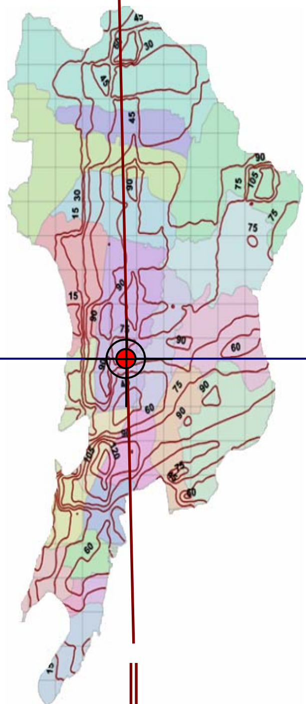

Final Report

Air Quality Assessment, Emissions Inventory and Source Apportionment Studies : Mumbai

Sponsor By :

Central Pollution Control Board, New Delhi

National Environmental Engineering Research Institute

November, 2010

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FOREWORD

The increasing disease burden due to air pollution has prompted many decision makers to take a close look at the changing air quality due to many sources. Air pollution has started to impact the economy of the urban centers as also the nation. An integrated approach must be considered by any implementing agency to formulate strategies and embark upon the action plan. Strategies for sector specific pollutants need to be drawn from scientific evidences which are concrete and clear.

This report has been an outcome of the Auto Fuel Policy document of Government of India recommended for carrying out source apportionment studies to fill the knowledge gap. Central Pollution Control Board (CPCB) and Ministry of Environment and Forests coordinated the study to delineate the status of Particulate Matter levels and investigate their sources in 6 major cities in India. The study for Mumbai was carried out by NEERI, Mumbai Zonal Center with the support of other scientists from Nagpur and Delhi. The present study included components like assessment of present air quality status at seven different sites in Mumbai, quantification of percentage share of air pollutant emissions attributable to transport, industrial, commercial, residential and other activities. It also included projected growth trend in emissions for the next 5 and 10 years from various source categories. Different impact scenarios were generated for development of appropriate action plan and finally delineate the impact of implementation of sector wise short and medium term interventions for air quality improvement.

The institute wishes to place on record the cooperation extended by the CPCB officials, Dr.V.Rajgopalan, Mr.J.M.Mauskar, Prof. S.P. Gautam, Dr.B.Sengupta, Mr.J.K. Kamyotra, Dr. A.L.Agarwal, Dr. Prashant Gargava; Mr. Abhijit Pathak, Prof. Virendra Sethi and Prof. R.S.Patil from CESE Department, IIT-Bombay; Desert Research Institute (DRI), Nevada, USA and Technical Committee Members for their valuable inputs during the study.

Contributions from Maharashtra Pollution Control Board, Brihanmumbai Municipal Corporation, and the office of Regional Transport Commissioner and other organizations who provided secondary data and information are gratefully acknowledged.

(S.R.Wate)

November, 2010

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Abridged Report: Mumbai

1.0 Introduction

Urban air quality issues have emerged as a major concern impacting quality of life. The high disease burden due to air pollution has started to impact the economy of the urban centers. The common knowledge of air pollution impacts on human health has not yet led to comprehensive plans to combat the rising levels of air pollution level exposure.

Pollutants of all origin should be considered in entirety for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc. Strategies for sector specific pollutants need to be drawn from scientific evidences which are concrete and clear. These facts can be derived from the use of multitude of techniques such as emission inventory, dispersion modeling, receptor modeling and finally prioritization based on cost effectiveness analysis of varied options. The present study had following major issues which have been addressed in the report:

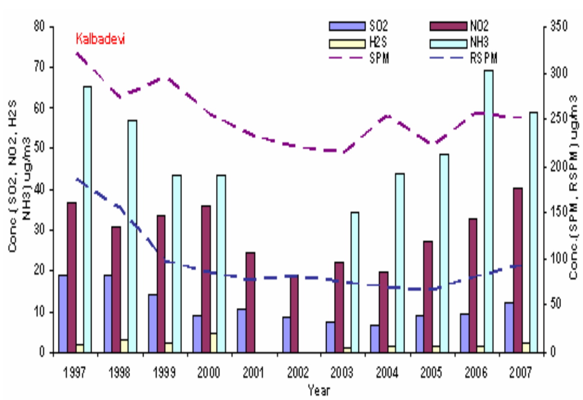
- Assessment of present air quality status at seven different sites in Mumbai.
- Quantification of percentage share of air pollutant emissions attributable to transport, industrial, commercial, residential and other activities.
- Projected growth trend in emissions in the next 5 and 10 years from various source categories with a view to generate different impact scenarios for development of appropriate action plan.
- Impact of implementation of sector wise short and medium term interventions for implementation in ambient air quality. In case of vehicular sector, the options suggested are better vehicle technology, better maintenance practices, improved traffic management, improved tail pipe treatment, improved fuel quality etc. Whereas, in industrial sector growth or decline of industries, fuel quality improvement, fuel shift, improved emission control technologies and shifting of industries are possible options. With respect to area source, growth of population, fuel quality improvement, better management, fuel shift, road dust elimination, change in social practices etc are the options, suggested to control the emissions.

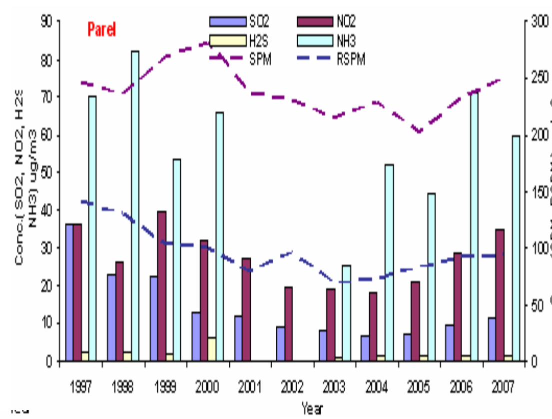
The study was divided into distinct phases which included ambient air quality assessment and analysis, emission inventory of all sources, receptor modeling, and dispersion modeling and action plan development.

2.0 Ambient Air Quality Monitoring

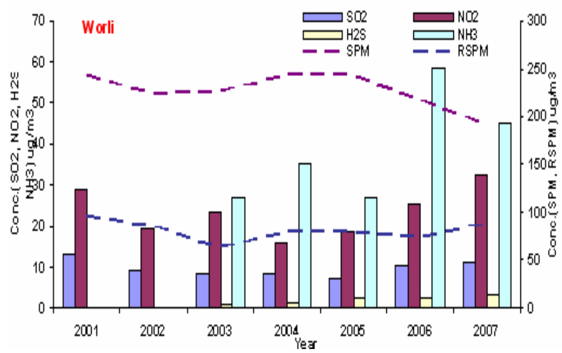
2.1 *Past Trends of Air Quality*

Under National Ambient Air Quality Monitoring Programme (NAAQM), NEERI is monitoring the air quality at three locations viz. Kalbadevi, Parel, Worli for last 20 years. MPCB (Maharashtra Pollution Control Board) also carries out air quality monitoring at three stations viz. Sion, Mulund and Bandra for the criteria pollutants. The air quality trends are presented in **Fig E1.**





NEERI's Monitoring Sites



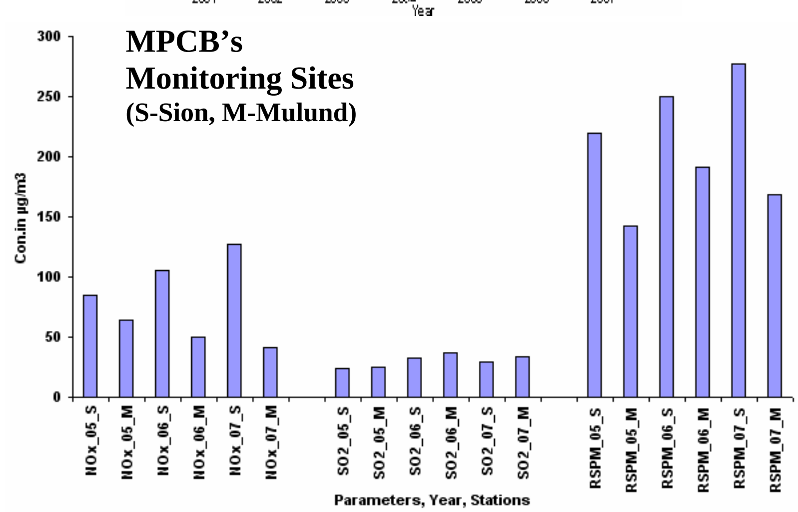


Fig E1 : Past Air Quality Trends Monitored by NEERI & MPCB

2.2 *Present Study*

Mumbai city air quality was monitored with a view to establish the current levels and also to collect samples for source apportionment related analyses. Seven representative sampling sites were selected, representing Greater Mumbai Region viz. Colaba as Control site, Mahul as Industrial site, Andheri and Mulund as kerb sites, Dadar as Commercial, Khar as Residential site for upper income group and Dharavi as Slum Residential site. Design of air quality monitoring location included the factors such as population density, meteorology, topography, etc. During the study, proper guidelines were followed for the selection of the monitoring stations. Air quality monitoring was accomplished by carrying out air quality monitoring for 30 days continuously in each season for three seasons viz. summer, post monsoon, winter. In all the seven selected locations, level of pollutants such as SPM, PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, Aldehydes, NMHC and HC were recorded. Further, PM_{10} samples were analyzed for EC/OC, and elements and ions including molecular markers for representative samples. Some limited $PM_{2.5}$ samples were also analyzed for elements and ions. The average concentrations of different pollutants at selected monitoring sites are presented in **Fig E2**.

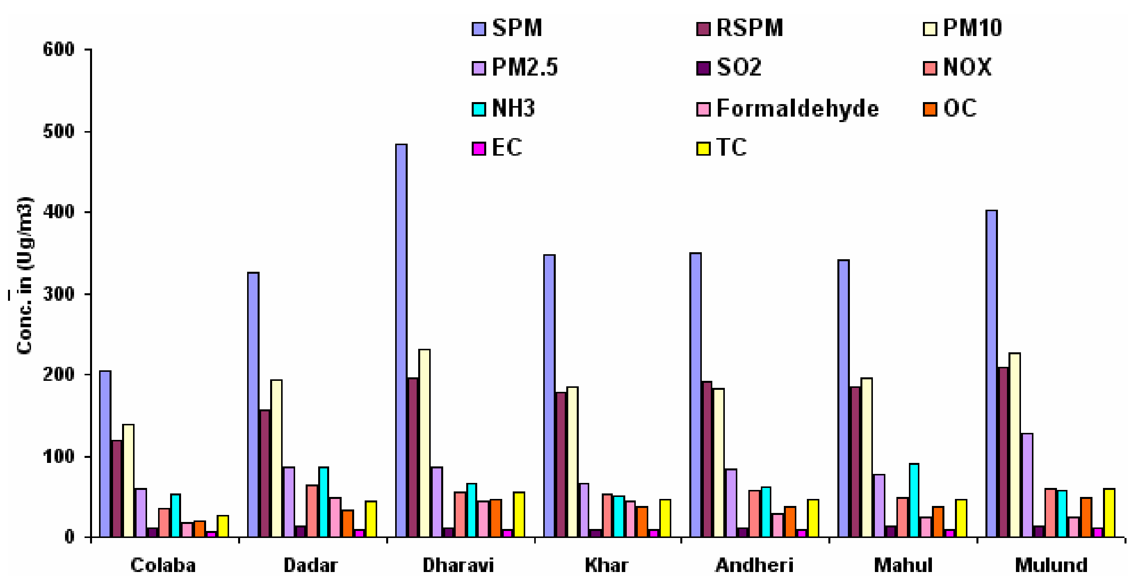


Fig E2 : Average Concentrations of Different Pollutants at Seven Monitoring Sites

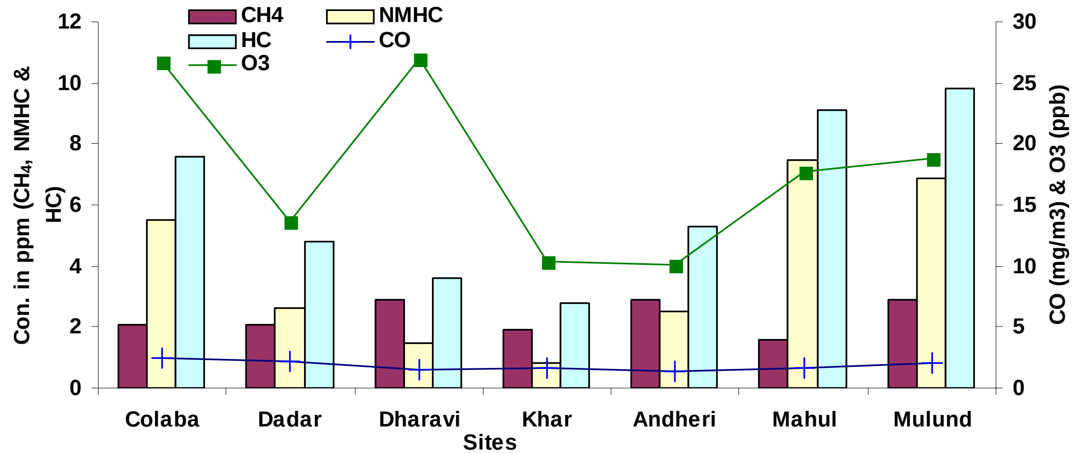


Fig E2 : Average Concentrations of Different Pollutants at Seven Monitoring Sites

As evident from **Fig E2,** Colaba is the least polluted site, justifying its selection as control site. The concentration of PM_{10} is highest in Dharavi due to smelting, biomass burning, coal combustion, oil burning and vehicles. Mahul shows maximum concentration of SO_2 due to industrial sources. NO_2 has maximum concentration at Dadar, predominantly due to vehicular exhaust. Khar as a residential site showed low pollution levels compared to other sites, except the control site at Colaba.

3.0 Molecular Marker Analysis

Ambient air quality samples were subjected to molecular marker analysis as well. Representative samples were taken from different seasons and all the seven sites for analysis at Desert Research Institute, DRI, USA, using in-injection port thermal desorption gas chromatography /mass spectrometry technique. **Fig E3** represents average concentration of Molecular Markers like PAH, n – alkane, alkenes, hopanes, levoglucosan etc at seven sites. Molecular marker analysis also brings out the indications of dominant local sources. With a view to assess the variability of markers in comparison to Colaba, all values of other sites were compared by dividing the levels by the markers concentration at Colaba as given in **Table E1.**

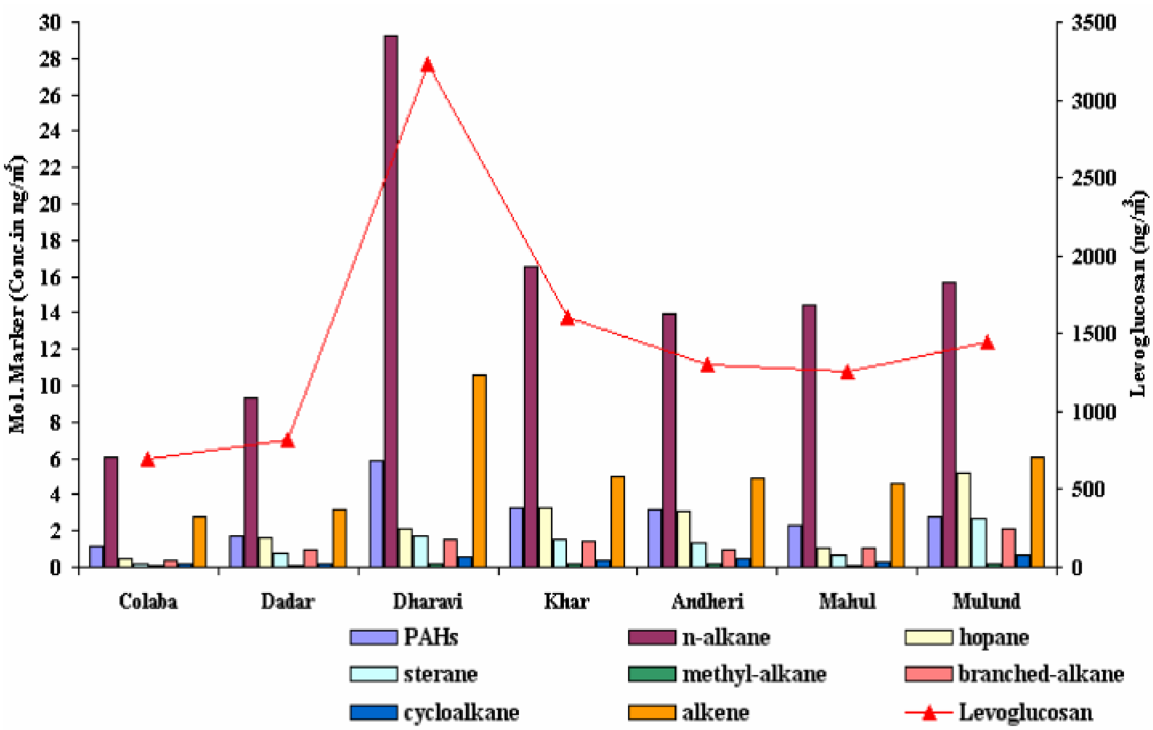


Fig E3: Average Concentrations of Molecular Markers at Selected Monitoring Sites

Table E 1: Comparison of Molecular Marker Concentration with Background Site (Colaba)

	Dadar	Dharavi	Khar	Andheri	Mahul	Mulund
PAHs	1.5	**5.1**	2.9	2.8	2.0	2.4
***n*-alkane**	1.5	**4.8**	2.7	2.3	2.4	2.6
Hopane	**3.8**	**4.8**	**7.6**	**7.1**	2.5	**12.0**
Sterane	**3.4**	**7.2**	**6.3**	**5.7**	2.9	**11.5**
Methyl-alkane	1.3	1.5	1.6	1.6	1.2	1.7
Branched-alkane	2.2	**3.7**	**3.3**	2.3	2.5	**5.0**
Cycloalkane	1.5	**4.0**	2.6	**3.4**	2.1	**4.6**
Alkene	1.1	**3.7**	1.8	1.7	1.6	2.1
Levoglucosan	1.2	**4.7**	2.3	1.9	1.8	2.1

In Colaba, the concentrations of all the molecular markers are lower than all the other sites. For example, PAH concentration at Colaba is 5.1 times lower than its concentration at Dharavi; n-alkane concentration is 4.8 times lower than that at Dharavi. Mulund being a kerbsite has hopanes and steranes concentration 12 and 11.5 times higher than that observed at Colaba. Due to combustion activities and foundry operations at Dharavi and Mulund, these sites have 3.7 and 2.1 times higher concentration of alkenes than Colaba. The concentration of Levoglucosan at Dharavi is 4.7 times higher mainly because of greater extent of wood and biomass burning.

Presence of higher levels of hopanes and steranes at all other sites (highest at Mulund) indicates that vehicular combustion sources are uniformly present across the city. Even residential site at Khar shows high hopanes and steranes, indicators of petrol and diesel combustion.

Dharavi site indicates its complexity of sources as it represents a place of domestic, commercial, small industries, refuse combustion, pottery making etc.

4.0 Chemical Characterization of PM

Chemical characterization of PM_{10} and $PM_{2.5}$ was carried out by estimating different ions and elements. Percent contribution of carbonaceous species, crustal, non crustal elements, ions along with the unidentified fraction of PM_{10} and $PM_{2.5}$ for different season and monitoring sites are presented in **Fig E4.**

Percent contributions of crustal, non crustal, ions, EC, OC and unidentified part vary depending upon the site specific activities, land use and meteorology. Monitoring results of all locations indicate that all the pollutants have maximum concentration during winter season due to meteorological conditions such as temperature inversion and low wind speed. Though winter does not lead to large scale burning of wood, as is common in Delhi, the measured concentrations are higher in Mumbai. Visibility reduction due to fine particles has started its impact in Mumbai as well, which are mainly due to fine particles presence in atmosphere. Figure below presents the total mass which comprises of all fractions of PM in terms crustal, non-crustal, ions, EC, OC and un-identified portion.

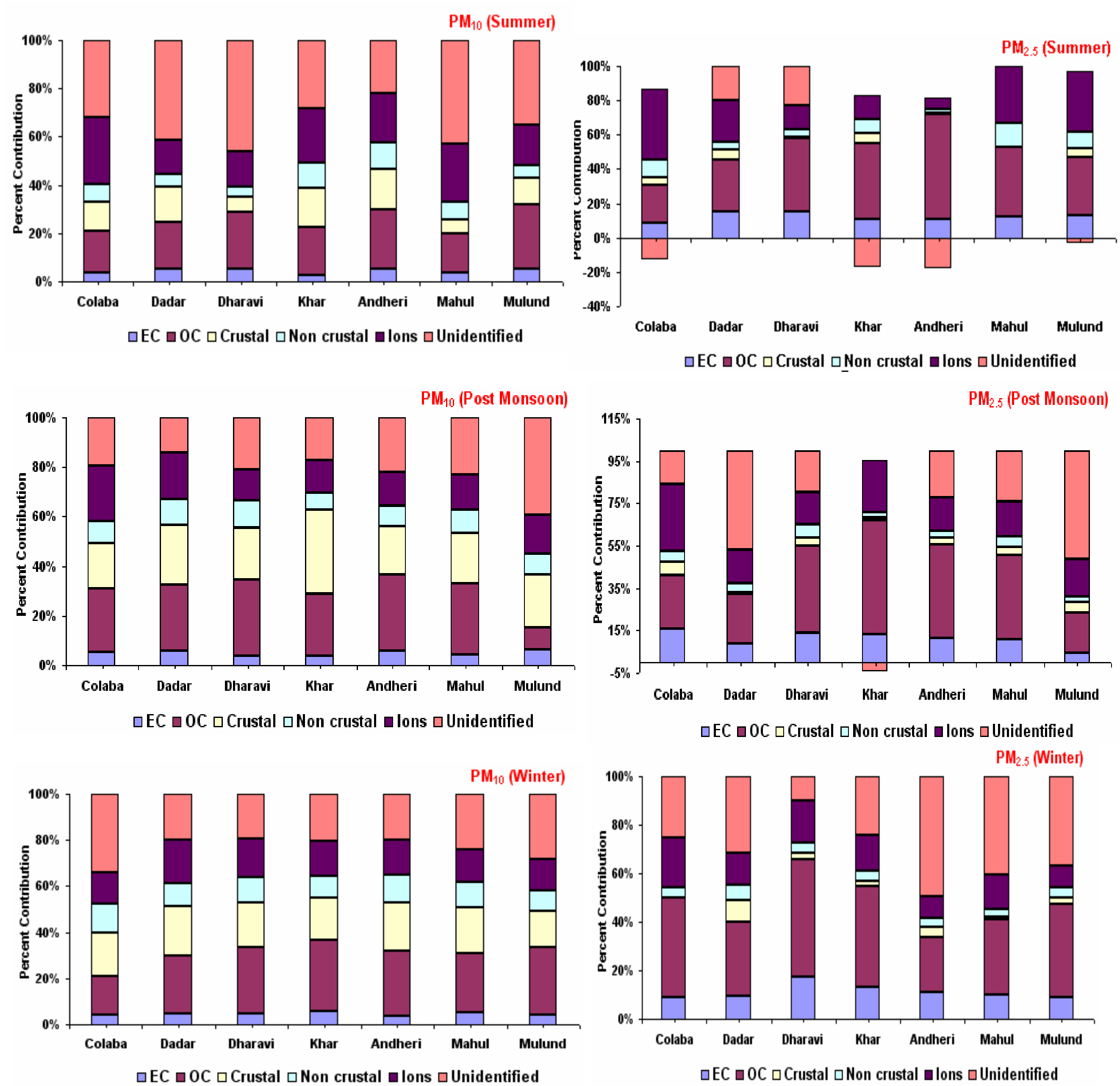
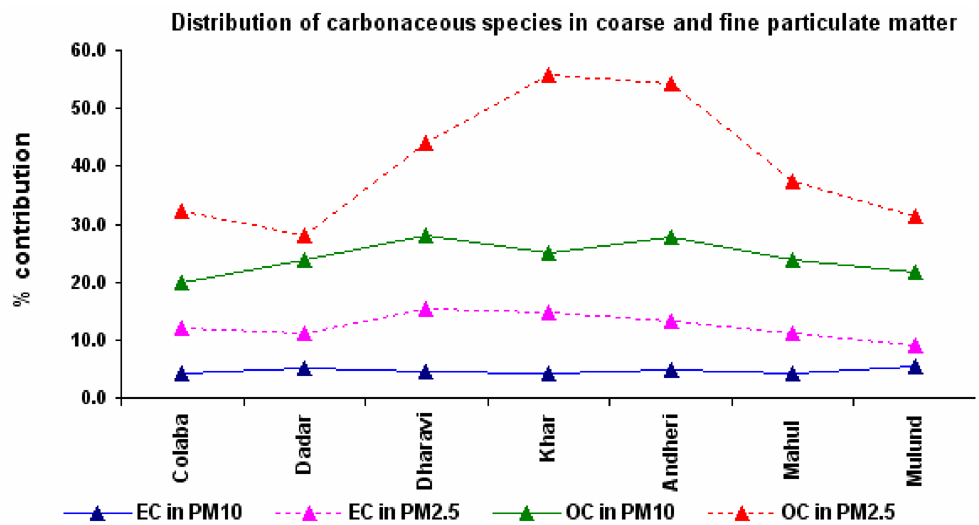


Fig E4: Percent Contribution of Elements, Ions, EC, OC and Unidentified fraction in PM_{10} and $PM_{2.5}$ in three seasons at seven sites

All PM_{10} samples were analyzed for 36 elements and 10 ions with a view to interpret the source contribution. Overall, the monitoring data for PM_{10} indicates lower contributions of combustion sources. However, when the similar analysis is performed for data pertaining to $PM_{2.5}$, a different picture emerges. **Fig E5** presents the distributions of carbonaceous species (EC and OC) and crustal and non crustal elements in PM_{10} and $PM_{2.5}$ at all seven sites. As can be witnessed, the percentage of OC as well as EC in much higher than in PM_{10}. Similarly, non crustal elements percentages are higher in $PM_{2.5}$ than crustal elements. Mass concentration crustal element dominates in PM_{10} mass fraction.



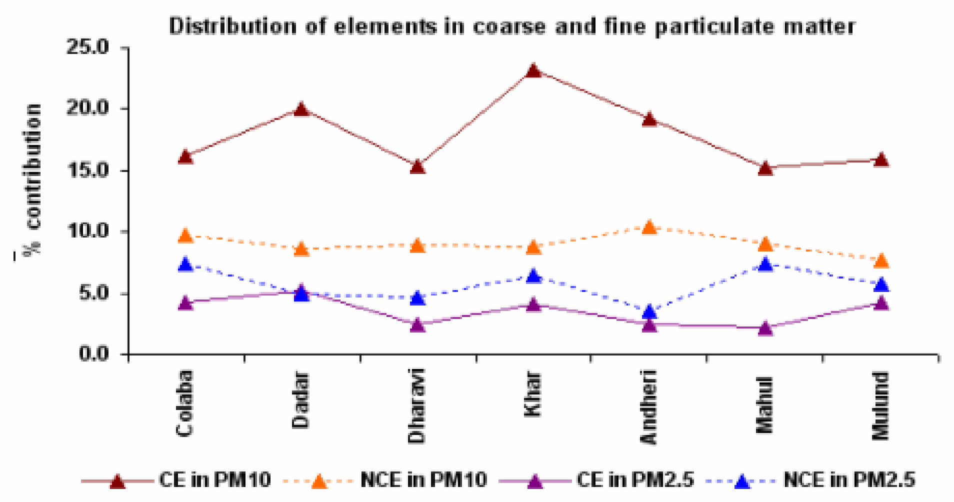


Fig E5: Percent Contribution of EC, OC, Crustal Elements and Non Crustal Elements in PM_{10} and $PM_{2.5}$

It is important to note that though $PM_{2.5}$ fraction mass is lower at all places, the percentage mass of Elemental Carbon (EC), Organic Carbon (OC), and non crustal elements is higher compared to PM_{10}. The carbonaceous fractions and toxic elements like Cr, Pb, Zn etc. which are mainly contributed by combustion sources such as wood/leaf and refuse burning, vehicles, kerosene burning etc dominates the fine particle range. It is crucial to consider the fine particle compositions as they contain the most toxic components of the PM. It is evident from many studies that vehicles particle emissions are mostly (almost 99%) less than 1 µm but large in number. As most of the fine particles can possibly enter the human respiratory systems, their potency for health damage is high. In coming years, the control of PM will necessitate not only mass of PM but also the number concentrations mainly contributed in fine ranges.

5.0 Emission Inventory

Emission inventory is an integral part of air pollution management option analysis. It is also necessary for projections and modeling of future scenarios. All relevant information and data on emission inventory which were available through available sources were collected. Primary surveys were also carried out for identification and spatial distribution of sources in whole Mumbai city (ward wise). Emission inventory for zone of influence (2 km x 2 km area) around each ambient air quality monitoring location was also prepared using primary survey.

5.1 *Vehicular Sources*

For vehicular sources, vehicle count surveys were carried out for all different types of roads (highways, major roads and minor roads) with respect to their categories viz. HDDV, 2 wheelers, 3 wheelers, Taxis, Car (Petrol and Diesel) with focus on zone of influence around each monitoring locations. Counts were also made at many strategic locations for the whole city emission inventory.

5.2 *Area Sources*

Estimation of area sources was arrived at by taking total area under each emission source category and type. Emission estimates were determined based on scientific judgment and considering available information on emission factors. Some data sets were separately analyzed for Indian conditions based on secondary data information. Emission loads were calculated for different areas sources such as bakery, crematoria, open eatout, hotels and restaurants, domestic sector, open burning, building construction etc. Localized activities viz. marine vessels, railway locomotive and airport emissions were also computed and included in the city estimates.

5.3 *Industrial Sources*

Industrial sector in Mumbai has been witnessing negative growth. A total of 40 industries apart from stone crushers were identified with air polluting potential as per the database from Maharashtra Pollution Control Board. Information relating to consumption of fuels such as Furnace Oil (FO), Light Diesel Oil (LDO), Low Sulphur Heavy Stock (LSHS), and Compressed Natural Gas (CNG) by the industries in the MCGM area was obtained. All emissions were estimated for all types of industries viz. power plant (1), chemical and other industries (39) with the help of published emission factors.

Emission loads from vehicles, area and industries for the city are presented below in **Table E2** and percentage distributions for all sources and pollutants are presented in **Fig E6.**

In Mumbai city, PM is mainly contributed from area sources (36.7%) like bakeries, hotels, construction activities etc. Area sources also contribute to 69.3% and 68.3% of HC and CO concentration in the city. Industries (point source) contribute to 93.8% of SO_2 followed by 47.5% contribution to total NOx and 28.1% of particulate matter. PM contributions are well distributed amongst vehicular, industries and road dust categories (35.3%).

Table E2: Emission Load for Mumbai City from All Sources

	PM	CO	SO_2	NOx	HC
a) Area Source					
Bakeries	1554.6	11348.1	25.2	120.1	10287.4
Crematoria	300.7	2213.0	7.9	44.4	1991.9
Open eat outs	281.6	167.8	16.2	9.4	0.1
Hotel restaurants	593.1	755.2	274.0	499.0	25.4
Domestic sector	564.9	19723.7	1262.0	9946.9	368.1
Open burning	734.0	2292.0	27.0	164.0	1173.0
Landfill Open Burning	2906.0	9082.0	108.0	649.0	4649.0
Construction Activity	2288.9				
Locomotive (Cen.+ Wes. Rly)	514.0	3147.0	1449.0	19708.0	
Aircraft	75.6	788.4	77.0	985.5	32.3
Marine vessels	1.8	3.3	19.7	17.9	1.5
Total (A)	**9815.3**	**49520.5**	**3266.0**	**32144.2**	**18528.6**
B) Industrial Source					
Power plant	5628.3	3215.7	24473.3	28944.5	1266.6
39 Industries	503.7	879.7	28510.2	8435.2	116.8
Stone crushers	1394.3				
Total (B)	**7526.3**	**4095.4**	**52983.5**	**37379.7**	**1383.4**
C) Line Source					
2 wheelers	70.1	3303.2	2.7	540.5	1221.2
3 wheelers	225.9	1320.9		363.7	3943.5
Car diesel	313.8	1150.5	87.2	1063.3	435.8
Car petrol	15.7	7867.5	13.1	313.7	496.6
HMV	916.7	4435.5	126.7	6875.0	273.5
Taxies	2.6	778.6		13.0	467.1
Paved Road dust	3163.0				
Unpaved Road dust	4761.4				
Total (C)	**9469.2**	**18856.2**	**229.7**	**9169.2**	**6837.7**
Total (A+B+C)	**26810.8**	**72472.1**	**56479.2**	**78693.1**	**26749.7**

* All values expressed in T/yr., -- Vehicle Fuel used CNG/LPG

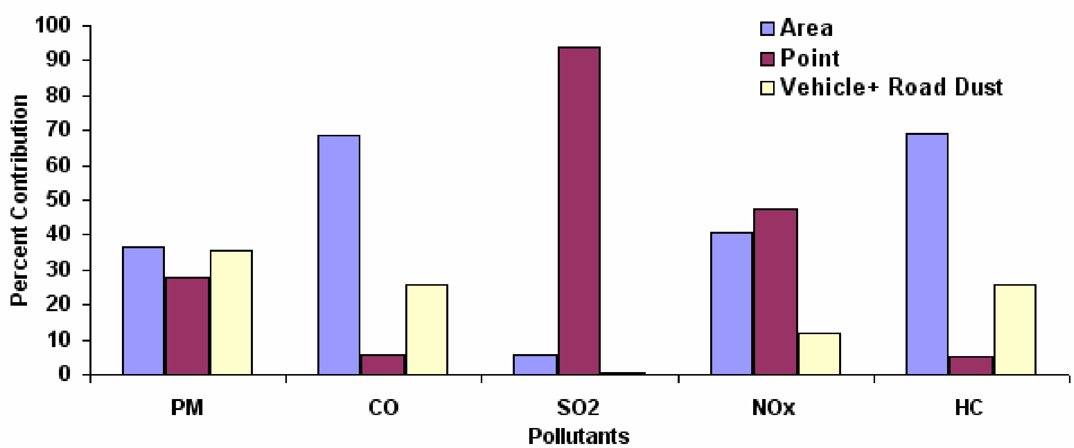


Fig E6: Percent emission load from all sources for different pollutants in Mumbai City

Source category wise PM_{10} emission load for whole Mumbai city is presented in **Fig E7**. Major contribution of PM is from power plant, followed by unpaved road dust, paved road dust, and landfill open burning. Amongst the vehicular categories, HDDV contributes maximum load. The figure clearly indicates that percentage contributions of small sources when combined together could be significant.

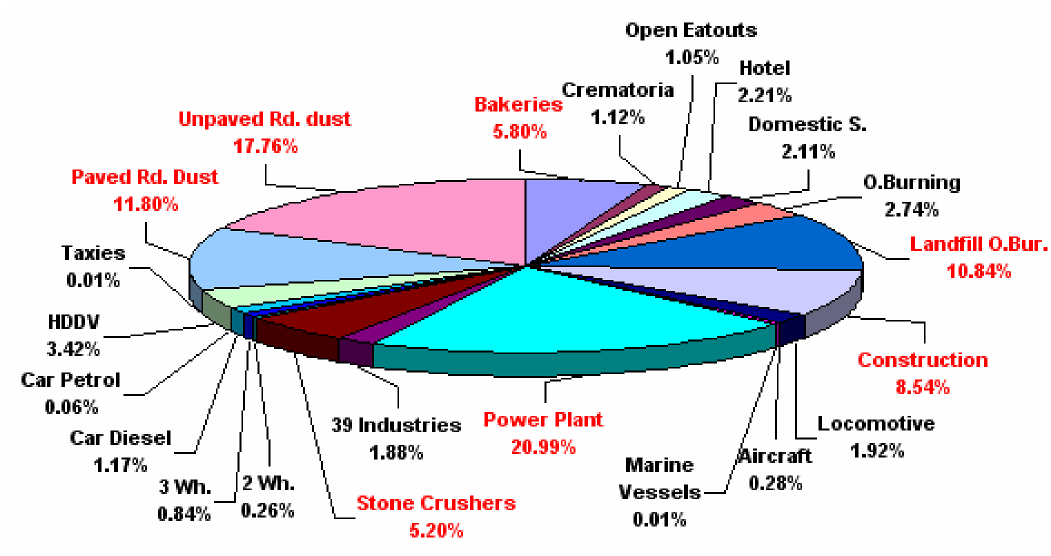


Fig E7: Source category wise PM load in Mumbai City

It is important to note that high load contribution does not necessarily lead to high ambient contribution of a particular source at the receptor site. This is due to the fact that emission distribution in atmosphere depends upon multitude of factors such as local meteorology, location, height of release, atmospheric removal processes and diurnal variation. Further, it is equally important that fine particles which constitute higher fractions of toxics are mostly released at ground level sources such as vehicles, refuse burning, bakeries-crematoria, road side eateries, airport and railways ground operations etc. Since mass based emission inventories do not provide the complete picture of real contributions at the levels of exposure, it is pertinent to use chemical analysis data with appropriate receptor models such as Chemical Mass Balance Model.

There is no single method which provides the complete idea about the urban air pollution sources, their strength, exposure assessment at the receptor, probability of high concentrations, seasonal variations, predicted values etc. In view of such high probable variation in large data sets about the air pollution levels which city has to grapple with, dispersion models are needed decision for action plan effectiveness analysis.

6.0 Receptor Modelling and Source Apportionment

Receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor concentrations. Common types of receptor models include CMB (Chemical Mass Balance) and Factor Analysis. The analytical results were used to run factor analysis and CMB models.

Comparing the results of Factor Analysis and CMB model, it has been found that few sources are predominant and also common in both the models. The sources which have been found common in both these approaches are given in **Table E3**.

Table E3: Source Attribution from Receptor Modeling

Sites	Sources common to FA and CMB	Additional sources of CMB
Colaba	Soil dust, Vehicular emission	Marine, Fuel Oil, Wood and LPG Combustion, Biomass Burning, Ammonium Nitrate, Ammonium Sulfate
Dadar	Soil dust, Vehicular emission	Fuel Oil, Wood and LPG Combustion, Coal (Tandoor), Marine, Ammonium Nitrate, Ammonium Sulfate
Dharavi	Soil dust, Vehicular emission, Coal combustion, Refuse burning	Kerosene, LPG and Wood Combustion, Marine, Ammonium Nitrate, Ammonium Sulfate
Khar	Soil dust, Vehicular emission, Road dust	LPG, Wood Combustion, Marine, Ammonium Nitrate, Ammonium Sulfate, Ammonium Bi-Sulfate
Andheri	Soil dust, Vehicular emission, Kerosene and coal combustion	Fuel Oil and Wood Combustion, Marine, Ammonium Sulfate, Ammonium Nitrate, Ammonium Bi-Sulfate
Mahul	Soil dust, Vehicular emission, Petroleum refining	Fertilizer Industry, Coal (Power Plant), Marine, Fuel Oil and Wood and LPG Combustion, Biomass Burning, Ammonium Nitrate, Ammonium Sulfate, Ammonium Bi-Sulfate
Mulund	Soil dust, Vehicular emission	Secondary Smelting Ind., Fuel Oil, Wood and LPG Combustion, Coal (Tandoor), Biomass Burning, Ammonium Nitrate, Ammonium Bi-Sulfate

CMB results are primarily meant to apportion and indicate PM sources. Through the use of this model, overall major sources have been identified; however, sometimes mass apportionment may not be representative due to issues related to mass closure (not 100%), collinearity issues and measurement uncertainty. Marine aerosol is another source which leads to collineraity problem with other sources with K^+, Na^+ and Cl^- ions. Overall, CMB results have indicated that the major factors are in line with factor analysis.

Common molecular markers specified in source profiles and identified in ambient air samples includes Alkanes such as n-Hentriacontane, n-Pentatriacontane and n-Tritriacontane; PAHs like Benzo [b] fluoranthene, Benzo [k]fluoranthene, Benzo[e]pyrene, Indeno[1,2,3-cd]pyrene and Picene, as also Levoglucosan. These molecular markers along with CMB analysis indicate the presence of major sources such as vehicles, biomass burning, kerosene and coal burning.

7.0 Dispersion Modelling: Existing Scenario

Air quality dispersion modeling exercise was undertaken with a view to delineate the immediate sources and their impact on measurement locations. Dispersion modeling tool was also used for the whole city air quality scenario generation for different emission loads. The existing scenario model runs were undertaken to establish the dispersion pattern of pollutants due to local meteorology and emission from all possible sources. The site specific model runs were taken up with local meteorological data. It was found that meteorology for all sites varied widely in a given season as shown **Fig E8**. Such variation points out that local meteorology play an important role in pollutants dispersion.

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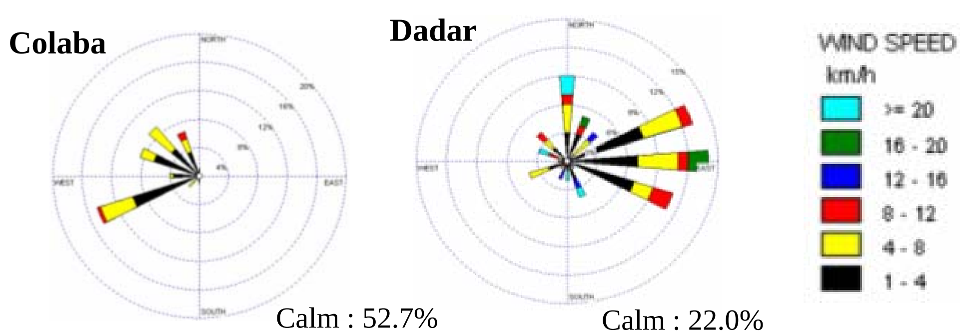


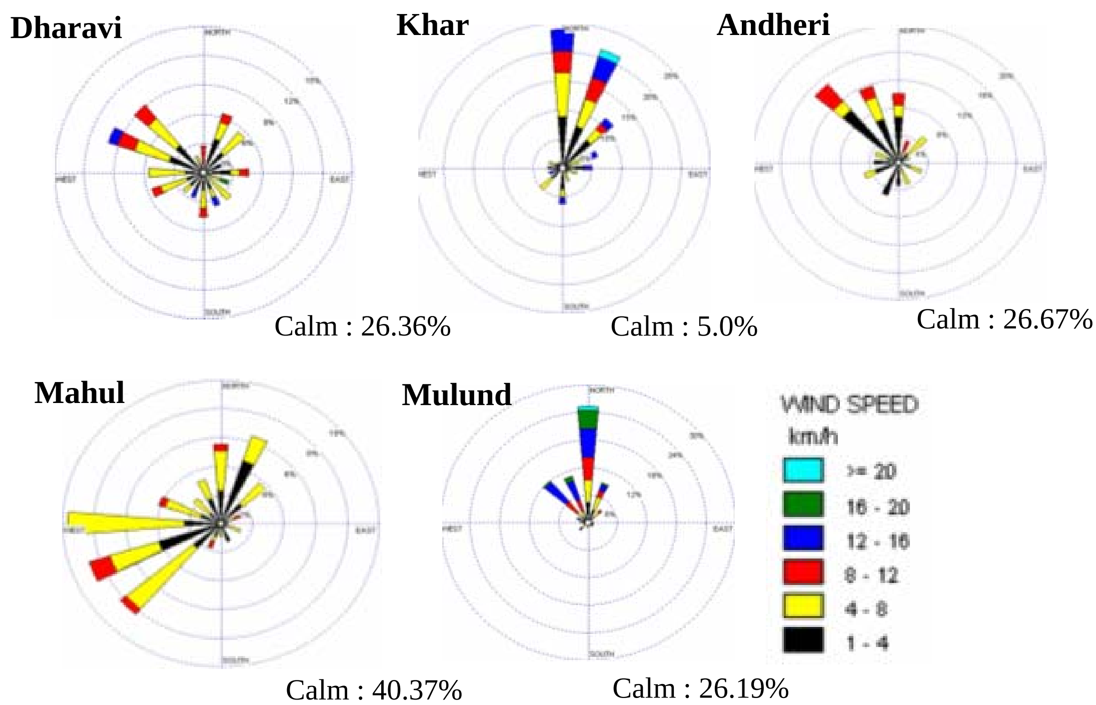


Fig E8 : Site Specific Windroses

Comparison of measured and predicted concentrations of PM and NOx is presented in **Fig E9.**

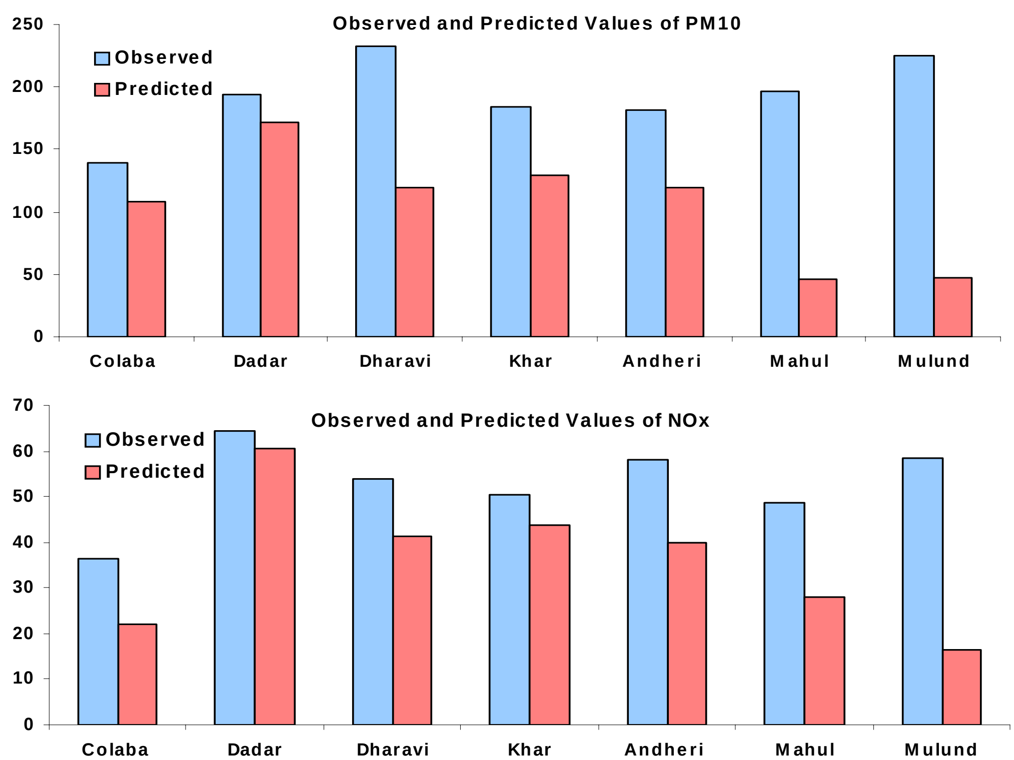


Fig E9 : Comparison of measured and predicted concentrations for PM_{10} and NOx

The measured PM_{10} concentrations are highest at Dharavi followed by Mulund and Mahul. Colaba, the background site appears to be the cleanest site. Comparison of measured and predicted concentrations shows that site specific average concentrations predicted using primary survey based emission inventory are close to measured values to a large extent. Uncertainties related to emission inventories at some locations lead to difference between predicted and observed values. City wise modeling result shows higher variation at seven sites which uses whole city inventory. This variation is highest for PM as emission inventories for PM are variable for many sectors such as refuse burning, landfill waste burning, construction activities, illegal small scale industrial operations, dust from variable load conditions, road constructions etc. Besides whole city model run includes sources which are only from the city.

However, Mumbai city has large adjoining areas whose sources have not been accounted for. NOx values across the city in both cases are much closer to measured values. The highly complex meteorology during summer compared to other seasons could be the major factor for larger difference in predicted values of summer season. The modeling results indicate that PM_{10} is mainly contributed by road dust, whereas vehicular sector dominates NOx at most of the sites.

8.0 Projected Emissions in 2012 and 2017

The whole city was divided in to 2 x 2 Km grid. For each grid, area, industries and vehicular source strengths were computed fro present situation viz. 2007. Later projections were made for the year 2012 and 2017 based on various factors. Grid based Emission inventories for BAU applicable to 2007, 2012 and 2017 have been given **Fig. E10 and E11.** These projected figures have been used for control scenario model runs and comparison with BAU situation. As can be seen from these figures, the grids representing eastern and western traffic corridors, show increasingly darker grids (with higher loads) for PM and NOx emission loads.

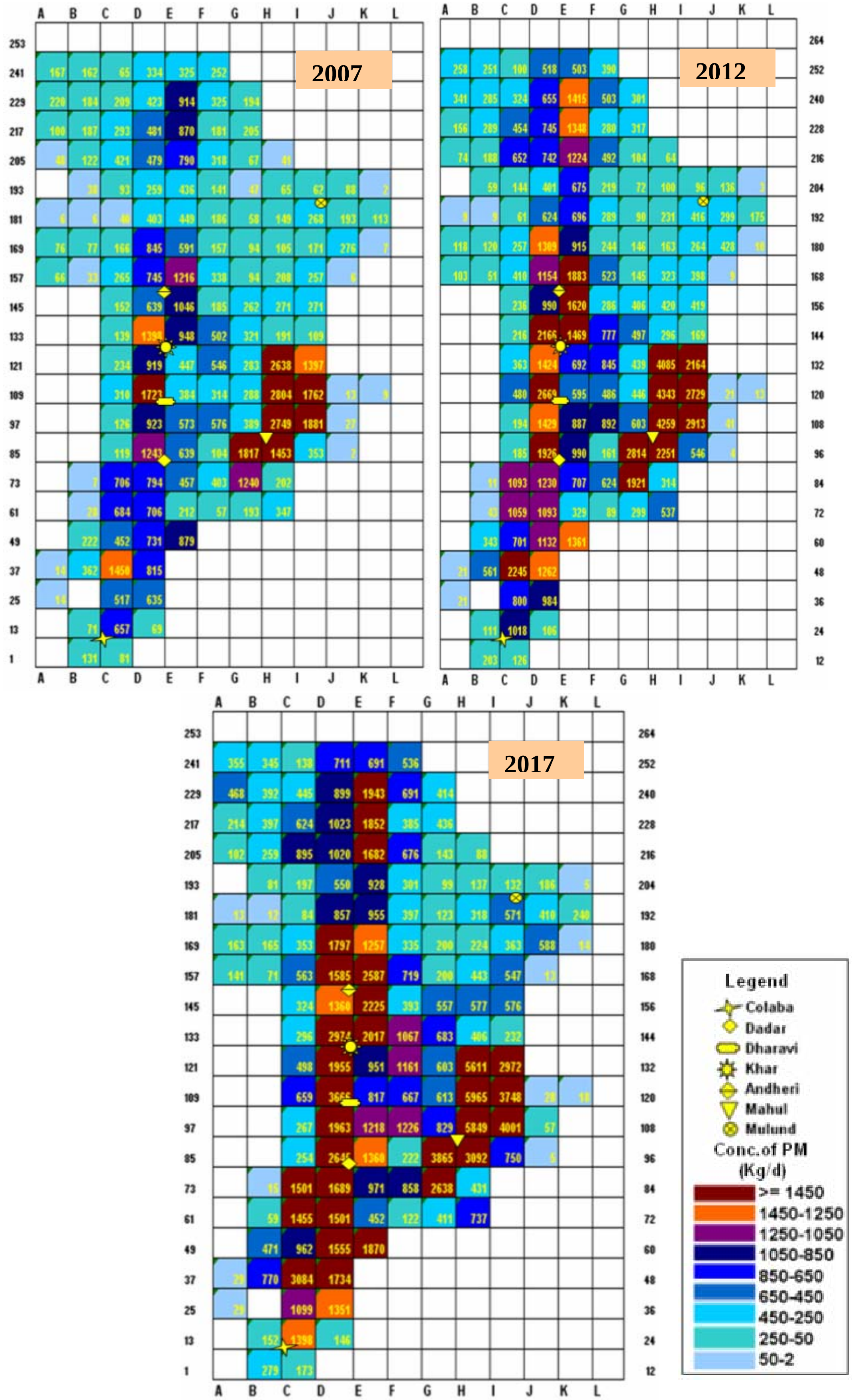


Fig E10: Grid Wise PM Emission Load for 2007, 20012 and 2017, Mumbai

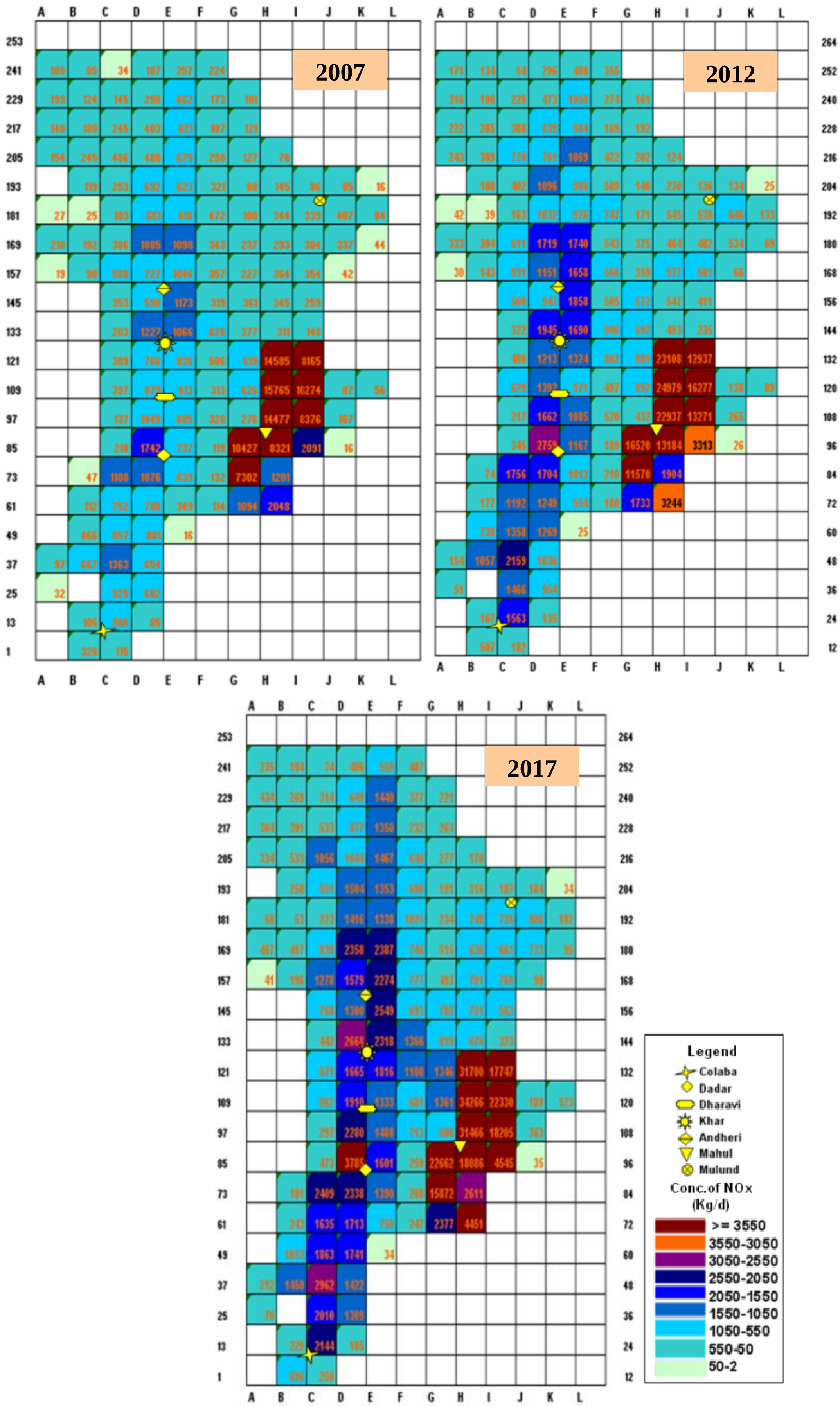


Fig E11: Grid Wise NOx Emission Load for 2007, 20012 and 2017, Mumbai

9.0 Emission Control Options and Analysis

Based on emission inventory and CMB modeling results of all the sources viz. industrial, area and vehicular, various generic strategies can be adopted. Though overall it appears that PM should be targeted as the main pollutant, which exceeds the limit in the city. Other pollutants will also reduce with the adoption of these strategies for PM reduction. Reduction of these pollutants could be considered as co benefits of that implemented strategy. However, it's important to note that NOx values, which show values lower than the current standards, may become one of the more potent pollutants from health point of view. Its rate of production is directly linked with vehicular population. The combination of its ground level concentration along with hydrocarbons provide ample window of short term high concentration of ozone.

PM reduction strategies given here are mainly for PM_{10}, however, the reduction in fine particulate matter (less than $PM_{2.5}$) will yield higher health benefits. The overall impacts of $PM_{2.5}$ on all residents indicate that though the levels are low, exposure of population is very high. Though PM_{10} emissions from vehicles may show low percentage contribution, but the fine fraction ($PM_{2.5}$) will have a very high exposure and impact on human population. Major control strategies for area, industrial and vehicular sources are presented in **Table E4**.

Table E4 delineates strategies for vehicular sector by considering three ideas: -

- Reduce emissions per unit of fuel.
- Reduce fuel consumption per unit distance.
- Reduce vehicles distance travelled.

On the other hand for industries in Mumbai, it is mainly based on fuel change and industrial policy such as: better and cleaner technology or shifting of industries. Area sources strategies are more complex; however fuel change is one of the major options, besides management options.

Table E4 : Control Strategies considered in the study

A) Framework for Selecting Measures to Address Urban Air Pollution – Vehicles

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(1) Strategy: Reducing Emissions per Unit of Fuel			
Fuel Quality Improvement	Sulphur Reduction	Delineating tighter diesel fuel standards	Phasing out fuel subsidies, uniform pricing all over the state followed by country
Installation of after treatment devices	Fitment of Diesel Oxidation Catalyst, catalytic converter in older vehicles	Tighter diesel fuel standards particularly for Sulphur to bring down its level up to 50 ppm. Emission test frequency to be more for those without the after treatment devices	Differential taxation to those with and without after treatment device
Tackle fuel adulteration	Markers for detection	Better specification of fuel quality for detection as well as booking the offenders. Monitoring fuel quality in a specified laboratory, making companies accountable	Oil companies to finance the setting up of a laboratory, Fines and cancellation of license
Use of alternative fuels	CNG and LPG use Bio fuels	Promote its use in private sector as well as organized sector through administrative orders	Differential taxation for older vehicles changing to CNG/LPG, Incentive for new owners to buy CNG/LPG vehicles. Low cost bio fuels
Renewal of vehicle fleet	Phase out vehicles above a certain age	Scrappage of older vehicles	Older vehicles to remain on road if it passes the fitness test as well as emission test, however higher tax to be paid as the vehicle gets older
Improve traffic flow	Synchronized signal corridors	Coordination with other institutions to check indiscriminate parking , and enforce one way system at peak hours	Congestion pricing Higher parking fees
(2) Strategy: Reducing Fuel Consumption per unit Distance			
Change to better technology engines	4 stroke engines for two –three wheelers, Bharat stage III engines with DOC for older diesel vehicles, All new diesel vehicles to be Bharat stage III and above	Standards for fuel economy need to be specified Useful age of the vehicles to be specified by the manufacturer	Tax break for older vehicles changing to new engine with DOC or DPF
Improve vehicle I&M	I&M programs that are difficult to cheat; computerized data capture and control of tests	Strict enforcement with socially acceptable failure rates	Better infrastructure, manpower augmentation, Strict fines
Better road maintenance	Investment in better road maintenance technology to avoid frequent relaying	Standards for road construction specified in terms of guaranteed life of the road	Financial incentives for contractors using better technology for road construction

Table E4 (Contd..) : Control Strategies considered in the study

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(3) Strategy: Reduce Vehicle Distance Traveled			
Increase private vehicle occupancy		Encourage car pooling	Congestion pricing
Promote better and more public transport	Dedicated bus lanes; user friendly MRTS	Reform of public transport – competition, privatization etc	Subsidize public transport by taxing private car users
Demand management		1. Limit parking 2. Limit the use of vehicles in congested areas 3. Allow odd /even no. private vehicles on specified days.	- High one time tax on purchase of a new vehicle - High parking fees - Road user charges - Higher taxes per vehicle km traveled - Allow to ply a vehicle (odd/even) with charges
Encourage non motorized transport	Pedestrian friendly walkways / subways	Protection of pedestrian facilities	Financial incentives for pedestrian friendly design
Reduce dust re-suspension	Road paving / cleaning	Coordination with all institution working in the area of road and pavement maintenance, digging for utilities etc. One agency to monitor the working practices.	Steep fines to agencies leaving the debris-dust on the roads after the completion of jobs.

B) Framework for Selecting Measures to Address Urban Air Pollution – Industries

Fuel change	For power plant the fuel change leads to technology change as well. However, newer technologies are more efficient and long term cost effective. Other industries may experience lower level of technology issues.	MPCB* can make the rule stringent and link with Mumbai Air Action Plan	High cost initially. However, in longer run more cost effective
Industrial Policy	• Specifying technology needs policy review. • Area specific location policy	Detail feasibility study for technology as well as land use based policy issues.	Financial incentive to burn cleaner fuel or use of cleaner technology

*MPCB – Maharashtra Pollution Control Board

Table E4 (Contd..) : Control Strategies considered in the study

C) Framework for Selecting Measures to Address Urban Air Pollution – Area Sources

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
Fuel change - Domestic	No major technical issue	Adequate administrative measures in place	No major cost involved facilitation for awareness needed. Low cost fuel to slums
Fuel change - Bakeries/Crematoria	Need for technical evaluation	Standards to be specified to drive technical changes	Medium cost
Fuel change – Railways/airport/ship	No major technical issue	Administrative directions needed	Medium cost
Resuspended dust	• Pavement to be wall to wall • Better sweeping system • Better road paving technology issue	Regulatory push required for better road paving technologies	• Minor cost • Fines for poor road surfaces
Construction	Improved construction practices, no technology issue	Regulatory push and surveillance needed for better compliance	Minor costs of regulation and surveillance

10.0 Prioritization of Management /Control Options

Management options for each sectors need to be prioritized with a view to understand the issue of implementation. Implementations are highly influenced not only by the idea of the improvement alone but also by the nature of the recommendations, fiscal and administrative barriers, effectiveness, implementing agencies and acceptance from large group of stakeholders. The Prioritization also takes into account the earlier recommendations made by Lal Committee under the order of Hon'ble High Court, Mumbai, 2000. Many of the recommendations have been implemented; however few which are still relevant and applicable in current scenario have been included in the recommendations made for control options. **Box-1** gives a summary of

Box 1: Highlights of Lal Committee Recommendations, 2000

- **Reduction of sulphur content of diesel and Benzene content of petrol to acceptable limits**
- **Use of alternative fuel such as CNG/ reformulated gasoline etc**
- **Desirability and feasibility of converting existing buses / taxi to CNG**
- **Applicability of EURO I and EURO II norms to commercial (non-private) vehicles**
- **Desirability and feasibility of phasing out vehicles over a certain age limit**
- **Financial incentives for replacement of old taxis and auto rickshaws with clean fuel**
- **Action required to be taken in respect of two wheelers and three wheelers utilizing two stroke engines**
- **Measures to Prevent Fuel Adulteration**
- **Effect of the use of unleaded petrol without catalytic converters**
- **Incentive for conversion to cleaner technologies (CNG kits and catalytic converters)**
- **Desirability and feasibility of ensuring pre-mixed oil, petrol and 2 T and banning supply of loose 2 T oil**
- **Proper management and regulation of traffic**
- **Effective methods of monitoring and improving prescribed emission norms**

types of recommendations of Lal Committee. Annexure of Chapter 7 gives the complete list of Lal Committee recommendations. Prioritization issues are also driven by the comparative account of short term and long term implementation dilemma. Low cost with high effectiveness and low cost with shorter implementation period shall be a better option, when compared with high effectiveness with high costs or long implementation period. Though some of the options were selected on the basis of PM reduction potential, their possible co-benefits in reducing NOx and other pollutants were also considered during the process of prioritizing. **Table E5** presents some of the prioritized control options including management options.

The prioritized control options are based on high effectiveness in pollution load reduction leading to improvement in ambient air quality. The benefits of better air quality despite increase in vehicles (Option 1 to 4) and all other activities in Mumbai for **Preferred Scenario I** can be seen in **Fig E12.**

Table E5: Summary of Prioritized Options for the City

Category		**Control Options**	**Scenario 2012**	**Scenario 2017**
Vehicle Sources	**1**	New Vehicle Standards	▪ Bharat IV from 2010	▪ Bharat IV from 2010 ▪ Bharat VI from 2015
	2	Electric vehicles	▪ 2 wheelers – 5% ▪ 3 wheelers – 20% ▪ Taxies – 20% ▪ Public transport buses -5%	▪ 2 wheelers – 10% ▪ 3 wheelers – 30% ▪ Taxies – 30% ▪ Public transport -10%
	3	CNG/ LPG	▪ Taxies – 80% ▪ 3 wheelers – 80% ▪ Public transport – 25%	▪ Taxies – 70% ▪ 3 wheelers – 70% ▪ Public transport – 40%
	4	Ban or scrapping of 15 year old vehicles	▪ 1997 vehicles to scrapped commercial vehicles ▪ Ban > 8 years vehicle	Continued
	5	Inspection and Maintenance	New I&M regulations (50% population)	Full compliance -100%
	6	Synchronization of traffic	20% improvement	40% improvement
	7	Public Transport	10% VKT reduction	20% VKT reduction
	8	Ban of odd /even vehicles	50% reduction from private vehicles	50% reduction from private vehicles
Industrial Sources		Shifting of Fuel	▪ 39 Industries - FO, LSHS, HSD to LDO - Coal & Others to NG	No Change
			▪ Power Plant - LSHS to LDO - Coal to NG (50%)	100% to NG

Table E5: Summary of Prioritized Options for the City

Category	Control Options	Scenario 2012	Scenario 2017
Area Sources	Domestic	▪ 25% of slums to use LPG/ PNG ▪ 50% of non slum to use LPG/PNG	▪ 50% of slum to use LPG ▪ 100% same
	Hotel & Restaurants	50% of coal to LPG	75% of coal to LPG
	Open Eat outs	Since these operations are illegal, difficult to quantify	
	Bakeries	▪ 25% LPG, ▪ 25% Electric	▪ 50% LPG, ▪ 25% Electric
	Crematoria	50% Electric	75% Electric
	Open Burning	50% reduction in open burning	100% reduction in open burning
	Landfill Burning	100% stoppage of Landfill burning	100% stoppage of Landfill burning
	Bldg. Construction	50% reduction in emissions of PM	50% reduction in emissions of PM
	Road Dust Paved	15% reduction in emissions of PM	15% reduction in emissions of PM
	Unpaved	40% reduction in emissions of PM	100% reduction in emissions of PM
	Ports	Awareness and Management	
	Airports	Awareness and Better Inventory	
	Railways	100% on electric	100% on electric

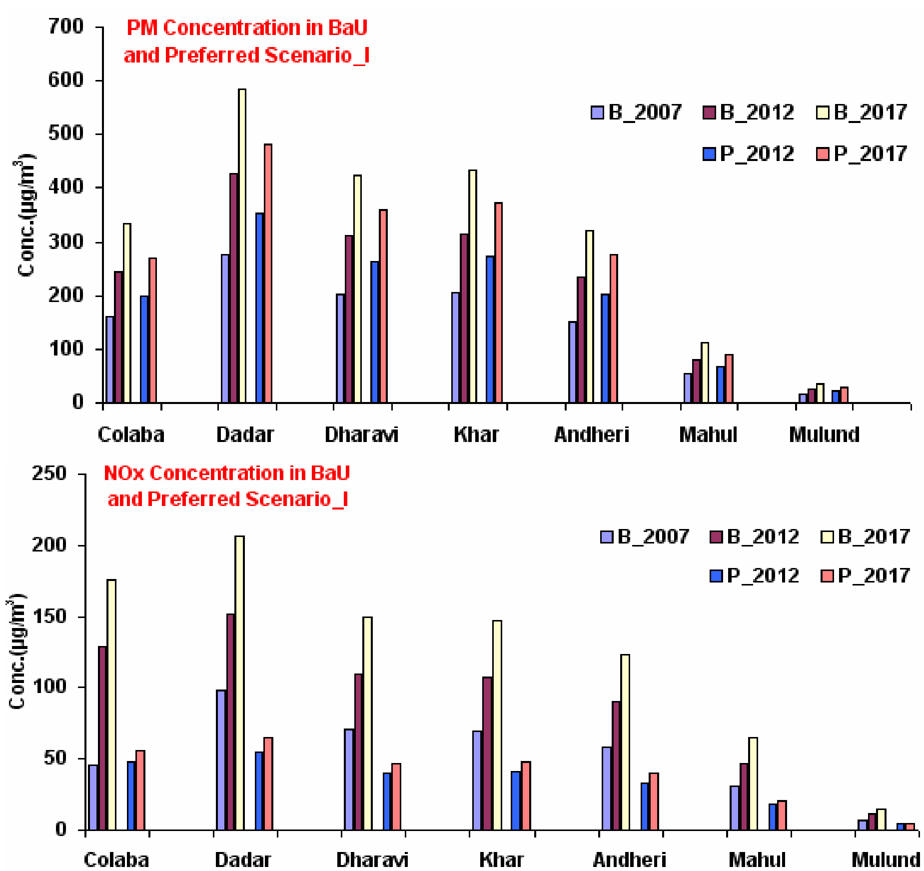
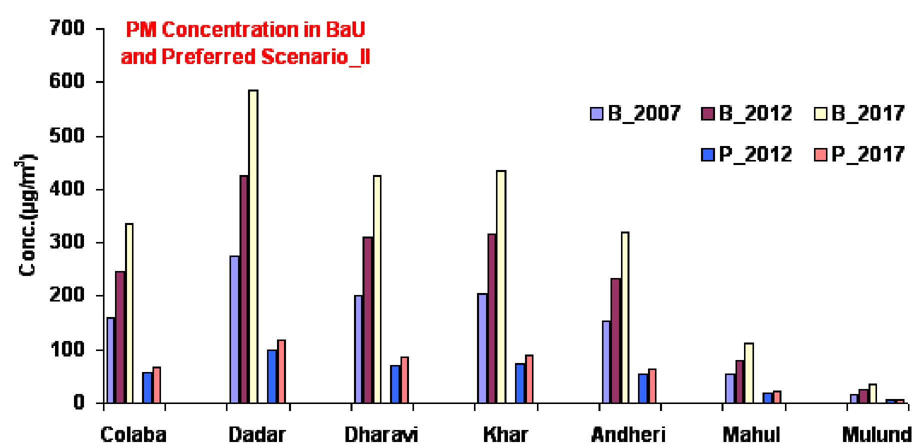


Fig E12 : PM and NOx Scenario Compared with BaU of 2007, 2012 and 2017 and Preferred Scenario (I) of 2012 and 2017

The predicted ground level concentrations show improvement all across the city. Results shown for the seven sampling locations indicate that though NOx levels would be met most of the time, PM levels will exceed at many locations, except at Mahul and Mulund. As can be seen in the figure, the emission levels would become highly un-acceptable with regard to the PM and NOx levels especially if no control scenario continues till 2012 and 2017.

As can been seen from **Fig E12 (Preferred Scenario I)** PM values continue to exceed the standard of 100 μg/m^3. Therefore, to reduce PM ambient concentrations in the city, other options of vehicle sources viz. 5, 6, 7 and 8 will need to be implemented simultaneously. The ambient air scenario with these additional options will bring down PM levels at most of the places below the standards as shown in **Fig E13** i.e. **Preferred Scenario II**.



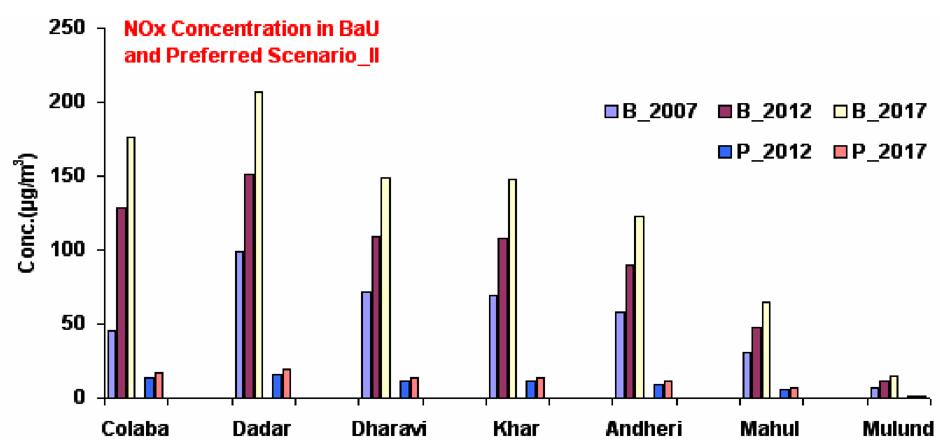


Fig E13 : PM and NOx Scenario Compared with BaU of 2007, 2012 and 2017 and Preferred Scenario (II) of 2012 and 2017

11.0 Benefits of Control Options

Technical and management options for all the sectors viz. industries, area and vehicular delineated and discussed earlier will lead to direct benefits in terms of PM and NOx reduction. However, these control options will also lead to highly valuable co benefits as detailed in **Table E6.** Some of the other pollutants, which are likely to reduce, are SO_2, CO, hydrocarbons, aldehydes etc. Besides these pollutants, an additional co benefit anticipated is reduction of green house gases (GHG) in the atmosphere.

Use and support for higher public transport share in overall mobility model of the city will give substantial reduction in CO_2 and other GHG. Sustainable mobility which is based on accessibility, affordability and rapid movement will get a boost from the lower urban pollution and decreasing GHG levels.

Table E6: Benefits associated with prioritized control / management options

Action Components	Direct benefits	Co-benefits
Vehicular Sector		
Reduce fuel adulteration	• Reduced adulteration will lead to reduced PM /NOx (difficult to quantify) • Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM	One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its lifetime
Alternative fuels • **CNG/LPG** • **Biofuels**	• High, more than 90 % reduction in PM can be achieved compared to diesel • Similar to diesel but low SO_2 and low PM	• Will lead to substantial reduction in CO and HC emission, however, NOx values may go up • Low SO_2 emission
Congestion reduction	High emission due to fuel burning at idle or slow moving traffic	• It will reduce traffic junction hotspot of all the pollutants. • It will also reduce continuous source of dust
Standards for new and In-use vehicles	• Marginal improvement from newer vehicles except when implementation is for Euro V & VI • In-use vehicles emission reduction can be substantial	As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types
Higher usage of Public Transport	Effectiveness is high as less and less road space will be occupied by private vehicles, faster movement of public transport in comfort shall lead to low emissions	Future growth of the city will entirely depend upon the levels of public transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency

Table E6: Benefits associated with prioritized control / management options

Action Components	Direct benefits	Co-benefits
Industrial Sector		
Alternate Fuel	The higher percentage of use of cleaner fuel has already resulted in better air quality in the city	Better air quality in terms of SO_2, CO and HC will be achieved.
Location Specific emission Reduction	Medium as the power plant has already been subjected to strict S levels as well as PM emission by MPCB	High level emission shall have lower PM and other gaseous pollutants
Fugitive Emission control	For localized region, effective. Particularly for industries with fine particles raw material or products. High efficiencies can be achieved for quarries.	Local area air quality improvement could be highly effective.
Area Source		
Improve fuel used for domestic purposes	Likely to improve indoor air quality	It would alleviate large section of population with high indoor pollution of other sources leading to lower disease burden and better quality of life
Bakeries /crematoria	Local grid based PM can be reduced	Reduction in PM as well as odour will take place and is likely to improve the local air quality
Biomass/trash burning, landfill waste burning	Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids	High level improvement in local area ambient air quality not only for PM but other pollutants
Resuspension	Highly effective for kerb-side air quality	Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being
Illegal SSI	Local area improvement can be moderately good	It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem
Construction	Large scale improvement in local area is expected.	Spillage on road and further re-suspension of dust can be minimized

12.0 Conclusions and Recommendation

The study has shown that ambient air quality improvement is a very complex process. Mumbai city ambient air quality has shown improving trends with respect to PM_{10}, SO_2 and NO_2 during the period of 2000-2005. However, in last few years PM decline is not apparent and NO_2 levels have shown slow increasing trend. All the analysis and modeling results indicate that many small steps or one big step for a particular sector will not yield results of better air quality. An integrated bunch of steps are likely to achieve improved air quality which will be sustainable. The city of Mumbai will also need integration of its efforts with nearby urban centers and also alignment with overall national goals for better air quality. Besides the control options presented earlier, following steps are warranted.

12.1 *Vehicular Sector*

A. In this sector measure of better engine technology needs to be combined with better fuel quality and extended emission warranties for the designated life of the vehicles.
B. Fuel quality improvement and its maintenance should be with oil companies. Adulteration possibility at fuel pump should be completely eliminated. This can be achieved through the cooperation and planning of oil companies.
C. CNG/LPG as an alternative fuel for all air quality improvement programme is not sustainable. This is valid more for the public transport vehicles as for any reason if the supply stops the public transport system will collapse. Further, this option cannot be implemented in all cities. Therefore, public transport system should be based on multiple options such as clean diesel (with or without after treatment devices), CNG/LPG, electric and in future hydrogen and other fuel.
D. Vehicle inspection and maintenance need to be improved significantly as most of the vehicle emission are from in use vehicles. Centralized inspection and maintenance with very transparent system is need of the hour.
E. Vehicle scrappage policy should be implemented with a system and provision of scrappage yard in each city.
F. Management options relating to reduction in vehicles on road need multiple options. Ban on odd and even vehicles should be combined with additional charging scheme to avoid people buying another vehicle. All funds collected from congestion charges, parking fees, odd/even vehicle plying fee etc should be shared with public transport company to make it competitive, cost effective and efficient.

12.2 *Industrial Sources*

A. Industries decline in the city has led to large decrease in air pollution, however, fuel shift in existing industries will further improve the ambient air quality.
B. There are many air quality monitoring stations located in limited area of Chembur-Mahul region. All these are managed by industries. This resource should be well distributed with centralized data linkage with MPCB, which will provide very useful data base for city air quality management.

12.3 *Area Sources*

A. Open refuse burning and landfill site burning are the most important issues for ambient air quality. This needs very quick and credible solution to stop this emission.

B. Road dust from paved and unpaved roads in the city is largely responsible for high PM. The code for road and pavement construction should be well written and implemented.
C. Large scale construction and demolition of buildings in the city give high local dust contribution leading to health impacts. These practices need adequate rules and compliance to reduce emissions.
D. Bakeries and crematoria emissions can be reduced through implementation of fuel shift combined with awareness programmes.

12.4 *Public Processes*

The air quality improvements can not be achieved alone by above measures without adopting other management practices which are not end-of –the- pipe but are preventive in nature.

A. Strong emphasis on public transport is the only option which can keep sustainable air quality goals. Low cost, easily accessible, faster travel and comfortable to ride are the major objectives needed to be embedded in public transport policy countrywide.
B. Public transport cross subsidization either directly or by providing fuel at lower cost needs the top priority by policy makers
C. Awareness programmes for policy makers, people, drivers-mechanic, traffic police, health professionals, academicians etc. will bring the importance of better air quality.

The sustainable air quality goals can be achieved by a continuous process of updating knowledge, taking action and taking review of the benefits accrued. This process allows mid-course correction and improvement. Improvement in scientific understanding and its incorporation in policy of better air quality should be a continuous process.

The quality of urban air at the levels of exposure needs to be improved. In the current scenario, the exposure due to fine fractions containing toxic constituents and NOx is high. The decline in pollution would be limited when the vehicle density may become maximum and roads will not be able to take it any more numbers to move. In those situations, the public transport options not only within the city but also in adjoining areas will need high levels of augmentation.

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Chapter 1
Introduction

1.1 Preamble

Air Quality has been a complex issue in most of the urban areas due to a variety of source contribution through fugitive and line emissions. Air pollution results in long-term reduction of productivity leading to deterioration of economic condition of a country. Therefore, controlling air pollution to reduce risk of poor health, to protect the natural environment and to contribute to our quality of life is a key component of sustainable development. All the anthropogenic air pollution emissions could be attributed to industries, mobile sources, construction, garbage burning, agriculture etc. The sources are becoming more complex day by day as also emissions. Ambient air monitoring programme of India has been guiding the policy makers, however, inadequacies of QA/QC in the overall monitoring, data gathering and interpretations add more complexity to the problem.

1.2 Background of the Study

The auto fuel policy report submitted to Government of India (www.envfor.gov) in the year, 2002, has identified the lack of knowledge in the area of source apportionment. This is due to the fact that emission inventory based planning leads to misleading prioritization of actions plans for control of air pollution. Source apportionment on the other hand could provide the answer to the issue of major contributing sources at the point of receptors. Ambient levels of gaseous pollutants have shown declining trend in recent past due to many initiatives of the government as well as due to judiciary. The particulate matter, however, has not shown decline, which is a cause of concern. This is also due to the fact that PM can be surrogate parameters for other pollutants as well. With this background, air pollution source apportionment studies were initiated in six major cities with participation of oil companies, leading research institutes, Central and State Pollution Boards and Ministry of Environment and Forests Government of India. For the city of Mumbai and Delhi, NEERI has been retained for carrying out the study.

1.3 General Description of City

Mumbai, formerly known as Bombay, is the capital of the state of Maharashtra, and the most populous city of India, with an estimated population of about 16 million (India's national census of 2001) in an area of 468 km^2. Mumbai is located on Salsette Island, off the west coast of

Maharashtra. Along with its neighboring suburbs, it forms the world's 4th most populous metropolitan area. Mumbai is the commercial and entertainment capital of India. It has attracted migrants from all over India because of the immense business opportunities, making the city a potpourri of various communities and cultures. It is also one of the rare cities to accommodate a national park, the Sanjay Gandhi National Park, within its city limits.

Average elevation area of Mumbai is from 10 to 15 metres. The northern part of Mumbai is hilly, and the highest point of the city is at 450 meters. Mumbai suffers from the major urbanization problems seen in many fast growing cities in developing countries - widespread poverty and poor public health, traffic congestion and low level of civic activities, employment for a large section of the population. With available space at a premium, Mumbai residents often reside in cramped, relatively expensive housing, usually far from workplaces, and therefore require long commutes on crowded local trains, or clogged roadways. According to the Municipal Corporation estimates in 1993 over 55% of the residents of Greater Mumbai lived in slums.

1.3.1 Climate

The climate of the city, can be classified into three seasons. Mumbai being in the tropical zone and near to the Arabian Sea has high humidity throughout the year. The monsoon rains lash the city between June to September, supplying most of the city's annual rainfall of 2,200 mm (85 in). The city experience mild winter between November and February which is characterized by moderate levels of humidity and cool weather. Cold northerly winds are responsible for a mild chill during December to February. Annual temperatures range from a high of 38°C to a low of 11°C.

1.3.2 Transport

Most of Mumbai's inhabitants rely on public transport to travel to and from their workplace. The city also lacks car parking spaces, suffers traffic bottlenecks due to limited roads. The major public transportation facility is catered by the Mumbai Suburban Railway, which comprises of three separate networks running along the length of the city, in a north-south direction. Public buses cover almost all parts of the metropolis. The bus fleet consists of single-decker, double-decker, air-conditioned and vestibule buses. Taxis, accommodating up to four passengers, cover most of the metropolis. Auto rickshaws, allowed to operate only in the suburban areas, are the main form of hired transport. These three-wheeled vehicles can accommodate up to three passengers. Numbers of registered vehicles are presented in **Table 1.1**.

Table 1.1: Number of Registered Vehicles (Mumbai)

Year	2000	2001	2002	2003	2004	2006	2007
HMV/Buses	82172	86837	78338	79754	75567	72159	77567
Cars/Jeeps	329546	344870	353417	366805	384258	436213	464139
Taxis	58696	62447	63679	54809	56459	57383	55486
3 W	97565	101914	104829	98527	102224	104899	104862
2 W	407306	440517	475352	527108	584180	714209	792512
Other	53980	57789	55412	56130	52243	8784	8879
Total	1029265	1094374	1131027	1183133	1254931	1393647	1503445

* Transport Commissioner Office, MCGM

1.4 Need of the Study

Of many pollutants, Particulate Matter in recent past has been considered one of the most potent pollutants with regard to its impact on human health. PM with aerodynamic diameter less than 10 µm (PM_{10}), especially the finer particle fraction $PM_{2.5}$ (particulate matter with aerodynamic diameter less than 2.5 µm), have been shown to be associated with increases in mortality (Dockery and Pope, 1994; Schwartz et al., 1996), asthma (Anderson et al., 1992) and visibility degradation (Kim et al., 2006). Given that PM is emitted into the atmosphere by a number of anthropogenic and natural sources, the physical and chemical patterns may vary considerably. Both natural and anthropogenic emissions supply primary (direct emission of PM) and secondary (formed from gaseous precursors) PM. On a global scale, PM emissions reach 3400 million tonnes/yr (IPCC, 1996). Anthropogenic sources account for only 10% of total PM emissions, whereas the natural primary PM emissions reach 85% (2900 million tonnes/yr).

A comprehensive understanding of the above stated issues and related issues on global, regional, and local scales require the ability to determine accurately the sources of natural and anthropogenic aerosols and their precursors. On the other hand, local sources when emitting in a limited region with low assimilative capacity, can cause severe air pollution problems. The present study examines the contribution of these sources to aerosol mass, which is an important factor in the development of effective strategies for the control of aerosol-associated problems.

Besides PM, other pollutants and their sources are needed to be inventoried with a view to ascertain the point of generation. The gaseous pollutants such as NO_2, SO_2, Ozone and VOCs are also known to use PM as a surrogate to carry and deposit themselves. Pollutants of all origin should be considered in entirety for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc.

Strategies for sector specific pollutants need to be drawn from scientific evidences which are concrete and clear. These facts can be derived from the use of multitude of techniques such as emission inventory, dispersion modeling, receptor modeling and finally cost effectiveness analysis of varied options. Therefore, a comprehensive study has been proposed for six cities in India. NEERI has carried out this study for Mumbai and Delhi.

1.4.1 Previous Studies on Air Quality in Mumbai City

A) Ambient Air Quality Monitoring Programme of NEERI

NEERI has been monitoring ambient air quality at three stations each in 10 major cities including Mumbai for over more than a decade, under the NAAQM (National Ambient Air Quality Monitoring) program, with part financial support from CPCB (Central Pollution Control Board). The samples are collected twice a week at each site, throughout the year. Monitoring is carried out for Total Suspended Particulate Matter, Respirable Particulate Matter, SO_2, NO_2, H_2S and NH_3. The three sites represent three activity zones namely residential, commercial and industrial. The average concentration trends of SPM, RSPM, SO_2, NO_2, H_2S, NH_3 for the years 1997 to 2007 are shown in **Figures 1.1.**

The air quality trends shows that over a period of about 10 years, SO_2 has shown consistent decline, whereas NO_2 values declined till 2002, but has started showing marginal increase. SPM values have been receding; however, RSPM values have shown increase after few years of declining phase.

The Bandra site was shifted in the year 2001 to Worli both representing residential areas. The trends of other two sites remain reasonably in similar direction. Parel site which was designated industrial site has changed to commercial in last 10-12 years.

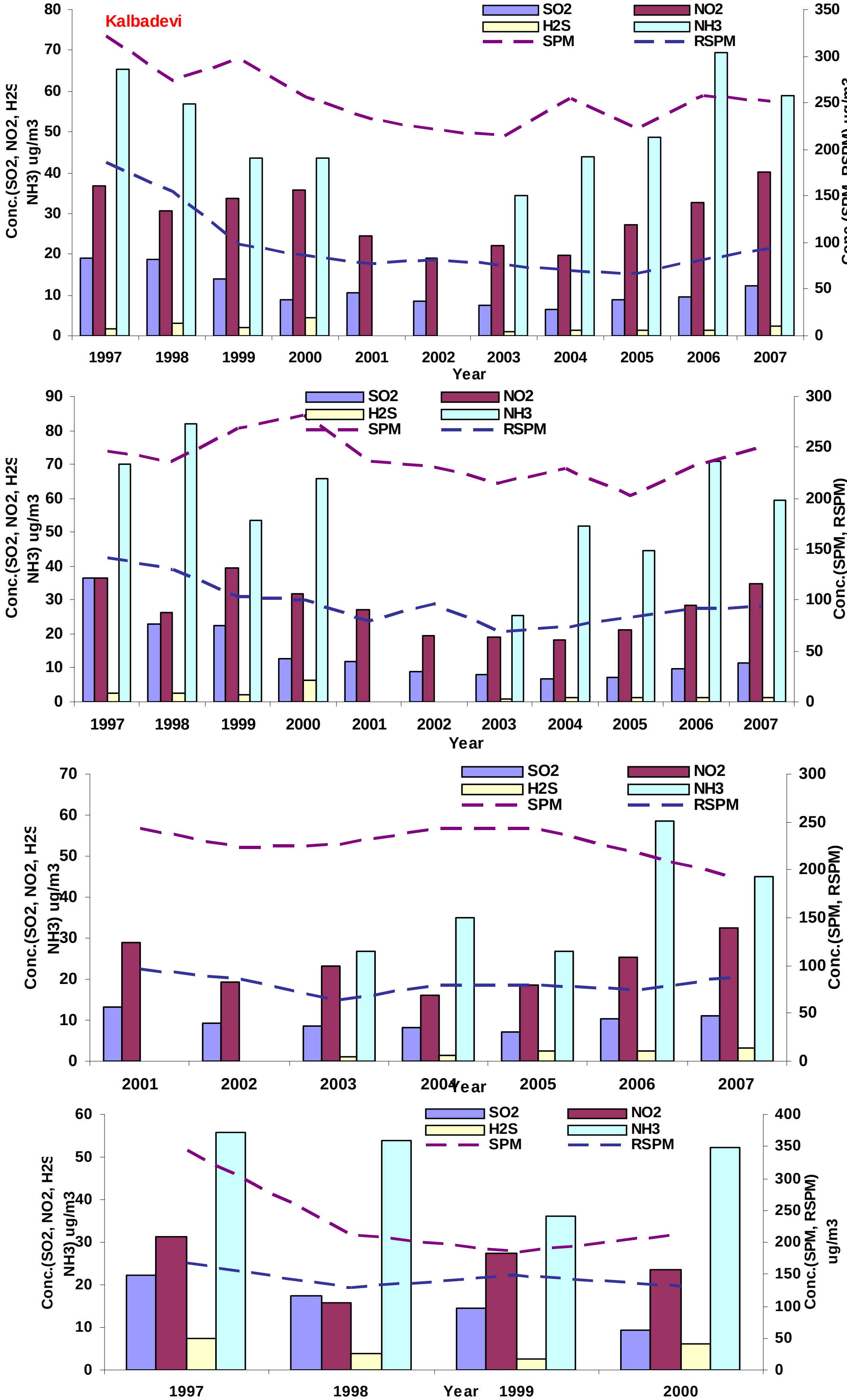


Figure 1.1: Average Concentration Trend of NAAQM- Mumbai (NEERI)

B) Air Quality Monitoring Programme of BMC

The Brihanmumbai Municipal Corporation (BMC) initiated an Air Quality Monitoring Network (AQMN) consisting of nine ambient air quality-monitoring stations in 1978. The network was gradually expanded to twenty fixed ambient air quality-monitoring stations in 1982. These stations were operated manually using High- Volume Samplers once a week. Wind direction and speed were also recorded at these sites. Over a period of time, BMC had to relocate some of its monitoring sites due to various operational difficulties and discontinued a few; Seweree station was discontinued in 1998 and Mahul was abandoned in 1996/97. After January 2000, the AQMN was restricted to only 6 fixed ambient air quality monitoring stations with a sampling frequency of twice a week as envisaged in the standards laid down by CPCB. The 6 stations are Khar, Worli, Bhandup, Andheri, Borivali and Maravali. **Table 1.2** shows summary of results of six sites. Temperature and relative humidity are also recorded at each of these stations. The AQMN was supported with a mobile laboratory (monitoring van) from January 1997. This van has the capability to monitor additional parameters such as PM_{10}, HC (methane/non-methane), O_3 and H_2S as well as meteorological parameters viz. wind speed, wind direction, temperature and relative humidity. For the first three years, this van was primarily used to respond to complaints arising from different areas of the city as well as to monitor traffic pollution at various locations. Since January 2000, this van is used on regular basis to monitor kerbside air quality at three locations (traffic junctions at Andheri, Wadala and Mahim) for 2 days each week as per the directive of the Hon'ble High Court.

Table 1.2: Ambient Air Quality Levels at Fixed Monitoring Sites (April 2004-March 2007)

Annual Avg.

Site	Concentration µg/m3														
	SO_2			NO_2			NH_3			SPM			Lead		
Year	**04-05**	**05-06**	**06-07**	**04-05**	**05-06**	**06-07**	**04-05**	**05-06**	**06-07**	**04-05**	**05-06**	**06-07**	**04-05**	**05-06**	**06-07**
Worli	24	21	12	29	39	27	75	78	54	145	185	150	0.1	0.2	0.1
Khar	15	19	12	53	67	51	90	79	67	235	278	266	0.1	0.2	0.2
Andheri	23	16	10	47	51	46	85	79	61	275	220	308	0.2	0.1	0.2
Bhandup	28	24	12	38	49	53	77	73	59	230	255	220	0.1	0.2	0.2
Borivali	17	14	10	20	25	17	85	75	54	117	170	118	0.1	0.1	0.1
Maravali	28	27	20	59	74	51	458	263	176	316	401	392	0.2	0.3	0.4
CPCB Std.	**60 µg/m3**			**60 µg/m3**			**100 µg/m3**			**140 µg/m3**			**0.75 µg/m3**		

* Environmental Status Report (2006-07), MCGM

C) Air Quality Monitoring Network of MPCB

MPCB (Maharashtra Pollution Control Board) carries out air quality monitoring at three stations viz. Sion, Mulund and Bandra for the criteria pollutants. One continuous monitoring station is also operated at Bandra Kurla Complex. The AAQ reports are given to media on daily basis. The Mobile van is allotted specifically to Mumbai city area for complaint based air monitoring. **Table 1.3** presents the summary of results at three stations. Average value of SO_2 at Sion and Mulund was 29 and 32 $\mu g/m^3$ during 2005-07, whereas average NO_2 values are 106 and 52 $\mu g/m^3$ at respective sites, whereas the average RSPM concentration at Sion and Mulund is 249 and 167 $\mu g/m^3$ respectively.

Table 1.3: Ambient Air Quality Monitored at the Traffic Junctions for the Period from 2005-2007

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept.	Oct.	Nov.	Dec.
Sion Junction													
2005	SO_2	23	18	21	26	25	26	24	23	21	24	27	33
	NO_2	79	77	81	98	75	76	73	84	74	81	91	124
	RSPM	208	216	222	235	236	241	224	208	186	219	211	228
2006	SO_2	58	44	39	27	28	28	28	24	26	23	30	37
	NO_2	235	229	180	54	51	56	42	39	77	76	125	107
	RSPM	235	342	269	319	275	187	170	137	229	264	290	280
2007	SO_2	41	37	32	30	27	24	23	24	23	25	33	--
	NO_2	162	153	147	117	94	118	100	94	122	132	165	--
	RSPM	296	297	312	316	315	288	298	172	173	280	300	--
Mulund Junction													
2005	SO_2	21	25	27	19	18	24	17	32	25	26	30	36
	NO_2	72	63	57	57	28	54	76	78	64	67	77	78
	RSPM	127	134	141	147	122	113	86	38	95	209	206	294
2006	SO_2	41	45	27	30	32	29	35	20	38	54	52	35
	NO_2	119	57	65	51	42	49	46	36	40	28	31	36
	RSPM	245	282	222	201	144	146	165	148	133	191	179	234
2007	SO_2	86	22	29	16	18	15	31	27	22	39	64	--
	NO_2	40	32	28	39	42	51	47	53	44	36	41	--
	RSPM	253	157	147	170	138	141	158	133	136	198	217	--

(Website:MPCB)

D) Particulate Matter Reduction in Greater Mumbai Region, 2001

The particulate matter concentrations in Greater Mumbai were observed to be higher than the prescribed Central Pollution Control Board (CPCB) standards and World Health Organization (WHO) guidelines through out the year at all monitoring sites. The health effects of air pollution have been known for a long time. Realizing the high values of particulate matter concentrations in Greater Mumbai, NEERI was retained by Mumbai Metropolitan Region Development Authority (MMRDA), under World Bank financed programme, to prepare strategies and action plans for particulate matter reduction in Greater Mumbai region. It was also a first attempt to address air pollution problem with transport planning means under the World Bank financed MUTP (Mumbai Urban Transport Project). The study included inventorizing the PM sources, developing PM reduction strategies and, preparing and prioritizing PM reduction action plan. As a part of the study SPM and RSPM were monitored at 16 locations for 1 month during December 2001. **Table 1.4** gives the summary of the monitored data.

Table 1.4: Average Air Quality Status of SPM & PM_{10} (Unit: $\mu g/m^3$) in December 2001

Sr.	Station	SPM					PM_{10}				
		8hr. Max	**8hr. Min**	**24 hr. Avg**	**SD**	**98 Percentile**	**8hr. Max**	**8hr. Min**	**24 hr. Avg**	**SD**	**98 Percentile**
Control											
1	Colaba	272	100	181	45	266	146	29	78	31	145
2	Borivali	404	96	207	75	389	169	28	86	34	161
Kerbside											
3	Haji Ali	664	188	366	142	660	207	45	114	38	196
4	MetroCinema	656	212	448	132	646	312	84	186	61	308
5	Sion	705	330	539	97	692	230	91	156	38	227
6	Chembur Naka	575	203	385	96	565	193	75	138	34	193
7	Vile Parle	896	209	736	143	882	450	168	315	71	443
8	Mulund	637	362	504	66	634	272	124	182	42	266
Air Quality											
9	Mazgaon Dock	547	182	356	87	532	213	61	135	40	209
10	Khar	535	225	373	76	523	197	105	154	24	192
11	Mankhurd	538	125	320	118	506	245	41	114	46	209
12	Goregaon	360	103	249	70	360	176	27	95	38	164
13	Andheri	618	195	331	110	577	289	62	135	60	284
14	Vikroli	528	158	340	94	495	219	51	116	39	193
15	Bhandup	529	180	343	89	528	353	87	152	59	305
16	Ghatkopar	538	230	357	87	532	181	84	120	23	171

PM Reduction Action Plan Report, NEERI, Mumbai 2003

As is evident from the monitored values at 16 locations, SPM and RSPM values exceed the current standards. High levels recorded in residential areas were cause of concern. The study delineated technological and public processes which could lead to PM reductions. Cost effectiveness and institutional mechanisms were also detailed in presented in this report.

1.5 Objectives and Scope of Work of Present Study

The six cities study initiated for other cities viz. Delhi, Mumbai, Pune, Kanpur, Banglore and Chennai by CPCB have similar objectives as given hereunder:

1.5.1 Objectives

- To measure baseline Ground Level Concentration (GLC) of air pollutants and air toxic levels in different parts of the city including background, residential, commercial/mixed area and source specific "hot spots" viz. Kerbsides, industrial zones, etc.
- To prepare inventory for the various air pollutants, their emission rates and pollutant loads from various sources along with spatial and temporal distribution in the city of Mumbai.
- To conduct source apportionment studies for PM_{10} and $PM_{2.5}$ and prioritize the source categories for evolving cost-effective air pollution mitigation strategies/plans.
- To assess the impact of sources on ambient air quality under different management/ interventions/ control options.
- Draw a roadmap of short term and long term measures as considered appropriate and cost effective to ensure "Cleaner air in urban areas"

1.5.2 Scope of the Study

The over all project scope include air quality monitoring, complete characterization of deposited dust (PM_{10}) and limited $PM_{2.5}$, emission inventory, receptor and dispersion modeling and sources apportionment. The major areas of work encompassed and completed under the study are as follows:

A) Ambient Air Quality Monitoring

- The ambient air quality monitoring was undertaken at seven locations in Mumbai
- Air monitoring stations were installed at locations such as kerbside, residential, industrial and background (away from all the sources). The sites were decided in consultation with the representatives of Technical Committee and the team of CPCB
- The air pollutants studied in this study include SPM, PM_{10}, $PM_{2.5}$,SO_2, NO_2, CO, O_3, (OC/EC, Ions and elements; as part of PM_{10}) Aldehydes, Total hydrocarbon(THC), nonmethane hydrocarbon (NMHC), Poly aromatic hydrocarbons (PAH), Benzene, 1-3 butadiene. Monitoring protocol frequency of sampling, sampling and analytical methods, chemical speciation for PM_{10}, $PM_{2.5}$ etc. was followed as per the details given in Chapter 2.
- Ambient air quality monitoring was carried out at about 3 – 10 meters height from the ground level.

- In order to capture diurnal variations of air quality due to variations in the activities and meteorological settings, three time slots viz. (i) 06.00 to 14.00 hrs; (ii) 14.00 to 22.00 hrs; and (iii) 22.00 to 06.00 hrs was selected. Data reporting was however, for 24-hourly averaging period
- Meteorological monitoring was carried out simultaneously at each station at the same height of ambient monitoring for parameters such as wind speed, wind direction, temperature and relative humidity. Solar insolation was also measured at one station in the city.

B) Emission Inventory

All relevant information/data on emission inventory which were available through secondary sources were collected. Primary surveys were carried out for identification and spatial distribution of sources and preparation of detailed emission inventory for zone of influence (2km x 2km area) around each ambient air quality monitoring location.

- The zone of influence (2km x 2km) around each monitoring location was first surveyed for identification of source types/categories.
- In this zone of influence around each ambient air quality monitoring station, following methodology was used for estimating emissions:
  a. For industries, after proper identification of all significant categories/sectors, emission factors of USEPA, WHO, etc. as well as information available with Pollution Control Boards, industries & other sources were looked into and based on scientific judgment and suitable rationale, emission factors were used for emission load calculation. A summary of common emission factor was also circulated by CPCB which were used. However, some city specific sources project team’s literature was used. Representative statistical sample of the sources were used to work out emission estimates.
  b. For vehicular sources, vehicle count surveys were carried out for all different types of roads (highways, major roads and minor roads) with focus on zone of influence around each monitoring locations. At selected locations, traffic surveys were carried out. The purpose of vehicle count data collection was to estimate total emission from line sources within the city as well as in the zone of influence. Chapter 3 presents the location for vehicle count. Vehicle emission inventory shall also need to estimate vintage technology and average use pattern. Parking lot surveys as well as petrol pump survey were carried out. With a view to established fuel used and average driving pattern of citizens.
- Estimation of area sources was arrived at by taking total area under each emission source category/type and emission estimates were determined based on scientific judgment and

considering available information on emission factors and their normalization for Indian conditions based on secondary data information.

Emission inventory estimates were developed for all seven sites (zone of influence with 2 x 2 Km area) and later for the whole city.

C) Dispersion and Receptor Modelling

Dispersion and receptor modeling approach has been with a view to establish the sources and understand the dynamic of air pollutants movement. A detailed and relatively reliable emission inventory is required by adopting common methodology for all the major sources within 2 km x 2 km zone. Sampling locations are focused for receptor and dispersion modeling predictions. However, at city level only dispersion modeling has been used.

- ISCST 3 has been used for dispersion modeling of particulate matter and NO_2. The overall city level emission inventory based on secondary data and the detailed micro-level emission inventory compiled by primary survey at 7 locations were used as input to the model. The model run accounted for both the inventories simultaneously. Iso-concentration plots were generated for the whole city.
- For the dispersion model calibration exercise, the correlation curves adopting PM_{10}, (which is the pollutant of concern) for the measured Vs observed concentration should be drawn for regression analysis.
- Future concentration estimates were drawn under different scenarios using the above calibrated dispersion model.
- CMB 8.2 version has been used for receptor modeling. In this case, the monitored receptor chemical concentration data and source profiles (based on information available through other studies) are key inputs to the model. All the major sources in the 2km x 2km grid around the 7 monitoring stations were considered.

1.5.3 Deliverables

The study report has many deliverables based on extensive work plan.

- Present air quality status of Mumbai
- Percentage share (quantification of contribution) of air pollutant emissions that are attributable to transport sector, industrial, commercial, residential and other activities.
- Percentage share in air pollutant emissions released through each category of vehicle (2/3 wheelers, passenger cars, light duty vehicles, multi-utility vehicles, buses, and trucks) and

each category of fuels (Gasoline, CNG/ LPG and Diesel). Sub categorization in terms of technology of the vehicles within the aforesaid category, age of the vehicle and the impact of inspection and maintenance practices, pre-Euro /India 2000 vehicles etc.

- Based on projected growth trend in emissions in the next 5 and 10 years for various source categories, different impact scenarios have been generated and corresponding action plan have been evolved.
- Impact on ambient pollution levels for implementation of short/medium term interventions for the following:

Vehicular sources

a. Better vehicle technology
b. Better maintenance of vehicles
c. Improved traffic management
d. Better road conditions and pavements
e. Improved tail pipe treatment/catalytic converter/particulate filter
f. Improved use of oxygenates/ performance additives
g. Improved fuel quality.

Industrial sources

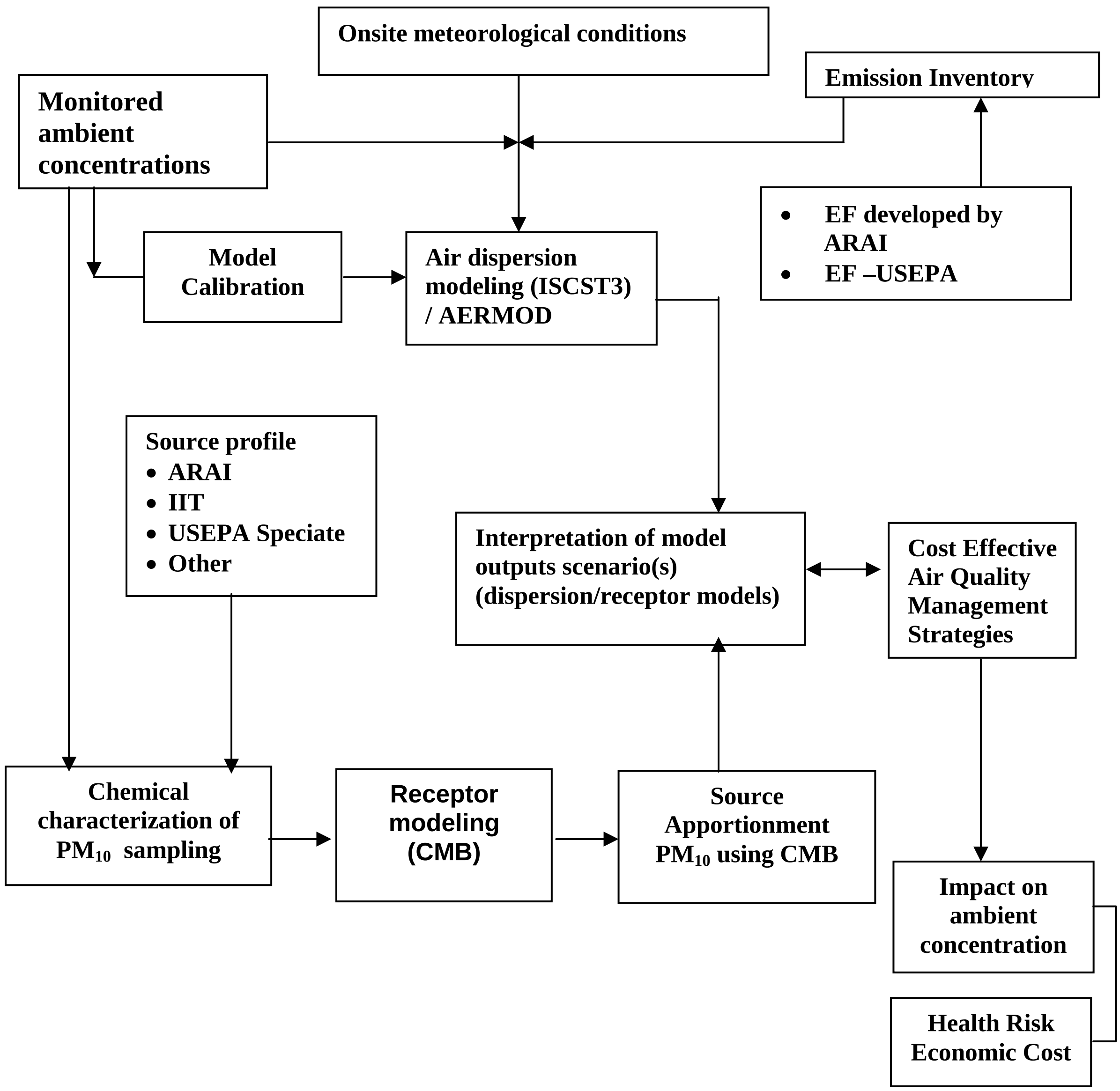
a. Growth or decline of industries
b. Fuel quality improvement
c. Fuel shift
d. Better production technologies
e. Improved emission control technologies
f. Industrial sitting policy

Area sources

a. Growth of population
b. Fuel shift
c. Fuel quality improvement
d. Better management
e. Road dust elimination by better I&M
f. Public process and social customs

1.6 Approach to the Study

Mumbai sutdy is part of six city study which also comprises of source profile estimation by IIT, Mumbai and ARAI, Pune. The later was also responsbile for vehicular emission factors with varying fuel quality and vitages of vehicles. The study aimed at accompolishing the above task throgh comprhensive monitoring and modelling result analysis for devising strategies and action plans. The overall appraoch of the study is shown below :



1.7 Report Structure

The report is divided into eight chapters

***Chapter 1**:* The chapter gives brief background of the study with city description and sources of air pollution. It also covers past air quality studies and points out the research gaps giving direction to the present need of the study. The objectives, scope of work with deliverables are presented in this chapter.

Chapter 2: This chapter identifies air pollutants to be monitored with brief methodologies on site selection, air quality monitoring and analysis techniques. Descriptive analysis and correlation of various pollutants for three seasons is presented. Chemical speciations of PM_{10} with mass closure analysis are also described.

Chapter 3: Inventory of all sources is presented in this chapter. The chapter starts with a brief description of various categories of sources and data collection methods, activity; methodology of emission load calculation with appropriate factors etc. Issues related to emission inventory of each category are also delineated.

Chapter 4: Chemical composition of PM_{10} is used for apportionment of sources. Factor analysis results have been discussed to understand the sources qualitatively. Later, chemical mass balance model application to estimate percent contribution of each source has been presented in the chapter.

Chapter 5: This chapter discusses dispersion modeling using ISCST3 model. It provides details of micro-level emission inventory based on primary survey at 7 locations for model runs.

Chapter 6: Whole city model runs have also been presented in this chapter. The future growth scenario for 5-10 years, emission control and prevention option and analysis for area, industrial and vehicular sources have been delineated in this chapter.

Chapter 7: Prioritized list of management /control options and action plan is described in this chapter. .

Chapter 8: Major outcomes of the project are highlighted in this chapter along with recommendations for implementation.

Annexures: Detailed methodologies in the form of standard operating procedures (QA/QC), actual data, secondary data, emission factors, grid wise emission loads, molecular marker methodology and results, dispersion modeling (ISCST-3) results, CPCB control strategies, Mumbai development plants are presented.

Chapter 2
Air Quality Status

2.1 Introduction

The source apportionment of air pollutants warrants a comprehensive air quality monitoring. This was accomplished by carrying out air quality monitoring for 30 days continuously in each season for three seasons. In all the seven selected locations, level of pollutants such as SPM, PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, Benzene, 1, 3 - Butadiene, Aldehydes, NMHC and HC were recorded. Further, PM_{10} samples are analyzed for EC/OC, ions and PAH including molecular marker.

2.2 Methodology

Design of air quality monitoring includes the factors such as population density, meteorology, topography, etc. During the study, proper guidelines were followed for the selection of the monitoring stations. Seven sampling sites were selected which were representative of Greater Mumbai Region. Of these, one site was selected as control site, one as industrial site, two as kerb sites, and one as residential site of upper income group and last one as a residential site in slum. Final selection of monitoring stations was completed in consultation with the technical committee and CPCB. The locations of sampling sites are presented in **Table 2.1** and study area is depicted in **Figure 2.1 and Figure 2.2.** Each site description has been presented in next section with a view to bring out the overall characteristics of sites. Data has been discussed for different seasons for all sites. Correlation and mass closure has been discussed at the end, where all sites have been compared together for all other monitoring attributes. Mass closures for all sites have been carried out as per protocol given in Data Validation Workbook: Session 4 – Particulate Matter.

Table 2.1 Details of Air Quality Monitoring Sites

Sampling Site	Type	Sampling Height in(m)
Colaba	Control	3
Dharavi	Residential, Slum	6
Khar	Residential, upper income group	6
Mahul	Industrial	3
Dadar	Commercial	3
Andheri	Kerb	7
Mulund	Kerb	5

Sampling Sites

1. **Colaba (Control)**
2. **Dadar (Commercial)**
3. **Dharavi (Residential -1)**
4. **Khar (Residential -2)**
5. **Andheri (Kerb-1)**
6. **Mahul (Industrial)**
7. **Mulund (Kerb-2)**

Figure 2.1: Study Domain and Sampling Sites in Mumbai

Colaba

Dadar

Dharavi

Khar

Andheri

Mahul

Mulund

Figure 2.2 : Sampling Site Photographs – Study Area Mumbai

2.2.1 Site Description

1) Colaba: It represents the "Background Site" for the study region and was located in the campus of Municipal Sewage Pumping Station. It has Arabian Sea on one side and residential area on the other side. The southern side is occupied by a military cantonment, including the Navy Nagar. Near the sampling site, there is an Army Canteen and a Church (Afghan Church). This area is also characterized by residential areas like Parsi Colony, Colaba market, Navy Nagar. There are number of restaurants (mainly small scale) and some big hotels like Taj President Hotel, Diplomat and Kailash Parbat. Colaba attracts many visitors and locals for shopping clothes and antique goods. Due to many corporate offices along with tourist spots such as Gateway of India, Museums and Movie theaters the number of open eat outs is very high. In the vicinity of Colaba, Backbay Bus Depot contributes to transport related emissions. Major roads starting from this end of Mumbai are Bhagat Singh Marg and Jaganath Bhosle Marg which goes to Churchgate and C.S.T Terminal respectively. These roads experience heavy traffic during office hours as also on holidays. Apart from land base activity, fishing vessels are operated from Sassoon Dock area and Ferry boats are operated from Gateway of India to Elephanta. No industrial activities are located in this area but dock area may be contributing some air emissions.

2) Dadar: It represents the "Commercial Site" and monitoring was carried out at Dadar Fire Station, located at central region of Dadar. Dadar is situated in the heart of the city and is connected to city from south side by Ambedkar Road, A.B.Road, Tulsi Pipe Road, N.M.Joshi Marg, from North side by Prabhadvi, Bandra Mahim Road, and on eastern side by Sion Hospital Road, Rafi Kidwai Marg, and Reay Road. Public transport and also intercity buses (Pune, Nashik, Panvel etc) operate from this area; which is evident from large scale parking of vehicle in this area. The site is also surrounded by residential area viz. Parel, Worli, Prabhadvi, Shivaji Park, Wadala, Mahim, and Matunga. People come to Dadar area for shopping as it has large number of garment, jewellery, and household appliances shops. Dadar area has number of open eat outs and hotels. Adjacent to Dadar on eastern side, Wadala and Kidwai area are dominated by slums, scrap dealers, wooden works, godowns, garages and spare part dealers. Due to these activities, heavy duty vehicles lead to poor road conditions. There are two crematoria in the vicinity of Dadar site. Contiguous area of Dadar, such as Parel and Lower Parel area have industrial estates, textile and dye processing units, corporate offices viz. Peninsula Corporate Park etc.

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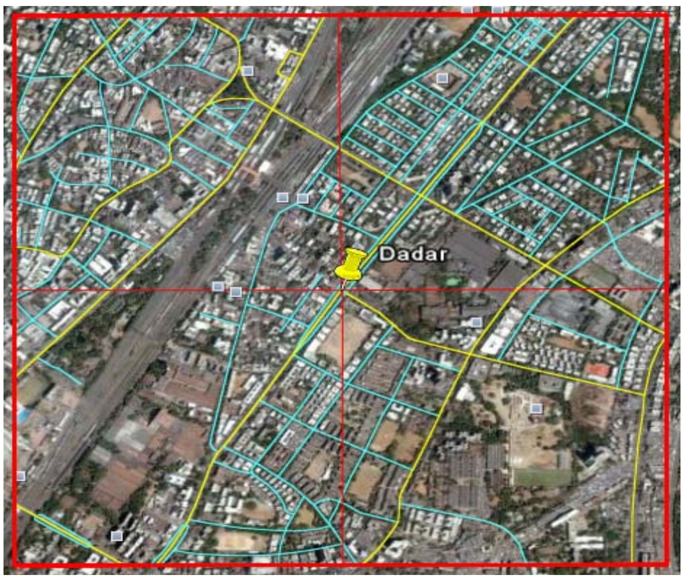
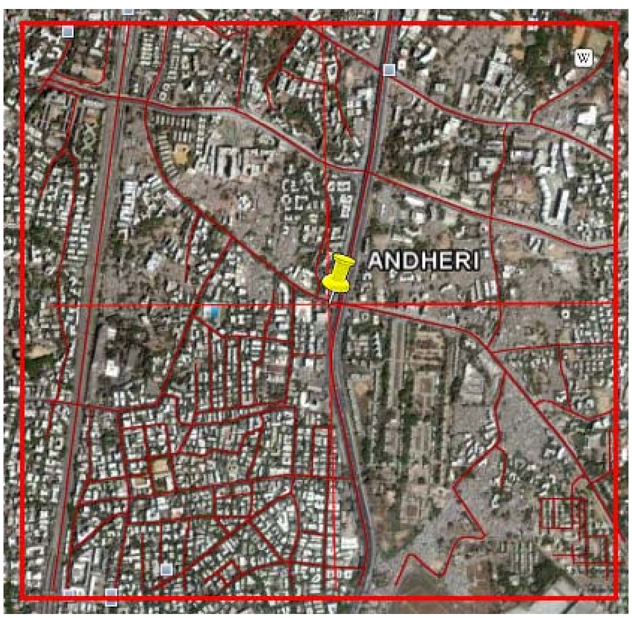


3) Dharavi: It represents, 'residential slum' site as it is Asia's largest slum having a population of more than 1 million people, who live in poor sanitation and unhygienic conditions. Dharavi is located between Mumbai's two main suburban railway lines, i.e. Western and Central Railways. Mahim and Bandra areas are on the west, and to its north Mithi River is situated, which empties into the Arabian Sea through the Mahim Creek. Major areas on south and east side are Sion and Matunga respectively. Dharavi area is spread over around 175 hectares. In addition to the many small scale traditional pottery and textile industries, there are large numbers of recycling and processing units where recyclable primary waste comes from other parts of Mumbai. About 15,000 single-room factories of small scale operations mainly glassworks, leathers, plastic pellets, jewellery, small scale food industries, welding operations etc. are located within this area. Waste created from these activities is burnt openly. Bakeries are one of the most prominent food processing industries. Inner roads of Dharavi area in the slum are mostly unpaved and major unpaved road in the vicinity of sampling site is known as '90 feet Road'. Dharavi connects eastern suburbs to western suburb. In addition, corporate offices are located in the adjacent area of Dharavi called Bandra Kurla Complex. This are observed high vehicles movements during office hours. Due to offices many open eat outs have also emerged. Dharavi is very close to residential (non slum) areas viz. Kala Nagar and Matunga Labour camp.

4) Khar represents the "Residential Site.", the monitoring was carried out at building top of a Veterinary Dispensary. Residential areas like Pali Hill, Khira Nagar, Santacruz and Vakola are located close to this area, because of which many shops, hotels and open eat outs, are located in this zone. A patch of slum area is seen in Khardanda- koliwada. Apart from this, commercial area like Bandra Linking Road is located in the vicinity. The major roads include Western Express Highway, S.V. Road, Bandra Kurla Complex road, and Santacruz Station Road. These roads connect Southern Mumbai with Western suburbs and therefore contribute to the vehicular traffic in this area. High building construction activities at different places was observed in the study area. No industries are located in the study zone.

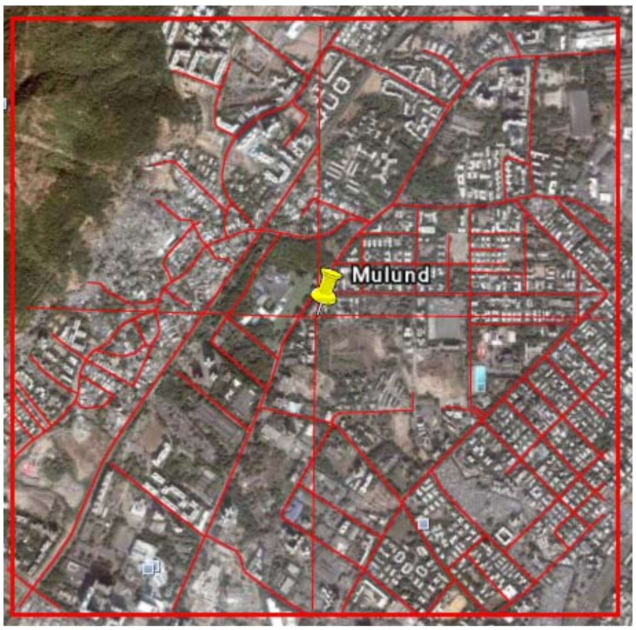
5) Andheri: It represents "Kerb Site" as it is located close to Western Express Highway. The monitoring was carried on the terrace of HDFC Bank. This area has high vehicular traffic, mainly on the roads like Western Express highway, S.V. Road, Chakala Road, and Andheri Kurla Road. The prominent features of the site are Flyovers (one exactly opposite to the site and the other one is on the Western Express Highway), Domestic Airport on the eastern side, Juhu Chowpaty and Pawanhans Air base on the west and Marol MIDC area on the north side. Because of Airport, there are number of five star hotels like Orchid, Sahara Star etc. These hotels are frequently visited by many people, which add to the traffic in the study area. Juhu Chowpaty being a tourist spot attracts many visitors thereby contributing to traffic. This area also has number of Hotels such as Sea Princess, J. W. Marriott and Tulip Star etc. Residential area is observed at places like Vile Parle (E), Airport Colony, Irla, Amboli Naka and Marol. The region has high number of shops, small hotels and open eat outs. MIDC area comprises of various industries. For example, Pharmaceutical like German Remedies, Franco Indian Pharma, Hindustan Basic Drugs etc.; engineering industries like National Metal Industries, Fiat India Pvt. Ltd etc; textile industries like Universal Knitting Mills, Premier Textile Processors. However, most of these industries are non air polluting units.



6) Mahul: It represents "Industrial Site" in Chembur area. The sampling was carried out at BPCL Sports Complex. Some part of the site is occupied by Mahul Creek and salt pans. Major industries in the area are BPCL, HPCL, Indian Oil Blending Ltd and chemical plant like RCF. Tata Thermal Power Plant is located in the nearby area. Containers and heavy duty vehicles from these area use Port Trust Road, Mahul Road, and Ramakrishna Chemburkar Marg. Heavy duty vehicles operate on Eastern Express Highway to go towards Wadala Truck Terminal. Due to continuous movement of heavy vehicles road conditions are bad. The other traffic also contributes mainly from roads connected to city by Eastern Express Highway and roads towards panvel. The residential block mainly covers Anushakti Nagar Colony, Tata Colony, BPCL, RCF Colony, Mhada Colony; Chembur Colony area. The area has fewer restaurants and open eat outs; however it has many shops of different types. Wadavali is in the vicinity of Mahul, which is a slum, where garages, scraps and other auxiliaries industries works are located.

7) Mulund: Mulund is a north-eastern suburb of Mumbai. Air quality monitoring was carried out at fire station. The two major arterial roads in Mulund are L.B.S. Road upto Mulund Check Naka and the Eastern Express Highway. The Eastern Express Highway runs through Mulund East which provides an easy transport route during heavy traffic. Many arterial roads in Mulund are concretised, thus not needing resurfacing every year. Mulund has become crowded over the years leading to the sharp increase in vehicles. Mulund is home to several prominent manufacturing establishments. Notable among them are the pharmaceutical companies - Hoechst, Wellcome, Glaxo, Merind and Johnson & Johnson. Engineering companies like Richardson Cruddas, British Oxygen, Chicago Pneumatic, ACC, Agfa & Gabriel and Asian Paints. Many of these establishments are making way for modern shopping malls and luxurious apartment complexes altering the landscape. Johnson and Johnson, however continues to remain a landmark in Mulund. Old buildings and structures gave way to big bright new malls and

Cineplex's. This change is most apparent along the L.B.S. Road which today is lined with two major shopping malls, R-Mall and Nirmal Lifestyle (one of India's largest malls). These malls cater to food courts inside the premises. Malls attract lot of high income group visiting in private vehicles. Mulund has many regions which uses Piped Gas for the past five years or more. Sonapur area around Mulund has many marble granite shops, scrap dealers, timber marts and many garages. Major residential colonies are Tata Colony, Mhada Colony, Vina Nagar, Vaishali Nagar, Gamdevi (slum).



2.2.2 Pollutants Monitored

Total suspended particulates (TSP), RSPM, PM_{10}, $PM_{2.5}$, SO_2, NO_2, NH_3, Aldehydes, CO, CH_4, Total Nonmethane Hydrocarbon, and Total Hydrocarbon were monitored at all the seven air-monitoring sites. Air Quality was monitored at each site for thirty days for the three season viz. summer, post monsoon and winter.

2.2.3 Measurement and Frequencies

Air quality pollutants were monitored as per the guide lines provided by CPCB as presented in **Table 2.2**, whereas chemical speciation methodologies adopted is given in **Table 2.3. Table 2.2** presents the details of sampling instrument, frequency, flow rate, sampling principle and the period of sampling for each monitoring attributes.

Table 2.2: Ambient Air Pollutants and their Standard Measurement Procedures as per CPCB

Particulars	Parameters						
	SPM	**PM_{10}**	**$PM_{2.5}$**	**NO_2**	**SO_2**	**CO**	**OC/EC**
Sampling Instrument	High Volume Sampler	Multichannel (4 channel) Speciation Sampler	FRM Partisol ($PM_{2.5}$) sampler Or Equivalent	Impingers attached to HVS	Impingers attached to HVS	Automatic analyser	PM_{10} Sampler Particulate collected on Quartz filter
Sampling Principle	Filtration of aerodyna-mic sizes	Filtration of aerodynamic sizes with a size cut by impaction	Filtration of aerodynamic sizes with a size cut by impaction followed by cyclone separation	Chemical absorption in suitable media	Chemical absorption in suitable media	Suction by Pump As per instrument specification	Filtration of aerodynamic sizes with a size cut by impaction
Flow rate	0.8-1.2 m^3/min	16.7 LPM	16.7 LPM	1.0 LPM	1.0 LPM	0.2 – 0.5 LPM	16.7 LPM
Sampling Period	8 change of filter, 24 Hourly Reporting	20 days 24 hourly and 10 days 8 Hourly filter change	24 hourly	4 Hourly change of absorbing media, 24 Hourly Reporting	4 Hourly change of absorbing media, 24 Hourly Reporting	Real time analysis and 8/24 hourly reporting	24 hourly Or 8 / 24 Hourly
Sampling frequency	30 Days continuous in each season, for three seasons	30 Days continuous in each season, for three seasons	One week continuous. First 2 days with Quartz, next 3 days with Teflon and next 2 days again with quartz filter	30 Days continuous in each season, for three seasons	30 Days continuous in each season, for three seasons	One week continuous during 30 days of monitoring in each season	30 Days continuous in each season, for three seasons

Table 2.2 (Contd..) Ambient Air Pollutants and their Standard Measurement Procedures as per CPCB

Particulars	Parameters						
	SPM	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	OC/EC
Analytical instrument	Electronic Balance	Electronic Balance	Electronic Micro Balance	Spectrophoto-meter	Spectrophoto-meter	GC - FID with Methaniser	OC/EC Analyser
Analytical method	Gravimetric	Gravimetric	Gravimetric	Colorimetric Jacobs & Hochheiser Modified method	Colorimetric Improved West & Gaeke Method	CO as Methane	TOR/TOT Method NIOSH 5040
Minimum Reportable value	5 $\mu g/m^3$	5 $\mu g/m^3$	5 $\mu g/m^3$	9 $\mu g/m^3$	4 $\mu g/m^3$	0.1 ppm	0.2 μg/ 0.5 cm^2 punch

Particulars	Ions	VOC (Benzene and 1,3 Butadiene,)	O_3	Aldehyde	NMHC	HC	PAHs (Included in organic Markers)
Sampling Instrument	PM10 Sampler Particulate collected on Teflon filter	Low volume sampling pump connected to Adsorption Tube	Automatic analyser	Impingers attached to HVS / RDS	Low volume sampling pump connected to Tedlar bags	Low volume sampling pump connected to Tedlar bags	PM_{10} Sampler
Sampling Principle	Filtration of aerodynamic sizes with a size cut by impaction	Active pressurised sampling / Adsorption	Suction by Pump	Chemical Absorption Or Active pressurised sampling	Suction by Pump	Auto suction by pump	Filtration of aerodynamic sizes
Flow rate	16.7 LPM	0.2 - 0.5 LPM	As per instrument specification	0.5 LPM	As per instrument specification	As per instrument specification	16.7 LPM
Sampling Period	24 hourly Or 8 / 24 Hourly	8 Hourly sampling and 24 Hourly Reporting	One week continuous Real time analysis and 8/24 hourly reporting	8 Hourly sampling and 24 Hourly Reporting	8 Hourly sampling and 24 Hourly Reporting	8 Hourly sampling and 24 Hourly Reporting	Weekly composite of left over Quartz filter after OC/EC analysis
Sampling frequency	30 Days continuous in each season, for three seasons	Twice during 30 days of monitoring in each season	One week continuous during 20 days of monitoring in each season	Twice in 30 days of monitoring in each season	Once in every week during 30 days of monitoring in each season	Once in every week during 30 days of monitoring in each season	04 weekly composite samples per season
Analytical instrument	Ion Chromato-graph	GC-ATD-FID / MS Or GC-FID / MS	Automatic analyser	Spectrophotometer	GC - FID with Methaniser	GC - FID with Methaniser	GC-MS
Analytical method	Ion Chromato-graphy	USEPA method TO-1/ TO-2 / TO-4 / TO-10 / TO-14	UV-Photometry	Colorimetric (MBTH method)	FID Analysis	FID Analysis	GC-MS
Minimum Reportable value		0.1 ppb	2 ppb	$\mu g/m^3$	0.05 ppm	0.05 ppm	1 ng/m^3

Notes:
1. Benzene 1,3 Butadiene and Alkanes may be done by adsorption followed by GC-ATD-FID Analysis using selective Adsorption tubes.
2. Methodology for molecular marker has been provided separately

Table 2.3 details all the chemical analysis along with molecular marker for particulate matter. These analysis data has been used for CMB 8.2 receptor models.

Table 2.3: Target Physical and Chemical Components (groups) for Characterization of Particulate Matter for Source Apportionment

<table>
<tr><th colspan="2">Components</th><th>Required filter matrix</th><th>Analytical methods</th></tr>
<tr><td colspan="2">PM_{10} / $PM_{2.5}$</td><td>Teflon or Nylon filter paper. Pre and post exposure conditioning of filter paper is mandatory</td><td>Gravimetric</td></tr>
<tr><td colspan="2">Elements (Na, Mg, Al, Si, P, S, Cl, Ca, Br, V, Mn, Fe, Co, Ni, Cu, Zn, As, Ti, Ga, Rb, Y, Zr, Pd, Ag, In, Sn, La Se, Sr, Mo, Cr, Cd, Sb, Ba, Hg, and Pb)</td><td>Teflon filter paper</td><td>ED-XRF, GT-AAS or ICP-AES or ICP-MS</td></tr>
<tr><td colspan="2">Ions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, SO_4^{-2},PO_4^{-2}, K^+, NH_4^+, Na^+)</td><td>Teflon filter paper (Same teflon filter paper can be utilised if ED-XRF is used for elements analysis)</td><td>Ion chromatography with conductivity detector</td></tr>
<tr><td colspan="2">Carbon Analysis (OC, EC and Carbonate Carbon)</td><td>Quartz filter. Prebaking of quartz filter paper at 600 ºC is essential</td><td>TOR/TOT method</td></tr>
<tr><td colspan="2">Molecular markers</td><td rowspan="6">The left over quartz filter paper after OC/EC analysis should be taken as composite sample (for one week) to represent a location and specified duration of exposure. This implies that 30 composite samples will be analyzed in each season.</td><td rowspan="6">Extraction, followed by GC-MS analysis with and without derivatization</td></tr>
<tr><td>Alkanes</td><td>n- Hentriacontane
n-Tritriacontane
n- Pentatriacontane</td></tr>
<tr><td>Hopanes</td><td>22, 29, 30 – Trisnorneohopane
17α(H), 21β(H)-29 Norhopane
17α(H), 21β(H) Norhopane</td></tr>
<tr><td>Alkanoic Acid</td><td>Hexadecanamide
Octadecanamide</td></tr>
<tr><td>PAHs</td><td>Benzo[b]fluoranthene
Benzo[k]fluoranthene
Benzo[e]pyrene
Indeno[1,2,3-cd]fluoranthene
Indeno[1,2,3-cd]pyrene
Phenylenepyrene
Picene Coronene</td></tr>
<tr><td>Others</td><td>Stigmasterol
Levoglucosan</td></tr>
</table>

2.3 Quality Assurance /Quality Control

Details of calibration coding, and quality checks with SOP of analytical instruments is presented in **Annexure 2.1.**

2.4 Monitoring Results

Air quality monitoring was carried out for three seasons viz. summer, post monsoon and winter. Results have been presented for all seven sites monitored in three different seasons.

2.4.1 Summer Season

Colaba Site: The observed concentrations for summer season are presented in **Table SC.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for summer season at Colaba are presented in **Figure SC.1**

Table SC.1: Air Quality Status at Colaba (Summer)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	77.0	438.0	159.0	342.3	71.0	30
RSPM (µg/m^3)	17.0	194.0	52.0	158.4	36.0	30
PM_{10} (µg/m^3)*	50.0	151.0	91.0	136.8	23.0	31
$PM_{2.5}$ (µg/m^3)**	16.0	41.0	29.0	NA	13.0	3
SO_2 (µg/m^3)	4.0	9.0	5.0	9.2	2.0	30
NO_2 (µg/m^3)	9.0	94.0	18.0	63.1	16.0	30
NH_3 (µg/m^3)	10.0	159.0	47.0	113.1	28.0	30
CO (mg/m^3)	0.3	5.1	2.9	5.0	1.8	5
Formaldehyde (µg/m^3)	10.0	26.0	18.0	NA	11.3	2
CH_4 (ppm)	1.1	1.2	1.1	NA	0.1	2
Nonmethane HC (ppm)	8.5	21.5	15.0	NA	9.2	2
Total HC (ppm)	9.5	22.7	16.1	NA	9.3	2
OC (µg/m^3)	5.1	35.2	11.4	29.8	6.6	31
EC (µg/m^3)	1.0	17.1	3.3	11.6	3.1	31
TC (µg/m^3)..	6.6	52.3	14.6	41.4	9.5	31

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Colaba exceeded 17% of the time of CPCB residential mixed standard of 200 µg/m^3, whereas RSPM exceeded 6% of the time during sampling period. As the site is background site, mainly natural sources are likely to contribute to SPM. The 24 hourly average concentrations of SO_2, and NH_3 were within CPCB limits, whereas NO_2 exceeded the standard 3% during study period. The monthly average of PM_{10} was 91 µg/m^3. Trends of temporal values of PM_{10} show that concentrations are higher during daytime and decrease during nighttime. CO values ranged between 0.3-5.1 mg/m^3, formaldehyde ranged between 10-26 µg/m^3, whereas Total Hydrocarbon ranged between 9.5-22.65 ppm.

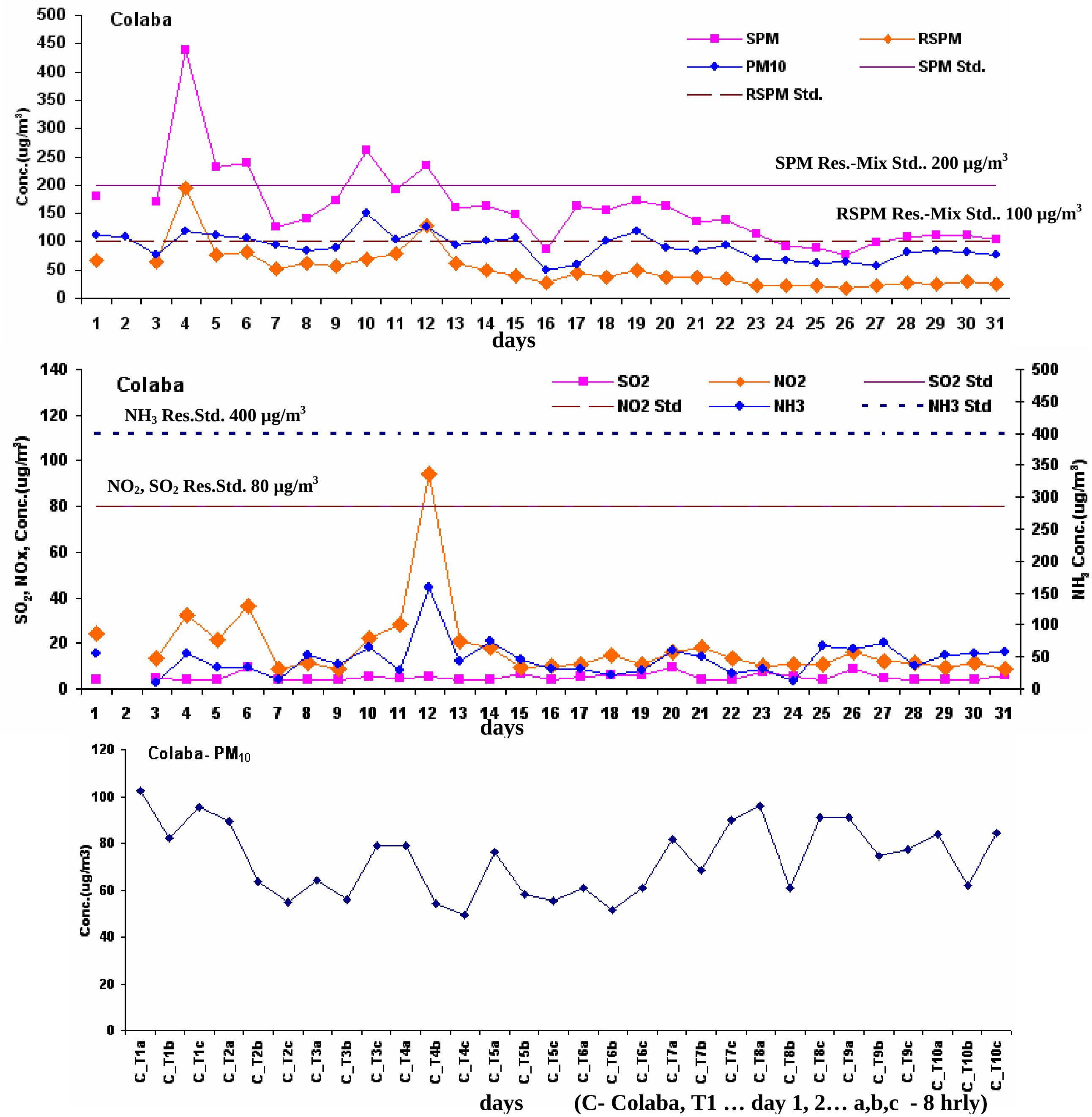


Figure SC.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Colaba (Summer)

Figure SC.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

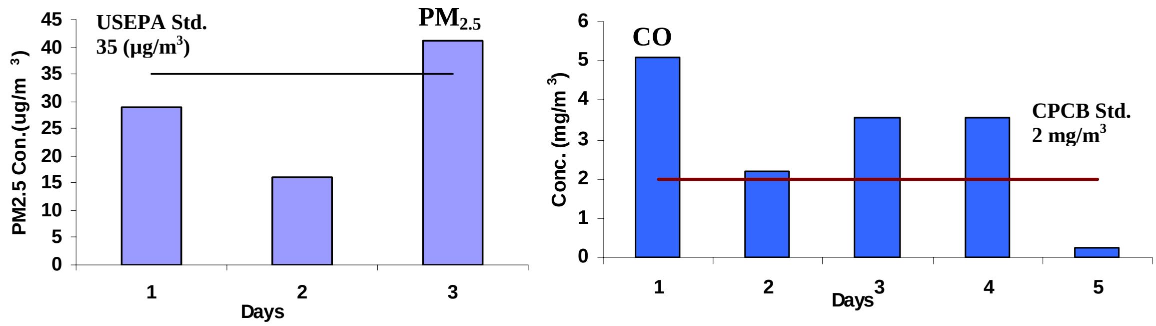


Figure SC.2: Observed Concentrations of $PM_{2.5}$ and CO at Colaba (Summer)

The concentration of $PM_{2.5}$ exceeded the US EPA standard of 35 µg/m^3, 33% of the times whereas CO concentration during the sampling period exceeded 80% of the times the CPCB standard of 2 µg/m^3 for the residential and mix use area possibly due to vehicular emissions and biomass burning.

Figure SC.3 show Methane, Non Methane and THC concentrations and **Figure SC.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not analyzed during summer season.

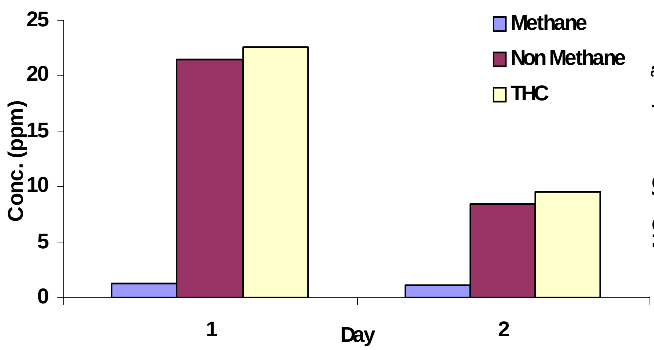


Figure SC.3 : Hydrocarbon Concentration

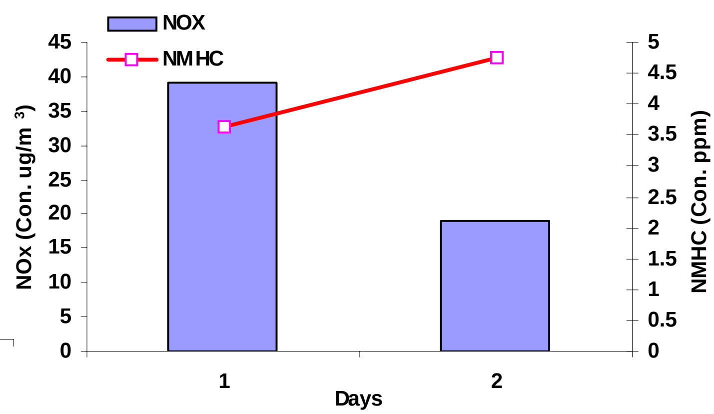


Figure SC.4 : NO_2 and NMHC Concentrations

Figure SC.5 presents diurnal variation of CO concentrations.

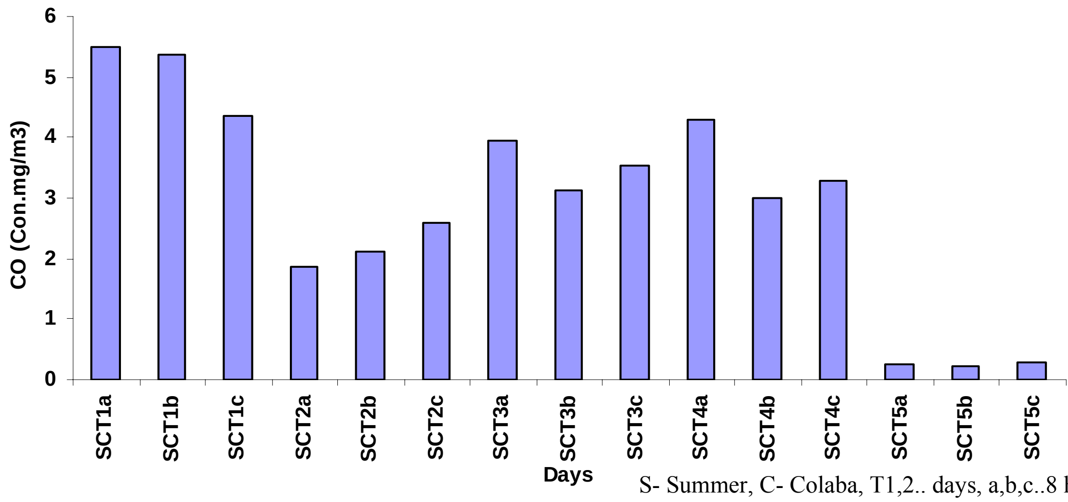


Figure SC.5: Diurnal Variation of CO

Diurnal variation in CO shows high variation with a high of 5.1 and low of 0.3 mg/m$^{3.}$

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2 , NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SC.6 and SC.7.**

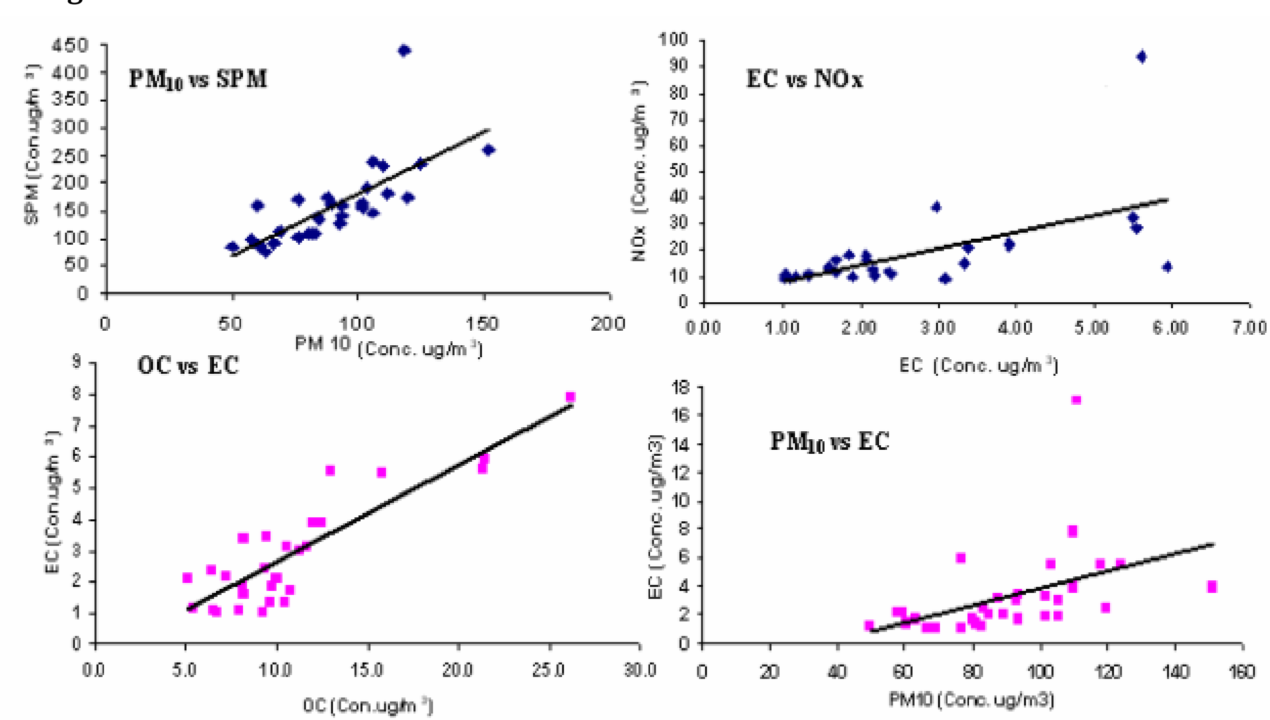


Figure SC.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.72) indicating the presence of sources contributing to coarse particulate matter like soil, sea spray as well as the fine particulate matter like vehicles and biomass burning. EC and NO_2 also show reasonable correlation (R=0.59) indicating that vehicular emission is contributing to both EC and NO_2. EC and OC show very good correlation (R = 0.88) indicating that the sources like vehicles and biomass burning are contributing to OC and EC. Correlation coefficient for PM_{10} and EC is 0.45 indicating that EC does not correlate with PM_{10}.

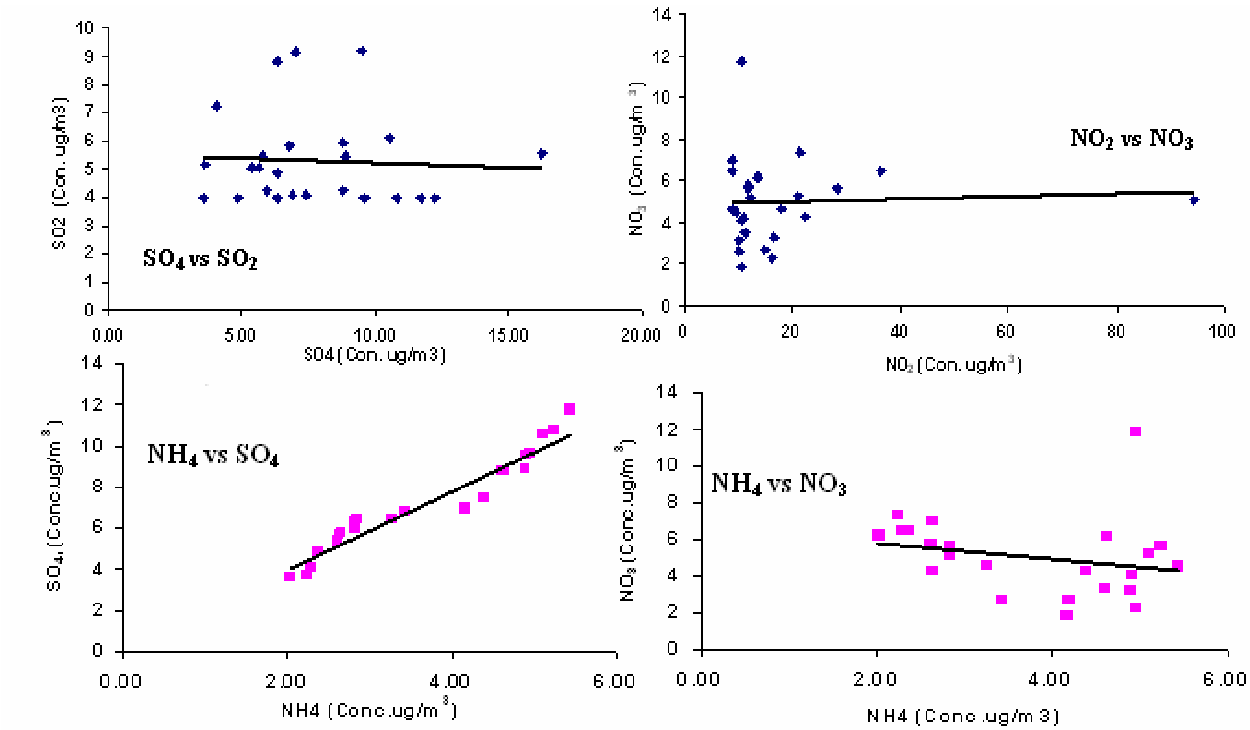


Figure SC.7 : Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} are not correlated. NO_2 and NO_3^- correlate poorly indicating that NO_2 is not getting converted to NO_3^-. NH_4^+ and SO_4^{2-} show excellent correlation (R=0.96) indicating that NH_4^+ is neutralizing SO_4^{2-} and resulting in the formation of $(NH_4)_2SO_4$. NH_4^+ and NO_3^- also show no correlation which could be due to the fact that at high ambient temperature particulates nitrates are volatile *[Sharma et.al., 2007]*.

Carbon concentrations at Colaba site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SC.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.424	.445	.438
OC	.424	1.000	.920	.992
EC	.445	.920	1.000	.962
TC	.438	.992	.962	1.000

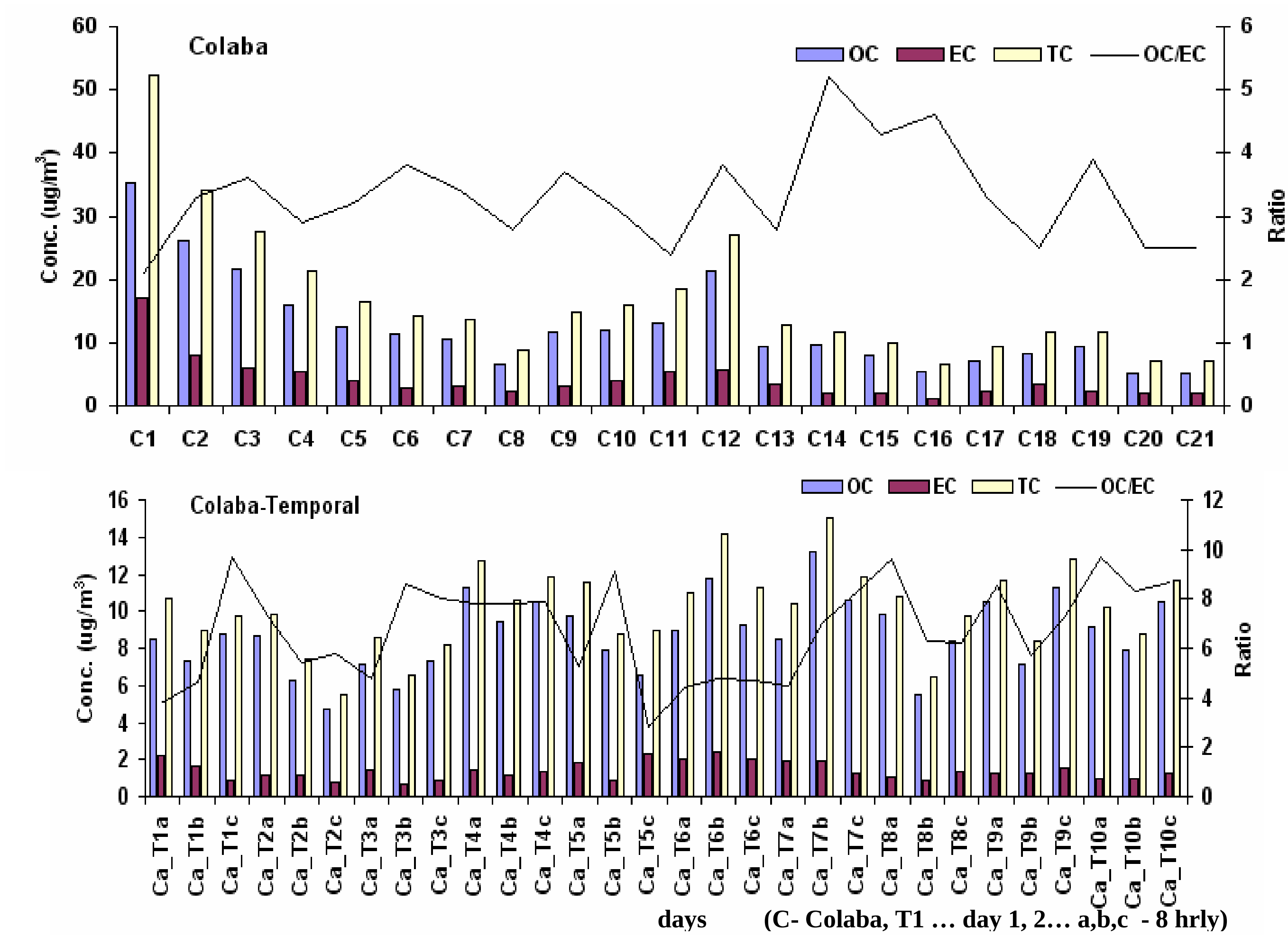


Figure SC.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Colaba Site (Summer)

At Colaba site OC varied between 5.1-35.2 $\mu g/m^3$ with an average value of 11.4 $\mu g/m^3$. The EC concentration varied between 1.0-17.1 $\mu g/m^3$ with an average value of 3.3 $\mu g/m^3$. OC/EC ratio varied from 2.1 to 8.9 with an average ratio of 4.4. Percentage of OC, EC and TC in PM_{10} was 12.5, 3.6 and 16.1 whereas in $PM_{2.5}$ it was 21.5, 11.9 and 33.7 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (µg/m^3) in PM_{10} is shown in **Figure SC.9**.

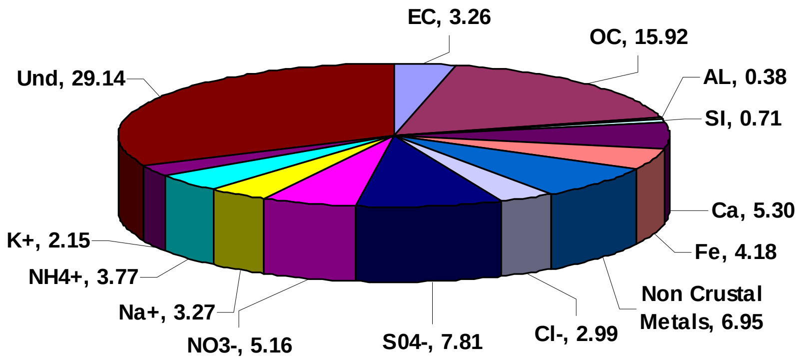


Figure SC.9 : Mass Closure Concentrations (µg/m^3) at Colaba

Percent composition of PM_{10} after mass closure shows that maximum contribution is from ions which contribute to about 28% of the particulate matter. High concentration of SO_4^{2-} and NO_3^- are due to secondary aerosols, vehicles and sea spray. Other ions like Cl^- and Na^+ are from sea spray, NH_4^+ from vehicles and K^+ is from biomass burning. OC and EC contribute to 17 % and 4 % respectively indicating the contribution from biomass burning and vehicular exhausts. Crustal elements account for 12% of the total particulate matter indicating the contribution from soil whereas non crustal elements account for 8% of the total particulate matter indicating the contribution from other anthropogenic sources. 31 % of the total PM_{10} is unidentified.

Dadar Site : The observed concentrations for summer season are presented in **Table SD.1**.The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM and PM_{10} and gaseous pollutants for summer season at Dadar are presented in **Figure SD.1.**

Table SD.1: Air Quality Status at Dadar (Summer)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	197.0	758.0	335.0	624.1	134.0	29
RSPM (µg/m^3)	47.0	154.0	90.0	151.3	31.0	29
PM_{10} (µg/m^3)*	49.0	204.0	116.0	183.0	34.0	29
$PM_{2.5}$ (µg/m^3)**	27.0	47.0	37.0	NA	9.0	5
SO_2 (µg/m^3)	4.0	15.0	6.0	12.8	3.0	29
NO_2 (µg/m^3)	11.0	60.0	31.0	54.9	11.0	29
NH_3 (µg/m^3)	5.0	297.0	59.0	196.3	53.0	29
CO (mg/m^3)	1.0	3.4	2.4	3.3	1.0	7
Formaldehyde (µg/m^3)	20.0	93.0	57.0	NA	51.6	2
CH_4 (ppm)	0.9	0.9	0.9	NA	0.0	2
Nonmethane HC (ppm)	3.6	4.8	4.2	NA	0.8	2
Total HC (ppm)	4.5	5.7	5.1	NA	0.8	2
OC (µg/m^3)	11.28	27.2	16.3	24.6	3.11	30
EC (µg/m^3)	2.65	8.43	5.8	8.2	1.4	30
TC (µg/m^3)..	13.9	31.9	22.0	30.2	3.4	30

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Dadar exceeded 100% of the time CPCB residential mixed standard of 200 µg/m^3, whereas RSPM exceeded 34% of the time during sampling period. As this site is kerbsite, re-suspended dust could be the reason for high SPM concentration. Residential /Mixed standards may not be appropriate to compare for sites near traffic. The 24 hourly average concentrations of SO_2, NO_2 and NH_3 were within CPCB limits. The monthly average of PM_{10} was 116 µg/m^3. A trends of temporal values of PM_{10} shows that concentrations are higher mostly during 10 pm to 6 am, this may be due to site being closer to inter–city bus stand, where buses ply during late night and early morning hours. PM_{10} values correlates well with NO_2 values. CO values ranged between 1.03-3.35 mg/m^3, formaldehyde ranged between 20-93 µg/m^3, whereas Total Hydrocarbon ranged between 4.5-5.7 ppm

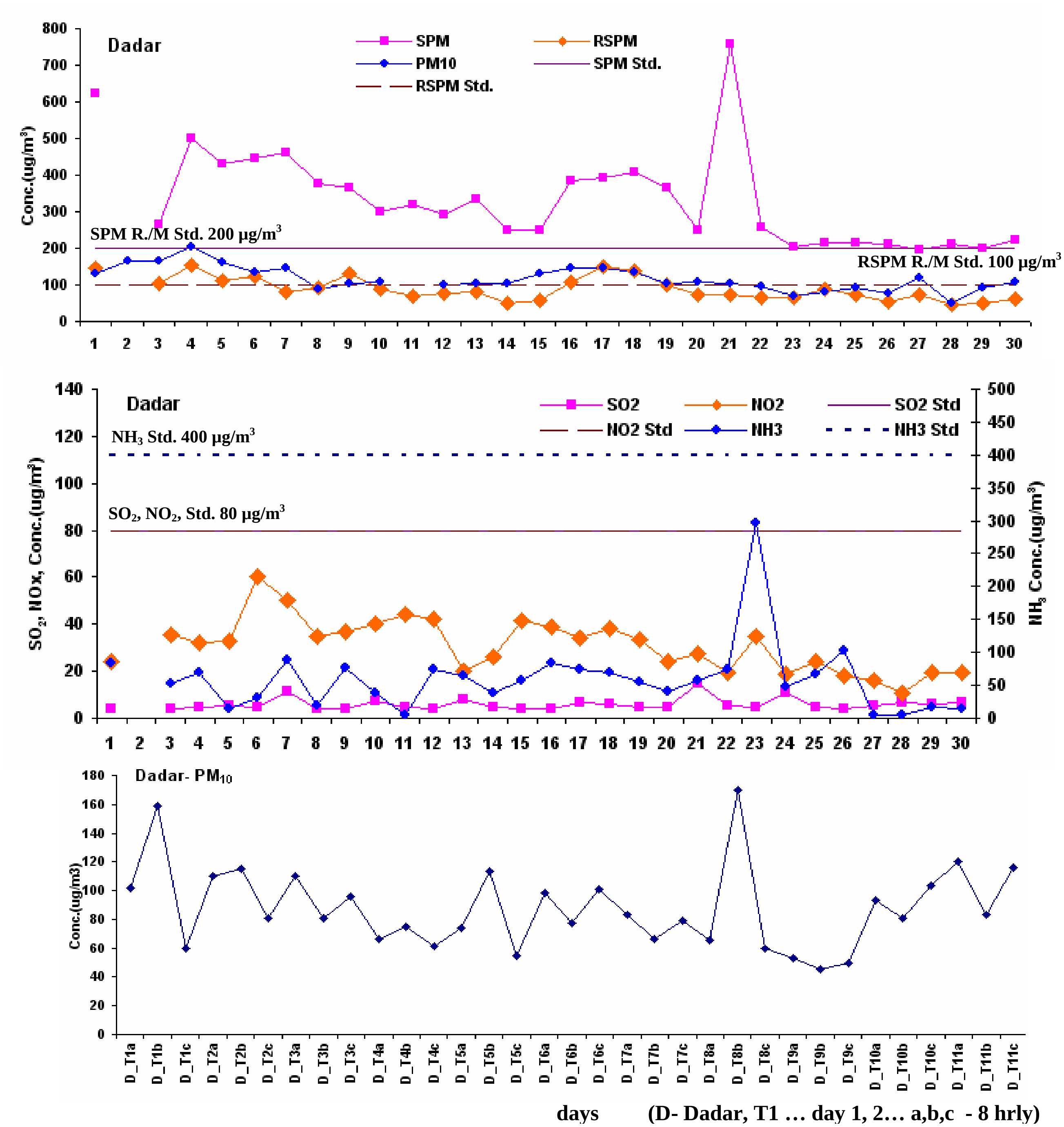


Figure SD.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Dadar (Summer)

* High value at particular day indicates outlier due to certain site specific activity.

.**Figure SD.2** shows the variation of $PM_{2.5}$ and CO during the summer period.

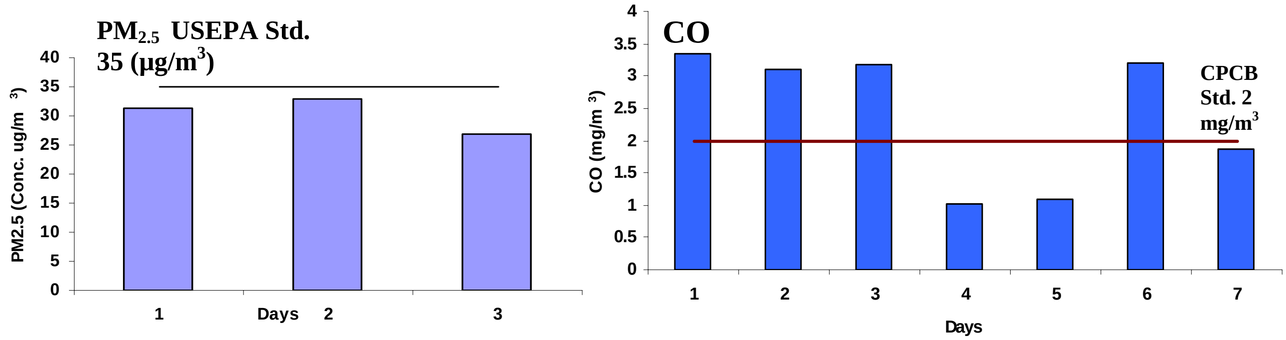


Figure SD.2 : Observed Concentrations of $PM_{2.5}$ and CO at Dadar (Summer)

The concentration of $PM_{2.5}$ was within the limits of US EPA standard of 35 µg/m^3 due to the sources such as road dust and sea spray which contribute to the coarse particulate matter. The CO concentration during the sampling period exceeded 57% of times the CPCB standard of 2 µg/m^3 for the residential and mix use area possibly due to vehicular emissions and refuse burning.

Figure SD.3 shows Methane, Non Methane and THC concentrations and **Figure SD.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not be analyzed during summer season.

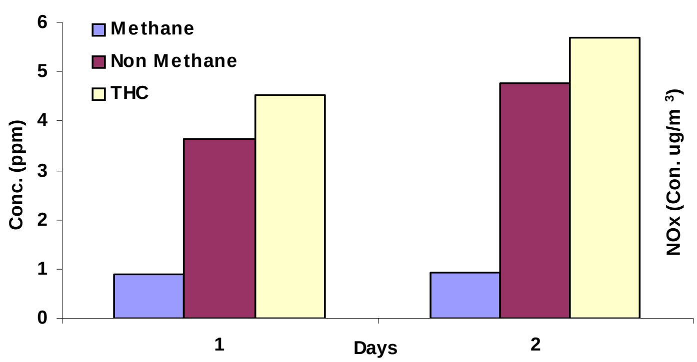


Figure SD.3 : Hydrocarbon Concentration

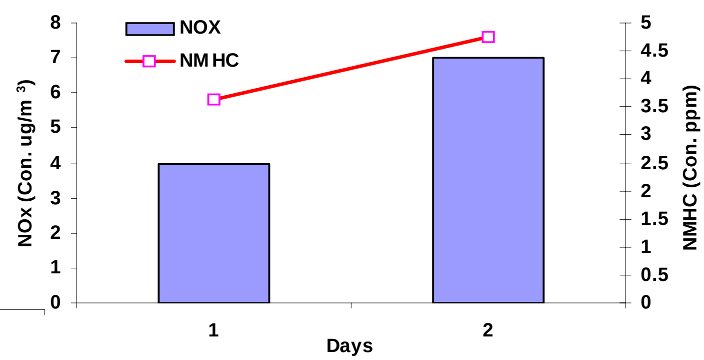


Figure SD.4 : NO_2 and NMHC Concentrations

Figure SD.5 presents diurnal variation of CO concentration during summer.

