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Air quality assessment, emission inventory and source apportionment study for Bangalore city

Final report

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Executive summary

Background

Air pollution is of concern in many cities in India. At most of these cities, the concentration of particulate matter is high as compared to the ambient air quality standards. However, the development of effective control strategies for air pollution abatement requires knowledge of the relative importance of the various sources that contribute to the particulate matter concentration. The auto fuel policy report submitted to Government of India by Mashelkar Committee had identified the knowledge gap in the area of source apportionment. Keeping this in view, the Central Pollution Control Board (CPCB) and the Ministry of Environment & Forests (MoEF), Govt. of India are steering the programme on source apportionment in six cities in the country. TERI is responsible for carrying out the air quality assessment, emission inventory and source apportionment study for Bangalore.

About Bangalore – sources of air pollution

Over the years, the profile of Bangalore has changed drastically and is currently better known as one of the country's major IT hub rather than as a "garden city". With economic development, there has been tremendous pressure on the environment. Deterioration of the air quality in Bangalore can be attributed to rapid increase in population and corresponding fuel combustion activities, which include transport, industrial, and domestic sectors. The population of Bangalore urban agglomerate increased to about 76 lakhs in 2007. The number of vehicles too increased rapidly to about 25 lakhs in 2007, majority of which are private vehicles such as two-wheelers and cars. In terms of contribution to the air pollution load (especially particulate matter), besides the transport sector emissions, the movement of vehicles over paved roads leads to re-suspension of road dust that also contributes to the particulate matter emissions. Though there are no major highly polluting industries in Bangalore, however there do exist a number of industries located in some of the earmarked industrial areas in the city. These industries include Engineering, Metal, Textile, Wood, Printing, Rubber & Plastics, Chemicals, Glass, etc. Diesel Generator (DG) sets are additional source of pollution because of power cuts. Besides the industries, most of the commercial establishments and some households in Bangalore have DG sets. Domestic fuel combustion too has been proportionately rising with the rise in population.

Other sources of air pollution in the city include restaurants, hotels, bakeries which burn fuel for cooking purposes. Construction activities across the city also add to the PM emission load.

Objectives

The main objectives of the study are:-

1. To measure baseline air pollutants and air toxic levels at different parts of Bangalore, which includes "hot spots " on kerb sides as well.
2. To inventorise various pollutants in Bangalore.
3. To project emission inventories under different control options.
4. To conduct source apportionment study of particulate matter.
5. Preparation of an air quality action plan after prioritising of control options.

Approach to the study

A common methodology for the study has been designed by the CPCB for all the executing agencies in the 6 cities. Accordingly, the study in Bangalore has focussed on air quality monitoring, development of emission inventory, dispersion and receptor modelling and finally development of an air quality management plan. A schematic for the overall approach for the source apportionment study is shown in figure 1.

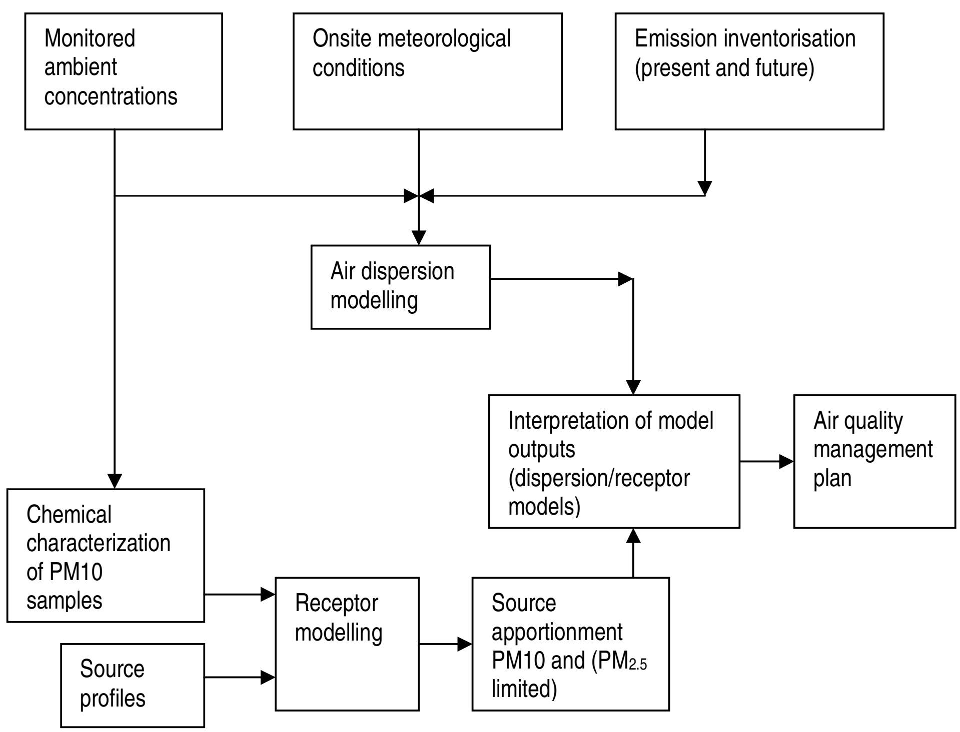


Figure **1** Overall approach for the source apportionment study

Air quality status

Air quality monitoring was carried out for three seasons at seven air quality monitoring stations (figure 2) in Bangalore. The parameters monitored included particulate matter (SPM,RSPM, PM_{10}, $PM_{2.5}$), gaseous pollutants (NO_X as NO_2, SO_2, CO, O_3,), carbon (EC, OC), ions, elements, hydrocarbons (total HC, NMHC), VOCs (Benzene, 1-3 Butadiene), aldehyde, and molecular markers (alkanes, hopanes, alkanoic acid, PAHs, and others such as stigmasterol and levoglucosan). The frequency of monitoring, sampling principle, and the analytical methodology was finalised in consultation with CPCB so that broadly all the cities followed a common methodology.

SPM concentrations have violated the standards at kerbside locations (CSB and Victoria road) as well as at industrial location (Peenya) and one residential location (Kammanahalli) (figure 3). RSPM values are also exceeding the standard at a traffic location (Victoria road) and are close to the standard at the other traffic location (CSB), industrial (Peenya) and residential location (Kammanahalli). $PM_{2.5}$ values show daily exceedences at traffic location (CSB and Victoria road) and on an average are close to the CPCB standard (proposed). For Domlur and Background location, particulate matter concentrations remained under the standards in all the three seasons.

In case of gaseous pollutants (figure 4), SO_2 concentrations are well within limits for three seasons at all the seven air quality monitoring locations, while NO_2 concentrations violate the standards at kerbside locations, CSB and Victoria road in some seasons. On an average across the three seasons, the NO_2 values are close to the standards at the traffic locations. O_3 concentrations are observed to be relatively higher at the background location and Domlur (residential) and IGICH (hospital/residential) locations. CO concentrations generally violate the prescribed CPCB standards at all locations except at Background and Domlur. CO and O_3 show consistent diurnal variation during many days.

Chemical characterization of carbon, ions, elements and molecular markers of PM_{10} and $PM_{2.5}$ samples have been carried for each site for three seasons. Total carbon values were high at kerbside locations (CSB and Victoria road). Also, the EC/OC ratio is highest at CSB showing higher diesel consumption. Calcium ion concentration was observed to be dominant at all the locations. Also, sodium, and potassium were present in significant quantities at certain locations.

High concentrations of sulphate are measured at all the locations. Also, significant concentrations of chloride were also observed at most of the locations. Higher levels were observed for elements such as Na, Fe, Ca, and Mg, in all the three seasons. Al, Si and Zn were also observed at certain locations in different seasons.

Amongst the molecular marker, in general, Coronene, Hentriacontane, Tritriacontane and Hopane were found to be relatively higher.

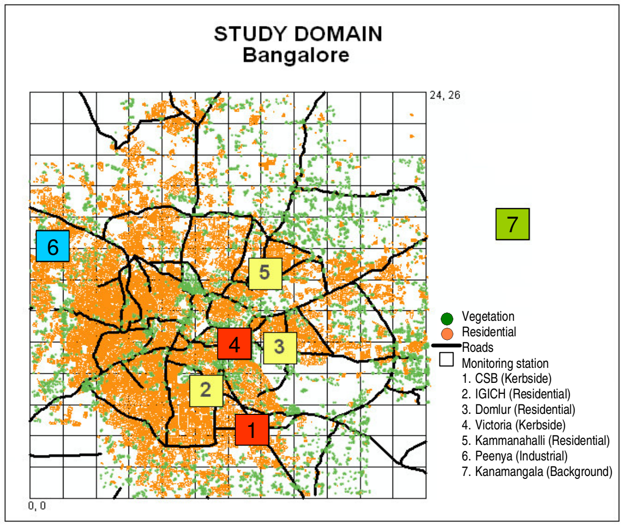


Figure **2** Study domain showing the location of the air quality monitoring locations

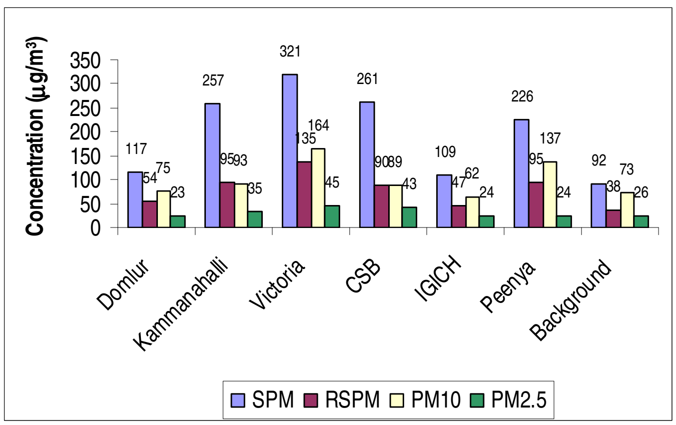


Figure **3** Average concentration of SPM, RSPM, PM_{10}, $PM_{2.5}$ during three seasons

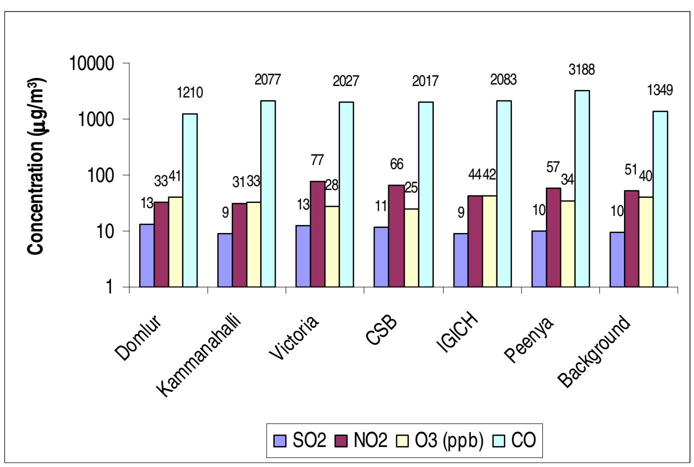


Figure **4** Average concentration of gaseous pollutants during three seasons

Emission inventory

Bangalore city (as per survey of India map, 2002) has been divided into grids of 2x2 km^2. Emission inventory has been prepared for the city as a whole as well as for the 2x2 km^2 zone of influence around the monitoring sites. Information has been collected from secondary sources to establish a baseline profile for the city. Primary surveys were conducted for each sector i.e. Transport, Domestic, Industries, and others to estimate activity levels across various sectors. During primary surveys, traffic count survey was undertaken at 25 locations across the city. Further, parking lot surveys and fuel pump surveys were carried out for ascertaining the vintage of the vehicles, distances travelled per day, fuel-wise distribution, technological mix etc. Emission factors for transport sector were adopted from ARAI report. However, for other sources CPCB's suggested common emission factors were used. Emission inventory has been prepared for the base year 2007. Emissions are allocated to each of the grid using GIS tools for further input to the air quality models.

In the current study, emission inventory is prepared for various sectors and for various pollutants. The total pollution load in Bangalore in 2007 is estimated to be 54.4 T/d for PM_{10}, 217.4 T/d for NO_X and 14.6 T/d for SO_2. At the city level, the major sources of PM10 emissions are transport (42%), road dust re-suspension (20%), construction (14%), industry (14%), DG set (7%) and domestic (3%) (figure 5). Like wise, at the city level, the major sources of NO_X are transport (68%), DG set (23%), industry (8%), and domestic (1%) (figure 6). In the case of SO_2, at the city level, industry (56%), DG set (23%) and transport (16%) are the major sources. The pollutant wise sectoral breakup of emission loads are presented in Table 1.

Table 1 Total emission loads (T/d) in Bangalore

	PM_{10}	NO_X	SO_2
Transport	22.4	146.36	2.31
Road Dust	10.9	0.00	0.00
Domestic	1.8	2.73	0.68
DG Set	3.6	50.96	3.35
Industry	7.8	17.19	8.21
Hotel	0.1	0.20	0.02
Construction	7.7	0.00	0.00
Total	54.4	217.4	14.6

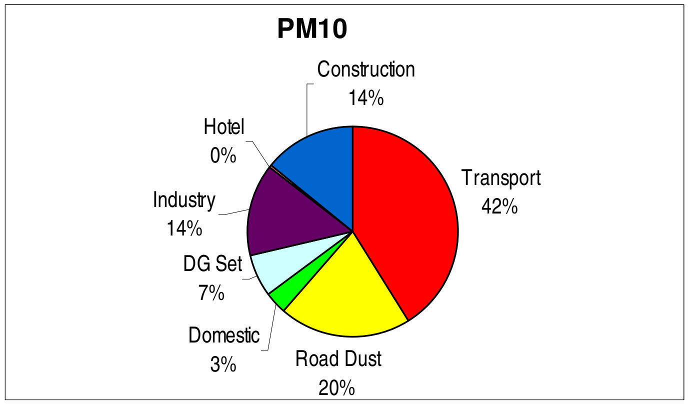


Figure **5** Percentage share of different sources in total PM_{10} emission loads

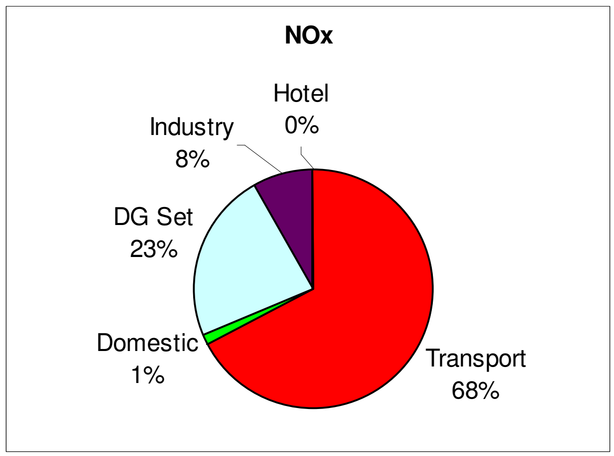


Figure **6** Percentage share of different sources in total NO_X emission loads

Receptor modelling and source apportionment

Emission of pollutants from the sources and its effect i.e., pollutant levels in ambient air can be related using modelling techniques. The two widely used modelling techniques are receptor modelling and dispersion modelling.

Receptor models use 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. Receptor models are generally contrasted with dispersion models that use pollutant emissions rate estimates, meteorological transport, and chemical transformation mechanisms, to estimate the contribution of each source to receptor concentrations. The two types of models are complementary, with each type having strengths that compensate for the weaknesses of the other.

Receptor models are retrospective as they can only assess the impacts of air pollution source categories on pollutant concentrations that have already been monitored. Receptor modelling involves sampling of the pollutants (for example PM_{10}) and analyzing its chemical composition. In the current study, the particulate matter samples collected during the three seasons have been analysed for anions, cations, elements, organic carbon and elemental carbon, and molecular markers. This information is used for receptor modelling.

CMB (Chemical Mass Balance) is used in this study for receptor modelling for source apportionment of particulate matter. In addition, factor analysis method is also used for ascertaining the likely sources that contribute to pollution at the various monitoring sites.

The indicative sources based on Factor Analysis of PM_{10} samples for the different sites are presented in Table 2.

Table 2 Indicative sources based on Factor Analysis for the different sites

S. No.	*Site*	*Site description*	*Indicative sources*
1	Silk Board	Traffic location	Motor vehicle exhaust, secondary particulate matter, construction activities, natural soil, road dust
2	Victoria road	Traffic location	Motor vehicle exhaust, natural soil, road dust, biomass burning, secondary particle formation
3	Peenya	Industrial	Road dust, residual oil burning, crustal soil dust, industrial sources, metal industries, motor vehicle exhaust, construction activities
4	Domlur	Residential	Soil and road dust, secondary particle formation, motor vehicle exhaust, storm water drain, biomass burning
5	Kammanahalli	Residential	Road dust, coal combustion, vegetative burning, secondary particle formation, resuspended soil, motor vehicle exhaust
6	IGICH	Hospital /Residential	Road dust, natural soil, secondary particle formation, construction activities, motor vehicle exhaust, incinerator combustion
7	Kanamangala/ Background	Background	Natural soil, crustal source, road dust, vehicular sources, biomass burning, secondary particle formation

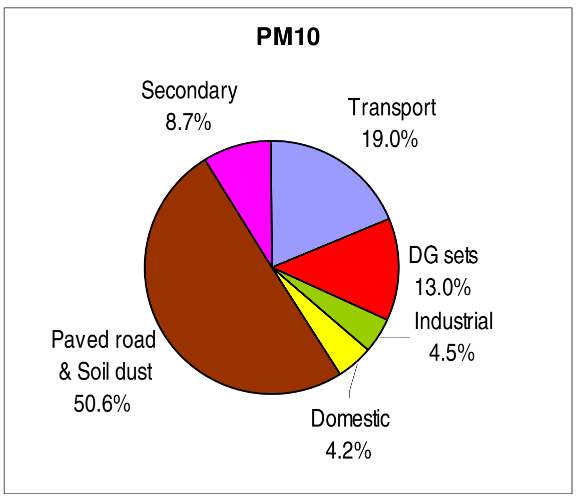
The source profile abundances (i.e. the mass fraction of a chemical from each source type) and the receptor concentrations, with appropriate uncertainty estimates, served as input data to CMB. The output consists of the amount contributed by each source type represented by a profile to the total mass, as well as to each chemical species. CMB calculates the values for the contributions for each source.

The source profiles for vehicular sources were developed by ARAI while those for non-vehicular sources were developed by IIT Mumbai. It may however be noted that the results of the CMB modelling have to be analysed keeping into consideration the limitations due to the existence of co-linearity amongst the source profiles.

CMB8.2 modelling of PM_{10} for 7 locations in Bangalore suggests that there is a wide variation in the contribution of various sources to PM_{10} concentrations at various sites as well as in different seasons. Overall, it is seen that major sectoral contributors to the PM_{10} concentration are dust from paved road and soil; transport; DG sets; and secondary particle formation. Domestic and industrial sectors have small contributions. Likewise, in the case of $PM_{2.5}$, it emerges out that the transport sector has a major contribution to the $PM_{2.5}$ concentrations, followed by significant contribution from DG sets and secondary particulates. Contributions from other sectors like domestic and industries are small.

Figure 7 shows the contribution of various sources to PM_{10} and $PM_{2.5}$ based on the CMB8.2 modelling results. Some of the key points are :

- Share of transport sector increase from 19% in PM_{10} to 50% in $PM_{2.5}$, depicting dominance of finer particles in the vehicular exhaust.
- Share of anthropogenic sources has been eclipsed by dust contributions, in case of PM_{10}. However, $PM_{2.5}$ clearly shows the significant contribution of anthropogenic sources.
- DG sets have emerged out as an important source of air pollution. Their contribution is 13% & 25% in PM_{10} and $PM_{2.5}$, respectively.
- Contribution of industries to the particulate matter is low in Bangalore, primarily due to absence of any large scale air polluting units. However, their contribution in the industrial zone (Peenya) is high.
- Overall, domestic sector has a small contribution in both PM_{10} and $PM_{2.5}$. However, few locations have shown substantial contribution which is attributable to wood burning in the region.
- Share of secondary particulates is higher in $PM_{2.5}$ than in PM_{10}, depicting their finer size.



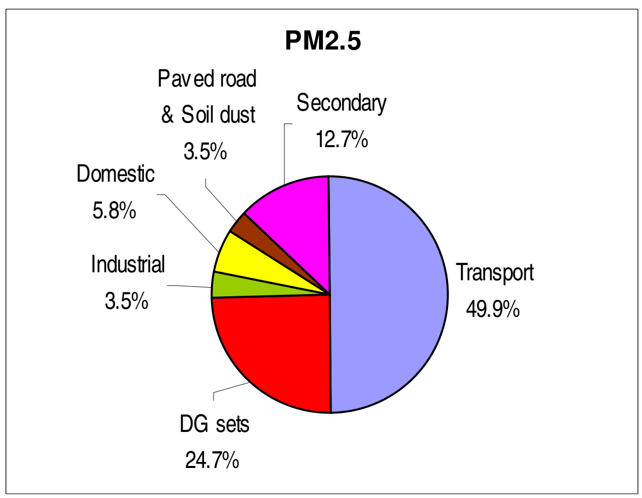


Figure **7** Comparison of PM_{10} and $PM_{2.5}$ source contribution in Bangalore city (average of 3 seasons)

Dispersion modelling : existing scenario

Industrial Source Complex Short-term (ISCST3) model has been used for dispersion modelling. The field data collected during the primary monitoring as well as from secondary sources were used as inputs to the model. This included appropriate estimation of emissions from the various sources based on the activity data and the relevant emission factors (common factors provided by CPCB). The emission data were input to the model along with the meteorological data to calculate the predicted PM_{10} and NO_X concentration values. For modelling purpose, the total city area of 624 sq Km were divided into 2*2 sq km area grids. Further, 2*2 sq Km area grids around the six air quality monitoring stations were divided into 0.5*0.5 sq area.

Existing Scenario: PM_{10} and NO_X

Dispersion modelling of PM_{10} and NO_X is carried out both for the city level as well as for the six air quality monitoring stations. The pockets of highest concentration of PM_{10} are well captured by the contours at the city level whereby they correspond to high industrial (Peenya industrial area) and traffic activities close to the central hub of the city (Figure 8). Likewise, the contours at the city level for predicted 24-hourly average NO_X concentration again capture well the pockets of high concentration in terms of activity levels corresponding to high traffic and DG set usage (Figure 9).

