**14.94**	**538.36**	**437.60**	**18.71**

Table 7.6(b): Improvements in NOx Levels (based on top 150 (24-hr) air concentrations): Scenario-4



Grid No	NOx Scenario 4: (2+12+10) Control Option+(15+17+24) BAU					
	2012 BAU (ug/m3)	2012 C (ug/m3)	% Reductio	2017 BAU (ug/m3)	2017 C (ug/m3)	% Reduction
K-G-033	43.30	34.39	20.58	59.89	47.04	21.45
K-G-049	83.69	69.12	17.41	121.81	99.33	18.45
K-G-062	87.28	71.82	17.72	118.90	96.02	19.24
K-G-064	111.63	86.68	22.34	162.14	126.34	22.08
K-G-075	104.76	66.33	36.68	142.55	117.87	17.31
K-G-078	128.55	107.05	16.73	167.17	136.33	18.45
K-G-080	102.44	80.75	21.17	144.25	112.45	22.05
K-G-091	85.93	69.33	19.32	121.57	96.62	20.53
K-G-095	89.68	71.93	19.79	126.95	100.44	20.88
K-G-108	80.50	65.35	18.83	113.14	89.82	20.62
Overall	**91.78**	**72.27**	**21.25**	**127.84**	**102.23**	**20.03**

7.3 Best Scenario

Figures 7.1 to 7.8 present the effectiveness of the selected scenarios for PM_{10} and NOx air quality improvements. These figures also enable comparison of selected scenario-induced air quality improvements with air quality of BAU scenario. The modeling results definitely show the improvements but at least for PM_{10}, one is still far from achieving the 24-hr air quality standards in all parts of the city. Out of these scenarios, the overall improvement in air quality is shown below in Table 7.7 for ten critical grids.

Table 7.7: Overall Percent improvement in Air Quality for ten Critical grids w.r.t. Scenario

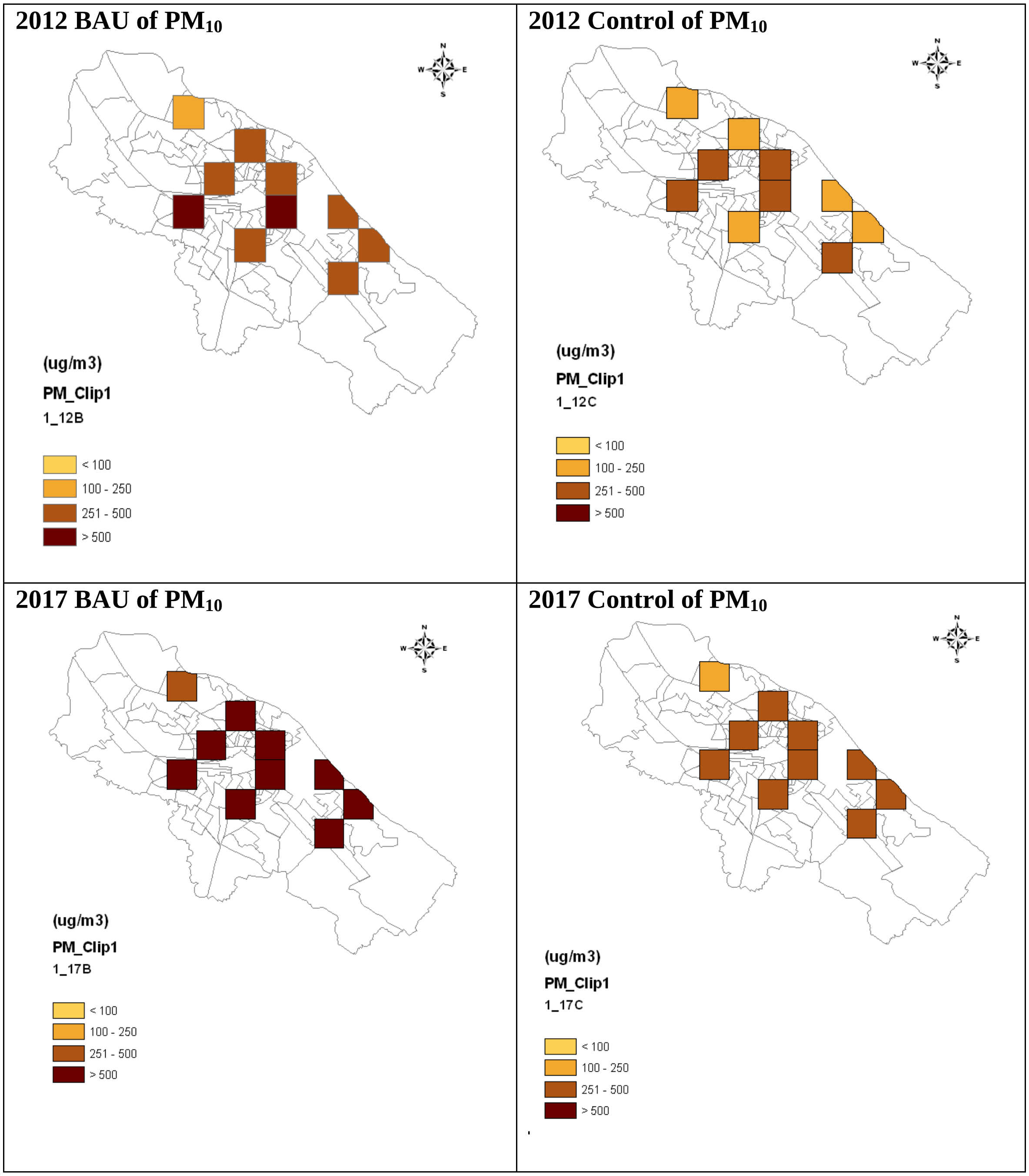
Pollutant	Scenario-1(%)		Scenario-2 (%)		Scenario-3(%)		Scenario-4(%)	
	2012	2017	2012	2017	2012	2017	2012	2017
PM_{10}	37	47	38	45	40	51	15	19
NOx	31	27	28	26	40	33	21	20

It can be concluded that scenario 3 having combination of the following options (Table 7.8) yields the best possible improvement both for PM_{10} and NO_x. It is clearly seen from Figures 7.1 to 7.8 that scenario 3 (Figures 7.5 and 7.6) provides best possible air quality out of all the scenarios that were considered.

Table 7.8: Most Promising Control Options: Scenario 3

S. No.	Control Option	Details
1.	Control Option-2	Implementation of BS – VI norms w.e.f 2012
2.	Control Option-5	CNG/LPG to commercial Vehicles w.e.f. 2008
3.	Control Option-11	Improvement in Inspection and Maintenance of vehicles w.e.f. 2008
4.	Control Option-12	Banning of 15 year old private vehicles w.e.f 2012
5.	Control Option-15	Particulate control systems in industry w.e.f. 2012
6.	Control Option-17	Domestic-Use of Natural Gas/LPG w.e.f. 2012
7.	Control Option-19	DG Sets: No Power cut (Area source) w.e.f. 2012
8.	Control Option-21	Converting unpaved roads to paved roads w.e.f 2012
9.	Control Option-23	Sweeping and watering (mechanized) w.e.f. 2012
10.	Control Option-24	Strict compliance to ban of open burning w.e.f. 2012

Figure 7.1: Modeling Results for Scenario-1 of PM_{10} (for 10 critical grids only)



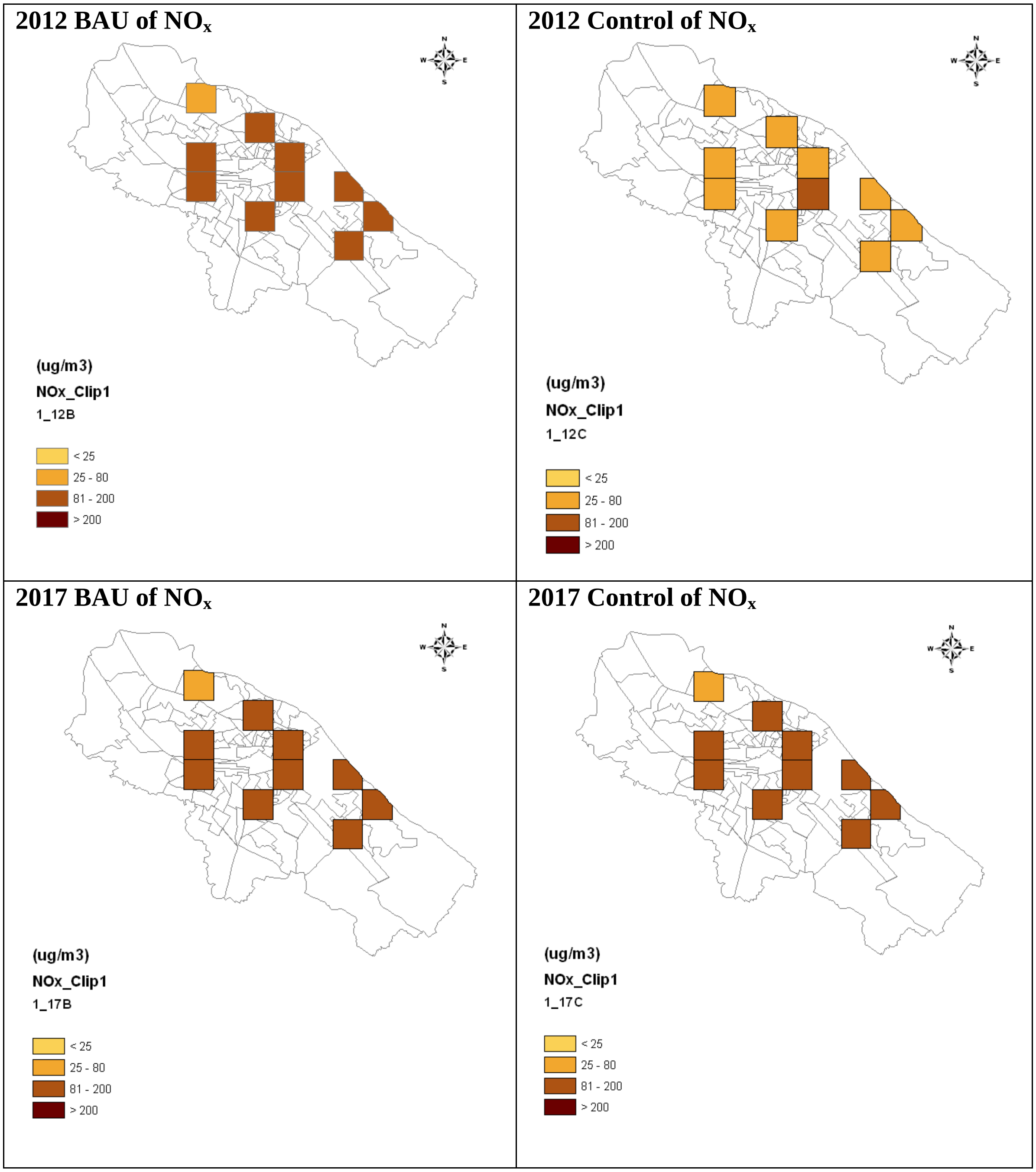
2012 BAU of PM_{10}

2012 Control of PM_{10}

2017 BAU of PM_{10}

2017 Control of PM_{10}

Figure 7.2: Modeling Results for Scenario-1 of NO_x (for 10 critical grids only)



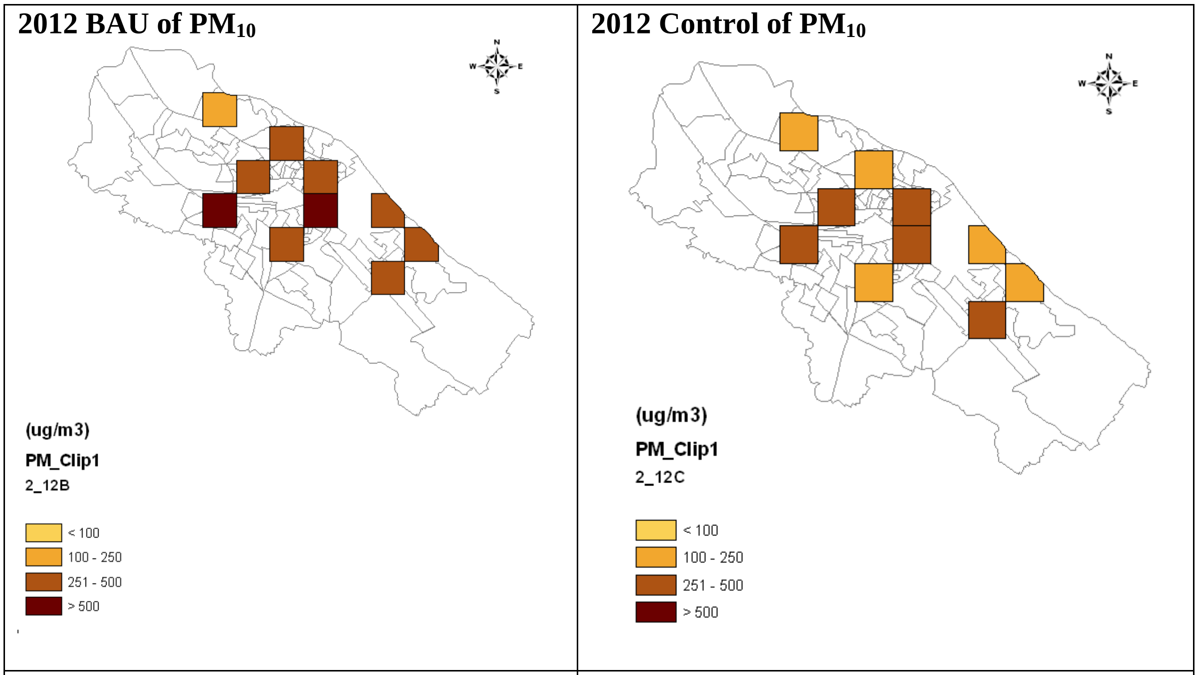
2012 BAU of NO_x

2012 Control of NO_x

2017 BAU of NO_x

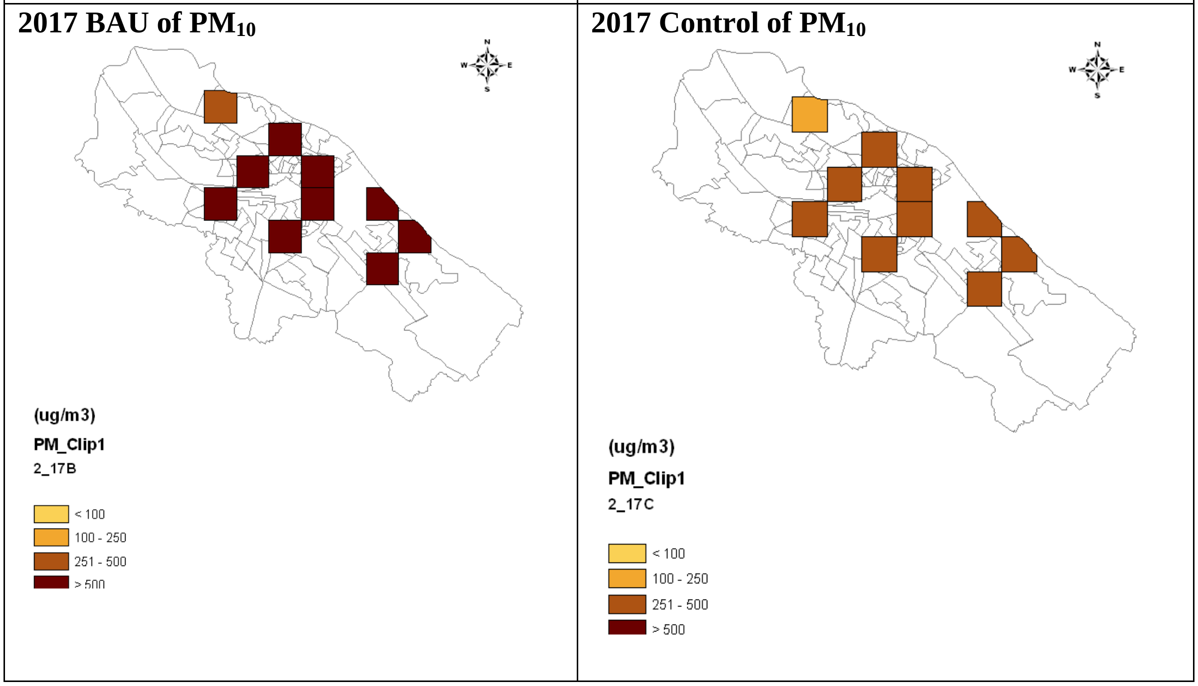
2017 Control of NO_x

Figure 7.3: Modeling Results for Scenario-2 of PM_{10} (for 10 critical grids only)



2012 BAU of PM_{10}

2012 Control of PM_{10}



2017 BAU of PM_{10}

2017 Control of PM_{10}

Figure 7.4: Modeling Results for Scenario-2 of NO_x (for 10 critical grids only)

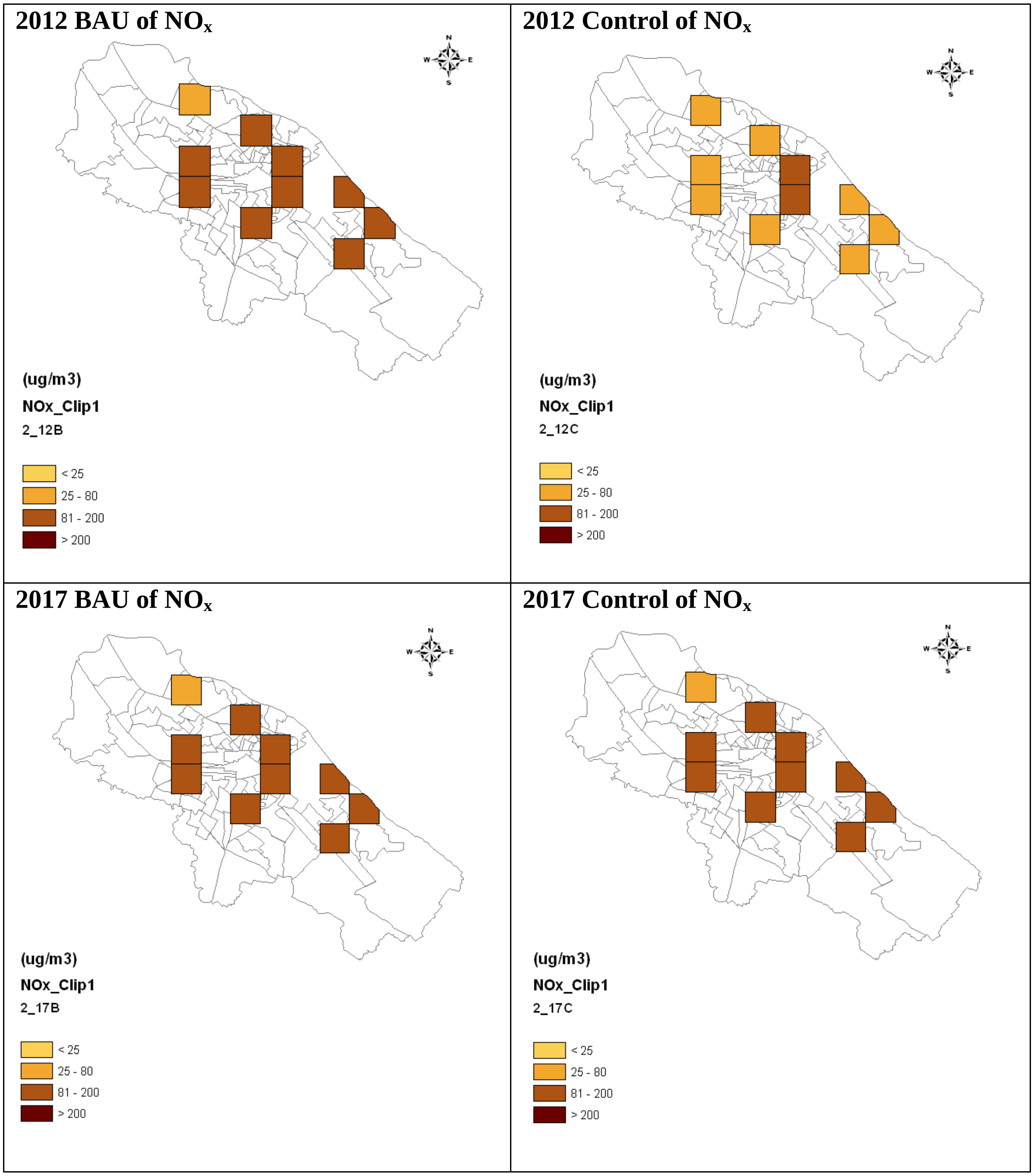


Figure 7.5: Modeling Results for Scenario-3 of PM_{10} (for 10 critical grids only)

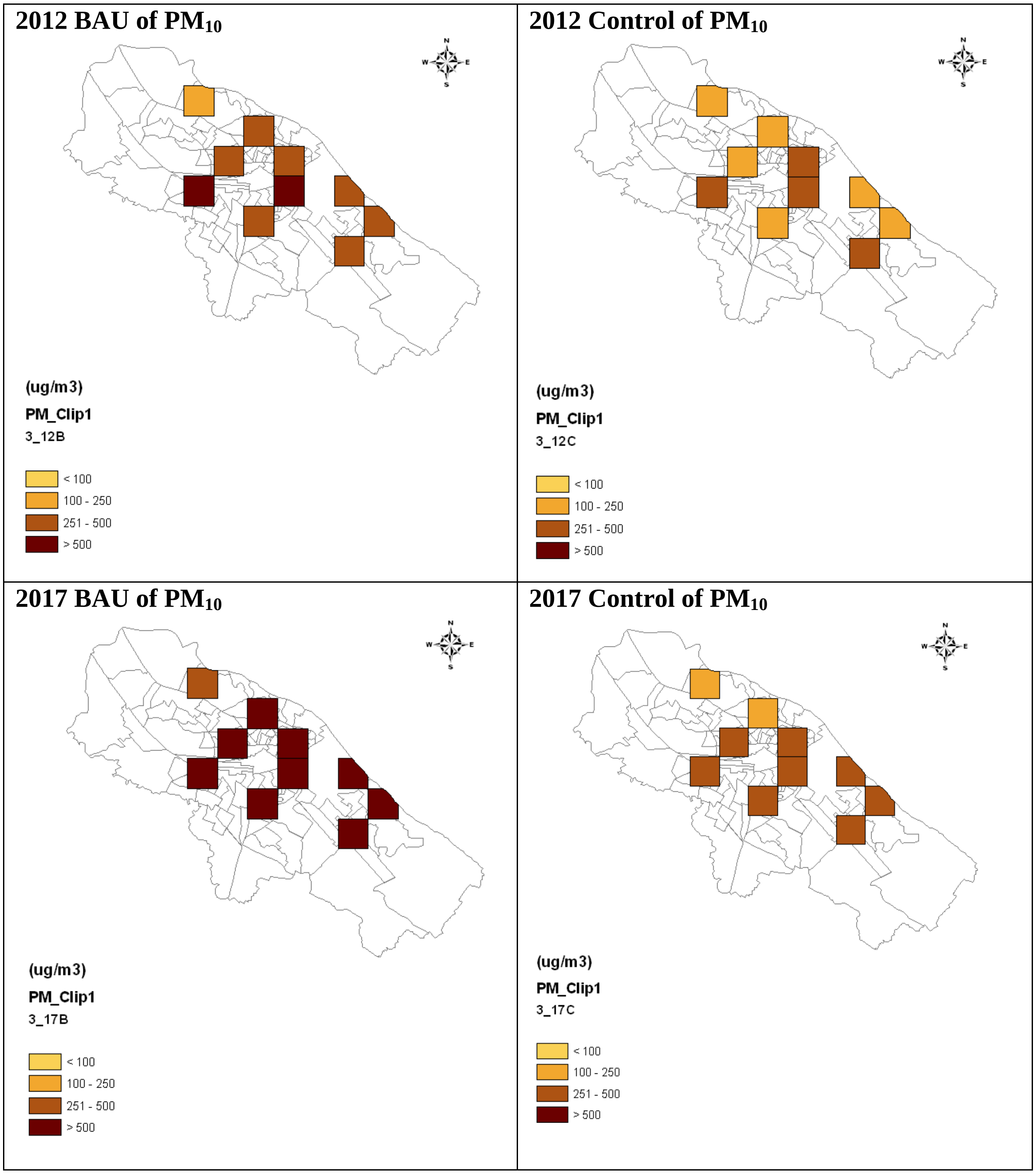


Figure 7.6: Modeling Results for Scenario-3 of NO_x (for 10 critical grids only)

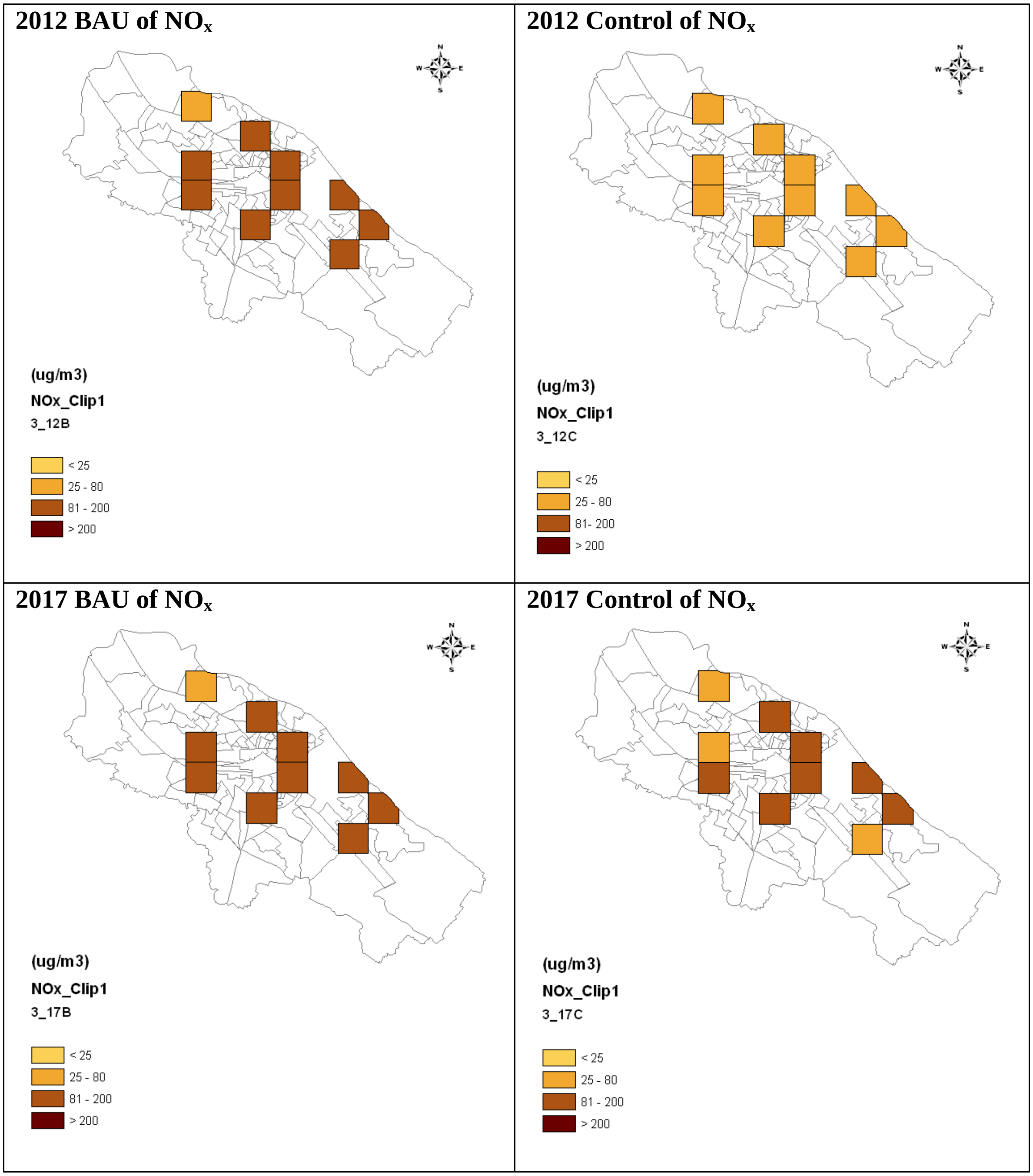


Figure 7.7: Modeling Results for Scenario-4 of PM_{10} (for 10 critical grids only)