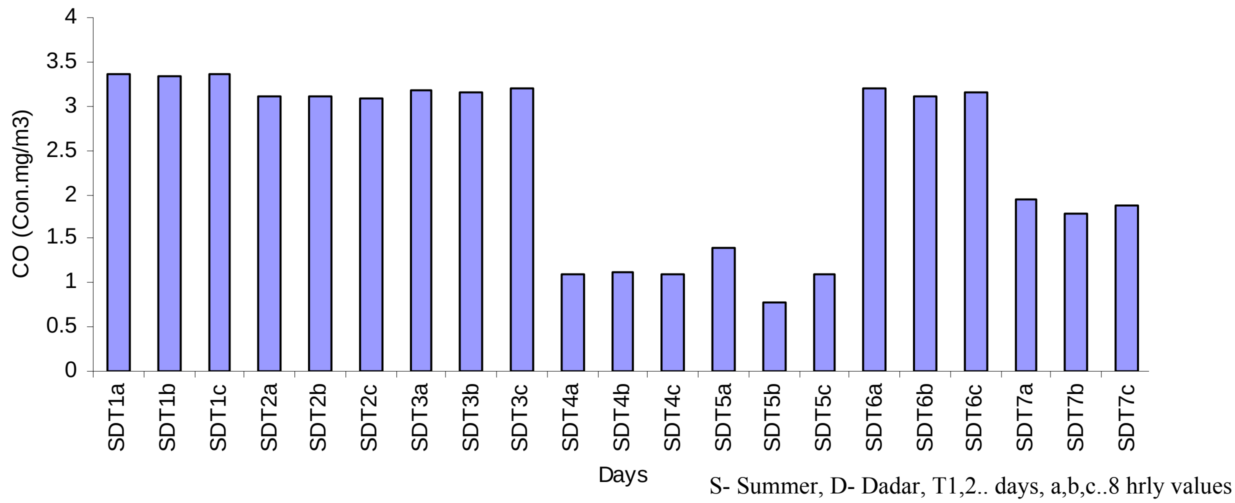


Figure SD.5 : Diurnal Variation of CO

No significant diurnal variation of CO is observed during summer.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2 , NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SD.6 and SD.7**

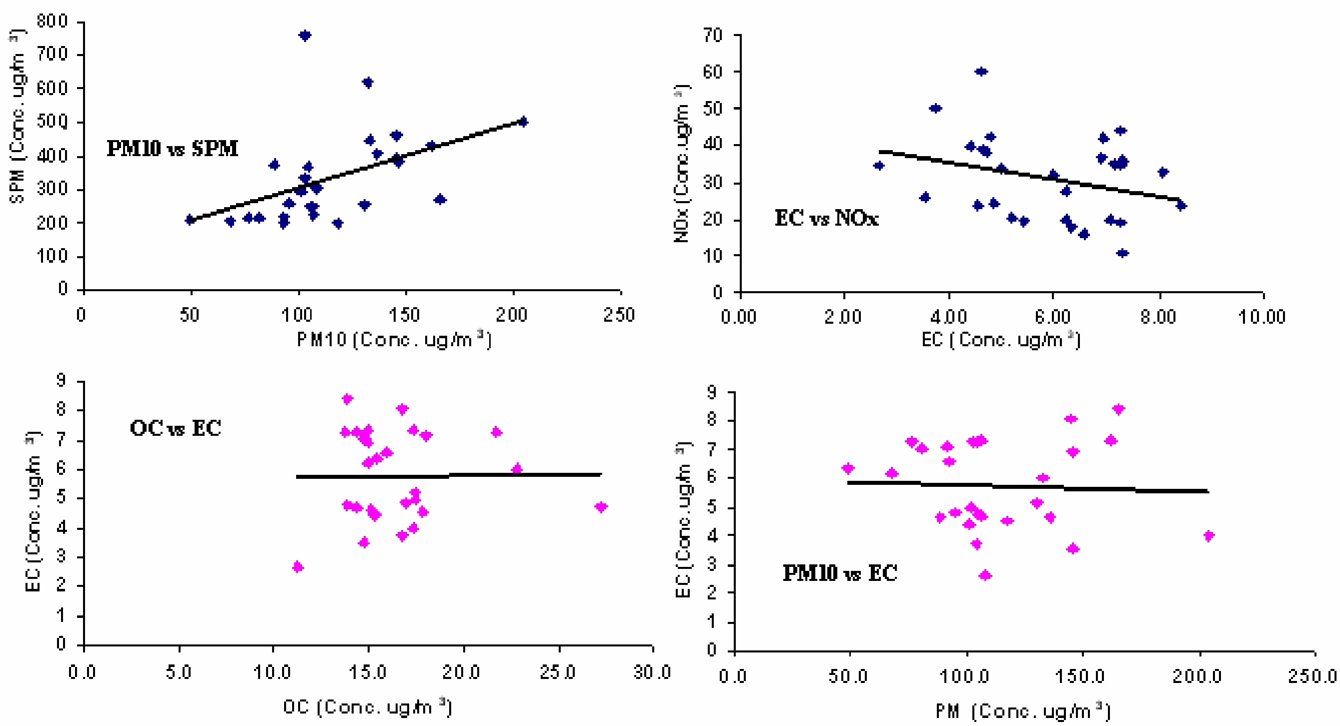


Figure SD.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show moderate correlation (R = 0.46) indicating the presence of sources contributing to coarse particulate matter like road dust and sea spray. EC and NO_2 show negative correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show very poor correlation (R =0.019) indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC: EC is 3.05, there may be formation of secondary organic carbon aerosols *[Zhang et.al.,2007]* and the sources of the secondary OC might be atmospheric transport/ transformation of anthropogenic organic species *[HO et.al., 2003]*.

PM_{10} and OC show poor correlation where PM_{10} and EC have even worse correlation.

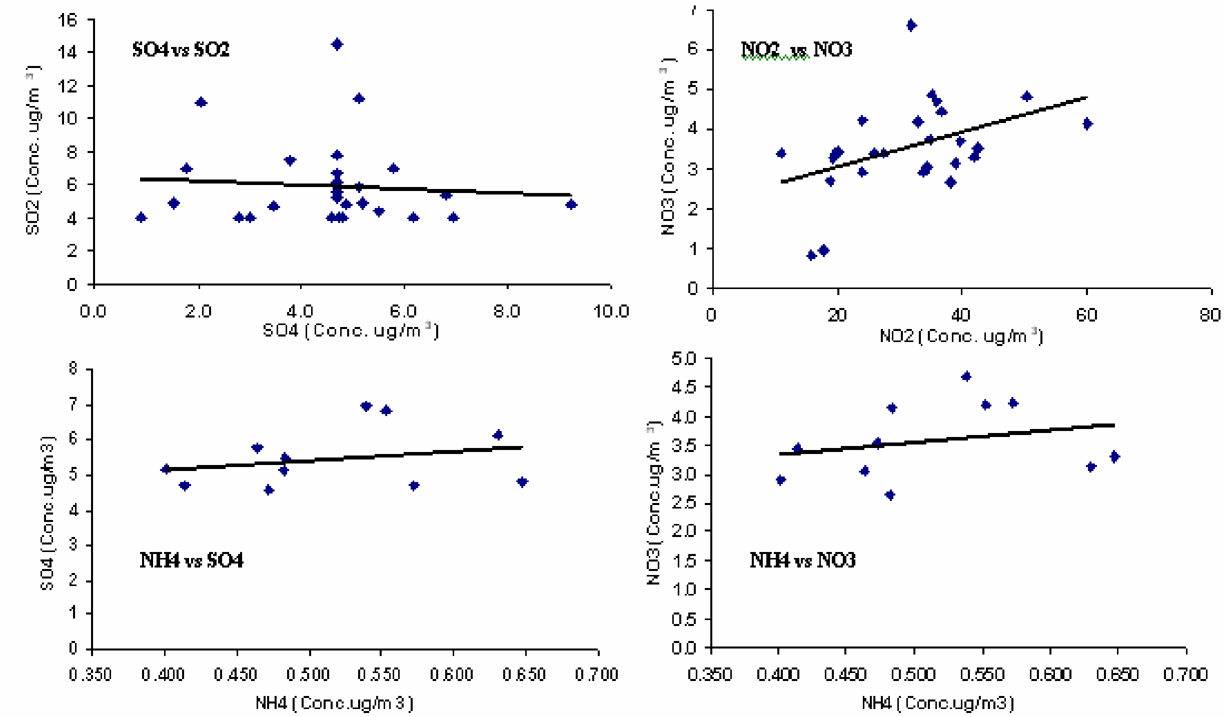


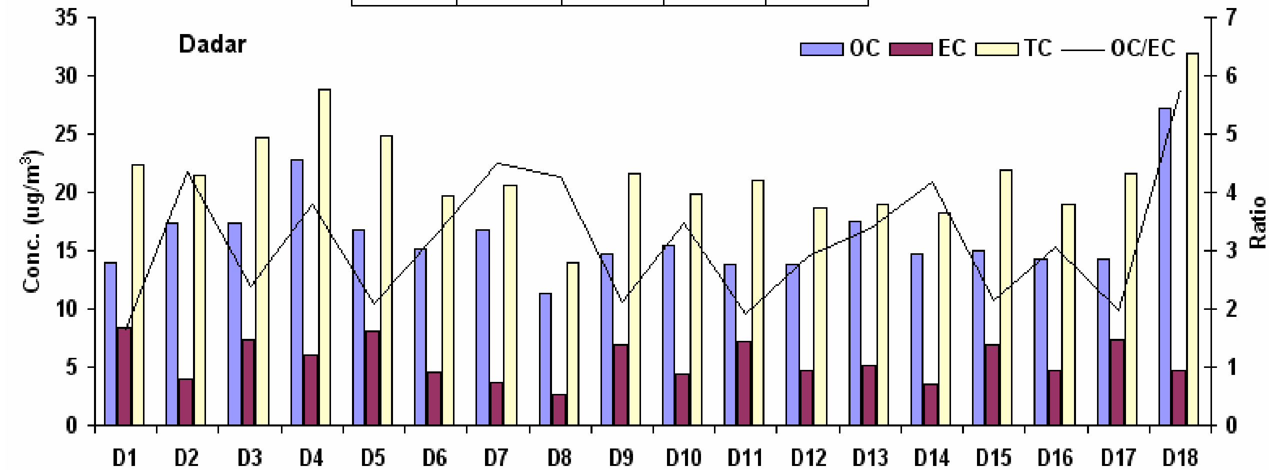
Figure SD.7 : Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show no correlation. NO_2 and NO_3^- correlate moderately (R = 0.44) indicating that NO_2 is not getting converted to NO_3^- and sources such as automobile exhaust, secondary aerosols and sea spray are contributing to NO_3^-. NH_4^+ with SO_4^{2-} as well as NO_3^- does not show significant correlation.

Carbon concentrations at Dadar site in PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SD.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM10	OC	EC	TC
PM10	1.000	.010	-.048	-.031
OC	.010	1.000	.019	.876
EC	-.048	.019	1.000	.455
TC	-.031	.876	.455	1.000



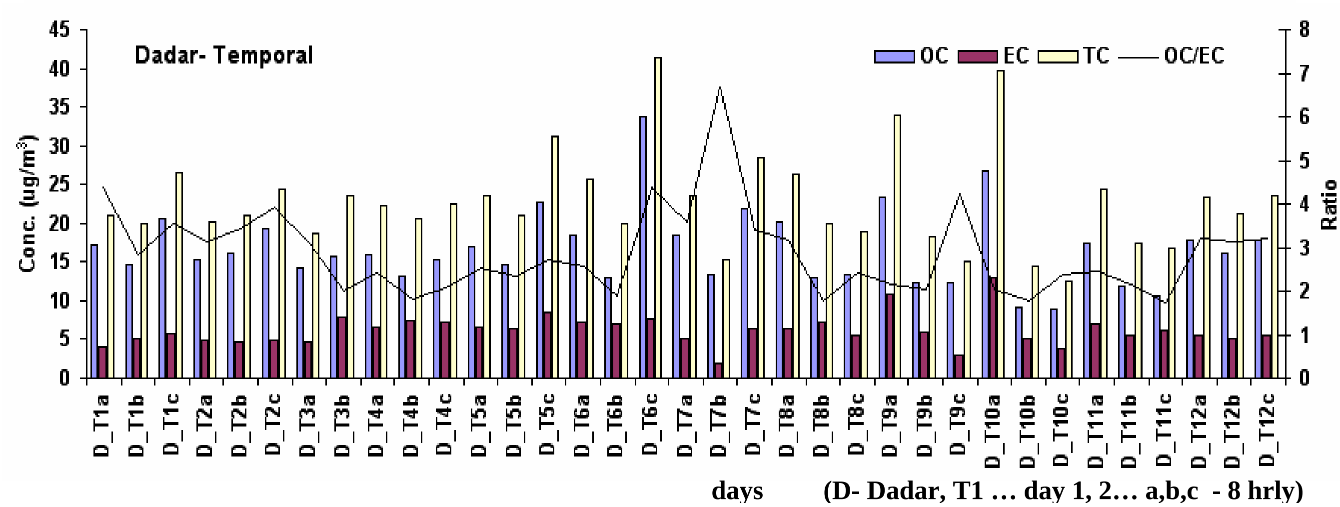


Figure SD.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Dadar Site (Summer)

At Dadar site OC varied between 11.2-.27.2 $\mu g/m^3$ with an average value of 16.3 $\mu g/m^3$. The EC concentration varied between 2.65-8.43 $\mu g/m^3$ with an average value of 5.8 $\mu g/m^3$. OC/EC ratio varied from 1.6 to 5.7 with an average ratio of 3.05. Percentage of OC, EC and TC in PM_{10} was 14.1, 5 and 22 whereas in $PM_{2.5}$ it was 21.4, 15.4 and 37 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations ($\mu g/m^3$) in PM_{10} **(Figure SD.9)**

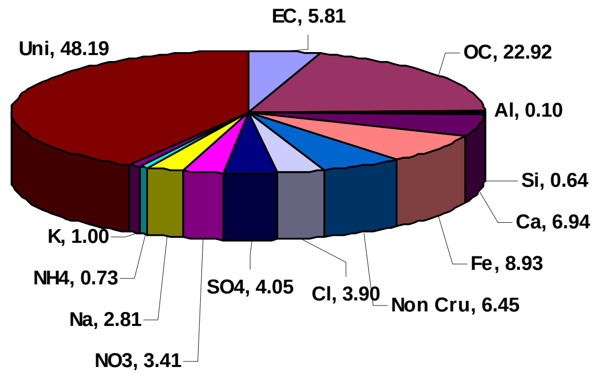


Figure SD.9 : Mass Closure Concentrations ($\mu g/m^3$)at Dadar

Percent composition of PM_{10} after mass closure show that maximum contribution is from carbonaceous matter. OC and EC account for 20% and 5% respectively and thus indicate the contribution of sources like automobile exhaust and refuse burning. Crustal elements account for 14% of the total particulate matter indicating the contribution from road dust whereas non crustal elements account for 6% of the total particulate matter indicating the contribution from anthropogenic activities viz. refuse burning and vehicles. Out of the total particulate matter, ions account for 14 %. High concentration of SO_4^{2-} and NO_3^- is due to secondary aerosols, vehicles and sea spray. Other ions like Cl^- and Na^+ are released from sea spray, NH_4^+ is emitted from vehicles and K^+ is from biomass burning. 41% of the total PM_{10} is unidentified.

Dharavi Site: The observed concentrations for summer season are presented in **Table SDh.1** the detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for summer season at Dharavi are presented in **Figure SDh.1.**

Table SDh.1 : Air Quality Status at Dharavi (Summer)

Pollutants	**Min**	**Max**	**Avg**	**98 percentile**	**SD**	**N**
SPM (µg/m^3)	186.3	698.0	400.8	697.0	132.8	28
RSPM (µg/m^3)	56.0	288.0	133.4	268.0	64.6	28
PM_{10} (µg/m^3)*	91.0	299.5	176.9	297.0	53.0	30
$PM_{2.5}$ (µg/m^3)**	43.0	120.0	74.0	NA	37.0	4
SO_2 (µg/m^3)	4.0	24.0	6.0	16.4	4.0	30
NO_2 (µg/m^3)	12.0	76.0	36.4	74.4	15.8	28.0
NH_3 (µg/m^3)	14.0	135.0	64.9	135.0	33.0	28.0
CO (mg/m^3)	0.9	5.2	2.4	5.1	1.8	6
Formaldehyde (µg/m^3)	22.0	40.0	31.0	NA	12.7	2
CH_4 (ppm)	1.9	2.0	2.0	NA	0.0	2
Nonmethane HC (ppm)	1.1	1.2	1.2	NA	0.0	2
Total HC (ppm)	3.1	3.2	3.2	NA	0.0	2
OC (µg/m^3)	10.6	74.8	29.8	69.1	13.9	30
EC (µg/m^3)	4.12	20.5	8.9	18.1	3.75	30
TC (µg/m^3)..	17.8	84.3	38.8	78.5	14.8	30

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages of suspended particulate matters at Dharavi exceeded 96% of the time CPCB residential /mixed standard of 200 µg/m^3, whereas RSPM exceeded 57% of the time standard of 100 µg/m^{3}during sampling period. The ratio of RSPM to SPM was 33% and $PM_{2.5}$ to PM_{10} was 42% indicating higher $PM_{2.5}$ concentration. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 exceeded the standard 3% during study period. The monthly average of PM_{10} was 177 µg/m^3. A trend of temporal values of PM_{10} shows that similar concentration was prevalent during all the shifts indicating a constant source throughout 24 hourly periods. CO values ranged between 0.87-5.16 mg/m^3, formaldehyde ranged between 22-40 µg/m^3, whereas average concentration of Total Hydrocarbon 3.2 ppm.

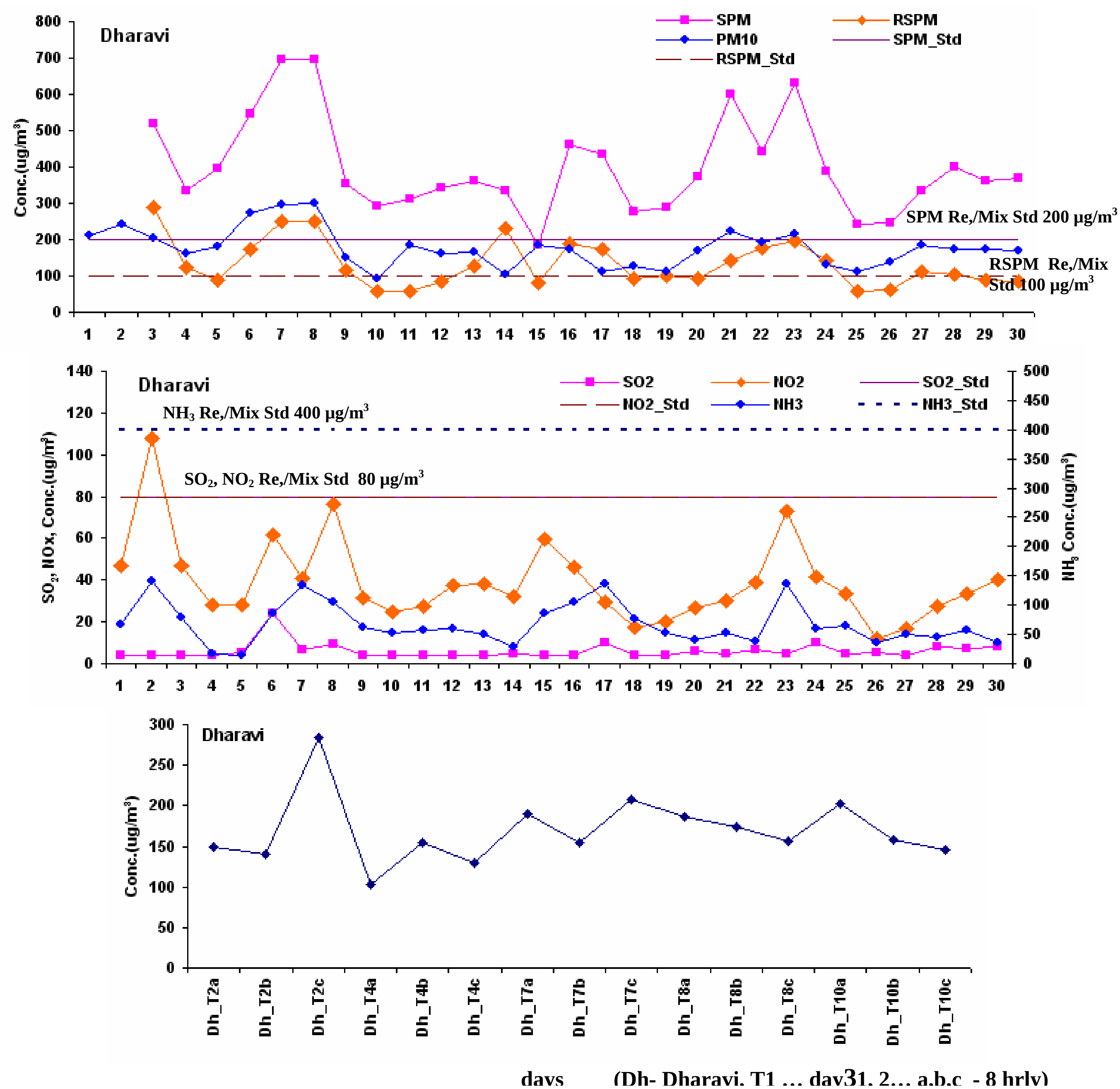


Figure SDh.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Dharavi (Summer)

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Figure SDh.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

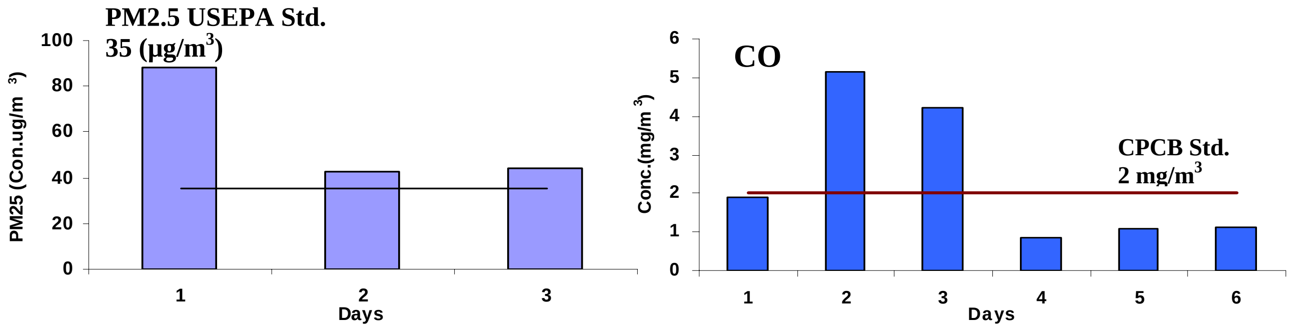


Figure SDh.2 : Observed Concentrations of $PM_{2.5}$ and CO at Dharavi (Summer)

The concentration of $PM_{2.5}$ was exceeding all the times the US EPA standard of 35 µg/m^3 due to the sources such as smelting, biomass burning, coal combustion etc which contribute to fine particulate matter. The CO concentration during the sampling period exceeded 33% of the times the CPCB standard of 2 µg/m^3 for the residential and mix use area possibly due to biomass burning and vehicular emissions

Figure SDh.3 shows Methane, Non Methane and THC concentrations and **Figure SDh.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not be analyzed during summer.

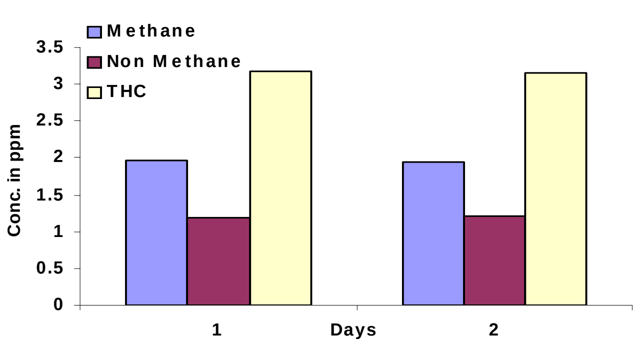


Figure SDh.3 : Hydrocarbon Concentration

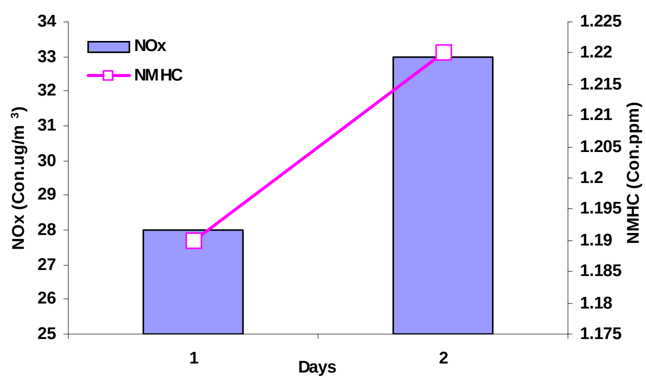


Figure SDh.4 : NO_2 and NMHC Concentrations

Figure SDh.5 presents diurnal variation of CO concentrations during summer.

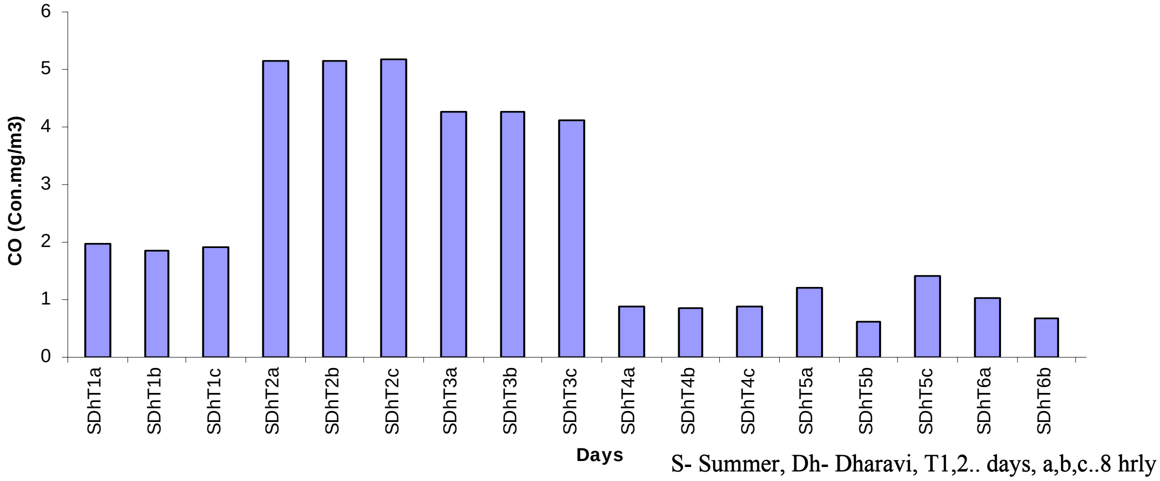


Figure SDh.5 : Diurnal variation of CO

No specific trend was observed in diurnal variations of CO.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2 , NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SDh.6 and SDh.7**

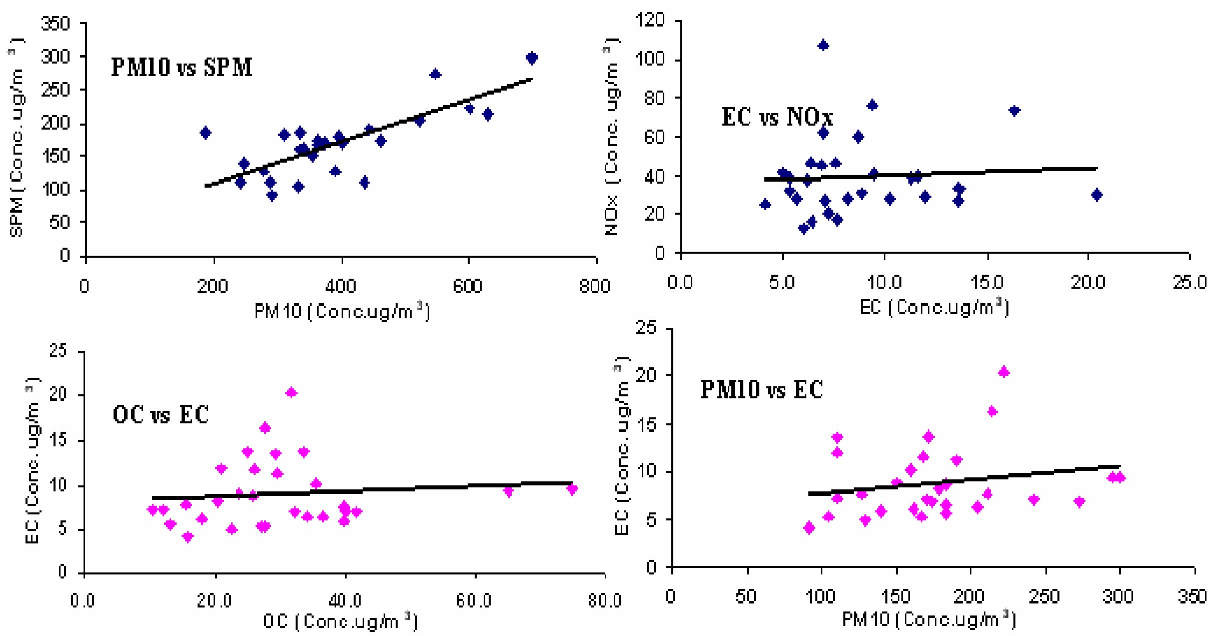


Figure SDh.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show significant correlation (R = 0.79) due to the presence of sources like soil and sea spray which contribute to coarse particulate matter along with fine particulate matter contributing sources like biomass burning, coal combustion, oil burning and vehicles. EC and NO_2 show very poor correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC also show poor correlation indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC/EC is 3.8, there may be formation of secondary organic carbon aerosols. Correlation coefficient for PM_{10} and EC is 0.19 indicating EC tend to be in the fine particle fraction.

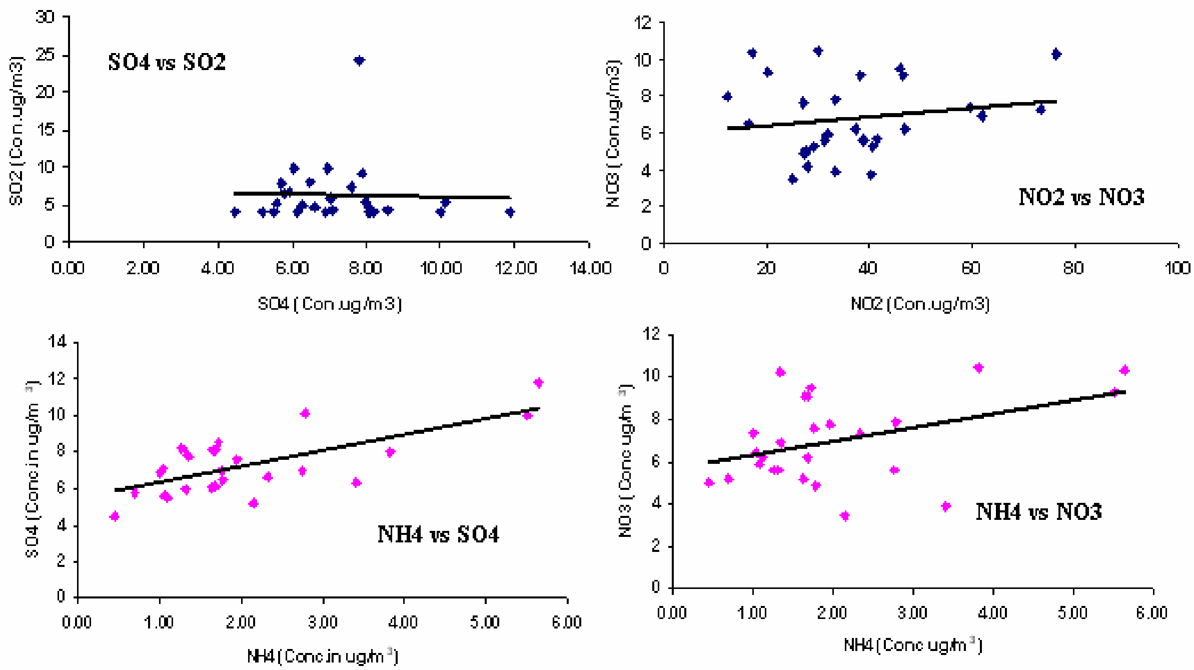


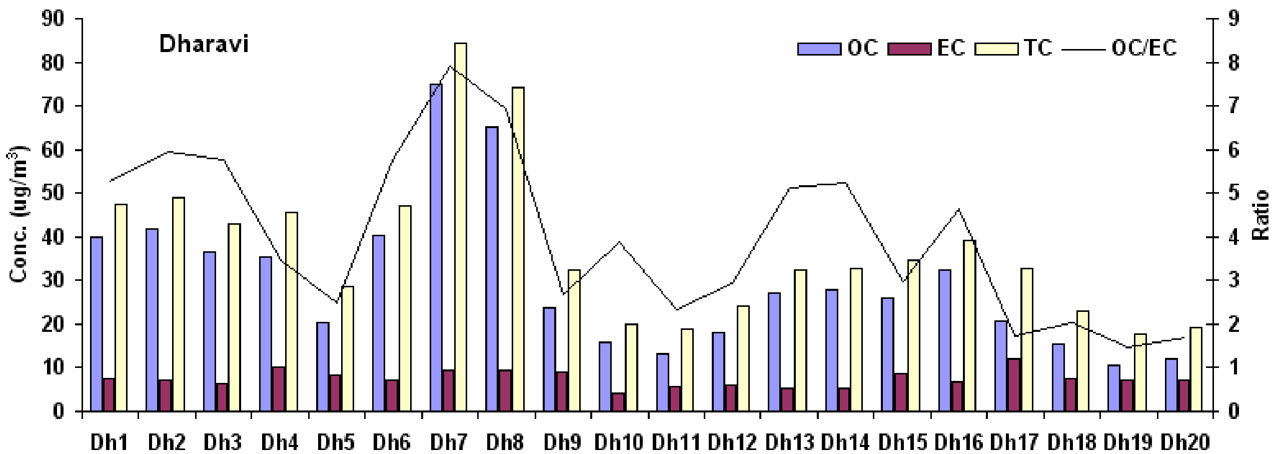
Figure SDh.7 : Correlation plots of gaseous pollutants vs. ions

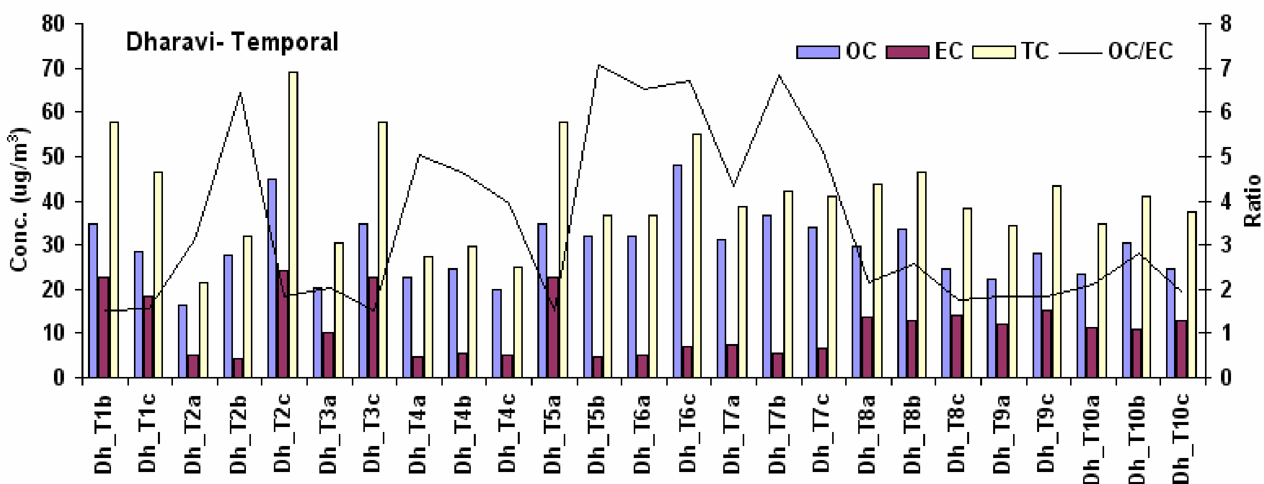
SO_2 and SO_4^{2-} show no significant correlation. NO_2 and NO_3^- also do not strongly correlate indicating that NO_2 is not getting converted to NO_3^- and sources such as automobile exhaust and other secondary aerosols are contributing to NO_3^-. NH_4^+ and SO_4^{2-} show good correlation (R=0.69) indicating that NH_4^+ is neutralizing $SO_4^{2-}$and resulting in the formation of $(NH_4)_2SO_4$. NH_4^+ and NO_3^- show moderate correlation (R=0.42) indicating that NH_4^+ is neutralizing NO_3^- to a lesser extent. [Sharma et.al., 2007]

Carbon concentrations at Dharavi site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SDh.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM10	OC	EC	TC
PM10	1.000	.741	.197	.745
OC	.741	1.000	.121	.968
EC	.197	.121	1.000	.366
TC	.745	.968	.366	1.000





SO_2, NO_2 Std. 80 µg/m^3

days (Dh- Dharavi, T1 … day 1, 2… a,b,c - 8 hrly)

Figure SDh.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Dharavi Site (Summer)

At Dharavi site OC varied between 10.6-74.8 µg/m^3 with an average value of 29.9 µg/m^3. The EC concentration varied between 4.1-20.5 µg/m^3 with an average value of 8.9 µg/m^3. OC/EC ratio varied from 1.5 to 7.9 with an average ratio of 3.8. Percentage of OC, EC and TC in PM_{10} was 16.9, 5.1 and 21.9 whereas in $PM_{2.5}$ it was 30.4, 15.6 and 46.1 percent respectively.

Mass fraction of elements, ions and carbons in terms of Concentration (µg/m^3) in PM_{10} is presented in **Figure SDh.9.**

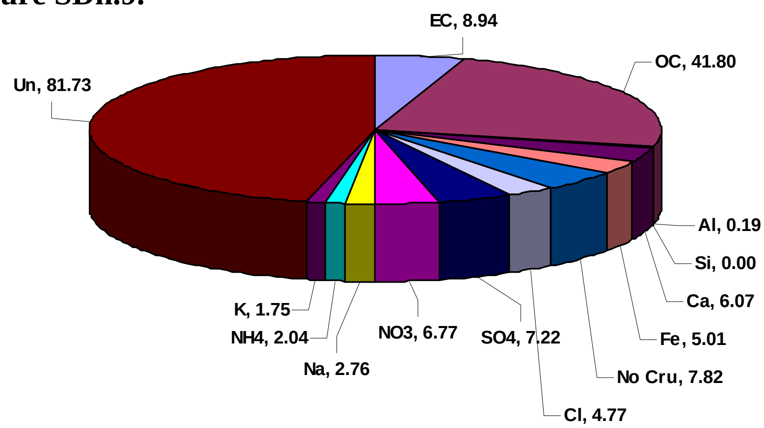


Figure SDh.9: Mass Closure Concentrations (µg/m^3) at Dharavi

Percent composition of PM_{10} after mass closure show that maximum contribution is from carbonaceous matter. OC and EC account for 24% and 5% respectively and thus indicate the contribution of sources like automobile exhaust, biomass burning and oil burning. Ions account for 14 % of the total particulate matter. Concentration of SO_4^{2-} and NO_3^- is due to secondary aerosols, vehicles and sea spray. Other ions like Cl^- and Na^+ are released from sea spray, NH_4^+ is emitted from vehicles whereas K^+ is from bio mass burning. Crustal elements account for 6% of the total particulate matter indicating the contribution from soil whereas non crustal elements account for 4% of the total particulate matter indicating the contribution from sources like smelting, biomass burning and vehicles. About 47 % of the total PM_{10} is unidentified

Khar Site: The observed concentrations for summer season are presented in **Table SK.1.** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for summer season at Khar are presented in **Figure SK.1.**

Table SK.1: Air Quality Status at Khar (Summer)

Pollutants	Min	**Max**	**Avg**	**98 percentile**	**SD**	**N**
SPM (µg/m^3)	85.7	204.0	145.6	202.5	34.4	27
RSPM (µg/m^3)	32.6	128.2	65.4	125.6	29.1	29
PM_{10} (µg/m^3)*	41.0	94.5	62.0	93.3	15.7	30
$PM_{2.5}$ (µg/m^3)**	14.0	15.0	14.5	NA	1.0	2
SO_2 (µg/m^3)	4.0	8.0	5.0	7.7	1.0	29
NO_2 (µg/m^3)	6.0	34.0	14.0	20.5	6.0	29
NH_3 (µg/m^3)	5.0	172.0	41.0	122.6	33.0	27
CO (mg/m^3)	0.3	2.2	0.6	0.8	0.6	10
Formaldehyde (µg/m^3)	18.0	34.0	26.3	33.7	8.0	3
CH_4 (ppm)	1.7	1.8	1.75	NA	0.0	2
Nonmethane HC (ppm)	1.2	1.2	1.2	NA	0.0	2
Total HC (ppm)	3.0	3.0	3.0	NA	0.0	2
OC (µg/m^3)	5.6	19.4	10.2	18.7	3.1	27
EC (µg/m^3)	0.6	5.1	2.1	5.0	1.1	27
TC (µg/m^3)..	6.1	24.5	12.3	23.7	4.0	27

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Khar exceeded 7% of the time CPCB residential /mixed standard of 200 µg/m^3, whereas RSPM exceeded 17% of the time standard of 100 µg/m^3 during sampling period. The ratio of RSPM to SPM was 45% indicating higher share of RSPM concentration and $PM_{2.5}$ to PM_{10} was 24%. The 24 hourly average concentrations of SO_2, NO_2 and NH_3 were within CPCB limits. The monthly average of PM_{10} was 62 µg/m^3. A trend of temporal values of PM_{10} shows high concentrations during 2 pm to 10 pm. CO values ranged between 0.31-2.24 mg/m^3, formaldehyde ranged between 18-34 µg/m^3, whereas average concentration of Total Hydrocarbon 3 ppm.

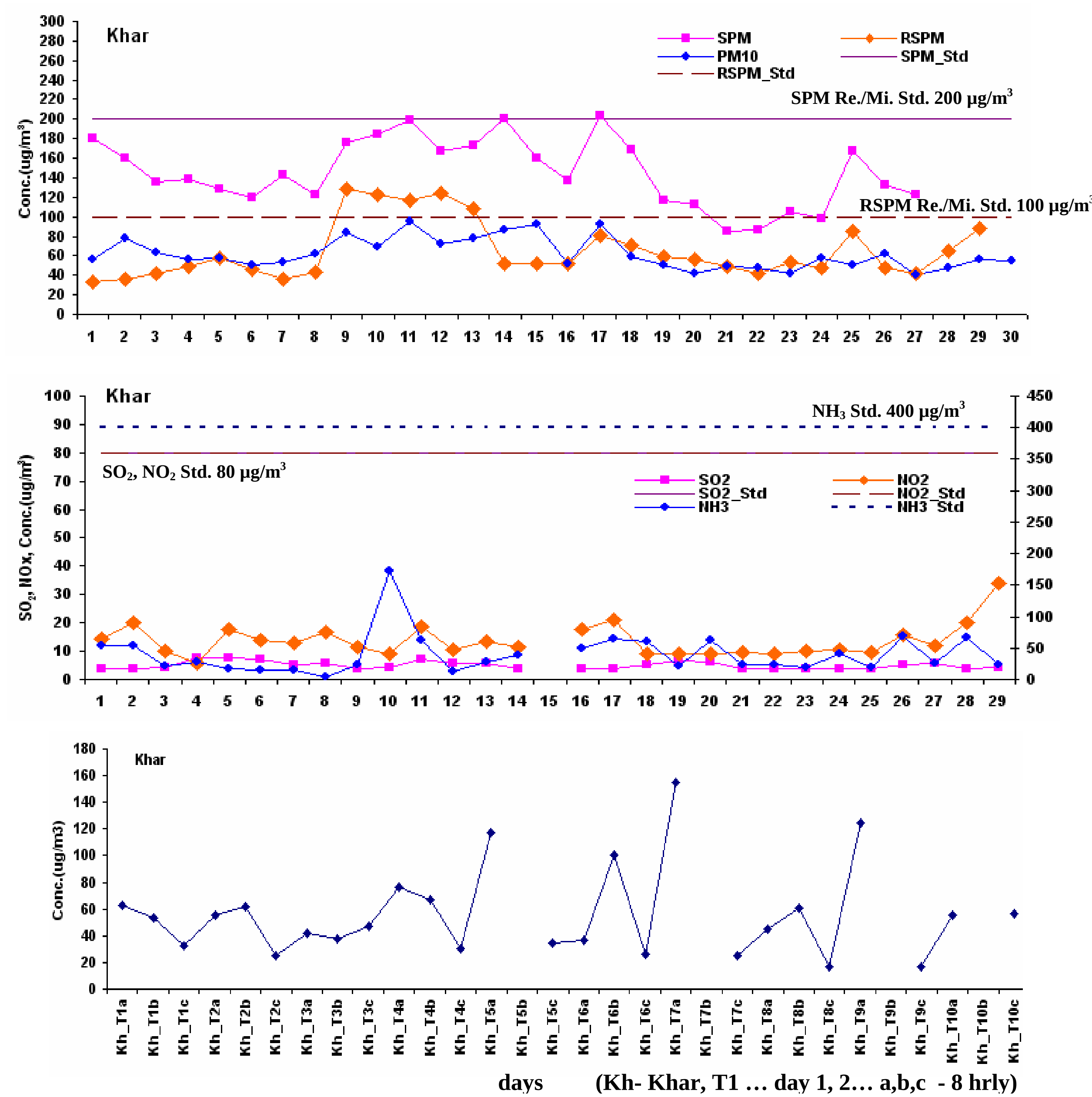


Figure SK.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Khar

Figure SK.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

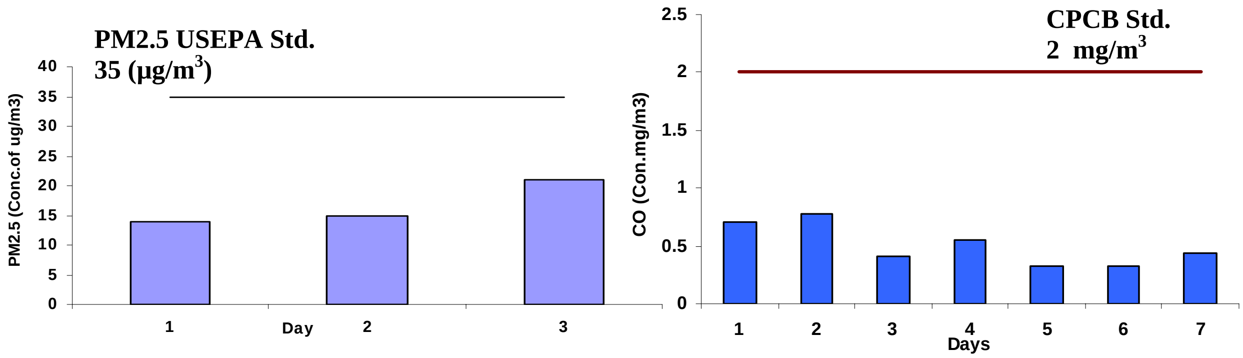


Figure SK.2: Observed Concentrations of $PM_{2.5}$ and CO at Khar (Summer)

The concentration of $PM_{2.5}$ was within limits of the US EPA standard of 35 $\mu g/m^3$ due to the sources such as soil, road dust which contribute to coarse particulate matter are predominant in this area. The CO concentration during the sampling period was within the limits of the CPCB standard of 2 $\mu g/m^3$ for the residential and mix use area.

Figure SK.3 shows Methane, Non Methane and THC concentrations and **Figure SK.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not be analyzed during summer.

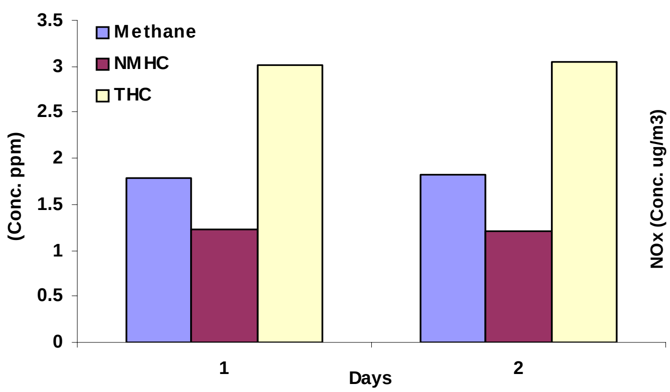


Figure SK.3 : Hydrocarbon Concentration

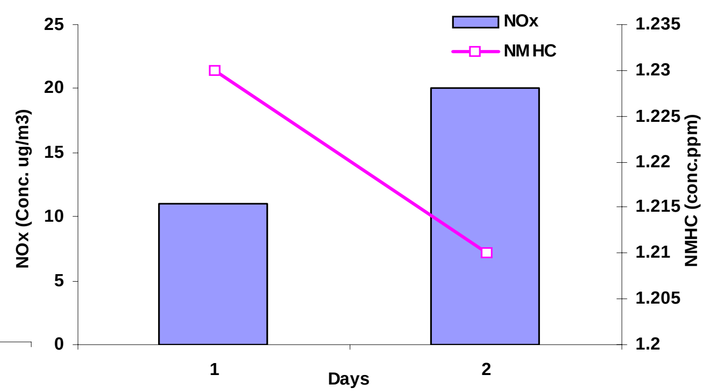
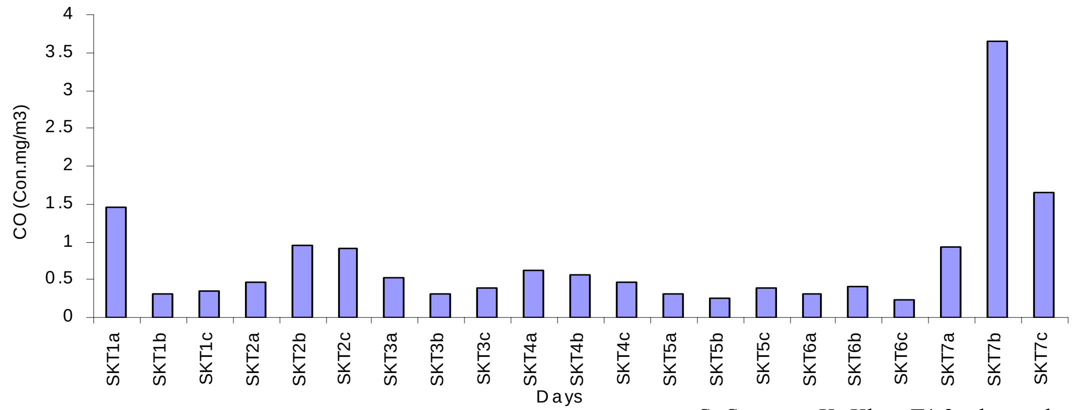


Figure SK.4 : NO_2 and NMHC Concentrations

Figure SK.5 presents diurnal variation of CO concentrations.



S- Summer, K- Khar, T1,2.. days, a,b,c..8 hrly values

Figure SK.5: Diurnal variation of CO at Khar

Diurnal variation in CO shows moderate variation with a high of 2.2 and low of 0.3 mg/m^3.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2 , NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SK.6 and SK.7.**

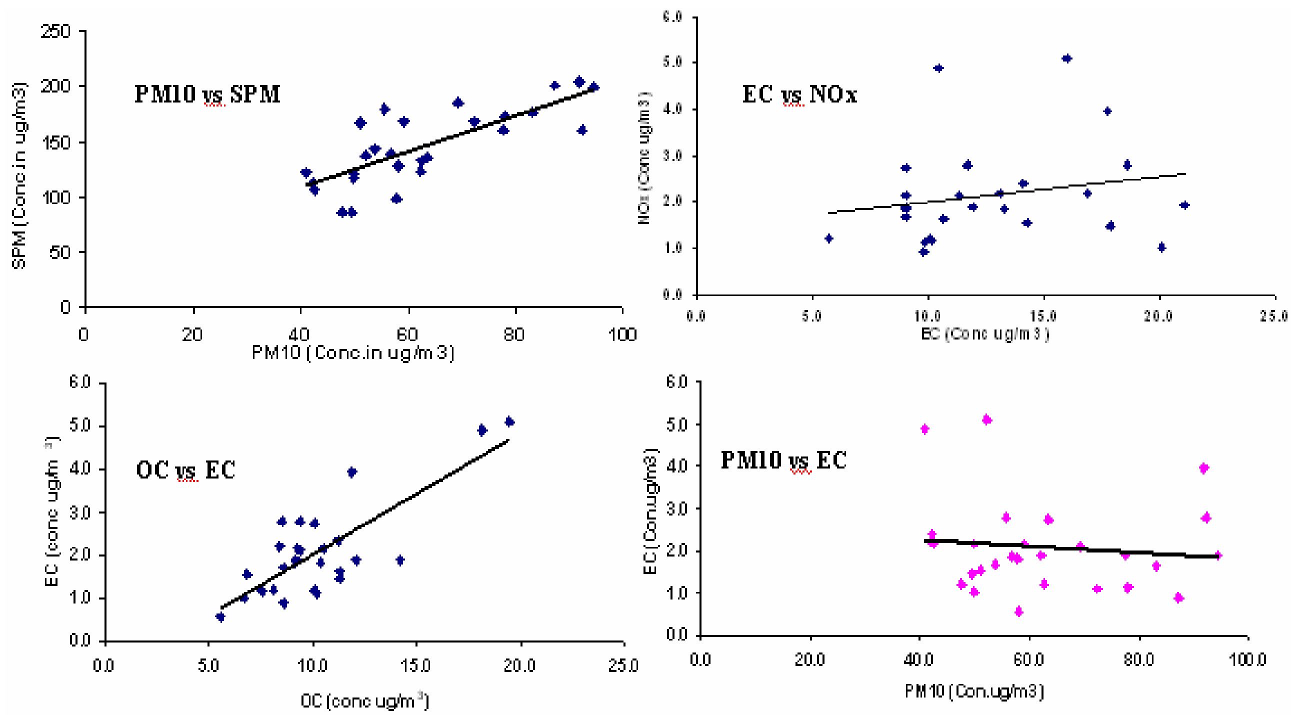


Figure SK.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show significant correlation (R=0.77) due to the presence of sources like soil, road dust which contribute to coarse particulate matter along with fine particulate matter contributing sources like biomass burning and vehicles. EC and NO_2 show very poor correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show good correlation (R=0.79) indicating that sources like vehicles and biomass burning are contributing to both OC and EC. Correlation coefficient for PM_{10} and EC is very poor.

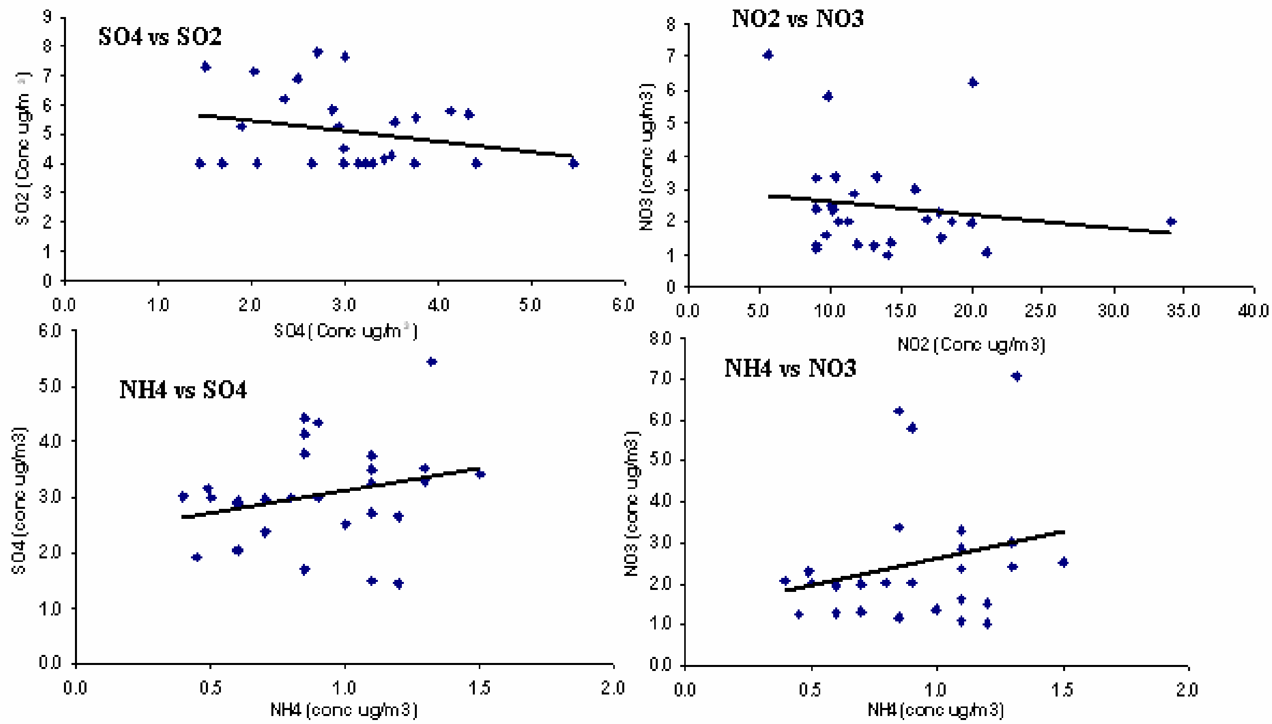


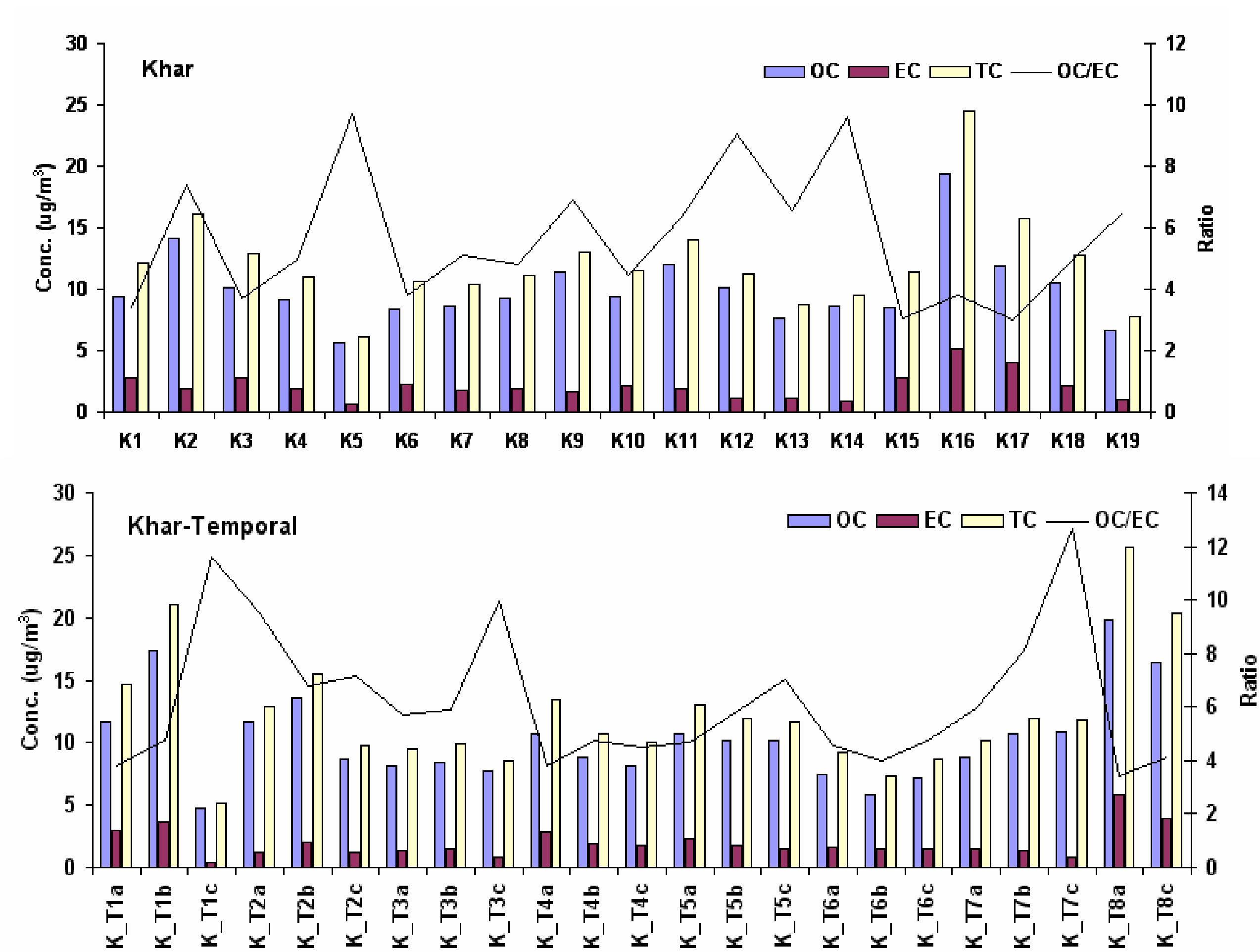
Figure SK.7 : Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show negative correlation indicating that SO_2 is moderately getting converted to SO_4^{2-} and it is due to other sources like vehicles, road dust and biomass burning. NO_2 and NO_3^- negative correlation indicates that NO_2 is getting converted to NO_3^- to a lesser extent and sources such as automobile exhaust, secondary aerosols are contributing to NO_3^-. NH_4^+ and SO_4^{2-} show poor correlation indicating that NH_4^+ is not neutralizing SO_4^{2-}. NH_4^+ and NO_3^- show poor correlation indicating that NH_4^+ is rarely neutralizing NO_3^-.

Carbon concentrations at Khar site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SK.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	-0.035	-0.099	-0.055
OC	-0.035	1.000	0.782	0.985
EC	-0.099	0.782	1.000	0.878
TC	-0.055	0.985	0.878	1.000



days (K- Khar, T1 … day 1, 2… a,b,c - 8 hrly)

Figure SK.4 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Khar Site (Summer)

At Khar site OC varied between 5.6-19.4 μg/m^3 with an average value of 10.2 μg/m^3. The EC concentration varied between 0.6-5.1 μg/m^3 with an average value of 2.1 μg/m^3. OC/EC ratio varied from 3.2 to 9.7 with an average ratio of 5.8. Percentage of OC, EC and TC in PM_{10} was 16.5, 3.4 and 19.9 whereas in $PM_{2.5}$ it was 49, 16 and 65 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (μg/m^3) in PM_{10} is shown in **Figure SK.9.**

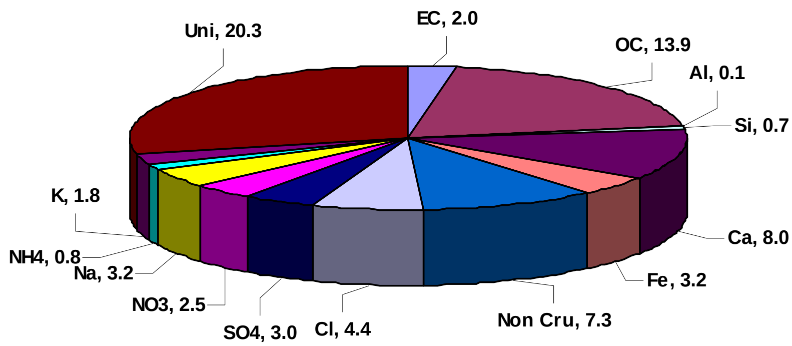


Figure SK.9 : Mass Closure Concentrations (μg/m^3) at Khar

Percent composition of PM_{10} after mass closure show that maximum contribution is from carbonaceous matter. OC and EC account for 20% and 3% respectively and thus indicate the contribution from sources like automobile exhaust and biomass burning. Ions account for 22% of the total particulate matter. High concentration of SO_4^{2-} and NO_3^- is due to secondary aerosols, vehicles. Other ions like Cl^- and Na^+ are released from sea spray, NH_4^+ is emitted from vehicles and K^+ is from biomass burning. Crustal elements account for 17% of the total particulate matter indicating the contribution from soil and road dust whereas non crustal elements account for 10% of the total particulate matter indicating the contribution from sources like vehicles and biomass burning. 28% of the total PM_{10} is unidentified.

Andheri Site : The observed concentrations for summer season are presented in **Table SA.1** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for summer season are presented in **Figures SA.1**

Table SA.1 : Air Quality Status at Andheri (Summer)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM ($\mu g/m^3$)	116.0	676.0	255.0	559.0	126.0	28
RSPM ($\mu g/m^3$)	40.0	223.0	112.0	196.7	47.0	28
PM_{10} ($\mu g/m^3$)*	48.0	144.0	84.0	136.0	28.0	24
$PM_{2.5}$ ($\mu g/m^3$)**	25.0	29.0	28.0	NA	2.0	3
SO_2 ($\mu g/m^3$)	4.0	57.0	8.0	17.3	10.0	28
NO_2 ($\mu g/m^3$)	9.0	39.0	17.0	38.0	10.0	26
NH_3 ($\mu g/m^3$)	10.0	353.0	81.0	301.6	71.0	28
CO (mg/m^3)	0.2	3.9	1.2	3.7	1.3	8
Formaldehyde ($\mu g/m^3$)	13.0	49.0	31.0	NA	25.5	2
CH_4 (ppm)	3.7	3.8	3.75	NA	0.0	2
Nonmethane HC (ppm)	6.0	6.0	6.0	NA	0.0	2
Total HC (ppm)	9.7	9.8	9.75	NA	0.0	2
OC ($\mu g/m^3$)	7.5	28.6	14.5	27.2	6.0	25
EC ($\mu g/m^3$)	1.3	10.4	4.1	9.7	2.7	25
TC ($\mu g/m^3$)..	9.2	36.2	18.6	35.9	8.4	25

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Andheri exceeded 64% of the time CPCB residential /mixed standard of 200 $\mu g/m^3$, whereas RSPM exceeded 50% of the time standard of 100 $\mu g/m^3$ during sampling period. The ratio of RSPM to SPM was 44% indicating higher share of RSPM concentration and ratio of $PM_{2.5}$ to PM_{10} was 33%. The 24 hourly average concentrations of SO_2, NO_2 and NH_3 were within CPCB limits. The monthly average of PM_{10} was 84 $\mu g/m^3$. A trend of temporal values of PM_{10} shows high concentrations during 6 am to 2 pm, due to high vehicle movements during peak hours. CO values ranged between 0.2-3.9 mg/m^3, formaldehyde ranged between 13-49 $\mu g/m^3$, whereas average concentration of Total Hydrocarbon 9.75 ppm.

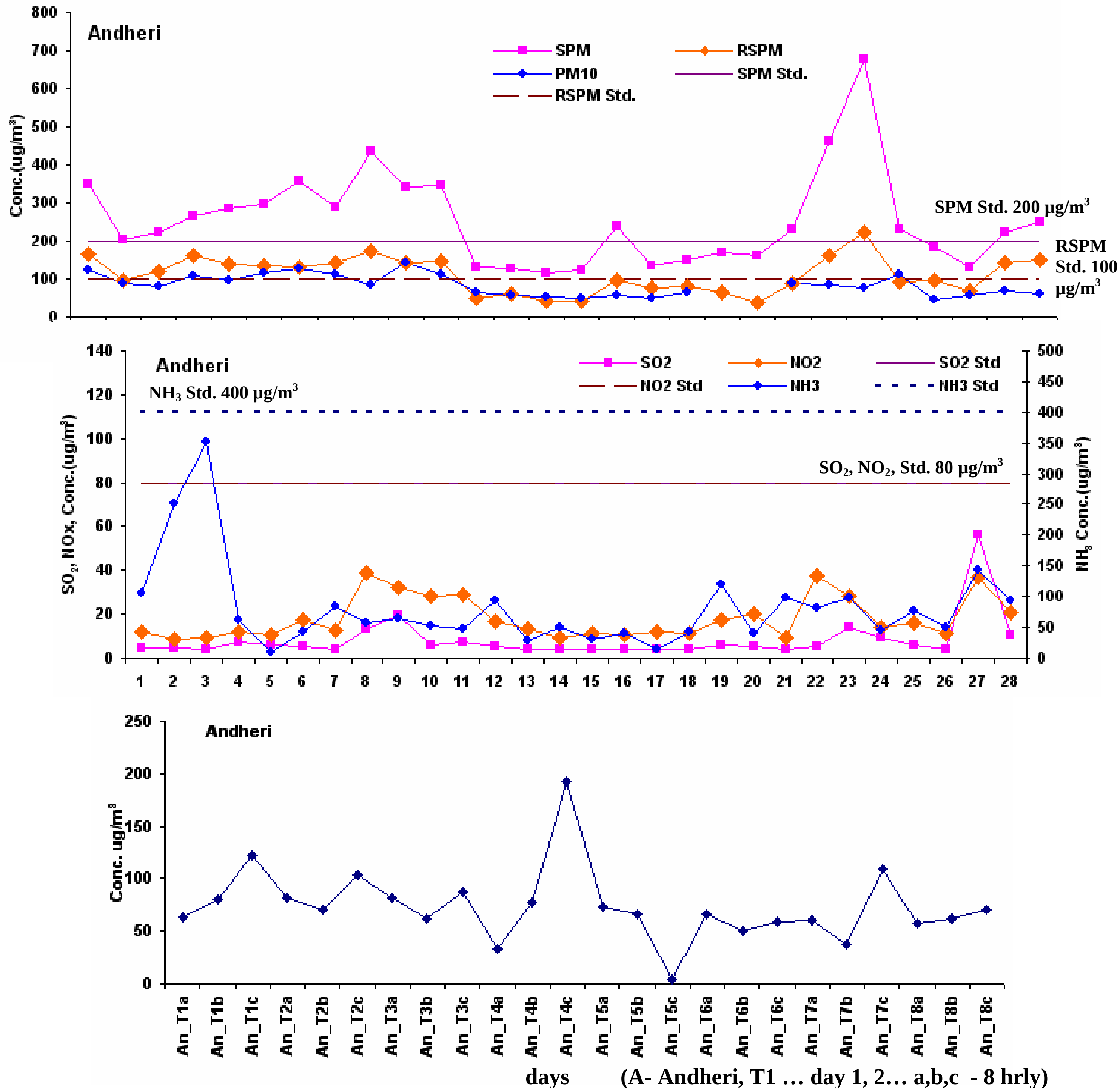


Figure SA.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Andheri (Summer)

* High value at particular day indicates outlier due to certain site specific activity.

Figure SA.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

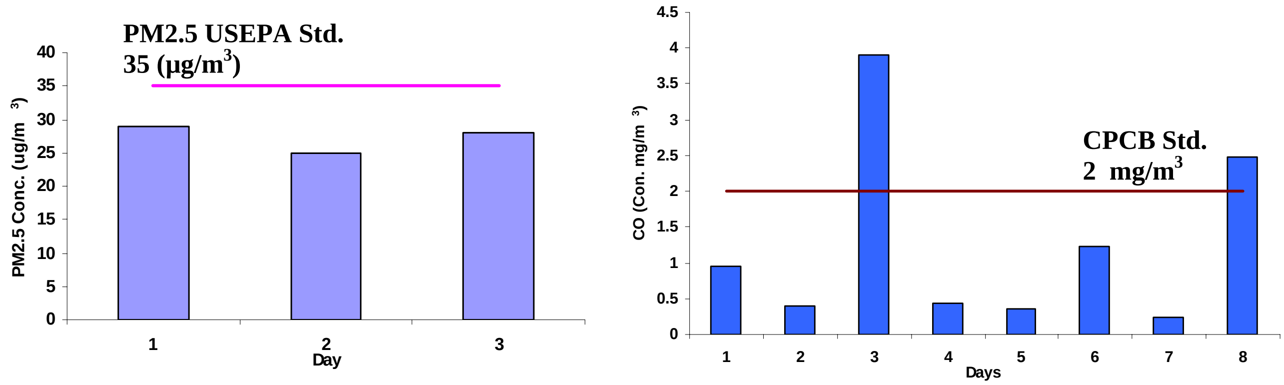
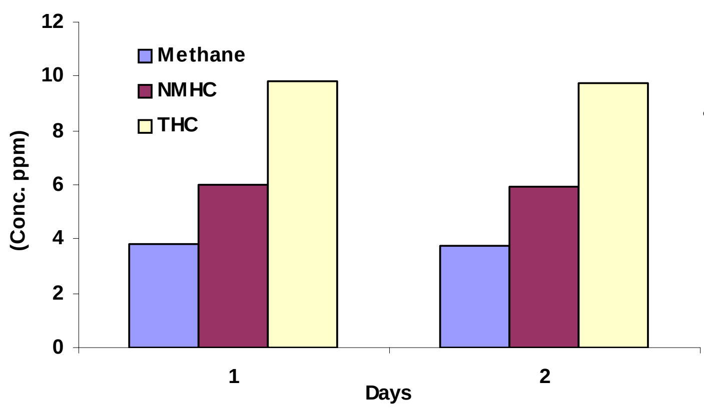


Figure SA.2 : Observed Concentrations of $PM_{2.5}$ and CO at Andheri (Summer)

The concentration of $PM_{2.5}$ was within limits of the US EPA standard of 35 µg/m^3 due to the sources such as soil, road dust which contribute to coarse particulate matter. The CO concentration during the sampling period was exceeding 25 % of the time the limits of the CPCB standard of 2 µg/m^3 for the residential and mix use area.

Figure SA.3 shows Methane, Non Methane and THC concentrations and **SA.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not be analyzed during summer season.



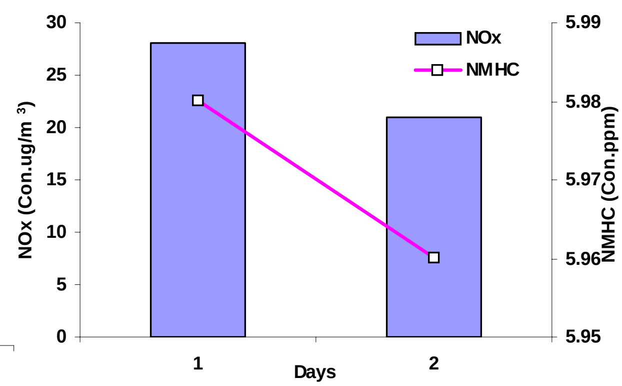


Figure SA.3 : Hydrocarbon Concentration

Figure SA.4 : NO_2 and NMHC Concentrations

Figure SA.5 presents diurnal variation of CO during summer period**.**

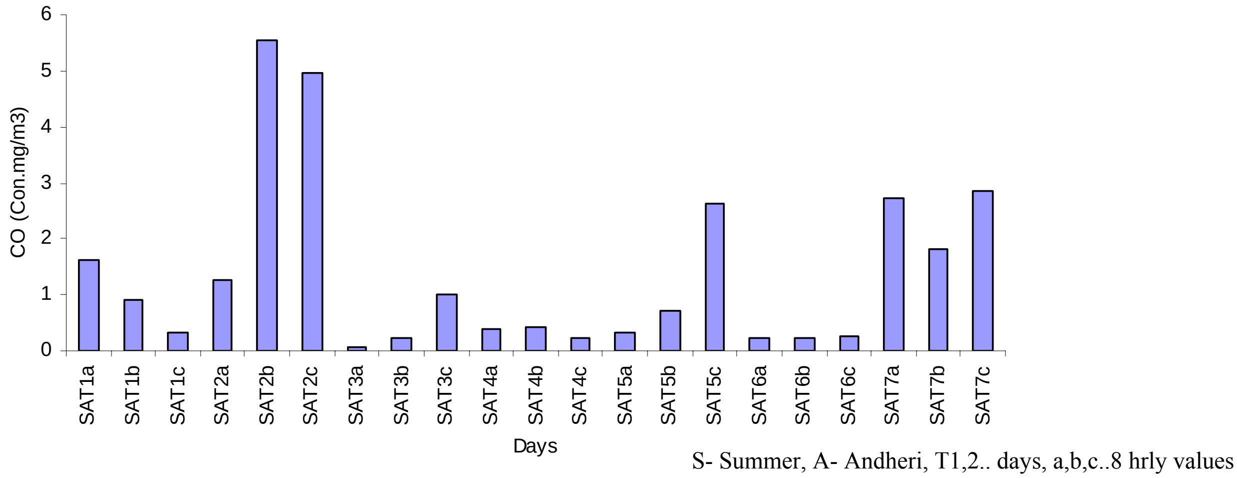


Figure SA.5 : Diurnal variation of CO at Andheri

Diurnal variation in CO shows high variation with a high of 3.9 and low 0.2 mg/m^3.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2 , NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SA.6 and SA.7.**

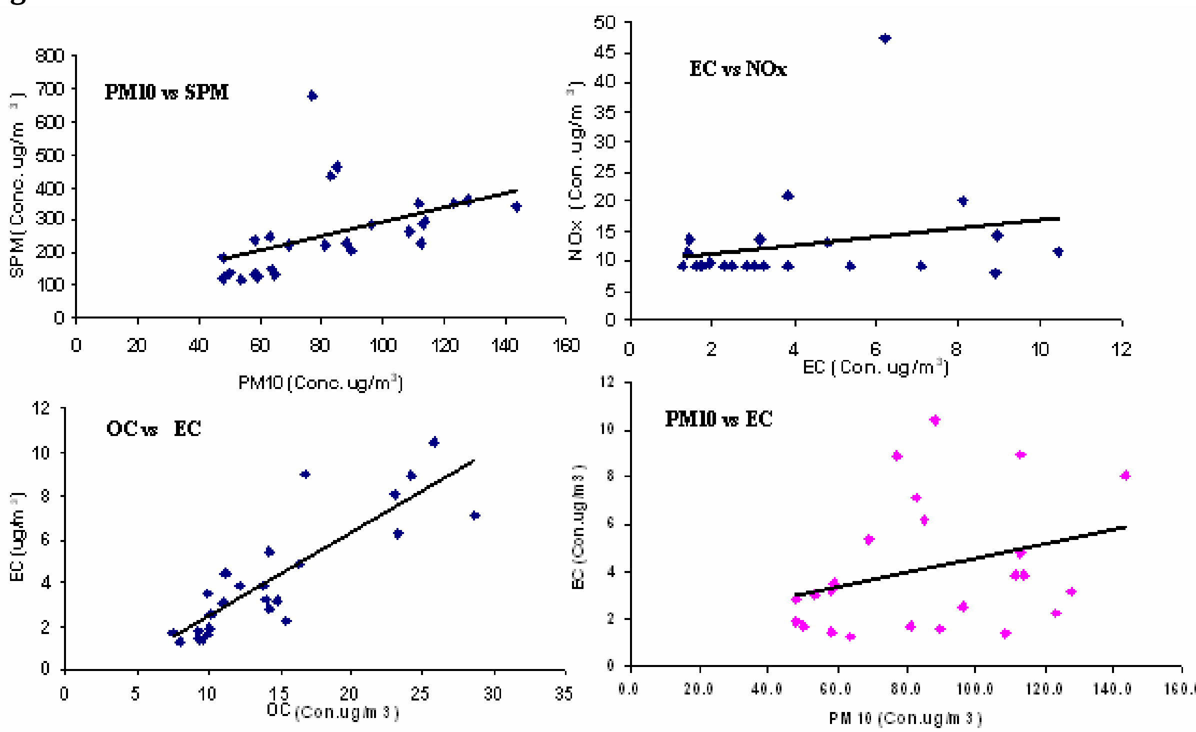


Figure SA.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show moderate correlation (R=0.48) due to the presence of sources like soil, road dust which contribute to coarse particulate matter along with fine particulate matter contributing sources like vehicles, coal burning, and biomass burning. EC and NO_2 show very poor correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show good correlation (R=0.86) indicating that EC and OC emitted from primary sources like vehicles, coal burning, biomass burning and oil burning. Correlation coefficient for PM_{10} and EC is 0.31 indicating EC tend to be in the fine particle fraction.

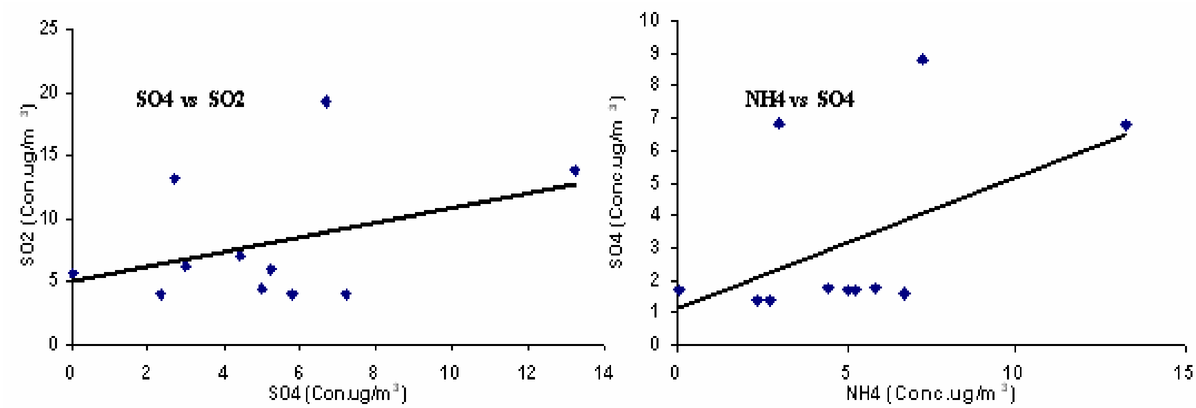


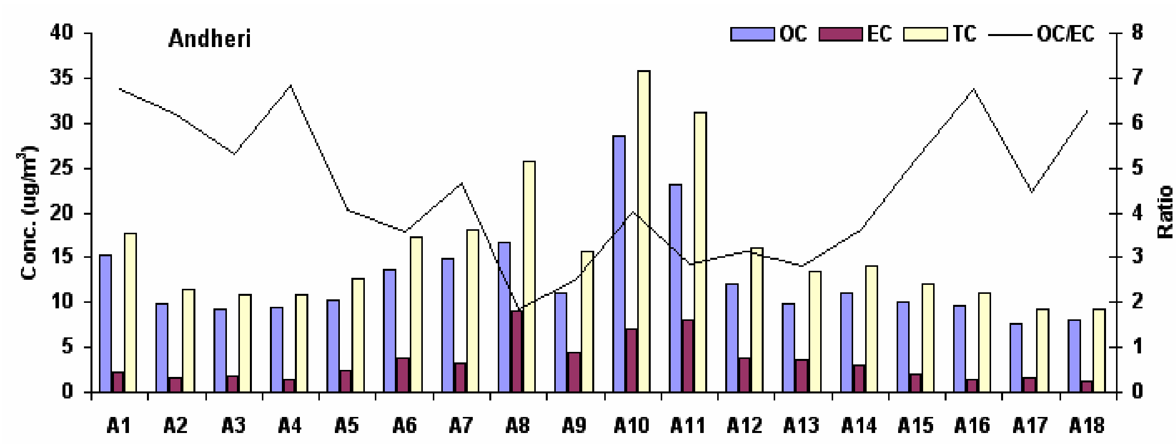
Figure SA.7 : Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show poor correlation indicating that SO_2 is not getting converted to SO_4^{2-} and it is due to other sources like vehicles, road dust, secondary aerosols, biomass burning etc. NH_4^+ and SO_4^{2-} show good correlation (R=0.50) indicating that NH_4^+ is neutralizing SO_4^{2-} and resulting in the formation of $(NH_4)_2SO_4$. Due to inadequate data of NO_3^- , correlations between NO_2 and NO_3^- and NH_4^+ and NO_3^- are not calculated.

Carbon concentrations at Andheri site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SA.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM10	OC	EC	TC
PM10	1.000	.325	.311	.331
OC	.325	1.000	.866	.986
EC	.311	.866	1.000	.936
TC	.331	.986	.936	1.000



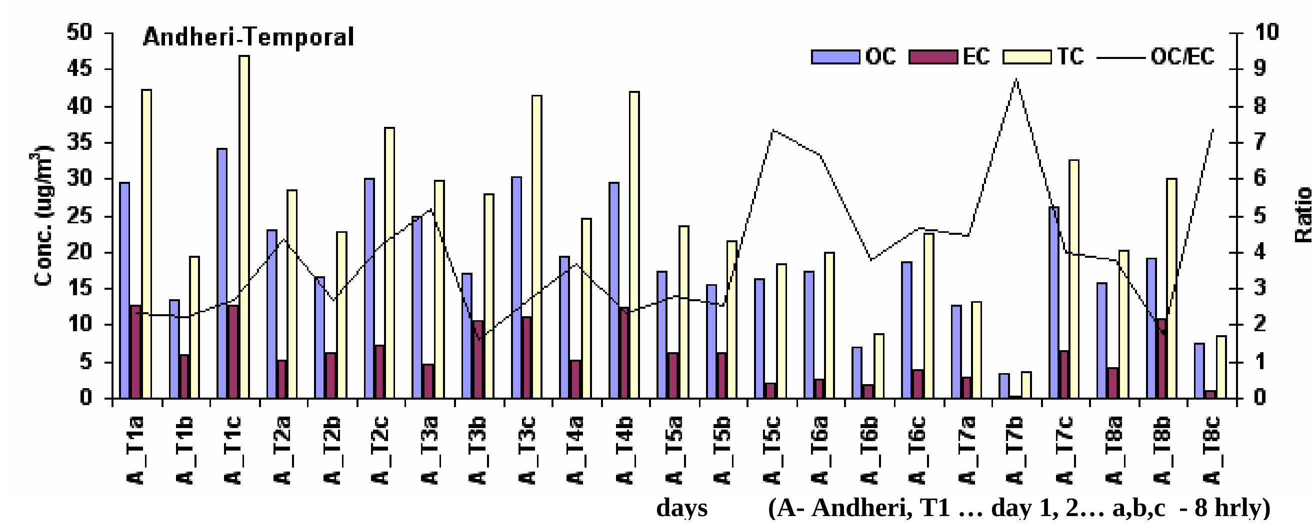


Figure SA.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Andheri Site

At Andheri site OC varied between 7.5.-28.6 μg/m^3 with an average value of 14.5 μg/m^3. The EC concentration varied between 1.3-10.4 μg/m^3 with an average value of 4.1 μg/m^3. OC/EC ratio varied from 9.2 to 36.2 with an average ratio of 18.6. Percentage of OC, EC and TC in PM_{10} was 17.7, 5.2 and 22.8 whereas in $PM_{2.5}$ it was 67, 17 and 85 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations ($\mu g/m^3$) in PM_{10} is presented in **Figure SA.9.**

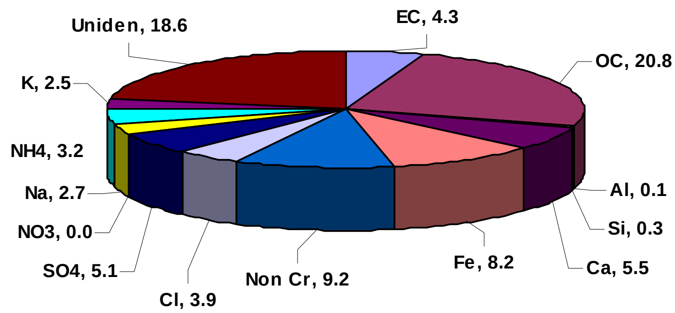


Figure SA.9 : Mass Closure Concentrations ($\mu g/m^3$) at Andheri

Percent composition of PM_{10} after mass closure show that maximum contribution is from carbonaceous matter. OC and EC account for 24% and 5% respectively and thus indicate the contribution from sources like automobile exhaust, coal burning, biomass burning and oil burning. Ions account for 21 % of the total particulate matter. High concentration of SO_4^{2-} is due to road dust, secondary aerosols, vehicles. Other ions like Cl^- and Na^+ are released from sea spray, NH_4^+ is emitted from vehicles and K^+ is from biomass burning. Crustal elements account for 17% of the total particulate matter indicating the contribution from soil and road dust whereas non crustal elements account for 11% of the total particulate matter indicating the contribution from sources like vehicles, coal burning, biomass burning and oil burning. 22 % of the total PM_{10} is unidentified.

Mahul Site: The observed concentrations for summer season are presented in **Table SM.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations SPM, RSPM, PM_{10} and gaseous pollutants for summer season at Mahul are presented in **Figure SM.1**.

Table SM.1 : Air Quality Status at Mahul (Summer)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM ($\mu g/m^3$)	116.0	640.0	239.0	469.0	99.0	29
RSPM ($\mu g/m^3$)	54.0	198.0	117.0	187.0	39.0	28
PM_{10} ($\mu g/m^3$)*	55.0	181.0	98.0	170.0	29.0	29
$PM_{2.5}$ ($\mu g/m^3$)**	13.0	23.0	17.0	NA	4.0	4
SO_2 ($\mu g/m^3$)	4.0	28.0	7.0	25.0	6.0	29
NO_2 ($\mu g/m^3$)	10.0	38.0	20.0	36.3	8.0	29
NH_3 ($\mu g/m^3$)	5.0	791.0	112.0	531.2	140.0	29
CO (mg/m^3)	0.5	2.9	1.9	2.9	1.1	6
Formaldehyde ($\mu g/m^3$)	23.0	33.0	28.0	NA	7.1	2
CH_4 (ppm)	0.9	1.0	0.9	NA	0.0	2
Nonmethane HC (ppm)	17.5	24.6	21.1	NA	5.0	2
Total HC (ppm)	18.4	25.5	22.0	NA	5.0	2
OC ($\mu g/m^3$)	6.1	16.7	11.5	16.5	3.0	29
EC ($\mu g/m^3$)	1.4	6.4	3.6	5.7	1.2	29
TC ($\mu g/m^3$)..	7.5	21.4	15.1	20.9	3.8	29

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Mahul exceeded 3% of the time CPCB industrial standard of 500 $\mu g/m^3$, whereas RSPM exceeded 17% of the time standard of 150 $\mu g/m^3$during sampling period. The ratio of RSPM to SPM was 49% indicating high RSPM concentrations at industrial sites and ratio of $PM_{2.5}$ to PM_{10} was 17%. The 24 hourly average concentrations of SO_2, and NO_2 were within CPCB limits and NH_3 exceed 3% during study period. Higher concentrations of NH_3 could be due to fertilizer industry around sampling site. The monthly average of PM_{10} was 98 $\mu g/m^3$. A trend of temporal values of PM_{10} shows high concentrations during 10 pm to 6 am and 6 am to 2 pm. CO values ranged between 0.50-2.92 mg/m^3, formaldehyde ranged between 23-33 $\mu g/m^3$, whereas Total Hydrocarbon ranged between 18.4-25.5 ppm.

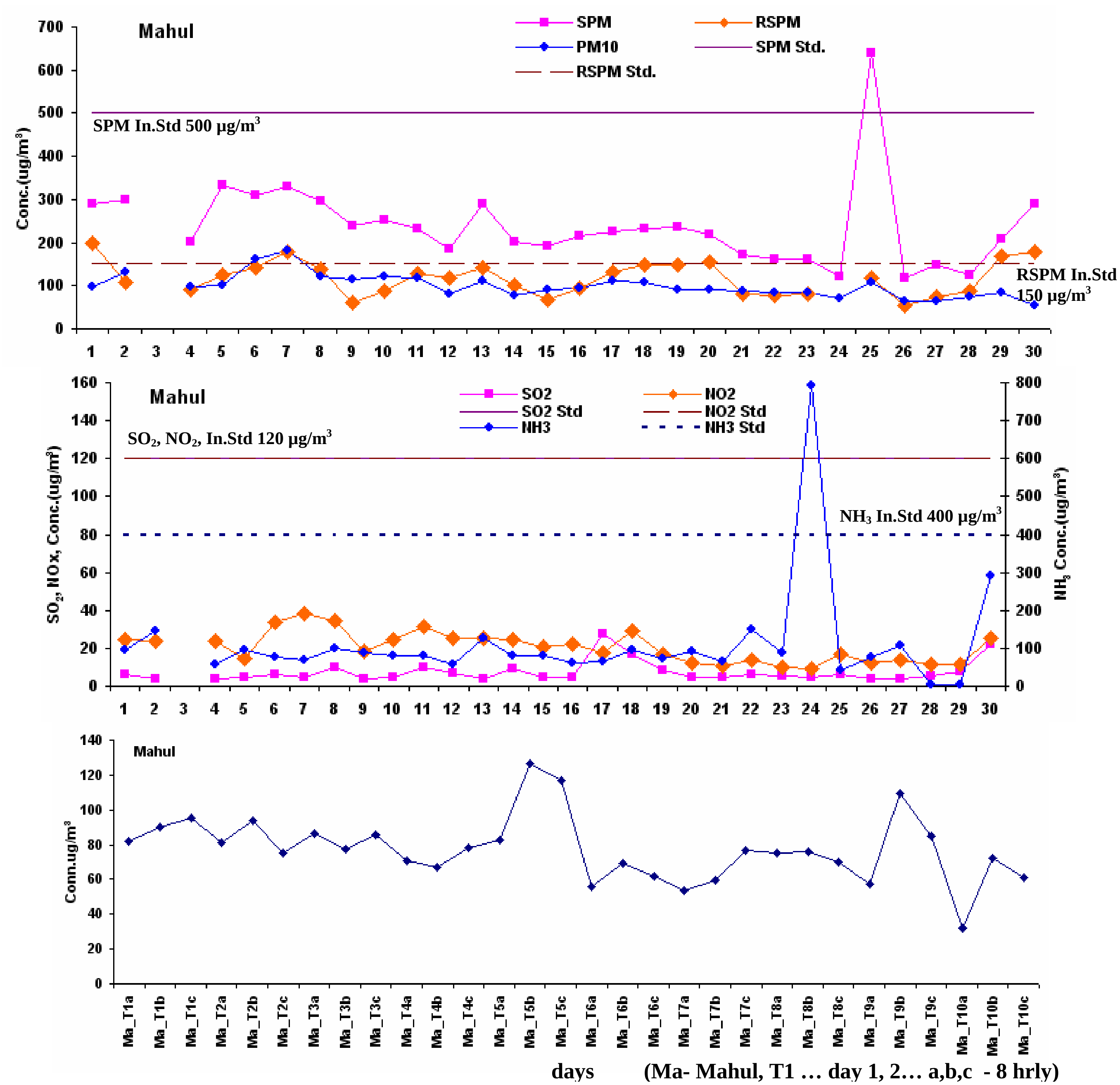


Figure SM.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Mahul (Summer)

* High value at particular day indicates outlier due to certain site specific activity.

Figure SM.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

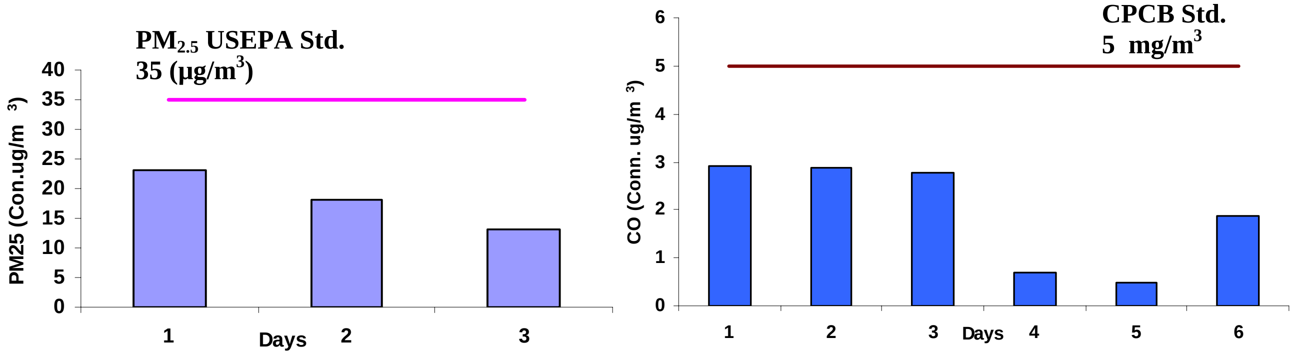


Figure SM.2 : Observed Concentrations of $PM_{2.5}$ and CO at Mahul (Summer)

The concentration of $PM_{2.5}$ was within limits of the US EPA standard of 35 μg/m^3 due to the sources such as soil and sea spray which contribute to coarse particulate matter. The CO concentration during the sampling period was within the limits of the CPCB standard of 5 μg/m^3 for industrial area.

Figure SM.3 shows Methane, Non Methane and THC concentrations and **Figure SM.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not be analyzed during summer season

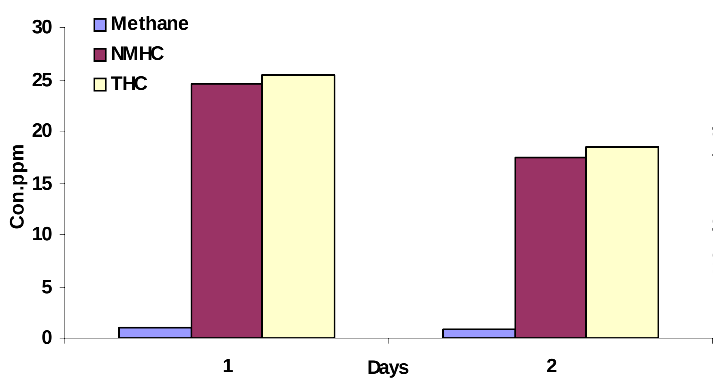


Figure SM.3 : Hydrocarbon Concentration

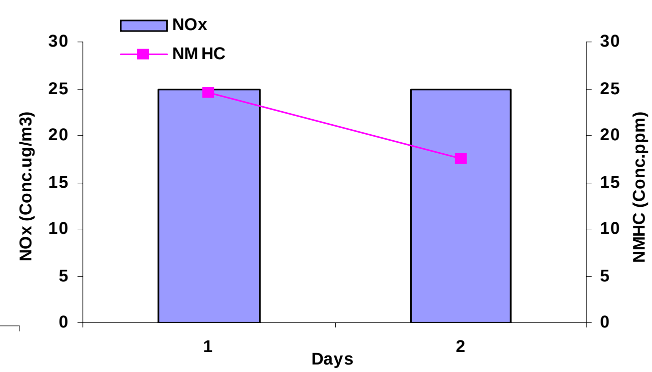


Figure SM.4 : NO_2 and NMHC Concentrations

Figure SM.5 presents diurnal variation of CO during summer.

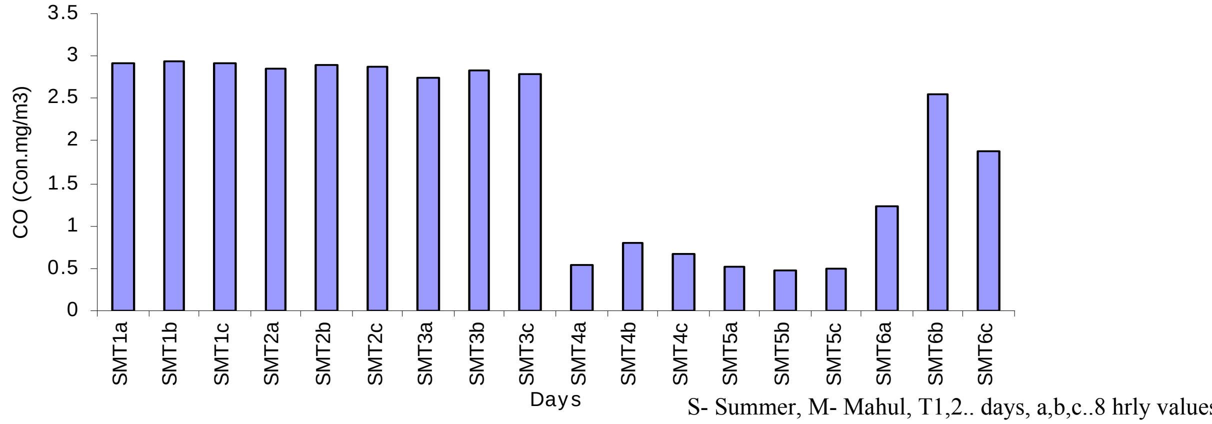


Figure SM.5 : Diurnal variation of CO at Mahul

Diurnal variation in CO doesn't show any particular trend.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2 , NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SM.6 and SM.7.**

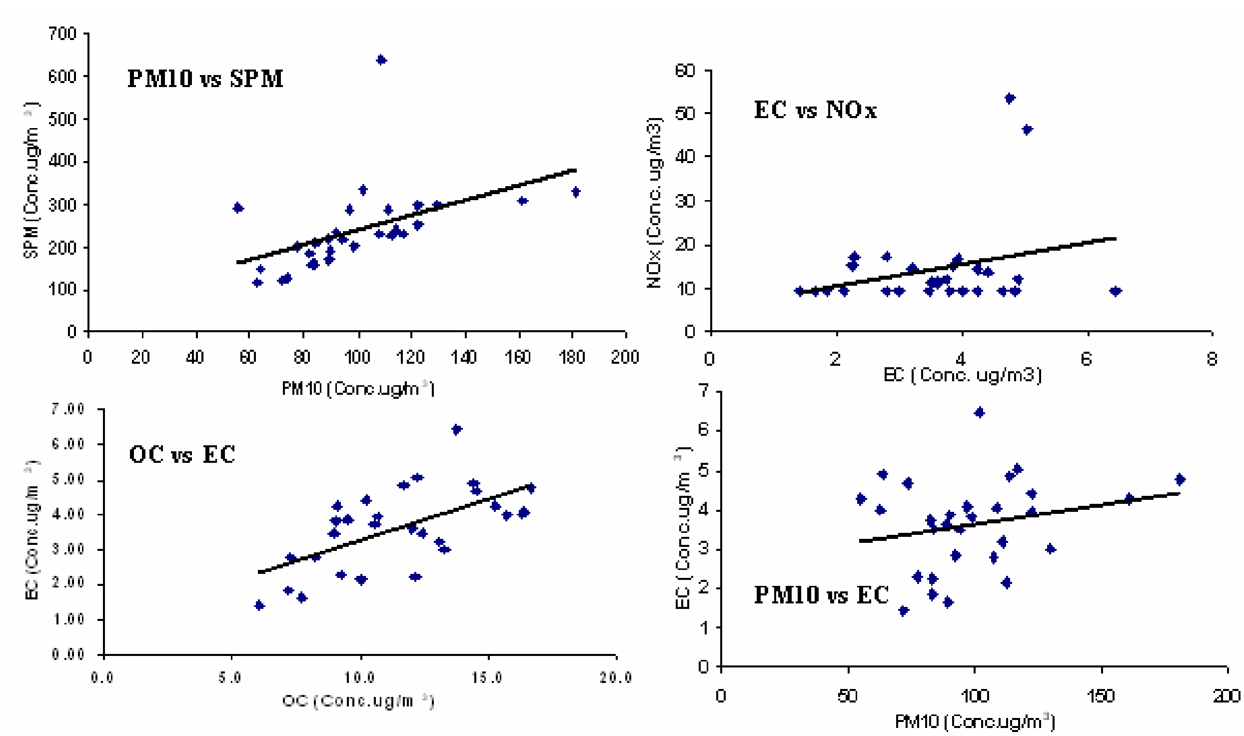


Figure SM.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show moderate correlation (R=0.49) due to the presence of sources like soil and sea spray which contribute to coarse particulate matter along with fine particulate matter contributing sources like heavy vehicles, oil burning and coal burning. EC and NO_2 show very poor correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show good correlation (R=0.62) indicating that sources like heavy vehicles, oil burning, coal burning are contributing to both OC and EC. Correlation coefficient for PM_{10} and EC is 0.23 indicating EC tend to be in the fine particle fraction.

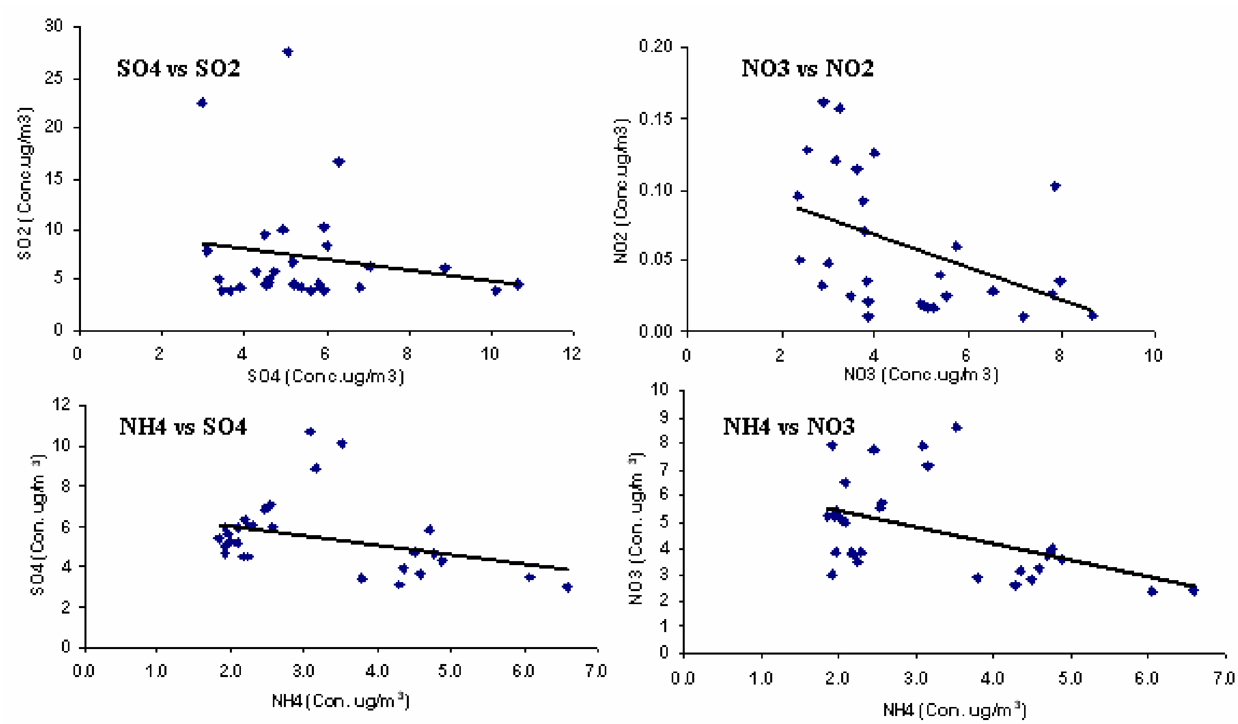


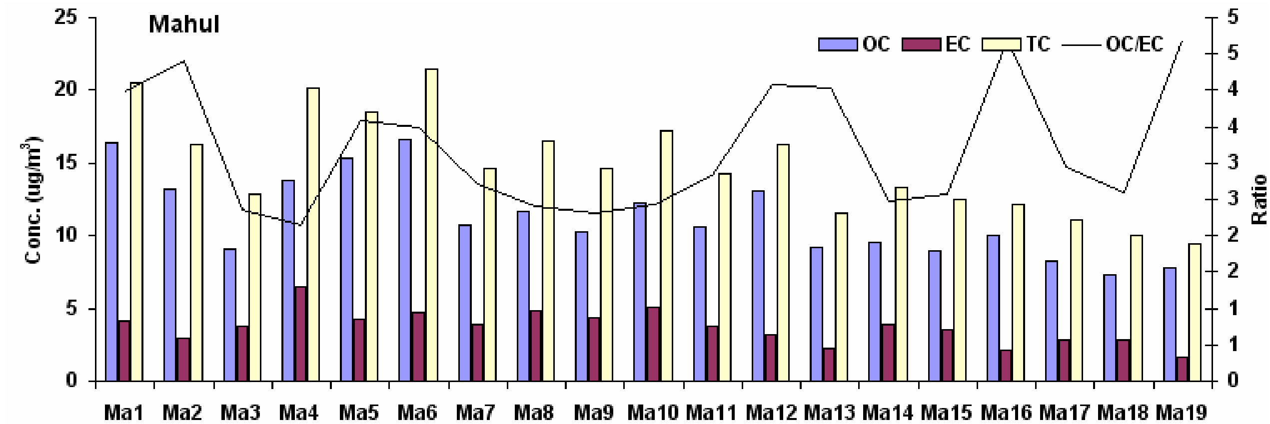
Figure SM.7 : Correlation plots of gaseous pollutant vs ions

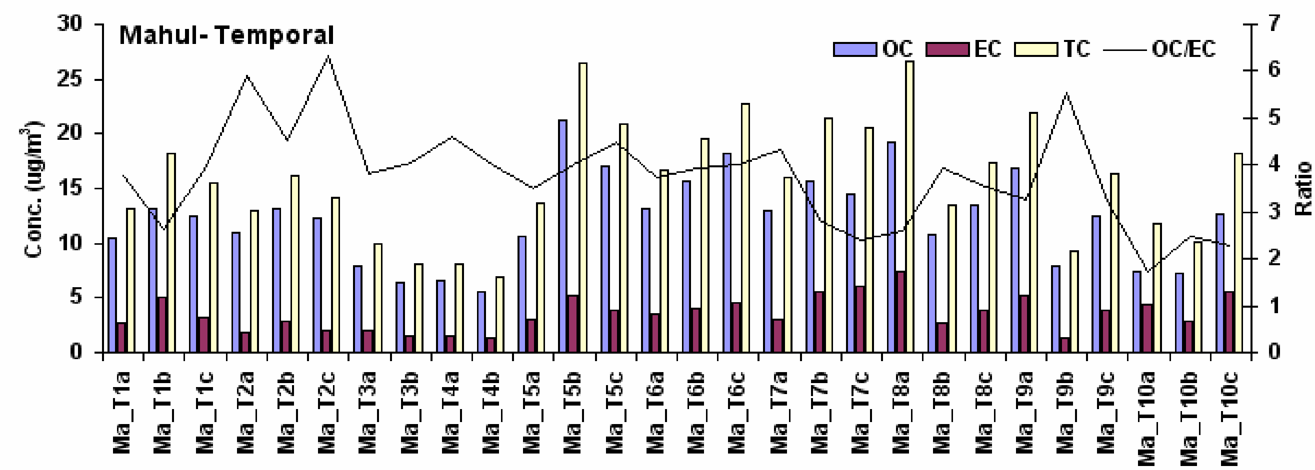
SO_2 and SO_4^{2-} show negative correlation indicating that SO_2 is moderately getting converted to SO_4^{2-} and it is due to other sources like vehicles, oil burning. NO_2 and NO_3^- correlate moderately indicating that NO_2 is getting converted to NO_3^- but it is mainly coming from sources such as automobile exhaust and industries. NH_4^+ and SO_4^{2-} show poor correlation indicating that NH_4^+ is not neutralizing SO_4^{2-}. NH_4^+ and NO_3^- show poor correlation indicating that NH_4^+ is not neutralizing NO_3^-.

Carbon concentrations at Mahul site with PM_{10} and $PM_{2.5}$ is given **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SM.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.345	.235	.322
OC	.345	1.000	.619	.969
EC	.235	.619	1.000	.789
TC	.322	.969	.789	1.000





days (Ma- Mahul, T1 … day 1, 2… a,b,c - 8 hrly)

Figure SM.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Mahul Site (Summer)

At Mahul site OC varied between 6.1.-16.7 μg/m^3 with an average value of 11.5 μg/m^3. The EC concentration varied between 1.4-6.4 μg/m^3 with an average value of 3.6 μg/m^3. OC/EC ratio varied from 2.1 to 5.6 with an average ratio of 3.4. Percentage of OC, EC and TC in PM_{10} was 11.6, 3.6 and 15.2 whereas in $PM_{2.5}$ it was 31, 13.2 and 41.1 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (μg/m^3) in PM_{10} is presented in **Figure SM.9.**

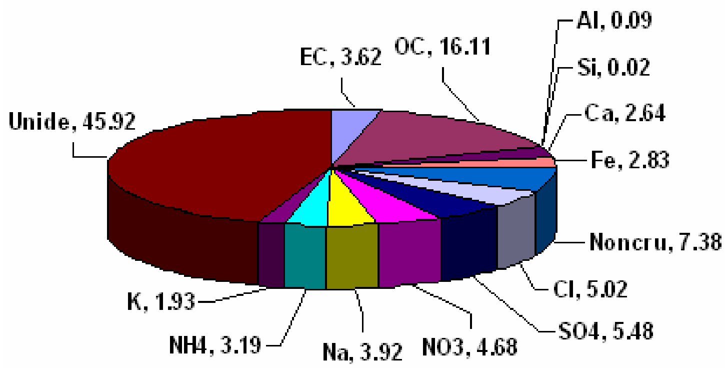


Figure SM.9 : Mass Closure Concentrations (μg/m^3) at Mahul

Percent composition of PM_{10} after mass closure shows that maximum contribution is from ions which accounts for 24% of the total particulate matter. High concentration of SO_4^{2-} and NO_3^- is due to secondary aerosols, vehicles and sea spray. Other ions like Cl^- and Na^+ are released from sea spray; NH_4^+ is emitted from fertilizer industry and heavy vehicles whereas K^+ is from biomass burning. OC and EC account for 16% and 4% respectively and thus indicate the contribution from sources like heavy vehicles, oil burning and coal burning. Crustal elements account for 6% of the total particulate matter indicating the contribution from soil whereas non crustal elements account for 7% of the total particulate matter indicating the contribution from sources like petrochemical industries, heavy vehicles, oil burning and coal burning. 43% of the total PM_{10} is unidentified.

Mulund Site: The observed concentrations for summer season are presented in **Table SMu1.** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for summer season at Mulund are presented in **Figure SMu.1.**

Table SMu1: Air Quality Status at Mulund (Summer)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	230	626	352	535.6	86.5	28
RSPM (µg/m^3)	79	323	189	318.3	77	29
PM_{10} (µg/m^3)*	90	254	163	248.0	55	30
$PM_{2.5}$ (µg/m^3)**	60	64	62	NA	2	3
SO_2 (µg/m^3)	4	10	5	9.6	2	29
NO_2 (µg/m^3)	24	155	51	124.1	26	29
NH_3 (µg/m^3)	14	149	64	143.4	35	29
CO (mg/m^3)	0.63	5.13	2.3	5.1	2.06	7
Formaldehyde (µg/m^3)	7	37	22	NA	21.2	2
CH_4 (ppm)	1.88	2.09	1.99	NA	0.148	2
Nonmethane HC (ppm)	12.9	22.65	17.76	NA	6.89	2
Total HC (ppm)	14.75	24.70	19.7	NA	7.03	2
OC (µg/m^3)	1.78	54.8	32.7	54.2	13.4	30
EC (µg/m^3)	0.6	19.9	8.8	17.1	4.0	30
TC (µg/m^3)..	2.44	74.7	41.5	67.0	16.3	30

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Mulund exceeded all the times CPCB residential /mixed standard of 200 µg/m^3, whereas RSPM exceeded 89% of the time standard of 100 µg/m^{3}during sampling period. The ratio of RSPM to SPM was 54% and $PM_{2.5}$ to PM_{10} was 38% indicating higher share of finer particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 exceeded the standard 7% during study period. The monthly average of PM_{10} was 163 µg/m^3. A trend of temporal values of PM_{10} shows that similar concentration during all the shifts. CO values ranged between 0.63-5.13 mg/m^3, formaldehyde ranged between 7-37 µg/m^3, whereas average concentration of Total Hydrocarbon is 19.7 ppm.

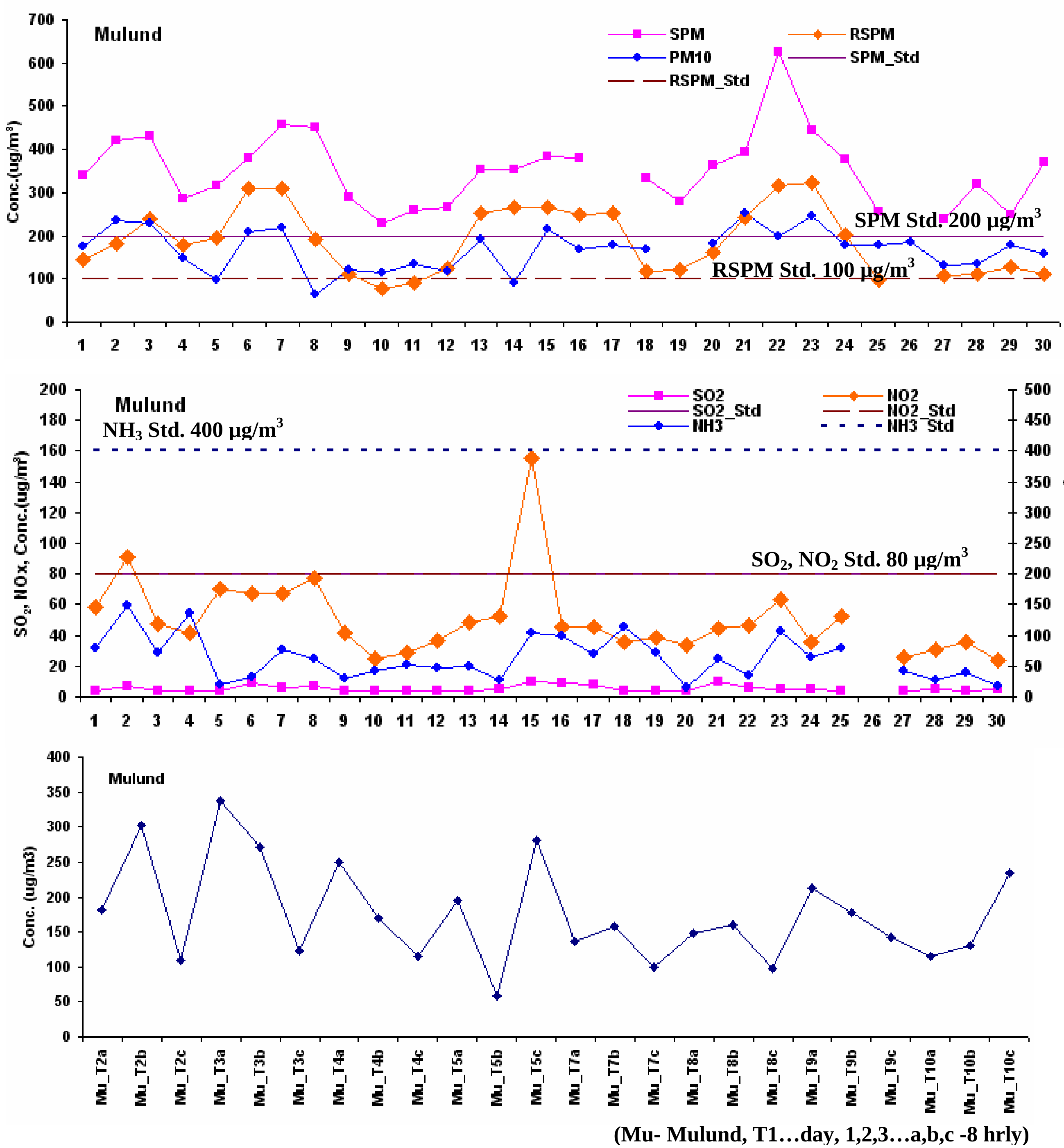
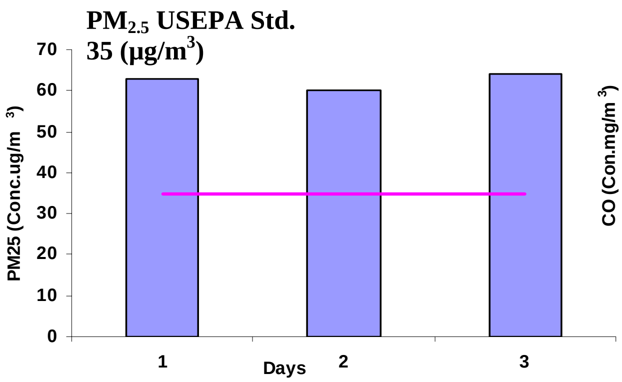


Figure SMu.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Mulund (Summer)

* High value at particular day indicates outlier due to certain site specific activity.

Figure SMu.2 shows the variation of $PM_{2.5}$ and CO during the summer period.



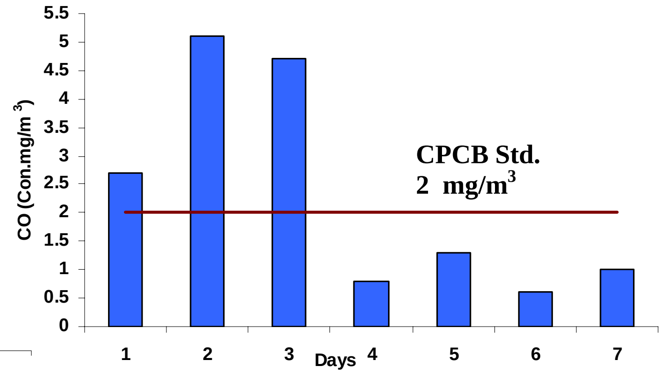


Figure SMu.2 : $PM_{2.5}$ and CO Concentration at Mulund

The concentration of $PM_{2.5}$ exceeded all the times the limits of the US EPA standard of 35 $\mu g/m^3$ due to the sources such as industries, vehicles and oil burning which contribute to fine particulate matter. The CO concentration during the sampling period exceeded 42.8 % of the time the limits of the CPCB standard of 2 $\mu g/m^3$ for residential and mix use area

Figure SMu.3 shows Methane, Non Methane and THC concentrations and **Figure SMu.4** shows NO_2 vs NMHC concentrations during summer season. O_3 and VOC could not be analyzed during summer season

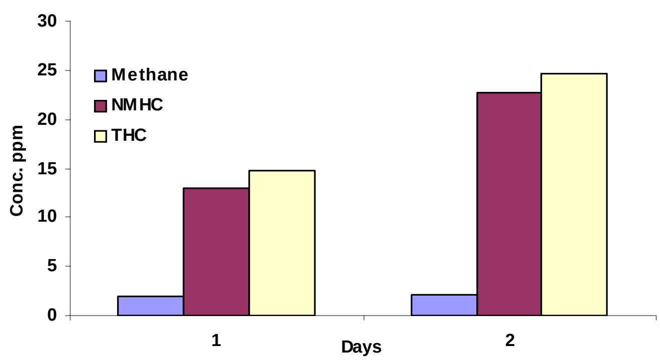


Figure SMu.3 : Hydrocarbon Concentration

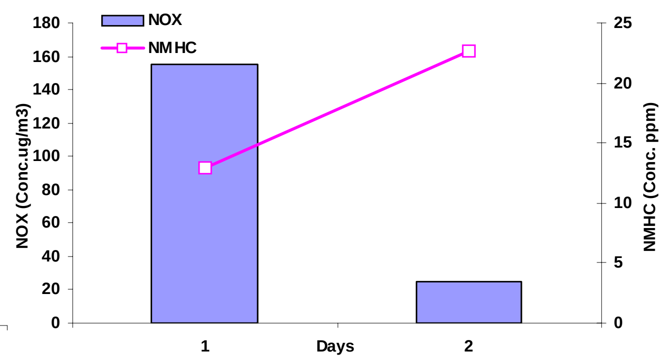


Figure SMu.4 : NO_2 and NMHC Concentrations

Figure SMu. 5 presents diurnal variation of CO concentrations.

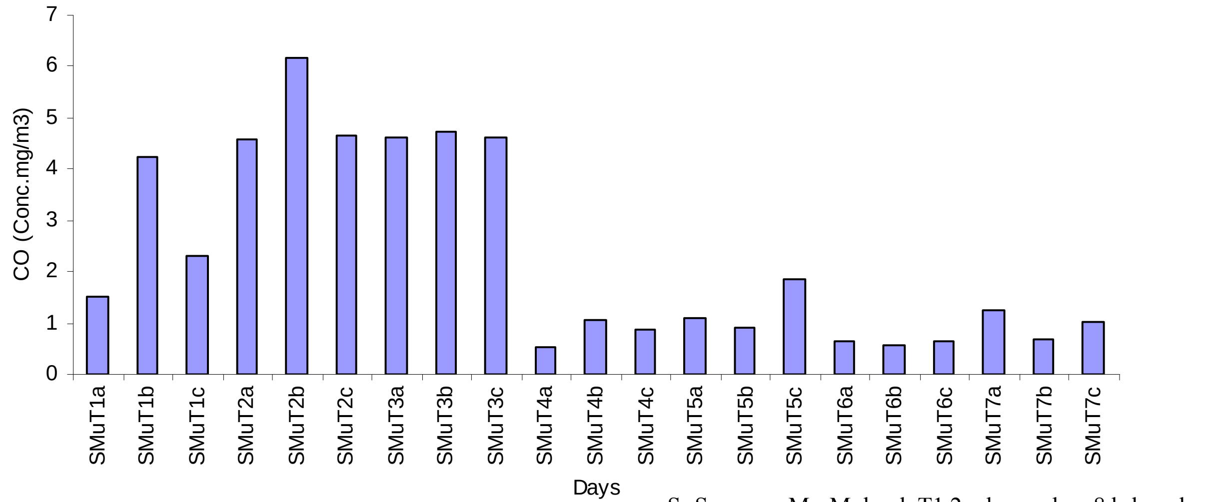


Figure SMu.5: Diurnal Variation of CO at Mulund

Diurnal variation is seen during night and early morning time.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^-, NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures SMu.6 and SMu.7.**

Correlation plots of carbons vs dust and gaseous parameters are shown in Figure **SMu.6**

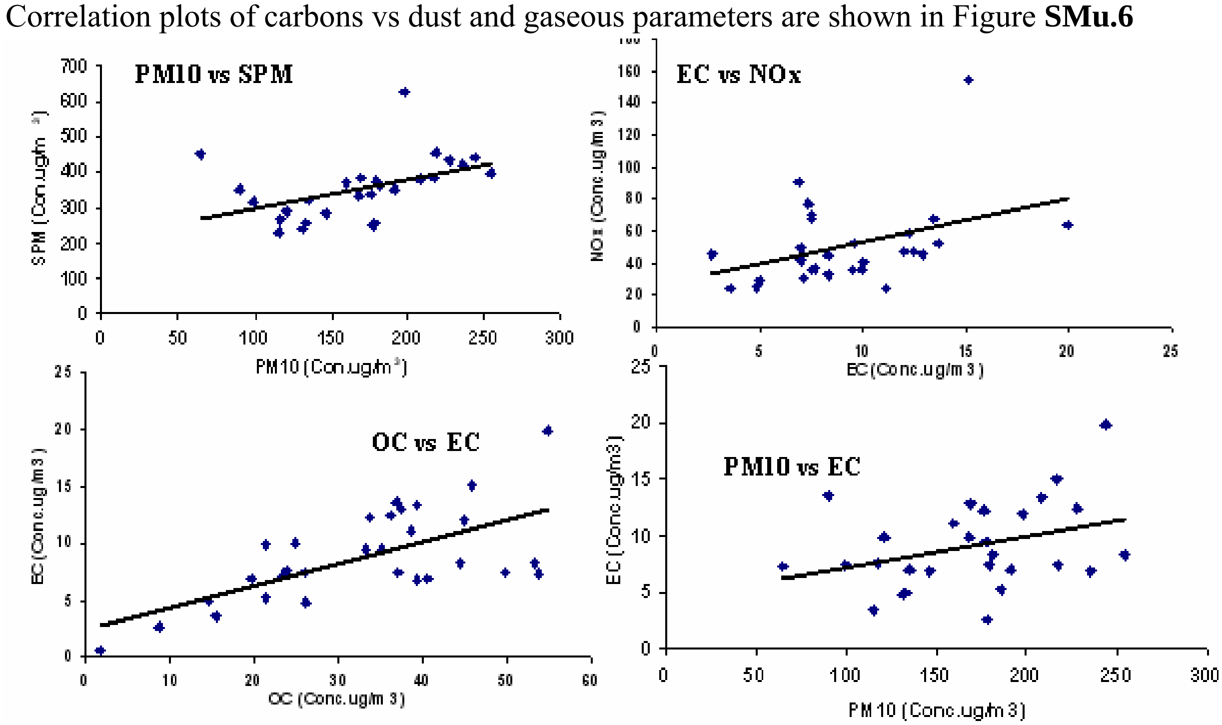


Figure SMu.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show moderate correlation due to the presence of sources like soil and road dust which contribute to coarse particulate matter along with fine particulate matter contributing sources like industries, vehicles and oil burning. EC and NO_2 show moderate correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show good correlation (R=0.66) indicating that sources like vehicles and oil burning are contributing to OC and EC. PM_{10} and EC show poor correlation indicating that EC tend to be in the fine particle fraction.

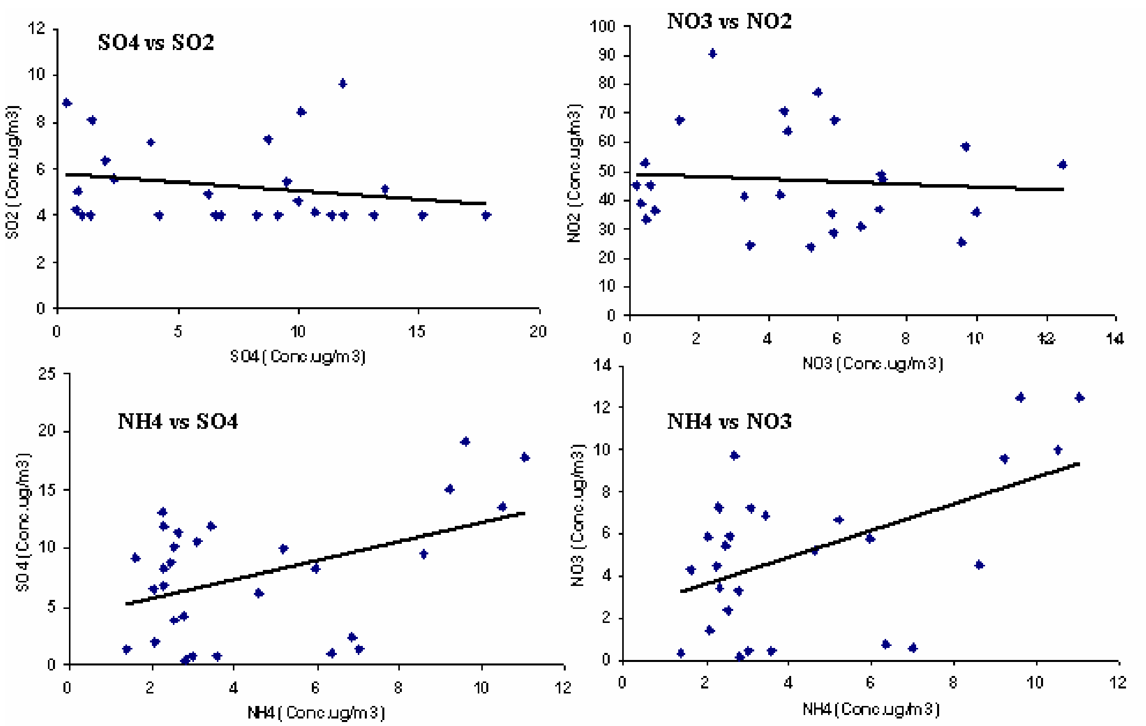


Figure SMu.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show moderately negative correlation indicating that very less amount of SO_2 is getting converted to SO_4^{2-}. NO_2 and NO_3^- show very poor negative correlation indicating that NO_2 is not getting converted to NO_3^- but it is probably coming from sources such as automobile exhaust. NH_4^+ and SO_4^{2-} show moderate correlation (R=0.45) indicating that NH_4^+ is neutralizing SO_4^{2-}. NH_4^+ and NO_3^- show good correlation (R=0.52) indicating that NH_4^+ is neutralizing NO_3^- and resulting in the formation of NH_4NO_3.

Carbon concentrations at Mulund site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure SMu.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.442	.352	.456
OC	.442	1.000	.589	.979
EC	.352	.589	1.000	.742
TC	.456	.979	.742	1.000

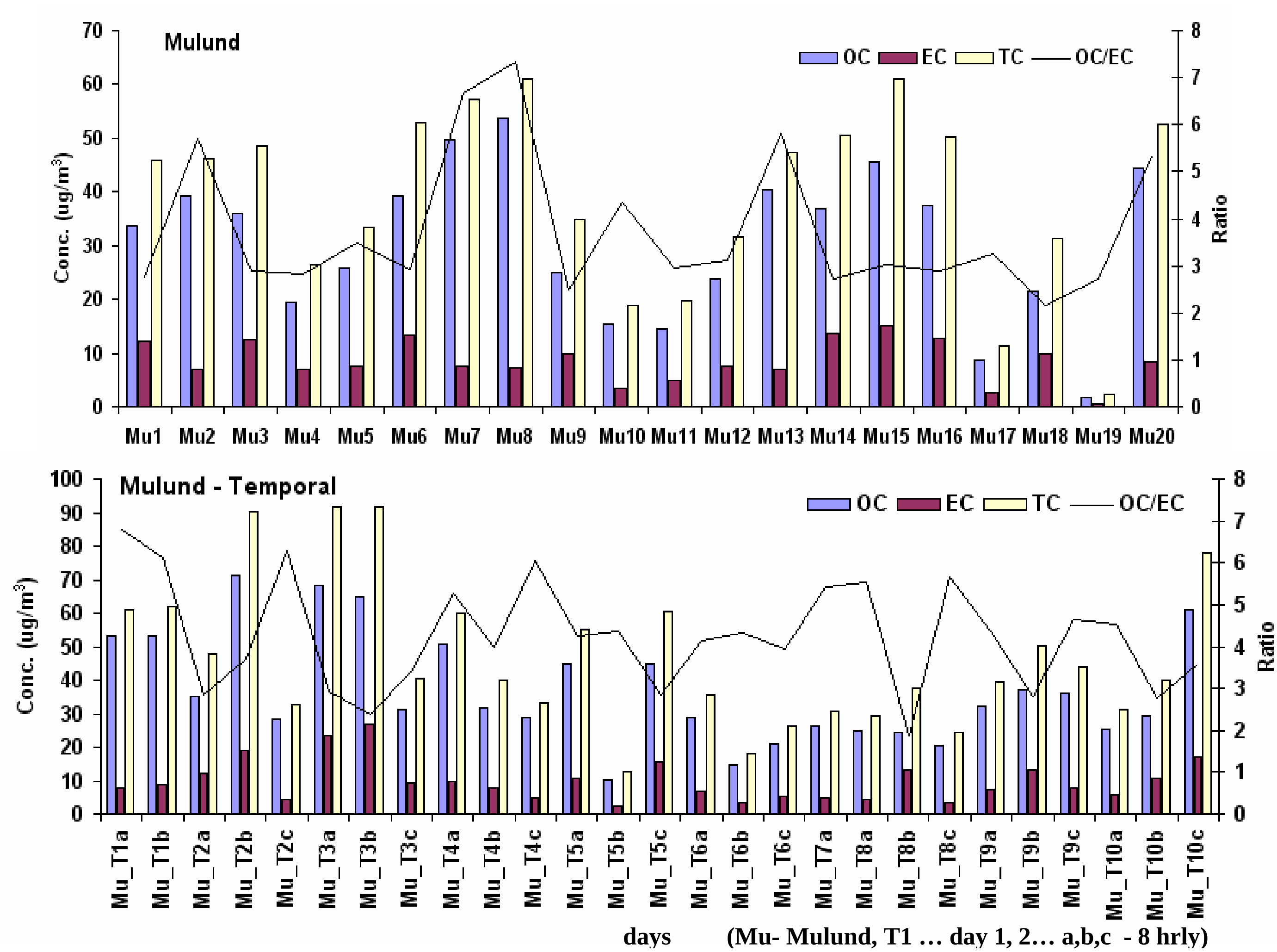


Figure SMu.8: 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Mulund Site (Summer)

At Mulund site OC varied between 1.7-54.8 µg/m^3 with an average value of 32.7 µg/m^3. The EC concentration varied between 0.6-19.9 µg/m^3 with an average value of 8.84 µg/m^3. OC/EC ratio varied from 2.16 to 7.35 with an average ratio of 3.99. Percentage of OC, EC and TC in PM_{10} was 20.1, 5.4 and 25.5 whereas in $PM_{2.5}$ it was 25.97, 13.73 and 39.71 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure SMu.9.**

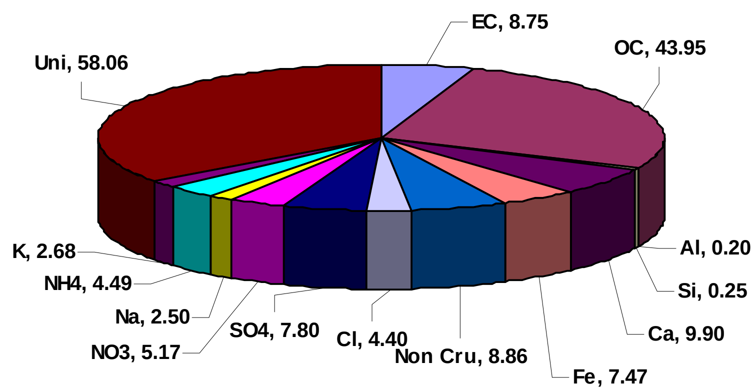


Figure SMu.9: Mass Closure Concentrations (µg/m^3) at Mulund

Percent composition of PM_{10} after mass closure show that maximum contribution is from carbonaceous matter. OC and EC account for 27% and 5% respectively and thus indicate the contribution from sources like vehicles and oil burning. Ions account for 16% of the total particulate matter. High concentration of SO_4^{2-} is due to vehicles, oil burning. NH_4^+ is emitted from vehicles and industries whereas biomass burning acts as the source of K^+. Cl^- and Na^+ are contributed from sea spray. Crustal elements account for 11% of the total particulate matter indicating the contribution from soil and road dust whereas non crustal elements account for 5% of the total particulate matter indicating the contribution from sources like vehicles, industries and oil burning. 36 % of the total PM_{10} is unidentified.

2.4.2 Post Monsoon Season

Colaba Site: The observed concentrations for post monsoon season are presented in **Table PC.1** the detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season are presented in **Figures PC.1**

Table PC.1: Air Quality Status at Colaba (Post monsoon)

Pollutants	**Min**	**Max**	**Avg**	**98 percentile**	**SD**	**N**
SPM (μg/m^3)	125.0	343.0	204.6	317.6	54.8	28
RSPM (μg/m^3)	63.0	218.0	128.1	212.6	39.6	28
PM_{10} Tef (μg/m^3)*	63.0	229.0	139.5	212.3	39.1	28
PM_{10} Tef_1 (μg/m^3)*	65.0	222.0	141.4	212.3	38.5	28
$PM_{2.5}$ (μg/m^3)**	52.0	71.0	59.7	NA	10.0	3
SO_2 (μg/m^3)	4.0	27.0	12.7	24.3	6.1	28
NO_2 (μg/m^3)	13.0	76.0	37.7	74.9	18.8	28
NH_3 (μg/m^3)	13.0	152.0	53.1	137.4	33.6	28
CO (mg/m^3)	2.0	4.5	2.9	4.4	0.9	7
Formaldehyde (μg/m^3)	8.8	29.1	19.0	NA	14.4	2
CH_4 (ppm)	2.0	2.16	2.09	NA	0.07	4
Nonmethane HC (ppm)	0.13	1.09	0.53	NA	0.40	4
Total HC (ppm)	2.13	3.25	2.62	NA	0.47	4
O_3 (ppb)	19.9	41.7	31.4	41.6	8.3	7
OC (μg/m^3)	11.6	41.9	27.6	41.0	8.9	26
EC (μg/m^3)	2.1	17.5	7.7	17.2	4.3	26
TC (μg/m^3)..	13.7	59.5	35.3	56.7	12.0	26

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Colaba exceeded 57% of the time of CPCB residential mixed use area standard of 200 μg/m^3, whereas RSPM exceeded 75% of the time during sampling period. As site being controlled area natural sources contribute to SPM. The ratio of RSPM to SPM was 63% and $PM_{2.5}$ to PM_{10} was 42% indicating presence of fine and coarse particles. The 24 hourly average concentrations of SO_2, NO_2 and NH_3 were within CPCB limits, the monthly average of PM_{10} was 140.4 μg/m^3. Trends of temporal values of PM_{10} show that concentrations are higher mostly during night time and decrease during evening time. CO values ranged between 2.0-4.5 mg/m^3, formaldehyde ranged between 8.8-29.1 μg/m^3, Total Hydrocarbon ranged between 2.1-3.2 ppm, whereas Ozone values ranged from 19.9- 41.7 ppb.

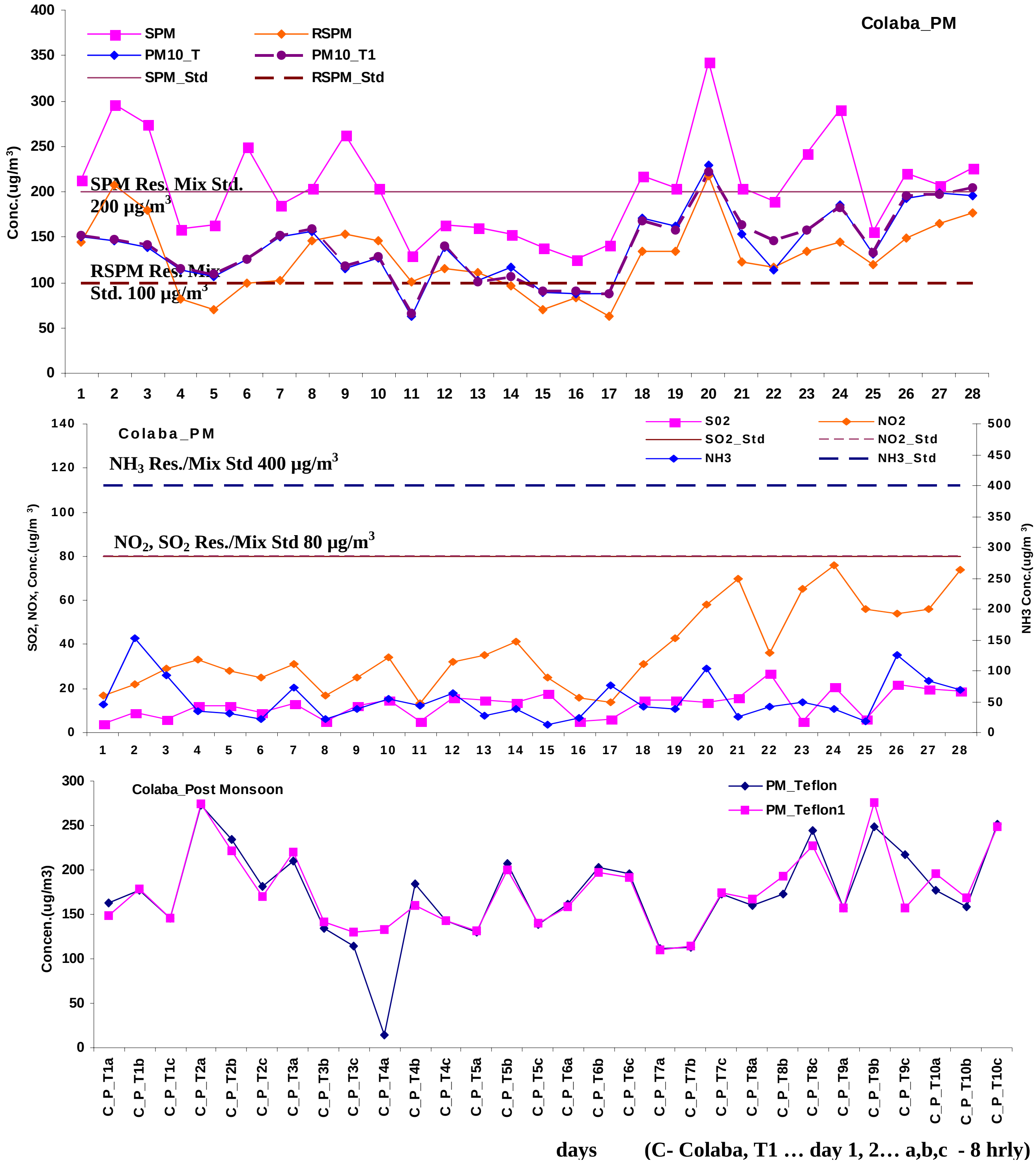


Figure PC.1: Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Colaba during Post Monsoon

* Low value of PM_{10} indicates outlier or it could be due to instrument problem.

Figure PC.2 shows the variation of $PM_{2.5}$ and CO at Colaba (Post monsoon)

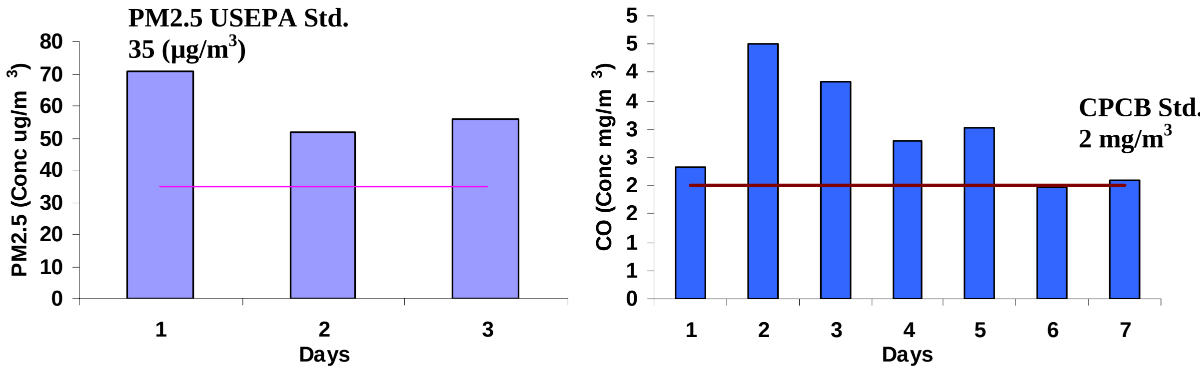


Figure PC.2: Observed Concentrations of $PM_{2.5}$ and CO at Colaba (Post Monsoon)

The concentration of $PM_{2.5}$ exceeded the US EPA standard of 35 µg/m^3 all the time due to the sources like vehicular emission and biomass burning which contribute to the fine particulate matter. The CO concentration during the sampling period exceeded 85.7% of the times the CPCB standard of 2 µg/m^3 for the residential and mix use area due to vehicular emissions and biomass burning.

Figure PC.3 shows Methane, Non Methane and THC concentrations and **Figure PC.4** shows NO_2 vs NMHC concentrations during post monsoon season.

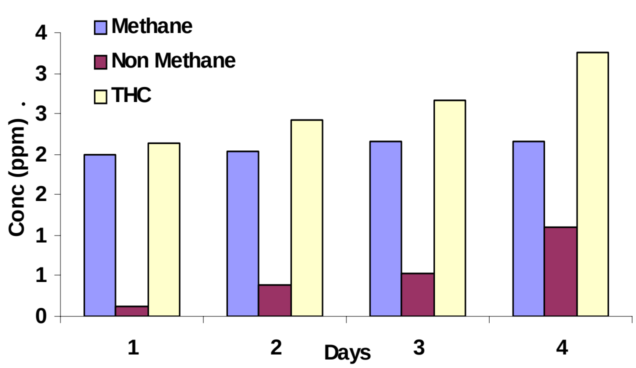


Figure PC.3: Hydrocarbon Concentration.

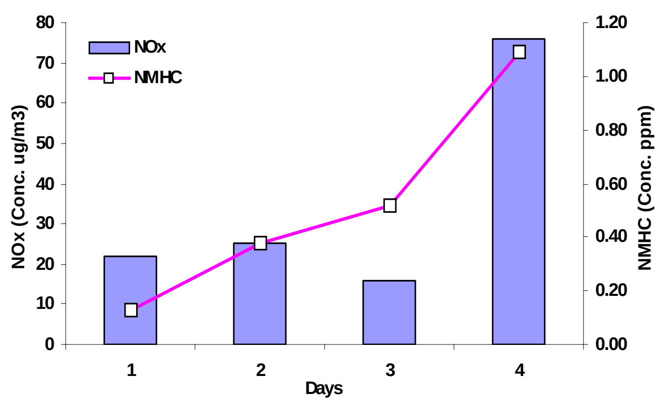
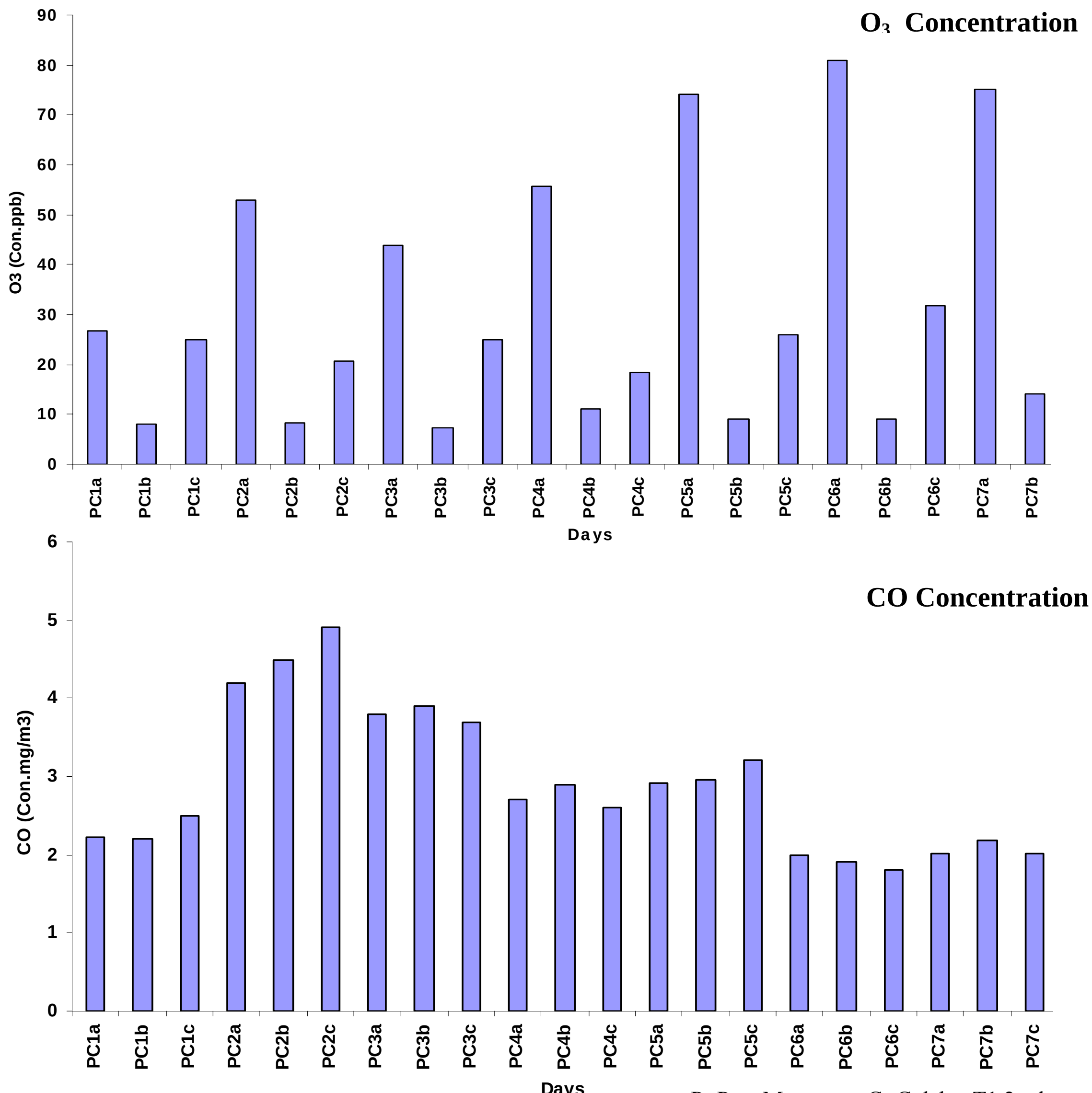


Figure PC.4: NO_2 and NMHC Concentration

Figure PC.5 presents diurnal variation of O_3 and CO during post monsoon.



P- Post Monsoon , C- Colaba, T1,2.. days, a,b,c..8 hrly

Figure PC.5: Diurnal variation of O_3 and CO

Diurnal variation in CO shows high values in the morning due to peak hour traffic, whereas ozone showed high concentrations during morning hours as it has high vehicular emission and more photochemical activity favouring the formation of ozone.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^-, NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PC.6 and PC.7.**

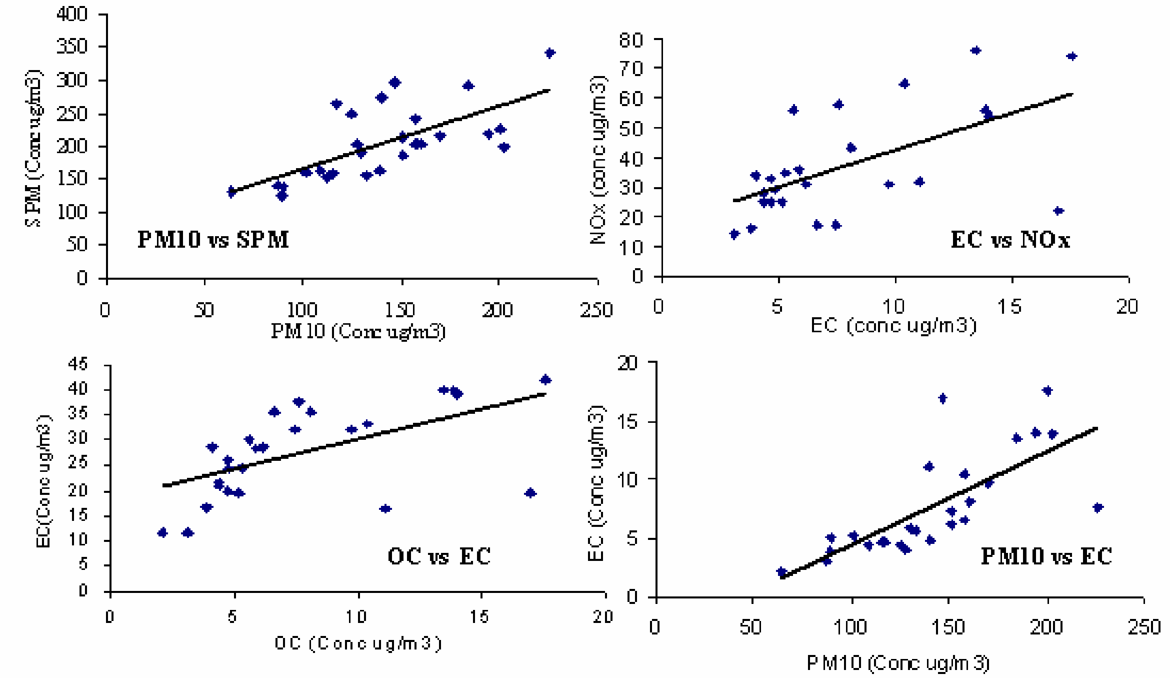


Figure PC.6 : Correlation Plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.68) indicating the presence of sources contributing to coarse particulate matter like soil, sea spray as well as the sources contributing to the fine particulate matter like vehicles and biomass burning. EC and NO_2 show good correlation (R=0.62) indicating that vehicular emissions are contributing to EC and NO_2. EC and OC show very good correlation (R=0.59) indicating that primary sources like vehicles and biomass burning are contributing to OC and EC. Correlation coefficient for PM_{10} and EC is 0.73 indicating that PM_{10} and EC are emitted from primary sources like vehicles and biomass burning.

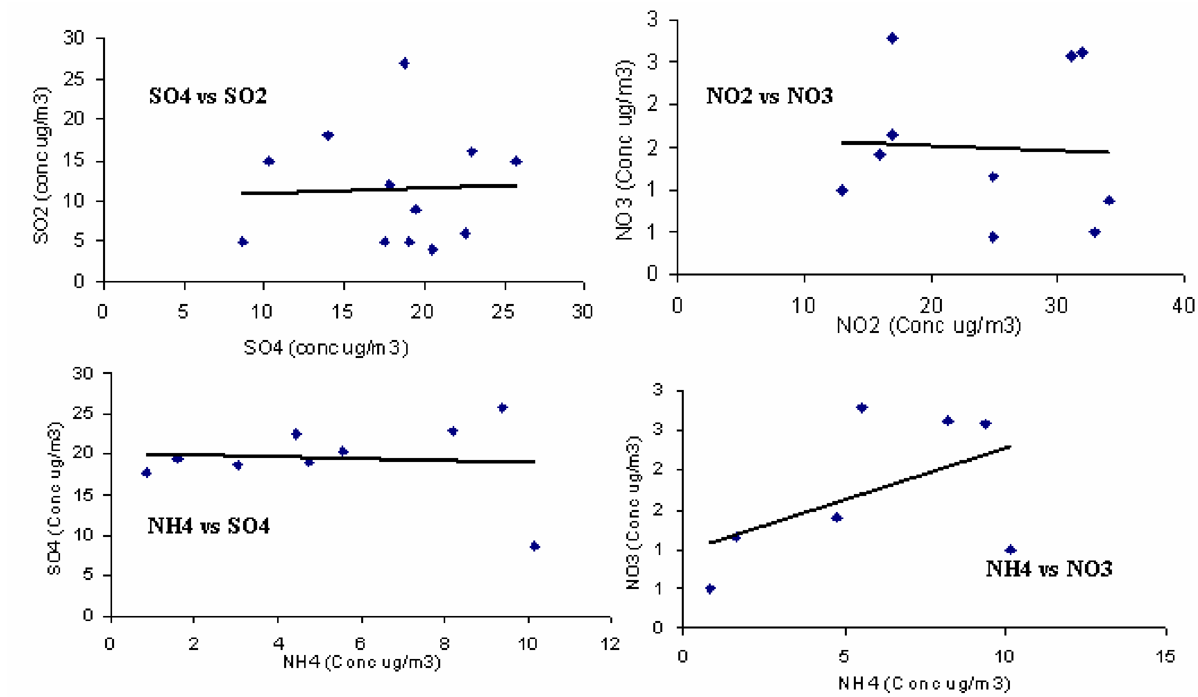


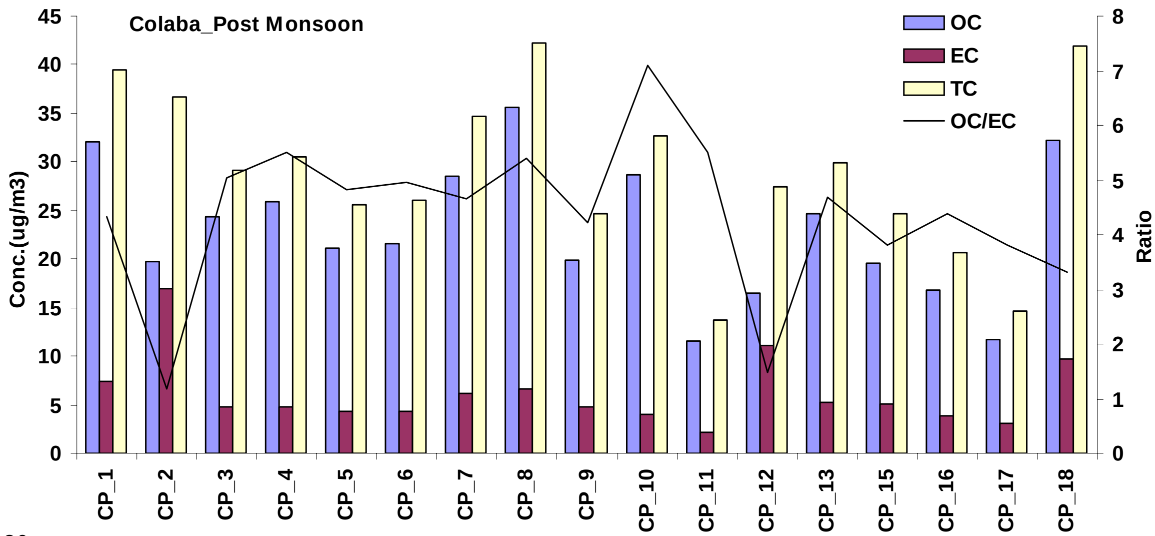
Figure PC.7 : Correlation plots of gaseous pollutant vs ions

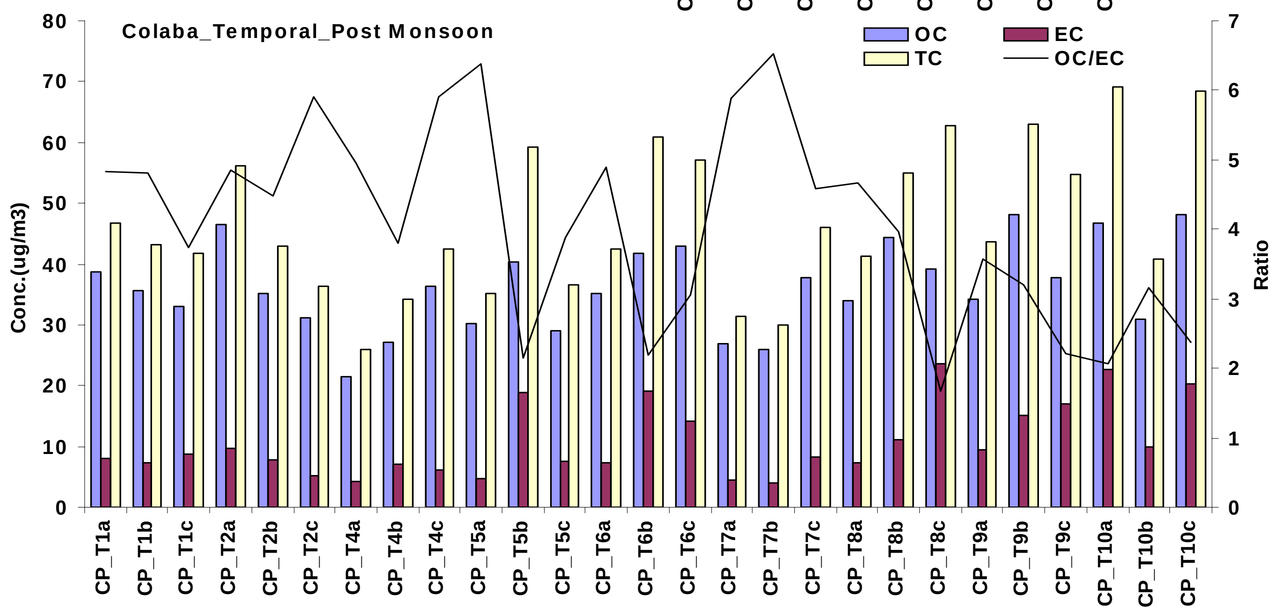
SO_2 and SO_4^{2-} show poor correlation indicating SO_2 is not getting converted to SO_4^{2-} as also NO_2 and NO_3^- show negative correlation. NH_4^+ and SO_4^{2-} show poor negative correlation indicating that NH_4^+ is not neutralizing SO_4^{2-}. NH_4^+ and NO_3^- show good correlation (R=0.52) indicating that NH_4^+ is neutralizing NO_3^- and resulting in the formation of NH_4NO_3.

Carbon concentrations at Colaba site with PM_{10} and $PM_{2.5}$ is presented in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PC.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	**OC**	**EC**	**TC**
PM_{10}	1.000	.879	.741	.916
OC	.879	1.000	.588	.954
EC	.741	.588	1.000	.801
	.916	.954	.801	1.000





days (P- Post Monsoon, C- Colaba, T1 … day 1, 2… a,b,c - 8 hrly)

Figure PC.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Colaba Site (Post Monsoon)

At Colaba site OC varied between 11.6-41.9 µg/m^3 with an average value of 27.6 µg/m^3. The EC concentration varied between 2.1-17.5 µg/m^3 with an average value of 7.7 µg/m^3. OC/EC ratio varied from 1.2 to 7.1 with an average ratio of 4.3. Percentage of OC, EC and TC in PM_{10} was 19.5, 5.4 and 25.01 whereas in $PM_{2.5}$ it was 18.0, 15.4 and 35.3 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (µg/m^3) in PM_{10} is shown in **Figure PC.9.**

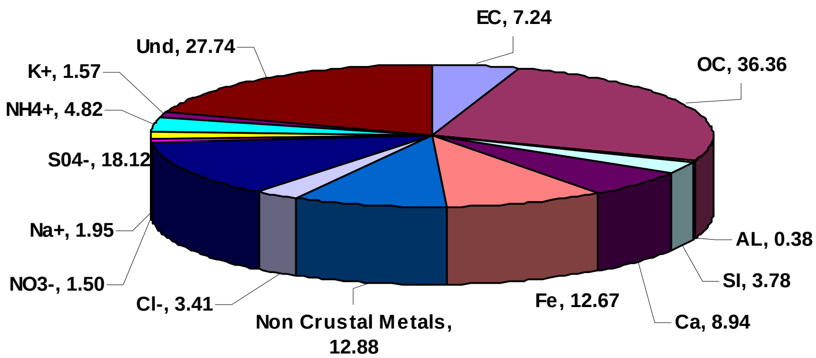


Figure PC.9 : Mass Closure Concentrations (µg/m^3) at Colaba

Percent composition of PM_{10} after mass closure shows that maximum contribution is from carbonaceous material. OC and EC contribute to 26% and 5% respectively indicating the contribution from vehicular exhausts and biomass burning. Ions contribute to 22% of the particulate matter. High concentration of SO_4^{2-} is due to secondary aerosols, vehicles and sea spray. Other ions like Cl^- and Na^+ are from sea spray, NH_4^+ from vehicles and K^+ is from biomass burning. Crustal elements account for 18% of the total particulate matter indicating the contribution from soil whereas non crustal elements account for 9% of the total particulate matter indicating the contribution from smelting, vehicles and biomass burning. 20% of the total particulate matter is unidentified.

Dadar Site: The observed concentrations for post monsoon season are presented in **Table PD.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season are presented in **Figures PD.1.**

Table PD.1: Air Quality Status at Dadar (Post monsoon)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	204.0	503.0	350.7	480.3	70.1	19
RSPM (µg/m^3)	81.0	272.0	180.0	265.8	49.8	25
PM_{10} Tef (µg/m^3)*	108.0	416.0	211.9	369.5	69.8	24
PM_{10} Tef_1 (µg/m^3)*	102.0	418.0	212.8	362.8	65.2	24
$PM_{2.5}$ (µg/m^3)**	98.0	134.0	111.7	NA	19.5	3
SO_2 (µg/m^3)	5.0	30.0	15.0	29.5	7.2	25
NO_2 (µg/m^3)	32.0	92.0	63.0	91.5	16.4	25
NH_3 (µg/m^3)	31.0	235.0	103.0	198.0	47.8	25
CO (mg/m^3)	0.9	2.3	1.2	2.1	0.5	7
Formaldehyde (µg/m^3)	19.4	45.3	32.4	NA	18.3	2
CH_4 (ppm)	1.2	2.2	1.8	NA	0.5	4
Nonmethane HC (ppm)	1.0	4.4	1.9	NA	1.7	4
Total HC (ppm)	3.1	5.6	3.8	NA	1.2	4
O_3 (ppb)	10.1	25.7	14.4	24.5	5.3	7
OC (µg/m^3)	14.8	84.4	40.4	71.7	14.4	24
EC (µg/m^3)	5.2	26.3	11.9	24.6	4.7	24
TC (µg/m^3)..	23.8	110.7	52.2	93.4	17.6	24

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Dadar exceeded all the times of the time of CPCB residential mixed standard of 200 µg/m^3, whereas RSPM exceeded 92% of the time during sampling period. As this site is kerbsite, re-suspended dust could be the reason for high SPM concentration. The ratio of RSPM to SPM was 51% and $PM_{2.5}$ to PM_{10} was 52% indicating dominance of finer particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 exceeded 16% of the times. The monthly average of PM_{10} was 212.36 µg/m^3. No specific in temporal trends observed in the PM_{10} concentrations. CO values ranged between 0.9-2.3 mg/m^3, formaldehyde ranged between 19.4-45.3 µg/m^3. Total Hydrocarbon ranged between 3.1-5.6 ppm whereas Ozone values ranged between 10.1-25.7 ppb

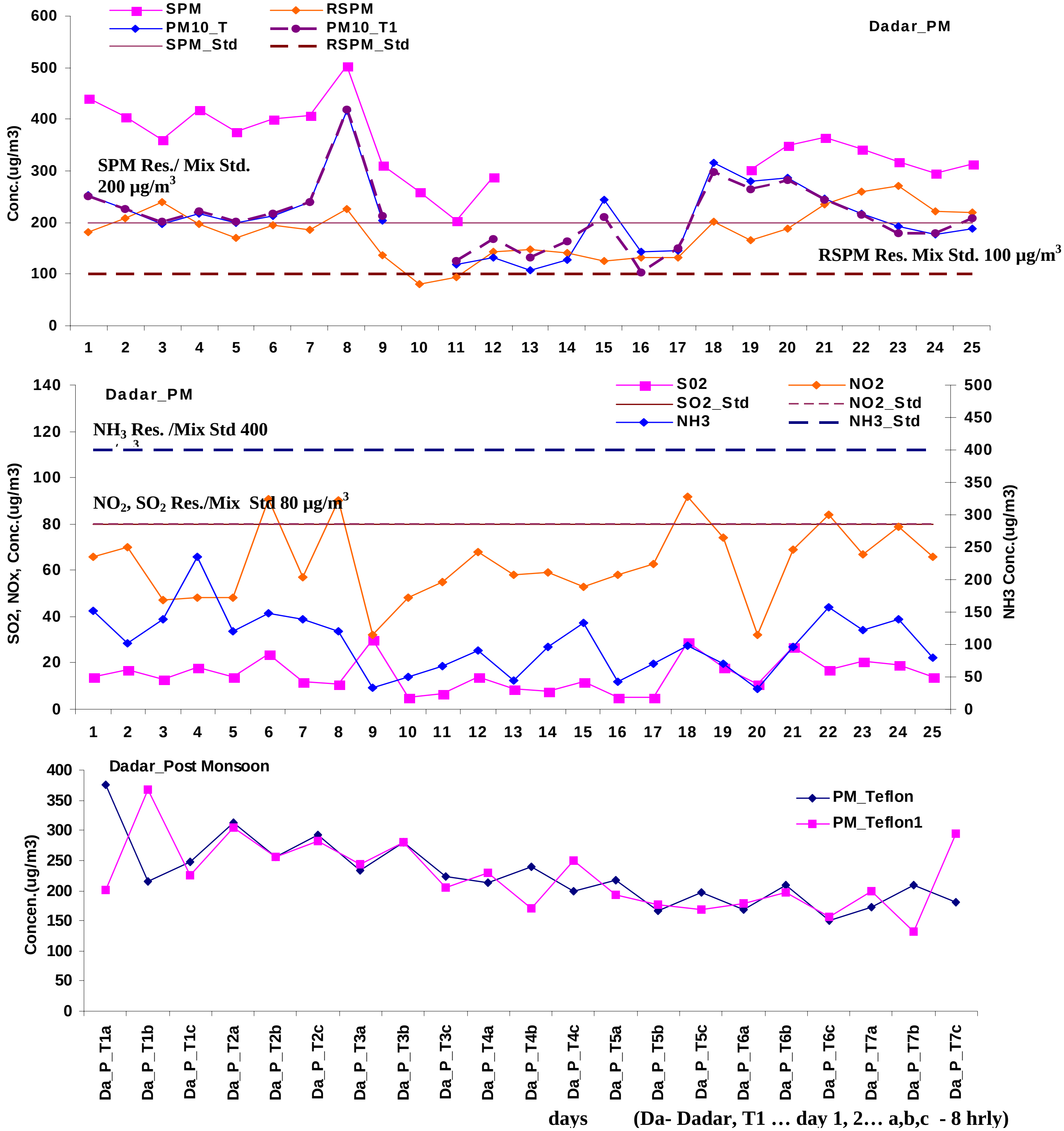


Figure PD.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Dadar During Post Monsoon

Figure PD.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

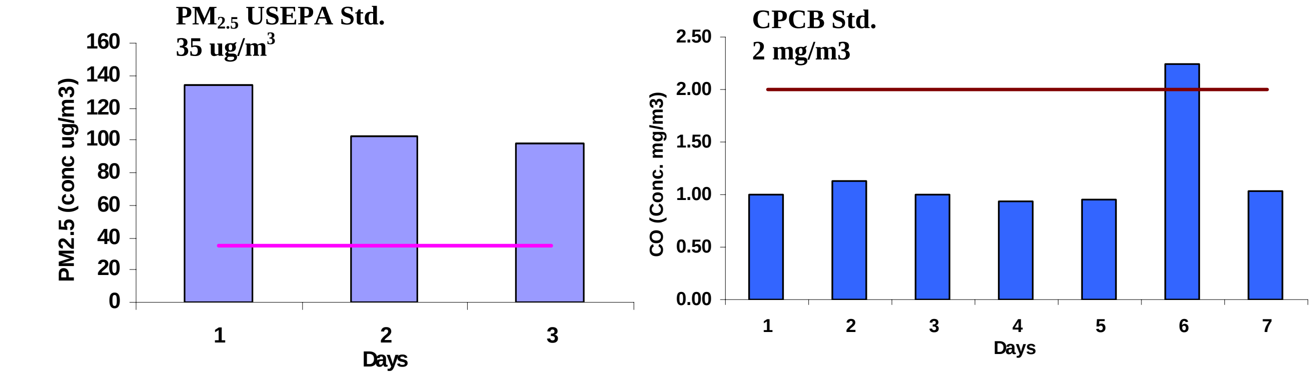


Figure PD2 : Observed Concentrations of $PM_{2.5}$ and CO at Dadar (Post Monsoon)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 µg/m^3 due to the sources like smelting, vehicular exhaust; refuse burning etc which contribute to the fine particulate matter. Automobile exhaust and refuse burning contributes to CO concentration and it exceeded 14.29 % of the times the CPCB standard of 2 µg/m^3 for the residential and mix use area.