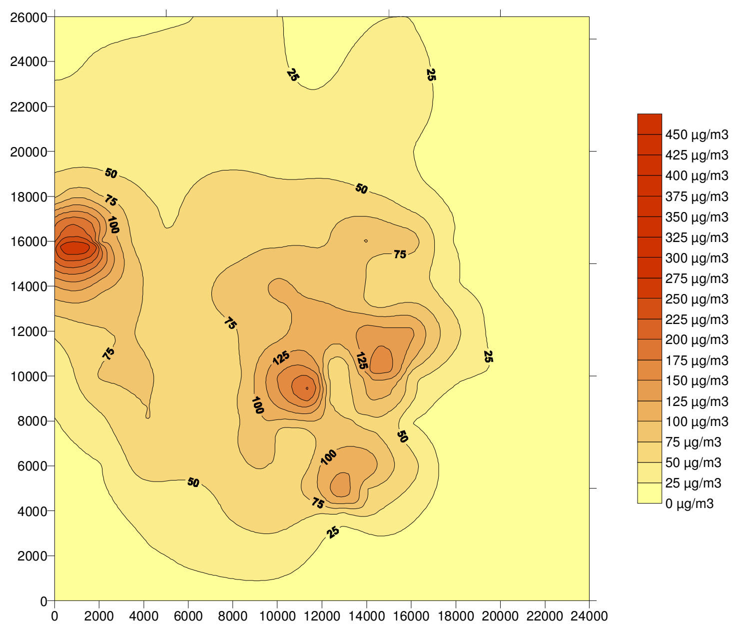


Figure **8** Contours for 24-hourly average PM_{10} concentration (µg/m^3) for first (winter) season during 2007

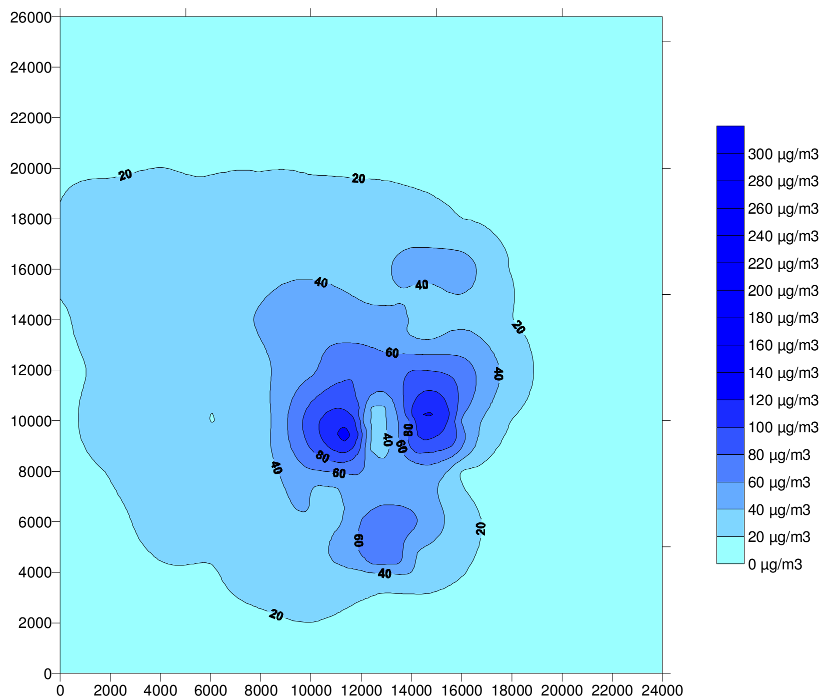


Figure **9** Contours for 24-hourly averaged NO_X concentration (µg/m[3]) for first (winter) season during 2007

Since the worst season in terms of air quality concentration is winter season, thus, further simulations of BAU and alternate options scenarios were carried out using background meteorology (dominant meteorology) of the first season i.e. winter season.

Emission control options and analysis

Future scenario analysis is carried out for 2012 and 2017 to evaluate:-

a) Business as usual scenario (BAU) and
b) Alternate scenarios (with interventions to abate air pollution levels)

BAU - Business as usual scenario

BAU scenario depicts growth in different sectors such as growth in population, vehicles, industries, construction activities, DG sets etc. The scenario does not account for any intervention to abate air pollution levels except BS-IV norms for vehicles which are already in the current road map.

Growth patterns

Sector specific growth rates are applied to project current (2007) data to 2012 and 2017. The details are presented in Table 3.

Table 3 Growth rates of different sectors

S.No	Sector	Description of growth
1	Domestic	Population growth rate of 3.1% as listed in Master Plan - 2015
2	Transport	Vehicle-wise growth rates were calculated using the last five years data (2002-2007). BS-IV norms are taken into account from 2010.
3	Industrial	5.85% as depicted in Industrial development plan
4	DG sets	Based on population growth rates for domestic sets and based on energy consumption for commercial DG sets.
5	Construction	Based on population growth rates
6	Road dust	Based on increase in VKT (from transport sector)
7	Eating joints	Based on population growth rates

Based on above, BAU scenario is developed and emissions loads for PM_{10} and NO_X are presented in Figures 10 and 11. The total emissions of PM_{10} increase from 54.4 T/d in 2007 to 95.8 T/d in 2017. Likewise, NO_X emissions during the same period increase from 217 T/d to 460 T/d.

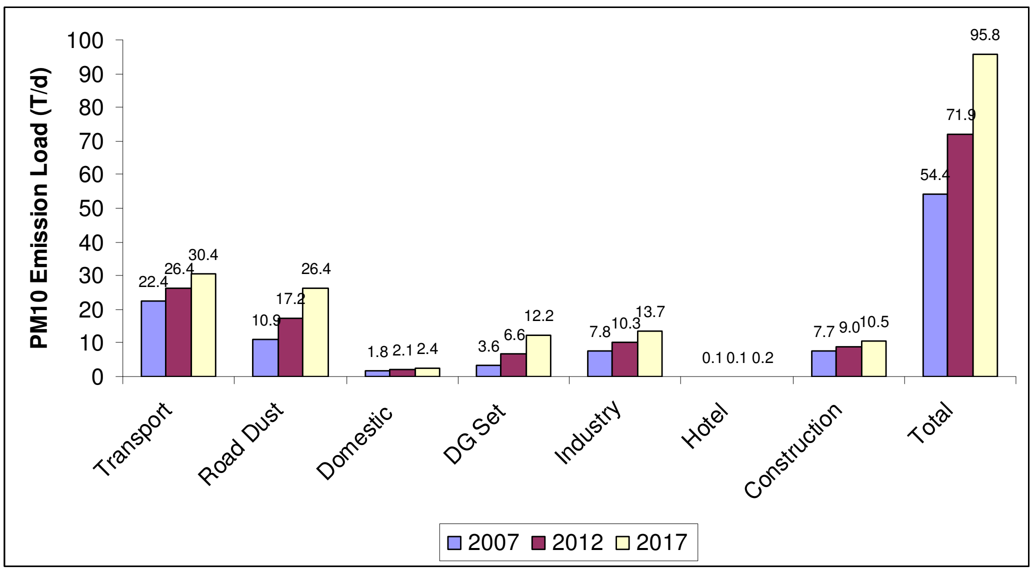


Figure **10** Sectoral and total PM_{10} emission load under BAU scenario during 2007-2017

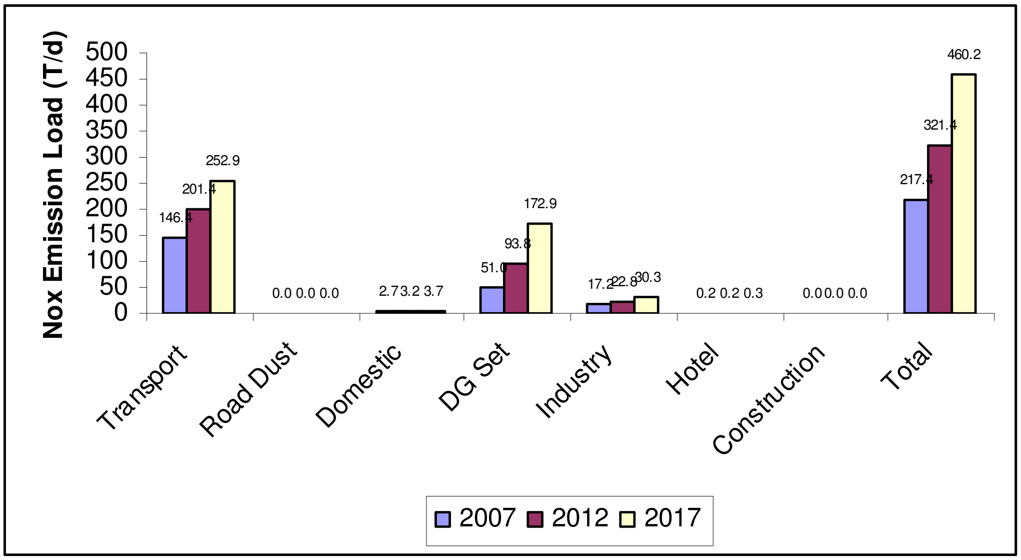


Figure **11** Sectoral and total NO_X emission load under BAU scenario during 2007-2017

Dispersion modelling - BAU Scenarios 2012 and 2017

Model simulations were carried out for the BAU and alternate scenarios using the worst meteorology season i.e., winter season in the case of Bangalore.

Figure 12 indicates that the predicted 24-hourly averaged PM_{10} concentrations for the years 2007, 2012 and 2017 under the BAU scenario at six air quality monitoring stations.

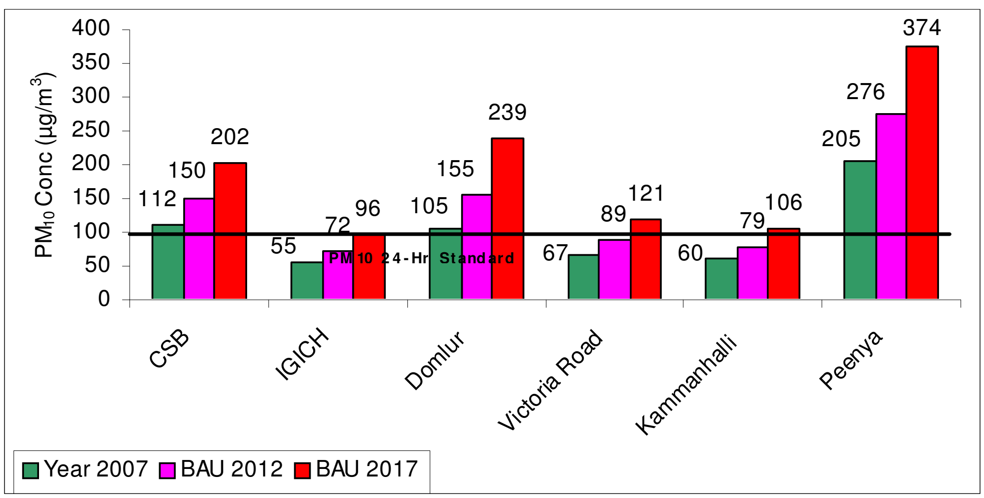


Figure **12** Predicted 24-hourly average PM_{10} concentrations (µg/m^3) for base year (2007) and BAU (2012, 2017)

As an illustration, the PM_{10} predicted 24 hourly average concentration values during the winter season for year 2012 and 2017 under BAU scenario are shown in Figure 13 and 14, respectively.

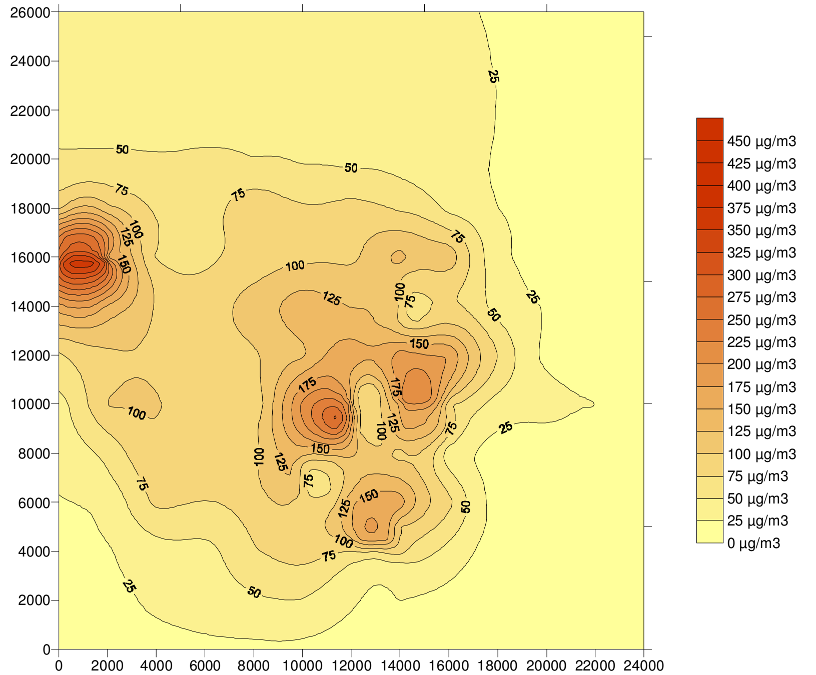


Figure **13** Contours for 24-hourly average PM_{10} concentration (µg/m³) for BAU 2012

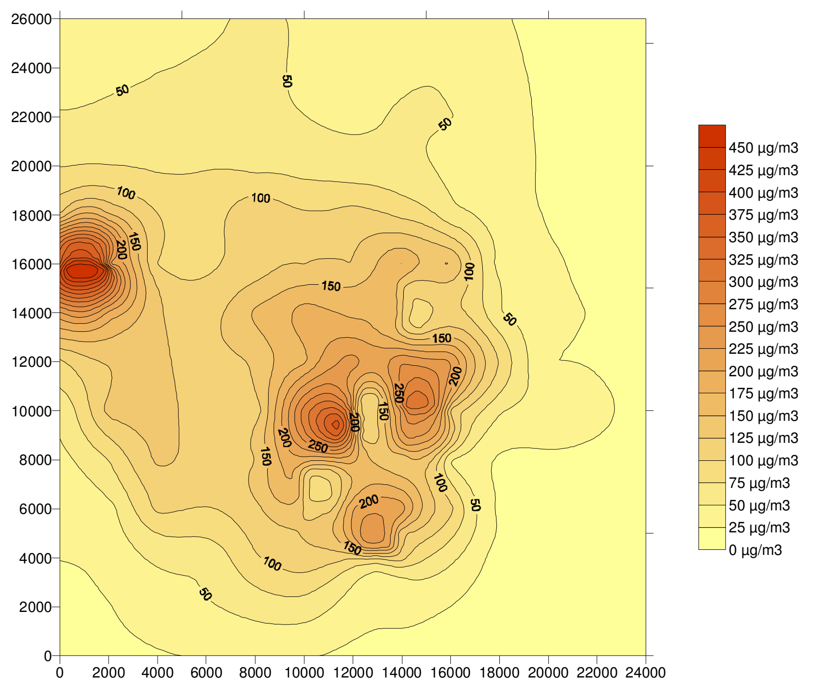


Figure **14** Contours for 24-hourly average PM_{10} concentration (µg/m³) for BAU 2017

As in the base year 2007, it is noted that the maximum concentration is observed close to Peenya industrial area and high traffic locations close to the central hub of the city. Also, compared to the base year 2007, the concentration values increase in BAU 2012 and show a further increase in 2017, which is in accordance with the increasing trend of the pollutant emissions.

Line source control options & analysis

Transport sector contributes substantially to the air pollution loads in Bangalore. Therefore, emission estimates of PM_{10} (Table 4) and NO_X (Table 5) are made for various technical interventions in the transport sector as per the chart provided by CPCB.

Table 4 Reduction in PM_{10} emission loads due to various technological interventions in transport sector in Bangalore

S.No	Strategy	2007	2012	2017	% reduction 2012	% reduction 2017	Remarks
1	BAU	22.4	26.4	30.4			CAGR 2002-2007, BS-IV from 2010, No bio-diesel ,Ethanol, or ban
2	BS-V	22.4	26.4	30.1	0%	-1%	BAU + BS -V has been applied from 2015
3	BS-VI	22.4	26.4	30.0	0%	-1%	BAU + BS -VI has been applied from 2015
4	ELECTRIC	22.4	25.8	29.1	-2%	-4%	BAU + Introduction of electric vehicle as per chart provided by CPCB
5	Hybrid	22.4	26.4	30.4	0%	0%	BAU + 1% hybrid cars in 2012 & 2% in 2017
6	CNG	22.4	25.4	26.6	-4%	-12%	BAU+ commercial vehicles (Bus/Car/3w)-25% conversion in 2012 and 100% in 2017
7	Ethanol	22.4	26.4	30.4	0%	0%	BAU + 10% Ethanol introduced in 2012-2017
8	Bio-diesel	22.4	26.3	30.2	-0.4%	-1%	BAU + 5% Biodiesel introduced in 2012 and 10% in 2017
9	H2/CNG	22.4	26.4	30.4	0%	0%	10% Vehicles in 2017
10	Diesel oxidation catalyst (DOC)	22.4	26.1	29.9	-1.0%	-1.7%	50% conversion of BS-II buses in 2012, and 100% in 2017
11	Diesel particulate filter (DPF)	22.4	26.2	30.1	-0.6%	-1.2%	50% conversion of BS-III buses in 2012, and 100% in 2017

Percentage reduction achieved in PM_{10} emission loads (as compared to the BAU of the respective year) by implementing various strategies in the transport sector are shown in Figure 15.

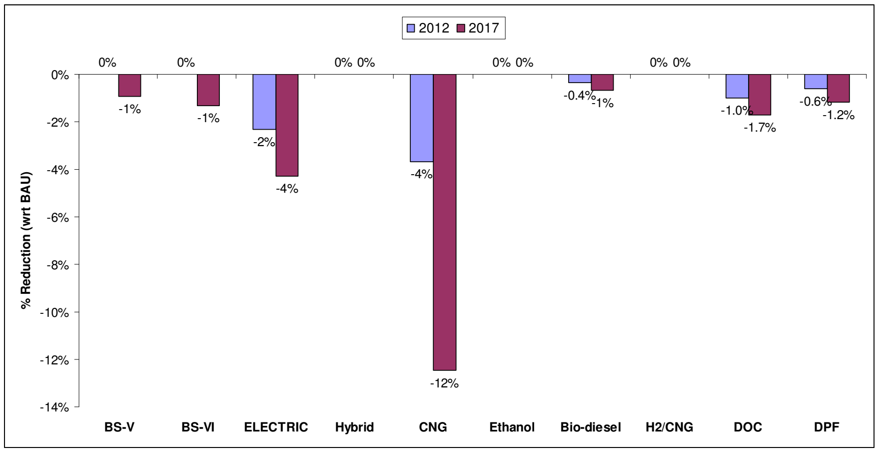


Figure **15** Percentage reduction achieved in PM_{10} emissions by implementing various strategies in the transport sector

Introduction of BS-V and BS-VI have minimal impact on PM_{10} emission loads because of their introduction in the year 2015. Introduction of electric vehicle can reduce the load to some extent and the strategy can be useful in some specific areas. Introduction of Hybrid vehicles and ethanol blending does not have any impact on PM_{10} emission loads. Blending of bio-diesel reduces the load marginally by 0.4-1% in 2012 and 2017, respectively. Likewise, introduction of DOC in BS-II buses and DPF in BS-III buses reduces the load only marginally. However, introduction of CNG in 3 & 4-wheeler commercial vehicles can reduce the PM_{10} emissions load by 4% in 2012 and 12% in 2017.

NO_X emission estimates made for various technical strategies in the transport sector are presented in Table 5 .

Table 5 Reduction in NO_X emission loads due to various technological interventions in transport sector in Bangalore

S.No	Strategy	2007	2012	2017	% reduction 2012	% reduction 2017	Description
1	BAU	146.4	201.4	252.9			CAGR 2002-2007, BS-IV from 2010, No bio-diesel ,Ethanol, or ban
2	BS-V	146.4	201.4	248.0	0%	-1.9%	BAU + BS -V has been applied from 2015
3	BS-VI	146.4	201.4	243.5	0%	-3.7%	BAU + BS -VI has been applied from 2015
4	ELECTRIC	146.4	196.3	241.4	-2.5%	-5%	BAU + Introduction of electric vehicles as per chart provided by CPCB.
5	Hybrid	146.4	201.3	252.8	-0.02%	-0.04%	BAU + 1% hybrid cars in 2012 & 2% in 2017
6	CNG	146.4	199.0	241.5	-1%	-4%	BAU+ commercial vehicles (Bus/Car/3w) - 25% conversion in 2012 and 100% in 2017

S.No	Strategy	2007	2012	2017	% reduction 2012	% reduction 2017	Description
7	Ethanol	146.4	201.1	252.6	-0.1%	-0.1%	BAU + 10% Ethanol introduced in 2012-2017
8	Bio-diesel	146.4	201.6	253.4	0.1%	0.2%	BAU + 5% Biodiesel introduced in 2012 and 10% in 2017
9	H2/CNG	146.4	201.4	240.6	0.0%	-4.9%	10% Vehicles in 2017
10	Diesel oxidization catalyst (DOC)	146.4	201.4	252.9	0.0%	0.0%	50% conversion of BS-II buses in 2012, and 100% in 2017
11	Diesel particulate filter (DPF)	146.4	201.4	252.9	0.0%	0.0%	50% conversion of BS-III buses in 2012, and 100% in 2017

Percentage reduction achieved in NO_X emission loads (as compared to the BAU of the respective year) by implementing various strategies in the transport sector are shown in Figure 16.

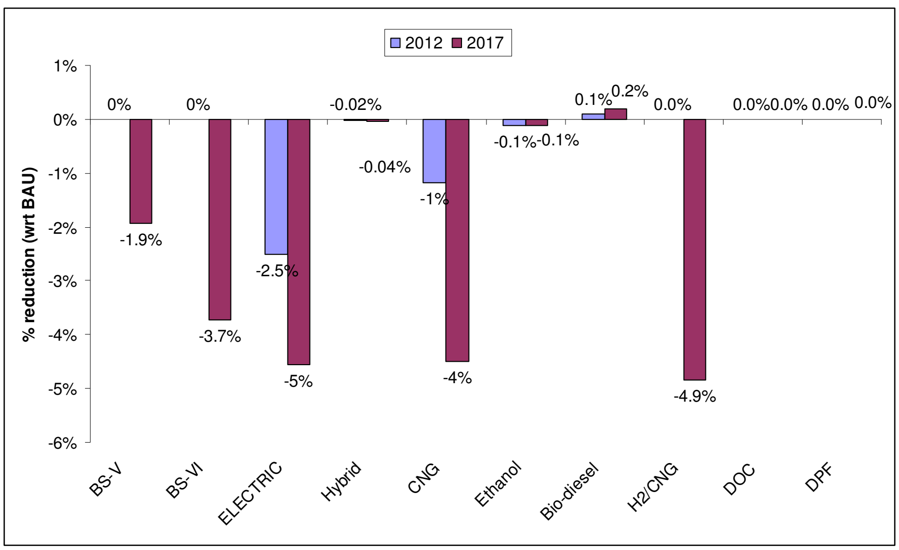


Figure **16** Percentage reduction achieved in NO_X emissions by implementing various strategies in the transport sector

Introduction of BS-V and BS-VI have minimal impact on NO_X emission loads because of their introduction in 2015. However, the impact is more than that seen in the case of PM_{10}. Introduction of electric vehicles can reduce the load up to 5 % in 2017 and the strategy can be useful in some specific areas. Introduction of hybrid vehicles and ethanol blending have very small impact on the NO_X emission loads. Blending of bio-diesel increases the load marginally by 0.1-0.2% in 2012 and 2017, respectively. Introduction of DOC in BS-II buses and DPF in BS-III buses does not have any impact on NO_X emissions. Introduction of CNG in commercial vehicles (bus, car, 3w), reduces the NO_X emission loads by 1% in 2012 and 4% in 2017. The impact is lower in case of NO_X than in the case of PM_{10}.