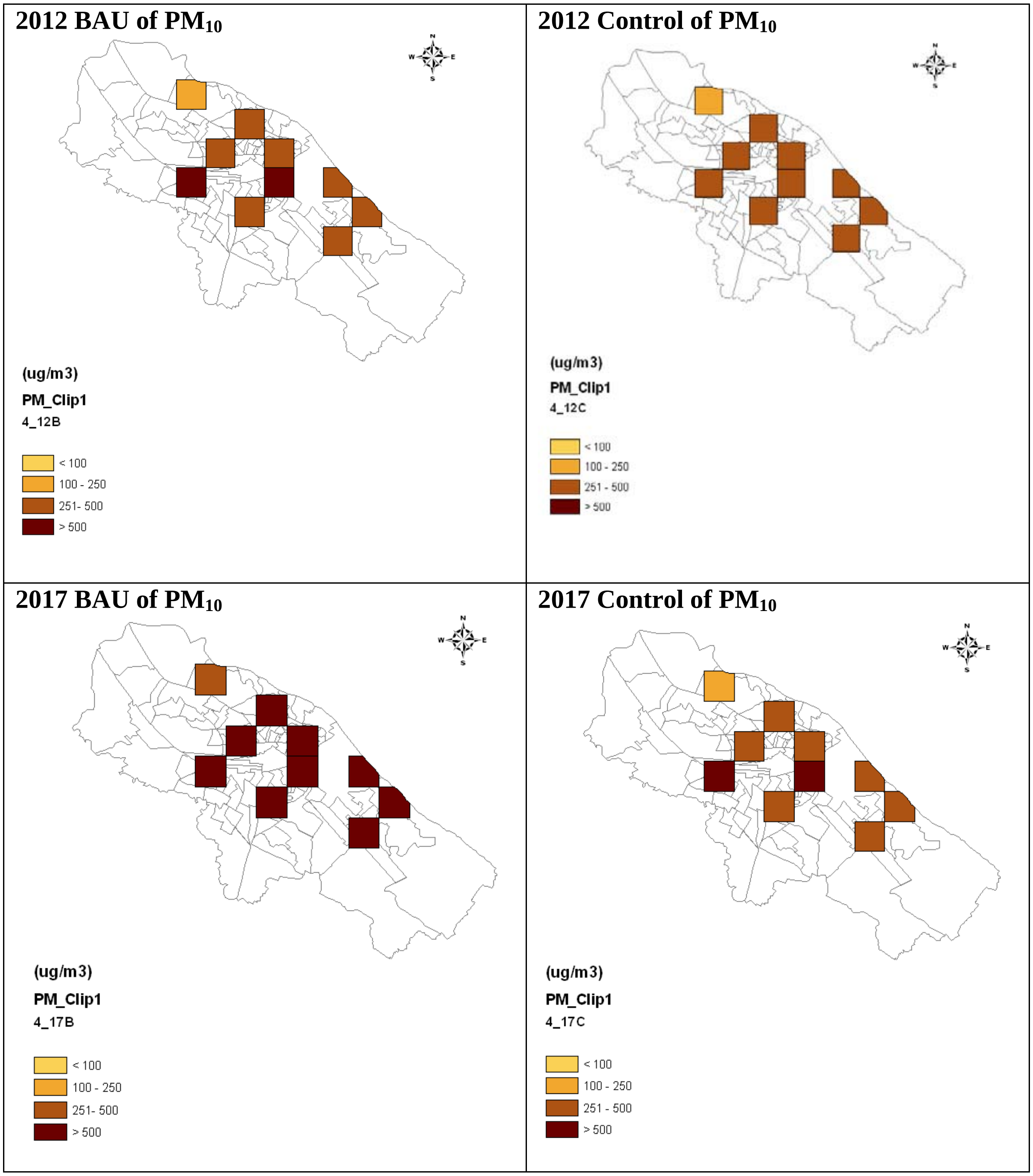
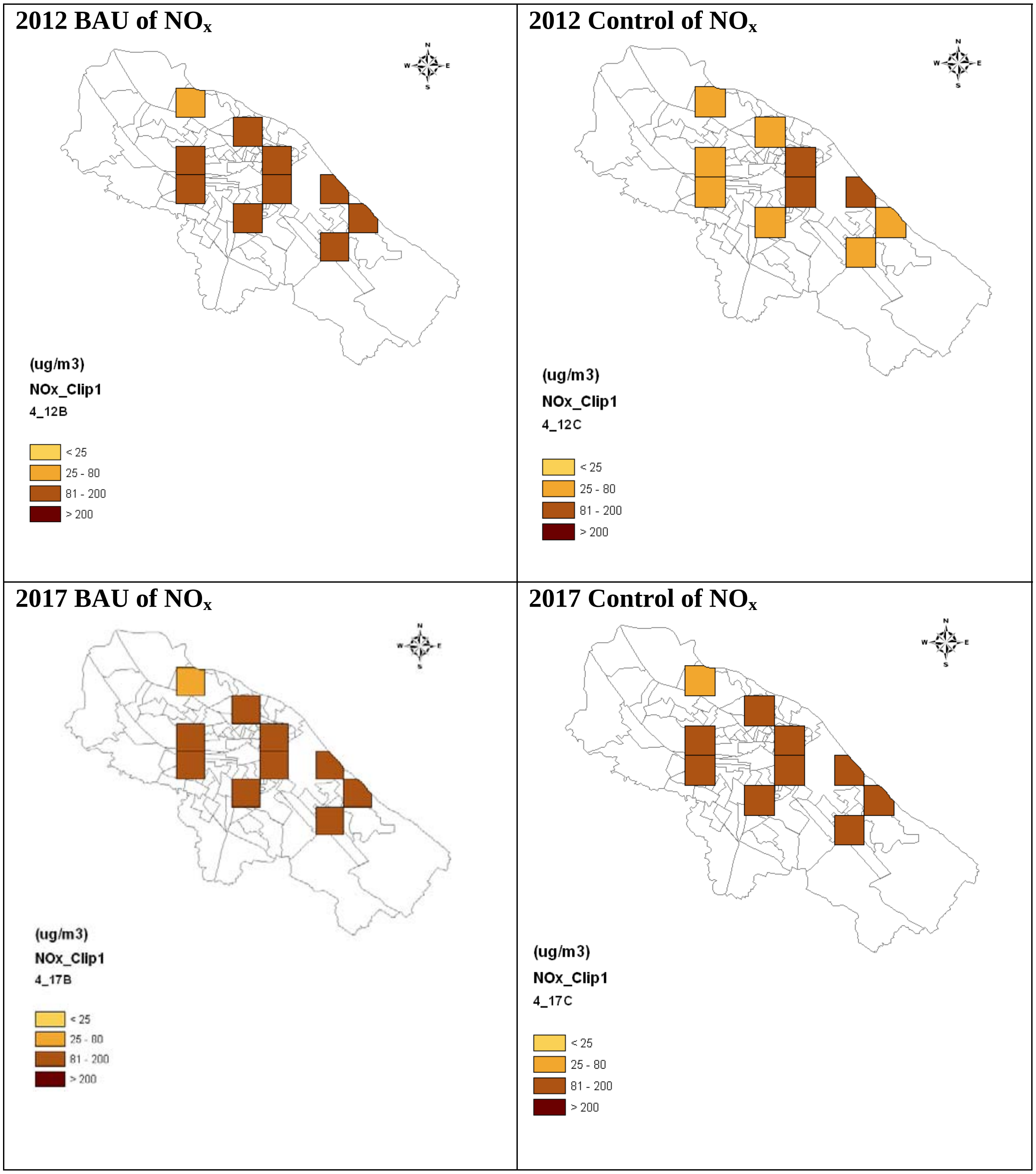


Figure 7.8: Modeling Results for Scenario-4 of NO_x (for 10 critical grids only)



7.4 Implementation of Scenario 3 and Air Quality

Figures 7.9 and 7.10 show the air quality scene of the city when the best selected scenario (Scenario 3) is implemented in the years 2012 and 2017. These Figures represent maximum daily air quality levels for 24 hours. Figures surely indicate that implementation of scenario 3 alone is not enough to turn the city into fully compliant with the air quality standard of 100 ug/m^3 for PM_{10} and 80 ug/m^3 for NOx, although there will be significant improvement in the air quality after implementation of the control options selected under scenario 3. There are certain pockets where air quality standards will be exceeded both for PM_{10} and NOx in spite measures taken under scenario 3. Therefore it is clear that we need to beyond Scenario 3 and prepare city specific control strategy.

The following conclusions come to the fore after implementation of Scenario 3.

- If no action is taken in 2012, entire city will totter under high air pollution when standards for PM_{10} exceeded over the entire city (Figure 7.9) with very high concentration of over 500 ug/m^3 (max 24-hour) in 16 sq-Km area.
- If no action is taken up to 2017 and city will have unbridled growth, not only the entire city will exceed the air quality standards, nearly 50 sq-km (nearly 1 /5th of city) areas may have air quality above 500 ug/m3 (max 24-hour).
- With the implementation of Scenario 3, the air quality will improve dramatically will fall short of achieving air quality standards for PM_{10} in 1/4 th part of the city and by the year 2017, almost 2/3 are will still be below desired air quality standard.
- NOx standard will be met in the year 2012 with control options however about 1/5th of the area will still exceed air quality standard for NOx.

Figures 7.11 to 7.13 present the average monthly air quality (of critical month in winter). It can be seen that for a long term average the air quality improve all through the city and it is below 100 µ/m^3 for PM_{10} below 80 µg/m^3 everywhere in the city. However, as specified above, there is still a challenge to meet the air quality for 24 hours averaging time at all places in the city and this aspect is discussed in Section 7.4.

7.5 Emission Reduction beyond Scenario 3

Table 7.9 presents emission levels in the ten critical grids under consideration and corresponding air concentration for Scenario 3. It can be seen on a critical day in winter season concentration may exceed by an average factor of 2.4. In other words, it is necessary that emissions in these grids should reduce to 40 percent of controlled emission of 2012 and 2017. This will require additional efforts to reduce the emission. Vehicles, road dust and domestic cooking are the important sources both in 2012 and 2017. It may be noted that that if vehicular pollution is reduced further by 50 percent which can best be done restricting entry of vehicles in these grids by 50 percent of projected level (e.g. by allowing odd number of vehicles the first day and the next day even number and the repeating the cycle); this need to be done by in winter months (November to January) only. The reduction in vehicles will also reduce the road dust by 50 percent. In addition, there should be total ban on any refuse or garbage burning w.e.f. from 2012.

The decision to restrict the public transport can put the general public to inconvenience. It is emphasized a network of public transport in terms of metro or elevated railway needs to be planned. Further, construction of flyovers at railway intersections (15 Nos.) will help in about 20 percent time saving that will result in 20 percent lowering of vehicular emission.

Table 7.9 (a): Emissions and Air Concentrations in ten Critical Grids after Scenario 3 – Year 2012

Critical Grids	LU Pattern	Pollution Load-Vehicles-Year 2012-Scenario-3 Control (kg/d)					Vehicles (kg/d)	Total Domestic (kg/d)	Road Dust (kg/d)	Open burring (kg/d)	Scen-3 (kg/d)	Scen-3 (ug/m3)
		2W	3W	4W	LCV	Bus/Truck						
K-G-033	Res-Commercial	1.67	8.74	1.76	5.63	8.77	26.57	32.03	22.07	3.34	84.01	136.45
K-G-049	Commercial	5.77	33.51	6.98	5.33	6.76	58.34	40.29	55.62	5.61	159.86	217.12
K-G-062	Residential	3.68	12.86	3.84	13.25	18.43	52.06	43.56	52.42	9.51	157.55	244.65
K-G-064	Commercial	5.36	36.93	7.21	8.22	9.37	67.08	47.10	43.35	9.55	167.09	263.79
K-G-075	Industrial	3.21	21.87	4.19	20.75	22.76	72.77	26.37	65.12	5.00	169.27	297.41
K-G-078	Industrial	3.72	12.71	2.74	14.69	20.04	53.91	33.83	62.54	7.22	157.50	267.40
K-G-080	Residential	1.92	9.05	1.98	4.62	6.44	24.01	21.53	19.47	3.53	68.55	237.39
K-G-091	Res-Commercial	3.52	16.84	3.70	12.96	14.12	51.14	41.99	45.15	8.41	146.69	239.72
K-G-095	Residential	2.63	14.39	2.97	8.14	11.34	39.48	26.75	36.25	4.09	106.58	239.86
K-G-108	Res-Commercial	1.82	10.47	2.48	11.11	16.72	42.61	23.13	36.32	3.79	105.85	253.39

Table 7.9 (b): Emissions and Air Concentrations in ten Critical Grids after Scenario 3: Year 2017

Critical Grids	LU Pattern	Veh (kg/d)	Domestic (kg/d)	Road Dust (kg/d)	Open buring (kg/d)	Scen-3 Emission (kg/d)	Scenario-3 Concentration(ug/m3)
K-G-033	Res-Commercial	44.77	26.70	27.93	0.00	99.40	147.23
K-G-049	Commercial	99.84	34.08	70.06	0.00	203.97	239.54
K-G-062	Residential	86.78	37.97	71.55	0.00	196.29	259.93
K-G-064	Commercial	114.90	40.10	55.39	0.00	210.39	299.27
K-G-075	Industrial	122.58	22.46	93.70	0.00	238.74	352.41
K-G-078	Industrial	90.05	29.06	87.05	0.00	206.15	295.72
K-G-080	Residential	70.50	18.54	66.11	0.00	155.15	250.08
K-G-091	Res-Commercial	86.04	37.79	57.73	0.00	181.55	261.95
K-G-095	Residential	66.67	22.35	52.56	0.00	141.58	262.86
K-G-108	Res-Commercial	71.35	19.84	45.90	0.00	137.09	281.94

Figure 7.9: Modeling Results Daily Average of PM_{10} (for all grids)

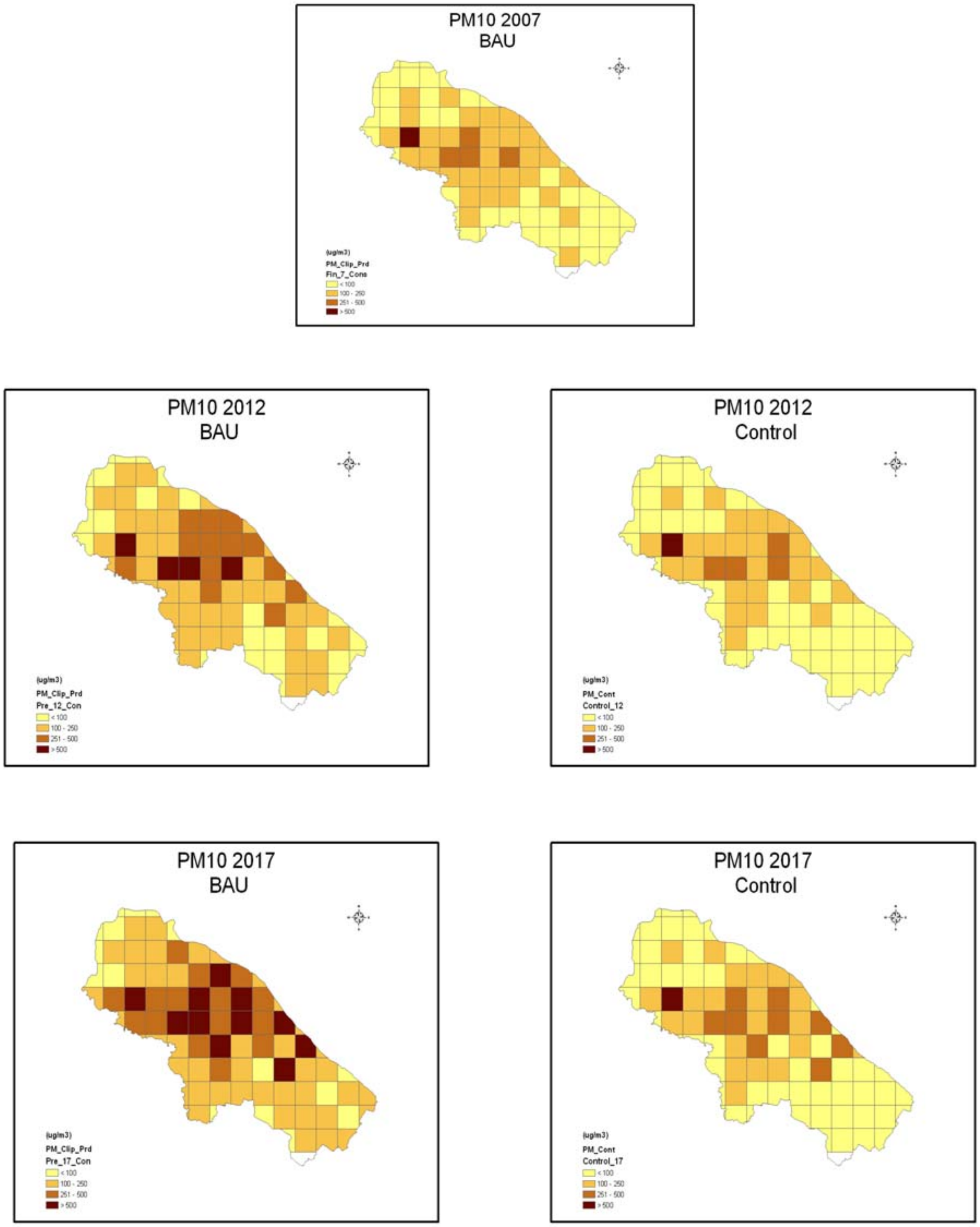


Figure 7.10: ISC Modeling Results Daily Average of NOx (for all grids)

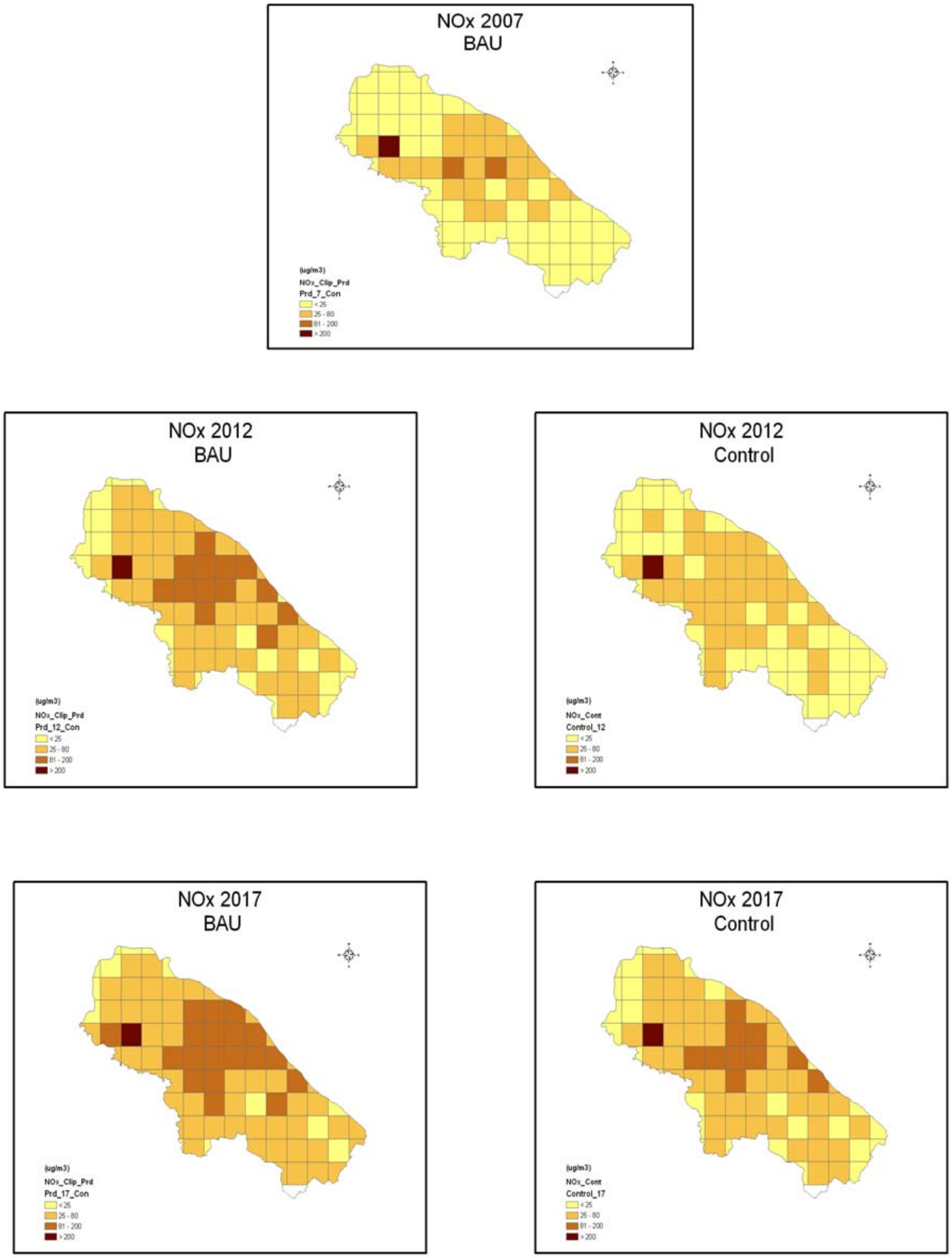


Figure 7.11: ISC Modeling Results Monthly Average of PM$_{10}$ (for all grids)

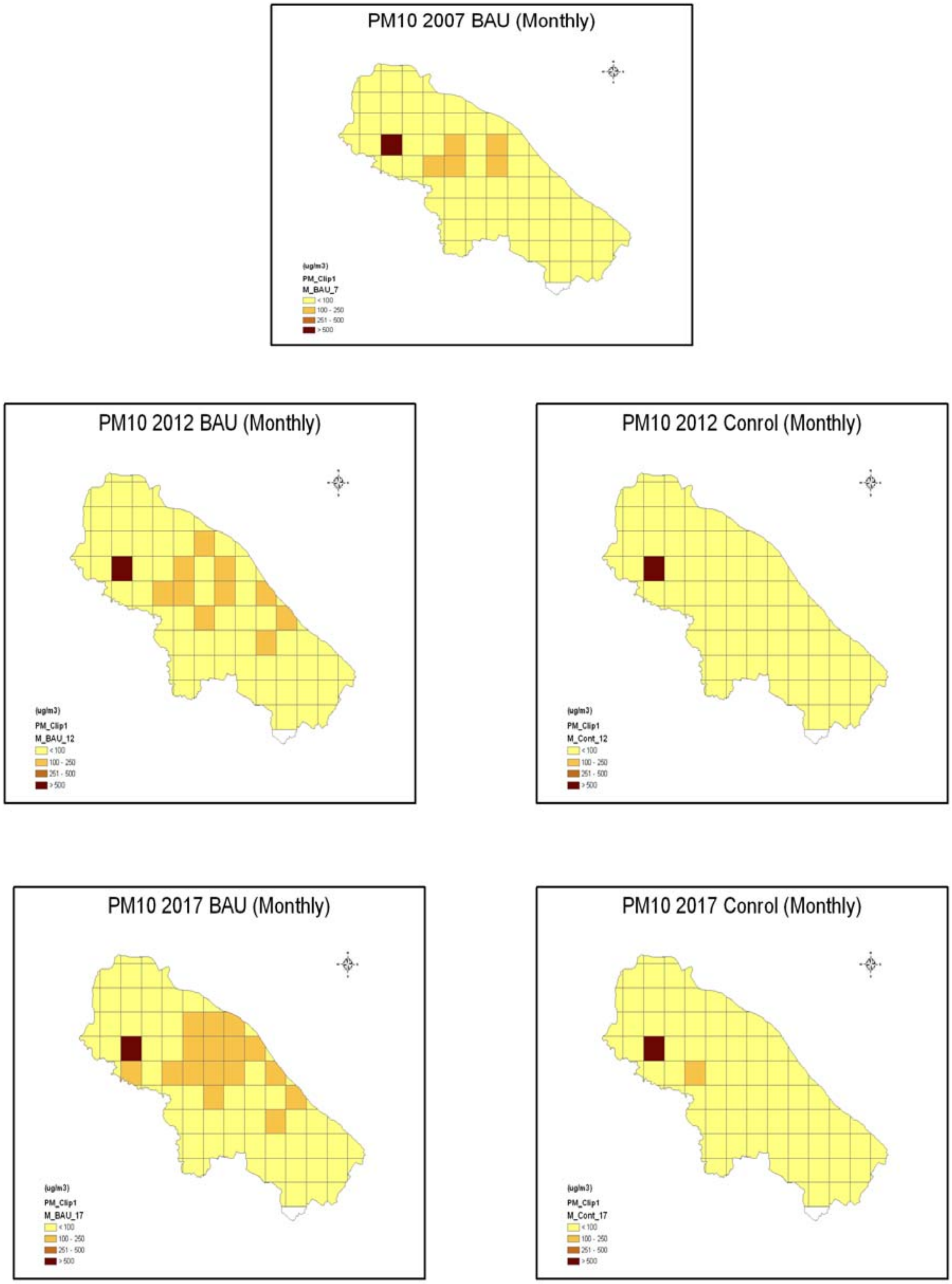
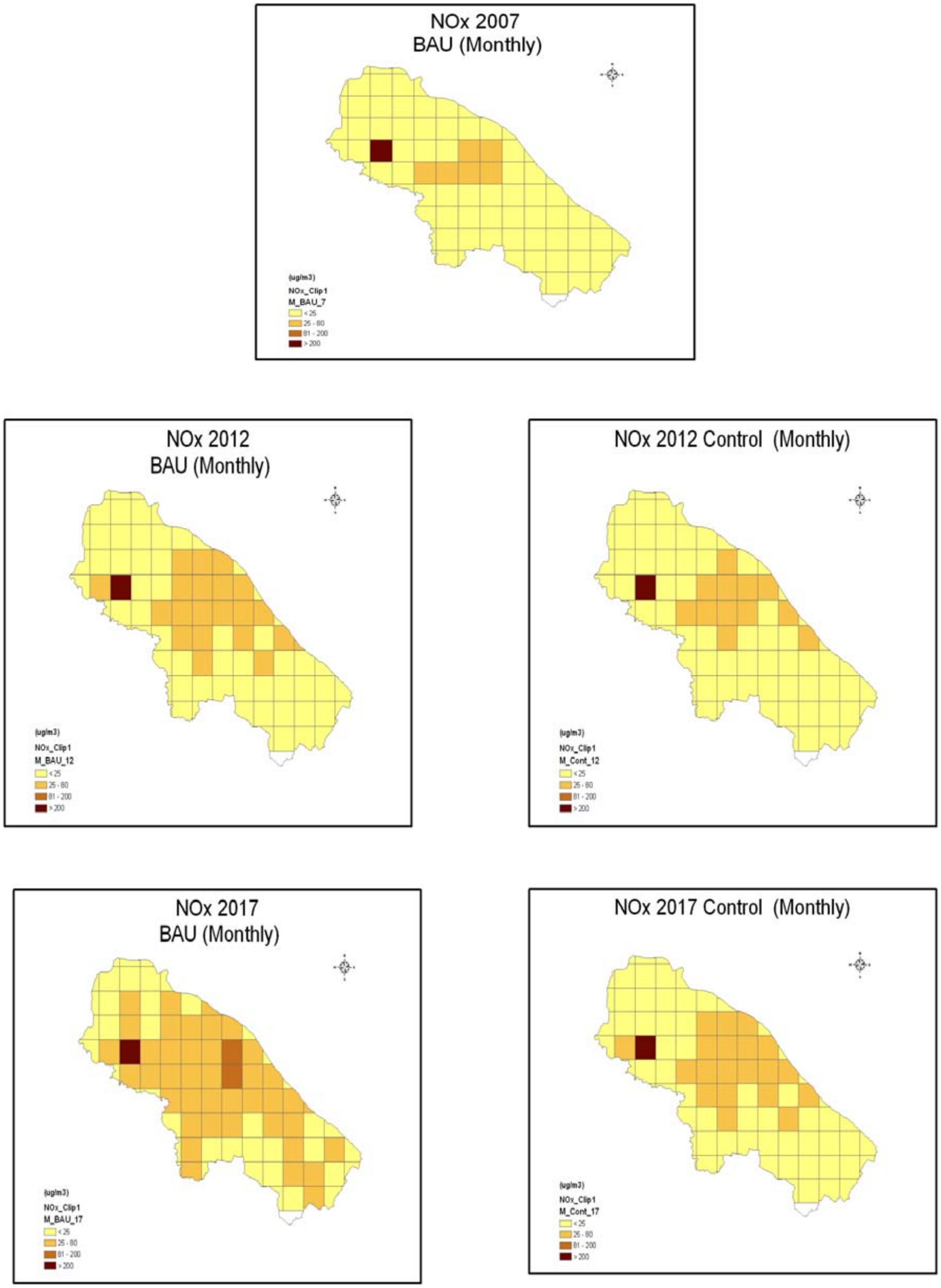


Figure 7.12: ISC Modeling Results Monthly Average of NOx (for all grids)



7.6 Action Plan

The overall action plan that will ensure compliance with air quality standards both for PM_{10} (100 µg/m^3) and NOx (80 µg/m^3) is presented in Table 7.10.

Table 7.10: Action Plan

S. No.	Details	2008	2009	2010	2011	2012	2013 - 2017
1.	Adoption of BS – VI for all vehicles						🟩 **From 2015**
2.	Banning of 15 year old private vehicles and 10 year old commercial vehicles					🟥	🟥
3.	CNG/LPG for Commercial Vehicles	🟨	🟨	🟨	🟨	🟨	🟨
4.	Particulate control systems in all industry				🟪	🟪	🟪
5.	Inspection and Maintenance of vehicles			🟧	🟧	🟧	🟧
6.	LPG for Domestic Sources (50% by 2012)				🟦	🟦	
7.	LPG for Domestic Sources (75% by 2017)						🟦
8	Inspection and Maintenance of DG sets				🟦	🟦	
9.	Ban on DG sets (100% Grid power)						🟦
10.	Unpaved to paved roads (50% by 2012)				🟩	🟩	
11	Unpaved to paved roads (100% by 2017)						🟩
12	Sweeping and watering of Road				🟪	🟪	🟪
13	Ban on open burning (100%)					🟧	🟧
14	Restricted vehicle Movement ~ 50% only (in winter in polluted areas)					🟦	🟦
15	Mass Rapid Transport System			🟩	🟩	🟩	🟩
16	Construction of flyovers (15 Nos.)			🟧	🟧	🟧	🟧

Chapter 8

Summary and Recommendations

8.1 Summary

To specifically address the issues of relative importance of emission sources and to plan control strategies for short- and long-term improvements in air quality in the City of Kanpur, Central Pollution Control Board, New Delhi sponsored this project. The project required very extensive air quality sampling and analysis of PM_{10}, $PM_{2.5}$, CO, HCHO, molecular markers and organic and inorganic contents of PM_{10} and $PM_{2.5}$ at seven locations covering various land use patterns and three seasons (summer, post-monsoon and winter). In addition, the project required receptor modeling to identify source receptor linkages and dispersion modeling to develop scenarios of air quality in the years 2012 and 2017 with and without various emission control options ranging from introduction of BS – VI emission norms, changing of fuel from domestic cooking, uses of electric vehicles, stringent pollution control in industry, changing of solid fuel in industry to liquid or gaseous fuel. This section presents findings of this massive project and to finally draw recommendations for improving the air quality to the extent of attaining air quality for by the year 2012 and ensure attainment until 2017 based on growth model of city.

The following findings can be drawn from this study:

8.1.1 Sampling and Analysis

- Particulate pollution is the main concern in the city where levels of SPM, PM_{10} and $PM_{2.5}$ are 2.5- 3.5 times higher than the acceptable levels.