Figure PD.3 shows Methane, Non Methane and THC concentrations and **Figure PD.4** shows NO_2 vs NMHC concentrations during post monsoon season.

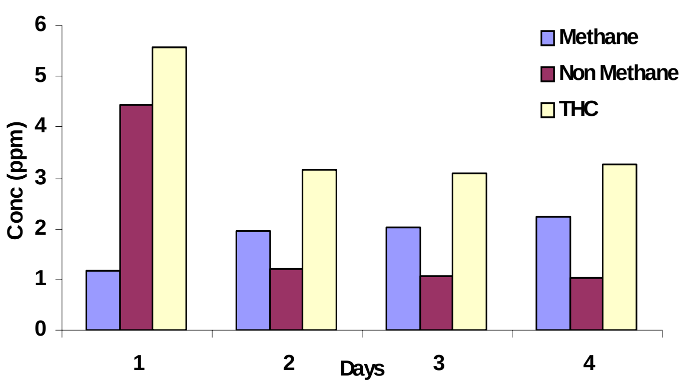


Figure PD.3: Hydrocarbon Concentration.

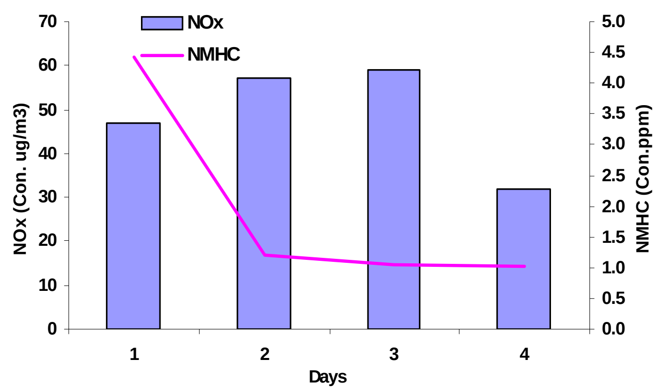


Figure PD.4: NO_2 and NMHC Concentration

Figure PD.5 presents diurnal variation of O_3 and CO during post monsoon.

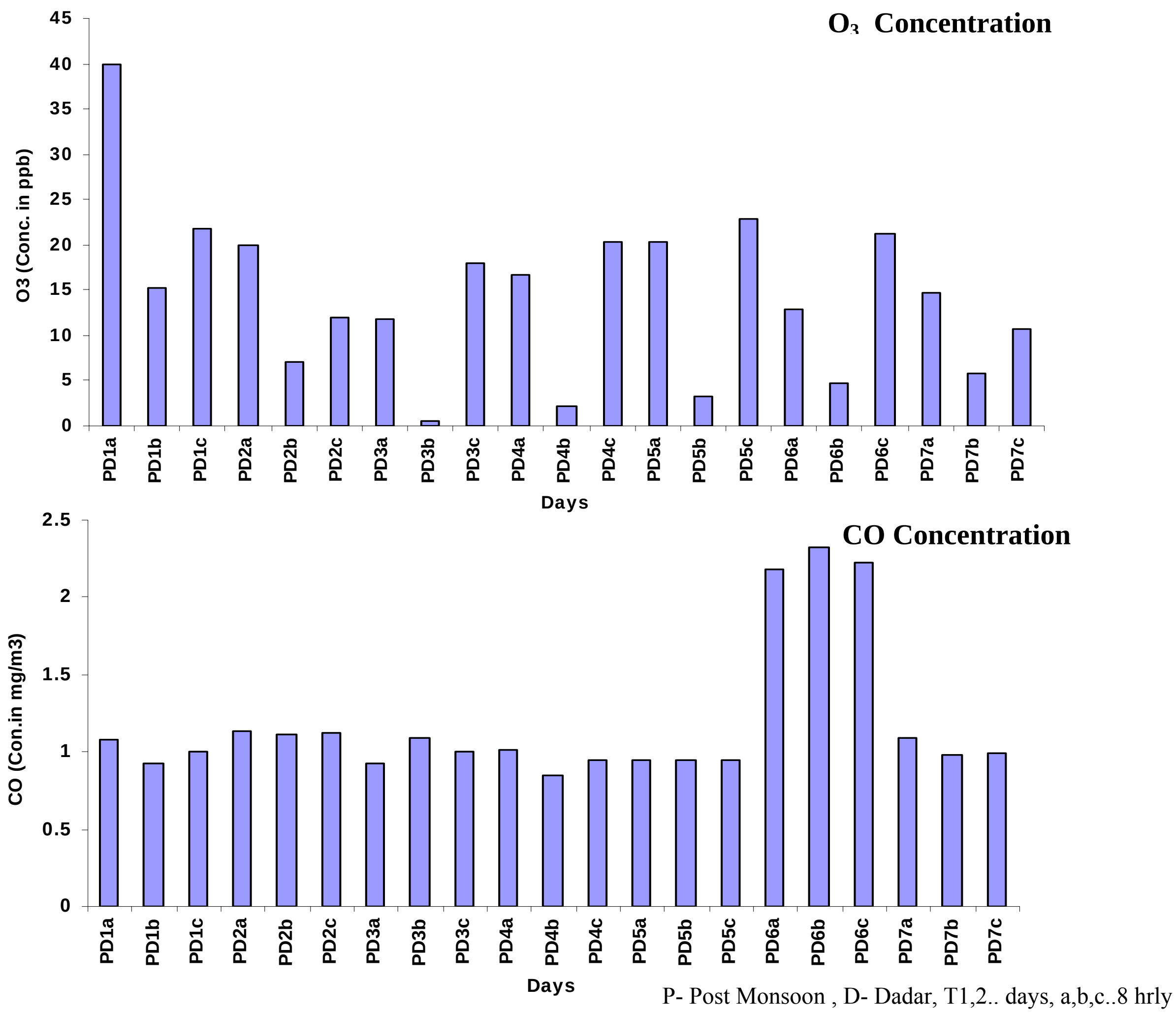


Figure PD.5 : Diurnal variation of O_3 and CO

CO concentration does not show any significant diurnal variation. Ozone showed high concentrations during morning and afternoon hours as these timings have more photochemical activity and vehicular traffic favouring ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PD.6 and PD.7.**

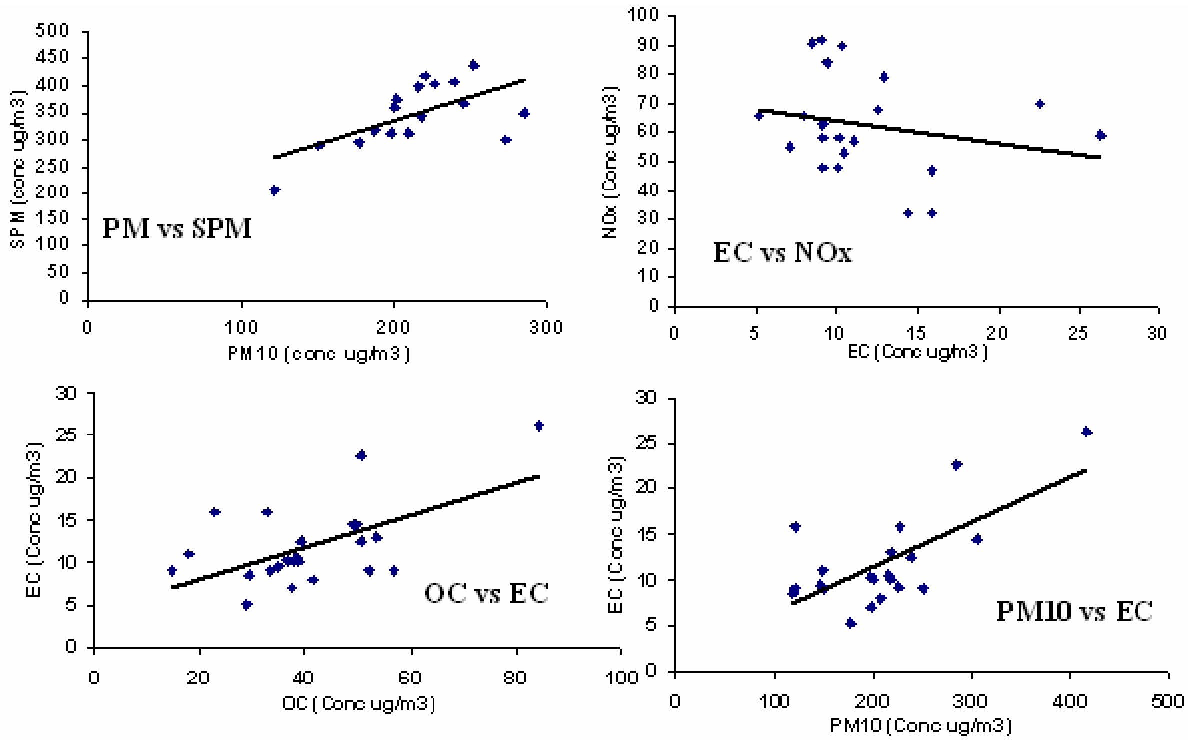


Figure PD.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.62) due to sources like road dust which contributes to coarse particulate matter, automobile exhaust and refuse burning contributing to fine particulate matter. EC and NO_2 show negative correlation indicating that vehicular emission is not the only source for EC. Due to sources like vehicles, refuse burning activities EC and OC show good correlation (R=0.57). PM_{10} and EC show good correlation (R=0.69) indicating that the sources contributing to both PM_{10} and EC are similar i.e. vehicles, refuse burning.

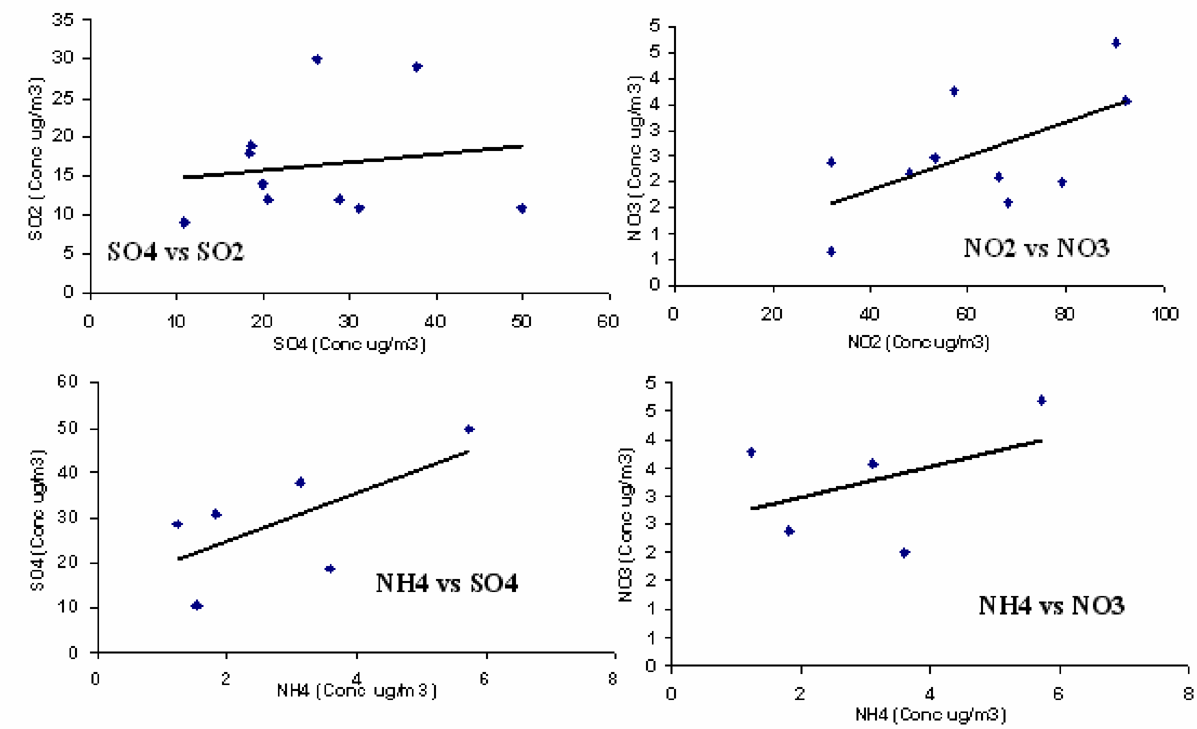


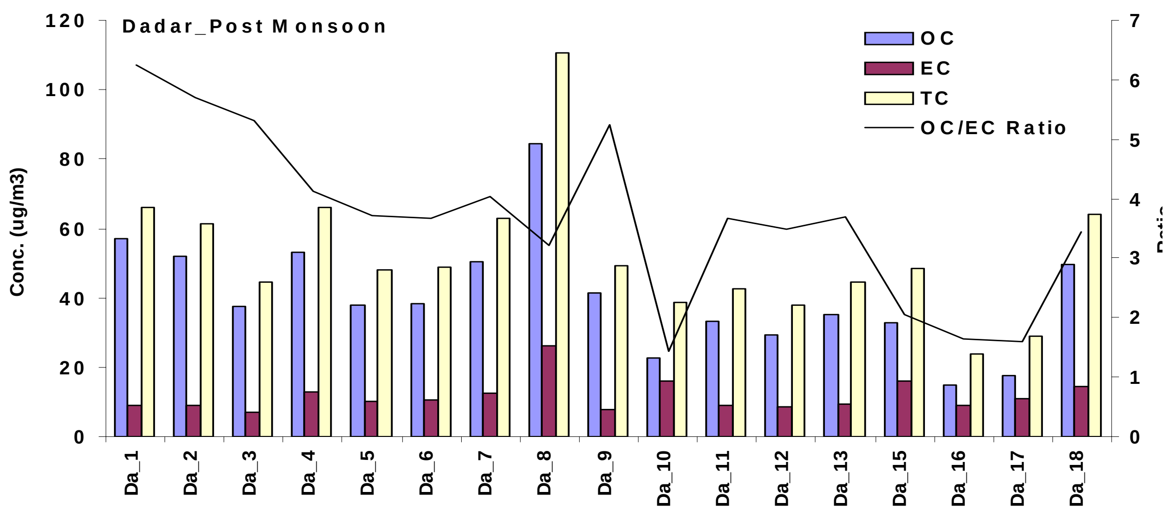
Figure PD.7 : Correlation plots of gaseous pollutant vs ions

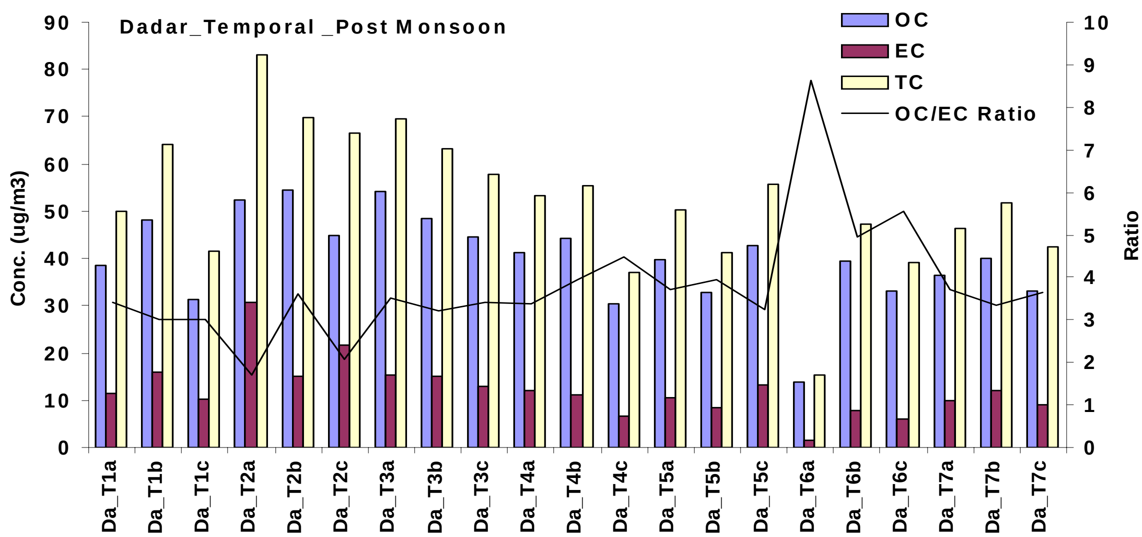
SO_2 and SO_4^{2-} correlate poorly indicating that SO_2 is not getting converted to SO_4^{2-}. NO_2 and NO_3^- show positive correlation (R=0.60) indicating that NO_2 is not getting converted to NO_3^- with a possibility of additional sources. NH_4^+ and SO_4^{2-} show good correlation (R=0.66) indicating that NH_4^+ is neutralizing SO_4^{2-} and resulting in the production of $(NH_4)_2SO_4$. NH_4^+ and NO_3^- show moderate correlation indicating that NH_4^+ is neutralizing NO_3^- and resulting in the formation of NH_4NO_3.

Carbon concentrations at Dadar site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PD.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	**OC**	**EC**	**TC**
PM_{10}	1.000	.882	.685	.909
OC	.882	1.000	.571	.975
EC	.685	.571	1.000	.738
TC	.909	.975	.738	1.000





days (Da- Dadar, T1 … day 1, 2… a,b,c - 8 hrly)

Figure PD.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Dadar Site (Post Monsoon)

At Dadar site OC varied between 14.8-84.4 µg/m^3 with an average value of 40.4 µg/m^3. The EC concentration varied between 5.2-26.3 µg/m^3 with an average value of 11.9 µg/m^3. OC/EC ratio varied from 1.4 to 6.3 with an average ratio of 3.6. Percentage of OC, EC and TC in PM_{10} was 19.0, 5.5 and 24.6 whereas in $PM_{2.5}$ it was 16.5, 9.2 and 25.7 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure PD.9**.

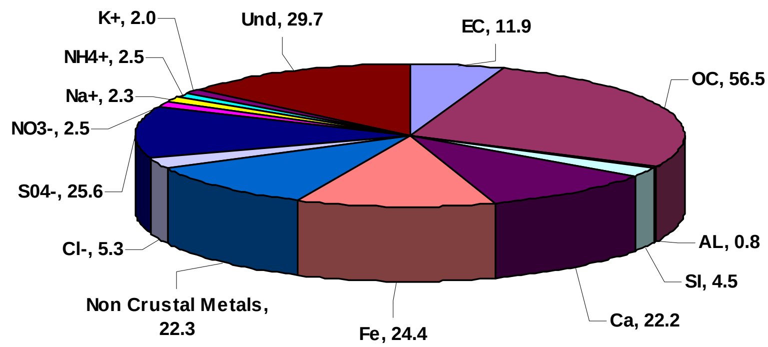


Figure PD.9 : Mass Closure Concentrations (µg/m^3) at Dadar

Percent composition of PM_{10} after mass closure shows that maximum contribution to the total PM_{10} loading is from the carbonaceous fraction. OC and EC account for 26% and 6% respectively and indicate the dominance of contribution by sources like vehicular traffic and refuse burning to PM_{10}. Crustal elements contribute 24% of the particulate matter in the form of sources like road dust. Automobile exhaust contributes to non crustal fraction of the particulate matter which accounts for 11%. The contribution from ionic fraction accounts for 19% of the total loadings. High concentration of SO_4^{2-} is observed due to road dust, automobile exhaust, and secondary aerosols. Sea spray also contributes to ions like Na^+ and Cl^-. 14% of the total fraction is unidentified.

Dharavi Site : The observed concentrations for post monsoon season are presented in **Table PDh.1** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season are presented in **Figure PDh.1**

Table PDh.1 : Air Quality Status at Dharavi (Post monsoon)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	304.0	642.0	501.2	639.6	83.8	25
RSPM (µg/m^3)	101.0	275.0	206.2	269.2	44.8	25
PM_{10} Tef (µg/m^3)*	185.0	315.0	244.6	298.7	29.5	25
PM_{10} Tef_1 (µg/m^3)*	187.0	328.0	244.9	304.0	32.4	25
$PM_{2.5}$ (µg/m^3)**	84.0	96.0	91.3	NA	6.4	3
SO_2 (µg/m^3)	5.0	53.0	15.8	39.1	9.3	25
NO_2 (µg/m^3)	33.0	75.0	53.1	71.2	10.4	25
NH_3 (µg/m^3)	30.0	103.0	64.4	101.6	23.2	25
CO (mg/m^3)	1.4	4.5	3.0	4.4	0.9	7
Formaldehyde (µg/m^3)	34.9	87.5	61.2	NA	37.2	2
CH_4 (ppm)	2.0	2.2	2.1	NA	0.3	4
Nonmethane HC (ppm)	0.8	1.1	1.0	NA	0.1	4
Total HC (ppm)	2.9	3.3	3.1	NA	0.4	4
O_3 (ppb)	21.7	57.5	32.5	54.8	12.1	7
OC (µg/m^3)	19.7	71.7	52.7	70.1	14.9	25
EC (µg/m^3)	4.4	26.9	8.4	21.9	5.1	25
TC (µg/m^3)..	24.4	87.4	61.1	86.8	17.3	25

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM at Dharavi exceeded all the times of CPCB residential mixed standard of 200 µg/m^3 and 100 µg/m^3 respectively, as site being slum residential having unauthorized industrial units along with unpaved roads contribute to high particulate matter. The ratio of RSPM to SPM was 41% and in case of $PM_{2.5}$ to PM_{10} it was 37%. The 24 hourly average concentrations of SO_2, NO_2, and NH_3 were within CPCB limits during the sampling period. The monthly average of PM_{10} was 244.7 µg/m^3. No specific in temporal trends observed in the PM_{10} concentrations. RSPM correlate fairly with SPM and PM, and moderately with NO_2. CO values ranged between 1.45-4.50 mg/m^3, formaldehyde ranged between 34.9-87.5 µg/m^3. Total Hydrocarbon ranged between 2.9-3.3 ppm whereas Ozone values ranged between 21.7-57.5 ppb.

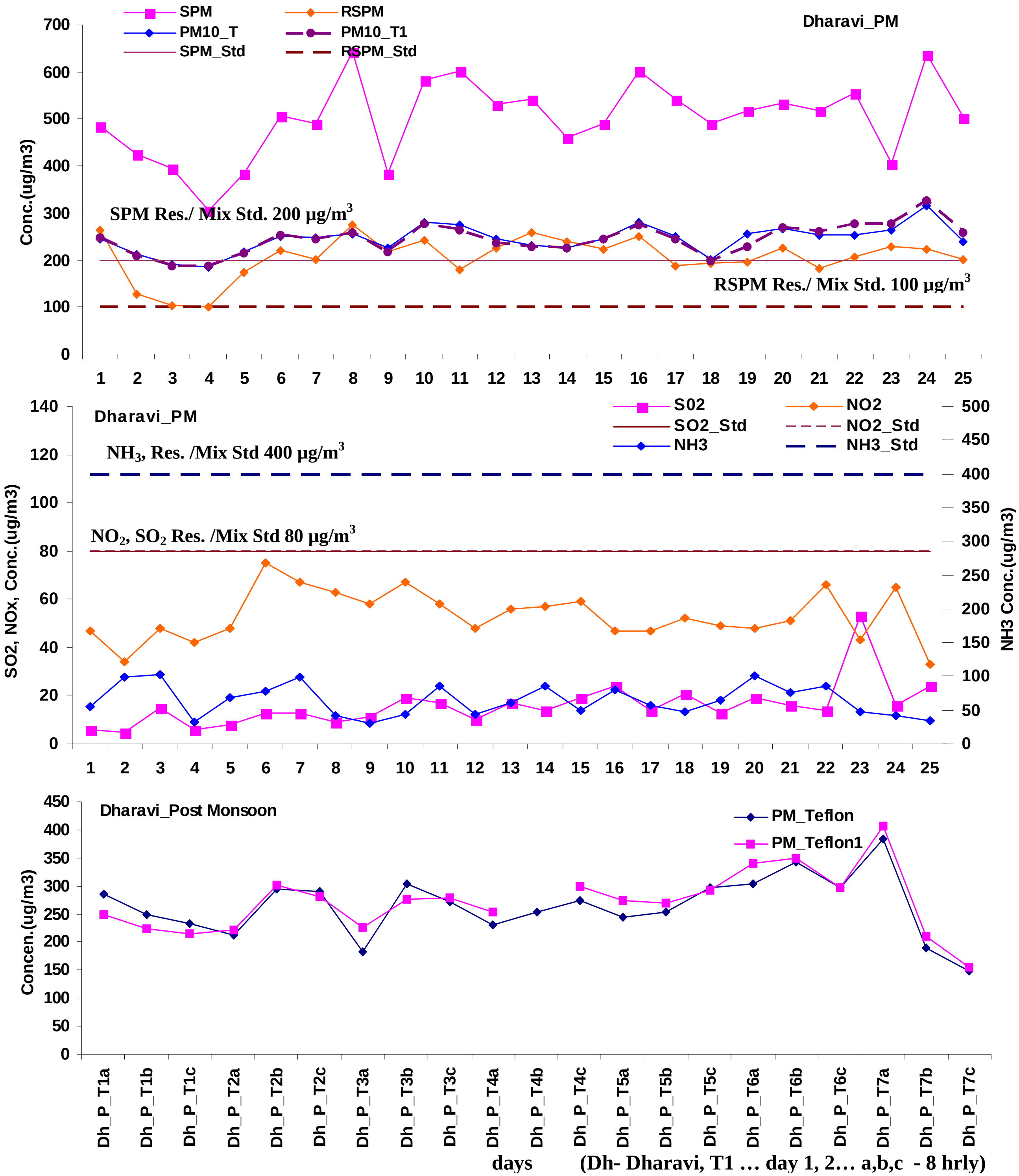


Figure PDh.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Dharavi During Post Monsoon

Figure PDh.2 shows the variation of $PM_{2.5}$ and CO during the summer period.

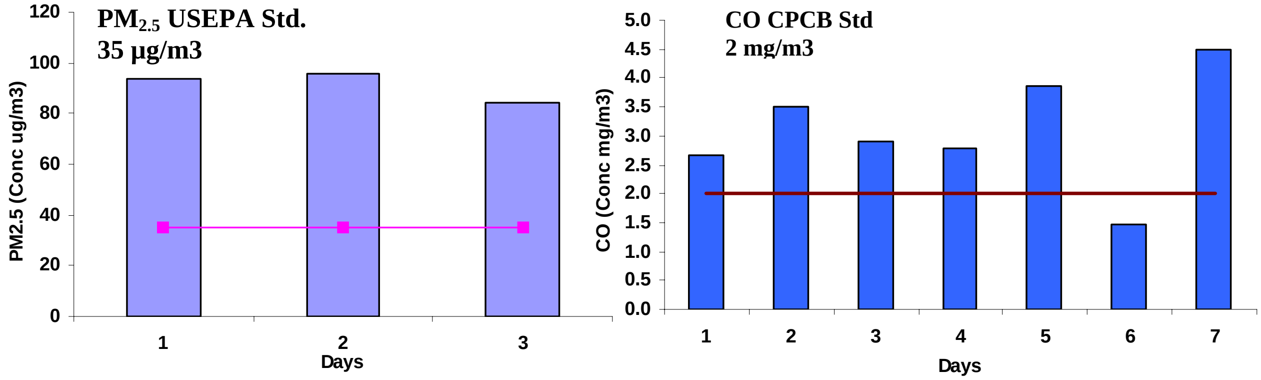


Figure PDh.2 : Observed Concentrations of $PM_{2.5}$ and CO at Dharavi (Post Monsoon)

High concentration of $PM_{2.5}$ is observed due to smelting operations, biomass burning, oil burning etc and it exceeds all the time the US EPA standard of 35 µg/m^3. The CO concentration during the sampling period was exceeding 87.5 of the times the limits of the CPCB standard of 2 µg/m^3 for the residential and mix use area due to biomass burning and vehicular exhaust

Figure PDh.3 shows Methane, Non Methane and THC concentrations and **Figure PDh.4** shows NO_2 vs NMHC concentrations during post monsoon season

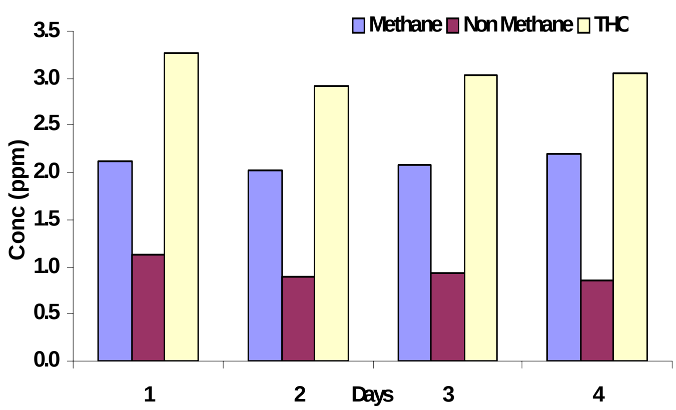


Figure PDh.3: Hydrocarbon Concentration.

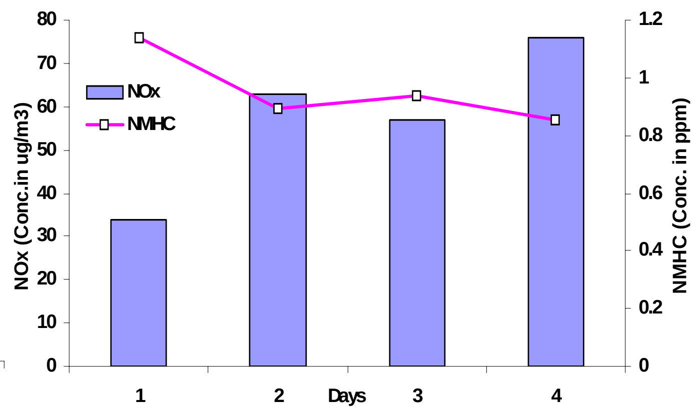
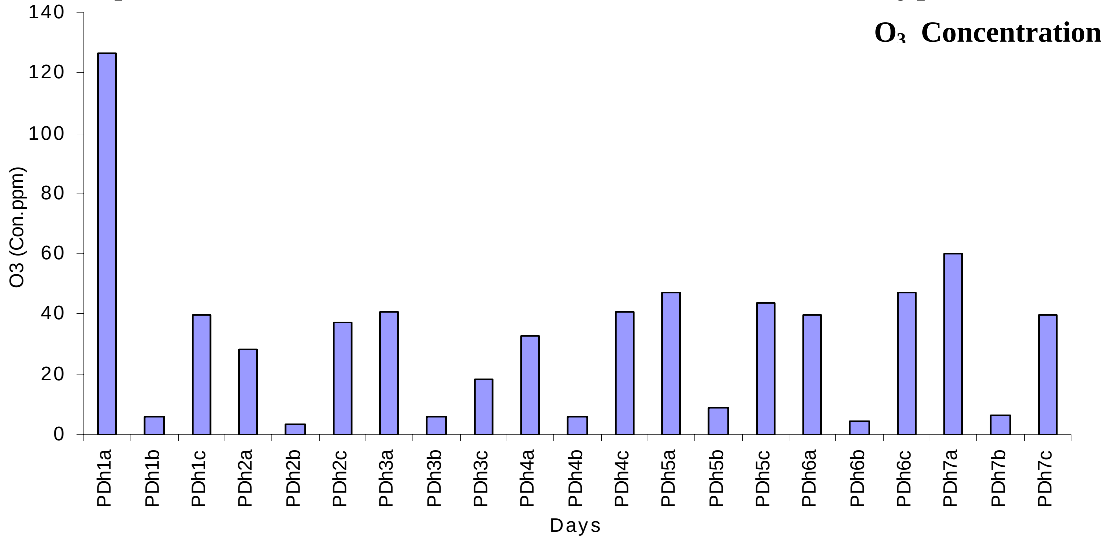
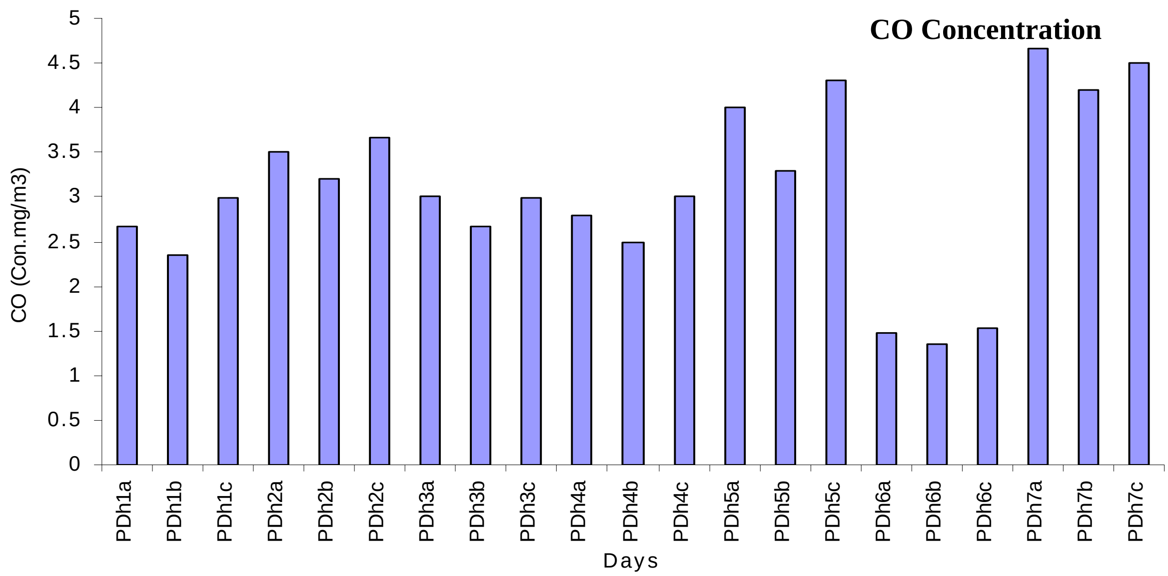


Figure PDh.4: NO_2 and NMHC Concentration

Figure PDh.5 presents diurnal variation of O_3 and CO concentrations during post monsoon.





P- Post Monsoon , Dh- Dharavi, T1,2.. days, a,b,c..8 hrly

Figure PDh.5 : Diurnal variation of O_3 and CO

No significant is seen in diurnal variation in CO, but higher concentration during morning hours due to vehicular traffic and biomass burning. Diurnal variation in ozone showed high concentrations 57.5 ppb and low concentration of 21.7 ppb.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PDh.6 and PDh.7.**

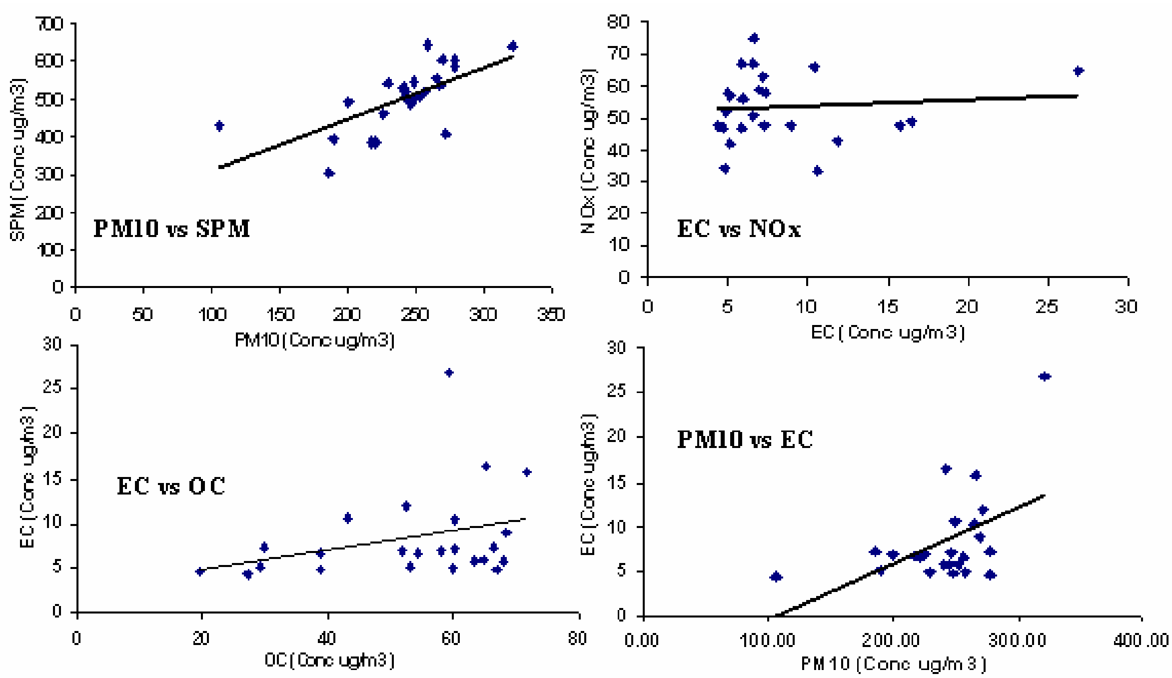


Figure PDh.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.67) due to sources like soil which contributes to coarse particulate matter and smelting, biomass burning and oil burning contributing to fine particulate matter. EC and NO_2 correlate very poorly indicating that vehicular emission is not the only source for EC. EC and OC show poor correlation indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC: EC is 7.3; there may be formation of secondary organic carbon aerosols. PM_{10} and EC show good correlation (R= 0.51) indicating that the sources contributing to PM_{10} and EC are same.

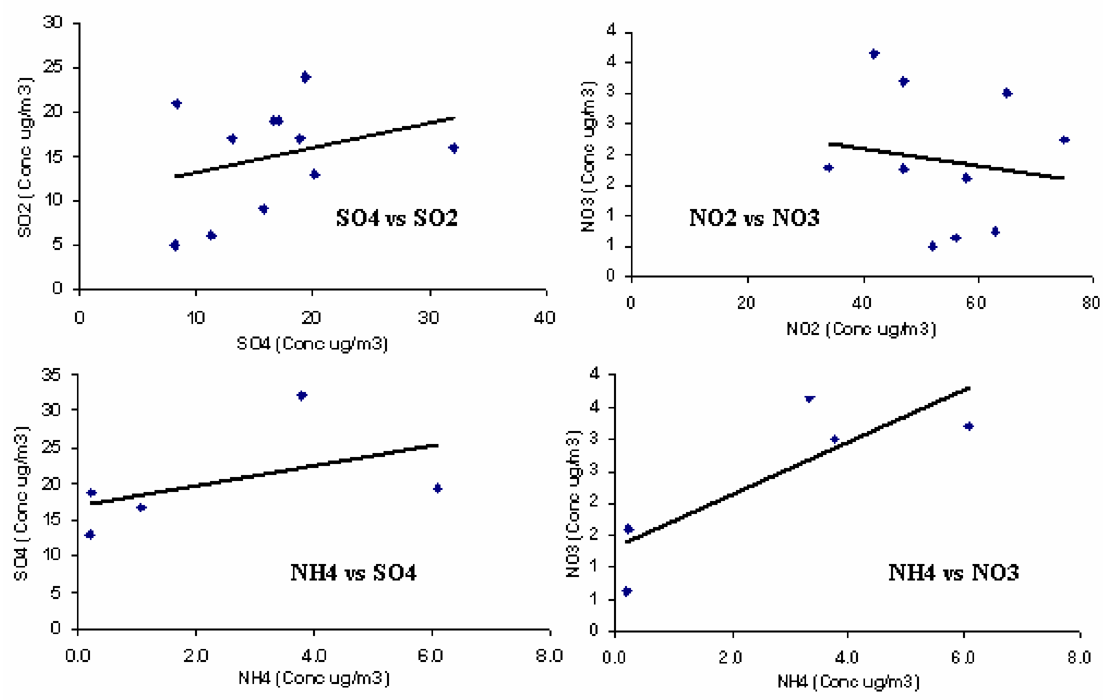


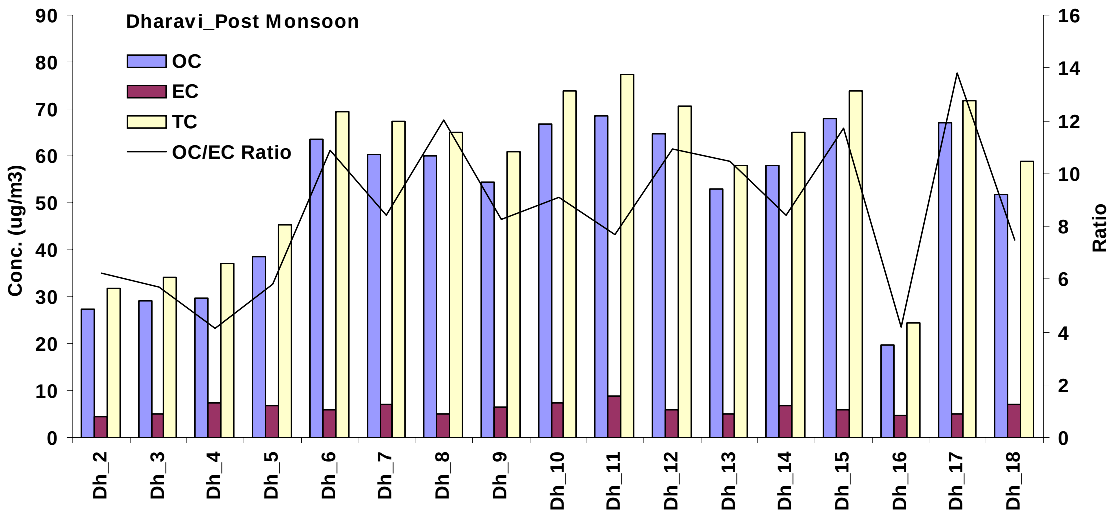
Figure PDh.7 : Correlation plots of gaseous pollutant vs ions

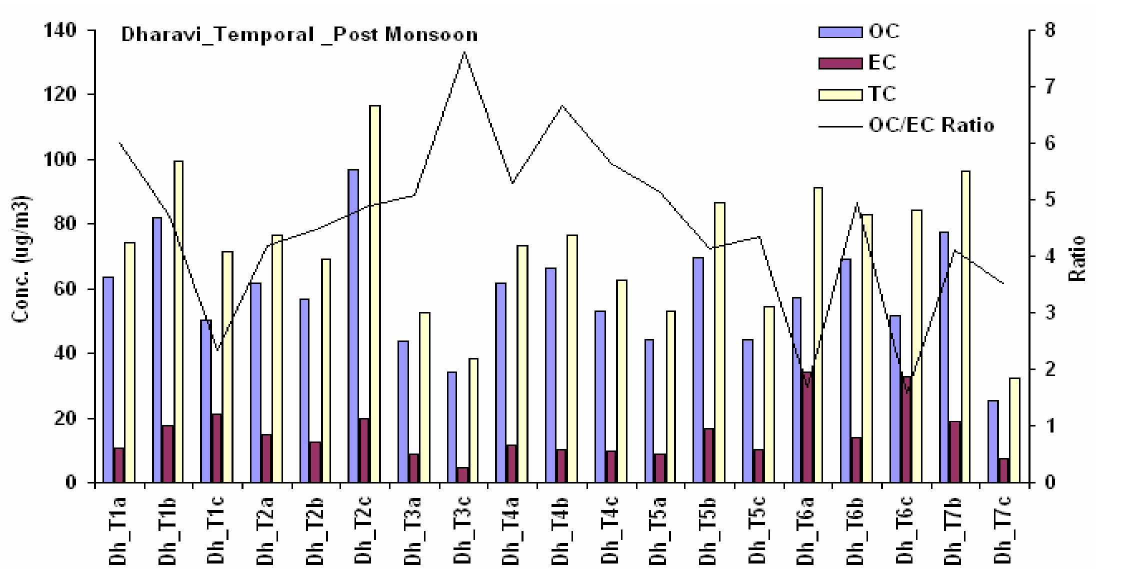
SO_2 and SO_4^{2-} correlate poorly indicating that SO_2 is not getting converted to SO_4^{2-} and activities like biomass burning and secondary aerosols are contributing to the formation of SO_4^{2-}. NO_2 and NO_3^- show poor negative correlation indicating that NO_2 is very rarely getting converted to NO_3^- and it is mainly coming from sources like biomass burning and other sources. NH_4^+ and SO_4^{2-} show moderate correlation (R=0.49) indicating that NH_4^+ is neutralizing SO_4^{2-} and resulting in the formation of $(NH_4)_2SO_4$. NH_4^+ and NO_3^- also show very good correlation (R=0.83) indicating that NH_4^+ is neutralizing NO_3^- and NH_4NO_3 is being formed.

Carbon concentrations at Dharavi site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PDh.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.505	.514	.591
OC	.505	1.000	.303	.960
EC	.514	.303	1.000	.558
	.591	.960	.558	1.000





days (Dh-Dharavi, T1 … day 1, 2… a,b,c - 8 hrly)

Figure PDh.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Dharavi Site (Post Monsoon)

At Dharavi site OC varied between 19.7-71.7 µg/m^3 with an average value of 52.7 µg/m^3. The EC concentration varied between 4.4-26.9 µg/m^3 with an average value of 8.4 µg/m^3. OC/EC ratio varied from 2.2 to 13.8 with an average ratio of 7.3. Percentage of OC, EC and TC in PM_{10} was 21.9, 3.5 and 25.4 whereas in $PM_{2.5}$ it was 29.4, 14.0 and 43.2 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (µg/m^3) in PM_{10} is presented in **Figure PDh.9.**

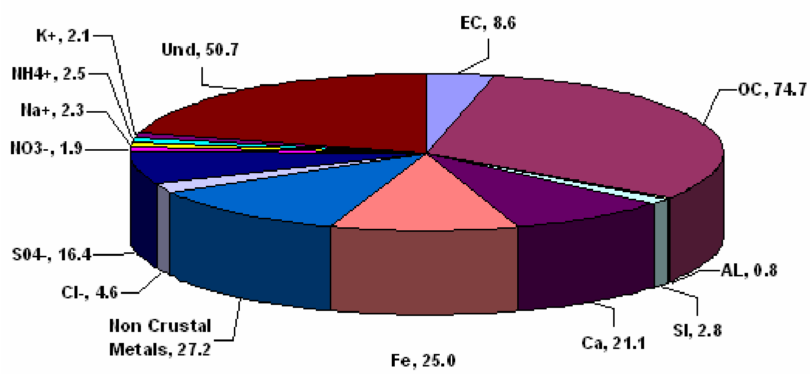


Figure PDh.9 : Mass Closure Concentrations at Dharavi

Percent composition of PM_{10} after mass closure indicates that maximum contribution is from carbonaceous fractions. OC and EC contribution accounts for 31% and 4% respectively as the sources contributing to OC and EC like biomass burning, coal combustion, oil burning and vehicles are predominant in this area. Crustal elements due to soil account for 21% of the total PM_{10} load whereas smelting, coal combustion etc contributes to non-crustal component, which accounts for 11% of the total particulate matter. The contribution from ionic fraction accounts for 12% of the total loadings. High concentration of SO_4^{2-} is observed due to biomass burning, coal combustion, oil burning, secondary aerosols and vehicles. Sea spray also contributes to ions like Na^+ and Cl^-. Source for NH_4^+ is vehicles and oil burning; whereas biomass burning emits potassium. 21% of the total particulate matter fraction is unidentified.

Khar Site : The observed concentrations for post monsoon season are presented in **Table PK.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season are presented in **Figures PK.1.**

Table PK.1 : Air Quality Status at Khar (Post monsoon)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	276.0	588.0	399.6	544.5	72.4	30
RSPM (µg/m^3)	137.0	296.0	210.0	279.8	40.2	30
PM_{10} Tef (µg/m^3)*	120.0	293.0	226.1	291.8	46.2	30
PM_{10} Tef_1 (µg/m^3)*	118.0	320.0	231.4	314.8	48.8	30
$PM_{2.5}$ (µg/m^3)**	66.0	107.0	83.0	NA	21.4	3
SO_2 (µg/m^3)	4.0	23.0	11.4	22.4	5.1	29
NO_2 (µg/m^3)	31.0	94.0	66.3	91.2	13.9	29
NH_3 (µg/m^3)	24.0	70.0	45.7	66.1	11.7	29
CO (mg/m^3)	0.6	5.3	1.4	4.7	1.6	8
Formaldehyde (µg/m^3)	51.0	58.5	54.8	NA	5.3	2
CH_4 (ppm)	1.0	1.6	1.3	NA	0.3	4
Nonmethane HC (ppm)	0.2	0.5	0.3	NA	0.2	4
Total HC (ppm)	1.5	2.0	1.8	NA	0.2	4
O_3 (ppb)	8.1	14.6	11.3	14.4	2.5	6
OC (µg/m^3)	3.4	79.0	43.4	72.1	19.8	28
EC (µg/m^3)	0.5	25.1	9.2	23.7	5.9	28
TC (µg/m^3)..	3.9	86.3	52.6	79.9	22.8	28

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM at Khar exceeded all the times of CPCB residential mixed standard of 200 µg/m^3 and 100 µg/m^3 respectively. The ratio of RSPM to SPM was 52% and $PM_{2.5}$ to PM_{10} was 36% indicating dominance of coarse fraction . The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 14% of the time than the CPCB standard. The monthly average of PM_{10} was 228.75 µg/m^3. Temporal trends of PM_{10} shows concentrations were high at morning time. CO values ranged between 0.6-5.3 mg/m^3, formaldehyde ranged between 51.0-58.5 µg/m^3, Total Hydrocarbon ranged between 1.5-2.0 ppm whereas Ozone values ranged between 8.1-14.6 ppb.

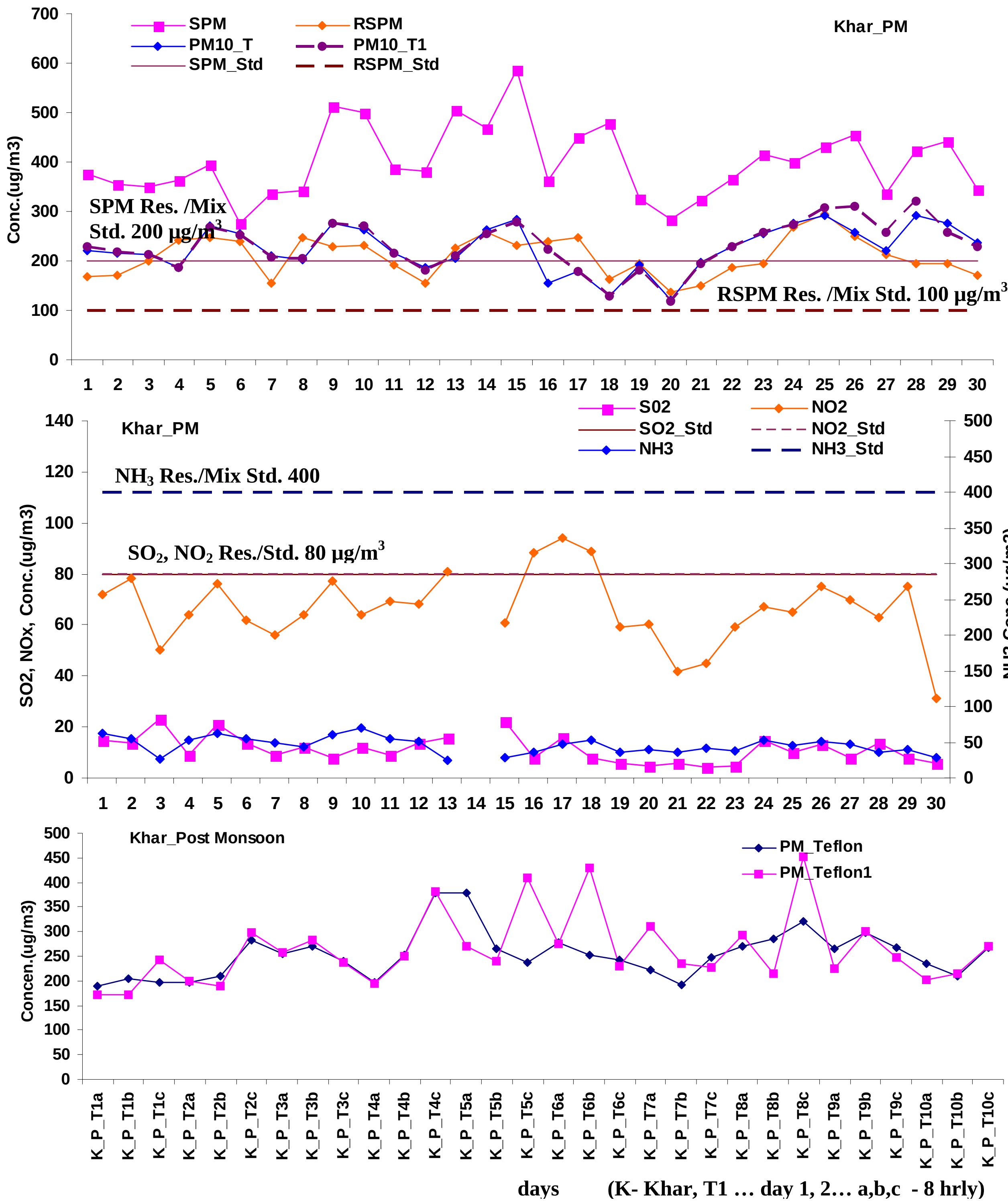
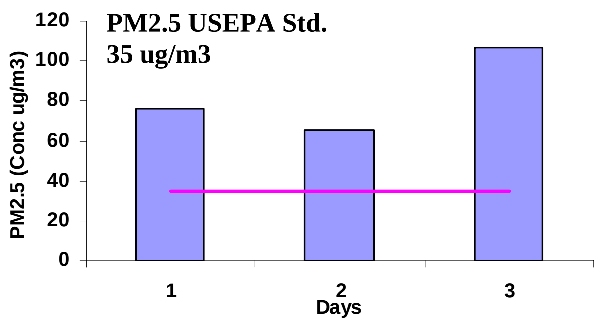


Figure PK.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Khar During Post Monsoon

Figure PK.2 shows the variation of $PM_{2.5}$ and CO during the post monsoon period.



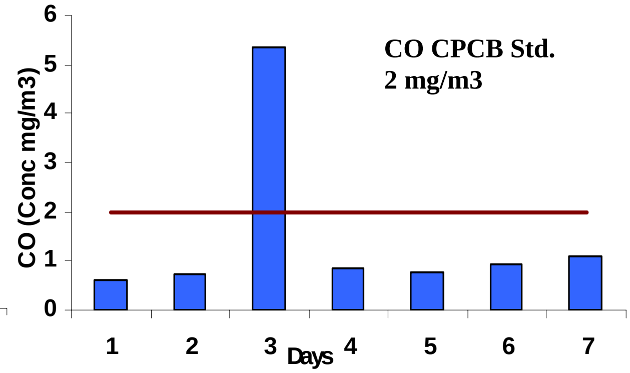


Figure PK.2 : Observed Concentrations of $PM_{2.5}$ and CO at Khar (Post Monsoon)

The concentration of $PM_{2.5}$ exceeded all the time the limits of US EPA standard of 35 µg/m^3 due to the sources such as vehicles and biomass burning which contribute to fine particulate matter. The CO concentration during the sampling period was exceeding 14% of the times of the CPCB standard of 2 mg/m^3 for the residential and mix use area.

Figure PK.3 shows Methane, Non Methane and THC concentrations and **Figure PK.4** shows NO_2 vs NMHC concentrations during post monsoon.

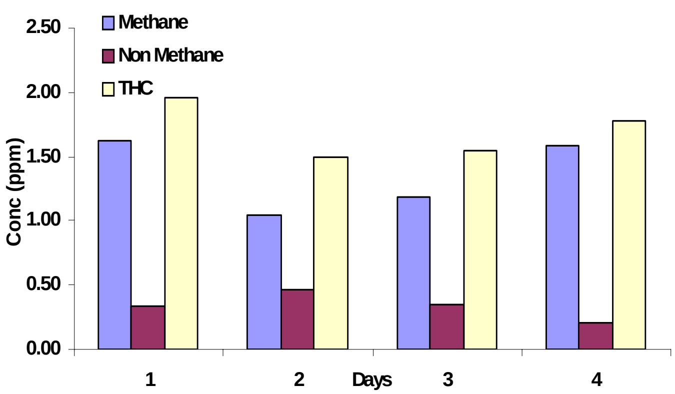


Figure PK.3: Hydrocarbon Concentration.

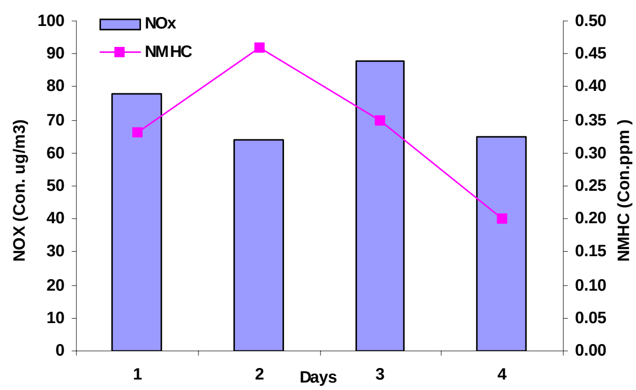


Figure PK.4: NO_2 and NMHC Concentration

Figure PK.5 presents diurnal variation of O_3 and CO during post monsoon at Khar.

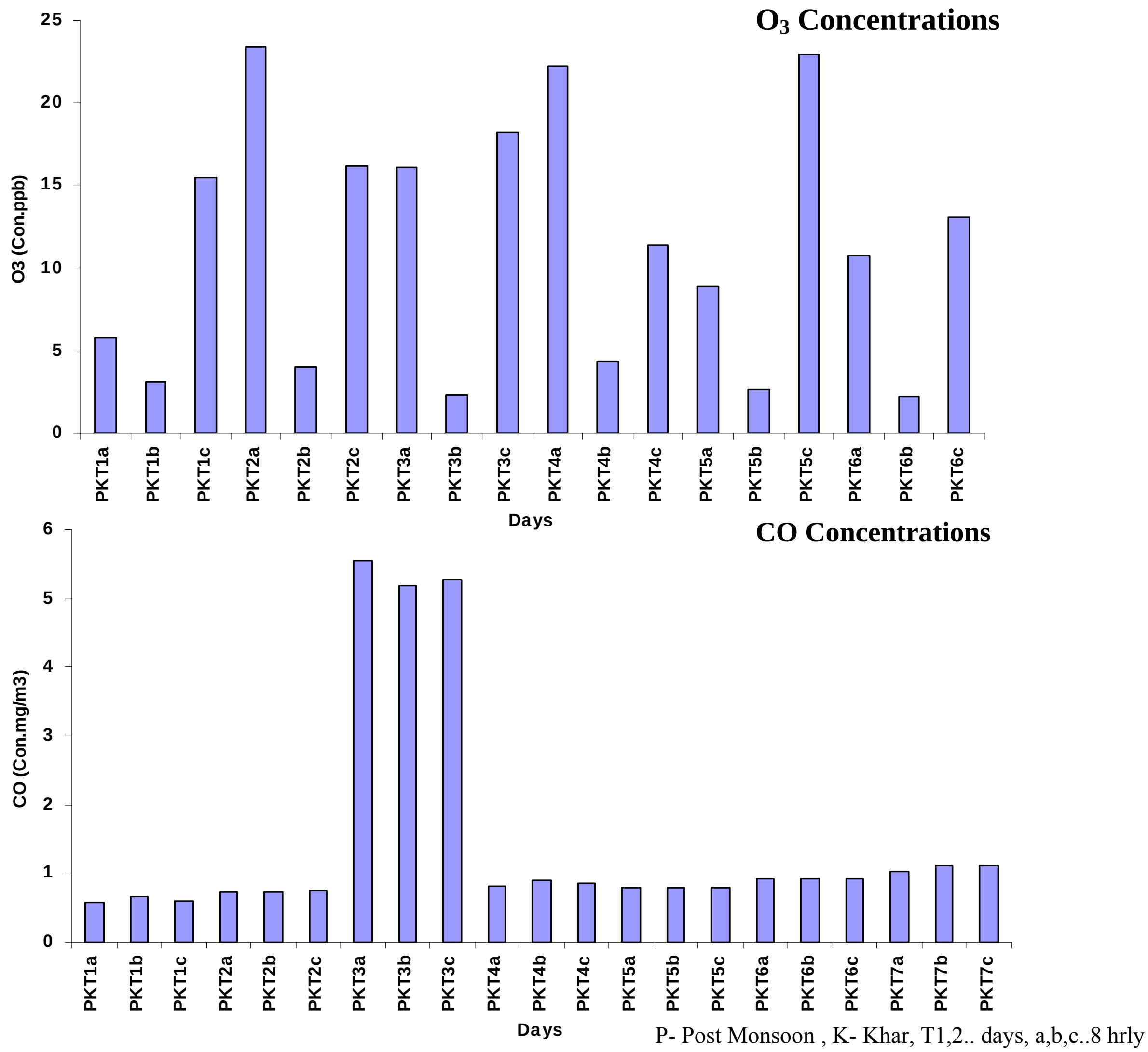


Figure PK.5: Diurnal variation of O3 and CO

Diurnal variation in CO shows no particular trend. Diurnal variation in ozone shows high values in morning and afternoon hours as these timings have high vehicular traffic and photochemical activity favouring the ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PK.6 and PK.7**.

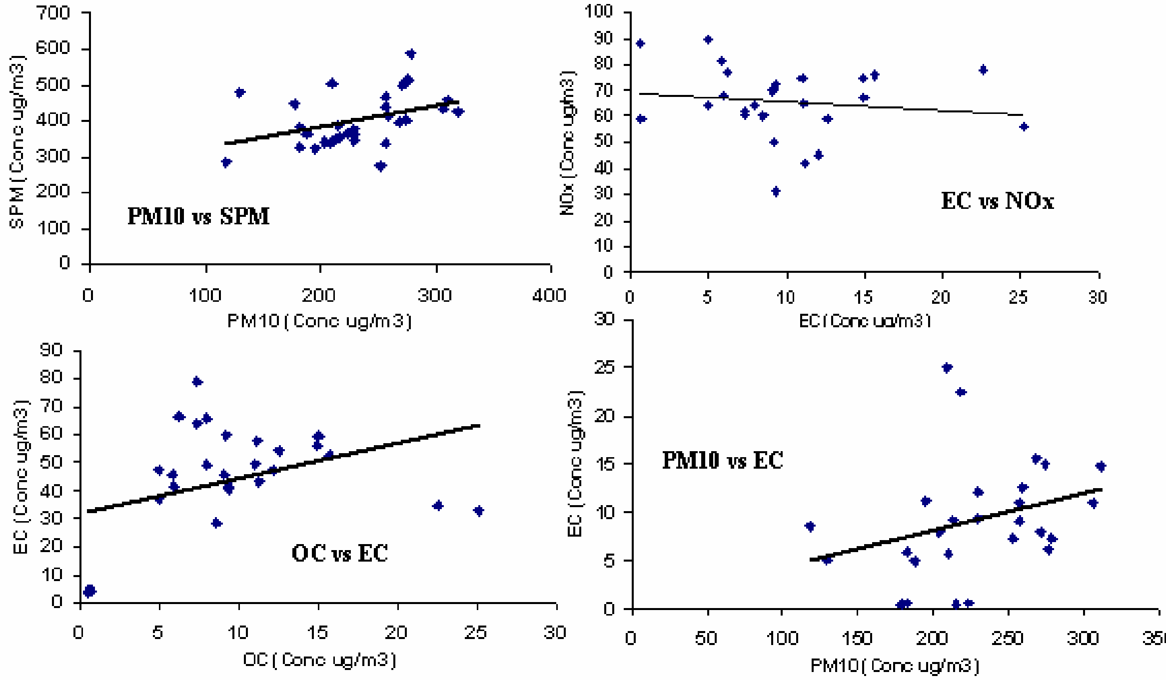


Figure PK.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show poor correlation indicating that PM_{10} and SPM are emitted from different sources. EC and NO_2 show poor negative correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show poor correlation indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC: EC is 5.8, there may be formation of secondary organic carbon aerosols. Correlation coefficient for PM_{10} and EC is 0.31 indicating that sources for PM_{10} and EC are different.

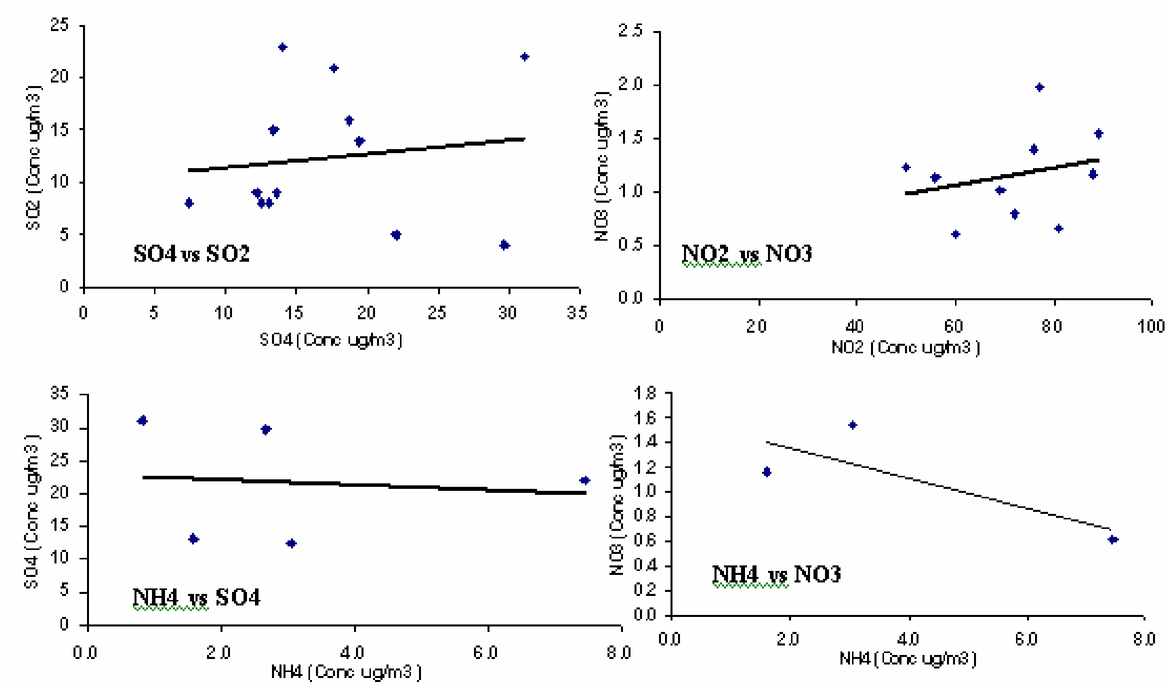


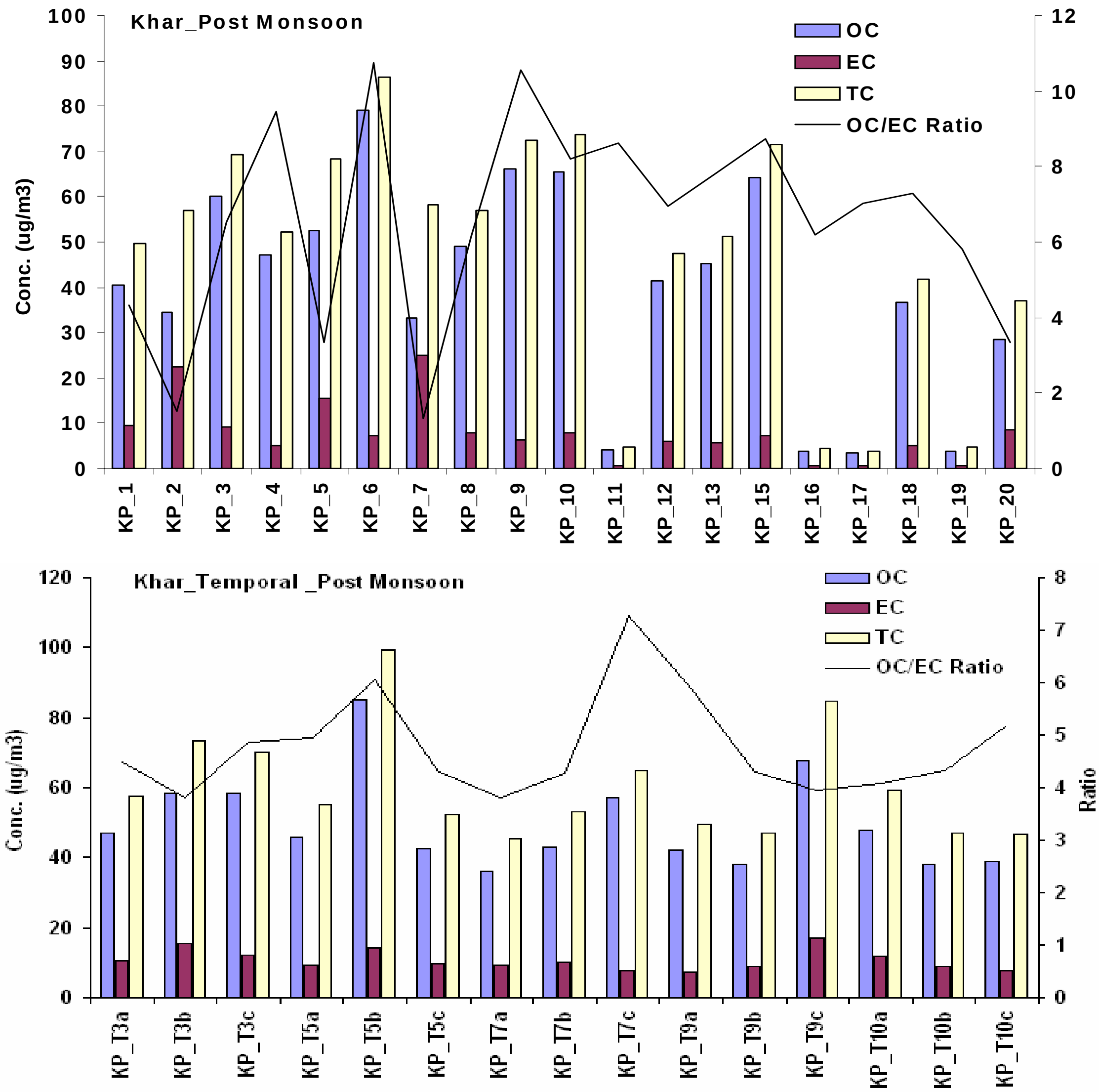
Figure PK.7 : Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show poor correlation indicating that SO_2 is not getting converted to SO_4^{2-} as also NO_2 and NO_3^- correlate poorly indicating that NO_2 is not getting converted to NO_3^-. NH_4^+ and SO_4^{2-} show poor correlation indicating that NH_4^+ is not neutralizing SO_4^{2-}. NH_4^+ and NO_3^- show negative correlation indicating that NH_4^+ is not neutralizing NO_3^-.

Carbon concentrations at Khar site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PK.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.573	.312	.581
OC	.573	1.000	.381	.971
EC	.312	.381	1.000	.592
TC	.581	.971	.592	1.000



days (K- Khar, T1 … day 1, 2… a,b,c - 8 hrly)

Figure PK.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Khar Site (Post Monsoon)

At Khar site OC varied between 3.4-79.0 µg/m^3 with an average value of 43.4 µg/m^3. The EC concentration varied between 0.5-25.1 µg/m^3 with an average value of 9.2 µg/m^3. OC/EC ratio varied from 1.3 to 10.8 with an average ratio of 5.8. Percentage of OC, EC and TC in PM_{10} was 18.9, 4.0 and 23.0 whereas in $PM_{2.5}$ it was 41.8 14.6 and 56.4 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure PK.9.**

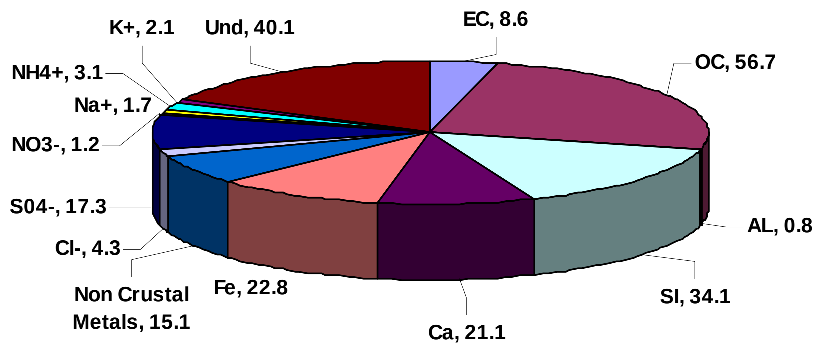


Figure PK.9 : Mass Closure Concentrations (µg/m^3) at Khar

Percent composition of PM_{10} after mass closure show that maximum contribution is from crustal elements due to sources of PM_{10}, such as soil, road dust. OC and EC account for 25% and 4% respectively and thus indicate the contribution from sources like automobile exhaust and biomass burning. Ions account for 13% of the total particulate matter. High concentration of SO_4^{2-} is probably due to secondary aerosols, vehicles. Other ions like Cl^- and Na^+ are released from sea spray, NH_4^+ is emitted from vehicles and the source of K is biomass burning. NO_3^- is mainly coming from vehicles and secondary aerosols. Non-crustal elements account for 7% of the total particulate matter indicating the contribution from vehicles, smelting and biomass burning. 18 % of the total PM_{10} is unidentified.

Andheri Site: The observed concentrations for post monsoon season are presented in **Table PA.1**. The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season at Andheri are presented in **Figure PA.1**

Table PA.1 : Air Quality Status at Andheri (Post monsoon)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM ($\mu g/m^3$)	253.0	742.0	398.6	616.7	86.8	25
RSPM ($\mu g/m^3$)	160.0	356.0	241.1	347.8	51.5	25
PM_{10} Tef ($\mu g/m^3$)*	170.0	285.0	220.5	279.5	30.4	24
PM_{10} Tef_1 ($\mu g/m^3$)*	177.0	289.0	226.3	283.5	35.5	24
$PM_{2.5}$ ($\mu g/m^3$)**	84.0	113.0	98.7	NA	14.5	3
SO_2 ($\mu g/m^3$)	5.0	34.0	13.5	28.5	6.5	24
NO_2 ($\mu g/m^3$)	57.0	97.0	78.9	96.1	11.2	24
NH_3 ($\mu g/m^3$)	16.0	82.0	46.4	76.9	15.4	24
CO (mg/m^3)	0.8	4.9	1.7	4.5	1.4	7
Formaldehyde ($\mu g/m^3$)	28.6	31.0	29.8	NA	1.7	2
CH_4 (ppm)	1.3	1.8	1.5	NA	0.3	4
Nonmethane HC (ppm)	0.3	1.1	0.7	NA	0.3	4
Total HC (ppm)	1.9	2.4	2.3	NA	0.5	4
OC ($\mu g/m^3$)	26.3	74.4	48.9	70.3	11.4	24
EC ($\mu g/m^3$)	6.2	31.9	12.7	28.2	6.1	24
TC ($\mu g/m^3$)..	44.5	81.0	62.0	80.0	10.4	24

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM at Andheri exceeded 84% the times of CPCB residential mixed standard of 200 $\mu g/m^3$ and 100 $\mu g/m^3$ respectively, as site being kerb site. The ratio of RSPM to SPM was 60% and $PM_{2.5}$ to PM_{10} was 44% indicating dominance of fine particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 42% of the time than the CPCB standard. The monthly average of PM_{10} was 223.4 $\mu g/m^3$. Temporal trends of PM_{10} shows concentrations were high at night time. CO values ranged between 0.8-4.9 mg/m^3, formaldehyde ranged between 28.6-31.0 $\mu g/m^3$, Total Hydrocarbon ranged between 1.9-2.4 ppm.

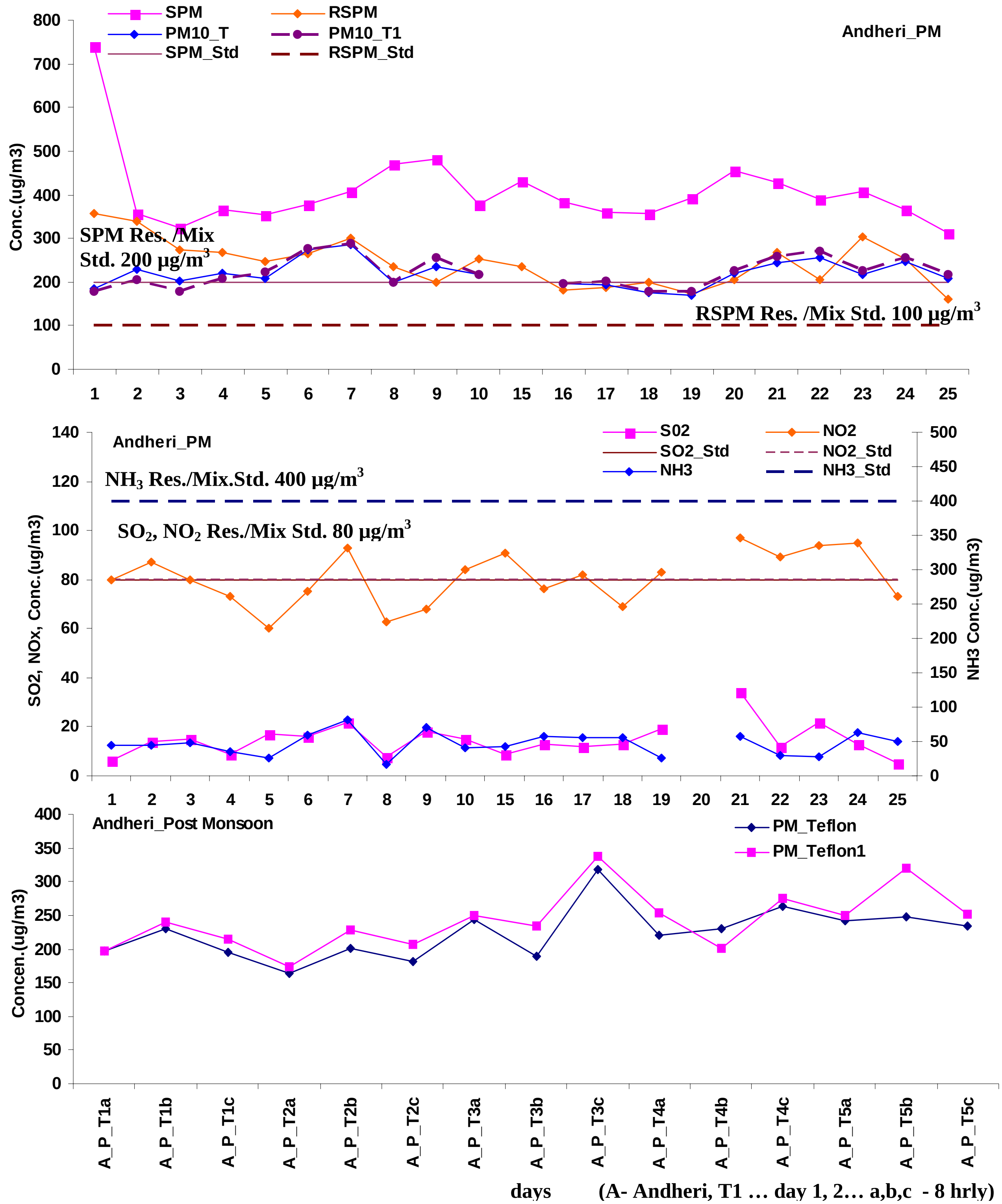
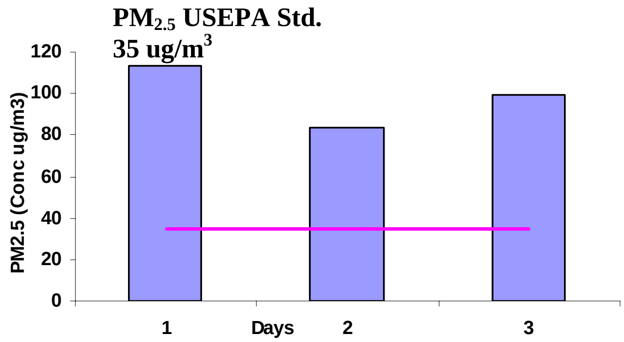


Figure PA.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Andheri During Post Monsoon

* High value at particular day indicates outlier due to certain site specific activity.

Figure PA.2 shows the variation of $PM_{2.5}$ and CO during the post monsoon period.



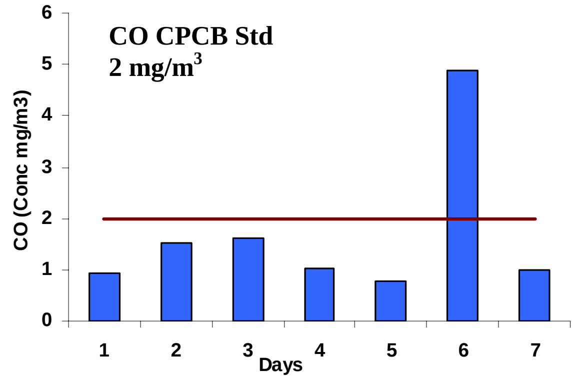


Figure PA.2: Observed Concentrations of $PM_{2.5}$ and CO at Andheri (Post Monsoon)

The concentration of $PM_{2.5}$ exceeded the US EPA standard of 35 µg/m^3 all the time due to the sources such as vehicles, coal burning, biomass burning and oil burning which contribute to fine particulate matter. The CO concentration during the sampling period was exceeding 14% of the time the limits of the CPCB standard of 2 mg/m^3 for the residential and mix use area due to vehicular exhaust and biomass burning.

Figure PA.3 shows Methane, Non Methane and THC concentrations and **Figure PA.4** shows NO_2 vs NMHC concentrations during post monsoon. Ozone could not be analyzed during post monsoon season.

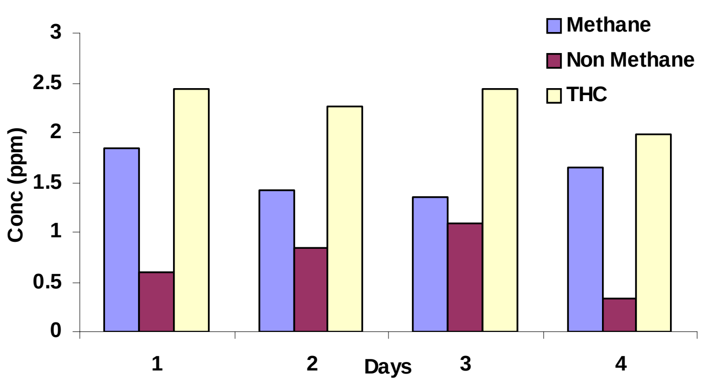


Figure PA.3 : Hydrocarbon Concentration

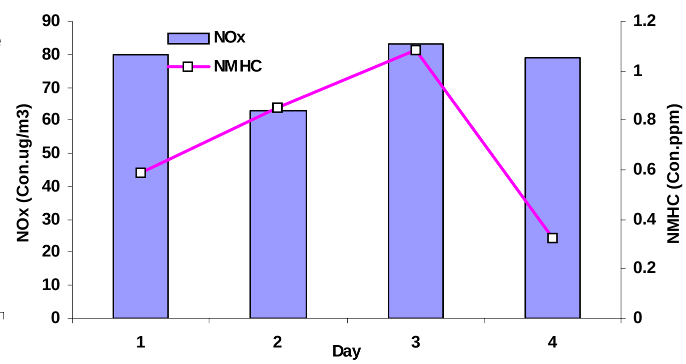


Figure PA.4 : NO_2 and NMHC Concentration

Figure PA.5 presents diurnal variation of CO concentration during post monsoon.

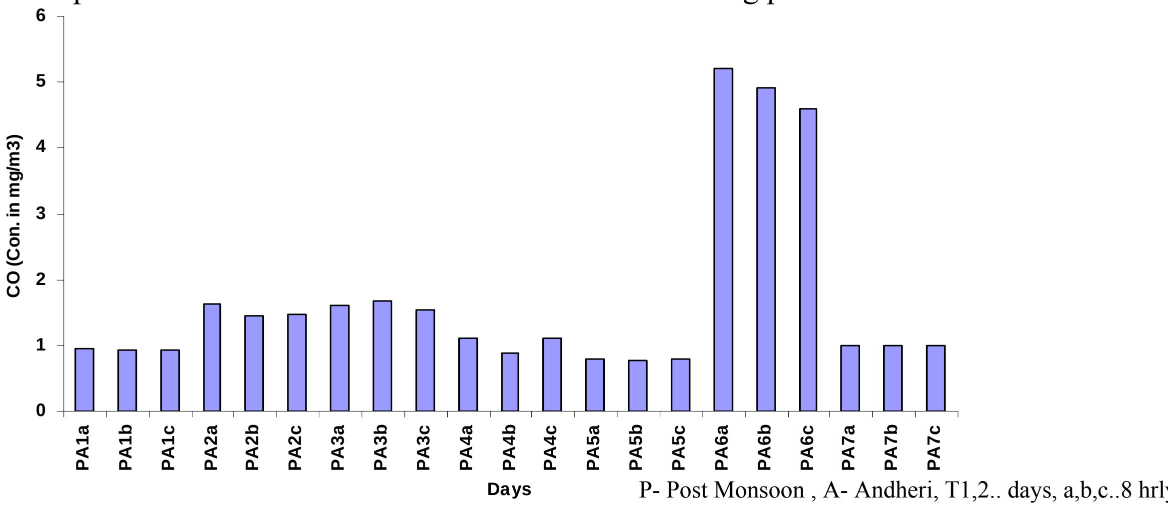


Figure PA.5 : Diurnal variation of CO

Diurnal variation in CO shows high variation with a high value of 4.9 and low of 0.8 mg/m^3.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PA.6 and PA.7.**

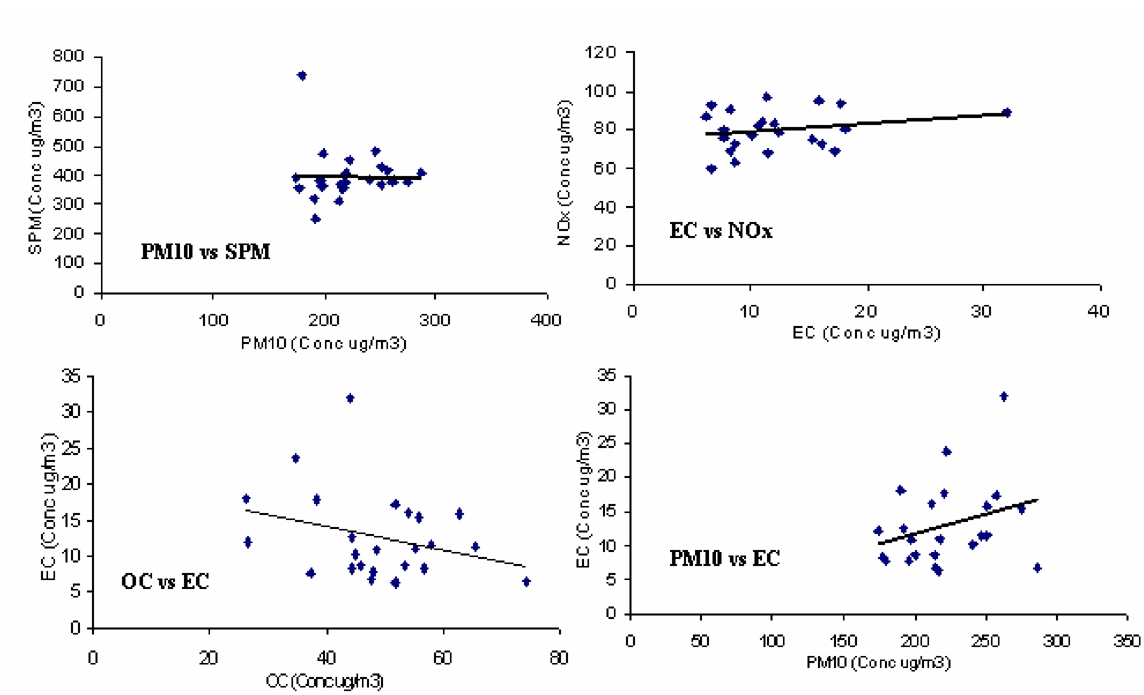


Figure PA.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show very poor negative correlation indicating sources contributing to fine particles are more viz. vehicle, oil burning etc. EC and NO_2 show very poor correlation indicating that vehicular emission is not the only contributing source to EC. EC and OC show very poor negative correlation indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC and EC is 4.7; there may be formation of secondary organic carbon aerosols. Correlation coefficient for PM_{10} and EC is 0.30 indicating that sources for PM_{10} and EC are different.

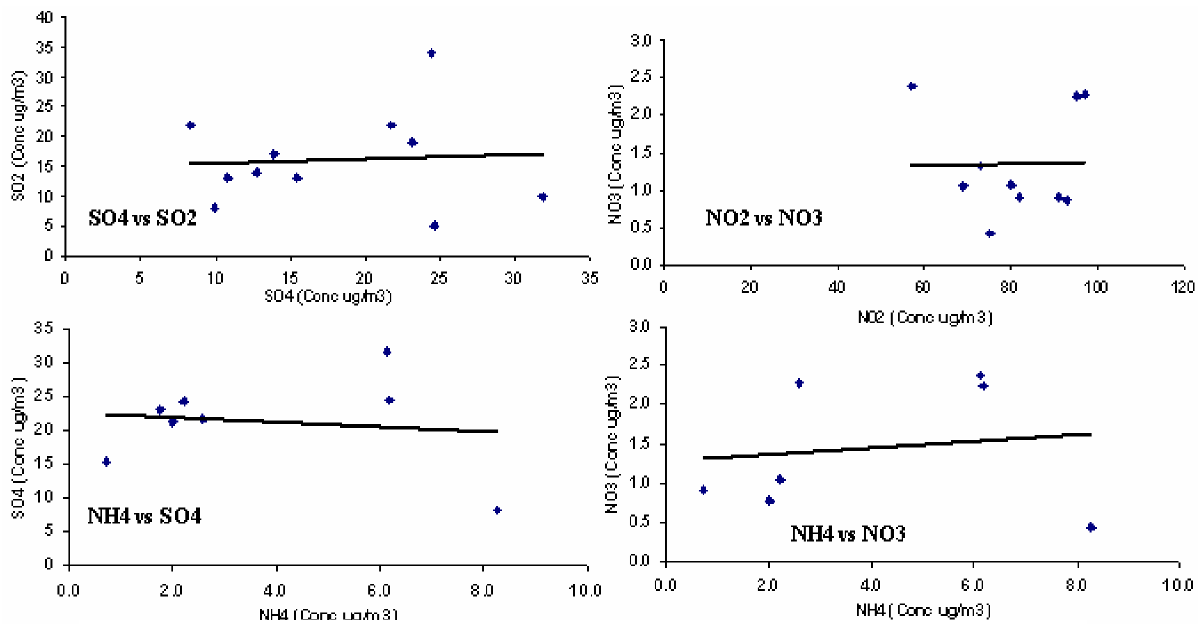


Figure PA.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} as also NO_2 and NO_3^- show poor correlation indicating SO_2 and NO_2 are not getting converted to SO_4^{2-} and NO_3^-. NH_4^+ and SO_4^{2-} show poor correlation indicating that NH_4^+ is not neutralizing SO_4^{2-}. NH_4^+ and NO_3^- also show poor correlation indicating that NH_4^+ is not neutralizing NO_3^-.

Carbon concentrations at Andheri site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PA.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.671	.297	.834
OC	.671	1.000	-.286	.834
EC	.297	-.286	1.000	.264
TC	.834	.834	.264	1.000

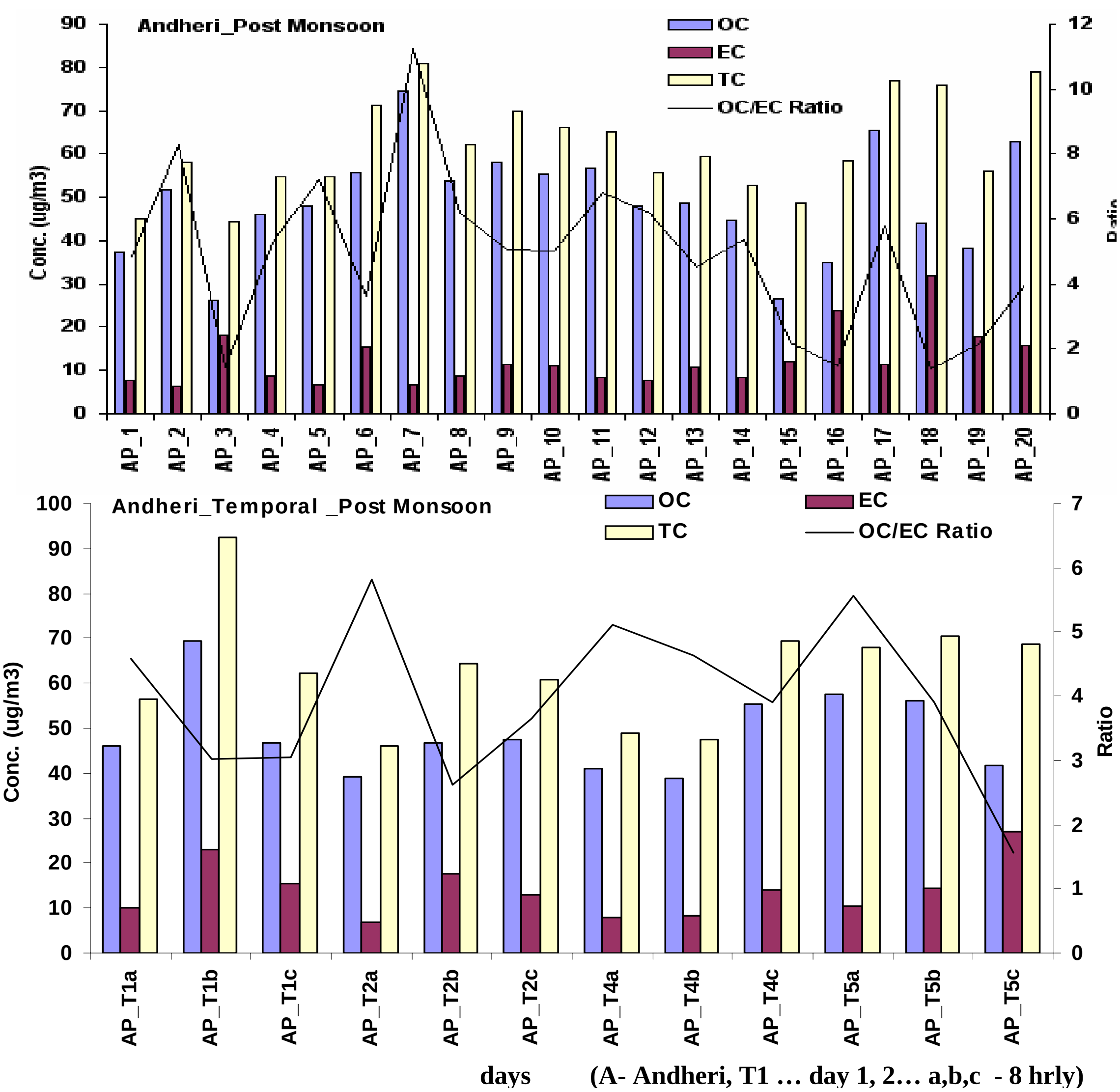


Figure PA.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Andheri Site (Post Monsoon)

At Andheri site OC varied between 26.3-74.4 µg/m^3 with an average value of 48.9 µg/m^3. The EC concentration varied between 6.2-31.9 µg/m^3 with an average value of 12.7 µg/m^3. OC/EC ratio varied from 1.4 to 11.2 with an average ratio of 4.7. Percentage of OC, EC and TC in PM_{10} was 21.9, 5.7 and 27.8 whereas in $PM_{2.5}$ it was 31.6, 11.7 and 43.3 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (µg/m^3) in PM_{10} is shown in **Figure PA.9.**

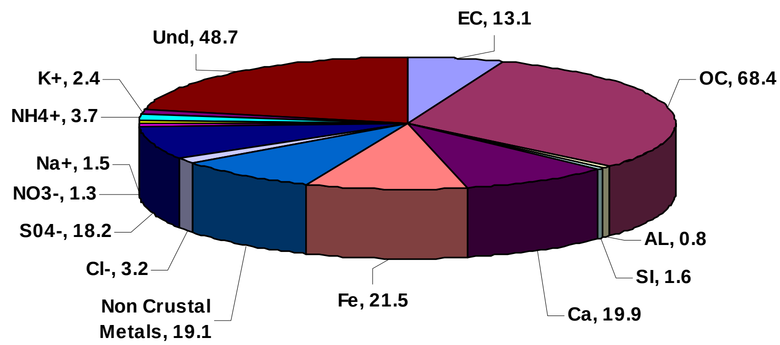


Figure PA.9 : Mass Closure Concentrations (µg/m^3) at Andheri

Percent composition of PM_{10} after mass closure shows that maximum contribution is from carbonaceous matter. OC and EC account for 30% and 6% respectively and thus indicate the contribution from sources like automobile exhaust, coal burning, biomass burning and oil burning. Crustal elements account for 20% of the total particulate matter indicating the contribution from soil; road dust whereas non crustal elements account for 9% of the total particulate matter indicating the contribution from sources like vehicles, coal burning, biomass burning and oil burning. Ions account for 14% of the total particulate matter. High concentration of SO_4^{2-} is due to road dust, secondary aerosols and vehicles. Other ions like Cl^- and Na^+ are released from sea spray; NH_4^+ is emitted from vehicles and K^+ is from biomass burning. 22% of the total PM_{10} is unidentified.

Mahul Site: The observed concentrations for post monsoon season are presented in **Table PM.1** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season are presented in **Figures PM.1**

Table PM.1 : Air Quality Status at Mahul (Post monsoon)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	237.0	497.0	391.6	493.5	64.3	30
RSPM (µg/m^3)	104.0	255.0	200.3	246.9	32.7	30
PM_{10} Tef (µg/m^3)*	100.0	461.0	232.6	365.8	60.2	30
PM_{10} Tef_1 (µg/m^3)*	101.0	286.1	220.4	279.9	42.1	29
$PM_{2.5}$ (µg/m^3)**	85.0	89.0	87.0	NA	2.0	3
SO_2 (µg/m^3)	4.0	25.0	14.9	24.4	5.6	29
NO_2 (µg/m^3)	35.0	99.8	57.2	98.2	17.6	29
NH_3 (µg/m^3)	15.0	117.0	59.8	113.6	26.8	29
CO (mg/m^3)	0.6	4.8	1.4	4.3	1.5	7
Formaldehyde (µg/m^3)	19.7	25.0	22.4	NA	3.7	2
CH_4 (ppm)	1.2	2.3	1.6	NA	0.4	6
Nonmethane HC (ppm)	0.1	0.8	0.5	NA	0.3	6
Total HC (ppm)	1.7	2.7	2.1	NA	0.4	6
O_3 (ppb)	15.7	27.9	22.6	27.7	4.8	7
OC (µg/m^3)	21.2	70.7	46.9	67.2	11.4	29
EC (µg/m^3)	5.4	18.8	8.7	15.3	3.0	29
TC (µg/m^3)..	27.5	82.4	55.7	79.8	13.0	29

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters were within permissible limit of CPCB standard of industrial area (500 µg/m^3). RSPM at Mahul exceeded 93% of the time of and CPCB industrial standard of 150 µg/m^3. The ratio of RSPM to SPM was 51% and $PM_{2.5}$ to $PM_{10}$was 40 indicating dominance of fine particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 4% of the time than the CPCB standard. The monthly average of PM_{10} was 218.6 µg/m^3. Temporal trends of PM_{10} show high concentrations during afternoon. CO values ranged between 0.6-4.8 mg/m^3, formaldehyde ranged between 19.7-25.0 µg/m^3, Total Hydrocarbon ranged between 1.8-2.7 ppm whereas Ozone concentrations ranged with 15.7-27.9 ppb.

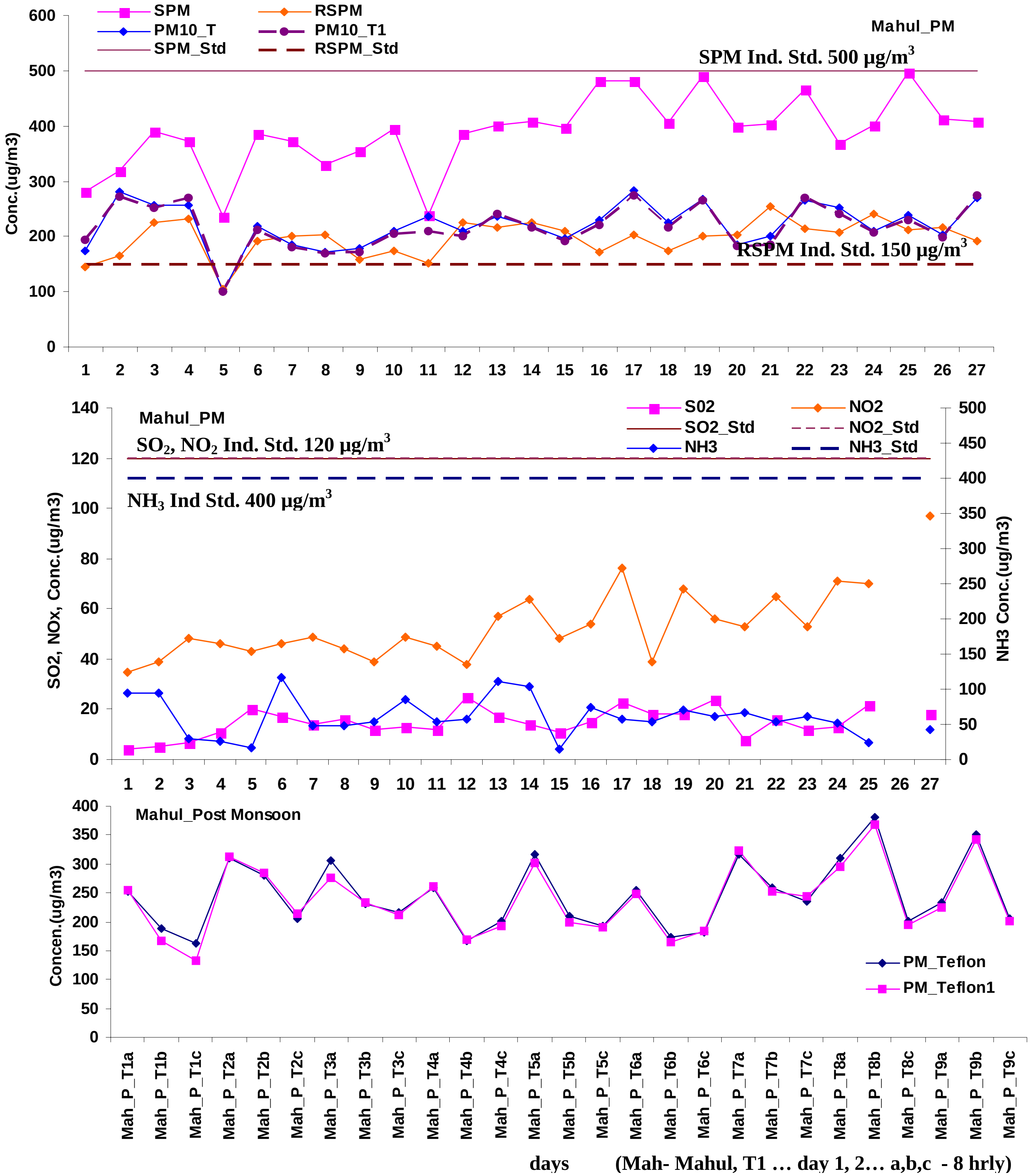


Figure PM.1: Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Mahul During Post Monsoon

Figure PM.2 shows $PM_{2.5}$ and CO during post monsoon season.

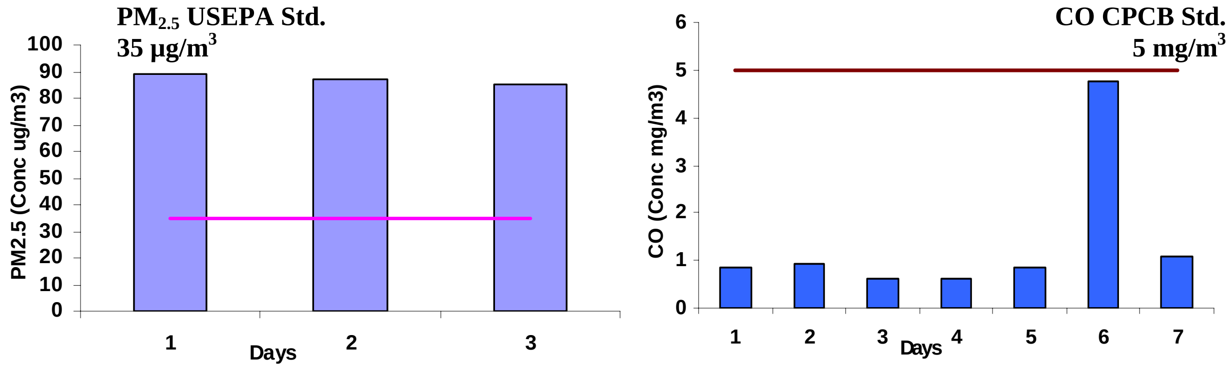


Figure PM.2: Observed Concentrations of $PM_{2.5}$ and CO at Mahul (Post Monsoon)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 µg/m^3 due to the sources like industries, heavy vehicle traffic, coal burning, oil burning etc which contribute to the fine particulate matter. The CO concentration during the sampling period was within the limits of CPCB standard of 5 mg/m^3 for the industrial area.

Figure PM.3 shows Methane, Non Methane and THC concentrations and **Figure PM.4** shows NO_2 vs NMHC concentrations during post monsoon.

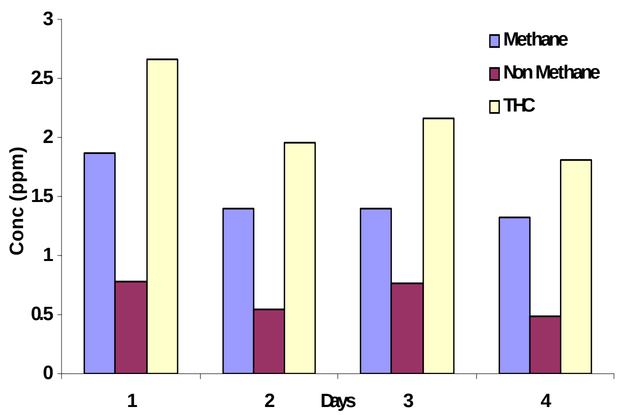


Figure PM.3: Hydrocarbon Concentration

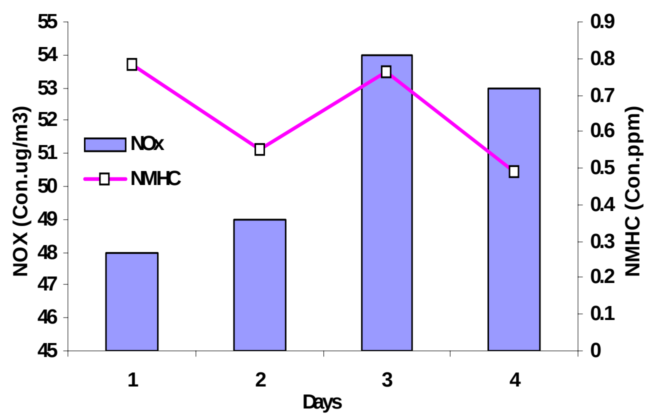
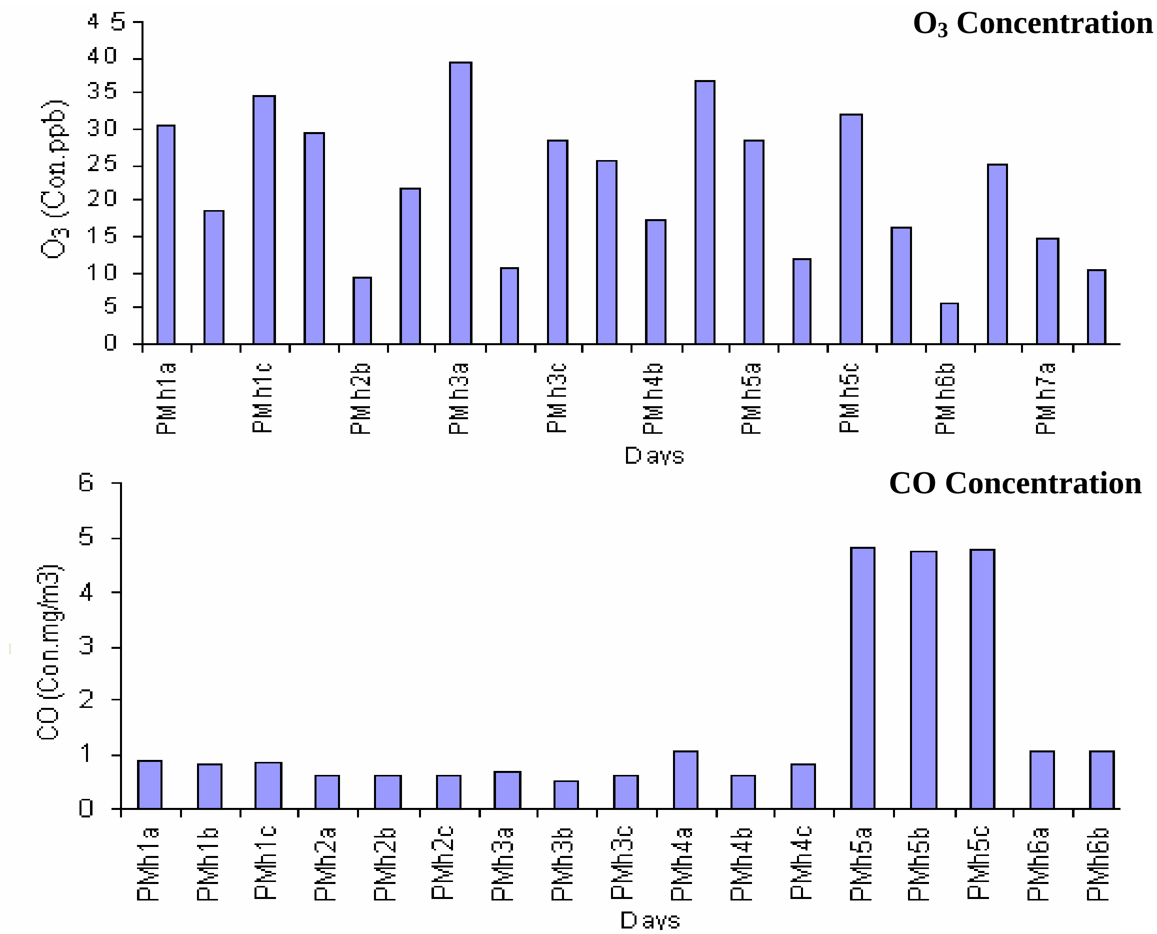


Figure PM.4: NO_2 and NMHC Concentration

Figure PM.5 presents diurnal variation of O_3 and CO during post monsoon at Mahul.



P- Post Monsoon , Mh- Mahul, T1,2.. days, a,b,c..8 hrly

Figure PM.5 : Diurnal variation O_3 and CO

CO doesn't show any particular trend in diurnal variation. Diurnal variation in ozone showed high concentrations during morning and afternoon due to vehicular traffic along with more photochemical activity favouring ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PM.6 and PM.7.**

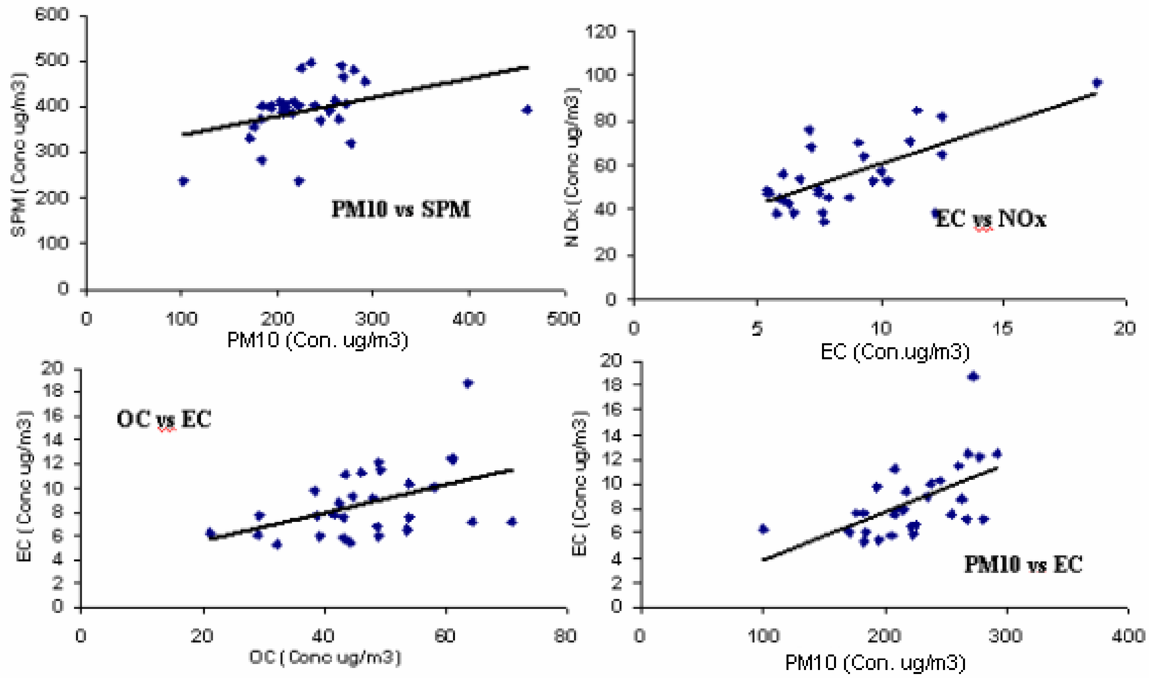


Figure PM.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show poor correlation due to number of industries, heavy vehicular traffic and coal burning which mainly contribute to fine particles. EC and NO_2 show good correlation (R = 0.67) indicating that sources like heavy vehicles are contributing to both EC and NO_2. EC and OC show moderate correlation which is indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC/EC is 5.7, there may be formation of secondary organic carbon aerosols. PM_{10} and EC show moderate correlation (R=0.57) indicating that for both, the contributing source is same.

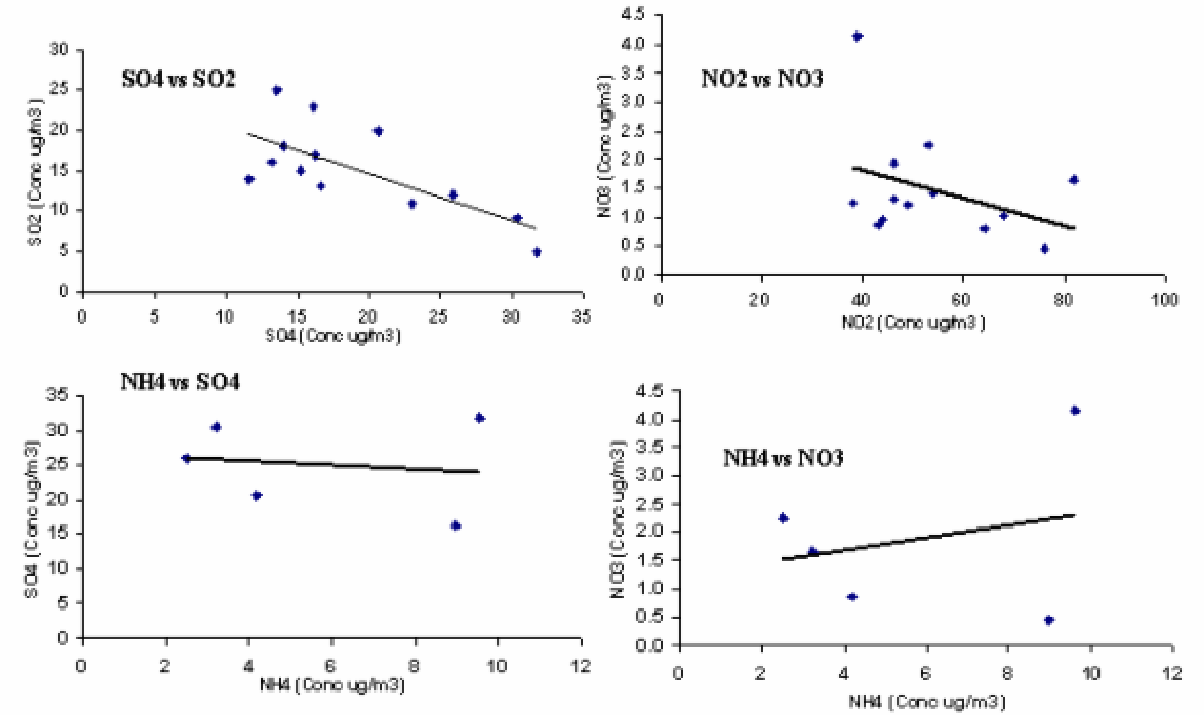


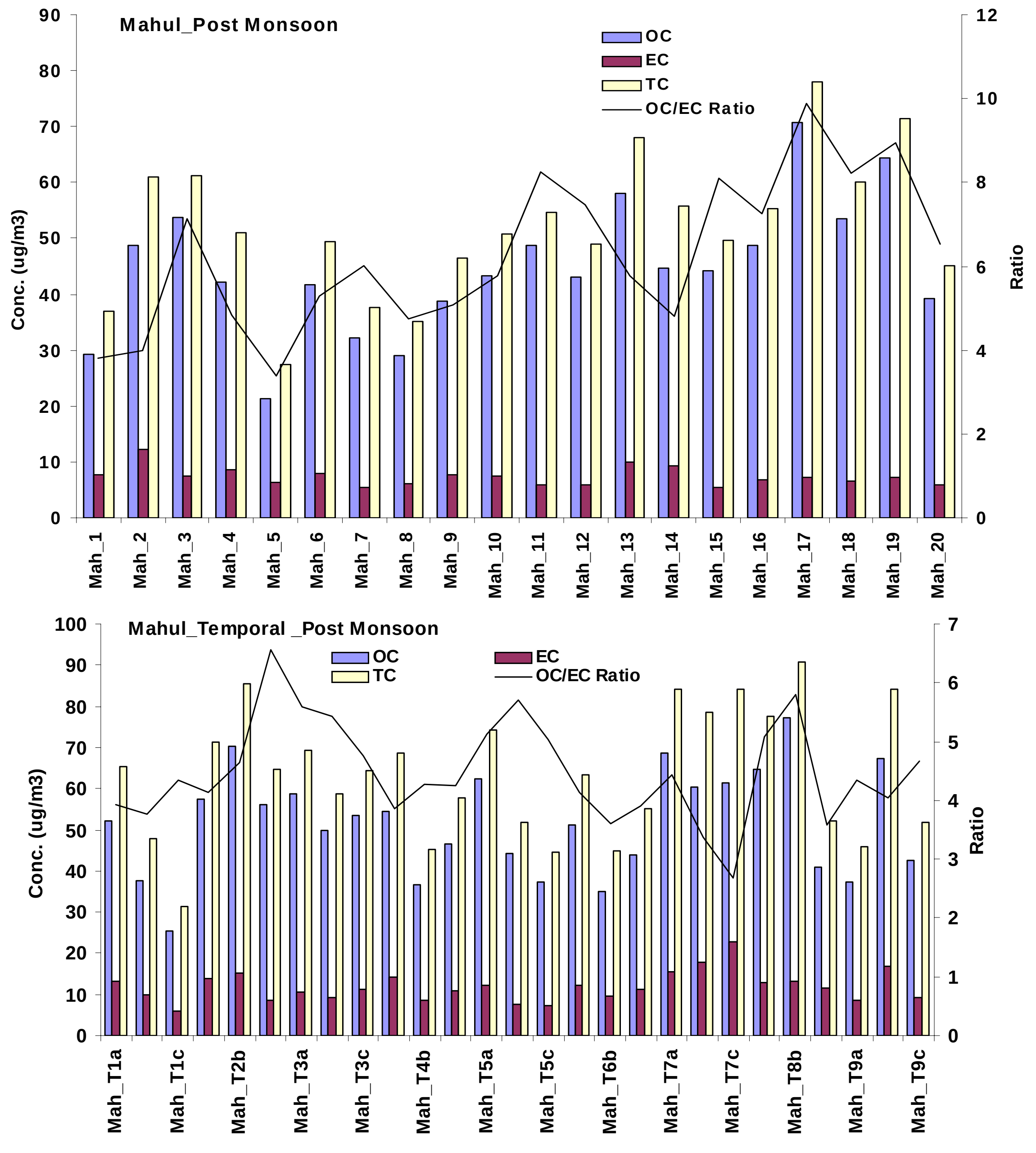
Figure PA.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show poor correlation indicating not getting converted to SO_4^{2-}. NO_2 and NO_3^- show moderate correlation indicating that NO_2 is getting converted to NO_3^- though to a very less extent. NH_4^+ and SO_4^{2-} show poor correlation indicating that NH_4^+ is not neutralizing SO_4^{2-}. NH_4^+ and NO_3^- show poor correlation indicating that NH_4^+ is neutralizing NO_3^- to a very less extent.

Carbon concentrations at Mahul site with PM_{10} and $PM_{2.5}$ are given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PM.8.**

Correlation Matrix of carboneous polluants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.874	.565	.890
OC	.874	1.000	.472	.980
EC	.565	.472	1.000	.638
TC	.890	.980	.638	1.000



days (Mah- Mahul, T1 … day 1, 2… a,b,c - 8 hrly)

Figure PM.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Mahul Site (Post Monsoon)

At Mahul site OC varied between 21.2-70.7 µg/m^3 with an average value of 46.9 µg/m^3. The EC concentration varied between 5.4-18.8 µg/m^3 with an average value of 8.7 µg/m^3. OC/EC ratio varied from 3.4 to 9.9 with an average ratio of 5.7. Percentage of OC, EC and TC in PM_{10} was 21.0, 3.9 and 25.0 whereas in $PM_{2.5}$ it was 28.3, 10.9 and 39.2 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration ($\mu g/m^3$) in PM_{10} is presented in **Figure PM.9**.

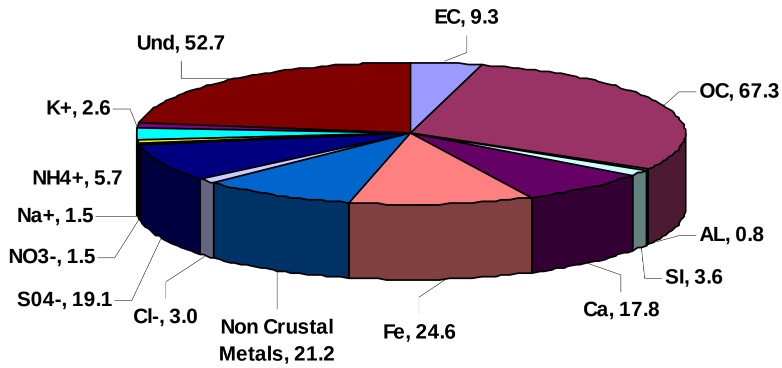


Figure PM.9: Mass Closure Concentrations ($\mu g/m^3$) at Mahul

Percent composition of PM_{10} after mass closure indicates that maximum contribution to the particulate matter is from carbonaceous fraction. OC contributes 30% and EC contributes 4%. The major sources contributing to OC and EC include heavy vehicles, oil burning and coal burning. The contribution of crustal elements is 20% and the source for these crustal elements is soil. Petrochemical industries, heavy vehicles, oil burning, coal burning are the sources for non-crustal elements which account for 9%. Ions contribute to 14% of the total PM_{10} with SO_4^{2-} having highest concentration due to vehicles, secondary aerosols and sea salt. High concentration of NH_4^+ is due to fertilizer industry, vehicles and oil burning. The source contributing to Na^+ and Cl^- is sea spray whereas K^+ is emitted from biomass burning. The unidentified fraction accounts for 23 % of the total fine particulate matter in Mahul.

Mulund Site : The observed concentrations for post monsoon season are presented in **Table PMu.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for post monsoon season are presented in **Figures PM.1**

Table PMu.1 : Air Quality Status at Mulund (Post monsoon)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	269.0	566.0	391.5	539.9	79.1	30
RSPM (µg/m^3)	102.0	308.0	179.4	280.7	44.9	30
PM_{10} Tef (µg/m^3)*	158.0	359.0	233.1	347.2	50.3	29
PM_{10} Tef_1 (µg/m^3)*	158.0	364.0	235.5	359.9	55.2	30
$PM_{2.5}$ (µg/m^3)**	159.0	220.0	189.5	NA	43.1	2
SO_2 (µg/m^3)	4.0	41.0	16.8	34.0	8.8	30
NO_2 (µg/m^3)	30.0	100.0	53.2	96.5	16.8	30
NH_3 (µg/m^3)	15.0	78.0	50.8	77.4	15.6	30
CO (mg/m^3)	0.5	2.1	1.1	2.1	0.7	7
Formaldehyde (µg/m^3)	21.7	40.5	31.1	NA	13.3	2
CH_4 (ppm)	2.1	2.4	2.2	NA	0.1	5
Nonmethane HC (ppm)	0.3	1.6	1.0	NA	0.5	5
Total HC (ppm)	2.5	4.2	3.2	NA	0.7	5
O_3 (ppb)	6.1	29.8	15.6	29.1	9.6	7
OC (µg/m^3)	24.5	89.4	51.0	87.9	15.8	29
EC (µg/m^3)	6.4	26.3	15.1	26.1	5.6	29
TC (µg/m^3)..	35.7	113.7	66.1	113.4	18.4	29

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM were exceeding permissible limit of CPCB i.e. 200 and 100 µg/m^3 respectively. The ratio of RSPM to SPM was 46% and $PM_{2.5}$ to PM_{10} was 80% indicating dominance of fine particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 7% of the time than the CPCB standard. The monthly average of PM_{10} was 234.3 µg/m^3. Temporal trends of PM_{10} shows high concentrations during afternoon. CO values ranged between 0.5-2.1 mg/m^3, formaldehyde ranged between 21.7-40.5 µg/m^3, Total Hydrocarbon ranged between 2.5-4.2 ppm whereas Ozone concentrations ranged with 6.1-29.8 ppb

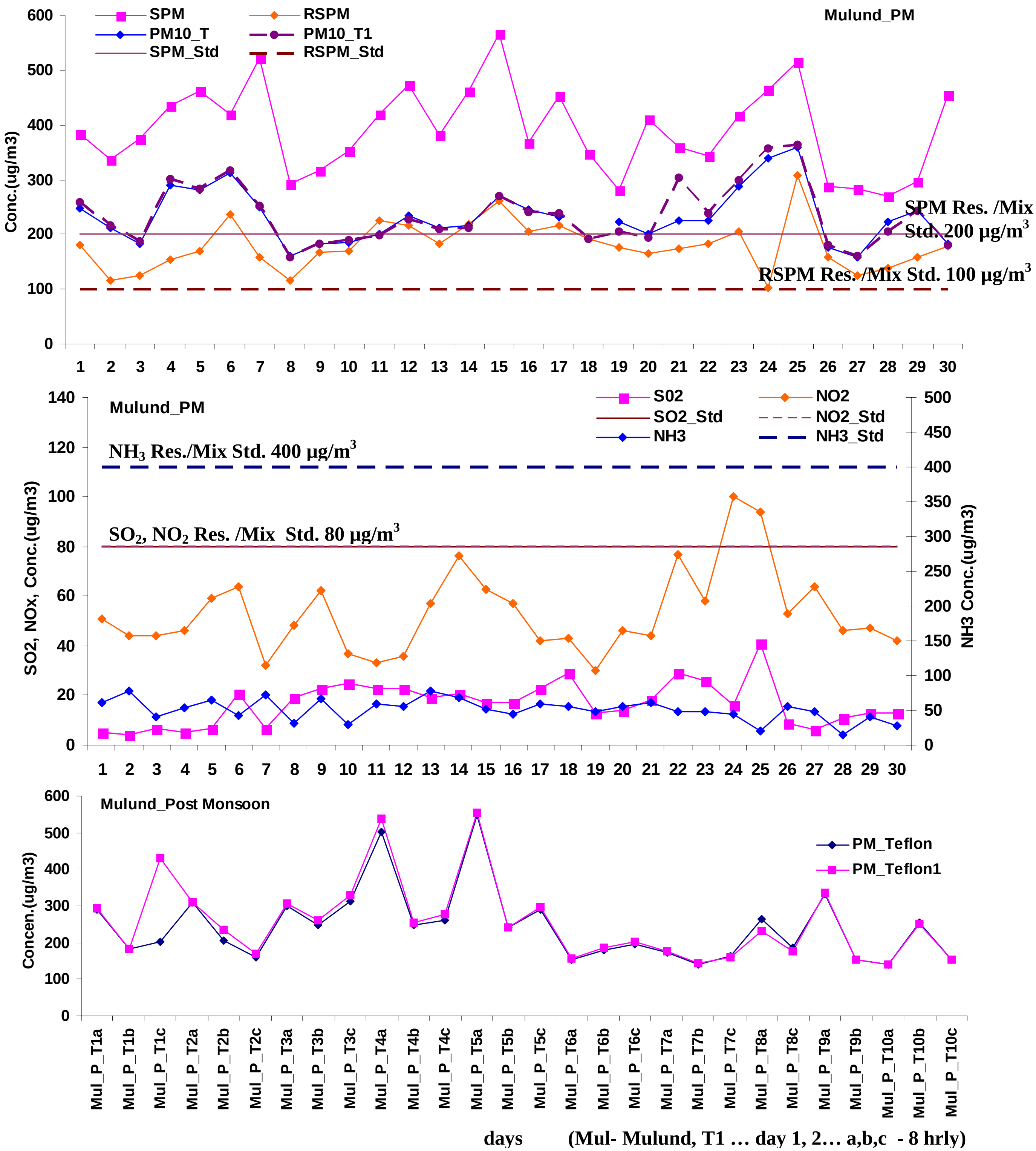


Figure PMu.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Mulund During Post Monsoon

* High value at particular day indicates outlier due to certain site specific activity.

Figure PMu.2 shows $PM_{2.5}$ and CO during post monsoon season.

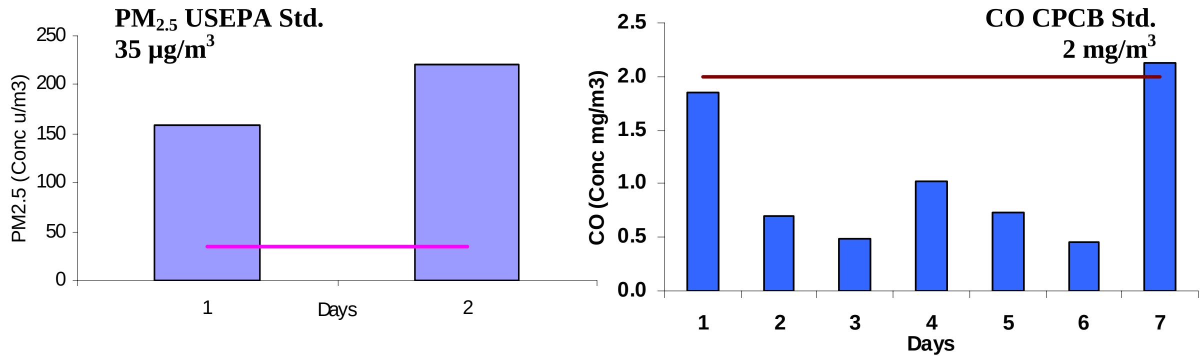


Figure PMu.2 : Observed Concentrations of $PM_{2.5}$ and CO at Mulund (Post Monsoon)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 µg/m^3 due to the sources like vehicles, industries and oil burning which contribute to the fine particulate matter. The CO concentration during the sampling period exceeded 14% of the times the CPCB standard of 2 mg/m^3 for the residential/mix use area.

Figure PMu.3 shows Methane, Non Methane and THC concentrations and **Figure PMu.4** shows NO_2 vs NMHC concentrations during post monsoon season.

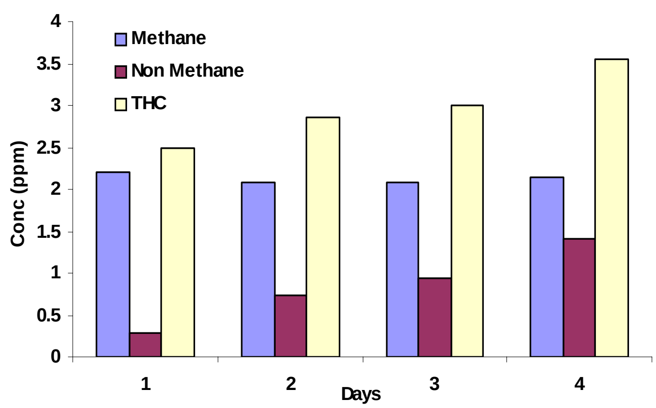


Figure PMu.3 : Hydrocarbon Concentration

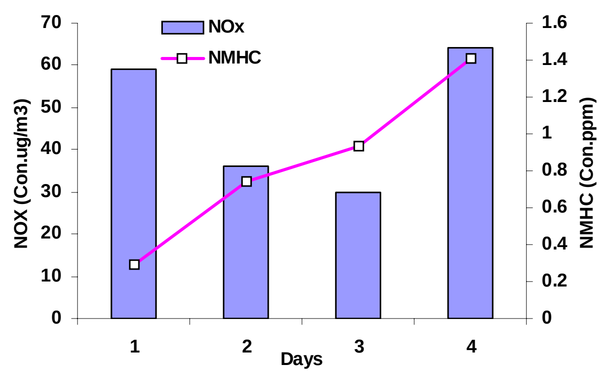


Figure PMu.4: NO_2 and NMHC Concentration

Figure PMu.5 shows diurnal variation of O_3 and CO concentration during post monsoon.

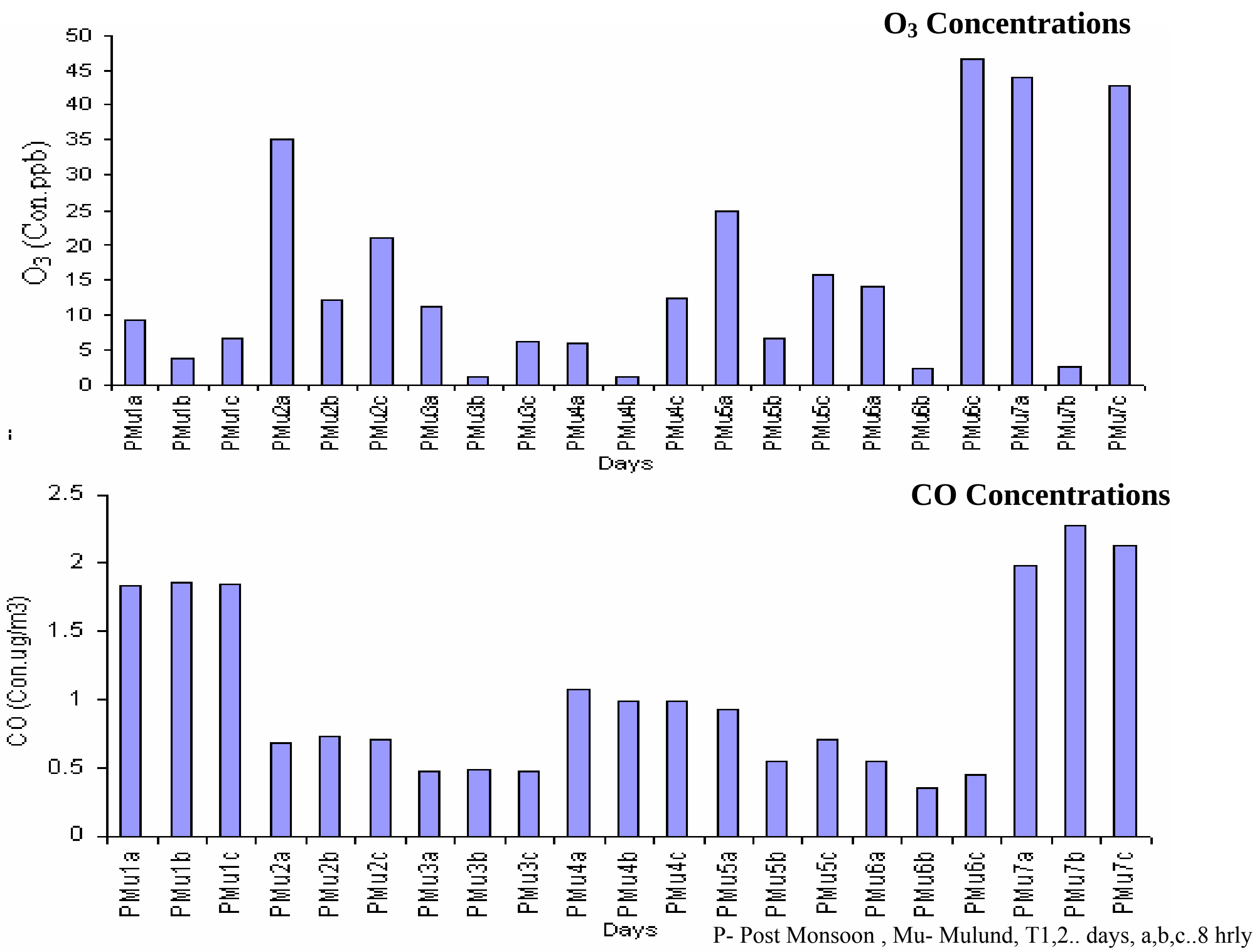


Figure PMu.5 : Diurnal variation of O_3 and CO

Diurnal variation in CO does not show any particulate pattern. Diurnal variation in ozone showed high concentrations during morning and afternoon hours as these timings have peak hour traffic and high photochemical activity favouring ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^-, NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures PMu.6 and PMu.7.**

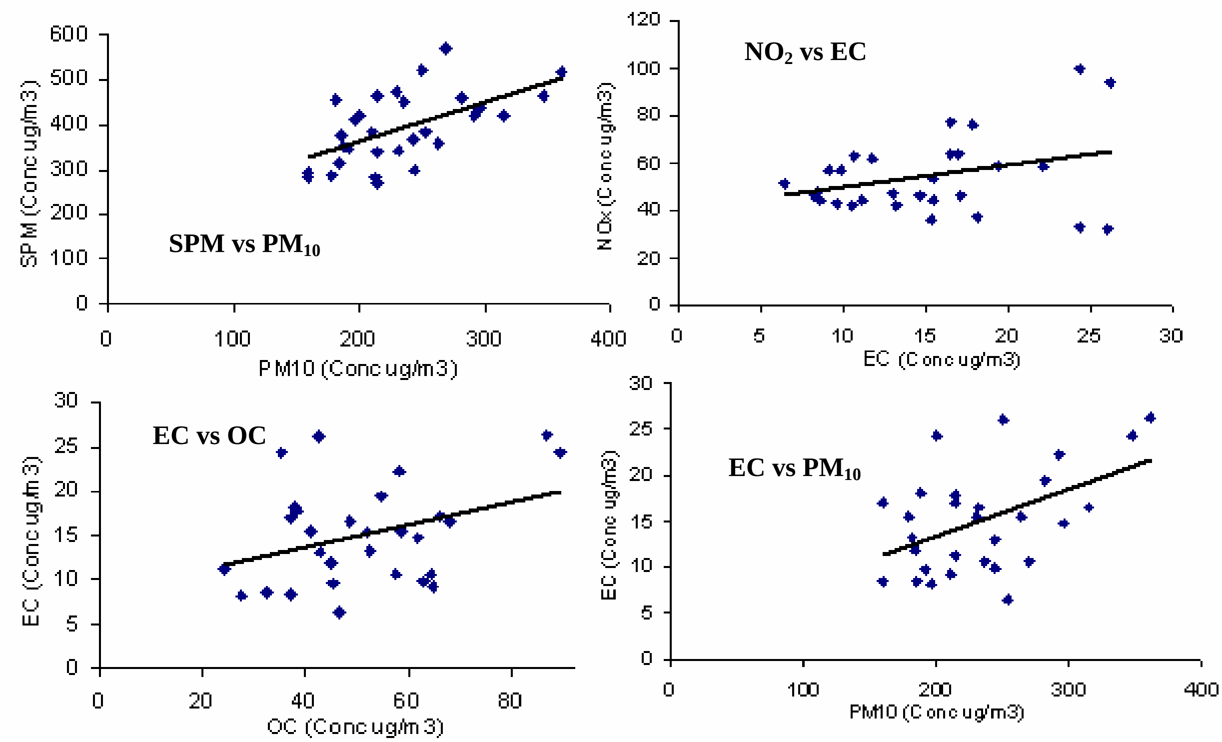


Figure PMu.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.58) due to industries, vehicular traffic and oil burning which mainly contribute to fine particles and soil and road dust are contributing to coarse particulate matter. EC and NO_2 correlate poorly indicating that vehicular emission is not the only source for EC. EC and OC show poor correlation, which indicates that OC and EC may not be released from a single dominant primary source and as average ratio of OC to EC is 3.7. PM_{10} and EC show moderate correlation indicating that for both, the contributing source is different.

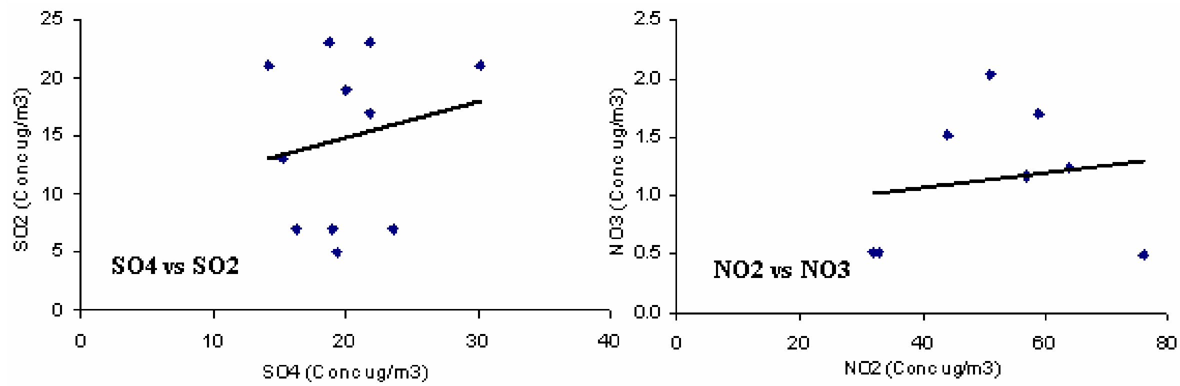


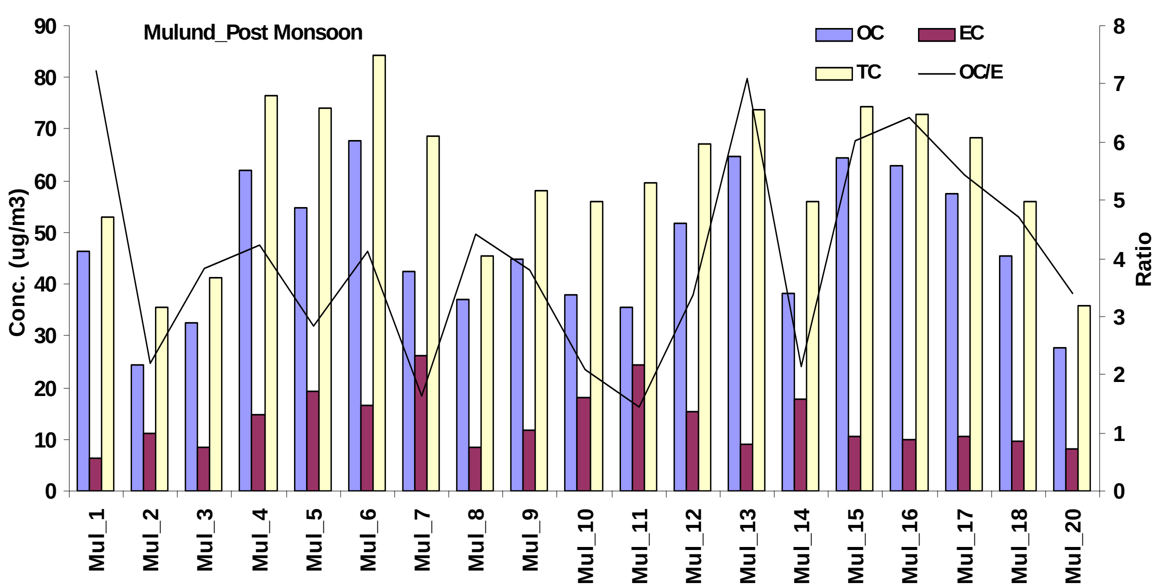
Figure PMu.7 : Correlation of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show poor correlation indicating that SO_2 is not getting converted to SO_4^{2-} and it is mainly coming from other sources like vehicles and oil burning. NO_2 and NO_3^- also show poor correlation indicating that NO_2 is not getting converted to NO_3^-. Correlation plots for NH_4^+ vs SO_4^{2-} and NH_4^+ vs NO_3^- could not be drawn due to insufficient data.

Carbon concentrations at Mulund site with PM_{10} and $PM_{2.5}$ is given **in Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure PMu.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.784	.483	.808
OC	.784	1.000	.353	.960
EC	.483	.353	1.000	.600
TC	.808	.960	.600	1.000



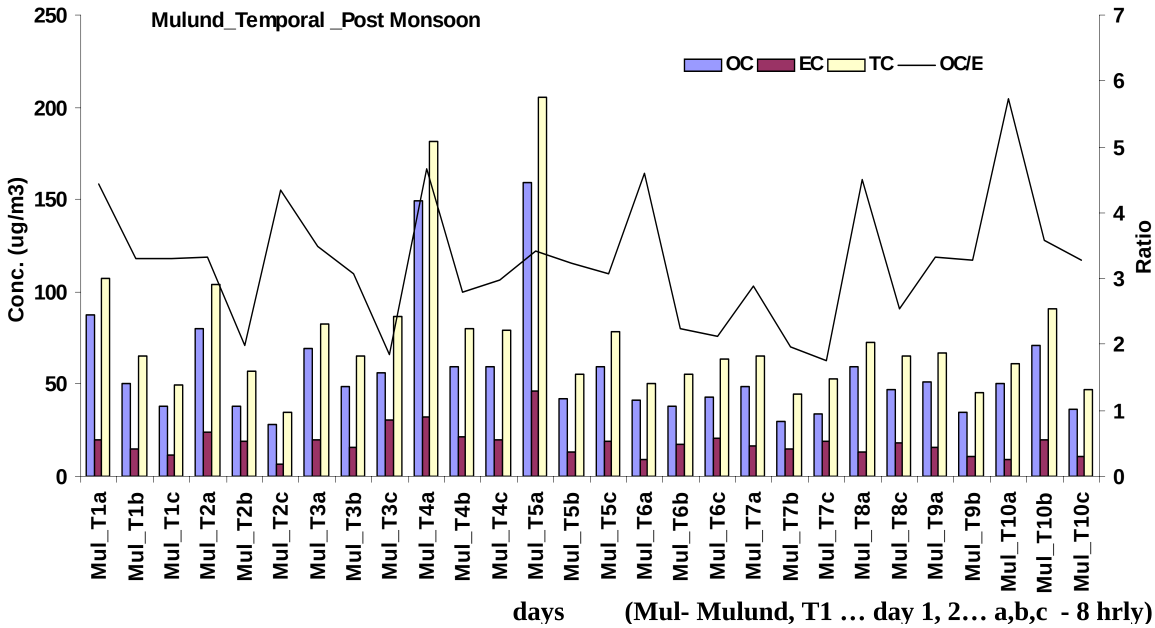


Figure PMu.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Mulund Site (Post Monsoon)

At Mulund site OC varied between 24.5-89.4 μg/m^3 with an average value of 51.0 μg/m^3. The EC concentration varied between 6.4-26.3 μg/m^3 with an average value of 15.1 μg/m^3. OC/EC ratio varied from 1.5 to 7.2 with an average ratio of 3.7. Percentage of OC, EC and TC in PM_{10} was 21.8, 6.4 and 28.2 whereas in $PM_{2.5}$ it was 13.8, 4.5 and 18.3 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (μg/m^3) in PM_{10} is presented in **Figure PMu.9.**

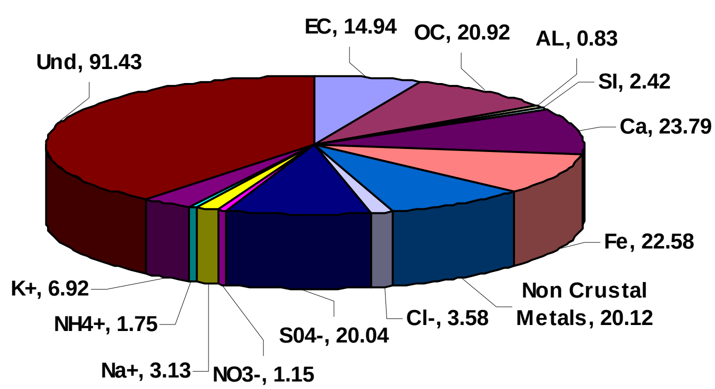


Figure PMu.9: Mass Closure Concentrations (μg/m^3) at Mulund

Percent composition of PM_{10} after mass closure indicates that maximum contribution to the particulate matter is from crustal elements. It accounts for 21% of the particulate matter and the major contributing source is soil. Ions contribute to 16% of the total PM_{10} with SO_4^{2-} having highest concentration due to vehicles and oil burning. Sea spray also contributes to Na^+ and Cl^-. NH_4^+ is mainly emitted from vehicles and industries. OC and EC account for 9% and 6% respectively due to emissions from vehicles and oil burning. Non-crustal elements accounts for 9% of the total particulate load and are mainly contributed from industries, vehicles and oil burning. The unidentified fraction accounts for 39% of the total fine particulate matter in Mulund.

2.4.3 Winter Season

Colaba Site : The observed concentrations for winter season are presented in **Table WC.1**. The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season at Colaba are presented in **Figure WC.1.**

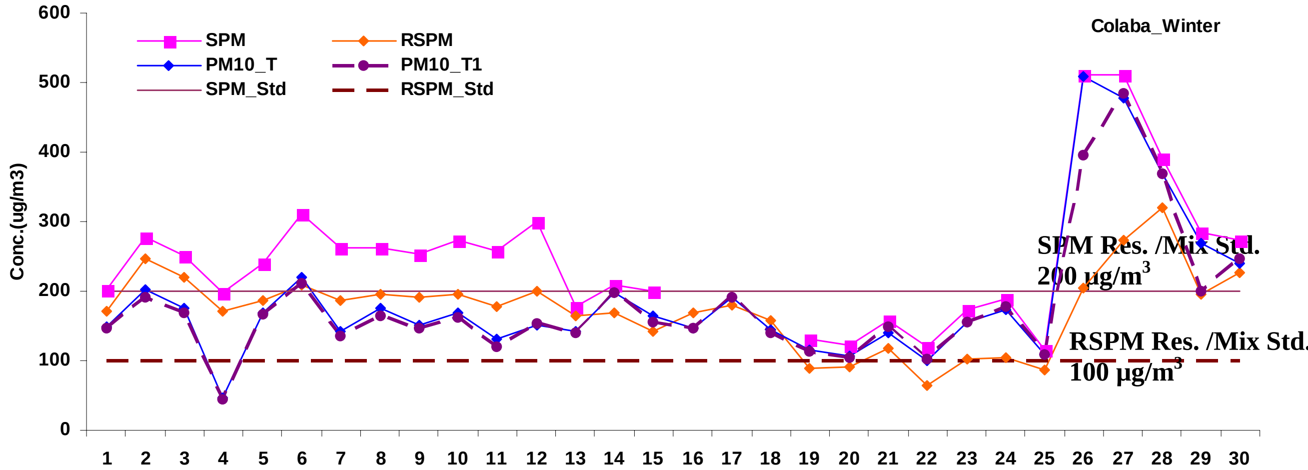
Table WC.1 : Air Quality Status at Colaba (Winter)

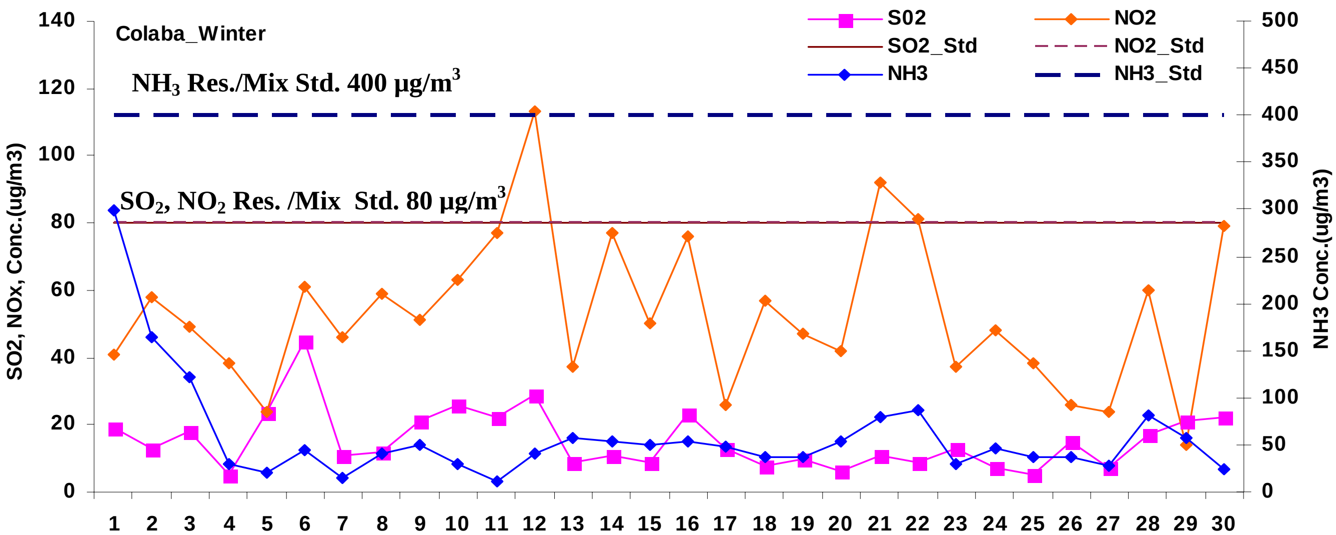
Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (μg/m^3)	115.3	511.9	246.2	511.8	101.0	27
RSPM (μg/m^3)	65.0	321.0	173.8	293.7	57.0	30
PM_{10} Tef (μg/m^3)*	46	369.0	173.6	334.8	64.9	30
PM_{10} Tef_1 (μg/m^3)*	44	395.0	173.5	380.5	73.7	30
$PM_{2.5}$ (μg/m^3)**	54.0	113.0	92.3	NA	33.2	3
SO_2 (μg/m^3)	5.0	45.0	15.4	35.7	8.7	30
NO_2 (μg/m^3)	14.0	113.0	53.0	100.8	22.4	30
NH_3 (μg/m^3)	11.0	299.0	58.7	221.3	55.2	30
CO (mg/m^3)	0.5	3.8	1.7	3.7	1.2	7
Formaldehyde (μg/m^3)	12.0	23.2	18.5	NA	5.8	2
CH_4 (ppm)	2.4	3.5	3.1	NA	3.5	4
Nonmethane HC (ppm)	0.8	1.1	1.0	NA	1.1	4
Total HC (ppm)	3.2	4.6	4.1	NA	4.6	4
O_3 (ppb)	14.3	27.8	21.9	27.3	4.2	7
OC (μg/m^3)	7.21	38.96	22.85	36.30	7.42	29
EC (μg/m^3)	2.17	14.64	8.15	14.21	3.06	29
TC (μg/m^3)..	9.38	47.12	30.99	44.83	8.63	29

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM were exceeding 63% and 87% of the time with respect to the permissible limit of CPCB i.e. 200 and 100 μg/m^3. The ratio of RSPM to SPM was 76% and $PM_{2.5}$ to PM_{10} was 50% indicating dominance of fine particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 10% of the time than the CPCB standard. The monthly average of PM_{10} was 183.7 μg/m^3. Temporal trends of PM_{10} show high concentrations during morning. CO values ranged between 0.5-3.8 mg/m^3, formaldehyde ranged between 12.0-23.2 μg/m^3, Total Hydrocarbon ranged between 3.2-4.6 ppm whereas Ozone concentrations ranged with 14.3-27.8 ppb





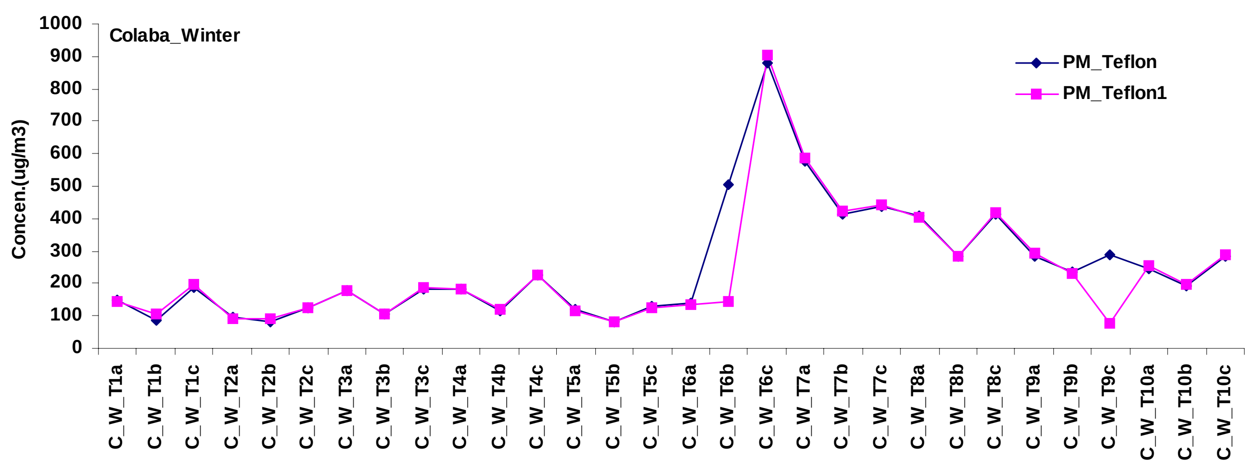


Figure WC.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Colaba During Winter

* High value at particular day indicates outlier due to certain site specific activity.

Figure WC.2 shows the variation of $PM_{2.5}$ and CO during winter period.

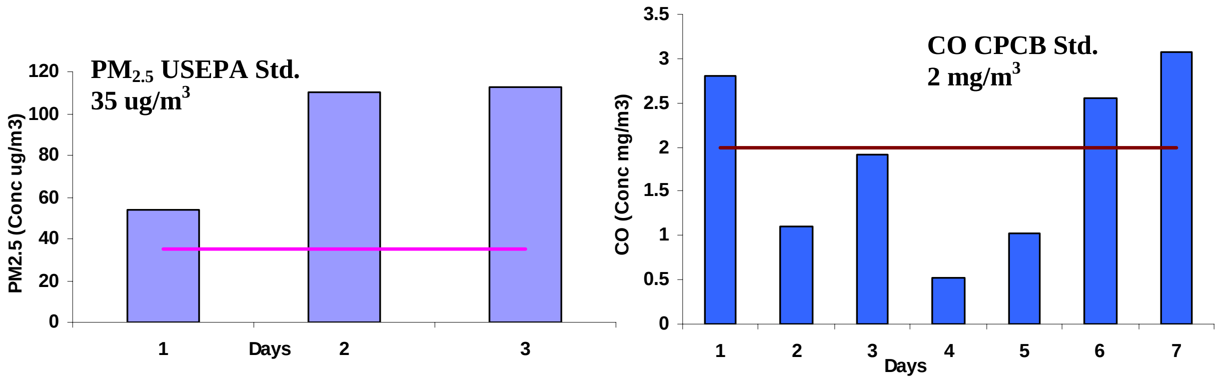


Figure WC.2 : Observed Concentrations of $PM_{2.5}$ and CO at Colaba (Winter)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 $\mu g/m^3$ due to the sources like diesel and petrol vehicles, biomass burning etc which contribute to the fine particulate matter. The CO concentration during the sampling period exceeded 42.8% of the times the CPCB standard of 2 $\mu g/m^3$ for the residential and mix use area due to vehicular emissions and biomass burning.

Figure WC.3 shows Methane, Non Methane and THC concentrations and **Figure WC.4** shows NO_2 vs NMHC concentrations during winter season.

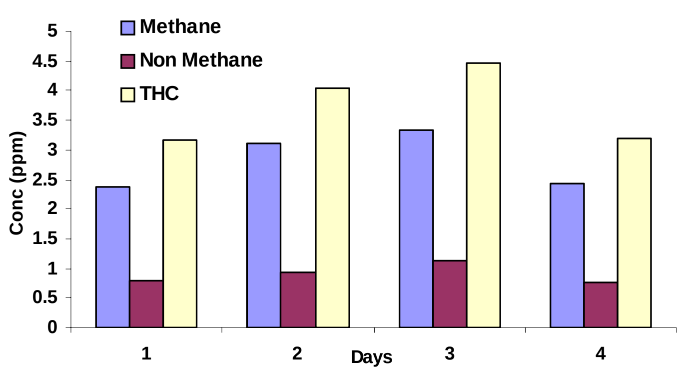


Figure WC.3 : Hydrocarbon Concentration

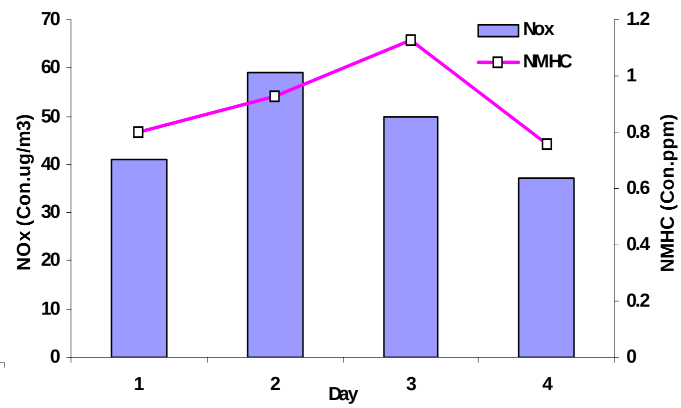


Figure WC.4 : NO_2 and NMHC Concentration

Figure WC.5 presents diurnal variation of O_3 and CO concentration.

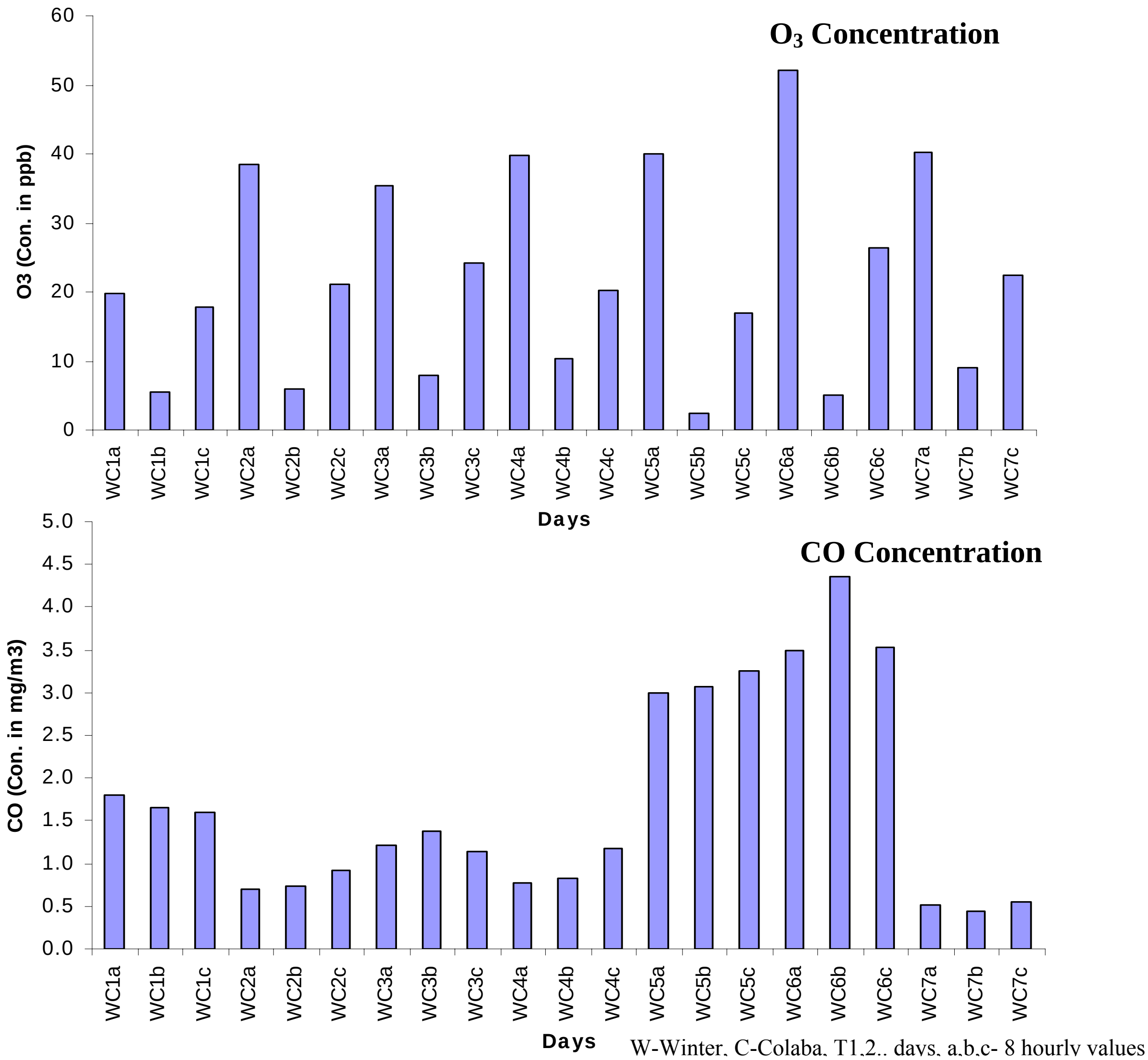


Figure WC.5 : Diurnal Variation of O_3 and CO

No significant trend was observed of CO concentrations. Diurnal variation of O_3 shows high variation with a high of 27.8 and low 14.3 ppb.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^-, NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WC.6 and WC.7**

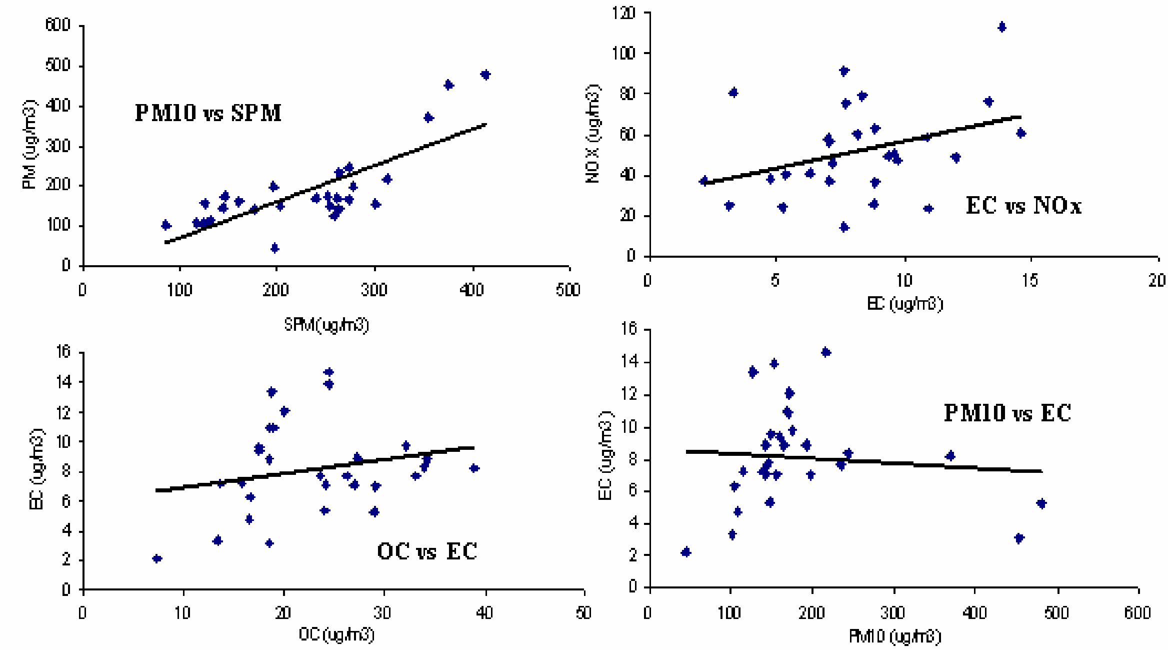


Figure WC.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.77) indicting the presence of sources contributing to coarse particulate matter like soil, sea spray as well as the fine particulate matter like, vehicles and biomass burning. EC and NO_2 correlate moderately indicating that vehicular emission is not the only source for EC. EC and OC show poor correlation indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC: EC is 3.1, there may be formation of secondary organic carbon aerosols. Correlation coefficient for PM_{10} and EC is very poor indicating that sources contributing to PM_{10} and EC are different.