Dispersion modelling – impact of interventions in transport sector

It is evident that the reduction in emission loads due to different control options is limited, though in some cases, a marginal impact was seen. Modelling exercise has been carried out for each of these technical control options in the transport sector to quantify the impact on ambient air quality. The percentage reduction in ambient air quality (highest 24 hourly PM_{10} concentrations) at each of the six monitoring locations has been calculated under the control options as compared to BAU for the years 2012 and 2017. It is seen that most of the control options do not have much impact on the ambient air quality except for electric vehicles and CNG introduction in the commercial fleet of vehicles. In the year 2017, the impact due to electric vehicles varies from 0.2-1.7 % while impact due to CNG vehicles varies from 0.7-5.6 % at these six air quality monitoring sites.

Other sectors – control options and analysis

For the industrial sector, two strategies were evaluated i.e., ban on new air polluting industries in the city limits, which means no further addition of emission loads in 2012 and 2017 and fuel shift in terms of conversion of all solid fuel fired combustion to LSHS in 2012 and LSHS/ HSD fired combustion to natural gas in 2017. The strategy of banning new industries results in reduction of 24% and 43% of PM_{10} emission loads compared to BAU in years 2012 and 2017, respectively. Likewise, this strategy for NO_X results in similar reductions in the years 2012 and 2017. The combined effect of ban and fuel shift strategies results in significant reductions for both the pollutants compared to BAU. PM_{10} reduced 57% and 80% and NO_X reduced 25% and 89% in the years 2012 and 2017, respectively.

Inspection and maintenance of DG sets results in 15% reduction of PM_{10} and NO_X emissions loads.

Strategy of wall to wall paving is considered for reduction of emissions due to road dust re-suspension. The strategy shows substantial reduction i.e. 11% in 2012 and 22% in 2017.
50% reduction in PM_{10} emission loads has been envisaged in view of better construction practices including proper loading/unloading of material, water spraying etc.

Scenario analysis

Four alternate scenarios (Alternate – I, Alternate – II, Alternate-III, and Alternate-IV are developed. These include the measures that are implemented under BAU scenario (including introduction of BS-IV norms in 2010) and in addition the following technical and management options:-

Sectors	Alternate-I	Alternate-II	Alternate-III	Alternate-IV
Description	Scenario with certain strategies to reduce the air pollution loads across various sectors.	Stringent scenario with many more strategies to reduce the air pollution load across various sectors as compared to Alternate- I scenario.	Scenario that contains additional set of measures that are not a part of the common control options as per the chart suggested by CPCB (for example, introduction of fuel efficiency standards, installation of control devices (DOC/DPF) on all diesel vehicles and DG sets).	Scenario with measures that are more oriented towards meeting the air quality standards in future
Transport	• Introduction of BS-V in 2015 • Ban on 10 year old commercial vehicles in 2012 and 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017) • Improvement in inspection and maintenance • Introduction of DOC in BS-II buses and DPF in BS-III buses	• Introduction of BS-VI in 2015 • Ban on 10-yr old commercial vehicles and 15-yr old private vehicles both in 2012 and 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on CNG (shift of PKT from private vehicles to public transport i.e. 10 % in 2012 and 20% in 2017) • Introduction of electric vehicles (1–2% 2w, 5-10% 3w and taxis, 5–10% buses in 2012 and 2017, respectively) • Improvement in inspection and maintenance • Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017) •	• Introduction of BS-VI in 2015 • Ban on 15 yr old commercial vehicles in 2012 and 10 yr old commercial vehicles in 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10 % in 2012 and 20% in 2017) • Introduction of electric vehicles (1 – 2% 2w, 5 - 10% 3w and taxis, 5 – 10% buses in 2012 and 2017, respectively) • Improvement in inspection and maintenance • Application of DOC/DPF after introduction of BS- IV fuel in 2010 to: *Old Buses and Trucks (pre BS-IV):reduction in PM_{10} - DOC : 22.5%, DPF : 70%* *Old Diesel Cars – pre BS-IV (about half of PM reduction is assumed as compared to that for buses/trucks) : reduction in PM_{10}-DOC: 10%, DPF : 35%* • Introduction of fuel efficiency standards (considering reduction of fuel consumption) *Light passenger vehicles : 10% between (2012-15) and 15% between (2015-17), Light duty Passenger cars : 20% between (2012-15) and 30% between (2015-17), Heavy duty vehicles : 20% between (2012-15) and 30% between (2015-17)*	• Introduction of BS-V in 2015 • Ban on 10 yr old commercial vehicles in 2012 and 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on CNG (shift of PKT from private vehicles to public transport i.e. 10 % in 2012 and 20% in 2017) • Introduction of electric vehicles (1 – 2% 2w, 5 - 10% 3w and taxis, 5 – 10% buses in 2012 and 2017, respectively) • Improvement in inspection and maintenance • Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017) • By-passing of trucks on the proposed peripheral ring road around Bangalore (which is broadly outside the study domain- assumed only 10% truck traffic within the city)
Industries	Ban on any new air polluting industries in city limits	• Ban on any new air polluting industries in city limits • Shift from solid fuel to liquid fuel (LSHS) in 2012 & NG in 2017 in existing industries	• Ban on any new air polluting industries in city limits • Shift from solid fuel to liquid fuel (LSHS) in existing industries in both 2012 and 2017	• Ban on any new air polluting industries in city limits • Shift from solid fuel to liquid fuel (LSHS) in 2012 and to NG in 2017 in existing industries
DG sets		• Inspection and maintenance	• Inspection and maintenance • DOC and DPF applied to commercial DG sets (>12 kVA) in 2010. Reduction in PM_{10} :DOC : 22.5%, DPF : 70% (reductions taken same as those in the case of buses)	• No power cuts i.e. no usage of DG sets in the city
Road dust re-suspension		• Wall to wall paving	• Wall to wall paving	• Wall to wall paving • Reduction of road dust re-suspension due to by-passing of trucks
Construction		• Better construction practices	• Better construction practices	• Better construction practices

The estimated emission loads for PM_{10} and NO_X under BAU and four alternate scenarios are presented in Figure 17.

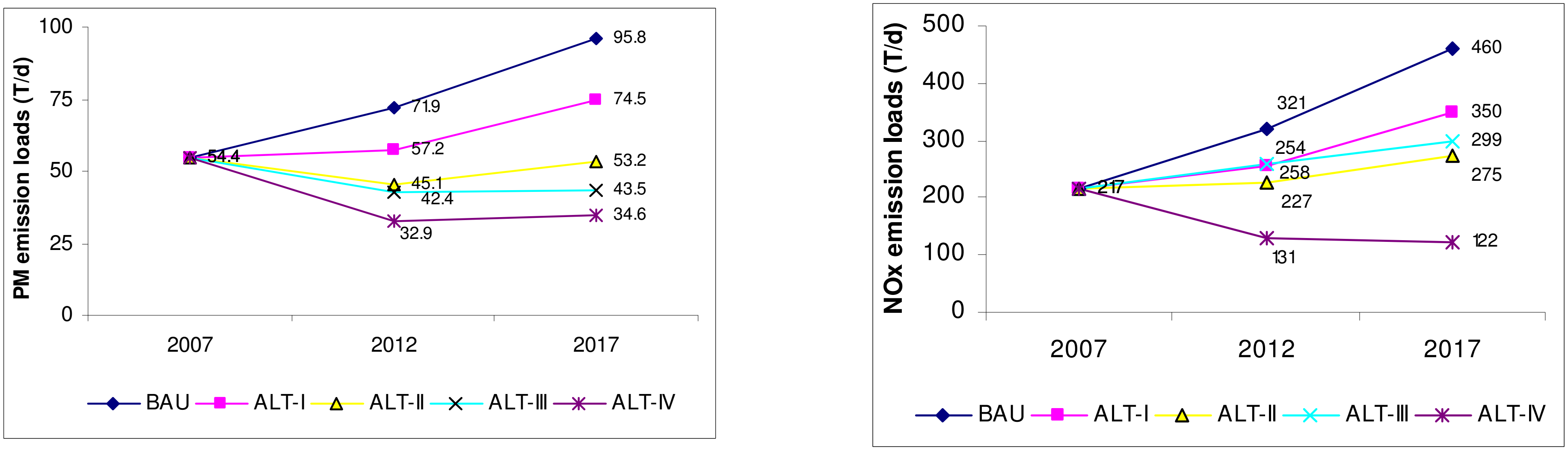


Figure **17** Estimated emissions loads for PM_{10} and NO_X under the BAU and four alternate scenarios

PM_{10} emission load

%PM reduction w.r.t. BAU

Scenario	2012	2017
ALT-I	-20%	-22%
ALT-II	-37%	-44%
ALT-III	-41%	-55%
ALT-IV	-54%	-64%

ALT-I scenario with less stringent measures shows a reduction of 20% in 2012 and 22% in 2017, respectively. However, ALT-II scenario with more stringent measures show reduction of 37% and 44%, in 2012 and 2017, respectively. ALT-III scenario that includes additional measures including installation of DOC/DPF control devices in all diesel vehicles as well as DG sets amounts to substantial reduction of 41% and 55% in the years 2012 and 2017, respectively. ALT-IV emerges out to be the best showing reductions of 54% and 64% in the above mentioned years mainly because of no power cuts (and thus no emissions from DG sets) and by-passing of the truck traffic.

Overall, it is seen that in 2017, the PM_{10} emission loads in Alternate-IV, Alternate-III and Alternate – II are lower (36%, 19% & 2.1 %, respectively) than in 2007, while those in Alternate – I are 37 % higher than in 2007. However, under the BAU scenario, the emission loads in 2017 show an increase of 76 % as compared to 2007.

NO_X emission load

% NOx reduction wrt BAU

Scenario	2012	2017
ALT-I	-21%	-24%
ALT-II	-29%	-40%
ALT-III	-20%	-35%
ALT-IV	-59%	-73%

ALT-I scenario with less stringent measures shows a reduction of 21% in 2012 and 24% in 2017, respectively. However, ALT-II scenario with more stringent measures show reduction of 29% and 40%, in 2012 and 2017, respectively. ALT-III scenario shows reductions of 17% and 33%, in 2012 and 2017, respectively. Here again, ALT-IV scenario shows the maximum reduction in NO_X emissions loads w.r.t. BAU i.e. 59% and 73%, respectively. The reduction is mainly because of no usage of DG sets and by-passing of trucks which are a significant source of NO_X emissions.

Overall, it is seen that in 2017, under the BAU scenarios, the emission loads in 2017 show an increase of 112 % as compared to 2007. Alternate-I, Alternate – II and Alternate – III scenarios, show that the NO_X emission loads are 61%, 26% and 38% more than in 2007, respectively. Only Alternate-IV scenario show a decrease of 44% NO_X emissions from the 2007 levels.

Model performance

Model simulations were carried out for alternate scenarios using the worst meteorology season i.e., first (winter) season.

Figure 18 indicates that the predicted 24-hourly average PM_{10} concentrations for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios at the six air quality monitoring stations in year 2012 ranged from 59 – 213 $\mu g/m^3$, 51 – 119 $\mu g/m^3$, 42 – 100 $\mu g/m^3$, and 30 -81 $\mu g/m^3$, respectively. Likewise in the year 2017, it ranged from 79 – 241 µg/m³, 65 – 182 µg/m³, 42 – 104 µg/m³ , and 32 – 75 µg/m³ for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios, respectively.

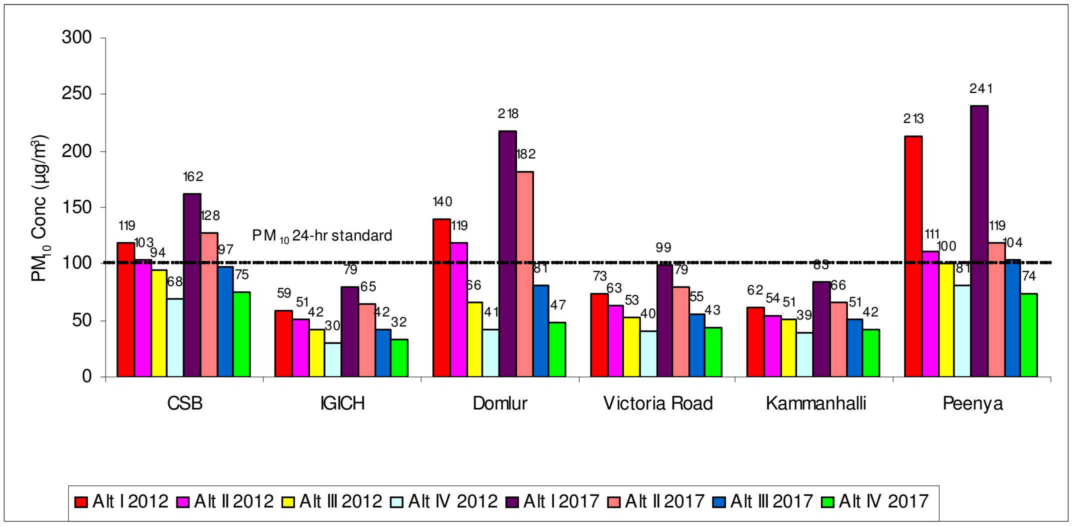


Figure **18** 24-hourly average PM_{10} concentrations (µg/m³) for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the year 2012 and 2017

The predicted 24-hourly highest PM_{10} concentrations for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios at the six air quality monitoring stations in year 2012 ranged from 100 – 267 µg/m³, 87 – 162 µg/m³, 77 – 148 µg/m³ and 55 – 107 µg/m³, respectively. Likewise, in the year 2017, it ranged from 135 – 294 µg/m³, 107 – 229 µg/m³ , 78 – 153 µg/m³ and 60 – 119 µg/m³ for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios, respectively.

Figure 19 indicates the percent reduction of 24-hourly highest PM_{10} concentration at different sites in Bangalore under the Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios w.r.t. BAU scenario for the years 2012 and 2017. It is evident that the PM_{10} ambient concentration reduces by 14-23 % in 2012 and 13-37 % in 2017 under the Alternate – I scenario as compared to BAU of the respective years. The reduction in PM_{10} ambient concentration under the Alternate – II scenario is 27-63 % in 2012 and 28-72 % in 2017 as compared to BAU of the respective years. Likewise, the reduction in PM_{10} ambient concentration under the Alternate – III scenario is 38-66 % in 2012 and 52-74 % in 2017 as compared to BAU of the respective years. Under Alternate –IV scenario, the reduction in PM_{10} ambient concentration is 55 - 72 % in 2012 and 62 - 81 % in 2017 as compared to BAU of the respective years.

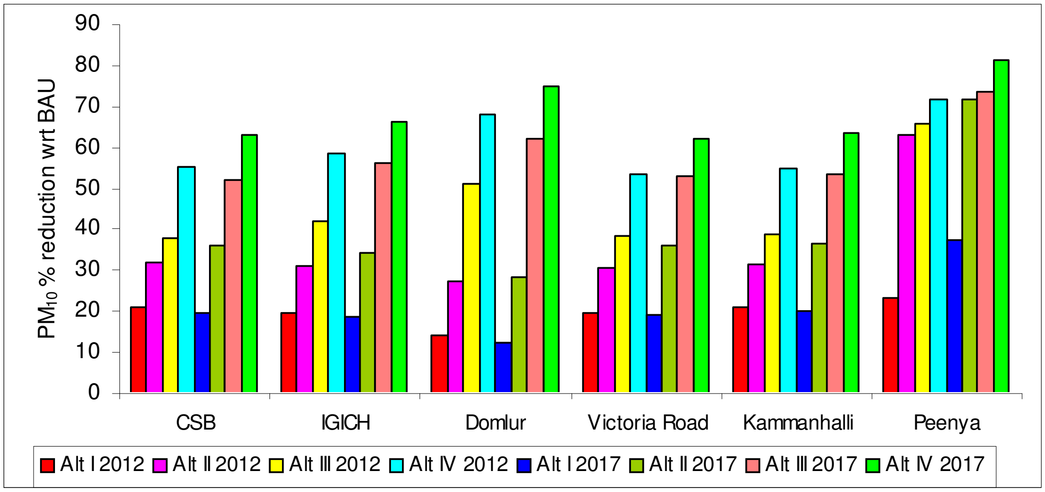


Figure **19** Percent reduction of predicted 24-hourly highest PM_{10} concentration (μg/m³) for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the years 2012 and 2017

Concentration contours for alternate scenarios

As an illustration, the PM_{10} predicted 24 hourly average concentration values during the winter season for Alternate – I, Alternate – II , Alternate – III and Alternate – IV scenarios for the year 2017 are shown in Figure 20, 21, 22 and 23 respectively. It is again seen from the contours that Alternate – I, Alternate – II , Alternate – III and Alternate – IV scenarios do show a significant decrease compared to BAU scenario in the year 2017. Alternate – III scenario shows more reduction in comparison to Alternate-I, and Alternate-II, due to the introduction of fuel efficiency standards in all the vehicles, DOC/DPF installation in all diesel vehicles (buses, trucks and cars) and commercial DG sets. The reduction is highest in Alternate – IV scenario which has additional control options that are more oriented towards meeting the air quality standards e.g., no power cuts and by-passing of trucks.

It is seen that there would be certain localised areas under Alternate-I and Alternate –II scenarios where the ambient air quality would still exceed the 24-hourly residential area standards for PM_{10}. However, in Alternate-III scenario, there is a substantial reduction in the area showing exceedence, and only small pockets in the central hub of the city and Peenya industrial area show exceedence. Finally, in Alternate –IV, the overall air quality in Bangalore improves tremendously and broadly all areas across the city conform to the ambient air quality standards in 2017. Only a very small region (about 1.5 km^2 near the central city areas such as Richmond town and Brigade road) shows marginal exceedence and thus, in this specific region, measures such as restriction of vehicular traffic could be implemented.

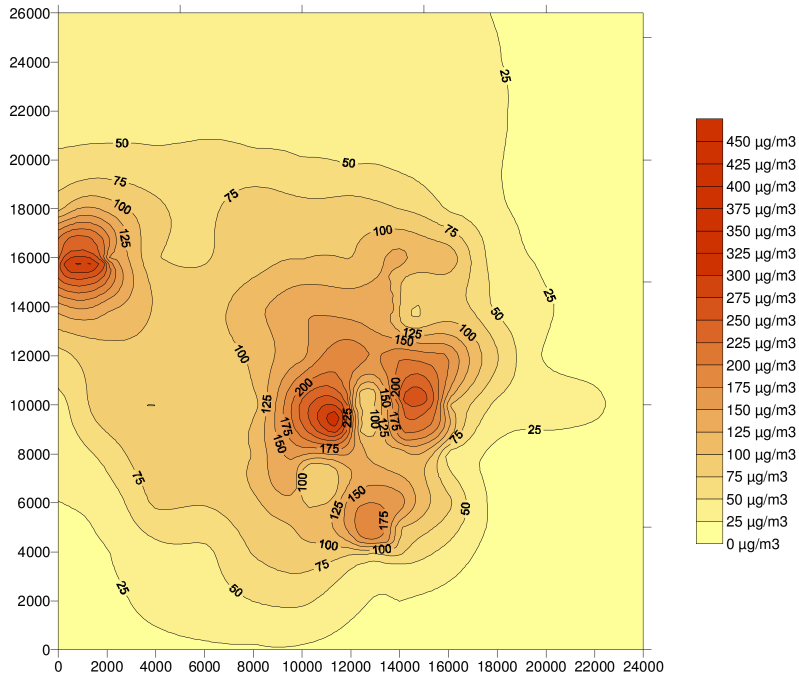


Figure **20** Contours for 24-hourly average PM_{10} concentration ($\mu g/m^3$) for Alternate – I scenario in 2017

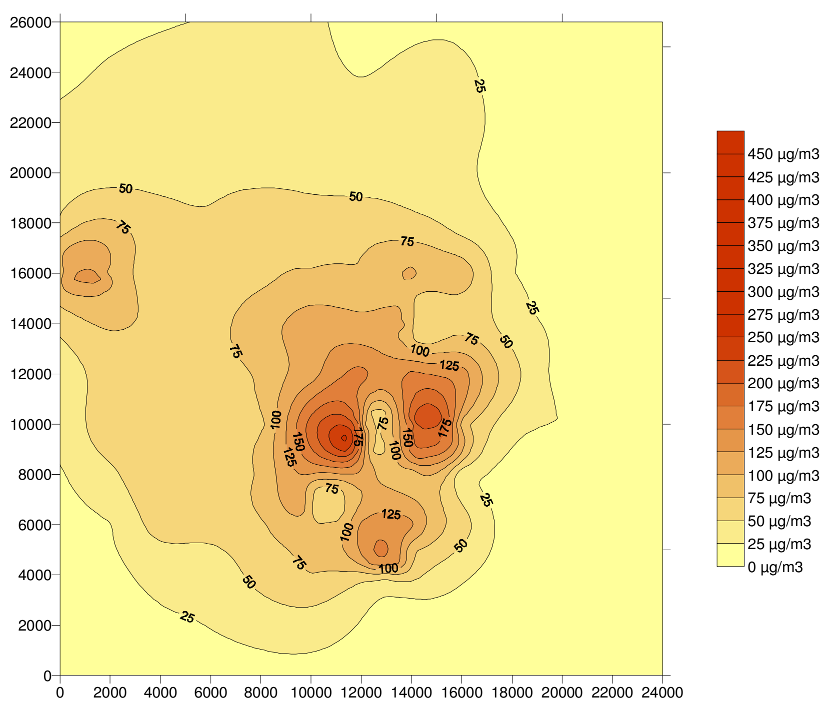


Figure **21** Contours for 24-hourly average PM_{10} concentration ($\mu g/m^3$) for Alternate - II scenario in 2017