- OC (organic carbon) levels are always much higher 2-4.5 times than EC levels. The ratio of EC/OC is variable from one location to another, indicating that sources, those contribute to particulate pollution are variable.

- While SPM levels show dramatic diurnal variation at all locations (being lower in night time), such a variation for PM_{10} and $PM_{2.5}$ is not apparent. Therefore, SPM levels will have significant contribution related to daily urban activities which may not be from combustion related sources.

- EC and OC almost account for 30 percent of $PM_{2.5}$, which is quite high and reflects as how badly is the city affected because of combustion and /or fuel related emissions which account for most respiratory problems.

- EC to OC ratio increase at traffic, kerb and industrial sites. Higher EC/OC ratio can again be attributed to diesel combustion at the sites and indicating these to be the hot spots for particulate pollution.

- NO_2 levels are found to be stabilized across all locations at about 20-25 $\mu g/m^3$.

- Elemental and ion analysis show abundance of soil constituents (e.g. Si, Fe, Ca, Na and NH_4^+, SO_4^{2-} and NO_3^- ions). This clearly suggests that there could be significant sources of particulate pollution from soil, road dust and presence of secondary particles.

- HCHO levels clearly correlated with traffic emissions.

- Industrial area shows significantly high fraction of coarse fraction ($PM_{10-2.5}$), which is quite characteristic of industrial emissions

- Kerb and traffic sites show high fraction of $PM_{2.5}$ ($PM_{2.5}/PM_{10}$ ratio as 0.78 and 0.92).

- Roadside locations are thus heavily influenced by the traffic related emissions and are the real hot spots in terms fine particles.

- As an urban background, $PM_{2.5}$ is nearly 65 percent of PM_{10}.
- CO levels were generally within air quality standards but levels clearly correlated with diurnal traffic pattern.

8.1.2 Air Quality Modeling

- For PM_{10}, the industrial site (Dadanagar) showed the highest concentration and the industries appear to contribute a significant pollution at this site (~ 40 percent).

- There are three prominent and probably equally important sources of PM_{10} (vehicles, road dust and domestic fuel burning) that contribute to about 80 percent of PM_{10} at all sampling sites (except for the industrial location).

- Contribution of the largest sources (Panki power plant) is not significant probably due to very high emission release.

- For NOx, 50-70 percent contribution is from vehicles at all sampling sites. It is only at industrial area (i.e. Dadanagar), where contribution of industries is seen and on a few occasions, the point source (power plant) also contributes to NOx at this site. At the kerbsite and commercial site almost entire NOx is from vehicles.

- Overall city specific modeling results follow the meteorology and emissions in each grid and there are clear hotspots. These hotspots vary depending on the season. PM_{10} hotspot in summer is in the industrial area and in winter season there are two equally important hotspots - industrial area and city center.

- NOx levels show two consistent hotspots where concentrations can really be very high: (i) industrial area and (ii) the city center. It is seen that emission are also high in these two areas.

- Post monsoon season resulted in the lowest concentrations at all sampling sites. Winter was the worst season from air quality point of view. In addition to low mixing heights in winter, consistently wind being in the same direction results in high concentration in certain areas.

- Model performance was found adequate (R-square 0.88 – 0.44 for observed and predicted values). Observed levels are generally higher than predicted levels both for PM_{10} and NOx. For PM_{10}, there is a significant part as background level.

8.1.3 Future Air Quality Scenario 2012 and 2017

- If no action is taken to reduce PM_{10} and NOx emissions, in 2012, entire city will totter under high air pollution when standards for PM_{10} will exceed over the entire city with very high concentration of over 500 $\mu g/m^3$ (max 24-hour) in 16 sq-Km area.

- If no action is taken up to 2017 and city will have unbridled growth, not only the entire city will exceed the air quality standards, nearly 50 sq-km (nearly 1 /5th of city) areas may have air quality much above 500 $\mu g/m^3$ (max 24-hour) for PM_{10}.

- NOx standard will be met in the year 2012 with control options however about 1/5th of the area will still exceed air quality standard for NOx.

8.2 Recommendations

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

- Implementation of BS – VI norms
- CNG/LPG to commercial Vehicles
- Improvement in Inspection and Maintenance of vehicles
- Banning of 15 year old private vehicles
- Particulate control systems in industry
- Domestic-Use of Natural Gas/LPG
- Converting unpaved roads to paved roads
- Sweeping and watering (mechanized)
- DG Sets: No Power cut

- Strict compliance to ban of open burning

By implementing the above options, air quality will improve dramatically but will fall short of achieving air quality standards for PM_{10} in 1/4 th part of the city and by the year 2017, almost 2/3 area will still be below the desired air quality standard.

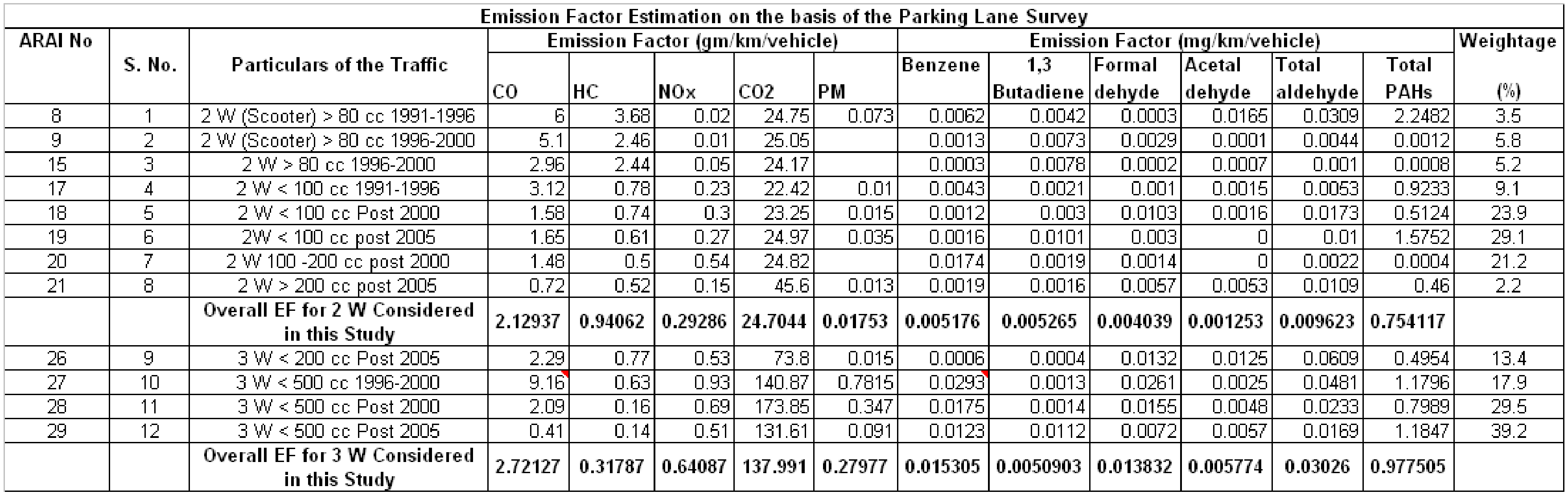
It is necessary that emissions in certain grids (area) should reduce to 40 percent of controlled emission of 2012 and 2017 (as recommended above). This will require additional efforts to reduce the emission. Vehicles, road dust and domestic cooking are the important sources both in 2012 and 2017. It may be noted that that if vehicular pollution is reduced further by 50 percent which can best be done by restricting entry of vehicles in critical areas by 50 percent of projected number of vehicles (e.g. by allowing odd number of vehicles the first day and the next day even number and the repeating the cycle). This needs to be done by in winter months (November to January) only. The reduction in vehicles will also reduce the road dust by 50 percent. In addition, there should be a total ban on any refuse or garbage burning from 2012.

The decision to restrict the public transport can put the general public to inconvenience. It is emphasized that a network of public transport in terms of metro or elevated railway needs to be planned. Further, construction of flyovers at all railway intersections (15 Nos.) will help in about 20 percent time saving that will result in 20 percent lowering of vehicular emissions and corresponding improvements in air quality.

The overall action plan that will ensure compliance with air quality standards both for PM_{10} (100 µg/m^3 – 24-hr average), $PM_{2.5}$ and NOx (80 µg/m^3) is presented below.

S. No.	**Details**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013 - 2017**
1.	Adoption of BS – VI for all vehicles						🟩 **From 2015**
2.	Banning of 15 year old private vehicles and 10 year old commercial vehicles					🟥	🟥
3.	CNG/LPG for Commercial Vehicles	🟨	🟨	🟨	🟨	🟨	🟨
4.	Particulate control systems in all industry				🟪	🟪	🟪
5.	Inspection and Maintenance of vehicles			🟧	🟧	🟧	🟧
6.	LPG for Domestic Sources (50% by 2012)				🟦	🟦	
7.	LPG for Domestic Sources (75% by 2017)						🟦
8	Inspection and Maintenance of DG sets				🟦	🟦	
9.	Ban on DG sets (100% Grid power)						🟦
10.	Unpaved to paved roads (50% by 2012)				🟩	🟩	
11	Unpaved to paved roads (100% by 2017)						🟩
12	Sweeping and watering of Road				🟪	🟪	🟪
13	Ban on open burning (100%)					🟧	🟧
14	Restricted vehicle Movement ~ 50% only (in winter in polluted areas)					🟦	🟦
15	Mass Rapid Transport System			🟩	🟩	🟩	🟩
16	Construction of flyovers (15 Nos.)			🟧	🟧	🟧	🟧

Annexure I-1 – Emission Factors for Vehicles



Emission Factor Estimation on the basis of the Parking Lane Survey

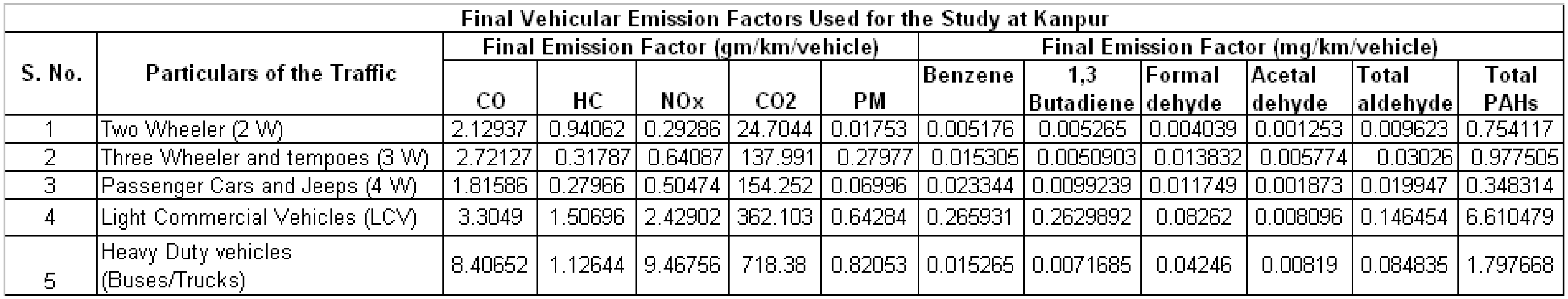
ARAI No	**S. No.**	**Particulars of the Traffic**	**Emission Factor (gm/km/vehicle)**					**Emission Factor (mg/km/vehicle)**						**Weightage**
			CO	HC	NOx	CO2	PM	**Benzene**	**1,3 Butadiene**	**Formal dehyde**	**Acetal dehyde**	**Total aldehyde**	**Total PAHs**	**(%)**
8	1	2 W (Scooter) > 80 cc 1991-1996	6	3.68	0.02	24.75	0.073	0.0062	0.0042	0.0003	0.0165	0.0309	2.2482	3.5
9	2	2 W (Scooter) > 80 cc 1996-2000	5.1	2.46	0.01	25.05		0.0013	0.0073	0.0029	0.0001	0.0044	0.0012	5.8
15	3	2 W > 80 cc 1996-2000	2.96	2.44	0.05	24.17		0.0003	0.0078	0.0002	0.0007	0.001	0.0008	5.2
17	4	2 W < 100 cc 1991-1996	3.12	0.78	0.23	22.42	0.01	0.0043	0.0021	0.001	0.0015	0.0053	0.9233	9.1
18	5	2 W < 100 cc Post 2000	1.58	0.74	0.3	23.25	0.015	0.0012	0.003	0.0103	0.0016	0.0173	0.5124	23.9
19	6	2W < 100 cc post 2005	1.65	0.61	0.27	24.97	0.035	0.0016	0.0101	0.003	0	0.01	1.5752	29.1
20	7	2 W 100 -200 cc post 2000	1.48	0.5	0.54	24.82		0.0174	0.0019	0.0014	0	0.0022	0.0004	21.2
21	8	2 W > 200 cc post 2005	0.72	0.52	0.15	45.6	0.013	0.0019	0.0016	0.0057	0.0053	0.0109	0.46	2.2
		Overall EF for 2 W Considered in this Study	**2.12937**	**0.94062**	**0.29286**	**24.7044**	**0.01753**	**0.005176**	**0.005265**	**0.004039**	**0.001253**	**0.009623**	**0.754117**	
26	9	3 W < 200 cc Post 2005	2.29	0.77	0.53	73.8	0.015	0.0006	0.0004	0.0132	0.0125	0.0609	0.4954	13.4
27	10	3 W < 500 cc 1996-2000	9.16	0.63	0.93	140.87	0.7815	0.0293	0.0013	0.0261	0.0025	0.0481	1.1796	17.9
28	11	3 W < 500 cc Post 2000	2.09	0.16	0.69	173.85	0.347	0.0175	0.0014	0.0155	0.0048	0.0233	0.7989	29.5
29	12	3 W < 500 cc Post 2005	0.41	0.14	0.51	131.61	0.091	0.0123	0.0112	0.0072	0.0057	0.0169	1.1847	39.2
		Overall EF for 3 W Considered in this Study	**2.72127**	**0.31787**	**0.64087**	**137.991**	**0.27977**	**0.015305**	**0.0050903**	**0.013832**	**0.005774**	**0.03026**	**0.977505**	

Emission Factor Estimation on the basis of the Parking Lane Survey

ARAI No	S. No.	Particulars of the Traffic	Emission Factor (gm/km/vehicle)					Emission Factor (mg/km/vehicle)						Weightage
			CO	HC	NOx	CO2	PM	Benzene	1,3 Butadiene	Formal dehyde	Acetal dehyde	Total aldehyde	Total PAHs	(%)
35	13	4W < 1000 cc 1996-2000	4.53	0.66	0.75	106.96	0.008	0.00095	0.0067	0.0013	0.00005	0.00835	0.1862	8.2
36	14	4W < 1000 cc Post 2000	1.3	0.24	0.2	126.37	0.004	0.0002	0.0031	0.0034	0.0012	0.0088	0.0955	19.8
37	15	4W 1000 - 1400 cc Post 2000	3.01	0.19	0.12	126.5	0.006	0.0007	0.0034	0.0034	0.0012	0.0079	0.1324	27.6
39	16	4W > 1400 cc Post 05	0.84	0.12	0.09	172.95	0.002	0.0003	0.0003	0.0003	0	0.0096	0.05	11.9
41	17	4W < 1600 cc Post 2000	0.72	0.14	0.84	156.76	0.19	0.0386	0.0528	0.0206	0.0021	0.0422	0.149	8.2
42	18	4W < 1600 cc Post 2005	0.06	0.08	0.28	148.76	0.015	0.0018	0.0007	0.0889	0.0033	0.0922	0.2109	8.2
51	19	4 W < 3000 cc Post 2000	1.94	0.89	2.46	242.01	0.48	0.008	0.006	0	0.003	0.006	2.604	9.0
52	20	4 W < 3000 cc Post 2005	0.25	0.19	0.67	255.98	0.096	0.2675	0.0403	0.0142	0.0083	0.037	0.1252	7.1
		Overall EF for 4W (Car/Jeep) Cosidered in this Study	**1.81586**	**0.27966**	**0.50474**	**154.252**	**0.06996**	**0.023344**	**0.0099239**	**0.011749**	**0.001873**	**0.019947**	**0.348314**	
53	21	LCV < 3000 cc 1991-96	3.07	2.28	3.03	327.29	0.998	0.5427	0.0094	0.1975	0.0117	0.2957	8.1284	19.6
54	22	LCV <3000 cc 1996-2000	3	1.28	2.48	333.31	0.655	0.2015	0.2147	0.1176	0.0059	0.2169	3.7742	36.3
55	23	LCV > 3000 cc Post 2000	3.66	1.35	2.12	401.25	0.475	0.1959	0.4154	0.0028	0.0083	0.0222	8.2679	44.1

Emission Factor Estimation on the basis of the Parking Lane Survey

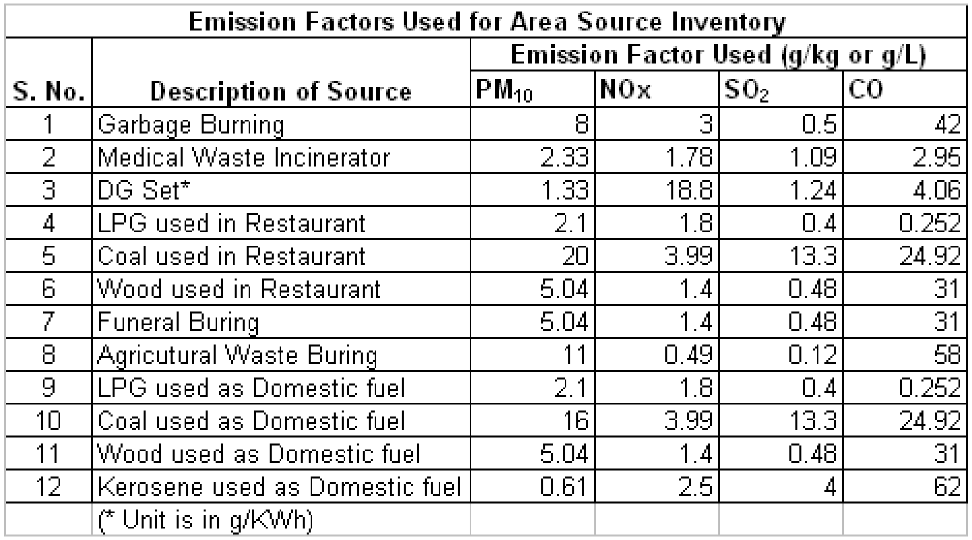
														Weightage
		Overall EF for LCV Considered in this Study	**3.3049**	**1.50696**	**2.42902**	**362.103**	**0.64284**	**0.265931**	**0.2629892**	**0.08262**	**0.008096**	**0.146454**	**6.610479**	(%)
56	24	Buses diesel > 6000 cc 1991-96	13.06	2.4	11.24	817.52	2.013	0.1529	0.0313	0.1007	0.0148	0.1259	1.0123	2.6
57	25	Buses diesel > 6000 cc 1996-2000	4.48	1.46	15.25	920.77	1.213	0.1008	0.0093	0.1015	0.0029	0.1191	3.6515	2.4
58	26	Buses diesel > 6000 cc Post 2000	12.14	0.39	11.5	668	0.795	0.0126	0.0017	0.0104	0.0136	0.0458	0.2833	26.3
59	27	Buses diesel > 6000 ccPost 2005	3.92	0.16	6.53	602.01	0.3	0.0101	0.0096	0.0523	0.0082	0.1458	1.3715	24.2
60	28	Buses CNG > 6000 ccPost 2000	3.72	3.75	6.21	806.5								14.0
61	29	Trucks > 6000 cc1991-2000	19.3	2.63	13.84	837.5	1.965	0.0199	0.0175	0.0925	0.0197	0.1374	4.5975	11.0
62	30	Trucks > 6000 cc Post 2000	6	0.37	9.3	762.39	1.24	0.0049	0.0074	0.061	0	0.0837	3.9707	19.4
		Overall EF for Buses/Trucks Considered in this Study	**8.40652**	**1.12644**	**9.46756**	**718.38**	**0.82053**	**0.015265**	**0.0071685**	**0.04246**	**0.00819**	**0.084835**	**1.797668**	



Final Vehicular Emission Factors Used for the Study at Kanpur

S. No.	Particulars of the Traffic	Final Emission Factor (gm/km/vehicle)					Final Emission Factor (mg/km/vehicle)					
		CO	HC	NOx	CO2	PM	Benzene	1,3 Butadiene	Formal dehyde	Acetal dehyde	Total aldehyde	Total PAHs
1	Two Wheeler (2 W)	2.12937	0.94062	0.29286	24.7044	0.01753	0.005176	0.005265	0.004039	0.001253	0.009623	0.754117
2	Three Wheeler and tempoes (3 W)	2.72127	0.31787	0.64087	137.991	0.27977	0.015305	0.0050903	0.013832	0.005774	0.03026	0.977505
3	Passenger Cars and Jeeps (4 W)	1.81586	0.27966	0.50474	154.252	0.06996	0.023344	0.0099239	0.011749	0.001873	0.019947	0.348314
4	Light Commercial Vehicles (LCV)	3.3049	1.50696	2.42902	362.103	0.64284	0.265931	0.2629892	0.08262	0.008096	0.146454	6.610479
5	Heavy Duty vehicles (Buses/Trucks)	8.40652	1.12644	9.46756	718.38	0.82053	0.015265	0.0071685	0.04246	0.00819	0.084835	1.797668

Annexure I-2 – Emission Factors for Area Sources



Emission Factors Used for Area Source Inventory

S. No.	Description of Source	Emission Factor Used (g/kg or g/L)			
		PM_{10}	NOx	SO_2	CO
1	Garbage Burning	8	3	0.5	42
2	Medical Waste Incinerator	2.33	1.78	1.09	2.95
3	DG Set*	1.33	18.8	1.24	4.06
4	LPG used in Restaurant	2.1	1.8	0.4	0.252
5	Coal used in Restaurant	20	3.99	13.3	24.92
6	Wood used in Restaurant	5.04	1.4	0.48	31
7	Funeral Buring	5.04	1.4	0.48	31
8	Agricutural Waste Buring	11	0.49	0.12	58
9	LPG used as Domestic fuel	2.1	1.8	0.4	0.252
10	Coal used as Domestic fuel	16	3.99	13.3	24.92
11	Wood used as Domestic fuel	5.04	1.4	0.48	31
12	Kerosene used as Domestic fuel	0.61	2.5	4	62
	(* Unit is in g/KWh)				

Annexure II -Grid wise Emission Load from Area, Point and Line Sources

Emission Inventory for PM_{10} from various Sources

			Emission of PM_{10} from various Sources (kg/d)												
S. No.	**Grid Id**	**Land-use Pattern**	**Vehicles**	**Soil-Road Dust**	**Domestic Fuel**	**Garbage Burning**	**Restaurant & Halwai**	**Agricultural Waste burning**	**DG Sets**	**Medical-waste Incinerator**	**Funeral Burning**	**Construction & Demoliton**	**Industries (area source, H<25 m)**	**Industries (point source, H>25 m)**	**Total**
1	**KS-G-003**	Institutional	11.80	8.82	8.93	2.25	3.07		0.33			0.02			35.22
2	**KS-G-004**	Institutional	8.01	3.52	4.65	1.22	1.77		0.34	0.52		0.01			20.05
3	**KS-G-015**	Institutional	7.74	3.40	3.90	1.22	1.77		0.13			0.02			18.20
4	**KS-G-016**	Institutional	8.58	8.19	13.46	3.61	5.73		0.88			0.01			40.46
5	**KS-G-017**	Institutional	16.24	32.57	9.24	2.80	3.07		0.53			0.02			64.48
6	**KS-G-018**	Agricultural	18.01	16.22	5.27	1.07		11.98				0.02			52.58
7	**KS-G-019**	Agricultural	8.01	3.52	12.66	2.69		11.98				0.01			38.88
8	**KS-G-029**	Institutional	7.74	3.40	11.23	3.36	3.07		0.61			0.02			29.44
9	**KS-G-030**	Institutional	12.69	5.58	27.70	6.34	5.73		0.59			0.02			58.65
10	**KS-G-031**	Institutional	25.19	37.12	15.96	5.01	5.73		0.59			0.02			89.64
11	**KS-G-032**	Institutional	15.95	16.32	7.35	1.75	1.77		0.78			0.02			43.95
12	**KS-G-033**	Residential	21.89	19.64	32.29	5.67	9.25		0.73			0.02			89.49
13	**KS-G-034**	Institutional	15.18	6.67	12.05	2.96	5.73		0.86		4.29	0.02			47.77
14	**KS-G-035**	Residential	24.45	10.75	11.80	3.37	4.93		0.37		5.14	0.02			60.84
15	**KS-G-043**	Agricultural	10.64	4.68	1.58	0.53	0.00	11.98				0.01			29.41
16	**KS-G-044**	Agricultural	12.69	5.58	1.98	0.53	0.00	11.98				0.02			32.78
17	**KS-G-045**	Agricultural	21.55	19.54	22.37	4.53	0.00	11.98				0.02			79.99
18	**KS-G-046**	Residential	17.14	7.53	17.54	4.90	4.93		0.33			0.02			52.39
19	**KS-G-047**	Agricultural	28.85	17.97	5.45	0.99	0.00	11.98				0.02			65.25
20	**KS-G-048**	Residential	45.42	32.17	14.96	3.89	4.93		0.30	0.72		0.01	34.03	0.74	137.16
21	**KS-G-049**	Commercial	48.32	5.15	39.54	9.51	12.01		0.86		7.34	0.01			122.73
22	**KS-G-050**	Residential	41.95	22.42	49.20	12.90	9.25		0.33		6.59	0.01			142.65
23	**KS-G-051**	Residential	18.54	12.41	32.72	8.88	9.25		0.32		13.33	0.01			95.45
24	**KS-G-057**	Agricultural	14.78	11.26	9.72	1.87		11.98				0.01			49.62
25	**KS-G-058**	Agricultural	34.62	38.74	10.01	1.86		11.98				0.01			97.22
26	**KS-G-059**	Residential	34.63	27.35	33.50	9.46	9.25		0.35	1.11		0.01	41.30	2334.50	2491.46
27	**KS-G-060**	Residential	24.26	19.12	42.37	11.78	9.25		0.38			0.01			107.17
28	**KS-G-061**	Residential	21.62	18.06	46.96	16.72	9.25		0.30			0.01			112.92
29	**KS-G-062**	Residential	42.52	46.15	45.04	16.12	9.25		0.30			0.01			159.39
30	**KS-G-063**	Residential	69.11	17.84	25.28	6.91	4.93		0.30			0.01			124.38

			Emission of PM_{10} from various Sources (kg/d)												
S. No.	**Grid Id**	**Land-use Pattern**	**Vehicles**	**Soil-Road Dust**	**Domestic Fuel**	**Garbage Burning**	**Resturant & Halwai**	**Agricultural Waste burning**	**DG Sets**	**Medical-waste Incinerator**	**Funeral Burning**	**Construction & Demoliton**	**Industries (area source, H<25 m)**	**Industries (point source, H>25 m)**	**Total**
31	**KS-G-064**	Commercial	55.64	11.77	47.40	16.19	12.62		4.17			0.00	0.15		147.95
32	**KS-G-065**	Commercial	43.70	19.21	34.52	14.41	10.56		6.92		4.39	0.00	0.10		133.82
33	**KS-G-066**	Commercial	10.88	4.78	32.68	13.37	7.58		6.94		12.94	0.00			89.16
34	**KS-G-072**	Agricultural	11.01	9.60	24.22	4.75		11.98				0.00			61.56
35	**KS-G-073**	Agricultural	23.76	19.77	76.49	15.60		11.98				0.00			147.60
36	**KS-G-074**	Residential	25.67	20.02	57.36	18.14	9.25		0.32			0.00			130.77
37	**KS-G-075**	Industrial	59.82	77.24	27.80	8.48	5.86		6.82			0.00	234.28	7.93	428.23
38	**KS-G-076**	Industrial	32.43	14.26	22.21	7.36	4.90		5.56			0.08	205.44	33.29	325.52
39	**KS-G-077**	Industrial	33.41	25.37	31.79	10.62	5.86		7.49			0.08	28.59	5.40	148.63
40	**KS-G-078**	Industrial	44.11	54.91	37.05	12.24	5.86		6.86			0.08	57.89	1.19	220.19
41	**KS-G-079**	Residential	42.04	21.98	21.06	6.23	4.93		0.29			0.08			96.60
42	**KS-G-080**	Residential	19.74	8.68	22.22	5.99	4.93		0.30			0.08			61.95
43	**KS-G-081**	Residential	11.82	9.12	16.96	4.76	4.93		0.31			0.08			47.98
44	**KS-G-087**	Residential	9.99	8.22	38.79	9.07	4.93		0.32			0.08			71.40
45	**KS-G-088**	Industrial	10.00	8.18	44.02	15.01	5.86		6.08			0.08			89.24
46	**KS-G-089**	Residential	26.63	20.73	19.59	6.15			0.26			0.08			73.45
47	**KS-G-090**	Residential	45.41	29.74	25.31	7.76			0.26			0.08			108.57
48	**KS-G-091**	Residential	41.94	30.99	41.47	14.26	9.12		0.19			0.06	0.98		139.01
49	**KS-G-092**	Residential	21.87	9.61	25.40	7.87	7.05		0.20			0.06			72.05
50	**KS-G-093**	Residential	30.58	25.08	26.38	7.15	7.05		0.15			0.06			96.45
51	**KS-G-094**	Agricultural	23.71	15.50	10.15	1.89		11.98				0.06			63.29
52	**KS-G-095**	Residential	32.52	23.14	27.64	6.94	7.05		0.16			0.06			97.50
53	**KS-G-096**	Industrial	8.83	3.88	32.99	12.56			7.14			0.06	39.19	9.46	114.12
54	**KS-G-103**	Agricultural	10.48	4.61	22.24	7.51		11.98				0.06			56.88
55	**KS-G-104**	Agricultural	25.05	19.08	30.78	6.03		11.98				0.06			92.98
56	**KS-G-105**	Residential	34.42	22.32	33.20	8.87			0.20			0.06			99.07
57	**KS-G-106**	Residential	29.35	22.15	17.82	5.24			0.22			0.06			74.84
58	**KS-G-107**	Protected													
59	**KS-G-108**	Residential	35.01	64.69	21.92	6.43	7.25		7.80			0.08	6.97	1.87	152.01
60	**KS-G-109**	Residential	22.26	14.83	18.11	5.00	6.37		0.22			0.08			66.87