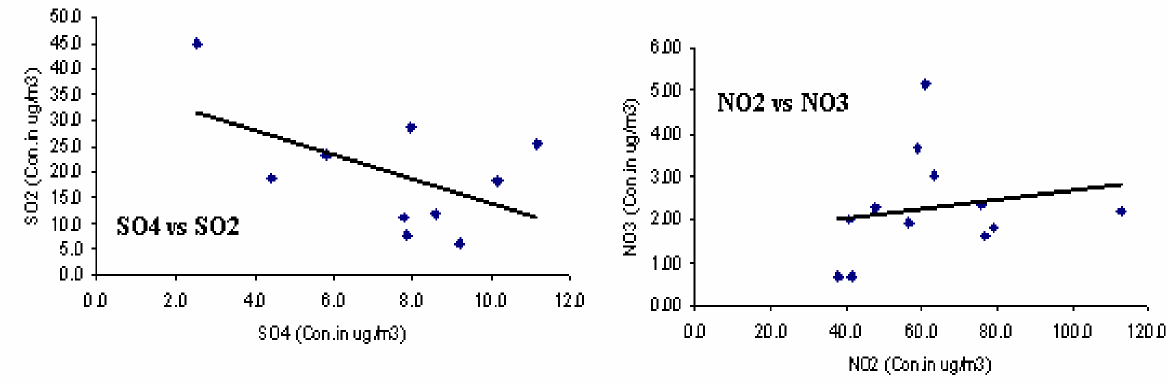


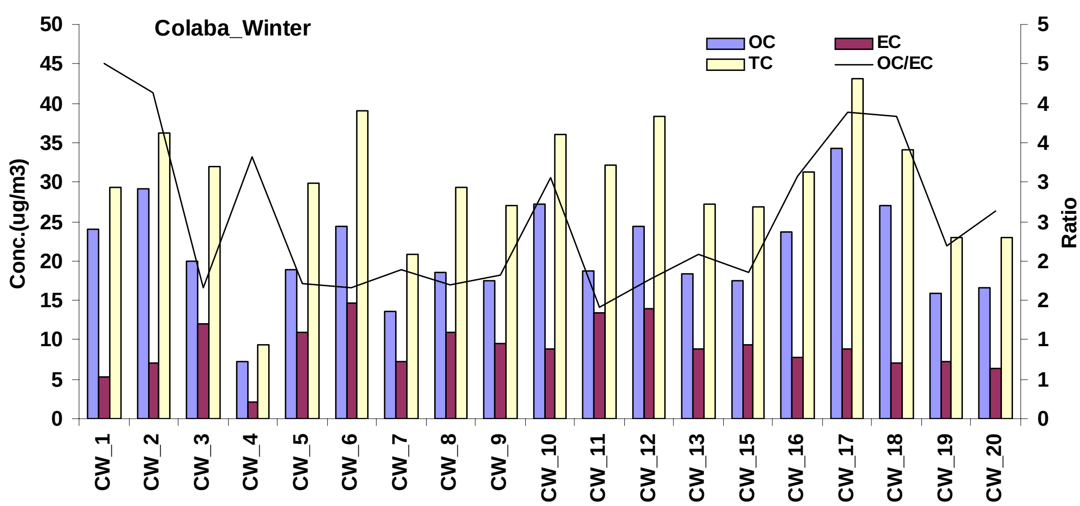
Figure WC.7 : Correlation plots of gaseous pollutants vs ions

SO_2 and SO_4^{2-} show negative correlation indicating that significant amount of SO_2 is getting converted to SO_4^{2-}. NO_2 and NO_3^- correlate poorly indicating that NO_2 is not getting converted to NO_3^-. Correlation plots for NH_4^+ vs SO_4^{2-} and NH_4^+ vs NO_3^- could not be plotted due to insufficient data.

Carbon concentrations at Colaba site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WC.8.**

Correlation Matrix of carbonaceous polluants vs PM_{10}

	PM_{10}	**OC**	**EC**	**TC**
PM_{10}	1.000	.506	-.102	.400
OC	.506	1.000	.224	.939
EC	-.102	.224	1.000	.546
TC	.400	.939	.546	1.000



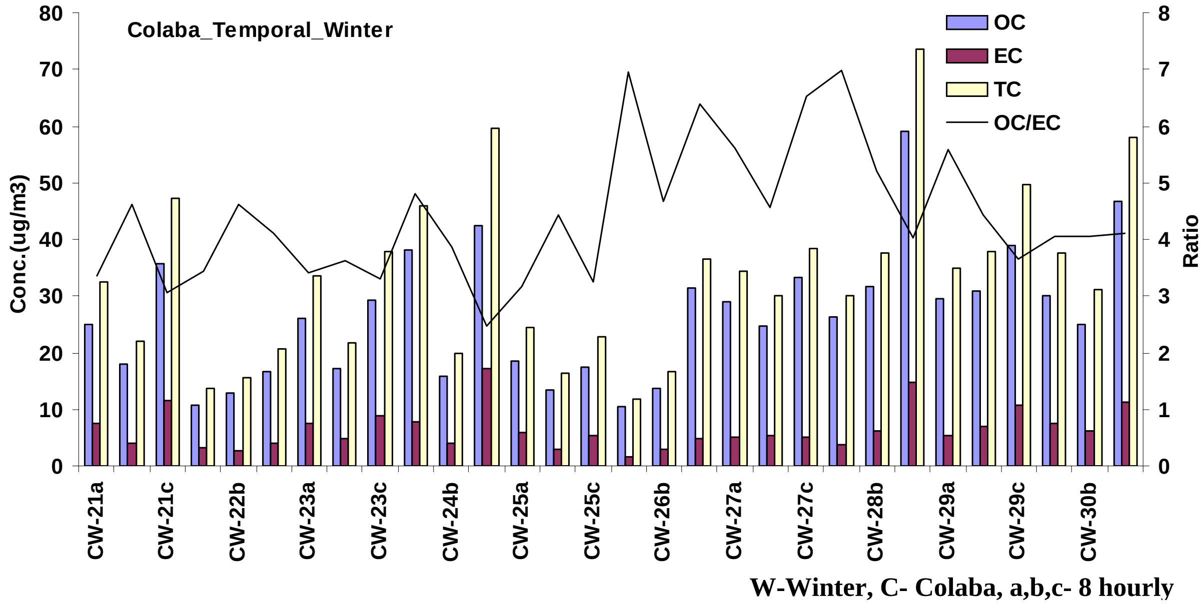


Figure WC.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Colaba Site (Winter)

At Colaba site OC varied between 7.2-38.9 with average value of 22.8 µg/m^3, whereas EC concentration varied between 2.2-14.6 with average value of 8.1 µg/m^3. OC/EC ratio varied between 1.4-5.9 with average ratio of 3.1. Percent of OC, EC and TC in PM_{10} was 12.4, 4.43 and 16.8 respectively, whereas in $PM_{2.5}$ it was 29.3, 8.8 and 38.1 respectively.

Mass fraction of Elements, Ions and Carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure WC.9.**

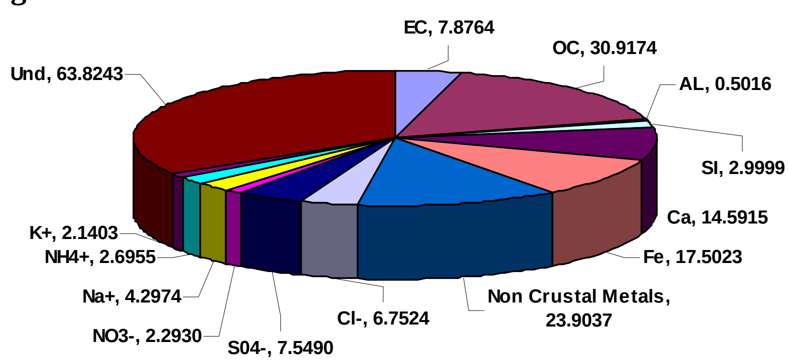


Figure WC.9 : Mass Closure Concentrations (µg/m^3) at ColabaWinter

Percent composition of PM_{10} after mass closure shows that the crustal elements contribute 19% of the particulate matter in the form of soil. OC and non crustal fractions contribute 16% and 13% respectively indicating the contribution from vehicular exhausts, biomass burning etc. Ions such as SO_4^{2-}, Na^+, Cl^-, K^+ etc contribute to 14% of the total PM_{10} loadings. The sources contributing to these ions include sea spray, biomass burning and secondary aerosols. Vehicles, marine vessels contribute to 4% elemental carbon. Unidentified fraction measures to 34% of the total mass of $PM_{10.}$

Dadar Site: The observed concentrations for winter season are presented in **Table WD.1** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season at Dadar are presented in **Figure WD.1**

Table WD.1: Air Quality Status at Dadar (Winter)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	176.7	423.2	291.5	414.7	65.7	30
RSPM (µg/m^3)	122.0	293.0	195.4	291.8	40.7	30
PM_{10} Tef (µg/m^3)*	137.0	390.0	250.2	384.2	65.7	30
PM_{10} Tef_1 (µg/m^3)*	96.0	386.0	246.1	381.1	69.8	30
$PM_{2.5}$ (µg/m^3)**	75.0	137.0	106.0	NA	31.0	3
SO_2 (µg/m^3)	6.0	31.0	15.8	30.5	6.3	28
NO_2 (µg/m^3)	47.0	148.0	98.7	146.9	26.8	28
NH_3 (µg/m^3)	33.0	225.0	93.5	202.9	41.6	28
CO (mg/m^3)	0.8	5.3	2.9	5.3	1.7	10
Formaldehyde (µg/m^3)	22.1	23.4	22.8	NA	0.9	2
CH_4 (ppm)	2.9	4.0	3.6	NA	0.4	4
Nonmethane HC (ppm)	0.9	2.2	1.7	NA	0.6	4
Total HC (ppm)	3.8	6.1	5.4	NA	1.0	4
O_3 (ppb)	10.6	17.1	12.8	2.1	16.6	7.0
OC (µg/m3)	19.0	90.7	45.2	17.0	84.3	25
EC (µg/m3)	5.8	22.2	11.7	4.8	21.4	25
TC (µg/m3)	26.7	113.1	56.8	20.2	104.4	25

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters at Dadar exceeded 93% of the time of CPCB residential mixed standard of 200 ug/m^3, whereas RSPM exceeded all the times during sampling period. The 24 hourly average concentrations of SO_2 and NH_3 are within the CPCB limits, whereas NO_2 exceeded 71% of the CPCB standard. The monthly average of PM_{10} was 260 µg/m^3. Trends of temporal values of PM_{10} show that the concentrations are higher during day time. CO values ranged between 0.8-5.3 mg/m^3. Formaldehyde ranged between 22.1- 23.4 µg/m^3, whereas THC ranged between 3.8-6.1 ppm.

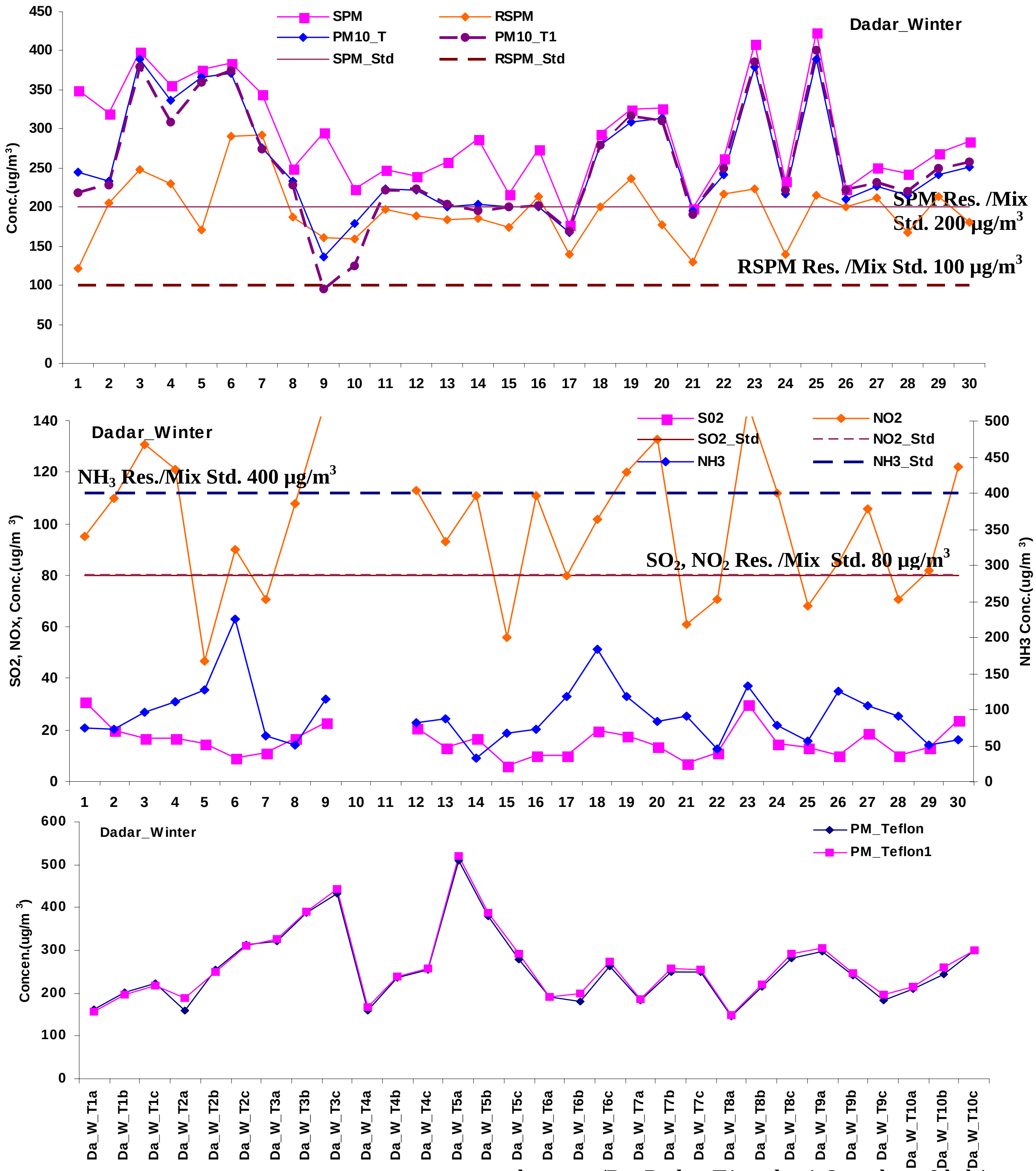


Figure WD.1 : Observed Concentration of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Dadar(Winter)

* High and Low value at particular day indicates outlier due to certain site specific activity.

Figure WD.2 shows the variation of $PM_{2.5}$ and CO during the winter period.

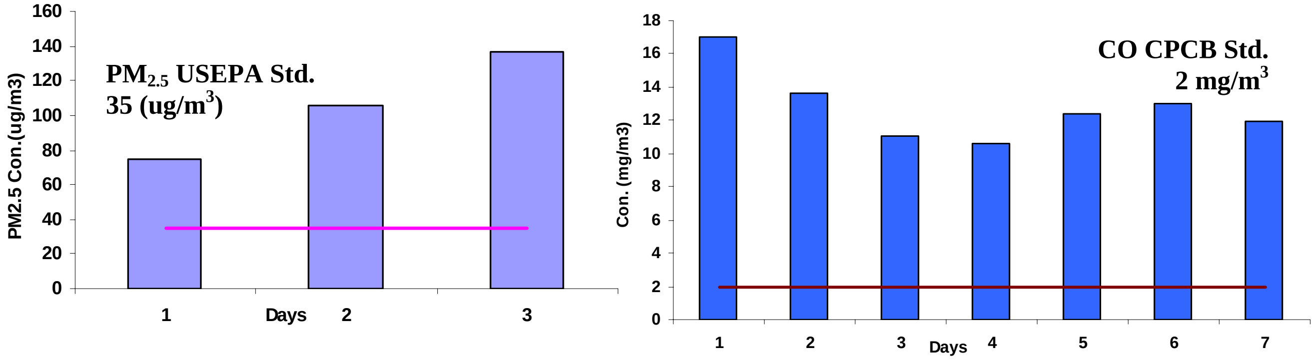


Figure WD.2 : Observed Concentrations of $PM_{2.5}$ and CO at Dadar (Winter)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 $\mu g/m^3$ due to the sources like the vehicular traffic, refuse burning etc which contribute to the fine particulate matter. Automobile exhaust and refuse burning contributes to high CO concentration and it exceeded all the times the CPCB standard of 2 mg/m^3 for the residential and mix use area.

Figure WD.3 shows Methane, Non Methane and THC concentrations and Figure **WD.4** shows NO_2 vs NMHC concentrations during winter season.

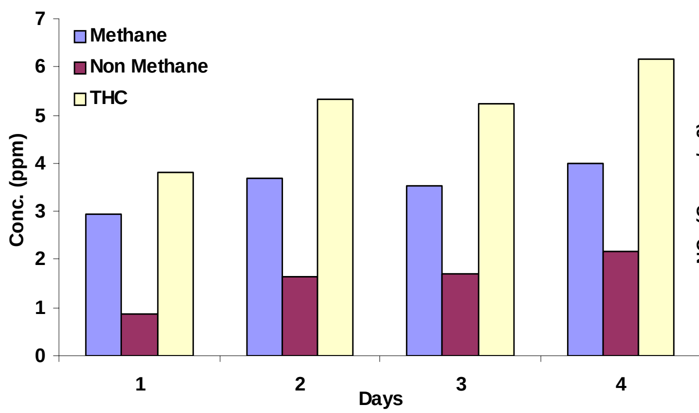


Figure WD.3 : Hydrocarbon Concentration

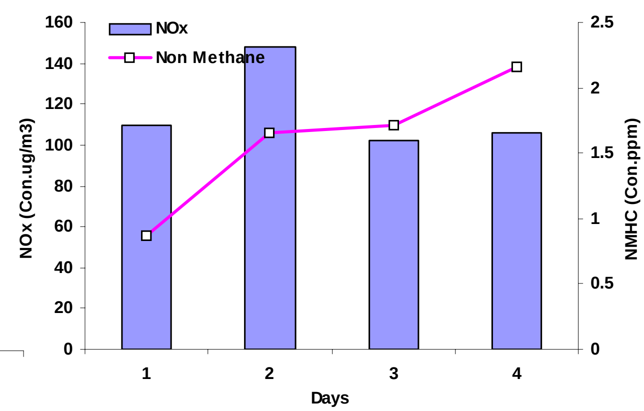


Figure WD.4 : NO_2 and NMHC Concentration

Figure WD.5 presents diurnal variation of O_3 and CO during winter at Dadar**.**

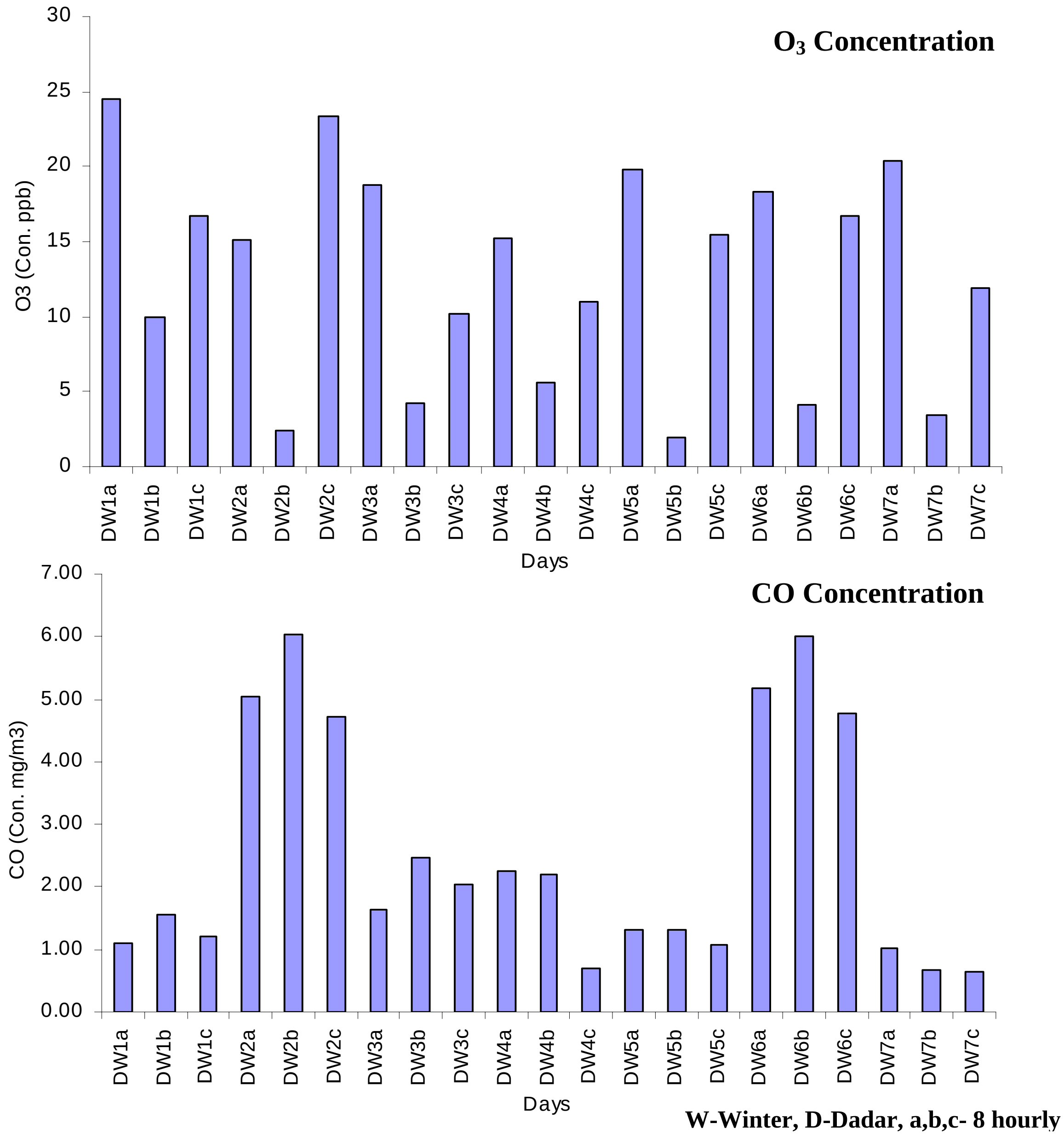


Figure WD.5 : Diurnal variation of O_3 and CO

No significant diurnal variation of CO was observed. Diurnal variation in ozone showed high concentrations during afternoon and morning hours as these timings have more photochemical activity favouring ozone formation

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^-, NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WD.6 and WD.7**

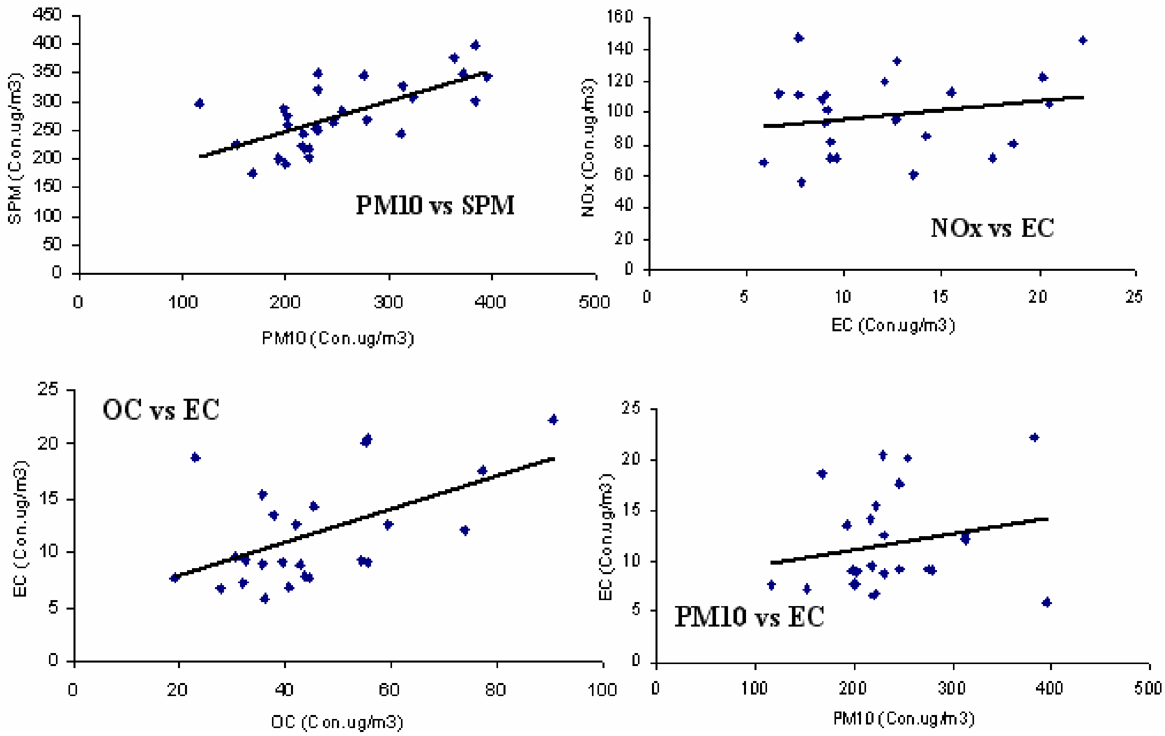


Figure WD.6 : Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.67) due to sources like road dust which contributes to coarse particulate matter and automobile exhaust and refuse burning which contribute to fine particulate matter. EC and NO_2 shows poor correlation indicating that vehicular emission is not the only source for EC. Good correlation between OC and EC (R=0.53) implies that motor vehicles exhaust is probably the dominant source. PM_{10} and EC correlate poorly indicating that the sources contributing to PM_{10} and EC are different.

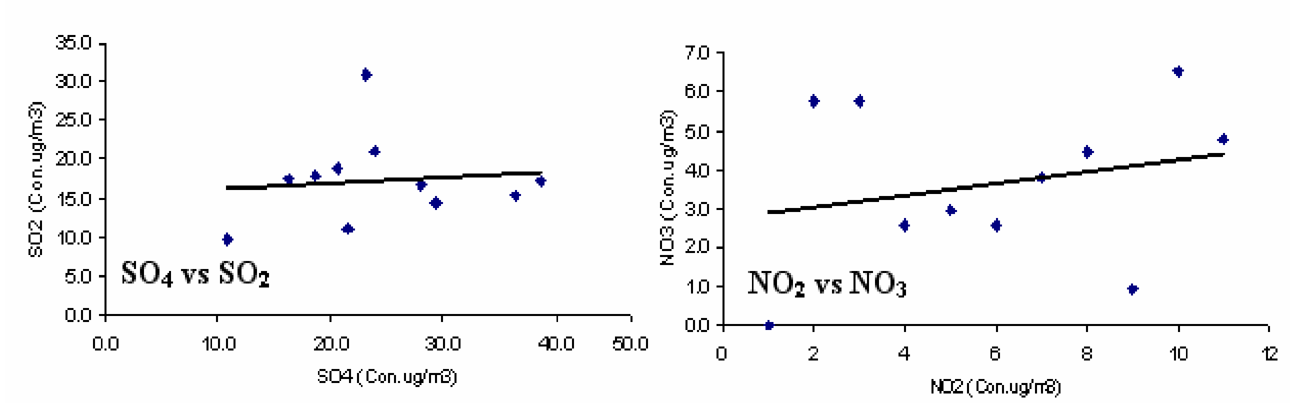


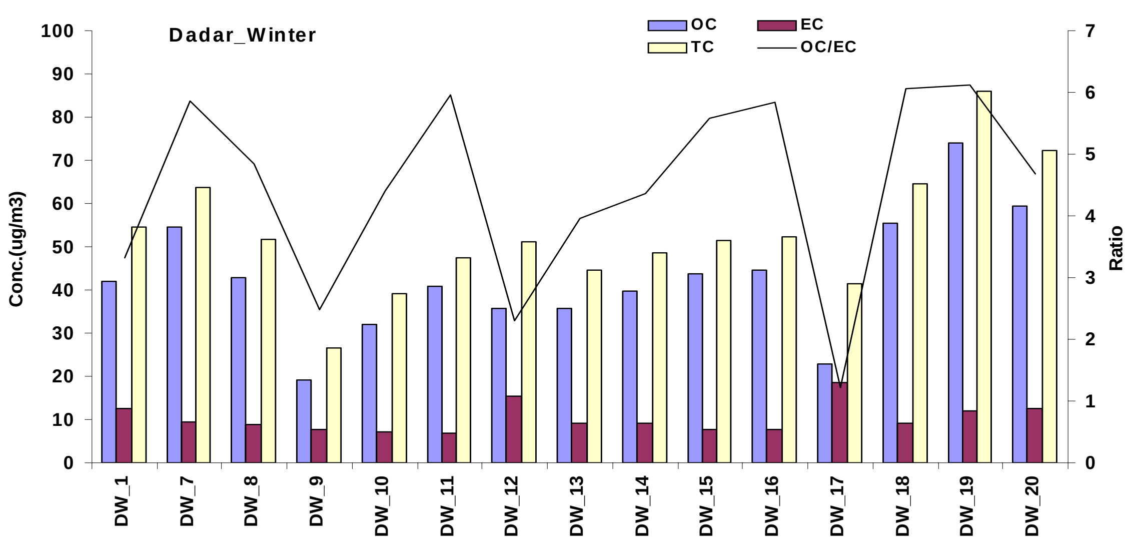
Figure WD.7 : Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} correlate poorly indicating that SO_2 is not getting converted to SO_4^{2-} and is mainly emitted from road dust, vehicular exhaust, refuse burning and due to secondary aerosol formation. NO_2 and NO_3^- show negative correlation indicating that NO_2, to a lesser extent is getting converted to NO_3^-. Correlation plots of NH_4^+ vs SO_4^{2-} and NH_4^+ vs NO_3^- are not plotted due to insufficient data.

Carbon concentrations at Dadar site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WD.8.**

Correlation Matrix of Carbonaceous polluants vs PM_{10}

	PM_{10}	**OC**	**EC**	**TC**
PM_{10}	1.000	.661	.207	.605
OC	.661	1.000	.531	.978
EC	.207	.531	1.000	.693
TC	.605	.978	.693	1.000



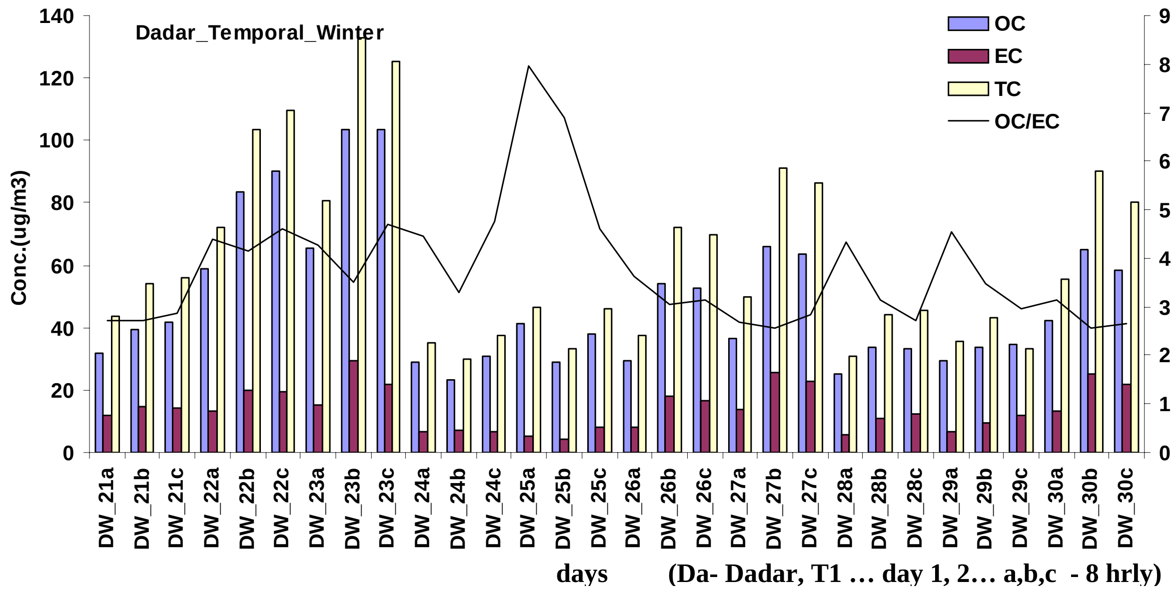


Figure WD.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Dadar Site (Winter)

At Dadar site OC varied between 19-91 μg/m^3 with an average value of 45 μg/m^3. The EC concentration varied between 5.8-22 μg/m^3 with an average value of 11.7 μg/m^3. OC/EC ratio varied from 1.2-6.4 with an average ratio of 4.1. Percentage of OC, EC and TC in PM_{10} was 17.8, 4.6 and 22.4 respectively, whereas in $PM_{2.5}$ it was 21.54, 9.17 and 30.7 respectively.

Mass fraction of elements, ions and carbons in terms of concentrations (μg/m^3) in PM_{10} is presented in **Figure WD.9**.

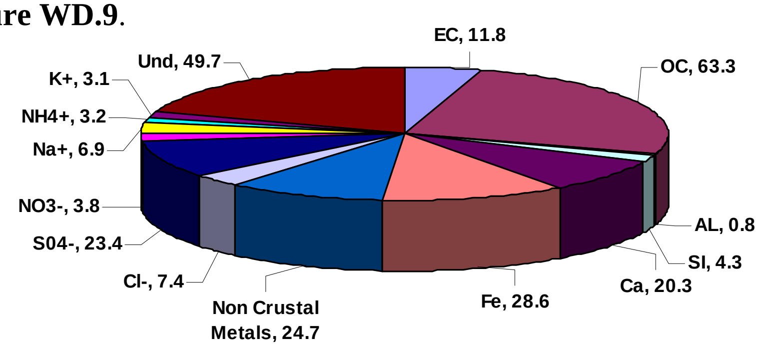


Figure WD.9 : Mass Closure Concentrations (μg/m^3) at Dadar Winter

Percent composition of PM_{10} after mass closure shows that maximum contribution to the total PM_{10} loading is from the carbonaceous fraction. OC and EC account for 25% and 5% respectively and indicate the dominance of contribution of sources like vehicular traffic and refuse burning to PM_{10}. Crustal elements contribute 21% of the particulate matter in the form of sources like road dust. Smelting operations, automobile exhaust contribute to non crustal fraction of the particulate matter. The contribution from ionic fraction accounts for 19% of the total loadings. High concentration of SO_4^{2-} is observed due to road dust, automobile exhaust, secondary aerosols. Sea spray also contributes to ions like Na^+ and Cl^-. 20% of the total fraction is unidentified.

Dharavi Site: The observed concentrations for winter season are presented in **Table WDh.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season at Dharavi are presented in **Figure WDh.1**

Table WDh.1 : Air Quality Status at Dharavi (Winter)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	289.0	859.0	551.7	781.9	123.9	30
RSPM (µg/m^3)	134.0	378.0	250.4	365.2	57.2	30
PM_{10} Tef (µg/m^3)*	139.0	469.0	270.7	446.3	83.5	28
PM_{10} Tef_1 (µg/m^3)*	147.0	467.0	274.3	439.6	86.6	29
$PM_{2.5}$ (µg/m^3)**	67.0	122.0	92.0	NA	27.8	3
SO_2 (µg/m^3)	7.0	21.0	12.5	19.8	3.9	30
NO_2 (µg/m^3)	28.0	119.0	69.6	119.0	20.6	30
NH_3 (µg/m^3)	16.0	148.0	67.4	143.9	31.0	30
CO (mg/m^3)	0.3	3.4	1.2	3.1	1.0	7
Formaldehyde (µg/m^3)	27.5	45.9	36.7	NA	13.0	2
CH_4 (ppm)	4.0	4.9	4.4	NA	0.4	4.0
Nonmethane HC (ppm)	2.0	2.6	2.3	NA	0.3	4.0
Total HC (ppm)	4.1	4.8	4.4	NA	0.3	4.0
O_3 (ppb)	15.4	25.6	21.5	25.5	3.6	7.0
OC (µg/m^3)	23.4	115.5	54.1	106.7	23.1	28
EC (µg/m^3)	4.1	21.7	11.6	20.8	5.2	28
TC (µg/m^3)	27.8	131.4	65.8	121.8	26.8	28

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM were exceeding permissible limit of CPCB i.e. 200 and 100 µg/m^3 respectively. The ratio of RSPM to SPM was 45% and $PM_{2.5}$ to PM_{10} was 34% indicating dominance of coarse particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 21% of the time than the CPCB standard. The monthly average of PM_{10} was 271.9 µg/m^3. No particular temporal trends of PM_{10} was observed. CO values ranged between 0.3-3.4 mg/m^3, formaldehyde ranged between 27.5-45.9 µg/m^3, Total Hydrocarbon ranged between 4.13-4.76 ppm whereas Ozone concentrations ranged with 15.39-25.60 ppb.

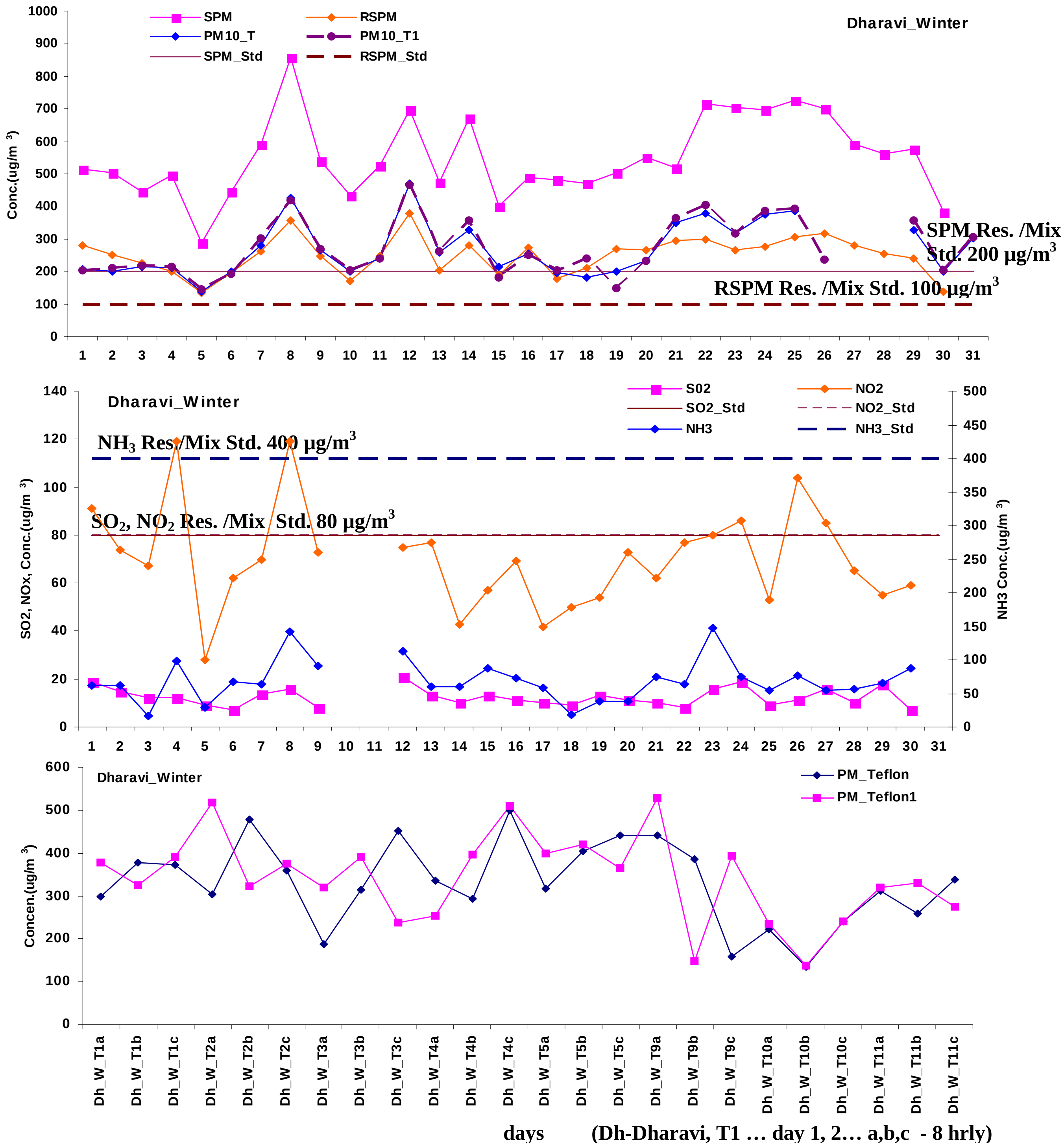


Figure WDh.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Dharavi During Winter

* Low value at particular day indicates outlier due to instrument problem.

Figure WDh.2 shows the variation of $PM_{2.5}$ and CO during the winter period.

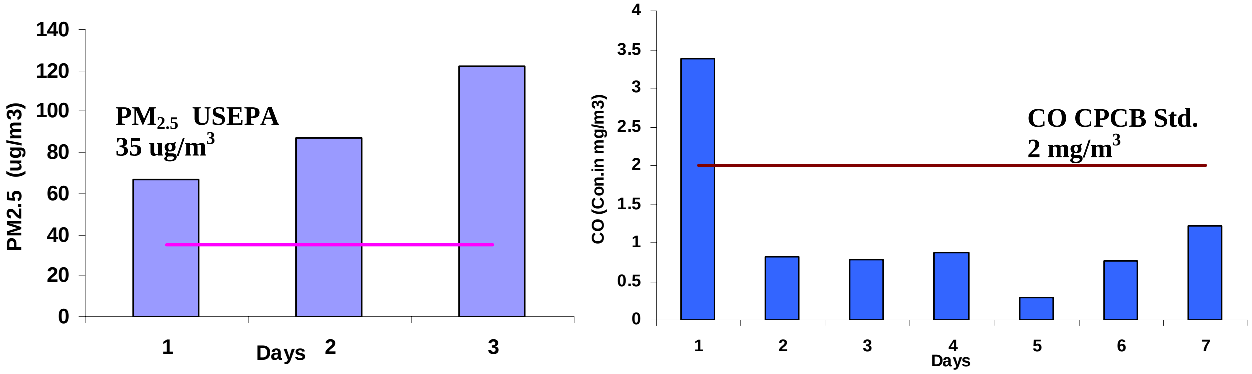


Figure WDh.2: Observed Concentrations of $PM_{2.5}$ and CO at Dharavi (Winter)

High concentration of $PM_{2.5}$ is observed due to smelting operations, biomass burning, oil burning etc and it exceeds all the time the US EPA standard of 35 µg/m^3. The CO concentration during the sampling period exceeded 14.3% of the times the CPCB standard of 2 mg/m^3 for the residential and mix use area due to biomass burning and vehicular exhaust

Figure WDh.3 shows Methane, Non Methane and THC concentrations and **Figure WDh.4** shows NO_2 vs NMHC concentrations during winter season

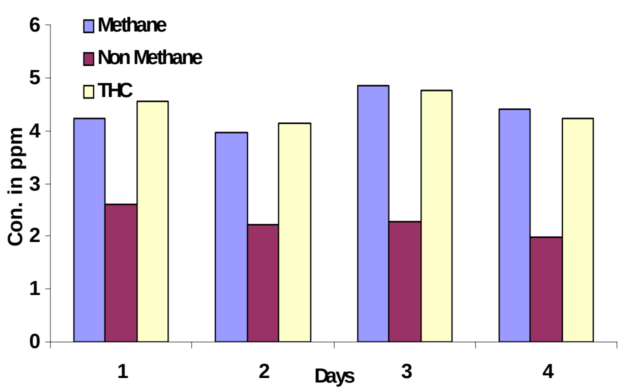


Figure WDh.3: Hydrocarbon Concentration

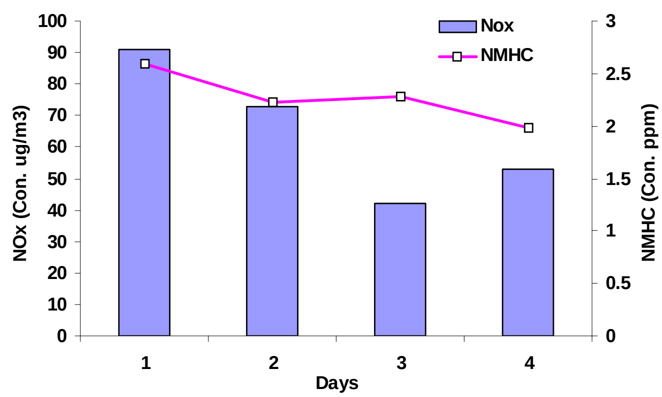


Figure WDh.4: NO_2 and NMHC Concentration

Figure WDh.5 presents diurnal variation of O_3 and CO during winter.

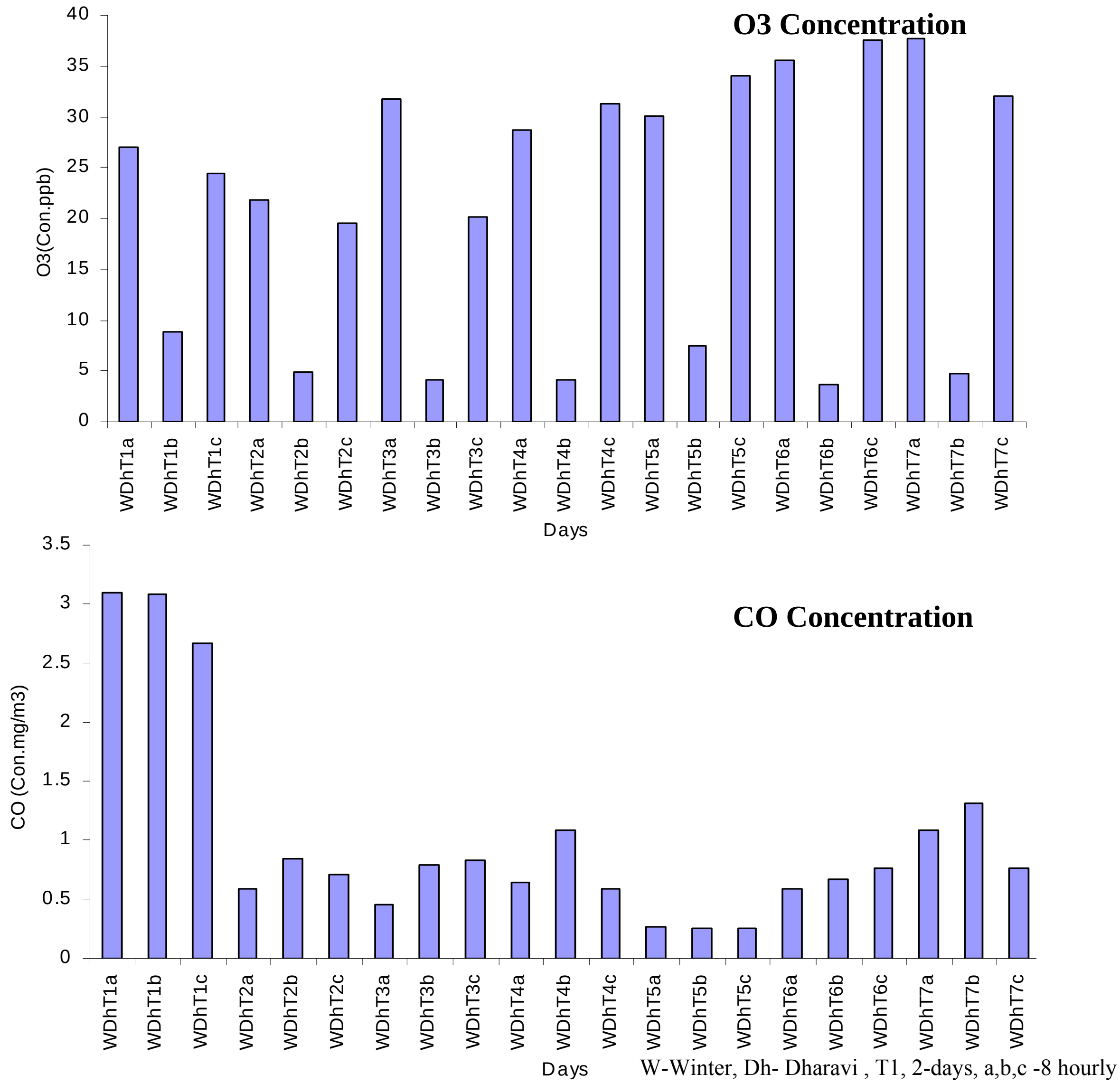


Figure WDh.5: Diurnal variation of O_3 and CO

CO doesn't show any particular trend in diurnal variation. Diurnal variation in ozone showed high concentrations during afternoon and morning hours as these timings have more photochemical activity favouring ozone formation

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WDh.6 and WDh.7.**

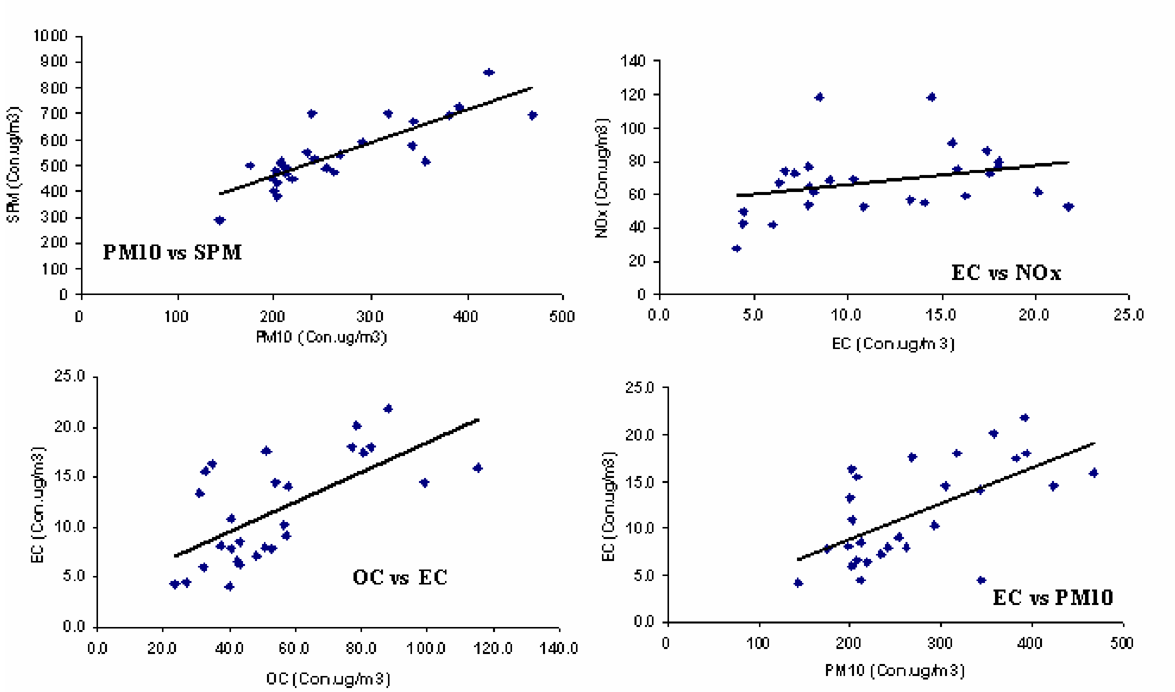


Figure WDh.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.83) due to sources like soil which contributes to coarse particulate matter and smelting, biomass burning and oil burning which contribute to fine particulate matter. EC and NO_2 correlate moderately indicating that vehicular emission is not the only source for EC. EC and OC show good correlation (R=0.66) due to presence of contributing factors like biomass burning, coal combustion, oil burning and vehicles. PM_{10} and EC show good correlation (R=0.62) indicating that the sources such as biomass burning, coal combustion and oil burning contribute to PM_{10} and EC.

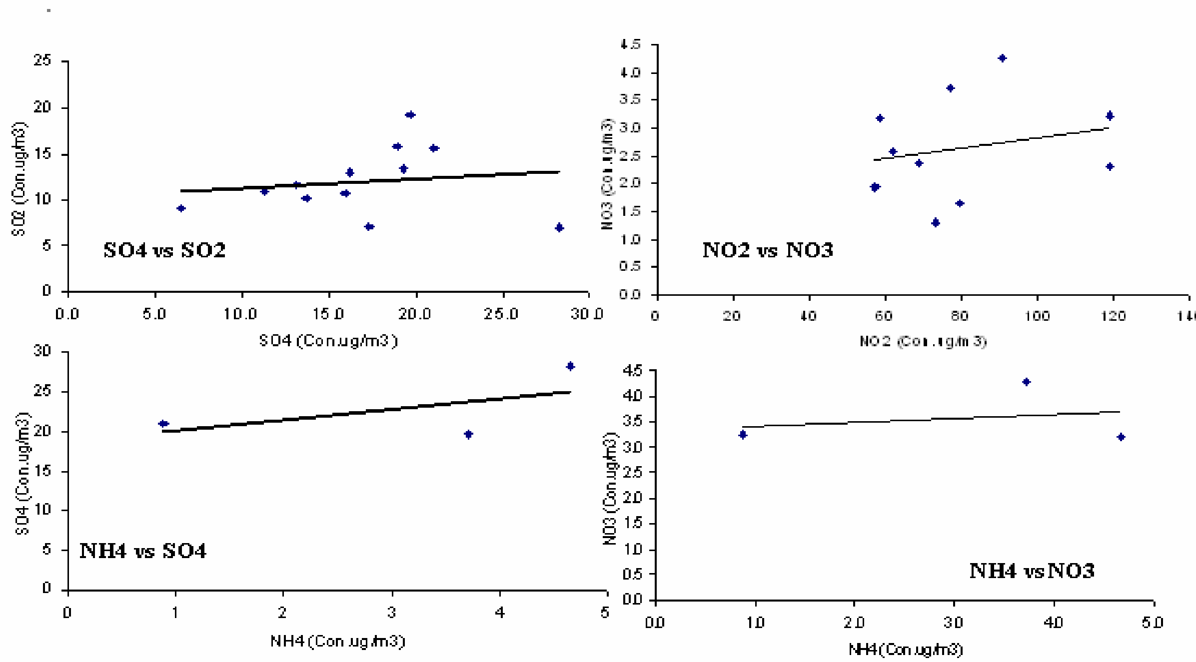


Figure WDh.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-}correlate poorly indicating that SO_2 is not getting converted to SO_4^{2-}. NO_2 and NO_3^- also show poor correlation indicating that NO_2 is not getting converted to NO_3^-. NH_4^+ and SO_4^{2-} show good correlation (R=0.59) indicating that NH_4^+ is neutralizing SO_4^{2-} as the conditions are favouring the formation of $(NH_4)_2SO_4$. $NH_4^+$and NO_3^- poor correlation indicating that NH_4^+ is not neutralizing NO_3^-.

Carbon concentrations at Dharavi site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WDh.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM10	OC	EC	TC
PM_{10}	1.000	.859	.623	.861
OC	.859	1.000	.658	.989
EC	.623	.658	1.000	.761
TC	.861	.989	.761	1.000

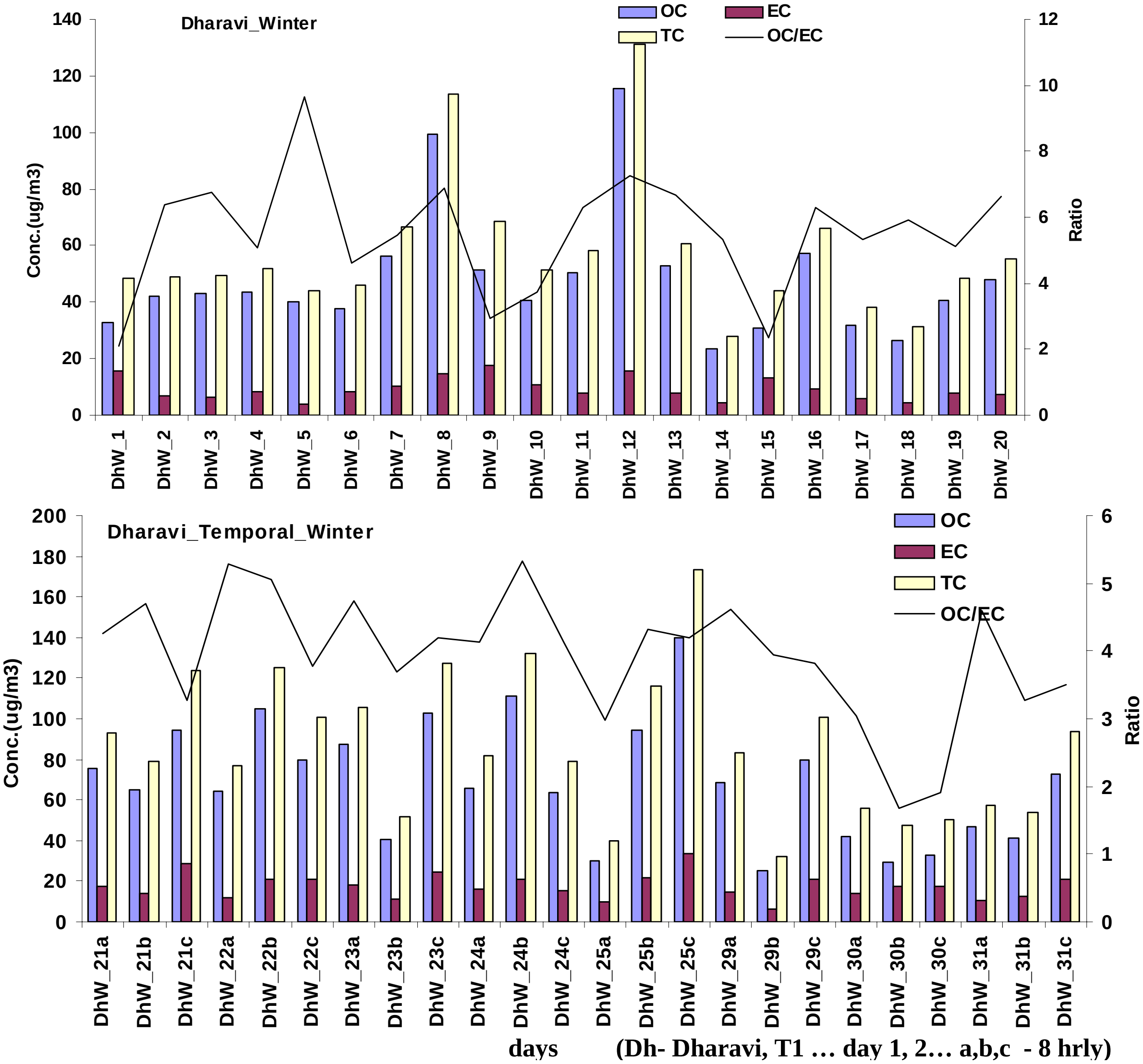


Figure WDh.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Dharavi Site (Winter)

At Dharavi site OC varied between 23.4-115.5 μg/m^3 with an average value of 54.1 μg/m^3. The EC concentration varied between 4.1-21.7 μg/m^3 with an average value of 11.6 μg/m^3. OC/EC ratio varied from 2.1 -9.6 with average ratio of 5.1. Percentage of OC, EC and TC in PM$_{10}$ was whereas 11.7, 5.8 and 17.6 in PM$_{2.5}$ it was 34.7, 17.2 and 51.8 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure WDh.9.**

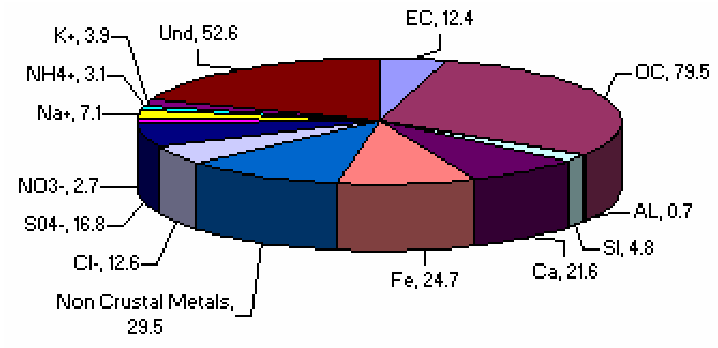


Figure WDh.9: Mass Closure Concentrations (µg/m^3) at Dharavi

Percent composition of PM_{10} after mass closure indicates that carbonaceous fractions contributes maximum to PM_{10}. OC and EC contribution accounts for 29% and 5% respectively as the sources contributing to OC and EC like biomass burning, coal combustion, oil burning and vehicles are predominant in this area. Crustal elements due to soil account for 19% of the total PM_{10} load whereas smelting, coal combustion etc contributes to non crustal component which accounts for 11% of the total particulate matter. Ions such as Na^+, Cl^- and SO_4^{2-} are originating from sources like sea spray, biomass burning etc; whereas 19% fraction of the total particulate matter is unidentified.

Khar Site: The observed concentrations for winter season are presented in **Table WK.1.** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season are presented in **Figures WK.1.**

Table WK.1 : Air Quality Status at Khar (Winter)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	288.0	812.0	494.7	741.8	120.8	30
RSPM (µg/m^3)	110.0	423.0	259.0	401.0	74.6	30
PM_{10} Tef (µg/m^3)*	163.0	458.0	270.6	440.0	82.0	30
PM_{10} Tef_1 (µg/m^3)*	139.0	423.0	255.6	402.7	78.9	30
$PM_{2.5}$ (µg/m^3)**	91.0	110.0	102.0	NA	9.8	3
SO_2 (µg/m^3)	6.0	41.0	11.7	28.6	6.7	28
NO_2 (µg/m^3)	39.0	129.0	74.8	124.1	25.0	28
NH_3 (µg/m^3)	13.0	342.0	68.1	300.4	71.2	28
CO (mg/m^3)	0.8	5.2	2.7	5.1	1.7	7
Formaldehyde (µg/m^3)	47.8	54.8	51.3	NA	4.9	2
CH_4 (ppm)	1.9	3.0	2.5	NA	0.5	4
Nonmethane HC (ppm)	0.9	1.1	1.0	NA	0.2	4
Total HC (ppm)	2.8	4.0	3.5	NA	0.4	4
O_3 (ppb)	7.5	12.0	9.5	11.8	1.5	7.0
OC (µg/m^3)	23.9	98.4	56.5	98.3	23.9	30
EC (µg/m^3)	7.0	26.5	14.5	24.9	5.3	30
TC (µg/m^3)	34.8	122.0	71.0	118.1	27.4	30

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM were exceeding permissible limit of CPCB i.e. 200 and 100 µg/m^3 respectively. The ratio of RSPM to SPM was 52% and $PM_{2.5}$ to PM_{10} was 38% indicating dominance of coarse particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 32% of the time than the CPCB standard. The monthly average of PM_{10} was 263.1 µg/m^3. Temporal trends of PM_{10} shows concentrations were high during early morning. CO values ranged between 0.8-5.2 mg/m^3, formaldehyde ranged between 47.8-54.8 µg/m^3, Total Hydrocarbon ranged between 2.8-4.0 ppm whereas Ozone concentrations ranged with 7.5-12.0 ppb.

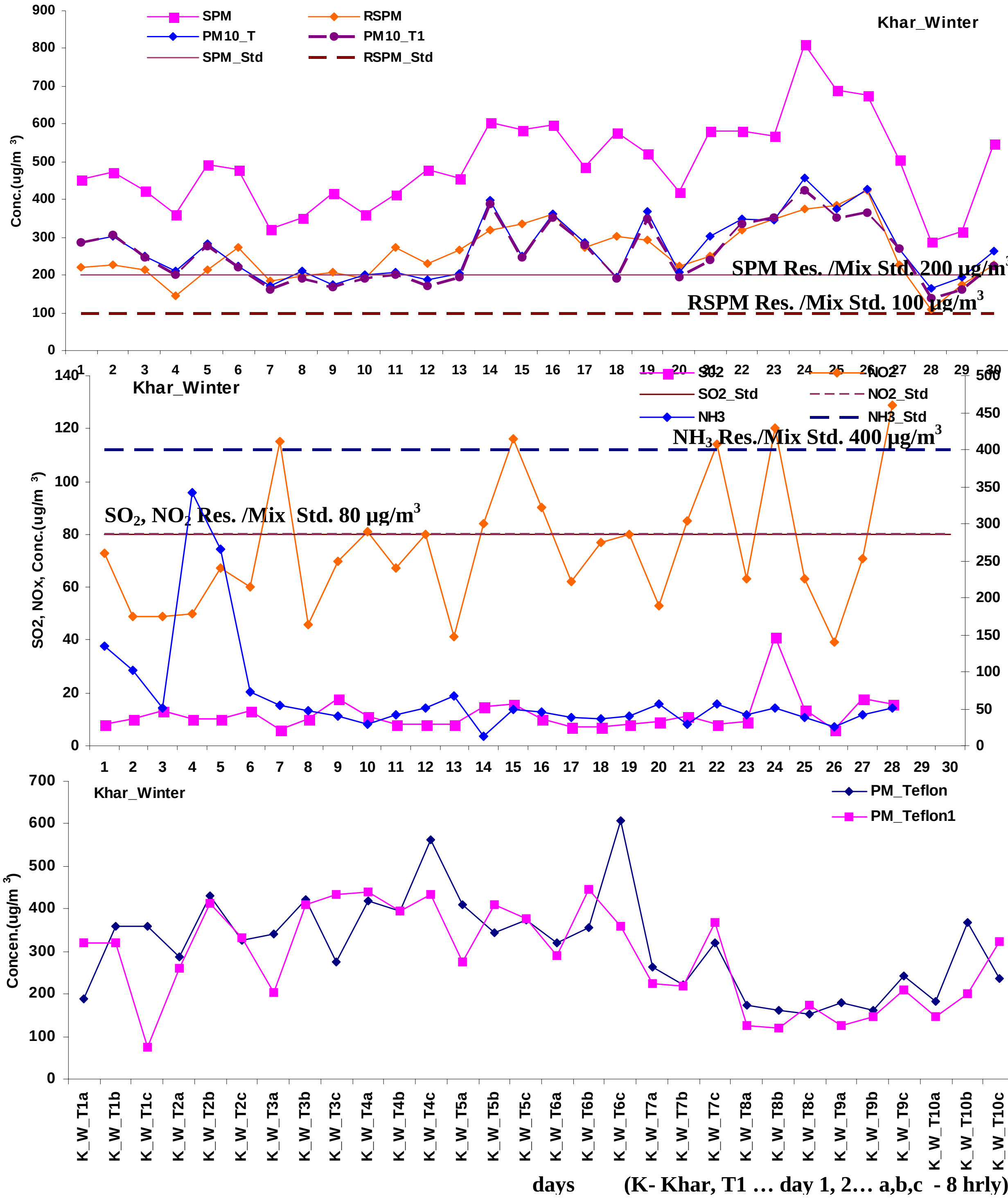
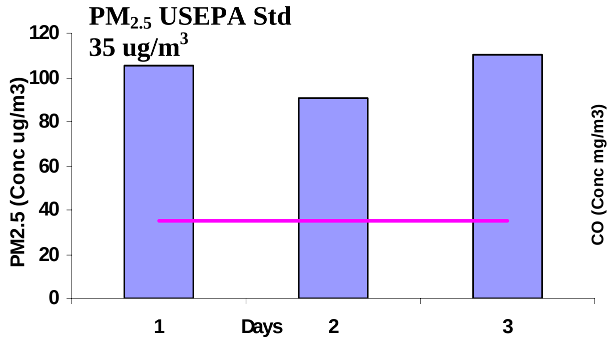


Figure WK.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Khar During Winter

* High value at particular day indicates outlier due to certain site specific activity.

Figure WK.2 shows the variation of $PM_{2.5}$ and CO during the summer season.



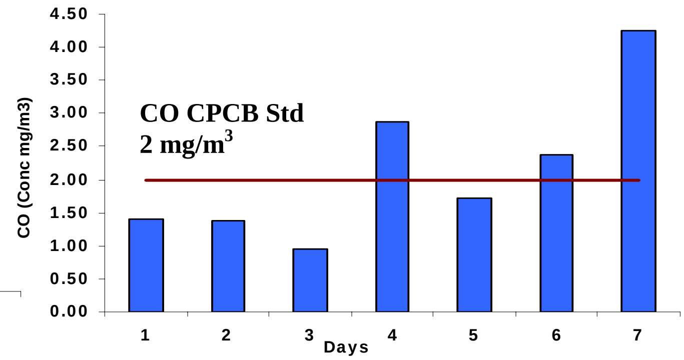


Figure WK.2 : Observed Concentrations of $PM_{2.5}$ and CO at Khar (Winter)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 µg/m^3 due to the sources like the vehicular traffic, and biomass burning which contribute to the fine particulate matter. The CO concentration during the sampling period exceeded 42.8% of the times the CPCB standard of 2 µg/m^3 for the residential and mix use area due to sources like biomass burning and vehicular exhaust.

Figure WK.3 shows Methane, Non Methane and THC concentrations and **Figure WK.4** shows NO_2 vs NMHC concentrations during post monsoon season

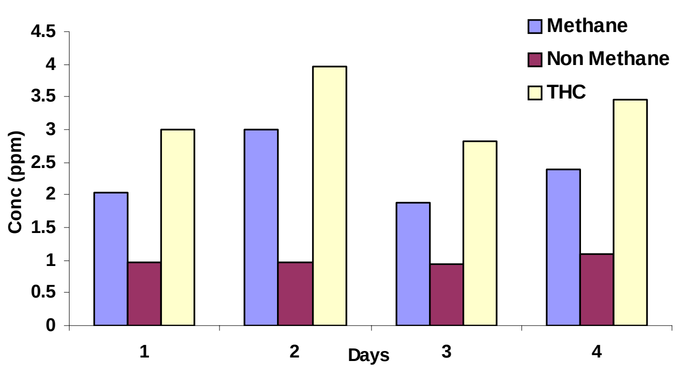


Figure WK.3 : Hydrocarbon Concentration

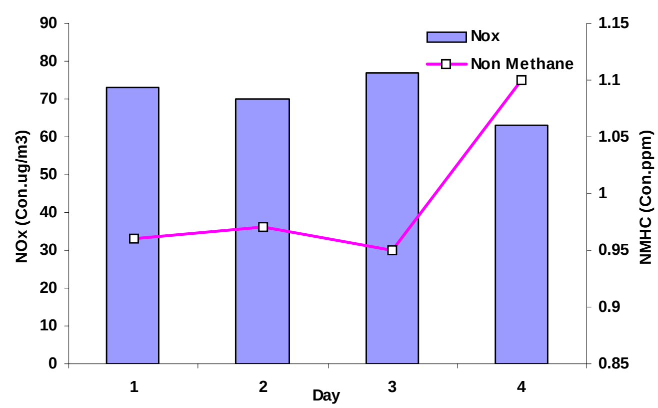


Figure WK.4 : NO_2 and NMHC Concentration

Figure WK.5 presents diurnal variation of O_3 and CO during winter.

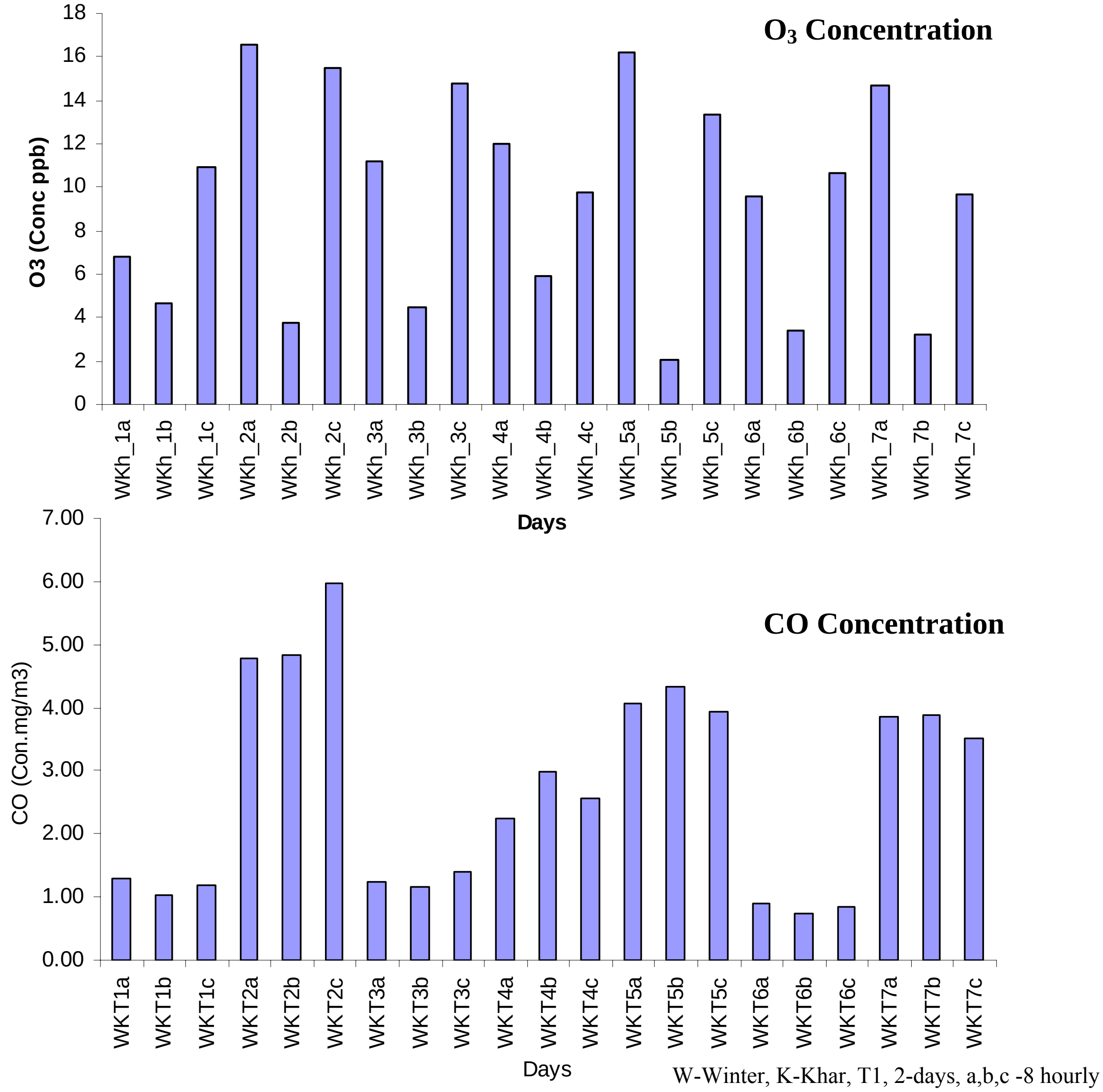


Figure WK.5 : Diurnal variation of O_3 and CO

No significant trend is observed in diurnal variation of CO. Diurnal variation in ozone showed high concentrations during afternoon and morning hours as these timings have more photochemical activity favouring ozone formation

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WDh.6 and WDh.7.**

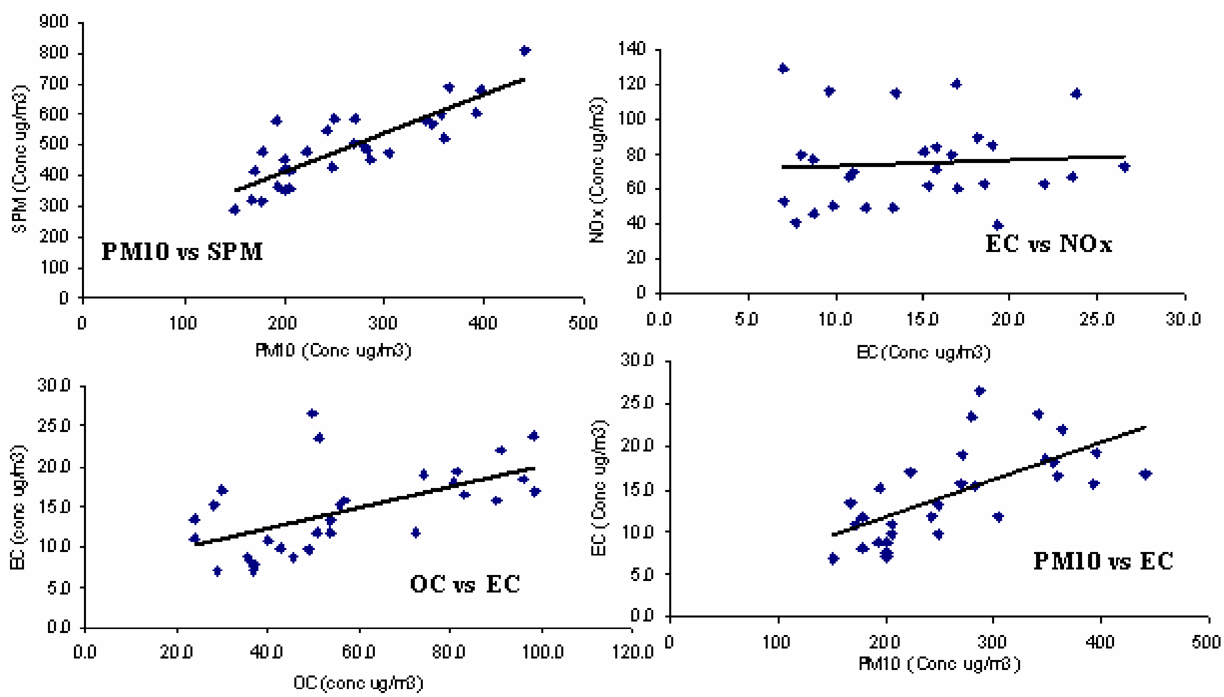


Figure WK.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.83) indicating the presence of sources contributing to coarse particulate matter like soil and road dust along with sources like vehicles, and biomass burning contributing to fine particles. EC and NO_2 correlate poorly indicating that vehicular emission is not the only source for EC. EC and OC show good correlation (R=0.59) due to sources like vehicular exhaust and biomass burning which contribute to OC and EC. PM_{10} and EC show good correlation (R=0.66) as sources such as vehicles and biomass burning, both contribute to PM_{10} and EC.

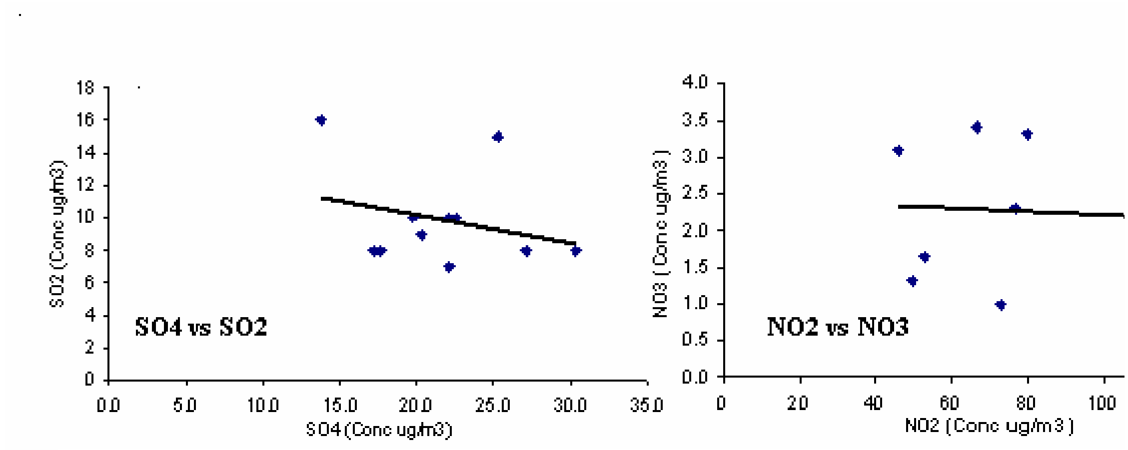


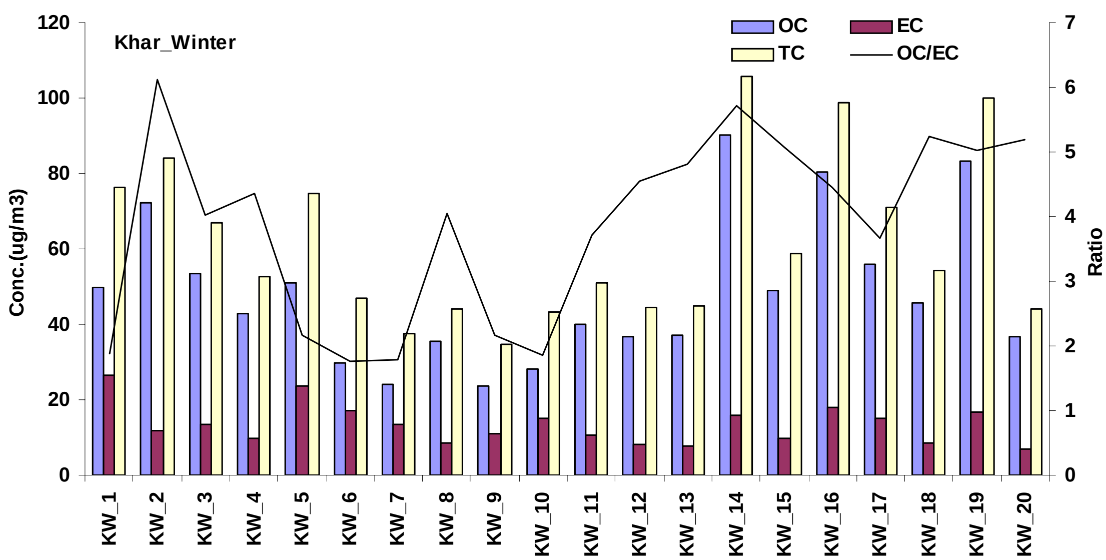
Figure WK.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show moderate negative correlation (R=-0.29) indicating that SO_2 is getting converted to SO_4^{2-} to a very less extent. NO_2 and NO_3^- show negative correlation indicating that NO_2 is getting converted to NO_3^- in a limited way. Correlation of NH_4^+ vs SO_4^{2-} and NH_4^+vs NO_3^- could not be plotted due to insufficient data sets.

Carbon concentrations at Khar site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WK.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	**OC**	**EC**	**TC**
PM_{10}	1.000	.927	.660	.938
OC	.927	1.000	.585	.988
EC	.660	.585	1.000	.706
TC	.938	.988	.706	1.000



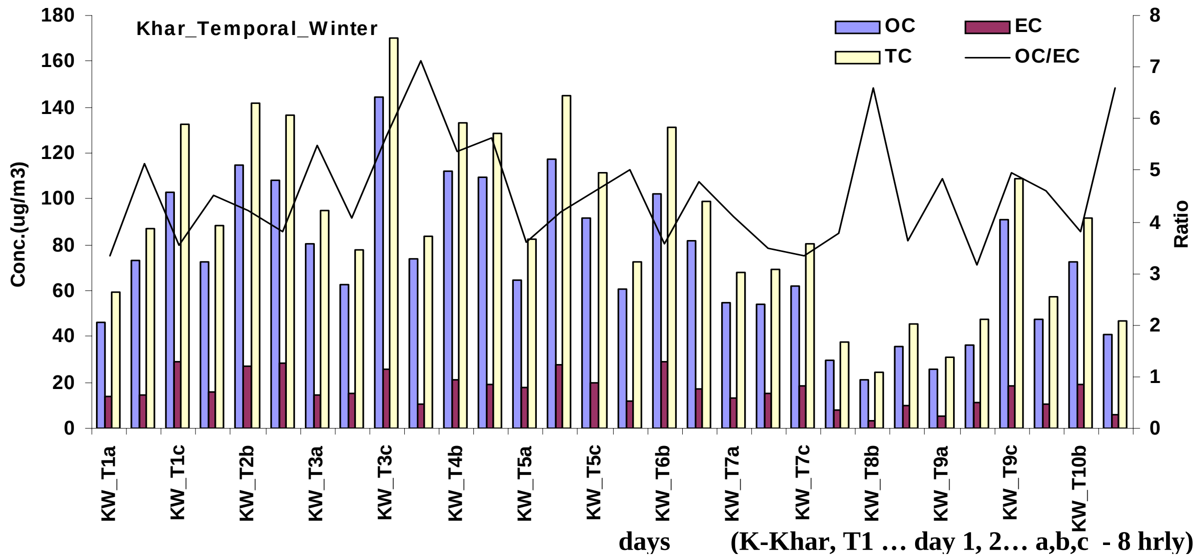


Figure WK.8 : 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Khar Site (Winter)

At Khar site OC varied between 23.9-98.4 µg/m^3 with an average value of 56.5 µg/m^3. The EC concentration varied between 7.0-26.5 µg/m^3 with an average value of 14.5 µg/m^3. OC/EC ratio varied from 1.8 to 6.1 with an average ratio of 4.1. Percentage of OC, EC and TC in PM_{10} was 21.5, 5.5 and 27.0 whereas in $PM_{2.5}$ it was 29.4, 13.3 and 42.7 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure WK.9**.

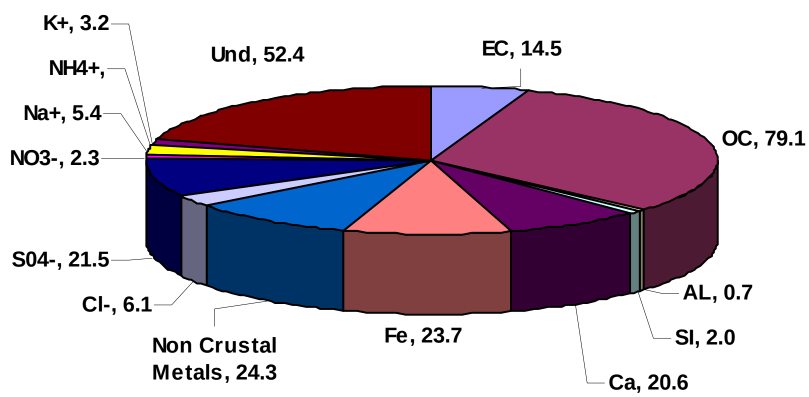


Figure WK.9 : Mass Closure Concentrations (µg/m^3) at Khar Winter

Percent composition of PM_{10} after mass closure indicates that carbonaceous fractions contributes maximum to PM_{10}. OC and EC contribution accounts for 31% and 6% respectively as the sources contributing to OC and EC like automobile exhaust and biomass burning are observed in this area. Crustal elements due to soil and road dust account for 18% of the total PM_{10} load whereas coal combustion etc contributes to non crustal component which accounts for 10% of the total particulate matter. Out of the total particulate matter, ions contribute to 15%. SO_4^{2-} has highest concentration amongst all the ions due to sources like vehicles, road dust and biomass burning in the study area. 20% fraction of the total particulate matter is unidentified.

Andheri Site: The observed concentrations for winter season are presented in **Table WA.1.** The detailed date wise concentrations are presented in **Annexure 2.2**. The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season are presented in **Figures WA.1**

Table WA.1: Air Quality Status at Andheri (Winter)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	207.7	570.0	396.5	566.2	98.1	29
RSPM (µg/m^3)	118.0	339.0	222.2	328.0	53.8	30
PM_{10} Tef (µg/m^3)*	87.0	438.0	241.7	391.6	70.0	30
PM_{10} Tef_1 (µg/m^3)*	120.0	429.0	231.8	389.6	66.5	30
$PM_{2.5}$ (µg/m^3)**	103.0	140.0	121.0	NA	18.5	3
SO_2 (µg/m^3)	5.0	26.0	11.2	24.8	5.1	30
NO_2 (µg/m^3)	29.0	130.0	78.7	121.3	21.2	30
NH_3 (µg/m^3)	26.0	82.0	56.7	81.4	16.6	30
CO (mg/m^3)	0.6	1.6	1.1	1.6	0.4	7
Formaldehyde (µg/m^3)	27.4	28.0	27.7	NA	0.4	2
CH_4 (ppm)	2.6	3.8	3.3	NA	0.5	4
Nonmethane HC (ppm)	0.8	1.1	0.9	NA	0.2	4
Total HC (ppm)	3.6	4.7	4.1	NA	0.5	4
O_3 (ppb)	7.8	12.9	10.1	12.8	1.8	7
OC (µg/m^3)	25.6	103.3	47.8	95.7	18.2	28
EC (µg/m^3)	3.0	21.2	9.3	19.0	4.5	28
TC (µg/m^3)..	30.1	120.2	57.1	114.9	22.2	28

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages of suspended particulate matter and RSPM were exceeding all the times than permissible limit of CPCB i.e. 200 and 100 µg/m^3 respectively. The ratio of RSPM to SPM was 57% and $PM_{2.5}$ to PM_{10} was 51% indicating dominance of coarse particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 40% of the time than the CPCB standard. The monthly average of PM_{10} was 236.8 µg/m^3.Temporal trends of PM_{10} shows high concentrations during early morning. CO values ranged between 0.6-1.6 mg/m^3, formaldehyde ranged between 27.4-28.0 µg/m^3, Total Hydrocarbon ranged between 3.6-4.7 ppm whereas Ozone concentrations ranged with 7.8-12.9 ppb.

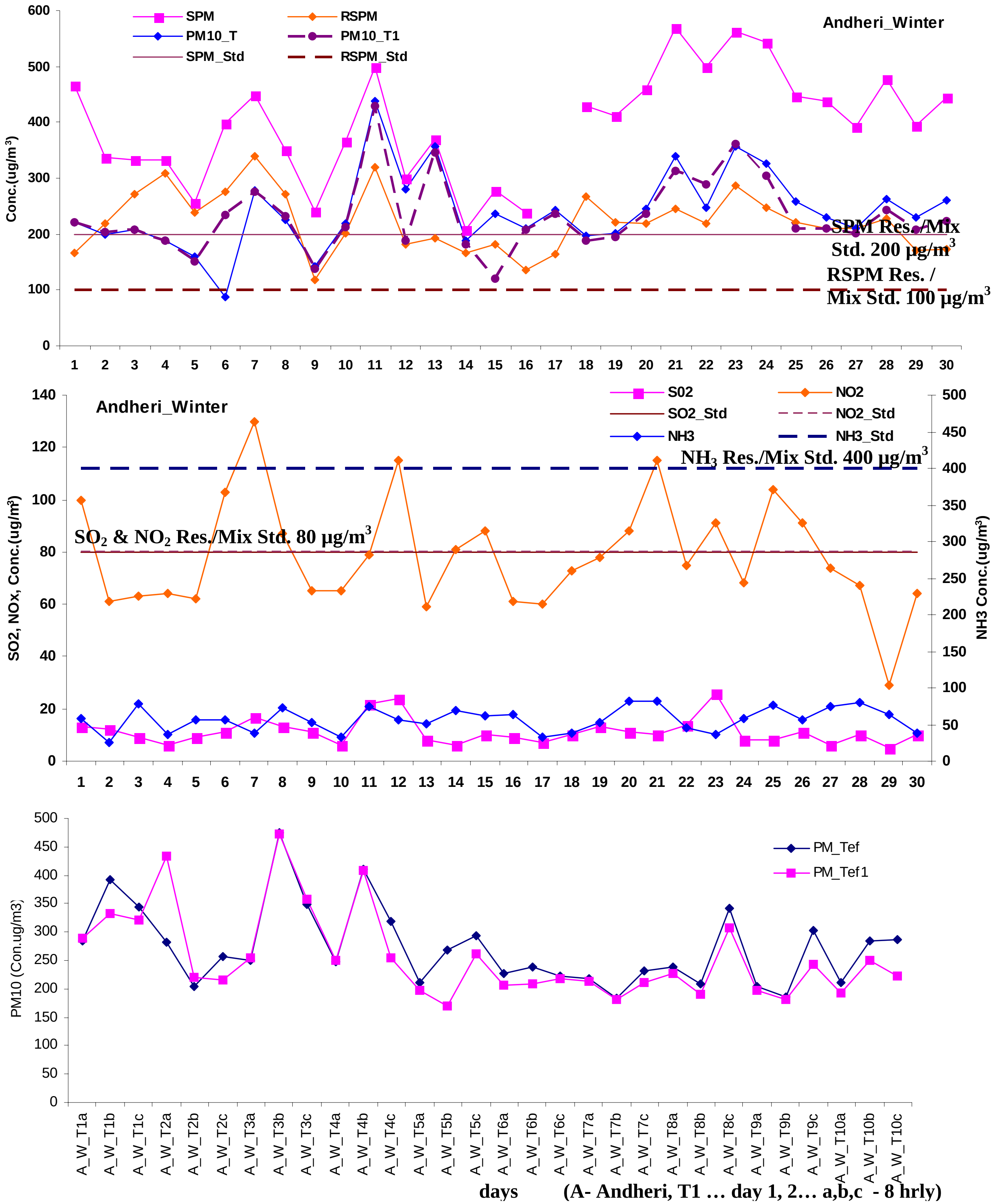


Figure WA.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Andheri During Winter

* High value at particular day indicates outlier due to certain site specific activity.

Figure WA.2 presents the variation of $PM_{2.5}$ and CO during winter.

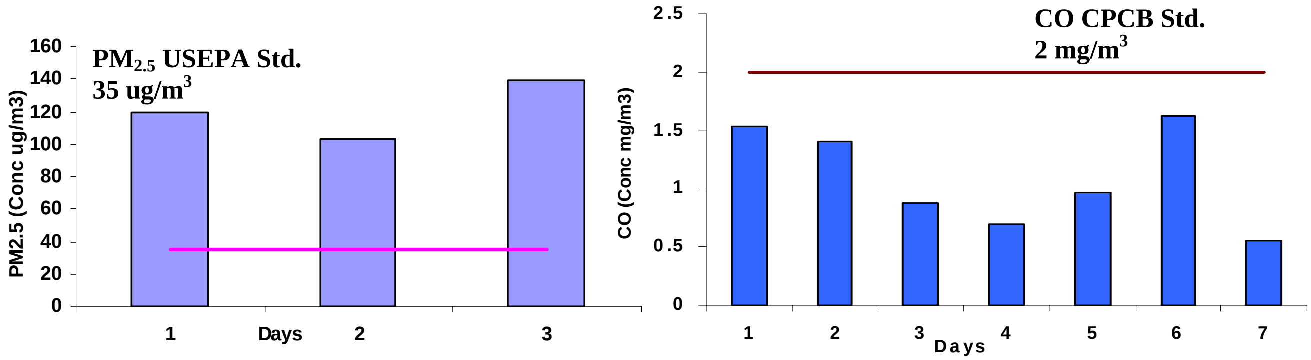


Figure WA.2: Observed Concentrations of $PM_{2.5}$ and CO at Andheri (Winter)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 $\mu g/m^3$ due to the sources like the vehicular traffic, coal burning, biomass burning and oil burning which contribute to the fine particulate matter. The CO concentration during the sampling period was within the limits of CPCB standard of 2 mg/m^3 for the residential and mix use area.

Figure WA.3 shows Methane, Non Methane and THC concentrations and **Figure WA.4** shows NO_2 vs NMHC concentrations during winter season.

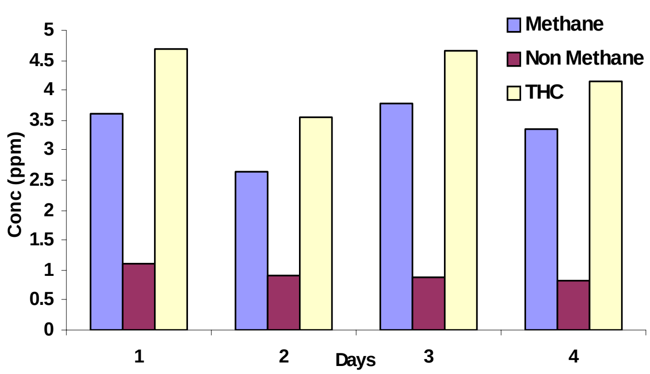


Figure WA.3 : Hydrocarbon Concentration

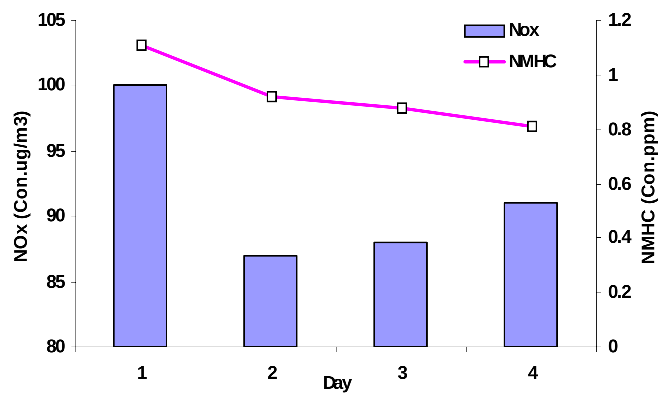


Figure WA.4 : NO_2 and NMHC Concentration

Figure WA.5 shows the diurnal variation of O_3 and CO during winter**.**

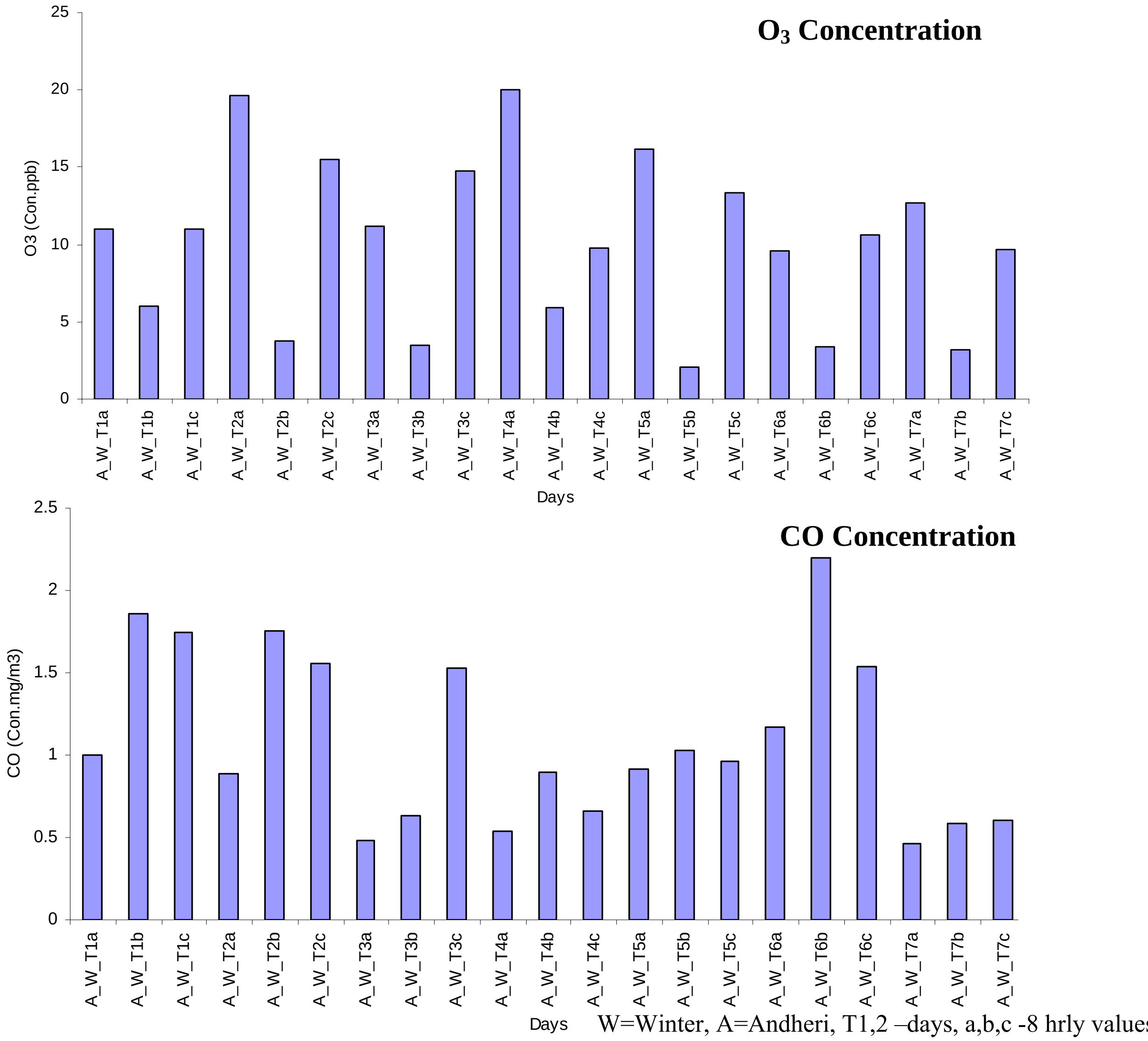


Figure WA.5: Diurnal variation of O_3 and CO

Diurnal variation in CO mostly shows high values during night time due to biomass burning. Diurnal variation in ozone showed high concentrations during afternoon and morning hours as these timings have more photochemical activity favouring ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WA.6 and WA.7.**

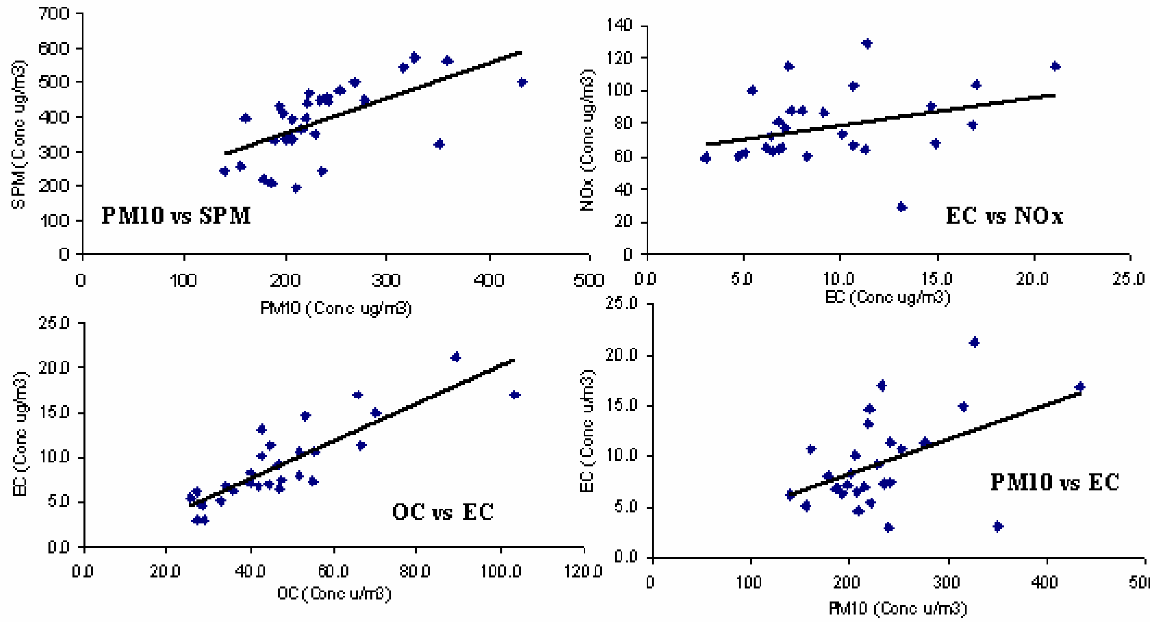


Figure WA.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show good correlation (R=0.62) indicating the presence of sources contributing to coarse particulate matter like soil and road dust along with sources like vehicles, smelting and biomass burning which contribute to fine particulate matter. EC and NO_2 correlate moderately indicating that vehicular emission is not the only source for EC. Good correlation between OC and EC (R=0.85) implies that motor vehicles exhaust is probably the dominant source as site being kerbsite. PM_{10} and EC show moderate correlation.

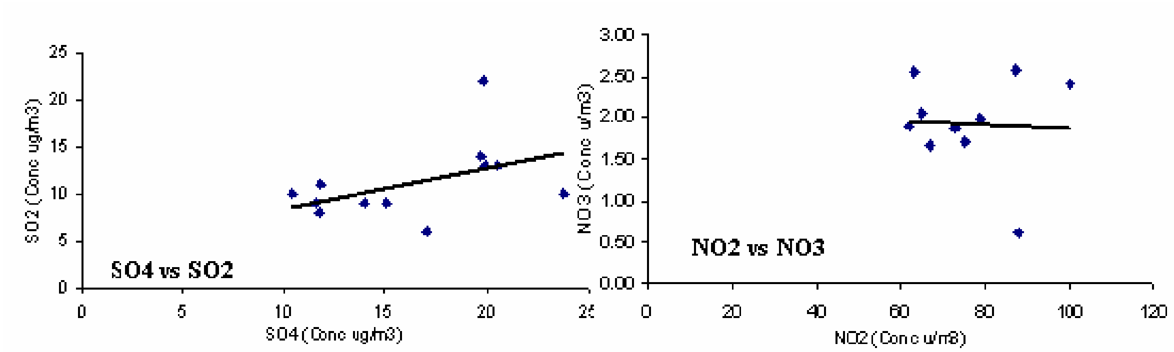


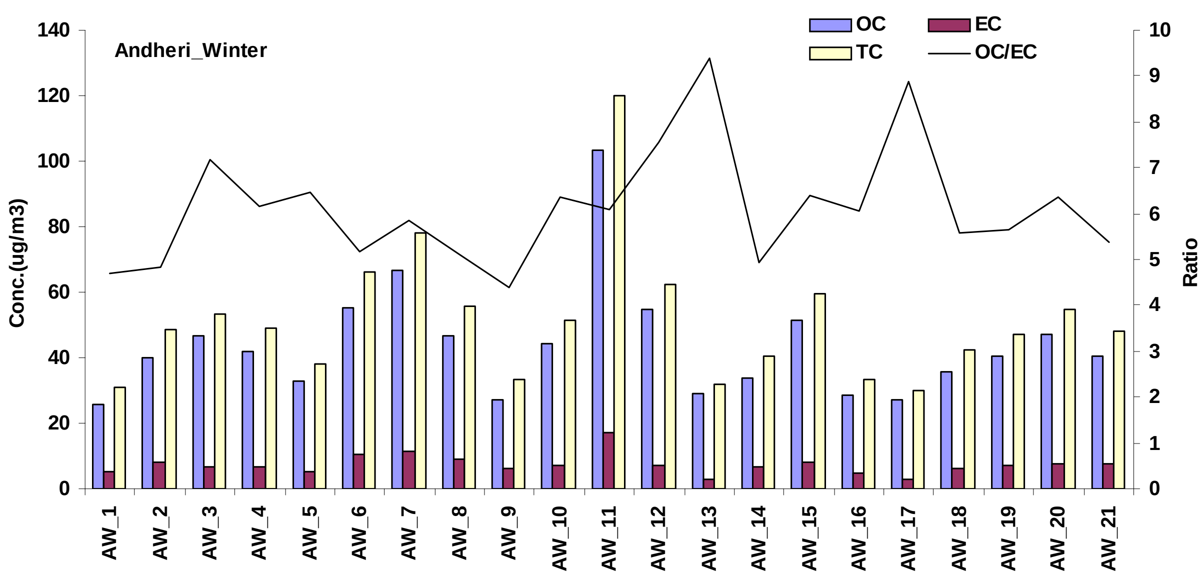
Figure WA.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show moderate correlation (R=0.45) indicating that SO_2 is not getting converted to SO_4^{2-} and it is mainly from other sources like road dust, vehicles and biomass burning. NO_2 and NO_3^- show moderate negative correlation indicating that NO_2 is not getting converted to NO_3^- and it could be due to other sources. Correlation plots for NH_4^+ vs. SO_4^{2-} and NH_4^+ and NO_3^- could not be plotted due to insufficient data.

Carbon concentrations at Andheri site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2.** 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WA.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.666	.477	.644
OC	.666	1.000	.853	.995
EC	.477	.853	1.000	.903
TC	.644	.995	.903	1.000



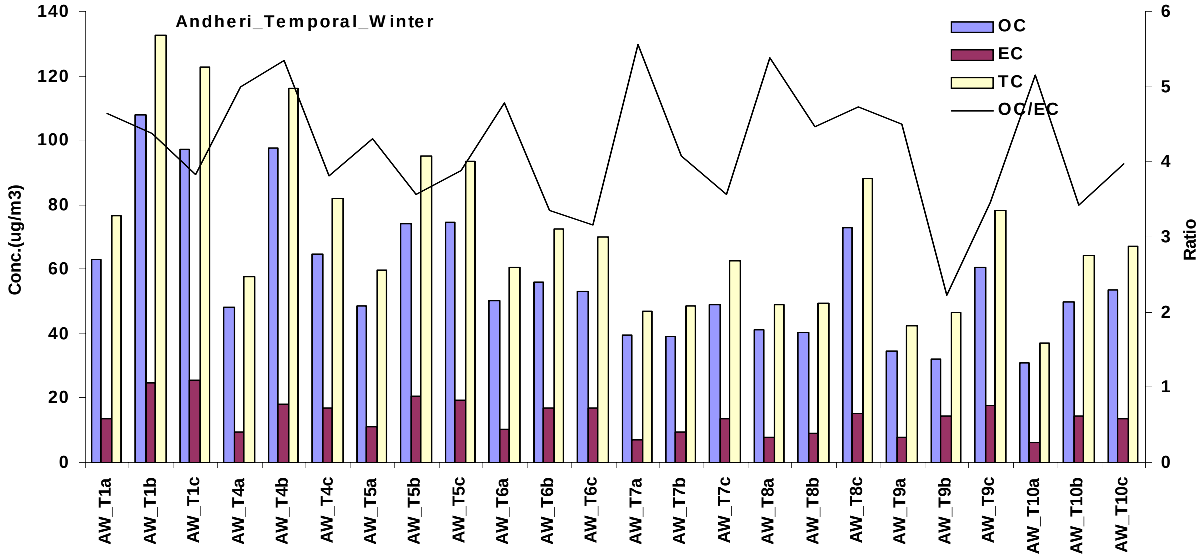


Figure WA.8: 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Andheri Site (Winter)

At Andheri site OC varied between 25.6-103.3 µg/m^3 with an average value of 47.8 µg/m^3. The EC concentration varied between 3.0-21.2 µg/m^3 with an average value of 9.3 µg/m^3. OC/EC ratio varied from 3.2 to 9.4 with an average ratio of 5.6. Percentage of OC, EC and TC in PM_{10} was 20.2, 3.9 and 24.1 whereas in $PM_{2.5}$ it was 16.4, 10.8 and 27.3 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure WA.9.**

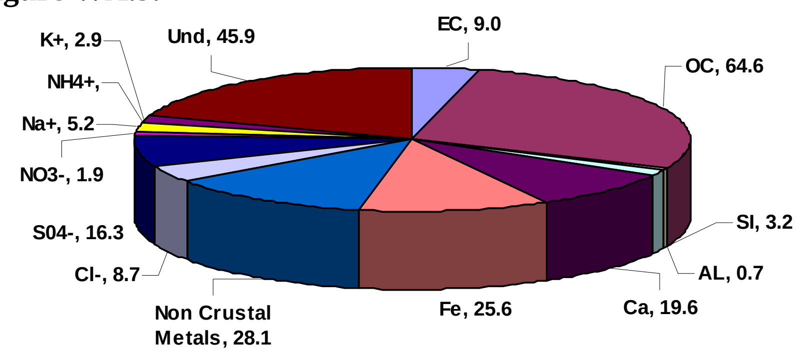


Figure WA.9: Mass Closure Concentrations at Andheri Winter

Composition of PM_{10} after mass closure indicates that maximum contribution to the particulate matter is from organic carbon and it accounts for 28 %. OC along with EC, which accounts for 4% of the total are mainly from sources such vehicles, coal burning and oil burning. The contribution of crustal elements is 21% and the sources for these include soil and road dust. Vehicles, coal burning, biomass and oil burning are the sources for non crustal elements which account for 12%. Ions contribute to 15% of the total PM_{10} with SO_4^{2-} having highest concentration due to road dust, vehicles etc. High concentration of Cl^- and Na^+ is due to sea spray. The unidentified fraction accounts for 20% of the total fine particulate matter in Andheri.

Mahul Site: The observed concentrations for winter season are presented in **Table WM.1.** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season are presented in **Figures WM.1.**

Table WM.1: Air Quality Status at Mahul (Winter)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM (µg/m^3)	241.0	502.0	395.0	500.8	66.5	30
RSPM (µg/m^3)	129.0	332.0	241.5	327.9	54.3	30
PM_{10} Tef (µg/m^3)*	179.0	393.0	271.1	379.7	54.7	30
PM_{10} Tef_1 (µg/m^3)*	178.0	407.0	270.6	383.8	52.7	30
$PM_{2.5}$ (µg/m^3)**	116.5	134.5	127.1	NA	9.4	3
SO_2 (µg/m^3)	7.0	35.0	18.4	34.4	7.3	30
NO_2 (µg/m^3)	29.0	97.0	72.0	96.4	18.0	30
NH_3 (µg/m^3)	35.0	249.0	97.2	247.8	55.4	30
CO (mg/m^3)	0.6	4.0	1.4	3.8	1.3	7
Formaldehyde (µg/m^3)	17.9	23.3	20.6	NA	3.8	2
CH_4 (ppm)	1.6	3.1	2.3	NA	0.6	4
Nonmethane HC (ppm)	0.7	1.1	0.9	NA	0.2	4
Total HC (ppm)	2.7	4.0	3.2	NA	0.5	4
O_3 (ppb)	10.5	15.1	12.8	15.0	1.6	7
OC (µg/m^3)	30.0	90.9	51.6	87.9	16.8	27
EC (µg/m^3)	5.6	33.5	14.9	28.8	6.3	27
TC (µg/m^3)	35.5	114	66.5	111.3	20.2	27

* PM_{10} values are indicative for Speciation sampler used in the study
** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages suspended particulate matters and RSPM were exceeding 3% and 93% of the time than permissible limit of CPCB i.e. 500 and 150 µg/m^3 respectively. The ratio of RSPM to SPM was 61.1% and $PM_{2.5}$ to PM_{10} was 46.9% indicating presence of both coarse and fine particles. The 24 hourly average concentrations of SO_2, NO_2 and NH_3 were within CPCB limits. The monthly average of PM_{10} was 271.0 µg/m^3. Temporal trends of PM_{10} show high concentrations during afternoon and early morning. CO values ranged between 0.6-4.0 mg/m^3, formaldehyde ranged between 17.9-23.3 µg/m^3, Total Hydrocarbon ranged between 2.7-4.0 ppm whereas Ozone concentrations ranged with 10.5-15.1 ppb.

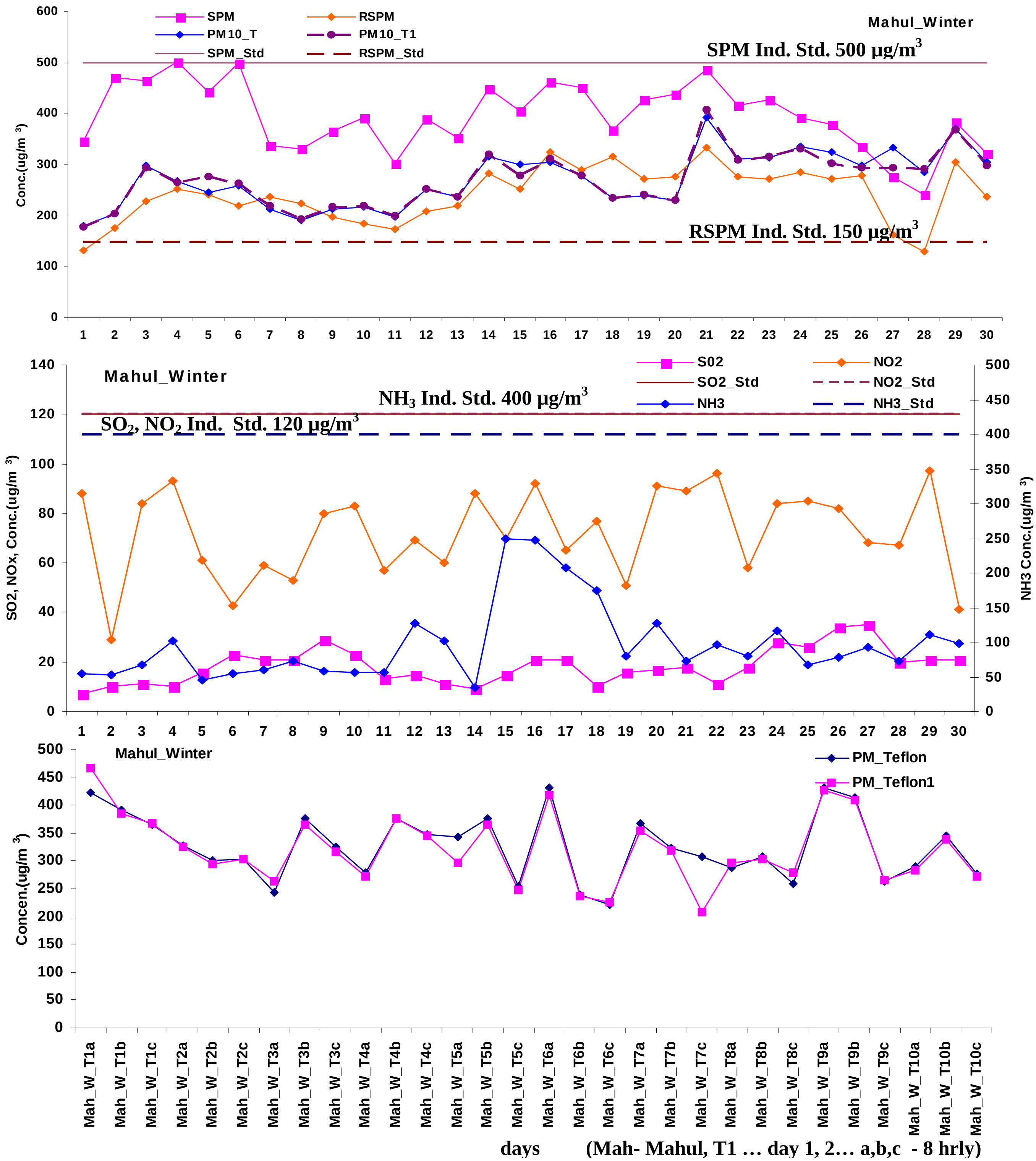
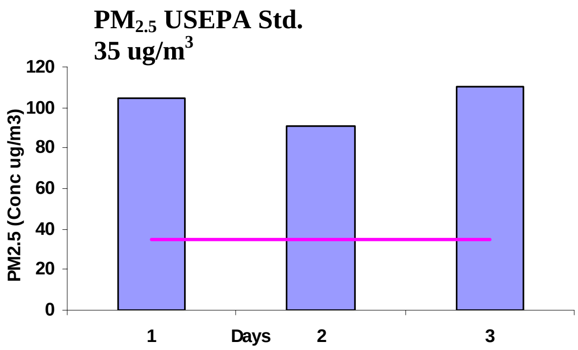


Figure WM.1 : Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Mahul During Winter

* High value at particular day indicates outlier due to certain site specific activity.

Figure WM.2 shows the variation of $PM_{2.5}$ and CO during the winter period.



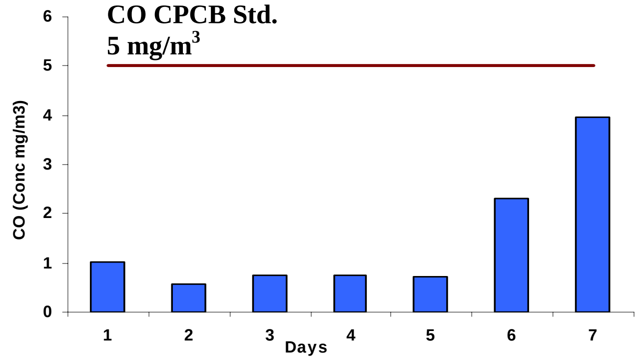


Figure WM.2: Observed Concentrations of $PM_{2.5}$ and CO at Mahul (Winter)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 $\mu g/m^3$ due to the sources like industries, heavy vehicle traffic, coal burning, oil burning etc which contribute to the fine particulate matter. The CO concentration during the sampling period was within the limits of CPCB standard of 5 $\mu g/m^3$ for the industrial area.

Figure WM.3 shows Methane, Non Methane and THC concentrations and **Figure WM.4** shows NO_2 vs NMHC concentrations during winter season.

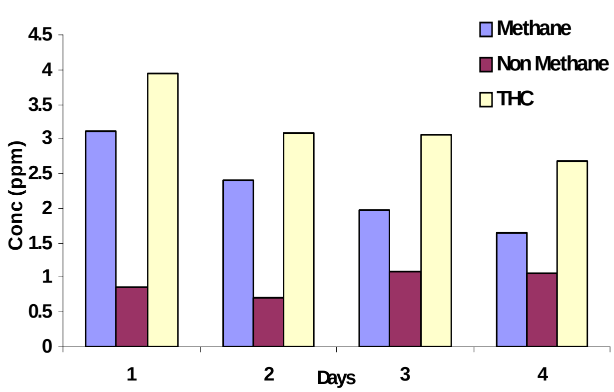


Figure WM.3: Hydrocarbon Concentration

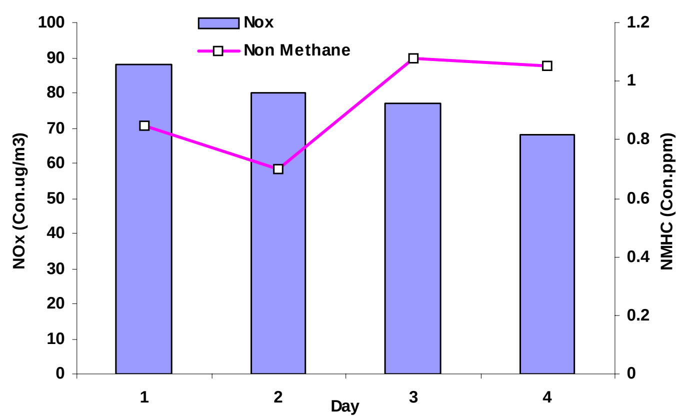
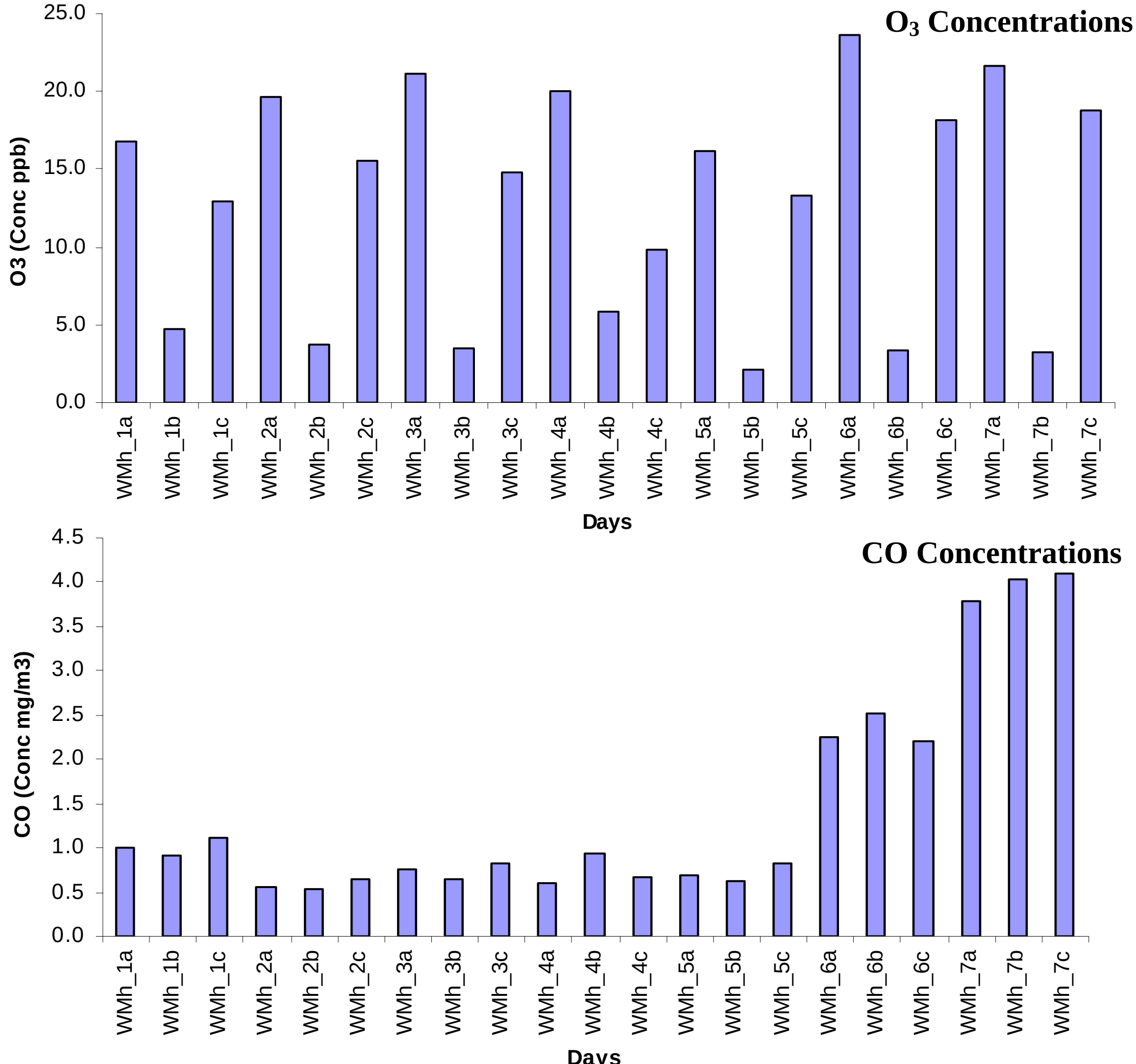


Figure WM.4: NO_2 and NMHC Concentration

Figure WM.5 presents diurnal variation of O_3 and CO concentration during winter.



W-Winter, Mh-Mahul, T1,2.. days, a,b,c-8 hourly values

Figure WM.5: Diurnal variation of O_3 and CO

No significant trend was observed in diurnal variation of CO. Diurnal variation in ozone showed high concentrations during afternoon hours as this time have more photochemical activity favouring ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^-, NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WM.6 and WM.7.**

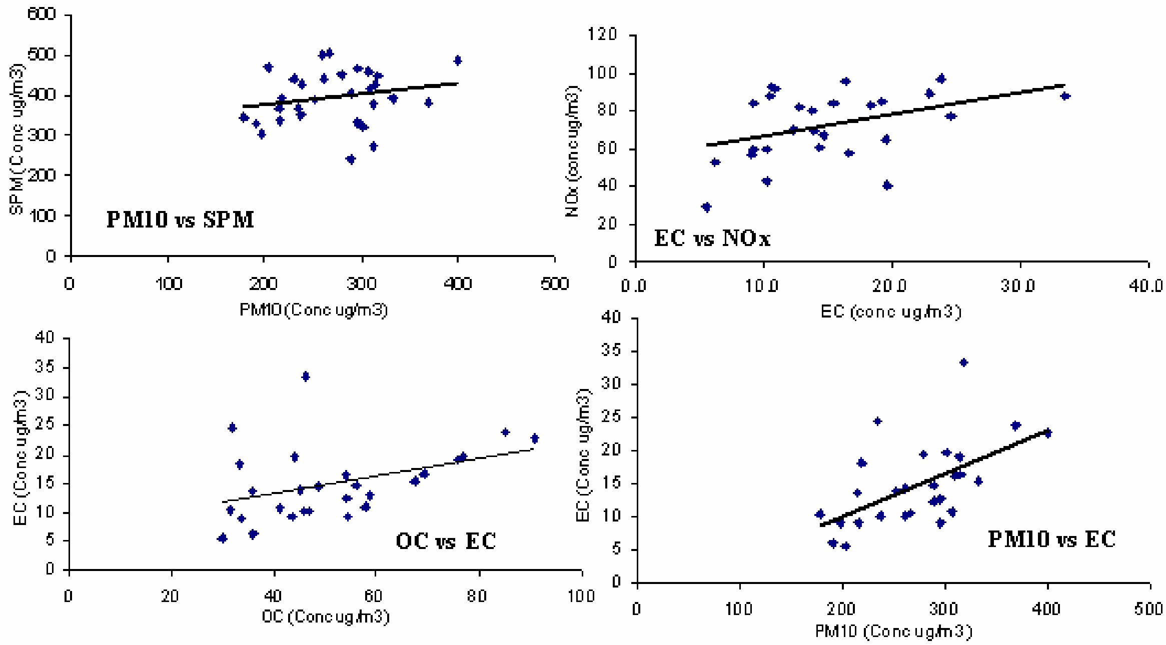


Figure WM.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show poor correlation due to number of industries, heavy vehicular traffic, coal burning which mainly contribute to fine particles. EC and NO_2 correlate moderately (R=0.41) indicating that vehicular emission is not the only source for EC. EC and OC show moderate correlation (R=0.41) which is indicating that OC and EC may not be released from a single dominant primary source and as average ratio of OC: EC is 3.8; there may be formation of secondary organic carbon aerosols. PM_{10} and EC show good correlation (R=0.57) indicating that for both, the contributing source is same.

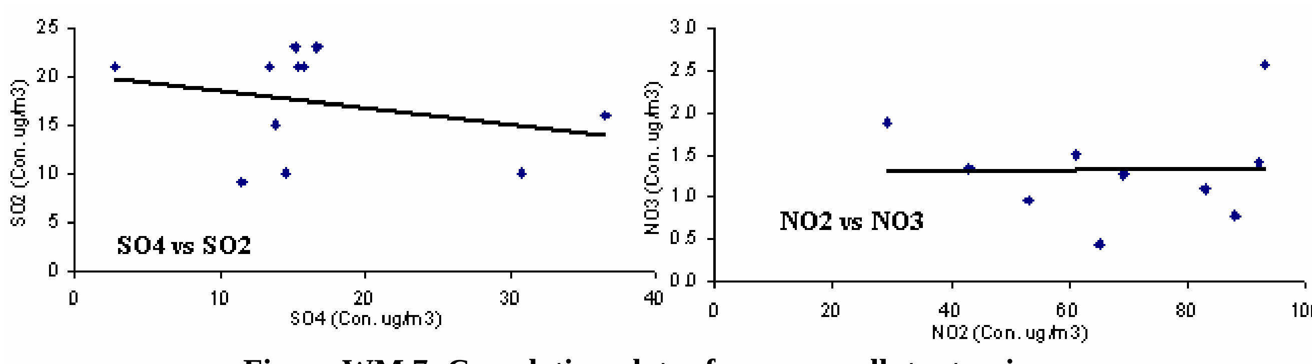


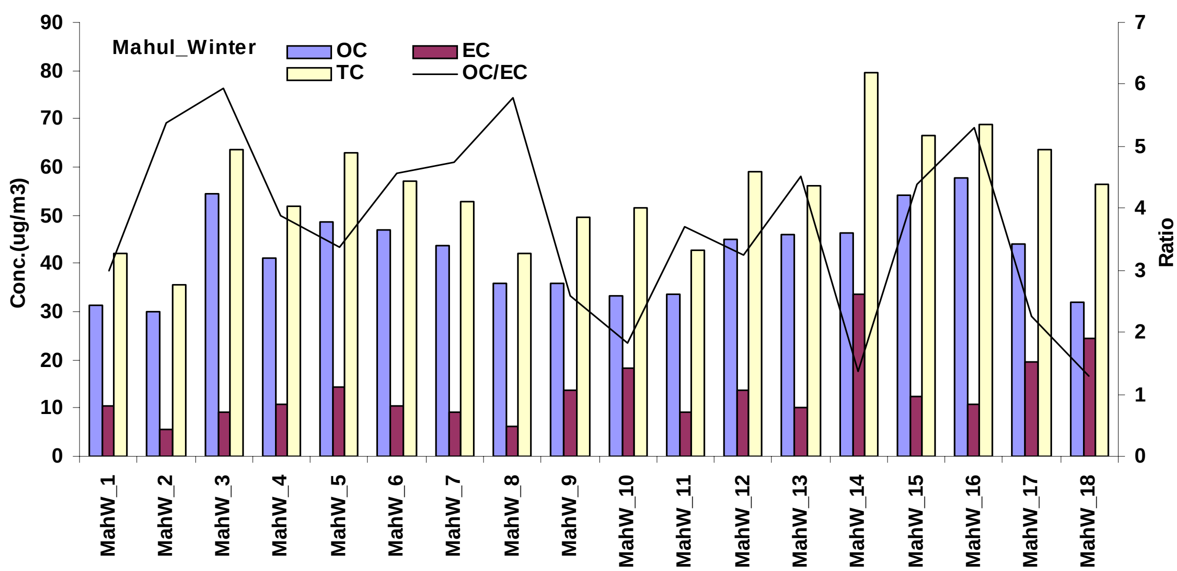
Figure WM.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show negative correlation indicating that SO_2 is getting converted to SO_4^{2-} to a very small extent and it is mainly coming from other sources like heavy vehicles, oil burning, and coal burning. NO_2 and NO_3^- show poor correlation indicating that NO_2 is not getting converted to NO_3^- and the contributing sources are heavy vehicles and industries. Correlation plots of NH_4^+ vs. SO_4^{2-} and NH4+ vs NO_3^- could not be plotted due to insufficient data

Carbon concentrations at Mahul site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WM.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	OC	EC	TC
PM_{10}	1.000	.900	.571	.926
OC	.900	1.000	.406	.959
EC	.571	.406	1.000	.649
TC	.926	.959	.649	1.000



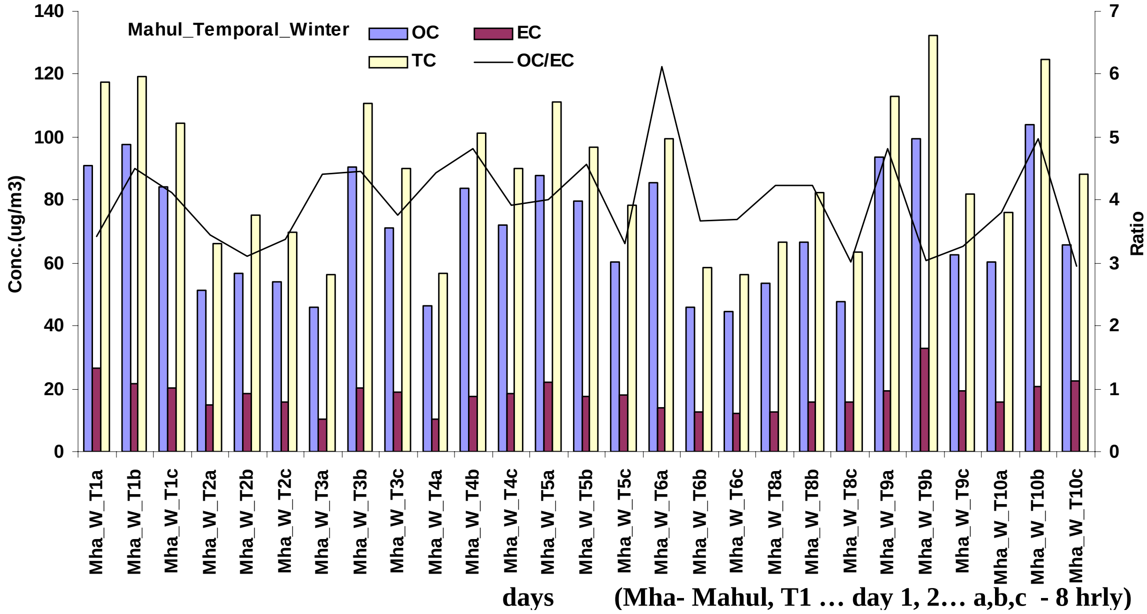


Figure WM.8: 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Mahul Site (Winter)

At Mahul site OC varied between 30.0-90.9 µg/m^3 with an average value of 51.6 µg/m^3. The EC concentration varied between 5.6-33.5 µg/m^3 with an average value of 14.9 µg/m^3. OC/EC ratio varied from 1.3-5.9 with an average ratio of 3.8. Percentage of OC, EC and TC in PM_{10} was whereas 19.0, 5.5 and 24.6 in $PM_{2.5}$ it was 27.9, 12.4 and 40.3 percent respectively.

Mass fraction of elements, ions and carbons in concentrations (µg/m^3) in PM_{10} is presented in **Figure WM.9.**

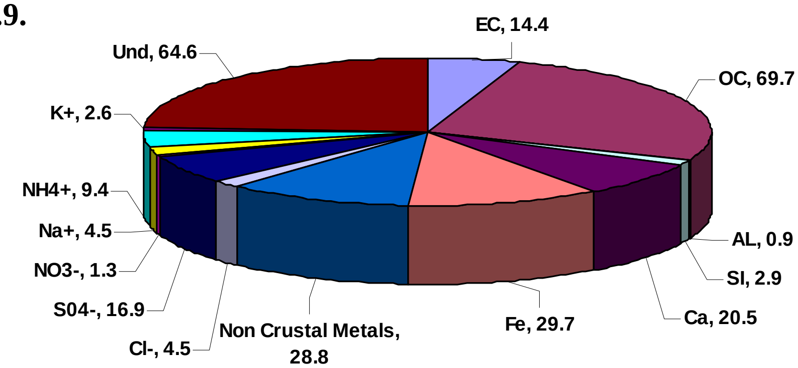


Figure WM.9: Mass Closure Concentrations at Mahul Winter

Percent composition of PM_{10} after mass closure indicates that maximum contribution to the particulate matter is from carbonaceous fraction (OC 26% and EC 5%) which accounts for 31%. The major sources contributing to OC and EC include heavy vehicles, oil burning and coal burning. The contribution of crustal elements is 20% and the source for these crustal elements is soil. Petrochemical industries, heavy vehicles, oil burning, coal burning are the sources for non crustal elements which account for 11%. Ions contribute to 14% of the total PM_{10} with SO_4^{2-} having highest concentration due to vehicles and secondary aerosols. High concentration of NH_4^+ is due to fertilizer industry, vehicles and oil burning. The unidentified fraction accounts for 24% of the total fine particulate matter in Mahul.

Mulund Site: The observed concentrations for winter season are presented in **Table WMu.1.** The detailed date wise concentrations are presented in **Annexure 2.2.** The 24 hourly average concentrations of SPM, RSPM, PM_{10} and gaseous pollutants for winter season are presented in **Figure WMu.1**

Table WMu.1 : Air Quality Status at Mulund (Winter)

Pollutants	Min	Max	Avg	98 percentile	SD	N
SPM ($\mu g/m^3$)	310.0	689.0	463.0	666.0	90.4	29
RSPM ($\mu g/m^3$)	108.0	456.0	260.4	450.2	81.1	30
PM_{10} Tef ($\mu g/m^3$)*	162.0	553.0	281.2	516.6	88.8	29
PM_{10} Tef_1 ($\mu g/m^3$)*	124.0	545.0	277.7	515.3	90.6	29
$PM_{2.5}$ ($\mu g/m^3$)**	89.0	165.0	130.7	NA	38.5	3
SO_2 ($\mu g/m^3$)	5.0	33.0	14.6	30.1	6.8	30
NO_2 ($\mu g/m^3$)	38.0	139.0	71.0	114.1	18.7	30
NH_3 ($\mu g/m^3$)	21.0	92.0	54.1	91.4	22.6	30
CO (mg/m^3)	0.6	4.1	2.68	4.08	1.38	7
Formaldehyde ($\mu g/m^3$)	18.2	21.9	20.0	NA	2.6	2
CH_4 (ppm)	4.3	4.7	4.5	NA	0.1	4
Nonmethane HC (ppm)	1.7	2.3	1.9	NA	0.2	4
Total HC (ppm)	6.0	7.0	6.4	NA	0.4	4
O_3 (ppb)	11.7	33.9	21.9	33.3	8.3	7
OC ($\mu g/m^3$)	26.2	101.5	58.1	97.1	15.8	29
EC ($\mu g/m^3$)	5.5	23.6	12.0	21.5	4.5	29
TC ($\mu g/m^3$)..	31.7	119.1	70.0	111.3	17.4	29

* PM_{10} values are indicative for Speciation sampler used in the study

** $PM_{2.5}$ values are indicative for FRM sampler used in the study, NA – Not Applicable

The 24 hourly averages of suspended particulate matters and RSPM were exceeding all the times than permissible limit of CPCB i.e. 200 and 100 $\mu g/m^3$ respectively. The ratio of RSPM to SPM was 57.5% and $PM_{2.5}$ to PM_{10} was 46.7% indicating dominance of fine particles. The 24 hourly average concentrations of SO_2, NH_3 were within CPCB limits, whereas NO_2 were exceeding 20% of the time than the CPCB standard. The monthly average of PM_{10} was 280 $\mu g/m^3$. No specific temporal trends were observed of PM_{10}. CO values ranged between 0.6-4.1 mg/m^3, formaldehyde ranged between 18.2-21.9 $\mu g/m^3$, Total Hydrocarbon ranged between 6.0-7.0 ppm whereas Ozone concentrations ranged with 11.7-33.9 ppb.

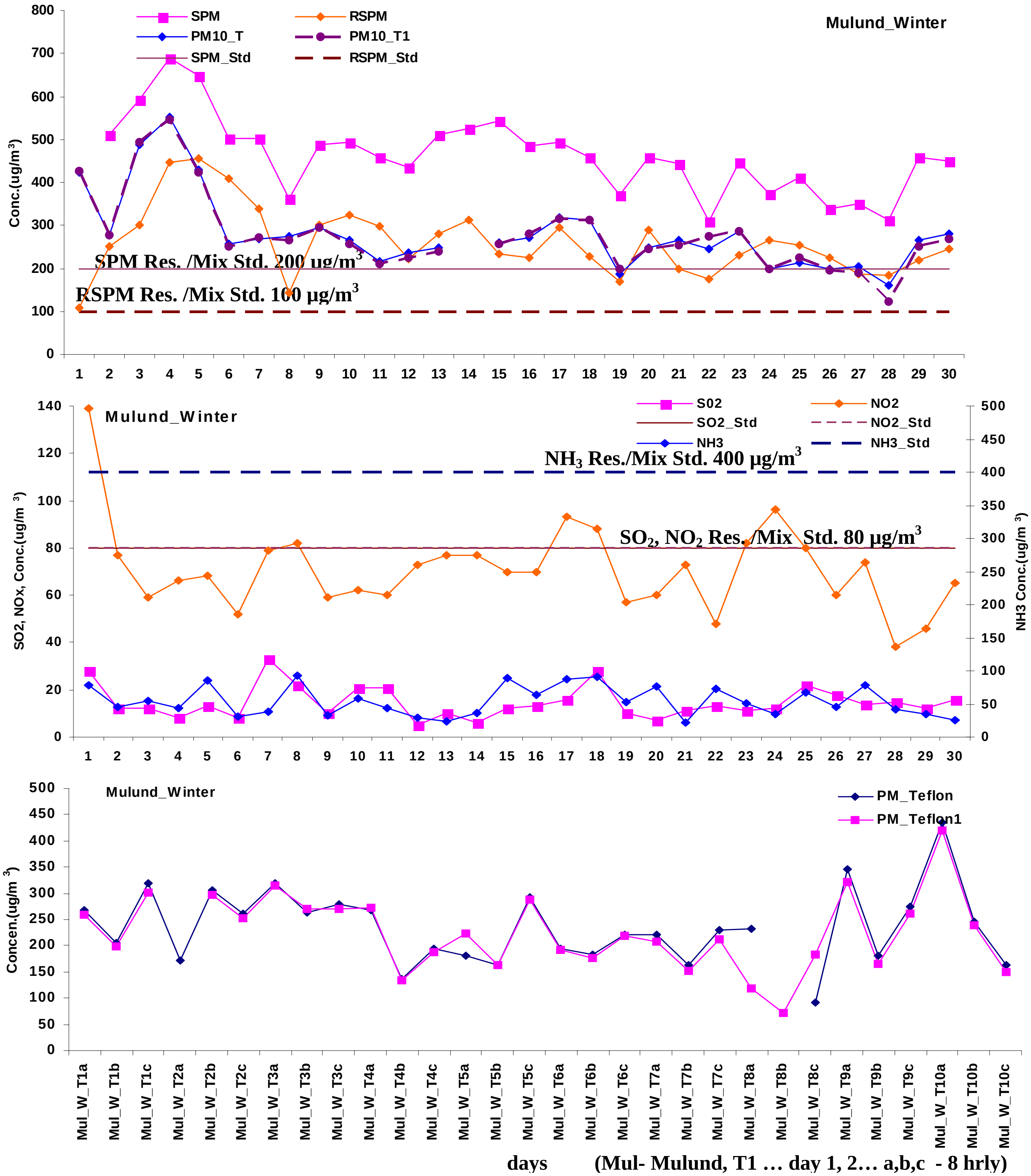


Figure WMu.1: Observed Concentrations of SPM, RSPM, SO_2, NO_2, NH_3 and PM_{10} (Speciation -24 Hr. & Temporal) at Mulund during Winter

* High value at particular day indicates outlier due to certain site specific activity.

Figure WMu.2 shows the variation of $PM_{2.5}$ and CO during the winter period.

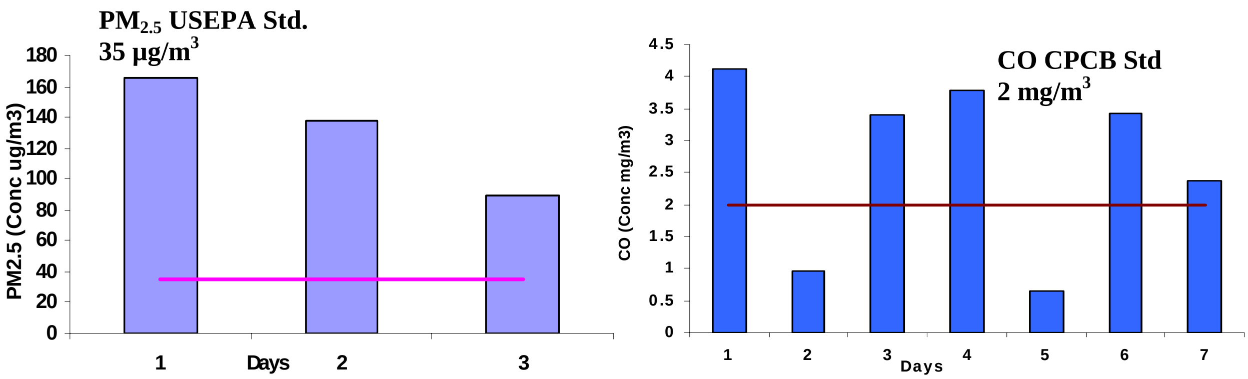


Figure WMu.2: Observed Concentrations of $PM_{2.5}$ and CO at Mulund (Winter)

The concentration of $PM_{2.5}$ exceeded all the time the US EPA standard of 35 $\mu g/m^3$ due to the sources like vehicles, industries and oil burning which contribute to the fine particulate matter. The CO concentration during the sampling period exceeded 71% of the times the CPCB standard of 2 mg/m^3 for the residential/mix use area

Figure WMu.3 shows Methane, Non Methane and THC concentrations and **Figure WMu.4** shows NO_2 vs NMHC concentrations during winter season.

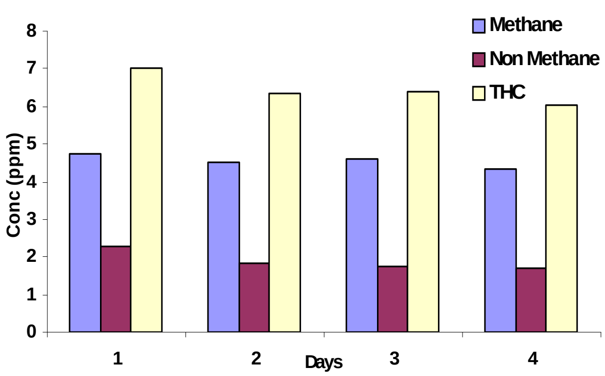


Figure WMu.3: Hydrocarbon Concentration

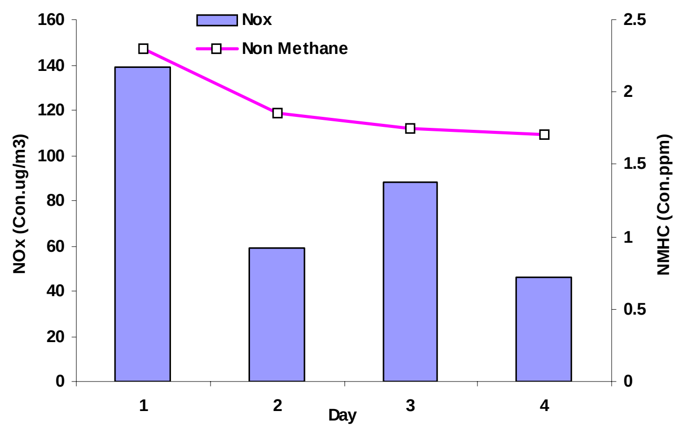


Figure WMu.4: NO_2 and NMHC Concentration

Figure WMu.5 presents diurnal variation of O_3 and CO during winter at Mulund.

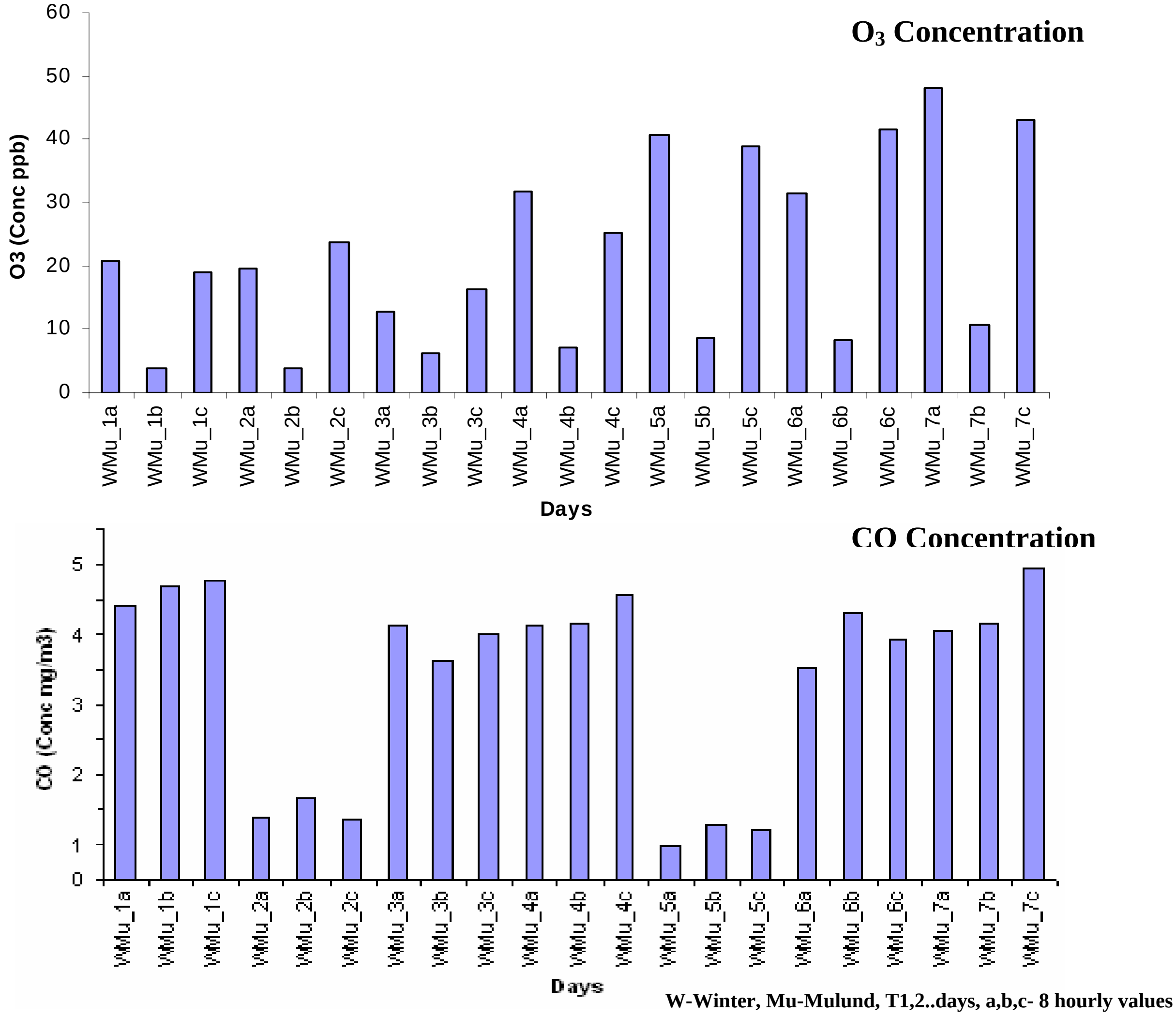


Figure WMu.5: Diurnal variation of O_3 and CO

No significant trend was observed in diurnal variation of CO. Diurnal variation in ozone showed high concentrations during morning and afternoon hours as these timings have high photochemical activity favouring ozone formation.

With a view to understand correlation of different pollutants, an attempt was made to plot PM_{10} vs SPM, EC vs NO_2, OC vs EC and PM_{10} vs EC. Further correlation plots were also drawn for SO_4^{2-} vs SO_2, NO_2 vs NO_3^- , NH_4^+ vs SO_4^{2-}, NO_3^- and NH_4^+ vs NO_3^-. These plots are presented in **Figures WMu.6 and WMu.7.**

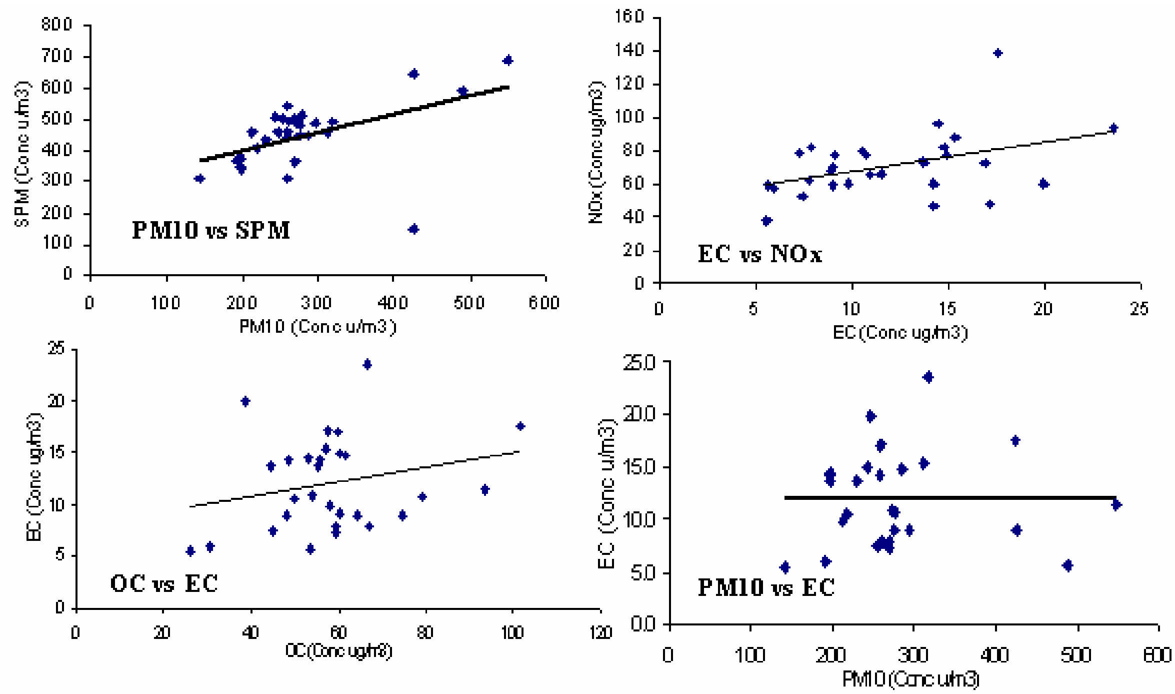


Figure WMu.6: Correlation plots of PM with EC, NO_2 and OC and EC

PM_{10} and SPM show moderate correlation (R=0.49) due to industries, vehicular traffic and oil burning which mainly contribute to fine particles. EC and NO_2 correlate moderately (R=0.41) indicating that vehicular emission is not the only source for EC. EC and OC show poor correlation which indicates that OC and EC may not be released from a single dominant primary source and as average ratio of OC to EC is 5.4, there may be formation of secondary organic aerosols. PM_{10} and EC show very poor correlation indicating that for both, the contributing source is different.

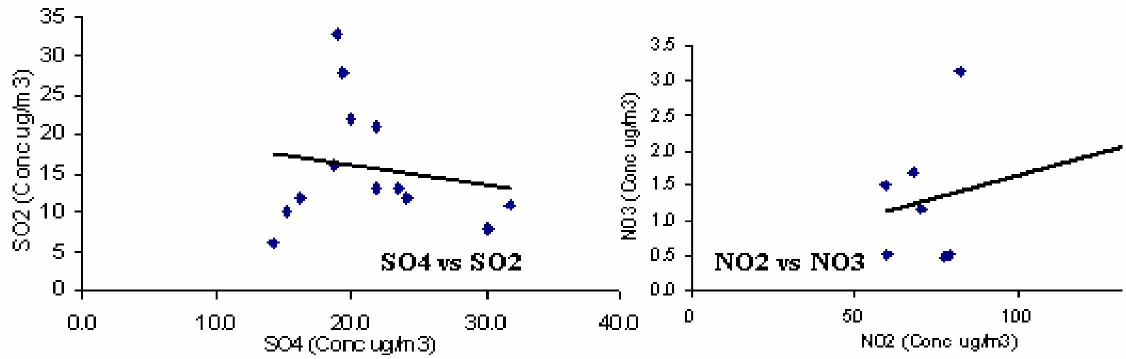


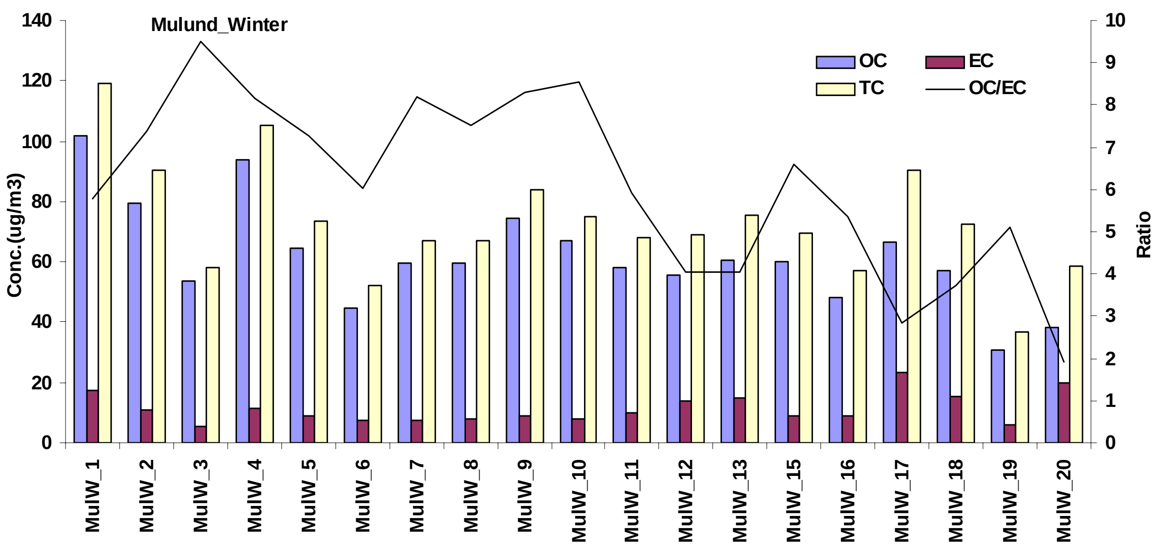
Figure WMu.7: Correlation plots of gaseous pollutant vs ions

SO_2 and SO_4^{2-} show negative correlation indicating that SO_2 is getting converted to SO_4^{2-} to a very small extent and it is mainly coming from other sources like vehicles, oil burning. NO_2 and NO_3^- show poor correlation indicating that NO_2 is not getting converted to NO_3^-. Correlation plot for NH_4^+ vs SO_4^{2-} and NH_4^+ and NO_3^- could not be plotted due to insufficient data set.

Carbon concentrations at Mulund site with PM_{10} and $PM_{2.5}$ is given in **Annexure 2.2**. 24 hourly and temporal trends of OC, EC and TC with respect to their ratios are presented in **Figure WMu.8.**

Correlation Matrix of carboneous pollutants vs PM_{10}

	PM_{10}	**OC**	**EC**	**TC**
PM_{10}	1.000	.681	.011	.612
OC	.681	1.000	.249	.968
EC	.011	.249	1.000	.485
TC	.612	.968	.485	1.000



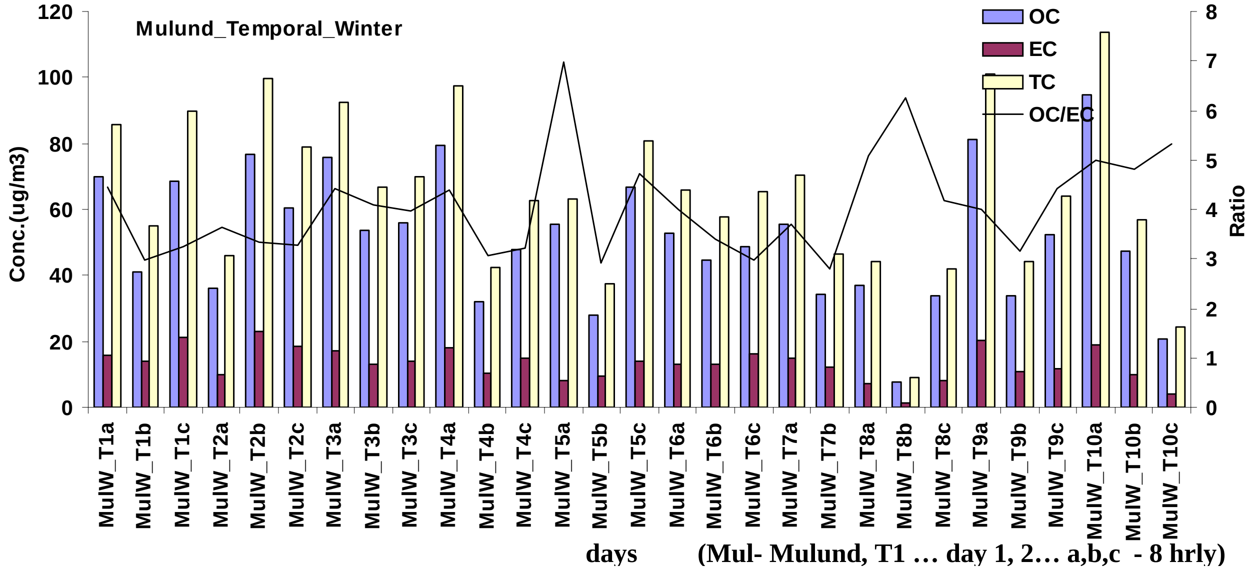


Figure WMu.8: 24 Hrly and Temporal Trends of Organic, Elemental and Total Carbon with OC/EC Ratio at Mulund Site (Winter)

At Mulund site OC varied between 26.2-101.5 µg/m^3 with an average value of 58.1 µg/m^3. The EC concentration varied between 5.5-23.6 µg/m^3 with an average value of 12.0 µg/m^3. OC/EC ratio varied from 1.9-9.5 with an average ratio of 5.4. Percentage of OC, EC and TC in PM_{10} was whereas 20.8, 4.3 and 25.0 in $PM_{2.5}$ it was 27.2, 9.0 and 36.2 percent respectively.

Mass fraction of elements, ions and carbons in terms of concentration (µg/m^3) in PM_{10} is presented in **Figure WMu.9.**

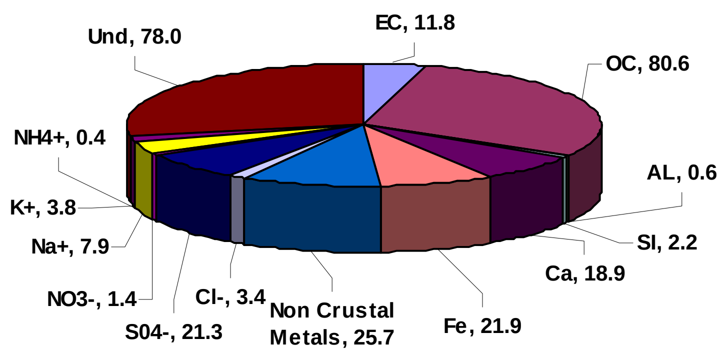


Figure WMu.9: Mass Closure Concentrations (µg/m^3) at Mulund

Percent composition of PM_{10} after mass closure indicates that maximum contribution to the particulate matter is from carbonaceous fraction (OC 29% and EC 4%) which accounts for 33%. The major sources contributing to OC and EC include vehicles and oil burning. The contribution of crustal elements is 16% and the source for these crustal elements is soil and road dust. Industries, vehicles and oil burning are the sources for non crustal elements which account for 9%. Ions contribute to 14% of the total PM_{10} with SO_4^{2-} having highest concentration due to vehicles. Sea spray contributes to Na^+ and Cl^-. The unidentified fraction accounts for 28% of the total fine particulate matter in Mulund.

2.5 Correlation of Pollutants

A summary of correlation coefficient of pollutant at different sites is presented in **Table 2.4**.

Table 2.4: Correlation Coefficient of Pollutants at Different Sites

	PM_{10} vs SPM			EC vs NO_2			OC vs EC			PM_{10} vs EC		
	Sum	**P_M**	**Win**	**Sum**	**P_M**	**Win**	**Sum**	**P_M**	**Win**	**Sum**	**P_M**	**Win**
Colaba	0.72	0.68	0.77	0.59	0.62	0.36	0.88	0.59	0.22	0.45	0.73	-0.10
Dadar	0.46	0.62	0.67	-0.29	-0.22	0.21	0.02	0.57	0.53	-0.05	0.69	0.21
Dharavi	0.79	0.67	0.83	0.07	0.09	0.30	0.12	0.32	0.65	0.19	0.51	0.62
Khar	0.77	0.39	0.83	0.21	-0.14	0.07	0.79	0.38	0.59	-0.09	0.31	0.66
Andheri	0.48	-0.06	0.62	0.26	0.23	0.35	0.86	-0.30	0.85	0.31	0.30	0.48
Mahul	0.49	0.39	0.21	0.28	0.67	0.41	0.62	0.46	0.41	0.23	0.57	0.57
Mulund	0.45	0.58	0.49	0.40	0.31	0.41	0.66	0.35	0.24	0.35	0.48	0.01

	SO_4 vs SO_2			NO_2 vs NO_3			NH_4 vs SO_4			NH_4 vs NO_3		
	Sum	**P_M**	**Win**	**Sum**	**P_M**	**Win**	**Sum**	**P_M**	**Win**	**Sum**	**P_M**	**Win**
Colaba	-0.06	0.05	-0.52	0.05	-0.06	0.2	0.96	-0.08	**	-0.23	0.52	**
Dadar	-0.09	0.15	0.11	0.44	0.60	-0.33	-0.61	0.66	**	-0.54	0.43	**
Dharavi	-0.03	0.29	0.14	0.17	-0.16	0.22	0.69	0.49	0.58	0.42	0.83	0.24
Khar	-0.24	0.14	-0.29	-0.16	0.26	-0.07	0.27	-0.11	**	0.25	-0.79	**
Andheri	0.39	0.06	0.45	**	0.02	-0.05	0.50	-0.13	**	**	0.15	**
Mahul	-0.18	-0.71	-0.28	-0.45	-0.36	0.02	-0.35	-0.14	**	-0.47	0.26	**
Mulund	-0.20	0.19	-0.16	-0.08	0.15	0.36	0.45	**	**	0.52	**	**

** Insufficient data set

As can been seen from these results, PM and EC correlation is very high in post monsoon and winter, with poor correlation in summer indicating high temperature combustion sources. EC and NO_2 are not high but many places they show average correlation indicating vehicles contribution. SO_2 v/s SO_4^{--} as also NO_2 v/s NO_3^{-} correlation is mostly absent except some places where it is in the lower range < 0.5, thus indicating that they are not dominant sources for secondary aerosols. Amongst the secondary aerosol formation, correlation of NH_4^{+} v/s SO_4^{--} is higher and with higher frequency compared to NH_4^{+} v/s NO_3^{-}. It indicates that NH_4^{+} and SO_4^{--} have significant sources and are present in same areas.

2.6 Comparison of Seven Sites

Air quality of seven sites varies due to site characteristics, meteorology of different season and possibly emission rates. **Figure 2.3** presents the seasonal variables for all seven sites for major pollutants such as SPM, PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO. **Figure 2.4** present the average of all pollutants for all three seasons. Sites wise seasonal pollutant load is presented in detailed in **Annexure 2.2**.