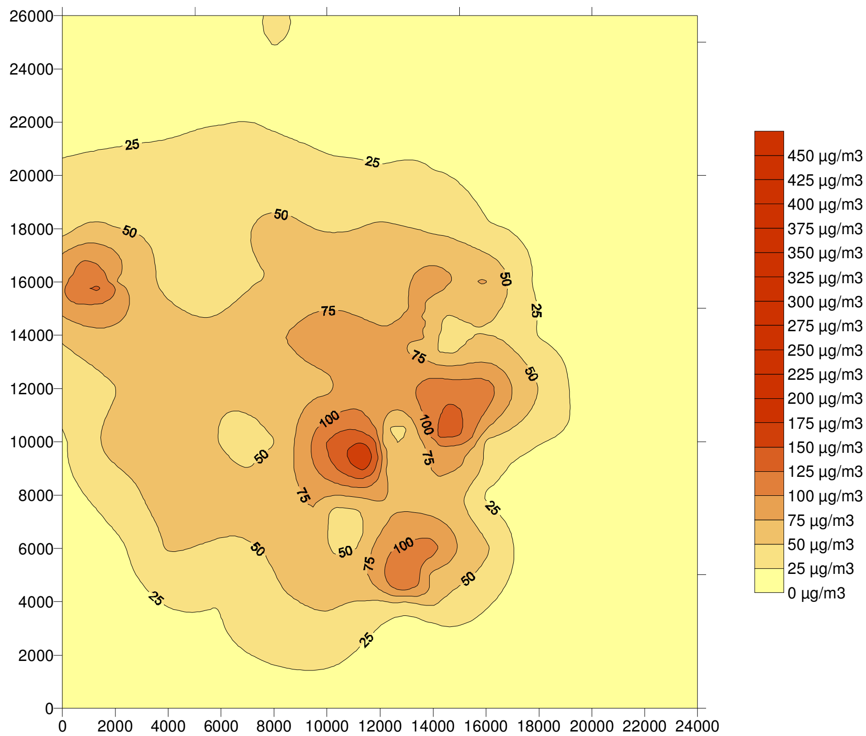


Figure **22** Contours for 24-hourly average PM_{10} concentration (µg/m^3) for Alternate - III scenario in 2017

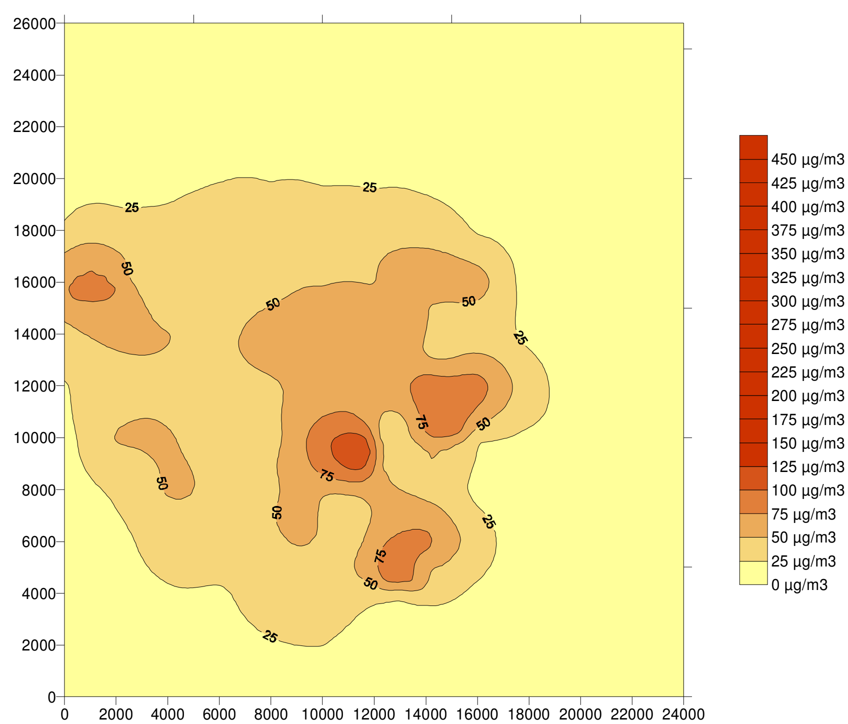


Figure **23** Contours for 24-hourly average PM_{10} concentration (µg/m^3) for Alternate - IV scenario in 2017

Prioritized list of management/control options

Based on emission inventory and receptor modelling approach, the major common sources of PM_{10} are transport and road dust re-suspension. DG sets and industry show significant contributions in different approaches. In addition, due to major construction activities ongoing in Bangalore, construction sector also contributes to the emission load. Therefore, in the case of Bangalore, control strategies need to be devised for transport, road dust re-suspension, industry, DG sets, and soil dust/construction. In addition, CMB8.2 quantification shows secondary particulates as an additional source. The control strategies for primary pollutant like SO_2 and NO_X would results in the reduction of the secondary particulates as well.

Prioritization of control options

For prioritizing the list of management/ control options, an analysis is made of the percentage reduction in the overall emission load as compared to the BAU total emission load in the respective years i.e. 2012 and 2017 (Figure 24).

Under the Alternate-I scenario, the percentage reductions in the various sectors are as follows:

- 2012 : Transport (16.8%), industry (3.6%)
- 2017 : Transport (16.1%), industry (6.2%).

Under the Alternate-II scenario the percentage reductions in the various sectors are as follows:

- 2012 : Transport (18.7%), industry (8.3%), construction (6.3%), road dust (2.6%) and DG sets (1.4%).
- 2017 : Transport (19.4%), industry (11.5%), road dust (6.2%), construction (5.5%) and DG sets (1.9%).

Under the Alternate-III scenario the percentage reductions in the various sectors are as follows:

- 2012 : Transport (16.4%), industry (8.3%), DG sets (7.4%), construction (6.3%), and road dust (2.6%)
- 2017 : Transport (23.0%), DG sets (10.2%), industry (9.8%), road dust (6.2%), and construction (5.5%)

Under the Alternate-IV scenario the percentage reductions in the various sectors are as follows:

- 2012 : Transport (19.6%), road dust (10.8%), DG sets (9.2%), industry (8.3%), and construction (6.3%),
- 2017 : Transport (19.4%), DG sets (12.8%), industry (11.5%), road dust (14.7%), and construction (5.5%)

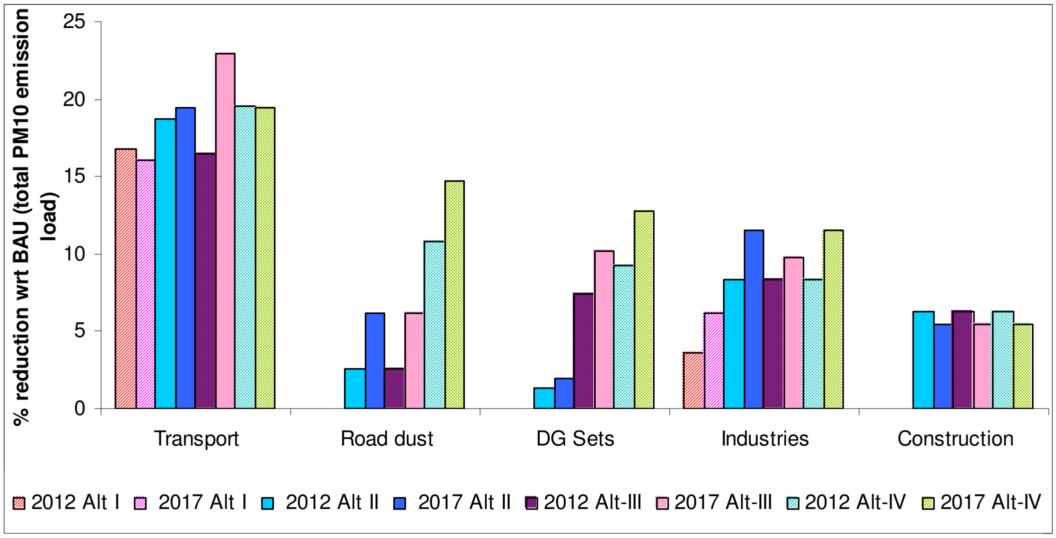


Figure **24** Percent PM_{10} emission load reduction in different sectors under Alternate scenarios as compared to the total pollution load under BAU scenario

Further, within the transport sector, the percentage reduction in the emission load in 2012 by various individual measures as compared to the total load in BAU is as follows:

- 2012 : by-passing of trucks -leading to reduction of exhaust emissions as well as re-suspended road dust (15%), banning of old commercial vehicles (12.2%), installation of DOC-DPF in half of the pre-2010 diesel vehicles (9.1%), inspection /maintenance programme (1.5%), enhancement of public transport based on CNG (1.4%), introduction of CNG in commercial vehicles (1.4%), enhancement of public transport based on diesel (1.2%), introduction of electric vehicles (0.9%), retrofitment of DOC-DPF in public transport buses (0.4%).

Likewise, for the year 2017, the percentage reductions are as follows:

- 2017 : by-passing of trucks -leading to reduction of exhaust emissions as well as re-suspended road dust (13.8%), installation of DOC-DPF to all pre-2010 diesel vehicles (13%), banning of old commercial vehicles (12.5%), introduction of CNG in commercial vehicles (4%), inspection /maintenance programme (2.5%), enhancement of public transport based on CNG (1.7%), enhancement of public transport based on diesel (1.5%), introduction of electric vehicles (1.4%), and synchronisation of traffic signals (1.3%).

Strategies in other sectors have also resulted in significant reduction of PM_{10} emissions.

- No DG set usage (due to no power cuts) leads to reduction of 12.8% in PM_{10} emissions in 2017.
- Installation of DOC & DPF devices in DG sets lead to a reduction of 8.3% in 2017. In addition, I&M programme for DG sets also shows a reduction of 1.9%.
- Wall to wall paving reduces the road dust emissions by 6.2 %, and better construction practices show a reduction of 5.5% in 2017.
- Banning new air polluting industries in the city limits reduces the emissions by 6.2% in 2017. Further, shift of industrial fuel to natural gas shows a reduction of 5.3% while in case of LSHS it is 3.6% in the year 2017.

The prioritised list of key interventions in terms of reduction in total PM_{10} emission loads in 2017 are given in Table 6 and also represented graphically in Figure 25.

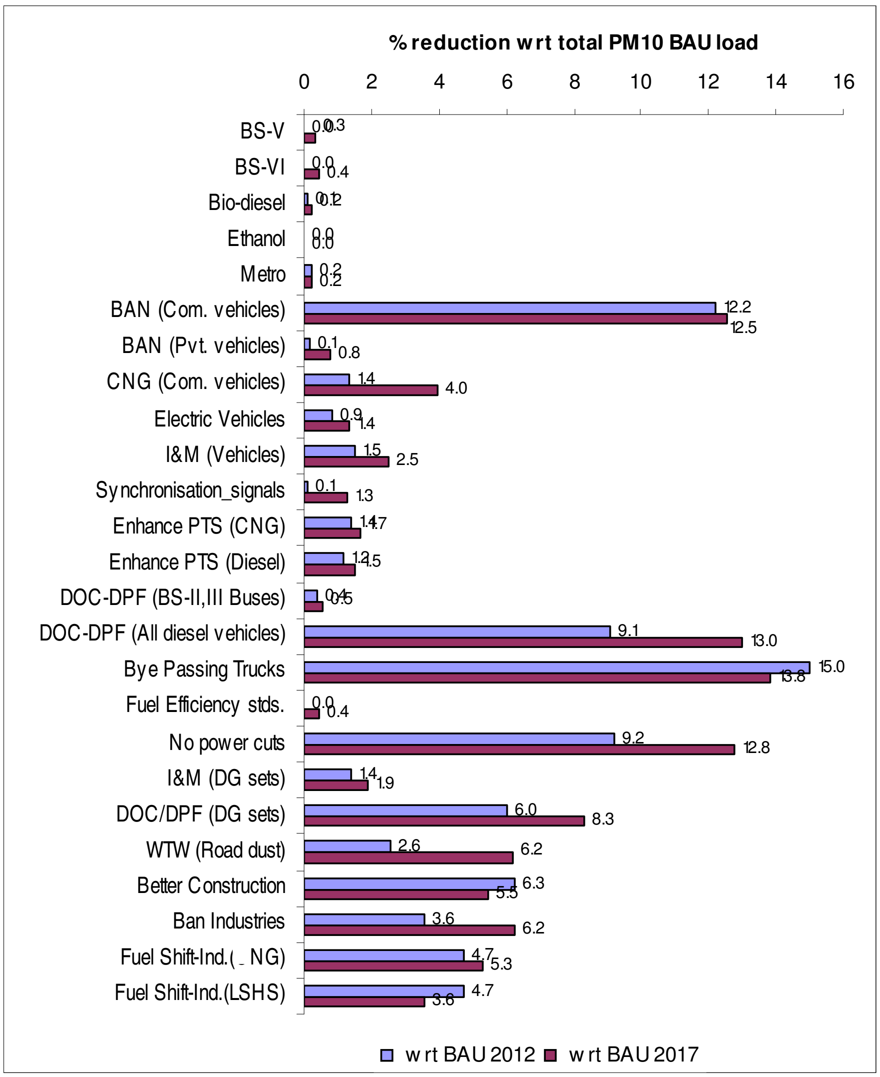


Figure **25** Percent PM_{10} emission load reduction due to various individual interventions as compared to the total pollution load under BAU scenario in the years 2012 & 2017

Table 6 Prioritised list of key interventions in terms of reduction in total PM_{10} emission loads in 2017

S.No	Strategy	% reduction in total PM_{10} emission loads in 2017
1	By-passing of trucks through the proposed peripheral ring road around Bangalore	13.8%
2	Installation of DOC and DPF devices in all pre-2010 diesel vehicles	13.0%
3	No power cuts leading to zero usage of DG sets	12.8%
4	Ban on 10 year old commercial vehicles in 2012 and 2017	12.5%
5	Ban on any new industries in city limits(6.2%) and fuel shift towards cleaner fuel NG (5.3%) in existing industries	11.5 %
6	Installation of DOC and DPF devices in DG sets	8.3%
7	Wall to wall paving for reduction of road dust	6.2%
8	Better construction practices	5.5%
9	Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017)	4.0%
10	Improvement in inspection and maintenance for vehicles	2.5%
11	Inspection and maintenance for DG sets	1.9%
12	Enhancement of public transport system based on CNG (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017)	1.7%
13	Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017)	1.5%

Besides the above strategies, other options such as staggered business timings and no vehicle zones in hot spots would also be helpful in improving the air quality. Fiscal measures such as congestion charges, enhanced parking charges etc. would be helpful in reducing the usage of private vehicles. More importantly, rationalisation of excise duty on vehicles and appropriate fuel pricing policies could play an important role in curbing the growth of more polluting private vehicles. Other measures such as appropriate landuse planning to curb travel demand, enhancing virtual mobility, car pooling etc would contribute to air quality improvements. However, in order to implement many of these strategies, the basic requirement is to have an efficient mass public transport system in place.

Selection of various control options shows an impact in terms of reduction in emission loads eventually translating into reduction of PM_{10} ambient concentrations. The benefits are anticipated in terms of improvements in the ambient air quality at the six ambient air quality stations as well as at the city level thereby leading to improved health and ecological benefits.

Action plan

S.No	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
1	Transport	Strengthening of Public transport system - Metro implementation on schedule - Enhance share of public mass transport system on diesel - Conversion/ enhancement of public transport to CNG	High	Govt of India, State Government, BMRCL (Bangalore Metro rail Corporation Ltd.), Transport Department- Bangalore, BMTC (Bangalore Metropolitan Transport Corporation), GAIL	Medium term	Leveraging the JNNURM funding mechanism for public transportation improvement Public-private partnership models to be explored The metro network needs to be progressively expanded. Bangalore currently does not have a CNG network. There are plans to set up such a network in future. ULSD would also be available by April 2010 in Bangalore. Retro-fitted 2-stroke three wheelers on LPG in Bangalore have higher PM emissions compared to OE 2-stroke/ 4-stroke LPG/Petrol. Thus retro-fitment of 2-stroke 3-wheelers is not an effective control option.
		Ban on old commercial vehicles (10 year) in the city	High	Transport department - Bangalore	Short-term	Fiscal incentives/ subsidies for new vehicle buyers A plan should be devised for gradual phase out with due advance notice. Careful evaluation of socio-economic impact of banning required. In the long run, a ban/ higher tax on private vehicles (> 15 years) could be looked into.
		By-passing of trucks through the proposed peripheral ring road around Bangalore	High	Traffic Police, Transport department	Short-term	Has high potential in reducing the pollutant load in the city
		Progressive improvement of vehicular emissions norms (BS-V, BS-VI)	Low	MoRTH, MoPNG, Ministry of Heavy Industry and Public Enterprises, MoEF, Oil companies, Automobile manufacturers	Medium to Long term	Auto-fuel road map should be developed well in advance to plan the progressive improvement of emissions norms and corresponding fuel quality norms. Though the impact is low, its potential is high in the long term when gradually fleet renewal takes place.
		Installation of pollution control devices (DOC/DPF) in all pre-2010 diesel vehicles	High	Transport department	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction. Retro-fitment of DOC in BS-II buses and DPF in BS-III buses is technically feasible.
		Introduction of fuel efficiency standards	Low	BEE, Ministry of Power, Ministry of Heavy Industry and Public Enterprises, MoRTH, Automobile manufacturers	Medium	Impact is low since it is applied only to new vehicles registered after 2012. However, its potential is high in the long term when gradually fleet renewal takes place.
		Introduction of hybrid vehicles/ electric vehicles	Low - medium	Ministry of Finance, Ministry of Heavy Industry and Public Enterprises, Automobile manufacturers, State	Short-Medium	Appropriate fiscal incentives need to provided; Electric vehicles would be especially effective in high pollution zones. Impact determined by the extent of switchover to hybrid/ electric vehicles.

				government,		
		Effective Inspection and maintenance regime for vehicles	Medium	Transport Department, Traffic police	Short to Medium	Initial focus could be on commercial vehicles; Capacity development in terms of infrastructure for fully computerized testing/certification and training of personnel. Linkage of all PUC centres for better data capture.
		Alternative fuels such as ethanol, bio-diesel	Low	MNRE, MoRD, MoPNG, MoA, Oil companies,	ongoing	There are operational issues regarding availability and pricing that need to be sorted.
		Reduction in private vehicle usage/ ownership		Min. of Finance, State Government NGOs General public	Medium term	A pre-requisite for curbing the growth of private vehicles is the provision of an effective mass based transport system. Strategies such as costlier parking, higher excise duties/sales tax on private vehicles, car pooling would be helpful.
		Improve traffic flow	Medium	Traffic police, Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP),	Short	Synchronization of signals, one way roads, flyovers, widening of roads, removal of encroachments, staggering of office timings to reduce peak flow and congestion. Application of IT tools for traffic management (Intelligent transport system)
		Fuel adulteration	n.a	Govt. of India, Oil companies, Food and civil supplies department- Bangalore	Short	Re-assess subsidy on kerosene, strict vigilance and surveillance actions, better infrastructure in terms of testing laboratories
2	Road dust	-Construction of better quality roads -Regular maintenance and cleaning/sweeping of roads -Reduction in vehicular fleet and trips	n.a	Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP), NHAI	Short - Mediumterm	Effective enforcement of road quality norms is required. Landscaping/ greening of areas adjacent to roads
		Wall to wall paving for reduction of road dust	High	Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP)	Short term	Interlocking tiles may be used so that water percolation takes place.
3	Industries	Fuel shift towards cleaner fuels	High	KSPCB, Directorate of Industries and Commerce, Industry associations, GAIL, Oil companies	Short-Medium term	Shift from solid fuels to liquid fuels (LSHS) and subsequently to gaseous fuels (CNG)
		Ban on any new air polluting industry in city limits	High	KSPCB, Department of Forest, Ecology and Environment, Department of Industries and Commerce, Karnataka Industrial Area Development Board	Short term	Industrial estates/zones may be developed well outside the city
		Strengthening of enforcement mechanism for pollution control	n.a	KSPCB, Industry associations,	Short term	This would ensure greater compliance with standards. In addition, cleaner technology options need to be promoted and appropriate incentives to be defined. Voluntary measures such as ISO certifications to be encouraged.
4	Power/ DG sets	No power cuts leading to zero usage of DG sets	High	Bangalore Electricity Supply Company, Karnataka Power Corporation Ltd.	Medium term	Adequate tie-ups need to be ensured

		Installation of pollution control devices (DOC/DPF) in DG sets	High	KSPCB, DG set manufacturers	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction
		Effective Inspection and maintenance regime for large DG sets	Medium	KSPCB, Chief Electrical inspectorate	Short to Medium	
5	Construction	Better enforcement of construction guidelines (which should reflect Green Building concepts)	High	KSPCB, SEAC (State expert appraisal committee), Bruhat Bengaluru Mahanagara Palike (BBMP),	Short term	
6	Other sectors	Integrated land-use development of Bangalore taking environmental factors into consideration	n.a.	Bangalore Metropolitan Region Development Authority, Bangalore Development Authority, Bruhat Bengaluru Mahanagara Palike (BBMP)	Medium term	Holistic development of the entire region including peripheral areas.
		Open burning/ Waste burning to be discouraged	n.a	Bruhat Bengaluru Mahanagara Palike (BBMP), KSPCB	Short term	Organic matter could be used for compost formation and methane gas generation
		Domestic sector – biomass burning to be reduced	Low	Food and civil supplies department, Oil companies	Medium	Rural areas should be encouraged to shift to cleaner fuels
		Virtual mobility- using ICT information and communication technology	n.a	Department of Information Technology& Biotechnology, Government of Karnataka;	Short-Medium term	Reduced number of trips.
		Strengthening of air quality monitoring mechanism in terms of number of stations as well as pollutants monitored. Capacity building of KSPCB staff.	n.a	KSPCB	Short	Good quality data is an important input in assessing the change in air quality and the impact of policy interventions. Continuous monitoring stations to be promoted.
		Environmental education and awareness activities	n.a	Education department, Schools/Colleges, CBOs, NGOs	Short	Also, sensitization programmes for policy makers.

* Impact is determined in terms of percent reduction in total emission load for PM_{10} for the study period upto 2017 subject to the assumptions listed in chapter 6 (High impact > 5% reduction; medium impact 1-5% reduction; low impact < 1% reduction; n.a = not quantified or not quantifiable). Time frame: Short (upto 2012), Medium (2012-2017)

CHAPTER 1 Introduction

1.1 Background of the study

Growing air pollution is of concern for many urban cities in India and other developing countries around the world. There is considerable evidence that anthropogenic particles at concentrations typical of urban air sheds, directly affect human health. Suspected adverse health effects of even low levels of air pollution have led to increased concern over how air pollution can be best controlled. The development of effective control strategies for PM_{10} and $PM_{2.5}$ air pollution abatement in turn require knowledge of the relative importance of the various sources that contribute to the particulate matter concentrations at ambient air monitoring sites. The auto fuel policy report submitted to Government of India by Mashelkar Committee had identified the knowledge gap in the area of source apportionment. Keeping this in view, oil companies in India in association with premier research institutions initiated work on source apportionment to evolve efficient and feasible solutions to ensure better environment in selected cities, which could be extended to other parts of the country. Subsequently, the Central Pollution Control Board (CPCB) and the Ministry of Environment & Forests (MoEF), Govt. of India took over the programme on source apportionment in various cities in the country. The Govt. of India has constituted a steering committee headed by the Secretary, MoEF and a technical committee headed by the Chairman, CPCB to oversee the above project. TERI has been entrusted with responsibility of carrying out the air quality assessment, emission inventory and source apportionment study for Bangalore.