			Emission of PM_{10} from various Sources (kg/d)												
S. No.	Grid Id	Land-use Pattern	Vehicles	Soil-Road Dust	Domestic Fuel	Garbage Burning	Restaurant & Halwai	Agricultural Waste burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Construction & Demoliton	Industries (area source, H<25 m)	Industries (point source, H>25 m)	Total
61	**KS-G-110**	Residential	19.30	8.48	18.95	5.40	6.37		0.17			0.08			58.75
62	**KS-G-111**	Protected													
63	**KS-G-117**	Residential	11.61	8.89	22.67	5.77	6.37		0.20			0.08			55.60
64	**KS-G-118**	Residential	26.98	20.71	32.86	6.71	6.37		0.20			0.08			93.91
65	**KS-G-119**	Residential	15.82	6.95	25.92	5.31	6.37		0.20			0.08			60.65
66	**KS-G-120**	Residential	16.51	7.26	28.16	5.78	6.37		0.14			0.08			64.30
67	**KS-G-121**	Agricultural	17.56	7.72	10.62	1.54		11.98							49.43
68	**KS-G-122**	Agricultural	15.55	6.84	11.85	1.73		11.98							47.94
69	**KS-G-123**	Agricultural	28.53	23.66	5.22	0.77		11.98							70.16
70	**KS-G-124**	Protected													
71	**KS-G-125**	Agricultural	26.63	11.71	10.88	1.62		11.98							62.80
72	**KS-G-126**	Agricultural	13.73	6.03	10.71	1.54		11.98							43.98
73	**KS-G-131**	Residential	8.83	3.88	22.81	4.16	7.05		0.14			0.08			46.96
74	**KS-G-132**	Agricultural	26.07	20.36	5.15	0.75		11.98							64.32
75	**KS-G-133**	Agricultural	8.98	3.95	11.73	1.74		11.98							38.38
76	**KS-G-135**	Agricultural	11.31	4.97	5.16	0.77		11.98							34.18
77	**KS-G-136**	Agricultural	19.89	12.27	5.19	0.76		11.98							50.09
78	**KS-G-137**	Agricultural	28.46	16.05	5.31	0.77		11.98							62.58
79	**KS-G-138**	Agricultural	24.09	21.33	5.12	0.76		11.98							63.28
80	**KS-G-139**	Agricultural	10.66	4.69	11.75	1.76		11.98							40.83
81	**KS-G-140**	Agricultural	12.67	9.10	5.16	0.80		11.98							39.71
82	**KS-G-150**	Agricultural	11.46	5.04	5.19	0.79		11.98							34.45
83	**KS-G-151**	Agricultural	18.86	12.28	23.49	3.32		11.98							69.93
84	**KS-G-152**	Agricultural	20.77	20.14	5.24	0.75		11.98							58.88
85	**KS-G-153**	Agricultural	13.18	9.78	11.65	1.74		11.98							48.33
	Total in the City		**1917.63**	**1353.29**	**1763.10**	**475.61**	**304.85**	**359.33**	**80.75**	**2.35**	**54.03**	**2.52**	**648.92**	**2394.39**	**9356.78**

Emission Inventory for NO_X from various Sources

		Emission of NO_X from various Sources (kg/day)											
S. No.	Grid Id	Land-use Pattern	Vehicles	Domestic Fuels	Garbage Burning	Restaurant & Halwai	Agricultural Waste burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Industries (area source, H<25 m)	Industries (point source, H>25 m)	Total
1	**KS-G-003**	Institutional	66.18	4.61	0.84	0.77		4.61					77.01
2	**KS-G-004**	Institutional	41.60	2.35	0.46	0.43		4.81	0.40				50.06
3	**KS-G-015**	Institutional	40.21	2.11	0.46	0.43		1.88					45.09
4	**KS-G-016**	Institutional	46.49	6.98	1.35	1.45		12.37					68.64
5	**KS-G-017**	Institutional	106.04	4.96	1.05	0.77		7.48					120.31
6	**KS-G-018**	Agricultural	104.77	2.64	0.40	0.00	0.53						108.34
7	**KS-G-019**	Agricultural	41.60	6.41	1.01	0.00	0.53						49.55
8	**KS-G-029**	Institutional	40.21	6.07	1.26	0.77		8.61					56.92
9	**KS-G-030**	Institutional	65.88	13.98	2.38	1.45		8.33					92.01
10	**KS-G-031**	Institutional	154.87	8.93	1.88	1.45		8.38					175.51
11	**KS-G-032**	Institutional	95.48	3.73	0.65	0.43		11.07					111.37
12	**KS-G-033**	Residential	123.44	15.64	2.13	2.39		10.34					153.93
13	**KS-G-034**	Institutional	78.80	6.14	1.11	1.45		12.13		1.19			100.82
14	**KS-G-035**	Residential	126.93	6.01	1.26	1.25		5.23		1.43			142.11
15	**KS-G-043**	Agricultural	55.24	0.85	0.20	0.00	0.53						56.82
16	**KS-G-044**	Agricultural	65.88	1.00	0.20	0.00	0.53						67.61
17	**KS-G-045**	Agricultural	125.54	11.19	1.70	0.00	0.53						138.96
18	**KS-G-046**	Residential	88.96	8.77	1.84	1.25		4.61					105.43
19	**KS-G-047**	Agricultural	156.95	2.62	0.37	0.00	0.53						160.48
20	**KS-G-048**	Residential	252.61	7.46	1.46	1.25		4.21	0.55		15.37	2.55	285.47
21	**KS-G-049**	Commercial	227.51	19.76	3.57	3.10		12.18		2.04			268.15
22	**KS-G-050**	Residential	223.18	24.31	4.84	2.39		4.68		1.83			261.23
23	**KS-G-051**	Residential	102.03	16.34	3.33	2.39		4.46		3.70			132.25
24	**KS-G-057**	Agricultural	83.21	4.81	0.70	0.00	0.53						89.25
25	**KS-G-058**	Agricultural	211.71	4.90	0.70	0.00	0.53						217.84
26	**KS-G-059**	Residential	196.27	16.82	3.55	2.39		4.96	0.85		40.19	8099.70	8364.72
27	**KS-G-060**	Residential	137.45	21.26	4.42	2.39		5.36					170.87
28	**KS-G-061**	Residential	123.86	24.57	6.27	2.39		4.31					161.40
29	**KS-G-062**	Residential	261.17	23.14	6.05	2.39		4.25					296.99
30	**KS-G-063**	Residential	339.70	12.43	2.59	1.25		4.21					360.18

		Emission of NO_X from various Sources (kg/day)											
S. No.	Grid Id	Land-use Pattern	Vehicles	Domestic Fuels	Garbage Burning	Restaurant & Halwai	Agricultural Waste burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Industries (area source, H<25 m)	Industries (point source, H>25 m)	Total
31	**KS-G-064**	Commercial	266.65	23.63	6.07	3.35		59.01			0.19		358.89
32	**KS-G-065**	Commercial	226.87	18.21	5.40	2.81		97.88		1.22	0.13		352.51
33	**KS-G-066**	Commercial	56.47	16.81	5.01	2.07		98.10		3.60			182.05
34	**KS-G-072**	Agricultural	63.61	11.74	1.78	0.00	0.53						77.67
35	**KS-G-073**	Agricultural	136.03	37.44	5.85	0.00	0.53						179.85
36	**KS-G-074**	Residential	145.12	29.29	6.80	2.39		4.57					188.17
37	**KS-G-075**	Industrial	368.62	13.69	3.18	1.52		96.35			227.74	56.66	767.75
38	**KS-G-076**	Industrial	168.34	11.05	2.76	1.25		78.55			232.82	112.36	607.12
39	**KS-G-077**	Industrial	187.98	15.81	3.98	1.52		105.92			106.41	58.71	480.33
40	**KS-G-078**	Industrial	273.05	18.25	4.59	1.52		96.93			393.20	4.56	792.10
41	**KS-G-079**	Residential	222.99	10.83	2.33	1.25		4.10					241.51
42	**KS-G-080**	Residential	102.51	11.23	2.25	1.25		4.27					121.50
43	**KS-G-081**	Residential	66.67	8.72	1.79	1.25		4.42					82.85
44	**KS-G-087**	Residential	57.07	18.84	3.40	1.25		4.47					85.03
45	**KS-G-088**	Industrial	57.06	21.90	5.63	1.52		85.88					171.99
46	**KS-G-089**	Residential	150.53	10.34	2.31	0.00		3.68					166.86
47	**KS-G-090**	Residential	249.04	13.27	2.91	0.00		3.65					268.87
48	**KS-G-091**	Residential	234.16	22.77	5.35	2.33		2.74			11.53		278.88
49	**KS-G-092**	Residential	113.52	13.43	2.95	1.76		2.78					134.44
50	**KS-G-093**	Residential	174.55	13.21	2.68	1.76		2.18					194.38
51	**KS-G-094**	Agricultural	130.01	4.91	0.71	0.00	0.53						136.16
52	**KS-G-095**	Residential	180.87	13.37	2.60	1.76		2.24					200.84
53	**KS-G-096**	Industrial	45.86	16.89	4.71	0.00		100.92			105.71	72.60	346.68
54	**KS-G-103**	Agricultural	54.41	11.02	2.82	0.00	0.53						68.78
55	**KS-G-104**	Agricultural	141.02	15.10	2.26	0.00	0.53						158.91
56	**KS-G-105**	Residential	188.47	16.62	3.33	0.00		2.88					211.29
57	**KS-G-106**	Residential	164.95	9.12	1.97	0.00		3.16					179.19
58	**KS-G-107**	Protected											
59	**KS-G-108**	Residential	224.38	11.35	2.41	1.85		110.27			80.84	6.48	437.59
60	**KS-G-109**	Residential	122.42	9.21	1.87	1.63		3.16					138.29

			Emission of NO_X from various Sources (kg/day)										
S. No.	**Grid Id**	**Land-use Pattern**	**Vehicles**	**Domestic Fuels**	**Garbage Burning**	**Restaurant & Halwai**	**Agricultural Waste burning**	**DG Sets**	**Medical-waste Incinerator**	**Funeral Burning**	**Industries (area source, H<25 m)**	**Industries (point source, H>25 m)**	**Total**
61	**KS-G-110**	Residential	100.19	9.75	2.02	1.63		2.37					115.96
62	**KS-G-111**	Protected											
63	**KS-G-117**	Residential	65.44	11.36	2.17	1.63		2.80					83.39
64	**KS-G-118**	Residential	152.10	14.37	2.52	1.63		2.80					173.41
65	**KS-G-119**	Residential	82.12	11.36	1.99	1.63		2.90					100.00
66	**KS-G-120**	Residential	85.69	12.31	2.17	1.63		2.03					103.82
67	**KS-G-121**	Agricultural	91.17	4.62	0.58	0.00	0.53						96.91
68	**KS-G-122**	Agricultural	80.73	5.14	0.65	0.00	0.53						87.05
69	**KS-G-123**	Agricultural	163.24	2.26	0.29	0.00	0.53						166.32
70	**KS-G-124**	Protected											
71	**KS-G-125**	Agricultural	138.23	4.73	0.61	0.00	0.53						144.10
72	**KS-G-126**	Agricultural	71.26	4.67	0.58	0.00	0.53						77.04
73	**KS-G-131**	Residential	45.86	9.99	1.56	1.76		2.03					61.20
74	**KS-G-132**	Agricultural	147.46	2.26	0.28	0.00	0.53						150.53
75	**KS-G-133**	Agricultural	46.64	5.13	0.65	0.00	0.53						52.95
76	**KS-G-135**	Agricultural	58.69	2.26	0.29	0.00	0.53						61.77
77	**KS-G-136**	Agricultural	108.05	2.27	0.29	0.00	0.53						111.14
78	**KS-G-137**	Agricultural	152.57	2.32	0.29	0.00	0.53						155.72
79	**KS-G-138**	Agricultural	139.67	2.24	0.29	0.00	0.53						142.74
80	**KS-G-139**	Agricultural	55.33	5.16	0.66	0.00	0.53						61.68
81	**KS-G-140**	Agricultural	70.57	2.26	0.30	0.00	0.53						73.66
82	**KS-G-150**	Agricultural	59.47	2.27	0.30	0.00	0.53						62.57
83	**KS-G-151**	Agricultural	103.32	10.21	1.25	0.00	0.53						115.31
84	**KS-G-152**	Agricultural	122.77	2.29	0.28	0.00	0.53						125.87
85	**KS-G-153**	Agricultural	73.83	5.11	0.65	0.00	0.53						80.12
	Total in the City		**10571.37**	**873.17**	**178.35**	**78.13**	**78.13**	**1141.49**	**1.80**	**15.01**	**1214.11**	**8413.62**	**22503.07**

Emission Inventory for SO_2 from various Sources

			Emission of SO_2 from Various Sources (kg/day)										
S. No.	Grid Id	Land-use Pattern	Vehicles	Domestic Fuels	Garbage Burning	Restaurant & Halwai	Agricultural Waste Burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Industries (area source, H<25 m)	Industries (Point source, H>25 m)	Total
1	**KS-G-003**	Institutional	2.99	5.40	0.14	1.70		0.30					10.53
2	**KS-G-004**	Institutional	2.01	2.87	0.08	0.97		0.32	0.25				6.49
3	**KS-G-015**	Institutional	1.94	2.24	0.08	0.97		0.12					5.36
4	**KS-G-016**	Institutional	2.12	8.11	0.23	3.20		0.82					14.47
5	**KS-G-017**	Institutional	4.07	5.36	0.18	1.70		0.49					11.80
6	**KS-G-018**	Agricultural	4.59	3.29	0.07	0.00	0.13						8.08
7	**KS-G-019**	Agricultural	2.01	7.82	0.17	0.00	0.13						10.13
8	**KS-G-029**	Institutional	1.94	6.47	0.21	1.70		0.57					10.88
9	**KS-G-030**	Institutional	3.18	17.16	0.40	3.20		0.55					24.48
10	**KS-G-031**	Institutional	6.33	8.83	0.31	3.20		0.55					19.22
11	**KS-G-032**	Institutional	4.09	4.54	0.11	0.97		0.73					10.43
12	**KS-G-033**	Residential	5.51	20.80	0.35	4.92		0.68					32.26
13	**KS-G-034**	Institutional	3.81	7.40	0.19	3.20		0.80		0.41			15.79
14	**KS-G-035**	Residential	6.13	7.24	0.21	2.66		0.34		0.49			17.08
15	**KS-G-043**	Agricultural	2.67	0.91	0.03	0.00	0.13						3.74
16	**KS-G-044**	Agricultural	3.18	1.22	0.03	0.00	0.13						4.57
17	**KS-G-045**	Agricultural	5.50	13.98	0.28	0.00	0.13						19.89
18	**KS-G-046**	Residential	4.30	10.96	0.31	2.66		0.30					18.52
19	**KS-G-047**	Agricultural	7.28	3.52	0.06	0.00	0.13						11.00
20	**KS-G-048**	Residential	11.54	9.37	0.24	2.66		0.28	0.34		30.91	0.61	55.94
21	**KS-G-049**	Commercial	12.78	24.73	0.59	6.57		0.80		0.70			46.17
22	**KS-G-050**	Residential	10.55	31.11	0.81	4.92		0.31		0.63			48.32
23	**KS-G-051**	Residential	4.69	20.49	0.56	4.92		0.29		1.27			32.21
24	**KS-G-057**	Agricultural	3.75	6.14	0.12	0.00	0.13						10.14
25	**KS-G-058**	Agricultural	8.90	6.39	0.12	0.00	0.13						15.53
26	**KS-G-059**	Residential	8.80	20.85	0.59	4.92		0.33	0.52		36.39	1928.50	2000.90
27	**KS-G-060**	Residential	6.16	26.40	0.74	4.92		0.35					38.57
28	**KS-G-061**	Residential	5.50	28.03	1.04	4.92		0.28					39.77
29	**KS-G-062**	Residential	10.10	27.40	1.01	4.92		0.28					43.70
30	**KS-G-063**	Residential	18.38	16.05	0.43	2.66		0.28					37.80

			Emission of SO_2 from Various Sources (kg/day)										
S. No.	**Grid Id**	**Land-use Pattern**	**Vehicles**	**Domestic Fuels**	**Garbage Burning**	**Restaurant & Halwai**	**Agricultural Waste Burning**	**DG Sets**	**Medical-waste Incinerator**	**Funeral Burning**	**Industries (area source, H<25 m)**	**Industries (Point source, H>25 m)**	**Total**
31	**KS-G-064**	Commercial	14.89	29.72	1.01	6.93		3.89			0.30		56.74
32	**KS-G-065**	Commercial	10.96	20.42	0.90	5.87		6.46		0.42	0.20		45.22
33	**KS-G-066**	Commercial	2.73	19.86	0.84	4.20		6.47		1.23			35.32
34	**KS-G-072**	Agricultural	2.80	15.58	0.30	0.00	0.13						18.81
35	**KS-G-073**	Agricultural	6.04	48.80	0.97	0.00	0.13						55.95
36	**KS-G-074**	Residential	6.52	35.12	1.13	4.92		0.30					47.98
37	**KS-G-075**	Industrial	15.11	17.64	0.53	3.21		6.36			99.71	6.49	149.04
38	**KS-G-076**	Industrial	8.13	13.95	0.46	2.72		5.18			143.13	27.50	201.07
39	**KS-G-077**	Industrial	8.48	19.97	0.66	3.21		6.99			20.17	4.38	63.86
40	**KS-G-078**	Industrial	10.63	23.50	0.76	3.21		6.39			51.58	0.99	97.07
41	**KS-G-079**	Residential	10.57	12.79	0.39	2.66		0.27					26.68
42	**KS-G-080**	Residential	4.95	13.74	0.37	2.66		0.28					22.00
43	**KS-G-081**	Residential	3.00	10.30	0.30	2.66		0.29					16.55
44	**KS-G-087**	Residential	2.54	24.93	0.57	2.66		0.30					30.98
45	**KS-G-088**	Industrial	2.54	27.66	0.94	3.21		5.66					40.01
46	**KS-G-089**	Residential	6.76	11.58	0.38	0.00		0.24					18.97
47	**KS-G-090**	Residential	11.48	15.07	0.49	0.00		0.24					27.27
48	**KS-G-091**	Residential	10.41	23.45	0.89	4.90		0.18			0.91		40.75
49	**KS-G-092**	Residential	5.48	14.99	0.49	3.89		0.18					25.04
50	**KS-G-093**	Residential	7.77	16.48	0.45	3.89		0.14					28.73
51	**KS-G-094**	Agricultural	5.99	6.54	0.12	0.00	0.13						12.79
52	**KS-G-095**	Residential	8.24	17.82	0.43	3.89		0.15					30.53
53	**KS-G-096**	Industrial	2.21	20.15	0.79	0.00		6.66			31.31	9.78	70.90
54	**KS-G-103**	Agricultural	2.63	14.03	0.47	0.00	0.13						17.26
55	**KS-G-104**	Agricultural	6.36	19.60	0.38	0.00	0.13						26.46
56	**KS-G-105**	Residential	8.70	20.73	0.55	0.00		0.19					30.17
57	**KS-G-106**	Residential	7.44	10.88	0.33	0.00		0.21					18.86
58	**KS-G-107**	Protected											
59	**KS-G-108**	Residential	8.63	13.23	0.40	4.00		7.27			14.78	1.54	49.85
60	**KS-G-109**	Residential	5.63	11.13	0.31	3.55		0.21					20.83

			Emission of SO_2 from Various Sources (kg/day)										
S. No.	**Grid Id**	**Land-use Pattern**	**Vehicles**	**Domestic Fuels**	**Garbage Burning**	**Restaurant & Halwai**	**Agricultural Waste Burning**	**DG Sets**	**Medical-waste Incinerator**	**Funeral Burning**	**Industries (area source, H<25 m)**	**Industries (Point source, H>25 m)**	**Total**
61	**KS-G-110**	Residential	4.84	11.51	0.34	3.55		0.16					20.39
62	**KS-G-111**	Protected											
63	**KS-G-117**	Residential	2.95	14.14	0.36	3.55		0.18					21.18
64	**KS-G-118**	Residential	6.85	13.98	0.42	3.55		0.18					24.98
65	**KS-G-119**	Residential	3.97	11.65	0.33	3.55		0.19					19.68
66	**KS-G-120**	Residential	4.14	12.39	0.36	3.55		0.13					20.57
67	**KS-G-121**	Agricultural	4.40	5.26	0.10	0.00	0.13						9.89
68	**KS-G-122**	Agricultural	3.90	5.84	0.11	0.00	0.13						9.97
69	**KS-G-123**	Agricultural	7.26	2.54	0.05	0.00	0.13						9.97
70	**KS-G-124**	Protected											
71	**KS-G-125**	Agricultural	6.68	5.55	0.10	0.00	0.13						12.46
72	**KS-G-126**	Agricultural	3.44	5.36	0.10	0.00	0.13						9.03
73	**KS-G-131**	Residential	2.21	11.18	0.26	3.89		0.13					17.68
74	**KS-G-132**	Agricultural	6.62	2.57	0.05	0.00	0.13						9.37
75	**KS-G-133**	Agricultural	2.25	5.83	0.11	0.00	0.13						8.32
76	**KS-G-135**	Agricultural	2.83	2.53	0.05	0.00	0.13						5.55
77	**KS-G-136**	Agricultural	5.02	2.58	0.05	0.00	0.13						7.78
78	**KS-G-137**	Agricultural	7.17	2.80	0.05	0.00	0.13						10.15
79	**KS-G-138**	Agricultural	6.14	2.53	0.05	0.00	0.13						8.85
80	**KS-G-139**	Agricultural	2.67	6.12	0.11	0.00	0.13						9.04
81	**KS-G-140**	Agricultural	3.21	2.53	0.05	0.00	0.13						5.92
82	**KS-G-150**	Agricultural	2.87	2.58	0.05	0.00	0.13						5.63
83	**KS-G-151**	Agricultural	4.77	11.99	0.21	0.00	0.13						17.10
84	**KS-G-152**	Agricultural	5.31	2.63	0.05	0.00	0.13						8.11
85	**KS-G-153**	Agricultural	3.34	5.82	0.11	0.00	0.13						9.40
	Total in the City		**485.25**	**1054.67**	**29.73**	**166.24**	**3.92**	**75.29**	**1.10**	**5.15**	**429.40**	**1979.79**	**4230.52**

Emission Inventory for CO from various Sources

			Emission of CO from Various Sources (kg/day)										
S. No.	Grid Id	Land-use Pattern	Vehicles	Domestic Fuels	Garbage Burning	Restaurant & Halwai	Agricultural Waste Burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Industries (area source, H<25 m)	Industries (point source, H>25 m)	Total
1	**KS-G-003**	Institutional	192.64	37.70	11.82	5.08		0.99					248.23
2	**KS-G-004**	Institutional	144.12	20.21	6.41	3.00		1.04	0.66				175.44
3	**KS-G-015**	Institutional	139.28	15.33	6.43	3.00		0.41					164.44
4	**KS-G-016**	Institutional	135.39	56.48	18.93	9.19		2.67					222.66
5	**KS-G-017**	Institutional	221.35	36.75	14.72	5.08		1.62					279.52
6	**KS-G-018**	Agricultural	279.27	23.30	5.63	0.00	63.16						371.36
7	**KS-G-019**	Agricultural	144.12	55.02	14.11	0.00	63.16						276.41
8	**KS-G-029**	Institutional	139.28	44.15	17.63	5.08		1.86					208.00
9	**KS-G-030**	Institutional	228.21	120.90	33.29	9.19		1.80					393.39
10	**KS-G-031**	Institutional	363.70	59.16	26.32	9.19		1.81					460.19
11	**KS-G-032**	Institutional	236.98	31.90	9.17	3.00		2.39					283.44
12	**KS-G-033**	Residential	350.74	148.85	29.75	16.10		2.23					547.68
13	**KS-G-034**	Institutional	272.98	51.93	15.54	9.19		2.62		26.41			378.68
14	**KS-G-035**	Residential	439.70	50.86	17.69	8.50		1.13		31.62			549.50
15	**KS-G-043**	Agricultural	191.34	6.19	2.78	0.00	63.16						263.48
16	**KS-G-044**	Agricultural	228.21	8.63	2.79	0.00	63.16						302.78
17	**KS-G-045**	Agricultural	333.46	98.86	23.79	0.00	63.16						519.26
18	**KS-G-046**	Residential	308.18	77.51	25.71	8.50		0.99					420.90
19	**KS-G-047**	Agricultural	490.41	25.26	5.19	0.00	63.16						584.03
20	**KS-G-048**	Residential	756.97	66.33	20.44	8.50		0.91	0.91		45.60	15.94	915.59
21	**KS-G-049**	Commercial	996.81	174.89	49.91	19.74		2.63		45.14			1289.12
22	**KS-G-050**	Residential	733.03	220.96	67.70	16.10		1.01		40.55			1079.36
23	**KS-G-051**	Residential	310.58	144.95	46.62	16.10		0.96		81.96			601.17
24	**KS-G-057**	Agricultural	240.27	43.61	9.82	0.00	63.16						356.86
25	**KS-G-058**	Agricultural	496.47	45.53	9.77	0.00	63.16						614.93
26	**KS-G-059**	Residential	557.74	147.22	49.67	16.10		1.07	1.40		105.21	507.50	1385.91
27	**KS-G-060**	Residential	391.04	186.47	61.83	16.10		1.16					656.60
28	**KS-G-061**	Residential	342.90	194.43	87.76	16.10		0.93					642.12
29	**KS-G-062**	Residential	713.49	191.64	84.64	16.10		0.92					1006.79
30	**KS-G-063**	Residential	1255.76	114.20	36.29	8.50		0.91			4.65		1420.31

			Emission of CO from Various Sources (kg/day)										
S. No.	Grid Id	Land-use Pattern	Vehicles	Domestic Fuels	Garbage Burning	Restaurant & Halwai	Agricultural Waste Burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Industries (area source, H<25 m)	Industries (point source, H>25 m)	Total
31	**KS-G-064**	Commercial	1029.02	210.38	85.00	19.92		12.74			3.10		1360.16
32	**KS-G-065**	Commercial	785.89	141.18	75.66	16.17		21.14		27.03			1067.06
33	**KS-G-066**	Commercial	195.61	138.79	70.18	11.29		21.19		79.61			516.67
34	**KS-G-072**	Agricultural	172.38	111.45	24.95	0.00	63.16						371.93
35	**KS-G-073**	Agricultural	377.33	347.84	81.88	0.00	63.16						870.20
36	**KS-G-074**	Residential	414.68	246.23	95.23	16.10		0.99					773.22
37	**KS-G-075**	Industrial	823.25	125.47	44.52	9.51		20.81			1050.53	113.19	2187.28
38	**KS-G-076**	Industrial	583.14	98.86	38.63	7.85		16.96			287.53	719.23	1752.20
39	**KS-G-077**	Industrial	543.59	141.50	55.78	9.51		22.87			51.73	36.71	861.69
40	**KS-G-078**	Industrial	714.70	167.14	64.25	9.51		20.93			174.06	25.02	1175.61
41	**KS-G-079**	Residential	737.26	89.42	32.68	8.50		0.89					868.75
42	**KS-G-080**	Residential	355.09	96.75	31.44	8.50		0.92					492.70
43	**KS-G-081**	Residential	191.43	72.02	24.99	8.50		0.95					297.89
44	**KS-G-087**	Residential	159.10	178.18	47.59	8.50		0.97					394.34
45	**KS-G-088**	Industrial	159.53	195.96	78.80	9.51		18.55					462.34
46	**KS-G-089**	Residential	430.53	80.01	32.28	0.00		0.80					543.62
47	**KS-G-090**	Residential	764.21	104.45	40.76	0.00		0.79					910.20
48	**KS-G-091**	Residential	692.47	158.89	74.84	15.63		0.59			5.56		947.98
49	**KS-G-092**	Residential	393.26	103.54	41.31	11.69		0.60					550.39
50	**KS-G-093**	Residential	487.50	116.46	37.54	11.69		0.47					653.65
51	**KS-G-094**	Agricultural	399.26	46.84	9.93	0.00	63.16						519.18
52	**KS-G-095**	Residential	537.50	127.55	36.42	11.69		0.48					713.65
53	**KS-G-096**	Industrial	158.85	141.14	65.96	0.00		21.79			63.22	195.48	646.44
54	**KS-G-103**	Agricultural	188.48	99.56	39.45	0.00	63.16						390.64
55	**KS-G-104**	Agricultural	407.26	139.61	31.65	0.00	63.16						641.67
56	**KS-G-105**	Residential	580.50	146.54	46.55	0.00		0.62					774.21
57	**KS-G-106**	Residential	478.23	76.22	27.52	0.00		0.68					582.65
58	**KS-G-107**	Protected											
59	**KS-G-108**	Residential	482.91	92.20	33.75	11.78		23.81			23.31	40.46	708.23
60	**KS-G-109**	Residential	373.22	78.16	26.24	10.14		0.68					488.45

			Emission of CO from Various Sources (kg/day)										
S. No.	Grid Id	Land-use Pattern	Vehicles	Domestic Fuels	Garbage Burning	Restaurant & Halwai	Agricultural Waste Burning	DG Sets	Medical-waste Incinerator	Funeral Burning	Industries (area source, H<25 m)	Industries (point source, H>25 m)	Total
61	**KS-G-110**	Residential	347.07	80.43	28.34	10.14		0.51					466.48
62	**KS-G-111**	Protected											
63	**KS-G-117**	Residential	188.53	99.90	30.32	10.14		0.60					329.49
64	**KS-G-118**	Residential	437.72	159.36	35.24	10.14		0.60					643.07
65	**KS-G-119**	Residential	284.49	126.12	27.90	10.14		0.63					449.27
66	**KS-G-120**	Residential	296.83	137.09	30.35	10.14		0.44					474.83
67	**KS-G-121**	Agricultural	315.83	52.68	8.11	0.00	63.16						439.78
68	**KS-G-122**	Agricultural	279.65	58.84	9.07	0.00	63.16						410.71
69	**KS-G-123**	Agricultural	453.54	25.87	4.05	0.00	63.16						546.61
70	**KS-G-124**	Protected											
71	**KS-G-125**	Agricultural	478.85	54.14	8.49	0.00	63.16						604.64
72	**KS-G-126**	Agricultural	246.85	53.03	8.07	0.00	63.16						371.11
73	**KS-G-131**	Residential	158.85	112.15	21.84	11.69		0.44					304.97
74	**KS-G-132**	Agricultural	421.16	25.39	3.94	0.00	63.16						513.64
75	**KS-G-133**	Agricultural	161.56	57.88	9.15	0.00	63.16						291.75
76	**KS-G-135**	Agricultural	203.32	25.43	4.03	0.00	63.16						295.93
77	**KS-G-136**	Agricultural	338.81	25.60	3.99	0.00	63.16						431.56
78	**KS-G-137**	Agricultural	492.86	26.44	4.05	0.00	63.16						586.50
79	**KS-G-138**	Agricultural	375.73	25.16	4.01	0.00	63.16						468.06
80	**KS-G-139**	Agricultural	191.66	58.07	9.23	0.00	63.16						322.12
81	**KS-G-140**	Agricultural	208.96	25.43	4.21	0.00	63.16						301.76
82	**KS-G-150**	Agricultural	206.03	25.60	4.16	0.00	63.16						298.94
83	**KS-G-151**	Agricultural	317.76	116.93	17.44	0.00	63.16						515.29
84	**KS-G-152**	Agricultural	314.45	25.98	3.94	0.00	63.16						407.52
85	**KS-G-153**	Agricultural	215.57	57.41	9.15	0.00	63.16						345.28
	Total in the City		**32186.68**	**7826.47**	**2496.97**	**505.82**	**1894.67**	**246.51**	**2.98**	**332.32**	**1814.49**	**1653.53**	**48960.44**

AIII-1: SOP for Speciation Sampler Model 2300

Application and Description of the Equipment

The Partisol® Model 2300 Speciation Sampler is a 4-channel sampling platform for particulate matter-related and gaseous species. Four flow channels can be operated simultaneously, each at a flow rate of up to 16.7 l/min (~1 m^3/h) to achieve thermodynamic conditions comparable with $PM_{2.5}$ FRM samplers. This also allows more material to be collected on each 47 mm filter for analysis than at lower flow rates. Active volumetric flow control maintains a constant volumetric flow rate specified by the user by incorporating four mass flow controllers and ambient temperature and pressure sensors. Sampled volumes are reported in either volumetric or standard terms. Flow rate set points can be defined by channel at a range of 5 to 18 l/ min (16.7 l/ min default).