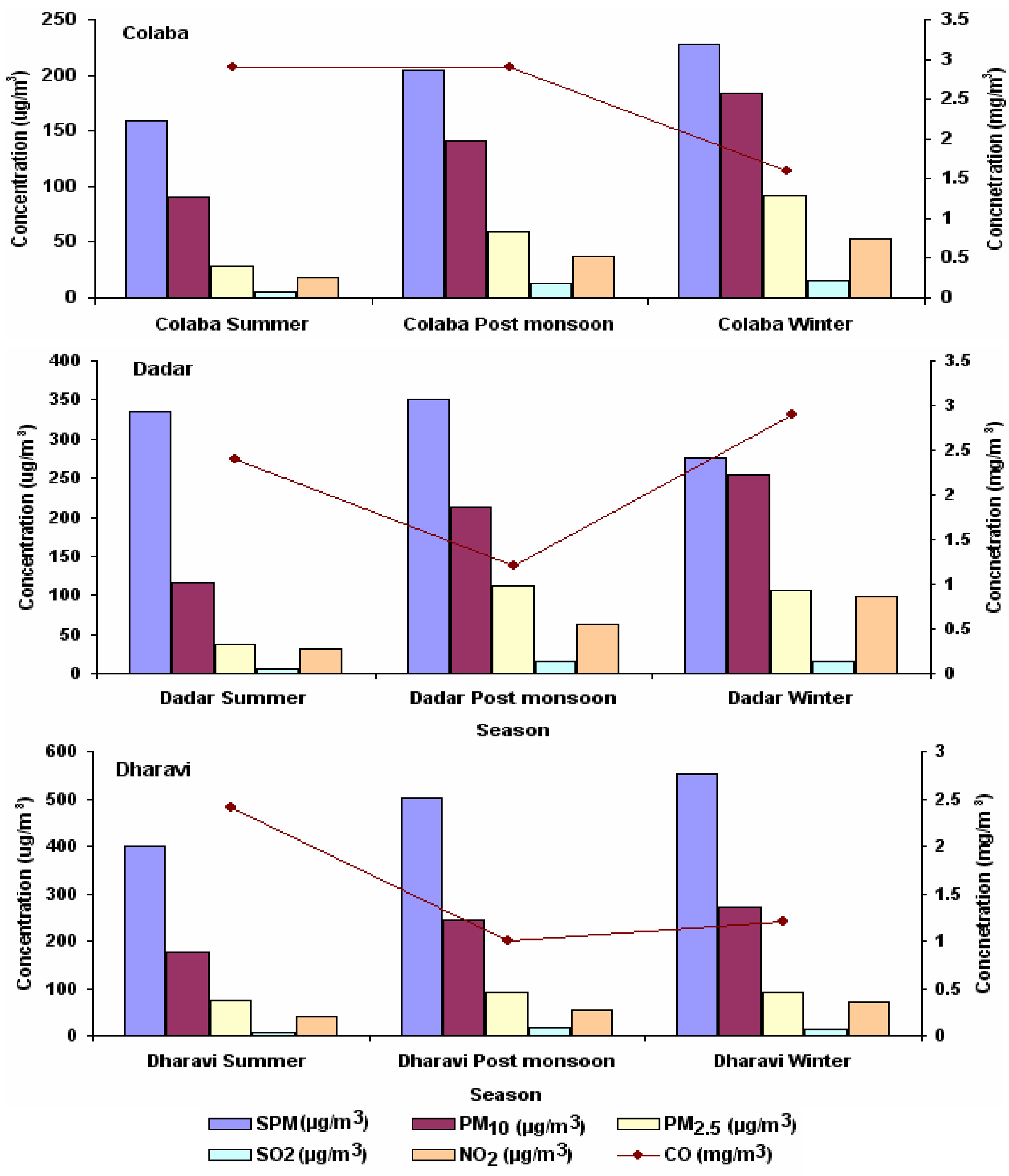


Figure 2.3 : Seasonal Variation of Pollutants for Seven Sites

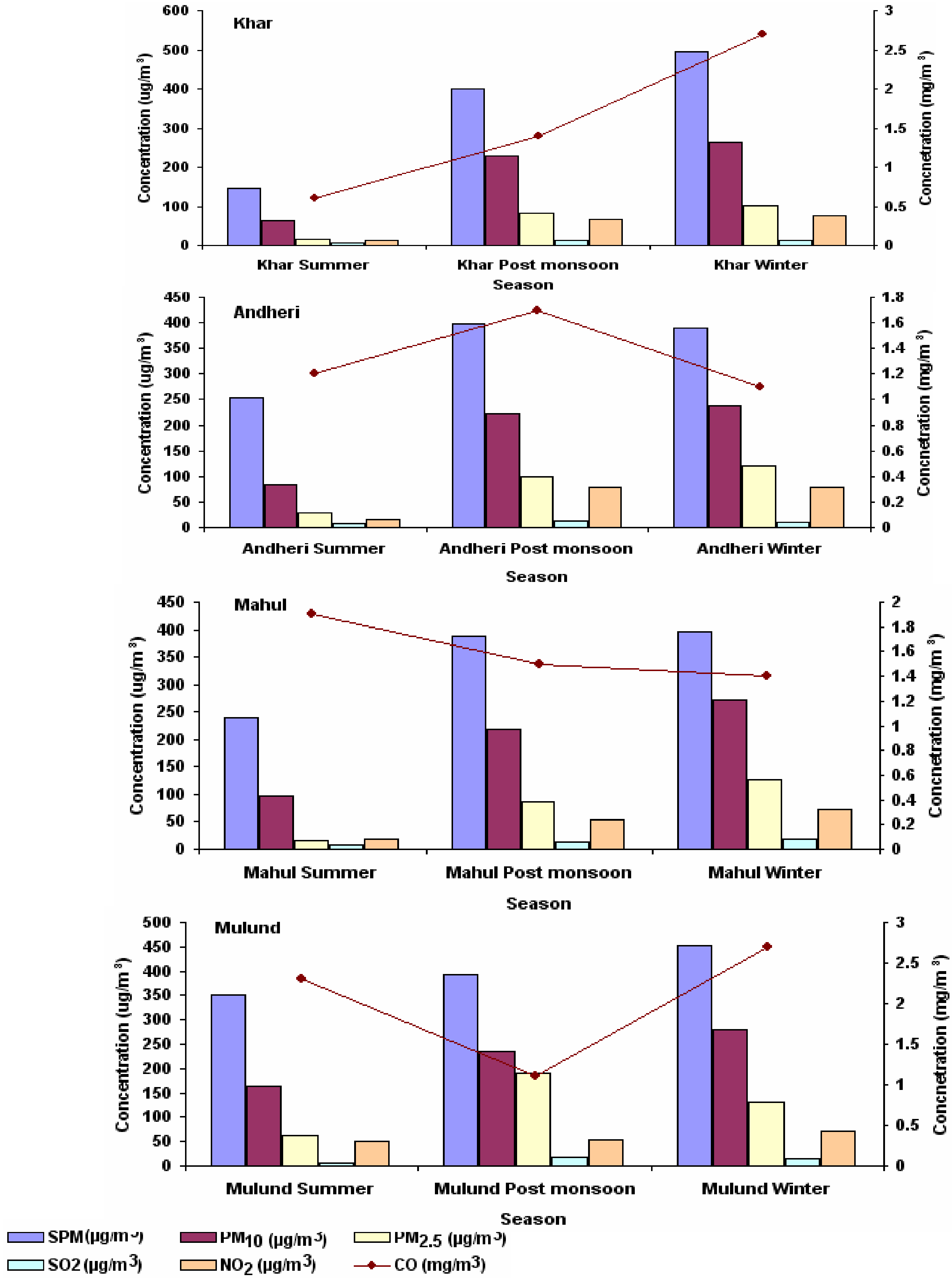


Figure 2.3 (Contd...) : Seasonal Variation of Pollutants for Seven Sites

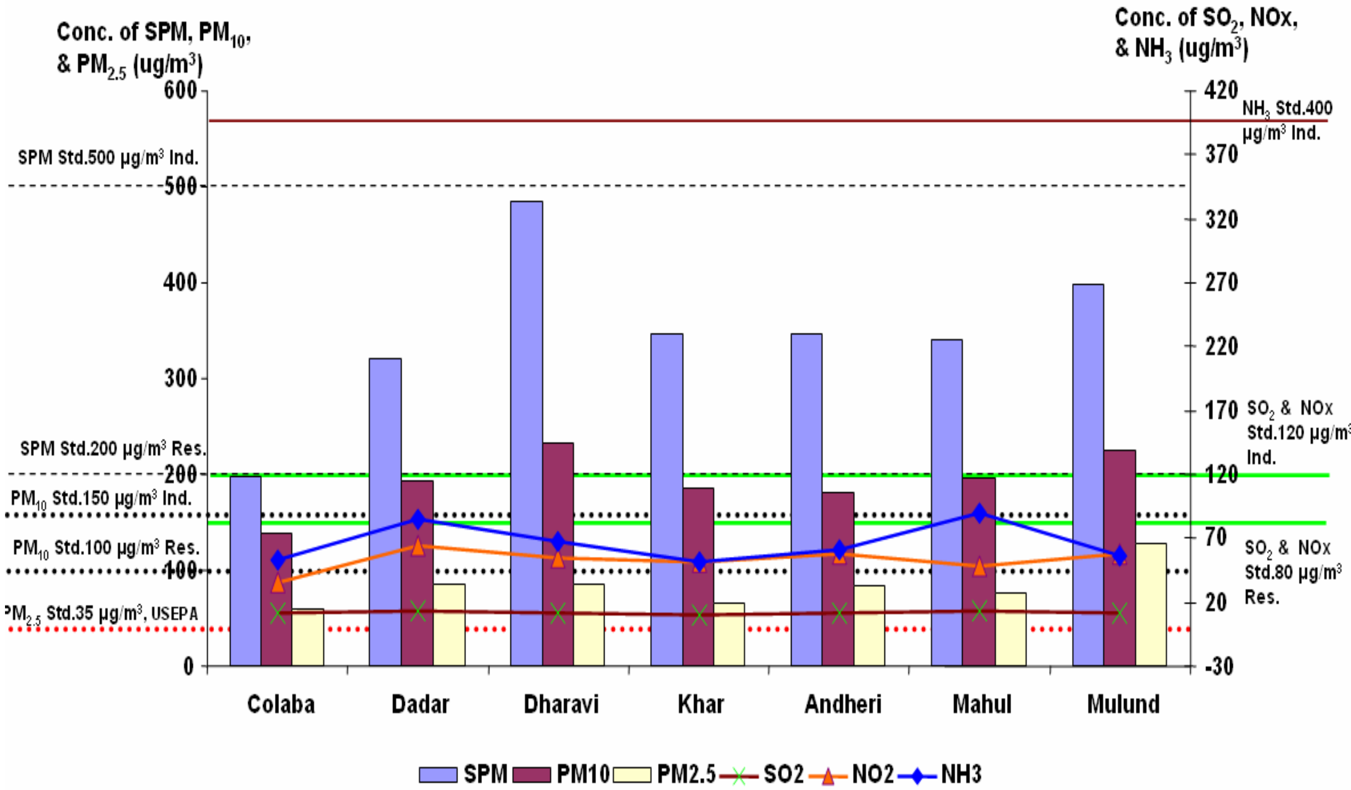


Figure 2.4: Average Concentration of Pollutant at Different Sites

Concentration of SPM exceeded the CPCB standard of 200 µg/m^3 for residential and mix use area in all the sites. Highest concentration of SPM was found in Dharavi followed by Mulund. In case of Mahul, the SPM concentration was within the CPCB standard of 500 µg/m^3 indicating the predominance of finer particles due to industries in this area. Concentration of RSPM exceeded the CPCB standard of 100 µg/m^3 for residential and mix use area in all the sites. Mulund site has maximum concentration of RSPM mainly due to vehicles and industries in this area. Dharavi has maximum concentration of PM_{10} (231.4 µg/m^3) due to activities like large number of small scale industries operating in this area along with other sources like refuse burning, vehicular exhaust etc. US EPA limit of 35 µg/m^3 for $PM_{2.5}$ was exceeded at all the sites. Highest concentration of $PM_{2.5}$ was observed in Mulund due to vehicles, industries, oil burning, refuse burning etc.

The concentration of gaseous pollutants like SO_2, NO_2 and NH_3 were always within the range of CPCB standard of 80 µg/m^3 for residential and mix use area and 120 µg/m^3 for industrial area in case of SO_2 and NO_2 and 400 µg/m^3 in case of NH_3. Due to Thermal Power Plant in the vicinity of Mahul sampling site, highest concentration of SO_2 (13.4 µg/m^3) was observed there. NO_2

concentration was higher in "kerbsites" like Dadar, Mulund and Andheri (64.2 µg/m^3, 58.4 µg/m^3 and 58.2 µg/m^3 respectively) due to heavy vehicular traffic. Highest concentration of NH_3 was observed at Mahul site due to the fertilizer industry.

As evident from **Figure 2.3** and **Figure 2.4**, almost all the pollutants have maximum concentration during winter season due to meteorological conditions like temperature inversion and low wind speed.

The Average concentration of CO, CH_4, NMHC, HC and O_3 is presented in **Figure 2.5.** The average concentration of CO exceeded the limit of 2 mg/m^3 for residential and mix use area in Colaba and Dadar due to vehicles and biomass burning. Highest values of formaldehyde was noticed in Dadar (49.4 µg/m^3) followed by Khar (44.1 µg/m^3) and Dharavi (43.0 µg/m^3) mainly due to CNG vehicles plying in these areas. Methane emissions are mainly contributed from biomass burning, vehicular emissions, landfill site, biodegradable waste etc. From the monitored values, above mentioned sources are major contributors to high methane concentration in Dharavi, Andheri and Mulund. Highest concentration of Non methane hydrocarbon was observed in Mahul (7.5 ppm) followed by Mulund (6.9 ppm) due to industries located in these areas along with the biomass burning. Ozone formation is favoured due to photo oxidation reaction of NO_2, VOC and other hydrocarbons. Findings show high values of ozone in Dharavi (27 ppb) which may be due to high NO_2 concentration and low values of total hydrocarbon.

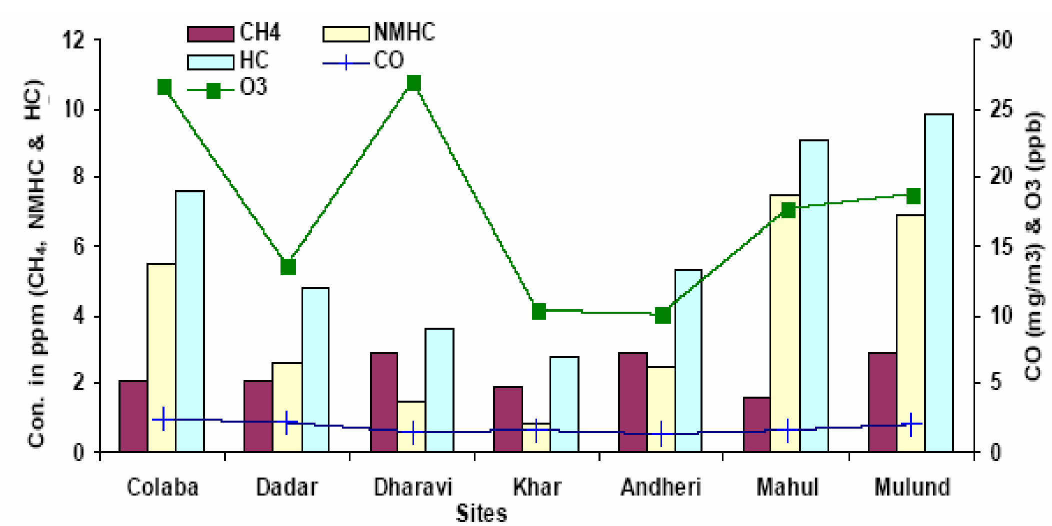


Figure 2.5 : Average Concentrations of Different Pollutants at Selected Monitoring Sites

Average concentration of OC, EC and TC is presented in **Figure 2.6**. Highest concentration of carbonaceous fraction (organic and elemental carbon) was found in Mulund (47.3 μg/m³and 12.0 μg/m³) followed by Dharavi (45.6 μg/m³ and 9.7 μg/m³) due to vehicles, refuse burning and residual oil burning.

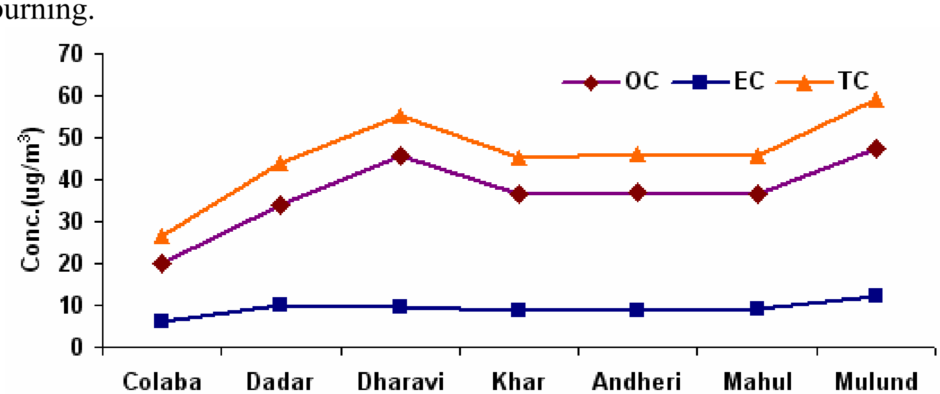


Figure 2.6: Average Carbon Concentrations at Seven Sites

2.6.1 Comparison of Coarse (PM_{10}) and Fine ($PM_{2.5}$) Particulate Matter Composition after Mass Closure

In order to evaluate and to reduce the impact of aerosols on health, any programme aimed at controlling the levels of PM demands the knowledge of the particle size distribution, chemical composition and sources. Mass closure is one of the methods used to characterize the relative contribution of different components such as elements, ions and carbonaceous species to particulate matter. *(Almeida et al., 2006).* **Figure 2.7 through 2.9** presents the mass closure at seven for PM_{10} and $PM_{2.5}$.

2.6.1.1 Summer: Mass Closure

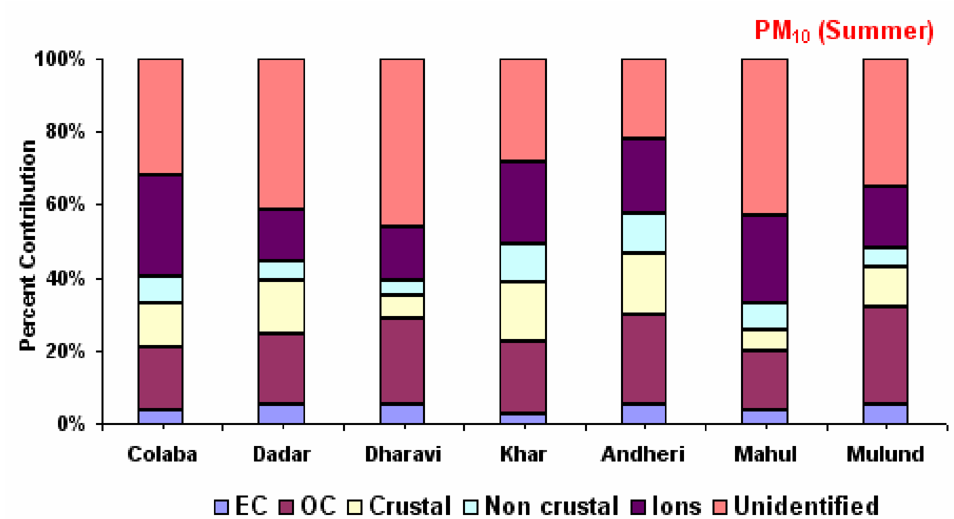


Figure 2.7: Mass Closure of PM_{10} Summer

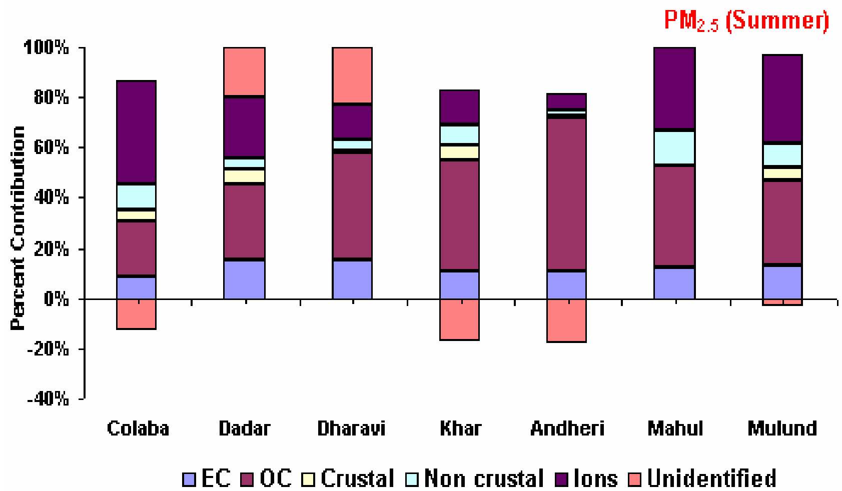


Figure 2.7 (Contd...): Mass Closure of $PM_{2.5}$ Summer

Figure 2.7 shows that in **Summer** season, for coarse particulate matter at ***Colaba*** (background site) maximum contribution is made from ionic species (27.6%) followed by organic carbon (17.5%), crustal elements (11.6%), non crustal elements (7.6%) and elemental carbon (3.6%). 32% of total PM_{10} remains unidentified. In case of fine particulate matter, ions account for 55.8% followed by OC (30.1%), non crustal elements (13.8%), EC (12.0%) and crustal elements (6.0%). The unidentified portion accounts for -17.7%. This negative discrepancy could be attributed to volatilization of organic compounds *(Rees et al., 2004)*.

Dadar being a kerbsite, main component of PM_{10} is organic carbon (19.8%) contributed by vehicles; followed by 14.3% of crustal elements from the resuspension of road dust. Ions account for 13.7%, non crustal elements account for 5.6% and elemental carbon accounts for 5.0% of the total particulate matter load. 41.6% of the portion remains unidentified. In case of fine particulate matter, organic carbon accounts for increase value of 30.1%. Other components which contribute to the fine particulate matter at Dadar are ions (24.7%), EC (15.4%), crustal elements (5.8%) and non crustal elements (4.2%). 19.8% portion of the total fine particulate matter remained unidentified. The unidentified portion is possibly due to aerosol bound water.

At ***Dharavi*** (slum residential), OC contributes to 23.6% of the total load of coarse particulate matter. Next highest contribution is from ions (14.3%), followed by crustal elements (6.4%), EC (5.1%) and non crustal elements (4.4%). Unidentified portion is 46.2%. In case of fine particulate matter at this site, probable activities like refuse burning, biomass burning, vehicles etc measures up to 42.6% of organic carbon. The other significant contribution is from elemental carbon which account for 15.6% of the total fine particulate mass. Unidentified portion is 23.1%.

The coarse particulate matter at ***Khar,*** which represents the residential area, has highest contribution from ions (22.2%) followed by OC (19.5%), crustal elements (16.7%), non crustal elements (10.3%) and EC (2.8%). In finer particulate, however, vehicles and biomass burning contributes to 67.9% of organic carbon. Ions account for 21.1% of the fine particulate matter followed by EC (16.3%), non crustal elements (12.5%) and crustal elements (8.6%). A negative mass of 26.3% remains unidentified, probably due loss of organic compounds due to volatilization.

Andheri being a kerbsite, main portion of coarse particulate matter is organic carbon (24.7%) due to vehicles. Ions contribute 20.6% followed by crustal elements (16.7%), non crustal elements (10.9%) and EC (5.1%). On the other hand, in finer fraction 95.9% contribution of organic carbon corroborate with Andheri being a kerb site.

PM_{10} at ***Mahul***, an industrial site, has maximum contribution from ions (24.4%). OC accounts for 16.2% followed by non crustal elements (7.4%), crustal elements (5.6%) and EC (3.6%). 42.6% of the total particulate load remains unidentified. In case of $PM_{2.5}$ at Mahul, heavy duty vehicles, petroleum refineries contribute to 40.7% organic carbon. Ions constitute 33.1% followed by non crustal elements (13.4%) and EC (12.4%).

Mulund representing kerbsite has highest contribution from OC (26.7%) due to vehicular exhaust, refuse burning and oil burning activities at industries in the vicinity of the sampling location. Next highest contribution is from ions (16.4%) and followed by crustal elements (10.8%), non crustal elements (5.4%) and EC (5.3%). 35.3% of the total coarse particulate matter remains unidentified; whereas in finer fraction, major contribution is from ions (37.7%) followed by OC (36.4%) and EC (13.7%).

2.6.1.2 Post Monsoon: Mass Closure

Figure 2.8 presents the mass closure for PM_{10} and $PM_{2.5}$ for Post monsoon season.

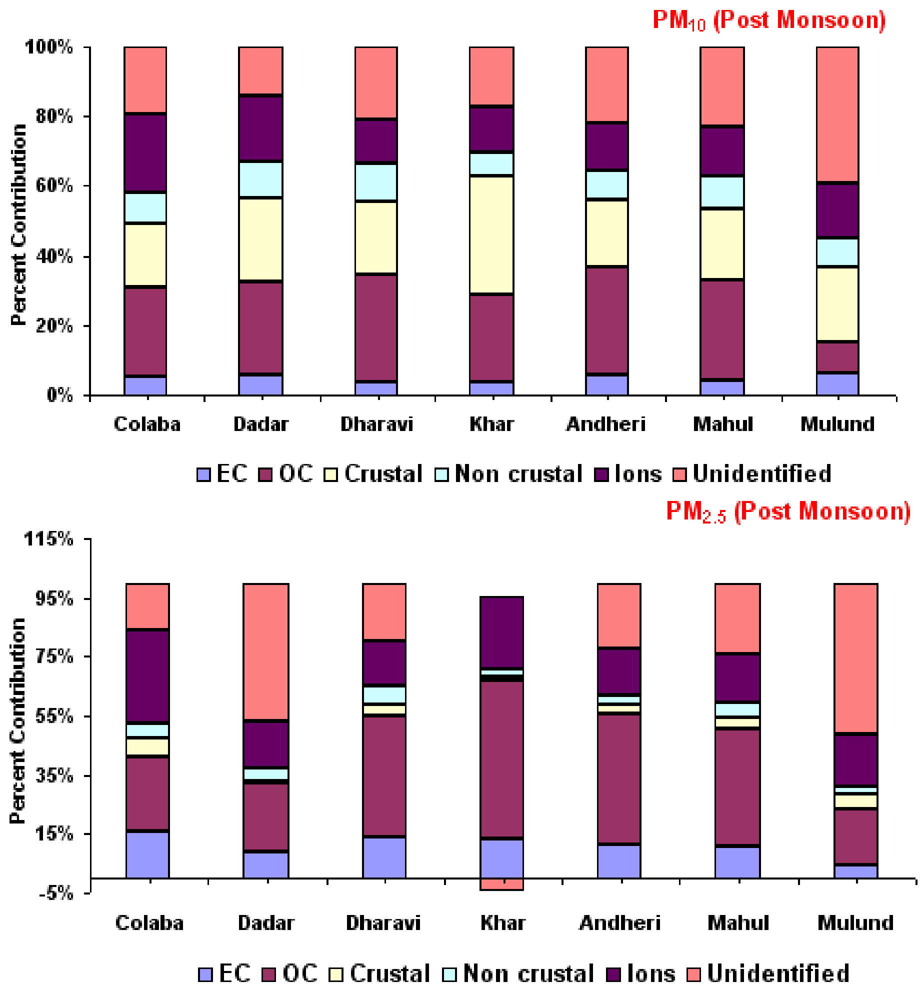


Figure 2.8: Mass Closure of PM_{10} and $PM_{2.5}$ Post Monsoon

For coarse particulate matter at ***Colaba***, maximum contribution is made from carbonaceous fraction (30.8%) followed by ions (22.2%), crustal elements (18.2%), non crustal elements (9.1%). 19.6% of total PM_{10} remains unidentified. In case of fine particulate matter, the contribution from carbonaceous fraction is 41.1%. Ions account for 32.1%. Contribution from crustal elements is (6.6%) and that from non crustal elements is (4.6%). The unidentified portion accounts for 15.7%.

Dadar being a kerbsite, main component of PM_{10} is organic carbon and elemental carbon, together contributing to 32.2%; followed by 24.4% of crustal elements, probably due to the resuspension of road dust. In case of fine particulate matter, organic carbon and elemental carbon accounts for 32.4%. Other components which contribute to the fine particulate matter at this site are ions (15.9%), non crustal elements (4.2%) and crustal elements (0.6%). 46.8% portion of the total fine particulate matter remained unidentified and could possibly be due to aerosol bound water.

At ***Dharavi***, OC contributes to 31.0% of the total load of coarse particulate matter, probably due to refuse burning and biomass combustion. Next highest contribution is from crustal elements (20.7%), followed by ions (12.4%), non crustal elements (11.3%) and EC (3.6%). Unidentified portion is 21.1%. In case of fine particulate matter at this site, organic carbon measures up to 41.1% due to activities like refuse burning, biomass combustion etc. The other significant contribution is from ions (15.3%) and followed by elemental carbon which account for 13.7%, 6.4% from non crustal elements and 3.7% from the crustal elements. Unidentified portion is 19.7%.

The coarse particulate matter at ***Khar,*** which represents the residential area, has highest contribution from crustal elements (34.4%) followed by OC (24.8%), ions (12.9%), non crustal elements (6.6%) and EC (3.8%). In finer particulate, vehicles and biomass burning contributes to 58.6% of organic carbon. Ions account for 27.5% of the fine particulate matter followed by EC (14.6%).

Andheri being a kerbsite, main constituent of coarse particulate matter is organic carbon (30.6%). Crustal elements contribute 19.6% followed by ions (13.6%), non crustal elements (8.5%) and EC (5.9%). 21.8% of the total coarse particulate load is unidentified. In finer fraction, 44.2% contribution of organic carbon corroborate with Andheri being a kerb site. Next highest contribution is from ions (15.7%) and followed by EC (11.7%)

PM_{10} at ***Mahul***, an industrial site, has maximum contribution from OC (29.2%). Crustal elements account for 20.3% followed by ions (14.5%), non crustal elements (9.2%) and EC (4%) with 22.8% of the total particulate load unidentified. In case of $PM_{2.5}$ at Mahul, heavy duty vehicles, petroleum refineries contribute to 39.8% organic carbon. Ions constitute 16.4% followed by EC (10.9%), non crustal elements (5.4%) and crustal elements (3.4%).

Mulund representing kerbsite has highest contribution from crustal elements (21.2%) due to resuspension of road dust. Next highest contribution is from ions (15.7%) and followed by OC (9.0%), non crustal elements (8.6%) and EC (6.4%). In finer fraction, major contribution is from OC (19.2%) due to vehicles and followed by ions (17.2%), crustal elements (4.8%), EC (4.5%) and non crustal elements (2.7%). Unidentified portion is 51.6%.

2.1.6.3 Winter : Mass Closure

Mass closure for fine and coarse particles is presented in **Figure 2.9.**

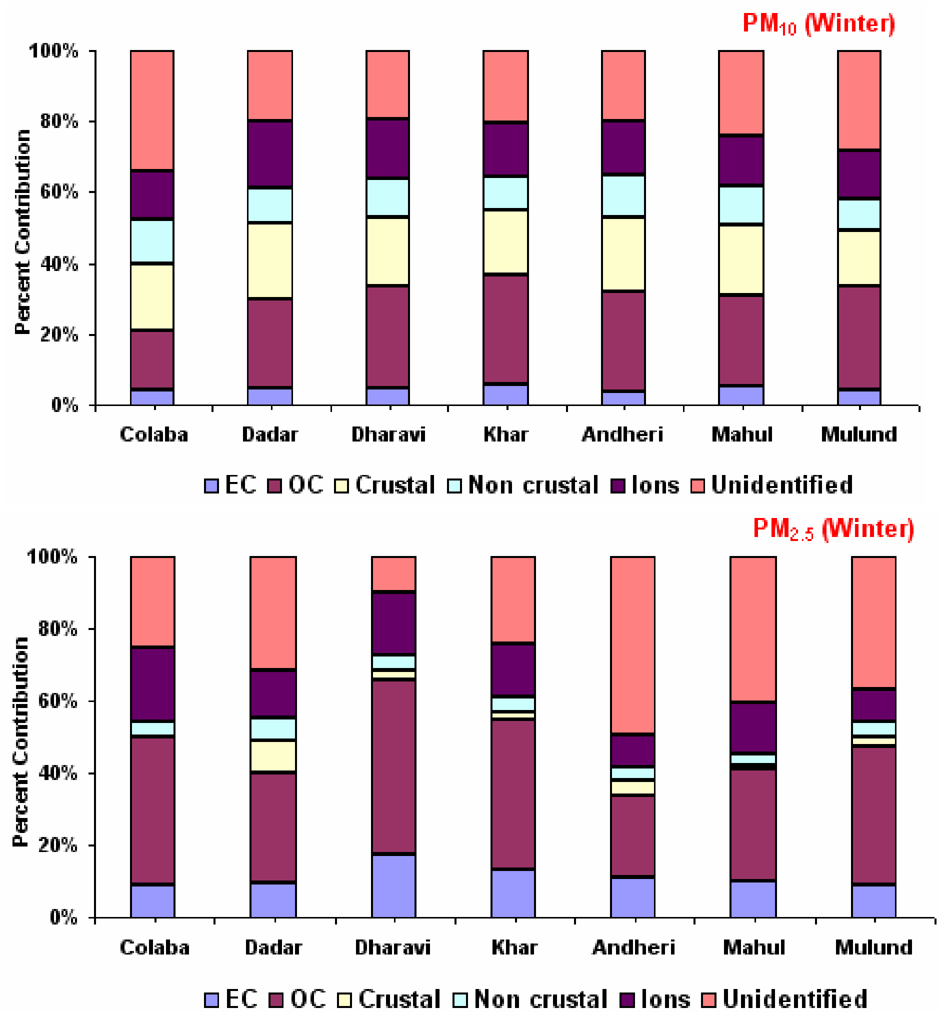


Figure 2.9: Mass Closure of PM_{10} and $PM_{2.5}$ Winter

In **Winter** season, for coarse particulate matter at ***Colaba***, representing background site the maximum contribution is from crustal elements (18.9%) due to soil. OC accounts for (16.5%) followed by ions (13.7%). In case of fine particulate matter, due to activities like vehicular exhaust and biomass burning, maximum contribution is of OC (41.1%). Ions account for 20.9% followed by EC (8.9%), non crustal elements (3.7%) and crustal elements (0.2%).The unidentified portion accounts for 25.1%.

Dadar being a kerbsite location, the main component of PM_{10} is organic carbon (25.2%) which is contributed by vehicles; followed by 21.5% of crustal elements, probably due to the resuspension of road dust. In case of fine particulate matter, organic carbon accounts for 30.7%. Other components which contribute to the fine particulate matter at this are ions (12.7%), EC (9.3%), crustal elements (9.1%) and non crustal elements (6.3%). 31.8% portion of the total fine particulate matter remained unidentified and is possibly due to aerosol bound water.

At ***Dharavi***, representing slum residential site, OC contributes to 29.2% of the total load of coarse particulate matter, probably due to refuse and biomass burning. Next highest contribution is from crustal elements (19.0%), followed by ions (17.0%), non crustal elements (10.9%) and EC (4.6%). In case of fine particulate matter at this site, organic carbon measures up to 48.5% due to activities like refuse and biomass burning, kerosene combustion etc. The other significant contribution is from ions (17.6%) and followed by elemental carbon which account for 17.2%.

The coarse particulate matter at ***Khar,*** which represents the residential area, has highest contribution from OC (30.9%) followed by crustal elements (18.4%), ions (15.0%), non crustal elements (9.5%) and EC (5.7%). About 20.5% of the total portion remained unidentified. In finer particulate, vehicles and biomass burning contributes to 41.2% of organic carbon. Ions account for 14.8% of the fine particulate matter followed by EC (13.3%), non crustal elements (4.3%) and crustal elements (2.2%). 24.2% remains unidentified.

Andheri being a kerbsite, main constituent of coarse particulate matter is carbonaceous species accounting for 31.8% due to vehicles and other sources. Crustal elements contribute 21.2% followed by ions (15.1%), non crustal elements (12.1%). In finer fraction, 33.8% is contributed by organic and elemental carbon. Next highest contribution is from ions (8.6%), crustal elements (4.0%) and non crustal elements (3.8%).

PM_{10} at ***Mahul***, an industrial site, has maximum contribution from OC (25.8%). Crustal elements account for 19.9% followed by ions (14.5%), non crustal elements (10.6%) and EC (5.3%). In case of $PM_{2.5}$ at Mahul, it appears that heavy duty vehicles, petroleum refineries contribute to 31.4% organic carbon. Ions constitute 14.2% of fine particulate matter followed by EC (9.9%).

Mulund representing kerbsite has highest contribution from OC (29.0%) due to multiple combustion sources. Next highest contribution is from crustal elements (15.7%) and followed by ions (13.7%), non crustal elements (9.2%) and EC (4.3%). In finer fraction, major contribution is from OC (38.2%) and EC (9.0%), both due to vehicular exhaust, refuse burning and oil burning in nearby industries.

It is important to note that though $PM_{2.5}$ fraction mass is lower at all places, the percentage mass of Elemental Carbon (EC) as well as Organic Carbon (OC) increases significantly. Even in case of non crustal elements viz. Pb, Zn, Cd, Cu etc., the same trend is observed. The carbonaceous fractions and non crustal elements are mainly contributed by combustion sources such as wood /leaf and refuse burning, vehicles, kerosene burning etc. It is evident from many studies that vehicles particle emissions are mostly (almost 99%) less than 1 µm. As most of the fine particles can possibly enter the human respiratory systems, their potency for health damage is high. So, it is crucial to consider the fine particle compositions as they contain the most toxic components of the PM.

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Chapter 3
Emission Inventory

3.1 Introduction

Emission estimation for the whole of Mumbai Region and site specific area necessitates assessing the load from major pollutants from the entire existing source i.e., Area source (domestic, bakeries, crematoria etc.), Point (industrial) and Line source (vehicular).

3.2 Area Source

An area source may be defined as a collection of similar units within a geographic area. Area sources collectively represent individual sources that are small and numerous and that can not be inventoried as specific point, mobile or biogenic sources. Area sources include the following groups, viz. bakeries, hotels/restaurants, crematories, construction activity, garages, domestic cooking, open eat outs, paved/unpaved road dust, solid waste dumping ground, refuse burning, ports/dock, aircrafts and railways. In subsequent sections, these sources have been described along with the methodologies delineated for load estimation.

3.2.1 Bakery

Description. : Bread and pav is an essential item of Mumbaikars. Bakeries operate in the midst of the city as one of the area source activity. According to MCGM, there are about 547 bakeries operating in Mumbai, but Bakers Association reports that there are about 1500 bakeries. Wood burning is main source of pollution from bakeries. They are distributed in entire city area. Mostly bakeries operate for 16 hours in a day and the peak season of business is December and January. Discussion with baker association pointed out that on an average bakeries have 2 ovens operating and the average amount of wood consumed per oven is 250 Kg/day. Diesel consumption for oven operating is about 60 liters/day. Data regarding bakeries in each ward was obtained from MCGM, Public Health Department. On the basis of discussions with Bakers Association President and other MCGM officials and also after conducting primary survey for 2 km x 2 km at seven locations, average wood and diesel consumption per oven was quantified. The number of bakeries operating ward wise as per MCGM is given in **Table 3.1**.

Table 3.1: Ward wise Distribution of Bakeries in Mumbai (2005-06)

Ward	No. of Bakeries	Ward	No. of Bakeries	Ward	No. of Bakeries	Ward	No. of Bakeries
A	114	F/N	13	K/W	33	P/N	28
B	51	G/S	4	L	7	R/S	4
C	52	G/N	32	M/E	1	R/N	5
D	29	H/E	18	M/W	15	S	7
E	27	H/W	26	N	4	T	5
F/S	21	K/E	41	P/S	10	**TOTAL**	**547**

Based on the primary survey estimates it was found that most of the bakeries use about 90% firewood and remaining 10% use diesel. Some of the bakeries also use electric ovens and PNG, however to a very limited extent. In the estimate presented in **Table 3.2** only wood and diesel consumptions have been used.

Table 3.2: Ward wise Wood and Diesel Consumption in Bakeries

Ward	Wood Bakeries	Diesel Bakeries	Wood Consumption Total (Kg/day)	Total Diesel Consumption (Kiloliter/day)
A	103	11	51300	0.684
B	46	5	22950	0.306
C	47	5	23400	0.312
D	26	3	13050	0.174
E	24	3	12150	0.162
F/S	19	2	9450	0.126
F/N	12	1	5850	0.078
G/S	4	0	1800	0.024
G/N	29	3	14400	0.192
H/E	16	2	8100	0.108
H/W	23	3	11700	0.156
K/E	37	4	18450	0.246
K/W	30	3	14850	0.198
L	6	1	3150	0.042
M/E	1	0	450	0.006
M/W	14	2	6750	0.09
N	4	0	1800	0.024
P/S	9	1	4500	0.06
P/N	25	3	12600	0.168
R/S	4	0	1800	0.024
R/N	5	1	2250	0.03
S	6	1	3150	0.042
T	5	1	2250	0.03
TOTAL	**492**	**55**	**246150**	**3**

Emission Estimations:

Emissions (Kg/d) = No. of Bakeries x Fuel Consumption (Kg/d) x Emission Factor

Number of registered bakeries with MCGM = 547
Number of bakeries with Baker Association = 1500
Wood consumption in a day = 250 (Kg/d/oven) x 2 Ovens = 500 Kg/d
Diesel consumption in a day = 60 (l/d)
Emission factor used are listed **Annexure 3.1**
Emission Factor for Wood Burning = 17.3 (Kg/t) (PM_{10})
Emission Factor for Diesel Burning = 0.25 (Kg/kl) (SPM)
Emission from wood burning (PM_{10}) = 492 (547 x 0.9) x 500 x 15.57 = 4258.3 (Kg/d)
Emission from diesel burning (PM_{10}) = 55 (547 x 0.10) x (60/1000) x 0.25 = 0.82 (Kg/d)

In similar way emission for others pollutants have been estimated as given in **Table 3.3 and Table 3.4.**

Table 3.3: Emission Loads from Bakeries for all Wards

Wards	Wood					Diesel					Total				
	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
A	887.5	6479.2	10.3	66.7	5873.9	0.17	0.43	4.13	1.88	0.08	887.7	6479.6	14.4	68.6	5874.0
B	397.0	2898.6	4.6	29.8	2627.8	0.08	0.19	1.85	0.84	0.04	397.1	2898.8	6.5	30.6	2627.8
C	404.8	2955.4	4.7	30.4	2679.3	0.08	0.20	1.88	0.86	0.04	404.9	2955.6	6.6	31.3	2679.3
D	225.8	1648.2	2.6	17.0	1494.2	0.04	0.11	1.05	0.48	0.02	225.8	1648.3	3.7	17.5	1494.2
E	210.2	1534.5	2.4	15.8	1391.2	0.04	0.10	0.98	0.45	0.02	210.2	1534.6	3.4	16.3	1391.2
F/S	163.5	1193.5	1.9	12.3	1082.0	0.03	0.08	0.76	0.35	0.02	163.5	1193.6	2.7	12.7	1082.0
F/N	101.2	738.9	1.2	7.6	669.8	0.02	0.05	0.47	0.21	0.01	101.2	739.0	1.7	7.8	669.8
G/S	31.1	227.3	0.4	2.3	206.1	0.01	0.02	0.14	0.07	0.00	31.1	227.3	0.5	2.4	206.1
G/N	249.1	1818.7	2.9	18.7	1648.8	0.05	0.12	1.16	0.53	0.02	249.2	1818.8	4.1	19.2	1648.8
H/E	140.1	1023.0	1.6	10.5	927.5	0.03	0.07	0.65	0.30	0.01	140.1	1023.1	2.3	10.8	927.5
H/W	202.4	1477.7	2.3	15.2	1339.7	0.04	0.10	0.94	0.43	0.02	202.4	1477.8	3.2	15.6	1339.7
K/E	319.2	2330.2	3.7	24.0	2112.5	0.06	0.15	1.49	0.68	0.03	319.3	2330.4	5.2	24.7	2112.5
K/W	256.9	1875.6	3.0	19.3	1700.3	0.05	0.12	1.20	0.54	0.02	257.0	1875.7	4.2	19.8	1700.3
L	54.5	397.8	0.6	4.1	360.7	0.01	0.03	0.25	0.12	0.01	54.5	397.8	0.9	4.2	360.7
M/E	7.8	56.8	0.1	0.6	51.5	0.00	0.00	0.04	0.02	0.00	7.8	56.8	0.1	0.6	51.5
M/W	116.8	852.5	1.4	8.8	772.9	0.02	0.06	0.54	0.25	0.01	116.8	852.6	1.9	9.1	772.9
N	31.1	227.3	0.4	2.3	206.1	0.01	0.02	0.14	0.07	0.00	31.1	227.3	0.5	2.4	206.1
P/S	77.9	568.4	0.9	5.9	515.3	0.02	0.04	0.36	0.17	0.01	77.9	568.4	1.3	6.1	515.3
P/N	218.0	1591.4	2.5	16.4	1442.7	0.04	0.11	1.01	0.46	0.02	218.0	1591.5	3.5	16.9	1442.7
R/S	31.1	227.3	0.4	2.3	206.1	0.01	0.02	0.14	0.07	0.00	31.1	227.3	0.5	2.4	206.1
R/N	38.9	284.2	0.5	2.9	257.6	0.01	0.02	0.18	0.08	0.00	38.9	284.2	0.7	3.0	257.6
S	54.5	397.8	0.6	4.1	360.7	0.01	0.03	0.25	0.12	0.01	54.5	397.8	0.9	4.2	360.7
T	38.9	284.2	0.5	2.9	257.6	0.01	0.02	0.18	0.08	0.00	38.9	284.2	0.7	3.0	257.6
Kg/day	**4258.4**	**31088.7**	**49.2**	**320.0**	**28184.2**	**0.821**	**2.068**	**19.815**	**9.026**	**0.394**	**4259.1**	**31090.6**	**69.3**	**329.0**	**28184.7**
T/year	**1554.3**	**11347.4**	**18.0**	**116.8**	**10287.2**	**0.299**	**0.755**	**7.233**	**3.294**	**0.144**	**1554.6**	**11348.1**	**25.3**	**120.1**	**10287.4**

Site-specific emissions of all seven sites viz. Colaba, Dadar, Dharavi, Khar, Andheri, Mahul and Mulund in the grids size 2 km x 2 km, of major pollutants has been estimated and given in **Tables 3.4.** City wise estimates are based on total bakeries population as explained earlier.

Table 3.4: Emission Load Due to Bakeries at Seven Sampling Sites

Sites	Wood					Diesel				
	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
Colaba	62.12	453.54	0.72	4.67	411.17	0.012	0.030	0.289	0.132	0.006
Dadar	78.75	574.89	0.91	5.92	521.18	0.015	0.038	0.366	0.167	0.007
Dharavi	82.83	604.72	0.96	6.22	548.23	0.016	0.040	0.385	0.176	0.008
Khar	51.69	377.38	0.60	3.88	342.13	0.010	0.025	0.241	0.110	0.005
Andheri	54.69	399.27	0.63	4.11	361.96	0.011	0.027	0.254	0.116	0.005
Mahul	12.30	89.80	0.14	0.92	81.41	0.002	0.006	0.057	0.026	0.001
Mulund	5.99	43.76	0.07	0.45	39.67	0.001	0.003	0.028	0.013	0.001

Table 3.4a: Emission Load Due to Bakery at Seven Sampling Sites

Sites	PM	CO	SO_2	NOx	HC
Colaba	62.13	453.57	1.01	4.80	411.18
Dadar	78.77	574.92	1.28	6.08	521.18
Dharavi	82.85	604.76	1.34	6.40	548.23
Khar	51.70	377.41	0.84	3.99	342.13
Andheri	54.70	399.29	0.89	4.23	361.97
Mahul	12.30	89.81	0.20	0.95	81.41
Mulund	5.99	43.77	0.10	0.46	39.67

* All values expressed as Kg/d

.

Major pollutants from bakeries are CO, HC and PM_{10} due to wood burning, highest PM_{10} concentration was found at Dharavi (82.85 Kg/d) and Dadar (78.77 Kg/d) followed by Colaba and Andheri. Large numbers of bakeries authorized as well as unauthorized are operating in Dharavi. Khar site adjacent to Bandra also has many bakeries operating in the area. Mahul and Mulund have minor contributions of emission load from bakery sector as these sites are mainly industrial area.

Issues

There is some level of uncertainty in the emission estimation of bakeries due to gap between number of bakeries registered with MCGM and as reported by Baker's Association. The number of bakeries could be more than registered with MCGM. Emission load difference load approximately 3 times as shown in **Table 3.5**.

Table 3.5: Emission Estimates of Bakeries Reported by MCGM vis-a-vis Baker's Association

Bakery Number	Fuel Type	Consumption (MT or kl/day)	Pollutants Emission Rate (Kg/day)				
			PM	CO	SO_2	NOx	HC
MCGM (Registered) 547	**Wood**	246.15	4258.4	31088.7	49.2	320.0	28184.2
	Diesel	3	0.821	2.068	19.815	9.026	0.394
	Total		**4259.1**	**31090.81**	**69.05**	**329.02**	**28184.57**
Bakers Association (1500)	**Wood**	675	11677.50	85252.50	135.00	877.50	77287.50
	Diesel	9	2.250	5.670	54.338	24.750	1.080
	Total		**11678.85**	**85258.17**	**189.34**	**902.25**	**77288.58**

- Emission load for bakeries operating on electric ovens have not been estimated, as they are miniscule.

Finally the overall estimates for this sector have been based on bakeries registered with MCGM as they are more realistic and verifiable.

3.2.2 Crematoria

Description: As per Hindu tradition, deaths rites are carried out primarily using wood. According to MCGM there are about 80 Hindu crematoria in Mumbai city. Of these, 34 are wood based and 11 are electrically operated by MCGM, whereas 35 wood based crematoria are operated by private agencies. Average wood requirement for burning the dead bodies, on the basis of primary survey and consultation with MCGM officials, is about 300 Kg and 3 liters (2.43 Kg) of kerosene. Major pollutants are PM_{10}, CO, HC, SO_2, NOx**.** Data regarding crematoria in each ward was obtained from MCGM's Public Health Department. The number of crematoria operating wards wise and number of Hindu deaths in each ward as per MCGM is given in **Table 3.6**.

Table 3.6: Ward Wise Distribution of Crematoria and Registered Hindu Deaths (2005)

WARD	Municipal. CEMETERY (Wood)	Municipal. CEMETERY (Electricity)	Private Cementary	Death Reported in Each Ward
A	--	--	--	1723
B	--	--	--	912
C	--	1	1	1135
D	--	--	--	2793
E	1	--	--	3374
F/S	1	1	--	3779
F/N	2	1	2	4009
G/S	2	1	2	2519
G/N	2	1	--	3595
H/E	2	--	1	4285
H/W	1	--	2	2485
K/E	3	--	--	4137
K/W	2	1	4	3849
L	2	--	2	3777
M/E	2	--	4	3312
M/W	3	1	1	2443
N	2	--	1	3092
S	1	2	--	3160
T	--	--	--	2000
P/N	3	--	8	3837
P/S	--	--	--	2141
R/N	3	1	5	2005
R/S	1	1	2	2657
R/C	1	--	--	2593
Total	**34**	**11**	**35**	**69612**

-- Crematoria is not present in the respective wards

Assumption

Based on the consultation and visits, it appears that about 30% of bodies are burnt in electric crematoria in respective ward where electric crematoria exists and remaining 70% are burnt in wood crematoria. Despite presence of electric crematoria most of the population prefers using wood based cremation. Since there are no crematoria in Ward A and B, it is assumed that cremation from A and B wards will be in neighboring wards, accordingly deaths have been distributed in ward C, D and E. Similarly deaths from ward T are distributed in the respective neighboring wards. Ward wise wood consumption, kerosene consumption and number of bodies burnt in crematoria are given in **Table 3.7.**

Table 3.7: Ward Wise Distribution of Bodies Burnt and Wood and Kerosene Consumption

Ward	Number of Bodies burnt in Electric Crematoria	Number of Bodies burnt in Wood Crematoria	Total Wood Consumption (Kg)	Total Kerosene Consumption (Kg)
A	--	--	--	--
B	--	--	--	--
C	1413	3298	989310	8013
D	--	--	--	--
E	1568	3659	1097674	8891
F/S	1134	2645	793609	6428
F/N	1203	2806	841931	6820
G/S	756	1763	529017	4285
G/N	1078	2516	754852	6114
H/E	--	4284	1285200	10410
H/W	--	2485	745432	6038
K/E	--	4137	1241108	10053
K/W	1155	2694	808206	6546
L	--	3777	1133248	9179
M/E	--	3312	993510	8047
M/W	733	1710	513078	4156
N		3092	927595	7514
S	1068	2492	747578	6055
T	--	--	--	--
P/N	--	4237	1270985	10295
P/S	--	2541	762366	6175
R/N	721	1683	504965	4090
R/S	917	2140	642043	5201
R/C	--	2593	778030	6302

Emission Estimations:

Emission (TSP) =No. of Hindu Death /yr (0.7) * wood required per body (Kg) * emission factor

And Number of Hindu Death /yr (0.3)* fuel used (kerosene –liters) * emission factor

Number of Registered death in Mumbai = 69612

Taking 70% of total dead bodies in fire wood crematoria = 57866 (deaths/yr)

Emission factor for wood burning, kerosene and electric crematoria are listed in **Annexure 3.1.**

Emission Factor (PM_{10}) Wood Consumption = 17.3 (Kg/t)

Emission Factor (SPM) Kerosene = 1.95 (Kg/t)
Emission Factor (PM_{10}) Kerosene = 0.61 (Kg/t)
Emission Factor Electric crematoria = 0.000025 (Kg/body)

Emission (PM_{10}) from wood burning = 57866 (deaths/yr) * 0.3 (t) * 17.3 (Kg/t) = 300325 (Kg/yr)

[Average kerosene consumption /body =3 liters*0.81 (density in Kg/l) = 2.43 (Kg) =0.00243 (T)]

Emission (PM) from Kerosene burning = 57866 (deaths/yr) * 0.00243 (T) * 1.95 (SPM) (Kg/t)
+ 0.61 (PM) (Kg/t) = 400 (Kg/year)

Emission (PM_{10}) from Electric burning = 11746 (deaths/yr) * 0.000025 (Kg/t) = 0.29 (Kg/yr)

In similar way emission for others pollutants have been estimated as given **Table 3.8.** Site-specific contribution of the pollutant emission load is given in **Table 3.9.** Site specific emissions have been derived from the primary survey.

Total emission load from crematoria indicates that Dadar, Dharavi and Khar are the major contributors as they are reporting more death during particular year. CO is the major pollutant followed by HC, PM_{10} and NOx as the major source in wood burning.

Table 3.8: Ward wise Emission Estimates for Crematoria

Wards	Wood					Electric				Kerosene				
	PM	CO	SO_2	NOx	HC	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
C	17115.0	124950.0	198.0	1286.0	113276.0	199.3	76.9	435.3	18.4	25.1	608.0	39.2	24.5	186.3
E	18990.0	138636.0	220.0	1427.0	125684.0	221.1	85.3	483.0	20.4	0.0	674.6	43.5	27.2	206.7
F/S	13729.0	100233.0	159.0	1032.0	90868.0	159.9	61.7	349.2	14.7	27.9	487.7	31.5	19.7	149.5
F/N	14565.0	106336.0	168.0	1095.0	96401.0	169.6	65.4	370.4	15.6	20.1	517.4	33.4	20.9	158.6
G/S	9152.0	66815.0	106.0	688.0	60572.0	106.6	41.1	232.8	9.8	21.4	325.1	21.0	13.1	99.6
G/N	13059.0	95338.0	151.0	981.0	86431.0	152.0	58.7	332.1	14.0	13.4	463.9	29.9	18.7	142.2
H/E	22234.0	162321.0	257.0	1671.0	147155.0	0.0	0.0	0.0	0.0	19.2	789.9	51.0	31.9	242.1
H/W	12896.0	94148.0	149.0	969.0	85352.0	0.0	0.0	0.0	0.0	32.6	458.1	29.6	18.5	140.4
K/E	21471.0	156752.0	248.0	1613.0	142107.0	0.0	0.0	0.0	0.0	18.9	762.8	49.2	30.8	233.8
K/W	13982.0	102076.0	162.0	1051.0	92540.0	162.8	62.8	355.6	15.0	31.5	496.7	32.1	20.0	152.2
L	19605.0	143129.0	227.0	1473.0	129757.0	0.0	0.0	0.0	0.0	20.5	696.5	44.9	28.1	213.4
M/E	17188.0	125480.0	199.0	1292.0	113757.0	0.0	0.0	0.0	0.0	28.8	610.6	39.4	24.6	187.1
M/W	8876.0	64802.0	103.0	667.0	58747.0	103.3	39.9	225.8	9.5	25.2	315.3	20.3	12.7	96.6
N	16047.0	117155.0	186.0	1206.0	106210.0	0.0	0.0	0.0	0.0	13.0	570.1	36.8	23.0	174.7
S	12933.0	94419.0	150.0	972.0	85598.0	150.6	58.1	328.9	13.9	23.5	459.4	29.6	18.5	140.8
P/N	21988.0	160525.0	254.0	1652.0	145528.0	0.0	0.0	0.0	0.0	19.0	781.1	50.4	31.5	239.4
P/S	13189.0	96287.0	152.0	991.0	87291.0	0.0	0.0	0.0	0.0	0.0	468.5	30.2	18.9	143.6
R/N	8736.0	63777.0	101.0	656.0	57819.0	101.7	39.2	222.2	9.4	32.3	310.3	20.0	12.5	95.1
R/S	11107.0	81090.0	128.0	835.0	73514.0	129.3	49.9	282.5	11.9	19.3	394.6	25.5	15.9	120.9
R/C	13460.0	98265.0	156.0	1011.0	89084.0	0.0	0.0	0.0	0.0	12.8	478.2	30.9	19.3	146.5
Kg/day	**822.8**	**6007.0**	**9.5**	**61.8**	**5445.7**	**4.5**	**1.8**	**9.9**	**0.4**	1.2	**29.2**	**1.9**	**1.2**	**9.0**
Ton./year	**300.3**	**2192.5**	**3.5**	**22.6**	**1987.7**	**1.7**	**0.6**	**3.6**	**0.2**	0.4	**10.7**	**0.7**	**0.4**	**3.3**

Table 3.8 (Contd...)

Table 3.8a: Ward wise Emission Estimates for Crematoria

Wards	Bodies Burnt				Total				
	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
C	465.0	179.4	1015.7	42.9	17140.1	126222.3	493.5	2761.5	113523.6
E	515.9	199.0	1126.9	47.6	18990.0	140047.6	547.8	3064.1	125958.7
F/S	373.0	143.9	814.8	34.4	13756.9	101253.6	396.1	2215.7	91066.6
F/N	395.7	152.7	864.4	36.5	14585.1	107418.7	419.5	2350.7	96611.7
G/S	248.6	95.9	543.1	22.9	9173.4	67495.3	264.0	1477.0	60704.3
G/N	354.8	136.9	775.0	32.7	13072.4	96308.7	376.5	2106.8	86619.9
H/E	604.0	233.0	1319.5	55.7	22253.2	163714.9	541.0	3022.4	147452.8
H/W	350.4	135.2	765.3	32.3	12928.6	94956.5	313.8	1752.8	85524.7
K/E	583.3	225.1	1274.2	53.8	21489.9	158098.1	522.3	2918.0	142394.6
K/W	379.9	146.6	829.8	35.0	14013.5	103115.4	403.5	2256.4	92742.2
L	532.6	205.5	1163.5	49.1	19625.5	144358.1	477.4	2664.6	130019.5
M/E	466.9	180.2	1020.0	43.1	17216.8	126557.5	418.6	2336.6	113987.2
M/W	241.1	93.0	526.8	22.2	8901.2	65461.7	256.2	1432.3	58875.3
N	436.0	168.2	952.3	40.2	16060.0	118161.1	391.0	2181.3	106424.9
S	351.4	135.6	767.5	32.4	12956.5	95380.4	373.3	2086.9	85785.1
P/N	597.4	230.5	1304.9	55.1	22007.0	161903.5	534.9	2988.4	145822.5
P/S	358.3	138.2	782.7	33.0	13189.0	97113.8	320.4	1792.6	87467.6
R/N	237.3	91.6	518.4	21.9	8768.3	64426.3	251.8	1409.1	57945.4
R/S	301.8	116.4	659.2	27.8	11126.3	81915.7	319.8	1792.6	73674.6
R/C	365.7	141.1	798.8	33.7	13472.8	99108.9	328.0	1829.1	89264.2
Kg/day	**22.35**	**8.62**	**48.83**	**2.06**	**824.0**	**6063.1**	**21.8**	**121.8**	**5457.2**
Ton.//Year	**8.16**	**3.15**	**17.82**	**0.75**	**300.7**	**2213.0**	**8.0**	**44.4**	**1991.9**

Table 3.9: Emission Load from Crematoria at Seven Sampling Sites (Kg/day)

Sites	Wood					Electric				Kerosene				
	PM	CO	SO_2	NOx	HC	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
Dadar	14.37	104.92	0.17	1.08	95.11	0.17	0.06	0.37	0.02	0.030	0.51	0.03	0.02	0.16
Dharavi	12.15	88.68	0.14	0.91	80.39	0.12	0.05	0.27	0.01	0.010	0.43	0.03	0.02	0.13
Khar	11.94	87.17	0.14	0.90	79.02	0.00	0.00	0.00	0.00	0.010	0.42	0.03	0.02	0.13
Andheri	9.45	68.96	0.11	0.71	62.52	0.03	0.01	0.07	0.00	0.010	0.34	0.02	0.01	0.10
Mahul	6.20	45.26	0.07	0.47	41.03	0.03	0.01	0.06	0.00	0.010	0.22	0.01	0.01	0.07
Mulund	3.90	28.46	0.05	0.29	25.80	0.05	0.02	0.10	0.00	0.000	0.14	0.01	0.01	0.04

Table 3.9a: Emission Load (contd.) from Crematoria at Seven Sampling Sites (Kg/day)

Sites	Bodies Burnt					Total				
	CO	SO_2	NOx	HC		PM	CO	SO_2	NOx	HC
Dadar	0.39	0.15	0.85	0.04		14.4	106.0	0.4	2.3	95.3
Dharavi	0.33	0.13	0.72	0.03		12.2	89.6	0.4	1.9	80.6
Khar	0.32	0.13	0.71	0.03		12.0	87.9	0.3	1.6	79.2
Andheri	0.26	0.10	0.56	0.02		9.5	69.6	0.2	1.4	62.6
Mahul	0.17	0.06	0.37	0.02		6.2	45.7	0.2	0.9	41.1
Mulund	0.11	0.04	0.23	0.01		3.9	28.8	0.1	0.6	25.9

* Values expressed as Kg/day, Colaba – No crematoria

Issues

- Hindu cremation processes vary substantially due to the quantity and type of wood used and type of pyres prepared.

3.2.3 Open Eat outs

Description: In India, the national policy for urban street vendors /hawkers notes that street vendors constitute approximate 2% of the population of a metropolis. In Mumbai, around commercial centers mainly street hawkers / open eat outs operate providing meals /snacks and tea. Municipal Corporation /government consider street vendors as encroachers, but this forms an important unorganized sector of business. On the basis of primary survey, 70% of the vendors use kerosene as fuel followed by LPG -20% and coal about 10%. The average consumption of kerosene per day is approximately 8 liters, 4 Kg/day LPG and 10 Kg/day of coal for cooking purpose. Average operating hours of street vendors is 12 hours. Data regarding number of street vendors is not available since it is considered as illegal operation. Therefore, MCGM regularly takes action on street vendors and the data is documented. Based on the data of areas of such action taken on number of street vendors by MCGM (License Department), surveys were carried out. These number have been checked by visiting representative areas where these eat outs are prevalent. Distribution of open eat outs is presented in **Table 3.10**.

Assumption

- Fuel use pattern was estimated on the basis of primary survey which involved consultations with operators

Table 3.10: Ward wise Distribution of Open Eat outs

	Street Vendors	S. Vendors Operated on Kerosene	S. Vendors Operated on LPG	S. Vendors Operated on Coal	Kerosene Consumption	LPG Consumption	Coal Consumption
A	154	108	31	15	861	123	154
B	39	27	8	4	218	31	39
C	31	22	6	3	173	25	31
D	19	13	4	2	107	15	19
E	10	7	2	1	58	8	10
F/S	77	54	15	8	429	61	77
F/N	134	94	27	13	752	107	134
G/S	36	25	7	4	203	29	36
G/N	54	37	11	5	300	43	54
H/E	30	21	6	3	170	24	30
H/W	43	30	9	4	240	34	43
K/E	71	50	14	7	399	57	71
K/W	213	149	43	21	1193	170	213
P/S	46	32	9	5	256	37	46
P/N	16	11	3	2	89	13	16
R/S	29	20	6	3	161	23	29
R/C	18	12	4	2	98	14	18
R/N	6	4	1	1	33	5	6
L	39	27	8	4	219	31	39
M/E	30	21	6	3	169	24	30
M/W	44	31	9	4	249	36	44
N	52	36	10	5	290	41	52
S	11	8	2	1	62	9	11
T	32	23	6	3	180	26	32

Emission Estimates

Per capita consumption for each type of fuel is taken as

For Kerosene – 8 lits/stall/day, For LPG – 4 Kg /day, For Coal – 10 Kg/day

Total emissions = emissions from kerosene burning + LPG burning + Coal burning

Emission from kerosene burning (PM) per day
= Number of street vendors operating on kerosene x fuel consumption per day x emission factor
= 108 x 8 x 0.81 (density)/ 1000 x 0.61 =0.426 Kg/d

Emission from LPG burning (PM) per day
= Number of street vendors operating on LPG x fuel consumption per day x emission factor
= 31 x 4 / 1000 x 2.10 = 0.2604 Kg/d

Emission from Coal burning (PM) per day
= Number of street vendors operating on Coal x fuel consumption per day x emission factor
= 15 x 10 /1000 x 20 = 3 Kg/d

Emission factors for LPG and Kerosene burning are listed in **Annexure 3.1**.

Emission for others pollutants have been also estimated similarly as given in **Table 3.11.**

Site-specific contribution of the pollutant emission load is given in **Table 3.12**

Site-specific emission distribution shows that Andheri, Dadar areas have maximum contribution, as these areas are commercial, and mixed (industrial estates, shopping malls) spots, where likelihood of floating population is high. Next highest is in Dharavi where small scale industries like meat cooking, pulses frying etc. are prepared and sold. Since Dharavi is a slum, many illegal open eat outs are operated compared to restaurants in other areas. High emission are also estimated for Khar as this site is close to Bandra which is a commercial area with shopping complexes where many open stalls are operated. CO is the major contributor followed by SO_2, PM_{10}, and NOx.

Table 3.11: Emission Load from Open Eat Out

Wards	Kerosene				LPG					Coal				
	PM	CO	SO_2	NOx	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
A	0.525	53.39	3.44	2.15	0.258	0.062	0.049	0.443	0.018	95.35	3.83	2.05	0.61	0.01
B	0.133	13.54	0.87	0.55	0.066	0.016	0.012	0.112	0.004	24.18	0.97	0.52	0.16	0.00
C	0.106	10.72	0.69	0.43	0.052	0.012	0.010	0.089	0.004	19.15	0.77	0.41	0.12	0.00
D	0.065	6.64	0.43	0.27	0.032	0.008	0.006	0.055	0.002	11.85	0.48	0.25	0.08	0.00
E	0.036	3.63	0.23	0.15	0.018	0.004	0.003	0.030	0.001	6.48	0.26	0.14	0.04	0.00
F/S	0.262	26.62	1.72	1.07	0.129	0.031	0.025	0.221	0.009	47.53	1.91	1.02	0.31	0.00
F/N	0.459	46.64	3.01	1.88	0.226	0.054	0.043	0.387	0.015	83.29	3.35	1.79	0.54	0.01
G/S	0.124	12.58	0.81	0.51	0.061	0.015	0.012	0.104	0.004	22.45	0.90	0.48	0.14	0.00
G/N	0.183	18.59	1.20	0.75	0.090	0.022	0.017	0.154	0.006	33.2	1.33	0.71	0.21	0.00
H/E	0.104	10.57	0.68	0.43	0.051	0.012	0.010	0.088	0.004	18.88	0.76	0.40	0.12	0.00
H/W	0.147	14.89	0.96	0.60	0.072	0.017	0.014	0.124	0.005	26.59	1.07	0.57	0.17	0.00
K/E	0.244	24.77	1.60	1.00	0.120	0.029	0.023	0.205	0.008	44.23	1.78	0.95	0.28	0.00
K/W	0.728	73.95	4.77	2.98	0.358	0.086	0.068	0.613	0.025	132.06	5.31	2.83	0.85	0.01
P/S	0.156	15.86	1.02	0.64	0.077	0.018	0.015	0.132	0.005	28.31	1.14	0.61	0.18	0.00
P/N	0.054	5.52	0.36	0.22	0.027	0.006	0.005	0.046	0.002	9.85	0.40	0.21	0.06	0.00
RS	0.098	9.99	0.64	0.40	0.048	0.012	0.009	0.083	0.003	17.85	0.72	0.38	0.11	0.00
R/C	0.060	6.10	0.39	0.25	0.029	0.007	0.006	0.051	0.002	10.88	0.44	0.23	0.07	0.00
R/N	0.020	2.04	0.13	0.08	0.010	0.002	0.002	0.017	0.001	3.65	0.15	0.08	0.02	0.00
L	0.134	13.58	0.88	0.55	0.066	0.016	0.013	0.113	0.005	24.25	0.97	0.52	0.16	0.00
M/E	0.103	10.45	0.67	0.42	0.051	0.012	0.010	0.087	0.003	18.67	0.75	0.40	0.12	0.00
M/W	0.152	15.43	1.00	0.62	0.075	0.018	0.014	0.128	0.005	27.56	1.11	0.59	0.18	0.00
N	0.177	17.98	1.16	0.72	0.087	0.021	0.017	0.149	0.006	32.11	1.29	0.69	0.21	0.00
S	0.038	3.82	0.25	0.15	0.018	0.004	0.004	0.032	0.001	6.82	0.27	0.15	0.04	0.00
T	0.110	11.19	0.72	0.45	0.054	0.013	0.010	0.093	0.004	19.97	0.80	0.43	0.13	0.00
Kg/day	**4.22**	**428.48**	**27.64**	**17.28**	**2.07**	**0.50**	**0.39**	**3.55**	**0.14**	765.15	**30.75**	**16.41**	**4.92**	**0.06**
Ton/year	**1.54**	**156.40**	**10.09**	**6.31**	**0.76**	**0.18**	**0.14**	**1.30**	**0.05**	279.28	**11.23**	**5.99**	**1.80**	**0.02**

Table 3.11a: Total Emission Load from Open Eat out

Wards	Total Emission Load				
	PM	CO	SO_2	NOx	HC
A	96.13	57.28	5.54	3.20	0.03
B	24.38	14.53	1.40	0.82	0.00
C	19.31	11.50	1.11	0.64	0.00
D	11.95	7.13	0.69	0.41	0.00
E	6.53	3.89	0.37	0.22	0.00
F/S	47.92	28.56	2.77	1.60	0.01
F/N	83.98	50.04	4.84	2.81	0.03
G/S	22.64	13.50	1.30	0.75	0.00
G/N	33.47	19.94	1.93	1.11	0.01
H/E	19.04	11.34	1.09	0.64	0.00
H/W	26.81	15.98	1.54	0.89	0.01
K/E	44.59	26.58	2.57	1.49	0.01
K/W	133.15	79.35	7.67	4.44	0.04
P/S	28.54	17.02	1.65	0.95	0.01
P/N	9.93	5.93	0.58	0.33	0.00
RS	18.00	10.72	1.03	0.59	0.00
R/C	10.97	6.55	0.63	0.37	0.00
R/N	3.68	2.19	0.21	0.12	0.00
L	24.45	14.57	1.41	0.82	0.01
M/E	18.82	11.21	1.08	0.63	0.00
M/W	27.79	16.56	1.60	0.93	0.01
N	32.37	19.29	1.87	1.08	0.01
S	6.88	4.09	0.40	0.22	0.00
T	20.13	12.00	1.16	0.67	0.00
Kg/day	**771.44**	**459.73**	**44.44**	**25.75**	**0.20**
Ton/year	**281.58**	**167.81**	**16.22**	**9.41**	**0.07**

Table 3.12: Site Wise Total Emission Load from Open Eat

Sites	Kerosene					LPG					Coal				
	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
Colaba	0.04	3.74	0.24	0.15	0.04	0.02	0.00	0.00	0.03	0.00	6.68	0.27	0.14	0.04	0.00
Dadar	0.09	9.50	0.61	0.38	0.09	0.05	0.01	0.01	0.08	0.00	16.97	0.68	0.36	0.11	0.00
Dharavi	0.06	6.17	0.40	0.25	0.06	0.03	0.01	0.01	0.05	0.00	11.03	0.44	0.24	0.07	0.00
Khar	0.04	3.82	0.25	0.15	0.04	0.02	0.00	0.00	0.03	0.00	6.83	0.27	0.15	0.04	0.00
Andheri	0.08	8.02	0.52	0.32	0.08	0.04	0.01	0.01	0.07	0.00	14.33	0.58	0.31	0.09	0.00
Mahul	0.02	2.38	0.15	0.10	0.02	0.01	0.00	0.00	0.02	0.00	4.25	0.17	0.09	0.03	0.00
Mulund	0.00	0.42	0.03	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.75	0.03	0.02	0.00	0.00

***All values expressed as Kg/d**

Sites	Total Emission				
	PM	CO	SO_2	NOx	HC
Colaba	6.74	4.01	0.38	0.22	0.04
Dadar	17.11	10.19	0.98	0.57	0.09
Dharavi	11.12	6.62	0.65	0.37	0.06
Khar	6.89	4.09	0.4	0.22	0.04
Andheri	14.45	8.61	0.84	0.48	0.08
Mahul	4.28	2.55	0.24	0.15	0.02
Mulund	0.75	0.45	0.05	0.02	0.00

Issues

- Fuel consumption given by street vendor during primary survey may not be very reliable
- The actual number of street vendors could be high /low than the estimated depending upon time, season and locations.

3.2.4 Hotel & Restaurants

Description: Information on hotels and restaurants was obtained directly by consulting the members of Hotel and Restaurant Owners Association of Mumbai. There are around 1404 Hotels with minimum 3-star facilities in Mumbai. There were 5806 hotels and restaurants registered with BMC up to March 2005, under class I, II and III categories. Ward-wise break up is presented in **Table 3.13**. During the discussions with the concerned people, it was revealed that the actual number of tea stalls/snack bars/fast food centres could be more than twice the registered number. In addition, there are a number of staff canteens of various establishments in Mumbai. Hotels and Restaurants use LPG cylinders and coal for their operation. LPG commercial cylinders are used for cooking and coal is used in the tandoor bhattis. The primary survey of Hotels and Restaurants gave an average LPG consumption of 3 Cylinders (19 Kg capacity) and coal consumption of 8 Kg per hotel/restaurant as per the survey.

Table 3.13: Ward wise Number of Hotels & Restaurants: 2005 (Registered under MCGM)

Name	Class I	Class II	Class III	Total
A	128	108	421	657
B	23	1	210	234
C	27	17	252	296
D	101	67	275	443
E	58	19	480	557
F/S	52	4	151	207
F/N	61	10	146	217
G/S	40	12	216	268
G/N	38	19	242	299
H/E	33		111	144
H/W	7	26	116	149
K/E	154	23	147	324
K/W	123	8	273	404
L	69	1	248	318
M/E	20		56	76
M/W	106	4	125	235
N	10	2	54	66
P/S	60		1	61
P/N	84	3	151	238
R/S	48	1	95	144
R/N	47		40	87
S	64	3	127	194
T	51	2	135	188
Total	**1404**	**330**	**4072**	**5806**

For 2007, same number has been assumed

Emission Estimations

- Emission Load from LPG

Since LPG burning doesn't comprise of coarse particles, an assumption that only $PM_{2.5}$ particles are present in the LPG emissions is made and considered as PM.

Total emissions ($PM_{2.5}$) due to LPG burning in Hotels

= Number of Hotels x LPG consumption (Tons/day) x Emission Factor (Kg/MT) **(Annexure 3.1)**

Total $PM_{2.5}$ emissions due to LPG burning in Hotels

= 5806 x (3x19/1000 Tons/day) x 2.1 Kg/MT = 695.5 Kg/Day

However, for calculation purposes, it has been referred to as PM_{10}.

- Emission Load from Coal

Total emissions (PM) due to coal burning in Hotels

= No. of Hotels x Coal consumption (Tons/day) x Emission Factor (Kg/MT)

= 5806 x 8/1000 Tons/day x 20 Kg/MT = 929.6 Kg/Day

In similar way emission for others pollutants have been estimated and their ward wise distribution is presented in **Table 3.14**.

Site-specific contribution of the pollutant emission load is given in **Table 3.15**

Site-specific major contributions of PM from hotel and restaurant are higher from Dadar and Dharavi area as the sites are predominantly commercial in nature. Large number of hotels and restaurants are in the vicinity of these sampling locations. Next highest emissions are for Andheri, Colaba and Khar. CO is the major pollutant followed by PM, NOx, SO_2 and HC emissions.

Table 3.14: Ward wise Distribution of Emission Load from Hotel and Restaurants

Wards	LPG (Class I+II+III)					Coal (Class I+II+III)					Total (Class I+II+III)				
	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
A	78.64	18.7	15	133.6	5.4	105.1	193.4	69.9	21	2.6	183.76	212.1	84.9	154.6	8.0
B	28.01	6.66	5.34	47.6	1.9	37.44	88.32	24.9	7.47	0.9	65.45	95.0	30.2	55.1	2.8
C	35.43	8.43	6.75	60.21	2.4	47.36	105.9	31.5	9.45	1.2	82.79	114.3	38.2	69.7	3.6
D	53.03	12.6	10.1	90.11	3.6	70.88	129.8	47.1	14.1	1.8	123.91	142.4	57.2	104.3	5.4
E	66.67	15.9	12.7	113.3	4.5	89.12	203	59.3	17.8	2.2	155.79	218.8	72.0	131.1	6.8
F/S	24.78	5.89	4.72	42.1	1.7	33.12	70.57	22	6.61	0.8	57.9	76.5	26.7	48.7	2.5
F/N	25.97	6.18	4.95	44.14	1.8	34.72	70.37	23.1	6.93	0.9	60.69	76.6	28.0	51.1	2.6
G/S	32.08	7.63	6.11	54.51	2.2	42.88	94.1	28.5	8.55	1.1	74.96	101.7	34.6	63.1	3.3
G/N	35.79	8.51	6.82	60.82	2.4	47.84	104.1	31.8	9.54	1.2	83.63	112.6	38.6	70.4	3.6
H/E	17.36	4.13	3.31	29.49	1.2	23.2	50.84	15.4	4.63	0.6	40.56	55.0	18.7	34.1	1.8
H/W	17.84	4.24	3.4	30.31	1.2	23.84	47.65	15.9	4.76	0.6	41.68	51.9	19.3	35.1	1.8
K/E	38.78	9.23	7.39	65.9	2.6	51.84	89.31	34.5	10.3	1.3	90.62	98.5	41.9	76.2	3.9
K/W	48.36	11.5	9.21	82.17	3.3	64.64	133.4	43	12.9	1.6	113	144.9	52.2	95.1	4.9
L	38.06	9.06	7.25	64.68	2.6	50.88	112.6	33.8	10.2	1.3	88.94	121.7	41.1	74.8	3.9
M/E	9.22	2.19	1.76	15.66	0.6	12.32	26.32	8.19	2.46	0.3	21.54	28.5	10.0	18.1	0.9
M/W	28.13	6.69	5.36	47.8	1.9	37.6	70.97	25	7.5	0.9	65.73	77.7	30.4	55.3	2.9
N	7.9	1.88	1.5	13.42	0.5	10.56	23.52	7.02	2.11	0.3	18.46	25.4	8.5	15.5	0.8
P/S	7.42	1.77	1.41	12.61	0.5	9.92	12.36	6.6	1.98	0.3	17.34	14.1	8.0	14.6	0.8
P/N	28.49	6.78	5.43	48.41	1.9	38.08	76.95	25.3	7.6	1	66.57	83.7	30.8	56.0	2.9
R/S	17.24	4.1	3.28	29.29	1.2	23.04	47.45	15.3	4.6	0.6	40.28	51.6	18.6	33.9	1.8
R/N	10.53	2.51	2.01	17.9	0.7	14.08	25.32	9.36	2.81	0.4	24.61	27.8	11.4	20.7	1.1
S	23.22	5.52	4.42	39.46	1.6	31.04	63.4	20.6	6.19	0.8	54.26	68.9	25.1	45.7	2.4
T	22.5	5.35	4.29	38.24	1.5	30.08	63.99	20	6	0.8	52.58	69.3	24.3	44.2	2.3
Kg/day	**695.5**	**165**	**133**	**1182**	**47**	**929.6**	**1904**	**618**	**186**	**23**	**1625.1**	**2068.9**	**750.7**	**1367.3**	**70.5**
Tons/year	**253.8**	**60.4**	**48.4**	**431.3**	**17.0**	**339.3**	**694.8**	**226.0**	**67.7**	**8.5**	**593.1**	**755.2**	**274.4**	**499.0**	**25.5**

Table 3.15: Site wise Emission Load from Hotel & Restaurants

Sites	LPG (Class I+ II+ III)					Coal (Class I+ II+ III)					Total Emission Load				
	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
Colaba	5.51	1.31	1.05	9.35	0.37	7.36	13.54	4.89	1.47	0.18	12.87	14.85	5.94	10.82	0.55
Dadar	12.43	2.96	2.37	21.13	0.85	16.62	35.76	11.05	3.32	0.42	29.05	38.72	13.42	24.45	1.27
Dharavi	11.45	2.72	2.18	19.46	0.78	15.31	33.13	10.18	3.05	0.38	26.76	35.85	12.36	22.51	1.16
Khar	4.96	1.18	0.94	8.42	0.34	6.62	13.60	4.40	1.32	0.17	11.58	14.78	5.34	9.74	0.51
Andheri	7.85	1.87	1.49	13.33	0.53	10.49	19.61	6.97	2.09	0.26	18.34	21.48	8.46	15.42	0.79
Mahul	3.55	0.84	0.68	6.03	0.24	4.75	9.20	3.16	0.95	0.12	8.3	10.04	3.84	6.98	0.36
Mulund	2.55	0.61	0.49	4.34	0.17	3.41	6.97	2.27	0.68	0.09	5.96	7.58	2.76	5.02	0.26

* Values expressed as Kg/day

Issues

- Domestic cylinders are also consumed in the commercial sector illegally for which data was not easily available.

3.2.5 Domestic Sector

Description: There are 24 wards in Greater Mumbai. The total numbers of cylinder LPG consumption during the year 2005 in domestic sector were reported to be 12,507,480 of 14.6 Kg each. BPCL and HPCL respectively shared 65% and 35% of the total supply. LPG is the major fuel used (80-85%) in Greater Mumbai. Besides, about 15-20% Kerosene is used as fuel by domestic use, roadside tea/snack stalls. Based on primary survey it is estimated that most of the slum population (88%) consumes kerosene as major cooking fuel. Average kerosene consumption by a slum household is about 25 Liters/month and average kerosene consumption by a non-slum household is 3 Liters/month. The number of members in a slum household and non-slum household is assumed to be 6 and 5 respectively. Ward wise fuel consumption viz. LPG–Cylinder consumption and Slum and Non-slum kerosene consumption is presented in **Table 3.16**. Ward wise LPG cylinders consumption data is obtained from State Level Oil Coordination Committee (SLOC).

Table 3.16: Ward wise Fuel Consumption in Domestic Sector

Ward	Area	LPG Consumption (No. of Cylinders/Yr)	Slum Kerosene Consumption (lit/d)	Non Slum Kerosene Consumption (lit/d)
A	Colaba	268500	8454	2999
B	Wadi Bunder/ Dongri	121932	2601	2438
C	Marine Lines/Girgaon	291576	0	4058
D	Tardev/ M. Central	570408	5283	6896
E	Byculla	127212	7250	7762
FN	Matunga Rd, (W)	110328	19661	5090
FS	Wadala/Parel	520884	42270	4399
GN	Mahim /Sion, Dadar	949668	21355	6082
GS	Worli/ Prabhadevi	526872	46712	4911
HE	Bandra (E)/Khar, Santacruz	589212	33110	6847
HW	Bandra (W)	124428	36901	1432
KE	Andheri, Santacruz	1195248	65550	6757
KW	Jogeshwari, Andheri (W)	1186836	43872	7693
L	Kurla (W), Ghatkopar	488604	91480	2386
ME	Govandi/ Mankhurd	489720	64160	4254
MW	Sion/ Trombay Rd, Chembur	554064	44573	1860
N	Ghatkopar (E/W)	447324	60391	3691
PN	Malad (E/W)	940104	29233	4546
PS	Goregaon	760140	70586	5807
RS	Malad, Kandivali	204414	45288	5274
RC	Kandivali, Borivali	428208	24034	6799
RN	Dahisar, Borivali	725490	23553	3883
S	Bhandup (W), Vikroli	623472	82367	1959
T	Mulund	262836	16136	4279
Total		**12507480**	**884821**	**112104**

Emission Estimation

- Emission Load from LPG

Total emissions (PM) from LPG burning for domestic cooking
= Number of LPG cylinders consumed x Capacity of the cylinder (14.6 Kg) x Em. Factor (Kg/MT)
= 12507480 /365 x 14.6 x 2.1/1000 Kg/d= 1050.63 Kg/Day

Census data was obtained from Census 2001, Percentage of Slum population from each ward is calculated according to *(Dr.D.P.Singh, Slum Population In Mumbai:Part I,Population – ENVIS Centre IIPS,Vol.3,No.1, March, 2006)*
Number of Household was calculated on the assumption that there are 6 members from one slum-household and 5 members in non -slum household

Kerosene consumption per slum household = 25 liters/month = 0.833Liters/Day
Kerosene consumption per non-slum household = 3liters/month = 0.1 Liters/Day

Total emissions (PM) from kerosene burning per day in a household = number of households x kerosene consumption (tons/day) x emission factor (Kg/MT)

Total emissions (PM) from kerosene burning per day in a slum household
= (6373263/6) x (0.833L/day x 0.8175/1000) x 0.61 g/Kg = 441.2 Kg/day

Total emissions (PM) from kerosene burning per day in a non-slum household
= (5605187/5)*(0.1 L/day x 0.8175/1000) x 0.61 g/Kg = 55.87 Kg/Day

All $PM_{2.5}$ emissions are estimated to be in terms of PM_{10}. Domestic emission load from LPG and kerosene with respect to their pollutants have been estimated and their ward wise distribution is presented in **Table 3.17**. Site-specific contribution of the pollutant emission load is given in **Table 3.18.** All emission factors used are given in **Annexure 3.1.**

Domestic sector maximum emission of PM is from Dharavi area. Both kerosene and LPG emissions are high in Dharavi site. Dadar site has the next maximum emission of PM. Amongst other pollutants, CO is the major pollutant followed by NOx, SO_2, PM, HC respectively.

Table 3.17: Ward wise Distribution of Emission Load from Domestic Sector

Wards	Kerosene				LPG					Total				
	PM	CO	SO_2	NOx	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
A	5.7	580.2	37.4	23.4	22.6	75.8	4.3	541.3	21.7	28.3	656.0	41.7	564.7	21.7
B	2.5	255.3	16.5	10.3	10.2	34.4	2.0	245.8	9.8	12.7	289.7	18.5	256.1	9.8
C	2.0	205.6	13.3	8.3	24.5	82.3	4.7	587.8	23.5	26.5	287.9	18.0	596.1	23.5
D	6.1	617.0	39.8	24.9	47.9	161.0	9.1	1149.9	46.0	54.0	778.0	48.9	1174.8	46.0
E	7.5	760.6	49.1	30.7	10.7	35.9	2.0	256.5	10.3	18.2	796.5	51.1	287.2	10.3
F/S	12.3	1254.0	80.9	50.6	43.8	147.0	8.3	1050.1	42.0	56.1	1401.0	89.2	1100.7	42.0
F/N	23.3	2364.4	152.5	95.3	9.3	31.1	1.8	222.4	8.9	32.6	2395.5	154.3	317.7	8.9
G/S	13.7	1390.1	89.7	56.1	44.3	148.7	8.4	1062.2	42.5	58.0	1538.8	98.1	1118.3	42.5
G/N	25.7	2615.4	168.7	105.5	79.8	268.0	15.2	1914.5	76.6	105.5	2883.4	183.9	2020.0	76.6
H/E	19.9	2024.4	130.6	81.6	49.5	166.3	9.4	1187.9	47.5	69.4	2190.7	140.0	1269.5	47.5
H/W	19.1	1942.1	125.3	78.3	10.5	35.1	2.0	250.8	10.0	29.6	1977.2	127.3	329.1	10.0
K/E	36.0	3663.3	236.3	147.7	100.4	337.3	19.1	2409.6	96.4	136.4	4000.6	255.4	2557.3	96.4
K/W	25.7	2612.5	168.5	105.3	99.7	335.0	19.0	2392.7	95.7	125.4	2947.5	187.5	2498.0	95.7
L	46.8	4755.5	306.8	191.8	41.0	137.9	7.8	985.0	39.4	87.8	4893.4	314.6	1176.8	39.4
M/E	34.1	3466.1	223.6	139.8	41.1	138.2	7.8	987.3	39.5	75.2	3604.3	231.4	1127.1	39.5
M/W	23.1	2352.4	151.8	94.9	46.5	156.4	8.9	1117.0	44.7	69.6	2508.8	160.7	1211.9	44.7
N	31.9	3246.6	209.5	130.9	37.6	126.3	7.2	901.8	36.1	69.5	3372.9	216.7	1032.7	36.1
P/S	16.8	1711.3	110.4	69.0	63.9	214.5	12.2	1532.4	61.3	80.7	1925.8	122.6	1601.4	61.3
P/N	38.1	3870.3	249.7	156.1	79.0	265.3	15.0	1895.2	75.8	117.1	4135.6	264.7	2051.3	75.8
R/S	25.2	2561.6	165.3	103.3	17.2	57.7	3.3	412.1	16.5	42.4	2619.3	168.6	515.4	16.5
R/C	15.4	1562.1	100.8	63.0	36.0	120.9	6.9	863.3	34.5	51.4	1683.0	107.7	926.3	34.5
R/N	13.7	1390.0	89.7	56.1	60.9	204.8	11.6	1462.6	58.5	74.6	1594.8	101.3	1518.7	58.5
S	42.0	4272.2	275.6	172.3	52.4	176.0	10.0	1256.9	50.3	94.4	4448.2	285.6	1429.2	50.3
T	10.2	1034.3	66.7	41.7	22.1	74.2	4.2	529.9	21.2	32.3	1108.5	70.9	571.6	21.2
Kg/d	**496.9**	**50507.5**	**3258.5**	**2036.6**	**1050.6**	**3530.1**	**200.1**	**25215.1**	**1008.6**	**1547.5**	**54037.6**	**3458.6**	**27251.7**	**1008.6**
T/year	**181.4**	**18435.2**	**1189.4**	**743.4**	**383.5**	**1288.5**	**73.0**	**9203.5**	**368.1**	**564.9**	**19723.7**	**1262.4**	**9946.9**	**368.1**

Table 3.18: Site wise Emission Load from Domestic Sector

Sites	Kerosene				LPG					Total				
	PM	CO	SO_2	NOx	PM	CO	SO_2	NOx	HC	PM	CO	SO_2	NOx	HC
Colaba	0.4	40.61	2.62	1.64	1.579	5.305	0.301	37.891	1.516	2.0	45.9	2.9	39.5	1.5
Dadar	8.44	859.21	55.42	34.66	23.67	79.53	4.51	568.08	22.72	32.1	938.7	59.9	602.7	22.7
Dharavi	8.47	862.3	55.62	34.78	24.35	81.815	4.638	584.393	23.376	32.8	944.1	60.3	619.2	23.4
Khar	5.41	550.37	35.51	22.19	6.05	20.328	1.152	145.197	5.808	11.5	570.7	36.7	167.4	5.8
Andheri	5.94	604.15	38.97	24.36	18.52	62.24	3.53	444.59	17.78	24.5	666.4	42.5	469.0	17.8
Mahul	5.04	512.53	33.07	20.67	7.945	26.695	1.513	190.681	7.627	13.0	539.2	34.6	211.4	7.6
Mulund	4.62	469.94	30.32	18.95	5.761	19.357	1.097	138.261	5.53	10.4	489.3	31.4	157.2	5.5

* Values expressed as Kg/d

3.2.6 Open Burning

Description: Open burning is the burning of any matter in such a manner that products of combustion resulting from the burning are emitted directly into the ambient (surrounding outside) air without passing through an adequate stack, duct or chimney. Open burning is an illegal method of burning solid waste; materials commonly disposed of in this manner include municipal waste, auto body components, wood refuse, small scale industrial refuse and leaves. As per the discussions with MCGM officials, it was found that about 2% of the total solid waste generated in each ward is openly burnt and about 10% of the total solid waste is burnt in the wards containing solid waste landfill sites as given in **Table 3.19**. The quantity of ward wise solid waste generated was obtained from MCGM, solid waste management division.

Table 3.19 : Ward wise Solid Waste Generation and their Open Burning Percent Contribution & Landfill Site, (2005)

Wards	Solid waste generation in Tonnes	Open Burning		Wards	Solid waste generation in Tonnes	Open Burning
A	400.5	8.01		K/W	411.8	8.236
B	132.3	2.646		P/S	202.5	4.05
C	258.8	5.176		P/N	333	6.66
D	522	10.44		R/S	160.7	3.214
E	504	10.08		R/C	301.5	6.03
F/S	292.5	5.85		R/N	150.8	3.016
F/N	315	6.3		L	417.6	8.352
G/S	373.5	7.47		M/E	281.3	5.626
G/N	531	10.62		M/W	299.3	5.986
H/E	253.8	5.076		N	229.5	4.59
H/W	324	6.48		S	261	5.22
K/E	337.5	6.75		T	180.5	3.61

Landfill Sites	Solid Waste at Landfill Site	Open Burning (10%)
Gorai (R/S)	1195	119
Deonar (M/E)	4104	410
Mulund (T)	626	63

Emission Estimation

Total emissions (PM) from open burning of solid waste

= Amount of solid waste generated (tons) x percentage of solid waste burnt x emission factor (Kg/MT) = [7474.4 (tons) x 2% (non dumping site) + 5925 (Landfill site) x 10%] x 8 (Kg/MT) = **5935.90 Kg/Day.**

Emission factors are given in **Annexure 3.1.**

In similar way emission for others pollutants have been estimated and their ward wise distribution is presented in **Table 3.20**.

Table 3.20: Ward Emission Load from Open Burning (Kg/d)

Wards	PM	CO	SO_2	NOx	HC
A	107.65	336.42	4.01	24.03	172.22
B	35.56	111.13	1.32	7.94	56.89
C	69.57	217.39	2.59	15.53	111.28
D	140.31	438.48	5.22	31.32	224.46
E	135.48	423.36	5.04	30.24	216.72
F/S	78.62	245.70	2.93	17.55	125.78
F/N	84.67	264.60	3.15	18.90	135.45
G/S	100.4	313.74	3.74	22.41	160.61
G/N	142.73	446.04	5.31	31.86	228.33
H/E	68.22	213.19	2.54	15.23	109.13
H/W	87.09	272.16	3.24	19.44	139.32
K/E	90.72	283.50	3.38	20.25	145.13
K/W	110.69	345.91	4.12	24.71	177.07
P/S	54.43	170.10	2.03	12.15	87.08
P/N	89.51	279.72	3.33	19.98	143.19
R/S	43.19	134.99	1.61	9.64	69.10
R/C	81.04	253.26	3.02	18.09	129.65
R/N	40.54	126.67	1.51	9.05	64.84
L	112.25	350.78	4.18	25.06	179.57
M/E	75.62	236.29	2.81	16.88	120.96
M/W	80.45	251.41	2.99	17.96	128.70
N	61.69	192.78	2.30	13.77	98.69
S	70.16	219.24	2.61	15.66	112.23
T	48.52	151.62	1.81	10.83	77.62
Kg/d	**2009.11**	**6278.50**	**74.74**	**448.46**	**3213.99**
T/yr	**734**	**2292**	**27**	**164**	**1173**

Emission Load from Landfill Open Burning

Wards	PM	CO	SO_2	NOx	HC
Gorai (R/S)	1605.71	5017.85	59.74	358.42	2568.66
Deonar (ME)	5515.84	17237.00	205.20	1231.21	8823.70
Mulund (T)	841.13	2628.54	31.29	187.75	1345.56
Kg/day	**7962.68**	**24883.38**	**296.23**	**1777.38**	**12737.92**
Tonnes/year	**2906**	**9082**	**108**	**649**	**4649**

Site-specific contribution of the pollutant emission load is given in **Table 3.21.**

Table 3.21: Site wise Total Emission Load from Open Burning

	PM	CO	SO_2	NOx	HC
Colaba	7.54	23.55	0.28	1.68	12.06
Dadar	46.11	144.09	1.72	10.29	73.76
Dharavi	46.3	144.70	1.72	10.34	74.07
Khar	22.88	71.49	0.85	5.11	36.59
Andheri	18.18	56.82	0.68	4.06	29.08
Mahul	14.09	44.04	0.52	3.15	22.55
Mulund	7.71	24.12	0.29	1.72	12.35

* Values expressed as Kg/day

PM contribution is highest at Dharavi followed by Dadar due open burning sector. Open burning contributions are in the following order viz. Khar, Andheri, Mahul, Mulund and a very minor contribution from Colaba. CO and HC are major pollutants from this sector.

Issues: Refuse burning refers to common burning of street litter and leaves, although little is know about the magnitude of the practice. No documented data on rate of burning, area of dump, unauthorized activity of the rag pickers are available. Landfill sites burning do not come under any of the seven sampling sites representing 2x2 km area.

3.2.7 Paved & Unpaved Dust

Description: As motor vehicle moves over road surface which leads to resuspension of dust from unpaved roads or settled dust from the paved surface by the turbulent wake of the vehicle and emitted as particulate matter. Emissions are estimated as a function of the silt loading of the paved surface and mean weight of the vehicles traveling over the surface. Data source such as road length, vehicle km traveled and depot, truck terminal was obtained from MMRDA, MCGM and RTO, Mumbai and primary survey of some roads for vehicle counting.

- **Emission Estimates for Paved Dust**

Vehicle Weight –Mumbai *

Vehicle Count 2005		%Vehicle Count (A)	Avg.Weight (Kg) (B)	Veh. Weight by % (A*B) (Kg)
2 W	19224	0.20	175	35.07
3 W	22074	0.23	450	103.56
HDDV	8875	0.09	20000	1850.56
LDDV	10075	0.11	7500	787.79
Taxi	8264	0.09	1425	122.77
Cars	27405	0.29	1425	407.14
Total	**95917**			**3.30**

* *Strengthening Environmental Management at the State Level (Cluster) Component E- Strengthening Environmental Management at West Bengal Pollution Control Board, TA No. 3423-IND, Asian Development Bank, Nov. 2005*

Annual /Long Term Avg. E. Factor E = (k (sL/2)0.65 (W/3)1.5-C) (1-P/4N).

E = particulate emission factor (having units matching the units of k)
k = particle size multiplier for particle size range and units of interest
sL = road surface silt loading (grams per square meter) (g/m^2)
W = average weight (tons) of the vehicles traveling on the road
P=No. of wet days with at least 0.254 mm of precipitation during avg. period
C= Break and tire wear correction ($PM_{2.5}$=0.1005, PM_{10}=0.1317)
N = No. of days in averaging period (365 /year, 30/monthly, 91/seasonal);

Values of k (g/vkt) = $PM_{2.5}$ -1.1, PM_{10}-4.6
EF (PM_{10}) = (k (sL/2)0.65 (W/3)1.5-C) (1-P/4N)
=(4.6*((0.531/2)^0.65)*((3.3/3)^1.5)-0.1317)*((1-120/(4*365)))
EF ($PM_{2.5}$) = (k (sL/2)0.65 (W/3)1.5-C) (1-P/4N)
= (1.1*((0.531/2)^0.65)*((3.3/3)^1.5)-0.1005)*((1-120/(4*365)))

For VKT – calculate
lb/vmt to gms/vkt =0.94 (VKT * 0.94)
VKT from all shifts * $PM_{2.5}$ (#) = Emission load
VKT from all shifts * PM_{10} (#) = Emission load

Emission Estimation for Unpaved Dust

Annual /Long Term Avg. E. Factor, E = {([k (s/12)a (S/30)d] /(m/0.5)c-C)} *(365-P)/ 365

E = size specific emission factor, (lb/vmt),
s= surface material silt content (%),
m= surface material moisture content (%),
S=mean vehicle speed (mph);
k =particle size multiplier (lb/vmt),
P=No. of wet days with at least 0.254 mm of precipitation during avg. period
C= Break and tire wear correction ($PM_{2.5}$=0.00036, PM_{10}=0.00047) - lb/VMT
Public Roads-
Constant k (lb/vmt) - $PM_{2.5}$= 0.21, PM_{10}=1.386;
a-$PM_{2.5}$=1, PM_{10}=1,
c-$PM_{2.5}$=0.2, PM_{10}=0.2;
d-$PM_{2.5}$=0.5, PM_{10}=0.5

EF ($PM_{2.5}$) = {([k (s/12)a (S/30)d] /(m/0.5)c-C)} *(365-P)/ 365
=(((0.21*(18.4/12)^1*(21.08/30)^0.5)/(6.5/0.5)^0.2-0.00036))*(365-120)/365

0.108229719 lb/vmt =30.50995781 g/vkt

EF (PM_{10}) = {([k (s/12)a (S/30)d] /(m/0.5)c-C)} *(365-P)/ 365
=(((1.386*(18.4/12)^1*(21.08/30)^0.5)/(6.5/0.5)^0.2-0.00047))*(365-120)/365
0.715595516 lb/vmt =201.7263759 g/vkt

Emission Load

- <u>Total Paved Dust Emission Load for Whole City</u>
  PM= 8666 Kg/d

- <u>Total Unpaved Dust Emission Load for Whole City</u>
  PM= 13045 Kg/d

Site-specific contribution of the pollutant emission load is given in **Table 3.22.**

Table 3.22: Site wise Emission Load from Paved & Unpaved Dust

Sites	PM Load	
	Paved	Unpaved
Colaba	2.9	4.4
Dadar	243.3	366.2
Dharavi	229.9	346.0
Khar	101.3	152.4
Andheri	66.5	100.1
Mahul	232.2	349.5
Mulund	224.5	337.9

* Values expressed as Kg/d

PM emission load is highest at Dadar followed by Dharavi. Uncertainty with respect to all sites all across the whole city will be high as still loadings can vary from place to place.

The paved and unpaved road dusts get resuspended and act as source due to vehicles; however, they also act as area source.

3.2.8 Building Construction

Description: Real estate sector is a booming business in Mumbai. Converting mills to mall is a new phenomena observed in the city. Slum rehabilitation programme have also leads to large scale construction of new buildings and towers. The building construction dust source category provides estimates of the fugitive dust particulate matter due to caused by construction and demolition activities while building residential, commercial, industrial and institutional or governmental structures. Particulate emissions are predominantly due to site preparation work, which may include scrapping, grading, loading, digging, compacting, lights –duty vehicle travel and other operations. Data source for construction was obtained from Building construction department MCGM. The number of construction activities ward wise is given in **Table 3.23**.

Assumption

- Based on discussion with MCGM officials for new buildings and alteration /addition a ratio of 56 and 44% respectively.
- The project duration was estimated as 18 months for new buildings, 6 months for addition /alteration.
- The area of influence of each construction activity was taken as 0.5 acres for new building and 0.2 acres for addition /alteration. This was the most prevalent areas noticed during the primary. However, some places sizes vary more than the above mentioned values.

Table 3.23: Ward Wise distribution of Construction Activities

Wards	Build Construction	New Building	Alteration/ Addition
A	3	1	2
B	3	1	2
C	7	2	5
D	7	2	5
E	7	2	5
F/S	15	5	10
F/N	15	5	10
G/S	15	5	10
G/N	15	5	10
H/E	16	6	10
H/W	27	15	12
K/E	17	10	7
K/W	26	12	14
P/S	25	10	15
P/N	26	11	15
R/S	26	12	14
R/C	25	15	10
R/N	21	12	9
L	18	10	8
M/E	13	8	5
M/W	16	9	7
N	11	6	5
S	25	10	15
T	21	9	12

Emissions Estimation

For the purpose of estimating emissions, it is assumed that the fugitive dust emission is related to the acreage affected by construction

Step 1 –Total No. of construction activities in each region. This was obtained from MCGM

Step 2 – Acres disturbed

For new buildings, = 0.5 acres are disturbed per activity

For addition / alteration = 0.2 acres per activity are disturbed

Step 3 – Months of activity

New buildings = 18 months, Addition / alteration = 6 months

Step 4 – Acre –months of activity

For new building = 18 x total number of acres disturbed

For addition / alteration = 6 x total number of acres disturbed

Step 5 – PM_{10} Tons /years = 1.2 x total number of acre – months

(AP42, Section 13.2.3.3– PM_{10} - 1.2 tones/ acres months)

Ward wise emission load of PM during construction activity is presented in **Table 3.24**.

Table 3.24: Ward wise Emission Load of PM in acre months during Construction Activity

Wards	New Building (acre /months)	Alteration (acre /months)
A	11	3
B	11	3
C	22	7
D	22	7
E	22	7
F/S	54	14
F/N	54	14
G/S	54	14
G/N	54	14
H/E	65	14
H/W	162	17
K/E	108	10
K/W	130	20
P/S	108	22
P/N	119	22
R/S	130	20
R/C	162	14
R/N	130	13
L	108	12
M/E	86	7
M/W	97	10
N	65	7
S	108	22
T	97	17

- **Total Emission Load =2288.9 tones /year**
  (New Building = 1976.4 tones/ year, alternation building = 312.5 tones /year)

Site-specific contribution of the pollutant emission load was derived based on primary survey as given in **Table 3.25.**

Table 3.25: PM_{10} load due to Building Construction at Seven Sites

	PM load from New Buildings in Kg/d	PM load from Alteration of buildings in Kg/d	Total PM Load (Kg/d)
Colaba	1.4	1.1	2.5
Dadar	39.0	31.2	70.1
Dharavi	41.4	27.5	68.9
Khar	39.8	11.0	50.9
Andheri	39.3	14.1	53.3
Mahul	21.7	13.0	34.7
Mulund	68.6	25.2	93.9

Mulund and Dadar have maximum particulate emission load due to construction activity.

Issues

- The activity is assumed to occur 6 days a week with 8 hours duration of working hours
- The current methodology assumes that all construction operations emit the same levels of PM on per acre basis.
- The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction. The estimates of acreage disturbed are limited in their accuracy, as explained above
- Emission due to vehicle movement during construction activity is not calculated

Non Road Mobile Emissions

3.1.9 Locomotive

Description: There are two types of locomotive used in most railway systems, first being electric and the other diesel. In Mumbai, most rail operations are on electric, however, a small percentage of movements are on diesel. Yard locomotives are primarily responsible for moving rail carts within a particular railway yard which consume diesel in Diesel Hydraulic Locomotive. There are three types of operations where diesel is consumed. These are "Mainline for hauling coaches or wagons within railway zone", "shunting for moving rail carts within railway yard" and "maintenance of locomotive within shed (workshop)". As per reported data, 25 shunting engines in western line and 10 in central line are operating. Working pattern of these engines include 24 hours of running or operation with a speed of 12 km /hour having 6 cylinder engine of 700 HP Hydraulic Engine. Shunting trains operation is required to maintain the smooth running of large number of trains from Western and Central line. Fuel consumption data is given in **Table 3.26.** Data about number of locomotive yards in operation, locomotives in use for Western and Central Railway were obtained from Diesel Loco Shed Mumbai Central. Total locomotive emission load from Western and Central lines is presented in **Table 3.27.** This emission load includes yard and line haul operations as well.

Table 3.26: Total Diesel Consumption from Western and Central Line

Western Line		Central Line	
Jan-05	236410	Apr-05	243600
Feb-05	251475	May-05	267464
Mar-05	227800	Jun-05	276148
Apr-05	231160	Jul-05	290094
May-05	248710	Aug-05	299453
Jun-05	254550	Sept-05	284650
Jul-05	250500	Oct-05	324500
Aug-05	241130	Nov-05	250175
Sep-05	246910	Dec-05	296200
Oct-05	244280	Jan_06	295625
Nov-05	244602	Feb_06	243975
Dec-05	236117	Mar_06	285282
Jan-06	256575	Apr_06	260700
Feb-06	253705	May_06	277000
Mar-06	213800	Jun_06	300190
Apr-06	250070	Jul_06	278575
May-06	230755	Aug_06	282450
Jun-06	250785		
Jul-06	252780		
Aug-06	199244		

* Values in Liters/Month

Average number of locomotive running =
Total Diesel Consumption / 30 (days) / 856 (liters per locomotive)
= 242660 / 30 / 856 = 10 approx
(Source: Mexico Emission Inventory vol. V)

Emission Estimation

$$\text{Emissions} = \Sigma EY_{pi} = \sum_{i=1}^{n} \text{Fuel consumption x Emission Factor}$$ **(Annexure 3.1)**

Where,

EY_{pi} = Estimated annual emissions (Kg) for pollutant p for inventory area i for yard railroad operations;

n = Number of yard locomotives that operate in inventory area i

Issues

- As there are two/ three loco sheds in each region, movements within sheds are not known for estimation.

Table 3.27: Yearly Emission load from Locomotive Sector (Western Line: Line Haul, Yard and Total Operation)

Months	Line Haul Operation				Yard Operation				Total Operation (Line Haul + Yard)			
	PM	CO	NOx	SO_2	PM	CO	NOx	SO_2	PM	CO	NOx	SO_2
Jan-05	330.97	1773.08	13971.83	1016.56	1075	6969	39319	2906	1405.97	8741.83	53290.58	3922.81
Feb-05	352.07	1886.06	14862.17	1081.34	1075	6969	39319	2906	1427.07	8854.81	54180.92	3987.59
Mar-05	318.92	1708.50	13462.98	979.54	1075	6969	39319	2906	1393.92	8677.25	52781.73	3885.79
Apr-05	323.62	1733.70	13661.56	993.99	1075	6969	39319	2906	1398.62	8702.45	52980.31	3900.24
May-05	348.19	1865.33	14698.76	1069.45	1075	6969	39319	2906	1423.19	8834.08	54017.51	3975.70
Jun-05	356.37	1909.13	15043.91	1094.57	1075	6969	39319	2906	1431.37	8877.88	54362.66	4000.82
Jul-05	350.70	1878.75	14804.55	1077.15	1075	6969	39319	2906	1425.70	8847.50	54123.30	3983.40
Aug-05	337.58	1808.48	14250.78	1036.86	1075	6969	39319	2906	1412.58	8777.23	53569.53	3943.11
Sep-05	345.67	1851.83	14592.38	1061.71	1075	6969	39319	2906	1420.67	8820.58	53911.13	3967.96
Oct-05	341.99	1832.10	14436.95	1050.40	1075	6969	39319	2906	1416.99	8800.85	53755.70	3956.65
Nov-05	342.44	1834.52	14455.98	1051.79	1075	6969	39319	2906	1417.44	8803.27	53774.73	3958.04
Dec-05	330.56	1770.88	13954.51	1015.30	1075	6969	39319	2906	1405.56	8739.63	53273.26	3921.55
Jan-06	359.21	1924.31	15163.58	1103.27	1075	6969	39319	2906	1434.21	8893.06	54482.33	4009.52
Feb-06	355.19	1902.79	14993.97	1090.93	1075	6969	39319	2906	1430.19	8871.54	54312.72	3997.18
Mar-06	299.32	1603.50	12635.58	919.34	1075	6969	39319	2906	1374.32	8572.25	51954.33	3825.59
Apr-06	350.10	1875.53	14779.14	1075.30	1075	6969	39319	2906	1425.10	8844.28	54097.89	3981.55
May-06	323.06	1730.66	13637.62	992.25	1075	6969	39319	2906	1398.06	8699.41	52956.37	3898.50
Jun-06	351.10	1880.89	14821.39	1078.38	1075	6969	39319	2906	1426.10	8849.64	54140.14	3984.63
Jul-06	353.89	1895.85	14939.30	1086.95	1075	6969	39319	2906	1428.89	8864.60	54258.05	3993.20
Aug-06	278.94	1494.33	11775.32	856.75	1075	6969	39319	2906	1353.94	8463.08	51094.07	3763.00
Kg/d	**225**	**1205**	**9498**	**691**	**717**	**4646**	**26213**	**1937**	**942**	**5851**	**35711**	**2629**
Ton,/year	**82**	**440**	**3467**	**252**	**262**	**1696**	**9568**	**707**	**344**	**2136**	**13035**	**960**

Table 3.27 (Contd...): Yearly Emission load from Locomotive Sector (Central Line: Line Haul, Yard and Total Operation)

Months	Line Haul Operation				Yard Operation				Total Operation (Line Haul + Yard)			
	PM	**CO**	**NOx**	**SO_2**	**PM**	**CO**	**NOx**	**SO_2**	**PM**	**CO**	**NOx**	**SO_2**
Apr-05	341.04	1827.00	14396.76	1047.48	430	2788	15728	1163	771.04	4614.50	30124.26	2209.98
May-05	374.45	2005.98	15807.12	1150.10	430	2788	15728	1163	804.45	4793.48	31534.62	2312.60
Jun-05	386.61	2071.11	16320.35	1187.44	430	2788	15728	1163	816.61	4858.61	32047.85	2349.94
Jul-05	406.13	2175.71	17144.56	1247.40	430	2788	15728	1163	836.13	4963.21	32872.06	2409.90
Aug-05	419.23	2245.90	17697.67	1287.65	430	2788	15728	1163	849.23	5033.40	33425.17	2450.15
Sep-05	398.51	2134.88	16822.82	1224.00	430	2788	15728	1163	828.51	4922.38	32550.32	2386.50
Oct-05	454.30	2433.75	19177.95	1395.35	430	2788	15728	1163	884.30	5221.25	34905.45	2557.85
Nov-05	350.25	1876.31	14785.34	1075.75	430	2788	15728	1163	780.25	4663.81	30512.84	2238.25
Dec-05	414.68	2221.50	17505.42	1273.66	430	2788	15728	1163	844.68	5009.00	33232.92	2436.16
Jan-06	413.88	2217.19	17471.44	1271.19	430	2788	15728	1163	843.88	5004.69	33198.94	2433.69
Feb-06	341.57	1829.81	14418.92	1049.09	430	2788	15728	1163	771.57	4617.31	30146.42	2211.59
Mar-06	399.39	2139.62	16860.17	1226.71	430	2788	15728	1163	829.39	4927.12	32587.67	2389.21
Apr-06	364.98	1955.25	15407.37	1121.01	430	2788	15728	1163	794.98	4742.75	31134.87	2283.51
May-06	387.80	2077.50	16370.70	1191.10	430	2788	15728	1163	817.80	4865.00	32098.20	2353.60
Jun-06	420.27	2251.43	17741.23	1290.82	430	2788	15728	1163	850.27	5038.93	33468.73	2453.32
Jul-06	390.01	2089.31	16463.78	1197.87	430	2788	15728	1163	820.01	4876.81	32191.28	2360.37
Aug-06	395.43	2118.38	16692.80	1214.54	430	2788	15728	1163	825.43	4905.88	32420.30	2377.04
Kg/d	**221.95**	**1189.02**	**9369.48**	**681.70**	**244**	**1580**	**8912**	**659**	**465.62**	**2768.60**	**18281.73**	**1340.45**
Ton./Year	**81**	**434**	**3420**	**249**	**89**	**577**	**3253**	**241**	**170**	**1011**	**6673**	**489**

3.2.10 Aircraft

Description: Emission estimates from aircrafts have been made for the domestic and international airports. These two airport terminals are spread over two different locations about 4 kms apart in the west of Mumbai at Andheri. Terminal 1 is meant for domestic flights only and is located at Santa Cruz. Terminal 2 is located at Sahar for international flights. Emissions from aircraft originate from fuel burned in aircraft engines. Emissions from aircrafts are calculated from the aircraft movements in an LTO cycle. 1 LTO = 2 aircraft movements (http://www.aeat.co.uk/netcen/airqual/ naei/annreport/annrep99/app1_210.html). The aircraft movement details were obtained from the report given at the website.
(http://www.aai.aero/mumbai/ aircraft_movement.jsp).

Emission Estimation

Total emissions from aircrafts = Number of LTO cycles x Emission Factor **(Annexure 3.1)**

Total annual emissions (PM_{10}) from aircrafts

= Number of LTO cycles x Emission factor (Kg/ LTO)

= 76404/2 LTO x 0.99 Kg/LTO = 75640 Kg

Emission load due to Aircraft Movement from international, domestic and other aircrafts (private) is presented in **Table 3.28**

Table 3.28: Emission Load due to Aircraft

	PM	CO	SO_2	NOx	VOC
International	19651.25	121083.48	31759.60	516093.50	3969.95
Domestic	50835.02	605912.30	41078.80	426192.55	25674.25
Others	5153.27	61422.84	4164.26	43204.20	2602.66
Kg/day	**207.23**	**2160.05**	**210.97**	**2699.97**	**88.35**
Ton./year	**75.64**	**788.42**	**77.00**	**985.49**	**32.25**

Issues

- Aircraft emissions calculations were based on aircraft movements only
- Other details of vehicles movement for cargo, passenger, crew etc. could not be obtained due to non responsive authorities.
- Aircraft types and capacities based variations for emissions could not be accounted for.

3.2.11 Marine Vessels

Description: Marine vessels include boats and ships which are used for transport of people, goods and military purposes. Air pollutants are also emitted when ships/ vessels are waiting in the bay for docking space. A survey was carried out to established average fuel consumption. Fishing vessels consume about 20 liters/d diesel, and other vessels consume about 60-70 liters/d of diesel. Activity information such as type and number of vessels – (fishing, govt., commercial), average duration of stay, vessel, transit, waiting in the bay for dock space etc. was obtained from Mumbai Port Trust, fishing community and Central Marine Fisheries Research Institute, Mumbai.

Type of vessels operated annually in the Mumbai Coast

Bulk = 3861, Container = 727, Gen. Cargo = 2199, Fishing Vessels (Trawlers =2258, Gillneters= 386, Dolnetters = 1037, Liners= 44, Others =87) = 3812

Emission Estimation

Emission load = Vessel type x time spent x fuel consumed x emission factor **(Annexure 3.1)**

Emission loads due to marine vessel are presented in **Table 3.29**

Table 3.29: Emission Load from Marine Vessels

	PM	CO	SO_2	NOx	HC
Bulk	1235.33	2218.80	13192.85	11993.50	995.46
Container	68.52	123.07	731.76	665.23	55.21
Gen. Cargo	507.23	911.04	5416.98	4924.53	408.74
Fishing Vessels	33.77	60.65	360.62	327.83	27.21
Ton./Year	**1.84**	**3.31**	**19.70**	**17.91**	**1.48**

Issues :

- Naval and Coast Guard Vessel is not available since it is of classified nature
- Repairs works related activity in Dockyard and BPT areas were not accounted.

3.3 Point (Industrial) Sources

The emission pattern is determined using the existing industrial structure including the power plant. New economic trends brought opportunities and threats to the Mumbai region. Since 1991, when Indian government decided to open up the economy to foreign investors, major investments were made in new economic activities and large complexes were set up to cater to the IT Industry needs. For example special export promotion zones known as SEEPZ has been created in the western suburb of Andheri as a starting point of new economy based on Information Technology supported by Computer Industry. At the same time, auto industry, pharmaceutical and other traditional industries showed the tendency to move out of the region to newer locations in Maharashtra and / or other states. Today, Mumbai is dominated by the service sector economy. The white-collar workers are rapidly replacing the blue-collar work force and as a result Mumbai is emerging as an important financial center in Global Economy. Service sectors like Education, Communications, Tourism, Transportation, Health Care, Entertainment and Administrative Functions dominate the new economy. Surrounding towns are also experiencing a relative decline in the industrial activities as the necessity for the expansion of residential areas and this is forcing the industries to move to other areas. However, these areas are suitable for locating the small-scale industries.

Stationary sources can be divided into two major subcategories, viz. point and area sources. Point sources are generally large emitters with one or more emission points at a permitted facility with an identified location. Examples include food processing facilities, oil production and refinery facilities, steam generators, boilers, process heaters, glass manufacturing, etc. The emissions from point sources are generally calculated using emission factors obtained from direct measurements (e.g., source testing). EPA's document entitled, *Compilation of Air Pollutant Emissions Factors* (AP-42), or California Air Resource Board's material balance formula are the major resources for emission factors of point sources. The simplest method of calculating emissions is to multiply the process rate (how much or how often an activity occurs) by an emissions factor (mass of air pollutant emitted per unit time of activity) and a control factor (percent of emissions not allowed to reach the atmosphere).

Chemical, oil refineries, petrochemical, fuel-based power plant, textiles, fertilizer and other industries are the major point sources of emissions in Mumbai region. These industries are located mainly in the eastern and northeastern corridor of the region. Large industrial areas are mainly concentrated in Chembur, Andheri and along LBS Marg starting from Kanjur Marg to Mulund. Western region also has some industries, with potential sources of air pollution. **Figure 3.1** shows locations of these industries in the city. Fossil fuel used by the industries for boilers or manufacturing process remains the single potential source of discharging emissions into the atmosphere from their stacks. For proper estimate of emissions, the effectiveness of an existing control device must be applied in the emission calculation. Emissions are estimated for pollutants such as SPM, PM_{10}, CO, HC, SO_2 and NOx. In order to workout emission loads from industries due to burning of fossil fuel, information on fuel consumption in industries and the information on industries typology capacity etc. was obtained from Maharashtra Pollution Control Board (MPCB).

The information also included MPCB classification viz. large, medium and small as well as red, orange and green categories based on labour employed and consumption of water, fuel and power. According to MPCB, the polluting industries are classified as red (highly polluting), orange (moderately polluting) and green (low polluting) in nature. There are 40 air polluting industries in Mumbai. Out of these 40 industries, 29 are large scale, 5 medium scale and 6 are small scale industries. In addition, there are 26 stone crushers in Kandivali area, the information on stone crushers was also obtained from MPCB, Mumbai.

Emission inventory from industries has considered working hours considered: for industries,
MSI =16 hrs, LSI = 22 hrs, SSI = 12 hrs. 1 Barrel–159 lit, LSHS, FO is assumed to be residual oil. LDO and HSD are assumed to be distilled oil.

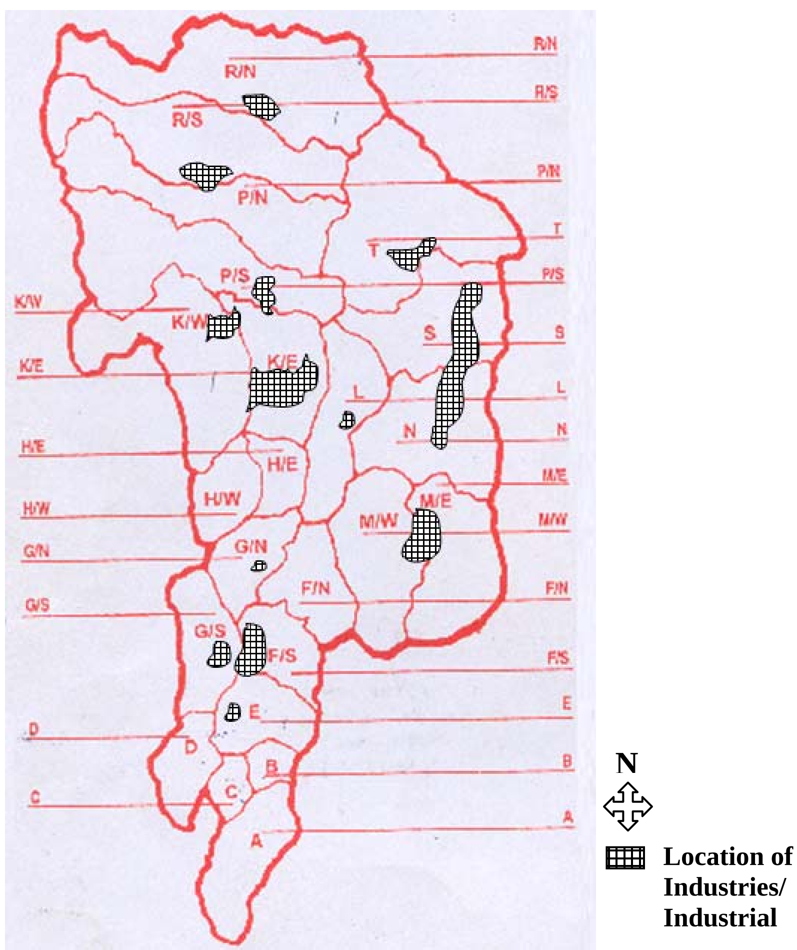

Figure 3.1: Location of Industries in MCGM Area

3.3.1 Approach/Methodology

A total of 40 industries apart from stone crushers were identified with air polluting potential. Information relating to consumption of fuels such as Furnace Oil (FO), Light Diesel Oil (LDO), Low Sulphur Heavy Stock (LSHS), and Compressed Natural Gas (CNG), by the industries in the MCGM area has been obtained from MPCB. The gross emissions are estimated for all types of industries viz. power plant (1), chemical and other industries (39) with the help of published emission factors.

Emission factors published by TERI, New Delhi are used because the data on type of combustion equipment used for firing and other operating parameters like fuel quality, efficiency of boilers were not readily available with the industries in the region which are essential.

Total emissions were calculated and distributed into various wards in accordance with the actual location of industries. Site specific estimation for seven locations were based on survey of the locations as per MPCB records.

Various emissions factors used in this report are presented in **Table 3.30**.

Table 3.30: Emission Factors applied for Industrial Emissions

S. No.	Type of Fuel	Unit	S	Emission Factors (Kg/Unit)					
				TSP	SO_2	NO_x	HC	CO	Ash
For Other 39Industries									
1.	LSHS	KL	0.45	1.25*S + 0.38	19.25*S	7.5	0.12	0.63	
2.	FO	KL	4.0	1.25*S + 0.38	19.25*S	7.5	0.12	0.63	
3.	LDO	KL	1.8	0.25	17.25*S	2.75	0.12	0.63	
4.	HSD	KL	1.0	0.25	17.25*S	2.75	0.12	0.63	
5.	LPG/FG	KL	0.02	0.21	0.01*S	1.45	0.036	0.19	
6.	NG	m^3	-	160 E-06	9.6 E-06	2800 E-06	48 E-06	272 E-06	
7.	Coal / Coke	MT	0.5*	6.5*A	19S	7.5	0.5	1.0	45
8.	Kerosene##	Kg/t	0.25	0.06	17S	2.5	--	--	--
For Power Plant**									
1.	LSHS	KL	0.45	1.25*S + 0.38	19.25*S	6.25	0.12	0.63	
2.	NG	m^3	-	160 E-06	9.6 E-06	2800 E-06	48 E-06	272 E-06	
3.	Coal	MT	0.15	6.5*A	19*S	7.5	0.5	1	6

Source: URBAIR Report, Bombay, 1992

A: Percentage ash in coal = 45% and S: Percentage Sulphur
Other than Power Plant, efficiency of Cyclone considered as 75%

* * Power plant

Π **Coal**

A - % Ash: 2- 10% Avg. 6%
S - % Sulphur: 0.1 – 0.2%, Avg. 0.15%
ESP Eff. : 99.5%
FGD Eff. : 99%

Π **LSHS**

- Sulphur: 0.45%

Density [b] of Fuels (Kg/m³)

LSHS	943
FO	943
LDO	860
LPG	504
HSD	860

Source:

a. Environmental effects of energy production, transformation and consumption in the National Capital Region submitted to the Ministry of Environment & Forest, by Tata Energy Research Institute (TERI), New Delhi, February 1992

b. Indian Oil Corporation Ltd, Vadodara

3.3.2 Data Analysis

The available information on 40 industries was categorized with respect to their products as power, pharmaceutical, chemicals/petrochemicals; textile and food/beverages and others are presented in **Table 3.31.** Their distribution as per their geographic locations in MCGM is shown in **Table 3.32**. It is observed that industries under category "others" belong to engineering type of industries form the largest group. The fuels used in these industries include LSHS, FO, LDO, HSD, LPG/FG, NG and coal. The estimated emissions from existing 39 industries and one power plant are given in **Table 3.33.** The emissions from stone crushers are estimated by using URBAIR 1992 emission factors. In URBAIR report, these are considered as discrete area sources, while in the present estimates, it is considered under point sources under small-scale sector. This is due to its potential contribution towards particulate pollution.

Table 3.31: Category wise Distribution of Air Polluting Industries, 2001

S. No.	Category	Number
1.	Power	1
2.	Chemical	3
3.	Refinery / Terminal	4
4.	Pharmaceutical	1
5.	Textile / Printing / Dye	6
6.	Food & Beverages	3
7.	Dock	2
8.	Others (Engg. Rubber, Paints, Oil, Misc.)	20
Industries		**40**
9.	Stone Crushers	26
	Total	**66**

Table 3.32: Ward wise Distribution of Air Polluting Industries

S. No.	Ward	Number
Industries		
1.	A	2
2.	E	2
3.	FS	4
4.	GS	1
5.	GN	1
6.	HE	1
7.	KE	2
8.	L	2
9.	ME	5
10.	N	5
11.	PS	1
12.	RS	3
13.	RN	2
14.	S	4
15.	T	5
		40

Stone Crushers	
RS	22
RN	4
Total	**66**

Table 3.33: Present Emission Scenario
For 39 Industries

Fuel Type	Quantity (TPD)	Emissions in Kg / day					
		TSP	PM_{10}	SO_2	NOx	CO	HC
FO	764	434	369	62129	6080	511	97
LSHS	1309	131	65	12028	10414	875	167
LDO	99	3	1	3578	318	73	14
HSD	7	0.2	0.1	127	20	5	1
NG	51681	0.87	0.87	0.5	145	14	2.48
Coal	73	95	90	208	548	73	37
Kerosene	0.17	0.001	0.001	1	1	--	--
LPG	4	0.2	0.2	0.002	13	2	0.3
Others	183	0.8	194.3	36.4	5575.8	858.2	--
Total	**54120**	**665.07**	**720.47**	**78107.90**	**23114.80**	**2411.20**	**318.78**

The emission load was calculated based on 90% reduction due to control equipments in industries.

Power Plant

Fuel Type	Quantity	Emissions in Kg / day					
		TSP	PM_{10}	SO_2	NOx	CO	HC
LSHS	4500 Tpd	509.4	254.7	50523.6	35790.0	3006.4	572.6
NG	3347 m^3/day	0.05	0.05	0.03	9.37	0.91	0.16
Coal	5800 Tpd	7540	7163	16530	43500	5800	2900
Total Emission T/day		8.0	7.4	67.1	79.3	8.8	3.5

3.3.3 Total Emission Estimation

The total emission scenario includes contribution from power plant, 39 industries as well as from stone crushers. The total estimated emissions from point sources are about 12.7, 8.2, 145.2, 120.4, 11.2 and 3.8 Tpd of TSP, PM_{10}, SO_2, NOx, CO and HC respectively as presented in **Table 3.34**.

Table 3.34: Total Industrial Emissions in Brihanmumbai

Sr.	Sector	Emissions (Tpd)					
		TSP	PM_{10}	SO_2	NO_x	CO	HC
1.	Power Plant	8.00	7.42	67.05	79.30	8.81	3.47
2.	39 Industries	0.66	0.72	78.11	23.11	2.41	0.32
3.	Stone Crushers	3.82					
	Total	**12.48**	**8.14**	**145.16**	**102.41**	**11.22**	**3.79**

For grid wise emissions estimation, the whole region of the city was divided into equal grids of 2 km x 2 km size and the wards were overlaid on these grids. The grid wise emissions from various industries in those wards have been estimated based on their actual locations. Chemicals and petrochemicals are another group of air polluting industries located in Chembur - Mahul region. Among this group, the major air polluting industries are HPCL, BPCL, RCF located in M/E ward. 39 industries contribute 53.8% SO_2, 22.6% NOx, 21.4% CO, 8.44% HC, 5.4% TSP and 8.8% PM_{10}. Power plant contributes 63% and stone crushers contribute 30.12% of the TSP emissions.

3.3.4 Site Specific Emission Estimate

Emissions from point sources and stone crushers are presented in **Table 3.35**. The spatial distribution of emissions indicates that maximum contribution is from ME ward where all the large-scale air-polluting industries such as HPCL, BPCL, RCF, are located.

Table 3.35: Ward wise Emission Load due to 40 industries including power plant

Ward	TSP	PM_{10}	SO_2	NOx	CO	HC
A	18.17	12.08	2115.31	884.61	74.53	14.20
E	1.61	1.37	231.08	22.51	1.89	0.36
FS	3.32	2.81	489.06	74.19	6.80	1.30
GS	0.43	0.36	61.24	5.97	0.50	0.10
GN	2.15	1.83	308.00	30.00	2.52	0.48
HE	0.29	0.27	17.72	30.80	2.94	0.52
KE	9.45	8.02	1396.04	135.55	12.01	2.29
PS	0.75	0.64	107.78	10.50	0.88	0.17
RS	0.44	0.34	59.40	48.32	5.75	1.06
RN	9.54	8.10	1393.67	135.46	11.80	2.25
L	0.22	0.21	19.19	29.84	3.26	0.59
ME	8630.66	8072.53	130715.03	100140.33	10975.13	3745.08
N	4.37	3.68	760.45	136.08	15.79	2.93
S	26.83	22.79	3909.58	380.88	33.11	6.31
T	6.15	4.34	3586.79	348.61	70.49	13.17
Total	**8714.38**	**8139.37**	**145170.33**	**102413.64**	**11217.41**	**3790.80**

- **All values are in Kg/ day.**

Ward wise Emission Load due to Stone Crushing Activities

	RS	RN
TSP	1200	2625

The grid wise emissions from point sources at seven sampling locations viz. Colaba, Dadar, Dharavi, Khar, Andheri, Mahul and Mulund in 2 Km x 2 Km area grid are presented in **Table 3.36**. The spatial distribution of emissions indicates that maximum contribution is from Mahul–Chembur area being an industrial site.

Table 3.36: Contribution of Total Emission at Various Sampling Sites

Sites	TSP	PM_{10}	SO_2	NOx	CO	HC
Colaba#	0.00	0.00	0.00	0.00	0.00	0.00
Dadar#	0.00	0.00	0.00	0.00	0.00	0.00
Dharavi#	0.00	0.00	0.00	0.00	0.00	0.00
Khar	0.00	0.00	0.00	0.00	0.00	0.00
Andheri	0.97	0.85	115.70	40.34	3.75	0.68
Mahul	581.17	654.76	63636.56	20838.73	2167.35	272.19
Mulund	1.99	1.67	342.42	33.23	3.62	0.69
Total	**584.13**	**657.28**	**64094.68**	**20912.30**	**2174.72**	**273.55**

Mahul -BPCL, HPCL, RCF, Mulund - Johnson & Johnson, Andheri - Godfrey Phillips, ParleProducts.Ltd.
No industry, All values expressed as Kg/day

Highest TSP emissions are from Mahul followed by Mulund and Andheri. The major large scale industries are refineries; power plant and fertilizer industry are located in Mahul site.

3.3.5 Percentage Distribution of Pollutants from Industrial Sources

The total TSP Emissions from Industries is 8714.38 Kg/day. **Figure 3.2** depicts that burning of coal contribution is about 85.71% followed by FO (4.87%) and LSHS (7.19%).

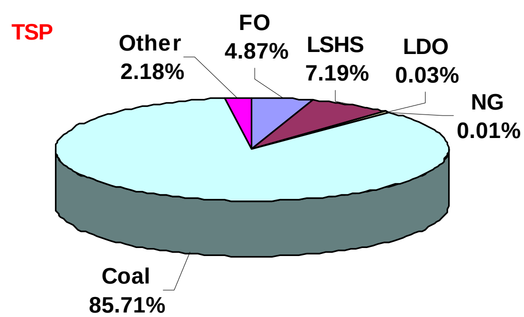

Figure 3.2 : TSP Contribution from Industries

Total PM_{10} emissions from industries are 8139.37 Kg/day. **Figure 3.3** depicts that the burning of Coal contributes 89.11% of the total PM_{10} emissions, FO contributes to about 4.53% and LSHS contributes to about 3.93% respectively of the total PM_{10} emissions

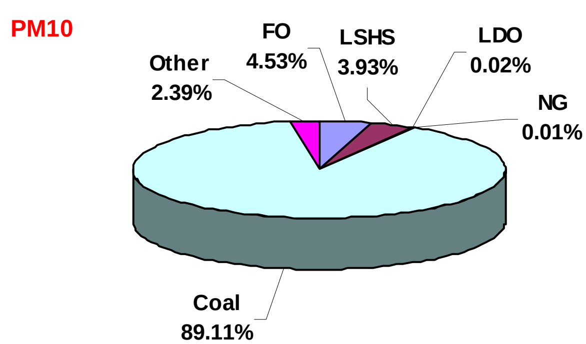

Figure 3.3 : PM_{10} Contribution from Industries

The total SO_2 emission from industries is 145170 Kg/day. **Figure 3.4** shows that LSHS contributes 43.09%, Fuel Oil, LDO and Coal contributes to about 42.8%, 2.46% and 11.5% respectively of the total SO_2 emissions.

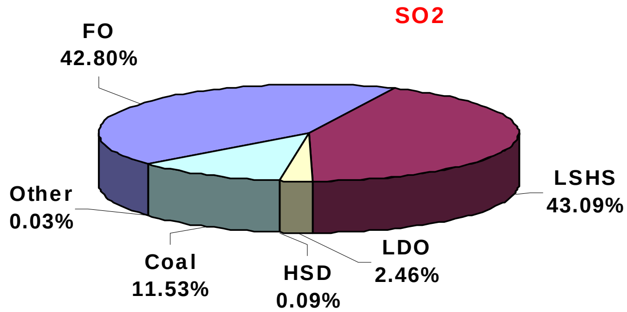

Figure 3.4: SO_2 Contribution from Industries

The total NOx emission from industries is 102414 Kg/day. **Figure 3.5** depicts that LSHS and Coal contributes to a maximum of 45.12% and 43.01% of the total NOx emissions.

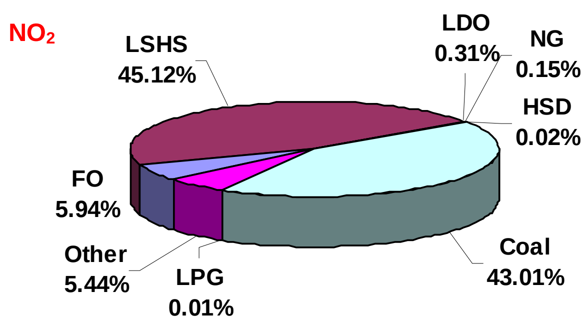

Figure 3.5: NOx Contribution from Industries

The total CO emission from industries is 11217 Kg/day. **Figure 3.6** depicts that Coal contributes to a maximum of 52.3% followed by LSHS 34% of the total CO emissions.

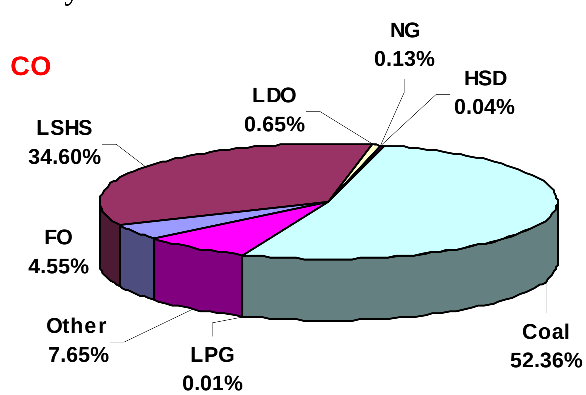

Figure 3.6: CO Contribution from Industries

The total HC (as VOC) Emissions from industries is 3791 Kg/day. **Figure 3.7** shows that Coal contributes maximum 77.4% of the total HC emissions. LSHS and FO contribute to 19.5% and 2.57% respectively of the total HC emissions.

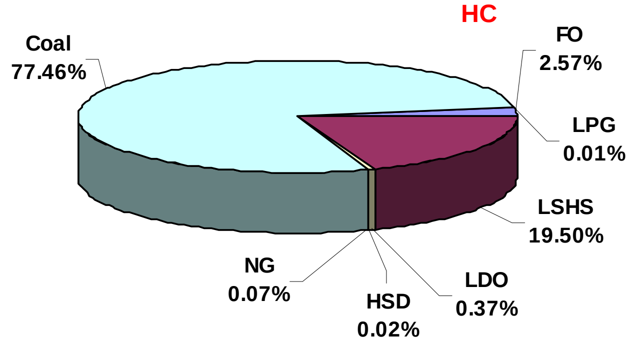

Figure 3.7: HC Contribution from Industries

3.3.6 Data Constraints / Assumptions

- Emissions have been worked on the basis of fuel consumption only.
- A wide variation in the data on fuel supplied by the refineries to the industries and the data obtained from the consent forms of MPCB on fuel consumption is observed. This indicates some other source of fuel supply and consumption whose details are not available for estimating the point source emissions. It necessarily does not mean that the fuel supplied goes to industries alone.

3.4 Line (Vehicular) Source:

Mumbai is the commercial and financial capital of India. During the last 4 decades there has been growth in vehicle ownership in the city, particularly in the suburban areas, resulting in immense traffic pressure and increasing road bottlenecks. The vehicular population in the last four decades increased from 1.5 lakhs in 1971 to 10.9 lakhs in 2001 to the current about 15 lakhs in the year 2007. The World Bank funded MUTP focuses mainly on strengthening of mass transport particularly improvements in suburban railway services in terms of efficiency and capacity, with very few proposals of road improvements.

a. *Road*s: The road length in Mumbai is about 2,000 km, comprising of about 1,950 km of MCGM maintained roads and about 50 km of State Highways (23.55 km of Eastern Express Highway from Sion to Thane and 25.33 km of Western Express Highway from Bandra to Dahisar). All the roads in the city are surfaced, with about 17.5 per cent concretized and the rest black-topped. The structural conditions of the roads are generally very good, though the riding surface deteriorates during monsoons as witnessed during the unprecedented rains and flooding during the rains of July 2005. MCGM carries routine pre-monsoon works in order to reduce the damage due to rains. A key issue, though is the digging of roads by utility agencies / companies for laying utility lines throughout the year, which after road restoration leaves the road in a bad condition.

b. *Flyovers and Bridge*s: Currently MCGM maintains 11 flyovers, 47 ROBs (Road over Bridges) and 104 bridges. In addition, for pedestrian facilitation MCGM has constructed 68 foot-over- bridges (FOB) and 28 pedestrian subways. As a measure to improve the road infrastructure to facilitate smooth traffic flow, a committee appointed by the Government of Maharashtra had recommended the construction of 55 flyovers. Maharashtra State Road Development Corporation (MSRDC), Government of Maharashtra was appointed to implement the proposed works of which about 45 flyovers have been constructed already. MCGM is also undertaking works pertaining widening, rehabilitation and construction of 19 different types of bridges, such as ROB, FOB, flyovers, subways, out of which 6 have been completed.

Mumbai has a good coordinated pubic transport system and is known to be the best system in India. About 85 per cent of the total trips are carried out through mass transport systems, almost equally divided among bus transport provided by Bombay Electric Supply and Transport (BEST)

Corporation, an MCGM undertaking and the suburban railway system operated by Central and Western Railway Divisions of Indian Railways.

Vehicular pollution is one of the major sources of air pollution. The method used to estimate emissions includes data collection on vehicle counts, vehicle kilometer traveled, secondary data on vehicle registered, types of vehicles, age of vehicles, fuel used etc.

Registered motor vehicle population is given in **Table 3.37**. Percentage growth of vehicles is presented in **Figure 3.8**.

Table 3.37: Motor Vehicle Population in Mumbai (2000-2007)

Year	2000	2001	2002	2003	2004	2006	2007
HMV/Buses	82172	86837	78338	79754	75567	72159	77567
Cars/Jeeps	329546	344870	353417	366805	384258	436213	464139
Taxis	58696	62447	63679	54809	56459	57383	55486
3 W	97565	101914	104829	98527	102224	104899	104862
2 W	407306	440517	475352	527108	584180	714209	792512
Other	53980	57789	55412	56130	52243	55240	53150
Total	1029265	1094374	1131027	1183133	1254931	1442109	1549723

Source : Transport Commissioner Office

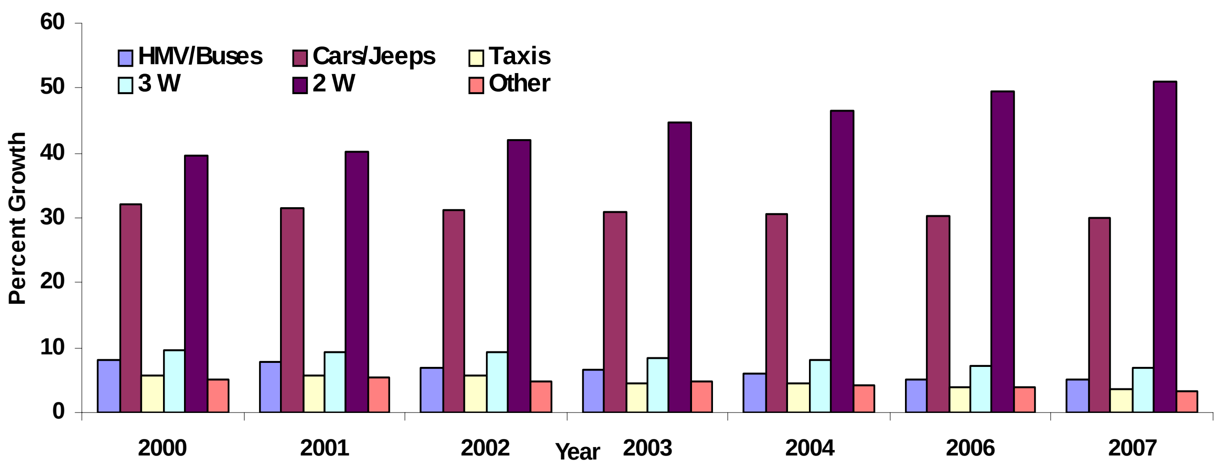

Figure 3.8: Increase of Registered Vehicles in Mumbai

3.4.1 Primary Survey and Methodology

Major work elements included in the preparation of vehicular emission inventory were:

- Vehicle counts at representative major traffic junctions in different parts of Greater Mumbai.
- Estimation of grid-wise road length.
- Estimation of VKT (Vehicle Kilometers Traveled) for different categories of vehicles.
- Selection of appropriate emission factors from the ARAI vehicle emission study.
- Preparation of emission inventory (grid-wise) and identification of major sources / hot spots in each grid.
- Emission growth projections.

Grid wise emission inventory preparation includes the following procedural steps:

- Division of study area into grids of 2 km X 2 km size
- Identification of major nodes which represent major traffic junctions
- Calculation of road length between the nodes and estimation of grid-wise road length
- Collection of data on number and type of vehicles traveling between nodes through field studies
- Estimation of vehicle kilometers (Km) traveled by each type of vehicle in each grid

$$VKT_I = RL_j * N_I$$

Where, VKT_I = Vehicle Km traveled by vehicle type I,
RL_j = Road length in grid j
N_I = Number of vehicles travelling between nodes for vehicle type I per day,

- Selection of appropriate emission factor for each type of vehicle
- Estimation of particulate matter emissions from each grid

$$PM_j = N * \sum_{J=1}^{m} VKT_I * Ef_I$$

Where, PM_j = Particulate matter load in tones/year for grid j
N = Number of activity days in a year
Ef_I = Emission factor for a vehicle type I

- Projected emission inventory (with alternative control options) preparation

$$PM\ projected_j = N * \sum_{J=1}^{m} VKT_I * EfI * \eta_k$$

Where, PM Projected $_j$ = Projected particulate matter load in tones/year for grid j
η_k = Efficiency of control option K

3.4.2 Vehicle Count

In order to arrive at the actual grid-wise vehicular emissions scenario, vehicular counts on major traffic corridors as well as within the city were planned. Road map of the city as given in **Figure 3.9** was used to arrive at the locations of the vehicle counting. For this purpose, the Greater Mumbai transportation network was divided into three parts (I) Western Corridor transportation network (ii) Eastern Corridor transportation network and (iii) South Mumbai transportation network

Video as well as manual counting of the traffic movement was undertaken at each of the above identified traffic junction for a period of two days. The counting was continuously carried out on each day representing the following time periods.

Shift	**Traffic**	**Duration**	**No. of Hrs**
I	Morning Peak	0700 to 1100	4
II	Afternoon Average	1100 to 1700	6
III	Evening Peak	1700 to 2200	5
IV	Night Average	2200 to 0700	9

Following categories of vehicles were covered in these counts:

- Cars
- Taxis
- Heavy Duty Diesel Vehicles (HDDV) + Buses
- Three Wheelers
- 2 Wheelers

3.4.3 Vehicle Kilometers Traveled (VKT) Estimation

Vehicle Kilometers Traveled (VKT) estimation by each type of vehicle in each grid per day was estimated by using length of roads between major nodes/traffic junctions from Greater Mumbai Region Map (AUTOCAD)as also length in each grid. Road length in each grid and number of vehicles (of different types) plying in the same are taken into account while estimating vehicle kilometer traveled in each grid by the respective vehicle. Major and minor roads at seven sampling sites for primary data collection of vehicles are given in **Table 3.38**.

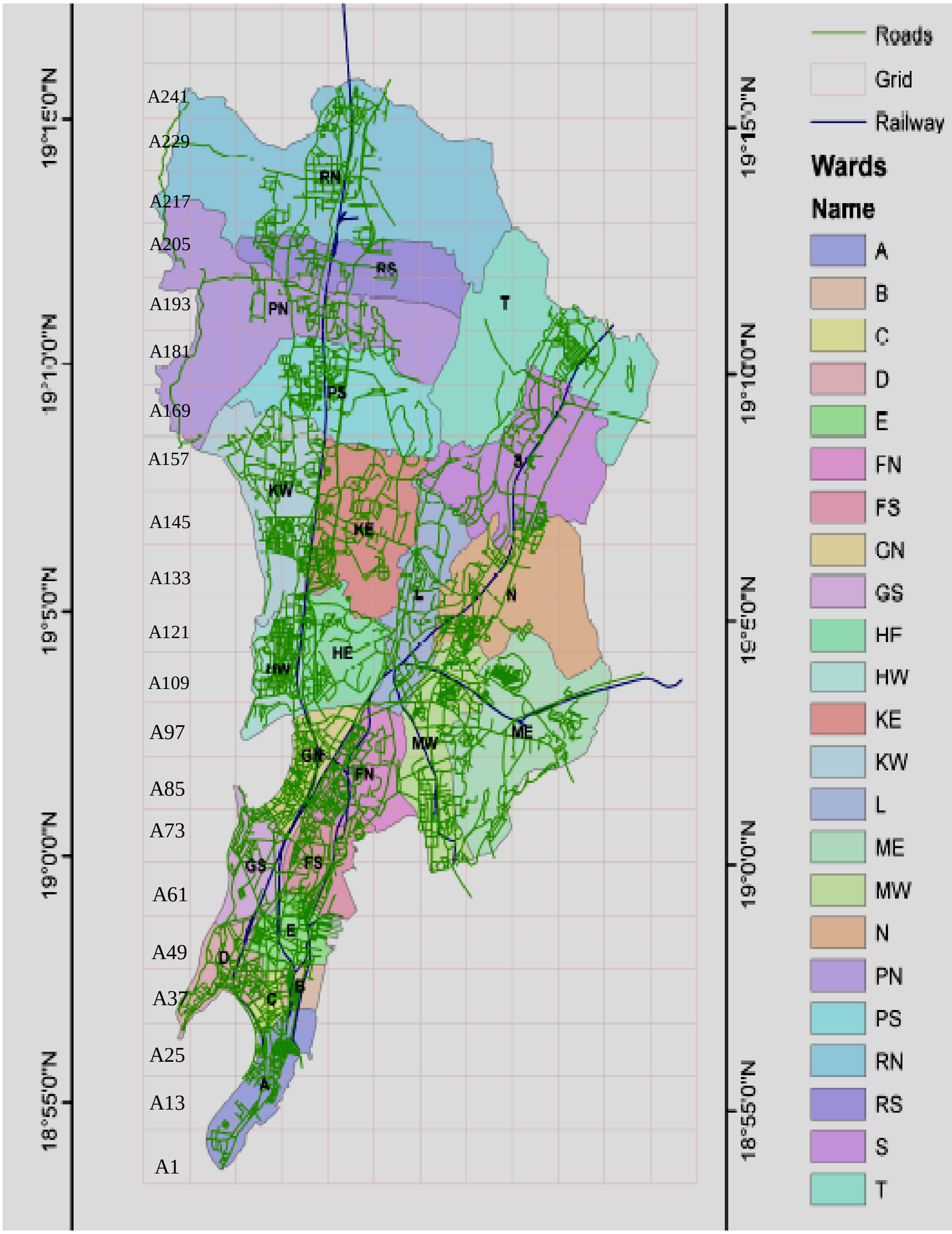

Figure 3.9: Roads of Mumbai

Table 3.38 : Identified Roads/ Traffic Junctions around Monitoring Sites for Vehicle Counts

Junction	Major Road	Minor Road
Colaba		
D.S.Jog Chowk (Near Rly.Qtrs)	Jagnath Bhosle Marg Nathalal Parekh Marg Prakash Peth Marg	Queen Road
BEST Marg, Wesley Church	Shahid Bhagat Singh Marg P.J.Ramchandai Marg (Strand Rd.) BEST Road	B.Beharam Rd. Henry Rd.
Dadar		
Bandra Mahim Road	A.S.Gaya Marg Cadell Road S.V.Road Ali Yavar Jung Road Raheja Hospital Rd.	K.C.Marg Sion Bandra Link Road Mahim Sion Link Road Tulsi Pipe Road L.K.Mehta Marg
Tulsi Pipe Road (Telephone Colony)	Senapati Bapat Marg Manmala Tank Path Shitaladevi Temple Road	Lady Hardinge Road Mia Mahamood Chhotani Rd.
Near Sion Hospital (Between Rail Br.+Signal Sion)	Laxmibai Kelkar Marg Vicent Road Kidwai Road Matunga Road	Jayshankar Yagnik Road M.T.Sangam Road Road No. Sulochana Sethi Marg
A.B.Road (Century Bazar)	S.Savarkar Road Dr. A.B.Road Sayani Road Prabhadevi New Road Sudam Kalu A. Marg Khan Abdul Ghafar Marg Pochkhanwala Road Pandhurang Budkar Marg	Old Prabhadevi Marg P. Balu Marg Kaka Saheb Gadgil Marg (Ked gali) Appasaheb Marathe Marg Sadanand Tandel Marg
Dr.Ambedkar Rd.	Dr. Baba Saheb Ambedkar Road Curry Road Br. Jijibhai Lane Sane Guruji Marg Dattaram Lad Marg	Dr. Boreges Marg Dr. S.S.Rao K.E.M. Road Jerabai Wadia Road G.D.Ambekar Marg J. Bhatankar Marg (Elphinstone Rd)
Reay Road (Kidwai Marg)	K.E.M Rd R.A.Kidwai Road Shrikant Hadkar Marg T. Jeevraj Road	Zakeria Bander Road Sewari Cemetery Road Golanji Hill Road Dockyard Road Ferry Road
Tulsi Pipe (Lower Parel)	Senapati Bapat Marg Dr. E.Moses Road Ganpatrao Kadm Marg Fergusson Road Gowalia Chawl Lane	Sitaram Jadhav Marg J. Marg Drainage Channel Marg

Table 3.38 (Contd...): Identified Roads/ Traffic Junctions around Monitoring Sites for Vehicle Counts

Junction	Major Road	Minor Road
Dadar (Contd..)		
N.M.Joshi Marg (Lower Parel)	N.M.Joshi Marg Curry Road -Mahadeo Palav Marg Arthur Road	Sakhubai Mohite Marg Fergusson Road
Dharavi		
Near Matunga King Circle Towards Wadala	Rafi Kidwai Rd. Wadala Road No. 15 Matunga Road Tilak Road	Katrak Road Phadanvis Flyover Sewari Cross Road D.S.Baretto Road
V.Naik Road-CLI	Mahim Sion Link Road Station Road Agra Road Laxmibai Kelkar Road	N.S. Mankar Road Sion Trombay Road Vidas Marg
Agra Road Swadeshi Mills	LBS Marg Maharashtra Nature Park Road Mahim Sion Link Rd –Station Rd.	E.E.Highway Laxmibai Kelkar Road 90^{th} Feet Road M.Gandhi Road Swadeshi Mill Road Sarveshwar Mandir Road
Mahim Sion Link Road	Sion Bandra Link Rd. Mahim Sion Link Rd Station Rd Agra Rd – LBS Marg V.Naik Road	90^{th} Feet Road MMRDA Road Ali Yavar Road Tulsi Pipe Road Raheja Hospital Road N.Dharmadhikari Road Madhusudan Kalekar Road BKC Road
After Mahim Causeway Near Laka or Link Rd.	S.V.Road Turner Road Guru Nanak Marg Varaskar Marg Hill Road –Ramdas Naik Road Linking Road	Bazar Road MRS Marg S.G.Joshi Marg NL Road Jarimari Road Ali Yavar Marg
Khar		
W.E.H. (Kherwadi)	W.E.Highway Sion Bandra Link Road Mahim Sion Link Road Station Road	MMRDA Road Santacruz Chembur Link Road S.V.Road Mahim Causeway Road Ram Mandir Road S.D.Mandir Road
Bandra Kurla Complex Road	Agra Road – LBS Marg BKC Road MMRDA Road Sion Bandra Link Road Ali Yavar Jung Marg	CST Road S.G.Barve Marg H.Wadia Marg New Mills Road

Table 3.38 (Contd...): Identified Roads/ Traffic Junctions around Monitoring Sites for Vehicle Counts

Junction	Major Road	Minor Road
Khar (Contd..)		
Satacruz Chembur Link Rd. Below Bridge	Ali Yavar Jung Road (WEH) Santacruz Chembur Link Rd. Station Road Jawaharlal Nehur Road	Pipeline Road Devi Road C.Shivaji Road
W.E.H. (Marble Market)	W.E.Highway Satacruz Chembur Link Road Ali Yavar Jung Marg Nehru Road	Jawaharalal Nehru Marg Station Road Airport Road S.V.Road Dayaldas Road
S.V.Road, Santacruz (Khira Nagar)	S.V.Road Juhu Tara Road P.V.Avsare Marg	Sambhaji Udyan Road Podar Road, Sai Baba Road Dattatraya Marg, M.M.Lane V.N.Bhargav Road, 6^{th} Road
Juhu Tara Road	Juhu Tara Road Juhu Road S.B.Patil Road Relief Road	Gangoli Road Linking Road S.V.Road
Andheri		
Juhu Tara Rd. Near Tulip Hotel	Juhu Road Vaikunthlal Mehta Road Juhu Tara Road Gurunanak Road	Sant Tukaram Marg North South Road (No. 11,12, 12A) S.K.Marg, Balraj Sahani Road A.B.Nair Marg
W.E.H. Prof. N.S. Phadke Rd.,Andheri-E	Prof. N.S.Phadke Marg Guru Hargovindji Road Western Express Highway Sir M.V.Road Mathuradas Vasanj Rd.	Sahar Road Chakala Road Nagardas Road Mahakali Caves Rd.
Andheri Kurla Road	Andheri Kurla Road Mathuradas Vasanj Rd. IA Project Road Guru Harigovindji Road	Church Road Kadam wadi Road Ramkrishna Mandir Road Pipe Line Road Bagarka Road Cross Road
WEH (Hari Nagar)	W.E.Highway Andheri Kurla Road Mathuradas Vasanj Rd. Prof. N.S. Phadke Rd., B.D.Sawant Marg	R.K.Singh Road Parsi Panchayat Road Jijamata Road Mahakali Cave Road

Table 3.38 (Contd...): Identified Roads/ Traffic Junctions around Monitoring Sites for Vehicle Counts

Junction	Major Road	Minor Road
Andheri (Contd..)		
S.V.Road (Shivaji Nagar)	S.V.Road Station Road, Sahakar Road Jayprakash Road C.D.Barfiwala Road N.S.Phadke Road Ambole Phatak Road	Dout Baugh Road Bardawadi Road New Nagardas Road R.K.Paramahaus Road
New Link Road Belle View	Versova Road Andheri Link Road Ceasar Road Lokhandwala Complex Road Balasaheb Sawant Road	Veer Desai Road Guru Nanak Road Devle Road Bhakti Vedanta Swami Road St. Louis Convent Rd.
Also in Khar Area		
Juhu Tara Road	Juhu Tara Road, Juhu Road, S.B.Patil Road, Relief Road	Gangoli Road, Linking Road S.V.Road
W.E.H. (Marble Market)	W.E.Highway Satacruz Chembur Link Road Ali Yavar Jung Marg, Nehru Road	Jawaharalal Nehru Marg Station Road, Airport Road S.V.Road, Dayaldas Road
S.V.Road, Santacruz (Khira Nagar)	S.V.Road, Juhu Tara Road P.V.Avsare Marg	Sambhaji Udyan Road Podar Road, Sai Baba Road Dattatraya Marg, M.M.Lane V.N.Bhargav Road, 6th Road
Mahul		
C.Shivaji Chowk Near Chembur	Sion Trombay Marg V.N.Purav Marg Waman Patil Marg	Ramkrishna Chembur Marg Kalwada Borla Road D.Quarry Marg Trilok Kapur Marg N.B.Patil Marg D.Sarawati Marg
Ashish Theater RCF Colony	Ramkrishna Chemburkar Marg RCF Road Bharat Petroleum Road	B.D.Patil Marg C.Gidwani Marg
Suman Nagar Chowk Sion Trombay Rd., Kurla	V.Naik Road Sion Trombay Marg Eastern Express Highway	S.G.Barve Marg (CST Road) Hemu Kalani Marg V.N.Purav Marg Vasant Rao Naik Marg Ramkrishna Chembur Marg Ghatkopar Mahul Road Labour Camp Road
Ramkrishna Chembur Marg (Navjeevan Society)	Ghatkopar Mahul Road Sion Trombay Road Ramkrishna Chemburkar Road Hemu Kalani Road Choitram Gidwai Marg V.N.Purav Marg	CST Road E.E.Highway D.K.Sandu Marg Chembur Govandi Road P.L.Lokhande Marg K.N.Gaikwad Marg Inlaks Hospital Road

Table 3.38 (Contd...): Identified Roads/ Traffic Junctions around Monitoring Sites For Vehicle Counts

Junction	Major Road	Minor Road
Mahul (Contd..)		
Port Trust Road	Mahul Road Port Trust Road Corridor Road RCF Road	Manik Patil Road
Mahul Road	Mahul Road Port Trust Road L.N.Nadkarni Road Haji Bander Road	Hay Bander Road MPT Road Sewri Fort Road Salt Pan Road Sewri Koliwada Road RCF Road
Towards Truck Terminal	E.E.Highway Mahanagar Gas Road Sion Trombay Road	Rods Coming from Pratiksha Nagar and Mahada Transit Camp Road coming from KJ Somiya Medical College
Mulund		
LBS Marg Mulund Check Naka	L.B.S.Marg Guru Govind Singh Marg Dr. Rajendra Prasad Road	Mataji Road Eastern Express Highway ACC Road P.Kheraj Road Main Rd.(Waghle Estate) Balrajeshwar Marg, Hill Bridge Rd.
Road from Airoli Going to Mulund	LBS Marg Goregaon Mulund Link Road Eastern Express Highway Road Coming from Airoli Br.	Pt. Jawaharlal Nehru Road Bhandup Village Road M.D.Keni Road Navghar Road
E.E.H. Before Flyover	E.E.Highway Jogeshwari Vikhorli Link Road Road coming from Airoli Br.	Kanjur Village Road M.D.Keni Road
E.E.H- Near ACC	E.E.Highway Mental Hospital Road LBS Road Gokhale Road	Road No.9 Lokmanya Tilak Road Kopari Road Arun Kumar Vaidya Road
LBS Marg Near Bhandup Ind. Area	LBS Marg Goregaon Mulund Link Road Lake Road Gaodevi Road Darga Road	Gurugobind Singh Road Madam Mohan Malviya Road Pt. Jawaharlal Nehru Road Bhandup Village Road Bhattiwada Road
Goregaon Mulund Link Road (Near Khindipada)	Goregaon Mulund Link Road Gurugobind Singh Road Lake Road Goandevi Road LBS Road	Darga Road Gam devi Path Link Road

3.4.4 Emission Factors

ARAI has developed emissions factors in 2007 of different categories and vintage of vehicles along with variation with fuel. **Table 3.39** presents the summary of emission factor developed by ARAI.

Table 3.39: Emission Factors Calculated by Automotive Research Association of India (ARAI), 2007

Type of Vehicle	Vintage	Capacity	Emission Factors (g/km)			
			CO	HC	NOx	PM
Motor cycle (2 stroke)	1996-2000	>80cc	2.96	2.44	0.05	--
	Post 2000 #	<1000cc	1.65	0.61	0.27	0.035
Three wheeler (CNG retro)	post 2000 #	<200cc	0.69	2.06	0.19	0.118
Car (petrol)	post 2000 #	1000-1400cc	3.01	0.19	0.12	0.006
Car (diesel)	1996- 2000#	1600 -2400 cc	0.66	0.25	0.61	0.180
	post 2000	<1600cc	0.51	0.2	0.67	0.12
Taxis (CNG)	post 2000#	1000-1400cc	0.60	0.36	0.01	0.002
Bus-1 (Diesel)	1991-2000	>6000cc	19.3	2.63	13.84	1.965
Bus-2 (Diesel & CNG)	post 2000#	>6000cc	6.00	0.37	9.30	1.240

 # Factors used for emission load calculation

Source: Air Quality Monitoring Project-Indian Clean Air Programme (ICAP), The Automotive Research Association of India, 08, 2007

3.4.5 Existing Vehicle Emission Inventory

Vehicular count data obtained through measurements at different roads/junctions and grid wise road length along with emission factors were used for quantifying the emission loads from the grids. Vehicular count data of each traffic junction/road has been extrapolated /distributed/ allocated to all the adjacent/nearby grids taking into account (in relation to and in proportion to) the road network, length of major and minor roads in each grid, traffic in up and down directions, intensity of traffic and contribution of grid activities to the traffic observed at the traffic junctions/roads.

3.4.5.1 Site wise Vehicle Emission Inventory

Site wise vehicular emissions of all types of vehicles with respect to CO, NOx, HC and PM_{10} emitted in Kg/d are presented in **Table 3.40**. SO_2 emissions are calculated based on VKT and sulphur content (Diesel 300 ppm and Gasoline 30 ppm) as SO_2 emission factor was not available.

Table 3.40: Emission Load from All Category Vehicles (Kg/day)

Sites	PM	CO	NOx	HC	SO_2
Colaba	27.81	227.91	201.16	35.49	4.13
Dadar	115.84	1816.90	747.56	327.77	21.32
Dharavi	60.54	974.62	379.30	191.21	11.22
Khar	104.35	1214.42	575.32	617.88	13.63
Andheri	72.59	919.97	375.16	441.28	10.29
Mahul	26.80	239.61	174.69	84.78	2.16
Mulund	32.60	323.29	148.61	293.54	2.98
Total	**440.5**	**5716.7**	**2601.8**	**1992.0**	**65.7**

Percentage pollutant load at sampling sites is presented in **Figure 3.10** at sampling sites.

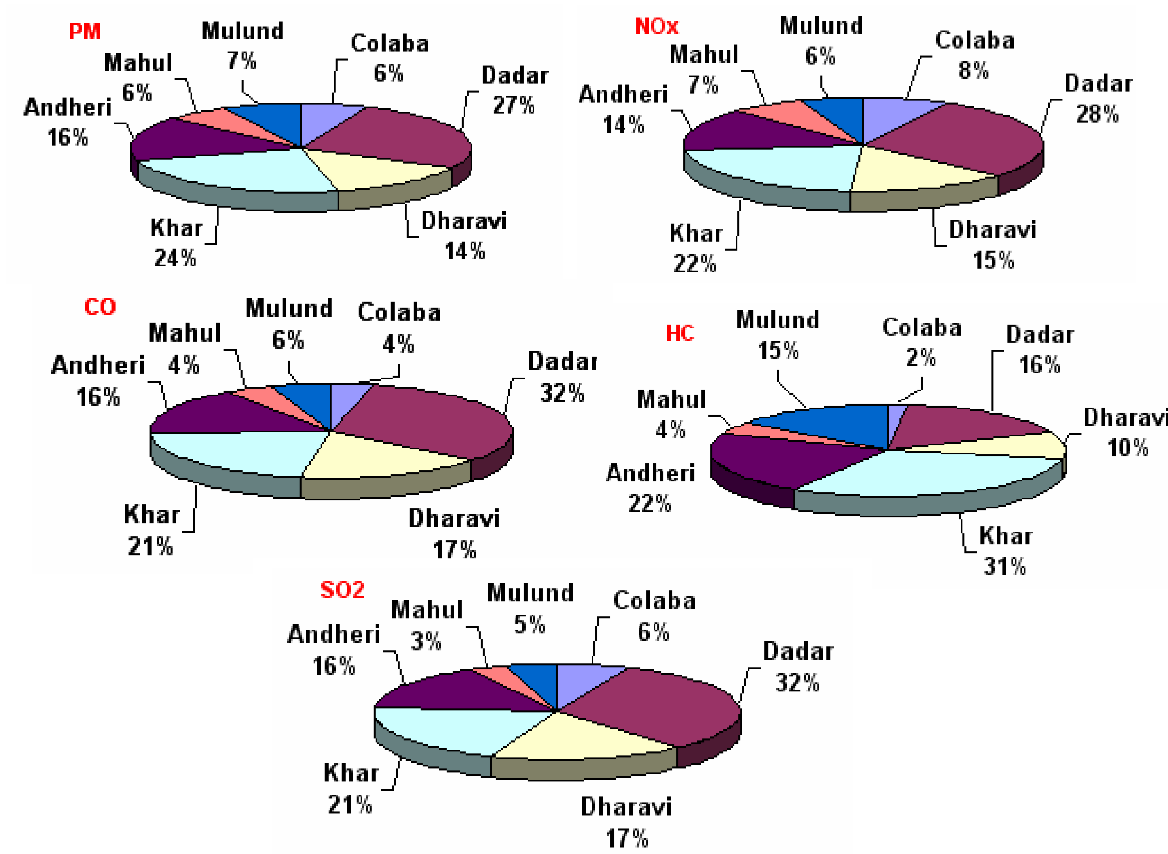

Figure 3.10: Percentage Pollutant Load at Different Sites

CO emission load was highest at Dadar (32%) and lowest at Mahul (4%). Vehicles at Dadar contribute to 28% of NOx. However, HC emission load was maximum at Khar (31%) followed by Andheri (22%) and lowest for Colaba (2%). The percentage contribution of particulates was maximum at Dadar (27%) followed by Khar (24%), Andheri (16%), Dharavi (14%), Mulund (7%), Colaba and Mahul (6%) each. The highest emission load of pollutants at Dadar is due to heavy traffic and commercial activities. It is also due to its location on a main arterial road viz. Dr. Ambedkar Road and the site is situated next to inter city bus station. Dharavi has reasonably higher emissions because it acts as link between eastern and western suburbs and also receives traffic from South Mumbai. Same is the case of Andheri which is located on Western Express Highway and very close to Mumbai Airport. Vehicle category wise distribution of pollutants is given in **Table 3.41**.

Table 3.41: Vehicle Category wise Distribution of Pollutants at Seven Sites

Site/ Category	PM (Kg/d)	NOx (Kg/d)	CO (Kg/d)	HC (Kg/d)
Heavy Duty Diesel Vehicles /Buses				
Colaba	24.8	186.1	120.1	7.4
Dadar	71.6	537.2	346.6	21.4
Dharavi	35.0	262.6	169.4	10.4
Khar	55.7	418.1	269.7	16.6
Andheri	32.9	246.9	159.3	9.8
Mahul	20.3	152.4	98.3	6.1
Mulund	13.2	98.9	63.8	3.9
Car (Petrol)				
Colaba	0.10	2.00	50.21	3.17
Dadar	1.75	34.91	875.58	55.27
Dharavi	0.98	19.55	490.36	30.95
Khar	0.90	17.96	450.52	28.44
Andheri	0.88	17.63	442.14	27.91
Mahul	0.13	2.69	67.49	4.26
Mulund	0.17	3.45	86.57	5.46
Car (Diesel)				
Colaba	2.11	7.14	7.72	2.93
Dadar	34.91	118.30	127.99	48.48
Dharavi	19.55	66.25	71.68	27.15
Khar	17.96	60.87	65.86	24.95
Andheri	17.63	59.74	64.63	24.48
Mahul	2.69	9.12	9.87	3.74
Mulund	3.45	11.70	12.65	4.79
Taxies (CNG)				
Colaba	0.05	0.26	15.39	9.23
Dadar	0.44	2.18	130.65	78.39
Dharavi	0.22	1.09	65.58	39.35
Khar	0.18	0.88	52.96	31.77
Andheri	0.06	0.30	17.89	10.74
Mahul	0.04	0.22	12.92	7.75
Mulund	0.02	0.12	6.93	4.16
3 Wheelers				
Dharavi	1.15	1.86	6.75	20.15
Khar	24.67	39.72	144.25	430.65
Andheri	18.38	29.59	107.45	320.79
Mahul	2.88	4.64	16.87	50.35
Mulund	14.29	23.00	83.54	249.39
2 Wheelers				
Colaba	0.73	5.65	34.51	12.76
Dadar	7.13	55.00	336.11	124.26
Dharavi	3.62	27.96	170.84	63.16
Khar	4.90	37.82	231.11	85.44
Andheri	2.73	21.04	128.59	47.54
Mahul	0.72	5.58	34.11	12.61
Mulund	1.48	11.42	69.77	25.79

* 3 Wheelers are not plying on the roads of Colaba and Dadar.