1.2 General description of city

Bangalore city, which lies in the Bangalore Urban district, is the capital of Karnataka. A study domain of 24x26 km^2 have been considered as per the survey of India map 2002 (Figure 1.1). The study domain for the current work is presented in Figure 1.2.

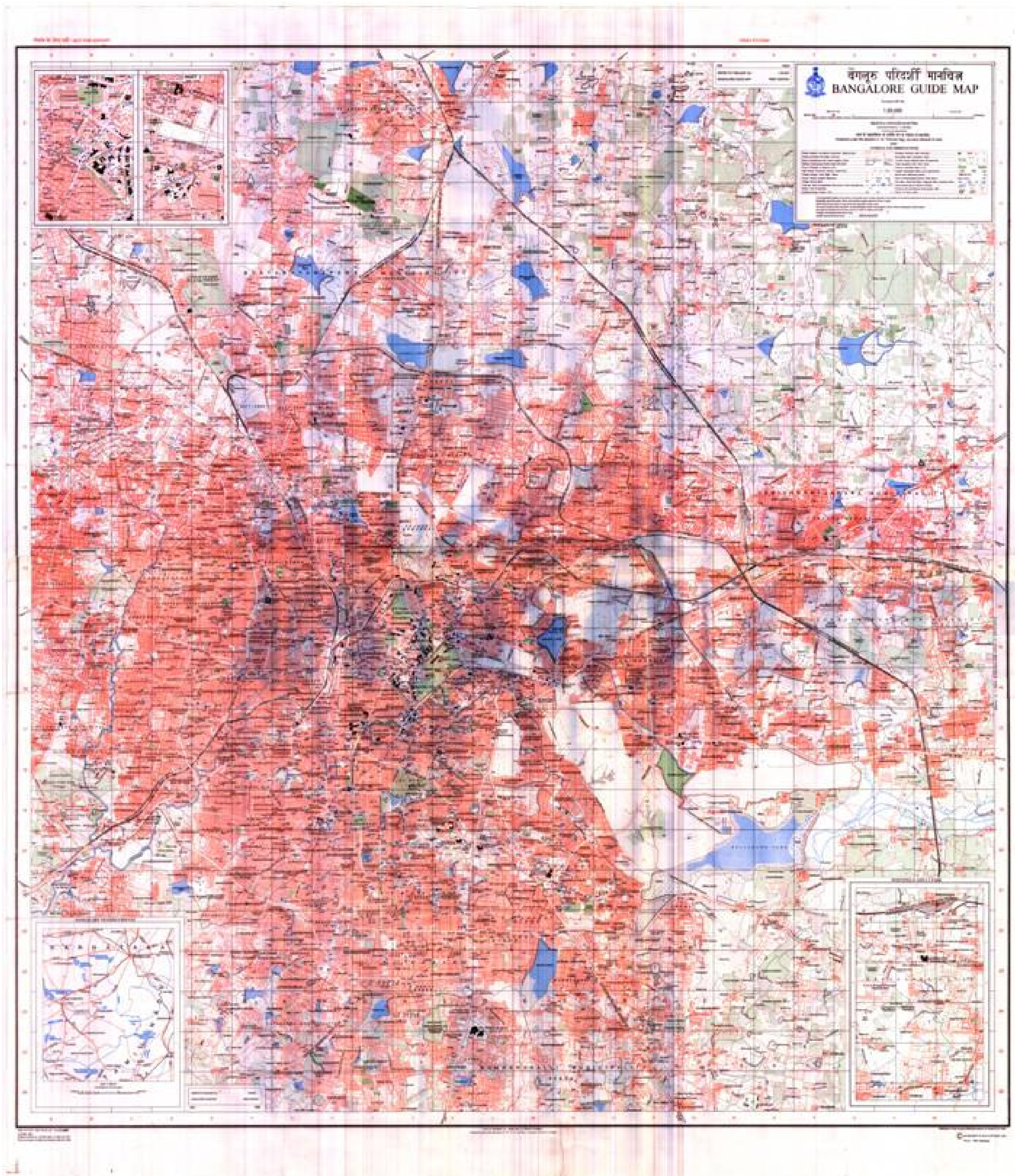


Figure **1.1** Survey of India map for Bangalore city

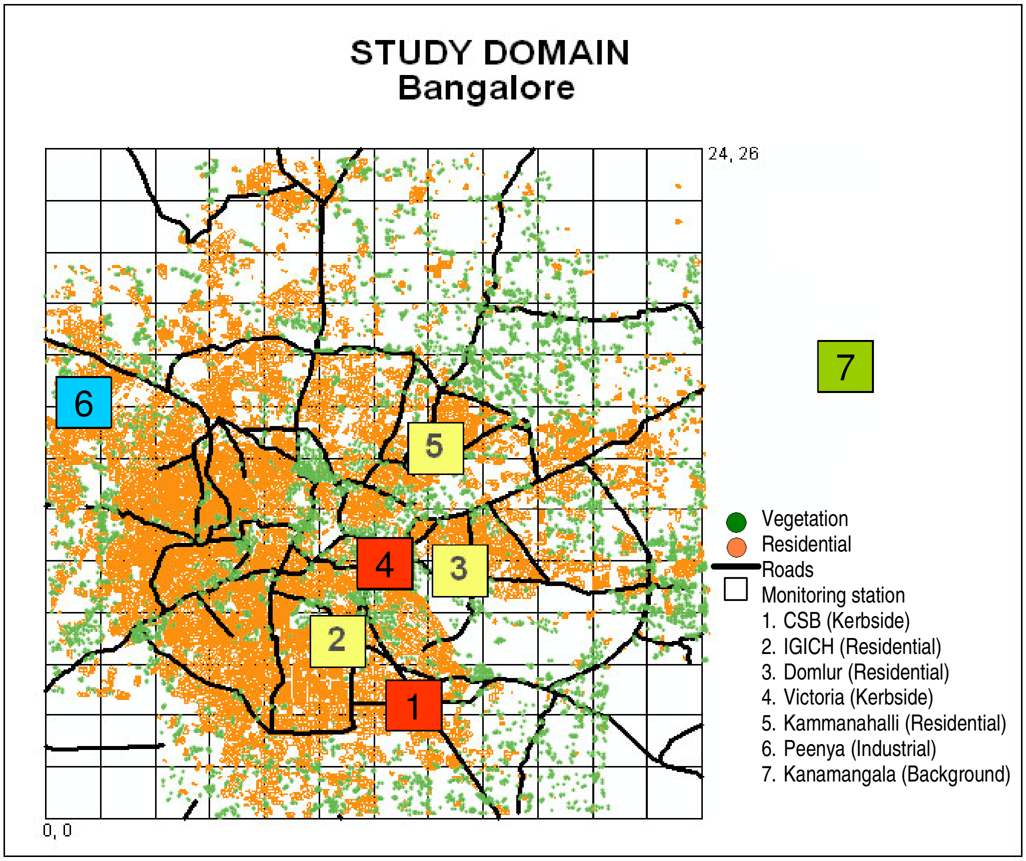


Figure **1.2** GIS representation of Bangalore city

1.2.1Climate

Details about the thirty year average climatological data (1951-1980) have been collected from India Meteorological Department and the same are shown in Appendix –I. It contains monthly averaged data during the above period for temperature, pressure, rainfall, wind speed, wind direction, cloud cover, and visibility.

Climate data suggests that in Bangalore, maximum temperature varies from 25-34 °C, while minimum varies from 15-21°C. There is an average rainfall of about 970 mm per year with nearly 60 rainy days. Average wind speed varies between 7-14 km/h.

1.2.2 Source activities

Bangalore, the capital city of Karnataka, is the fifth biggest city in India with a population of about 5.7 million as in 2001 (Census of India, 2001). This rapidly rising population of Bangalore city demands a whole range of civic services, including the vital transportation facilities. Domestic fuel combustion has been proportionately rising with the rise in population. Though most of the population is using cleaner fuels such LPG or kerosene, still 5% of the population is dependant on firewood for domestic cooking.

More than 21 lakhs of vehicles have been registered by 2005 in the city, majority of which are private vehicles such as two-wheelers and cars. Rise in population demands increase in public transport such as diesel buses and three wheelers. Moreover, to cater to the city demands, movement of heavy vehicles such as trucks and LCVs have also increased. Movement of this huge fleet of vehicles causes emissions of pollutants at low height, which have deteriorating effect over air quality. Also, resuspension of road dust also contributes to the PM emissions due to movement of vehicles over the paved roads.

Bangalore also has a number of industries mainly located in Peenya industrial area. Industries include Textile, Wood, Printing, Leather, Rubber & Plastics, Chemicals, Glass, Metal, Engineering etc. Emissions released from the stacks also contribute to the total emission loads in the city and therefore have implications over the air quality.

DG sets are additional source of pollution because of power cuts. Most of the commercial establishments and some households in Bangalore are dependent on DG sets power for certain duration of day.

Other sources of air pollution in the city include restaurants, hotels, bakeries which burn fuel for cooking purposes. Construction activities across the city also add to the PM emission load.

1.3 Need for the study

Bangalore, the capital of Karnataka, is the principal administrative, cultural, commercial and industrial centre of the state of Karnataka. Over the years it has changed drastically and currently better known as one of the country's major IT city. With economic development, there has been tremendous pressure on ecological resources. Air quality is one of the environmental parameters, which has been negatively influenced by the economic growth of the city. Particulate matter levels at some locations are above the residential areas limits. Deterioration of the air quality in Bangalore can be attributed to rapid increase in population and corresponding fuel combustion activities, which include transport, industrial, and domestic sectors. However, to devise policies to reduce PM levels in the city, there is a need to know the percentage share of each source towards the total PM concentration. Thus, this study has been launched in Bangalore with TERI as an executing agency.

1.4 Objectives and scope of work

The main objectives of the study are:-

1. To measure baseline air pollutants and air toxic levels at different parts of Bangalore, which includes "hot spots " on kerb sides as well.
2. To inventorise various pollutants in Bangalore.
3. To project emission inventories under different control options.
4. To conduct source apportionment study of particulate matter.
5. Preparation of an air quality action plan after prioritising of control options.

1.5 Approach to the Study

A common methodology for the study has been designed by the CPCB for all the executing agencies in the 6 cities. Accordingly, the study in Bangalore has focussed on air quality monitoring, development of emission inventory, dispersion and receptor modelling and finally development of an air quality management plan. The detailed tasks undertaken in each of these aspects are discussed in subsequent chapters. A schematic for the overall approach for the source apportionment study is shown in figure 1.3.

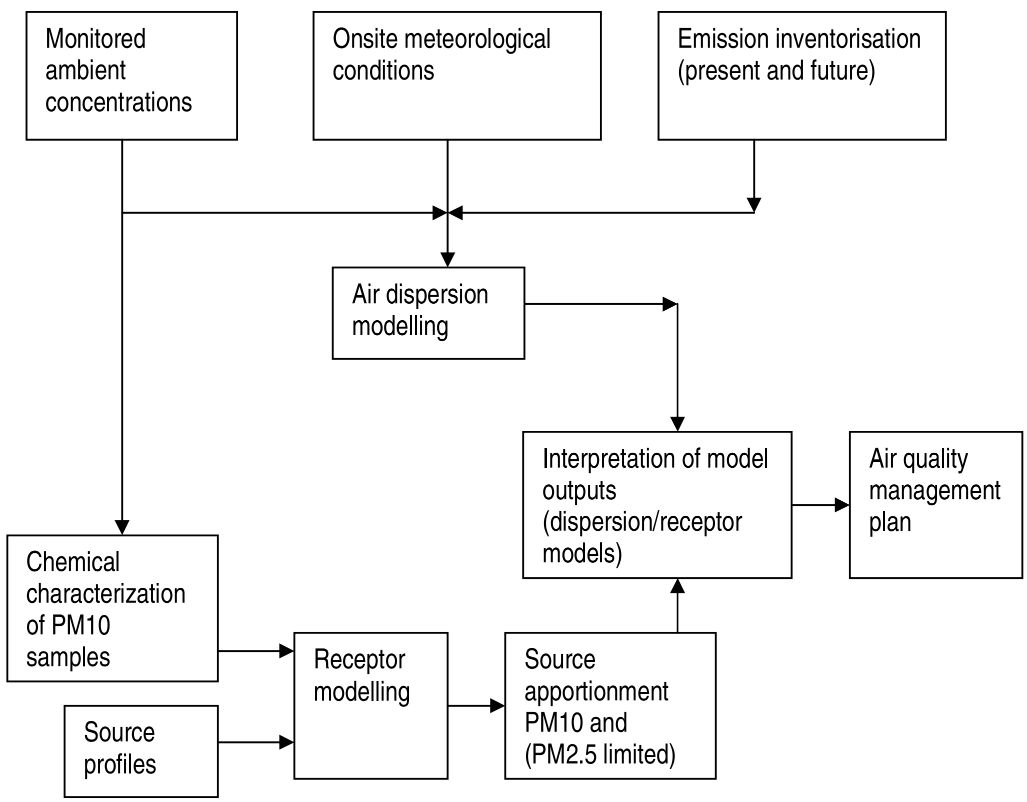


Figure **1.3** Overall approach for the source apportionment study

1.6 Report structure

This report is divided into 7 chapters. Besides the introductory chapter (chapter 1), the 2nd chapter deals with the air quality status at the 7 monitoring sites in Bangalore during the 3 seasons. Chapter 3 deals with the development of emission inventory using both primary survey data as well as secondary data. The emission inventory for various pollutants is developed for the 2×2 km^2 zones of influence around each monitoring sites as well as the entire city. Chapter 4 deals with receptor modelling and its application for source apportionment. Chapter 5 deals with dispersion modelling under the existing scenario while chapter 6 deals with the various emissions control options and its analysis in terms of impact of emission loads. Chapter 7 covers the citywide dispersion modelling for select options for future scenarios, prioritisation of management/ control options and development of an action plan for the control of air pollution.

CHAPTER 2 Air Quality Status

2.1 Introduction

With rise in economic activities in Bangalore, there has been rapid rise in population of the city. Rising population has implications for vehicular growth and other fuel combustion activities. Vehicles have grown over 25 lakhs in 2007, with major contribution from private vehicles. Apart from vehicles, industries, DG sets, domestic fuel burning, road dust re-suspension and construction activities also contribute to deterioration of air quality. SPM and RSPM levels are above the residential standards at some locations. In the recent years, NO_X concentrations have also been rising. However, SO_2 levels have declined and are well within the residential area limits.

2.2 Methodology

Profiling of seven sites

Population density, meteorology, major polluting sources, transport network, topography, etc are the main criteria for the design of air quality monitoring network. In addition, due consideration is given to security aspects as well as availability of power supply while choosing the sites. Representative monitoring sites (7) were selected in such a way that they represent kerbside, residential, industrial, sensitive (hospital), and outskirts (background station).Primary surveys were carried out by the TERI in zone of influence (2x2 sq Km) for the seven sites selected under the project for setting up the air quality monitoring stations. The following sub-sections detail out the characteristics of the selected seven sites .

TERI, Domlur (Residential location)

This residential monitoring location in Domlur located at 12°57’50’’ latitude and 77°38’15’’ longitude as shown in Figure 2.1 and marked as ‘R’.

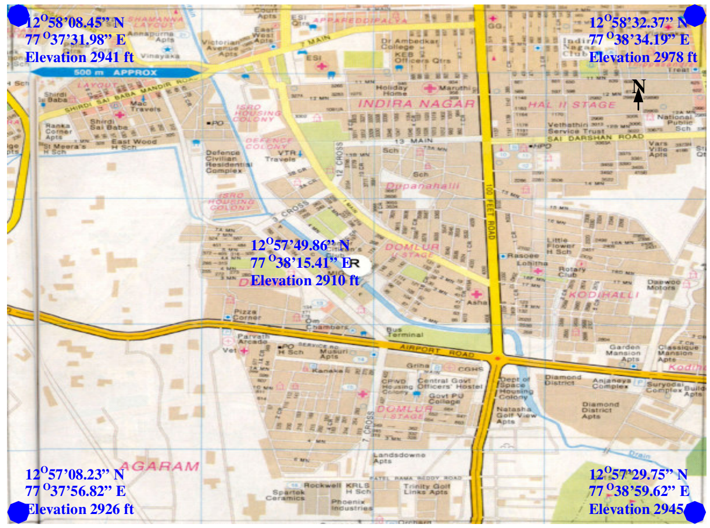


Figure **2.1** Sampling location at Domlur

Teri, Domlur represents a residential location as per CPCB sampling location selection guidelines. In the extensive survey of 2x2 sq km area of this location approximately 55% are observed as independent houses and 45% flats or apartments.

In context of commercial activities, there are majority of shops and showrooms primarily on the airport road, and 100 ft road in Indira Nagar. There are majority of IT related companies located in 2x2 sq km area of sampling point. Also, it is observed that there are number of restaurants, bakeries and few big hotels. IT establishments, shops, hospitals, hotels and some restaurants are using DG sets in case of power failure.

During survey it was observed that 47% were two-wheeler and 34% were cars. Auto-rickshaws were found to be 16% of the total fleet. Heavy vehicles were less than 3%.

Many construction activities for shopping complexes and houses are observed in this area. A water drain is also passing in vicinity of this sampling location.

Kammanahalli (Residential location namely 'R1')

This monitoring site in Kammanahalli was selected as the second residential location. This is located at 13°00'25" latitude and 77°37'46" longitude as shown in Figure 2.2 and marked as 'R1'.

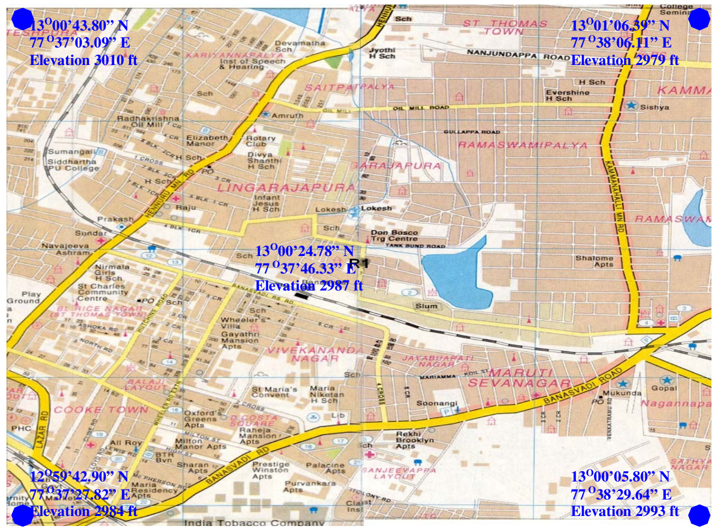


Figure **2.2** Sampling location at Kammanahalli

This densely populated location is selected as residential area for this study. There are about 92% independent houses and only 8% are flats. This area has a majority of houses from the low income profile. 15% of the households have installed DG sets for backup in case of power failure.

In terms of commercial activities, medium and large size shops are observed in zone of influence for this sampling location. DG sets of varying capacity as power backup are also used.

During the survey, it was observed that 57% were two-wheeler and 18% were cars. Auto-rickshaws were found to be 20% of the total fleet. Heavy vehicles were less than 5%.

In primary survey, it was seen that construction activities in this area are more. Few heavy construction activities e.g. flyover and roads, are also observed in 2x2 sq km area of this location.

Victoria road (Traffic location namely 'T1')

Sampling point at Victoria road is selected as one of the traffic location in this study. This is located at 12°58'00" latitude and 77°36'44" longitude as shown in Figure 2.3 and marked as 'T1'.

Figure **2.3** Sampling location at Victoria Road

In this area, there are 48% independent houses and 52% apartments/flats located primarily on down side area of the Richmond road. There are many commercial complexes in this area and it seems to be a heavy commercial activity zone as MG road, Brigade road and Richmond road falls in zone of influence of this site. However, no manufacturing process activity is found in this area. Almost all of these showrooms and shops have installed DG sets of varying capacity for power backup.
Also, it is observed that there are many restaurants, bakeries, and number of big hotels.

This sampling site represents a traffic location. The total road length comprises of 28% as major roads and 72% as minor roads. 11 major traffic junctions are also seen in the vicinity of this location. During survey it was observed that 47% were two-wheeler and 29% were cars. Auto-rickshaws were found to be 19% of the total fleet. Heavy vehicles were less than 5%. Many construction activities are also seen in this area.

CSB (Traffic location namely 'T')

This sampling point at ring road is selected as another traffic location in this study. This is located at 12°55'00" latitude and 77°37'18" longitude as shown in Figure 2.4 and marked as 'T'.

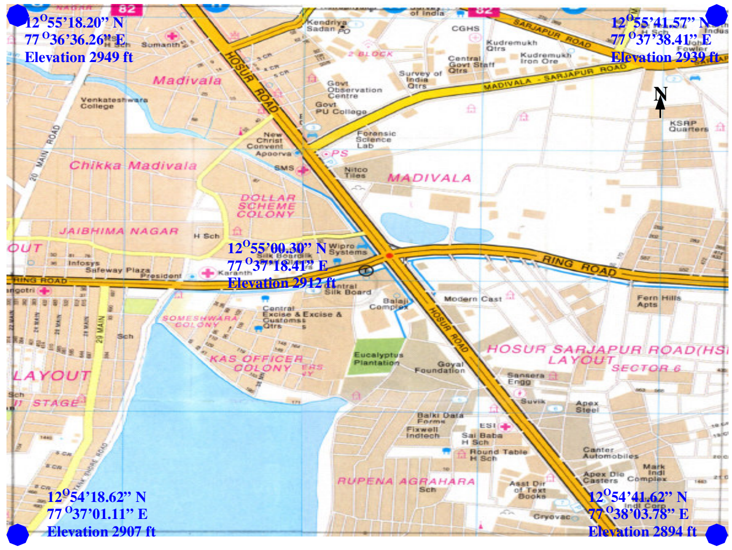


Figure **2.4** Sampling location at CSB

66% of the houses are independent houses in different area categories. Shops and IT companies are primarily located in zone of influence for this site. Few, restaurants, bakeries and eating joints are also there. Shops, IT companies, hospitals, and restaurants have installed DG sets for power backup.

Major and minor roads comprise 28 and 72 %, respectively in the road network for 2x2 sq km area of this site. High volume of heavy-duty diesel (HDD) vehicles plying mainly on Hosur road and ring road is observed for this sampling area. During the survey, it was observed that 14% of the vehicles were heavy-duty diesel vehicles while 46% were two-wheeler and 27% were cars. Auto-rickshaws were found to be 13% of the total fleet. Heavy construction activities (flyover, metro rail) were going on near Hosur road.

IGICH (Hospital/Residential location namely 'S')

Indira Gandhi Institute of Child Health (IGICH) was selected as representation of the hospital/residential area in the city. This is located at 12°56'23" latitude and 77°35'46" longitude as shown in Figure 2.5 and marked as 'S'.