	Flow Rate (liter per minute)	
Filter paper	**For $PM_{2.5}$**	**For PM_{10}**
PTFE filter paper	16.7	16.7
Nylon filter paper	10	16.7
Quartz filter paper	10	16.7

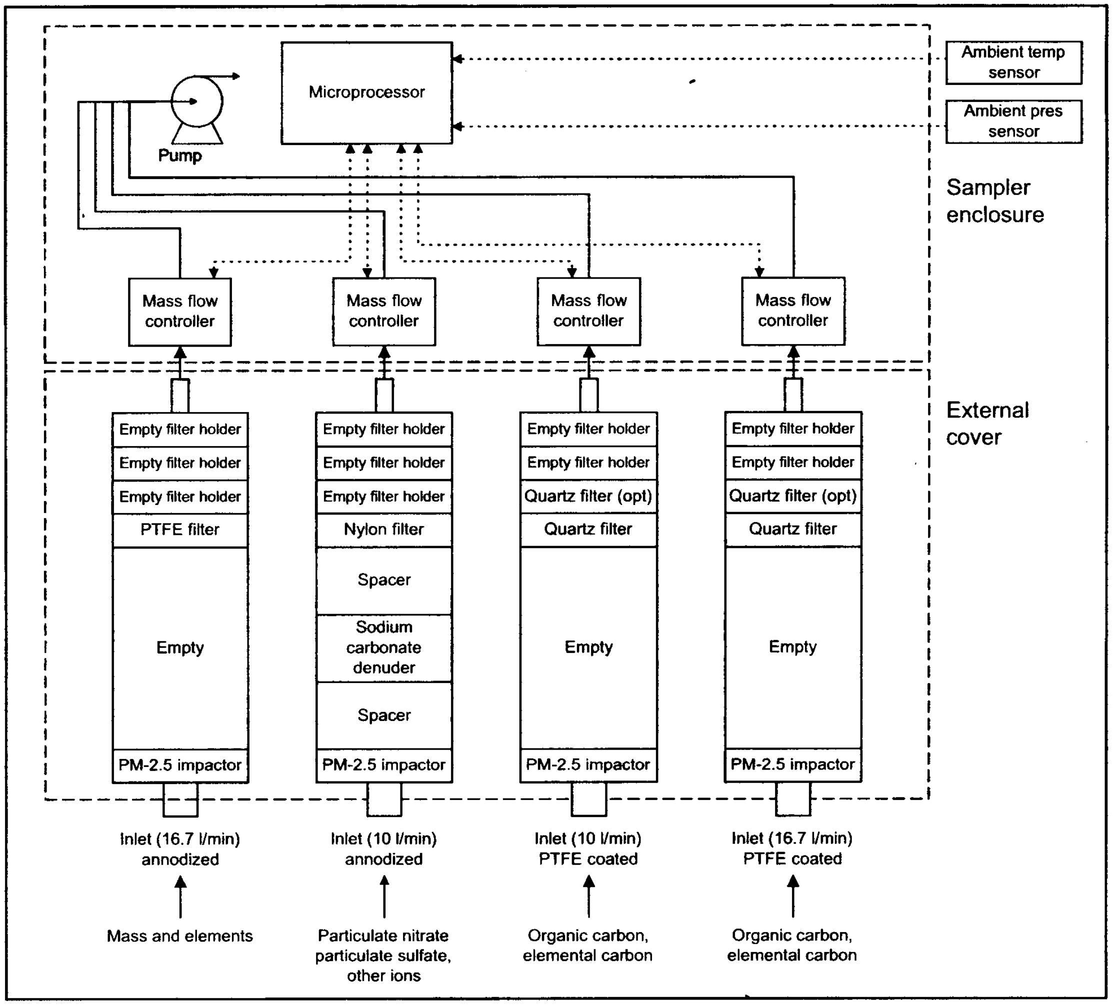
Three types of internal data storage as follows:

- *Interval Data* stored every 5 minutes contain averaged ambient temperature, ambient pressure, and sample flow rates.
- *Filter Data* contain a set of values related to each speciation cartridge exposed, including sampled Volumes (in standard or volumetric terms), averaged meteorological data, error condition flagging and power outage time stamps.
- *Input Data* are stored at a user-defined interval and include averages of meteorological data and inputs from external sources and operating information. If an optional wind vane/anemometer is connected to the sampler, each input data record contains the average wind speed, and vector-based averages of wind velocity and direction. The default averaging and storage interval is 30 minutes.

Bidirectional RS232 communication allows current operating data, interval data, filter data and input data to be downloaded. Standard equipment includes a 9-to-9 pin cable for linking the sampler to a personal computer (PC), and basic communication software.

Principle

4-channel speciation sampler gives out for determining the concentration of suspended particulate, Indoors as well as outdoors. The particles sampled on the filter can be gravimetrically evaluated and also analyzed. With regards to dust components e.g. metals, ions (sulphate, nitrate), OC/EC and other ions. The air sample is drawn in through the inlet by a vacuum pump. The air flow rate is measured by an orifice plate installed between the filter and the vacuum pump. The sampled air then flows from the pump, through a separator for the abrasive carbon dust of pump’s vanes, to the outlet in device.



Flow Schematic for Partisol Model 2300 Speciation Sampler

Lab Equipment and Facilities

The following equipment and materials are required for chem-comb cartridge preparation and honeycomb (HC) denuder cleaning, coating and extraction:

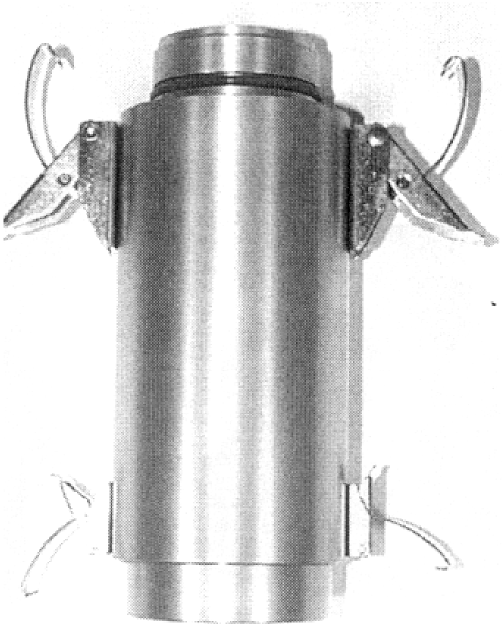
- Ultra-pure water system (18 mega Ohm resistance)
- Acid gas, ammonia and particle-free clean-air source
- Clean-air (acid gas, ammonia and particle-free), positive-pressure hood or glove box
- Lab balance (sensitivity: 0.001 mg)
- Calibrated automatic and dispensing pipettes
- Manifold
- Routine lab glassware

- Powder-free vinyl (PVC) gloves
- Coating solution
- Milli-Q water
- Kimwipes
- Silicon vacuum grease
- Laboratory liquid detergent.

Preparation of Impactor: Cleaning and Greasing of Impactor Plates

Use subsequently a hot soap solution, pure water and ethanol to clean impactor plates that have been used in the field (and new ones). Dry the plates with the porous side down on clean tissue paper. The purpose of cleaning the Impactor plate is to remove particles from the grease. It is not a problem if some grease remains on the plate. Put one drop of the of silicon oil on the porous side of the impaction plate. The plate absorbs grease, so it may not be visible after a while. Don't add more grease otherwise it may result in spilling of grease.

ChemComb system Housing



Honeycomb System Housing for the ChemComb Cartridge

Teflon-Coated Inlets

New inlets must be thoroughly rinsed with mill-Q water. They should be allowed to dry, covered with Kimwipes, in room air. Store the clean, dry inlets on Kimwipe-covered trays, with additional Kimwipes placed on top of them.

Note: If it is necessary to dry the inlets rapidly, rinse them with methanol and allow them to dry on the kimwipe-covered tray, or use the clean –air system to dry them more rapidly.

Impactor Plates

Cleaning New Impactor Plates before Use

Following steps are maintained to clean new impactor plates before use:

- New impactor plates must be cleaned in an ultrasonic bath. Use a 1-quart bath, filled with tap distilled water that has a few drops of laboratory liquid detergent in it. Use a specially made rack to support the plates in the bath. The impactor plates must not touch each other because sonication causes the Teflon coating to be deposited on the porous stainless steel plate.
- Sonication impactor plates for 15 minutes.
- Rinse the impactor plates thoroughly with distill water and then sonicate again for 5 minutes with distill water only.
- Repeat the rinse and sonicate procedure (with distill water only) until all the detergent has been removed.
- Cover the impactor plates with Kimwipes and allow the impactor plates to dry in room air. If you must dry the impactor plates rapidly, rinse them with methanol.
- Store the clean impactor plates in a clean ziplocked bag.

Cleaning of Used Impactor Plates

Previously used impactor plates will require more thorough cleaning than new impactor plates. Follow these steps to clean used impactor plates:

- Wipe the collected material and grease from the impactor plates with a clean Kimwipe. You also can use a soapy brush.
- Follow steps 1-4 given above. During sonication, grease used to catch large particulate matter may detach from the impactor plates. This may cause a dark cloudiness in the sonication bath water.
- Following sonication, rinse the impactor plates and then repeat the sonication treatment with detergent solution as many times as necessary until no more grease detaches from the plates during sonication .

- After the grease has been thoroughly removed from the impactor plates, use repeated rinses and sonication baths with distilled water to completely remove the remaining detergent.
- Cover the impactor plates with Kimwipes and allow the impactor plates to dry in room air. If you must dry the impactor plates to dry in room air. If you must dry the impactor plates rapidly, rinse them with methanol.
- Store the clean impactor plates in a clean ziplocked bag.

Coating the Impactor Plates

Follow these steps to coat the impactor plates with grease:

- Place the impactor plates on a clean flat surface with the indented circular reservoir facing upward.
- Apply a small amount of Dow Corning high vacuum grease (59-006460) to the indented reservoir area of the impactor plate.
- Using a straight razor scrape any excess grease off the impactor plate. This should leave enough to completely fill the indented reservoir area.
- Either insert the impactor plate directly into the chemcomb inlet for sampling, or store the plates into the inlet, ensure that the greased reservoir area is facing the air flow stream. The greased reservoir area should not be visible when looking into the chemcomb inlet. If you are going to store the impactor plates for future use, go to step5.
- To keep the grease on the plates from contracting the flat bottom sides of the other impactor plates, stack the greased plates in pairs with the greased plates facing each other.
- Make stacks of 16 plates and tape them together.
- Store each stacks of 16 plates in a clean ziplocked bag until ready for shipment or use.

(Note: The impactor plates must be dry before they are coated with grease).

After every sampling run, scrape out the greased area in the center of the impactor that has visible particulate matter buildup. Replace the scraped out grease with new grease from the tube and repeat steps 3-7.

Filter Handling and Initial Inspection

You may use various types of 47 mm-diameter filters to sample particular matter that passes through the chemcomb cartridges. Ensure that your filters are clean and do not touch them with yours fingers. Filters should be stored at the laboratory in filter holder and should be stored be transported to and from the sampling site in a capped chemcomb cartridges.
Use non-serrated forceps to handle the 47 mm filters.

Inspect each filter visually for integrity before use. Check for the following:

- Pinholes
- Chaff or flashing
- Loose material
- Discoloration
- Non-uniformity

Pre-Sampling Filter Equilibration

Follow these steps to equilibrate the 47 mm filters before use. Use filter holders to store filters in the laboratory.

- Place a label on the cover of each filter holder and number each dish.
- Equilibrate each filter for at least 24 hours under the following conditions: the equilibration room must be held at a constant relative humidity between 30% and 40%, with a variability of not more ±5%.The equilibration room must be held at a constant temperature between 20^0C and 23^0C with a variability of not more than $\pm 2^0$C.

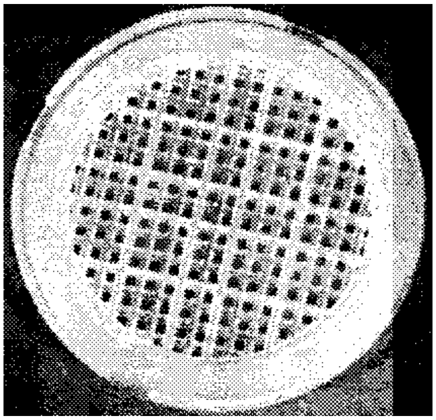
Pre-Sampling Filter Weighing

Follow these steps to weigh the 47 mm collection filters (tare weight) before sampling:

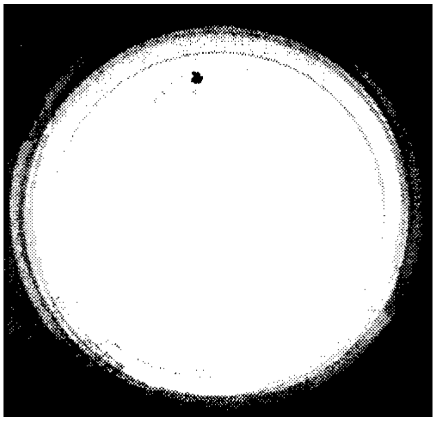
- Ensure that each filter has been equilibrated for at least 24 hours before weighing.
- Filters must be weighed on a microbalance with a resolution of at least 1µg (0.001 mg). Be sure to warm up the balance before weighing filters.
- Weigh each filter at least once (three times recommended), recording the mass in grams. The average mass reading is the initial filter weight, Wi (g). Use appropriate techniques

to neutralize static charges on the filter. This pre-sampling weighing must take place within 30 days of the sampling period.

- Unlatch the top rim of the chemcomb cartridge and separate it from the body housing.
- Place the filter inside a plastic filter screen.

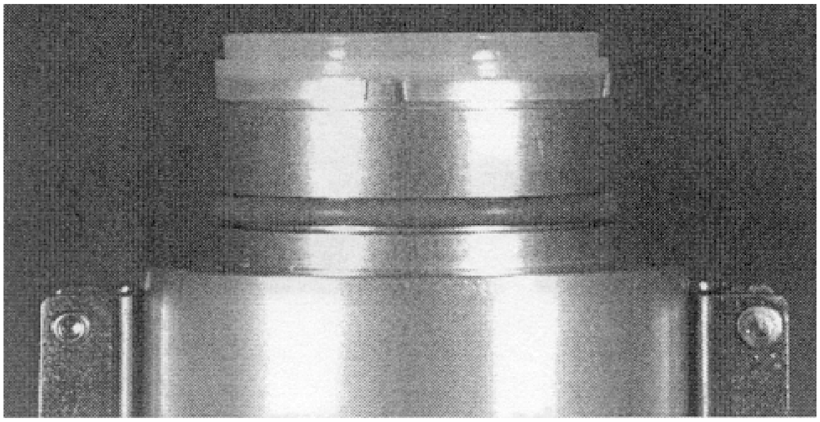


Plastic Filter Screen for Filter

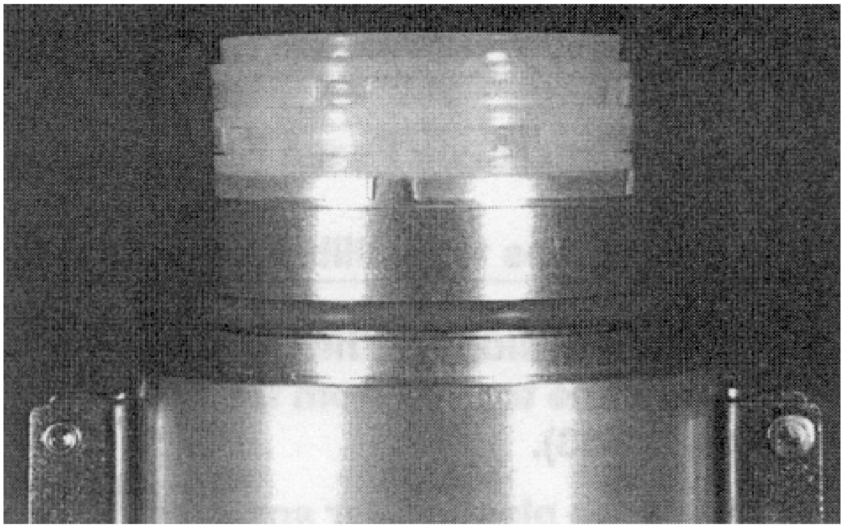


Filter Installed in a Plastic Filter Screen

- Place this filter and plastic filter screen face down on the top rim of the ChemComb. If desired, you may place up to three more plastic filter screens with filters installed on top of this first filter.



Plastic Filter Screen Installed on the Body Housing of a Chemcomb Cartridge



Three Plastic Filter Screen Installed on the Body Housing of a Chemcomb Cartridge

- Slide the top rim of the ChemComb housing down on the top of the plastic filter screens. Ensure that the top and middle pieces of the ChemComb cartridge are pushed completely together. Latch both sides tightly.
- Place a small yellow cap on the hose connection port.

Post Collection Filter Equilibration

Follow these steps to equilibrate the 47 mm filters after sampling:

- Unlatch both sides of the top rim of the ChemComb cartridges and separate the top rim from the main housing of the cartridge.
- Remove the plastic filter screen(s) from the ChemComb cartridges.
- Remove the 47 mm filter from the plastic filter screen and set it in its filter holder. Examine the filter for defects that may have occurred during sampling.
- Place the filter holder cover under the bottom half of the dish.
- Place a paper towel over the open filter holder during equilibration.
- Record the filter number, relative humidity, temperature, date and time at the beginning of this post-collection equilibration.
- Equilibrate each filter for at least 24 hours under the following conditions: the equilibration room must be held at a constant relative humidity between 30% and 40% with a variability of not more than ±5% relative humidity. The equilibration room must

be held at a constant temperature between 20^0C and 23^0C, with a variability of not more than ±2^0C.

Post-Collection Filter Weighing

Follow these steps to weigh the 47 mm collection filters after sampling:

- Ensure that the filters have been equilibrated for at least 24 hours before weighing.
- Filter must be weighed on a microbalance with a resolution of at least 1μg (0.001 mg).Ensure that the balance has been allowed to warm up before weighing the filters.
- Remove the filter from its filter holder.
- Weigh each filter at least once (three times recommended), recording the mass in grams (Figure 3-49).The average mass reading is the final filter weight, W_f(g).
- Return the filter to its filter holder, place the filter holder cover over it and store it for archival purposes.
- Document the relative humidity, temperature, date and time of the post-collection weighing.
- The “zero” reading of the microbalance should be verified between each filter weighing.
- Determine the net mass filter loading (DW) using the following formula:

$$DW = W_f - Wi$$

Where:

DW = the net mass filter loading

W_f = the final filter weight (calculated in step 4)

W_i = the initial filter weight (calculated in step 3, section 3.6)

Ensure that the figures used in this computation were obtained from the same filter and balance.

Chemcomb Installation and Removal

Installing Chemcomb Collars

Before installing chemcomb cartridges into the partisol speciation sampler, you must insert collars onto the cartridges.

Follow these steps to install collars onto the chemcomb cartridges:

- Locate a square ChemComb collar.
- Slide a collar onto the filter pack out let port of a ChemComb cartridge (top rim of the cartridges).
- Make sure that the top edge of the collar is approximately 0.38 inches below the metal edges of the top rim of the filter pack outlet port and that the hose connection is parallel to the grooved track on either side of the collar.
- Using a 7/64 hex wrench, tighten the screw in the corner of the collar.

Installing Chemcomb Cartidges

Follow these steps to install a chemcomb cartridge into the Partisol Speciation Sampler:

- Open the chemcomb shelter door.
- Line up the groove in the collar on the ChemComb with the edges of the tray inside the shelter box and slide the ChemComb cartridges onto the tray.
- Ensure that the inlet port on the chemcomb fits securely inside the hose connection.
- Repeat steps 2-3 to install the desired number of cartridges.
- Close the shelter door and latch it.

Removing Chemcomb Cartidges

Follow these steps to remove chemcomb cartridges from the partisol speciation sampler:

- Open the chemcomb shelter door.
- Slide the chemcomb cartridges out of the tray. The hose connection should disconnect easily.
- Close the shelter door and latch it.

Software Overview

This section describes the steps involved in turning the Partisol Speciation Sampler on and off, navigating through its basic screens and interacting with the unit.

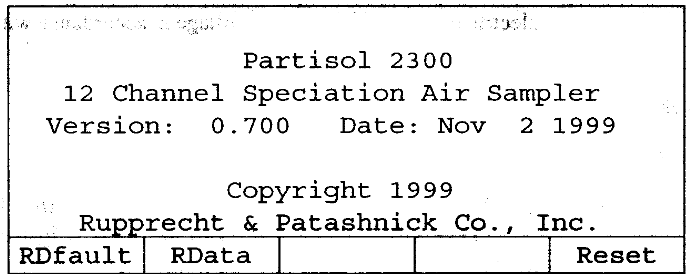
Turning on the Partisol Speciation Sampler

Follow these steps to turn on the sampler:

- Install the chemcomb cartridges in the shelter.
- Press the power switch on the main panel (lower left) to its "on" (1) position to activate the sampler.
- If necessary, turn the adjustment knob, located to the right of the keypad/display, to adjust the contrast of the liquid crystal display (LCD).

Title Screen

The title screen momentarily appears on the sampler's display to identify the model number of the unit and the revision number of the installed software.



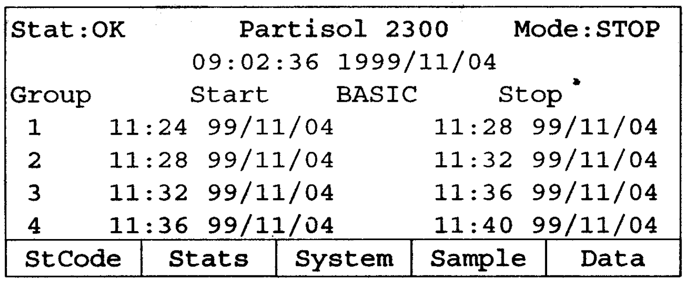
```
            Partisol 2300
  12 Channel Speciation Air Sampler
 Version:  0.700   Date: Nov  2 1999

           Copyright 1999
   Rupprecht & Patashnick Co., Inc.
```

Title Screen.

Main Screen

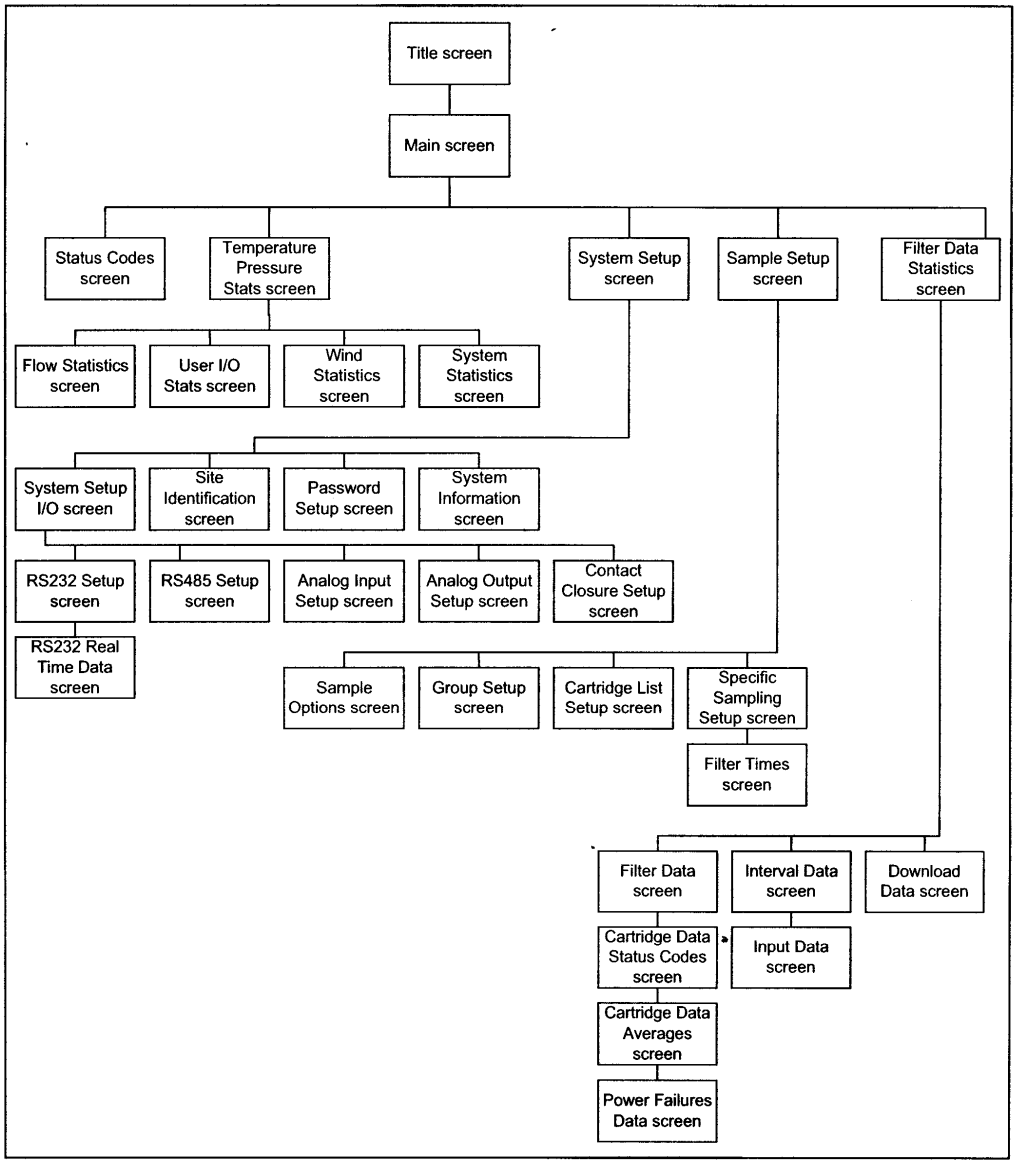
After a few seconds, the title screen is automatically by the main screen. The main screen contains different information depending on the sampler's operational mode. When the sampler is in the stop or wait operating modes ("stop" or "wait"), the main screen will show scheduled operational parameters. When the sampler is in the sampling operating mode

("SAMP"), the Main screen will show current operational information. Information common to both screens includes summary information regarding the sampling program currently defined by the user, the current operating mode and the existence of any status conditions.



```
Stat:OK        Partisol 2300     Mode:STOP
             09:02:36 1999/11/04
Group        Start     BASIC      Stop *
 1     11:24 99/11/04       11:28 99/11/04
 2     11:28 99/11/04       11:32 99/11/04
 3     11:32 99/11/04       11:36 99/11/04
 4     11:36 99/11/04       11:40 99/11/04
 StCode | Stats | System | Sample | Data
```

Main Screen in STOP Operating Mode.



Flow Chart for the Entire Operation of 4-CSS

Master Menu

The master menu provides another means of gaining access to other screens in the unit's software. It can sometimes provides a more direct route to other program screens than navigating through the hierarchy of screens using regular soft function keys.
Press<MENU> to display the master menu screen.

Edit Mode

The unit is the normally in the Browse Mode, which allows the user to move from screen to screen with ease. In a number of screens, however, the user may want to change the unit's operating parameters. In such a case, the user must enter the Edit Mode.
Press <EDIT>to enter the Edit Mode from the Browse Mode.