In order to arrive at the emission load generated at each traffic scenario/different traffic intensity periods on any given day viz. Morning Peak, Afternoon Average, Evening Peak and Night Average in each grid, a separate estimate have been made for Mumbai City.

The heavy duty diesel vehicles give highest emissions of NOx followed by CO, PM and HC. Petrol cars give highest CO followed up by HC, NOx and PM whereas diesel cars give highest CO followed up by NOx, HC and PM. CNG taxies contribute more CO followed by HC, NOx and PM. Three wheelers on the other hand give highest HC, followed by CO, NOx and PM whereas 2 wheelers give higher contribution of CO followed by HC, NOx and PM. Shift wise total emission vary considerably vehicle category wise. It has been seen that most of the places, evening peak hours are extended late in the night and therefore, night emissions load are also high. Vehicle Kilometer Travelled at Mumbai City and each of seven sites varies for different categories of vehicles as is evident from **Figure 3.11 and Annexure 3.2**. Dadar area has dominant VKT from all categories of vehicles except three wheelers as this category is not allowed to ply in this part of the city.

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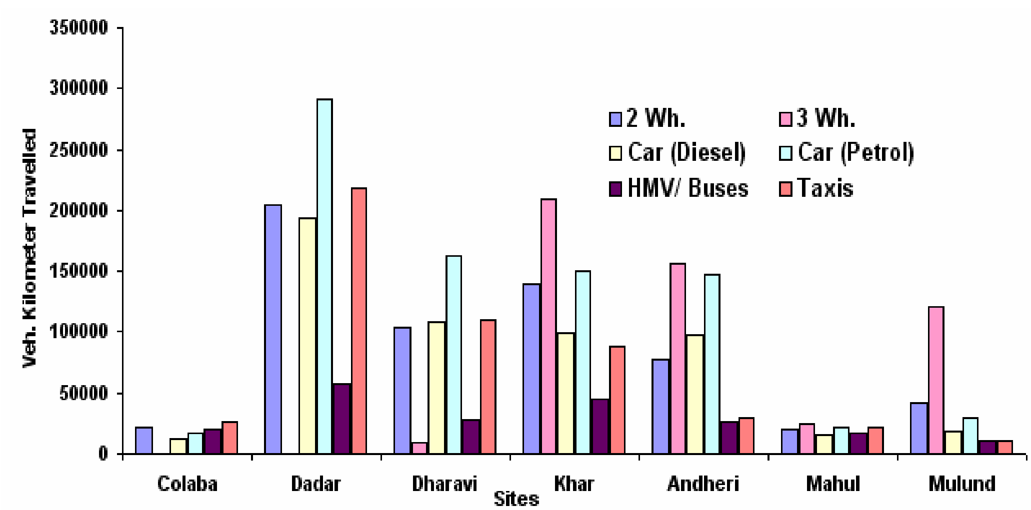

Figure 3.11: Vehicle Kilometer Travelled at Monitoring Sites

Higher Percentage distribution of Petrol and Diesel Cars at Dadar is due to commercial area, where high traffic movement takes place. Dadar being a central part of Mumbai has heavy traffic movement. Other sites such as Dharavi has high VKT of cars (petrol and diesel) due to Bandra Kurla Complex area having corporate offices and also serves as a joining area between western –eastern city viz. Sion Bandra Link Road.

Taxis are mainly operated in the central and south Mumbai; therefore higher VKT is estimated for Dadar. Andheri and Khar are also higher VKT from Taxis as people commute from airport to South Mumbai for business transaction as important offices are situated in this area.

3 Wheelers (auto rickshaw) VKT is high at Khar, Andheri and Mulund as these sites are mainly commercial and residential areas. 2 Wheelers are commonly used for personal transportation. These mainly operate from residential areas to near by stations, work place, schools and colleges and center of the city. In Mumbai there is an increase of 2 Wheelers as compared to other mode of transportation. Its population has gone up beyond 50% of the total vehicle population. Higher VKT was observed at Dadar and Khar area.

3.4.5.2 Whole City Vehicular Emission Inventory

Besides seven sites specific vehicle emission inventory as presented earlier, the data collected for vehicle counts and road lengths, were used to prepare city emission inventory. Methodology described earlier remains same; however, the estimates have been made for 2 km x 2 km grids with respect to the entire city. These estimates have been further used for grid wise projections, input to dispersion modeling and scenario generation. Emission loads computed for all grids as shown in earlier **Figure 3.9** were used for dispersion modeling. **Table 3.42** presents the total emission loads as per different vehicle categories.

Table 3.42: Total Emission load from different categories of vehicle for the City of Mumbai

	PM	NOx	SO_2	CO	HC
2 Wheelers	192.1	1480.8	7.4	9049.9	3345.8
3 Wheelers	618.9	996.4	--	3618.9	10804.1
Car Diesel	859.7	2913.2	238.9	3152.1	1194.0
Car Petrol	43.0	859.5	35.9	21554.8	1360.5
Heavy Duty Diesel Vehicles	2511.5	18835.6	347.1	12152.1	749.3
Taxies	7.1	35.6	--	2133.2	1279.7
Total	**4232.3**	**25121.1**	**629.3**	**51660.8**	**18733.4**

* All values expressed in Kg/d., -- CNG is used as fuel

NOx is mainly contributed by HDDV, followed by diesel cars. HDDV also dominate PM_{10} emission load with about 2511.5 Kg/d followed by Car Diesel with a load of 859.7 Kg/d.

3.5 Emission Loads from All Sources

Emission loads for all the sites and the whole city from all sources have been computed. Site specific analysis of inventory has been discussed before the whole city inventory.

Colaba: Emission loads were calculated for area, point and line sources and are presented in **Table 3.43.**

Category	PM	CO	SO_2	NOx	HC
Bakery	62.13	453.57	1.01	4.80	411.18
Open eat outs	6.74	4.01	0.38	0.22	0.04
Hotels	12.87	14.85	5.94	10.82	0.55
Domestic	2.0	45.9	2.9	39.5	1.5
Open burning	7.54	23.55	0.28	1.68	12.06
Construction	2.5				
Area Sources	**93.78**	**541.88**	**10.51**	**57.02**	**425.33**
Paved road dust	2.90				
Unpaved road dust	4.37				
Vehicles	27.81	227.91	4.13	201.16	35.49
Total Emission	**128.86**	**769.79**	**14.64**	**258.18**	**460.82**

* All values expressed in kg/d

At Colaba site, area sources accounts for 78% of PM and major contributing sources are bakery and hotels, whereas remaining 22% is contributed from vehicles.

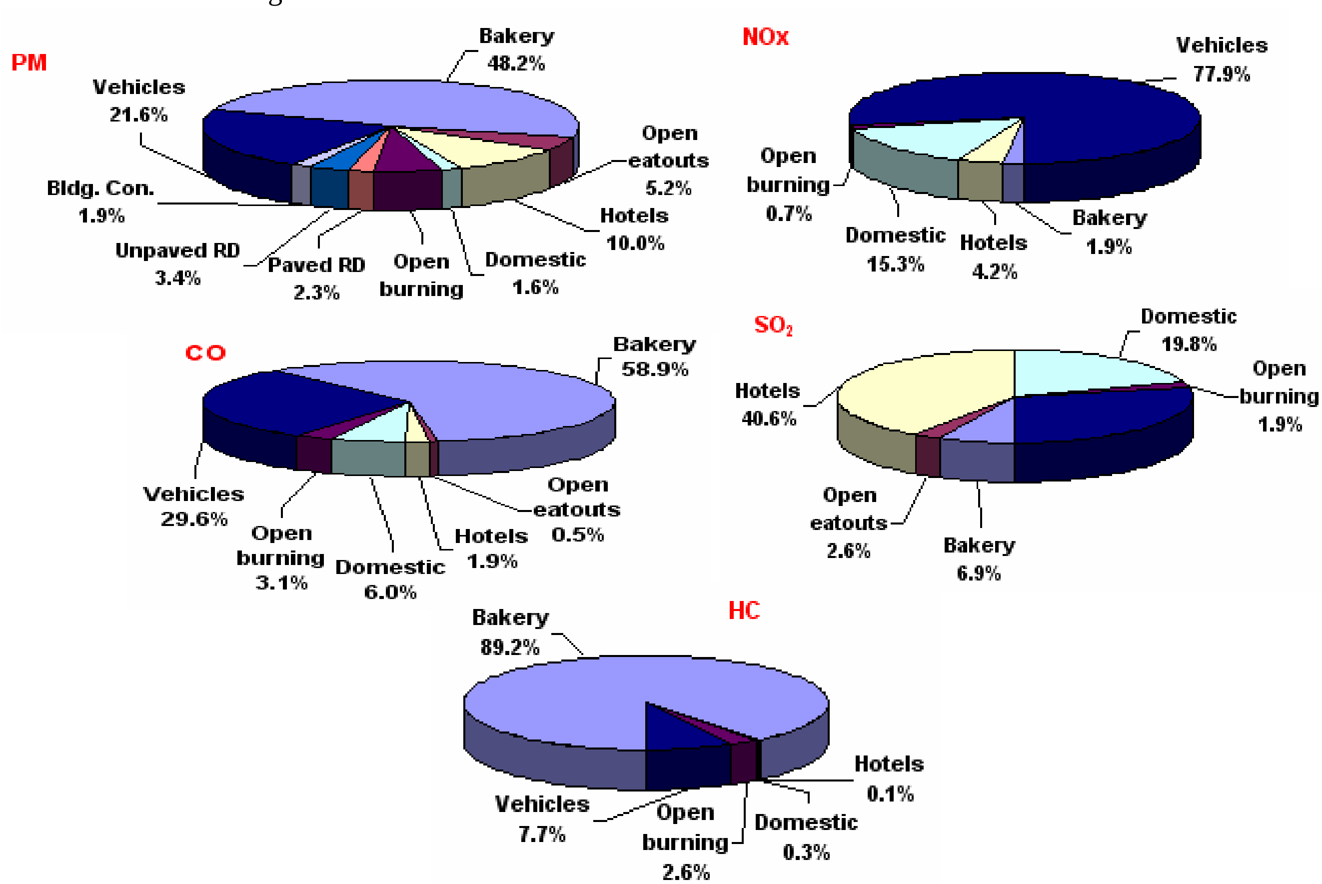

Figure 3.12: **Percentage Contribution of Different Source Categories to Various Pollutants at Colaba**

Contribution of pollutant from different categories of vehicles is given in **Figure 3.13.**

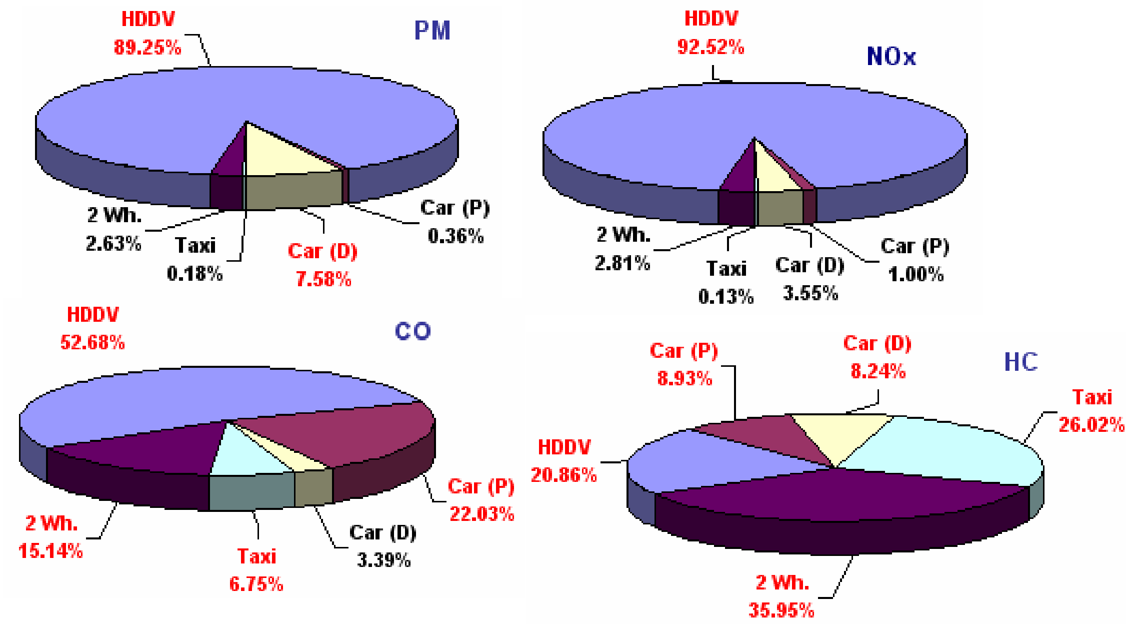

Figure 3.13: Contribution of different pollutants by different categories of Vehicles at Colaba Site

Dadar: Emission loads were calculated for area, point and line sources and are presented in **Table 3.44.**

Category	PM	CO	SO_2	NOx	HC
Bakery	78.77	574.92	1.28	6.08	521.18
Crematoria	14.4	106.0	0.4	2.3	95.3
Open eatouts	17.11	10.19	0.98	0.57	0.09
Hotels	29.05	38.72	13.42	24.45	1.27
Domestic	32.1	938.7	59.9	602.7	22.7
Open burning	46.11	144.09	1.72	10.29	73.76
Bldg. Con.	70.1				
Area Source	**287.64**	**1812.62**	**77.7**	**646.39**	**714.3**
Paved road dust	243.30				
Unpaved road dust	366.24				
Vehicles	**115.84**	**1816.90**	**21.32**	**747.56**	**327.77**
Total Emission	**1013.02**	**3629.52**	**99.02**	**1393.95**	**1042.07**

* All values expressed in kg/d

Major contributors at Dadar site to PM emission are area source (88.6%) followed by vehicle (11.4%). Bakeries and building construction are dominant area sources.

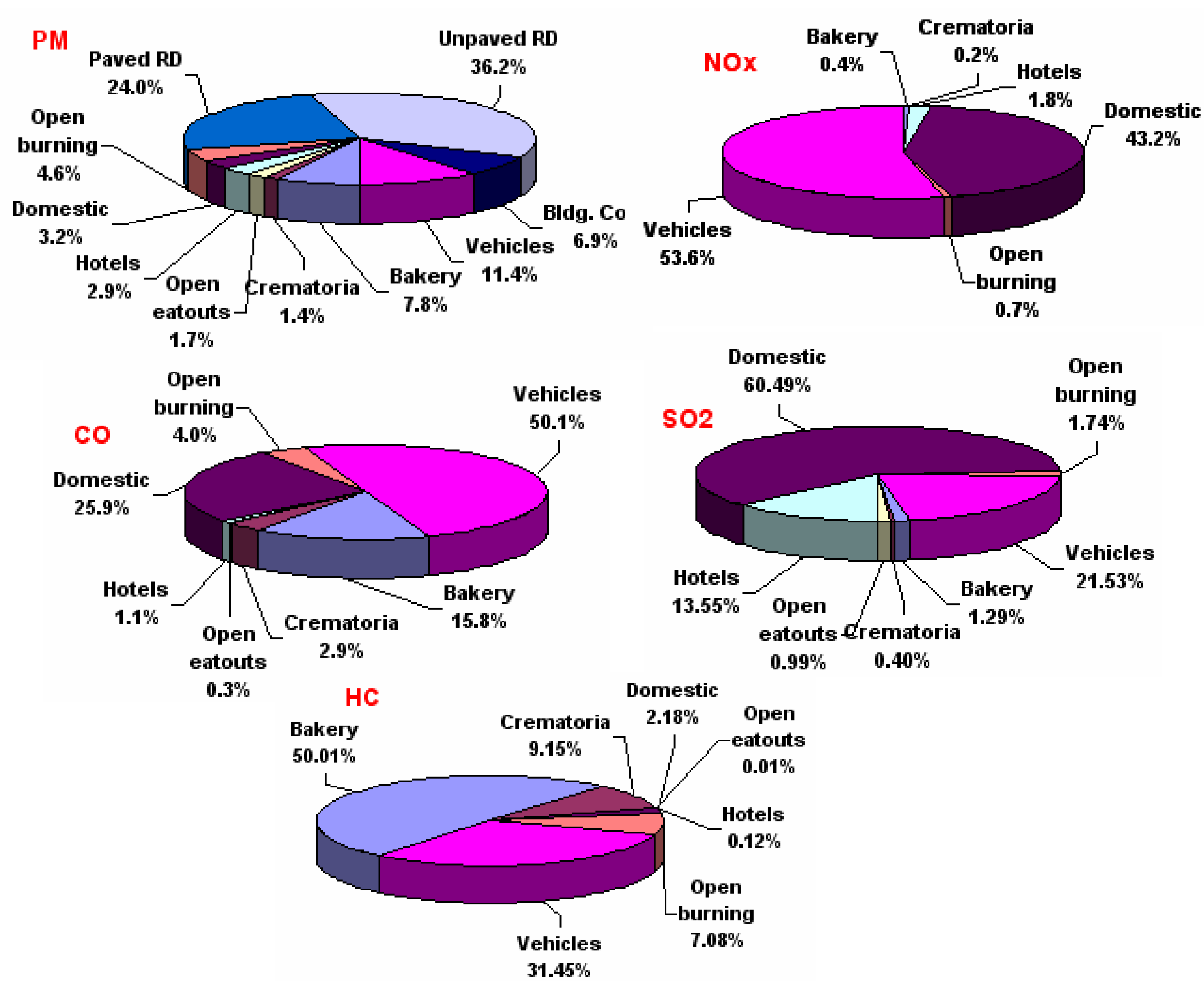

Figure 3.14: Percentage Contribution of Different Source Categories to Various Pollutants at Dadar

Contribution of pollutant from different categories of vehicles is given in **Figure 3.15.**

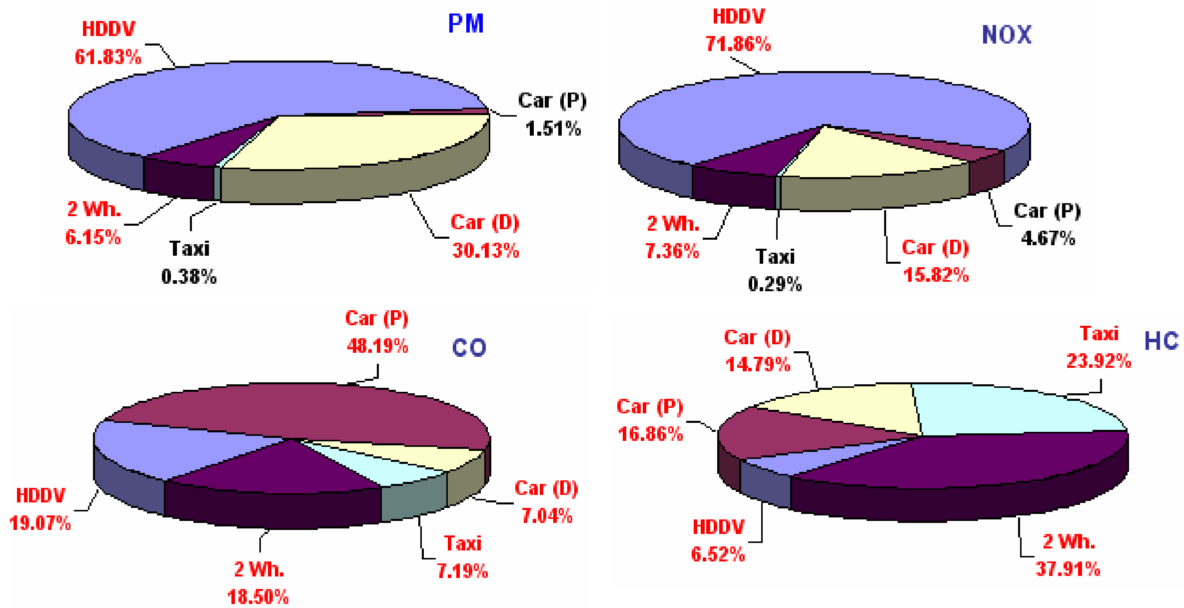

Figure 3.15: Contribution of different pollutants by different categories of Vehicles at Dadar Site

Dharavi: Emission loads were calculated for area, point and line sources and are presented in **Table 3.45.**

Category	**PM**	**CO**	**SO_2**	**NOx**	**HC**
Bakery	82.85	604.76	1.34	6.40	548.23
Crematoria	12.2	89.6	0.4	1.9	80.6
Open eatouts	11.12	6.62	0.65	0.37	0.06
Hotels	26.76	35.85	12.36	22.51	1.16
Domestic	32.8	944.1	60.3	619.2	23.4
Open burning	46.3	144.70	1.72	10.34	74.07
Bldg. Con.	68.9				
Area Source	**280.93**	**1825.63**	**76.77**	**660.72**	**727.52**
Paved road dust	229.88				
Unpaved road dust	346.04				
Vehicles	**60.54**	**974.62**	**11.22**	**379.30**	**191.21**
Total Emission	**917.39**	**2800.25**	**87.99**	**1040.02**	**918.73**

* All values expressed in kg/d

At Dharavi site, area sources accounts for 93.4% of PM and major contributing sources are bakery, building construction and open burning, whereas remaining 6.6% is contributed from vehicles.

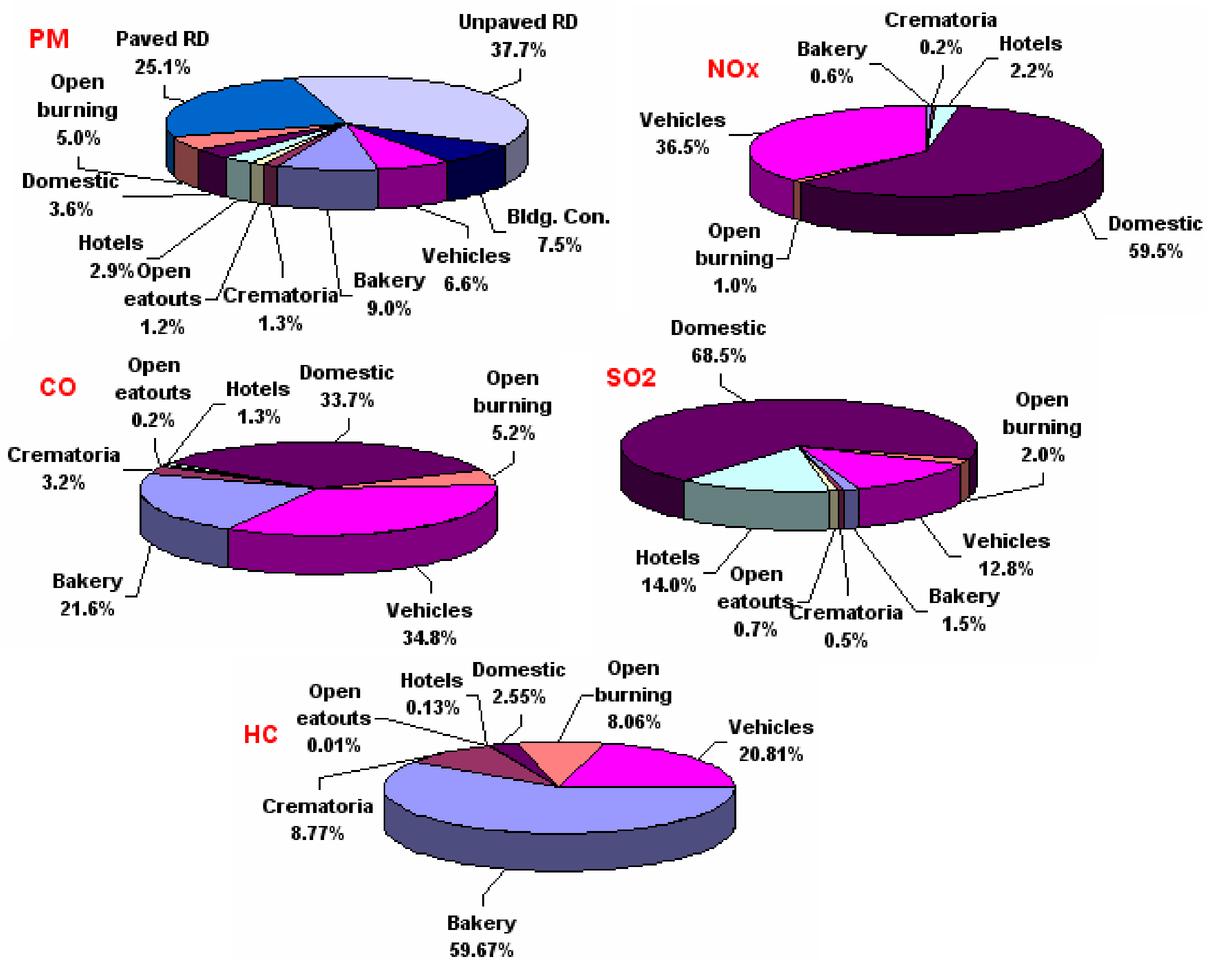

Figure 3.16: **Percentage Contribution of Different Source Categories to Various Pollutants at Dharavi**

Contribution of pollutant from different categories of vehicles is given in **Figure 3.17.**

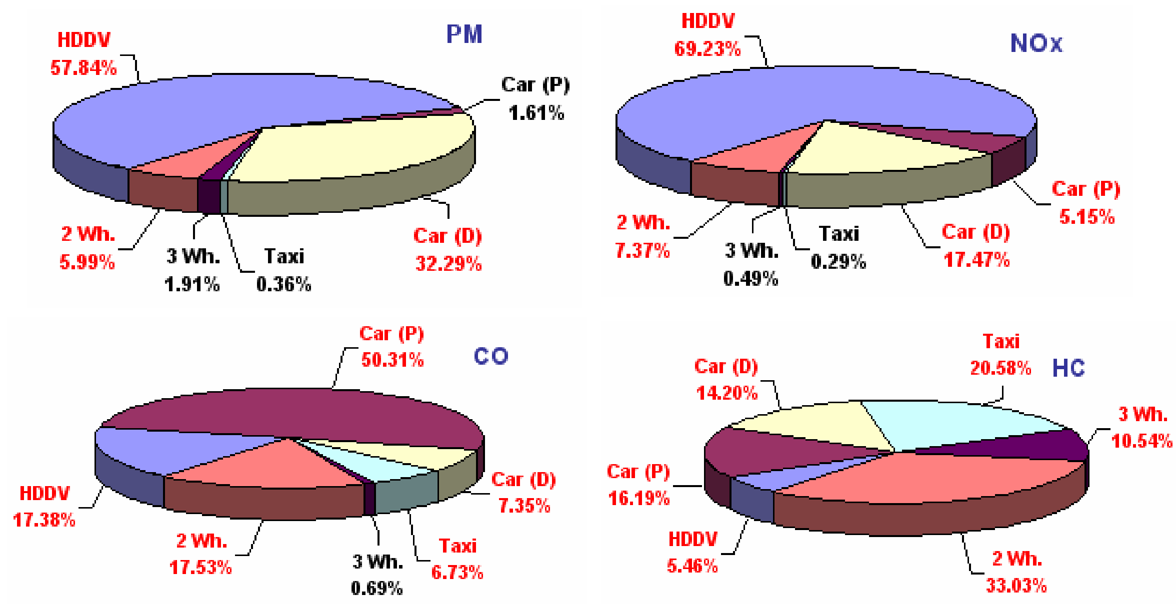

Figure 3.17: Contribution of different pollutants by different categories of Vehicles at Dharavi Site

Khar: Emission loads were calculated for area, point and line sources and are presented in **Table 3.46.**

Category	PM	CO	SO_2	NOx	HC
Bakery	51.70	377.41	0.84	3.99	342.13
Crematoria	12.0	87.9	0.3	1.6	79.2
Open eatouts	6.89	4.09	0.4	0.22	0.04
Hotels	11.58	14.78	5.34	9.74	0.51
Domestic	11.5	570.7	36.7	167.4	5.8
Open burning	22.88	71.49	0.85	5.11	36.59
Bldg. Con.	50.9				
Area Source	**167.45**	**1126.37**	**44.43**	**188.06**	**464.27**
Paved RD	232.17				
Unpaved RD	349.49				
Vehicles	**104.35**	**1214.42**	**13.63**	**575.32**	**617.88**
Total Emission	**853.46**	**2340.79**	**58.06**	**763.38**	**1082.15**

* All values expressed in kg/d

At Khar site, area sources accounts for 87.8% of PM and major contributing sources bakery, building construction and open burning, whereas remaining 12.2% is contributed from vehicles.

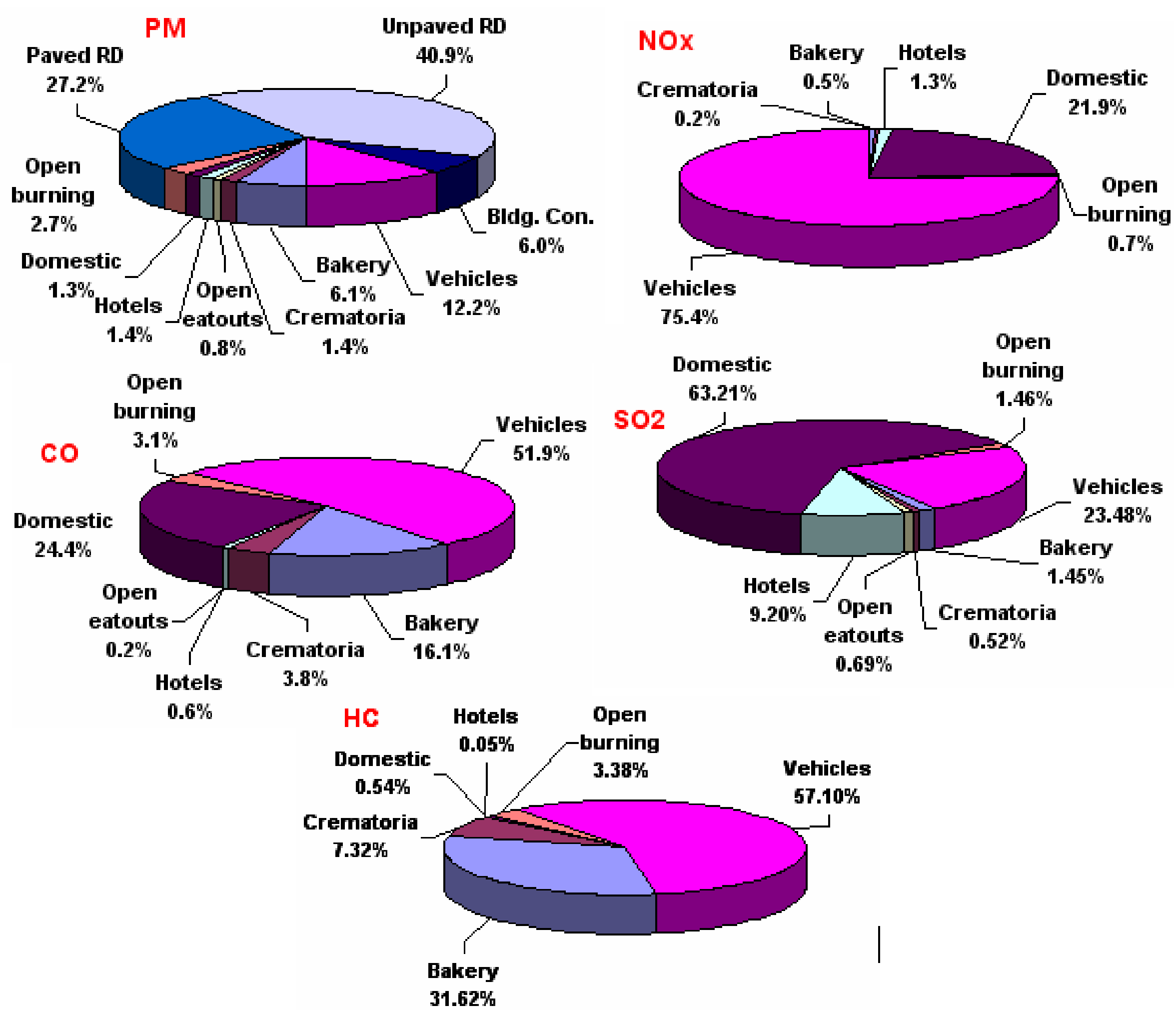

Figure 3.18: **Percentage Contribution of Different Source Categories to Various Pollutants at Khar**

Contribution of pollutant from different categories of vehicles is given in **Figure 3.19.**

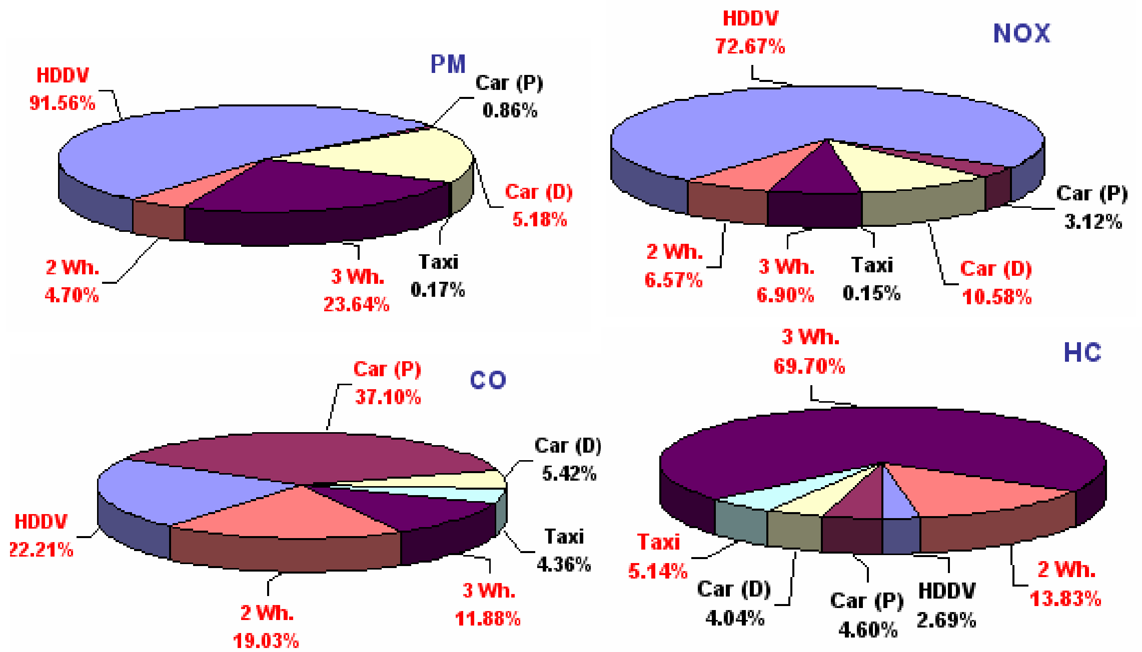

Figure 3.19: Contribution of different pollutants by different categories of Vehicle at Khar Site

Andheri: Emission loads were calculated for area, point and line sources and are presented in **Table 3.47.**

Category	PM	CO	SO_2	NOx	HC
Bakery	54.70	399.29	0.89	4.23	361.97
Crematoria	9.5	69.6	0.2	1.4	62.6
Open eatouts	14.45	8.61	0.84	0.48	0.08
Hotels	18.34	21.48	8.46	15.42	0.79
Domestic	24.5	666.4	42.5	469.0	17.8
Open burning	18.18	56.82	0.68	4.06	29.08
Bldg. Con.	53.3				
Area Source	**192.97**	**1222.2**	**53.57**	**494.59**	**472.32**
Paved RD	224.50				
Unpaved RD	337.93				
Vehicles	**72.59**	**919.97**	**10.29**	**375.16**	**441.28**
Industries	**0.85**	**3.75**	**115.7**	**40.34**	**0.68**
Total Emission	**755.40**	**1200.13**	**47.11**	**483.64**	**471.74**

* All values expressed in kg/d

At Andheri site, area sources accounts for 91.1% of PM and major contributing sources are bakeries and building construction, whereas remaining 8.8% is contributed from vehicles and 0.1% contribution is from industries.

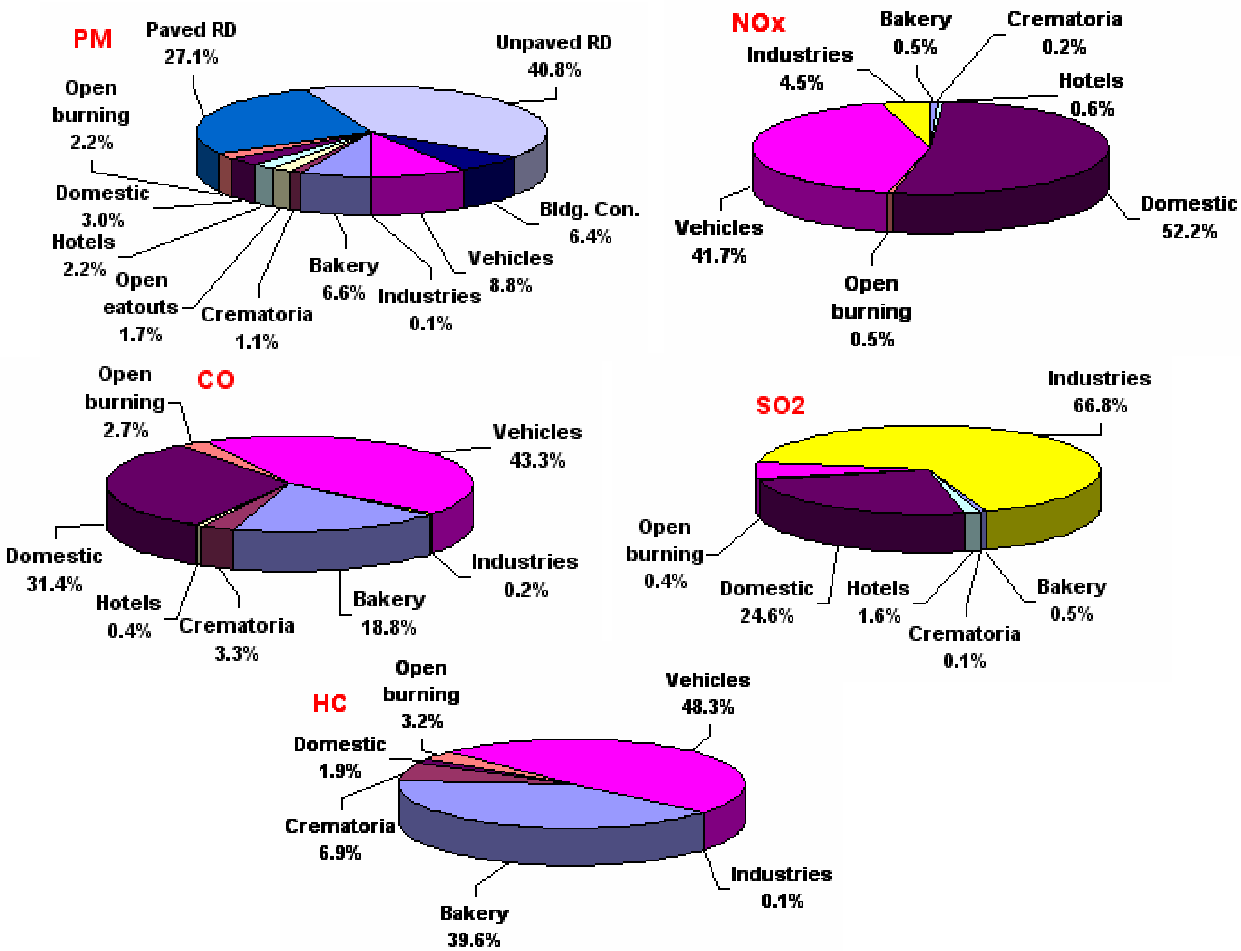

Figure 3.20: **Percentage Contribution of Different Source Categories to Various Pollutants at Andheri**

Contribution of pollutant from different categories of vehicles is given in **Figure 3.21.**

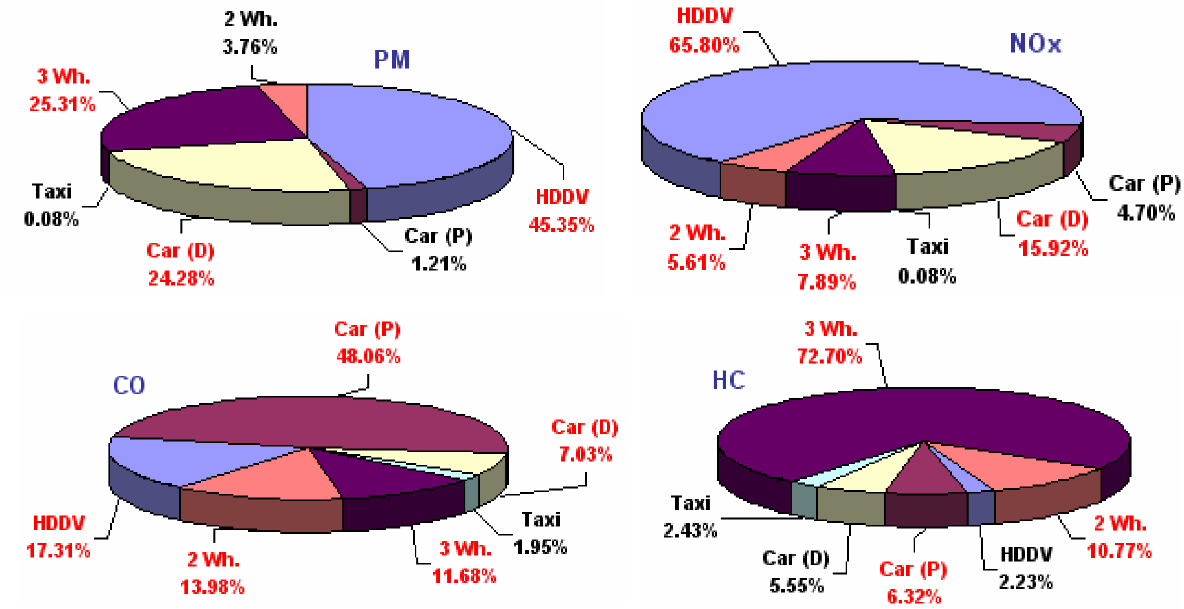

Figure 3.21: Contribution of different pollutants by different categories of Vehicle at Andheri Site

Mahul: Emission loads were calculated for area, point and line sources and are presented in **Table 3.48.**

Category	PM	CO	SO_2	NOx	HC
Bakery	12.30	89.81	0.20	0.95	81.41
Crematoria	6.2	45.7	0.2	0.9	41.1
Open eatouts	4.28	2.55	0.24	0.15	0.02
Hotels	8.3	10.04	3.84	6.98	0.36
Domestic	13.0	539.2	34.6	211.4	7.6
Open burning	14.09	44.04	0.52	3.15	22.55
Bldg. Con.	34.7				
Area Source	**92.87**	**731.34**	**39.6**	**223.53**	**153.04**
Paved RD	101.27				
Unpaved RD	152.45				
Vehicles	**26.80**	**239.61**	**2.16**	**174.69**	**84.78**
Industries	**196.43**	**650.21**	**19090.97**	**6251.62**	**81.66**
Total Emission	**569.82**	**1621.15**	**19132.73**	**6649.85**	**319.50**

* All values expressed in kg/d

At Mahul site, area sources accounts for 60.8% of PM and major contributing sources are Building construction and open burning, whereas remaining 34.5% is contributed from industries and 4.7% is from vehicles

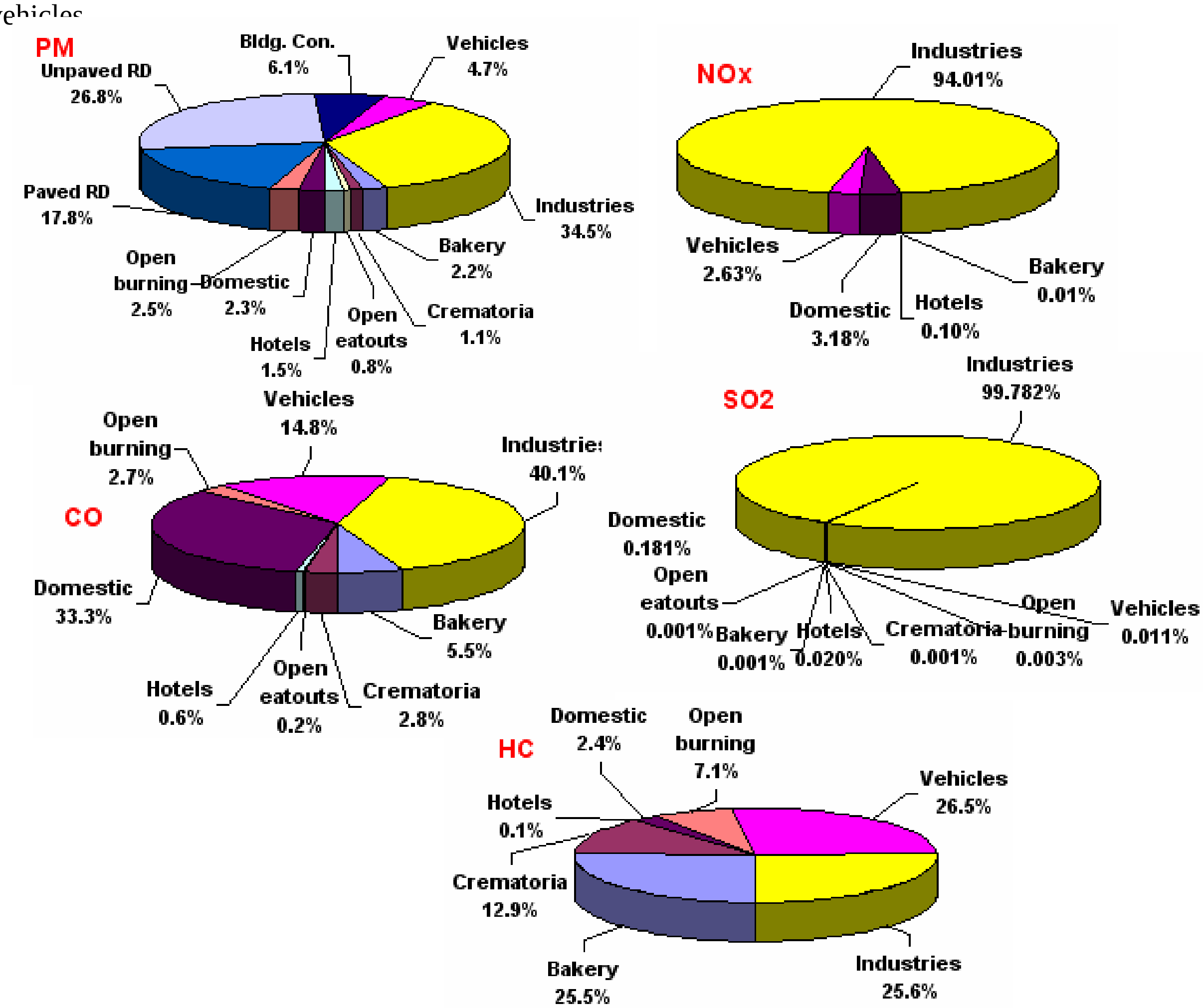

Figure 3.22: **Percentage Contribution of Different Source Categories to Various Pollutants at Mahul**

Contribution of pollutant from different categories of vehicles is given in **Figure 3.23.**

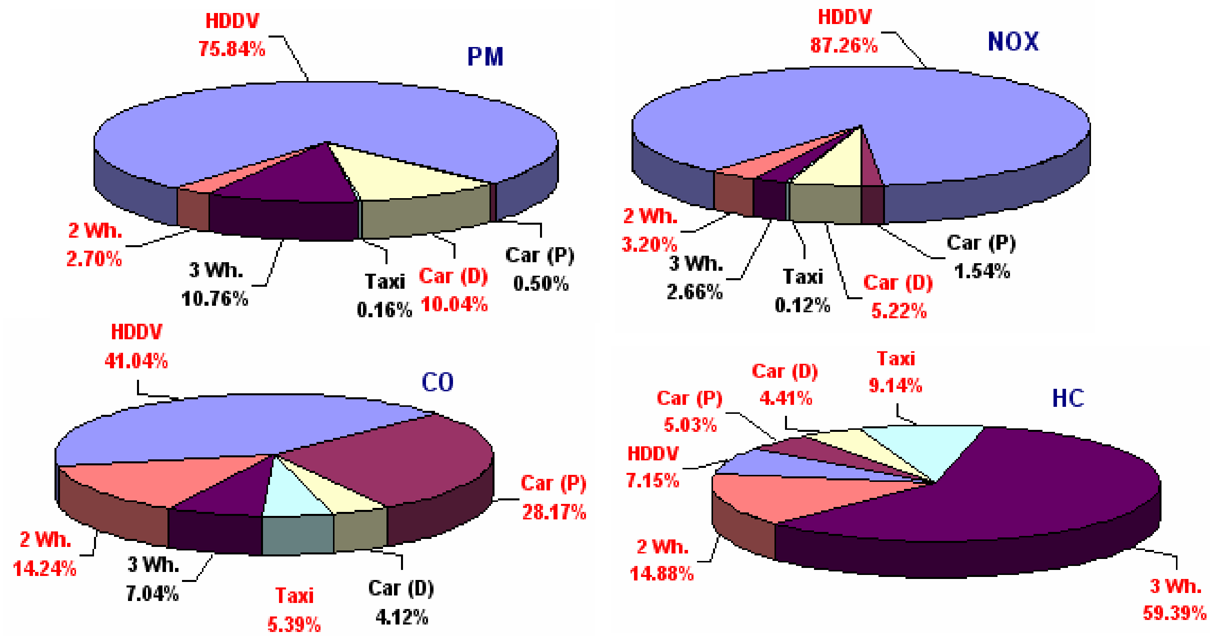

Figure 3.23: Contribution of different pollutants by different categories of Vehicle at Mahul Site

Mulund: Emission loads were calculated for area, point and line sources and are presented in **Table 3.49.**

Category	PM	CO	SO_2	NOx	HC
Bakery	5.99	43.77	0.10	0.46	39.67
Crematoria	3.9	28.8	0.1	0.6	25.9
Open eatouts	0.75	0.45	0.05	0.02	0.00
Hotels	5.96	7.58	2.76	5.02	0.26
Domestic	10.4	489.3	31.4	157.2	5.5
Open burning	7.71	24.12	0.29	1.72	12.35
Bldg. Con.	93.9				
Area Source	**128.61**	**594.02**	**34.7**	**165.02**	**83.68**
Paved RD	66.49				
Unpaved RD	100.09				
Vehicles	**32.60**	**323.29**	**2.98**	**148.61**	**293.54**
Industries	**2.3**	**5.4**	**367.4**	**50.4**	**0.8**
Total Emission	**330.09**	**922.72**	**405.08**	**364.02**	**377.98**

* All values expressed in kg/d

At Mulund site, area sources accounts for 89.4% of PM and major contributing sources are building construction and domestic, whereas remaining 9.9% is contributed from vehicle source and 0.7% is from industries.

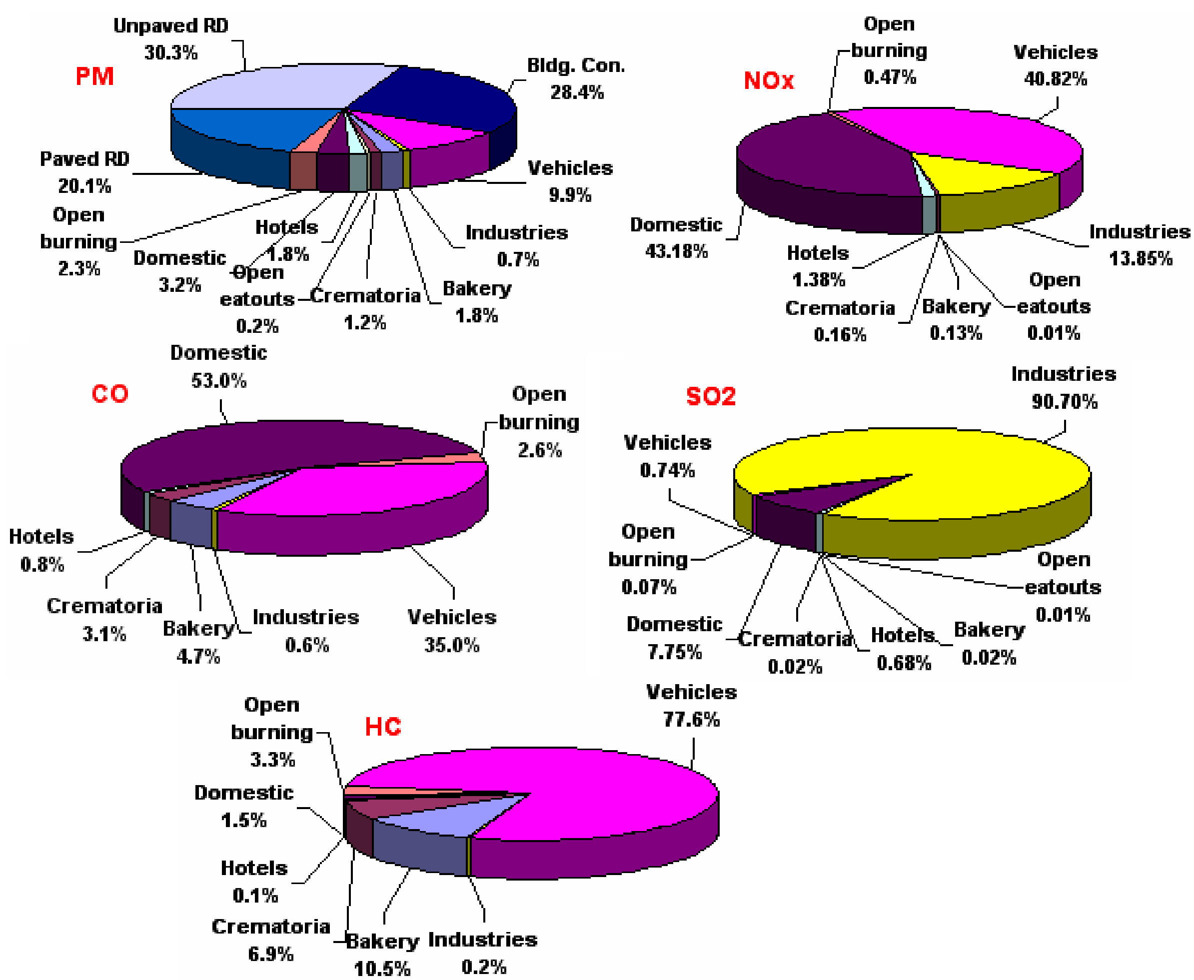

Figure 3.24: **Percentage Contribution of Different Source Categories to Various Pollutants at Mulund**

Contribution of pollutant from different categories of vehicles is given in **Figure 3.25.**

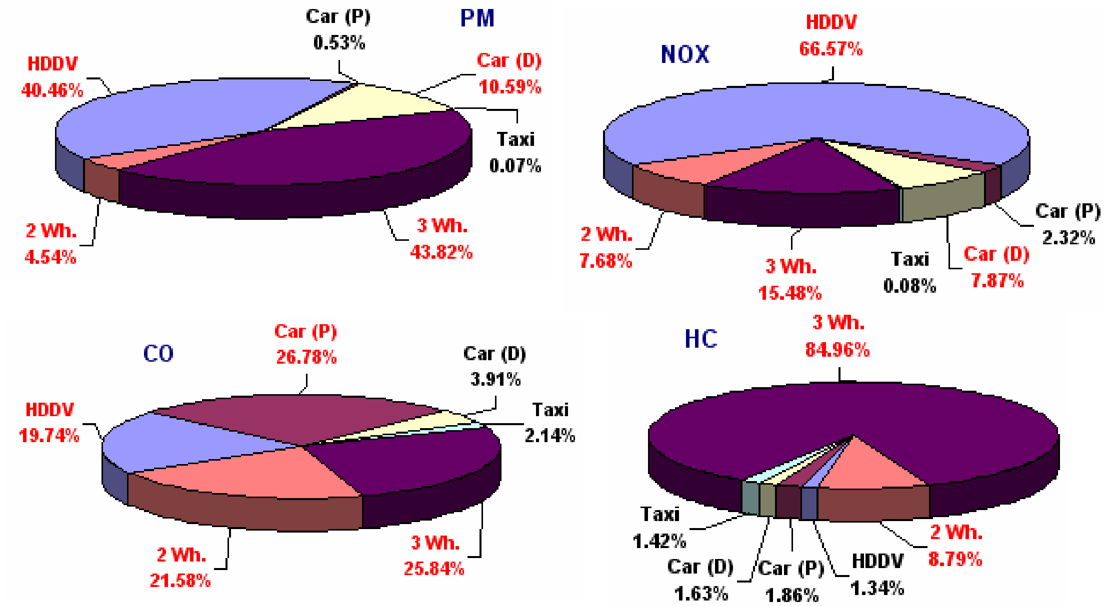

Figure 3.25: Contribution of different pollutants by different categories of Vehicle at Mulund Site

3.5.1 Whole city Total Emission Load

Emission loads from vehicles, area and industries for the city are presented in **Table 3.50** and percentage distributions for all sources and pollutants are presented in **Figure 3.26.**

Table 3.50: Emission Load for Mumbai City from All Sources

	PM	CO	SO_2	NOx	HC
A) Area Source					
Bakeries	1554.6	11348.1	25.2	120.1	10287.4
Crematoria	300.7	2213.0	7.9	44.4	1991.9
Open eat outs	281.6	167.8	16.2	9.4	0.1
Hotel restaurants	593.1	755.2	274.0	499.0	25.4
Domestic sector	564.9	19723.7	1262.0	9946.9	368.1
Open burning	734.0	2292.0	27.0	164.0	1173.0
Landfill Open Burning	2906.0	9082.0	108.0	649.0	4649.0
Construction Activity	2288.9				
Locomotive (Cen +We Rly)	514.0	3147.0	1449.0	19708.0	
Aircraft	75.6	788.4	77.0	985.5	32.3
Marine vessels	1.8	3.3	19.7	17.9	1.5
Total (A)	**9815.3**	**49520.5**	**3266.0**	**32144.2**	**18528.6**
B) Industrial Source					
Power plant	5628.3	3215.7	24473.3	28944.5	1266.6
39 Industries	503.7	879.7	28510.2	8435.2	116.8
Stone crushers	1394.3				
Total (B)	**7526.3**	**4095.4**	**52983.5**	**37379.7**	**1383.4**
C) Line Source					
2 wheelers	70.1	3303.2	2.7	540.5	1221.2
3 wheelers	225.9	1320.9		363.7	3943.5
Car diesel	313.8	1150.5	87.2	1063.3	435.8
Car petrol	15.7	7867.5	13.1	313.7	496.6
HDDV	916.7	4435.5	126.7	6875.0	273.5
Taxies	2.6	778.6		13.0	467.1
Paved Road dust	3163.0				
Unpaved Road dust	4761.4				
Total (C)	**9469.2**	**18856.2**	**229.7**	**9169.2**	**6837.7**
Total (A+B+C)	**26810.8**	**72472.1**	**56479.2**	**78693.1**	**26749.7**

* All values expressed in T/yr., -- Vehicle Fuel used CNG/LPG

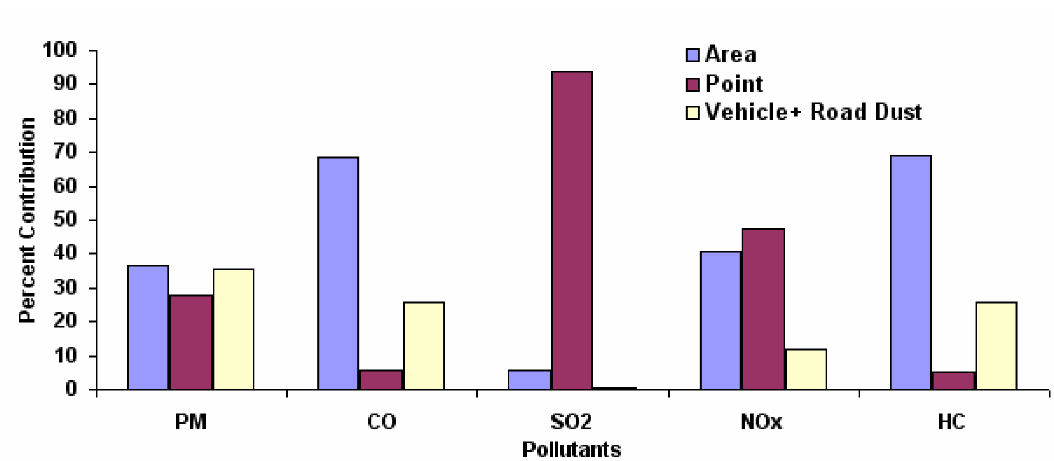

Figure 3.26 : Percent emission load from all sources in Mumbai City

In Mumbai city, PM is mainly contributed from area sources (36.7%) like bakeries, hotels, construction activities etc. Area sources also contribute to 69.3% and 68.3% of HC and CO concentration in the city. Industries (point source) contribute to 93.8% of SO_2 followed by 47.5% contribution to total NOx and 28.1% of particulate matter. PM contribution is also high from vehicular and road dust category (35.3%).Grid wise emission load from area, industries and vehicular sector has been presented in **Annexure 3.3**.

3.6 Grid wise emission Load of Mumbai

The grid wise emission load of PM and NOx for Mumbai during 2007, 2012 and 2017 is delineated in **Figures 3.27 through 3.32**. In 2007, PM load is highest at Mahul area followed by Girgaon, Dadar, Dharavi, Khar-Santacruz and Andheri. The NOx load is mainly coming from industrial area and it is also high along the Eastern and Western Express highway.

The projections of emission load for 2012 and 2017 have been computed based on population growth. The emission load distribution over the whole of Mumbai has been assumed to remain proportionately high in 2012 and 2017. In 2012, PM load is high around industrial area around Mahul, followed by Girgaon, Dadar, Dharavi, Khar-Santacruz and Andheri, whereas in 2017 it is high along the western part of Mumbai. In case of NOx in 2012, the concentrations are high at industrial site and along the eastern and western corridor of Mumbai, which increases further in 2017.

The emission loads of 2012 and 2017 have been used to carry out dispersion modeling in **Chapter 6**.

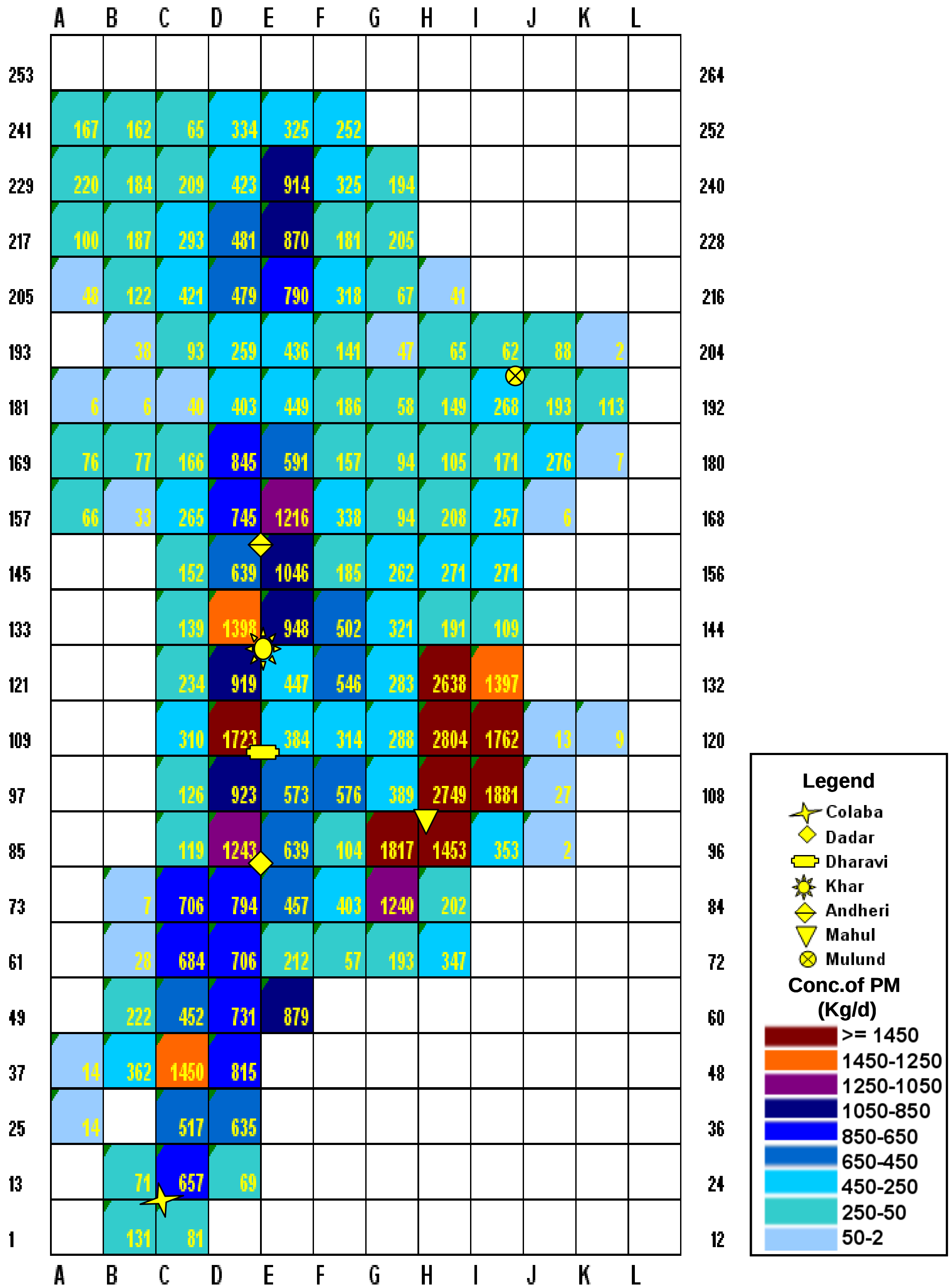

Figure 3.27: Grid Wise PM Emission Load for 2007, Mumbai

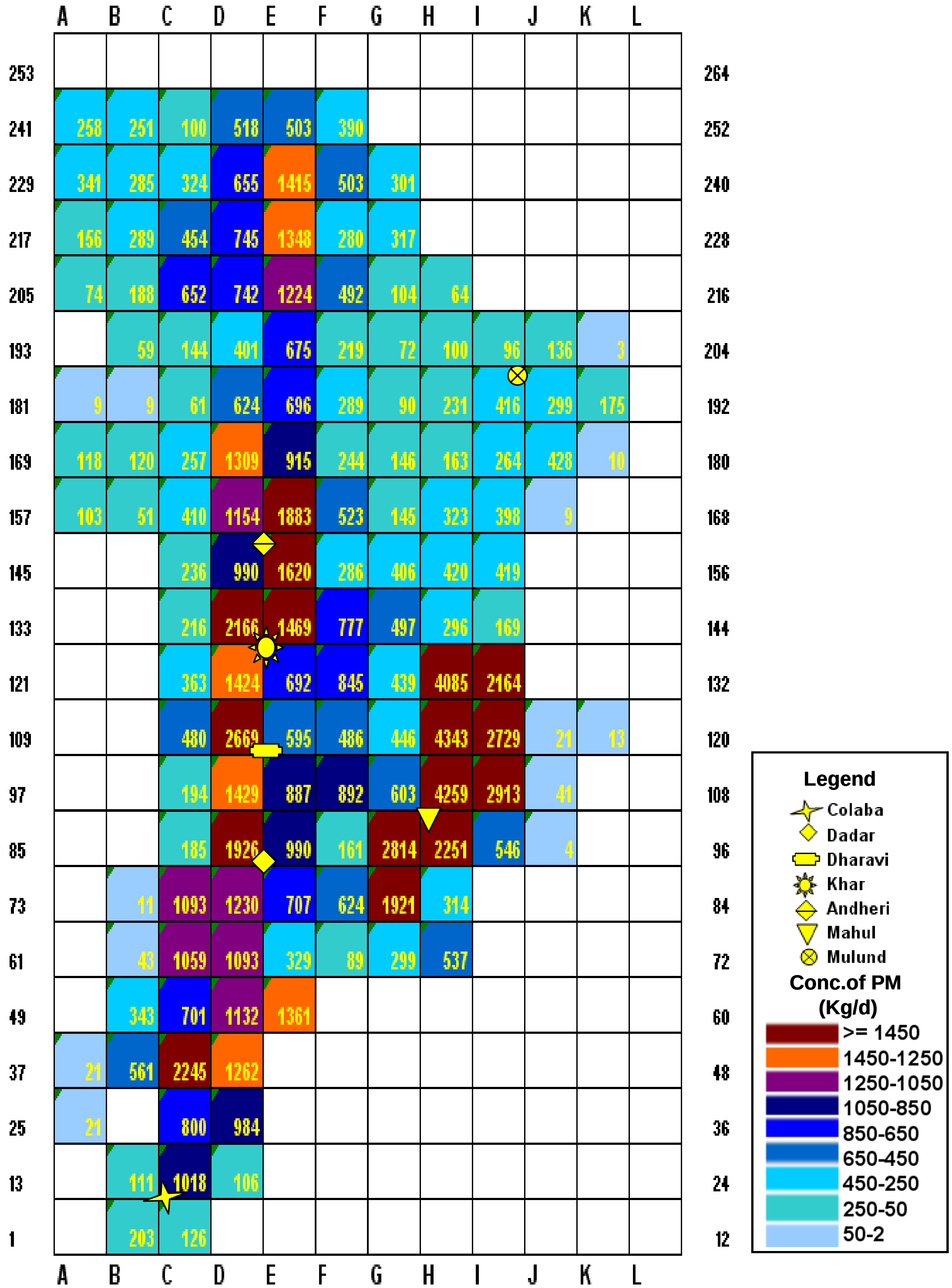

Figure 3.28: Grid Wise PM Emission Load for 2012, Mumbai

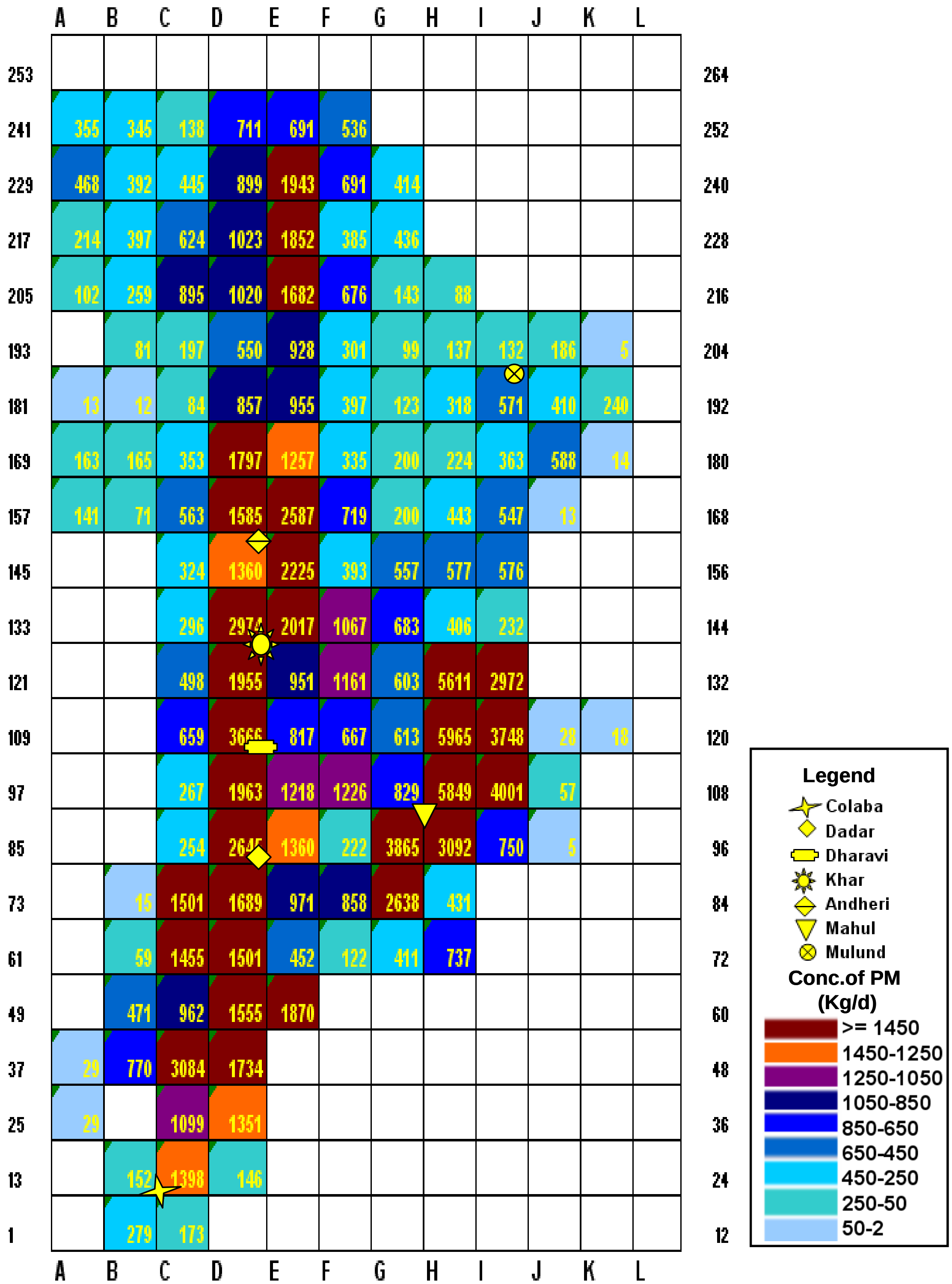

Figure 3.29: Grid Wise PM Emission Load for 2017, Mumbai

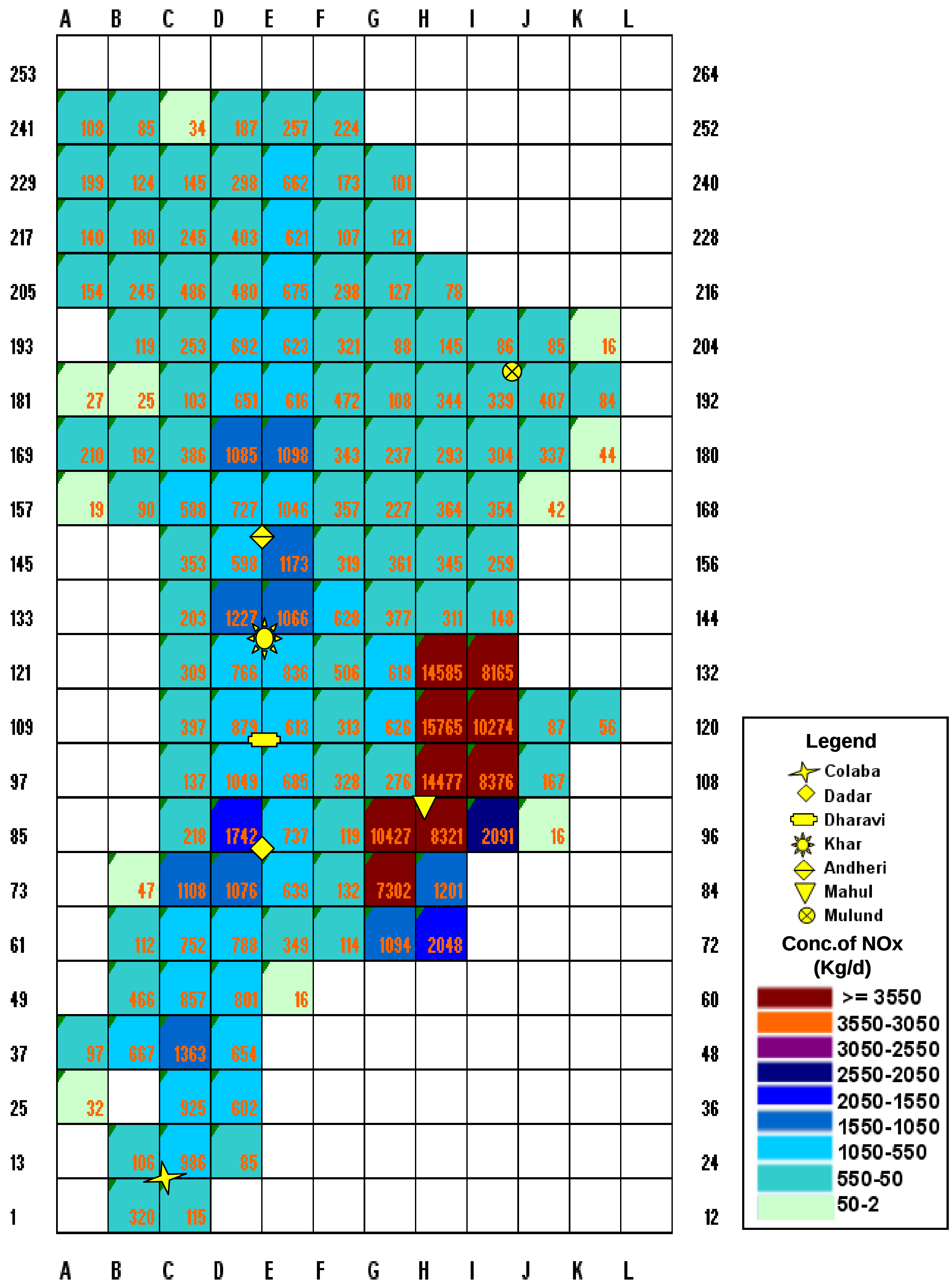

Figure 3.30: Grid Wise NOx Emission Load for 2007, Mumbai

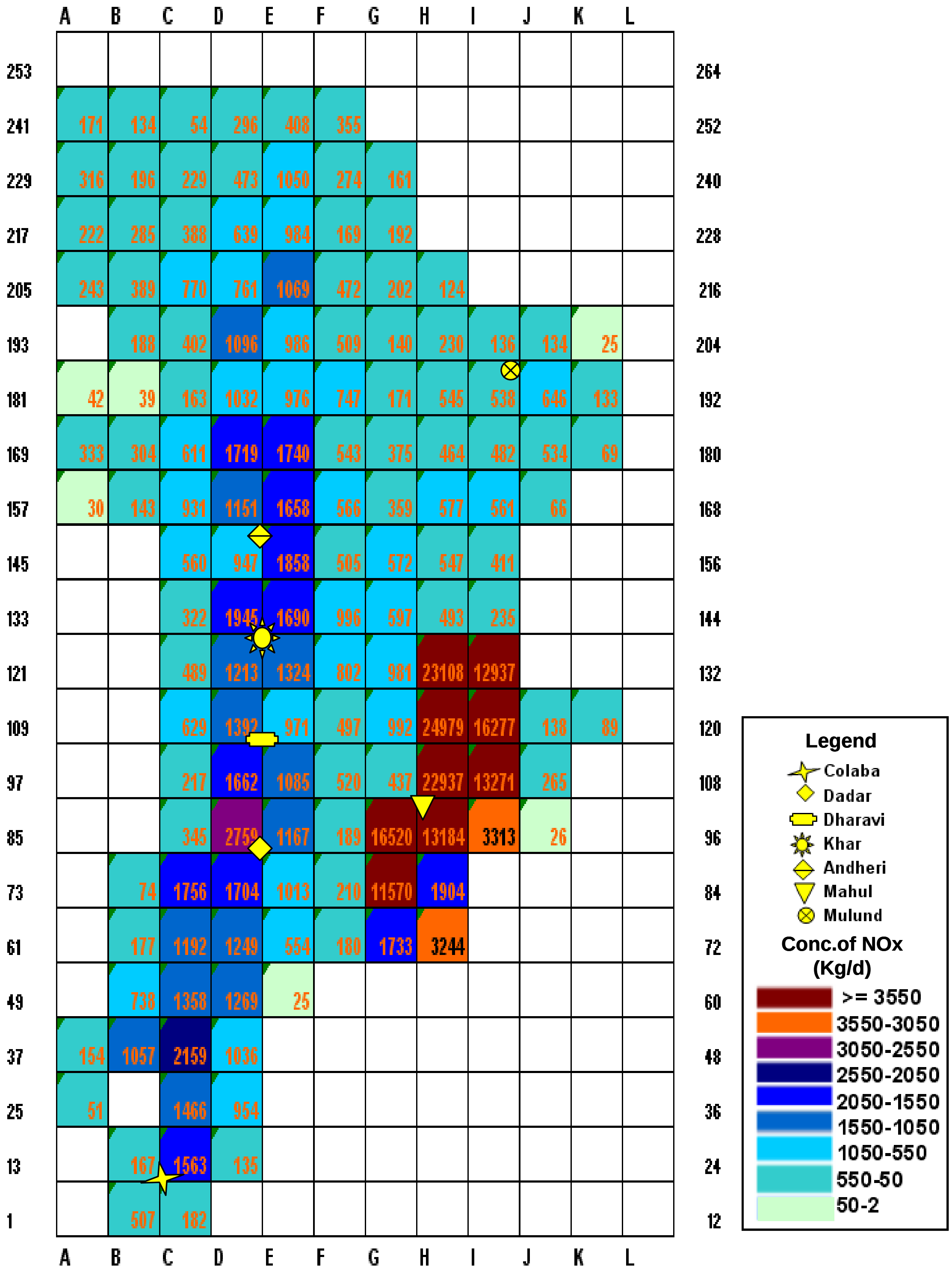

Figure 3.31: Grid Wise NOx Emission Load for 2012, Mumbai

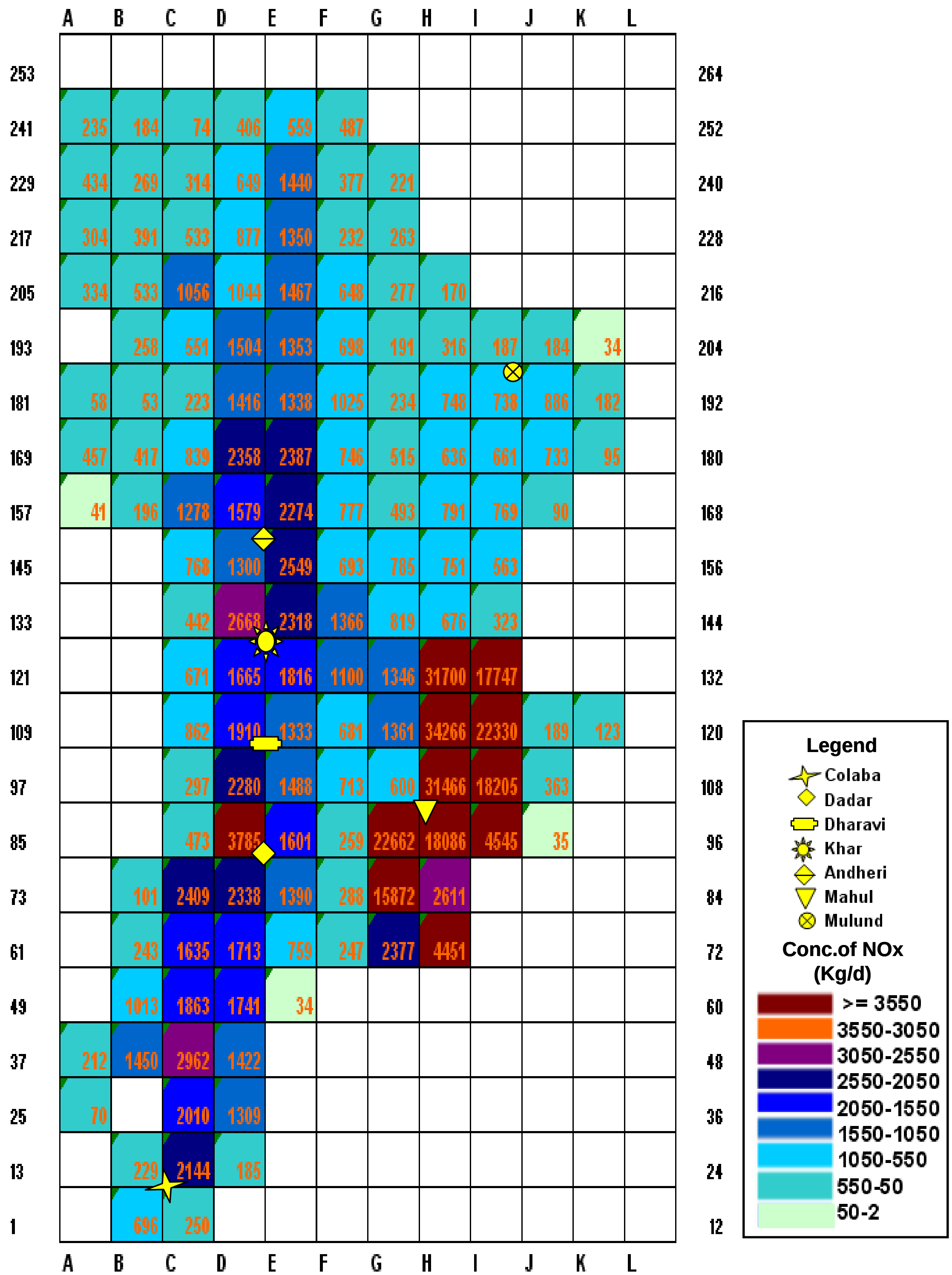

Figure 3.32: Grid Wise NOx Emission Load for 2017, Mumbai

Chapter 4

Receptor Modelling and Source Apportionment

4.0 Introduction

Receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor. Receptor models are based on the same scientific principles as source dispersion models, but they are inferential rather than predictive of source contributions. Common types of receptor models include CMB (Chemical Mass Balance), factor analysis. Other forms are principal component analysis, empirical orthogonal functions, multiple linear regression, enrichment factors, neural networks, cluster analysis, Fourier Transform time series, and a number of other multivariate methods. Descriptions of these models and some of their variations are given in *Henry et. al., (1984)* and *Hopke (1985)*. Chemical mass balance is the fundamental receptor model, which includes with all other approaches including Principal Components Analysis (PCA) and Multiple Linear Regression (MLR) based on the use of the mass balance concept.

4.1 Receptor Models

Several models described above can be used as either source-oriented or receptor-oriented models. An ammonium nitrate chemical equilibrium model, for example, can be used as a source model within the context of an air quality model. It can also be used as a receptor model when ammonia, nitric acid, ammonium nitrate, temperature, and relative humidity measurements are available at a receptor. In this study, factor analysis has been carried out prior to CMB modeling with a view to understand a priori major components.

4.2 Factor Analysis Methodology and Results

The Factor Analysis (FA) model applied in the field of air pollution is expressed as

$$C_{it} = \sum_{j=1}^{n} L_{ij} \times S_{jt} + E_{it}$$

where C_{it} is the normalized value of concentration of i^{th} species for t^{th} sample, n is the number of sources, S_{jt} is the factor score of the j^{th} common factor (j^{th} source) for t^{th} sample. L_{ij} is the factor loading of the i^{th} species of the j^{th} source and E_{it} is the residual of i^{th} species in the t^{th} sample not

*

accounted by the N sources or factors. The two vectors L and E are unknown in Factor Analysis and are obtained by assuming various covariance relationships between the vectors S and E. (Johnson and Wichern, 2002) and finally solving the covariance or correlation matrix as an eigenvalue –eigenvector decomposition problem. A principal component analysis of particulate elemental data recorded in Boston allowed *Thurston and Spengler (1985)* the estimation of mass contribution for five fine particulate sources (rail, motor vehicles, coal, oil and marine salt). Kumar et al (2001) applied Varimax rotated Factor Analysis (FA) for quantitative apportionment of the sources contributing to the suspended particulate matter (SPM) at two traffic junctions at Mumbai. Computer software like SPSS, SAS are available in the market and have made factor analysis more accurate and easy to use. The eigen vectors or components are typically more easily interpretable if a VARIMAX rotation, which transforms the eigen vectors to make each of them representative of individual sources of variation, is applied. .

Henry et. al (1984) suggested that the maximum number of samples (n) for Factor Analysis should be such that $n > 30 + (V+3)/2$ where V represents the number of variables. Results of varimax rotated factor analysis carried out on various ambient air components using SPSS software (SPSS, 11.5) at seven sites in Mumbai and the corresponding possible sources are presented below.

4.2.1 Colaba

The varimax rotated factor matrix for Colaba is given in **Table 4.1**. Kaiser- Meyer- Olkin (KMO) measure of sampling adequacy is 0.801 indicating factor analysis is acceptable. The total percentage of variance explained by five factors was 75.4% at Colaba. Factor 1 explains 43.7 % variance and is highly loaded with Al, Ca, Fe, and Mg; thus it can be interpreted as soil dust. Factor 2 explains 13.2 % of the variance and contains high loadings Cd, Pb and Zn. These elements are used as markers for smelting operations. Factor 3 shows high loading of SO_4^{2-} with percentage variance of 8.2 %. Soil is another possible source for SO_4^{2-}. However, as the sampling station was located near to the seashore this factor can be interpreted as secondary aerosols. Factor 4 explains 5.8 % of the total variance and was highly loaded with EC, OC and NOx, which are indicative pollutants of the vehicular emissions. Factor 5 shows high loading of Na, Cl and Ba with 4.5 % of the variance. It also has high loadings of K and hence this factor represents contributions from sea spray and biomass burning.

Table 4.1 Rotated Component Matrix at Colaba

	1	2	3	4	5
SO_2	0.1342	0.0981	0.4494	**0.5647**	0.2270
NOx	0.0385	0.0233	**0.5720**	**0.4648**	0.1841
NH_3	0.0146	-0.1207	0.2230	0.2323	0.0749
OC	0.2882	0.3989	0.1385	**0.7608**	-0.1569
EC	0.0288	0.2288	0.2024	**0.8514**	-0.0201
TC	0.2280	0.3727	0.1672	0.8363	-0.1263
CL	0.2226	0.0760	0.4225	0.0006	**0.6944**
SO_4	0.3182	0.1902	**0.7663**	0.2943	0.2153
NO_3	-0.2106	-0.3378	-0.7396	0.0117	0.1545
NA	0.1117	0.0503	-0.0949	-0.0364	**0.8947**
NH_4	-0.0976	0.0928	-0.0601	0.0071	0.0477
KS	0.0040	-0.0756	-0.1463	-0.0528	**0.8207**
CA	-0.2163	-0.1031	-0.7258	-0.3420	0.3848
AL	**0.9070**	0.2742	0.1941	0.1753	0.0263
BA	0.5074	0.0733	0.1175	0.1472	**0.5592**
CA	**0.8686**	0.3045	0.0715	0.1698	0.1738
CD	0.1430	**0.8187**	-0.0165	0.1766	0.0726
CR	0.2958	0.0577	0.0923	0.1874	0.0244
CU	0.4836	**0.6173**	0.3527	0.3657	0.0673
FE	**0.9184**	0.2719	0.1225	0.1152	0.0666
IN	0.3593	**0.6077**	0.3290	0.3999	0.1977
K	**0.7291**	0.3123	0.3972	0.3316	0.1414
MG	**0.9735**	-0.0333	-0.0333	-0.0129	0.0781
MN	**0.9135**	0.2665	0.1930	0.1651	0.0278
NI	0.0786	-0.1997	**-0.8726**	-0.1940	0.0158
P	0.2800	**0.6402**	0.2678	0.0710	-0.1281
PB	0.1088	**0.7380**	0.2759	0.3820	-0.0759
SI	0.4746	0.4699	0.2740	0.0528	-0.1303
SR	**0.9809**	-0.0066	-0.0226	0.0065	0.1047
TI	0.5990	0.5465	0.3724	0.3073	0.0467
ZN	0.3300	0.6580	0.3026	0.4280	0.1139

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 10 iterations.

4.2.2. Dadar

The varimax rotated factor matrix for Dadar is given in **Table 4.2**. KMO measure of sampling adequacy is 0.816 indicates that the factor analysis is acceptable. The total variance explained by the four factors is 76%. Factor 1 explains 48.3 % variance and shows high loadings of Fe, Al, Si, Ca, Mg and Ti indicating the crustal contribution. Dadar being the kerbsite, it can be interpreted as road dust. This factor also has high loadings of Cr and In which indicate contribution from the smelting operation. Factor 2 is characterized by high NOx, OC, Cu, SO_4, and NH_4. It could be represented by auto exhaust emissions and secondary aerosol formation. This factor also includes K and Cl suggesting that part of this factor may be attributed to refuse or biomass burning. Factor 3 explains 8.5 % variance and mainly shows loadings of Na and Ca, which indicate contribution

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from the sea spray. Factor 4 explains 5.5 % of the total variance and has high loadings of Cd indicating the contribution of automobile exhaust.

From the overall factor characterization for Dadar, it can be concluded that the sources are of mixed type suggesting that the vehicular movement is responsible for the resuspension of the road dust and secondary aerosol formation.

Table 4. 2: Rotated Component matrix of Dadar

	1	**2**	**3**	**4**
SO_2	0.1900	**0.7226**	-0.0177	0.2319
NOx	0.1855	**0.7356**	0.3007	-0.0414
NH_3	0.0836	**0.5306**	-0.1981	-0.0545
OC	0.2471	**0.8134**	0.3107	0.1226
EC	0.2610	**0.6941**	0.1731	0.1413
TC	0.2632	**0.8284**	0.2950	0.1329
CL	0.1819	0.4419	0.4764	-0.0992
SO_4	0.4217	**0.7602**	0.2100	0.0422
NO_3	-0.0704	-0.0824	**0.6512**	-0.1396
NA	0.0321	0.1560	**0.8725**	0.0050
NH_4	0.3465	**0.7020**	0.3926	-0.0571
K	0.2508	**0.6156**	0.6640	-0.0206
CA	0.0766	0.3137	**0.8005**	0.0800
AL	**0.9362**	0.3077	0.0245	0.0747
CD	0.0882	0.0155	-0.0757	**0.9597**
CR	**0.8783**	0.0562	-0.0440	-0.0228
CU	0.5753	**0.6918**	0.0094	0.1364
FE	**0.9339**	0.2094	0.0889	0.0602
IN	**0.8140**	0.2824	0.0462	-0.0091
MG	**0.8254**	0.0978	0.1580	0.0417
MN	**0.9359**	0.3079	0.0269	0.0686
PB	0.1361	0.1340	-0.0673	**0.9503**
SB	**0.6045**	0.4536	-0.2039	0.3116
SI	**0.6896**	0.2974	0.1105	0.3248
SR	**0.8464**	0.2423	0.0989	0.1399
TI	**0.6265**	**0.5566**	0.0498	0.4718
ZN	**0.8325**	0.3239	0.0749	0.0210

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

4.2.3 Dharavi

The varimax rotated factor matrix for Dharavi is given in **Table 4.3**. KMO measure of sampling adequacy is 0.880 indicating that the factor analysis is acceptable. Factor 1 explains 55 % variance and has high loadings of Al, Fe, Mg and Ti indicating the contribution of soil. It also has high loading of Cr, In indicating smelting operation carried out at the sampling site. Factor 2 has a high factor loading of K, Cl, Na and Ca indicating the contributory sources like biomass burning and

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sea spray. It has 12.2 % of the variance. Factor 3 explains 6.5 % variance and has high loading of SO_2 and Se indicating coal combustion. It also has high loadings of Cd, which is an indicator of oil burning activity. Both the above-mentioned activities give rise to secondary aerosols, which are indicated by high loadings of SO_4 and NO_3. Factor 4 explains 5.2 % variance and has high loadings of OC, EC and NOx and thus can be interpreted as vehicular contribution.

Table 4.3: Rotated Component Matrix of Dharavi

	1	2	3	4
SO_2	0.3065	0.0395	**0.6900**	0.0750
NOx	0.0530	**0.4558**	0.4020	**0.5837**
NH_3	-0.0504	0.0240	-0.0539	**0.6721**
OC	0.3897	0.1852	0.3652	**0.7057**
EC	0.3121	0.2268	-0.1887	**0.6618**
TC	0.4066	0.2061	0.2799	**0.7562**
CL	0.1788	**0.9050**	0.0552	0.2316
SO_4	0.4989	0.4329	0.4738	0.1172
NO_3	-0.4351	-0.2419	**-0.6579**	0.0327
NA	0.1614	**0.9136**	-0.0304	0.2008
NH_4	0.2286	0.6358	-0.0873	-0.1787
KS	0.2008	**0.7963**	0.0634	0.2617
CA	0.1710	**0.7319**	0.3399	0.2233
AL	**0.9150**	0.1973	0.2775	0.1274
BA	**0.8814**	0.1979	0.3006	0.0981
CD	**0.6722**	0.2700	**0.5638**	0.1400
CR	**0.7948**	-0.1562	0.1630	0.2611
CU	**0.7728**	0.4301	0.2697	0.1398
FE	**0.8810**	0.3148	0.2650	0.1357
IN	**0.9296**	0.0431	0.1769	0.1458
MG	**0.8206**	0.2546	0.2298	-0.0092
MN	**0.9136**	0.1911	0.2879	0.1187
NI	**0.7965**	0.1282	0.2963	0.2498
PB	**0.7071**	0.0487	**0.5745**	-0.0118
SE	0.3172	-0.3564	**0.5978**	0.1001
SI	**0.7674**	0.2460	-0.1382	0.1677
SR	**0.8661**	0.2691	0.2750	0.0291
TI	**0.9144**	0.2058	0.2003	0.1933
ZN	**0.9202**	0.1161	0.2034	0.1265

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

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4.2.4 Khar

The varimax rotated factor matrix for Khar is given in **Table 4.4**. KMO measure of sampling adequacy is 0.895 indicating that the factor analysis is acceptable. The total variance explained by the three factors is 74.9%. Factor 1 explains 60.4 % variance with high loadings of OC, EC and NOx as also of Al, Fe, Mg, Mn, Si and Ti. This could be interpreted as contribution from soil and road dust as also fuel combustion. Factor 2 explains 10 % of the variance and contains high loadings of Cu, Ni, Cd and Zn indicates smelting activity. Khar is residential area; smelting activity is not in close vicinity. Such occurrence may be due to transport from nearby regions. High loadings of K are probably due to biomass burning. Factor 3 explains 4.5 % variance with high loadings of Na, Cl can be interpreted as sea spray.

Table 4. 4: Rotated Component Matrix of Khar

	1	**2**	**3**
SO_2	0.3702	0.5243	-0.2079
NOx	**0.5013**	**0.6494**	-0.0912
NH_3	-0.1550	0.4440	-0.0658
OC	**0.5383**	**0.6685**	0.0813
EC	0.4317	**0.6982**	0.1531
TC	**0.5364**	**0.7007**	0.0998
CLS	0.0557	0.0575	**0.7471**
SO_4S	**0.5210**	**0.7114**	0.1684
NO_3S	-0.1723	-0.1341	**0.5884**
NAS	-0.0438	0.3442	**0.7680**
KS	0.3278	**0.7448**	0.4705
CAS	0.4105	**0.8075**	0.1906
AL	**0.8830**	0.3989	-0.1634
BA	**0.5403**	**0.5883**	-0.0652
CD	**0.6775**	0.4083	0.1644
CR	**0.8817**	0.0596	-0.2850
CU	**0.7597**	**0.5138**	0.0858
FE	**0.8521**	0.4820	-0.0637
IN	**0.7660**	**0.5151**	0.0934
MG	**0.8534**	0.4695	-0.0340
MN	**0.8899**	0.3885	-0.1661
NI	**0.8548**	0.1391	-0.1130
PB	0.5119	**0.6064**	0.2149
SI	**0.6758**	-0.0466	0.2077
SR	**0.8088**	0.5185	-0.0361
TI	**0.8643**	0.4698	-0.0350
ZN	**0.7763**	**0.5163**	0.0784

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.

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4.2.5 Andheri

The varimax rotated factor matrix for Andheri is given in **Table 4.5**. KMO measure of sampling adequacy is 0.803 indicating that the factor analysis is acceptable. The total variance explained by 6 factors is 83%. Factor 1 explains 53.1 % variance and has high loadings of Al, Fe, Ti and Si indicating contribution from soil; whereas high loadings of Cu, Fe, Zn and Si can be interpreted as contribution from road dust. High loadings of SO_4 are due to formation of secondary aerosols. Factor 2 has high loadings of OC, EC and NOx with variance of 11.8 %. It can be interpreted as contribution from vehicular and other combustion sources. Factor 3 comprises of high loadings of Na and Cl and the contributing factor can be considered to be the marine aerosol. This factor explains 5.6 % variance. Factor 4 explains 4.9 % variance with high loadings of Se can be interpreted as coal burning contribution. Factor 5 explains 3.8 % variance and has high loadings of K, which is due to biomass burning. Factor 6 with high loadings of Cr explains 3.6 % variance and can be interpreted as contribution from oil burning.

Table 4.5 Rotated Component Matrix of Andheri

	1	2	3	4	5	6
SO_2	0.0663	0.1973	-0.1102	-0.1140	**0.8661**	-0.1019
NOx	**0.5411**	**0.5752**	0.0804	0.3487	0.3674	0.0315
NH_3	-0.1360	-0.0500	0.0685	**-0.7555**	0.1262	0.0447
OC	0.4511	**0.8241**	0.0558	0.0871	0.1098	-0.0255
EC	0.3216	**0.7179**	-0.2584	0.0711	0.0330	0.0870
TC	0.4549	**0.8583**	-0.0135	0.0897	0.0996	-0.0008
CL	0.1721	0.2104	**0.8429**	0.0150	-0.0609	-0.0797
SO_4	**0.6182**	0.4407	-0.0613	0.3898	0.2528	0.0054
NA	0.2590	-0.2200	**0.8466**	0.0661	0.0693	0.0624
K	0.2400	-0.0373	0.3093	0.1240	**0.5606**	**0.5490**
CA	**0.5229**	0.1365	0.4229	0.3244	0.1651	0.3565
AL	**0.9028**	0.3413	-0.0416	0.1590	0.0516	0.1145
BA	**0.5191**	0.2175	-0.3221	0.1868	0.1435	-0.0496
CD	**0.7476**	0.3545	0.0454	0.3073	0.1729	0.2032
CR	-0.0849	0.0453	-0.0663	-0.0798	-0.1049	**0.9336**
CU	**0.8892**	0.2811	0.1983	0.0727	0.0985	0.0308
FE	**0.9073**	0.2809	0.1449	0.1117	0.0992	0.0056
MG	**0.8748**	0.2445	0.1554	0.2144	0.0532	-0.0803
MN	**0.9012**	0.3383	-0.0661	0.1579	0.0465	0.1207
NI	**-0.6540**	-0.4218	-0.1036	-0.4426	-0.2885	0.1880
PB	**0.6898**	0.1484	-0.1680	0.3231	0.0863	0.0190
SE	-0.3925	-0.4596	-0.2566	**-0.5625**	-0.1271	-0.0857
SI	**0.8849**	0.0231	0.3040	-0.0968	-0.0392	0.0303
SR	**0.8776**	0.2599	0.1956	0.1723	0.0563	-0.0737
TI	**0.9135**	0.3185	-0.0393	0.1449	0.0869	-0.0271
V	0.4827	0.3150	-0.6334	0.2893	0.0821	-0.0371
ZN	0.8405	0.2611	0.1311	0.0585	0.0728	-0.0334

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations.

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4.2.6 Mahul

The varimax rotated factor matrix for Mahul is given in **Table 4.6**. KMO measure of sampling adequacy is 0.895 indicating that the factor analysis is acceptable. Factor 1 explains 60.9 % variance and has high loadings of Al, Fe, Mg and Ti. It can be interpreted as contribution from soil. High loadings of V and Ni could be due to petrochemical industries in Mahul area. High loadings of Mg, Mn, Cu, NOx, EC, OC, Pb could be due to heavy-duty vehicles in that area; while high loadings of Ni and V can be interpreted as contribution from oil burning. It also has high loadings of Se, Cr and K, which can be interpreted as contribution from coal burning; Factor 2 explains 8.1 % variance to high loadings of SO_4 and NH_4, which can be interpreted as contribution from secondary aerosols. Factor 3 with high loadings of Na can be interpreted as sea salt contribution with variance of 6.1%; whereas high loadings of NH_4 could be due to fertilizer industry in Mahul area.

Table 4.6: Rotated Component Matrix of Mahul

	1	2	3
SO_2	**0.6339**	0.1602	-0.1037
NOx	**0.8469**	0.2649	0.0137
NH_3	-0.0494	-0.1299	0.4367
OC	**0.8135**	0.2903	-0.0977
EC	**0.7166**	0.2017	0.1663
TC	**0.8301**	0.2844	-0.0387
CLS	0.0722	-0.8015	0.2573
SO_4S	0.5231	**0.6131**	-0.1357
NO_3S	-0.6585	-0.3694	0.1192
NAS	-0.0230	-0.2292	**0.8322**
NH_4S	0.6288	0.3625	**0.5364**
KS	0.3623	0.7071	0.0482
CAS	0.4394	**0.5954**	0.4559
AL	**0.9359**	0.2135	-0.1143
BA	0.3318	0.3110	-0.1071
CD	0.1852	-0.1276	-0.5128
CR	**0.7245**	0.1724	-0.0499
CU	**0.9403**	0.2094	0.0012
FE	**0.9377**	0.1633	-0.0687
IN	**0.9269**	0.0982	0.0446
MG	**0.9226**	0.1275	-0.0728
MN	**0.9385**	0.2196	-0.1069
NI	**0.8277**	0.0154	-0.3414
P	**0.6115**	0.1856	0.0907
PB	**0.7553**	0.0339	-0.4302
SE	**0.7626**	0.3290	0.1977
SI	**0.7653**	0.0496	-0.3372
SR	**0.7774**	0.2913	-0.0364
TI	**0.9345**	0.2031	-0.1878
V	**0.8118**	0.2125	-0.3962
ZN	**0.9410**	0.1071	0.0699

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations.

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4.2.7 Mulund

The varimax rotated factor matrix for Mulund is given in **Table 4.7**. KMO measure of sampling adequacy is 0.828 indicating that the factor analysis is acceptable. The total variance explained by the four factors is 69.4%. Factor 1 explains 45.6 % variance with high loadings of Al, Fe, and Ti indicating the contribution from soil; whereas industries in Mulund may be responsible for high loadings of Cr, In, Mn, Zn etc. Factor 2 explains 10.6% variance with high loadings of K, which may be due to biomass burning. Factor 3 with variance of 6.9% has high loadings of OC, EC and NO_x indicating contribution from vehicular exhaust at Mulund, which represents kerbsite. Factor 4 explains 6.2% variance with high loadings of NH_4 and NO_3 indicating the contribution due to secondary aerosols. High loadings of V are due to oil burning activity of industries in the vicinity of the site.

Table 4.7: Rotated Component Matrix of Mulund

	1	2	3	4
SO_2	0.5013	-0.0832	0.4814	-0.1541
NOx	0.0292	0.2684	**0.7315**	-0.1449
NH_3	-0.2479	0.0678	0.1253	-0.1140
OC	0.3525	0.2000	0.8173	-0.0864
EC	0.2674	-0.2816	**0.7003**	0.0480
TC	0.3685	0.0978	**0.8714**	-0.0621
CL	-0.2287	0.0169	-0.1798	**0.6435**
SO_4	**0.6643**	0.2729	0.3446	0.1794
NO_3	-0.4971	-0.0933	-0.1378	**0.5651**
NA	0.1509	0.8412	0.0340	0.2034
NH_4	-0.3879	-0.3550	-0.2063	**0.6821**
KS	-0.0961	**0.5023**	0.0827	**0.6322**
CA	0.0212	**0.8998**	0.0625	0.0631
AL	**0.8899**	0.0878	0.2425	-0.2432
BA	0.3735	0.0266	0.0884	-0.1165
CD	**0.7012**	0.2326	0.1229	-0.0218
CR	**0.8217**	-0.2146	0.1192	-0.0409
CU	**0.8459**	0.1470	0.2856	-0.0438
FE	**0.8470**	0.2970	0.2070	-0.2493
IN	**0.8541**	0.2210	0.1714	-0.1057
MG	**0.6757**	0.5115	0.1122	-0.3139
MN	**0.8914**	0.0737	0.2371	-0.2381
NI	**0.5874**	0.4388	0.1385	-0.0352
PB	**0.6727**	0.0455	0.1810	-0.0077
SI	**0.7769**	0.1028	0.3432	-0.1337
SR	**0.5249**	**0.6529**	0.0976	-0.3298
TI	**0.9143**	0.0417	0.1961	-0.1953
V	0.2973	0.3510	0.1025	**0.6690**
ZN	**0.8516**	0.2365	0.1872	-0.1070

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations.

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4.3 Chemical Mass Balance

The Chemical Mass Balance (CMB) air quality model is one of several receptor models that have been applied to air resources management. The CMB receptor model *(Friedlander, 1973; Cooper and Watson, 1980; Gordon, 1980, 1988; Watson, 1984; Watson et al., 1984; 1990; 1991; Hidy and Venkataraman, 1996)* consists of a solution to linear equations that express each receptor chemical concentration as a linear sum of products of source profile abundances and source contributions. For each run of CMB, the model fits speciated data from a specified group of sources to corresponding data from a particular receptor (sample). The source profile abundances (i.e., the mass fraction of a chemical or other property in the emissions from each source type) and the receptor concentrations, with appropriate uncertainty estimates, serve as input data to CMB. The output consists of the amount contributed by each source type represented by a profile to the total mass, as well as to each chemical species. CMB calculates values for the contributions from each source and the uncertainties of those values. Several solution methods have been proposed for the CMB equations: 1) single unique species to represent each source (tracer solution) *(Miller et al., 1972)*; 2) linear programming solution *(Hougland, 1983)*; 3) ordinary weighted least squares, weighting only by uncertainty of ambient measurements *(Friedlander, 1973; Gartrell and Friedlander, 1975)*; 4) ridge regression weighted least squares *(Williamson and DuBose, 1983)*; 5) partial least squares *(Larson and Vong, 1989; Vong et al., 1988)*; 6) neural networks *(Song and Hopke, 1996)*; and 7) effective variance weighted least squares *(Watson et al., 1984)*. The effective variance weighted solution is generally applied because it:

1. theoretically yields the most likely solutions to the CMB equations, providing model assumptions are met
2. uses all available chemical measurements, not just so-called “tracer” species
3. analytically estimates the uncertainty of the source contributions based on uncertainty of both the ambient concentrations and source profiles gives greater influence to chemical species with lower uncertainty in both the source and receptor measurements than to species with higher uncertainty. The effective variance is a simplification of a more exact, but less practical, generalized least squares solution proposed by *Britt and Luecke (1973)*.

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4.3.1 CMB Mathematics

The source contribution (S_j) present at a receptor during a sampling period of length T due to a source j with constant emission rate E_j is

$$S_j = D_j \cdot E_j \qquad \ldots \ldots (1)$$

where $$Dj = \int_0^T d[\, u(t),\ \sigma(t),\ xj]dt$$

is a dispersion factor depending on wind velocity (u), atmospheric stability (σ), and the location of source j with respect to the receptor (x_j). All parameters in Equation 2 vary with time, so the instantaneous dispersion factor, D_j, must be an integral over time period T (Watson, 1979).

Various forms for D_j have been proposed *(Pasquill, 1974; Seinfeld and Pandis, 1998; Benarie, 1976)*, some including provisions for chemical reactions, removal, and specialized topography. None are completely adequate to describe the complicated, random nature of dispersion in the atmosphere. The advantage of receptor models is that an exact knowledge of D_j is unnecessary.

If number of sources, J, exists and there is no interaction between their emissions to cause mass removal, the total mass measured at the receptor, C, will be a linear sum of the contributions from the individual sources.

$$C = \sum_{j=1}^{J} D_j \,.\, E_j = \sum_{j=1}^{J} S_j \qquad \ldots\ldots\ldots(2)$$

Similarly, the concentration of elemental component i, C_i will be

$$C_i = \sum F_{ij} \,.\, S_j \qquad i = 1,\ldots\ I \qquad \ldots\ldots(3)$$

where:

F_{ij} = the fraction of source contribution S_j composed of element i.

The number of chemical species (I) must be greater than or equal to the number of sources (J) for a unique solution to these equations.

An estimate of the uncertainty associated with the source contributions is an integral part of several of these solution methods. Weighted linear least squares solutions are preferable to the tracer and linear programming solutions as:

1. theoretically they yield the most likely solution to the CMB equations, providing model assumptions are met
2. they can make use of all available chemical measurements, not just the so-called tracer species

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3. they are capable of analytically estimating the uncertainty of the source contributions
4. there is, in practice, no such thing as a "tracer."

The effective variance solution developed and tested by *Watson et al. (1984)* delineates that a solution

1. provides realistic estimates of the uncertainties of the source contributions (owing to its incorporation of both source profile and receptor data uncertainties)
2. gives greater influence to chemical species with higher precisions in both the source and receptor measurements than to species with lower precisions.

The effective variance solution is derived by minimizing the weighted sums of the squares of the differences between the measured and calculated values of C_i and F_{ij} *(Britt and Luecke, 1973; Watson et al., 1984)*. The solution algorithm is an iterative procedure which calculates a new set of S_j based on the S_j estimated from the previous iteration. It is carried out by the following steps expressed in matrix notation. A superscript k is used to designate the value of a variable at the k^{th} iteration.

- Set initial estimate of the source contributions equal to zero.

$$S^{k=0}_j = 0 \qquad \text{……… (4)}$$

- Calculate the diagonal components of the effective variance matrix, V_e. All off-diagonal components of this matrix are equal to zero.

$$V^k_{eii} = \sigma^2_{Ci} + \sum (S^k j)^2 \cdot \sigma^2_{Fij} \qquad \text{………(5)}$$

- Calculate the k+1 value of S_j

$$S^{k+1} = (F^T(V^k_e)\text{-}1\ F)^{-1}\ F^T(V^k_e)^{-1}C \qquad \text{…….. (6)}$$

- Test the $(k+1)^{th}$ iteration of the S_j against the k^{th} iteration. If any one differs by more than 1%, then perform the next iteration. If all differ by less than 1%, then terminate the algorithm.

$$\text{If } \left| (S^{k+1}_j - S^k_j)/\ S^{k+1}_j \right| > 0.01, \text{ go to step 2}$$

$$\text{……… (7)}$$

$$\text{If } \left| (S^{k+1}_j - S^k_j)/\ S^{k+1}_j \right| \le 0.01, \text{ go to step 5}$$

- Assign the $(k+1)^{th}$ iteration to Sj and Sj. All other calculations are performed with these final values.

$$\sigma^2_{Sj} = [F^T (V^{k+1} e)^{-1} Fjj]^{-1} \qquad \text{……… (8)}$$

where: C= (C1...CI) T, a column vector with Ci as the i^{th} component
S= (S1...SJ) T, a column vector with Sj as the j^{th} component
F= an I x J matrix of Fij, the source composition matrix

*

σCi=one standard deviation precision of the Ci measurement
σFij=one standard deviation precision of the Fij measurement
Ve= diagonal matrix of effective variances

The effective variance solution algorithm is very general, and it reduces to most of the solutions cited above with the following modifications:

- When the σF^{ij} are set equal to zero, the solution reduces to the ordinary weighted least squares solution.
- When the σF^{ij} are set equal to the same constant value, the solution reduces to the unweighted least squares solution.
- When a column is added to the F_{ij} matrix with all values equal to 1, an intercept term is computed for the variable corresponding to this column.
- When the number of source profiles equals the number of species (I=J), and if the selected species are present only in a single, exclusive source profile, the solution reduces to the tracer solution.
- When the $(F^T(V_e^k)^{-1} F)$ is re-written as $(F^T(V_e^k)^{-1} F- \phi I)$ with "ϕ" equal to some non-zero number, known as the smoothing parameter, and "I" equal to the identity matrix, the solution becomes the ridge regression solution *(Williamson and DuBose, 1983)*.

Formulas for the performance measures are:

$$\text{Reduced chi square} = \chi^2 = 1/(I-J) \sum_{i=1}^{I} [(C_i - \sum_{j=1}^{J} F_{ij} S_j)^2 / V_{eii} \quad \text{.........} \quad (9)$$

$$\text{Percent Mass} = 100(\sum S_j)/C_i \quad \text{where } C_i \text{ denotes the total measured mass}$$

$$\text{R square} = 1 - [(I-J) \chi^2] / [\sum C_i^2 / V_{eii}] \quad \text{.........} \quad (10)$$

$$\text{Modified Pseudo-Inverse Matrix} = (F^T(V_e)^{-1}F)^{-1} F^T (V_e)^{-1/2} \quad \text{.. .....} \quad (11)$$

The Singular Value Decomposition of the weighted **F** matrix is given by (Henry, 1992)

$$V_e^{1/2} F = UDV^T \quad \text{.........} \quad (12)$$

where **U** and **V** are IxI and JxJ orthogonal matrices, respectively, and where **D** is a diagonal matrix with J nonzero and positive elements called the singular values of the decomposition. The columns of **V** are called the eigenvectors of the composition and their components are associated with the source types.

CMB model works with many assumptions. The output of CMB model, therefore, needs to be implemented in light of these assumptions presented in the Box below :

*

Assumptions of Chemical Mass Balance Model
• Compositions of source emissions are constant over the period of ambient and source sampling; • Chemical species do not react with each other (i.e. they add linearly); • All sources with a potential for contributing to the receptor have been identified and have had their emissions characterized; • The number of sources or source categories is less than or equal to the number of species; • The source profiles are linearly independent of each other; and • Measurement uncertainties are random, uncorrelated and normally distributed.

The degree to which these assumptions are met in application depends to a large extent on the particle and gas properties measured at source and receptor. CMB model results are evaluated by using several fit indices such as R^2 ($\geq$0.8), χ^2 ($\leq$ .0), percent mass accounted for (80–120%), T-statistics ($\geq$ 2.0), and the residuals and uncertainty ratios ($\geq$0.2 to 2.0).

4.3.2 Source Profiles

Source profiles for use in CMB model in the present study were developed by ARAI Pune for vehicular emissions and IIT Bombay for other sources. The emission sources considered in this study are given in **Table 4.8.**

Table 4.8 : Short listed of source Profiles for the seven sites

Source Profiles	Colaba	Dadar	Dharavi	Khar	Andheri	Mahul	Mulund
Paved & Unpaved Road (composite)	*	*	*	*	*	*	*
Soil dust	*	*	*	*	*	*	*
Aggregate dust	*	*	*	*	*	*	*
Kerosene & LPG Combustion	*	*	*	*	*	*	*
Coal combustion	*	*	*	*	*	*	*
Wood residue combustion	*	*	*	*	*	*	*
Petroleum refining (Combust. & Non Combust.) & Fertilizer Ind.						*	
Marine aerosol	*	*	*	*	*	*	*
Solid Waste & Biomass Burning	*	*	*	*	*	*	*
Fuel oil combustion	*	*	*	*	*	*	*
Composite of gasoline and diesel vehicles	*	*	*	*	*	*	*
Passenger car gasoline and diesel vehicles	*	*	*	*	*	*	*
3 Wheeler CNG			*	*	*	*	*
Secondary Aerosol	*	*	*	*	*	*	*

The source profiles representing the distribution of chemical abundances are given in **Annexure 4.1**. The scale used is logarithmic scale in reverse order.

*

4.4 Molecular Marker Analysis

Ambient air quality samples were subjected to molecular marker analysis. Representative samples were taken from different seasons and different sites for analysis at Desert Research Institute, DRI, USA using in-injection port thermal desorption gas chromatography /mass spectrometry technique. Methodology of the analysis and results are given in **Annexure 4.2**. Average concentrations of molecular marker for all seven sites are presented in **Figure 4.1.**

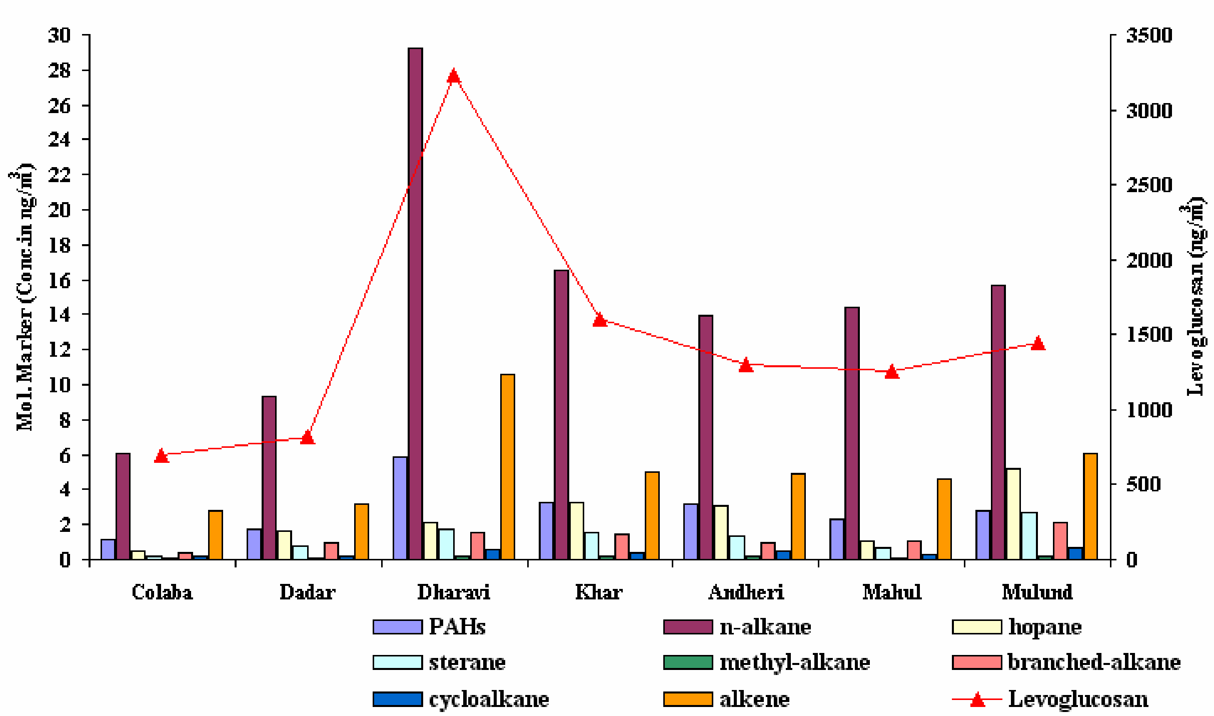

Figure 4.1: Concentrations of Molecular Markers at Seven Sites

Categories of molecular markers identified are PAH, n-alkane, hopane, sterane, methyl-alkane, branched –alkane, cycloalkane, alkene and levoglucosan. Highest concentration of PAH was observed at Dharavi (5.84 ng/m^3) which could be due to gasoline vehicles, coal burning and fuel oil consumption. Maximum n-alkane concentrations (29.19 ng/m^3) are also found at Dharavi due to gasoline and diesel vehicles, fuel oil combustion and refuse burning activities. Mulund and Andheri being kerb sites, show of Hopanes levels of 5.2 and 3.1 ng/m^3 respectively. This could be attributed to gasoline and diesel vehicles plying in these areas. Sterane concentrations are also high at Mulund. Branched-alkane concentrations are high at Mulund, Dharavi and Andheri (2.1, 1.5 and 1.0 ng/m^3 respectively) which could be attributed to refuse burning activities. Cycloalkane concentration is highest at Mulund (0.7 ng/m^3) followed by Dharavi (0.6 ng/m^3) due to vehicular

*

exhaust. Alkene concentrations are higher at Dharavi (10.5 ng/m^3) and Mulund (6.0 ng/m^3) due to internal combustion activities, foundry operations. At Mahul, due to petroleum refineries the concentration of alkene is 4.8 ng/m^3. Maximum concentrations of Levoglucosan are observed at Dharavi (3225.7 ng/m^3) followed by Khar and Mulund (1607.9 and 1445.3 ng/m^3 respectively) due to wood, biomass and mix refuse burning.

In Colaba, the concentration of all the molecular markers is comparatively much lower than all the other sites. For example, PAH concentration at Colaba is 5.1 times lower than its concentration at Dharavi; n alkane concentration is 4.8 times lower than that at Dharavi. Mulund being a kerbsite has hopanes and steranes concentration 12 and 11.5 times higher than that observed at Colaba. Due to combustion activities and foundry operations at Dharavi and Mulund, these sites have 3.7 and 2.1 times higher concentration of alkenes than Colaba. The concentration of Levoglucosan at Dharavi is 4.7 times higher than that observed at Colaba mainly because of greater extent of wood and biomass burning. These all the observations confirms with the fact that Colaba represents the background site in this study. Also, other sites show the enhanced markers prevalence based on local sources.

4.5 CMB Output

Selection of sources and their profiles for CMB run has been carried out on the basis of primary survey, factor analysis and elemental analysis. CMB analyses were carried out for summer, post monsoon and winter seasons for all the sites. CMB model results are evaluated by using several fit indices such r^2 (>0.8), χ^2 (less than 4) and %Mass (80 – 120%) which are given in **Table 4.9.**

Source contributions to PM_{10} observed at various sites of Mumbai are presented in **Figures 4.2** for all the sites. As can be seen from these figures, kerosene combustion and vehicles emerge as the main sources of PM_{10}.

*

Table 4.9: R^2, χ^2 and %Mass accounted of various sites at different seasons

	χ^2	R^2	%Mass
Colaba Summer	3.54	0.93	110.6
Colaba Post Monsoon	3.5	0.92	71
Colaba Winter	4.02	0.91	92.7
Dadar Summer	3.87	0.89	85.3
Dadar Post Monsoon	4.11	0.88	109.5
Dadar Winter	3.96	0.93	86.1
Dharavi Summer	3.39	0.9	93.6
Dharavi Post Monsoon	2.81	0.91	138.6
Dharavi Winter	3.95	0.94	99.9
Khar Summer	3.39	0.9	104.1
Khar Post Monsoon	1.72	0.94	72.6
Khar Winter	2.3	0.93	81.1
Andheri Summer	1.85	0.91	98.8
Andheri Post Monsoon	4.02	0.9	98.7
Andheri Winter	0.86	0.95	91.7
Mahul Summer	3.02	0.94	106.8
Mahul Post Monsoon	5.41	0.88	116.8
Mahul Winter	4.03	0.92	80.4
Mulund Summer	4.48	0.92	80.4
Mulund Post Monsoon	3.69	0.88	72.3
Mulund Winter	4.01	0.85	94.2

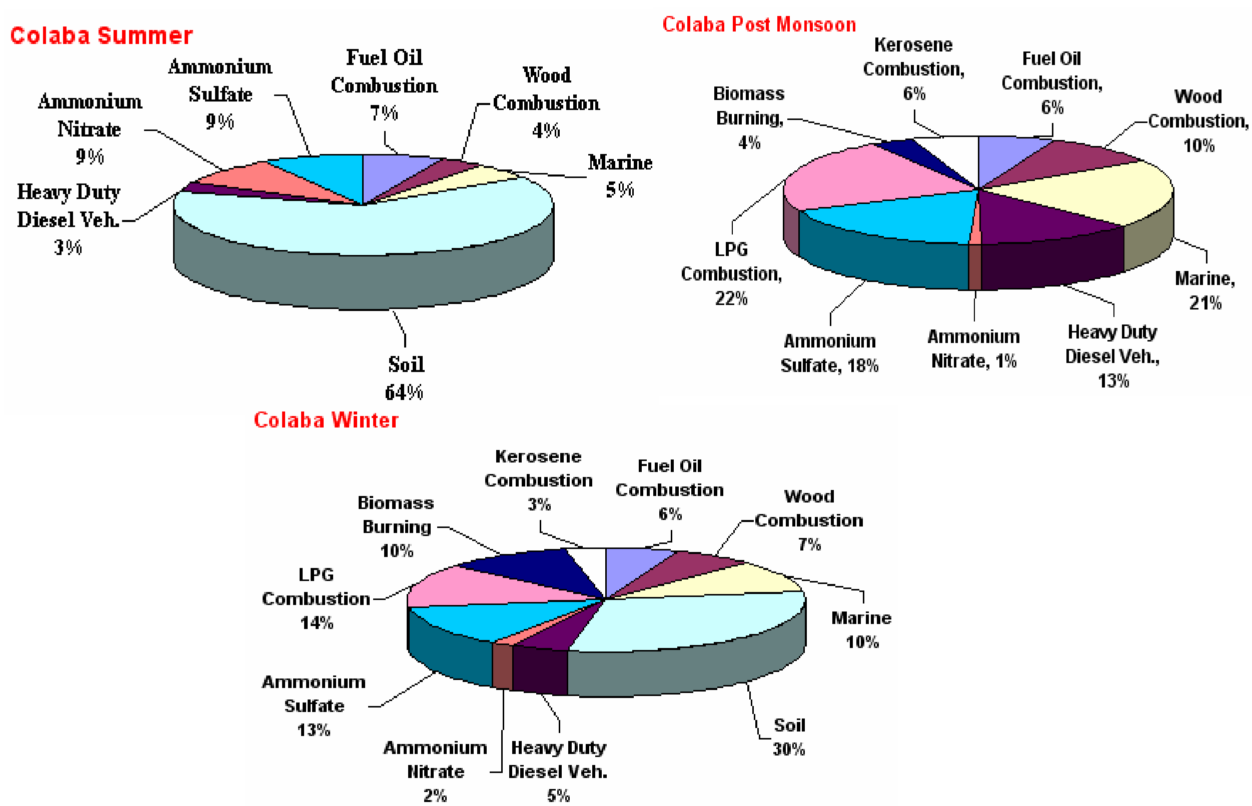

Figure 4.2: Seasonal Variation of CMB Results for Seven Sites

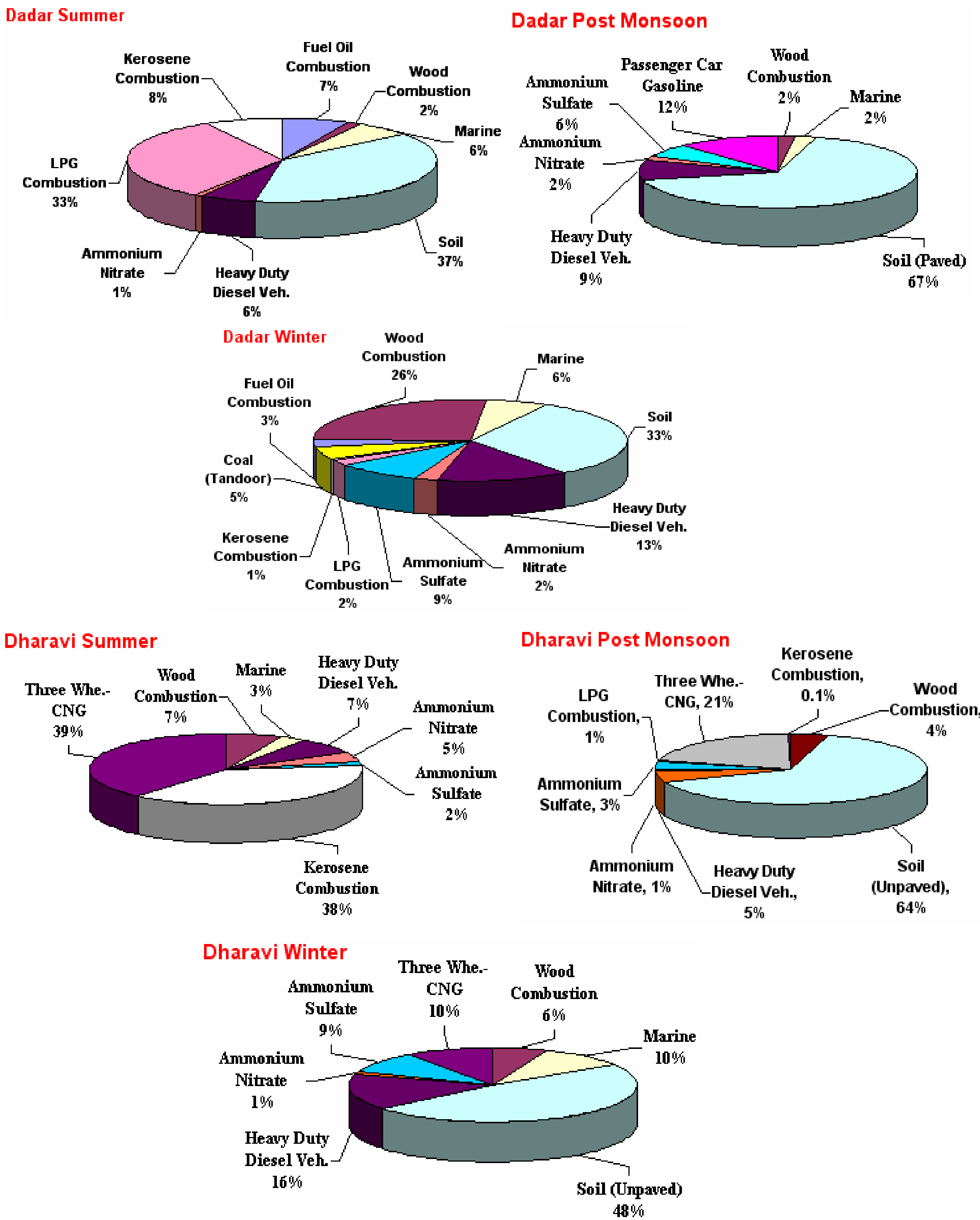

Figure 4.2 (Contd.): Seasonal Variation of CMB Results for Seven Sites

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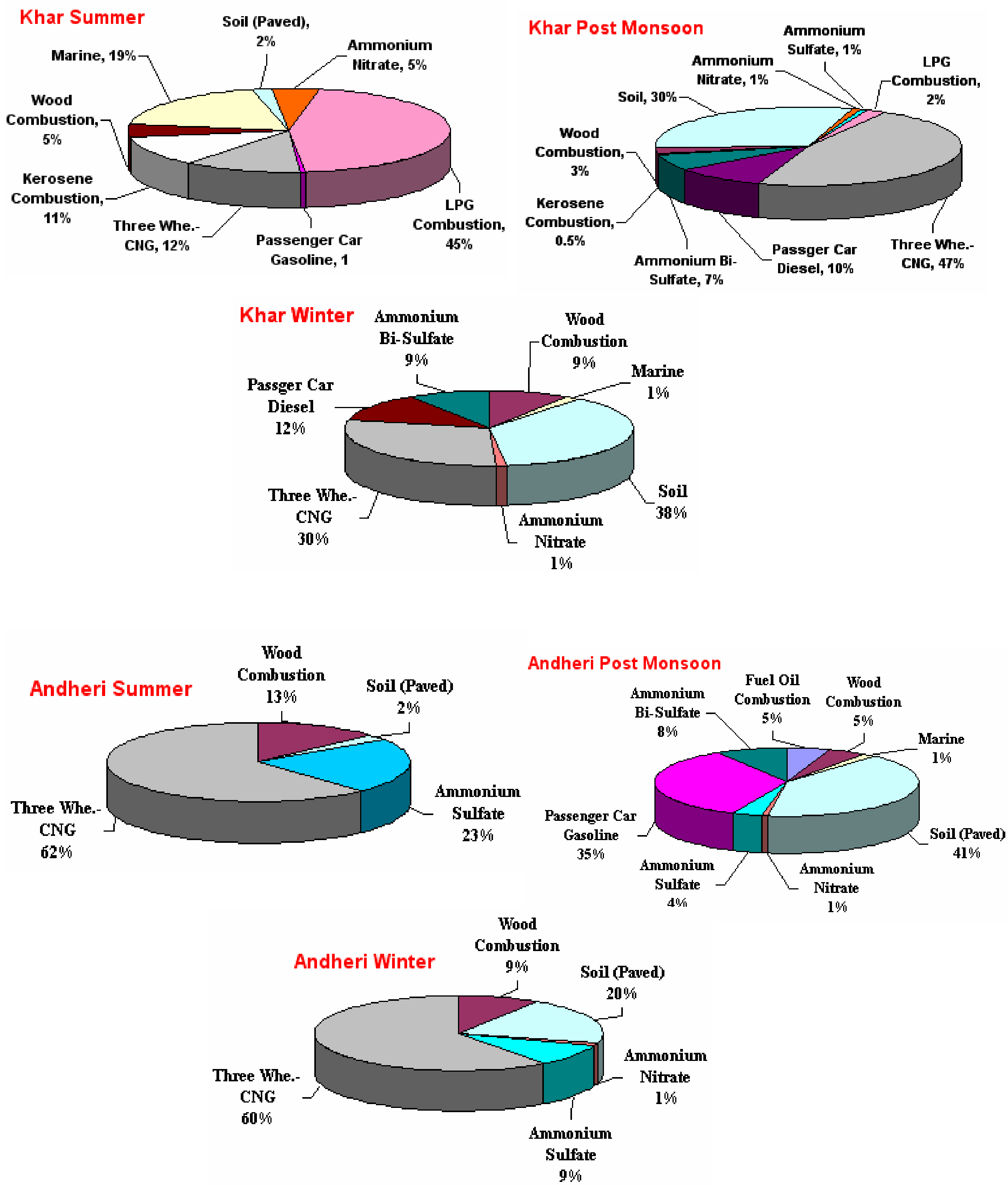

Figure 4.2 (Contd.): Seasonal Variation of CMB Results for Seven Sites

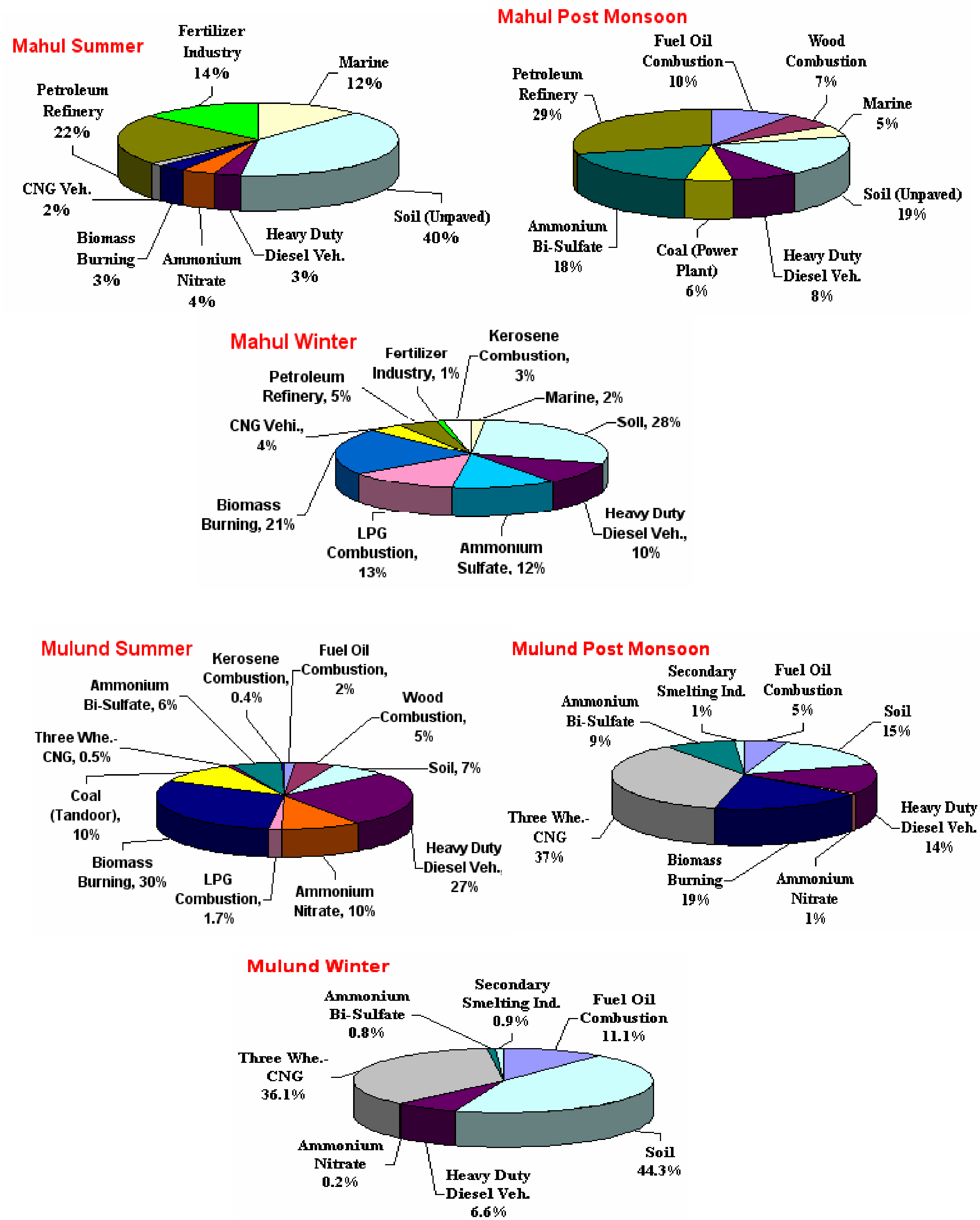

Figure 4.2 (Contd.): Seasonal Variation of CMB Results for Seven Sites

The CMB results indicate that there are sources which could be seen in both factor analysis and CMB. The extent of mass percentages which could be explained varies from site to site as can be seen from **Table 4.9**. *In Mumbai, domestic combustion is contributed by both LPG and kerosene. However, in CMB kerosene was not quantified, therefore LPG to kerosene ratio was estimated based on the emission inventory. The ratio of LPG -80% and kerosene -20% was adopted in CMB contribution.*

At Colaba site, mass was mainly contributed by mixed sources like, soil dust or aggregate dust, secondary aerosol like ammonium sulfate, marine aerosol. LPG and kerosene combustion, heavy duty vehicles, wood combustion are the other sources.

Dadar site, which is close to a major road and a commercial area, shows domination of aggregate dust or soil dust. High dust could be attributed to high vehicular traffic leading to resuspension. LPG and kerosene combustion is second dominant source followed by gasoline, diesel vehicles and wood combustion.

Dharavi site mostly shows domination of soil dust; however results represent the mix of multiple sources ranging from kerosene, three wheelers plying on CNG followed by diesel vehicles. CMB results are in alignment with factor analysis results.

Khar a residential area shows high contribution of LPG and kerosene combustion, three wheeler CNG vehicles and soil. Diesel passenger cars and ammonium bi-sulphate are the other sources. Wood residue combustion is observed in all three seasons, which could be due to bakeries operating in nearby areas.

Andheri, being a kerb site has maximum contribution of three wheeler CNG vehicles and gasoline passenger cars. It also shows high percentage of paved road soil. Secondary aerosols are also the significant contributors. Unlike factor analysis, biomass burning is not estimated in CMB analysis.

Mahul, an industrial site shows high percentage of soil dust or aggregate dust due to continuous movement of vehicles in this area. It has multiple source contribution ranging from petroleum refinery, fertilizer industry, diesel and gasoline vehicles, biomass burning and fuel oil combustion. Secondary inorganic aerosols are also the significant contributors.

*

Mulund site shows highest percentage of three wheeler CNG vehicles and biomass burning. Resuspension of road dust at this kerb site also contributes significantly. It has high percentage of heavy duty diesel vehicles. Fuel oil, wood and coal combustion are the other sources.

Table 4.10 presents the summary of major sources in different seasons at seven sites. The bold source name indicates that it is present in all the three seasons, whereas underlined source name shows its contribution in any two seasons.

Table 4.10: Summary of Major Sources in Different Seasons at Seven Sites

	Summer	**Post Monsoon**	**Winter**
Colaba	**Fuel Oil Combustion** **Wood Combustion** **Marine** Soil **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Ammonium Sulfate**	**Fuel Oil Combustion** **Wood Combustion** **Marine** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Ammonium Sulfate** LPG Combustion Kerosene Combustion Biomass Burning	**Fuel Oil Combustion** **Wood Combustion** **Marine** Soil **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Ammonium Sulfate** LPG Combustion Kerosene Combustion Biomass Burning
Dadar	Fuel Oil Combustion **Wood Combustion** **Marine** **Soil** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** LPG Combustion Kerosene Combustion	**Wood Combustion** **Marine** **Soil (Paved)** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** Ammonium Sulfate Passenger Car Gasoline	Fuel Oil Combustion **Wood Combustion** **Marine** **Soil** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** Ammonium Sulfate LPG Combustion Kerosene Combustion Coal (Tandoor)
Dharavi	**Wood Combustion** Marine **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Ammonium Sulfate** Kerosene Combustion **Three Whe.-CNG**	**Wood Combustion** Soil (Unpaved) **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Ammonium Sulfate** LPG Combustion Kerosene Combustion **Three Whe.-CNG**	**Wood Combustion** Marine Soil (Unpaved) **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Ammonium Sulfate** **Three Whe.-CNG**

*

Table 4.10 (Contd..) : Summary of Major Sources in Different Seasons at Seven Sites

	Summer	**Post Monsoon**	**Winter**
Khar	**Wood Combustion** Marine **Soil (Paved)** **Ammonium Nitrate** LPG Combustion Kerosene Combustion **Passenger Car Gasoline** **Three Whe.-CNG**	**Wood Combustion** **Soil** **Ammonium Nitrate** Ammonium Sulfate LPG Combustion Kerosene Combustion **Three Whe.-CNG** **Passenger Car Diesel** Ammonium Bi-Sulfate	**Wood Combustion** Marine **Soil** **Ammonium Nitrate** **Three Whe.-CNG** **Passenger Car Diesel** Ammonium Bi-Sulfate
Andheri	**Wood Combustion** **Soil (Paved)** **Ammonium Sulfate** Three Whe.-CNG	Fuel Oil Combustion **Wood Combustion** Marine **Soil (Paved)** Ammonium Nitrate **Ammonium Sulfate** Passenger Car Gasoline Ammonium Bi-Sulfate	**Wood Combustion** **Soil (Paved)** Ammonium Nitrate **Ammonium Sulfate** Three Whe.-CNG
Mahul	**Marine** **Soil (Unpaved)** **Heavy Duty Diesel Veh**. Ammonium Nitrate Biomass Burning CNG Veh. **Petroleum Refinery** Fertilizer Industry	Fuel Oil Combustion Wood Combustion **Marine** **Soil (Unpaved)** **Heavy Duty Diesel Veh**. Coal (Power Plant) Ammonium Bi-Sulfate **Petroleum Refinery**	**Marine** **Soil** **Heavy Duty Diesel Veh**. Ammonium Sulfate LPG Combustion Kerosene Combustion Biomass Burning CNG Vehi. **Petroleum Refinery** Fertilizer Industry
Mulund	**Fuel Oil Combustion** Wood Combustion **Soil** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** LPG Combustion Kerosene Combustion Biomass Burning Coal (Tandoor) **Three Whe.-CNG** **Ammonium Bi-Sulfate**	**Fuel Oil Combustion** **Soil** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** Biomass Burning **Three Whe.-CNG** **Ammonium Bi-Sulfate** Secondary Smelting Ind.	**Fuel Oil Combustion** **Soil** **Heavy Duty Diesel Veh.** **Ammonium Nitrate** **Three Whe.-CNG** **Ammonium Bi-Sulfate** Secondary Smelting Ind.

*

4.6 Conclusions

Comparing the results of Factor analysis and CMB model it has been found that few sources are identified by both the models. The common sources which have been found common in both these approaches as well as additional sources are given in **Table 4.11.**

Table 4.11: Sources from CMB and Factor Analysis

Sites	Sources common to FA and CMB	Additional sources of CMB
Colaba	Soil dust, Vehicular emission	Marine, Fuel Oil, Wood and LPG Combustion, Biomass Burning, Ammonium Nitrate, Ammonium Sulfate
Dadar	Soil dust, Vehicular emission	Fuel Oil, Wood and LPG Combustion, Coal (Tandoor), Marine, Ammonium Nitrate, Ammonium Sulfate
Dharavi	Soil dust, Vehicular emission, Coal combustion, Refuse burning	Kerosene, LPG and Wood Combustion, Marine, Ammonium Nitrate, Ammonium Sulfate
Khar	Soil dust, Vehicular emission, Road dust	LPG, Wood Combustion, Marine, Ammonium Nitrate, Ammonium Sulfate, Ammonium Bi-Sulfate
Andheri	Soil dust, Vehicular emission, Kerosene and coal combustion	Fuel Oil and Wood Combustion, Marine, Ammonium Sulfate, Ammonium Nitrate, Ammonium Bi-Sulfate
Mahul	Soil dust, Vehicular emission, Petroleum refining	Fertilizer Industry, Coal (Power Plant), Marine, Fuel Oil and Wood and LPG Combustion, Biomass Burning, Ammonium Nitrate, Ammonium Sulfate, Ammonium Bi-Sulfate
Mulund	Soil dust, Vehicular emission	Secondary Smelting Ind., Fuel Oil, Wood and LPG Combustion, Coal (Tandoor), Biomass Burning, Ammonium Nitrate, Ammonium Bi-Sulfate

CMB results are primarily meant to apportion and indicate PM sources. Overall major sources have been identified; however, the results vary considerably from day to day as well as season. Some of the major issues are: -

- Mass closure is not within the range and varies considerably.
- Collinearity issues of sources are significant e.g. marine aerosol collinearity with other sources with K^+, Na^+ and Cl^-.
- Collinearity of LPG profiles with other combustion sources has been noted.

*

- Since source profiles do not match completely with the ambient analysis for some significant compounds and elements, mass apportionment may show higher uncertainties.
- Absence of hopanes and steranes in source profile of vehicles and levoglucosan for other combustion sources may lead to low resolution in CMB results in terms of mass as well source identification.
- Source profile dependence on CMB output is significant. Therefore, there is a need to update the same with lower uncertainties.
- In future, molecular markers based CMB may be able to resolve the sources better and avoid collinearity issues.

Overall, CMB results have indicated that the major factors are in line with factor analysis. In subsequent **Chapters 6 and 7**, the output of air quality monitoring, emission inventory, CMB and dispersion modeling have been used to arrive at strategies and action plans for each sources such as vehicular, industrial and area sources.

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Chapter 5
Dispersion Modelling : Existing Scenario

5.1 Introduction

Air quality dispersion modeling exercise has been undertaken with a view to delineate the immediate sources and their impact on measurement locations. Dispersion modeling tool has been also used for the whole city air quality scenario generation for different emission loads. The existing scenario model runs are to establish the dispersion pattern of pollutants due to local meteorology and emission from all possible sources. Model runs also provide an idea about missing sources or additional sources which may have been accounted for earlier.

The scenarios for different seasons, locations and sources have been generated to bring out the contributions and their variability. The comparison of concentrations for the scenario has been carried out by considering the highest ten concentrations

5.2 Methodology of Dispersion Modelling

Air quality modelling was carried out for three seasons viz., summer, post monsoon and winter. The USEPA developed/validated ISCST-3 air quality model was used to predict spatial distribution of PM_{10} and NO_x concentrations in ambient air (USEPA, 1995). The model has various options including the capability to handle Polar or Cartesian coordinates, simulating point, area, and volume sources, consideration of wet and dry deposition, accounting for terrain adjustment, building downwash algorithm, etc. The data pertaining to source characteristics, meteorological parameters and receptor network required as input to the model include (i) source data: physical dimensions (stack location, stack height, stack top inner diameter), exit velocity, temperature of gas and pollutant emission rate, (ii) hourly meteorological data for the simulation period: wind speed, wind direction, ambient temperature, stability class and mixing height; and (iii) co-ordinates of sources (stacks) and receptor.

The ISCST3 model uses the following steady-state Gaussian plume equations for continuous point and area sources as presented below.

Equation for point source

$$C = \frac{QKVD}{2\pi u \sigma_y \sigma_z} \exp(-y^2/2\sigma_y^2) \qquad \ldots(1)$$

where Q is the source strength or emission rate (g s^{-1}), u is the mean wind speed (m s^{-1}), y is the cross wind distance (m), σ_y, σ_z, are the horizontal and vertical dispersion parameters (m), respectively, and K is the scaling coefficient to convert calculated concentrations to desired units. In Eq. (1), V is the term for vertical distribution of Gaussian plume and D is the decay term accounting for the pollutant removal by physical or chemical processes. The model employs Brigg's formulae to compute plume rise and make use of power law to determine wind speed corresponding to the stack height. The model runs were carried out separately for industrial, area, vehicular and road dust and all sources simultaneously to quantify their individual contribution as well as cumulative contribution towards the overall ground level concentrations. The industrial sources were considered as independent elevated point sources and the vehicular emissions that are line sources are considered as adjacent volume sources for input to the model. The 24 hourly variations of vehicular and area source emissions were also considered based on the hourly traffic volume/intensity and area source emissions. Most of the industrial units within the study area are assumed to be continuous process plants and hence the emission rate through the stacks is considered uniform throughout the day.

5.2.1 Modelling Domain

Air Quality modeling was carried out for 2 x 2 km area around each monitoring site as well as for the whole city of Mumbai. For air quality impact predictions, the study area was divided into 16 square grids each of size 0.5 km x 0.5 km. The receptor locations in the study area were configured in a square grid pattern to facilitate coverage of all the important sites located in and around major urban growth centers. The area sources were distributed in a square grid pattern and a uniform distribution of emissions within each grid was assumed. Hourly frequency distributions of wind speed, wind direction, ambient temperature, stability class and mixing height were used in the model. Atmospheric stability was determined using Pasquill modified Turner's (1964) method and the various stabilities ranging from A to F (unstable—A, B and C, neutral—D, stable—E and F) was determined based on wind speed, solar insolation and cloud cover. The data on solar insolation and cloud cover was collected from Indian Meteorological Department.

5.3 Meteorological data

Meteorological conditions play a vital role in transport and dispersion of pollutants in the atmosphere. The hourly surface meteorological data viz. wind speed and direction and surface temperature required as input to the model were collected at each site using a continuous wind monitoring instrument round the clock during March to June 15th (summer season), October, November and December 15th (post monsoon season) and 15th December to March (winter season). The mixing height was obtained from the report published by CPCB. **Figure 5.1** presents the diurnal variation in the mixing height. It was observed that moderately stable conditions prevailed during the night hours, whereas the atmosphere became unstable during noon hours. Maximum and minimum mixing heights of about 1200 and 50m were observed during afternoon (1200–1400 h) and early morning/late evening hours, respectively. The low values of mixing height that were observed during early morning or night hours could be due to occurrence of ground based inversions that affect dispersion pattern.

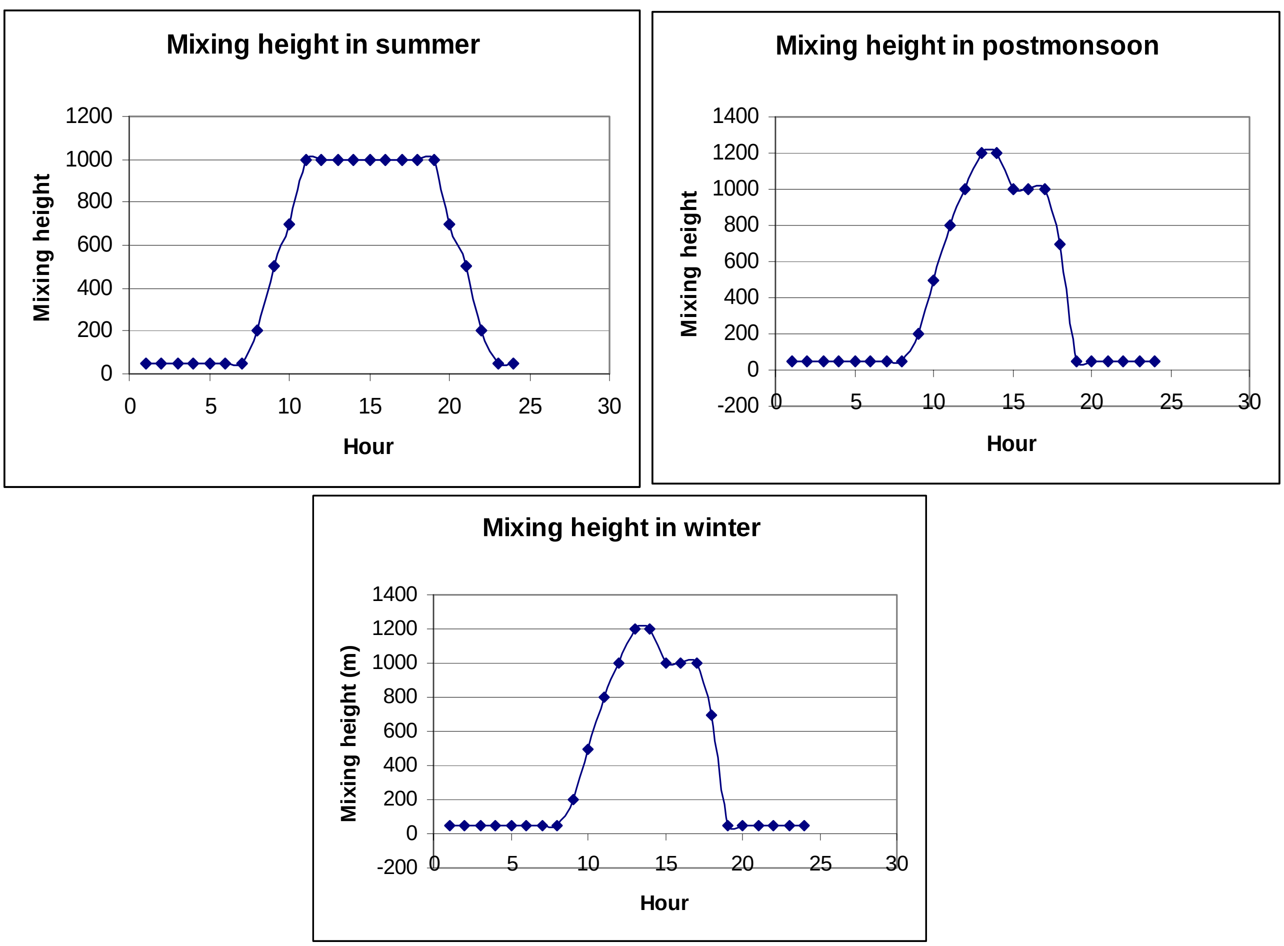

Figure 5.1: Mixing height in Mumbai in Three Seasons

5.4 Model runs

Air quality dispersion modeling carried out for 2 x 2 km area around each monitoring site has been detailed in the following sections. The overall Mumbai city model runs with all sources were also carried out to understand the impact of sources on various sites and compared the values with measured values.

5.4.1 Colaba

Colaba is the background monitoring station in this study. The study region is located in the southern most tip of Mumbai located in the campus of Municipal Sewage Pumping Station. It has Arabian Sea on one side and residential area on the other side. The southern side is occupied by a military cantonment, including the Navy Nagar. Google earth landuse picture is shown in **Figure 5.2**. The sources of pollution include, docks, residential (defence colony), naval transport pool, commercial activity/ offices, hotels, bus depot, petrol pumps, slum areas, bakeries etc. No industries are located in this study area.

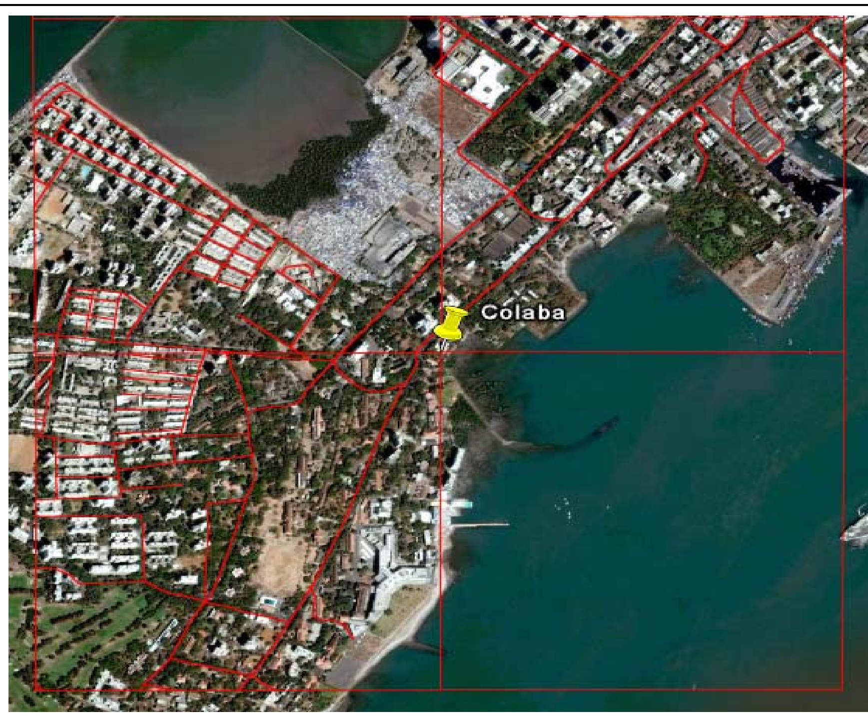

Figure 5.2: Landuse Pattern around 2 x 2 Km Colaba Site

The diurnal variations in stability classes and windroses for three seasons are given in **Figure 5.3**. The prominent direction during summer season are west south west and north west with a calm percentage of 53%. During post monsoon season the prevailing wind direction during day and night time were found to be from west south west with a calm percentage of 39%. In the winter season the prevailing wind direction during day and night time were found to be from north with a calm percentage of 53% during the study period.

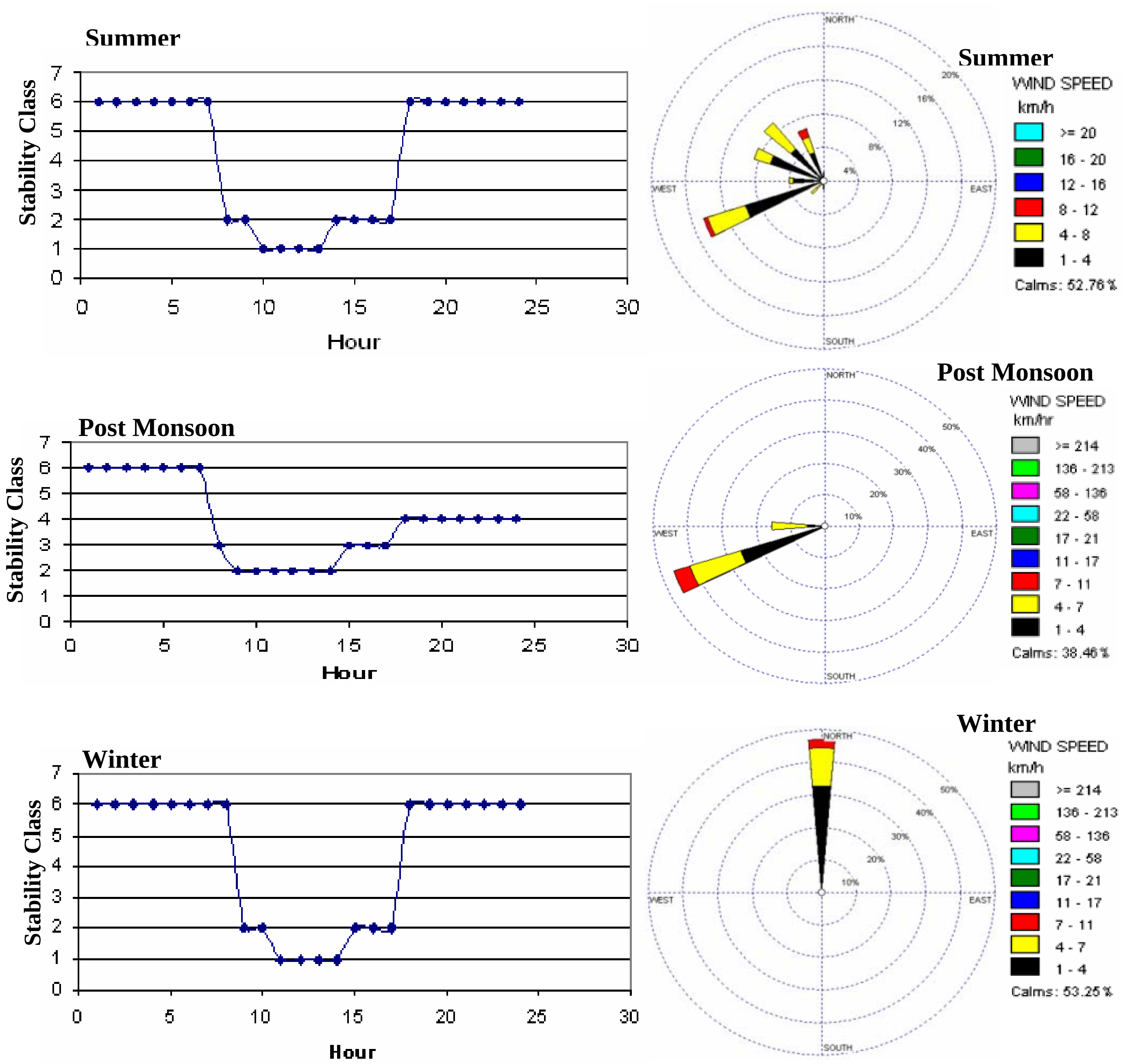

Figure 5.3: Seasonal Stability Classes and Wind rose for Colaba Site

The model runs were carried out separately for area, road, road side dust and vehicular sources to quantify their individual contribution towards the overall ground level concentration. Another model run was carried out by considering all sources together. The gridwise emission loads for different time and type of sources are presented in **Annexure 5. Table 5.1** gives the Comparison of (Maximum, Minimum and Average) PM_{10} concentrations for different scenarios by considering the highest ten concentrations.

Table 5.1: Comparison of PM_{10} concentrations at Colaba for different scenarios by considering the highest ten concentrations

	Minimum	**Maximum**	**Average**
Summer			
Area sources	1.3	1.3	1.3
Vehicular sources	15.0	19.4	17.4
Road side dust	87.9	120.5	103.7
All sources	104.2	140.7	122.5
Post Monsoon			
Area sources	0.5	0.5	0.5
Vehicular sources	5.4	7.7	6.6
Road side dust	29.2	45.62	34.6
All sources	35.0	53.7	44.6
Winter			
Area sources	1.4	1.5	1.4
Vehicular sources	17.4	25.2	21.6
Road side dust	102.8	160.1	131.6
All sources	121.5	186.2	154.0

* All values in $\mu g/m^3$

Table 5.1 indicate that contribution from road side dust is highest in winter at 131.6 $\mu g/m^3$ and lowest (34.6 $\mu g/m^3$) in post monsoon, on the other hand vehicle sources contribute maximum in winter with 21.6 $\mu g/m^3$ and lowest (6.6 $\mu g/m^3$) in post monsoon.

Table 5.2 gives ground level concentrations of PM_{10}. Road side dust contributes the maximum in all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 14.9, 16.1 and 14.5% respectively.

Table 5.2: Ground Level Concentrations of PM_{10} at Colaba Site

	Concentration (μg/m^3)	% Contribution
Summer		
Area sources	1.0	2.81
Vehicular sources	5.3	14.89
Road side dust	29.3	82.30
All sources	35.6	100.0
Post Monsoon		
Area sources	0.3	2.54
Vehicular sources	1.9	16.10
Road side dust	9.6	81.36
All sources	11.8	100.0
Winter		
Area sources	1.1	2.67
Vehicular sources	6.0	14.56
Road side dust	34.1	82.77
All sources	41.2	100.0

Comparison of NO_x concentrations for different scenarios by considering the highest ten concentrations for Colaba are given in **Table 5.3** show that vehicle source is the dominate source, area source contributions are very low.

Table 5.3: Comparison of NOx concentrations at Colaba for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.4	0.4	0.4
Vehicular sources	126.7	172.6	131.6
All sources	127.0	172.8	132.3
Post Monsoon			
Area sources	0.1	0.1	0.1
Vehicular sources	45.0	69.4	56.5
All sources	45.1	69.5	57.7
Winter			
Area sources	0.4	0.4	0.4
Vehicular sources	146.8	223.5	165.2
All sources	147.1	223.8	185.1

* All values in μg/m^3

Table 5.4 gives ground level concentrations of NOx at Colaba, indicates that NOx is mainly contributed by vehicles. The Colaba site which is close to the shore and does not have any major industrial or other sources, except vehicles show low values for PM and NOx concentrations.

Table 5.4: Ground Level Concentrations of NOx at Colaba Site

	Concentration (μg/m^3)	% Contribution
Summer		
Area sources	0.3	0.68
Vehicular sources	43.5	99.32
All sources	43.8	100.0
Post Monsoon		
Area sources	0.1	0.63
Vehicular sources	15.8	99.37
All sources	15.8	100.0
Winter		
Area sources	0.3	0.61
Vehicular sources	49.0	99.39
All sources	49.3	100.0

5.4.2 Dadar

Dadar is a commercial place in Mumbai and has a railway station on the Mumbai Suburban railway on both the western railway line and the central railway line. This makes it a major transit point and also the most crowded railway station on the Mumbai Suburban Railway.The monitoring site is located on Baba Saheb Ambedkar marg in Dadar T.T. This is a four lane road with heavy duty vehicles plying on the road. Pune taxi and bus terminal is located close to the site .One flyover is located very close to the monitoring site. No industries are located in 2 km x 2 km study area of Dadar. Google earth picture of land use pattern in Dadar is presented in **Figure 5.4.**

Figure 5.4: Landuse Pattern around 2 x 2 Km Dadar Site

Figure 5.5 present the diurnal variation in the atmospheric stability and windroses of three seasons. The prominent direction during summer season are east, east south east, east north east with a calm percentage of 22% During post monsoon season the prevailing wind direction during day and night time were found to be from east and north east with a calm percentage of 19%. During winter season the prevailing wind direction during day and nighttime were found to be from north with a calm percentage of 56% during the study period.