Figure **2.5** Sampling location at IGICH

Independent houses are more in this area comprising of about 66% of the total houses. High, medium and low income group people are resident in these houses.Shops of small and medium scale are observed in this area. Few shops and IT companies have installed DG sets for power backup. This area is primarily covered by hospitals and educational institutions. Few restaurants and bakeries are falling in influence zone of this site.

Road distribution pattern observed for this location is 23% main roads and 77% minor roads. During vehicle count survey, it was observed that 53% were two-wheeler and 22% were cars. Auto-rickshaws were found to be 19% of the total fleet. Heavy vehicles were less than 6%. There were also a few construction activities going on in the area.

Peenya Industrial Area (Industrial location namely 'I')

Peenya industrial area was selected as representation of the industrial area in Bangalore. It is located at 13°01'28" latitude and 77°30'40" longitude as shown in Figure 2.6 and marked as 'I'.

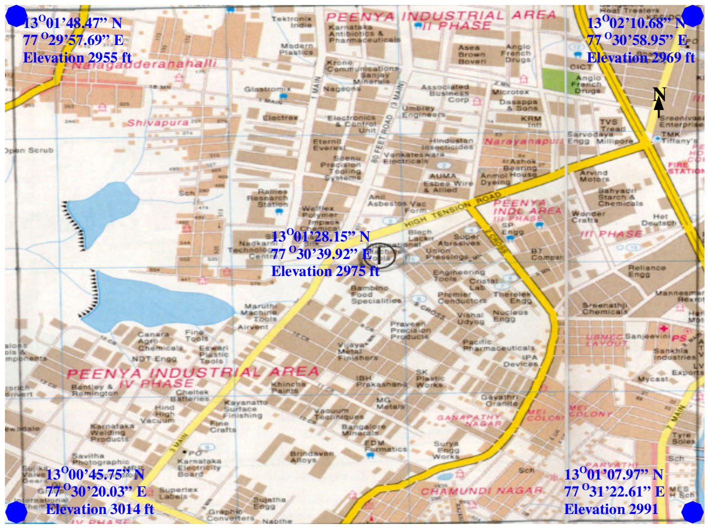


Figure **2.6** Sampling location at Peenya Industrial Area

Nelagadderanahalli area seems to be the only residential locality in 2x2 sq km for this site. 82 % of medium and small scale houses reflect this area as resident of medium and low income category of population. Peenya Industrial Area (PIA) is covered by industries of large, medium and small category. There are about 80% product manufacturing large, medium and small scale industries in this selected industrial location. However, percentage of small scale units is more in the zone of influence for this site. The main types of industries falling in the region include engineering, machine tools, metal smelting, chemicals, and pharmaceuticals. It is also to be noted that more than 70% units have installed DG sets of varying capacity for power backup.

No major traffic junction falls in 2x2 sq km area of this sampling location. However, 31.3% main roads and 68.8% minor roads are observed in zone of influence for this site. Heavy duty diesel vehicles are observed as one of the major types of vehicles plying in the zone of influence for this site and represent about 18% of the vehicle count. 57% were two-wheeler and 14% were cars. Auto-rickshaws were found to be 11% of the total fleet.

Few construction activities for small scale industries are also seen mainly in Peenya IInd stage area in the 2x2 km^2 area for this site.

Kanamangala, Whitefield (Background location namely 'B')

This sampling point representing background location is about 30 km away from the city and is located at 13º02'03" latitude and 77º46'05" longitude as shown in Figure 2.7 and marked as 'B'.

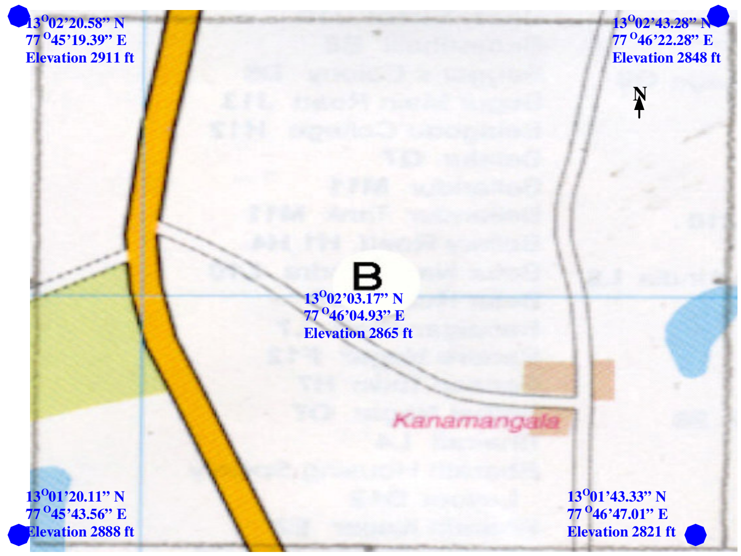


Figure **2.7** Sampling location at Kanamangala (Background location)

This area represents a background location, away from busy traffic and commercial activities of the city. It is located in the upwind direction. Farming/agricultural related activities are the major activities in this area. Eucalyptus plantation, mulberry trees, grains, fruits, vegetables, ground nuts etc. grown on about 70% of the land area falling in zone of influence for this site weights the selection of this site as a background location for this study. 10 % of the land in this area is covered by about 200 houses. 200 houses of low and medium income category people are seen. Few of the households were surveyed to be using biofuels.

There are three minor roads and only one major road in 2x2 sq km area of this location. Movements of tractors and plying of very few public transport buses and heavy duty diesel (HDD) vehicles were also seen in this area.

Two dry lakes and one garden are also seen in 2x2 sq km area of this site. Few construction activities are also observed in vicinity of Kanamangala linked road (minor road).

A summary description of the seven sampling sites in terms of the predominant activities in each of these areas are listed in Table 2.1

Table 2.1 Summary descriptions of the seven sampling sites in terms of the predominant activities

S.No	Site	Site Description	Predominant activity levels
1	Domlur	Residential	- High and medium income category population - Shops, showrooms and IT companies - Number of restaurants, bakeries and few big hotels - Vehicular distribution shows 47% 2-wheelers, 34% cars, 16% auto-rickshaws and 3% heavy vehicles.
2	Kammanahalli	Residential	- Low and medium income category population - Shops of medium scale - Restaurants, bakeries, dhabas and hotels - Vehicular distribution shows 57% 2-wheelers, 18% cars, 20% auto-rickshaws and 5% heavy vehicles.
3	Victoria Road	Kerbside	- Medium and low income category population - Heavy commercial activity zone, many commercial complexes - Restaurants, bakeries, and number of big hotels. - Vehicular distribution shows 47% 2-wheelers, 29% cars, 19% auto-rickshaws and 5% heavy vehicles.
4	CSB	Kerbside	- Mixed Population of all income groups - Shops and IT companies - Few, restaurants, bakeries and eating joints - High volume of heavy-duty diesel (HDD) vehicles - Vehicular distribution shows 46% 2-wheelers, 27% cars, 13% auto-rickshaws and 14% heavy vehicles.
5	IGICH	Hospital (Residential)	- Mixed Population of all income groups - Many hospitals and educational institutions - Shops of small and medium scale - Vehicular distribution shows 53% 2-wheelers, 22% cars, 19% auto-rickshaws and 6% heavy vehicles.
6	Peenya	Industrial	- Only one residential colony with medium and low income group population - Industries falling in the region include engineering, machine tools, metal smelting, chemical, and pharmaceuticals - High volume of heavy-duty diesel (HDD) vehicles - Vehicular distribution shows 57% 2-wheelers, 14% cars, 11% auto-rickshaws and 18% heavy vehicles.
7	Kanamangala, Whitefield	Background	- Plantation in 70% area of zone of influence - 10 % of area covered by about 200 medium income group houses. - Some bio-fuels usage for cooking - Movements of tractors and plying of very few public transport buses and HDD vehicles.

Monitoring Parameters & Framework

Monitoring parameters, sampling instruments, sampling principle, sampling period & frequency, and analytical methodologies are presented in Table 2.2a,b,c.

Table 2.2a Sampling and analytical protocol for source apportionment study being conducted at Bangalore

Particulars	Parameters														
	SPM	RSPM	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	*OC/EC*	Ions	VOC (Benzene and 1,3 Butadiene, Alkanes)	O_3	Aldehyde	NMHC	HC	PAHs (Included in organic Markers)
Sampling Instrument	High Volume Sampler	Respirable Dust Sampler (High Volume Sampler)	Multichannel (3 channel) Speciation Sampler	FRM Partisol ($PM_{2.5}$) sampler	Impingers attached to RDS	Impingers attached to RDS	Online CO analyzer/Low volume sampling pump connected to Tedler bags	PM_{10} Sampler Particulate collected on Quartz filter	PM_{10} 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	Filtration of aerodynamic 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	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	0.8-1.2 m3/min	0.8-1.2 m3/min	16.7 LPM	16.7 LPM	0.5 LPM/ 1 LPM	0.5 LPM/ 1 LPM	1.3 LPM	16.7 LPM	16.7 LPM	0.2 - 0.5 LPM	0.7 LPM	0.5 LPM	0.2 lpm	0.2 lpm	16.7 LPM
Sampling Period	8 hourly change of filter, 24 Hourly Reporting	8 hourly change of filter, 24 Hourly Reporting	24 hourly	24 hourly	8 hourly/4 hourly change of absorbing media, 24 Hourly Reporting	8 hourly/4 hourly change of absorbing media, 24 Hourly Reporting	Continuous sampling	24 hourly	24 hourly	8 Hourly sampling and 24 Hourly Reporting	One week continuous	8 Hourly sampling and 24 Hourly Reporting	Intermittent sampling in 24 hour	Intermittent sampling in 24 hour	Weekly composite of left over Quartz filter after OC/Ec analysis

Particulars	Parameters														
	SPM	RSPM	PM_{10}	$PM_{2.5}$	NO_2	SO_2	CO	*OC/EC*	Ions	VOC (Benzene and 1,3 Butadiene, Alkanes)	O_3	Aldehyde	NMHC	HC	PAHs (Included in organic Markers)
Sampling frequency	20 Days continuous in each season, for three seasons at One location only	20 Days continuous in each season, for three seasons	20 Days continuous in each season, for three seasons	One week continuous. 4 days Teflon, 3 days quartz	20 Days continuous in each season, for three seasons	20 Days continuous in each season, for three seasons	One week continuous during 20 days of monitoring in each season	20 Days continuous in each season, for three seasons	20 Days continuous in each season, for three seasons	Once during 20 days of monitoring in each season	One week continuous during 20 days of monitoring in each season	Once in 20 days of monitoring in each season	One week continuous during 20 days of monitoring in each season	One week continuous during 20 days of monitoring in each season	03 weekly composite samples per season
Analytical instrument	Electronic Balance	Electronic Balance	Electronic Balance	Electronic Micro Balance	Spectrophotometer	Spectrophoto-meter	NDIR based continuous analyser	OC/EC Analyser	Ion Chromatograph	GC-FID	Automatic analyser	Spectrophotometer	GC - FID with Methaniser	GC - FID with Methaniser	GC-MS
Analytical method	Gravimetric	Gravimetric	Gravimetric	Gravimetric	Colorimetric Improved Jacob&Hochheiser method	Colorimetric Modified west&Gake method	IR absorption according to Beer & Lamberts law	TOR Method	Ion Chromatography	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	5 µg/m^3	5 µg/m^3	5 µg/m^3	5 µg/m^3	9 µg/m^3	4 µg/m^3	0.05 ppm	0.5 cm^2 punch		0.1 ppb	2 ppb	1.0 µg/m^3	0.05 ppm	0.05 ppm	1 ng/m^3

Notes: 1. Benzene & 1,3 Butadiene being done by Charcoal adsorption followed by desorbtion in CS2 and GC-FID Analysis. 2. Methodology for molecular marker has been provided separately
3. To suitably split background monitoring into 3 periods so as to correspond to monitoring at other sites 4. CO and O3 monitoring for about 1 week per season

Table 2.2b Target physical and chemical components (groups) for characterization of particulate matter for source apportionment studies at Bangalore

Components	Required filter matrix	Analytical methods
PM_{10} / $PM_{2.5}$	Teflon filter paper. Pre and post exposure conditioning of filter paper is mandatory	Gravimetric
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)	Teflon filter paper	Flame AAS and GT-AAS and Hydride generation for As and Hg, ICP-MS
Ions (F^-, Cl^-, Br^-, NO_2^-, NO_3^-, $SO4^{-2}$, K^+, NH_4^+, Na^+, Ca^{++}, Mg^{++})	Teflon filter paper	Ion chromatography with conductivity detector

Components		Required filter matrix	Analytical methods
Carbon Analysis (OC, EC and Total Carbon)		Quartz filter. Prebaking of quartz filter paper at 600 ºC is essential	TOR method
Molecular markers*			
Alkanes	n- Hentriacontane n-Tritriacontane n- Pentatriacontane		
Hopanes	22, 29, 30 – Trisnorneohopane 17α(H), 21β(H)-29 Norhopane 17α(H), 21β(H) Norhopane		
Alkanoic acid	Hexadecanamide Octadecanamide	The left over quartz filter paper after OC/EC analysis. Pool of 20 days sample as the dust concentration in the filters at some locations were very low.	Extraction, followed by GC-MS/ GC-FID analysis with and without derivatization
PAHs	Benzo[b]fluoranthene Benzo[k]fluoranthene Benzo[e]pyrene Indeno[1,2,3-cd]fluoranthene Indeno[1,2,3-cd]pyrene Phenylenepyrene Picene Coronene		
Others	Stigmasterol Levoglucosan		

* Few molecular markers such as Indeno[1,2,3-cd]fluoranthene, Picene, Hopanes(above 3), Hexadecanamide could not be analysed. 17α(H), 21β(H)-Hopane was analysed instead.

Table 2.2c Other pollutants and their methods of analysis

Pollutants	Methods
SO_2	Spectrophotometric measurement, Improved West & Gaeke Method
NO_2	Spectrophotometric measurement, Jacobs & Hochheiser Method
CO	GC – FID with methaniser / NDIR based continuous analyzer
O_3	Automatic Analyzer, UV Photometric Method
Aldehydes	Spectrophotometric measurement
Benzene	Active sampling in charcoal adsorption, desorption in CS2 and GC-FID determination
1,3 Butadiene	GC - FID Method with suitable sorbent
HC	Sampling in Tedlar Bag followed by GC - FID
NMHC	By difference THC – Methane by GC – FID with methaniser

2.3 QA/QC (Calibration, coding, quality checks, etc.)

Development of standard operating procedures and QA/QC plan

Pilot experiments were conducted in the month of December (12th to 20thDecember 2006) to train the field and research staff and to finalize the standard operating procedures. Sampling data sheets were also prepared. Standard operating procedures for sampling and analysis of various parameters were prepared.

Quality Assurance and Quality Control

Adequate measures have been taken for quality assurance and quality control. Some of these are as follows:

- Regular calibration of equipments (SO_2, NO_2, CO, O_3, GC, IC, carbon analyzer) as per the following frequency
  - Calibration curve for SO_2 and NO_2 has been prepared once in a month with standard solution. One pint calibration check was done once in a day on the day of analysis.
  - Carbon analyzer has been calibrated with internal auto calibration on each day of analysis
  - External calibration for carbon analyzer with pure methane gas has been done once in 6 months
  - Online CO analyzer has been calibrated with CO span gas (11 ppm) and ZERO air in lab before shifting of the equipment to each location
  - Ozone analyzer has been calibrated with inbuilt auto calibration on weekly basis
  - High volume and respirable dust samplers were calibrated with orifice once in a season
  - Electronic balance has been calibrated every day with standard weights
  - Speciation and FRM sampler: leak check, flow audit every day
  - Use of blank filters (lab blank, field blank and also trip blank)
  - Lab blanks (approximately one in 30 filters) were used for blank correction
  - Approximately one field blank and one trip blank per location per season have been used
  - Standard calibration graph for methane analysis using GC has been prepared with 5, 2.5, and 1 ppm methane span gas with dilution.
  - One point calibration check with 5 ppm methane has been done on every day of analysis
  - Multipoint calibration for ion analysis has been done twice in a season

- The multi point ion calibration has been verified twice in a season with multi ions standards of 10 ppm of fluka standard
- In addition one point calibration check has been done on each day of analysis

- Data sheet verification
- Field inspection
- The above measures were also inspected by the QA/QC team from the Central Pollution Control Board during the 1st week of June 2007.

Summary of blank corrections is shown in Table 2.3

Table 2.3 Difference (mg) in post and pre-weights of lab blanks for different batches of filters used in the 1st season

S.No	Lab blanks
1	0.00027
2	0.00086
3	0.00431
4	0.00078
5	0.00037
6	0.01057
7	0.01013
8	0.00234
9	0.00107

In addition, field and trip blank values have also been noted.

2.4 Monitoring results

Monitoring results for various monitoring locations are presented in the following section

Domlur (Residential)

Figure 2.8 shows that average SPM, RSPM and PM2.5 concentrations have remained under the standards in all the three seasons. However, SPM/RSPM have shown violation during few days.

SO_2 and NO_2 have remained under the standards in all the seasons. CO concentrations have violated the standards in some instances. O_3 concentrations have violated the proposed CPCB standard during most days especially in second season (summer). CO and O_3 show consistent diurnal variation during all the days.

Kammanahalli (Residential)

SPM and RSPM concentration have violated the standards during first and second season, while PM2.5 concentrations have remained under the standards in all the three seasons. SO_2 have remained under the standards in all the three seasons. NO2 concentrations have violated the standards on few days during third season. CO concentrations have violated the standard during second season. O_3 concentrations have violated the proposed CPCB standard during many days in second & third season. CO and O_3 show consistent diurnal variation during all the days as shown in Figure 2.9.

CSB (Kerbside)

As shown in Figure 2.10, SPM, RSPM, and PM2.5 concentration have violated the standards during many days across the three seasons. SPM concentrations were highest during third season. Average RSPM values were close to the standard in the first season and were slightly above the standard in the third season.PM2.5 values were above the proposed CPCB standard in the first season.

SO_2 have remained under the standards in all the three seasons. NO_2 concentrations have violated the standard in the first season. CO concentrations have violated the standard during second season. Being a kerbside location, O_3 concentrations have remained below the proposed CPCB standard during all the seasons. CO and O_3 show consistent diurnal variation during all the days.

Victoria road (Kerbside)

SPM and RSPM concentration have violated the standards consistently during all the three seasons.PM2.5 too violates the proposed CPCB standard during the first season.

SO_2 have remained under the standards in all the three seasons. NO_2 concentrations have violated the standards during the second season. CO concentrations have violated the standard during first season. Being a kerbside location, O_3 concentrations have remained below the proposed CPCB standard during all the seasons. CO and O_3 show consistent diurnal variation during all the days as shown in Figure 2.11.

IGICH (Hospital/ Residential)

Figure 2.12 shows that SPM concentration were high during many days in the first season. However, on an average, all the three pollutants (SPM, RSPM, and PM2.5) have remained below standards during all the seasons.

SO_2 have remained under the standards in all the three seasons. NO_2 concentrations have violated the standard only during the third season. CO concentrations have violated the standard during first and third season. Average O_3 concentrations have violated the standard during the second (summer) season. Also, during the first season, few days show violation of the proposed CPCB standard. CO and O_3 show consistent diurnal variation during all the days.

Peenya (Industrial)

SPM concentration have violated the daily standard consistently in the first and second season. RSPM has also violated the 24 hourly residential ambient air quality standard during the first season. PM2.5 levels were below the standard in all the seasons.

SO_2 have remained under the standards in all the three seasons. NO_2 concentrations have violated the standard mainly during third season. CO concentrations have violated the standard during second and third season. O_3 concentrations have violated the standard on few days in all the seasons, however the average O_3 values remained below the standard. CO and O_3 show consistent diurnal variation during all the days as shown in Figure 2.13.

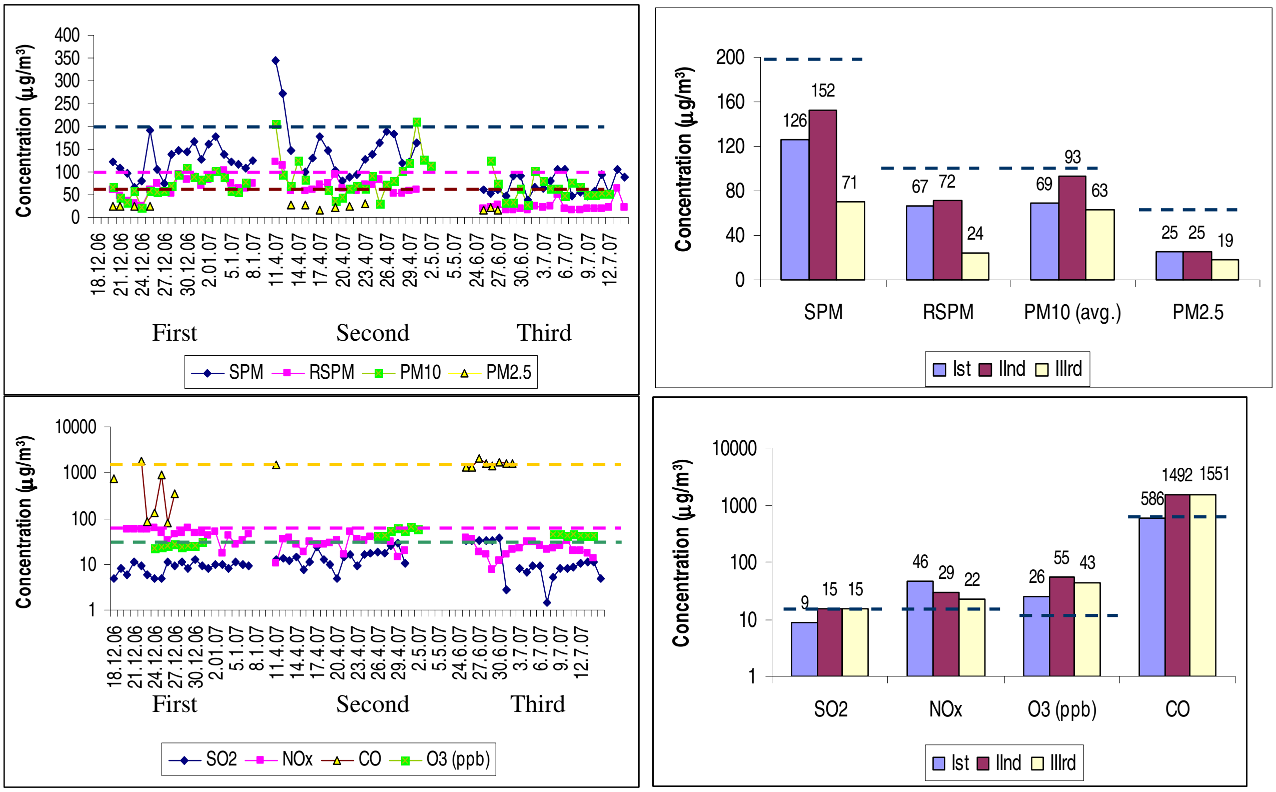
Kanamangala(Background)

As depicted in Figure 2.14, SPM, RSPM, and PM2.5 concentration have remained well below the limits during all the seasons.