Sampler Operation

Programming the Sampler

Follow these steps to program the sampler for a sampling run:

- Install the desired number of chemcomb cartridges in the chemcomb shelter.
- Ensure that your sampler is in the stop mode. Do a system check and a leak check, and verify the flow rate for each flow channel on your unit.
- In the main screen, press <F1: Stcodes> to display the status codes screen.
- In the status codes screen, ensure that there is no status codes reported and the present status of the unit is "OK". Then press <ESC> to return to the Main screen.
- In the main screen, press <F2: status>to display the temperature and pressure Statistics screen.
- In the temperature and pressure statistics screen, ensure that the current ambient temperature, pressure and relative humidity values are correct. Then press <ESC> to return to the main screen.
- In the main screen, press<F3: setup>to display the system setup screen.

- In the system setup screen, press<EDIT>. Enter the current date and time and then press<ENTER> to save these changes .Then press<ESC> to return to the main screen.
- In the main screen, press<F4: Sample> to enter the sample setup screen. Press <EDIT>, choose your sampling program and enter the start time, sampling duration and sample repeat time for your sampling run(s). Press<ENTER>to save these changes.
- In the sample setup screen, press<F1: Options> to enter the sample options screen. Press<EDIT>and choose the flow error mode and the continuous sampling and system check options. Press<ENTER> to save these changes and then <ESC> to return to the sample setup screen.
- While in the sample setup screen, press<F2: Group> to enter the group setup screen. Press<EDIT> and choose the group and channel options for your sampling run. Press <ENTER> to save these changes and hen <ESC> to return to the sample set up screen.
- While in the sample setup screen, press<F3: ChanLst> to enter the Cartridge list setup screen. Check the flow channel, cartridge grouping and flow rates for each cartridge in your sample run in this screen. Then press<EDIT> and enter the cartridge identification numbers (cartridge ID field). Press <ENTER>to save these changed and then <ESC> to return to the sample setup screen,
- While in the sampler setup screen, press <F4: SampSet.> to enter the specific sampling setup screen that matches the sampling program you selected in the sample Setup screen (setup 9). Check the values you have set for your sampling run(s). If these values are correct, press <ESC> to return to the sample setup screen. If the values are incorrect, check the System Setup screen and the Sample Setup screen to correct these values.
- Press <RUN/STOP>.The sampler will enter the Wait
  - Mode and then begin the sampling run at the programmed start time.

Software Setup and Operation:

Modes of Operation

The Partisol Speciation Sampler displays its current operating mode in the upper right -hand corner of the main screen, and certain other screens. Press <RUN/STOP> to switch between the non-sampling stop operating mode and the sampling program execution modes (wait, sampling, audit and done). In certain cases, the user must select <STOP> after pressing

<RUN/STOP> to re-enter the stop operating mode. The unit’s operating modes are defined as follows:

- **Stop Mode**

  In the stop operating mode (STOP), the user defines the sampling program using the sampling setup screen and its sub-screens. Because this is the only non-operational mode, all user- definable system parameters may be edited with the sampler in this mode.

  Note: It is not necessary to return to the stop mode to exchange cartridges. They can be exchanged while the device is sampling. Pressing <RUN/STOP>with the unit in the stop operating mode causes the sampler to advance to the wait or sampling operating modes.

- **Wait Mode**

  The Partisol Speciation Sampler resides in the Wait Operating Mode (WAIT) until the user the defined sampling condition are met for the next sampling run .At that point, the unit automatically enters the sampling operating mode and begins sample collection. Pressing <RUN/STOP> when in the wait operating mode offers the user the choice of entering the audit operating mode or the stop operating mode.

- **Sampling Mode**

  While in the sampling operating mode (SAMP), the sampler is currently in a user-defined sampling interval. Except in the case of Advanced or Episodic sampling with condition, the unit will draw a continuous air flow through the sample path when the proper sampling conditions are met. The unit controls the sample stream at the volumetric flow rate specified by the user (10 1/min by default). Unless the sample flow rate deviates from its set point by 10% for more than 5 minutes, the sampler remains in this mode until the stop sampling conditions are met.

  Pressing <RUN/ STOP. When in the sampling operating mode offers the user the choice of entering the audit operating mode is the stop operating mode.

- **Done Mode**

The sampler enters the done operating mode (DONE) when there are no more sampling conditions to be met. In other words, when sampling times date and durations are have been completed for all cartridges and groups of cartridges, then the unit will enter the done operating mode. Pressing <RUN/STOP> with the unit in this mode causes the sampler to return to the stop operating mode.

- **Error Mode**

The sampler proceed to the error mode (ERR) when the measured flow deviates from its point by 10% for 5 minutes, causing unit to break off sampling and display one of the following status codes: SA,SB,SC or SD (section 8) . These status codes correspond to the flow channel where the measured flow has deviated from its set point. Pressing <RUN/STOP> with the unit in the error operating mode causes the sampler to return to the stop operating mode.

- **Audit Mode**

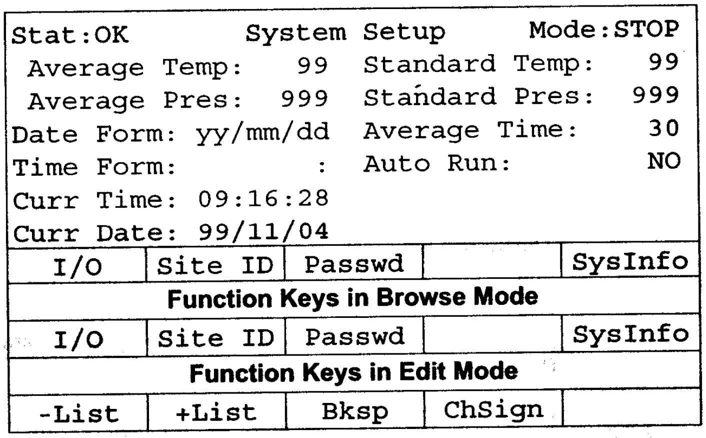
The Audit Operating Mode takes the unit off line and allows the user to exchange or clean components in the sampling train. Leak checks and flow verifications can also be done with the sampler in the Audit Mode.

When in the Wait or Sampling Mode, press <RUN/STOP>and select <F1: Audit> to enter the Audit Operating Mode .At this point, the sampler will suspend all regular operations until you complete your audit. After the audit is completed, press<RUN/STOP>to resume regular operations.

To prepare for an audit, press<RUN/STOP> and then select <F1: AUDIT>. The unit will then display its Main screen. While in the Main screen, press the <MENU> key. This will bring you to the Master Menu Screen, press <F 3: Audit >. Once you have completed your leak check or cleaning procedures, press <RUN/STOP> to resume sampling. Press <Esc> to display the Main screen.

System Setup

The unit's system setup screens set the global default sampling parameters for the numerous programming options available. The system setup screen defines whether the sampler uses the default ambient temperature and pressure setting, or standard temperature and pressure setting for maintaining and reporting flow rates in volumetric or standards terms. The System setup Screen also can be used to set the sampler to the current local time and date.



```
Stat:OK          System Setup        Mode:STOP
 Average Temp:    99  Standard Temp:    99
 Average Pres:   999  Standard Pres:   999
Date Form: yy/mm/dd   Average Time:     30
Time Form:         :  Auto Run:         NO
Curr Time: 09:16:28
Curr Date: 99/11/04
```

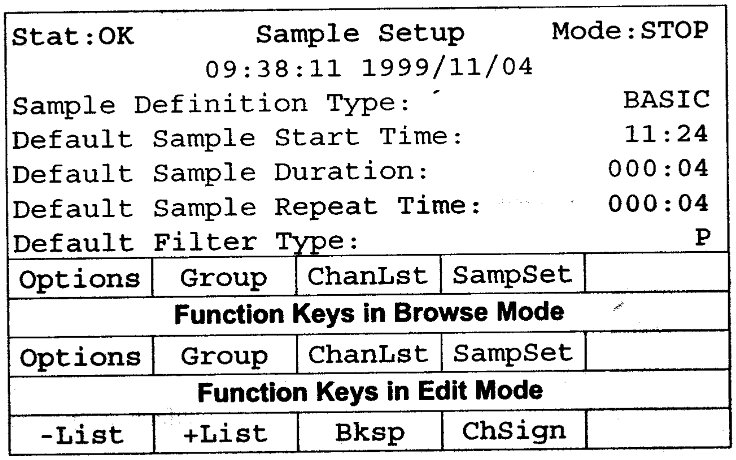
I/O	Site ID	Passwd		SysInfo
Function Keys in Browse Mode				
I/O	Site ID	Passwd		SysInfo
Function Keys in Edit Mode				
-List	+List	Bksp	ChSign	

System Setup Screen

Most of the parameters in this screen can be edited only in the sampler's stop operating mode. Press<F3: System> when in the main screen to enter the system setup screen. All of the fields in the system setup screen can be edited when the sampler is in the Stop operating mode. The following fields make up the system setup screen:

- Average temp
- Standard temp
- Average pres
- Standard pres
- Date form
- Average time
- Time form
- Auto run
- Curr time

Sample Setup Screen



```
Stat:OK        Sample Setup     Mode:STOP
            09:38:11 1999/11/04
Sample Definition Type:              BASIC
Default Sample Start Time:           11:24
Default Sample Duration:            000:04
Default Sample Repeat Time:         000:04
Default Filter Type:                     P
```

Sample Setup Screen

The sample setup screen allows the user to define global sampling parameters for the operation. Press<F4: Sample> when in the main screen to enter the sample setup screen. All of the fields in the sample setup screen can be edited when the sampler is in the stop operating mode.

The following fields make up the sample setup screen:

- Sample definition type
- Default sample start time
- Default sample duration
- Default sampling repeat time: The default sampling repeat time parameter will allow you to pause the unit while it is running in the continuous operation mode, offsetting the sample start time.
- Default filter type: This parameter allows the user to identify the default filter type. The default for this parameter is “P” (EPA filter)

Sample Options Screen

The sample options screen allows the user to choose the flow error mode, and continuous sampling and system check options.
While in the main screen, press<F4 Sample>to enter the sample setup screen. In the sample setup screen, press<F1: Options> to display the sample options screen.

The Samples Option screen displays the following information:

- Flow error mode: There are three options to choose from when setting the flow error mode: “ERR”, “WAIT” AND “NEXT”. If a flow error occurs when the flow error mode is set to “ERR”, the unit will stop sampling and enter the error mode. The user must then press<RUN/Stop> twice (once to enter the stop operating mode and then once more to initiate sampling) before the unit may continue sampling.
- Continuous sampling
- System check

Group Setup Screen

While in the main screen, press<F4: sample> to enter the sample setup screen. In the Sample Setup screen, press<F2: Group > to display the group setup screen.

Site Identification Screen

While in the main screen, press<F5: System >which takes you to the system setup screen. In the system setup screen, press<F2: Site ID>to display the site identification screen.

System Information Screen

The only field that can be edited in the system information screen is the sampler serial number field. While in the main screen, press <F3: System> to enter the system setup screen. In the system setup screen, press<F4: SysInfo>to display the system information screen.

Basic Sampling Setup Screen

The basic sampling setup screen will display if “BASIC” is selected as the sample definition method in the sample setup screen. The basic sampling program is the most commonly used sampling program. In this program, the unit samples continuously for the same duration with each cartridge until there are no more cartridges available.

The basic sampling setup screen uses the following fields to define the basic sampling program of the partisol speciation sampler:

- Start Date: The Start Date parameter determines the date (yy/mm/dd by default) on which sampling through the first cartridges sample will begin. When editing this parameter, treat each part of the date as separate fields.
- The current time is: The current time and date (hh:mm yy/mm/dd by default is displayed in this field.
- Sample will start at: This parameter defines the time of day the Partisol Speciation Sampler will begin sampling on the cartridges or group of cartridges. This start time by default is the time selected in the Sample Setup screen.
- Each sample will collect for: This parameter display the sampling duration in hours. The sampler will use the default duration from the Sample Setup screen.

Turning off the Partisol Speciation Sampler

Follow the steps below to turn off the hardware:

- If the device is not in the stop operating mode, press <RUN/STOP> to enter the stop operating mode.
- Press the power switch on the on the front panel of the partisol speciation sampler into it’s “off” (0) position.

Status Codes

The sampler displays operational status codes in the upper left-hand corner of the Main screen, and on several other screens. The unit shows a status of “OK” if no current status conditions exist. The sampler resets the status code to “OK” when it switches to the next sampling group.

The Status Codes screen displays a list and description of the currently active status condition. When in the Main screen, press <F1: Stcode> to enter the Status Codes screen.

OK	No current status conditions.
M	Flash memory.
C	Calibration
Y	System Reset.
Z	Power Failure
FA-FD	Flow (A-D) Out of Range.
SA-SD	Flow (A-D) Stop.
TA	Ambient Temperature.
TP	Pump Temperature.
TE	Electronics Temperature.
VP	Vacuum Pump Failed.
VV	Vacuum Vent Valve Failed.
VS	Vacuum System Failed.
OA-OD	Coefficient of Variation (A-D).
U	User Pressed Stop.
B1-B3	Bank (1-3) Failed.
LA-LD	Leak Check (A-D) Failed.
D	Audit Performed.

AIII-2: **Weather Monitoring Station**

Introduction

The Envirotech wind monitor has been designed to provide all three wind characteristics required for pollutant-dispersion and air- quality modeling. The system measures ambient temperature in degrees centigrade, wind speed in km/h and wind direction in degrees from north. The data logger of the system computes hourly averages of the three parameters and also standard deviations of the wind direction fluctuation on a real time basis. The hourly data stored in the logger memory and can be retrieved at appropriate intervals. The rate of the charge of direction i.e. fluctuation in directions or turbulence is measured as sigma theta. Sigma theta information is used to compute stability.

Principle of Operation

Sensors

Wind Speed Sensor

In cup-anemometer systems, horizontal wind speed is monitoring the rate of rotation of the cup assembly. In mechanical type of systems as the anemometer shafts drive a counter through a gear train while most chart recording systems employ a generator to develop a voltage proportional to a rate of shaft rotation. In both types systems low speed performance suffers on account of friction & inertial effects.

Wind Direction Sensor

In the wind direction sensor a balanced vane is coupled to a potentiometer. The microprocessor decodes the sensors signals and checks direction status every few seconds. The software in the logger then marks out in average wind direction for each minute. These minute values are stored in a buffer memory and used to work out the sigma theta (standard duration if 60 wind direction values) and averages Wind direction at the end of each hour and the system records this value as the representative direction for the period.

Temperature Sensor

The sensor is placed inside the wood and hood cover. It measures a ambient within the range -5^0 C to 50^0 C.

Field Micro logger Assembly

Field Micro logger Assembly is designed around the Z80 microprocessor and supports the following functions:

Sensor Interfaces

The standard WM251 system is supplied with sensors for wind speed, wind direction and temperature. The logger of the WM251 also has spare channels to additional sensors for parameters like humidity, solar radiation and a rain gauge. As part of the sensor interfaces function, the logger converts electrical outputs from each of the sensors to appropriate units. Respective conversion factors for the sensors are stored in the logger during installation.

Data Storage

Envirotech’s loggers store recorded in non-volatile electronic memory. The system records hourly averages values for each of the sensors connected. In each case status of individual sensors is checked every few seconds and the values stored in a data buffer. At the end of the recording interval average values of the sensors are calculated stored in data memory. For standard, the logger has sufficient memory to records a month’s data.

Data Display

To aid stand alone field operation a display and keyboard- assembly has been integrated with the logger unit. This key board used to enter “starting time” and the “starting date” information at the time of system initialization.

Installing the WS-15 Sensor Assembly

The WS-15 sensor assembly consists of a tri-pod stand, sensor holder, speed sensor, direction sensor, temperature sensor, humidity sensor, rain sensor and a sensor cables with appropriate connectors.

The following steps should be performed in sequence to install properly the WS-15 assembly:

- Connect lower flange to the three braces on the tripod stand.
- Loosen the allen –bolt in upper flange & mount the central pipe on the stand. Use a pipe wrench to tighten the pipe in lower flange, taking care to ensure that the holes on the pipe are aligned to the allen bolt in upper flange.
- Spread out tri-pod legs sufficiently so that the legs are approximately one meter apart at the base and tighten the allen bolt in appropriate hole.
- Mount the speed sensor in the slot in t-cross bar; tighten the sensor retaining bolt after inserting the sensor assembly in slot.
- Insert eyebolt into the cup holder and plug the cup so that the flat on its bush is aligned to the step in the holder. Gently tighten the nut of the eye-bolt so that the cup is firmly held. Repeat the operation for the other two cups to complete assembly.
- Insert the vane into the direction sensor; Ensure that the vane and counter balance are mounted as per the polarizing is provided on the sensor assembly. The marking shows the orientation required for the standard convention of the wind direction.
- Hold the direction sensor hub with its axis horizontal and adjust the length of the vane center-weight until the assembly rests horizontally indicating that it is balanced.
- Mount the Direction sensor assembly onto the T-cross bar.
- Mount temp. Sensor assembly on the T-cross bar.
- Mount the top of the tri-pod stand and plug in the sensor cable into each of the sensors T-cross bar.
- Orient the stands, so that the N mark on the direction sensor is aligned to the "Geographic North". The WS-15 sensor Assembly is now installed and ready for use.

Software Package

Wind rose V7.4 (release 1.0)

The System is supplied with a user friendly software package WM251 is provided into version V7.4. This is a modern software package designed to rapidly obtain trend information from Wind data. This software package provides a wind rose diagram in the standard in the standard circular format on the IBM-PC. While the package has been designed for use primarily with WM251, Some of the important features of the packages are.

Circular Wind rose Diagram

Wind rose diagram obtained by processing wind data with V7.4 package on an CGA monitor. The software allows scaling up or down of the wind rose scale, to obtain appropriately spaced prints on a standard A4 size paper.

Speed

Written in C language, the V7.4 package cuts down frequency distribution tabulation time by several orders of magnitude. Even long files for a complete season are processed with in a few minutes. The system allows data transfer from data-logger at 9600 baud so that a full month’s data can be transferred in less than a minute.

Maintenance

Envirotech’s WM251 wind monitor is microprocessor based data-logging instruments designed for operation in normal room environment for extended periods of time. While these systems do not require an air-conditioned environment they should be protected from extremely hot and dusty operating conditions. Like all electronic equipment they require stabilized mains supply and are particularly sensitive to voltage spikes. For trouble-free operation ensure that the systems are operated only through the constant voltage transformer (CVT) supplied with the system.

Maintenance of the Speed Sensor Assembly

The WS15 Speed Sensor system used with WM251 wind monitor use photo chopper placed in sealed sensor hub to minimize the mechanical friction and drag on the sensor shafts. Drawing No. 10201-00 show the important parts of the Speed Sensor. The Sensor use sealed bearings to support the sensor Shaft. The bearings are lubricated for life and will not require greasing, even while working in harsh environment. However, as a mechanical system constantly in use the bearings and sensor rotors are bound to wear with time. As a preventive maintenance schedule check the following every alternate month:

AIII-3: **Standard Operating Procedure for EC/OC Analysis**

Scope

This document describes the analysis of exposed quartz micro fiber filters for organic carbon (OC) and elemental carbon (EC) using a Desert Research Institute (DRI) Model 2001 Thermal/Optical Carbon Analyzer.

Operating Principle

Analyzer is based on the preferential oxidation of organic carbon and elemental carbon compounds at different temperatures. Organic compounds are volatilized from the sample deposit in a helium (He) atmosphere at low temperatures, while elemental carbon is not oxidized and removed. The carbon compounds are liberated under temperature and oxidation environments from a small sample using a 5/16 inch diameter punch (0.512 cm^2) taken from a quartz fiber filter. These compounds are converted to carbon dioxide (CO_2) by passing the volatilized compounds through an oxidizer (heated manganese dioxide, MnO_2). The CO_2 is reduced to methane (CH_4) by passing the flow through a methanator (hydrogen – enriched nickel catalyst). A flame ionization detector (FID) is used to quantify the methane. The optical component of the analyzer is used to correct for pyrolysis of organic carbon compounds to elemental carbon in order to avoid underestimation of OC and overestimation of EC. The sample reflectance and transmission are continuously monitored by a helium-neon laser and a photo detector throughout an analysis cycle. When pyrolysis takes place, there is an increase in light absorption resulting in a decrease in reflectance and transmission. Thus, by monitoring the reflectance/transmission, the portion of the elemental carbon peak corresponding to pyrolyzed organic carbon can be correctly assigned to the organic fraction.

Interferences

- The presence of certain minerals can affect the laser correction for pyrolysis. These minerals change color as the sample punch is heated, generally resulting in a sample that is darker. Some minerals may affect the laser reflectance by temporarily changing color or changing the surface texture of the deposit residue. These changes are reversible and highly temperature dependent. Colored organic compounds can affect the laser correction causing increased reflectance as these compounds are removed. The presence of certain elements (Na, K, Pb, Mn, V, Cu, Ni, Co, and Cr) as part of the deposit material has been shown to catalyze the removal of elemental carbon at lower temperatures.

- Water vapor can shift the FID baseline. Allowing adequate time for the sample punch to dry in the analyzer by passing gases over it will eliminate this effect.
- All surfaces are cleaned so that no contamination occurs. Filters are carefully handled in order not to contaminate them.

Apparatus and Materials

- DRI (Desert Research Institute) Thermal/Optical Carbon Analyzer Model 2001
- 5/16 inch diameter steel punching tool
- Furnace - 4800 Barnstead/Thermal Corporation
- Gases:
  - Compressed air for valves
  - Ultra zero air for FID
  - Hydrogen using a hydrogen generator (Whatman 75-34 Hydrogen Generator)
  - 10% oxygen balance helium – certified (Airgas, catalog # X02HE902003183)
  - Grade 5 helium
  - 5% methane balance helium – NIST standard (Scott-Marrin, Inc., catalog # 02-150A-350B)
  - 5% carbon dioxide balance helium – NIST standard (Scott-Marrin, Inc., catalog # 02-150A-580B)
- Chemicals:
  - Potassium hydrogen phthalate (KHP) (Fisher, catalog # P243-100)
  - Potassium hydrogen phthalate (Mallinckrodt, catalog # 6704-02) used as second source
  - Sucrose (EM Science, catalog # SX1075-1)
  - Manganese dioxide (MnO_2), crystalline, as an oxidizer in the oxygen oven (Nurnberg Scientific, catalog # C5162 or equivalent)

  - Nickelous nitrate [$Ni(NO_3)_2.6H_2O$], crystalline, used as a reducer in the methanator (Fisher Scientific, catalog # N62-500)
  - Chromosorb 60/80 mesh, used as a support for nickel catalyst in methanator (Supelco, catalog # 2-0165). Both nickelous nitrate and this support are for preparing the reduction catalyst in the methanator
  - Hydrochloric acid (HCl) concentrated for preparing KHP reagent.
  - Nanopure water
- Traps:
  - Oxygen trap (Trigon Technologies, catalog # TTO-100-4) for the helium gas
  - Hydrocarbon trap (Trigon Technologies, catalog # TTH-200-4) for helium gas
  - Moisture trap (Trigon Technologies, catalog # TTM-200-4) or other suitable trap for the hydrogen generator
- Porcelain Coors dishes for firing the quartz filters
- Tweezers, flat tip (Millipore, catalog # XX6200006)
- Glass petri dish
- Kim wipes
- Syringes:
  - Gas–tight 1000 µl and 2500 µl syringes for gas calibration injections (Hamilton, catalog # 81320 and 81420, respectively)
  - 10 µl and 25 µl syringe for liquid calibration injections (Hamilton, catalog # 80400 and 80030, respectively)
- Aim n Flame lighter by Script to light the FID
- Printer paper (8 1/2_ x 11_)
- Ink cartridge #20 for a Hewlett-Packard Deskjet 648C printer

Preparation of Standards

- The following standards are used to calibrate the carbon analyzer: 5% CH_4 in helium, 5% CO_2 in helium, and Potassium hydrogen phthalate.
- KHP is dried at 110^0C for two hours before preparation of a solution.
- After the KHP has cooled to room temperature, weigh and transfer 0.3829g of KHP into a clean, dry, glass 100 ml volumetric flask.

- Dissolve the KHP in the flask with about 50 ml nanopure water.
- Add 0.2 ml of concentrated HCl and dilute to volume with nanopure water.
- Mix the KHP solution thoroughly. This will make an 1800 ppm carbon solution of KHP.
- 5.7 Label the flask with chemical name, date of preparation, the initials of the chemist preparing the solution, and the exact concentration.
- 5.8 Store the KHP solution in a refrigerator until it is needed for calibration.
- 5.9 A second solution of KHP, the control, is prepared the same as the calibration solution using a different source of KHP.

Keithley Driverlinx Software Setup Panel

- Click on the icon to open the Keithley Driverlinx software. The meter panel is used in setting and checking signal levels, while Digital Input/Output panel (DIO) is used for checking the operation of valves, and sample boat positioning (See Figures 33 – 35, Pages 22 – 23 in OC/EC Instruction Manual).

- Click DIO to open the DIO panel. Select output of channel 1 in digital I/O configuration panel. Click on channel 1 from the digital output panel (middle panel). Then boxes (0–7) under output bits can be selected to activate the designated functions of the analyzer. Once turned on, the box will light up. Clicking on the same box will turn off that line.

- The assignment of the output bits:

Carle Valve Load	0
Back Valves	1
Carle Valve Inject	2
Front Valves	3
Sample Oven Fan	4
Sample Load	5
Sample Calibrate	6
Sample Analyze	7

System Leak Checking

- The two toggle shut-off valves in conjunction with the system oven pressure digital panel meter (DPM) located on front of the instrument above the rotameters are used for detecting leaks in the analyzer. The oven outlet toggle valve is located on the right side panel. The oven inlet toggle is on the front of the instrument.
- Make sure that He-1, He-2, and the pneumatic air are flowing and that the bridge of the sample boat inlet is sealed. If not, manually switch the sample boat to “Calibrate” to ensure the bridge is sealed.
- Close (flip downward on the handle) the oven outlet toggle valve. The Sample Oven Pressure should increase. When the pressure reaches about 5 psig, close the Oven Inlet toggle. The pressure should not decline very much over several minutes, if so there may be a leak. Normally, the areas where leaks are prone are the teflon ferrules around the thermocouple push rod and the quartz oven inlet and outlet. Tightening the nut should stop the leak. Check the septum ports also. The remaining two areas are the top and bottom seals of the quartz oven cross. If the leak persists, the oven may have a crack.
- When the system leaks checks are satisfactory, open the toggles to reestablish flow.

Flow Balancing

- Three needle valves on the analyzer’s right side panel provide adjustments needed to balance the flow.
- Make sure that the sample boat inlet bridge is closed, and that the flow rates have been set correctly and all the gases are flowing.
- Set the Watlow Controller Settings as follows: warm up the FID temperature to 125°C, heat up the oxidation and methanator ovens stepwise in approximately 150°C increments with approximately 20 minute holding time at each step until the oxidation oven is at 900°C, and the methanator is at 420°C. The temperature can be set by holding down on the set button of the controller and using the up or down arrows to adjust the setting (See Pages 47 – 52 in OC/EC Instruction Manual).

- Turn on the front valves (I/O line 3) at the Keithley DIO panel and note the absence of ball movement at the He-2 rotameter. If the ball jumps up, turn the front (He/O_2/He adjust) needle valve clockwise slightly. If the ball drops, turn the needle valve counter clockwise. Turn off the Front valves and let the flow stabilize for a couple of minutes. Repeat this step until little or no ball movement is observed (See Figures 33 – 35, Pages 22 – 23 in OC/EC Instruction Manual).

- Turn on the Back valves (I/O line 1) at the Keithley DIO panel. Adjust the middle (oven flow adjust) needle valve until the System Oven pressure is approximately 1psig. Slightly higher or lower pressures are not critical. Allow the pressure to stabilize a few minutes.
- Turn off the Back valves and observe the System Oven pressure. There should be little or no change. Adjust the rear (vent adjust) needle valve to 1 psig. Repeat this step as necessary and allow a few minutes between adjustments.

Calibration

The instrument is calibrated every six months or when the gas standard is changed whichever comes first. The following are used to calibrate the instrument: 5% CO_2 in helium, 5% CH_4 in helium, and KHP. The CH_4 in helium is also used as the end-of-run calibration automatically injected by the instrument. In addition, the manual calibration injections of 5% CO_2 in helium and 5% CH_4 in helium are performed at the beginning and ending of each analysis day to verify proper analyzer performance.

- A 5% CO_2 in helium gas is injected in the following volumes: 100 µl, 200ul, 500 µl, 1000 µl, and 1500 µl, respectively.
- A 5 % CH_4 in helium gas is injected in the following volumes: 100 µl, 200 µl, 500 µl, 1000 µl, 1500 µl, respectively.
- Then an 1800 ppm carbon KHP standard is used and is injected in the following volumes: 5 µl, 10 µl, 15 µl, and 20 µl, respectively. This gives a concentration of carbon as 9, 18, 27, 36 µg, respectively.

- The gas standard concentrations are corrected for temperature and pressure at the laboratory conditions using the Ideal Gas Law and certified percent concentration of gas in cylinder.
- The injection peak counts divided by the calibration peak counts is calculated, and the slope is determined by plotting calculated carbon in µg vs. peak area/calibration area. The line is forced through zero.
- The slope value determined from the three calibration standards is entered into the "carbon.par" table (ASCII file).
- The control standard, 10 µl of 1800 ppm carbon KHP, is injected onto a clean blank filter punch and analyzed to check the calibration. This source is different from the KHP calibration standard. Once the control value is within ± 10 % of its true value, the check standard can be run.
- The check standard, 10 µl of 1800 ppm carbon KHP, is placed on to a filter punch on the quartz boat. The check standard should be within ±10 % of its true value before continuing to analyze samples.
- A 5% CO_2 in helium or 5% CH_4 in helium gas is analyzed before analyzing samples to check the proper analyzer performance. The standards should be within ± 10% of their true value before continuing to analyze samples.

System Blanks

- System blanks are analyzed once a week to check to see if the system is clean.
- A blank filter punch is placed in the boat. After baking the system several times, the analysis is started. The system blank should be < 0.2 µg total carbon before analyzing any samples.