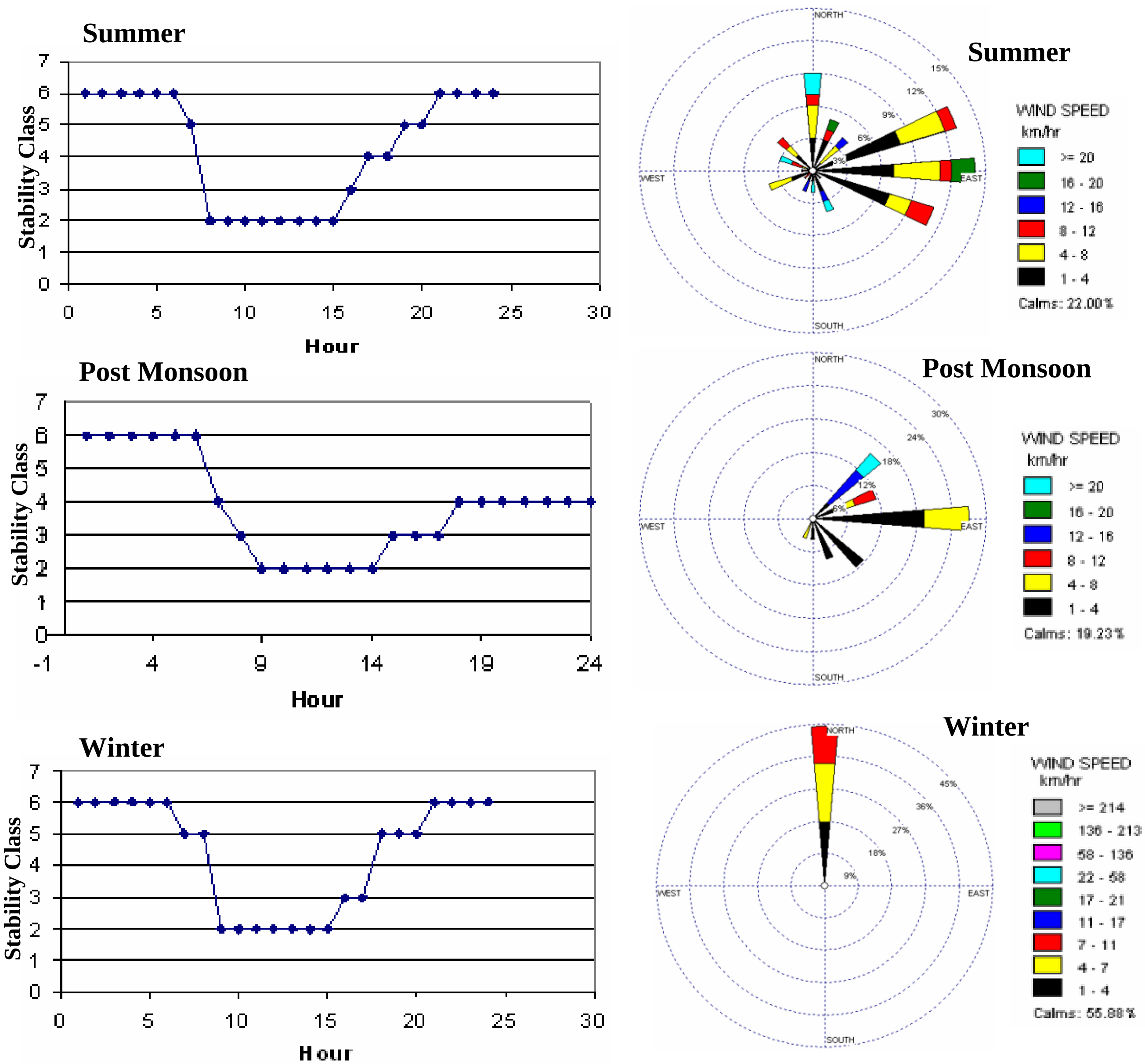

Figure 5.5: Seasonal Stability Classes and Windrose for Dadar Site

The gridwise emission loads for different time and type of sources are presented in **Annexure 5**. **Tables 5.5** gives the Comparison of PM_{10} concentrations for different scenarios by considering the highest ten concentration.

Table 5.5: Comparison of PM_{10} concentrations at Dadar for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.2	0.3	0.25
Vehicular sources	24.1	31.8	27.6
Road side dust	274.5	363.8	308.9
All sources	298.6	395.6	335.4
Post Monsoon			
Area sources	0.4	0.4	0.4
Vehicular sources	21.3	23.2	22.2
Road side dust	272.7	308.3	290.5
All sources	291.3	329.1	308.5
Winter			
Area sources	0.5	0.5	0.5
Vehicular sources	33.8	51.0	42.8
Road side dust	381.5	592.3	486.9
All sources	418.6	643.4	472.4

* All values in $\mu g/m^3$

It indicates that contribution from road side dust is highest in winter at 592.3 $\mu g/m^3$ and lowest (272.7 $\mu g/m^3$) in post monsoon. On the other hand, vehicle sources contribute maximum in winter (42.8 $\mu g/m^3$) and lowest (22.2 $\mu g/m^3$) in post monsoon. Average concentration shows contribution from road side dust is highest in winter at 486.9 $\mu g/m^3$ and lowest (290.5 $\mu g/m^3$) in post monsoon. On the other hand, area sources have almost negligible contribution.

Table 5.6 gives ground level concentrations of PM_{10}. Road side dust contributes the maximum in all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 6.0, 7.2 and 3.8% respectively.

Table 5.6: Ground Level Concentrations of PM_{10} at Dadar Site

	Concentration (µg/m^3)	**% Contribution**
Summer		
Area sources	0.2	0.17
Road side dust	7.1	5.96
Vehicular sources	111.8	93.87
All sources	119.1	100.0
Post Monsoon		
Area sources	0.2	0.23
Road side dust	81.2	92.59
Vehicular sources	6.3	7.18
All sources	87.7	100.0
Winter		
Area sources	0.4	0.20
Road side dust	193.8	95.99
Vehicular sources	7.7	3.81
All sources	201.9	100.0

Maximum, Minimum and average values of ten highest concentrations of NOx are given in **Table 5.7**. It shows that vehicle source mainly dominate the NO_x concentration. Area source contributions are very low.

Table 5.7: Comparison of NOx concentrations at Dadar for different scenarios by considering the highest ten concentrations

	Minimum	**Maximum**	**Average**
Summer			
Area sources	0.2	0.2	0.2
Vehicular sources	175.7	233.3	199.4
All sources	175.8	233.4	199.5
Post Monsoon			
Area sources	0.3	0.3	0.3
Vehicular sources	154.0	168.4	159.1
All sources	154.2	168.5	159.3
Winter			
Area sources	0.4	0.4	0.4
Vehicular sources	246.6	370.1	277.6
All sources	246.9	370.4	277.7

* All values in µg/m^3

Table 5.8 gives ground level concentrations of NOx at Dadar, indicates that NOx is mainly contributed by vehicles. It shows that the contribution from vehicles sources is maximum and is highest in winter. Contributions from area sources are very low.

Table 5.8: Ground Level Concentrations of NOx at Dadar Site

	Concentration (µg/m^3)	% Contribution
Summer		
Area sources	0.272	0.51
Vehicular sources	53.26	99.49
All sources	53.53	100.0
Post Monsoon		
Area sources	0.168	0.37
Vehicular sources	44.72	99.63
All sources	44.88	100.0
Winter		
Area sources	0.179	0.14
Vehicular sources	123.5	99.77
All sources	123.67	100.0

5.4.3 Dharavi

This monitoring site is located in the centre of the largest and highly populated slum pocket of Mumbai having a population of more than 1 million, who live in poor sanitation and unhygienic conditions. In addition to the traditional pottery and textile industries in Dharavi, there is an increasingly large recycling industry processing recyclable waste from other parts of Mumbai. Manufacturing activities of small scale is significant. The area has an estimated 15,000 single-room factories. Dharavi has severe problems with public health, due to the scarcity of toilet facilities, compounded by the flooding during the monsoon season. No major industries are located within 2 x 2 km area around the monitoring site. Google earth picture of land use pattern in Dharavi is presented in **Figure 5.6.**

Figure 5.6: Landuse Pattern around 2 x 2 Km Dharavi Site

The diurnal variation in stability class and windroses of three seasons are given in **Figures 5.7**. The prominent directions during summer season are west North West and North West with a calm percentage of 26%. During post monsoon season the prevailing wind direction during day and night time were found to be from east and north east with a calm percentage of 19%. During winter season the prevailing wind direction during day and night time were found to be from west south west with a calm percentage of 14% during the study period.

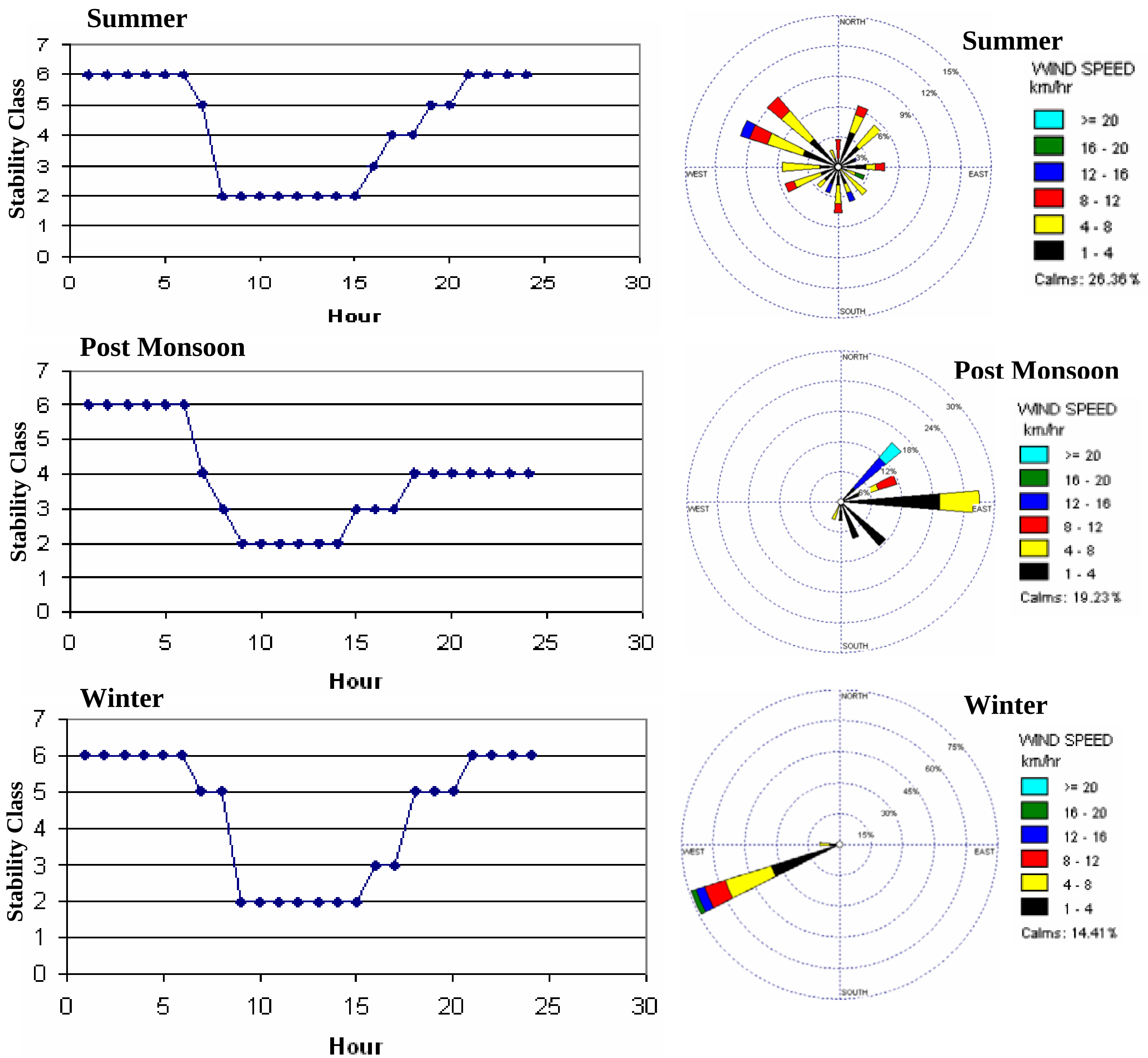

Figure 5.7: Seasonal Stability Classes and Windrose for Dharavi Site

The grid wise emission loads for different time and type of sources are presented in **Annexure 5**. The model runs were carried out separately for area, road, road side dust and vehicular sources to quantify their individual contribution towards the overall ground level concentration. Another model run was carried out by considering all sources together. **Tables 5.9** gives the comparison of PM_{10} concentrations for different scenarios by considering the highest ten concentration.

Table 5.9: Comparison of PM_{10} concentrations at Dharavi for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.5	0.5	0.5
Vehicular sources	20.9	24.0	21.2
Road side dust	187.2	207.1	195.4
All sources	208.9	229.5	216.6
Post Monsoon			
Area sources	0.3	0.3	0.3
Vehicular sources	15.7	18.0	16.9
Road side dust	180.0	204.2	189.2
All sources	199.2	249.8	214.2
Winter			
Area sources	0.5	0.5	0.5
Vehicular sources	28.3	30.8	29.6
Road side dust	269.7	312.3	282.4
All sources	289.1	319.7	301.6

* All values in $\mu g/m^3$

Table 5.9 indicates that the contribution from road side dust is highest in winter at 282.4 $\mu g/m^3$ and lowest of 189.2 $\mu g/m^3$ in post monsoon. On the other hand vehicle sources contribute maximum in winter with 29.6 $\mu g/m^3$and lowest 16.9 $\mu g/m^3$ of in post monsoon. Contribution from area sources is negligible

Table 5.10 gives ground level concentrations of PM_{10}. As observed in other sites, road side dust contributes the maximum in all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 9.4, 8.7 and 10.4% respectively.

Table 5.10: Ground Level Concentrations of PM_{10} at Dharavi Site

	Concentration (µg/m³)	**% Contribution**
Summer		
Area sources	0.5	1.09
Vehicular sources	4.3	9.37
Road side dust	41.1	89.54
All sources	45.9	100
Post Monsoon		
Area sources	0.3	0.42
Vehicular sources	6.2	8.68
Road side dust	64.9	90.90
All sources	71.4	100
Winter		
Area sources	0.4	0.40
Vehicular sources	10.5	10.45
Road side dust	89.6	89.15
All sources	100.5	100

Maximum, Minimum and average values of ten highest concentrations of NOx are given in **Table 5.11**. It shows that vehicle source mainly dominate the pollutant. Area source contributions are very low.

Table 5.11: Comparison of NOx concentrations at Dharavi for different scenarios by considering the highest ten concentrations

	Minimum	**Maximum**	**Average**
Summer			
Area sources	0.4	0.4	0.4
Vehicular sources	196.4	224.8	205.2
All sources	196.8	225.2	206.5
Post Monsoon			
Area sources	0.3	0.3	0.3
Vehicular sources	151.5	178.0	161.9
All sources	151.6	178.2	162.6
Winter			
Area sources	0.4	0.4	0.4
Vehicular sources	275.9	310.0	289.1
All sources	276.2	310.3	290.5

* All values in µg/m³

Table 5.12 gives ground level concentrations of NOx at Dharavi, indicates that NOx is mainly contributed by vehicles. It shows that the contribution from vehicles sources is maximum and is highest in winter. Contributions from area sources are very low.

Table 5.12: Ground Level Concentrations of NOx at Dharavi Site

	Concentration (µg/m^3)	% Contribution
Summer		
Area sources	0.38	1.08
Vehicular sources	35.03	98.92
All sources	35.41	100
Post Monsoon		
Area sources	0.21	0.42
Vehicular sources	50.15	99.56
All sources	50.37	100
Winter		
Area sources	0.35	0.40
Vehicular sources	86.95	99.58
All sources	87.32	100.0

5.4.4 Khar

The monitoring site in Khar is located on the S.V.road. The monitoring was carried out at the building top of a Veterinary Dispensary. This is a residential site dominated by high income group. The main sources of air pollution are vehicles, vegetable market, parking, restaurants /hotels, shopping centers etc. No industries are located in this 2 km x 2 km study area. The major roads include Western Express Highway, S.V. Road, Santacruz-Chembur Link road. Google earth landuse picture is shown in **Figure 5.8.**

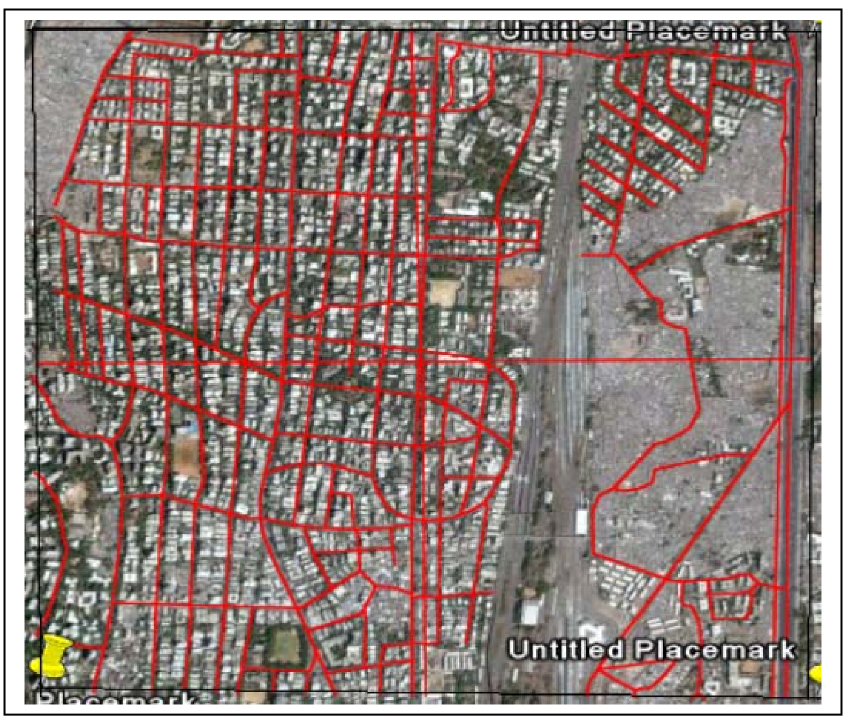

Figure 5.8: Landuse Pattern around 2 x 2 Km Khar Site

Figure 5.9 present the diurnal variation in the atmospheric stability and wind rose diagrams for three seasons. The wind roses show that the predominant direction of wind is from north and North northeast during the summer season, for post monsoon the wind mostly blows from north east, east and north while in winter season the wind blows from east, west and northwest. The percentage of calm winds are 25%, 42% and 48% in summer, post monsoon and winter season respectively.

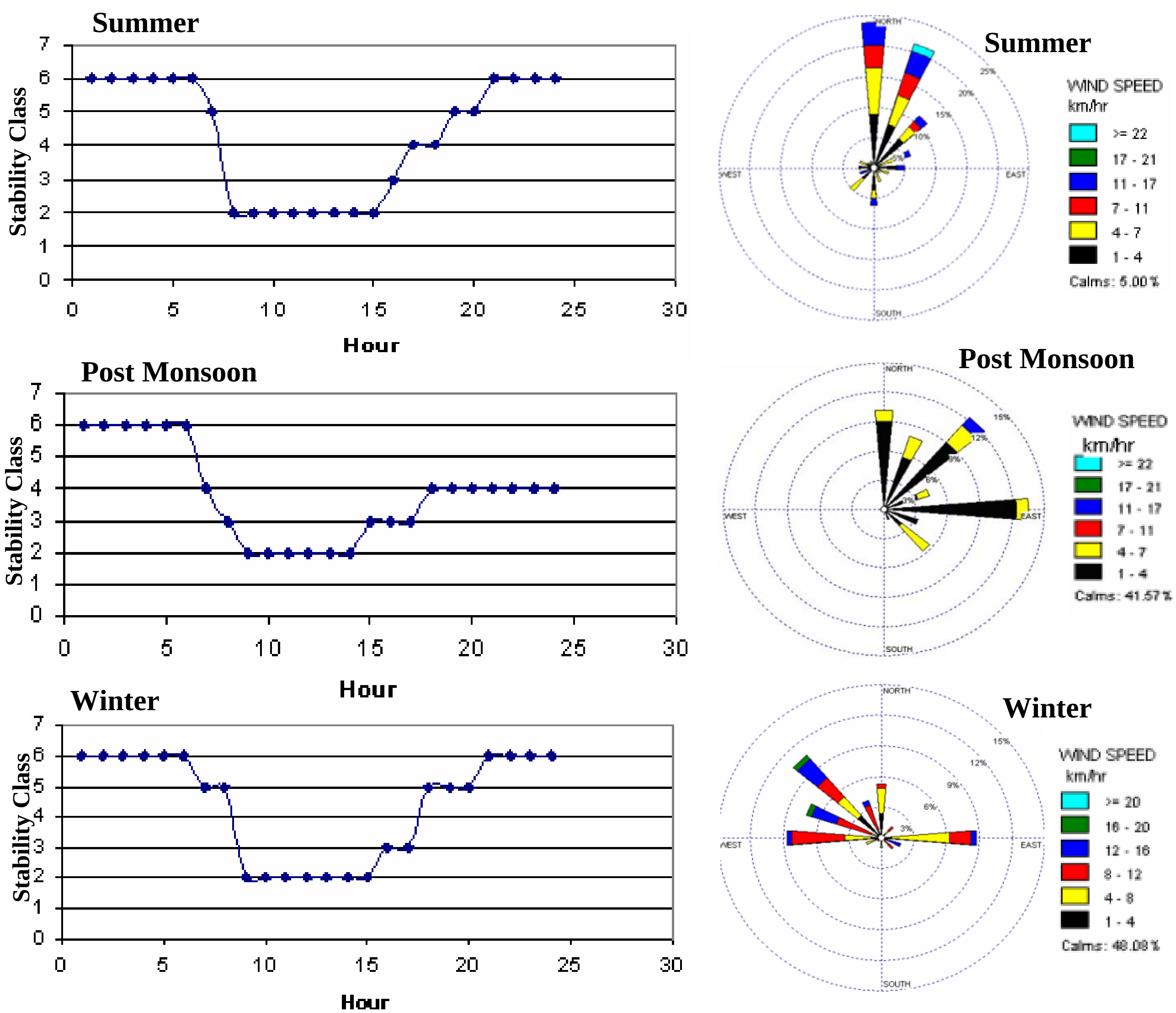

Figure 5.9: Seasonal Stability Classes and Windrose for Khar Site

The model runs were carried out separately for area, road, road side dust and vehicular sources to quantify their individual contribution towards the overall ground level concentration. Another model run was carried out by considering all sources together. Grid wise hourly emission loads from vehicular and area sources are given in the **Annexure 5**. **Tables 5.13** gives the comparison of PM_{10} concentrations for different scenarios by considering the highest ten concentration.

Table 5.13: Comparison of PM_{10} concentrations at Khar for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.5	0.5	0.5
Vehicular sources	15.7	23.5	19.7
Road side dust	194.1	277.3	221.1
All sources	255.3	452.1	329.7
Post Monsoon			
Area sources	0.3	0.3	0.3
Vehicular sources	10.9	18.6	15.0
Road side dust	124.4	213.2	154.5
All sources	181.6	373.1	266.4
Winter			
Area sources	0.4	0.5	0.5
Vehicular sources	38.9	43.0	42.0
Road side dust	457.1	504.2	469.7
All sources	836.9	911.8	860.4

* All values in $\mu g/m^3$

Table 5.13 indicate that contribution from road side dust is highest in winter at 469.7 $\mu g/m^3$ and lowest (154.5 $\mu g/m^3$) in post monsoon On the other hand, vehicle sources contribute maximum in winter with 42.0 $\mu g/m^3$ and lowest (15.0 $\mu g/m^3$) in post monsoon.

Table 5.14 gives ground level concentrations of PM_{10}. As observed in other sites, road side dust contributes the maximum in all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 7.09, 7.63 and 8.26% respectively.

Table 5.14: Ground Level Concentrations of PM_{10} at Khar Site

	Concentration (µg/m³)	**% Contribution**
Summer		
Area sources	0.3	0.22
Vehicular sources	9.7	7.09
Road side dust	126.87	92.69
All sources	136.87	100.0
Post Monsoon		
Area sources	0.2	0.26
Vehicular sources	5.9	7.63
Road side dust	71.2	92.11
All sources	77.3	100.0
Winter		
Area sources	0.4	0.26
Vehicular sources	12.5	8.26
Road side dust	138.4	91.47
All sources	151.3	100.0

Maximum, Minimum and average values of ten highest concentrations of NO_x are given in **Table 5.15**. It shows that vehicle source mainly dominate the pollutant. Area source contributions are very low**.**

Table 5.15: Comparison of NOx concentrations at Khar for different scenarios by considering the highest ten concentrations

	Minimum	**Maximum**	**Average**
Summer			
Area sources	0.2	0.2	0.2
Vehicular sources	121.0	164.7	135.2
All sources	121.2	164.8	135.6
Post Monsoon			
Area sources	0.1	0.1	0.1
Vehicular sources	80.5	130.8	97.9
All sources	80.6	130.9	98.0
Winter			
Area sources	0.2	0.2	0.2
Vehicular sources	269.7	302.4	277.7
All sources	269.8	302.5	278.0

* All values in µg/m³

Table 5.16 gives ground level concentrations of NOx at Khar, indicates that NOx is mainly contributed by vehicles. It shows that the contribution from vehicular sources is maximum and is highest in winter. Contributions from area sources are very low.

Table 5.16: Ground Level Concentrations of NOx at Khar Site

	Concentration (µg/m^3)	% Contribution
Summer		
Area sources	0.1	0.28
Vehicular sources	35.0	99.72
All sources	35.1	100.0
Post Monsoon		
Area sources	0.1	0.24
Vehicular sources	42.4	99.76
All sources	42.5	100.0
Winter		
Area sources	0.2	0.29
Vehicular sources	68.6	99.71
All sources	68.8	100.0

5.4.5 Andheri

The monitoring site is located on the Western Express Highway. The monitoring was carried on the terrace of HDFC Bank building. Andheri today has a population exceeding four million, and as per record is by far the most populous suburb of Mumbai. This area is characterized by high vehicular traffic, which is observed on the roads like Western Express highway, S.V. Road, Chakala Road, and Andheri Kurla Road. Contemporary West Andheri is largely a residential area, whereas East Andheri has a mixture of commercial and residential areas, including MIDC, SEEPZ, Saki Naka (an industrial area) etc. Two industries are located in the 2km x 2km area around the monitoring site.They are Parle products and Godfrey Phillips. Google earth landuse picture is shown in **Figure 5.10.**

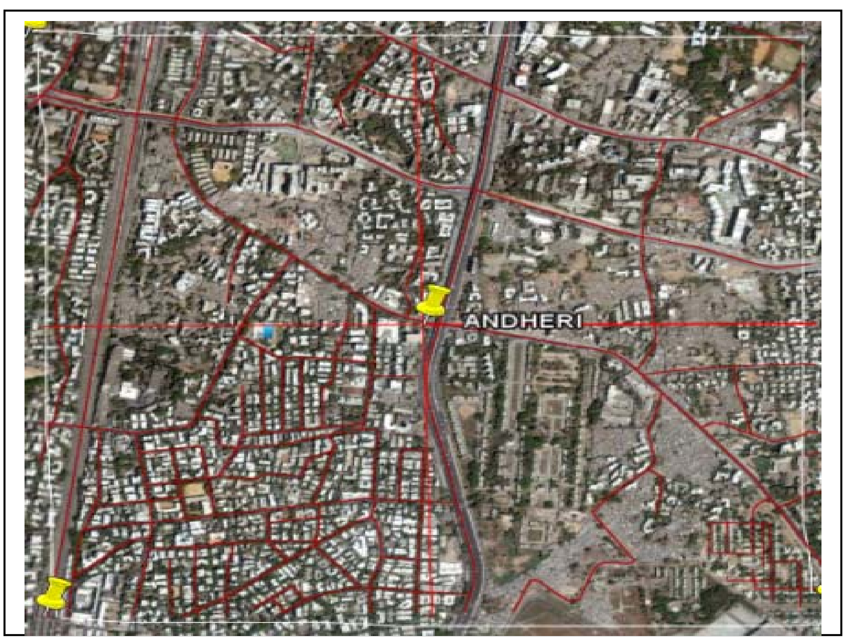

Figure 5.10: Landuse Pattern around 2 x 2 Km Andheri Site

The stability classes and iindicative wind rose diagrams for three seasons are shown in **Figures 5.11.** The wind roses show that the predominant direction of wind is from north west, north northwest and north during the summer season, for post monsoon the wind mostly blows from east, northeast and north while in winter season the wind blows from north east and north. The percentage of calm winds are 27%, 42% and 32% in summer, post monsoon and winter season respectively.

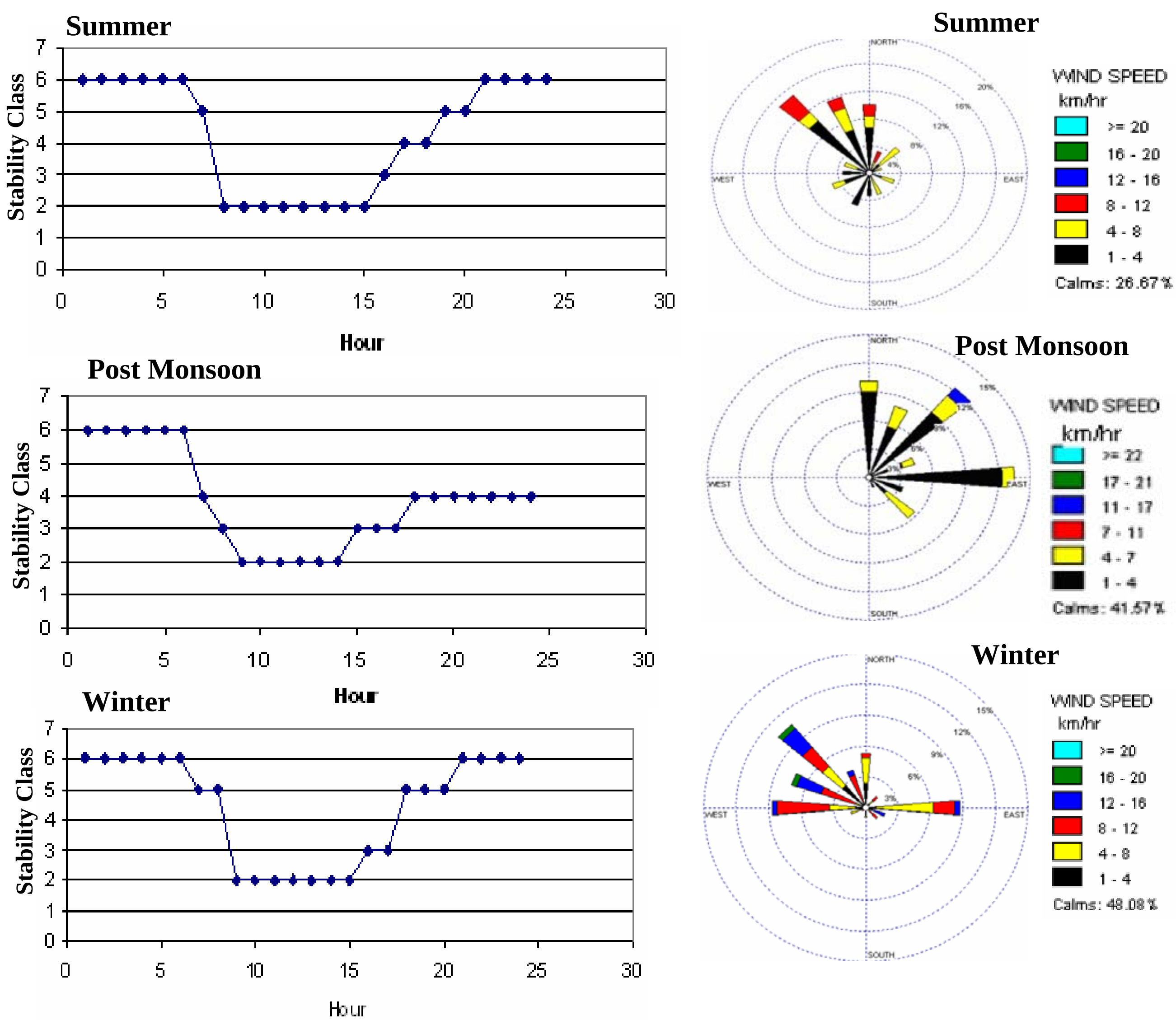

Figure 5.11: Seasonal Stability Classes and Windrose for Andheri Site

The model runs were carried out separately for area, road, road side dust and vehicular sources to quantify their individual contribution towards the overall ground level concentration. Another model run was carried out by considering all sources together. Grid wise hourly emission loads from vehicular and area sources are given in the **Annexure 5**. **Tables 5.17** gives the comparison of PM_{10} concentrations for different scenarios by considering the highest ten concentration.

Table 5.17: Comparison of PM_{10} concentrations at Andheri for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.3	0.3	0.3
Vehicular sources	50.5	55.9	52.6
Road side dust	398.6	447.5	414.2
Point sources	0.3	0.4	0.35
All sources	456.9	517.1	474.9
Post Monsoon			
Area sources	0.3	0.3	0.3
Vehicular sources	51.0	54.5	52.6
Road side dust	406.9	463.1	425.3
Point sources	0.4	0.6	0.5
All sources	453.8	512.0	475.8
Winter			
Area sources	0.3	0.3	0.3
Vehicular sources	56.4	61.1	57.7
Road side dust	432.2	495.6	453.9
Point sources	0.3	0.4	0.3
All sources	480.2	546.1	505.7

* All values in $\mu g/m^3$

It indicates that contribution from road side dust is highest in winter at 453.9 $\mu g/m^3$ and lowest of 414.2 $\mu g/m^3$ in summer. On the other hand, vehicle sources contribute maximum in winter with 57.7 $\mu g/m^3$ and lowest of 52.6 $\mu g/m^3$in summer and post monsoon. Contribution from area and point sources are low.

Table 5.18 presents the PM_{10} values likely to occur at Andheri Site. Road side dust contributes the maximum in all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 8.5, 10.5 and 12.4% respectively.

Table 5.18: Ground Level Concentrations of PM_{10} at Andheri Site

	Concentration (µg/m^3)	% Contribution
Summer		
Area sources	0.1	0.06
Vehicular sources	14.2	8.50
Road side dust	153.7	91.50
Point source	0.001	0.0
All sources	168.0	100.0
Post Monsoon		
Area sources	0.1	0.06
Vehicular sources	18.6	10.50
Road side dust	158.0	89.40
Point source	0.001	0.0
All sources	176.70	100.0
Winter		
Area sources	0.2	0.08
Vehicular sources	30.3	12.43
Road side dust	213.3	87.49
Point source	0.001	0.0
All sources	243.80	100.0

Maximum, Minimum and average values of ten highest concentrations of NO_x are given in **Table 5.19**. It also shows that vehicle source mainly dominate the pollutant and area source contributions are very low**.**

Table 5.19: Comparison of NOx concentrations at Andheri for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.2	0.2	0.2
Vehicular sources	212.9	233.7	221.2
Point sources	13.1	19.5	16.6
All sources	213.1	233.1	222.3
Post Monsoon			
Area sources	0.2	0.2	0.2
Vehicular sources	181.5	220.9	192.3
Point sources	17.2	20.9	19.1
All sources	181.9	220.9	192.6
Winter			
Area sources	0.3	0.3	0.3
Vehicular sources	211.9	247.0	221.7
Point sources	22.2	32.7	27.5
All sources	212.5	247.6	222.2

* All values in µg/m^3

Table 5.20 gives ground level concentrations of NOx at Andheri, indicates that NOx is mainly contributed by vehicles. It shows that the contribution from vehicles sources is maximum and is highest in winter. Contributions from area sources are very low.

Table 5.20: Ground Level Concentrations of NOx at Andheri Site

	Concentration (μg/m^3)	**% Contribution**
Summer		
Area sources	0.1	0.23
Vehicular sources	43.9	99.77
Point source	0.0	0.0
All sources	44.0	100.0
Post Monsoon		
Area sources	0.1	0.12
Vehicular sources	84.2	99.88
Point source	0.0	0.0
All sources	84.3	100.0
Winter		
Area sources	0.1	0.09
Vehicular sources	104.9	98.50
Point source	1.5	1.41
All sources	106.5	100.0

The PM_{10} and NOx emission load from Godfrey Philips are 0.5819 and 9.5440 kg/day. The PM_{10} and NOx emission load from Parle products are 0.2676 and 30.8001 kg/day.

5.4.6 Mahul

Mahul is located on the eastern part of Mumbai. Sources of pollution in this area include major industries such as Refineries, fertilizer / chemical industries, heavy duty vehicles, tankers and power plant. It represents "Industrial Site". The sampling was carried out at BPCL Sports Complex. Some part of the site is occupied by Mahul Creek and salt pans. Major industries in the area are refineries viz. BPCL, HPCL, Indian Oil Blending Ltd and chemical plant like RCF. Google earth landuse picture is shown in **Figure 5.12.**

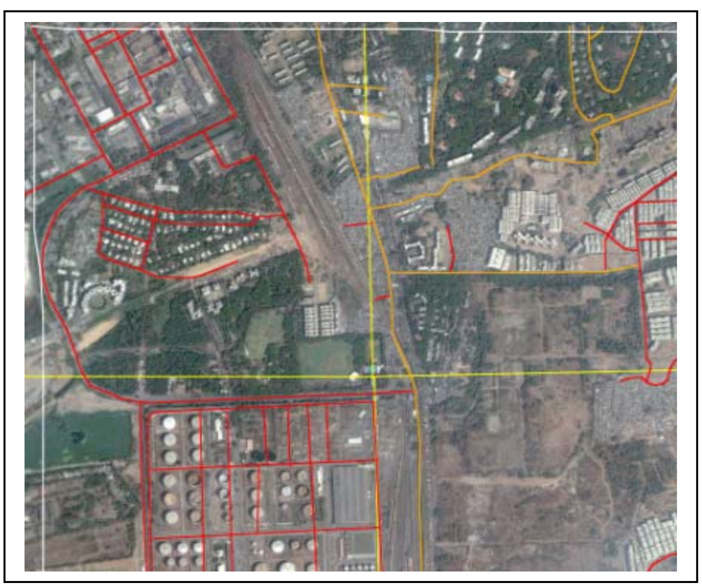

Figure 5.12: Landuse Pattern around 2 x 2 Km Mahul Site

Figure 5.13 present the diurnal variation in the atmospheric stability and indicative wind rose diagrams for three seasons. The wind roses show that the predominant direction of wind is from west, south west and west south west during the summer season. For post monsoon and winter the wind mostly blows from north. The percentage of calm winds are 40%, 43% and 53% in summer, post monsoon and winter season respectively

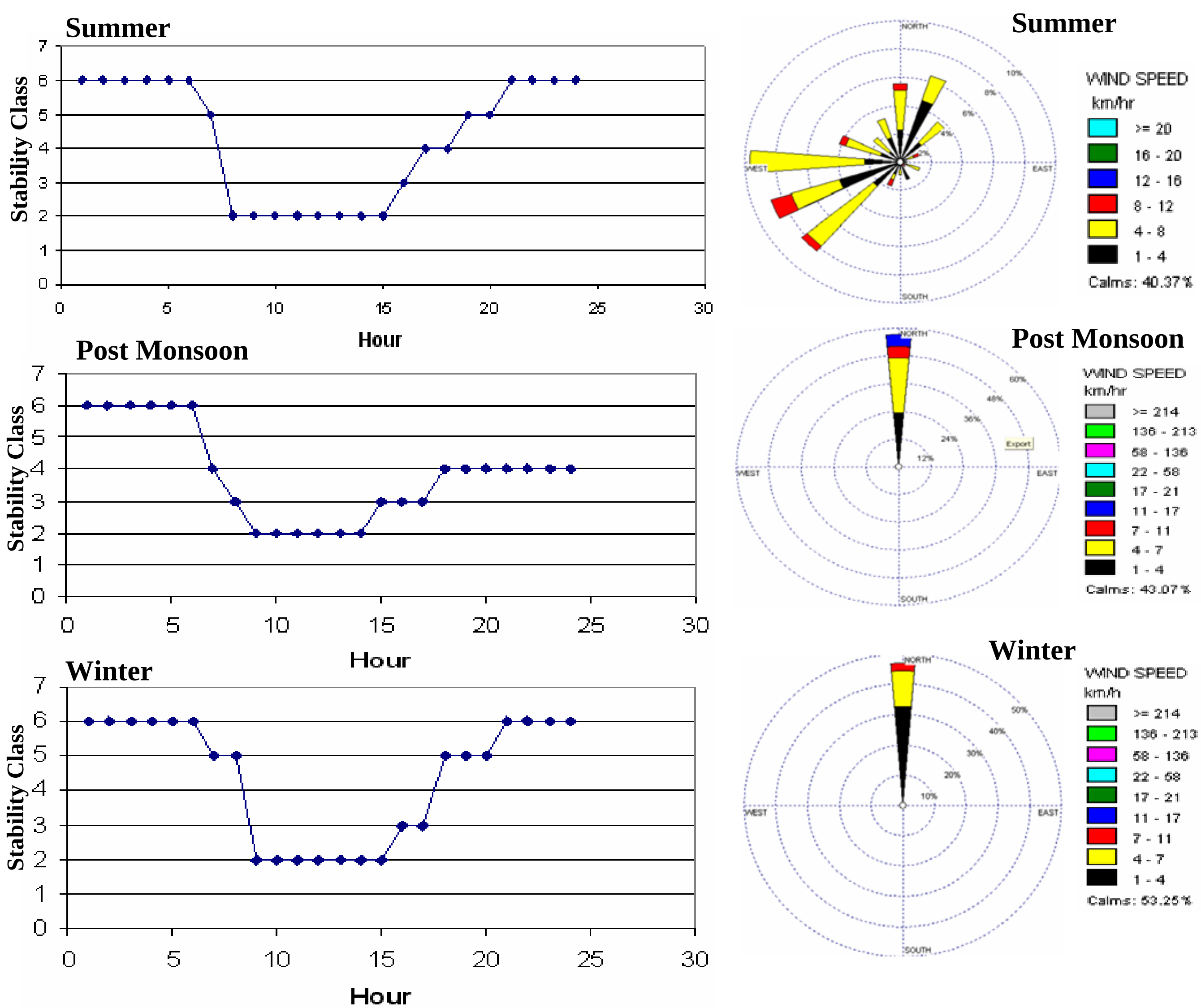

Figure 5.13: Seasonal Stability Classes and Windrose for Mahul Site

The model runs were carried out separately for area, road, road side dust and vehicular sources to quantify their individual contribution towards the overall ground level concentration. Another model run was carried out by considering all sources together. Grid wise hourly emission loads from vehicular and area sources are given in the **Annexure 5**. **Tables 5.21** gives the comparison of PM_{10} concentrations for different scenarios by considering the highest ten concentration.

Table 5.21: Comparison of PM_{10} concentrations at Mahul for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.2	0.2	0.2
Vehicular sources	39.5	41.3	40.5
Road side dust	318.6	333.2	322.8
Point Sources	27.9	19.3	22.0
All sources	343.9	359.6	348.4
Post Monsoon			
Area sources	0.2	0.2	0.2
Vehicular sources	27.8	31.2	29.0
Road side dust	217.1	243.5	230.0
Point Sources	16. 7	14.6	15.8
All sources	240.2	269.6	254.5
Winter			
Area sources	0.2	0.2	0.2
Vehicular sources	41.3	46.2	43.8
Road side dust	330.6	370.7	349.2
Point Sources	31.9	36.4	34.5
All sources	358.2	402.1	378.5

* All values in $\mu g/m^3$

It indicates that contribution from road side dust is highest in winter at 349.2 $\mu g/m^3$ and lowest (230 $\mu g/m^3$) in post monsoon On the other hand, vehicle sources contribute maximum in winter with 43.8 $\mu g/m^3$ and lowest (29.0 $\mu g/m^3$) in post monsoon. Road side dust contributes the maximum in all seasons but highest in winter.

Table 5.22 gives ground level concentrations of PM_{10}. Road side dust contributes the maximum in all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 11.0, 11.0 and 10.6% respectively.

Table 5.22: Ground Level Concentrations of PM_{10} at Mahul Site

	Concentration ($\mu g/m^3$)	% Contribution
Summer		
Area sources	0.1	0.06
Vehicular sources	18.8	11.00
Road side dust	146.4	85.87
Point Sources	5.207	3.10
All sources	170.50	100.0
Post Monsoon		
Area sources	0.2	0.19
Vehicular sources	11.7	11.01
Point Sources	0.0009	0.00
Road side dust	94.4	88.81
All sources	106.3	100.0
Winter		
Area sources	0.2	0.08
Vehicular sources	27.8	10.60
Point Sources	12.18	4.64
Road side dust	222.1	84.68
All sources	262.28	100.0

Maximum, Minimum and average values of ten highest concentrations of NO_x are given in **Table 5.23**. It shows that vehicle source mainly dominate the pollutant. Area source contributions are very low.

Table 5.23: Comparison of NOx concentrations at Mahul for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.2	0.2	0.2
Vehicular sources	253.0	264.5	256.2
Point sources	0.00013	0.00017	0.00015
All sources	264.3	276.8	268.0
Post Monsoon			
Area sources	0.1	0.1	0.1
Vehicular sources	176.9	198.5	187.4
Point sources	0.00015	0.00015	0.00015
All sources	188.5	210.5	197.9
Winter			
Area sources	0.2	0.2	0.2
Vehicular sources	263.7	295.5	278.2
Point sources	0.00006	0.00008	0.00007
All sources	280.9	313.9	294.2

* All values in $\mu g/m^3$

Table 5.24 gives ground level concentrations of NOx at Mahul, indicates that NOx is mainly contributed by vehicles. It shows that the contribution from vehicles sources is maximum and is highest in winter. Contributions from area sources are very low.

Table 5.24: Ground Level Concentrations of NOx at Mahul Site

	Concentration (μg/m^3)	**% Contribution**
Summer		
Area sources	0.18	0.18
Vehicular sources	101.54	99.82
Point sources	0.00003	0.00
All sources	101.72	100
Post Monsoon		
Area sources	0.14	0.19
Vehicular sources	73.54	99.81
Point sources	0.0000	0.00
All sources	73.69	100.0
Winter		
Area sources	0.12	0.11
Vehicular sources	111.74	99.89
Point sources	0.00001	0.00
All sources	111.86	100.0

5.4.7 Mulund

Mulund is a major north-eastern suburb of Mumbai. It is nestled alongside the foothills of the Sanjay Gandhi National Park with easy access to the Eastern Express Highway and Navi Mumbai through the Mulund-Airoli bridge.The two major arterial roads in Mulund are L.B.S. Road up to Mulund Check Naka and the Eastern Express Highway. The Eastern Express Highway runs through Mulund East which provides an easy transport route during heavy traffic. Many arterial roads in Mulund are concretized, thus not needing resurfacing every year. Mulund has become crowded over the years leading to the sharp increase in vehicles. Old buildings and structures are giving way to big bright new malls and cineplexes. This change is most apparent along the L.B.S. Road which today is lined with two major shopping malls, R-Mall and Nirmal Lifestyle. These malls cater to food courts inside the premises. Malls attract lot of high income group people visiting in private vehicles like two wheelers and four wheelers. Mulund has many regions which have been using Piped Gas for the past five years or more. In sonapur area around Mulund have many marble granite shops, scrap dealers, timber marts and many garages. Major residential colonies are Tata Colony, Mhada Colony, Vina Nagar, Vaishali Nagar, Gamdevi (slum). Google earth land use picture is shown in **Figure 5.14.** Two industries are located in this study area viz. Johnson and Johnson and Schrader Duncan Ltd.

Figure 5.14: Landuse Pattern around 2 x 2 Km Mulund Site

Figure 5.15 gives the diurnal variation of stability classes and wind roses of three seasons. The prominent direction during summer season is with a calm percentage of 26%. During post monsoon season the prevailing wind direction during day and nighttime were found to be from east and north east with a calm percentage of 19%. During winter season the prevailing wind direction during day and nighttime were found to be from north with a calm percentage of 55% during the study period.

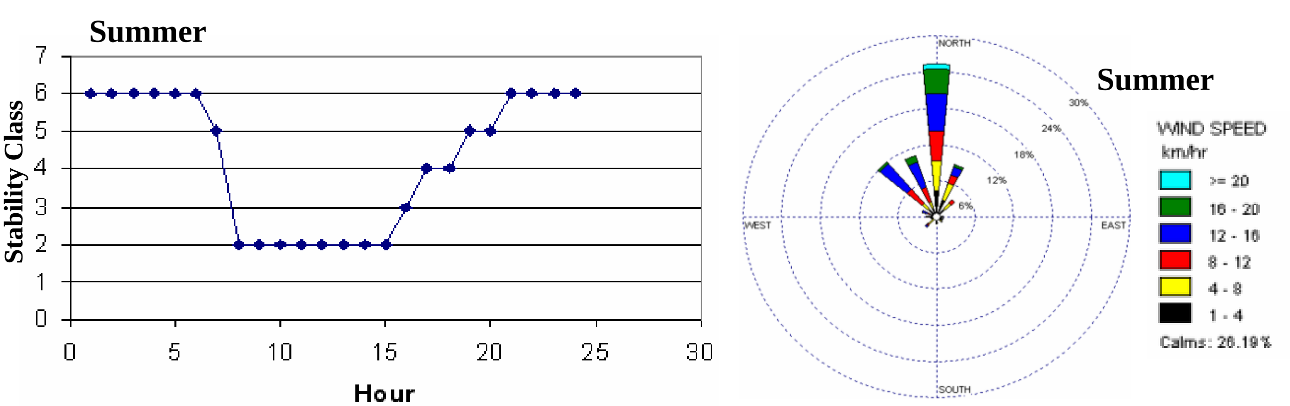

Figure 5.15: Seasonal Stability Classes and Windrose for Mulund Site

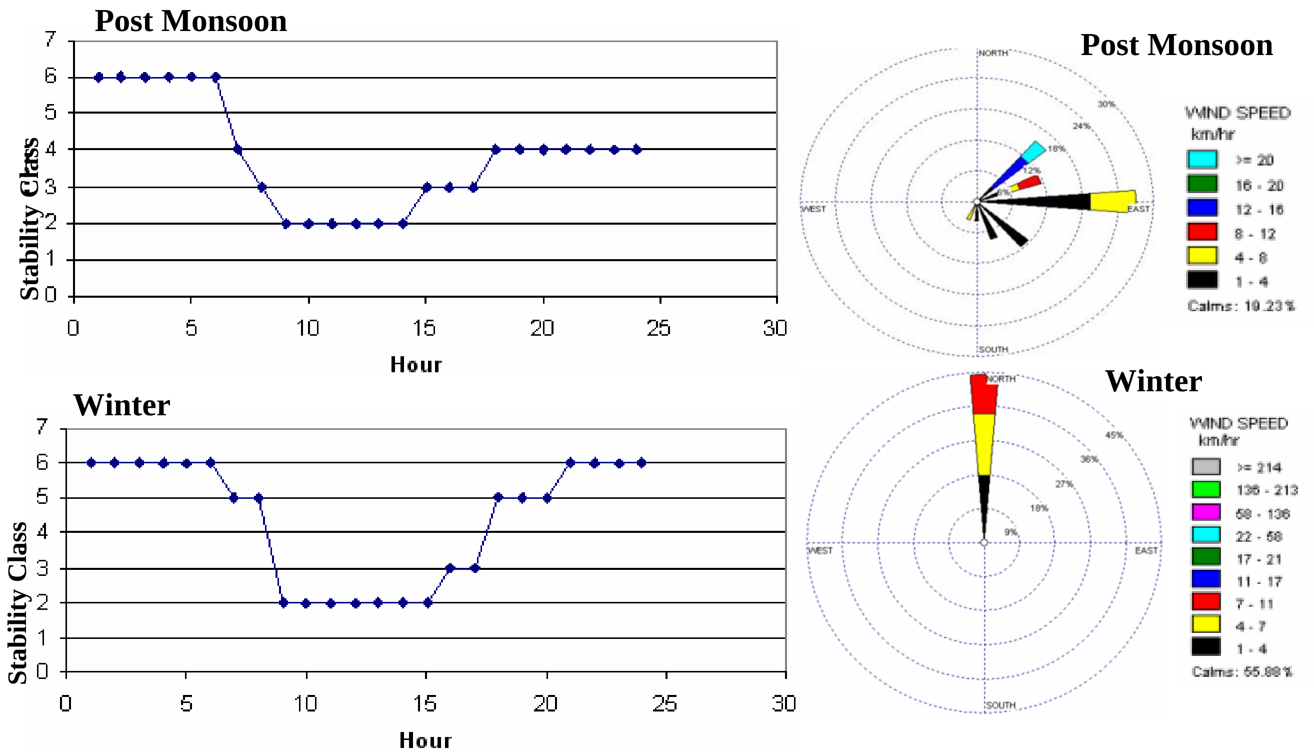

Figure 5.15: Seasonal Stability Classes and Windrose for Mulund Site

The model runs were carried out separately for area, road, road side dust and vehicular sources to quantify their individual contribution towards the overall ground level concentration. Another model run was carried out by considering all sources together. Grid wise hourly emission loads from vehicular and area sources are given in the **Annexure 5**. **Tables 5.25** gives the comparison of PM_{10} concentrations for different scenarios by considering the highest ten concentration.

Table 5.25: Comparison of PM_{10} concentrations at Mulund for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.1	0.1	0.1
Vehicular sources	43.7	45.4	44.6
Road side dust	465.5	482.8	474.1
Point sources	0.2	0.2	0.2
All sources	509.4	528.4	518.9
Post Monsoon			
Area sources	0.1	0.1	0.1
Vehicular sources	40.1	40.8	40.4
Road side dust	419.6	425.8	423.4
Point Sources	0.2	0.2	0.2
All sources	459.9	466.7	464.0
Winter			
Area sources	0.1	0.1	0.1
Vehicular sources	49.1	52.1	50.1
Road side dust	524.7	557.4	541.6
Point sources	0.3	0.4	0.4
All sources	573.7	609.6	592.3

* All values in $\mu g/m^3$

It indicates that contribution from road side dust is highest in winter at 541.6μg/m^3 and lowest of 423.4 μg/m^3 in post monsoon On the other hand, vehicle sources contribute maximum in winter with 50.1 μg/m^3 and lowest of 40.4 μg/m^3in post monsoon.

Table 5.26 gives ground level concentrations of PM_{10}. Road side dust contributes the maximum n all seasons but highest in winter. Percent contributions of vehicle sources in summer, post monsoon and winter are 8.60, 8.70 and 8.60% respectively.

Table 5.26: Ground Level Concentrations of PM_{10} at Mulund Site

	Concentration (μg/m^3)	% Contribution
Summer		
Area sources	0.04	0.00
Vehicular sources	20.7	8.60
Road side dust	220.0	91.40
Point sources	0.001	0.0
All sources	240.74	100.0
Post Monsoon		
Area sources	0.04	0.00
Vehicular sources	18.8	8.70
Road side dust	197.1	91.3
Point sources	0.001	0.0
All sources	215.9	100.0
Winter		
Area sources	0.05	0.00
Vehicular sources	13.6	8.60
Road side dust	144.9	91.40
Point sources	0.001	0.0
All sources	158.5	100.0

Maximum, Minimum and average values of ten highest concentrations of NOx are given in **Table 5.27.** It shows that vehicle source mainly dominate the pollutant. Area source contributions are very low**.**

Table 5.27: Comparison of NOx concentrations at Mulund for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.05	0.05	0.05
Vehicular sources	269.35	279.53	274.44
Point sources	4.70	4.82	4.77
All sources	272.22	282.57	277.43
Post Monsoon			
Area sources	0.06	0.07	0.06
Vehicular sources	247.25	251.84	249.54
Point Sources	3.91	4.04	3.98
All sources	249.67	254.37	251.99
Winter			
Area sources	0.08	0.09	0.08
Vehicular sources	301.86	320.35	311.55
Point sources	8.86	10.77	9.60
All sources	302.27	320.69	311.86

* All values in µg/m^3

Table 5.28 gives ground level concentrations of NOx at Mulund, indicates that NOx is mainly contributed by vehicles. It shows that the contribution from vehicles sources is maximum. Contributions from area sources are very low.

Table 5.28: Ground Level Concentrations of NOx at Mulund Site

	Concentration (µg/m^3)	% Contribution
Summer		
Area sources	0.033	0.03
Vehicular sources	115.84	99.97
Point sources	0.00	0.00
All sources	115.88	100.00
Post Monsoon		
Area sources	0.04	0.05
Vehicular sources	83.46	99.95
Point sources	0.00	0.00
All sources	83.50	100.00
Winter		
Area sources	0.027	0.02
Vehicular sources	127.11	99.97
Point sources	0.008	0.01
All sources	127.15	100.00

5.4.8 Inter Comparison of Seven Sites

Seven sites representing background, kerb and residential, commercial and industrial sites show variable contributions depending upon the local meteorology and source strengths. **Tables 5.29 and 5.30** summarize the average PM_{10} and NO_x at seven sites due to different sources. These values are average of ten highest concentrations for three seasons within the 2 Km x 2 Km areas.

Table 5.29: Average PM_{10} concentrations due to Different Sources

	Area Source	Vehicular Sources	Road side Dust	Point Source	All Sources
Colaba	1.0	15.2	89.97		107.03
Dadar	0.4	30.9	362.1		372.1
Dharavi	0.4	22.6	222.3		244.1
Khar	0.4	25.6	281.8		485.5
Andheri	0.3	54.3	431.1	0.4	485.5
Mahul	0.2	37.8	300.7	24.1	327.1
Mulund	0.1	45.0	479.7	0.3	525.1

The above table indicates that PM_{10} is highest at Mulund, followed by Khar and Andheri. At Mulund, it is 525 µg/m^3 mainly contributed by road side dust. Colaba is cleanest among all the sites with average PM_{10} concentration of 107.03 µg/m^3. The modeling results indicate that road side dust contributes the maximum followed by vehicular and area sources. Only at Mahul site, the point source contribution is higher due to big industries located in the region.

Table 5.30: Average NOx concentrations due to Different Sources

	Area Source	Vehicular Sources	Point Source	All Sources
Colaba	0.3	117.8		125.0
Dadar	0.3	212.0		212.2
Dharavi	0.4	218.7		219.9
Khar	0.2	170.3		170.5
Andheri	0.2	211.7	21.1	212.4
Mahul	0.2	240.6	0.0001	253.4
Mulund	0.1	278.5	6.1	280.4

Table 5.30 shows the average of ten highest concentrations of NOx. It is highest at Mulund followed by Mahul, Dharavi, Andheri, Dadar, and Khar. At Mulund it is 280.4 µg/m^3. Colaba values were much lower compared to other sites where concentration is 125.0 µg/m^3. Vehicular sources dominate the NOx contributions at all sites. The contributions by point and area sources are very low.

With a view to understand the possible variation in measured and predicted values at the seven sites, values of PM_{10} and NOx have been compared in **Table 5.31**.

Table 5.31: Comparison of Observed and Predicted PM_{10} and NO_x concentrations

	Observed PM_{10}	Predicted PM_{10}		Observed NOx	Predicted NOx
Summer					
Colaba	91.0	35.6		18.0	43.8
Dadar	116.0	119.1		31.0	53.5
Dharavi	176.9	45.9		39.0	35.4
Khar	62.0	136.9		14.0	35.1
Andheri	84.0	168.0		17.0	44.0
Mahul	98.0	170.5		20.0	101.7
Mulund	163.0	240.7		51.0	115.9
Post Monsoon					
Colaba	140.7	11.8		37.7	15.8
Dadar	212.4	87.7		63.0	44.9
Dharavi	244.8	71.4		53.1	50.4
Khar	228.8	77.3		66.3	42.5
Andheri	223.4	176.7		78.9	84.3
Mahul	218.7	106.3		53.5	73.7
Mulund	234.3	215.9		53.2	83.5
Winter					
Colaba	183.7	41.3		53.0	49.3
Dadar	253.3	201.9		98.7	123.8
Dharavi	272.5	100.5		69.6	87.3
Khar	263.1	151.3		74.8	68.8
Andheri	236.8	243.8		78.7	106.5
Mahul	270.9	262.3		72.0	111.9
Mulund	279.5	158.5		71.0	127.2

As can be seen from the table the highest variation is seen at Colaba. The model results when compared with measured concentrations for summer the variation is too large in terms of percentage difference. Model results are highly variable for summer both for PM_{10} and NOx. This high variation can be attributed to highly variable meteorology during summer. The site specific meteorology in Mumbai get very complex due to buildings and other structures. IMD meteorology has been seen to be not correlated most of the time with seven site meteorology. **Figure 5.16** gives the average of all season for PM_{10} and NOx. Measured PM_{10} concentrations for Colaba and Dharavi are considerably higher than other sties, when compared with predicated values. At Colaba, it can be attributed to non addition of PM from Naval Dockyard and some under estimation of shipping activities. On the other hand, at Dharavi, the large adjoining areas near the site has very complex and highly variable activities such as refuse burning, wood burning, small scale recycling industries etc. These activities could be responsible for high measured concentrations. NOx values are much more consistent at most of the sites as NOx sources are more evenly distributed. Highest variation is seen at Mahul and Mulund site, where predicted values exceed much more than other places. Higher predicted values at Mulund (a Kerb site) could be due to possibility of much cleaner vehicles operating than the emission factors considered. At Mahul site, lower observed values could be high influence of local meteorology and high elevation of emission.

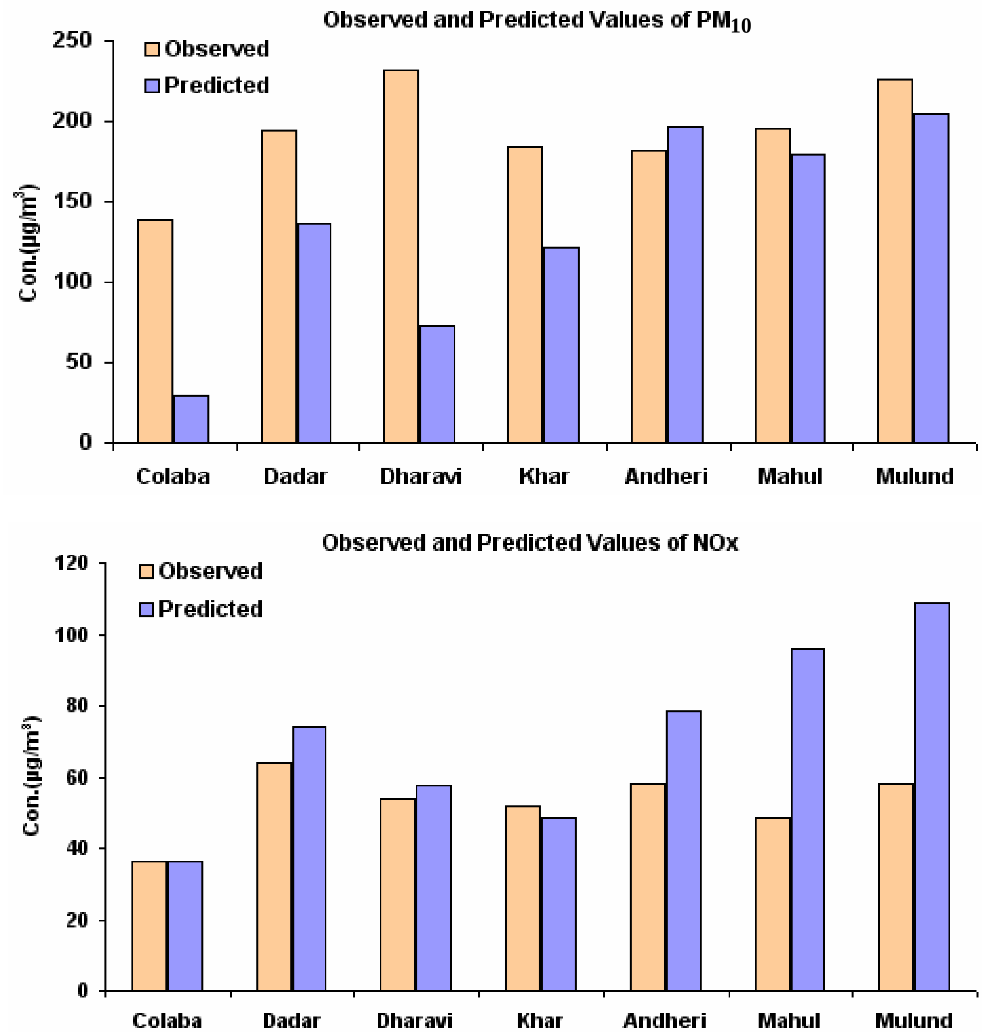

Figure 5.16: Average levels of observed and predicted PM_{10} and NOx at seven sites

5.5 Dispersion Modelling for the Whole Mumbai City

Air quality modeling was also carried out for the whole city of Mumbai. The Dispersion Modelling run for the Whole Mumbai City was carried out with a view to see the combined effect of all sources as also contribution of all grids to every other grid. The study area was divided into grids of size 2km x 2km. The 24 hourly emission loads for the city from all sources were computed and used. Details of loads have already been discussed earlier. The wind data used for the city modeling was for Dadar site as this site represented the city lower atmosphere better. Earlier modeling results with Santacruz IMD data did not yield better results when compared with measured values.

The model run yielded many values across the city of which 10 highest concentration points were selected to delineate the PM_{10}, and NOx profiles. **Table 5.32** presents the results of PM_{10} for different sources with the highest 10 concentrations, where as **Tables 5.33** presents the values of NOx. Whole city predicted values through isopleths are presented in **Figures 5.17 through Figure 5.22** for PM_{10} and NOx for all three seasons. As can been seen the maximum contribution for PM_{10} in all the three seasons is from road side dust followed by point sources and least is by vehicular sources.

Table 5.32: PM_{10} concentrations at Mumbai for different Scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	1.48	1.60	1.53
Vehicular sources	9.01	9.87	9.57
Road side dust	164.84	181.13	172.76
Point sources	19.90	45.70	32.56
All sources	175.63	191.76	183.27
Post Monsoon			
Area sources	1.05	1.25	1.15
Vehicular sources	6.30	6.63	6.49
Road side dust	108.60	126.20	114.72
Point sources	20.00	38.60	29.65
All sources	115.01	132.23	120.72
Winter			
Area sources	2.31	2.48	2.37
Vehicular sources	13.48	14.04	13.89
Road side dust	256.37	276.46	265.47
Point sources	18.80	71.56	44.55
All sources	270.72	291.48	280.13

All values in $\mu g/m^3$

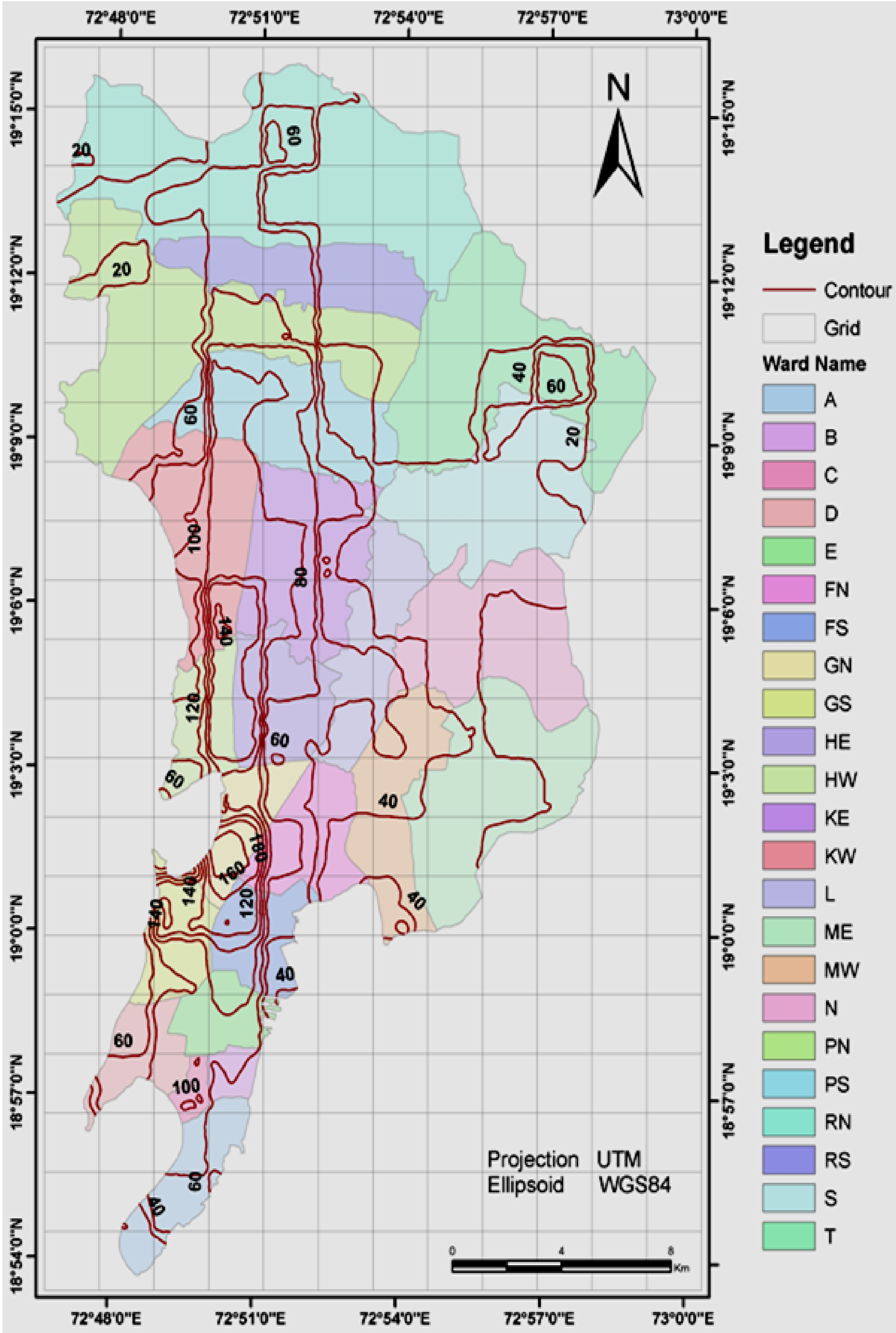

Figure 5.17: Isopleths of PM_{10} due to all Sources during Summer Season

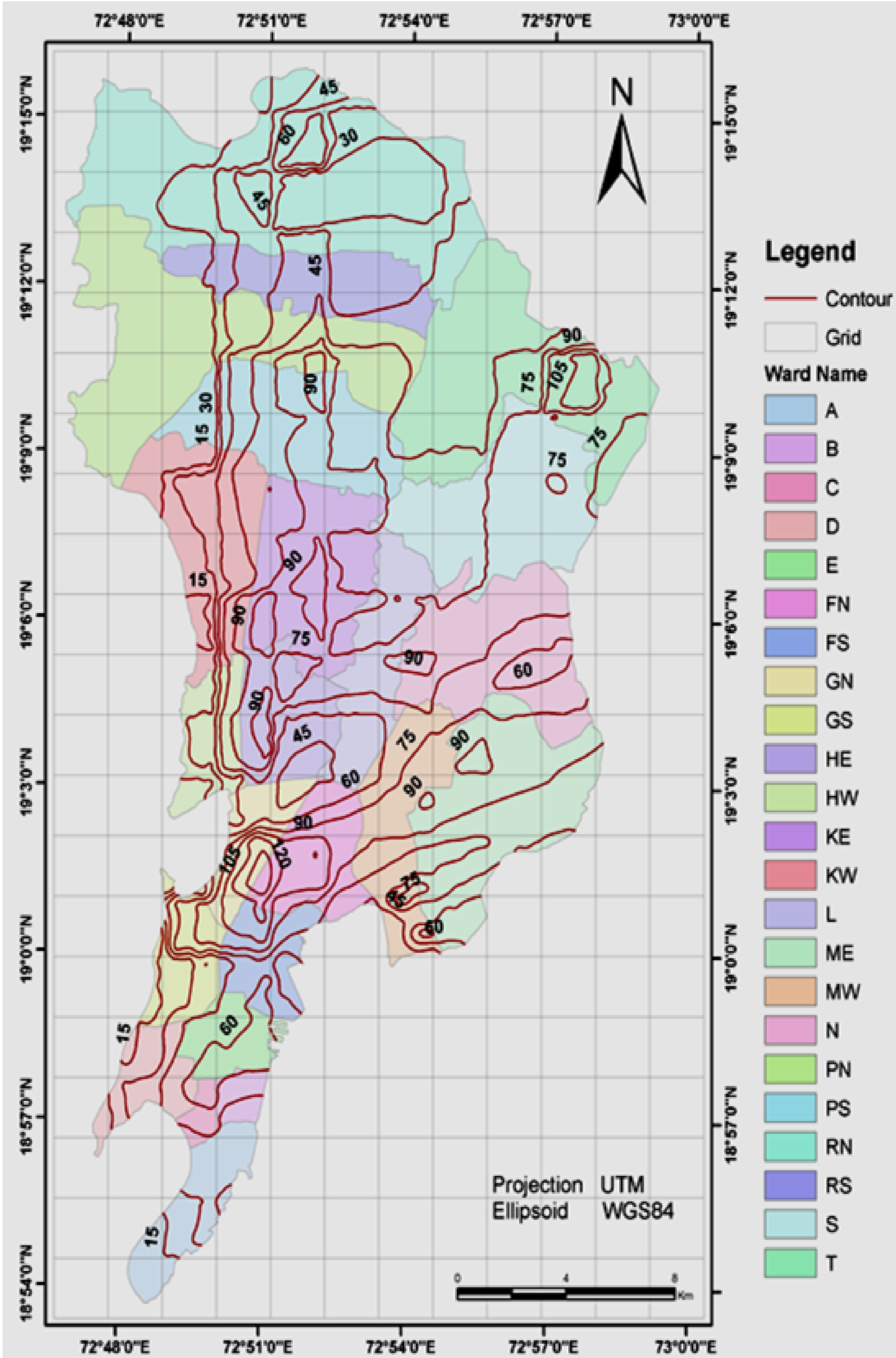

Figure 5.18: Isopleths of PM_{10} due to all Sources during Post Monsoon

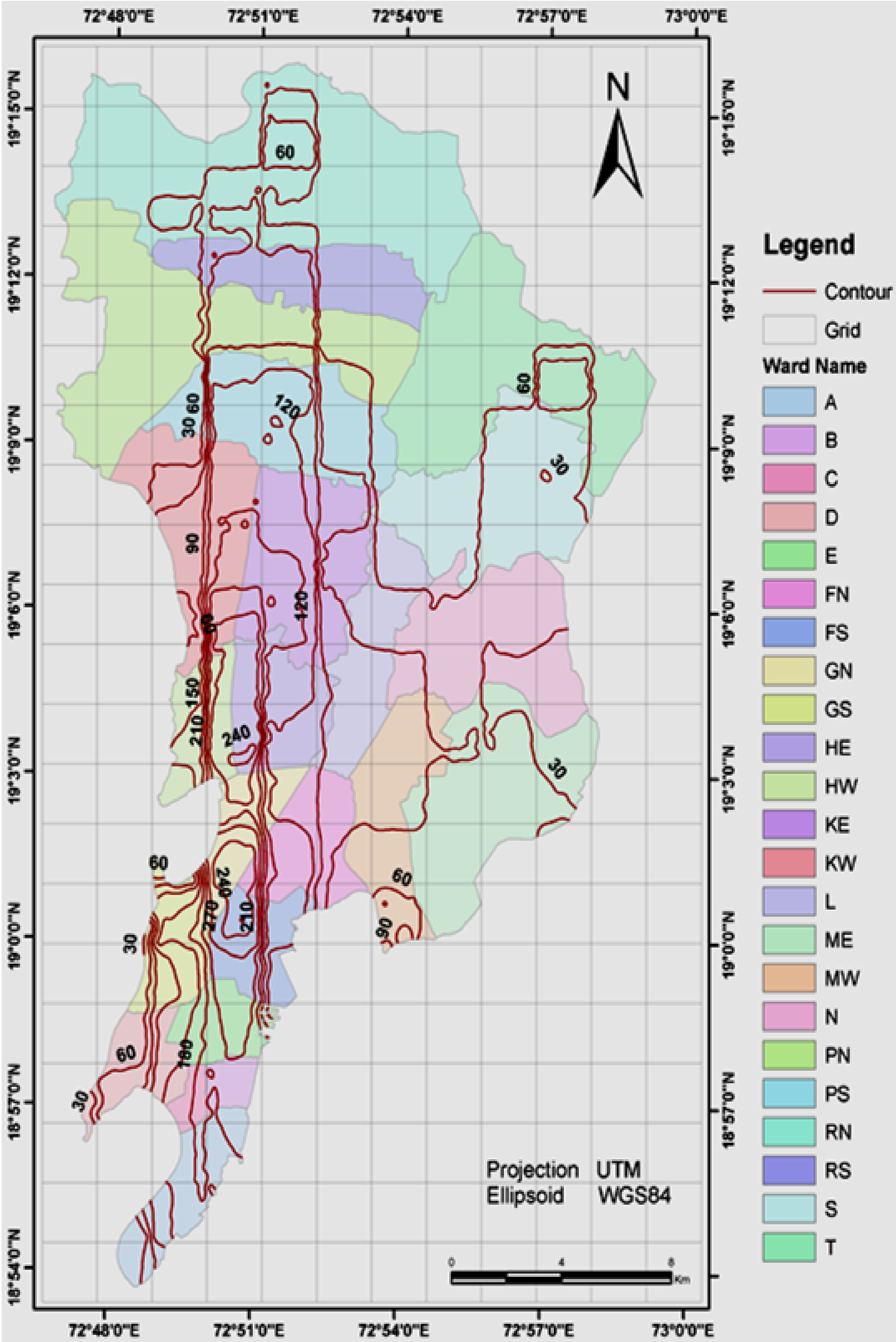

Figure 5.19 : Isopleths of PM_{10} due to all Sources during Winter

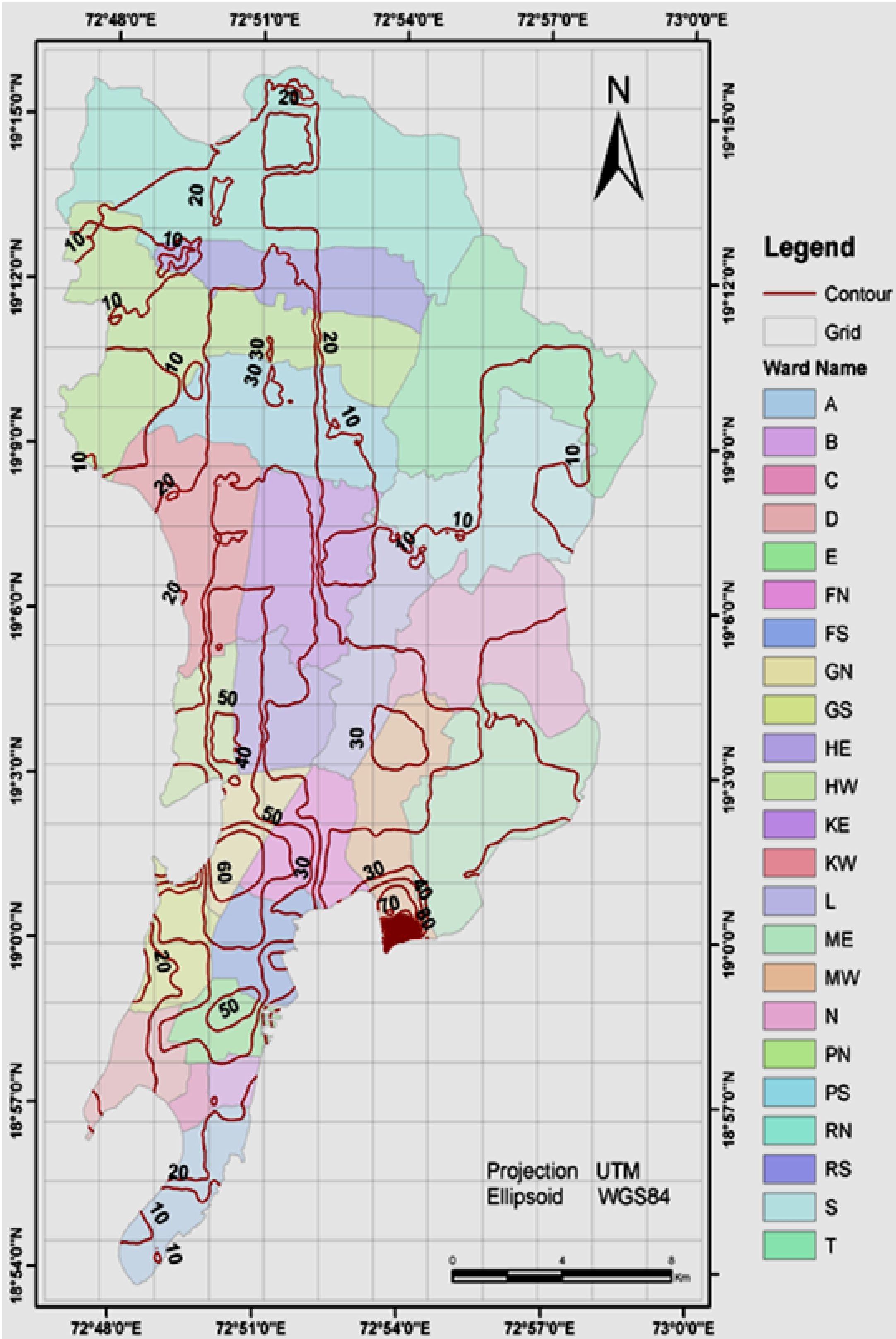

Figure 5.20: Isopleths of NOx due to all Sources during Summer

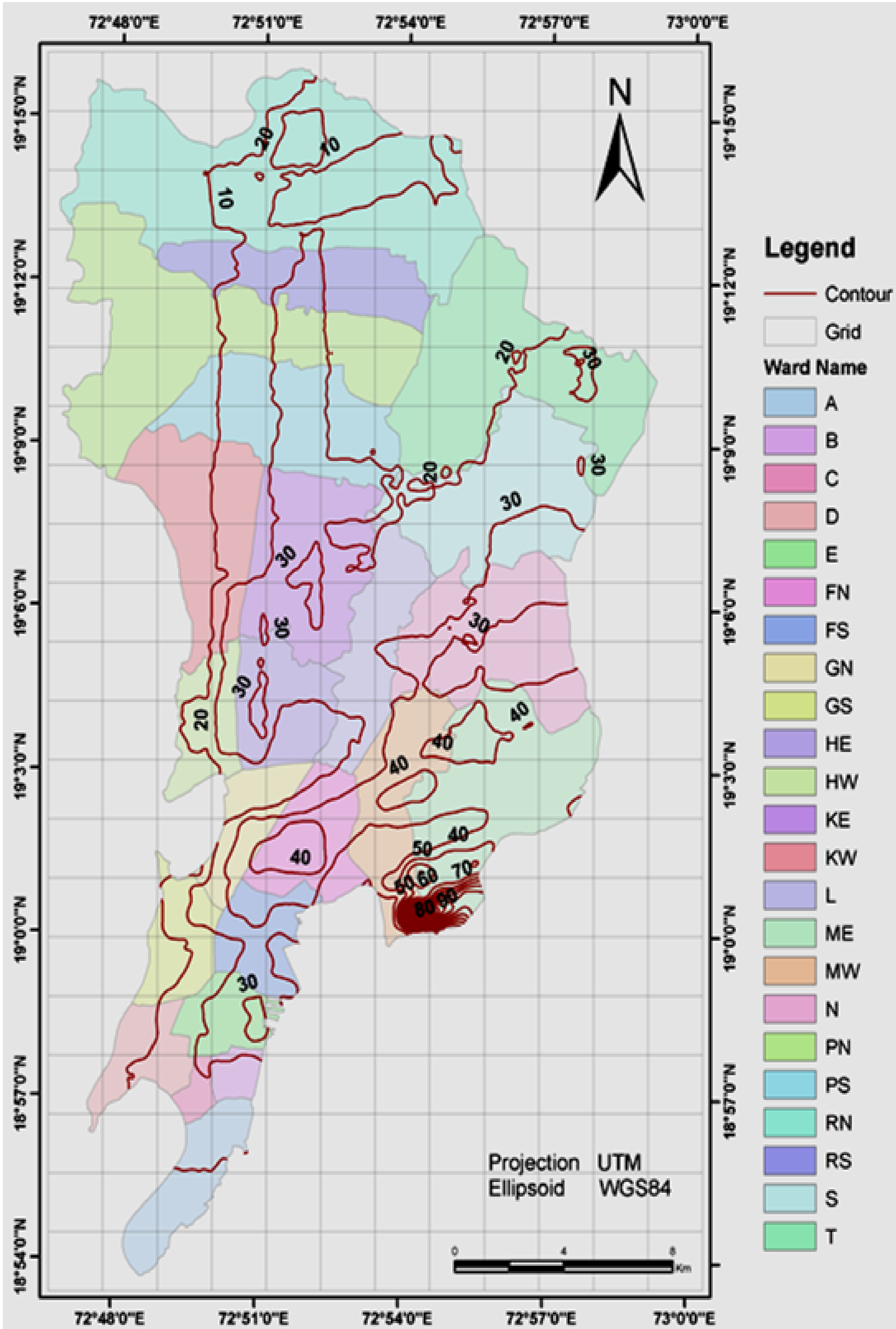

Figure 5.21: Isopleths of NOx due to all Sources during Post Monsoon

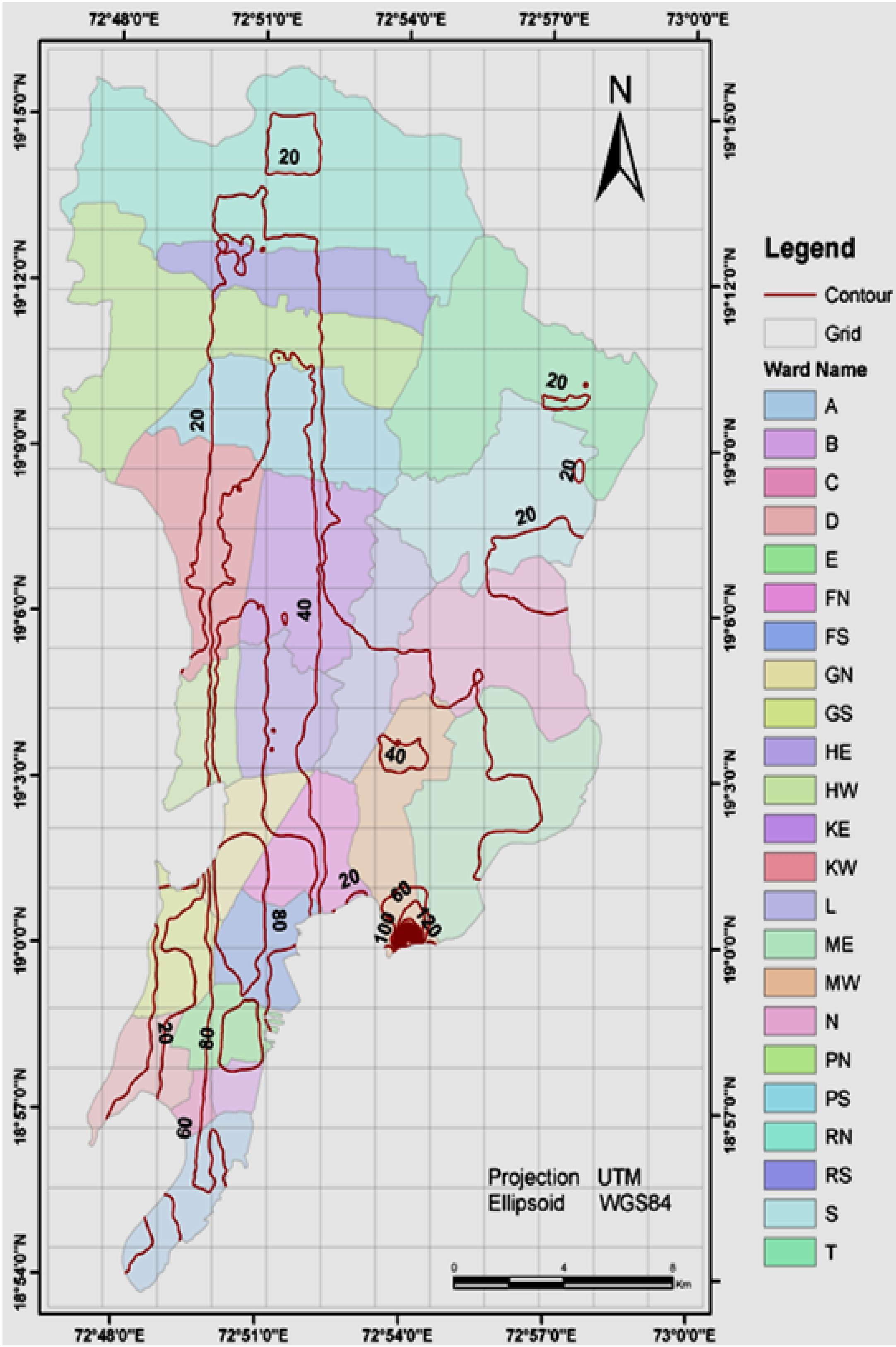

Figure 5.22: Isopleths of NOx due to all Sources During Winter

Table 5.33: Comparison of NOx concentrations at Mumbai for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.54	0.54	0.54
Vehicular sources	61.98	66.10	64.10
Point sources	27.30	184.50	76.87
All sources	66.21	201.06	99.29
Post Monsoon			
Area sources	0.37	0.40	0.39
Vehicular sources	43.59	47.16	45.60
Point sources	66.20	165.20	96.20
All sources	91.16	187.28	119.40
Winter			
Area sources	0.93	0.97	0.95
Vehicular sources	89.42	93.07	91.40
Point sources	28.20	278.40	107.51
All sources	91.02	303.36	151.59

All values in $\mu g/m^3$

An attempt was also made to compare the predicted concentrations when the model was run with entire city emission loads at seven sites with measured concentrations. **Table 5.34** given below gives the observed and predicted concentrations at seven monitoring sites for all the three seasons.

Table 5.34: Comparison of PM_{10} and NOx concentrations at Mumbai

	Observed PM_{10}	Predicted PM_{10}		Observed NOx	Predicted NOx
Summer					
Colaba	91.0	58.0		18.0	15.0
Dadar	116.0	145.0		31.0	59.0
Dharavi	178.0	82.0		39.0	42.0
Khar	62.0	126.2		14.0	48.0
Andheri	84.0	112.0		17.0	37.0
Mahul	99.0	55.0		20.0	20.0
Mulund	163.0	63.0		51.0	11.0
Post Monsoon					
Colaba	141.0	100.0		37.7	4.8
Dadar	212.0	102.0		63.0	33.0
Dharavi	245.0	68.0		53.1	17.0
Khar	229.0	58.0		63.3	21.5
Andheri	223.0	83.0		78.9	25.0
Mahul	219.0	32.0		53.5	32.0
Mulund	233.0	57.0		53.2	20.4
Winter					
Colaba	184.0	165.0		53.0	46.0
Dadar	253.0	268.0		98.7	90.0
Dharavi	263.0	207.0		74.8	65.0
Khar	273.0	203.0		69.6	62.0
Andheri	237.0	164.0		78.7	58.0
Mahul	271.0	52.0		72.0	32.0
Mulund	279.0	22.0		71.6	18.0

Figure 5.23 and 5.24 present the comparison of measured and predicted concentrations for PM_{10} and NOx for all seven sites.

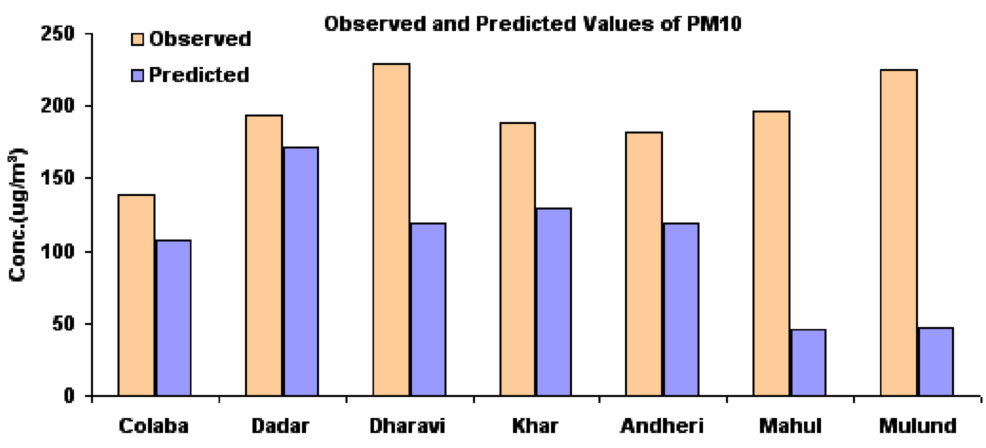

Figure 5.23: Comparison of measured and predicted concentrations for PM_{10} for all seven sites

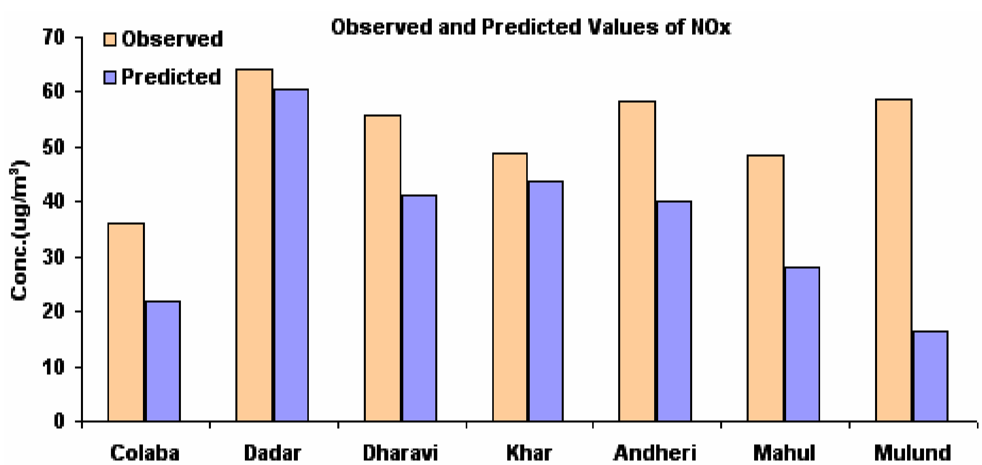

Figure 5.24: Comparison of measured and predicted concentrations for NOx for all seven sites

As can been seen from the **Table 5.34 and Figure 5.23** the variation is much larger between measured and predicted values when the predication is made with overall whole city inventory. This difference can be attributed to site specific local conditions. Other factor which gives lower prediction for PM_{10} and NOx is the uncertainty of emission inventory as many sources are highly diurnal and have high inter seasonal variation. Uncertain emission loads which influence local measured conditions are refuse, landfill site burning, small scale industries, Naval Dockyard emission, airport vehicles operations, variable conditions of road and highly uncertain schedule as well as emissions from construction sites.

City scale modeling is unable to account for more precise local sources. City based NOx predictions, however are much closer to measured concentrations as NOx sources are widely and evenly distributed.

5.6 Conclusions

Air quality modeling using ISCST3 model for all the seven specific sites, provides an insight into the possible contributions from all major sources. Two sets of modeling exercises were performed. The local sources and their impacts were assessed by using emission inventory of 2 km x 2 km based on primary survey. The other set of exercise was completed with overall emission inventory of the city and its impact on the seven sites. Contributions of all sources in all three seasons were estimated.

The measured PM_{10} concentrations are highest at Dharavi followed by Mulund. Colaba the background site appears to be the cleanest site. Comparison of measured and predicted concentrations shows that site specific average concentrations predicted using primary survey based emission inventory are close to measured values to large extent as can be seen. Uncertainties related to emission inventories at some locations lead to difference between predicted and observed values. City wise modeling shows higher variation at seven sites with whole city inventory. This variation is highest for PM as emission inventories for PM are variable for many sectors such as refuse burning, landfill waste burning, construction activities, illegal small scale industrial operations, dust from variable load conditions, road constructions etc. NOx values across the city in both cases are much closer to measured values. Primary survey based predicted values for NOx was more variable for summer than in postmonsoon and winter. The highly complex meteorology during summer compared to other seasons could be the major factor for larger difference in predicted values. The modeling results indicate that PM_{10} is mainly contributed by road dust, whereas vehicular sector dominates NOx at most of the sites.

In next Chapter, modeling techniques have been applied for all the sectors viz. vehicular, area and industrial and possible control options with specific objectives to get highest reduction. Strategies and control options analyses have been used for arriving at prioritize action plan.

Chapter 6

Emission Control Options and Analysis

6.1 Introduction

There are many sources of particulate matter emission impacting the ambient air quality of the city of Mumbai; however the major ones are automobiles, resuspended dusts and industries. The impact of the industrial sector is reducing due to various reasons such as closure of industries, shift to clean fuel, better compliances and discharge of emission at higher elevations. The emission inventory discussed earlier indicates that though point sources contribution is reasonably high particularly due to power plant in terms of total load; however its impact on the ambient air quality is low due to emissions at a higher elevation, providing high dilution and dispersion. CMB modeling carried out indicates that the impacts on PM mass due to industries are not high.

The monitored data of many other agencies such as MPCB, BMC and NEERI suggests that the ambient levels are highly impacted due to ground level emissions. The major ground level emission source is automobile sector. The mobile (line) source emissions are not only dependent upon the number of vehicles registered but also on the actual number plying on the roads, speed of movement and the conditions of vehicles besides many other factors. The area sources which emit at ground level also have significant impact on the PM levels in the atmosphere; however it could be more localized, particularly from the sources such as bakeries, crematories, construction etc. Some of the other major sources of the area sources are resuspension and garbage burning. Some of these sources can have significant local impact on the ambient air quality for a shorter duration.

Vehicle activity in the city has shown tremendous increase over a period of last 10 years. Vehicle kilometer travelled for the city has been showing consistent increase; however, at some junctions the traffic congestion is so high that VKT rise is ironically not so high but emission is high. Saturation traffic situation where average speed goes on decreasing, the VKT may not increase as vehicles are not crossing a point for a long time. Increased levels of vehicular activity and resulting high levels of air pollution have led to active anti air pollution campaign by the non governmental organization (NGO) and judiciary. Many citizens forum have actively demonstrated the need to improve the air quality by raising awareness, undertaking public debate and urging judiciary to force action.

On the other hand, amongst the area sources, the scenario is highly variable some areas where no development in terms of construction activities has been seen, the domestic fuel quality have seen improvement. Overall a city growth pattern indicates that domestic fuel has become cleaner, bakeries /crematoria situation have not changed so much. Construction/ demolition related emission has gone up, refuse burning has increase and road dust related emissions have also shown increase.

Industrial emission has been consistently declining as many industries have closed down. Even small-scale industrial units are changing into commercial offices. Large industries are mainly located in limited areas and their compliances have improved.

6.2 Summary of Prominent Sources

Emission inventory was carried for the seven representative sites of the city as well as for the whole city. The section presents the summary of emission inventory, CMB results and varied components of strategies.

6.2.1 Emission Inventory

Inventory methodology and results have already been discussed in **Chapter 3**. The summary of emission inventory prepared for Mumbai is given in **Table 6.1.**

Vehicle contributes 917 T/year of which HDDV is major contributors of PM. Total contribution from other vehicle categories for PM is about 628 T/ year. Industrial emission for PM is about 7526 T/year of total emission of 26811 T/year. Highest PM is from road dust (paved + unpaved road dust). Highest percentage of NOx is contributed from HDDV followed by Power Plant. Percent contributions of sources of PM and NOx are given in **Figure 6.1.**

The action plan presented later therefore, makes an attempt to delineate strategies on the basis of understanding of the PM and NOx sources and their possible contribution to the ambient and kerb side air quality. Each of the strategies will have to be looked at from the point of view of its impact level in terms of reduction in PM and NOx emissions (low, medium, high); its feasibility from implementation and administrative point of view (easy, moderately difficult and difficult); financial viability (low, medium and high costs) besides issues relating to their long and short term impacts.

Table 6.1: Emission Load for Mumbai City from All Sources

	PM	CO	SO_2	NOx	HC
a) Area Source					
Bakeries	1554.6	11348.1	25.2	120.1	10287.4
Crematoria	300.7	2213.0	7.9	44.4	1991.9
Open eat outs	281.6	167.8	16.2	9.4	0.1
Hotel restaurants	593.1	755.2	274.0	499.0	25.4
Domestic sector	564.9	19723.7	1262.0	9946.9	368.1
Open burning	734.0	2292.0	27.0	164.0	1173.0
Landfill Open Burning	2906.0	9082.0	108.0	649.0	4649.0
Construction Activity	2288.9				
Locomotive (Cen +We Rly)	514.0	3147.0	1449.0	19708.0	
Aircraft	75.6	788.4	77.0	985.5	32.3
Marine vessels	1.8	3.3	19.7	17.9	1.5
Total (A)	**9815.3**	**49520.5**	**3266.0**	**32144.2**	**18528.6**
B) Industrial Source					
Power plant	5628.3	3215.7	24473.3	28944.5	1266.6
39 Industries	503.7	879.7	28510.2	8435.2	116.8
Stone crushers	1394.3				
Total (B)	**7526.3**	**4095.4**	**52983.5**	**37379.7**	**1383.4**
C) Line Source					
2 wheelers	70.1	3303.2	2.7	540.5	1221.2
3 wheelers	225.9	1320.9		363.7	3943.5
Car diesel	313.8	1150.5	87.2	1063.3	435.8
Car petrol	15.7	7867.5	13.1	313.7	496.6
HDDV	916.7	4435.5	126.7	6875.0	273.5
Taxies	2.6	778.6		13.0	467.1
Paved Road dust	3163.0				
Unpaved Road dust	4761.4				
Total (C)	**9469.2**	**18856.2**	**229.7**	**9169.2**	**6837.7**
Total (A+B+C)	**26810.8**	**72472.1**	**56479.2**	**78693.1**	**26749.7**

* All values expressed as (T/Year)

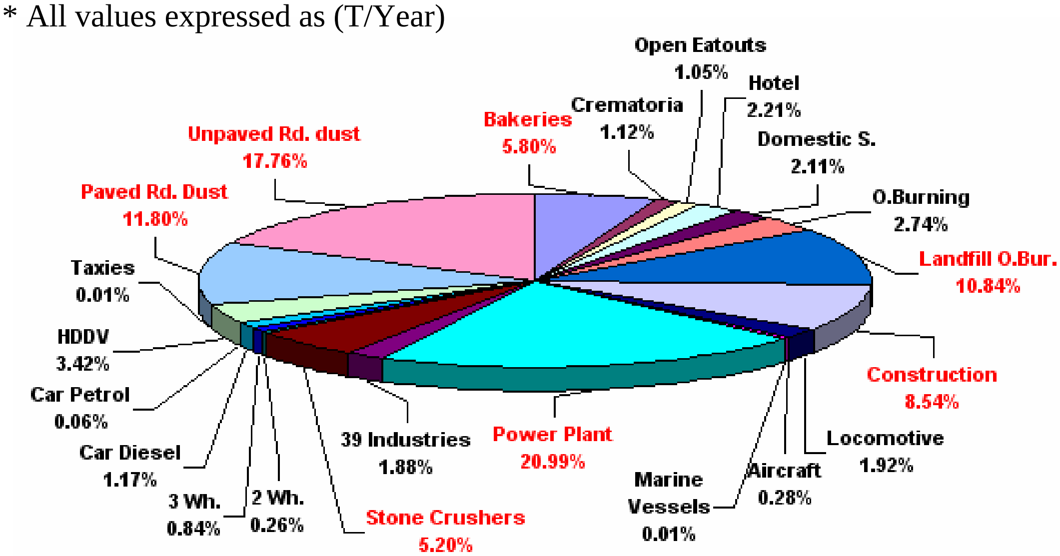

Figure 6.1: Percent contributions of PM from Various Sources in Mumbai City

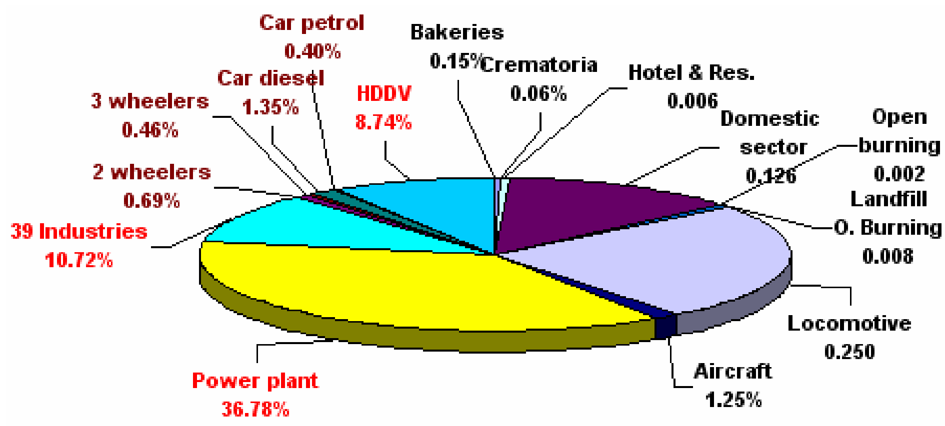

Figure 6.1 (Contd...): Percent contributions of NOx from Various Sources in Mumbai Cit

Cost effectiveness analysis and assessment of institutional aspects have been looked at from the angle of their sustained efficacies. Some of these issues need examination keeping in view the existing laws and recent directives of the court of the land (High or Supreme Courts). Components relevant to industrial, vehicle, area sources and public awareness for the purpose of delineating strategies are given in **Table 6.2**.

Table 6.2: Various Components Relevant to Delineating Strategies

Sr. No.	Sectors	Actions subcomponent	Possible Responsible agencies
Vehicular Source			
1.	Vehicle Technology	Engine technology, combustion efficiencies (cleaner engines), type of vehicles-2-4 stroke, CNG engines, electric vehicle etc.	Manufacturers
2.	Fuel Quality	Diesels levels, other fuels and their levels of sulphur, benzene etc.	Oil companies
3.	Fuel Mix	Petrol, Diesel, CNG, LPG, Biodiesel Demand and supply issues	Oil companies, Govt and judicial guidelines
4.	Inspection and Maintenance programme	PUC pattern, improvement in roadside inspection, lifetime monitoring, retrofitment	RTO, MoRTH etc.
5.	Standards	In-use vehicle standards, manufacturers standards (COP)	CPCB, MoRTH, SIAM others
6.	Traffic and congestion	Space available, road quality, traffic management, taxes, parking	RTO, MCGM
7.	Public Transport	Effectiveness and the benefits of certain measures to support public transportation system	BEST, NGO, MMRDA, Railways, Others
8.	Resupension of road dust	Measures to reduce by various means, sweeping, paving, wetting etc., pavement	MCGM, MMRDA

Table 6.2 (Contd..): Various Components Relevant to Delineating Strategies

Sr. No.	Sectors	Actions subcomponent	Possible Responsible agencies
Industrial Source			
1.	Growth of industries	Land use related issues, how the industrial growth will be directed in next decade in the city	Department of industries, Industrial associations
2.	Fuel Consumption	Based on the growth, positive or negative, the fuel consumption	MPCB, Oil companies
3.	Fuel Mix	Kind of fuel types needed, availability and cost, government directives	Oil companies, GAIL, MGL etc.
4.	Quarrying	Measures, land use issues	MPCB
Area Sources			
1.	Construction dust	Measures to reduce, guidelines for transportation of debris, excavation	MCGM, MPCB
2.	Refuse burning	Better collection and prevention of such activities	MCGM, MPCB
3.	Bakeries	Reduction of wood burning	MCGM, MPCB
4.	Crematoria and incinerator	Reduction of wood burning and air pollution control	MCGM, MPCB
5.	Domestic	Change in fuel use	MCGM, Mahanagar Gas
6.	Hotel and Restaurants	Use of fuel	MCGM
7.	Road side eat outs	Management, restrictions	MCGM
Public Awareness			
1.	Health	Assessment and promotion of health protection from the PM emissions exposure	Hospitals, NGO, MCGM
2.	Education	Reduction of transport needs, use of friendly mode of transport, free traffic zones, Pressure groups	NGO, RTO, DoEE
3.	Economic cost	Make people aware of the cost of pollution and provide knowledge of avoidance cost etc.	MCGM other Academic Agencies

6.2.2 Source Apportionment

Besides emission inventory, which provides an idea of load emitted in a grid and also total load added to the atmosphere, it is important to assess and measure the contribution from various sources using source apportionment analysis. Such analysis delineating various control options pertaining to the major sectors of concern. The detailed source apportionment analysis has been carried out using receptor modeling (CMB). Out of the several techniques used, factor analysis, principle component method and chemical mass balance, the latter is considered more close to the reality. However, the CMB method needs vary accurate source profiles in terms of various components and markers. In absence of precious information, analysis may lead to collinearity and higher uncertainties in interpretations.

CMB results discussed in **Chapter 4** indicate that the major particulates are contributed by re-suspended dust followed up by sources such as vehicles, secondary aerosols, wood /biomass burning, industries etc.

6.3 Future Growth Scenario

The emission inventory as discussed above indicates that specific sectors have certain sources which have potential of increase or decrease over a period time. In the current system, the future business as usual scenario of Mumbai after 5 and 10 years i.e. in the year 2012 and 2017 is considered. It has been assumed that there will not be any increase in industrial activities in 2012 and 2017. The vehicles and area sources would increase. The maximum, minimum and average concentrations of maximum ten occurrences of PM_{10} and NOx concentrations for winter seasons for 2012 and 2017 are given in **Tables 6.3 to 6.6. Figures 6.2 through 6.5** give the isopleths for PM_{10} and NOx for the year 2012 and 2017 during winter season.

Table 6.3: Comparison of PM_{10} concentrations in BAU 2012 of Mumbai for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	1.8	2.0	1.9
Vehicular sources	14.3	14.9	14.6
Road side dust	262.9	282.6	272.7
Point sources	19.90	45.70	32.56
All sources	278.7	298.8	288.4
Post Monsoon			
Area sources	1.4	1.6	1.5
Vehicular sources	9.8	10.5	10.1
Road side dust	169.0	204.7	182.7
Point sources	20.00	38.60	29.65
All sources	178.2	214.5	191.8
Winter			
Area sources	2.8	3.0	2.9
Vehicular sources	21.1	21.6	21.4
Road side dust	407.0	422.8	415.8
Point sources	18.80	71.56	44.55
All sources	429.7	445.9	438.4

All values in ($\mu g/m^3$)

Table 6.4: Comparison of NOx concentrations in BAU 2012 of Mumbai for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	0.7	0.7	0.7
Vehicular sources	98.6	103.3	100.4
Point sources	27.30	184.50	76.87
All sources	101.4	170.5	119.2
Post Monsoon			
Area sources	0.5	0.5	0.5
Vehicular sources	68.7	74.8	71.3
Point sources	66.20	165.20	96.20
All sources	98.3	218.7	129.6
Winter			
Area sources	1.1	1.2	1.2
Vehicular sources	140.1	142.4	141.3
Point sources	28.20	278.40	107.51
All sources	142.2	350.2	183.6

All values in $\mu g/m^3$

Table 6.5: Comparison of PM_{10} concentrations in BAU 2017 of Mumbai for different scenarios by considering the highest ten concentrations

	Minimum	Maximum	Average
Summer			
Area sources	2.0	2.1	2.0
Vehicular sources	19.7	20.5	20.0
Road side dust	361.3	388.4	374.6
Point sources	19.90	45.70	32.56
All sources	382.5	410.2	395.9
Post Monsoon			
Area sources	1.2	1.3	1.2
Vehicular sources	13.5	14.5	13.9
Road side dust	232.2	281.4	251.1
Point sources	20.00	38.60	29.65
All sources	244.7	294.6	263.4
Winter			
Area sources	3.0	3.2	3.1
Vehicular sources	29.0	29.7	29.4
Road side dust	559.4	581.0	571.4
Point sources	18.80	71.56	44.55
All sources	590.0	612.3	602.0

All values in $\mu g/m^3$

Table 6.6: Comparison of NOx concentrations in BAU 2017 of Mumbai for different scenarios by considering the highest ten concentration

	Minimum	Maximum	Average
Summer			
Area sources	0.7	0.7	0.7
Vehicular sources	135.5	141.9	138.0
Point sources	27.30	184.50	76.87
All sources	138.1	179.9	146.9
Post Monsoon			
Area sources	0.5	0.6	0.5
Vehicular sources	94.4	102.8	98.0
Point sources	66.20	165.20	96.20
All sources	112.9	231.3	143.1
Winter			
Area sources	1.2	1.3	1.2
Vehicular sources	192.5	195.7	194.2
Point sources	28.20	278.40	107.51
All sources	194.9	366.7	223.9

All values in $\mu g/m^3$

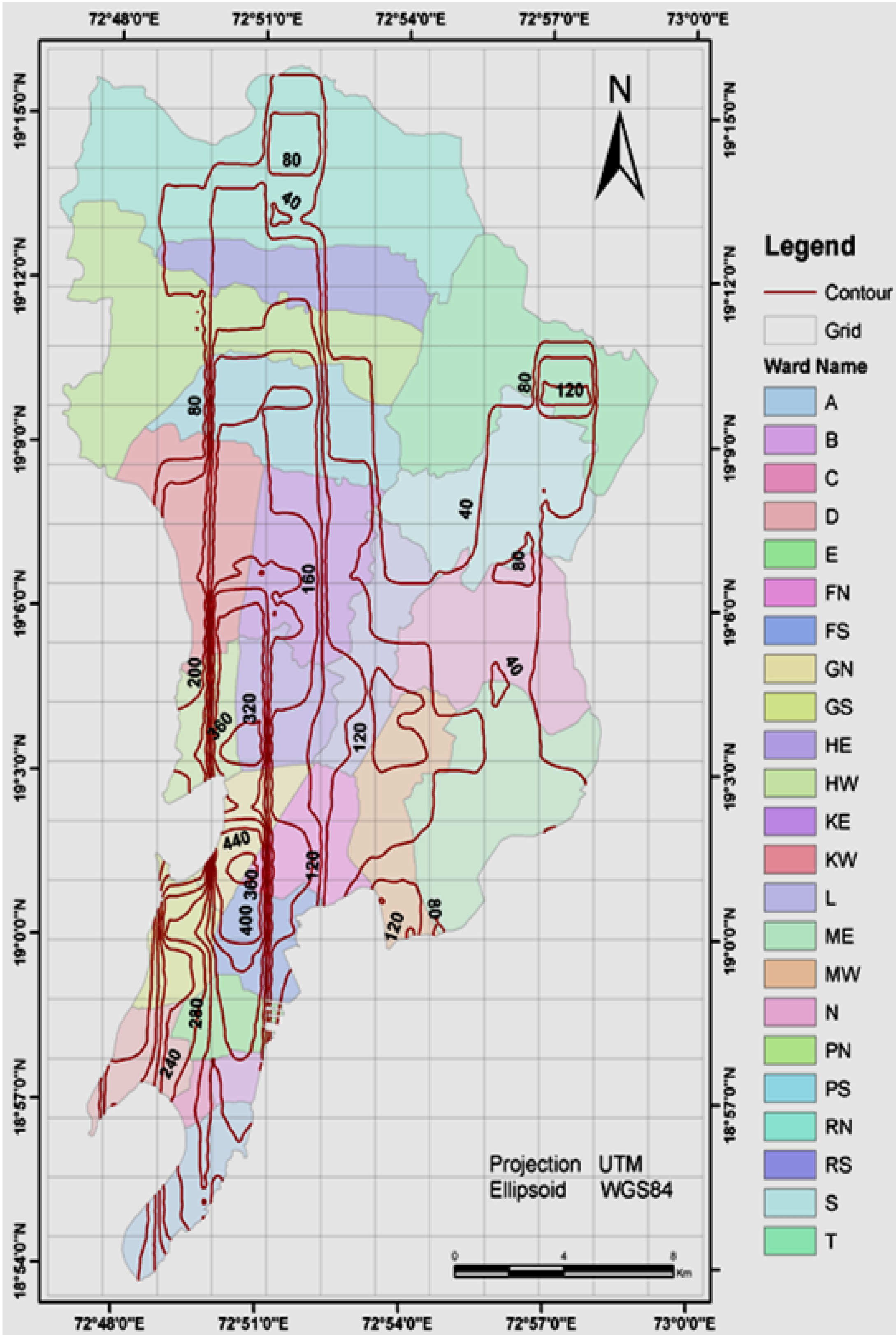

Figure 6.2: Isopleths of PM_{10} due to All Sources during Winter (BAU 2012)

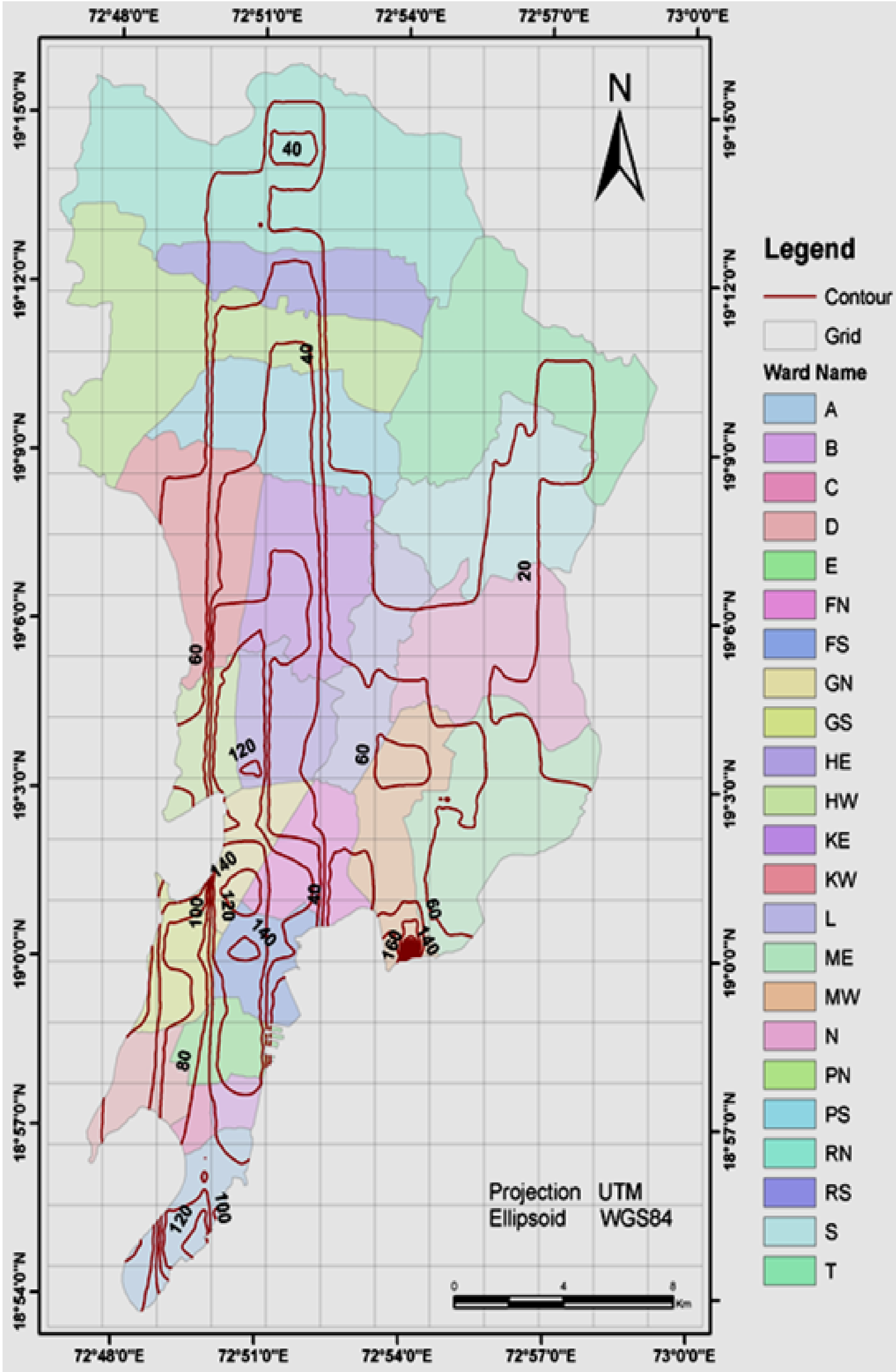

Figure 6.3: Isopleths of NOx due to All Sources during Winter (BAU 2012)

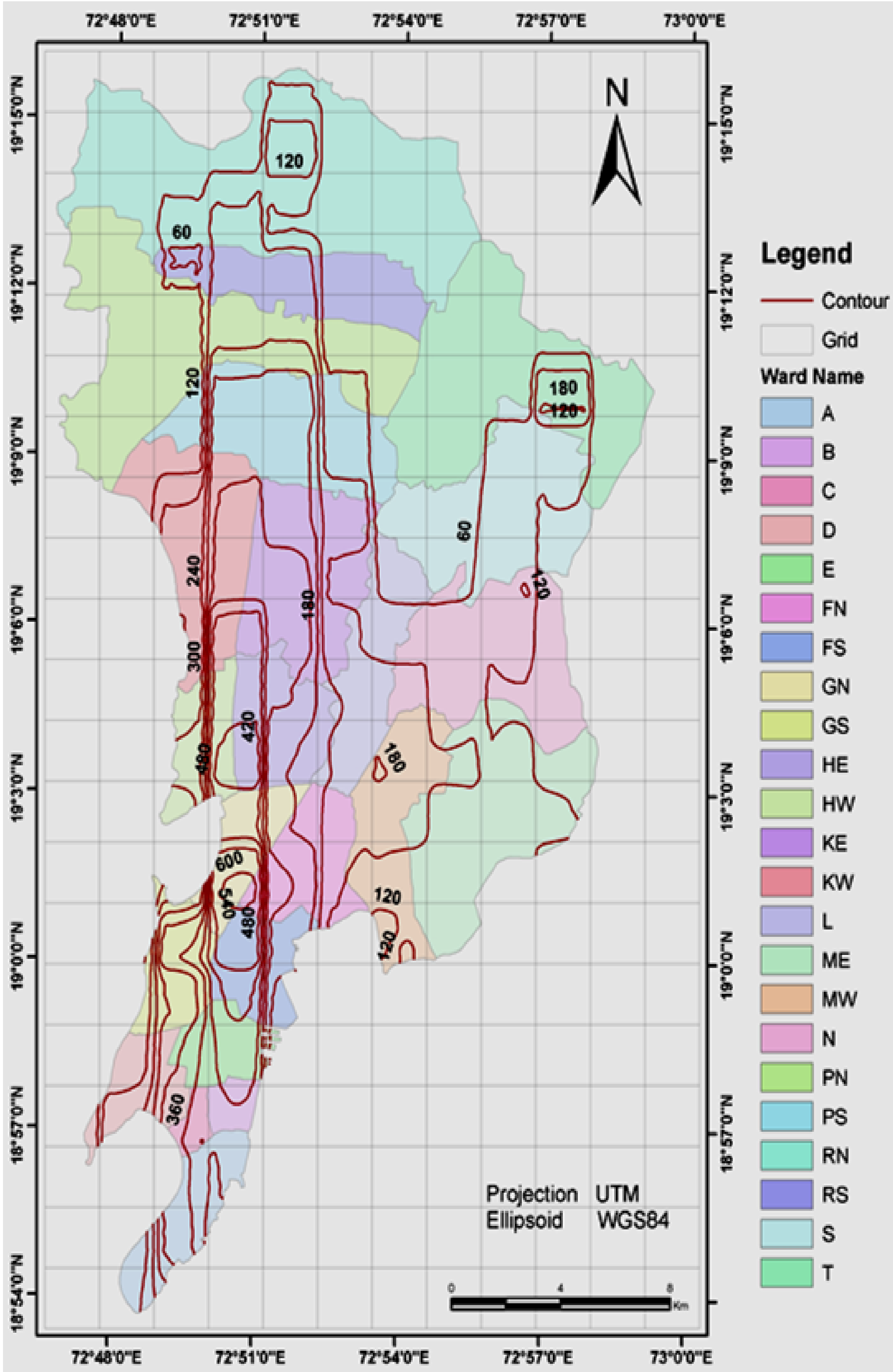

Figure 6.4: Isopleths of PM_{10} due to All Sources during Winter (BAU 2017)

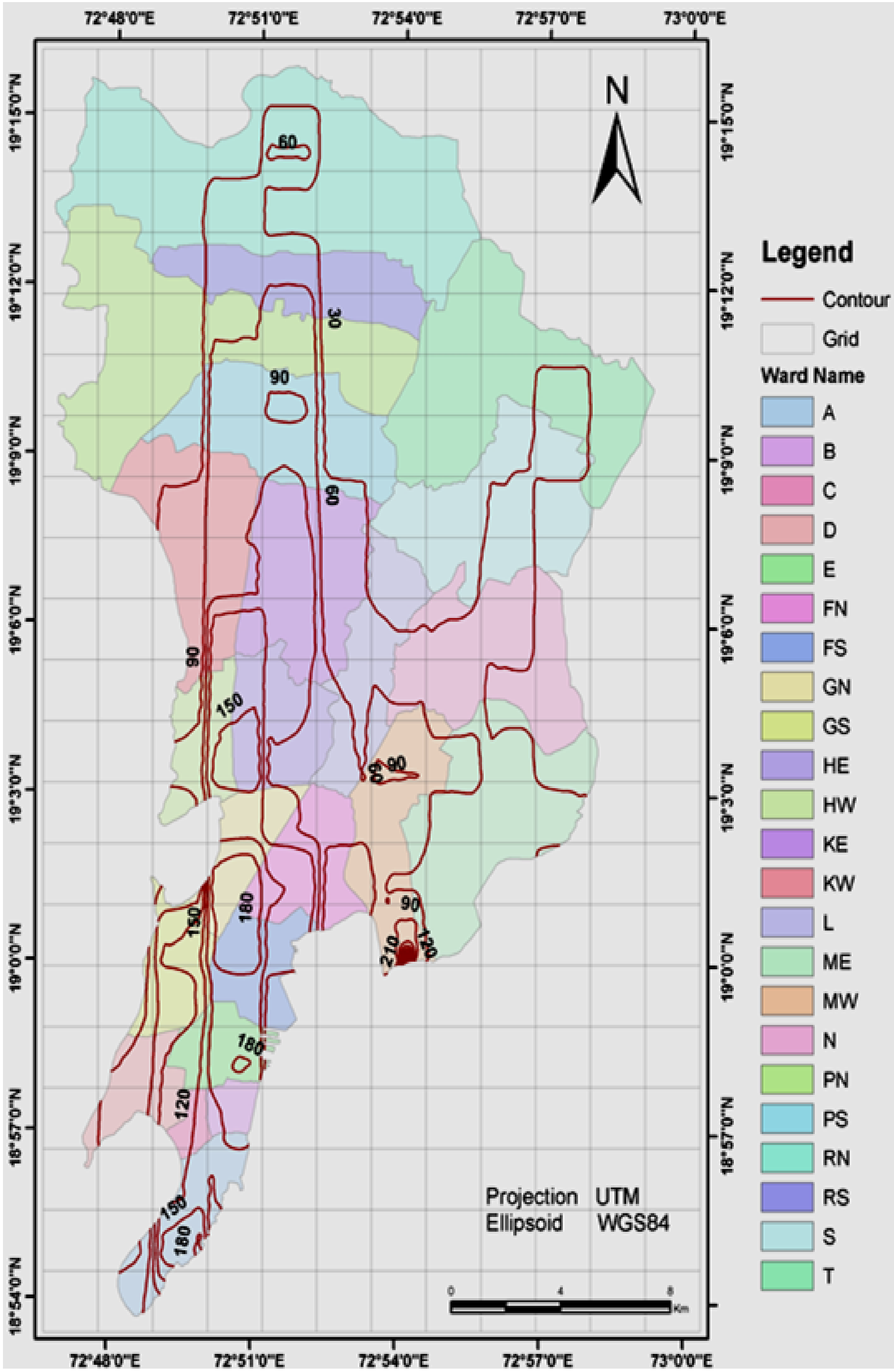

Figure 6.5: Isopleths of NOx due to All Sources during Winter (BAU 2017)

6.3.1 Vehicular Sources

Vehicle sector prediction for business as usual scenario has been one of the most complex situation. Based on the current road map, which only includes, implementation of Bharat IV by the year 2010 can be taken along with the rate of growth of different categories of vehicles. However, there is likelihood that 2012 and 2017 may specify higher norms. For the growth analysis, this has been considered along with Mumbai's High Court order, which states that all commercial vehicles with more than 8 years cannot ply within the city. Since the time horizon for BAU will have all vehicles getting replaced by the end of 8 years, the normal growth rate has been taken for commercial vehicles. Taxis number has been frozen and therefore, this sector will not see growth in numbers. The increase, however, is expected in VKT (Vehicle Kilometer Traveled) in all categories.

6.3.2 Area sources

Amongst the area sources, the most prominent for the city appears to be construction, road dust and biomass or refuse burning. Construction process in the city has seen a large upswing in last 10 years. This process was largely due to changing face of the city wherein Mumbai started changing from industrial city to service sector such BPO, financial services and other commercial services. Due to large-scale demand as also high cost of the real estate, many old and dilapidated building have been pulled down for bigger and taller buildings. Also, many slums have been converted into high rises. All these activities have added to high emissions of dust due to construction and demolition.

Refuse and other biomass burning have been on rise, as large slum population does not have adequate kerosene and LPG supply at affordable costs. These slum dwellers use all kind of combustible refuse for burning besides large scale burning of refuse at Mumbai landfill sites take place. Road dust problems are associated with silt loading of the roads, which neither are nor maintained very well. Though it appears a major source, it's a constantly changing source depending upon the season and also the maintenance practices of the road in the city. Other sources such as bakeries and Crematoria are not likely to increase so much except that as the real estate prices go up and reconstruction takes place, many of bakeries will most likely shift outside the city. Crematoria, however, shall not increase in numbers but may see higher deaths to handle in future. At current rate, they do not appear to be loaded and therefore can take the increased cremation load.

6.3.3 Industrial Sources

Industries in the city have been declining very rapidly. Most of the textile mills have closed down and these lands have been used for high-end residential and commercial complexes. Some of the major industries such as refineries, power plant, fertilizer plants etc are likely to remain till 2017. Many of these industries have planned expansion, however, as per MPCB guidelines; they can expand only if their future load does not exceed the current base emission loads. This will ensure that industrial sector shall not be major source of emissions in future through any additional loads, this concept has been applied for computing loads for the year 2012 and 2017.

6.4 Reduction Strategies

Based on emission inventory and CMB modeling results of all the sources viz. industrial, area and vehicular obtained under the present study, the subsequent sections will discuss the possible strategies for pollution reduction. The focus on reduction discussed will be mainly for PM and NOx as these pollutants are cause of concern. Other pollutants will also reduce with the adoption of strategies discussed here. Additional benefits should be taken as co benefits.

6.4.1 Vehicular Sources Reduction Strategies

One of the major contributors to Particulate Matter (PM) and NOx emissions in Mumbai region is vehicular exhaust. Particulates present in vehicular emissions are especially harmful due to their small size (under PM_{10}) and even larger number below $PM_{2.5}$. The fine particles are also important due to their harmful chemical composition. The most prominent sources of vehicle particulate emissions are diesel driven and two-stroke petrol driven vehicles. Keeping in view the large number of factors, which influence nature and quantity of vehicle emissions (**Box–6.1**), an integrated and comprehensive approach needs to be adopted to address both technical and non-technical issues. Based on the results of emission inventory and source apportionment analysis, specific strategies need to be ranked out of wide variety of reduction options available. Reduction strategies presented here take into consideration the current ambient air quality standards; exhaust emission standards, emission inventory, vehicular population composition, infrastructure availability and the techno-economic feasibility in Greater Mumbai Region.

The discussion has been presented in following order:

- Improvement in vehicle related components/technologies
- Improvement in fuel quality and alternate fuels
- After-exhaust treatment techniques and retrofitment
- Transport planning and traffic management
- Inspection & Maintenance programme
- Other options including phasing out old vehicles, revision of emission standards, anti-smoke campaign, upgraded PUC

As there are considerable differences in emission control options required for diesel and petrol driven vehicles, for new and in-use vehicles; it will be appropriate to address them separately. This approach will also help in planning and implementing the specific control options and also assessing their contributions towards emission reduction.

Box-6.1: Factors Effecting Vehicle Emissions

1. Vehicle/Fuel Characteristics

- Engine type and technology-two stroke, four stroke; diesel, otto, wankel, other engines; fuel injection, turbo charging, and other engine design features; type of transmission system
- Exhaust, crankcase, and evaporative emission control systems in place-catalytic converters, exhaust gas recirculation, air injection, stage II and other vapor recovery systems
- Engine mechanical condition and adequacy of maintenance
- Air conditioning, trailer towing, and other vehicle appurtenances
- Fuel properties and quality-contamination, deposits, sulfur, distillation characteristics, composition (e.g., aromatics, olefin content) additives, oxygen content, gasoline octane, diesel cetane
- Alternative fuels such as CNG, LPG, Bio Diesel
- Deterioration characteristics of emission control equipment
- Deployment and effectiveness of inspection/maintenance (I/M) and anti-tampering (ATP) program

2. Fleet Characteristics

- Vehicle mix (number and type of vehicles in use)
- Vehicle utilization (kilometers per vehicle per year) by vehicle type
- Age profile of the vehicle fleet
- Traffic mix and choice of mode for passenger/goods movements
- Emission standards in effect and incentives/disincentives for purchase of cleaner vehicles
- Adequacy and coverage of fleet inspection maintenance programs

3. Operating Characteristics

- Vehicle use patterns-number and length of trips, number of cold starts, speed, loading, aggressiveness of driving behavior
- Degree of traffic congestion, capacity and quality of road infrastructure, and traffic control systems
- Transport demand management programs

Source: Faiz and others 1995; Faiz and Aloisi de Larderal 1993

Many potential emission reduction options have been considered based on viability in the city and the major issues are pertaining to the overall vehicular sector emission reduction have been discussed here.

6.4.1.1 Improvement in Vehicle Related Components / Technologies

Diesel engine emissions are determined by the combustion process within the cylinder. This process is central to the operation of the diesel engine. Virtually every characteristic of the engine affects combustion in some way, and thus has some direct or indirect effect on emissions. Some of the engine systems affecting diesel emissions are the fuel injection system, the engine control system, air intake and combustion chamber, and the air changing system. Reduction in lubricating oil consumption can also affect hydrocarbon and PM emission. Various options of modified engine technologies are being continuously developed worldwide. Some of potential options being used at various levels of developments are:

- Combustion system types in direct injection (IDI) and direct injection (DI)
- Turbo-charging and Inter-cooling
- Lubricating oil control
- Improving air utilization in combustion chamber

Diesel Powered Vehicles

Until recently, the diesel engines were mostly used in heavy duty trucks and buses; however, their application for passenger cars and other light motor vehicles is showing a continuously increasing trend in India as also in many other parts of the world. Both Direct Injection (DI) and In-Direct Injection (IDI) diesel engine technologies have undergone revolutionary improvements, which have resulted in significant decrease of engine out particulate and other emissions. **Table 6.7 and Table 6.8** detail some of the technological advancements towards controlling engine out particulate emissions. These engine improvements are the primary responsibility of engine or automobile manufacturers to comply with the vehicle emission norms. Revision in exhaust emission standards is, therefore, warranted leading to manufacturers improving the engine technology. The proposed revision should be based on what could be achieved through engine and vehicle related modifications (coupled with fuel quality wherever needed) and possibly based on the experience of countries with more stringent emission norms already in force. Implementation of stringent mass emission norms is under consideration. This will call for using the fuel with 50 ppm sulfur content or much more advanced norms, which may require 15 ppm sulfur content in diesel.

Table 6.7: Emission Control Levels for Heavy-Duty Diesel Vehicles

Control level	Emissions limit at full useful life: Grams per kilowatt-hour	Emissions limit at full useful life: Grams per brake power power-hour	Controls required	Fuel economy (percent)	Estimated cost per engine (US dollars)
Uncontrolled	Nitrogen oxides –12.0 to 21.0 Particulate matter-1.0 to 5.0	9.0 to 16.0	None (PM level depends on smoke controls & maintenance level)	0	0
Minimal control	Nitrogen oxides-11.0 Particulate matter-0.7 to 1.0 Peak smoke-20 to 30% opacity	8.0 5.0 to 0.75	Injection timing Smoke limiter	-3 to 0	0-200
Moderate control	Nitrogen oxides-8.0 Particulate matter-0.7	6.0 0.5	Injection timing	-5 to 0	0-1500
1991 US standard (Euro 2)	Nitrogen oxides-6.7 (7.0) Particulate matter-0.34 (0.15)	5.0 0.25	Variable injection timing High-pressure fuel injection Combustion optimization	-5 to 5	1000-3000
Lowest diesel standards	Nitrogen oxides-2.7 to 5.5 Particulate matter-0.07 to 0.13	2.0 to 4.0 0.05 to 0.10	Electronic fuel injection Charge-air cooling Combustion optimization Exhaust gas recirculation Catalytic converter or particulate trap	-10 to 0	2000-6000
Alternative-fuel forcing	Nitrogen oxides-less than 2.7 Particulate matter-less than 0.07	2.0 0.04	Gasoline/three-way catalyst Natural gas lean-burn Natural gas/three-way catalyst Methanol-diesel	-30 to 0	0-5000

Note: Kilowatt-hours are converted to brake horsepower-hours by multiplying by 0.7452

a. Potential fuel economy improvements result from addition of turbo charging and intercooling to naturally aspirated engines.

b. Euro-2 emissions are measured in a steady-state cycle that underestimates PM emissions in actual driving. Actual stringency of control requirements is similar to that of US 1991

c. Not yet demonstrated in production vehicles

Source: Weaver 1990

Table 6.8: Emission Control Levels for Light-Duty Diesel Vehicles

Control level	**Emissions limit at full useful life (grams per kilometer)**	**Reduction (percent)**	**Controls required**	**Fuel economy (percent)**	**Estimated cost per engine (US dollar)**
Uncontrolled	Nitrogen dioxide –1.0 to 1.5 Particulate matter-0.6 to 1.0	0 0	None (PM level depends on smoke controls & maintenance level)	0	0
Moderate control	Nitrogen oxides-0.6 Particulate matter-0.4	40 33	Injection timing Combustion optimization	-5 to 0	0-500
1988 US standard (EU Directive 91/441/EEC)	Nitrogen oxides – 0.6 (HC+NOx 0.97) Particulate matter-0.13 (0.14)	40 78	Variable injection timing Combustion optimization Exhaust gas recirculation	-5 to 0	100-200
Advanced diesel technology	Nitrogen oxides-0.5 Particulate matter-0.05-0.08	40 92	Electronic fuel injection Combustion optimization Exhaust gas recirculation Catalytic converter or particulate trap	-10 to 0	200-500

a. Compared with uncontrolled levels, Source: Weaver 1990

Both mass emissions and idling emissions norms need to be revised to make necessary implementation of emission reduction technologies by the vehicle manufacturers and other enforcement authorities. As considerable quantity of PM emissions are emitted by in-use or old vehicles the first step improvement could be idling emission norms to be revised and implemented with proper inspection and maintenance system. The improved engine technology will help significantly in reducing particulate emissions from future vehicles as also the improved engines can be used for retrofitment on in-use diesel vehicles. Some of the key elements in controlling engine out emissions, which have already been practiced by vehicle manufacturers are mentioned in **Box-6.2**.

Box -6.2: Key Elements in Controlling Engine-out Emissions

- Minimize parasitic hydrocarbon and PM emissions (those not directly related to the combustion process) by minimizing injection nozzle sac volume and reducing oil consumption to the extent possible
- Reduce PM emissions, improve fuel-efficiency, and increase power and torque output by turbo charging naturally-aspirated engines, and increasing the boost pressure and improving the match between turbocharger and engine in already-turbocharged engines
- Reduce PM and NOx (with some penalty in HC) by cooling the compressed charge air as much as possible, via air-air or low temperature air-water after-coolers
- Recover the PM increase due to retarded timing by increasing the fuel injection pressure and controlling the fuel injection rate
- Improve air utilization (and reduce hydrocarbon and PM emissions) by minimizing parasitic volume in the combustion chamber, such as the clearance between piston and cylinder head clearance and between the piston and the walls of the cylinder
- Optimize in-cylinder air motion through changes in combustion chamber geometry and intake air swirl to provide adequate mixing at low speeds (to minimize smoke and PM) without over-rapid mixing at high speeds (which would increase hydrocarbon and NOx emissions, and fuel consumption)
- Control smoke and PM emissions in full-power operation and transient accelerations through improved control of fuel injection, under both steady state and (especially) transient conditions, frequently through electronic control of the fuel injection system

The emission inventory exercise indicates that at present the contribution of PM_{10} from all the diesel vehicles is about 1230 T/yr. The present emission from the diesel vehicles is about 79.6% of the total vehicular emissions. This estimate does not take into account PM emission due to paved and unpaved road dusts.

Petrol Vehicles

Petrol driven vehicles in Mumbai are less polluting for the PM emissions in comparison to diesel vehicles. They contribute about of the PM in comparison to the diesel vehicles per km. Emissions of PM from petrol driven vehicles amount to about 85.8 T/year from all the vehicles (mainly 2 wheelers and petrol cars) which is about 5.5 %.

The present state of petrol vehicles technology for new vehicles is adequate and in future it is likely to improve as the emission standards become much stricter from present EURO II and EURO III and EURO IV. The contribution of petrol driven cars is not very much significant from their individual PM contributions, but due to their numbers on the road which reduce the average speed on the road, congestion and their parking problems, they do pose problems of fine PM. This aspect has been separately discussed in transport related management issues.

Technology Options and Future Emission Pathways

Diesel Engines

Euro I : Well-tuned combustion system having optimized ports, combustion chambers, and fuel spray mixing system, turbo-charging (with or without intercooling) for heavy-duty and light-duty diesels, cars and vehicles with high power to weight ratio possibly with naturally aspirated engines, moderate-to-high fuel injection pressures (600-800 bar).

Euro II : Proper closely controlled fine-tuned combustion system, TCIC (turbo charging with intercooling) high injection pressures (800-1000 bar), valve closing orifice nozzles for heavy-duty vehicles and oxidation catalyst in case of light-duty vehicles and cars with need-based TCIC engine and minimal electronics, EGR with on/off control in certain applications.

Euro III : TCIC, four valve cylinder, closed loop cooled EGR, very high pressure injection pressures (1000 – 12000 bar), electronic unit injection or HPCR (high pressure common rail) fuel injection system with complete electronic control, oxidation catalyst for cars and light vehicles, regenerative particulate trap in some cases.

Euro IV and later : Same as Euro III with additional after treatment like particulate traps, De-NOx, catalyst and scrubbing system, NOx absorbers, water injection.

Advantages of Adopting These Technologies

- TCIC offers a great advantage in reducing emissions. Automobile manufactures should be forced to introduce TCIC engines. Retrofitment of some of the old engines with TC will reduce PM to a great level.
- TCIC is necessary, if diesel engines are not to termed as the engines of the devil.
- Innovation of combustion chamber and optimization like Hino and Isuzu engines.
- Fuel injection system holds the key to combustion and emission optimization. Electronic control is more required in fuel injection system and has started to come out to India. Auto industry should push electronic unit injection and HPCR technologies to prepare themselves to meet future stringent emission norms.
- Cooled EGR is another way to reduce NOx emissions but it should be applied with care
- After treatment such as oxidation catalysts and particulate traps very effective De-NOx catalysts are still under development. Oxidation catalyst properly matched helps in the reduction of HC, CO and PM.
- In cylinder air motion control by careful design and development of intake ports together with matching fuel spray distribution and bowl design is an essential requirement of the best combustion for diesel engines.
- Centralized vertical injectors offer excellent uniform fuel distribution inside the combustions chamber.
- Four-valve/ cylinder configuration facilitates the vertical injector location even though it does not offer any direct emission potential except for power increase.

Gasoline Engines

Euro I : Properly designed combustion system (ports and combustion chamber) and adoption of MPFI (multiport [sequential/spilt] fuel injection) with electronic engine management with knock –sensed ignition control, sensing of exhaust oxygen for A/F (air /fuel) control, two –or –three-way catalytic converter.

Euro II: Along with the above, secondary air pump (in certain cases) and three-way catalyst (heated in certain cases), EGR (exhaust gas recirculation) control (on/off or dynamic)

Euro III: In addition to Euro II level, closed loop catalyst combined with close control of Lambda (A /F ratio), OBD (on board diagnostics)

Euro IV, V : Heated catalyst, advanced catalyst formulation, exhaust trap / collector bag system, gasoline direct injection, NOx adsorbers, variable valve timing, and variable compression ratio.

Advantage of Adopting These Technologies

- MPFI (split, sequential) system with electronic engine management enables precise control of fuel at all operating modes such as acceleration, deceleration (fuel cut-off), idling, altitude, high and low temperature operation (i.e. reduced fuel for reduced air, and enrichment based on load).
- Multi point injection has many advantages over single-point injection due to its flexibility and precision control possibility.
- Knock sensing enables the engine to run retarded at the threshold of knock due to various reasons and allowing the engine to run at detonation borderline.
- Lambda sensing in exhaust helps precise A/ F ratio control required for the catalytic converters efficient functioning as well as A/F control in lean-burn system.
- OBD helps warning the user of malfunctioning of the system and components.
- Other sensors such as throttle position sensor, idle speed actuator, phase sensor, rpm sensor, air mass, pressure and temperature are essential features of the electronic engine management system.
- EGR helps in reducing NOx

Approximate cost of certain technology options

1. MPFI system –Rs. 15000-20000 (~45% duty and value added tax)
2. Turbocharger – Rs. 8000 –15000 (~50% duty)
3. Intercooler – Rs. 3000-5000
4. Catalytic convertor – Rs. 2000-5000 (25% duty) (inclusive of duty)

[Source: A.S.Subramanian, Recent Developments in Indian Emission Scenario and Effect of Fuel Quality on Emissions, Cleaning the Air, TERI, 2000].

CNG/ LPG Vehicle

The number of vehicles with CNG and LPG plying in the city is still not very large, however, the change in fuel for the retrofitted taxis have brought down the visible smoke from these vehicles. Engine technology for the CNG vehicles indicate that an original vehicle manufactured is much better than a retrofitted one in terms of cost, maintenance as well in terms of emission. CNG retrofitted taxies are ill maintained and have low pick-up and frequent breakdowns, lead up to showing of traffic movement.

There are three types of NGVs:

- Bi-fuel, where the vehicle can run on either natural gas or gasoline;
- Dual-fuel, where the vehicle runs either on diesel only or diesel and natural gas with the combustion of diesel used to ignite the natural gas; and
- Dedicated, engine running entirely on natural gas.

These vehicles can be either manufactured by original equipment manufacturers (OEM) or converted from vehicles that were originally manufactured to run on petrol or diesel only. Either way, there is an incremental cost relative to vehicles using conventional liquid fuels, or this additional cost has to be recovered from savings in operating costs, typically lower fuel costs. For minimizing emissions, OEM vehicles are considered superior to converted ones, but they are more expensive. Conversion of vehicles which are in poor condition, as well as poor conversions, are two of the most serious potential problems in developing country cities, and could even defeat the purpose of switching to natural gas. According to one estimate (Source: International Experience with CNG Vehicles, The World Bank, ESMAP Briefing Note 2, 2002), 50 to 70 per cent of vehicles being converted in developing countries may fail a good pre-conversion inspection with many requiring rebuilt engines and other repairs for an effective NGV programme.

Main reason for changing to CNG/ LPG is lower emissions compared to conventional diesel vehicles. However, replacing diesel with CNG is can be a good idea only if diesel emissions have major contribution to the ambient PM. The concern of very fine particles from CNG vehicles still remains.

The major advantages of NGVs are low particulate emissions, low emissions of airborne toxins, negligible emissions of oxides of sulfur (SO_x), and low odour and negligible noise and vibration.

Disadvantages of CNG, on the other hand are more expensive distribution and storage, higher vehicle cost, shorter driving range, heavier fuel tank and performance and operational problems.

It is important to understand that advanced technology petrol vehicles with three-way catalysts are very clean and therefore, fuel does not have any significant role. Under these circumstances, converting an advanced petrol vehicle to CNG/LPG could even increase, rather than decrease PM emissions.

CNG has significant advantage over conventional diesels. **Table 6.9** presents a comparison of CNG and diesel in terms of relative emissions.

Table 6.9: Emissions Benefits of Replacing Conventional Diesel with CNG in Buses

Fuel	CO	NOx	PM
Diesel	2.4 g/km	21 g/km	0.38 g/km
CNG	0.4 g/km	8.9 g/km	0.012 g/km
% reduction	84	58	97

* Frailley et. al., 'An Evaluation of Natural Gas vs Diesel in Medium Duty Buses, SAE Technical Paper Series, 2000-01, 2822, Pennsylvania.
Note: Medium-duty diesel buses, central business district test cycle, CO carbon monoxide; NOx oxides of nitrogen; PM particulate matter; g/km grams per kilometer.

The emergence of the so-called "clean diesel," may pose a challenge to the long-term future of CNG. Clean diesel technology relies on drastic reductions in the level of sulfur in diesel fuel (sulfur content of below 50 or below 15 for effective use of after-exhaust treatment devices as continuously regenerating particulate traps for reducing fine particles and lean deNox catalysts for reducing oxides of nitrogen (NOx). Existing information indicates that CNG may not have significant advantages over state-of-the-art clean diesel technology for particulate emissions.

Attempts are being made to produce ultra-low sulfur diesel at a fraction of the cost employing conventional technologies. Refineries in India are in a position to produce ultra-low sulfur diesel. At present, CNG remains the only commercially proven clean fuel alternative for heavy-duty engine applications. The clean diesel with less than 50 ppm or less will be another option of better fuel quality (**Box 6.3**). Many urban areas in India may not be in a position to invest the high cost of infrastructure. Besides availability of CNG at so many urban centers may be uncertain as the demand is growing at a rapid pace.

Box 3: Experience with Natural Gas Vehicles

- Poor conversion can lead to higher emissions, operational problems, and even accidents, giving NGVs a bad name. When gasoline vehicles were converted to NG, one of the unpleasant surprises in industrial countries was that the converted NGVs were found to be more polluting when tested for emissions in the case of recent model year vehicles.
- High –usage vehicle fleets which can exploit economies of scale –in setting up refueling infrastructure, staff training, vehicle maintenance and fuel purchase –are especially suited for NGVs.
- A champion coordinating activities among different stakeholders and publishing the benefits of NGVs are especially useful in the early days of a NGV program.
- Consistent reports of poor performance of NG buses manufactured in the early 1990s suggest that NG buses were not only more expensive to purchase but were also about 30 to 40 percent more expensive to maintain and had considerably reduced reliability. While many of these problems are being overcome, heavy-duty NG engine technology still needs some refinements.
- Successful NG bus programs are based on dedicated OEM, and not converted, buses. Conversion of existing diesel vehicles typically does not make happy customers.
- Transit bus operators in many, if not most, developing countries are cash-strapped, partly on account of fare controls. As a result, buses are not properly maintained, nor are the operators in a position and to accept the possibility of more repairs to deal with greater frequency of bus breakdowns. High emissions from diesel buses are not merely because of the choice of fuel, but are symptomatic of deeper problems, and the same problems may condemn CNG bus programs to failure.

Source: ESMAP, The World Bank Briefing Note –2

These options applicability need to be examined in consultation with vehicle manufacturers association (SIAM) regarding the vehicle technology improvements planned by them for vehicles proposed to be sold / introduced in metros cities like Mumbai.

Electric Vehicle

Electric vehicle (EV) uses chemical energy stored in rechargeable battery packs. It employs electric motors and motor controllers instead of internal combustion (IC) engines.

Vehicles using both electric motors and IC engines are examples of hybrid electric vehicles but they are not considered pure EVs because they operate in a charge-sustaining mode.

- Regular hybrid electric vehicles cannot be externally charged.
- Hybrid vehicles with batteries that can be charged externally to displace some or part of their power and gasoline fuel are called plug-in hybrid electric vehicles.

Battery electric cars are becoming more and more attractive with the advancement of new battery technology (Lithium Ion) that have higher power and energy density (i.e. greater possible acceleration and more range with less batteries) and higher oil prices. It can also be usedin public transport vehicles.

Electric vehicle for public utility vehicles have not been extensively planned. As an option for those vehicles, which have high VKT, this can be an attractive alternative for air pollution reduction. Though electric vehicles can not be considered completely pollution free due to its offsite emissions, however it can be an excellent option for city specific hot spot area pollution reduction. This option needs, however, consideration of creation of infrastructure related to battery charges stations, battery management, battery technology etc. Two wheeler and three-wheeler segment can produce major benefits by adopting this option.

6.4.1.2 Phasing Out of Vehicles

In India, practically no existing legislation leads to scrappage of vehicles or phase out time schedules for fuel inefficient and highly polluting vehicles. Major reasons for continuation of such practices are the capital cost of repurchase of new efficient vehicles and low revenue realized from the sale of old vehicles.

Two and three wheelers (mostly 2-stroke) are important modes of personalized transportation in growing middle class segment of Indian urban population. Two-wheelers meet about 19% of the total travel demand in terms of passenger-km in Indian major cities, while three-wheeled auto rickshaws have been evolving as most popular means of intermediate transportation mainly due to high cost of conventional 4-wheeled taxi transportation.

Due to low obsolescence rate of automobiles in India, the vehicle population continues to have a large proportion of old, high polluting vehicles. Most of the 2- and 3- wheelers in Mumbai registered before 1996 did not have problem with any emission standards through PUC check, as it is not adequate to check the levels.

Estimate suggests that these pre-1996 vehicles would contribute significantly towards air pollution; however, there are no substantial data available on their PM_{10} emissions. It may not be a feasible idea to repair or recondition (including conversion to other engine or fuel) these vehicles and it could be a cost effective option to phase out these old vehicles, if relative reduction in vehicle

PM_{10} emissions is considered. (Source : Xie J., Shah J.J. and Brandon C.J., Fighting Urban Air Pollution for Local and Global Goods' Workshop on Integrated Approach to Vehicular Pollution Control in Delhi, IAM, N.D. 16-18th April, 1998.)

It is, therefore, necessary to review the maximum usable life of vehicles, with special reference to older grossly polluting vehicles of more than 10-15 years of age. A practical approach with Government incentives is likely to ensure its successful implementation.

Two wheelers being sold presently in Mumbai are largely four stroke and users are also the owners of vehicles. Very little action may be possible in this sector. All the old fleet of 3 wheelers with high average life have been phased out or retrofitted with an alternate fuel such as CNG /LPG. Since maintenance costs are generally higher for retrofitted engines, it would be desirable that the older vehicles are slowly phased out and all the new vehicles should either be original CNG/LPG engine vehicles or petrol vehicles with 4 stroke engines meeting the prevalent norms. This is due to the fact that older vehicles (which are generally not fit) give low success rate of efficient long run with even cleaner fuel. Personal diesel vehicles, which have remained unaddressed with regard to any emission control programme, need to be brought in for structured scrapping or retro fitment

6.4.1.3 Improvement in Fuel Quality and Introduction of Alternate Fuels

Although considerable amount of work has been done during the past few years to improve the auto fuel quality, India has not fully formulated and implemented comprehensive policies, which take into account holistic considerations. Implementation of fuel quality changes/introduction of alternate fuels in Mumbai Region especially for particulate matter reduction can not be planned and considered in isolation and needs to be looked in totality along with other metros, in specific and country, in general.

The Committee headed by Dr. Mashelkar Committee was constituted by Government of India in 2001 for formulating a uniform National Auto Fuel Policy for the country including metros. The policy adopted an integrated approach and also reviewed the status of various "alternative fuel vehicles" in the country. Fuel quality changes as suggested in the Auto Fuel Policy are likely to be followed as per the road map specified therein. These policy options will be re-looked at again in light of new knowledge of sources.

(a) Improvement of Diesel Fuel Quality

The relationship between fuel characteristics, engine performance and exhaust emissions are complex, and sometimes there is a tradeoff between measures to control one pollutant and its effect on others. The fuel variables which have the most prominent effect on emissions are sulfur content, cetane number and the fraction of aromatic hydrocarbons contained in the fuel. A part of fuel (sulfur), which is not emitted as SO_2, is converted to various metal sulfates and to sulfuric acid and emitted in particulate form. Sulfate particles typically account for 0.05 to 0.10 g/kwh of particulates in heavy-duty engines, equivalent to as high as 10% of total particulate emissions (**Box 6.4**). The effect of sulfate particles is increased due to their hygroscopic nature. Apart from contributing to particulate emissions, Sulphur content has direct implications on after-exhaust treatment technologies using catalytic materials. Looking at recent developments in the field of diesel exhaust emissions control, it is imperative to reduce the sulfur content below 50 ppm by weight in due course of time.

Box 6.4: Sulphur In Diesel

Diesel emissions contain sulphur in particulate and gaseous form, and thus any reduction in sulphur has dual advantages. Recent evaluations carried out in Europe show the benefits of reduced sulphur in diesel fuel for lowering particulates. For example, preliminary data released from the Auto/Oil study showed that lowering the diesel fuel sulphur level from 2000 parts per million (ppm) to 500 ppm reduced overall particulates from light-duty diesels by 2.4 percent, and from heavy-duty diesel by 13 percent. The relationship between particulates and sulphur level was found to be linear; for every 100 ppm reduction in sulphur, there is a 0.16 percent reduction in particulates from light-duty vehicles and a 0.87 percent reduction from heavy-duty vehicles.

Option to Reduce the Sulphur Content of Diesel Fuel

- In the crude state, increase the proportion of low-sulphur crude oil
- Reduce the cut point of diesel fractions from both primary distillations as well as from the fractionation of secondary processing streams to 350-360^{0}C.
- Improve fractionation efficiency to eliminate inter-stream overlaps during fractionation of diesel oils
- Hydro-treat straight-run diesel and thermally cracked diesel and/or hydrofine; reduce proportions of FCC oil blended into final product diesel oil

Install hydro crackers that would enable production of very low-sulphur saturated diesel with high cetane numbers. (Source: CPCB News Letter 'Parivesh').

The other diesel parameters having effect on diesel particulate emissions are cetane number and aromatic hydrocarbon content.

Increased aromatic content is correlated with higher carbonaceous particulate emissions. This could be due to deterioration in cetane quality. Much of this deterioration can be recovered through the use of cetane enhancing additives. The cost of such additives is quite reasonable and therefore offers immediate cost-effective option. Reducing aromatic content through extra refining, however, is a more appropriate long term solution. Some indicative changes in particulate emissions with respect to diesel fuel properties are given in **Table 6.10 and 6.11.**

Table 6.10: Change in Light-Duty Diesel Vehicle Emissions with Variations in Diesel Fuel properties

Diesel Fuel Properties	CO	HC	NOx	PM	CO_2
Density 855 to 828 g/l	-17.1[b]	-18.9[c]	+1.4	-19.4	-0.9
Polyaromatics 8 to 1 percent	+4.0[c]	+5.5	-3.4	-5.2	-1.08
Cetane 50 to 58	-25.3	-26.3	-0.18 (NS)	+5.2	-0.37 (NS)
T95 370 to 325°C	-1.8	+3.4	+4.6	-6.9	+1.59
Sulfur 2000 to 500 ppm	-	-	-	-2.4	-

- Not applicable, NS = Non significant

a. Baseline properties density 855 g/l; polyaromatic content 8 percent; cetane number 50; T95 370°C; sulfur 2000 ppm

b. Negative values indicate decrease in emissions

c. Positive values indicate increase in emissions

Table 6.11: Change in Heavy-Duty Diesel Vehicle Emissions with Variations in Diesel Fuel Properties

Diesel fuel property	CO	HC	NOx	PM	CO_2
Density 855 to 828 g/l	+5.0[b]	+14.25[c]	-3.57	-1.59	+0.07
Polyaromatics 8 to 1 percent	0.08(NS)	-4.02	-1.66	-3.58	-0.60
Cetane 50 to 58	-10.26	-6.25	-0.57	0(NS)	-0.41
T95 370 to 325°C	+6.54	+13.22	-1.75	0(NS)	+0.42
Sulfur 2000 to 500 ppm	-	-	-	-13.0	-

- Not applicable, NS = Non significant

a. Baseline properties density 855 g/l; polyaromatic content 8 percent; cetane number 50; T95 370°C; sulfur 2000 ppm

b. Negative values indicate decrease in emissions, Positive values indicate increase in emissions

Source: Camarsa and Hubbin 1995; ACEA/EUROPIA 1995a

These Tables indicate that reducing fuel density and sulfur content have prominent effect on particulate emissions from light-duty & heavy duty diesel vehicles respectively.

(b) Alternate Fuels for Diesel Driven and Gasoline (2-Stroke) Vehicles

There are at least two ready options available as regards to the alternative fuels. They are Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG). These have already been evaluated to a certain extent and are in-use in India. The conversion kits are also commercially available for such converters. Application of alternative fuels can be considered in two ways:

- Conversion of existing vehicles
- Introduction of alternative fuel based new vehicles

Introducing Alternate Fuels for Diesel Vehicles

Feasibility of CNG as an alternate fuel to diesel has been extensively studied in many countries including India. Specially, the operational experience of its introduction in Indian metros particularly Delhi was reviewed and several committees evaluated the techno-economic feasibility of CNG as an alternative to diesel. Long term and continuous availability and infra-structural aspects need to be critically reviewed before considering CNG as a permanent alternative fuel. The future projections by Oil companies especially with respect to quality of diesel vis-à-vis advancements in the field of after exhaust diesel emissions control technologies should from the basis for comparing CNG as an alternative fuel under a long term strategy.

The vast experience on CNG conversion and log term CNG use has brought forward many issues which need to be critically and carefully assessed. The following inferences can be drawn from the previous experience on CNG:

- CNG in general, is a much cleaner fuel with respect to PM_{10} emissions as compared to diesel.
- The cost-effectiveness of CNG depends on many factors like its availability and constant supply; cost of CNG dedicated engines and conversion kits, infrastructure costs for CNG distribution etc.
- In general, CNG produces relatively less GHG emissions, VOCs, fuel cycle emissions and other toxic emissions
- There are certain safety issues related to the use of CNG
- Conversion of diesel vehicles to CNG was often found more successful only in case of new vehicles and used vehicles in very good condition. Conversion success also depends on the quality of conversion kits.

- With changing focus on fine particles such as $PM_{2.5}$ and also importance of particle number in place of mass, the toxicity issue of CNG related need consideration.

In the case of buses which are presently powered with diesel engines, the change over to CNG requires changing the engine from compression ignition mode to spark ignition mode. Conversion of diesel engines to CNG mode requires major modifications to reduce the compression ratio, fitment of carburetor, spark plug, ignition circuits and expansion valves to reduce pressure of CNG before induction into the cylinder. This calls for incorporation of many changes and is technologically not the best option. Newly designed and developed CNG engine including specially designed chassis for bus application is a better technological option.

There are a few CNG refueling stations in Mumbai; however, their numbers are increasing to cater the immediate needs to taxi operators. LPG has recently been introduced in India as an alternative fuel for passenger cars having four stroke engines. Usage of some percentage of new vehicles based on alternative fuels can be made mandatory as presented in Scenario development.

Biodiesel

Refers to a non-petroleum-based diesel fuel consisting of short chain alkyl (methyl or ethyl) esters, made by transesterification of vegetable oil or animal fat (tallow), which can be used (alone, or blended with conventional petrodiesel) in unmodified diesel-engine vehicles. Biodiesel is distinguished from the *straight vegetable oil* (SVO) (sometimes referred to as "waste vegetable oil", "WVO", "used vegetable oil", "UVO", "pure plant oil", "PPO") used (alone, or blended) as fuels in some *converted* diesel vehicles.

Hydrogen Fuel

A hydrogen economy is proposed to solve some of the negative effects of using hydrocarbon fuels in transportation, and other end-use applications where the carbon is released to the atmosphere. In the current hydrocarbon economy, the transportation of people and goods (so-called *mobile applications*) is fueled primarily by petroleum, refined into gasoline and diesel, and natural gas. However, the burning of these hydrocarbon fuels causes the emission of greenhouse gases and other pollutants. Furthermore, the supply of hydrocarbon resources in the world is limited, and the demand for hydrocarbon fuels is increasing, particularly in China, India and other developing countries. Hydrogen has a high energy density by weight. The fuel cell is also more efficient than an internal combustion engine . The internal combustion engine is said to be 20–30% efficient, while the fuel cell is 2-3 times more efficient than an internal combustion engine depending on the fuel cell.

6.4.1.4 After-Exhaust Treatment Technologies for PM Emission Reduction

a) Technologies for Diesel Vehicles

This approach to reduce vehicle exhaust emissions is to use a separate process to eliminate pollutants from the exhaust, after it leaves the engine, but before it is emitted into the environment. Two such technologies to control diesel PM emissions are being recently referred, and several demonstration / pilot studies are presently underway to study their techno-economic feasibility. These are:

- Diesel Particulate Filters (DPF) including CRT (Continuously Regenerated Trap)
- Diesel Oxidation Catalyst (DOC)
- Partial Flow Filter (Combination of DOC and Filter)

These technologies (especially DPF) are can be considered as an essential for option the diesel vehicles to meet the future stringent emission norms in many countries including in India.

Diesel Particulate Filter

A DPF system has a particulate filter media in the engine exhaust stream and some means of burning (oxidizing) of collected particulate matter from the filter. Manufacturing a filter capable of collecting soot and other particulate matter from the exhaust stream is straightforward, and effective trapping media have been developed and demonstrated. The shallow wall type wall-flow particulate filter is today, the most efficient soot collection device, attaining filtration efficiencies of the order of 90% or more at nominal operation conditions. The main problem of DPF system development is the removal of the soot effectively and regeneration of the filter. Diesel particulate matter consists of solid carbon coated with heavy hydrocarbons. This mixture ignites at 550 to 600°C, well above the normal range of diesel engine exhaust temperatures (150-400°C). Special means are therefore, needed to ensure ignition. Once ignited, however, this material burns at temperatures that can melt or crack the particulate filter. Initiating and controlling regeneration without damaging the trap is the central problem of trap-oxidizer development. Several means of DPF regeneration have been tried. These include: electrical, catalytic, fuel additive based etc.

CRTs work on oxidation of NO to NOx by an oxidation catalytic converter followed by a DPF where particulates can be oxidized with NOx. All these catalytic applications, however, require low sulfur diesel, at least below 50 ppm and their PM reduction efficiency and stability are often reported to be dependent on diesel sulfur content (**Table 6.12**). Invariably, good PM reduction efficiency is reported with ultra-low sulfur (10–50 ppm) diesel, while some DPF manufacturers also claim suitability of their device on 500 ppm diesel, however these will require very frequent cleaning.

Table 6.12: Emission Test Results from the Department of Environment and Transport for the Regions, Government of UK

Engine	Sulfur Content of Diesel	Impact of Particulate Trap on Particulate Emissions
Euro I diesel	50 ppm	75 per cent reduction
Euro I diesel	10 ppm	90 per cent reduction
Euro I diesel	50 ppm	Produced more sulfate particles when operated with a CRT compared to what it emitted when it operated without a CRT.

Source: Anon 2001, Summary report, Department of Environment and Transport for the Regions/Society of Motor Manufacturers and Traders/CONCAWE,

Diesel Oxidation Catalyst

In cylinder diesel PM control has greatly reduced PM emission levels. Progress has been most effective in reducing the soot portion of PM emissions, so the soluble organic fraction (SOF) of particulate matter now accounts for a much larger share. Depending on engine and operating conditions, the soluble organic fraction may account for 20 to 50 percent of PM emissions.

Oxidation catalysts of a diesel catalytic converter oxidize a large portion of the hydrocarbons present in the soluble organic fraction of PM emissions, as well as gaseous hydrocarbons, carbon monoxide, odor (from organic compounds such as aldehydes), and mutagenic emissions. Unlike a catalytic trap, the oxidizing catalytic converter does not collect solid particulate matter, which passes through in the exhaust. This eliminates the need for a regeneration system. Oxidation catalytic converters have been used in light-duty vehicles and sometimes demonstrated to be effective for heavy-duty applications as well. These catalysts have a negligible effect on fuel consumption.

The main difficulty with the usage of diesel oxidation catalyst on heavy-duty diesel engines is that they can cause the formation of sulfuric acid and sulfates from sulfur dioxide in the exhaust. If fuel sulfur levels are significant, these compounds can add considerably to particulate mass. Fuel with less than at least 0.05 percent sulfur by weight is required for diesel catalysts to perform well. However, chemical stability of catalysts remains a challenging task, and very low sulfur content of diesel will be desirable.

The important aspects of DPF and DOC applications are:

- To meet future diesel exhaust emissions standards, it is necessary to significantly control PM and NOx emissions. Considering difficulties of after-exhaust treatment for NOx treatment, and engine trade-off relation for NOx-PM emissions; PM reduction technologies such as DPF & DOC will play important role.
- Performance of DPF and DOC are reported to be critically dependent on diesel sulfur content (**Table 6.12**) and it may be necessary to aggressively reduce the diesel sulfur content in immediate future.
- Considering present less than 350 ppm diesel sulfur content for Indian Metro Cities suitable DPF and DOC technologies can be used, initially at pilot / demonstration level. [A demonstration study is currently being carried out for Pune Municipal Transport by NEERI, USEPA and other stake holders].
- If found effective and durable, these technologies can be considered for retro-fitment on in-use diesel vehicles. Their easy retro-fitment and effectiveness in controlling PM emissions (especially for DPF) could become very useful in controlling PM emissions from in-use, old vehicles.

Partial-flow filters

The partial flow filter is a flow through diesel particulate filter providing effective removal of diesel particulate matter with lower back pressure than conventional wall flow systems. It is ideal for retrofit on most diesel engines including light duty cycle and even two-stroke designs.

- Up to 60% reduction in particulate matter
- Greater then 80% reduction in CO and HC
- Easy Installation
- Maintenance free
- Fail safe—Does not block
- Improved sound attenuation

The partial flow filter uses a network of flow-through channels, consisting of corrugated metal foils and metal fiber fleece. These channels have a variable cross section through their length to transfer the exhaust gas through the catalyzed, stainless steel filter layer. Particles (PM_{10}) are collected on the surface of these fibres and oxidized. The catalytic coating provides a high particulate reduction across a wide range of exhaust flows and temperatures, whilst retaining similar back pressure characteristics to a conventional diesel oxidation catalyst. The design of this unit is also very effective in the reduction of carbon monoxide (CO), diesel hydrocarbons (HC) and diesel odour. Taking Euro 2 vehicles to Euro 3 standard for particulates. It is also suitable for off-road applications, taking Stage 1 and 2 engines to Stage 3a standards.

b) Technologies for Gasoline Driven Vehicles

2-stroke- two and three wheelers are the major contributors of PM emissions from petrol driven vehicles. Studies conducted suggest considerably different amounts of particulate emissions from 2-stroke vehicles; however, their large population in Mumbai makes them significant contributors to PM_{10} emissions.

The escape of exhaust borne lubricants to the surrounding environment is responsible for the majority of non-gaseous emissions, (white smoke and particulate matter), from vehicles powered by inefficient engines. White smoke refers to the aerosols responsible for the opacity observed engine exhaust streams. Particulate matter, as applied to these vehicles, includes both aerosols, consisting mainly of lubricant, and solid particles. Solid particles arise from combustion processes and can be carbon, (soot for example), or inorganic based. An additional component of PM is the hydrocarbons absorbed in or entrained on, the aerosol and solid particulate matter. It is commonly stated that lubricant quality, lubricant to fuel ratio, inadequate vehicle maintenance and adulteration of gasoline are the major factors responsible for PM emissions from 2-stroke vehicles.