SO_2 have remained under the standards in all the three seasons. NO_2 concentrations have violated the standard consistently during the third season. CO concentrations have remained below the standard during all seasons. Being a location in outskirts of the city, O_3 concentrations have been high, especially in second and third seasons. CO and O_3 show consistent diurnal variation during all the days.

Figure 2.8 : Air quality monitoring results for Domlur (Residential)

* NO_2 reported as NOx



For uniform depiction purpose 8-hourly O_3 values are averaged for each day

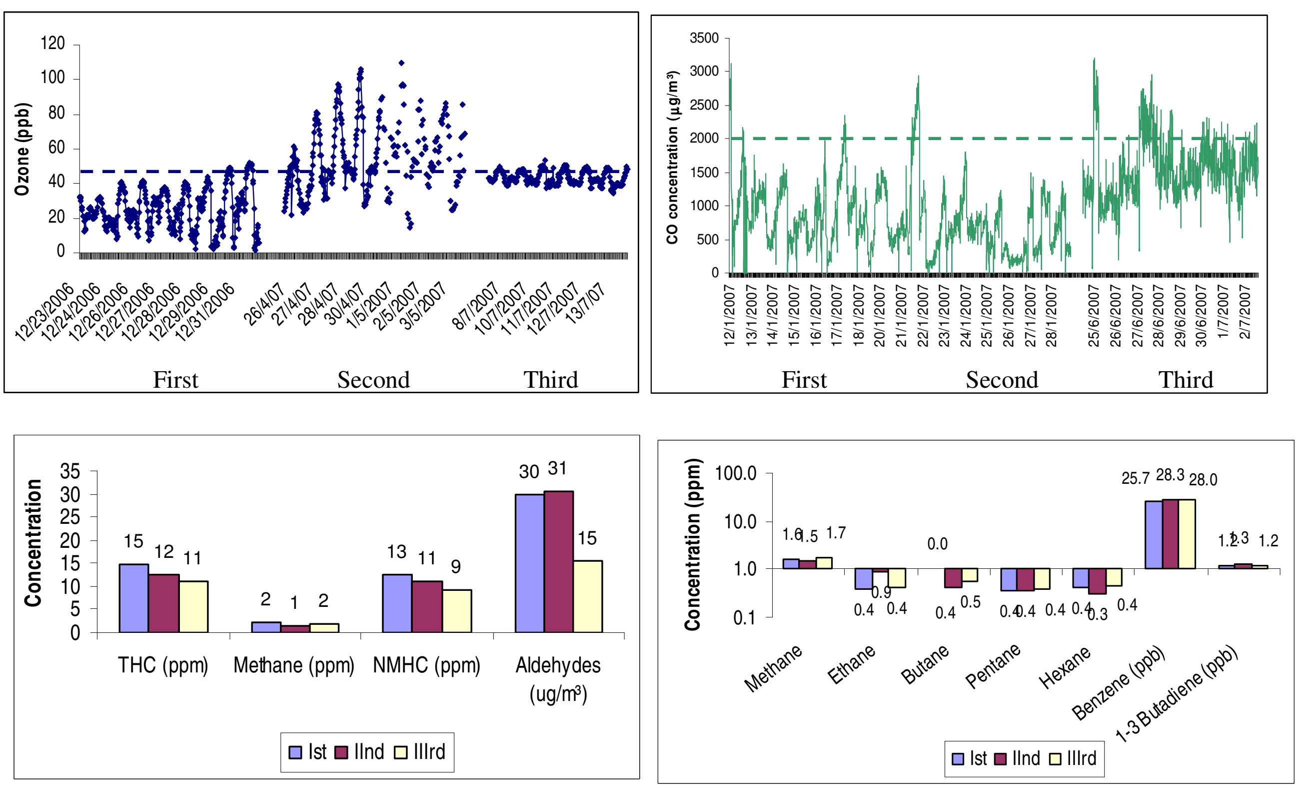
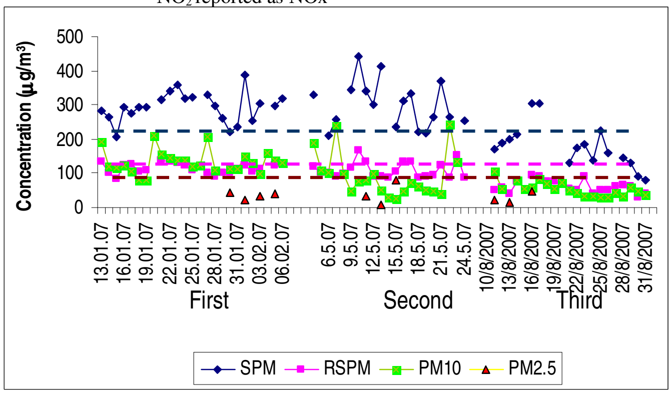
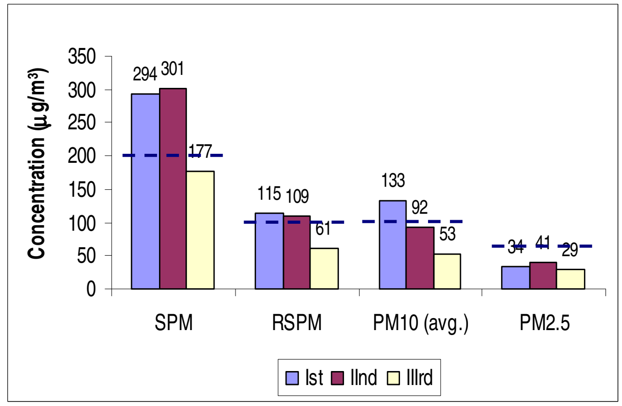
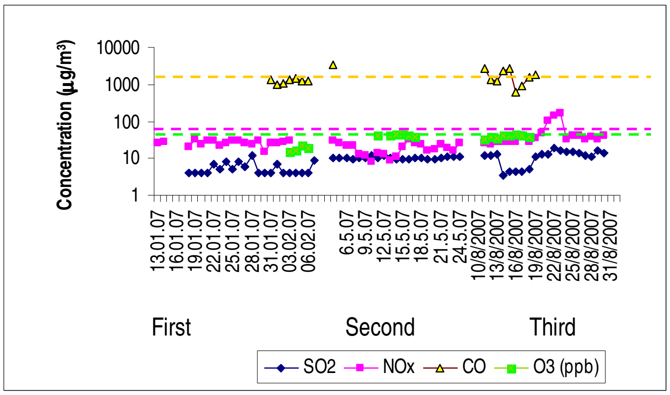


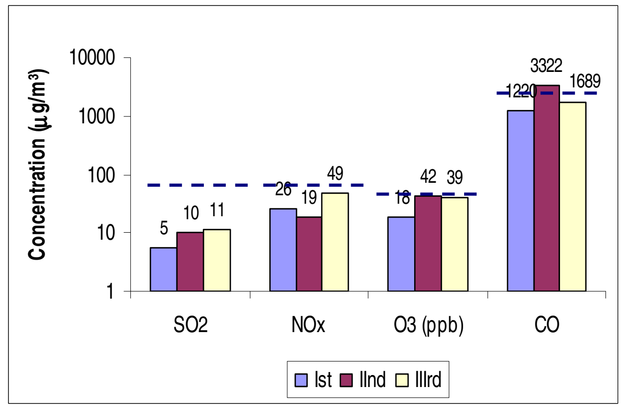
Figure 2.9: Air quality monitoring results for Kammanahalli (Residential)

* NO_2 reported as NOx

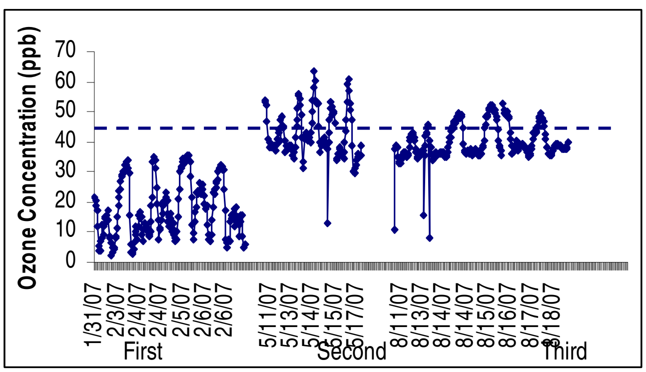


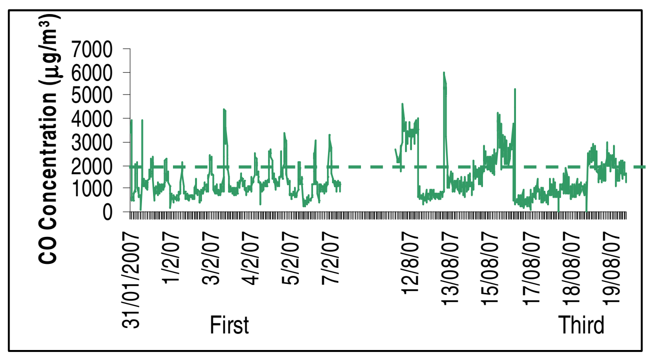




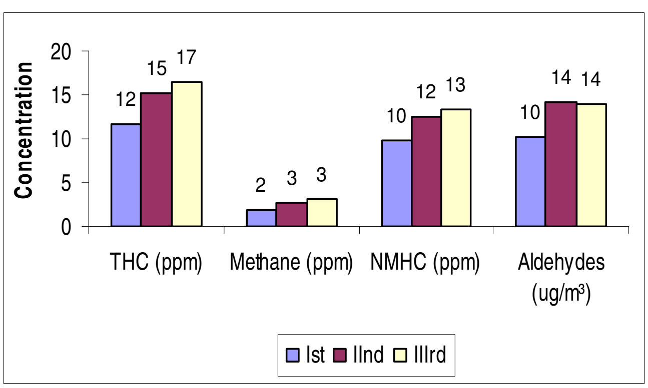


For uniform depiction purpose 8-hourly O_3 values are averaged for each day





Second season continuous data for CO not available



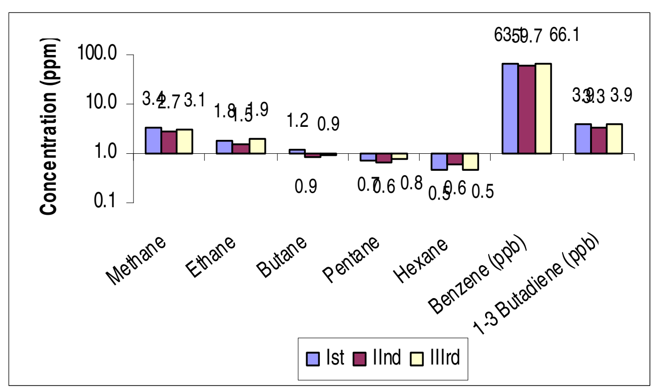


Figure 2.10: Air quality monitoring results for CSB (Kerbside)

* NO_2 reported as NOx

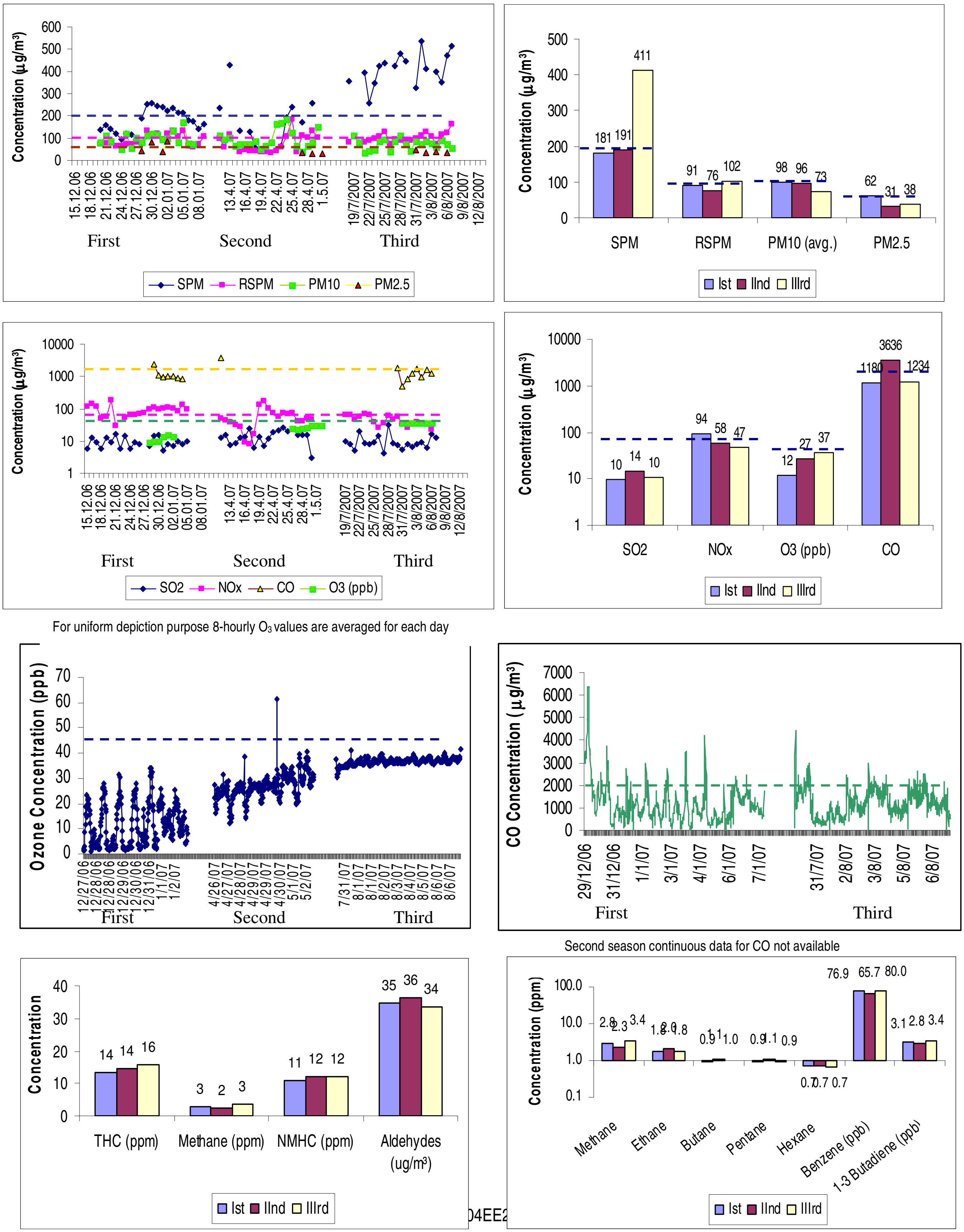


Figure 2.11: Air quality monitoring results for Victoria Road (Kerbside)

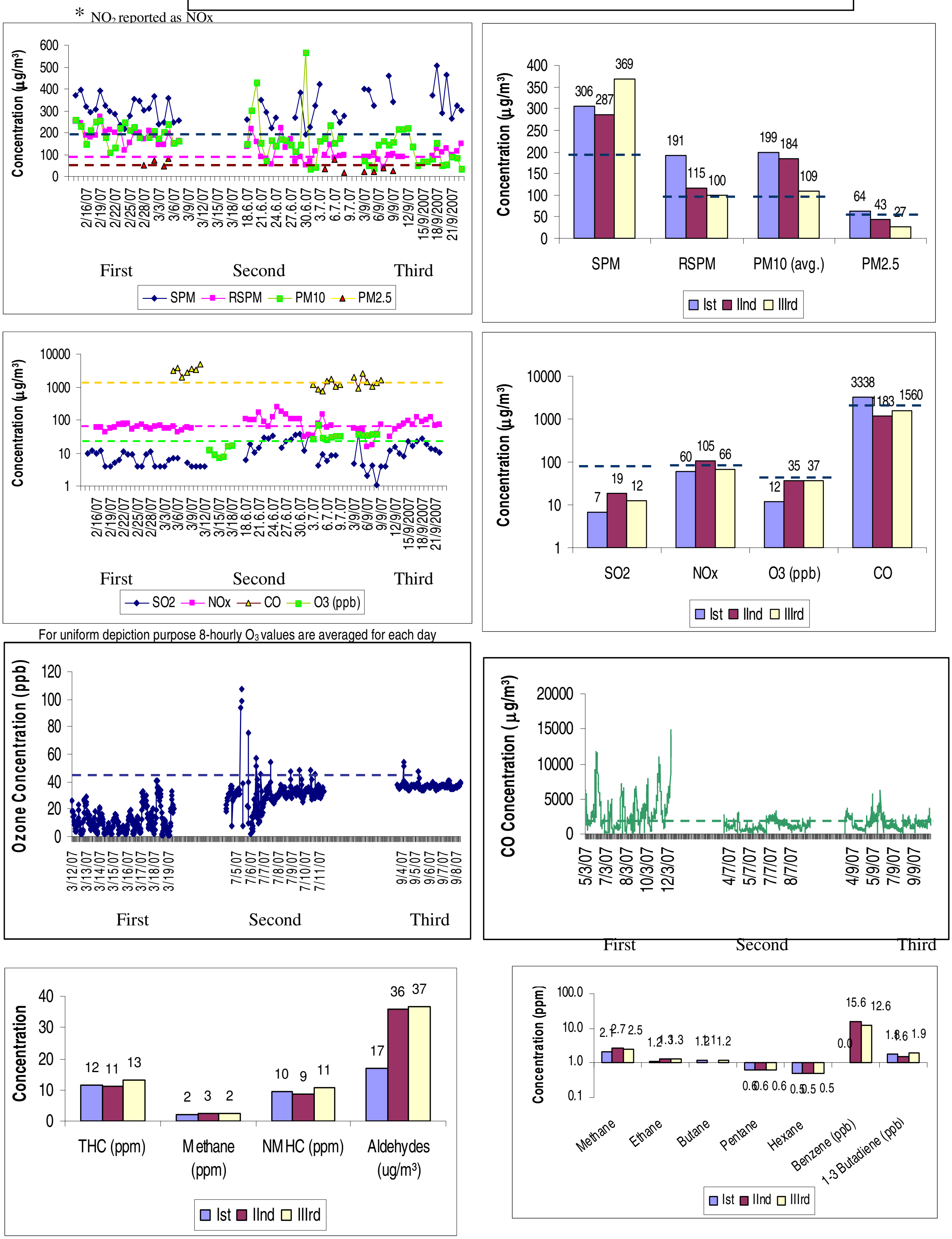


Figure 2.12: Air quality monitoring results for IGICH (Hospital/Residential)

* NO_2 reported as NOx

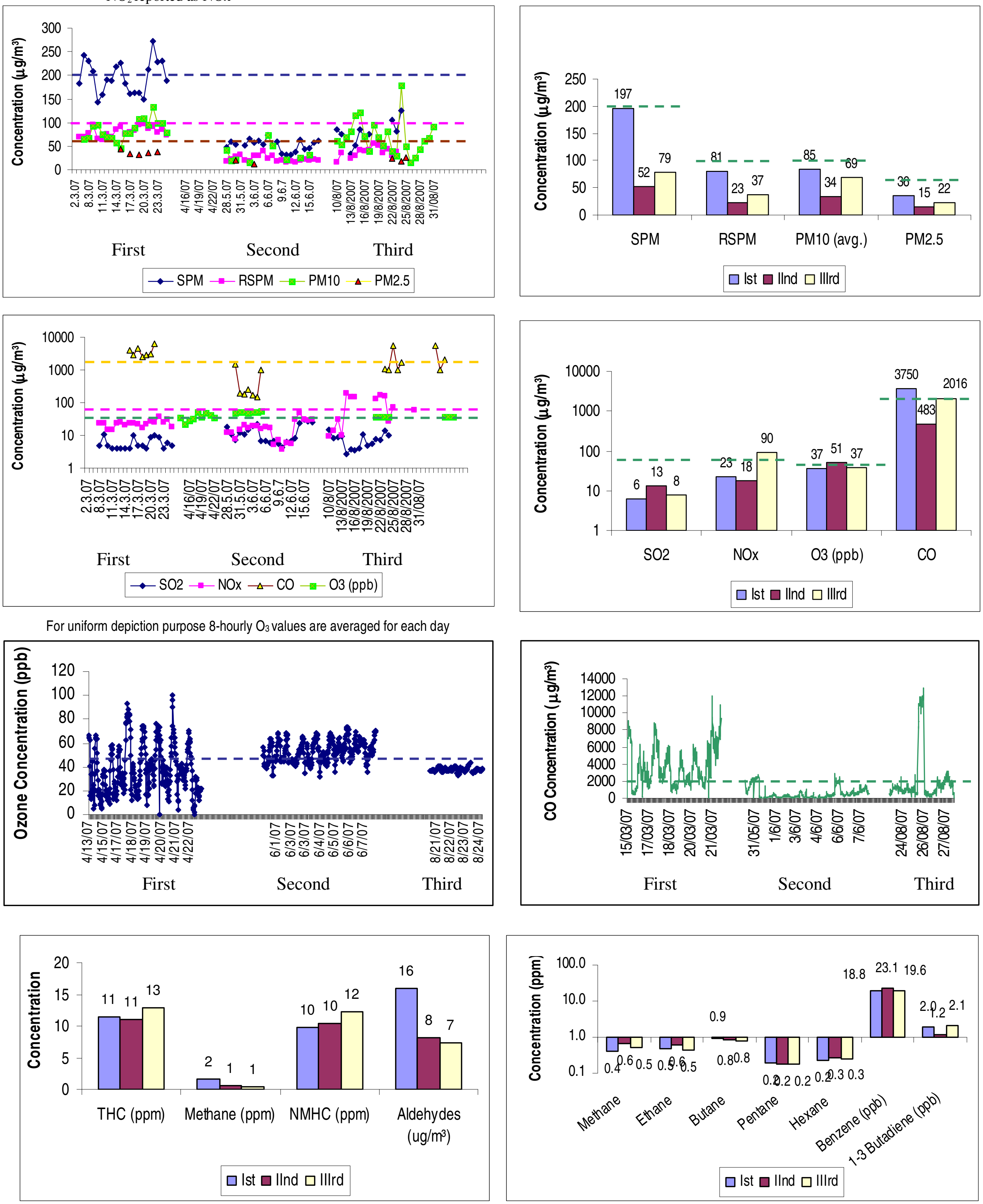
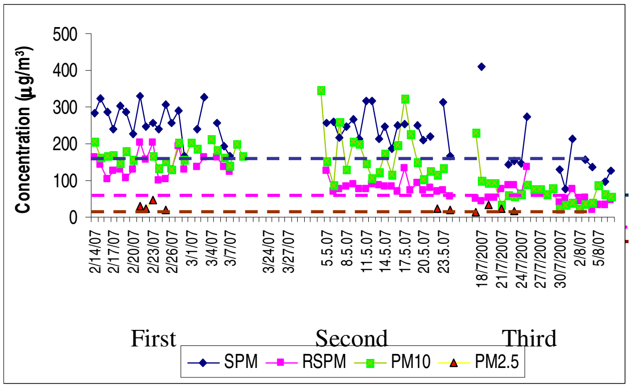
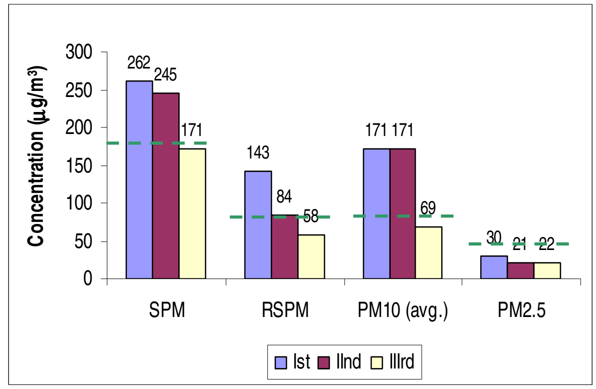
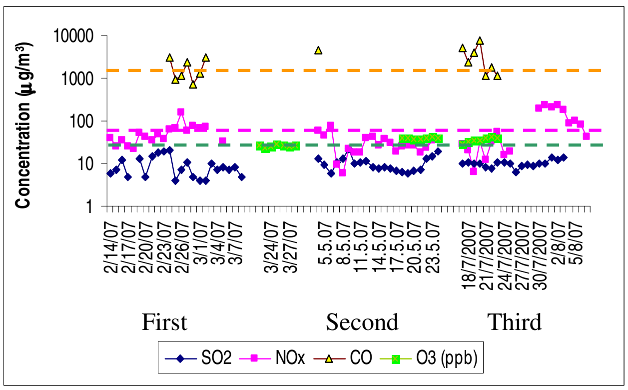