Routine OC/EC Analysis

- Check all the gases to make sure there is enough gas for the day. Turn on the gases and adjust the regulators on the gas tanks. Also, check the water level on the hydrogen generator and add water if needed.

- Increase the H_2 flow to the higher setting as marked on the rotameter (approximately 4.4). Wait for several minutes for the flow to stabilize. Light the FID with a lighter placed over the FID stack. A light pop sound indicates that the flame is lit. Check that the FID is lit by holding the bottom of a small beaker or a pair of tweezers over the FID exhaust stack and watching for condensation. After about 10 minutes at the high flow, turn the H_2 rotameter to 3.4, the operating setting.
- Check all gas flows at the analyzer. The correct settings are located on each rotameter. Adjust through the center of the ball.
- On the computer, click the DRICarb shortcut icon to start the carbon program.
- Leak test the system (See Section 7.0). Make sure the sample boat position is in the calibration position so that the bridge is closed before performing test. Once the leak test is satisfactory, open the toggles to re-establish flow.
- Balance the flow by adjusting the sample oven pressure to approximately 1.0 psig (See Section 8.0).
- Once the flow has been balanced, a clean blank filter punch can be loaded onto the boat, and the oven can be baked several times. This can be done by clicking on the analysis button on the computer screen, selecting sample, then cmdBakeOvenNIOSH. Click OK, and then run. Repeat the bake oven procedure at least three times.
- Make sure that the printer has enough paper, the printer cartridge is okay, and the printer is on.
- Once the oven has been baked, a 5% CO_2 in helium or 5% CH_4 in helium gas standard can be analyzed. Instead of selecting sample, calibrate is selected in the analysis program and cmdCalib-HeO_2 or cmdCalib-HeOnly from the command table. Once the software indicates to do so, load a 1000 µl syringe with 5% CO_2 in helium or 5% CH_4 in helium, and then inject into the septum port of the analyzer only after the software has prompted to do so.

- After the gas standard has been analyzed, 10 µl of an 1800 ppm carbon KHP control standard is analyzed. Sample is selected on the analysis program and cmdNIOSH from the command table. The analysis page containing the fields, sample ID, punch area (1.0 cm^2), deposit area (1.0 cm^2), and Tech initials are filled in. Click OK and then run. When the software has prompted to do so, load the 10 µl of KHP slowly on to the filter punch. Click OK and then enter the delay time required to dry the liquid standard on the filter punch. For each µl of liquid on the filter punch, 60 seconds of drying time (delay time) is required before the analysis will proceed. In this case, enter 600 seconds and click OK.

- Once the KHP standard has been analyzed and is within limits, the samples can be analyzed.
- Make sure that the tweezers, punching tool, and surface area used to punch on are thoroughly wiped clean with a dry kimwipe.
- Remove the sample petri dish from the refrigerator. On the computer screen, record the site name, sample ID (barcode), punch area, filter exposure area, and chemist's initials. Remove the filter from the Petri dish with tweezers onto a glass petri dish. A sample punch is removed by gently pushing down the punching tool. Rock the punching tool slightly to make sure that the punch is completely cut. This will leave the sample punch inside the punching tool. Place the punching tool on a clean surface and return the filter to the petri dish. Remove the sample punch from the punching tool by grasping the bottom edge with the tweezers. Place one sample filter punch in the sample boat, and gently push the sample punch using the large end of a pasteur (glass) pipette to make sure that the sample punch is seated in the well of the boat.
- Click OK after loading sample punch. Then click OK when the software prompts for delay time. The default value is 60 seconds. The sample will go through the sample analysis.
- Wipe the tweezers, petri dish, and punching tool with a clean kimwipe, and return the sample petri dish to the refrigerator.
- Log in the sample ID, date sampled, site name, date analyzed, and operator initials into the lab notebook.
- At the end of the run, a three page report will print out which includes the peak areas, final results, and the thermogram.
- A duplicate sample is run for every ten samples. A second filter punch is taken from the filter and analyzed.
- Once the samples are analyzed for the day, a 1000 µl of 5% CO_2 in helium or 5% CH_4 in helium is analyzed for the end of day check. Use the alternate gas standard from the one used in the morning and the alternate command program used in the morning.

- Once the end of day calibration run has printed, exit the carbon program. Shut off the toggle valves on the instrument for the Air, Cal Gas, and He/O_2. Then close the gas supply valves for the respective gases.
- From the report print out, the results are entered into the Laboratory Information Management System (LIMS).

Program Software

- The OC/EC analysis program reads command sequences from and writes data to an Access database file. This file is **C:\Carbon\Access\carbon.mdb. Clicking on the DriCarb shortcut icon** will open this file to start the analysis.
- The parameter file, carbon.par, is an ASCII file which contains analyzer specific information. This is where the calibration slope can be entered. The user can only read this file by using the Note Pad word processor.
- The command tables are in Microsoft Access. Each command table has all the steps for the analysis program. They contain all of the information for opening and closing the Carle valve, Back valve, Front valve, sample oven fan setting, and sample position setting (See pages 36 – 39, OC/EC Instruction Manual). Following are all of the command tables: **cmdBakeOvenImprove, cmdBakeOvenNiosh, cmdCalib-HeO$_2$, cmdCalib-HeOnly, cmdImprove, and cmdNiosh.**

Preparation of Filters

Filters are pre-fired for the OC/EC analysis before they are placed into the filter holders and shipped out to the field as follows:

- A Thermolyne 4800 Furnace is set to a temperature of 900°C.
- Quartz 47mm filters (Whatman cat no. 1851047) are visually checked for damage or holes. Several inspected filters are placed into a porcelain dish using tweezers.
- The porcelain dish with the quartz filters is placed into the furnace oven.
- After the oven reaches a temperature of 900°C, the porcelain dish with the quartz filters is baked for four hours.
- Once the filters have baked for four hours at 900°C, the furnace oven is turned off.

- Remove the porcelain dish with filters, after the oven has cooled off, the next morning.
- The filters are removed from the porcelain dish with tweezers, being careful not to damage any of the filters, and place them into a 50 mm petri dish and cover dish.
- Place the petri dish containing the filters into a desiccator for storage until use.

Limit of Detection

The Limit of Detection (LOD) for the method is determined initially during method development. The LOD is verified annually, or when there is a modification to the instrument that will affect its performance.

- The LOD for the OC/EC instrument was determined by analyzing seven replicates of a KHP standard solution.
- A 1 µl of a 450 ppm carbon KHP standard solution was injected onto a clean baked filter punch on the boat. This was repeated until seven replicates were analyzed.
- The standard deviation was determined for the seven replicates.
- The standard deviation times the student T value (3.143 for seven replicates) equals the LOD (See Section 15.0, equation 15.6).

Formulae and Calculations

- Ideal Gas Law:

$$n=\frac{PV}{RT}=\frac{\left(\frac{P_a}{760}\right)\left(10^{-6}\right)}{0.08206(T_a+273.15)}$$

Where,

n = moles/volume of gas

P_a = ambient pressure in mm Hg

T_a = ambient temperature in °C

V = volume of gas

R = gas constant

- To determine the calibration slope, the graph of µg of C (carbon) vs. injection peak counts/calibration peak counts is plotted.

- Carbon values per punch are converted to µg C/cm^2 by:

$$\mu g\ C/cm^2 = \frac{\mu g\ C/punch}{punch\ area\ in\ cm^2}$$

- Carbon values are converted to µg C/filter by:

$$\mu g\ C/filter = (\mu g\ C/cm^2)\ (filter\ exposure\ area\ in\ cm^2)$$

- To determine the micrograms of carbon per cubic meter (µ g/m^3):

$$\mu g\ C/cm^3 = \frac{\mu g\ C/filter}{flow\ rate\ in\ m^3}$$

or

µg/m^3 = µg of C (carbon)/punch area in cm^2 x (filter exposure area in cm^2)/flow rate in m^3

- Limit of Detection (LOD) = (standard deviation) x (3.143)

Related Terminology

IMPROVE_A Thermal Protocol: A thermal protocol is used in carbon analyzers to quantify carbon fractions evolved at different temperature plateaus. The IMPROVE_A thermal protocol derives from the Interagency Monitoring of Protected Visual Environments (IMPROVE) thermal protocol initiated in 1987.

Calibration Injection: The injection of calibration gases, either CO_2 or CH_4, into the sample stream at the beginning and end of each work day to check instrument performance.

Calibration Peak: The FID peak resulting from the automatic injection of methane calibration gas (CH4/He) at the end of each analysis run for each sample. All integrated peak areas are divided by the calibration peak area and multiplied by an instrument-specific calibration factor to obtain µg carbon per sample punch.

FID Split Time: The time at which the laser split occurs plus the transit time required for thermally evolved carbon to travel from the sample punch to the FID.

Organic Carbon: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere at 140, 280, 480 and 580°C plus pyrolyzed organic carbon. This is the same as Volatile Organic Carbon (VOC) plus high-temperature OC.

Elemental Carbon: Carbon evolved from the filter punch in a 98% He/2% O2 atmosphere at 580, 740, and 840 °C minus any pyrolyzed OC.

High Temperature OC: Carbon evolved from the filter punch in a He-only atmosphere at 280, 480, and 580°C plus pyrolyzed organic carbon. This is OC minus the first OC peak (OC_1).

High Temperature EC: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere at 740 and 840°C minus any pyrolyzed organic carbon present in these two peaks. This is EC minus the first EC peak (EC_1).

Laser Split: The separation between OC and EC, which depends on the laser measured reflectance and/or transmittance of the filter punch returning to its initial value. At this point all pyrolyzed OC has been removed and EC is beginning to evolve.

Lower Split Time: The time at which the laser-measured reflectance and/or transmittance of the filter punch reaches its initial value minus the precision of the laser signal (currently defined as 10 counts).

Pyrolysis: The conversion of OC compounds to EC due to thermal decomposition; this may be envisioned as "charring" during the organic portion of the analysis.

OC_1: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from ambient (~25 °C) to 140 °C.

OC_2: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 140 to 280 °C.

OC_3: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 280 to 480 °C.

OC_4: Carbon evolved from the filter punch in a He-only (>99.999%) atmosphere from 480 to 580 °C.

OP: The carbon evolved from the time that the carrier gas flow is changed from He to 98% He/2% O_2 at 580 °C to the time that the laser-measured filter reflectance (OPR) or transmittance (OPT) reaches its initial value. A negative sign is assigned if the laser split occurs before the introduction of O_2.

EC_1: Carbon evolved from the filter punch in a 98% He/2% O2 atmosphere at 580 °C.

EC_2: Carbon evolved from the filter punch in a 98% He/2% O2 atmosphere from 580 to 740 °C.

EC_3: Carbon evolved from the filter punch in a 98% He/2% O_2 atmosphere from 740 to 840 °C.

Regular Split Time: The time at which the laser-measured reflectance and/or transmittance of the filter punch reaches its initial value.

Total Carbon (TC): All carbon evolved from the filter punch between ambient and 840°C under He and 98% He /2% O_2 atmospheres.

Upper Split Time: The time at which the laser-measured reflectance and/or transmittance of the filter punch reaches its initial value plus the precision of the laser signal (currently defined as 10 counts).

AIII-4: Standard Operating Procedure for High Volume Samplers APM-430

Application and Description of the Equipment

This SOP is for operation and maintenance of the high volume sampler APM-430. The instrument is used for sampling of suspended particulate matter (SPM) in air. The samples are analysed for mass and/or speciation of dust components.

APM 430 is used for air sampling to measure the concentration of suspended particulate matter (form 1 µm to about 100 µm sizes) in atmospheric air. In this system, a large volume (1500 cubic meters) of atmospheric air is passed through a suitable filter medium over a period. The air flow rate is monitored by measuring the pressure drop across the Orifice plate (variable cut volume) which is placed between the filter holder and blower. The manometer scale is used to measure the pressure drop, which is calibrated in air flow units of cubic meters per minute. A time totalizer records the sampling time in minutes: hours. The weight of the conditioned filter paper before and after sampling is used to compute the concentration of SPM. The mass loading (MT) of total suspended particulates (TSP) was measured using the high volume air sampler.

The instrument is designed for outdoor use and can be operated without any particular rain protection provided the power connector is protected. A yellow LED will be lit when the temperature drops below 5°C and the automatic heating system is turned on. An automatic fan will be switched on at temperatures above 30°C. The dust was collected on Whatman GF/A size 25.4 × 20.32 cm glass fiber filter paper with a pore size of 1µm, operating at a flow rate of 1.1 to 1.7 m^3/min. The volumetric flow rate was measured using a calibrated orifice meter (attached part of APM430 samplers).

Installation of APM430

Place the sampler UPRIGHT position. First clean all outsides of the sampler, then wipe out all the internal surfaces and ‘filter holder/supporting net plate’ with tissue paper. The cleanliness of all surfaces (free from dust particles) must be assured. Check the level of water in flow measuring glass tube, fill to correct level, if necessary. We must assure that the filled water column must be free from any air bubble otherwise loose the drain plug slowly to escape the bubble while draining the water. Recheck the water level and fill it to 1mL mark. Tight the drain plug. Then SWITCH OFF the sampler ON/OFF switch (usually located at right corner top of the timer), connect the sampler with POWER SUPPLY (220V, The Neon lamp will Glow indicating the sampler is connected), and switch ON the sampler for a little while to check the proper working of TIMER, FLOW MESURING DEVICE, BLOWER etc. IN ANY OTHER PLEASE DO NOT SWITCH ON THE SAMPLER WITHOUT LAODING THE FILTER PAPER. After assuring that the sampler is working properly, then load the pre-weighed, marked filter paper above the Filter Supporting Plate (Wire mess plate). The filter must be exactly match with plate. There should not be any GAP or UNCOVERED PART OF PLATE, and then properly tight the UPPER Plate with purposely given tightening screws, to hold the filter paper correctly. Assure that the INBLOWING AIR should PASS only through the loaded filter paper. Set the timer correctly for the decided SAMPLING TIME (6, 8, 12, 16 or 24h). Recheck all the above, assure all instructions are followed then SWITCH ON the sampler.

Sample Handling and Transport

- It is very important that the filters are stored in filter holders or in resealable (zip) plastic bags during transport between the laboratory and the field.
- As far as possible try to transport the filters horizontally and with exposed side facing up.
- Make certain that the filters never are exposed to higher temperature than reached during sampling.

Setting up the Sampler

- Set up the instrument in desired place.
- The sampler should be upright on a solid surface. It is important that the inlet is located far from any obstruction that might influence on the airflow, like building walls and trees etc. Some pumps are known to release particles e.g. copper. Air from

such pumps should therefore be exhausted in a separate tube to at least 10 meter from the filter intake. Power should be maintained at 220 volts, 2 amp, single phase AC.

- Spread the GF/A filter paper on the impactor plate evenly and correctly, by the rough side on top.
- Make sure the filter is correctly placed and remember that the filters usually have a front side.
- Use tweezers, preferably of non-metallic material or teflon coated at least when heavy metals are to be determined. Never touch the filters with fingers. Use powder free gloves if tweezers are unavailable.
- Inspect the filter for any pinholes, irregularities etc. if found, select another one.
- Record the selected filter identification on the field log sheet.
- Load filter cartridge.
- Slip on (prepared) sampling head and latch.
- Water level in fluorate tube should be checked prior to start of sampling.

Menu Guided Operation, Immediate Start

- Read and record the total volume.
- Note down the date time at the start and the end of the exposure.
- Record any event that may influence the sampling i.e. power failure, storm, fires, rain etc.
- Note down the time totalizer from the instrument screen.
- Timed change of filter paper is ensured for 100% pure sampling.

The current menu feature is indicated by an arrow as shown below.

Switch on RED MAINS SWITCH.

Sampling Procedure Steps

1. START
2. CHECK FLUORATE LEVEL .
--

Then

3. NOTE DOWN TIME TOTALIZER
4. SET THE INSRUMENT TIME.

The initial time is subtracted from the elapsed time and difference is the total time of sampling. Average fluorate level is also calculated.

RESULTS

Sample Collection and Preparation for New Sampling

Open Filter Holder

Remove filter cartridge and pack for transport according to instructions. Do necessary maintenance if need be, i.e. cleaning impactor plate. Insert preloaded filter cartridge. Latch inlet.

Pre and Post-Sampling Filter Equilibration

Follow these steps to equilibrate the quartz filters before use:

- Use suitable envelops/box to carry and store the filter papers in the laboratory.
- Number the pre-conditioned and weighed filter paper and keep them in the labeled envelop after the sampling to carry to the laboratory.

Record the filter number, relative humidity, temperature, date and time at the beginning of equilibration.

Equilibrate each filter for either minimum 24 or up to 48 hours in the equilibration room having constant relative humidity of 30-40±5%, and constant temperature of 20-25ºC±2ºC.

Calibration

The HVS 430 has been properly calibrated before leaving the factory. Renewed calibration should take place according to your Quality Control, Quality Assurance System and the manufacturer's recommendation.

Responsibility

Personnel running this instrument should be acquainted with this SOP and follow the recommendations herein.

Equipment for calibration

This SOP assumes that the *Orifice meter (*actually a manometer) is at hand

Operation of the Orifice Meter

The orifice meter is really a differential manometer used to measure the pressure drop across an Orifice plate. It uses distilled water as the indicating fluid which must be topped up from time to time the brass screw mounted on the meter plate is a filling plug which must be opened to fill in the manometer fluid.

Maintenance of the Pump

The HVS has a Becker pump. Minimum acceptable width of a carbon vane is 10.5 mm. The vanes should actually be replaced when they have worn down to that width.

Never attempt to clean the pump with injection of detergent, water or solvents as accumulated carbon dust inside the pump house will cake and the pump will stall or even break because of the overload.

Vane Replacement

- Disconnect power, loosen the pump, disconnect tubing and bring it outside the housing.

- Undo the pump house nuts (4 pcs) and lift off the lid. Take out one vane, carefully noticing its orientation in respect to rotor, running direction and bevel of vane.
- Blow away any dust or deposits inside the pump. Use protective goggles to avoid damage to your eyes.
- Check the wear using calipers. Reject or accept vane. Always change all vanes at the same time.
- The filter cartridge on the pump's intake side should be cleaned or replaced if reduced pump performance is not caused by worn vanes.
- Both filter cartridges should at least be replaced after 5000 hours of operation.
- Reassemble in reverse order.
- Don't over torque the bolts when you fix the nuts. Tighten nuts in pairs diagonally opposed.
- Reset the operating hour counter that is; depress the lower white key and hold while you turn on the mains power switch.

Calculations

The SPM concentration is calculated as: $W = W_2 - W_1$ (gram)

Where, W_1: Weight of the preconditioned fresh filter paper (g), W_2: Weight of the conditioned filter paper after sampling of air for SPM (g) Note: Both W_2 and W_1 are to be measured after filter conditioning

Volume of air sampled (V): $V = Q \times T$ (Cubic Meters)

Where, Q: Average sampling rate (Cubic meters per minute), T: sampling Time (minutes)
Q_1=Initial sampling rate indicated by the Orifice Meter at the start of sampling.
Q_2=Final Sampling rate indicated the Orifice Meter just before the end of sampling.

Concentration of suspended particulate matter (PM_{10}) = W/V (grams/cubic meter)
= $(W/V) \times 10^6$ (µg/cubic meter)

Maintenance and Precaution

Maintenance of Blower

Check V- belt of Blower once in six month, if found loose kindly tighten it.

Maintenance of the Manometer Assembly

It is used distilled water as a manometer fluid. With time the water acquires residues and a precipitate forms which tends to clog the nozzles connecting the manometer must be flushed out at least once in three months. Don’t over tighten the plug since it would damage its seal ring.

AIII-5: Standard Operating Procedure of Respirable Dust Sampler (RDS) APM-460DX

Application and Description of the Equipment

This SOP is for operation and maintenance of the RDS-APM460 DX. The instrument is used for sampling of suspended particulate matter in air. The samples are analysed for mass and/or speciation of dust components. The sampler can be used for TSPM and PM_{10} other fractions decided by inlet configuration.

The sample air is drawn in through the inlet by an oil-less rotary vane vacuum pump, Becker VT 3.6/08. A μ-processor in the instrument determines the airflow by calculation based on the pressure difference across an orifice, ambient temperature and ambient pressure. Respirable Dust Samplers model no APM 460DX for monitoring TSPM as well as respirable fraction (PM_{10}) in ambient air along with optional attachment for gaseous sampling. It is based on the design standardized by USEPA. The designs of air inlet pipe and cyclone have been modified to provide a sharper cut-off. Digital timer has been replaced by the motorized timer for more accurate timing control. The manometer design has been modified for convenient operation and reducing parallax errors. An automatic flow controller has been provided. A brushless blower unit using a belt coupled induction meter. The flow rate of air through the cyclone remains constant at 1 m^3/min.

The instrument is designed for outdoor use and can be operated without any particular rain protection provided the power connector is protected. A yellow LED will be lit when the temperature drops below 5°C and the automatic heating system is turned on. An automatic fan will be switched on at temperatures above 30°C. The mains power should be switched on. The RDS 460 DX sampler is also designated as “medium volume sampler - MVS” by the manufacturer.

Respirable Dust Sampler Envirotech APM 460DX

Sample Handling and Transport

- It is very important that the filters are stored in filter holders or in resealable (zip) plastic bags during transport between the laboratory and the field.
- As far as possible try to transport the filters horizontally and with exposed side facing up.
- Make certain that the filters never are exposed to higher temperature than reached during sampling.

Setting up the Sampler

- Set up the instrument in desired place.
- The sampler should be upright on a solid surface. It is important that the inlet is located far from any obstruction that might influence on the airflow, like building walls and trees etc. Some pumps are known to release particles e.g. copper. Air from such pumps should therefore be exhausted in a separate tube to at least 10 meter from the filter intake. Power should be maintained at 220 volts, 2 amp, single phase AC.
- Spread the GF on the impactor plate evenly and correctly, by the rough side on top.

- Make sure the filter is correctly placed and remember that the filters usually have a front side.
- Use tweezers, preferably of non-metallic material or teflon coated at least when heavy metals are to be determined. Never touch the filters with fingers. Use anti-static powder free gloves if tweezers are unavailable.
- Inspect the filter for any pinholes, irregularities etc. if found, select another one.
- Record the selected filter identification on the field log sheet.
- Load filter cartridge.
- Slip on (prepared) sampling head and latch.
- Water level in fluorate tube should be checked prior to start of sampling.
- Rotameter value in gaseous sampling (for NO_X and SO_2) should be set at 1.0 *lpm*.
- Media for dissolving gases should be taken as an approx value (30ml) in our case.
- Impinger kit is filled with ice at every time of sampling.

Menu Guided Operation, Immediate Start

- Read and record the total volume.
- Note down the date time at the start and the end of the exposure.
- Record any event that may influence the sampling i.e. power failure, storm, fires, rain.
- Note down the time totalizer from the instrument screen.
- Timed change of filter paper is ensured for 100% pure sampling.
- Media is changed strictly timed after 4 hrs and time and fluorate levels are noted at each interval.

Switch on RED MAINS SWITCH.

Sampling Procedure Steps

1. Start

2. Check Flowrate Level .

Then

3. Note down Time Totalizer
4. Note down the Flowrate Value for Media at Start and Interval.

The initial time is subtracted from the elapsed time and difference is the total time of sampling. Average fluorate level is also calculated.

RESULTS

Sample Collection and Preparation of New Sampling

- Open filter holder.
- Remove filter cartridge and pack for transport according to instructions.
- Do necessary maintenance if need be, i.e. cleaning and re-greasing impactor plate.
- Reassemble inlet after inspection.
- Insert preloaded filter cartridge.
- Latch inlet.
- Collection of Media samples in culture tubes

Pre and Post-Sampling Filter Equilibration

Follow these steps to equilibrate the glass filters before use. Use suitable envelops/box to carry and store the filter papers in the laboratory. Number the pre-conditioned and weighed filter paper and keep them in the labeled envelop after the sampling to carry to the laboratory. Record the filter number, relative humidity, temperature, date and time at the beginning of equilibration.

Post- Sampling Filter Collection

Follow these steps to collect the filter paper after sampling:

- Inspect the equipment and record irregularities on the field form (such as pump not running anymore, sampling lines not connected to pump, construction work near site)
- Turn the pump off using the ON/OFF button.
- Read and record the elapsed time indicator and record the end time (local time, hh:mm) and end date.

- Remove the filter from the plate, fold 2 times to inner side and keep in the numbered envelop. Examine the filter for any defect that may have occurred during sampling.
- Record the filter number, relative humidity, temperature, date and time at the beginning of this post-collection equilibration. Equilibrate the filter paper before weighing. Record the weights.

Filter Blanks

In general, one filter blank per week is recommended. The filter blanks are to be **pre-equilibrated** under the same conditions as the filters which are to be used for sampling. In the same fashion, these should also be carried to the site, inserted into a sampler without starting the sampler (NO SAMPLING), taken out and stored in the carrying envelop in the site room for the sampling period, taken back to the equilibration room and weighed. If its weight exceeds to pre-weight that indicates a contamination problem either during transport or at the sampling site. Find the cause and solve it accordingly.

Calibration

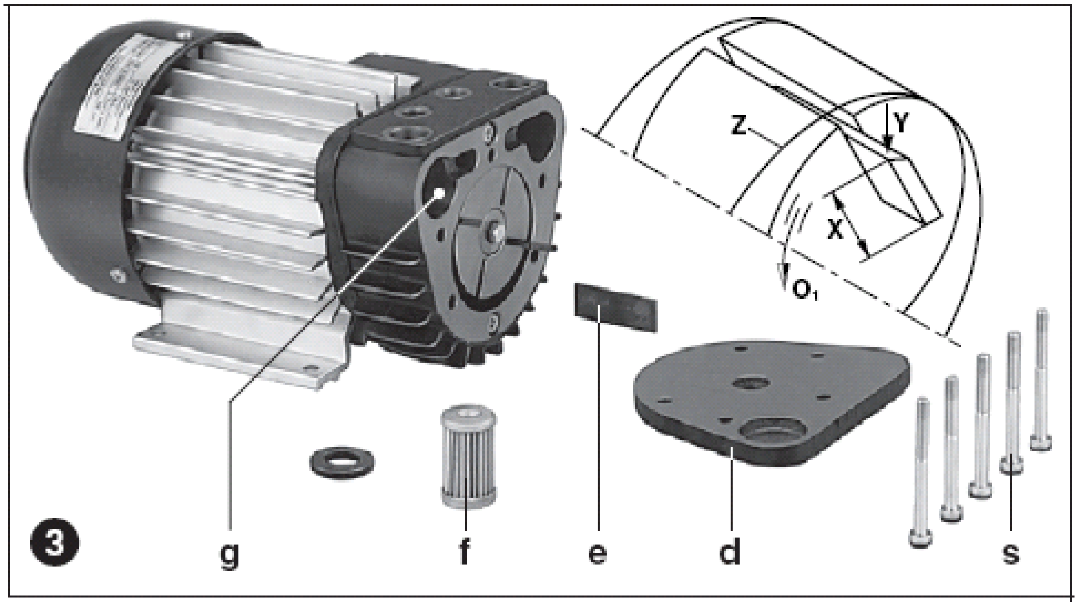
The RDS 460DX has been properly calibrated before leaving the factory. Renewed calibration should take place according to your quality control, quality assurance system and the manufacturer's recommendation.

Maintenance of the Pump

The RDS 460DX has a Becker pump. Minimum acceptable width of a carbon vane is 10.5 mm. The vanes should actually be replaced when they have worn down to that width.

Never attempt to clean the pump with injection of detergent, water or solvents as accumulated carbon dust inside the pump house will cake and the pump will stall or even break because of the overload.

Vane Replacement



- Disconnect power, loosen the pump, disconnect tubing and bring it outside the housing.
- Undo the pump house nuts (4 pcs) and lift off the lid. Take out one vane, carefully noticing its orientation in respect to rotor, running direction and bevel of vane.
- Blow away any dust or deposits inside the pump. Use protective goggles to avoid damage to your eyes.
- Check the wear using calipers. Reject or accept vane. Always change all vanes at the same time.
- The filter cartridge on the pump's intake side should be cleaned or replaced if reduced pump performance is not caused by worn vanes.
- Both filter cartridges should at least be replaced after 5000 hours of operation.
- Reassemble in reverse order.
- Don't over torque the bolts when you fix the nuts. Tighten nuts in pairs diagonally opposed.
- Reset the operating hour counter, that is; depress the lower white key and hold while you turn on the mains power switch.

Responsibility

Personnel running this instrument should be acquainted with this SOP and follow the recommendations herein.

Gaseous Sampling Attachment

In the model APM 460DX may be attached with the impingers (part APM 411 for gaseous sampling) in the suction side of the blower for sampling air passing through liquid absorbent filled in the impingers.