It has been demonstrated that catalytic after-treatment can reduce the PM emissions of a wide range 10-70%, depending of converter and vehicle specifications. Fuel sulfur is reported to show no substantial impact on PM formation and it is possible to achieve potential reduction simultaneously for CO, HC and PM emissions, using appropriate oxidative catalytic converter. Almost all the new 2-stroke vehicles produced after April 2000 in India are fitted with oxidative catalytic converter and they can also be expected to reduce PM emissions. Catalytic converter retro-fitment can be technically feasible to control PM emissions from old vehicles; however, it is essential to study its practical feasibility through a pilot study on Indian vehicles. The cost of catalytic converter and fuel efficiency loss are another two parameters, which will determine the cost-effectiveness of this PM reduction option.

6.4.1.5 Traffic & Road Transport Management

Most of the cities in India attribute their air pollution problem to the bad traffic management practices. It may not be true in all cases, however, the traffic management can prove to be crucial at certain locations, where no other strategies work either with regard to the traffic flow or air quality impact. Effective traffic management helps in many ways to reduce vehicular pollution. It reduces fuel consumption, travel duration and idling emissions with high concentration of pollutants. This is probably the only control option which could be used to improve site specific/ground specific vehicle PM_{10} and NOx emissions.

An effective traffic management system design will need consideration of many important issues as listed hereunder:

- Development of mass transportation system for small distance trips
- Adequate road infrastructure and competent road engineering appropriate for the city
- Adequate capability and resources of the police and other enforcement authorities
- Development of flyovers and alternate roads to divert traffic load from areas with high PM_{10} and NOx concentrations.
- Proper decentralized town planning
- Public understanding, respect and support for traffic management

Based on EI data for projected PM_{10} and NOx emissions, road network and traffic plans can be developed to reduce the emissions in areas/grids showing high emission levels. The approach can help in some of the problem regions which can not be tackled with other strategies such as change in fuel, vehicle technologies, stricter emission standards or inspection and maintenance. It does not mean that the other strategies mentioned above do not have any role to play; however, there are places where these strategies would not lead to solution of pollution reduction problem. Based on PM and NOx estimated and projected for various grids, following areas are the candidates for traffic management related issues.

City: Churchgate, Dr.Ambedkar Road, Parel, Dadar, Mahim (of these Dadar and Churchgate has highest emissions of PM due to very high VKT).

Western Suburbs: Bandra, Khar-Santacruz, Vile Parle, Andheri-Jogeshwari, Malad. Bandra and Andheri – Jogeshwari have the highest emissions with high VKT.

Eastern Suburbs: Sion-Chunabhati, Gidwani Marg, Mumbai-Panvel Road near Mankhurd. Sion has the highest emission with high VKT.

From the above, it can be seen that the areas designated as high PM and NOx level areas need traffic management solutions, which may not be same at all the places. For example, Churchgate scenario may improve, if the congestion reduction measures with regard to unauthorized parking are taken up. However, at Bandra no amount of measures relating to parking restrictions, vehicle technology improvement, and fuel quality improvement can bring the PM and NOx levels to an acceptable value. This is due to the fact that the occurrence of high PM and NOx levels at Bandra and some other locations in western suburbs is not only due to high vehicle kilometers traveled, but also due to high congestion resulting in extremely high idling emissions from all types of vehicles. At such locations, more road space creation is warranted, besides overall improvement of public transport system which is low cost, comfortable and accessible.

All the above mentioned locations will experience much worst situation by the year 2012. There is, therefore, a need to examine these locations from the point of view of smooth movement of vehicles along with other necessary measures to reduce emissions from vehicles already discussed above.

6.4.1.6 Inspection & Maintenance of Vehicles

As discussed earlier, presently two and three-wheelers have very high percentage population (more than 50 %) in the city. This is likely to increase in the next 10 years, if the rate of increase continues. These types of vehicles occupy an important position in India serving the transportation needs of the grooming middle class segment of the urban population. In Mumbai, the rise in 2 wheelers population particularly is due to paucity of effective mass transportation system which is not only cheap but also comfortable. Due to the mad rush in trains and high bus fares, large scale middle class population believes that owning 2 wheeler will solve its problem.

Old vehicles are expected to be on road for a long period in absence of scrapage policy. Therefore, their maintenance becomes quite crucial. According to studies, relatively simple and inexpensive maintenance such as cleaning, tuning and adjusting of carburetor and ignition system can reduce emissions in the range of 20-60%. This can provide the motivation and incentive for the vehicle users to incur the expenses on periodic maintenance.

In view of the above facts, an inspection & maintenance (I&M) programme should be adopted for the city. A centralized I&M programme can be worked out after assessing the infrastructure and cost related issues. Participation of vehicle manufacturers can also be very important as it could make the whole programme even more feasible. Manufacturer's repair and maintenance network can be extended further to deal with I&M requirements. This would be a kind of de-centralized I & M programme and would need careful monitoring to avoid fraudulent practices.

There is a need to extend implementation of I&M programme for privately owned four wheelers. The population of cars in the city is also significant with about 2,52,698 vehicles of 2000 vintage. Most of these cars may not have working catalytic converter and engines are of older technology. As badly maintained petrol vehicles can also be high emitters of fine particulates and NOx, therefore, there is a need to implement inspection and maintenance schedule for such vehicles.

Identification of Gross Polluters

One of the major advantages of I&M programme is that it helps in identifying the gross polluters. It has been often observed as also discussed above, that a small fraction of vehicles can seriously contribute to the total as well as local air quality deterioration. Various studies (Faiz, Weaver and Walsh, 1998) have shown that 5 % of the vehicle population causes 25% of all the emissions and larger percentage contribute to smaller emission levels.

The so called improved "Pollution Under Control" (PUC) programme already in force in India can be scrapped as its effectiveness has been limited. I&M programme need to be in place to bring about any change in pollution reduction.

A very few number of vehicles with malfunctioning or tampering of components are often responsible for generating excessive amount of emissions. However, identifying these vehicles and controlling their emissions is a difficult task on practical front. Although, an effective I&M programme can easily identify these vehicles and necessary repairs can be carried out. Yet, excessive emissions can be observed often & due to many reasons. Such vehicles may, therefore, keep on polluting environment until they go for next repair or I&M. It will, therefore, be important to identify such vehicles and take immediate action to control their emissions.

There can be two different possibilities, to identify such "Excessively Polluting" vehicles. The polluting vehicles categories can be identified and all the vehicles in that category can be asked to undergo checks and repair. The programme of such identification, checks and repair needs to be sustained at least for 3-4 years to obtain results. This is due to the fact that all the vehicles under this category can not be brought on one day for I&M for the necessary changes towards reduction in emissions. Visible smoking categories of vehicles noticed in Mumbai till date is garbage trucks, water tankers, diesel taxis and buses. There are other categories as well such as ST buses, contract and school buses, petrol vehicles etc. which also represent a good number of vehicles which contribute towards visible smoke and thereby fine particles. In the study conducted at Mumbai (R. Kumar et.al. 2002) the solution of grossly polluting vehicles has been delineated through inspection and certification systems.

Under the above two categories, there is a need to adopt two different methods, in which the organized sector as discussed above can be targeted first and the other smoking vehicles later through adoption of a proper Inspection and Maintenance schedule for the city. Identification of other types of vehicles which does not belong to a certain agency but have well distributed population could be done through manual inspection by traffic police during certain campaign drives planned for the purpose. Such campaigns can be organized either through the Department of Transport or supported by the Department along with NGOs such as WIAA, Clean Air etc

6.4.1.7 Resuspension of Dust

The resuspended particulate matter in the city varies considerably from area to area. The air quality monitoring and CMB model results during the study indicated that resuspended portion of the dust could be in the range of 10-60 % depending upon the road conditions such as paved or unpaved road. Source apportionment study also indicates that resuspended fraction is significant. These estimates indicate that resuspended PM need to be tackled at priority as many place in the city its contribution in the ambient air quality is substantial. Kerb side air quality is impacted even more.

As most of the city roads are paved compared to suburbs, contribution of resuspended fractions from the road dust is highest in the suburb. Of the suburbs, eastern suburbs contribute maximum PM from the road construction activity.

Control of resuspension dust will require multi-pronged approach as only paving the road is not sufficient to control the dust resuspension. Frequent digging, paving and construction along with inadequate sweeping can be major sources of the resuspension. This source of PM can be easily controlled with minimum expenses as it merely needs effective implementation of the road construction and its maintenance.

6.4.1.8 Line Source Control and Analysis

Vehicular sources strategies discussed earlier sections bring out the issue of selecting options which shall make bigger difference in emission loads and thus their impact on ambient air quality. Model runs were made for each option as given below; these options were run for the predictions, considering the ambient air quality based on technology. Management options are largely applicable across the city in a gross estimation. A summary of results of options for vehicular sources control runs is given in **Table 6.13.**

Table 6.13: Vehicular Source Control Options

Control Options	Scenario for 2012	Scenario for 2017
Technology based		
Implementation of BS – IV norms	BS – IV from 2010 (adopt progressive increment)	BS – IV from 2010 (adopt progressive increment)
Implementation of BS – V norms	BS – IV from 2010 (adopt progressive increment)	• BS – IV from 2010 (adopt progressive increment) • BS – V from 2015 (adopt progressive increment)
Implementation of BS – VI norms	BS – IV from 2010 (adopt progressive increment)	• BS – IV from 2010 (adopt progressive increment) • BS – VI from 2015 (adopt progressive increment)
Electric Vehicles	• Share of Electric vehicles in total city fleet • Two wheeler: 1%, • Auto Riksha and Taxi: 5% • Public buses: 5%	• Share of Electric vehicles in total city fleet – • Two wheeler: 2%, • Auto Riksha and Taxi: 10% • Public buses: 10%
Hybrid vehicles	Share of Hybrid vehicles in total city fleet (Gasoline powered four-wheelers only) – 1%	Share of Hybrid vehicles in total city fleet (Gasoline powered four-wheelers only) – 2%
CNG/LPG to commercial (all 3 and 4-wheelers)	25% conversion	100% conversion
Ethanol blending (E10 – 10% blend)	Share of Ethanol blended fuel – 10%	Share of Ethanol blended fuel – 10%
Bio-diesel (B5/ B10: 5–10% blend)	Share of Bio-diesel fuel– 5%	Share of Bio-diesel fuel – 10%
Hydrogen – CNG blend (H10/H20: 10 – 20% blend)	--	Share of Hydrogen blended (H%)fuel - 10% (for vehicles on CNG)
Retrofitment of Diesel Oxidation Catalyst (DOC) in 4-wheeler public transport (BS – II)	50% conversion	100% conversion
Retrofitment of Diesel Particulate Filter in 4-wheeler public transport(BS – III city buses)	50% conversion	100% conversion

Table 6.13 (Contd...): Vehicular Source Control Options

Control Options	Scenario for 2012	Scenario for 2017
Management based		
Inspection/ maintenance	New I&M regulation introduced and compliance by 50% anticipated	Strict compliance by 100%
Banning of 8 year old commercial vehicles	More than 8 years old vehicles are not allowed to ply within the city	More than 8 years old vehicles are not allowed to ply within the city
Banning of 15 year old private vehicle	Old vehicles (10 years +): nos. to be worked out	Old vehicles (10 years +): nos. to be worked out
Synchronization of traffic signals	Effective synchronization on all major roads (or about 10% of the prime roads)	Effective synchronization on all major & minor roads, excluding feeder roads (or about 20% of the prime roads)
5(a). Improvement of public transport: as per existing plan for the city	Incorporate city specific proposals on public transport with respect to Metro/mono rail, BRT, large buses contingent etc	Incorporate city specific proposals on public transport with respect to Metro/mono rail, BRT, large buses contingent etc.
5(b). Improvement of public transport: % share (VKT of cars, 2-wheelers and buses)	10% shift in VKT	20% shift in VKT
Fiscal incentives /disincentives like increased parking fee, proper fuel pricing policy, incentives for car pool, etc		
Banning odd/even vehicles on particular roads	Zero emissions from the vehicles off the roads	

As can be seen from results given in **Table 6.14**, technology change primarily do not bring down the emission drastically. The vehicular emission estimates and their contribution in PM_{10} values seem considerably low in the presence of dust from paved – unpaved roads. However, its important to note that all the emission of PM from vehicular sources are in the fine range e.g $PM_{2.5}$ and below. Fine particles presence in atmosphere which is largely contributed by vehicles, are toxic in nature. These particles presence in atmosphere leads to very high exposure resulting in enormous disease burden on the population exposed.

Table 6.14: Percent Reduction after Implementation of Control Options

Control Options	Scenario for 2012		Scenario for 2017	
	NOx	PM	NOx	PM
Implementation of BS – IV norms	44.5	1.30	44.6	1.30
Implementation of Bharat Stage IV from 2010 and Bharat Stage V from 2015			51.38	2.74
Implementation of Bharat Stage IV from 2010 and Bharat Stage VI from 2015			57.80	2.74
Electric Vehicles – * 2012 – two wheelers 5%; three wheeler -20% and taxi 20% and public buses 5%. * 2017 -two wheelers 10%; three wheelers -30% and taxi 30% and public buses 10%	2.23	0.13	2.24	0.14
hybrid Vehicles * 2012 -four wheelers 1%, * 2017 - four wheelers 2%.	0.11	0.0	0.22	0.0
Conversion vehicles to CNG/LPG – * 2012 - Taxis- 80% -three wheelers -80% and 25% of Public transport * 2017- Taxis- 80% -three wheelers -80% and 40% of Public transport	3.40	1.16	1.24	4.63
Ethanol blended fuel – 10%	0.49	0.0	0.49	0.0
Biodiesel -5% in 2012, 10% in 2017	-0.12	0.03	-0.24	0.06
Hydrogen CNG blended fuel- 10% in 2017	0.0	93.33	2.1	0.0
Retrofitment of diesel oxidation catalyst (DOC) in 4wheeler public transport (BSII) -50% conversion is expected in 2012 and -100% conversion in 2017	0.0	0.0	0.0	0.0
Retrofitment of Diesel particulate filter in 4 wheelers public transport (Bharat Stage II city buses) -50% conversion is expected in 2012 and -100% conversion in 2017	0.0	0.11	0.0	0.43
banning odd/even vehicles on particular day	49.53	49.80	49.63	49.78
synchronization of traffic signals	18.9	19.9	19.8	19.9
Wall to wall paving (brick) of all roads		13.99		14.00

Implementation of technologies in limited way e.g. 1% electric vehicle by 2012, do not yield significant benefits in terms of reduced emission loads or reduced ambient concentration of PM or NOx.

The option selection was based on many iteration with a view to achieve significant change in load and consequent reduced contribution in ambient air quality. **Table 6.15** presents options which are likely to achieve desired results as also those which are relevant to Mumbai city.

Table 6.15: Prioritized Control Options for Vehicles (#R)

1.	Implementation of Bharat Stage IV from 2010 and Bharat Stage VI from 2015
2	Electric Vehicles – * 2012 – two wheelers 5%; three wheeler -20% and taxi 20% and public buses 5%. * 2017 -two wheelers 10%; three wheelers -30% and taxi 30% and public buses 10%
3.	Conversion vehicles to CNG/LPG – * 2012 - Taxis- 80% -three wheelers -80% and 25% of Public transport * 2017 - Taxis- 80% -three wheelers -80% and 40% of Public transport
4.	Ban or scrapping of 15 year old vehicles – * 2012 –Scrap commercial vehicles of 1997, Ban > 8 years vehicle * 2017 – Continued
5.	Inspection and Maintenance – * 2012 - New I&M regulations (50% population) * 2017 - Full compliance -100%
6.	Public Transport – * 2012 - 10% VKT reduction * 2017-20% VKT reduction
7.	Ban of odd /even vehicles * 2012 -50% reduction from private vehicles * 2017 - 50% reduction from private vehicles

6.4.2 Point Source Pollution Reduction Strategies

The strategies for abatement of emissions from point sources include cleaner fuel substitution, change in basic production processes, and pollution abatement through flue gas treatment modifications of exit gas characteristics besides shifting of industries outside the city premises. The point sources emission inventory prepared indicates that power plant, some chemical industries and stone crushers are the major sources. The strategies mainly considered are based on cleaner fuel substitution as well as closing/shifting of industries outside the city region.

In order to assess the impact of particulate emissions from the industrial sources in Mumbai Region, dispersion modeling was also carried out by making use of the data with respect to stack and emission characteristics. ISCST3 (Industrial Source Complex Short Term) was used for modeling purposes and the whole region was divided into 2 km x 2 km grids and suitable assumptions was made, wherever found necessary to fill the data gaps. Details are given in **Chapter 5.** Meteorological data collected during the ambient air quality monitoring studies was also used during the modeling exercise. Scenarios were simulated was with power plant, all industries and stone crushers. The results of the modeling exercise were also used for delineating PM and NOx reduction strategies for point sources. Most of the control options pertaining to PM reduction as NOx control in limited number of industries will need very high incremental efforts.

The strategies are recommended for the following three broad sectors under short (5 yrs) and long (10 yrs) term scenarios.

- Industrial PM emissions (power plant)
- Industrial PM emissions (39 industries) excluding power plant
- Total industrial PM emissions (39 industries + power plant) along with stone crushers

The sector wise control strategies along with the possible reduction in PM emissions are suggested as presented in **Table 6.16**. The shift in cleaner fuel in these sectors is based on equivalent heat input estimation.

Table 6.16: Point Source Strategies for Short and Long Term

Point Sources Category	Major PM Emission Contributor	Control Strategies	
		Short Term (2012)	Long Term (2017)
Power Plant	• LSHS & coal major contributors towards PM emissions	• Shift to cleaner fuels i.e. LSHS to Light Diesel Oil (LDO) • Combustion technology up gradation for fuel change.	• Shift in cleaner fuels from LSHS & coal to Natural Gas (NG) • Combustion technology improvement with fuel change • Feasibility of conversion of thermal power production to gas based system.
Other Industries	• FO and coal are the major contributors towards PM emissions	• Shift to cleaner fuels (from FO to LDO)	• Shift to cleaner fuels from FO and coal to Natural Gas (NG) as per the availability • Feasibility of changing combustion technology to facilitate usage of gaseous fuels may be undertaken • Industrial development (expansion) should be based on cleaner gaseous fuel with no net increase in emissions.
Stone Crusher	• Contribution of total PM emissions from this sector is very high and impacts local area much more.	• Relocation as per MPCB strategy to be adopted and implemented at the earliest • No further extension for crushing within the city	• No further extension for crushing within the city

6.4.2.1 Point Source Control Options and Analysis

The industrial sector has been steadily declining in the city due to shifting development priorities and market forces. The major industrial units are located in Chembur – Trombay area. Tata Power Plant uses coal, NG and LSHS currently. Though the PM and NOx emissions from the power plant is within the city limit, the impact is not felt due to its location at the far end of the city. Predominant meteorology of the city also favours its negligible impact on urban PM and NOx concentrations as established through modeling results. Since the plant comes under the larger region of urban air shed of Mumbai and Navi Mumbai, it will be proper to shift the power generation with cleaner fuel. **Table 6.17A** presents the suggested changes and reduction in emission load.

Other industries use wide ranging fuels such as FO, LSHS, LDO, Coal, NG, Kerosene, HSD and others. The quantities used are not very large; however, their local impact could be high. In view of the varieties of fuel use, for better air quality, fuel cleaning through fuel switching has been thought to be useful. **Table 6.17B** presents the fuel switch options and emission loads in each case. An attempt has been made to align the use of clean fuel in the city for improving the air quality.

Stone crushers operated within the city used to be stopped as not only they are major contributor of PM but also are sources of high noise and high movement of heavy duty trucks within the city. Strategically, these units should be closed down by 2012. **Table 6.17C** presents the combined PM reduction for all point sources.

The above short and long term strategies for different sectors, if implemented effectively would reduce the PM emissions from 12485.07 kg/d to 3979.1 kg/d (i.e. about 68%) and 131.18 kg/d (i.e. about 98.9%) respectively.

Reduction of NOx emission load before and after control strategies is worked out in **Table 6.17D to 6.17F**. The NOx emissions would reduce from 99495.5 kg/d to 49736.7 kg/d (i.e. about 50%) and 22969.4 kg/d (i.e. about 76.9 %) respectively in the year 2012 and 2017.

Table 6.17: Point Source Emission Scenario Before & After Control Strategies: Short & Long Term Scenarios for PM

A. For Power plant

S. No.	Present PM Emissions			PM Emissions After Control Strategies					
				Short Term			Long Term		
	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)
1.	LSHS	4500 Tpd	509.4	LDO	4692	117.30	NG	4.88E+06	78.06
2.	NG	3347 m^3/day	0.05	NG	3.35E+03	0.05	NG	3.35E+03	0.05
3.	Coal	5800 Tpd	7540	NG (50%)	1.66E+06	26.54	NG	3.32E+06	53.07
				Coal (50%)	2900	3770.00			
Total (kg/d)			**8000**			**3913.89**			**131.18**
					% Reduction	**51.38**		**% Reduction**	**98.4**

B. For 39 Industries

S. No.	Present Total Emissions			Emissions After Control Strategies					
				Short Term			Long Term		
	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)
1.	**FO**	764	434.00	**LDO**	888	22.21	**--- No Change --**		
2.	**LSHS**	1309	131.00	**LDO**	1522	38.05			
3.	**LDO**	99	3.00	**LDO**	99	3.00			
4.	**HSD**	7	0.20	**LDO**	8	0.20			
5.	**NG**	51681	0.87	**NG**	51681	0.87			
6.	**Coal**	73	95.00	**NG**	41750	0.6680			
7.	**Kerosene**	0.17	0.00	**Kerosene**	0	0.0010			
7.	**LPG**	4	0.20	**LPG**	4	0.20			
7.	**Others**	183	0.80	**NG**		0.0029			
		Total (kg/d)	**665.07**			**65.21**			
					% reduction	**90.2**		**% reduction**	

C. Total Industrial Emissions in Mumbai Before & After Control Strategies

S. No.	Sector	Present PM Emissions (kg/d)	Emissions After Control Strategies (kg/d)	
			Short Term	Long Term
1.	**Power Plant**	**8000**	**3913.89**	**131.18**
2.	**39 Industries**	**665.07**	**65.21**	**--**
3.	**Stone Crushers****	**3820**	**--**	**--**
	Total	**12485.07**	**3979.1**	**131.18**
		% Reduction	**68.12**	**98.94**

\# Shift in cleaner fuel based on equivalent heat input estimation.

** According to MPCB, the existing stone crushers are to relocated from Mumbai suburbs

Table 6.17 (Contd...): Point Source Emission Scenario Before & After Control Strategies: Short & Long Term Scenarios for NOx

D. For Power plant

S. No	Present NOx Emissions			NOx Emissions After Control Strategies					
				Short Term			Long Term		
	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)
1.	LSHS	4500 Tpd	35790.19	LDO	4692	15006.19	NG	4.88E+06	13664.00
2.	NG	3347 m^3/day	9.37	NG	3.35E+03	9.38	NG	3.35E+03	9.4
3.	Coal	5800 Tpd	43500.00	NG (50%)	1.66E+06	4648.00	NG	3.32E+06	9296.00
				Coal (50%)	2900	21750.00			
Total (kg/d)			**79299.60**			**41413.60**			**22969.40**
					% Reduction	**47.80**		**% Reduction**	**71.00**

E. For 39 Industries

S. No.	Present Total Emissions			Emissions After Control Strategies					
				Short Term			Long Term		
	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)	Fuel type	Quantity	Emissions (Kg/day)
1.	**FO**	764	6076.37	**LDO**	888	2840.04	**--- No Change --**		
2.	**LSHS**	1309	10414.96	**LDO**	1522	4867.73			
3.	**LDO**	99	316.626	**LDO**	99	316.62			
4.	**HSD**	7	22.38	**LDO**	8	25.58			
5.	**NG**	51681	144.70	**NG**	51681	144.70			
6.	**Coal**	73	547.50	**NG**	41750	116.9			
7.	**Kerosene**	0.17	0.52	**Kerosene**	0	--			
7.	**LPG**	4	11.50	**LPG**	4	11.50			
7.	**Others**	183	2665.37	**NG**					
		Total (kg/d)	**20199.93**			**8323.1**			
					% reduction	**58.80**		**% reduction**	

F. Total Industrial Emissions in Mumbai Before & After Control Strategies

S. No.	Sector	Present NOx Emissions (kg/d)	Emissions After Control Strategies (kg/d)	
			Short Term	Long Term
1.	**Power Plant**	**79299.60**	**41413.60**	**22969.40**
2.	**39 Industries**	**20199.93**	**8323.10**	**--**
	Total	**99499.53**	**49736.7**	**22969.40**
		% Reduction	**50.00**	**76.91**

\# Shift in cleaner fuel based on equivalent heat input estimation.

** According to MPCB, the existing stone crushers are to relocated from Mumbai suburbs

6.4.3 Area Source Pollution Reduction Strategies

Emissions from area sources originate mainly from domestic fuel consumption, particularly LPG and kerosene. The other sources considered under area source emissions are hotels and restaurants, bakeries, crematoria (burning dead bodies), open burning, landfill burning, railways, ports, airports etc.

Area source emissions are high particularly for PM when compared with emissions from vehicular emissions. CMB results also indicate that PM contribution from road side dust is very high. Other area sources though called area sources, are limited to small regions and therefore, their impact does not seem to be wide ranging and across the city. For example, open burning can be common all through the city with some variation based on locality; however landfill open burning is limited to Deonar and Mulund. Of these two sites, Mulund does not have frequent burning problem compared to Deonar where fire is continuous phenomena except in monsoon. Similarly diesel based railway emissions are limited to Mumbai Central in Western line and Byculla – Kurla in central line.

From the point of emissions of NOx, railways appear to give highest load, however the impact is unlikely in major part of the city due to localized emission. Ports and airport emissions are also highly localized.

The strategic shift in the area source category shall be to opt for clean fuel and in some cases effective management steps to stop the emissions completely as in case of landfill open burning. Emission source wise control strategy and management plan is suggested in **Table 6.18.**

Table 6.18: Area Source Control Strategies

Source Category	Fuel Used	Control Strategy/Management Plan
Domestic	LPG Kerosene	• Further increase in use of LPG (more slum population coverage) • Ensure proper ventilation in kitchens to avoid indoor air pollution
Hotels and Restaurants, Open eat outs	LPG Kerosene Wood	• Further increase in the use of LPG by small hotels/restaurants and roadside tea/snack stalls • Ensure proper ventilation in kitchens to avoid indoor air pollution • Wood is mainly used in tandoors in restaurant, LPG/ electrically operated tandoors may be used
Bakeries	Wood Diesel	• Clean fuels like LPG/NG or electricity may be attempted for baking the bakery products. This will require change in current baking practices for which a separate study involving techno-economic feasibility is recommended. Incentives may be given to the bakeries for using cleaner fuels.
Landfill open burning	Refuse of all types are burnt	• This practice needs to be stopped by planning of dumping till sanitary landfills are made. • Treated water from Ghatkopar STP can be used effectively for any accidental fire. • Fast track steps for scientific SW management.
Construction building/ Road	• Fugitive emission • Fuel (Tar and Wood burning) for road paving	• Building construction/demolition codes need to be written and used with specific reference to PM control. Road construction/repair uses wood for melting tar. This technology needs to be abolished as over a large period of time, emissions are high.
Locomotive	Diesel (limited to shunting)	• Railways can shift to electricity as their whole operation is on electricity.
Port	Diesel	• Clean diesel programme should be initiated alongwith better engine I & M for small boats/ships. Bigger ships are controlled under MARPOL. Navy and BPT should be sensitized about use of clean fuel and emissions.
Crematoria	Wood Kerosene	• Increased use of electric crematoria. This will require participation of social organizations for increasing the awareness about need for forest conservation and environmental concerns, and to influence public opinion for change in religious practices. • All crematoria should be provided with efficient pyres and chimneys for release of emissions. • Further, a study involving usage of LPG burners in a closed furnace like electrical crematoria may be explored as substitute to existing practices. • Bodies related emissions from the pyre can be reduced by installing efficient PM control measures such as bag filters or cyclones
Airport	Diesel, Petrol, Aviation fuel	• Diesel and petrol consumption could not be computed for airport related vehicles such as loaders, buses, jeeps, food carts etc. Many of these remain operational throughout. These vehicles should be converted to run either on CNG or electric. • Plane idling emissions should be reduced

Anticipated Emissions Reduction

It is observed that the total particulate matter emissions from area sources, particularly due to burning of wood in bakeries and crematoria are high. Hence, the efforts should focus on finding out appropriate technology/management options, particularly on bakeries and crematoria. Other sectors also need large scale adoption of cleaner practices. The control scenarios as part of management plans for expected pollution load reduction due to area sources are given in **Table 6.19.**

Table 6.19: Area Source Emission Scenario with Control Options

Source	Present Emissions	PM Control Options	
		2012	2017
Domestic	564.9	• 25% of slums to use LPG/ PNG • 50% of non slum to use LPG/PNG	• 50% of slum to use LPG • 100% same
Hotel & Restaurants	593.1	50% of coal to LPG	75% of coal to LPG
Open Eat outs	281.6	Since these operation is illegal, difficult to quantify	
Bakeries	1554.6	25% LPG 25% Electric	50% LPG 25% Electric
Crematoria	300.7	50% Electric	75% Electric
Open Burning	734	50% open burning	100%
Landfill Burning	2906	100% Landfill burning	100%
Bldg. Construction	2289.9	50%	50%
Road Dust Paved	3163	15%	15%
Unpaved	4761.4	40%	100%
Ports	1.8	Awareness and Management	
Airports	75.6	Awareness and Better Inventory	
Railways	514	100%	100%

With the implementation of the short and long term scenarios, the total reduction in particulate matter from area sources would be more than 98%. Anticipated sector-wise particulate matter emission loads are given in **Table 6.20** below.

Table 6.20: Anticipated Reduction in Particulate Matter – Area Sources

Sector	Particulate Matter Emissions (Tones /Year)			
	Existing	% Contribution	Expected Emissions (Short Term), 2012	Expected Emissions (Long Term), 2017
Bakeries	1554.6	15.84	855.0	427.5
Crematoria	300.7	3.06	165.3	82.7
Open eat outs	281.6	2.87	Difficult to implement and project.	
Hotel restaurants	593.1	6.04	326.2	163.1
Domestic sector	564.9	5.76	466.0	155.3
Open burning	734	7.48	367 (50%)	-- (100%)
Landfill Open Burning	2906	29.61	-- (100%)	-- (100%)
Construction Activity	2288.9	23.32	1258.8	1258.8
Locomotive	514	5.24	Not computed	
Aircraft	75.6	0.77	Not computed.	
Marine vessels	1.8	0.02	Not computed.	

6.5 Control Options

Model runs were carried out taking into account the above mentioned control options separately and also in combination with relevant ones. These control options runs have been carried out mainly for winter seasons, which is likely to give worse projections.

All control options discussed earlier have been considered for model runs to access their effectiveness in terms of changes in highest ten concentrations in the city. **Table 6.21, 6.22 and 6.23** summarizes for control options 1 to 5, 6 to 10 and 11 to 15 respectively. These results are based on 2012 and 2017 expected emission loads. Ten highest concentrations for different control options are given in **Annexure 6**.

Table 6.21: Average of Ten Highest Concentrations after Implementation of Control Options 1 to 5

Control Options	Descriptions	2012		2017	
		PM	NOx	PM	NOx
Business as Usual		**438.4**	**183.6**	**602.0**	**223.9**
I	Implementation of Bharat Stage –IV norms from the year 2010. The expected reduction in emissions for gasoline vehicles is 47% for NO_X where as for diesel vehicles 45% for particulate matter and 50% for NO_X are expected	433.9	146.9	595.8	159.5
II	Implementation of Bharat Stage IV from 2010 and Bharat Stage V from 2015. So for 2012 the conditions are same as the scenario in 2012 in Control option I. The difference between Bharat Stage IV and Bharat Stage V are the emission factor for NOx decreases by 25% for Gasoline and the emission factor for PM for Diesel decreases by 90% for NOx 28%	433.9	146.9	589.0	152.2
III	Implementation of Bharat Stage IV from 2010 and Bharat Stage VI from 2015. So for 2012 the conditions are same as the scenario in 2012 in Control option I. For 2017, the PM_{10} load is same as Control II. The difference between Bharat Stage V and Bharat Stage VI are the emission factor for NOx decreases by 55% for Diesel	433.9	146.9	589.0	147.8
IV	Implementation of Electric Vehicles. In 2012 the Share of Electric vehicles in total city fleet is for two wheelers 1%; for auto riksha and taxi 5% and for public buses 5%. In 2017 the Share of Electric vehicles in total city fleet is for two wheelers 2%; for auto riksha and taxi 10% and for public buses 10%	--	181.4	595.8	120.4
V	Implementation of hybrid Vehicles. In 2012 the Share of hybrid vehicles in total city fleet is for gasoline powered four wheelers 1%. In 2017 the Share of hybrid vehicles in total city fleet is for gasoline powered four wheelers 2%	--	146.9	--	159.5

Table 6.22: Average of Ten Highest Concentrations after implementation of Control Options 6 to 10

Control Options	Descriptions	2012		2017	
		PM	**NOx**	**PM**	**NOx**
Business as Usual		**438.4**	**183.6**	**602.0**	**223.9**
VI	Conversion of all three and four wheelers to CNG/LPG Vehicles. In 2012 the Share of CNG/LPG vehicles in total city fleet is 25%. In 2017 the Share of CNG/LPG vehicles in total city fleet is 100%	433.9	146.9	595.8	159.5
VII	Implementation of Ethanol blended fuel. In 2012 and 2017 the Share of ethanol blended fuel will be 10%	--	146.9	--	159.5
VIII	Implementation of biodiesel. In 2012 the Share of biodiesel fuel will be 5%. In 2017 the Share of biodiesel fuel will be 10%. The expected reduction in emission factors is 10% for PM and 2.5% increase for NOx	433.9	146.9	595.8	159.5
IX	Implementation of Hydrogen – CNG blended fuel. In 2017 the Share of hydrogen blended fuel for vehicles on CNG will be 10%. The expected reduction in emission factors is 10% for NOx	433.4	164.8	595.3	159.5
X	Implementation of Retrofitment of diesel oxidation catalyst (DOC) in 4 wheeler public transport (BSII). Expected reduction of PM_{10} is about 22.5 % (as compared to BS – II vehicles). 50% conversion is expected in 2012 and 100% conversion in 2017	--	--	--	--

Table 6.23: Average of Ten Highest Concentrations after implementation of Control Options 11 to 15

Control Options	Descriptions	2012		2017	
		PM	NOx	PM	NOx
Business as Usual		438.4	183.6	602.0	223.9
XI	Implementation of Retrofitment of Diesel particulate filter in 4 wheelers public transport (Bharat Stage II city buses). In 2012 the Share of Retrofitted Diesel particulate filter in 4 wheelers will be 50%. In 2017 the Share of Retrofitted Diesel particulate filter in 4 wheelers will be 100%.The expected reduction in emission factors is 70% for PM as compared to Bharat Stage II and III vehicles	433.9	--	595.8	--
XII	Wall to wall paving (brick) of all roads, this leads to 15% reduction of PM emission for both 2012 and 2017	376.0	--	516.3	--
XIII	Banning odd/even vehicles on particular day which means Zero emissions from the vehicles off the roads	219.8	145.2	301.7	154.1
XIV	Synchronization of traffic signals	351.7	164.8	481.7	193.5
XV	Implementation of Bharat Stage IV from 2010 and Bharat Stage VI from 2015. This control option also includes conversion of 5% of 2 wheelers; 20% of 3 wheelers; 20% of Taxies and 5 % of public transport buses to Electric Vehicles. This control option also includes conversion of 80 % of taxies; 80% of 3 wheelers; 25% of public transport buses to CNG/LPG Vehicles. All these conversions will be implemented in 2012. In 2017, the following fuel change will be implemented. Conversion of 10% of 2 wheelers; 30% of 3 wheelers; 30% of Taxies and 10 % of public transport buses to Electric Vehicles. This control option also includes conversion of 80 % of taxies; 80% of 3 wheelers; and 25% of public transport buses to CNG/LPG Vehicles	363.0	141.2	495.6	143.7

The scenario XV considers the combination of most feasible option. It aims at addressing the major options linked with technology change, fuel mix change and use of electric vehicles.

Percent reduction of PM and NOx for 2012 and 2017 after implementing the control options is presented in **Figure 6.6**.

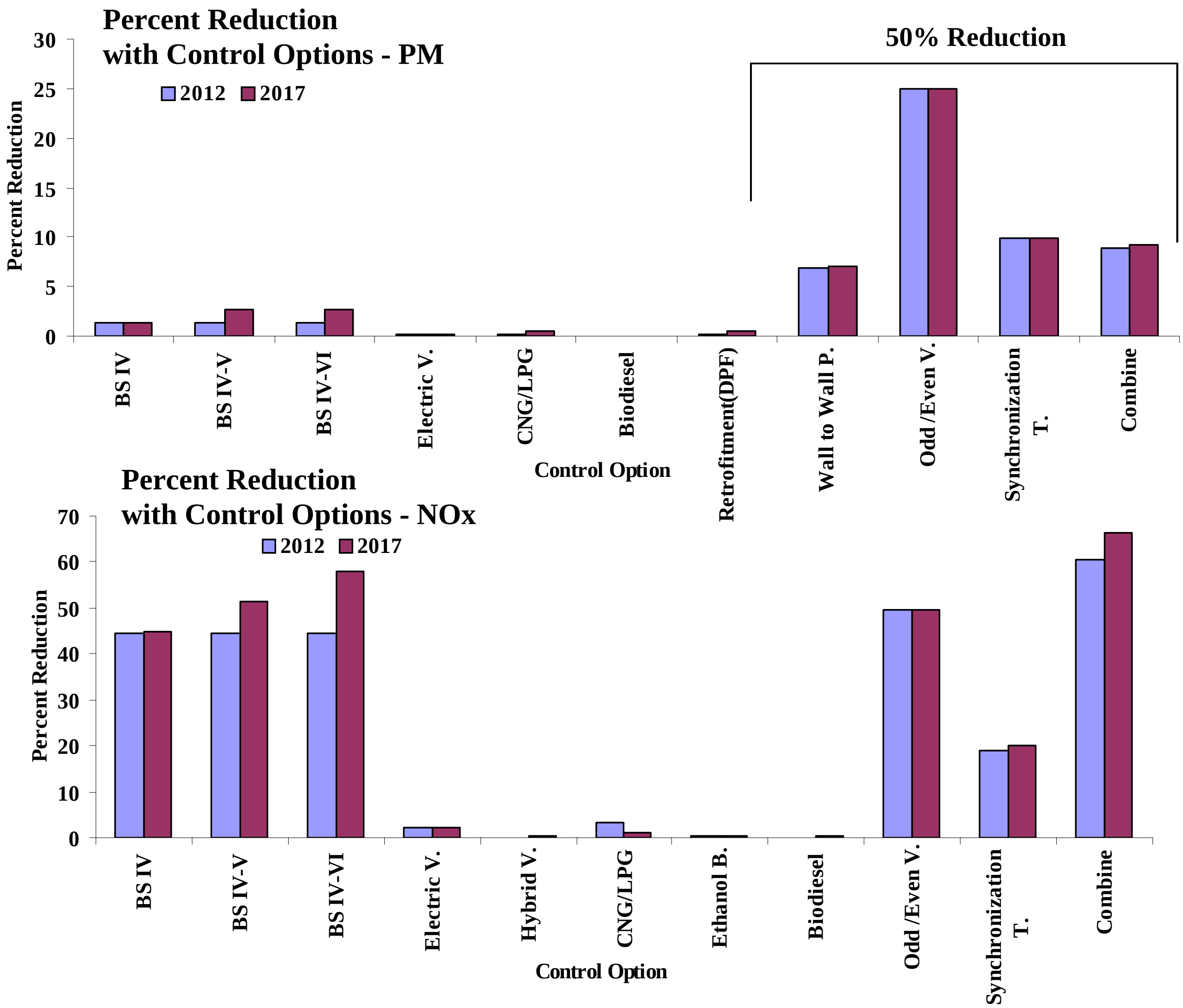

Figure 6.6: Percent Reduction with Control Options of PM and NOx for 2012 and 2017

Reduction in emission load of PM_{10} is maximum (49.8%) with banning odd/even vehicles on particular day for both 2012 and 2017. Wall to wall paving of roads, synchronization of traffic signals and control option XV lead to considerable reduction in emission load. The percentage reduction due to implementation of hydrogen CNG vehicles in 2017, retrofitment of diesel vehicles in four wheelers public transport, introduction of hybrid vehicles and ethanol blended fuel do not lead to considerable reduction in PM reduction.

NOx emission load is reduced maximum after implementing control option XV followed by implementation of control option III. Reduction in NOx is also considerable after implementing control options I, II and banning odd /even vehicles on particular day.

Further discussions on most preferred option to be applied to Mumbai with a view to meet PM and NOx standards have been presented in **Chapter 7**.

#R : References:

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Chapter 7
Prioritization of Management/Control Options

7.1 Introduction

Management options for each sectors need to be prioritized with a view to understand the issue of implementation. Implementations are highly influenced not only by the idea of the improvement alone but also by the nature of the recommendations, fiscal and administrative barriers, effectiveness, implementing agencies and acceptance from large group of stakeholders. Prioritization issues are also driven by the comparative account of short term and long term implementation dilemma. Low cost with high effectiveness, low cost with shorter implementation period shall be a better option when compared with high effectiveness with high costs or long implementation period. Some of these considerations have been used here to prioritized the options in each case of vehicular, industrial and area sources.

7.2 City wise Dispersion Modeling for selected Options for Future Scenario

A very comprehensive set of options have been examined for the purpose of understanding the issue of urban air pollution reduction and are given in **Annexure 7.1.** Short listed options and their estimated load reductions due to each of these options are given in **Table 7.1**. The dispersion run was carried out for many scenarios and based on options, where the effectiveness of PM and NOx reductions were significant, those were selected and included for the model run. Preferred Option I considered options 1 to 4 for vehicles, and all options for industries and area as referred in **Table 7.1** which is given in **Figure 7.1 through 7.4**. Preferred Option II (i.e. options 1 to 8 for vehicles and all options for industries and area), gives the PM and NOx concentrations for 2012 and 2017, and presented in iso-contours map in **Annexure 7.1**.

Though some of the options were selected on the basis of PM reduction potential, their possible co-benefits in reducing NOx and other pollutants were also considered during the process of prioritizing. The options considered are based on the discussion presented in **Chapter 6** earlier, describing the city specific situation and its possible impacts on air quality.

Model runs for the whole city included the major control options from all the three sources. The results of ten highest concentration of PM and NOx for 2012 and 2017 is presented in **Table 7.2.**

Table 7.1: Summary of options used for city based Model Run

Category		Control Options	Scenario 2012	Scenario 2017
Vehicle Sources	1	New Vehicle Standards	▪ Bharat IV from 2010	▪ Bharat IV from 2010 ▪ Bharat VI from 2015
	2	Electric vehicles	▪ 2 wheelers – 5% ▪ 3 wheelers – 20% ▪ Taxies – 20% ▪ Public transport buses -5%	▪ 2 wheelers – 10% ▪ 3 wheelers – 30% ▪ Taxies – 30% ▪ Public transport -10%
	3	CNG/ LPG	▪ Taxies – 80% ▪ 3 wheelers – 80% ▪ Public transport – 25%	▪ Taxies – 70% ▪ 3 wheelers – 70% ▪ Public transport – 40%
	4	Ban or scrapping of 15 year old vehicles	▪ 1997 vehicles to scrapped commercial vehicles ▪ Ban > 8 years vehicle	Continued
	5	Inspection and Maintenance	New I&M regulations (50% population)	Full compliance -100%
	6	Synchronization of traffic	20% improvement	40% improvement
	7	Public Transport	10% VKT reduction	20% VKT reduction
	8	Ban of odd /even vehicles	50% reduction from private vehicles	50% reduction from private vehicles
Industrial Sources		Shifting of Fuel	▪ 39 Industries - FO, LSHS, HSD to LDO - Coal & Others to NG	No Change
			▪ Power Plant - LSHS to LDO - Coal to NG (50%)	100% to NG
Area Sources		Domestic	▪ 25% of slums to use LPG/ PNG ▪ 50% of non slum to use LPG/PNG	▪ 50% of slum to use LPG ▪ 100% same
		Hotel & Restaurants	50% of coal use to LPG	75% of coal use to LPG
		Open Eat outs	Since these operation is illegal, difficult to quantify	
		Bakeries	▪ 25% LPG, * 25% Electric	▪ 50% LPG, * 25% Electric
		Crematoria	50% Electric	75% Electric
		Open Burning	50% control on open burning	100% control on open burning
		Landfill Burning	100% control of Landfill burning	100% control of Landfill burning
		Bldg. Construction	50% control on dust emission	50% control on dust emission
		Road Dust Paved	15% control on dust	15% control on dust
		Unpaved	40% control on dust	100% control on dust
		Ports	Awareness and Management	
		Airports	Awareness and Better Inventory	
		Railways	100% on electric	100% on electric

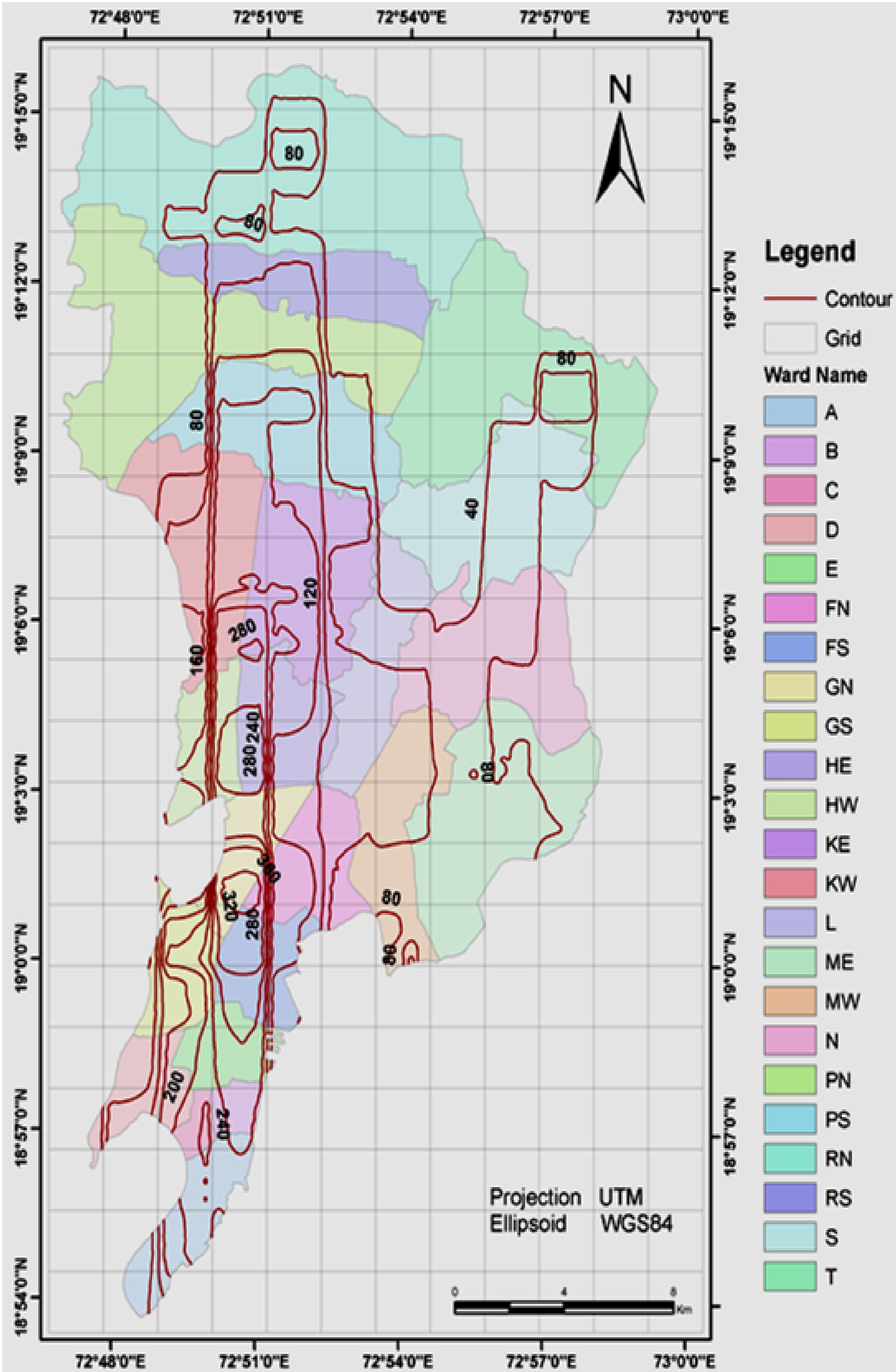

Figure 7.1: Preferred Options –I : Prediction of PM_{10} (2012)

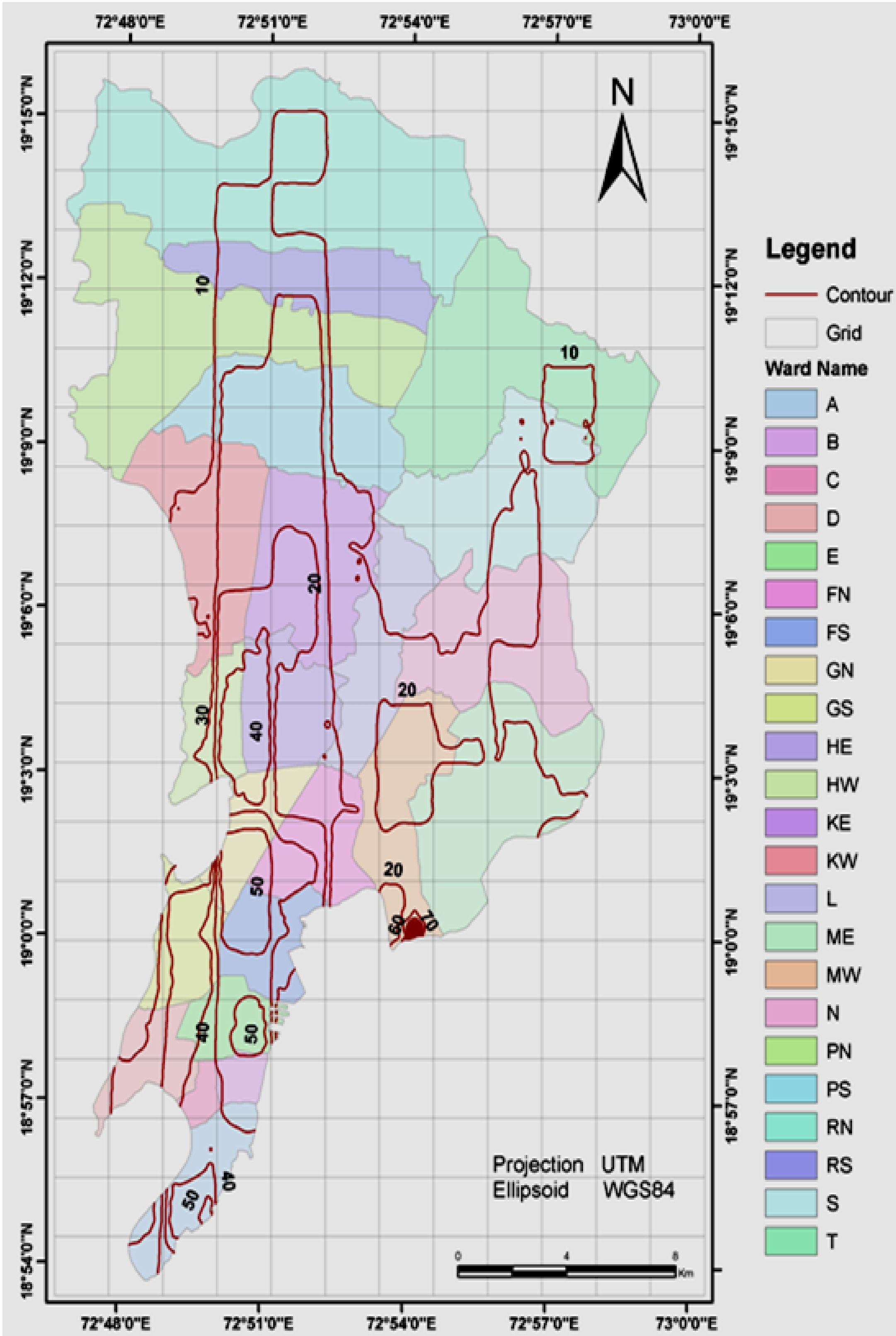

Figure 7.2: Preferred Options–I : Prediction of NOx (2012)

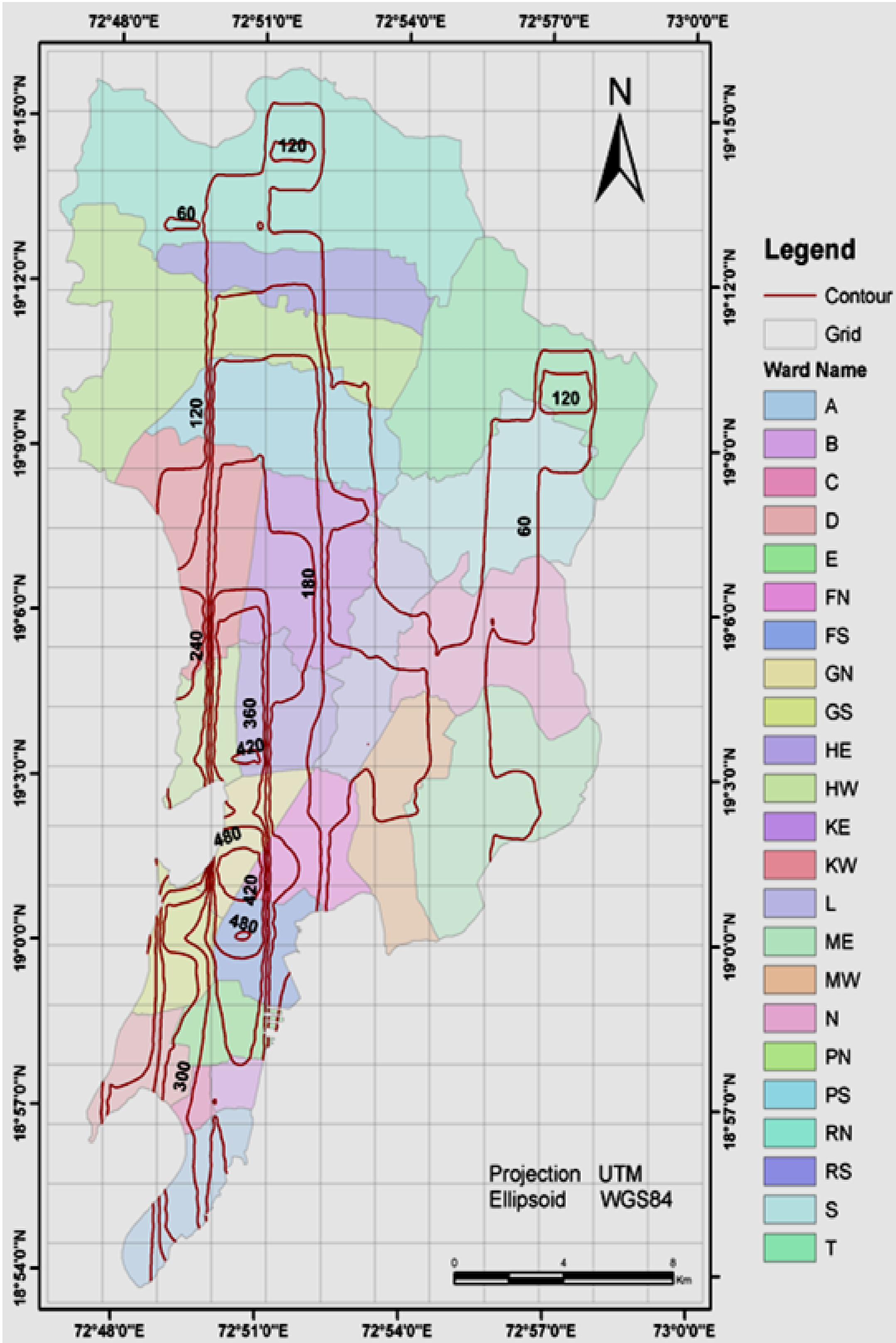

Figure 7.3: Preferred Options–I : Prediction of PM_{10} (2017)

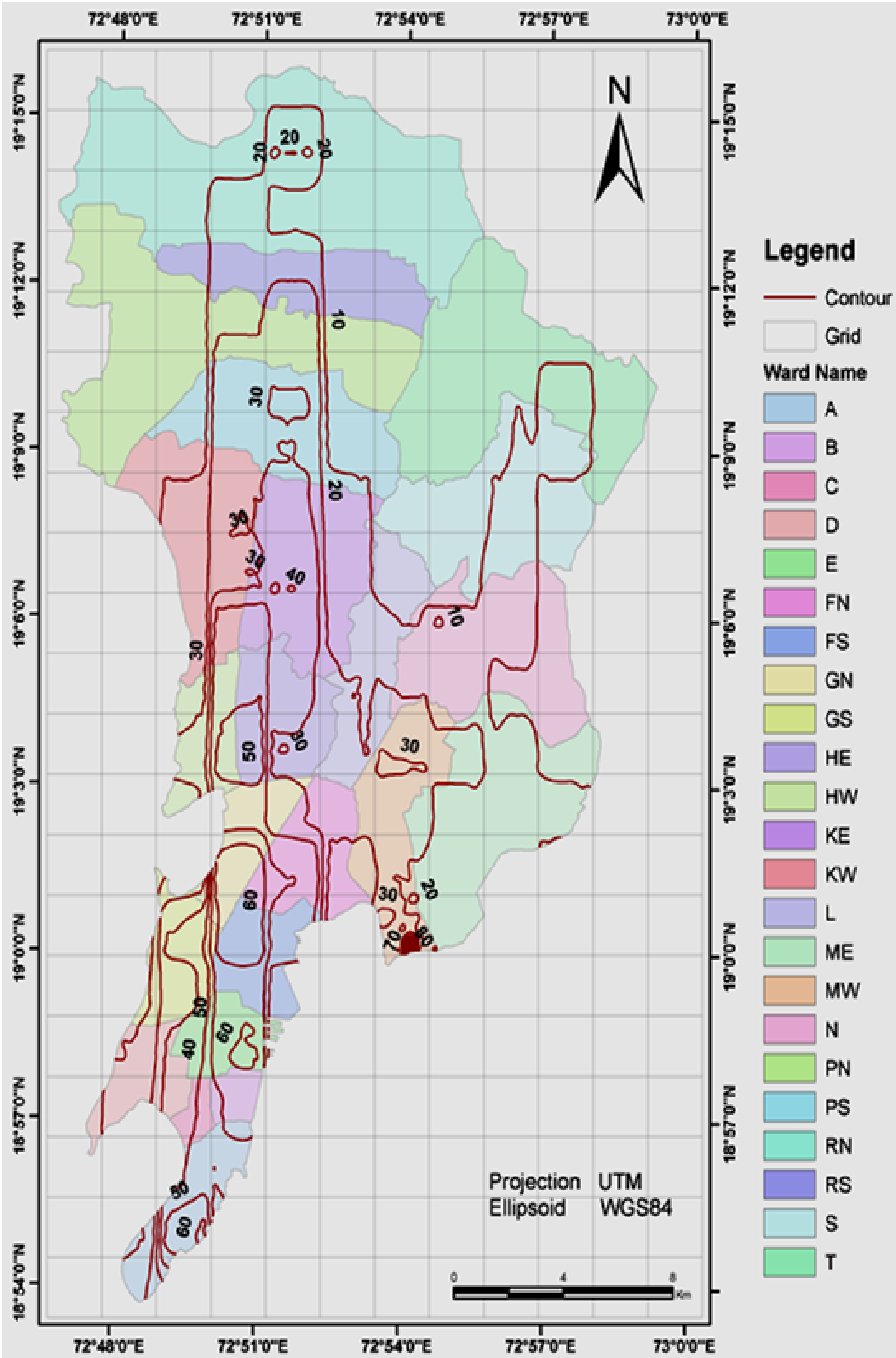

Figure 7.4: Preferred Options –I : Prediction of NOx (2017)

Table 7.2: Comparison of PM_{10} and NOx concentrations in preferred option in 2012 and 2017 by considering the highest ten concentrations

		Minimum	Maximum	Average
Preferred Option –I				
2012	PM_{10}	356.6	370.0	363.7
	NOx	55.8	143.3	73.3
2017	PM_{10}	485.1	503.8	495.5
	NOx	65.6	146.3	80.5
Preferred Option -II				
2012	PM_{10}	98.00	104.30	100.60
	NOx	16.3	119.5	45.8
2017	PM_{10}	118.3	126.0	121.40
	NOx	19.6	120.5	48.2

All values in ($\mu g/m^3$)

Ground level concentrations for seven sites after considering Preferred Option I (i.e. options 1 to 4 for vehicles, and all options for industries and area) and Preferred Option II (i.e. options 1 to 8 for vehicles and all options for industries and area) and its comparison with BaU concentrations of 2007, 2012 and 2017 is presented in **Figure 7.5 and 7.6.**

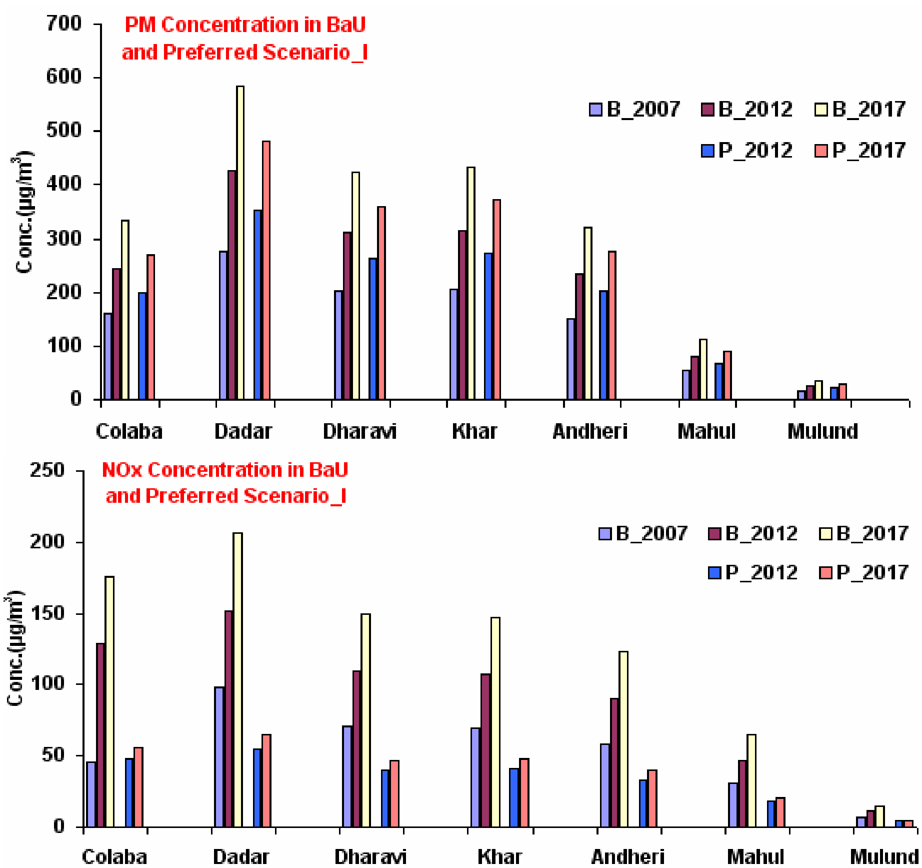

Figure 7.5: PM and NOx Scenario Compared with BaU of 2007, 2012 and 2017 and Preferred Scenario (I) of 2012 and 2017

The predicted ground level concentrations show improvement all across the city. Results shown for the seven sampling locations indicate that though NOx levels would be met most of the time, PM levels will exceed at many locations, except at Mahul and Mulund. As can be seen in the figure, the emission levels would become highly un-acceptable with regard to the PM and NOx levels especially if no control scenario continues till 2012 and 2017.

As can been seen from **Figure 7.5 (Preferred Scenario I)** PM values continue to exceed the standard of 100 µg/m^3. Therefore, to reduce PM ambient concentrations in the city, other options of vehicle sources viz. 5, 6, 7 and 8 will need to be implemented simultaneously. The ambient air scenario with these additional options will bring down PM levels at most of the places below the standards as shown in **Figure 7.6** i.e. **Preferred Scenario II**.

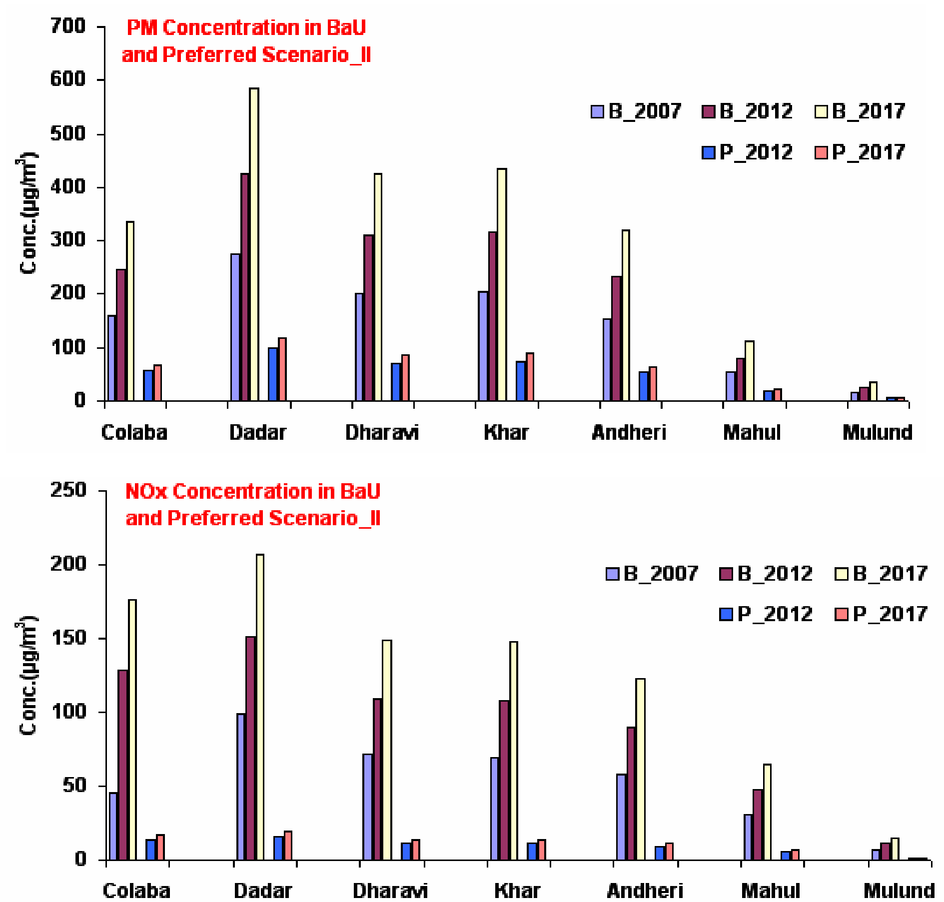

Figure 7.6: PM and NOx Scenario Compared with BaU of 2007, 2012 and 2017 and Preferred Scenario (II) of 2012 and 2017

7.3 Prioritized List of Management/ Control Options

Management options leading to reduction of pollutants have been prioritized using a framework based on various considerations such as technical, administrative and economic/fiscal issues. These issues are intricately linked with each other and without which a major initiative for large area air quality improvement may not be possible to undertake. **Tables 7.3 through 7.5** present the framework for the selection of measures for each sectors viz, vehicular (line), industrial (point) and area sources.

Table 7.3: Framework for Selecting Measures to Address Urban Air Pollution - Vehicles

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(1) Strategy: Reducing Emissions per Unit of Fuel			
Fuel Quality Improvement	Sulphur Reduction	Delineating tighter diesel fuel standards	Phasing out fuel subsidies, uniform pricing all over the state followed by country,
Installation of after treatment devices	Fitment of Diesel Oxidation Catalyst, catalytic converter in older vehicles	Tighter diesel fuel standards particularly for Sulphur to bring down its level up to 50 ppm. Emission test frequency to be more for those without the after treatment devices	Differential taxation to those with and without after treatment device
Tackle fuel adulteration	Markers for detection	Better specification of fuel quality for detection as well as booking the offenders. Monitoring fuel quality in a specified laboratory, making companies accountable	Oil companies to finance the setting up of a laboratory, Fines and cancellation of license
Use of alternative fuels	CNG and LPG use	Promote its use in private sector as well as organized sector through administrative orders	Differential taxation for older vehicles changing to CNG/LPG, Incentive for new owners to buy CNG/LPG vehicles
Renewal of vehicle fleet	Phase out vehicles above a certain age	Scrappage of older vehicles	Older vehicles to remain on road if it passes the fitness test as well as emission test, however higher tax to be paid as the vehicle gets older
Improve traffic flow	Synchronized signal corridors	Coordination with other institutions to check indiscriminate parking , and enforce one way system at peak hours	Congestion pricing Higher parking fees

Table 7.3 (Contd...): Framework for Selecting Measures to Address Urban Air Pollution - Vehicles

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(1) Strategy: Reducing Emissions per Unit of Fuel (Contd..)			
Reduce dust re-suspension	Road paving / cleaning	Coordination with all institution working in the area of road and pavement maintenance, digging for utilities etc. One agency to monitor the working practices.	Steep fines to agencies leaving the debris-dust on the roads after the completion of jobs.
(2) Strategy: Reducing Fuel Consumption per unit Distance			
Change to better technology engines	4 stroke engines for two –three wheelers, Bharat stage III engines with DOC for older diesel vehicles, All new diesel vehicles to be Bharat stage III and above.	Standards for fuel economy need to be specified Useful age of the vehicles to be specified by the manufacturer	Tax break for older vehicles changing to new engine with DOC or DPF
Improve vehicle I&M	I&M programs that are difficult to cheat; computerized data capture and control of tests	Strict enforcement with socially acceptable failure rates	Better infrastructure, manpower augmentation, Strict fines for not displaying pass sticker
Better road maintenance	Investment in better road maintenance technology to avoid frequent relaying	Standards for road construction specified in terms of guaranteed life of the road	Financial incentives for contractors using better technology for road construction
(3) Strategy: Reduce Vehicle Distance Traveled			
Increase private vehicle occupancy		Encourage car pooling	Congestion pricing
Promote better and more public transport	Dedicated bus lanes; user friendly MRTS	Reform of public transport – competition, privatization	Subsidize public transport by taxing private vehicle users
Demand management		Limit parking Limit the use of vehicles in congested areas	High one time tax on purchase of a new vehicle High parking fees Road user charges Higher taxes per vehicle km traveled
Encourage non motorized transport	Pedestrian friendly walkways / subways	Protection of pedestrian facilities	Financial incentives for pedestrian friendly design

Table 7.4: Framework for Selecting Measures to Address Urban Air Pollution - Industries

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
Fuel change	For power plant the fuel change leads to technology change as well. However, newer technologies are more efficient and long term cost effective. Other industries may experience lower level of technology issues.	Local PCB can make the rule stringent and link with Mumbai Air Action Plan	High cost initially. However in longer run more cost effective
Industrial Policy	• Specifying technology needs policy review. • Area specific location policy	Detail feasibility study for technology as well as land use based policy issues.	Financial incentive to burn cleaner fuel or use of cleaner technology

Table 7.5: Framework for Selecting Measures to Address Urban Air Pollution – Area Sources

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
Fuel change - Domestic	No major technical issue	Adequate administrative measures in place	No major cost involved facilitation for awareness needed
Fuel change - Bakeries/Crematoria	Need for technical evaluation	Standards to be specified to drive technical changes	Medium cost
Fuel change – Railways/airport/ship	No major technical issue	Administrative directions needed	Medium cost
Resuspended dust	• Pavement to be wall to wall • Better sweeping system • Better road paving technology issue	Regulatory push required for better road paving technologies	• Minor cost • Penalties for poor road surfacing
Construction	Improved construction practices, no technology issue	Regulatory push and surveillance needed for better compliance	Minor costs of regulation and surveillance

Based on the framework of each sector delineated above, each of the possible actions has been discussed in respect to their effectiveness, barriers to implementation and administrative issues. These options have also been considered for their co-benefits with regard to other pollutants adding values to the action planned. Mumbai city specific measures at national as well as local levels have also been finalized after interactions in various meetings and workshops. Implementing agencies roles and responsibilities finally take the process further. These agencies are likely to have direct and indirect role in implementation. **Tables 7.6, 7.7 and 7.8** present the considerations in prioritizing various measures for vehicular, industrial and area sources, respectively. The options discussed are also detailed with regard to action to be taken up at city, state or central levels.

Table 7.6: Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit Fuel Used						
S reduction in diesel	Technically feasible and being implemented	Moderate. Reported elsewhere 2000 to 300 ppm reduction in S leads to 2.5 – 13 % reduction in PM #	High cost. Being planned by Refineries as per the Auto Fuel Policy. The cost is in the range of 15000/35000 crores based on the levels of S	Improvement in emission standards as well as legislation for stringent fuel standards for S, Phasing out the subsidies on diesel. Bringing diesel cost at par in a state/centre	The S reduction will not only reduce the PM but also lead to correspondingly lower SO_2 emission leading to lower ambient SO_2 and sulphate. It will also allow better functioning of exhaust after treatment devices.	Oil companies, Ministry of Petroleum, vehicle manufacturer
Reduce fuel adulteration	Better quality fuel by adopting stricter fuel supply and dispensing system (e.g. Pure for Sure etc.) Chemical marker system	Reduced adulteration will lead to reduced PM (difficult to quantify). Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM	Present system of Anti Adulteration cell function needs major improvement in terms of higher manpower and spread. Presently one office at Mumbai looks after three states of western region. Success of marker system shall be highly dependent upon the joint working relation of Oil companies and AAC.	The current fuel specifications are too broad and therefore checking of conventional parameters such as density etc. does not reflect the adulteration. Finer fuel specifications are needed for implementation. Oil companies themselves can be proactive in proposing these values, which can be checked easily in any laboratory. They also need to be more accountable.	One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its entire lifetime.	Anti-Adulteration cell, Oil Companies, Vehicle owners

Source (Air pollution from motor vehicles, Faiz Asif, Weaver C.S. and Walsh M.P., The World Bank, Washington, D.C., 1996)

Table 7.6 (Contd..) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit Fuel Used						
Alternative fuels	• Technical infrastructure in Mumbai for dispensing CNG/LPG is fairly good and is improving	High, more than 90 % reduction in PM can be achieved compared to diesel #	Can be applicable mainly for vehicles, which are supposed to ply within the city. Applicable to only local public transport, taxies etc.	Incentive by the government authorities to private vehicle owners to shift to CNG/LPG.	Will lead to substantial reduction in CO and HC emission, however, NOx values may go up	Mahanagar Gas, Oil Companies marketing LPG, Local Government
	• Biofuels can be used upto 5-10% without any major technical issue.	Similar to diesel but low SO_2 and low PM	Can be easily implemented	Regulatory system allows	Low SO_2 emission	Ministry of Petroleum
Phase out of grossly polluting vehicles	No major technical problem	High, Estimate suggest 25% of these vehicle may contribute 75% of total emission $	Poor Inspection system both for emission as well as vehicle. New legislation may require changes in Motor Vehicles Act	New legislation needed for improved Inspection certification system, better testing facility.	Better compliance will lead to reduction of other pollutants as well. It will also lead to less pressure on complying vehicles	Transport Commissioner office, Ministry of Road Transport and Highway

Source (Air pollution from motor vehicles, Faiz Asif, Weaver C.S. and Walsh M.P., The World Bank, Washington, D.C., 1996)
$ Source (Impact of Better Traffic Management, South Asia Urban Air Quality Management, Briefing Note No. 5, ESMAP, The World Bank, 2002)

Table 7.6 (Contd...): Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit Fuel Used						
Congestion reduction	Improvement of roads, new roads, scientifically planned traffic management	High emission due to fuel burning at idle or slow moving traffic	Road quality improvement is a matter of technology and quality of work carried out. Concretization of road may be the solution. New road planning and Traffic management are being taken as integral part of the MUTP.	Better planning and training in traffic management Road construction norms to be evolved and implemented	It will reduce traffic junction hotspot of all the pollutants It will also reduce continuous source of dust	State Government, BMC, MMRDA, Transport police, other utilities.
Strategy : Vehicles: Emission Reduction per unit distance travelled						
Standards for new and In-use vehicles	No technical issue with new vehicles. For inuse old vehicles, technical feasibility needs to be established	Marginal improvement from newer vehicles except when implementation is for Euro V & VI. In-use vehicles emission reduction can be substantial	The process of in-use vehicles standards may take time as they need to be revised at central level. Inadequate infrastructure and manpower at local levels could be other major barriers.	After the legislation is in place, provision of strict penalty leading to cancellation of vehicle registration.	As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types	MoRTH, Transport Office Govt. Maharashtra
Introduction of new technology vehicles	New technology based vehicles emit less per unit distance travelled Electric vehicles	High compared to grossly polluting, moderate with respect to inuse vehicles	Emphasis to allow only a type of technology to be permitted may meet with resistance from manufacturer as well as buyer. (e.g. rule to allow only 4 stroke vehicle to be registered)	This needs to be backed with proper legislation. Else charge higher registration fee or subject them to carry out more frequent I&C test. Electric vehicles for grossly polluting high VKT vehicles are a good option. It needs regulatory push	It will lead to better compliance from on-road emission test and overall improvement in emission of all the pollutants. Electric vehicles provide localized benefits of no air pollution	MoRTH, Transport Office Govt. Maharashtra, MNRE

Table 7.6 (Contd...): Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit distance travelled						
Retrofitment of new engine/ Emission control device	Experience of other countries suggests that it can be feasible. However, in Indian scenario, a pilot retrofit programme to evaluate the efficacy needs to be undertaken. A small pilot project is on in Pune with USEPA, USTDA and NEERI	Engine replacement could lead to major reduction of PM. Emission control devices available (DPF, DOC) can remove PM upto 90%	Availability of new engines for retrofit. Vehicle manufacturers need to come forward. For Emission control devices, there are innumerable agencies. Cost sharing for its implementation.	Presently no legislation. Need to frame one including a mechanism by which the system can be evaluated by an appropriate agency.	Short time frame, high levels of compliance expected for all the in-use older vehicles.	MoRTH, Transport Office Govt. Maharashtra, vehicle manufacturer, vehicle fleet owners
Higher usage of Public Transport	Dedicated bus lane, better buses, low cost of travel, faster travel etc.	Effectiveness is high as less and less road space will be occupied by private vehicles, faster movement of public transport in comfort shall lead to low emissions	Feasibility to be established for bus lane. Finances for better buses Measures to reduce the cost of travel by way of cross financing.	Local level planning in coordination with all the authorities involved in MUTP.	Future growth of the city will entirely depend upon the levels of public transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency.	BMC, MMRDA, MSRDC,BEST,
Decrease Private vehicles on Road		Less private vehicles on road, high road space utilization	Awareness matched with better public transport. Need for barriers for buying a car	Higher parking charges, high registration fees, higher car user charges, sale linked with parking availability.	Private vehicles owners should must own their own garages, less parking on the roads, less congestion	BMC, MMRDA, RTO,

Table 7.6 (Contd...): Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit distance travelled						
Training and Awareness programme for car owners, public transport operators, drivers and mechanics	On use of alternative fuel, Inspection and certification, adulteration of fuels, use of public transport, less usage of private vehicles	May lead to 5-10% reduction of emission.	Resources for awareness and training, bringing the different groups together	Structure for such programme should be developed and integrated into legislation.	Savings by way of improved vehicle maintenance and operation	MMRDA, Transport Department, Other institutions involved in awareness campaign

Table 7.7: Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Industries

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Industries: Emission Reduction per unit Fuel Used						
S reduction in fuel	This process is currently on, however, the fuel S reduction is mainly for vehicular sector	High as many industries in Mumbai region use coal, HSD, LSHS, and FO	As the industrial growth is negative in Mumbai, the need of S reduction in conventional fuel is not being pressed upon	MPCB can specify the S levels for the fuel being used	S levels in fuel has been very strictly controlled for Tata Power. An example of this can be extended to other industries	MPCB, Industries
Combustion Processes	Change in combustion technology will be needed for shifting from coal/oil to natural gas	Moderate	Finances to change the process technology	No regulatory issue	It will lead to lower emission of CO and HC	MPCB
Alternate Fuel	Large no of industries are using NG and LPG	The higher percentage of use of cleaner fuel has already resulted in better air quality in the city		More allocation of NG/LPG to the industrial sector through MGL/GAIL/ Govt. of India	Better air quality in terms of SO_2, CO and HC will be achieved.	Mahanagar Gas, MPCB

Table 7.7(Contd...): Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Industries

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Industries: Emission Reduction by Industrial Policy and Standards						
Promoting Cleaner Industries	Use of cleaner production processes	Large scale shift shall result in major PM reduction	Finances to carry out these changes	MoEF can provide incentives to carry out the necessary change	It will lead to sustainable existence of industries within the city. Also lead to other pollutants reduction	MoEF, MPCB, BCCI, CII, CPCB
Location Specific emission Reduction	Specification of site specific emission standards	Medium as the power plant has already been subjected to strict S levels as well as PM emission by MPCB	Higher allocation of NG/LNG at lower cost is needed	State as well as central government can provide the necessary incentive on use of cleaner fuel by the power plant and other industries	High level emission shall have lower PM and other gaseous pollutants	GoM, MPCB, GoI, CPCB
Fugitive Emission control	Industrial process improvement better operation and maintenance	For localized region, very effective, particularly for industries with fine particles raw material or products. High efficiencies can be achieved for quarries.	Monitored data is scarce and therefore how and where to undertake the action will be limited	MPCB can work on the standards for fugitive emission and develop compliance system	Local area air quality improvement could be highly effective.	MPCB, Industries, CPCB

Table 7.8: Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution – Area Source

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Area Sources: Mixed sources and varied strategies						
Improve fuel used for domestic purposes	LPG/PNG major domestic fuel, however kerosene is still a major source in low income group/ better stoves or change in fuel to LPG	Likely to improve indoor air quality	Lack of finance to low income group, particularly in slums	Administrative mechanism to be evolved to provide low cost clean fuel to slum dwellers	It would alleviate large section of population with high indoor pollution of other sources leading to lower disease burden and better quality of life	Central and State Govt., MoPNG
Bakeries /crematoria	Electric/LPG source based bakeries needing changes in design. Many crematoria have electric system, but need to convert all the other into electric system	Local grid based PM can be reduced.	Awareness to bakeries that the quality can still be maintained with electric or LPG ovens. Similarly, despite electric crematoria being available, people prefer using wood based pyres	Strict monitoring of emissions from bakeries and crematoria	Reduction in PM as well as odour will take place and is likely to improve the local air quality	MMRDA, BMC and MPCB
Biomass/trash burning, landfill waste burning	Better control on collection and disposal at the respective sites. Landfill waste burning needs proper technology driven site management	Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids	Awareness and local control. Apathy to take urgent action. No burning day vow to be taken by BMC	MPCB needs to address this issues	High level improvement in local area ambient air quality not only for PM but other pollutants	BMC, MMRDA, MPCB

Table 7.8 (Contd...): Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution – Area Source

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers	Local/ National Stakeholders
Strategy : Area Sources: Mixed sources and varied strategies						
Resuspension	Vehicle movement related resuspension can be reduced by having better paved roads, regular sweeping and spray of water.	Highly effective for kerb-side air quality	Awareness and will to implement	Norms for road construction to be framed and implemented	Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being	BMC, MMRDA
Illegal SSI	Level of problem not well known. Need to understand what are the levels of operation and their contribution in each of the grids in the city	Local area improvement can be moderately good	Knowledge of the problem	Need for strict rules of such units and identification by MPCB/DIC and BMC	It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem	MPCB, DIC, BMC
Construction	Construction activities which involve demolition, digging, construction, vehicle movement etc. need information on how to minimize the dust	Large scale improvement in local area is expected.	Emphasis on better construction practices and management plan for air emission and its control by the implementing agencies	Penalty system to be employed by the local authorities for violating the best construction practices for air pollution control.	Spillage on road and further re-suspension of dust can be minimized	BMC, MMRDA, Builders Association
Airport	High emissions from Airport vehicles. Aircraft emissions assessment of problem needed	Airport vehicles management will yield emission reduction. Options of aerobridge, pooling of passenger, dedicated transport system.	Planning and assessment to delineate the solution	DGCA, AAI need to integrate this issue in their plan.	Airport emission for other pollutants will reduce. Exposure to workers and passengers will reduce.	DGCA, AAI, MPCB
Railways Emissions	All trains are being change to electric. Limited use of diesel locomotive. Resuspension due to train can be minimize by platform cleaning.	Low, as the extent of problem is not in large areas.	Awareness to railways	Practices and norms to be framed	Exposure to population will reduce	CR, WR, MRVC

7.3.1 Prioritization of Action Plan Components

The set of action components in each categories have been short-listed on the basis of analysis carried out in earlier chapter and sections. The major recommended actions are listed in **Table 7.9 through 7.11**, which are based on multiple factors presented earlier and also city specific consideration of development needs. It also takes into account the current practices introduced in the regulatory and administrative systems beside judiciary interventions. These tables delineate the prioritize action plan components for vehicles, industries and area sources.

Table 7.9: Prioritization of Action Components for Ranking – Vehicular Sources

Categories	Types	Components
F	Fuel Related	1. Sulphur reduction 2. Alternative Fuel CNG/LPG 3. Prevent fuel adulteration
T	Vehicle Technology related	1. Stringent Emission standards for new vehicles (Bharat IV, V and VI) 2. Electric vehicles for high VKT vehicles 3. Fuel Efficiency standards 4. Conversion of private diesel cars to CNG/LPG 5. Replacement of commercial diesel vehicles to CNG/LPG 6. Retrofitment of catalytic converter and diesel oxidation catalyst in older vehicles 7. Phase out of older vehicles 8. Retrofitment of older vehicles with Bharat Stage III engines with DOC
IU	In-Use vehicle	1. Improvement and compliance system in existing PUC 2. Inspection and identification of highly polluting vehicles 3. Augmentation of manpower and related infrastructure for Inspection and Certification
RT	Road and Traffic Control	1. Improvement of roads 2. Transportation planning and better road maintenance 3. Pavement improvement and better sweeping for less resuspension 4. Road Congestion –encroachment etc. 5. Traffic Management: signal synchronization, one way, pedestrian plaza
PP	Policy and Public Processes	1. Prioritization of public transport on roads (bus lanes, better buses, low cost of travel, faster travel, accessibility of transport). 2. Affordable public transport (cross-support from charges collected for higher car use charges, higher parking charges, higher registration costs, higher taxes on private mode of transport, low fuel cost for public transport 3. Incentive/subsidy for voluntary inspection and maintenance of vehicles 4. Incentive/subsidy to phase out grossly polluting vehicles 5. Drivers and Mechanics Training programmes 6. Public awareness on use of alternate fuel (CNG/LPG), adulteration of fuels, benefits of various maintenance measures.

Table 7.10: Prioritization of Action Components for Ranking – Industrial Sources

Categories	Types	Components
F	Fuel Related	1. Change of coal to NG 2. Change of LSHS to LDO
T	Technology related	1. Clean combustion technology 2. High efficiency control technology 3. Clean process technology
L	Location / Shifting	1. Stoppage of quarrying activity in city
O	Fugitive and other emissions	1. Industry specific plans 2. Compliance monitoring design for fugitive emissions

Table 7.11: Prioritization of Action Components for Ranking – Area Sources

Categories	Types	Components
F	Fuel Related	1. Low sulfur fuel for bakeries, crematoria, diesel locomotive, ships 2. PNG/ LPG for domestic fuel in place of kerosene 3. LPG/ CNG for bakeries, crematoria 4. NG/ electric for airport operations 5. Electric operations of diesel locomotives
B	Biomass /landfill burning	1. Open burning to be stopped 2. Landfill burning management 3. Open eatout burning of coal /kerosene to be regulated
C	Construction / demolition of buildings	1. Norms for building construction / demolitions 2. Regulation and compliance monitoring 3. Material movement control 4. Construction machineries use and its management
RC	Road Construction/ Repairs	1. Road quality norms to be revisited 2. Use and life of road warranties 3. Stoppage of wood burning for tar melting or re-surfacing of the road 4. Road repair technologies
PA	Public Awareness	1. Public awareness programme to empower citizens to report small sources but highly prevalent 2. Inclusion of road construction related burning in rules

All the above actions have been rated on the basis four criteria viz.

- Effectiveness
- Ease of implementation
- Cost implications
- Time frame

These criteria have been used on the basis of understanding of these options through discussions with local and national stake holders in various consultation meetings as well as in workshops. These criteria should not be considered as firm numbers as many of these cannot be easily quantified. The ranking carried out here therefore is of subjective in nature, however, these are based on relevant facts and analysis of their effectiveness. For example an action plan with “low cost” in **Fuel Related** category may not be same as in **Technology Related** “low cost”.

7.4 Benefits Anticipated from Prioritized Management/ Control Options

The prioritized control options and the management plans discussed above have variable benefits in terms of reduced emissions loads, improved air quality for PM and NOx and also many co-benefits. These co-benefits include reduction of other pollutants such as CO, HC, VOCs besides the benefits associated with time saving, low cost of travel, comfortable travel, better transport accessibility, lower health cost etc. Many of these can not be quantified and therefore needs to be internalized on the basis of understanding of the problems in a broader sense. **Table 7.12 through Table 7.14** presents the prioritized control options including management options with associated benefits from vehicular, industrial and area sources respectively.

Table 7.12: Benefits associated with prioritized control / management options –Vehicular

Action Components	Direct benefits	Co-benefits
S reduction in diesel	Moderate reported elsewhere 2000-300 ppm reduction in S leads to 2.5 – 13 % reduction in PM	The S reduction will not only reduce the PM but also lead to correspondingly lower SO_2 emission leading to lower ambient SO_2 and sulphate. It will also allow exhaust after treatment devices.
Reduce fuel adulteration	Reduced adulteration will lead to reduced PM (difficult to quantify). Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM	One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its lifetime
Alternative fuels • **CNG/LPG** • **Biofuels**	• High, more than 90 % reduction in PM can be achieved compared to diesel • Similar to diesel but low SO_2 and low PM	• Will lead to substantial reduction in CO and HC emission, however, NOx values may go up • Low SO_2 emission
Phase out of grossly polluting vehicles	High estimate suggest 25% of these vehicle may contribute 75% of total emission	Better compliance will lead to reduction of other pollutants as well. It will also lead to less pressure on complying vehicles
Congestion reduction	High emission due to fuel burning at idle or slow moving traffic	It will reduce traffic junction hotspot of all the pollutants. It will also reduce continuous source of dust
Standards for new and In-use vehicles	• Marginal improvement from newer vehicles except when implementation is for Euro V & VI • In-use vehicles emission reduction can be substantial	As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types
Introduction of new technology vehicles	High compared to grossly polluting, moderate with respect to inuse vehicles	It will lead to better compliance from on-road emission test and overall improvement in emission of all the pollutants. Electric vehicles provide localized benefits of no air pollution

Table 7.12 (Contd...): Benefits associated with prioritized control / management options –Vehicular

Action Components	Direct benefits	Co-benefits
Retrofitment of new engine/ Emission control device	Engine replacement could lead to major reduction of PM. Emission control devices available (DPF, DOC) can remove PM upto 90%	Short time frame, high levels of compliance expected for all the in-use older vehicles.
Higher usage of Public Transport	Effectiveness is high as less and less road space will be occupied by private vehicles, faster movement of public transport in comfort shall lead to low emissions	Future growth of the city will entirely depend upon the levels of public transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency
Decrease Private vehicles on Road	Less private vehicles on road, high road space utilization	Private vehicles owners should must own their own garages, less parking on the roads, less congestion
Training and Awareness programme car owners, public transport operators, drivers and mechanics	May lead to 5-10% reduction of emission	Savings by way of improved vehicle maintenance and operation

Table 7.13: Benefits associated with prioritized control / management options –Industrial

Action Components	Direct benefits	Co-benefits
S reduction in fuel	High as many industries in Mumbai region use coal, HSD, LSHS, and FO	S levels in fuel has been very strictly controlled for Tata Power. An example of this can be extended to other industries
Combustion Processes	Moderate	It will lead to lower emission of CO and HC
Alternate Fuel	The higher percentage of use of cleaner fuel has already resulted in better air quality in the city	Better air quality in terms of SO_2, CO and HC will be achieved.
Promoting Cleaner Industries	Large scale shift shall result in major PM reduction	It will lead to sustainable existence of industries within the city. Also lead to other pollutants reduction
Location Specific emission Reduction	Medium as the power plant has already been subjected to strict S levels as well as PM emission by MPCB	High level emission shall have lower PM and other gaseous pollutants
Fugitive Emission control	For localized region, effective. Particularly for industries with fine particles raw material or products. High efficiencies can be achieved for quarries.	Local area air quality improvement could be highly effective.

Table 7.14: Benefits associated with prioritized control / management options –Area Source

Action Components	Direct benefits	Co-benefits
Improve fuel used for domestic purposes	Likely to improve indoor air quality	It would alleviate large section of population with high indoor pollution of other sources leading to lower disease burden and better quality of life
Bakeries /crematoria	Local grid based PM can be reduced	Reduction in PM as well as odour will take place and is likely to improve the local air quality
Biomass/trash burning, landfill waste burning	Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids	High level improvement in local area ambient air quality not only for PM but other pollutants
Resuspension	Highly effective for kerb-side air quality	Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being
Illegal SSI	Local area improvement can be moderately good	It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem
Construction	Large scale improvement in local area air quality is expected.	Spillage on road and further re-suspension of dust can be minimized

7.5 Action Plan

The action plan has been presented based on the emission inventory and source apportionment analysis as discussed in earlier sections. The action plan development also involved discussions with various stakeholders such as public institutions, academics, transport operators associations, NGOs and others. The QA/QC team (formed for guidance and feedback) working with NEERI team provided many useful feedbacks and suggestions. In addition, all action plans have been aligned with ongoing plans as per Lal Committee Report prepared under the order of Hon'ble High Court, Mumbai, 2000 **(Annexure 7.2)** for vehicle emission control**.**

7.5.1 Recommended Action for Vehicular Sector

Major recommendations of the study as derived from the various study components and also consultation exercise are discussed here. It is, however, important to understand that all actions as listed in **Table 7.9** will need to be implemented in concerted efforts, without which a sustainable long term solution can not be realized.

7.5.1.1 Fuel Issues

Sulphur Levels in Fuel

It is well known that the introduction of low S diesel leads to bringing down the PM emission from all the diesel vehicles. Despite the introduction of low S level in the metro cities (Mumbai as well) at <350 ppm, it has been seen that the diesel being used by most of the operators of the HDDV and LDDV are of higher S level. The operators opine that this is happening due to the fact that outside the Greater Mumbai limit, the cost of the diesel is much lower. And, therefore, even if the owner wants to fill a cleaner diesel, drivers have tendency to fill from outside. The same will also be true for vehicles coming from outside the city and not registered within the city, which will still carry diesel with higher S content. Therefore, the S reduction plan only for cities does not necessarily get translated into cleaner vehicles.

To cater to this problem, following suggestions emerge:

- Price structure of the diesel in the whole of the state (and ideally for whole country) should be rationalized so that there are no incentives for buying diesel from outside the city or state.
- Alternately, the nearby cities and states should also be brought under the regime of same fuel quality, for which oil companies can be urged to maintain the same S levels in and around the city.
- In the interim period, a measure which can dissuade truck operators from buying high S fuel should be stricter, reliable and reproducible inspection for smoke levels.

7.5.1.2 Fuel Adulteration

Fuel adulteration is one of the major issues for vehicles, which mainly operate within the city and adjoining areas such as Thane, Navi Mumbai and Panvel etc. Further, the most of the lubricants presently being sold in the market are of low grade and that leads to high levels of emission. This is also true for vehicles being run on CNG as low-grade lubricants used in these vehicles also lead to high PM emission.

Following suggestions emerge:

- Oil companies can ensure better movement of their produce to ensure that the adulteration does not take place. This is valid for both petrol as well as diesel. Some of the schemes suggested are use of colour codes on the tanker transporting the fuel, regular testing of the fuel before it is filled in the bunks and after. This task can be undertaken effectively by the Oil Companies.

- The petrol pumps operators can be educated and trained to check the adulteration before they let the fuel get into the bunks. This will help monitor and fix responsibilities of the petrol pump operator.
- The procedure for such tests should be set up with the common understanding with the oil companies and operators. The protocol should be set up in a way that public and user can check its effectiveness, whenever desired.
- The oil companies should show pro-activeness in promoting the better lubricants.
- Ministry of petroleum should develop better specification for the lubricants to be used and its testing.
- Oil companies should also put their own manpower and machineries in checking effectively their products being sold from their outlets. (e.g. BPCL's Pure for Sure; HPCL's Club HP and IOC's Q & Q etc., which are being carried out in, limited way.)
- Ministry of petroleum has constituted anti adulteration cell for preventing the malpractices of fuel adulteration. Fuel quality standards are required to be strengthened and range of values for specified parameters required to be narrowed. Use of MARKER elements in fuel may ease the process of preventing adulteration and should be implemented on priority basis.
- Economic measures such as removing the disparity in petrol, diesel and kerosene prices will be required to remove incentives for such large scale malpractices.

7.5.1.3 Fuel Alternatives

Most of the operators of HDDV and LDDV operate within the city as well as outside. There are LDDV's which travel within the Mumbai and Navi-Mumbai areas or adjoining Mumbai. Metropolitan Regions. There is an apparent resistance to not change the fuel use pattern for many reasons such as:

- Unavailability of CNG in areas outside the city limit
- Unavailability of kits for such conversion to the older vehicles
- Retrofitment of older engines with the CNG kits is likely to be not efficient in terms of PM emission.
- Maintenance cost of such retrofitted vehicles is much higher.
- Unavailability of trained manpower for CNG operated vehicles outside the city limit

In view of the above factors, of which the availability of CNG outside the city limit could be the major factor for HDDV and LDDV's not changing to CNG. The bus operators such as BEST and other contract carriages will have slightly higher vehicles km trip. Further, the suggestion that older vehicles (such as 8 years and more) should be converted to CNG, may not be very effective as the vehicles have been found to deteriorate quickly in terms of emission. The reasons behind such situation could be many, and therefore, there is a need for very effective, reliable and reproducible inspection-certification system. Based on the various pros and cons discussed above following suggestions emerge:

- Vehicles should be subjected to strict, reliable and reproducible inspection for smoke levels.
- These vehicles should be brought under the operation by which the smoke levels are below 45 HSU by the use of DOC or DPF, whichever achieves the desirable result.
- Major operators such as BEST can maintain the proper mix of CNG and diesel buses, as their vehicles kilometer traveled is much higher. As long as BEST has an internal standard of 45 HSU and maintains all the vehicles at these levels by way of either improving the engine, or fitment of DOC/DPF, conversion to CNG may not be required. The buses, which cannot be brought under this level, can be phased out.

7.5.1.4 Engine Technology

The higher emission at present from the HDDV and LDDV can be attributed to the fact that a large number of them are with older technology engine. In future as planned, Bharat III standards would require a better engine technology from the manufacturer. The Bharat III norms are already in place for all metros; however, this is applicable only for new vehicles. The improvement in engine technology does not affect the old fleet.

Change of Engine

For effective reduction in the emission from diesel vehicles, it is felt that in-use vehicles may be allowed to replace their engines by Bharat III compliant engines duly approved by the test agencies. As this concept would need effective implementation format and agreement between the manufacturer and the buyer, it is desirable that a pilot study is undertaken to evaluate the effectiveness of such option. The other major aspect is that the rule and protocol for such changes should be applicable to the whole state and the attempt should also be made to take this matter at national level. For two and three wheeler sector, it is necessary that the entire new vehicles fleets are 4 stroke vehicles with catalytic converter to meet the future norms. Most of the old three wheelers have started converting to CNG/LPG. Here, the engine is not changed but a kit is installed. In this sector, there is no apparent need to consider engine change.

Suggestion emerging in this area:

- Undertake a pilot study with the major manufacturer of HDDV/LDDV engines to evaluate the effectiveness of engine replacement with better emission compliant engines. The study should also ensure the details of the mechanism of certification and testing of such engines from reputed test agencies in India, so that the local RTO can allow only the certified engines for replacement.
- Manufacturers and the state can take this further with the national authority (MoRTH) to issue guidelines for nationwide implementation
- Bharat III compliant engines therefore should be sold throughout India, rather than only in Metro.

7.5.1.5 Fitment of Emission Control Technology

The new vehicles meeting the requirement of Bharat III (applicable in Mumbai since 2005) have been designed to meet the norms specified for the manufacturer. In cases, where the engine is new and is under warranty, the manufacturer can be held responsible and necessary action can be taken. However, the moment warranty period is over, the responsibility of meeting the emission norms falls on the owner of the vehicle. The reasons of higher emission could be many as discussed earlier such as fuel quality, overloading, bad roads, poor maintenance etc. <u>Manufacturers have started giving emission warranty for all new passenger cars, 2-3 wheelers etc. since July 2001. Under this, commercial vehicles get emission warranty of 80,000 kms or 1 year whichever is earlier compared to private cars and two wheelers with 80,000kms and 3 years whichever is earlier. This emission warranty, however, is only for idling emission tests. Our idling norms are too lenient and therefore can be easily met.</u> Such warranty should be extended for the BS III norms to a new certification system.

The emission control devices such as catalytic converter for any of the vehicles are never monitored for its efficiency or its defects. As also mentioned in Auto-Fuel Policy document, that the utility and serviceability of the emission reduction technologies fitted to a vehicle in India is neither judged nor monitored. For example, a conversion kit or catalytic converter may not necessarily give stipulated service, if defective (even when new), there is no mechanism to identify those. In such a situation, the onus of proving the emission worthiness of the vehicles is always with the owner.

To address the issues pertaining to this, following suggestions have emerged:

- Evaluation of all the vehicles emission control system bought between 1995-2000 (catalytic converter were first introduced in the year 1995) through a proper inspection schedule.
- Evaluate the need for emission control device replacement for all the vehicles bought between 1995-2000
- There are large numbers of diesel private vehicles, which were not required to fit catalytic converter in the year 1995. Almost all of them will need fitment of emission control devices, as they together could be large enough in numbers for contribution of PM in the atmosphere.
- All the grossly polluting vehicles (identification through inspection mechanism) should be identified and appropriate fitment of the emission control devices should be made. This could be particularly required for all the vehicles plying only within the city, such as school buses, water tankers, garbage trucks etc.
- As retrofitment of emission control devices also needs a certain levels of fitness of the vehicle, it would be desirable to follow the norm after developing the same through the inspection and certification procedures.
- There is a need to undertake a pilot study to test the need and efficacy of emission control device retrofitment on older vehicles, before it is implemented for all the vehicles needing such fitment.
- Vehicle manufacturer should be asked to get the emission warranty for the complete period of the operation of the vehicle which should be based on Bharat norms. Therefore, there is a need to delineate the useful vehicles life along with the emission warranty for a longer period. The same may also be included in the MoRTH guidelines to be developed asking manufacturer to be proactive even when vehicles have been sold.

7.5.1.6 Phasing out of the Vehicles

Vehicles operating-standards and consequent maintenance decides the vehicles fitness as well as emission. The deterioration in the vehicle emission could be due to varied reasons, such as overloading, fuel quality, poor maintenance etc. However, there can be some estimates regarding the useful life of a vehicle, which could be defined by the manufacturer. Based on the deterioration of engine components, a general consensus could be reached on the basis of vehicles age. The phase out of older vehicles should be based on the rationale, which can have many combinations; however, it should invariably be linked with inspection and certification procedure.

Suggested measures are:

- The private vehicles older than 15 years may go through the inspection and certification every year
- The vehicles should be able to meet the current norms at that time of certification
- Vehicles between 8 and 15 years should go through inspection and certification every two years
- Other vehicles can go through the inspection every three years
- The vehicle owners can voluntarily phase out their vehicles after 15 years even if it meets the requirement of retrofitment. There should be an incentive for an owner to phase out his vehicle after 15 years. This could be given in the form of low registration cost or direct subsidy.
- Another important matter relating to the phase out mentioned often is that there are no designated places for scrapped vehicles. As an ever-growing city, the phase out of the vehicle will always take place, even if there is no scheme. In view of this fact, it is necessary that an area be designated for such scrapping by the BrihanMumbai Municipal Corporation along with MMRDA.

7.5.1.7 Inspection and Maintenance/ Certification

Most of the vehicles emission problem can be associated with poor maintenance of the vehicles. Also the poor inspection set-up does not help much in terms of identifying the polluting vehicles disabling taking appropriate steps.

The present certification method for different types of vehicles for fitness is also not adequate enough to weed out the emission in-efficient as well as highly deteriorated engine power. These vehicles are frequently found to be stranded on the roads or are not able to climb the flyovers gradient. The inspection certification procedure therefore needs dual approach leading to one goal, viz. low emission and fitness of vehicles on road/roadworthiness.

The suggestions emerging are:

- Design and testing of inspection and certification procedure for all types of vehicles. The first test design should have the basis of engine and overall vehicles fitness (roadworthiness). This could be undertaken for some types of vehicles first: Privately owned diesel cars of more than 10 years of age and commercial vehicles more than 8 years old.
- The inspection and certification system development and its implementation should include all the stakeholders.
- The Vahan-nagari as described above should be equipped with state-of-the-art testing set-up for all the types of emission as well as fitness testing. These test centers should have the facility to test all types of vehicles and the test results will reflect the reliability and reproducibility. It should produce is a certificate that will be robust enough to stand all the scrutiny from all the quarters.
- The design of the facility, its component, manpower details, types of equipment and calibration system, testing and communication system details should be worked out. Institutional arrangement for the same needs to be developed.

7.5.1.8 Roads and Pavement

Roads and traffic control related issues have some wider and local effect. As discussed earlier, the major points of concern with regard to the high vehicle density and associated higher emission loads, it would be necessary to address many of these problem areas from traffic point of view.

The suggestions pertaining to this sector is detailed below:

- City roads and suburban roads have main difference in terms of concrete and tar roads. City roads are better due to their concretized condition and therefore give less resuspended dust. In view of the above, it is suggested that the roads in suburb also need better paving.
- Need for better construction practices and codes for roads and pavement construction.
- Pavement improvement is the other major issues, should be taken up on priority. Dug-up pavements have shown that fine particles keep getting resuspended in the atmosphere as the pavements are either not maintained or after the digging, those are not brought back to their original conditions.
- Encroachment of roads space by slums are one of the major reasons for slow down of traffic and leading to higher per unit emission due to congestion.

- Parking on roads should be regulated along with a rule to allow purchase of vehicles only if parking place is available.

7.5.1.9 Transportation Planning and New Roads

The current density of vehicles on roads has resulted in exhaustion of space at many places as discussed earlier. Most of the places, there is a need to study the traffic movement and possible need of an additional corridor to take care of the existing vehicle movement. Many additional flyovers and public transport projects have been planned in the city. Summary of these plans are given in **Annexure 7.3.**

7.5.1.10 Traffic Management

A good traffic management can effectively reduce fuel consumption, emission, congestion and increase productivity of the city. A slow moving traffic requiring frequent acceleration, deceleration and long idling at various stops could contribute significantly even if the efficient engines are on roads, on better roads, better pavements and better maintained engines by well-behaved motorists. Levels of pollutants near the junctions with higher idling times, may reach an alarming proportion. Many of the traffic junctions in Mumbai have shown consistently high levels of pollutants (Particulate Matter as well as gaseous).The traffic management has potential to reduce PM and NOx emissions. Some of the suggestions are:

- Besides better road, there is a need for better pavements to prevent pedestrian from using road space that otherwise lead to congestion and accidents. Most of the problem sites are near the railway station and link to the main road.
- MUTP component for Station Area Improvement (SATIS) shall be able to provide the necessary augmentation of current conditions as it is being implemented at six locations viz.Borivli, Andheri, Dadar, Ghatkopar, Mulund and Kurla. There is a plan to implement at all stations.
- Implementation of skywalk by MMRDA in many areas will help in addressing the movement of people and vehicles.
- Better awareness, training and inspection of the road users in terms of abiding by the traffic rules, development of respect for traffic rules. (Need for training and awareness workshops)

- Augmentation of capability of the personnel involved, better resource availability in terms of manpower and infrastructure
- Need of better legislation, regulation and procedure with a view to effective implementation of the existing rules and regulations
- Good support from transport as well as other authorities in terms of imparting the recent knowledge as well as practices
- Coordination with all the other concerned authorities in the city.

7.5.1.11 Policy Level Instruments

There are various issues related to the policy matters which can have overall significant impact on the pollution reduction in the city. Some of these cannot be directly correlated emission reduction however; its impact can be seen in terms of improved ambient air quality.

Mumbai has been known to be city with higher public transport usage; the policy initiative should actually lead to promotion of better public transport. The public transport strategy has greater acceptability in Mumbai as it has low road space and traditionally the public transport systems have been very widely used.

Box: 7.1

For example, for one km of travel, a car consumes nearly five times more energy than a 52-seater bus with an average load factor of 82 percent. The corresponding consumption factor for two-wheeler is 2.6. The comparative fuel costs of a car and two-wheeler are 11.8 and 6.8 times respectively for the same distance. Besides, the major issue is that a car occupies 38 times more road space compared to a bus for a kilometer of a travel. Two wheelers space requirement is even higher at 54 times that of a bus*.

Further, the emission from a two-wheeler equivalent to a bus could add 27 percent higher, whereas the cars would cause 17 percent more pollution. The age of the bus can be of no major concern, when we compare the benefits that it could give in terms of fuel savings, emission and safety.

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* Report on the Expert Committee on Auto Fuel Policy, Chapter 15, Government of India, 2002.

Every stakeholders consulted during the process, have agreed the major focus of any future transport initiative should be based on low cost public transport. Some of these initiatives are discussed hereunder:

7.5.1.12 Prioritization of Public Transport on Roads

Public transport and its importance in the city of Mumbai need to be maintained for one most important reason. Once more and more people get used to personalized transport, it would be very difficult to bring them back into the fold of public transport users. The fact that personal vehicles are occupying more and more space on the road; it is felt necessary that disincentive mechanism should be developed for personal vehicle owners. There are many methods of carrying out this task, however, financial and space constraints can achieve the balance

As the road space is limited in Mumbai, the efficiency of the public transport can be maintained only if priority is given to the public transport vehicles. The objectives of such policy will be priority to the buses. Some of the suggestions are:

- Exclusive bus lanes should be identified. One of the major obstacles to this concept, which many suggest, is lack of road space for adopting dedicated bus lane system. However, as has been seen in many other countries[#] even in a narrow two lane roads, public transport priority system has been seen to be effective. Therefore, there is a need to undertake a project to demonstrate effectiveness of such system in Mumbai at one or two road stretches.

[#] - How Can Urban Bus Policy Reduce Air Pollution? Urban Air Pollution, Briefing Note No. 3, ESMAP, World Bank, 2001.

- Mumbai Transformation Unit of Govt. of Maharashtra has proposed BRTS for two major corridors. However, implementation has been poor. It needs to be pushed for implementation as it helps in not only ferrying people but also reduces green house gases.
- If one wishes to see higher bus utilization, it also has to see correspondingly higher service levels. This could be achieved by way of providing better frequency to reduce congestion during peak period, better bus quality in terms of sitting as well as standing space.

- The cost of the bus fare has been increasing at a steady pace. This is also seen almost every time when there is an increase in the diesel cost. What it leads to is that the bus fare for two-four persons becomes almost equivalent to either the taxi fare or attractive enough to own a private two or four wheeler. In such a situation, it is likely that increasing bus fare is becoming the main responsible agent for higher private vehicles purchase. The other reason, such as better roads with flyovers (faster travel) makes it attractive for private vehicle ownership.

Public transport fare pricing, therefore, should not only be dependent upon the actual cost, but on some other sources of income. In the case of BEST, cross subsidization from its own electric supply division is a good example.

- Bus fare reduction can be achieved from various means, but not alone from improving its own efficiency (as is normally believed). <u>The public transport should be cross-supported directly from the personalized vehicles either being purchased newly or older one running on the road. Funds generated from measures such as higher car user charges, higher parking charges, high registration fees, higher taxes on private mode of transport etc. should be directly transferred to them to achieve the low cost, better comfort, better frequency and faster travel.</u>
- Diesel or any fuel used for public transport should be sold at lower price to keep the bus fare lower.
- Certain areas of business district or identified regions of high congestion, free bus services can be provided. The cost can be recovered from parking, congestion and high fuel costs charged to personal vehicles.

7.5.1.13 Incentive/ Subsidy for Better Compliance towards I&M

Although the inspection and maintenance issue has been discussed earlier, the proactive approach of getting more and more people adopting the practice requires an incentive scheme. Such incentives could be given in-terms of specialized advice on how the vehicle maintenance should be carried out, as well as provide small grant for carrying out minor repairs when found polluting first time. However, if they are found to be flouting the emission norms, they can be asked to scrap the vehicle. This can be integrated into the improved in-use vehicle emission test standards.

7.5.1.14 Drivers & Mechanics Training Programme

Awareness campaign for various transport related issues such as use of alternate fuel, adulteration of fuels, benefits of various measures being adopted by the oil companies, government and others could be undertaken. This should mainly address the drivers and mechanics first and later include people/ groups as well government authorities engaged in the activities related to the transport sector.

7.5.2 Recommendations for Industrial Sector

- Major reduction industrial emission can be achieved by the fuel shift to cleaner fuel, though the overall emission scenario shows declining trend from this sector.
- The only power plant within the city, if it shifts to Natural Gas, major reduction in emission shall be achievable.
- With fuel change, it will be imperative to study the feasibility of adopting the new technology.
- The other industries also need to get larger share of the natural gas for combustion processes to shift from FO and LSHS.
- Diffused emissions from industries need a better assessment to delineate the control needs and level of control.
- <u>The data for small scale and unauthorized industries is scanty and at this stage to suggest the levels of contribution from these are difficult</u>. The source apportionment study and the data indicate large part of the PM from other sources, which also need further investigations. These investigations of sources should be undertaken by MPCB/ GoM.

7.5.3 Recommendations for Area Sector

- In domestic sources, though the reach of LPG and PNG is increasing, the use of kerosene and retrieved material from garbage are also burnt at large scale in slums and low-income areas. The use of trash of various kinds for cooking need better control as they contribute largely to local ambient air quality deterioration.
- Emission due to burning of garbage has been one of the major sources of area air pollution. There is a need to constantly monitor and provide urgent technical solution for these sites to avoid deliberate burning. BMC actions in this regard need immediate implementations.
- Hotel and restaurants normally use LPG; however, roadside eateries use wood and kerosene. Many of these are illegal and locally may be responsible for air pollution problems. Use of good stove and proper location for such eateries can reduce the problem to some extent.
- Largest wood burning in an authorized sector is by the bakeries. Though many of these have started changing to alternate fuel such as LPG, however, still large scale bakeries operations are based on wood. Therefore, there is a need to increase awareness and also fix some guidelines regarding the use of fuel by bakeries.
- Resuspended dust is one of the major contributors of PM, which could be due to construction/demolition of roads and buildings, vehicle movements as also from natural wind

induced sources. The road side dust reduction can be achieved by better pavement and good quality of roads combined with better sweeping

- Airport area emissions from vehicles need to be controlled using alternate fuel vehicles such as CNG or electric. It's important to assess the extent of problem from the airport operation for appropriate planning. Emission could be also reduced by use of aerobridge, optimizing vehicles use. High HC and VOCs emissions due to aircraft movement need assessment and documentation with a view to adopt international guidelines (IATA/ UFTAA) to reduce emissions and also green house gases.
- The electrical cremation system is readily available and also carries out awareness programmes to educate people about emissions reduction from crematoria. Crematoria need better control mechanism before the emission is let out through the chimney.

7.6 Summary

The prioritization of various options in all three categories have addressed mostly all the major reduction in the overall pollutants load reduction combined with ambient air quality improvement. However, many of these measures still may not lead to resolving very small area high concentration points which could be due to short term but high emission or high activity for a limited period and limited area. Such hot spots in the city of Mumbai could exist when a local road is dug up and/or being repaired, construction and demolition of buildings, biomass and refuse burning, industries short term emissions etc. All of such activities can be controlled and regulated through local efforts and constant vigil on the part of citizen, pollution control agency and respective responsible implementing agency.

One of the biggest issues for large metro city is land use pattern, which indirectly drives the growth pattern of the city and consequent vehicle increase. Frequent change in floor space index (allowing more built up per unit area) leads to large scale increase in vehicle ownership and their presence on road. Better air quality planning for the city also needs appropriate transport planning which is linked with land use.

All reductions planned will only reduce emissions from man made sources; however, natural background and dust would continue to remain in the atmosphere.

The benefits computed in the process described above will not only yield PM and NOx related pollution reduction but also co benefit of other pollutants (SO_2, VOCs, HC, CO etc) reductions as well. One of the other major co-benefits of these options (adoption of mass transport, use of cleaner fuel, efficient combustion etc) will provide large scale green house gas reduction. Mumbai as a big metro city will provide the impetus of overall mitigation of GHG. The benefits of air quality improvement plan suggested and delineated above again will not yield desired results if the adjoining urban centers and states do not adopt measures suggested for Mumbai as the objectives of clean air can not be kept limited to the political boundary of Mumbai when it is in close proximity of major urban centers.

Chapter 8
Highlights and Recommendations

8.1 Purpose of the Study

The air quality of urban centers across world has invited huge attention after it was recognized as a major health hazard besides its other impacts. India has been no exception with high vehicular density, industries within the city areas and multiple small scale sources contributing to high air pollution. With high population density, with more poor inhabitants, large numbers of residents are likely to get exposed to increasing air pollution.

The auto fuel policy report submitted to Government of India (www.envfor.gov) in the year, 2002, has identified the lack of knowledge in the area of source apportionment. This is due to the fact that emission inventory based planning leads to misleading prioritization of actions plans for control of air pollution. Source apportionment on the other hand could provide the answer to the issue of major contributing sources at the point of receptors. Ambient levels of gaseous pollutants have shown declining trend in recent past due to many initiatives of the government as well as pressure of judiciary. The particulate matter, however, has not shown decline, which is a cause of concern. This is also due to the fact that PM can be surrogate parameters for other pollutants as well. NO_2 values have shown increasing trend in many cities in India. The gaseous pollutants such as NO_2, SO_2, and ozone are also known to use PM as a surrogate to carry and deposit themselves.

Pollutants of all origin should be considered in entirety for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc. Strategies for sector specific pollutants need to be drawn from scientific evidences which are concrete and clear. These facts can be derived from the use of multitude of techniques such as emission inventory, dispersion modeling, receptor modeling and finally prioritization based on cost effectiveness analysis of varied options. The study report has many deliverables based on extensive work plan.

- Present air quality status with respect to site specific study for Mumbai
- Percentage share (quantification of contribution) of air pollutant emissions that are attributable to transport sector, industrial, commercial, residential and other activities.

- Percentage share in air pollutant emissions released through each category of sources viz. industries and area specific (refuse burning, biomass burning, resuspended dust, crematoria, cooking etc.)
- Based on projected growth trend in emissions in the next 5 and 10 years for various source categories, different impact scenarios for developing corresponding action plan.
- Impact of implementation of sector wise short/medium term interventions on ambient pollution levels. In case of vehicular sector the options suggested were better vehicle technology, better maintenance practices, improved traffic management, improved tail pipe treatment/catalytic converter/particulate filter, improved fuel quality. Whereas, in industrial sector growth or decline of industries, fuel quality improvement, fuel shift, improved emission control technologies and shifting of industries. With respect to area source, growth of population, fuel quality improvement, better management, fuel shift, road dust elimination, better I&M and other management options and social customs were the options suggested to control the emissions.

8.2 Ambient Air Quality

Mumbai city air quality was monitored with a view to establish the current levels and also to collect samples for source apportionment. Seven representative sampling sites were selected which were representative of Greater Mumbai Region viz. Colaba as Control site, Mahul as Industrial site, Andheri and Mulund as kerb sites, Dadar as Commercial, Khar as residential site for upper income group and Dharavi as slum residential site. Design of air quality monitoring included the factors such as population density, meteorology, topography, etc. During the study, proper guidelines were followed for the selection of the monitoring stations. Air quality monitoring was accomplished by carrying out air quality monitoring for 30 days continuously in each season for three seasons. At all the seven selected locations, level of pollutants such as SPM, RSPM, PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO, O_3, Aldehydes, NMHC and HC were recorded. Further, PM_{10} samples were analyzed for EC/OC, and all elements and ions including molecular markers for representative samples. The average concentrations of different pollutants at selected monitoring sites are presented in **Figure 8.1**.

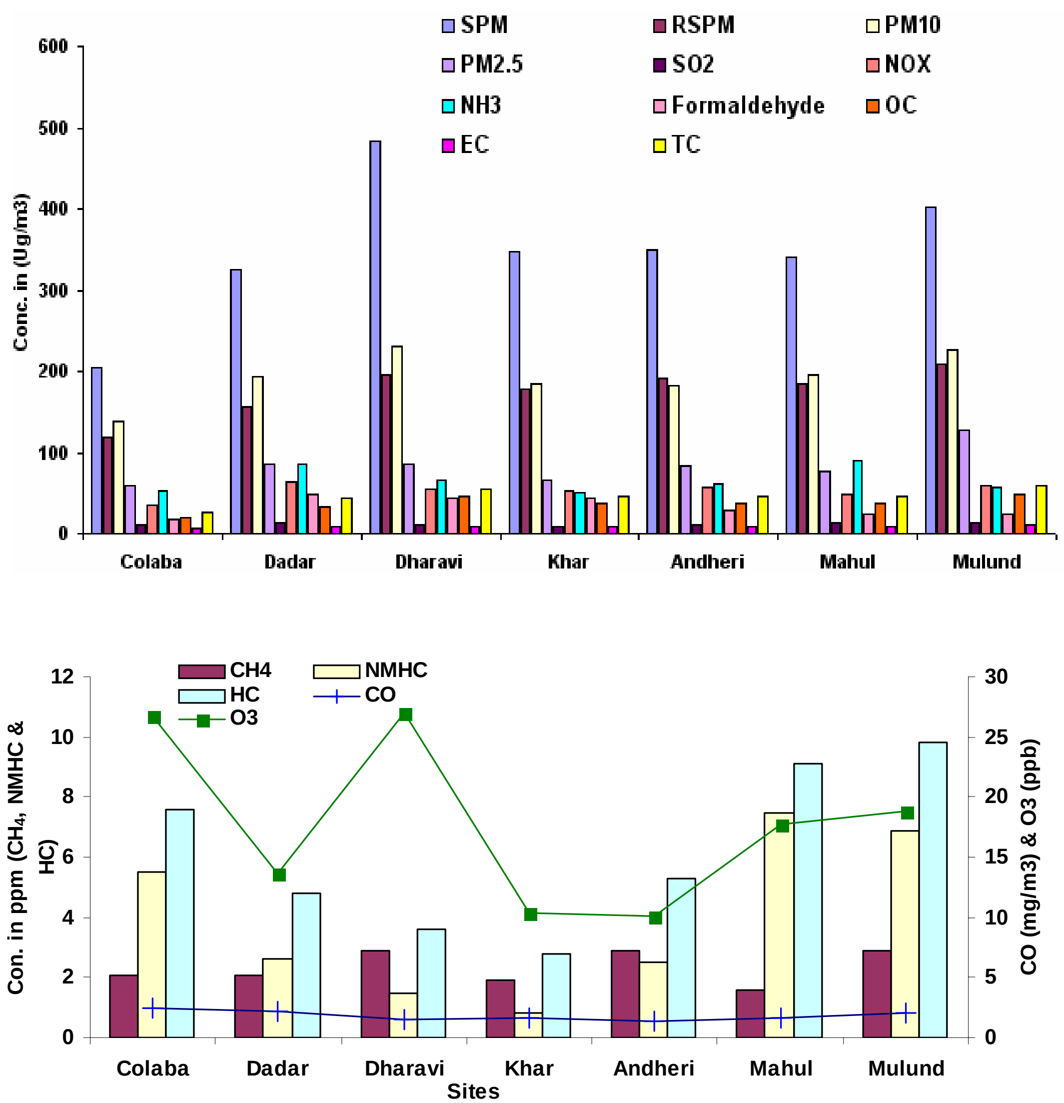


Figure 8.1 : Average concentrations of different pollutants at selected monitoring sites

As evident from **Figure 8.1** Colaba is the least polluted site which was selected as control site. The concentration of PM_{10} is highest in Dharavi due to smelting, biomass burning, coal combustion, oil burning and vehicles. Mahul shows maximum concentration of SO_2 due to sources like oil refineries and power plant. NO_2 has maximum concentration at Dadar, predominantly due to vehicular exhaust. Khar as a residential site has low pollution levels.

Chemical characterization of PM_{10} and $PM_{2.5}$ was carried out by estimating different ions and elements. Percent contribution of crustal, non crustal elements, ions along with the unidentified fraction of PM_{10} and $PM_{2.5}$ for different season and monitoring sites are presented in **Figure 8.2.**

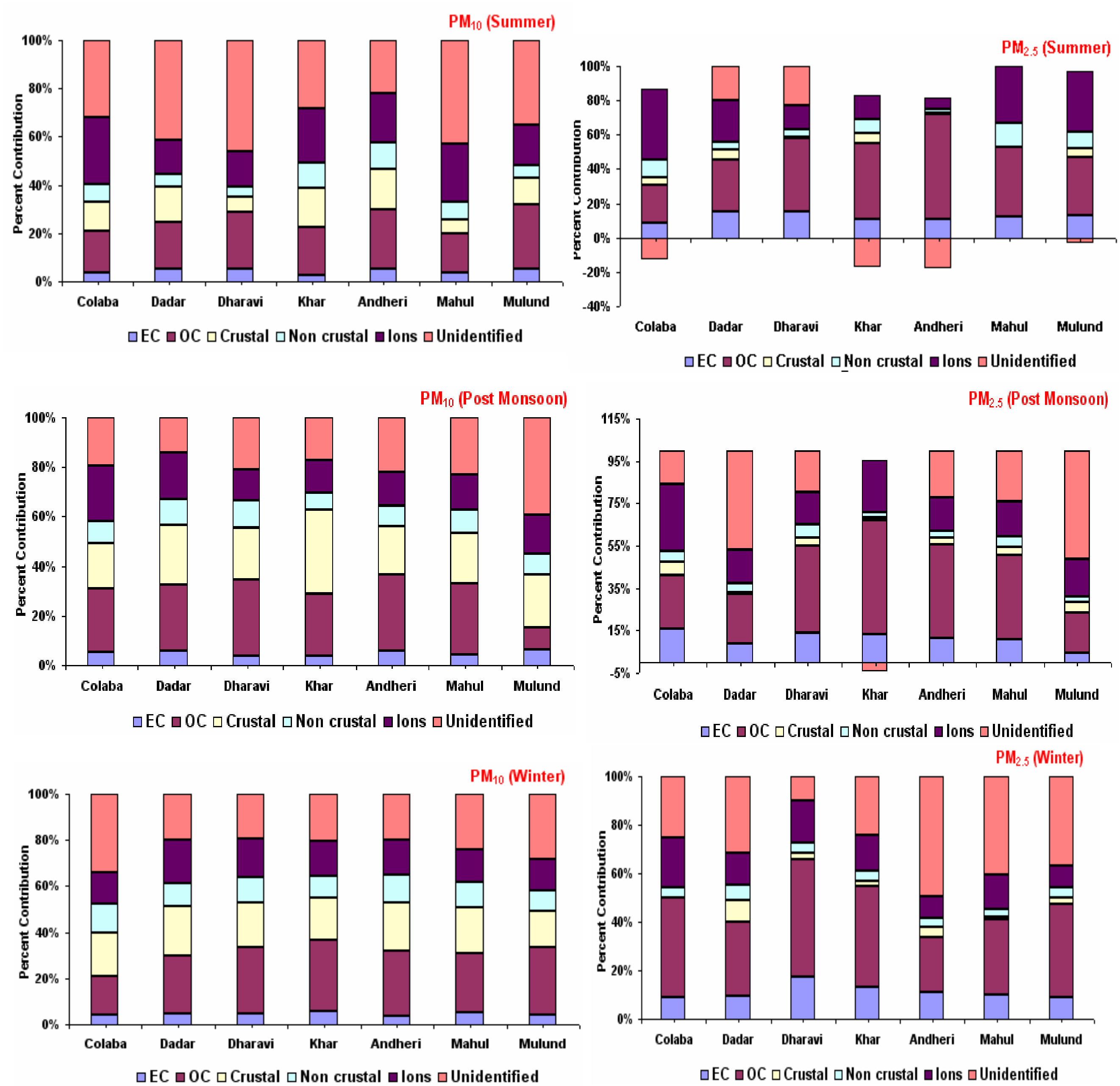


Figure 8.2: Percent Contribution of Elements, Ions, EC, OC and Unidentified fraction in PM_{10} and $PM_{2.5}$ in three seasons at seven sites

Overall, the monitoring data for PM_{10} indicates lower contributions of combustion sources. However, when the similar analysis is performed for data pertaining to $PM_{2.5}$, a different picture emerges. Percent contribution of carbon, crustal, non crustal, ions and unidentified is varying depending upon the site specific activities and topography.

By and large the monitoring result shows that almost all the pollutants have maximum concentration during winter season due to meteorological conditions like temperature inversion and low wind speed.

8.3 Emission Inventory

All relevant information/data on emission inventory which were available through secondary sources were collected. Primary surveys were carried out for identification and spatial distribution of sources in whole Mumbai city (ward wise). Emission inventory for zone of influence (2 km x 2 km area) around each ambient air quality monitoring location was also prepared.

Vehicular Sources

For vehicular sources, vehicle count surveys were carried out on all different types of roads (highways, major roads and minor roads) with respect to their categories viz. HDDV, 2 wheelers, 3 wheelers, Taxis, Car (Petrol and Diesel) with focus on zone of influence around each monitoring locations.

Area Sources

Estimation of area sources was arrived at by taking total area under each emission source category/type and emission estimates were made based on scientific judgment and considering available information on emission factors and their normalization for Indian conditions based on secondary data information. Emission load was calculated for different areas sources like bakery, crematoria, open eatout, hotels and restaurants, domestic sector, open burning, building construction etc. Localized activities viz. marine vessels, locomotive and airport emissions were also worked out.

Industrial Sources

A total of 40 industries apart from stone crushers were identified with air polluting potential as per the database from Maharashtra Pollution Control Board. Information relating to consumption of fuels such as Furnace Oil (FO), Light Diesel Oil (LDO), Low Sulphur Heavy Stock (LSHS), and Compressed Natural Gas (CNG), by the industries in the MCGM area has been obtained. The gross emissions are estimated for all types of industries viz. power plant (1), chemical and other industries (39) with the help of published emission factors.

Emission loads from vehicles, area and industries for the city are presented in **Table 8.1** and percentage distributions for all sources and pollutants are presented in **Figure 8.3.**

Table 8.1: Emission Load for Mumbai City from All Sources

	PM	CO	SO_2	NOx	HC
a) Area Source					
Bakeries	1554.6	11348.1	25.2	120.1	10287.4
Crematoria	300.7	2213.0	7.9	44.4	1991.9
Open eat outs	281.6	167.8	16.2	9.4	0.1
Hotel restaurants	593.1	755.2	274.0	499.0	25.4
Domestic sector	564.9	19723.7	1262.0	9946.9	368.1
Open burning	734.0	2292.0	27.0	164.0	1173.0
Landfill Open Burning	2906.0	9082.0	108.0	649.0	4649.0
Construction Activity	2288.9				
Locomotive (Cen.+ Wes. Rly)	514.0	3147.0	1449.0	19708.0	
Aircraft	75.6	788.4	77.0	985.5	32.3
Marine vessels	1.8	3.3	19.7	17.9	1.5
Total (A)	**9815.3**	**49520.5**	**3266.0**	**32144.2**	**18528.6**
B) Industrial Source					
Power plant	5628.3	3215.7	24473.3	28944.5	1266.6
39 Industries	503.7	879.7	28510.2	8435.2	116.8
Stone crushers	1394.3				
Total (B)	**7526.3**	**4095.4**	**52983.5**	**37379.7**	**1383.4**
C) Line Source					
2 wheelers	70.1	3303.2	2.7	540.5	1221.2
3 wheelers	225.9	1320.9		363.7	3943.5
Car diesel	313.8	1150.5	87.2	1063.3	435.8
Car petrol	15.7	7867.5	13.1	313.7	496.6
HMV	916.7	4435.5	126.7	6875.0	273.5
Taxies	2.6	778.6		13.0	467.1
Paved Road dust	3163.0				
Unpaved Road dust	4761.4				
Total (C)	**9469.2**	**18856.2**	**229.7**	**9169.2**	**6837.7**
Total (A+B+C)	**26810.8**	**72472.1**	**56479.2**	**78693.1**	**26749.7**

* All values expressed in T/yr., -- Vehicle Fuel used CNG/LPG

Percent contribution of pollutant due to different source categories is presented in **Figure 8.3**.

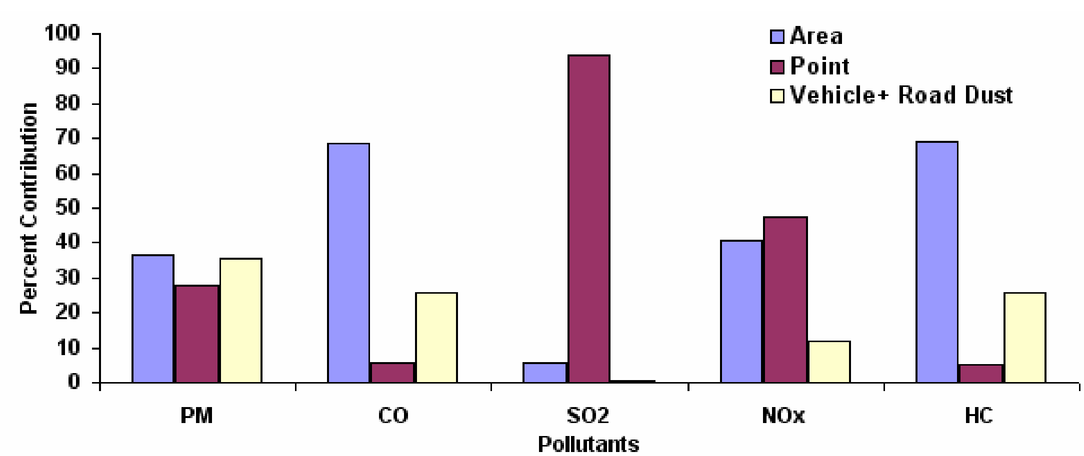
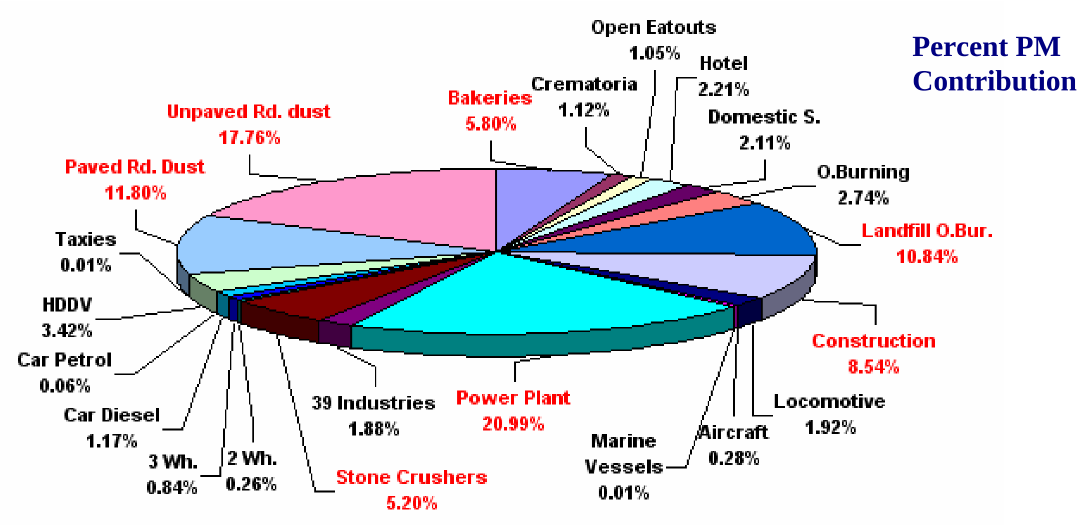


Figure 8.3: Percent emission load from all sources for different pollutants in Mumbai City

In Mumbai city, PM is mainly contributed from area sources (36.7%) like bakeries, hotels, construction activities etc. Area sources also contribute to 69.3% and 68.3% of HC and CO concentration in the city. Industries (point source) contribute to 93.8% of SO_2 followed by 47.5% contribution to total NOx and 28.1% of particulate matter. PM contribution is also high from vehicular and road dust category (35.3%). Source category wise PM_{10} and NOx emission load for whole Mumbai city are presented in **Figure 8.4**.



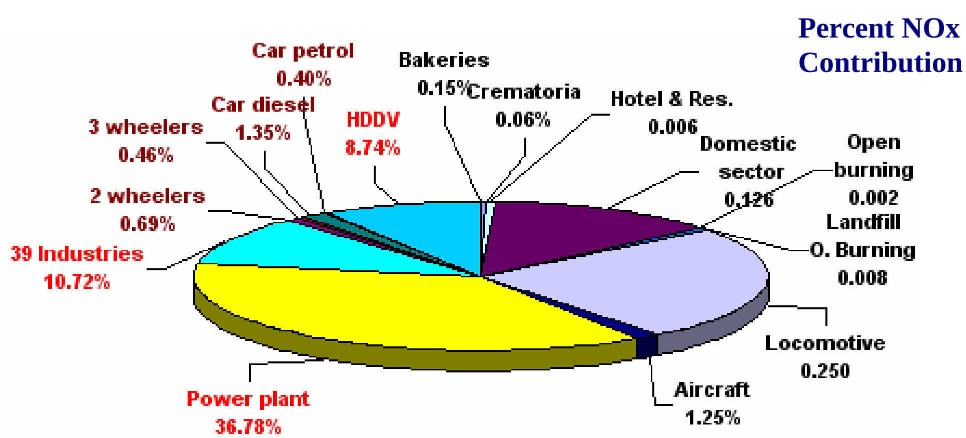


Figure 8.4: Percent contributions of PM_{10} and NOx from Various Sources in Mumbai City

Major contribution of PM is from power plant, followed by unpaved road dust, paved road dust, and landfill open burning. Amongst the vehicular categories HDDV contributes maximum load. It is important to note that high load contribution does not necessarily lead to high ambient contribution of a particular source at the receptor site. This is due to the fact that emission distribution in atmosphere depends upon multitude of factors such as local meteorology, location, height of release, atmospheric removal processes and diurnal variation.

8.4 Receptor Modelling and Source Apportionment

Receptor models use the chemical and physical characteristics of gases and particles measured at source and receptor to both identify the presence of and to quantify source contributions to receptor concentrations. Common types of receptor models include CMB (Chemical Mass Balance) and Factor Analysis.

Comparing the results of Factor Analysis and CMB model, it has been found that few sources are common in both the models. The sources which have been found common in both these approaches are given in **Table 8.2**.

Table 8.2: Source Attribution from Receptor Modeling

Sites	Sources common to FA and CMB	Additional sources of CMB
Colaba	Soil dust, Vehicular emission	Marine, Fuel Oil, Wood and LPG Combustion, Biomass Burning, Ammonium Nitrate, Ammonium Sulfate
Dadar	Soil dust, Vehicular emission	Fuel Oil, Wood and LPG Combustion, Coal (Tandoor), Marine, Ammonium Nitrate, Ammonium Sulfate
Dharavi	Soil dust, Vehicular emission, Coal combustion, Refuse burning	Kerosene, LPG and Wood Combustion, Marine, Ammonium Nitrate, Ammonium Sulfate
Khar	Soil dust, Vehicular emission, Road dust	LPG, Wood Combustion, Marine, Ammonium Nitrate, Ammonium Sulfate, Ammonium Bi-Sulfate
Andheri	Soil dust, Vehicular emission, Kerosene and coal combustion	Fuel Oil and Wood Combustion, Marine, Ammonium Sulfate, Ammonium Nitrate, Ammonium Bi-Sulfate
Mahul	Soil dust, Vehicular emission, Petroleum refining	Fertilizer Industry, Coal (Power Plant), Marine, Fuel Oil and Wood and LPG Combustion, Biomass Burning, Ammonium Nitrate, Ammonium Sulfate, Ammonium Bi-Sulfate
Mulund	Soil dust, Vehicular emission	Secondary Smelting Ind., Fuel Oil, Wood and LPG Combustion, Coal (Tandoor), Biomass Burning, Ammonium Nitrate, Ammonium Bi-Sulfate

CMB results are primarily meant to apportion and indicate PM sources. Through the use of this model, overall major sources have been identified; however, sometimes mass apportionment may not be representative due to issues related to mass closure (not 100%), collinearity issues and measurement uncertainty. Marine aerosol is another source which leads to collineraity problem with other sources having common K^+, Na^+ and Cl^- ions. Overall, CMB results have indicated that the major factors are in line with factor analysis.

Ambient air quality samples were subjected to molecular marker analysis. Representative samples were taken from different seasons and different sites for analysis at Desert Research Institute, DRI, USA, using in-injection port thermal desorption gas chromatography /mass spectrometry technique. Common molecular markers specified in source profiles and identified in ambient air samples includes Alkanes like n- Hentriacontane, n- Pentatriacontane and n-Tritriacontane; PAHs like Benzo[b]fluoranthene, Benzo[k]fluoranthene, Benzo[e]pyrene, Indeno[1,2,3-cd]pyrene and Picene, and also Levoglucosan. **Figure 8.5** represents average concentration of molecular markers at seven sites.

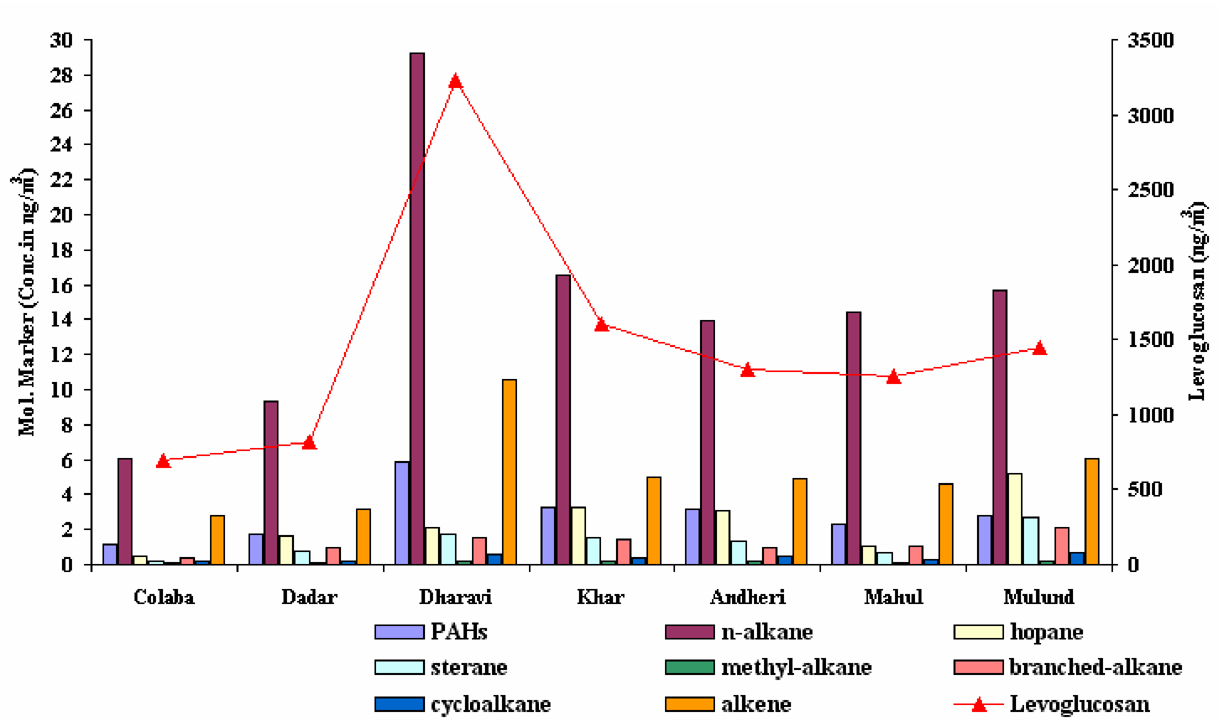


Figure 8.5: Average Concentration of Molecular Markers at seven sites

Highest concentration of PAH was observed at Dharavi (5.84 ng/m^3) which could be due to gasoline vehicles, coal burning and fuel oil consumption. Maximum n-alkane concentrations (29.19 ng/m^3) are also found at Dharavi due to gasoline and diesel vehicles, fuel oil combustion and refuse burning activities. Mulund and Andheri being kerb sites, show of Hopanes levels of 5.2 and 3.1 ng/m^3 respectively. This could be attributed to gasoline and diesel vehicles plying in these areas. Sterane concentrations are also high at Mulund. Branched-alkane concentrations are high at Mulund, Dharavi and Andheri (2.1, 1.5 and 1.0 ng/m^3 respectively) which could be attributed to refuse burning activities. Cycloalkane concentration is highest at Mulund (0.7 ng/m^3) followed by

Dharavi (0.6 ng/m^3) due to vehicular exhaust. Alkene concentrations are higher at Dharavi (10.5 ng/m^3) and Mulund (6.0 ng/m^3) due to internal combustion activities, foundry operations. At Mahul, due to petroleum refineries the concentration of alkene is 4.8 ng/m^3. Maximum concentrations of Levoglucosan are observed at Dharavi (3225.7 ng/m^3) followed by Khar and Mulund (1607.9 and 1445.3 ng/m^3 respectively) due to wood, biomass and mix refuse burning.

8.5 Dispersion Modelling: Existing Scenario

Air quality dispersion modeling exercise was undertaken with a view to delineate the immediate sources and their impact on measurement locations. Dispersion modeling tool has been also used for the whole city air quality scenario generation for different emission loads. The existing scenario model runs were to establish the dispersion pattern of pollutants due to local meteorology and emission from all possible sources. Comparison of measured and predicted concentrations of PM and NOx is presented in **Figure 8.6**.

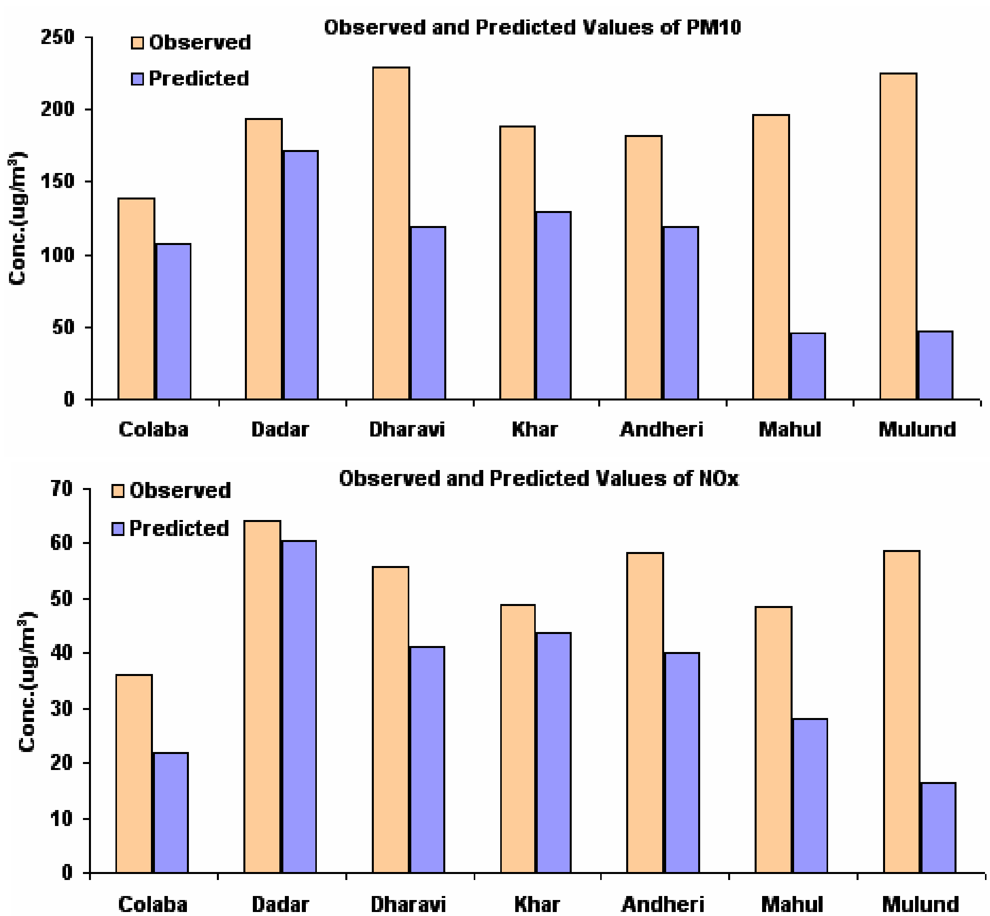


Figure 8.6: Comparison of measured and predicted concentrations for PM_{10} and NOx

The measured PM_{10} concentrations are highest at Dharavi followed by Mulund. Colaba, the background site appears to be the cleanest site. Comparison of measured and predicted concentrations shows that site specific average concentrations predicted using primary survey based emission inventory are close to measured values to a large extent. Uncertainties related to emission inventories at some locations lead to difference between predicted and observed values. City wise modeling result shows higher variation at seven sites which uses whole city inventory. This variation is highest for PM as emission inventories for PM are variable for many sectors such as refuse burning, landfill waste burning, construction activities, illegal small scale industrial operations, dust from variable load conditions, road constructions etc. Besides whole city run include sources which are of city origin, however, Mumbai city has large adjoining areas whose sources have not been included in the model run. These adjoining regions may be contributing to the observed concentrations. NOx values across the city in both cases are much closer to measured values. The highly complex meteorology during summer compared to other seasons could be the major factor for larger difference in predicted values of summer season. The modeling results indicate that PM_{10} is mainly contributed by road dust, whereas vehicular sector dominates NOx at most of the sites.

8.6 Emission Control Options and Analysis

Based on emission inventory and CMB modeling results of all the sources viz. industrial, area and vehicular various generic strategies can be adopted. Though, overall it appears PM is targeted as the main pollutant, which exceeds the limit in the city, however, other pollutants will also reduce with the adoption of these strategies. Reduction of these pollutants these could be considered as co benefits of that implemented strategy. Some of the control strategies for area, industrial and vehicular sources are presented in **Table 8.3**.

Table 8.3: Control Strategies considered in the study

A) Framework for Selecting Measures to Address Urban Air Pollution - Vehicles

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(1) Strategy: Reducing Emissions per Unit of Fuel			
Fuel Quality Improvement	Sulphur Reduction	Delineating tighter diesel fuel standards	Phasing out fuel subsidies, uniform pricing all over the state followed by country,
Installation of after treatment devices	Fitment of Diesel Oxidation Catalyst, catalytic converter in older vehicles	Tighter diesel fuel standards particularly for Sulphur to bring down its level up to 50 ppm. Emission test frequency to be more for those without the after treatment devices	Differential taxation to those with and without after treatment device
Tackle fuel adulteration	Markers for detection	Better specification of fuel quality for detection as well as booking the offenders. Monitoring fuel quality in a specified laboratory, making companies accountable	Oil companies to finance the setting up of a laboratory, Fines and cancellation of license
Use of alternative fuels	CNG and LPG use	Promote its use in private sector as well as organized sector through administrative orders	Differential taxation for older vehicles changing to CNG/LPG, Incentive for new owners to buy CNG/LPG vehicles
Renewal of vehicle fleet	Phase out vehicles above a certain age	Scrappage of older vehicles	Older vehicles to remain on road if it passes the fitness test as well as emission test, however higher tax to be paid as the vehicle gets older
Improve traffic flow	Synchronized signal corridors	Coordination with other institutions to check indiscriminate parking , and enforce one way system at peak hours	Congestion pricing Higher parking fees
Reduce dust re-suspension	Road paving / cleaning	Coordination with all institution working in the area of road and pavement maintenance, digging for utilities etc. One agency to monitor the working practices.	Steep fines to agencies leaving the debris-dust on the roads after the completion of jobs.
(2) Strategy: Reducing Fuel Consumption per unit Distance			
Change to better technology engines	4 stroke engines for two –three wheelers, Bharat stage III. engines with DOC for older diesel vehicles, All new diesel vehicles to be Bharat stage II and above.	Standards for fuel economy need to be specified Useful age of the vehicles to be specified by the manufacturer	Tax break for older vehicles changing to new engine with DOC or DPF

Table 8.3 (Contd...): Control Strategies considered in the study - Vehicles

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
(2) Strategy: Reducing Fuel Consumption per unit Distance			
Improve vehicle I&M	I&M programs that are difficult to cheat; computerized data capture and control of tests	Strict enforcement with socially acceptable failure rates	Better infrastructure, manpower augmentation, Strict fines for not displaying pass sticker
Better road maintenance	Investment in better road maintenance technology to avoid frequent relaying	Standards for road construction specified in terms of guaranteed life of the road	Financial incentives for contractors using better technology for road construction
(3) Strategy: Reduce Vehicle Distance Traveled			
Increase private vehicle occupancy		Encourage car pooling	Congestion pricing
Promote better and more public transport	Dedicated bus lanes; user friendly MRTS	Reform of public transport – competition, privatization etc	Subsidize public transport by taxing private car users
Demand management		Limit parking Limit the use of vehicles in congested areas	High one time tax on purchase of a new vehicle High parking fees Road user charges Higher taxes per vehicle km traveled
Encourage non motorized transport	Pedestrian friendly walkways / subways	Protection of pedestrian facilities	Financial incentives for pedestrian friendly design

B) Framework for Selecting Measures to Address Urban Air Pollution - Industries

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
Fuel change	For power plant the fuel change leads to technology change as well. However, newer technologies are more efficient and long term cost effective. Other industries may experience lower level of technology issues.	Local PCB can make the rule stringent and link with Mumbai Air Action Plan	High cost initially. However in longer run more cost effective
Industrial Policy	• Specifying technology needs policy review. • Area specific location policy	Detail feasibility study for technology as well as land use based policy issues.	Financial incentive to burn cleaner fuel or use of cleaner technology

C) Framework for Selecting Measures to Address Urban Air Pollution – Area Sources

Action Category	(a) Technical	(b) Administrative / Regulatory	(c) Economic / fiscal
Fuel change - Domestic	No major technical issue	Adequate administrative measures in place	No major cost involved facilitation for awareness needed
Fuel change - Bakeries/Crematoria	Need for technical evaluation	Standards to be specified to drive technical changes	Medium cost
Fuel change – Railways/airport/ship	No major technical issue	Administrative directions needed	Medium cost
Resuspended dust	• Pavement to be wall to wall • Better sweeping system • Better road paving technology issue	Regulatory push required for better road paving technologies	• Minor cost • Penalties for poor road surfaces
Construction	Improved construction practices, no technology issue	Regulatory push and surveillance needed for better compliance	Minor costs of regulation and surveillance

8.7 Prioritization of Management /Control Options

Management options for each sectors need to be prioritized with a view to understand the issue of implementation. Implementations are highly influenced not only by the idea of the improvement alone but also by the nature of the recommendations, fiscal and administrative barriers, effectiveness, implementing agencies and acceptance from large group of stakeholders. Prioritization issues are also driven by the comparative account of short term and long term implementation dilemma. Low cost with high effectiveness, low cost with shorter implementation period shall be a better option when compared with high effectiveness with high costs or long implementation period. Though some of the options were selected on the basis of PM reduction potential, their possible co-benefits in reducing NOx and other pollutants were also considered during the process of prioritizing. **Table 8.4** presents some of the prioritized control options including management options. **Table 8.5** presents direct and associated benefits from vehicular, industrial and area sources respectively.

Table 8.4: Summary of Prioritized Options for the City

Category		Control Options	Scenario 2012	Scenario 2017
Vehicle Sources	1	New Vehicle Standards	▪ Bharat IV from 2010	▪ Bharat IV from 2010 ▪ Bharat VI from 2015
	2	Electric vehicles	▪ 2 wheelers – 5% ▪ 3 wheelers – 20% ▪ Taxies – 20% ▪ Public transport buses -5%	▪ 2 wheelers – 10% ▪ 3 wheelers – 30% ▪ Taxies – 30% ▪ Public transport -10%
	3	CNG/ LPG	▪ Taxies – 80% ▪ 3 wheelers – 80% ▪ Public transport – 25%	▪ Taxies – 70% ▪ 3 wheelers – 70% ▪ Public transport – 40%
	4	Ban / scrapping of 8 year old vehicles	▪ 1997 vehicles to be scrapped ▪ Ban > 8 years vehicle (currently applicable in Mumbai)	Continued
	5	Inspection and Maintenance	New I&M regulations (50% population)	Full compliance -100%
	6	Synchronization of traffic	20% improvement	40% improvement
	7	Public Transport	10% VKT reduction	20% VKT reduction
	8	Ban of odd /even vehicles	50% reduction from private vehicles	50% reduction from private vehicles
Industrial Sources		Shifting of Fuel	▪ 39 Industries - FO, LSHS, HSD to LDO - Coal & Others to NG	No Change
			▪ Power Plant - LSHS to LDO - Coal to NG (50%)	100% to NG
Area Sources		Domestic	▪ 25% of slums to use LPG/ PNG ▪ 50% of non slum to use LPG/PNG	▪ 50% of slum to use LPG ▪ 100% same
		Hotel & Restaurants	50% of coal use to LPG	75% of coal use to LPG
		Open Eat outs	Since these operation is illegal, difficult to quantify	
		Bakeries	▪ 25% LPG, * 25% Electric	▪ 50% LPG, * 25% Electric
		Crematoria	50% Electric	75% Electric
		Open Burning	50% control on open burning	100% control on open burning
		Landfill Burning	100% control of Landfill burning	100% control of Landfill burning
		Bldg. Construction	50% control on dust emission	50% control on dust emission
		Road Dust Paved	15% control on dust	15% control on dust
		Unpaved	40% control on dust	100% control on dust
		Ports	Awareness and Management	
		Airports	Awareness and Better Inventory	
		Railways	100% on electric	100% on electric

Ground level concentrations for seven sites after considering Preferred Option I (i.e. options 1 to 4 for vehicles, and all options for industries and area) and Preferred Option II (i.e. options 5 to 8 for vehicles and all options for industries and area) and its comparison with BaU concentrations of 2007, 2012 and 2017 is presented in **Figure 8.7 and 8.8**.

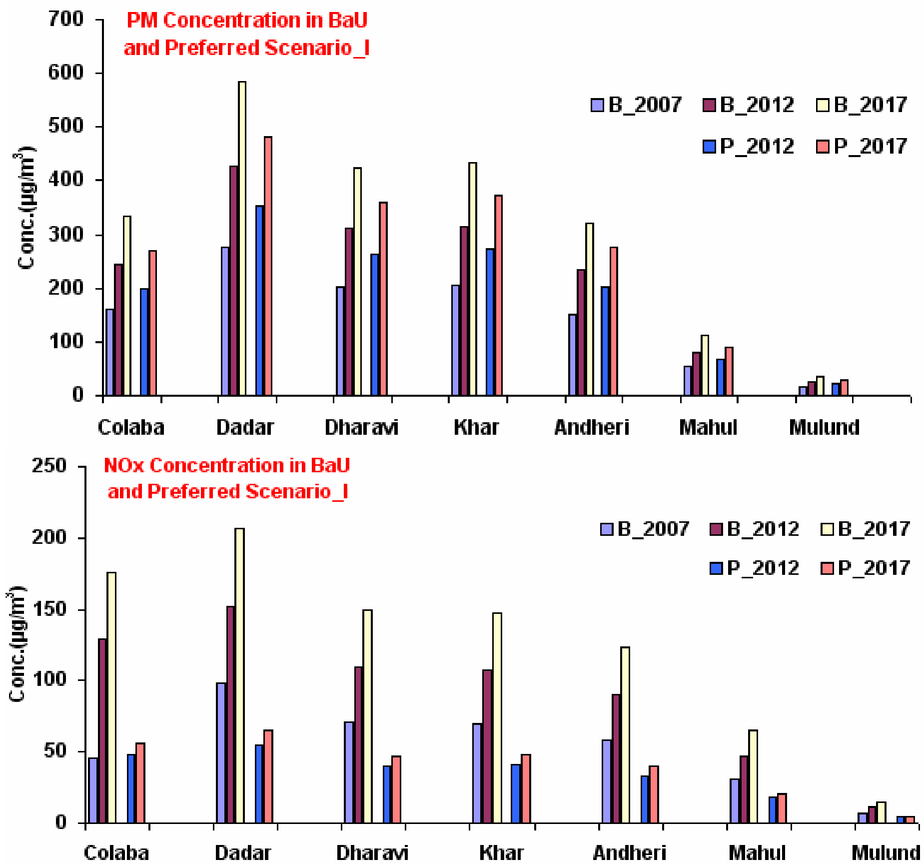
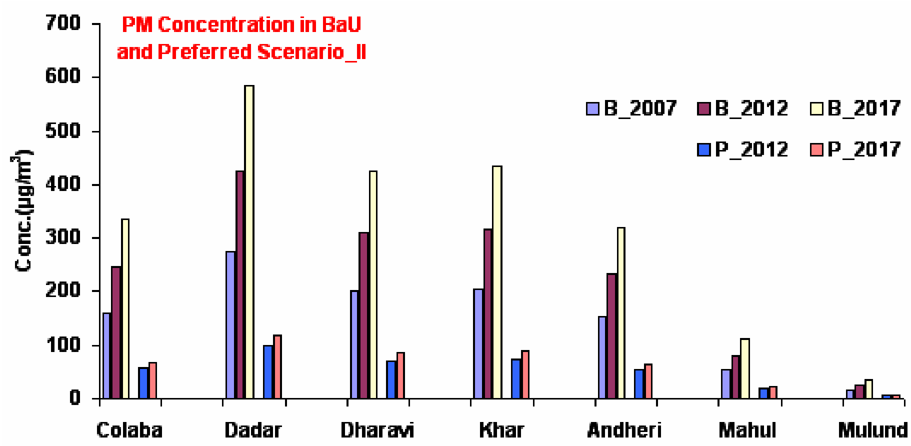


Figure 8.7: PM and NOx Scenario Compared with BaU of 2007, 2012 and 2017 and Preferred Scenario (I) of 2012 and 2017

The predicted ground level concentrations show improvement all across the city. Results shown for the seven sampling locations indicate that though NOx levels would be met most of the time, PM levels will exceed at many locations, except at Mahul and Mulund. As can be seen in the figure, the emission levels would become highly un-acceptable with regard to the PM and NOx levels especially if no control scenario continues till 2012 and 2017.

As can been seen from **Figure 8.7 (Preferred Scenario I)** PM values continue to exceed the standard of 100 µg/m^3. Therefore, to reduce PM ambient concentrations in the city, other options of vehicle sources viz. 5, 6, 7 and 8 will need to be implemented simultaneously. The ambient air scenario with these additional options will bring down PM levels at most of the places below the standards as shown in **Figure 8.8** i.e. **Preferred Scenario II**.



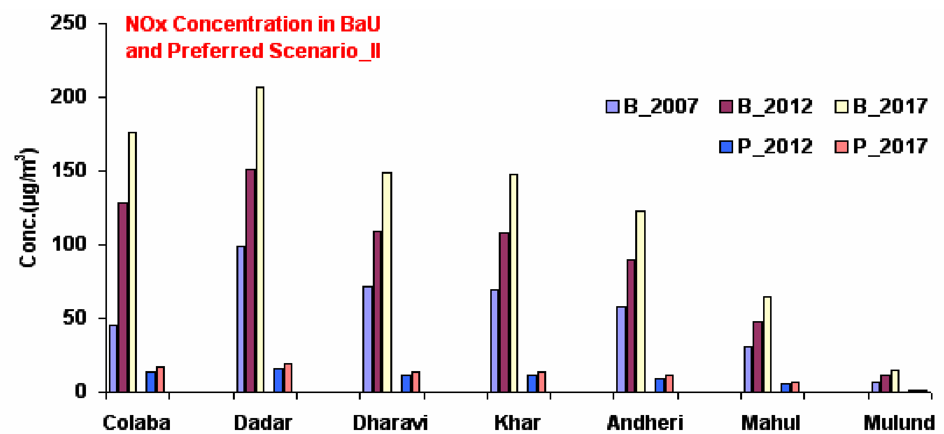


Figure 8.8: PM and NOx Scenario Compared with BaU of 2007, 2012 and 2017 and Preferred Scenario (II) of 2012 and 2017

Table 8.5: Benefits associated with prioritized control / management options

Action Components	Direct benefits	Co-benefits
Vehicular Sector		
Reduce fuel adulteration	Reduced adulteration will lead to reduced PM (difficult to quantify). Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM	One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its lifetime
Alternative fuels • **CNG/LPG** • **Biofuels**	• High, more than 90 % reduction in PM can be achieved compared to diesel • Similar to diesel but low SO_2 and low PM	• Will lead to substantial reduction in CO and HC emission, however, NOx values may go up • Low SO_2 emission
Congestion reduction	High emission due to fuel burning at idle or slow moving traffic	It will reduce traffic junction hotspot of all the pollutants. It will also reduce continuous source of dust
Standards for new and In-use vehicles	• Marginal improvement from newer vehicles except when implementation is for Euro V & VI • In-use vehicles emission reduction can be substantial	As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types
Higher usage of Public Transport	Effectiveness is high as less and less road space will be occupied by private vehicles, faster movement of public transport in comfort shall lead to low emissions	Future growth of the city will entirely depend upon the levels of public transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency
Industrial Sector		
Alternate Fuel	The higher percentage of use of cleaner fuel has already resulted in better air quality in the city	Better air quality in terms of SO_2, CO and HC will be achieved.
Location Specific emission Reduction	Medium as the power plant has already been subjected to strict S levels as well as PM emission by MPCB	High level emission shall have lower PM and other gaseous pollutants
Fugitive Emission control	For localized region, effective. Particularly for industries with fine particles raw material or products. High efficiencies can be achieved for quarries.	Local area air quality improvement could be highly effective.

Table 8.5 (Contd...): Benefits associated with prioritized control / management options

Action Components	Direct benefits	Co-benefits
Area Source		
Improve fuel used for domestic purposes	Likely to improve indoor air quality	It would alleviate large section of population with high indoor pollution of other sources leading to lower disease burden and better quality of life
Bakeries /crematoria	Local grid based PM can be reduced	Reduction in PM as well as odour will take place and is likely to improve the local air quality
Biomass/trash burning, landfill waste burning	Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids	High level improvement in local area ambient air quality not only for PM but other pollutants
Resuspension	Highly effective for kerb-side air quality	Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being
Illegal SSI	Local area improvement can be moderately good	It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem
Construction	Large scale improvement in local area is expected.	Spillage on road and further re-suspension of dust can be minimized

8.8 Conclusions

The study has shown that ambient air quality improvement is a very complex process. Mumbai city ambient air quality has shown improving trends with respect to PM_{10}, SO_2 and NO_2 during the period of 2000-2005. However, in last few years PM decline is not apparent and NOx levels have been seen to be increasing slowly. All the analysis and modeling results indicate that many small steps or one big step for a particular sector will not yield results of better air quality. An integrated bunch of steps will likely to achieve improved air quality which will be sustainable. The city of Mumbai will also need integration of its efforts with nearby urban centers and also alignment with overall national goals for better air quality. Besides the control options presented earlier, following steps are warranted.

Vehicular Sector

A. In this sector measure of better engine technology needs to be combined with better fuel quality and extended emission warranties for the designated life of the vehicles.

B. Fuel quality improvement and its maintenance should be with oil companies. Adulteration possibility at fuel pump should be completely eliminated. This can be achieved through the cooperation and planning of oil companies.

C. CNG/LPG as an alternative fuel for all air quality improvement programme is not sustainable. This is valid more for the public transport vehicles as for any reason if the supply stops the public transport system will collapse. Further, this option cannot be implemented in all cities. Therefore, public transport system should be based on multiple options such as clean diesel (with or without after treatment devices), CNG/LPG, electric and future hydrogen etc.

D. Vehicle inspection and maintenance need to be improved significantly as most of the vehicle emission are from in use vehicles. Centralized inspection and maintenance with very transparent system is need of the hour.
E. Vehicle scrappage policy should be implemented with a system of scrappage yard in each city.
F. Very strong emphasis on public transport need with financial support in terms of lower fuel cost by oil companies, cross subsidy from parking charges, congestion fee etc.

Industrial Sources

A. Industries decline in the city has led to large decrease in air pollution, however, fuel shift in existing industries will further improve the ambient air quality.
B. There are many air quality monitoring stations located in limited area of Chembur-Mahul region. All these are managed by industries. This resource should be well distributed with centralized data linkage with MPCB, which will provide very useful data base for city air quality management.
C. Small scale industries (illegal) are not fully known. It needs updating and control planning.

Area Sources

A. Open refuse burning and landfill site burning are the most important issues for ambient air quality. This needs very quick and credible solution to stop this emission.
B. Road dust from paved and unpaved roads in the city is largely responsible for high PM. The code for road and pavement constructed should be written well and implemented.
C. Large scale construction and demolition of buildings in the city give high local dust contribution leading to health impacts. These practices need adequate rules and compliance to reduce emissions.
D. Bakeries and crematoria emissions can be reduced through implementation of fuel shift combined with awareness programmes.

Other Processes

The air quality improvements can not be achieved alone by above measures without adopting other management practices which are not end-of –the- pipe but are preventive in nature.

A. Strong emphasis on public transport is the only option which can keep sustainable air quality goals. Low cost, easily accessible, faster travel and comfortable to ride are the major objectives needed to be embedded in public transport policy countrywide.

B. Public transport cross subsidization either directly or by providing fuel at lower cost needs the top priority by policy makers
C. Awareness programmes for policy makers, people, drivers-mechanic, traffic police, health professionals, academicians etc. will bring the importance of better air quality.
D. Land use and transport planning need to be looked at seriously for future sustainability of the cities

The sustainable air quality goals can be achieved by a continuous process of updating knowledge, taking action and taking review of the benefits accrued. This process allows mid-course correction and improvement. Improvement in scientific understanding and its incorporation in policy of better air quality should be a continuous process.