Calculations

The SPM concentration is calculated as: $W = W_2 - W_1$ (gram)

Where, W_1: Weight of the preconditioned fresh filter paper (g), W_2: Weight of the conditioned filter paper after sampling of air for SPM (g) Note: Both W_2 and W_1 are to be measured after filter conditioning

Volume of air sampled (V): $V = Q \times T$ (Cubic Meters)

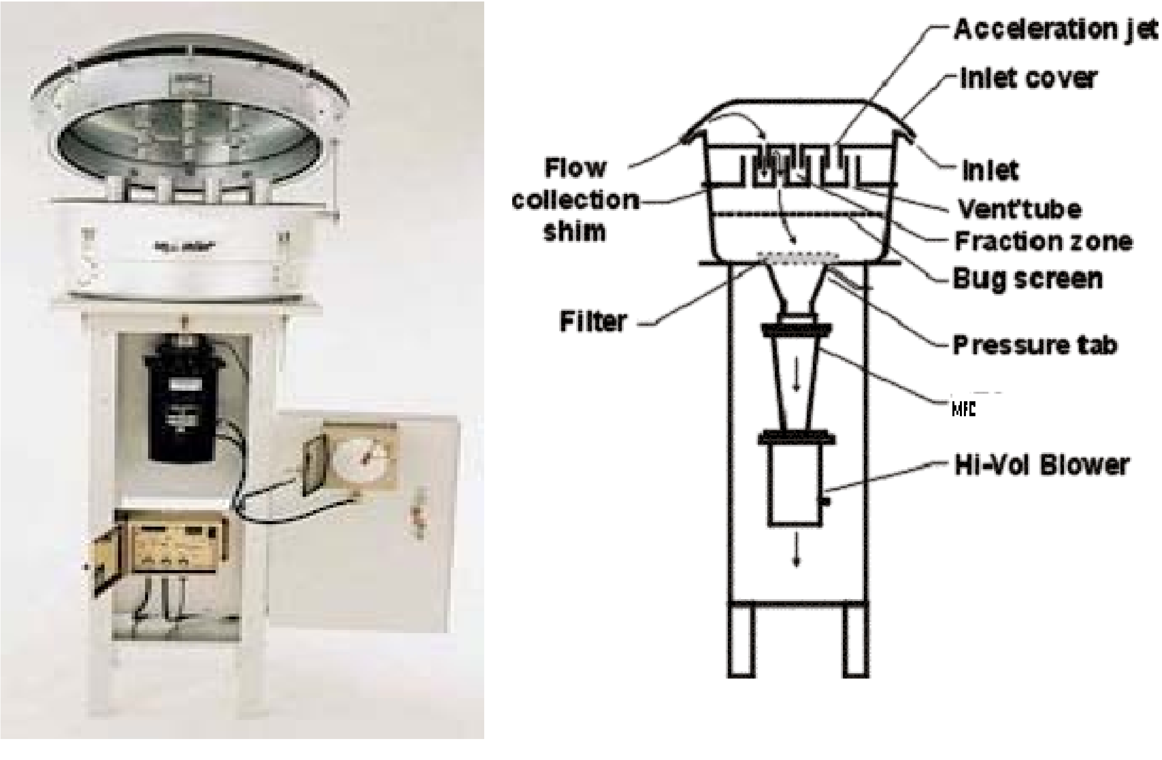
Where, Q: Average sampling rate (Cubic meters per minute), T: sampling Time (minutes)
Q_1=Initial sampling rate indicated by the Orifice Meter at the start of sampling.
Q_2=Final Sampling rate indicated the Orifice Meter just before the end of sampling.

Concentration of suspended particulate matter (PM_{10}) = W/V (grams/cubic meter)
= $(W/V) \times 10^6$ (µg/cubic meter)

AIII-6: Stanadard Operating Procedure of Packwill-PM$_{2.5}$ Sampler

Application and Description of the Equipment

This SOP is prepared for operation and maintenance of the Packwill (HVS) Model no: TE6070. The instrument is used for sampling of Particulate matter (PM) in air. The samples are analysed for mass and/or speciation of dust components. The sampler can be used for TSP, PM$_{10}$, PM$_{2.5}$ or other fractions decided by substrate configuration. The PM$_{2.5}$ high volume air sampler is complete with size selective inlet, outdoor anodized aluminum shelter, aluminum blower motor assembly, 8" x 10" stainless steel filter holder, mass flow controller with 20/60 cfm flow probe, 7-day mechanical timer, elapsed time indicator, continuous flow/pressure recorder, and filter paper cartridge (110 V/60 Hz or 220 V/50 Hz). The instrument is designed for outdoor use. The sample air is drawn in through the inlet by blower; a mass flow controller in the instrument determines the airflow by calculation based on the pressure difference across an orifice, ambient temperature and ambient pressure.



Description of High Volume Sampler (Packwill)

Size Selective Inlet

It is difficult to install the inlet in a vertical path into the shelter. Generally, it needs two persons to gently lower the inlet into the shelter. If the holes on the sides of the shelter do not exactly line up with holes in inlet shelter pan, it may be necessary to gently file away a small amount of material to align the holes. Mostly the inlet holes will be aligned by simply moving the inlet relative to the shelter until alignment. If the inlet hood does not fit onto acceleration plate, be sure that the spacers are not tightened until all of the washers, screws and spacers are loosely assembled. If inlet does not open properly, be sure that the strut is in correct position and strut slot is aligned with shoulder bolt. If the top tub and bottom tub do not seal together, be sure alignment pin in top tub goes into alignment pin “hole” in bottom tub. It is also necessary that the alignment pins on 1st stage plate are aligned with the alignment pin “holes” on bottom tub.

Adjustment hooks are provided to assure a seal between the top and bottom tube. To adjust, loosen nut with 3/8" wrench, adjust hook length until a tight seals develops then tighten nut. Shim plate clips are provided to assure the shim plate rests tightly against the first stage plate. Six adjustment screws and catches are provided to insure the seal between the inlet top section and the shelter base pan. Adjust catches, loosening the nuts with 3/8 wrench, adjust catch length until it seals then tighten. A shelter base pan gasket 16"x16" is provided to seal between the shelter base pan and inlet base pan. If a leak develops, replace this with gasket. All gaskets should be inspected for age or misuse. Replace as necessary.

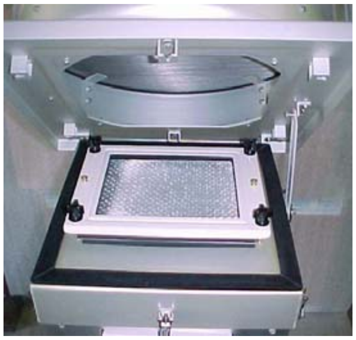
High volume PM_{10} size selective inlet (SSI) samples suspended particles in the air at 40 CFM (1.13 CMM) through the circumferential inlet. The symmetrical design insures wind direction insensitivity. The inlet design and internal configuration makes the collection efficiency independent of wind speed from 0 to 36 kilometers per hour. The particles are then accelerated through none circular acceleration nozzles, particles greater than 10 microns, aerodynamic diameter, impact onto a greased impaction shim plate.

The particles smaller than 10 microns are carried vertically upward by the air flow and down sixteen vent tubes to the 8" x 10" quartz or glass micro fiber filter, where they are collected. The large particles settle out in the impaction chamber on the collection shim plate and are removed by cleaning during prescribed maintenance periods. This inlet is adaptable to all Andersen instruments high volume systems.

Inlet of HVS (Packwill)

Closed inlet

Open Position



Expose Filter Cartridge

Substrates

Different Inlet Positions of HVS (Packwill)

It is important to maintain a constant flow rate because the cut-off is determined by the speed and mass of the particles. There are ten substrates for PM_{10} to $PM_{1.0}$.

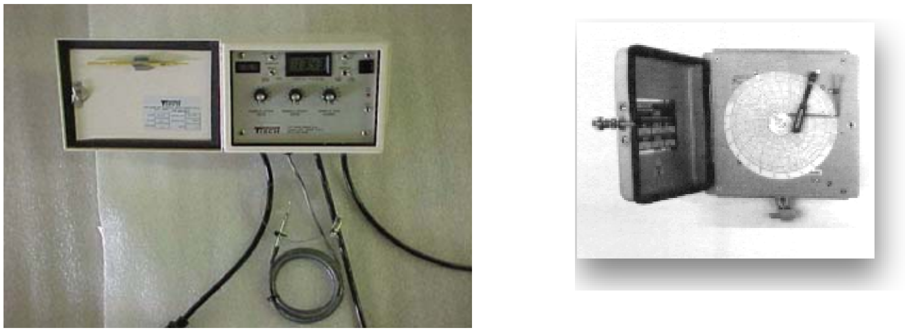
Dickson Continuous/Flow Pressure Recorder

Continuous air flow is accurately measured by the pressure transducer and a permanent record for every sampling period is recorder on a circular chart, offered as standard equipment on the PM_{10} Hi-Vols. The Model is furnished complete with CFM charts, cartridge pen point, and plug-in electrical transducer is mounted on the inside of the shelter door. If inking is done properly, then replace the pen. If pen arm is bent or pen arm lifter is damaged, thereby not allowing pen point to contact chart, replace the pen arm or pen arm lifter as necessary. A tight door seal is necessary to prevent drying of pen, replace if necessary. If pen does not respond properly to pressure/flow signal one of two solutions are available:

1. No rotation of chart indicates a defective chart drive. Replace as necessary.
2. Out of adjustment flow indications may exist if one adjusts the “adjustment screw” beyond its range. This condition allows the bellows to make contact with the chart drive thereby making the bellow movement inaccurate. Manufacturer re-adjustment is necessary.

Digital Timer/Programmer

This electronic timer/programmer can be programmed with a 0 to 8 day delay before sampling, a 1 to 9 day skip time between sampling and allows for sampling duration of 1, 2, 3, 4, 5, 6, 10, 12 or 24 hours. A built-in elapsed time indicator (non-resettable) records the total sampling to the nearest one-hundredth of an hour. All components are housed in a self-contained, weather-tight case with a hinged door providing complete programming access. If the timer does not activate the system at the desired time, see “Electrical Hookup Schematic” and timer instructions.



Digital Timer/Programmer

Sample Handling and Transport

- It is very important that the filters are stored in Envelope.
- As far as possible try to transport the filters horizontally and with exposed side facing up.
- Make certain that the filters are never exposed to higher temperature than reached during sampling.
- Do not touch filter paper with fingers.

- Filters should be stored at the laboratory in protective housing.
- The filter should be examined for any defects and the following procedure shall be adopted to check the same.
- The filters will be rejected on account of any of the following reasons:
    - Pinhole: A small hole appears as distinct and obvious bright point when examined through a source of light.
    - Chances of leakage: Any separation or lack of seal between the filter paper and its supporting plate.
    - Chaff or flashing: any external material on the reinforced plate or on the rubber seal area that would prevent an airtight seal during sampling.
    - Loose material: any extra material or dirt particles on the filter paper.
    - Discoloration and non-uniformity: any obvious discoloration and non-uniformity in the texture that might be evidence of contamination.

Setting up the Sampler

- Set up the instrument in desired place.
- The sampler should be upright on a solid surface. It is important that the inlet is located far from any obstruction that may influence on the airflow, like building walls and trees etc. Some pumps are known to release particles e.g. copper. Air from such pumps should therefore be exhausted in a separate tube to at least 10 meter from the filter intake.
- Fully open up the screw on upper right hand fixture for sampling tube.
- Slide sampling tube into fixture then push it firmly into bottom black push-fit elbow fitting (with blue release ring).
- Remember to push the blue release ring firmly down before you attempt to withdraw the inlet tube again. If not, you will risk damaging the push-fit fitting.
- Tighten fixture screw.
- Screw bottom part of filter holder on to top of sampling tube – finger tight only.
- Make sure the filter is correctly placed and remember that the filters usually have a front side.
- Use tweezers, preferably of non-metallic material or teflon coated at least when heavy metals are to be determined. Never touch the filters with fingers. Use anti-static powder free gloves if tweezers are unavailable.
- Inspect the filter for any pinholes, irregularities etc. if found, select another one.
- Record the selected filter identification on the field log sheet.
- Load filter cartridge.

- Slip on (prepared) sampling head and latch.

Menu Guided Operation and Immediate Start

- Before sampling, we should clean the out sides of the sampler, then wipe out the entire internal surface with tissue paper.
- Open the inlet and remove the impactor plate, net and filter holder from the sampler.
- Clean the impactor plate and greased on it.
- Place a numbered, pre-weighted filter paper in(position with its rough/exposed side up) filter holder by inspected the filter for any pinholes, irregularities etc.
- Put the filter holder on filter base properly.
- Keep the net on filter holder.
- Keep the impactor plate properly upon net.
- Close the inlet properly (above part of sampler).
- Open the flow rate unit.
- Adjust the flow chart paper on flow rate unit properly.
- Turn on the sampler from timer unit.
- Adjust the proper flow rate (40.0 CFM) from mass flow controller unit with adjuster.
- After adjusting flow rate we should close the door of mass flow controller unit & flow rate unit.

Always follow these steps:

1. Before sampling we should clean the sampler.
2. Do not clean the sampler during sampling.
3. Change the grease in every two days.
4. Place the filter paper precisely and check the rough (exposed) surface.
5. Fit the filter holder properly in filter base.
6. Do not forget to put the net on filter holder.
7. Do not press much the flow pointer.

Collection of Sample and Preparation of New Sampling

- After finishing the sampling, switch off the sampler first from mass flow controller unit and then from main switch.
- Open the inlet (upper part) of sampler.
- Remove the impactor plate.
- Remove the net.

- Loose the nut and remove the filter holder.
- Remove the exposed filter paper from filter holder with tweezer and fold the filter paper along its length and store the filter paper in a clean envelope.
- Remove the exposed flow chart paper from flow rate unit with carefully and put in envelope.
- Note down the date time at the start and the end of the exposure.
- Record any event that may influence the sampling i.e. power failure, storm, fires, rain etc.

Calibration

The TE-6070V TSP sampler should be calibrated:

1. Upon installation
2. After motor maintenance
3. At least once every quarter of a month
4. If orifice check is greater than 20.

Equipment for Calibration

This SOP assumes that the following equipment is at hand:

- Top loading adapter Plate.
- Roll-up style manometer.
- Tubing and carrying case
- Thermometer
- Barometer

Calibration Kit

This calibration kit model is recommended for all Tisch Environmental PM_{10} systems. This includes: variable orifice, NIST traceable calibration certificate, adapter plate, slack tube manometer, tubing and carrying case. The orifice in this calibration kit is variable to adjust sampler air flow from 15 to 60 CFM. By rotating the knob, filter resistance is simulated permitting calibration of the flow indicator at various points on the manometer, top loading adapter plate, roll-up style manometer 1/4" and carrying case. The calibration orifice should be re-certified annually according to Federal Guidelines

Calibration Kit

Calibration Procedure

1. Install the calibrator (orifice) and top loading plate on top of the filter holder. Tighten and make sure that there are no leaks. Note: No filters used during calibration procedure.
2. Turn on sampler and allow it to warm up to its normal operating temperature.
3. Conduct a leak test by covering the holes on top of the orifice and pressure tap on the orifice with your hands. Listen for a high-pitched squealing sound made by escaping air. If this sound is heard, a leak is present and the top loading adaptor hold-down nuts need to be re-tightened. Avoid running sampler for longer than 30 seconds at a time with the orifice blocked.
4. Open both ports on top of the manometer and connect tubing from the manometer port to the pressure tap on the orifice. Leave the opposite side of the manometer port open to the atmosphere.
5. Record the manometer reading from the orifice and the magnehelic reading from the side of the sampler. Both readings are in inches of water. Repeat this step for 5 points total by adjusting the orifice to 5 different positions between 10 and 25 on the magnehelic gauge.
6. Record the following information on the calibration sheet:
    a. Ambient air temperature (ºC)
    b. Ambient barometric pressure (inch Hg)
    c. Sampler serial number
    d. Orifice serial number

   e. Orifice Q_{act} slope and Q_{act} intercept
   f. Date of last certification for orifice
   g. Date of calibration
   h. Station location
   i. Operator's initials.

7. Convert the orifice readings to actual air flow using the equation according to operation manual.
8. Calculate the percent difference between the calibrator flow rates and the sampler flow rate by using the operation manual.
9. Ensure that the % differences are $\leq$ 4% for each of the 5 calibration points and record the % difference on the calibration form for each point. If greater than 4% difference, a leak may be present and the sampler should be recalibrated.
10. Draw a plot b/w sampler flow rate and calibrator flow rates. Calculate the slope and intercept of this curve. Calculate the Pearson coefficient. The Pearson coefficient should be ≥ 0.99. If < 0.99, recalibration should be performed as there may be a suspect air leak during calibration.

AIII-7: Standard Operating Procedure for Weighing of Filters

Principle

The mass of these particles is determined by the difference in filter weights prior to and after sampling. The concentration of particles in the designated size range is calculated by dividing the weight gain of the filter by the volume of air sampled.

Environmental Requirements

1. Preferably filters should be stored in conditioning room, where the temperature must be 20^0C ± 3 ^{0}C and relative humidity 50% ± 5%, if conditioning room is not available then filters should be stored in desiccator and the temperature and relative humidity must be controlled as much as possible both in desiccator as well as in the weighing room.
2. All the filters unexposed/exposed must be weighed after desiccation of 48 hrs.
3. All filters must be weighed twice to confirm the filter weights are stabilized.
4. The interval between two weighing must be at least 12 hours for unexposed Filters and for exposed Filters it must be between 24-72 hrs.

Equipments

1. Balance
2. Control weights
3. Calibrated weights
4. Control Filters
5. Tweezers
6. Desiccator (if conditioning room is unavailable)
7. Thermometer
8. Hygrometer

Precautions

1. Always use tweezers for handling the objects.
2. Filters should be handled carefully.
3. Filters should not be damaged, if damaged at initial weighing it should be totally discarded and if filters are damaged at final weighing, there must be note at the time of reporting the data.
4. Filters must be weighed immediately after picking up from the desiccator.

Actual Procedure

1. Make a note of the Temperature and Humidity inside the desiccator and weighing room.
2. Check for the bubble (it must be in centre)
3. Check for dust or any other particles and wipe off.
4. Tare the balance before every weighing.
5. Weigh the Control weights.
6. Update the Control Charts and check the weights so that they are within the upper and lower warning limits.
7. Weigh the unexposed/exposed filter papers.
8. Before every weighing sequence, weigh the Control Filters marked with CF and make a note.

Reporting the Data

1. Daily feed the result in designated excel spread sheet on computer.
2. Calculate the dust concentration.
3. Report the data to the concerned authority.
4. Take a printout of the daily report.
5. Store the printout in the designated paper file.

Take a weekly backup of the results in Pen-drive and store at designated place.

AIII-8: Standard Operating Procedure of Gas -Chromatography

Scope

Gas Analyzer GC is pre-plumed and ready to resolve H_2, O_2, N_2, CH_4, CO, ethane, CO_2, ethylene, NO_x, acetylene, propane, butanes, pentanes and C6 through C8. The basic version of multiple gas analyzer GC has a TCD detector only. A TCD-HID detector combination is also available. This gas chromatography is Model No. 910/310 of Buck Scientific Ltd (USA) made.

Operating Procedure

- Set the gas cylinder pressure 15-20 psi higher than the head pressure (helium carrier). The carrier head pressure used to generate the test chromatograms at the factory is printed on the right side of your GC. Typical head pressure for a Multi-Gas instrument operating at 20 ml/min is about 20 psi.
- Damage or destruction of the TCD filaments will occur if current is applied in the absence of flowing carrier gas. Always verify the carrier gas can be detected exiting the TCD carrier gas outlet before energizing the TCD. Labeled for identification, the carrier gas outlet is located inside the column Oven. Place the end of the tube in liquid and observe. If there is no bubble exiting the tube, there is flow problem. Do not turn on the TCD current if carrier gas flow is not detectable. A filament protection circuit prevents filaments damage if carrier gas pressure is not detected at the GC. But if cannot prevent filament damage under all circumstances. Any lack of carrier gas flow should be corrected before proceeding.
- Set the valve oven temperature to 90^0C.
- Turn the TCD current to low. Ignite FID is present. Turn Methanizer to 380^0C if present. Turn HID current on if present.
- Determine the elution time of ethane so that you can set an event program that will rotate the gas sampling valve at the right time during the run. Ethane is the first peak to elute from the silica Gel column after the H_2, O_2, N_2, CH_4, and CO, which are

separated by the molecular sieve column. If the valve is not rotated back to the Load position buy turning relay G off prior t ethane elution then the ethane and CO_2 will get stuck in the molecular Sieve column.

Type in n Event Program as follows:

0.00	zero
0.1	G on
0.3	G off

- Set the column oven temperature programs as follows :
  40^0C hold six min then ramp at 100/min to 200^0C
- In peak simple, zero the data system signal by clicking the auto zero button, then hit the space bar or the run button on your GC. Inject a sample that contains ethane into the gas. Sampling valve through inlet on valve oven.
- Revise the event table so that relay G turns off just before the ethane peak begins to rise from the baseline. A typical event table for this GC is:

0.00	Zero
0.05	G On
5.05	G off

- If the H_2, O_2, N_2, CH_4 and CO do not elute from the molecular sieve column before the elution of ethane, increase the valve oven temperature so that all peaks trapped on the molecular sieve column elute with in the required time.
- Following accessories are required at the time of analysis:
  - Hydrocarbon trap (Trigon Technologies, catalog # TTH-200-4) for helium gas
  - Moisture trap (Trigon Technologies, catalog # TTM-200-4) or other suitable trap for the hydrogen generator.
  - Syringes: (a) Gas–tight 1000 µl and 2500 µl syringes for gas calibration injections (Hamilton, catalog # 81320 and 81420, respectively); (b) 10 µl and 25 µl syringe for liquid calibration injections (Hamilton, catalog # 80400 and 80030, respectively).
  - Aim n flame lighter by Scripto to light the FID.
  - Printer paper (8 ½ cm x 11 cm).
  - Ink cartridge #20 for a Hewlett-Packard Deskjet 648C printer

Chemicals

Solvents

Low-residue or chromatographic-grade: - hexane, ethylene chloride, methanol (for standard dilutions, sample extractions and general sample preparations, column maintenance); Derivitizing / standards agents for old-style fused silica capillary columns.

Analytical Methods

The concentration of BTX was analyzed using gas chromatography (GC) (Buck Scientific model 910, USA) with a photo ionization detector (PID) as shown in figure below. The gas samples were collected periodically using a 5 mL gas tight SGE syringe and injected in to a column (RESTEK MXT) with an internal diameter of 0.53 mm, length of 30 m and thickness 1.0 µm. The operating specification of GC was set as: carrier gas (Helium) at 2.5 kg/cm^2 pressure; column oven temperature 60°C and; detector temperature 150°C. Injector temperature was held at 100°C. Every time 1 mL of gas sample from the reactor was injected in to the GC. The GC was calibrated at three levels (2 µg/ml, 20 µg/ml, and 200 µg/ml) of BTX standards (Merck make).

The benzene vapor was injected in to the reactor and the reactor was put in the sunlight and the system was rested for 30 minutes. Then 1 mL gas sample from the reactor was taken at thirty minute interval, through a syringe for analysis on GC for three to four hours continuously. The same procedure was followed for toluene and p-xylene. The same experiments for mixture of benzene, toluene, p-xylene was done. All experiments were repeated three times.

AIII-9: Standard Operating Procedure of HPLC

Materials Required

1) Glass centrifuge tube
2) Metecli's scissors
3) Aluminium foil
4) Parafilm
5) Exposed filter paper
6) HPLC grade extraction solvent (toluene)
7) HPLC grade acetonitrile (ACN)
8) HPLC grade water
9) Silica mesh – 100-150 micron
10) 0.22 Millipore filters
11) Clean glass ware (reagent bottles, 100- 200 ml flask, beakers etc.)
12) Acetone
13) Oven
14) Gloves
15) Tweezers
16) Filtration unit
17) Centrifuge
18) Sonicator
19) Rotary evaporator or Tubo Vap
20) HPLC
21) Sintered chromatographic column
22) Glass wool (optional)
23) 5-10 ml brown vials
24) crimp and septa
25) Metler balance (5 digit)

Procedure to Clean Utensils to Prevent Contamination

1) Keep all glasswares used for PAN analysis separate
2) Clean all glassware three times with acetone and thereafter three times with ACN.

3) Oven dry all glass ware at $100^{o}C$ for 20 min. Let it cool.
4) Clean the above glass ware with extraction solvent and cover them with Aluminium foil.
5) Put a sheet of Al foil on a clean table

Extraction

1) Put gloves and take the exposed filter with help of tweezers.
2) Mark filter paper no. , date and date of sampling in the log book, as in reagent bottles.
3) Cut the filter paper into small pieces and put into 100mL or larger marked reagent bottle.
4) Add about 0.7 to 1 µg of internal standard (Pyrene D_{10})
5) Add 60 mL of extraction solvent (Toluene).
6) Seal the cap of reagent bottle with Parafilm.
7) Put the bottles in the sonicator and sonicate for 30 min.
8) Remove from sonicator, decant in marked centrifuge tube. Since they may be more than one tube – record labeling in log book.
9) Put 30 mL extraction solvent in the used reagent bottle. Repeat steps 7 & 8.
10) Repeat step 9 again with 30 mL more solvent.

Centrifuge to Remove Filter Particle Interference

1) Put centrifuge tubes in machine and centrifuge at 800 rpm for 20-30 min.
2) Take the tubes out and filter the extract using 0.2 µ Millipore filter paper and filter assembly (sample).

Cleaning Extracted Sample

Column preparation

1) Take 10 g of 100-270 mesh size silica mesh. Make a slurry in 25mL of toluene.
2) Add to column
3) Add 1 cm of anhydrous sodium sulphate on top of the column.

4) In the slurry beaker, take 25 mL of toluene. Stir and add to column
5) Collect the 25 mL from bottom.
   (Note: Column should not be dry when using samples. The sample should be added within 10-15 min of adding toluene).
6) Put the sample in column and elute it with 50 mL extraction solvent. Collect a total of170 mL in 250 mL round bottom flask.
7) Put in rotary evaporator at 40^0C and concentrate to approx 1-2 mL. This could take anytime between 20 –60 min.

Changing Solvent

8) Put 3 mL ACN in the flask. Concentrate to 1 mL. Repeat process total of 3 times.
9) Take the concentrated sample out using micropipette and note the exact volume.
10) Put sample in 5-10 mL brown colored vials. Mark the vial with sample no. and final volume. Mark the volume present in vials with a permanent marker.
11) Crimp the vials with septa. Weigh and note in log book.
12) Store sample in refrigerator (freezer)
   (Note: Sample can be stored for approx 25 days depending on volatility and initial volume)

HPLC

Instrumentation

1) Pump, Quaternary low pressure
2) Fluorescence detector (for PAH ppb range) Channel 2 (L-7485) in software
3) UV detector (for PAH ppm range) Channel 1
4) Interface unit (Interfaces HPLC with computer using HSM software
5) HSM software
6) Column (5 µ PAH 20mm)
7) Online degassing system
8) Reodyne injector

Pump types explanation

a) Isochratic: one mobile phase or mixture from one inlet

- b) gradient
    - i) high pressure: 2 or more separate pumps
    - ii) low pressure: 1 pump with 2 or more inlets using gradient accessory

Method development

AIII-10: Standard Operating Procedure of Carbon Monoxide Analyzer

Scope of SOP

The model CO12M is a continuous carbon monoxide monitor specific to low carbon monoxide concentrations in ambient air under atmospheric conditions. It uses the principle of detection of the absorption in the infrared. Thanks to recent optical and electronics technologies, the device offers numerous advantages. It is nevertheless easy to use and is low-maintenance instrument.

Description of the Equipment

Front Panel

The front panel includes:

- A general switch
- A backlit liquid crystal display:
    - 16 lines * 40 columes (240*128 pixels)
    - The display provides the measurement values according to the selected unit, the information required for programming and testing the unit.
- A keyboard with 6 touch –sensitive keys
- The control and check functions of the unit are cotrolled through the keyboard.
- The function of each key varies with the difference screens or menus.

Rear Panel

The rear panel of CO12M contains:

- The electrical connectors and gas inlet/outlet connector.
- Gas inlets/outlets (right-hand side)
- Inlet of sample to be analyzed composed of fitting for 4/6 mm tube associated with a dust filter holder containing a teflon filtering membrane (5).

- The “span gas” inlet consists of a 4/6 fitting (6) for connection of an outside span gas, delivered at atmospheric pressure.
- The optional “Zero air” inlet (4), for connection of a test device for the outside Zero.
- The exhaust (7).

Electrical Equipment Connections (left-hand side)

The main power supply assembly consists of:

- A 3-contact socket (1) for connection of standard power cable and the general fuse: 1 A/220 V or /*115V (2).
- 1 standard 25-pin plug (10), for a serial links COM1 (RS 232C-RS422) and COM2 (RS232C).
- 1 standard 37 pin

Ventilation

Ventilation is achieved by a fan (3).

Main Features

- Programmable measurement range from 10 to 200 ppm with a minimum detectable of 0.05 ppm.
- Automatic calibration sequence, can be programmed or remote-controlled.
- Self-calibration.
- Memory storage of average measurements with a programmable period (capacity: 5700 averages).
- Continuous operating tests (infrared energy, flow rate, temperature and pressure).
- Analog output of CO concentration and 2 analog output of MUX value.

Principle of Measurement

The CO12M operates on the principle of infrared absorption according to Beer-Lambert Law. The carbon monoxide absorption spectrum is at a maximum at a wavelength of 4.67µm, which corresponds to the spectrum selected by by the optical filter.

Since the absorption spectrum is not continuous, a gaseous filter, referred as the “correlation wheel” is associated to the optical filter, thereby enabling highly selective measurement of the gas to be analyzed by eliminating interference by gases with extremely close Co absorption spectra.

CALIBRATION

OVERVIEW OF CALIBRATION AND CONCEPTS

To ensure the accuracy of the measurements performed using the CO12M monitor, the unit must be regularly checked, calibrated and adjusted, following the quality assurance plan of the user.

- Check of zero span point :
- This operation consists of comparing the monitor response, for zero air and a span point of the range used, to the gas standards used.

  This check is used to measure the monitor drift in time without modifying the adjustment coefficient. This check can be performed using the internal zero air and span.

  Frequency: generally 24 hours in automatic cycle mode.
- 2-point calibration:

  This is a procedure for checking and correcting the response of the monitor at zero and at a span point located at approximately 80% of the full scale of the measurement range used.

  Frequency: monthly, or more frequently if the monitor enables it.
- Span (multi point calibration):

  This involves a complete check up of the monitor performance characteristics (linearity).

  Frequency: quarterly, or following out-of-tolerance calibration check result requiring an intervention on the monitor.

Calculation

Use formula below to calculate the reading value in ppm from the value in % full scale to be taken into account:

$$[CO]_{read} = (S_{record} - Z_{co})/100 * ECH$$

Where:

Srecord is the value noted on the recorder, expressed in percentage of the full scale of the recorder,

ECH is full scale of the monitor,

Zco was measured previously.

Preventive Maintenance

Safety Instructions

- Operators must be observing the safety instructions at all times.
- Cut off the power supply when performing any work inside the unit.
- Take necessary precautions for handing dangerous products (for example, gloves, protective mask, etc).
- Only qualified personal should intervene on the unit.