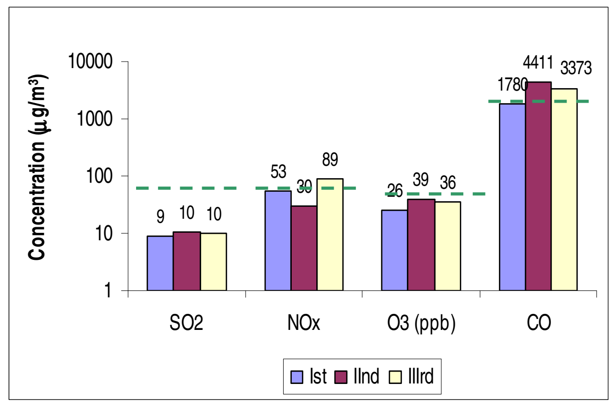
Figure 2.13: Air quality monitoring results for Peenya (Industrial)

* NO_2 reported as NOx

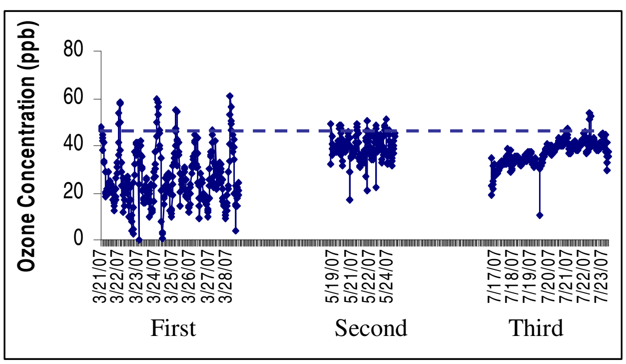


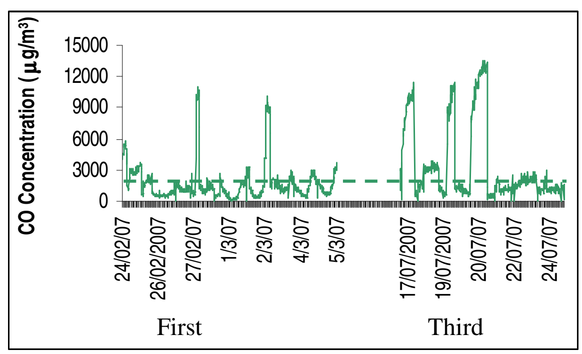




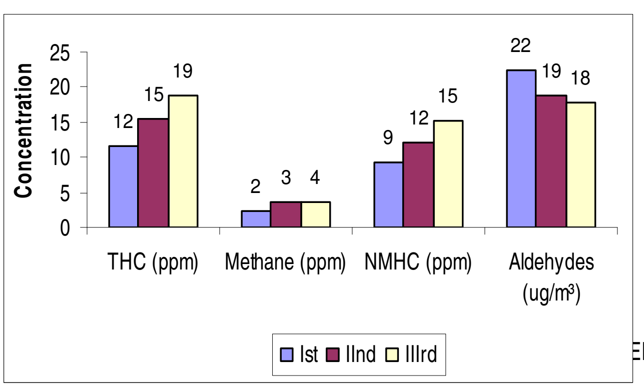


For uniform depiction purpose 8-hourly O_3 values are averaged for each day





Second season continuous data for CO not available



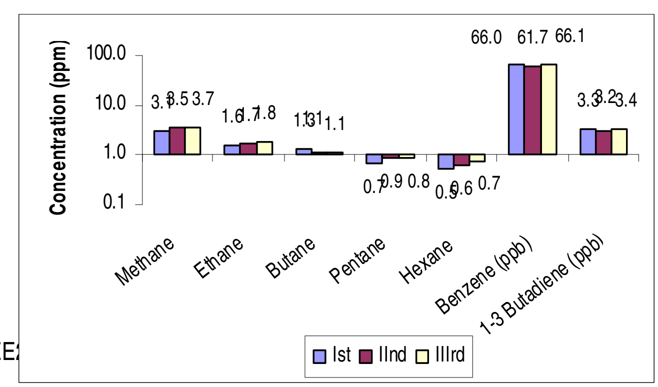
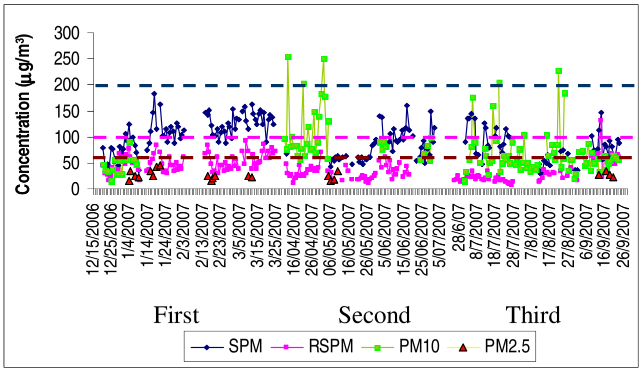
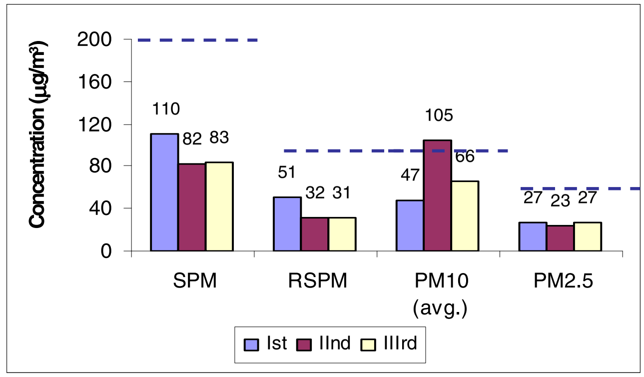
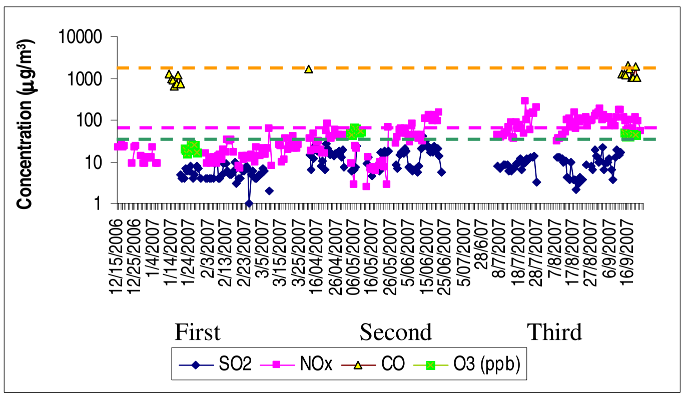


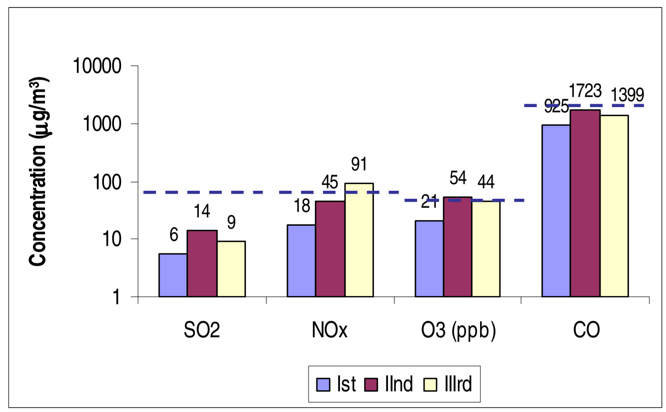
Figure 2.14: Air quality monitoring results for Kanamangala (Background)

* NO_2 reported as NOx

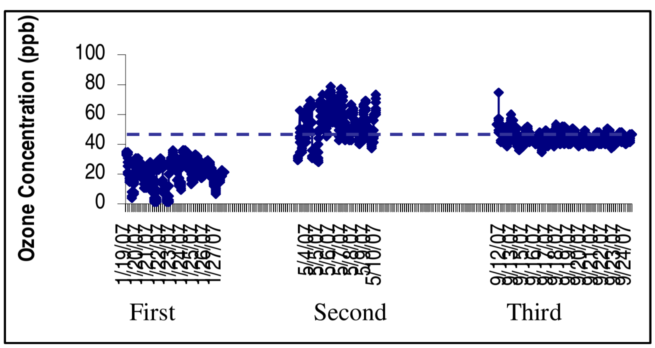


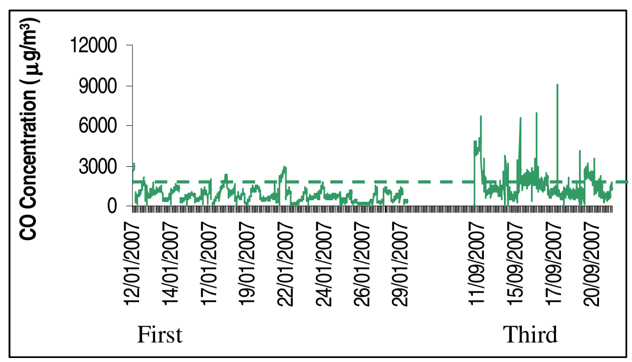




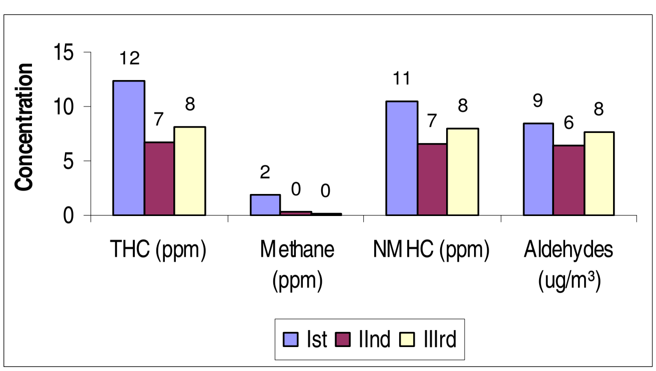


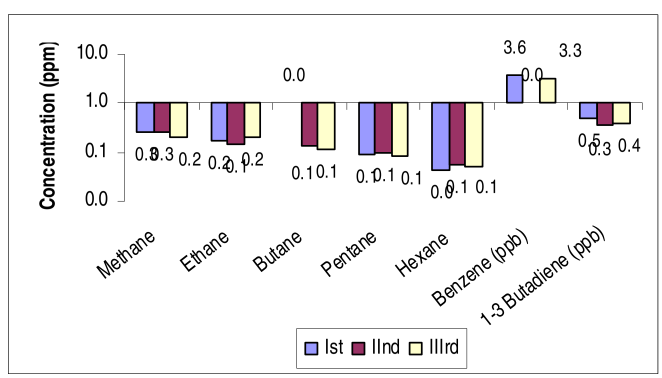
For uniform depiction purpose 8-hourly O_3 values are averaged for each day





Second season continuous data for CO not available





Summary – 3 season results

Average values for all the three seasons for different locations are presented in Figure 2.15 . Being the kerbside location, Victoria road and CSB have shown maximum SPM and RSPM concentration. However, industrial location, Peenya, and one of the residential location, Kammanahalli, also show high values.

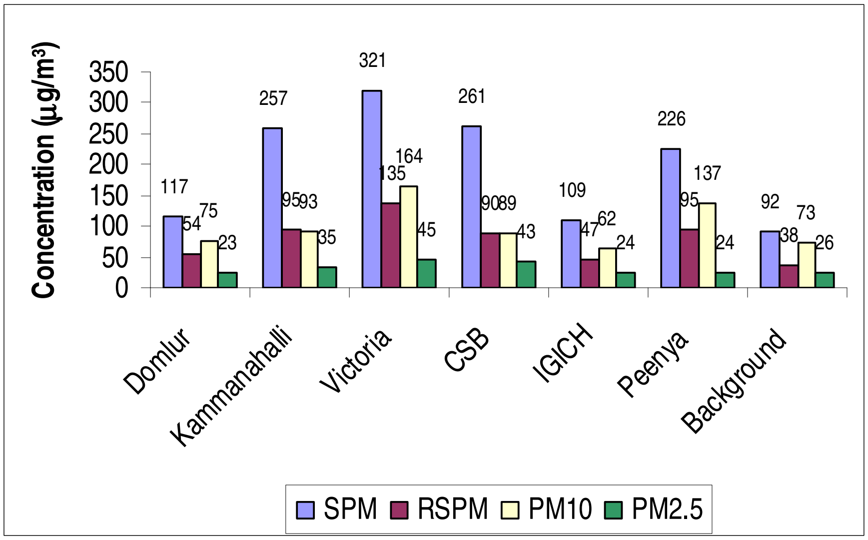


Figure **2.15** Average concentration of SPM, RSPM, PM_{10}, $PM_{2.5}$ during three seasons

SO_2 values are within the limits; NO_2 values are close to the standard at kerbside locations. O_3 concentrations are within the limits though very close to the proposed CPCB standard at some locations. CO concentrations violate the limits except at Background and Domlur location as shown in Figure 2.16.

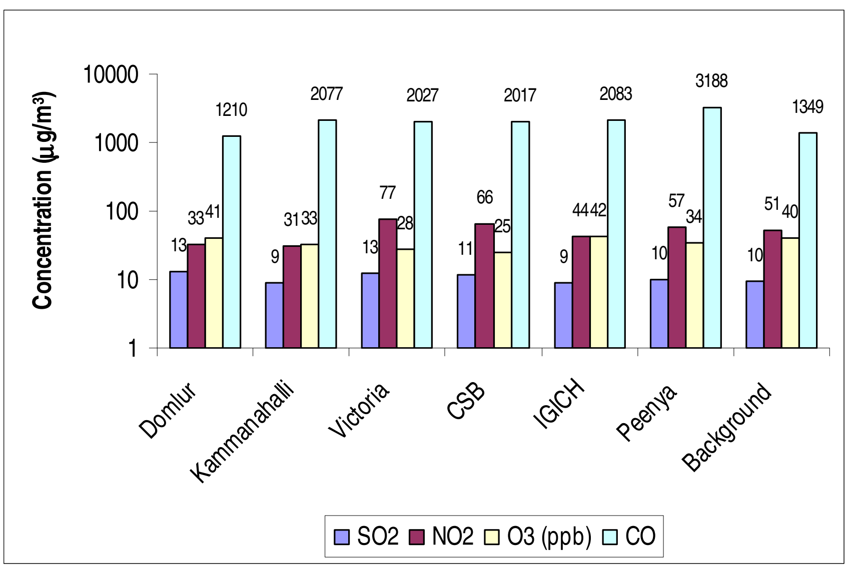


Figure **2.16** Average concentration of gaseous pollutants during three seasons

Violation of 24-hourly/ 8 -hourly residential area standard for different locations in Bangalore during the three seasons is depicted in Table 2.4.

Table 2.4 Air quality summary for compliance and exceedence

Pollutant	Domlur	Kammanahalli	Victoria	CSB	IGICH	Peenya	Kanamangla
	Residential	Residential	Traffic	Traffic	Hospital/ Residential	Industrial	Background
SPM	Compliance	Violation	Violation	Violation	Compliance	Violation	Compliance
RSPM	Compliance	Close to Standard	Violation	Close to Standard	Compliance	Close to Standard	Compliance
PM2.5	Compliance	Compliance	Close to Standard	Close to Standard	Compliance	Compliance	Compliance
NO_2	Compliance	Compliance	Close to Standard	Close to Standard	Compliance	Compliance	Compliance
SO_2	Compliance	Compliance	Compliance	Compliance	Compliance	Compliance	Compliance
CO	Compliance	Violation	Violation	Violation	Violation	Violation	Compliance
O_3	Close to Standard	Compliance	Compliance	Compliance	Close to Standard	Compliance	Close to Standard

* 8 hourly CO/ O3 concentrations were compared against corresponding standards.

Violation **Close to Standard** **Compliance**

Figure 2.17 shows the average value across three seasons of total hydrocarbon, non-methane hydrocarbon, aldehydes, benzene and 1,3-Butadiene concentrations at the 7 monitoring locations. Hydrocarbon concentrations have been found to be similar at all the locations except background where it is lower. Aldehydes were higher at kerbside locations. Benzene was found to be highest at CSB (kerbside) and Peenya (industrial).

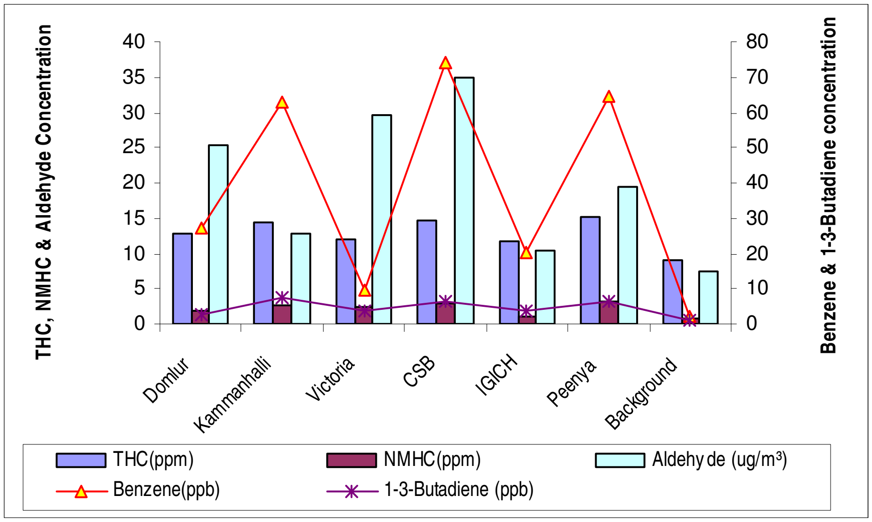


Figure **2.17** Average concentration of total hydrocarbon, non-methane hydrocarbon, aldehydes, benzene and 1,3-Butadiene during three seasons

PAHs were analysed along with few other molecular markers and the same are presented in Figures 2.18 (a) and 2.18 (b) for PM_{10} and $PM_{2.5}$, respectively.

In the case of PM_{10} samples, Benzo(e)pyrene and Hopane were measured highest at Victoria road (kerbside). Significant Coronene concentration was found at all the locations (except Background) which clearly depicts prevalence of vehicular emissions across the city. Levoglucosan concentrations were highest at Kammanahalli depicting biomass burning.

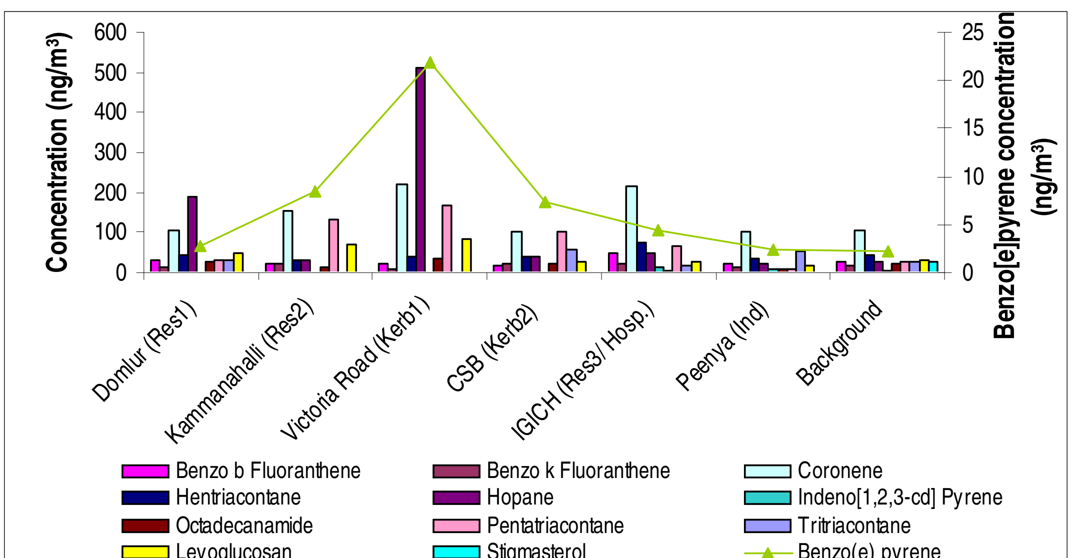


Figure **2.18 (a)** Average concentration of PAHs and other molecular markers in PM_{10} samples at 7 monitoring locations during three seasons

In the case of $PM_{2.5}$ samples, Benzo(e)pyrene was highest at Peenya industrial area and CSB (kerbside) indicating fuel oil/gasoline combustion. Significant Coronene concentration was found at many locations (except Background) indicating presence of vehicular sources. Pentatriacontane concentrations were high at Peenya, Kammanahalli, CSB and Victoria Road indicating tyre wear debris from vehicular sources. Levoglucosan concentrations were highest at IGICH and Peenya depicting biomass burning. Here, it may be noted that since the number of samples for PM_{10} and $PM_{2.5}$ were different, the results have to be interpreted carefully.

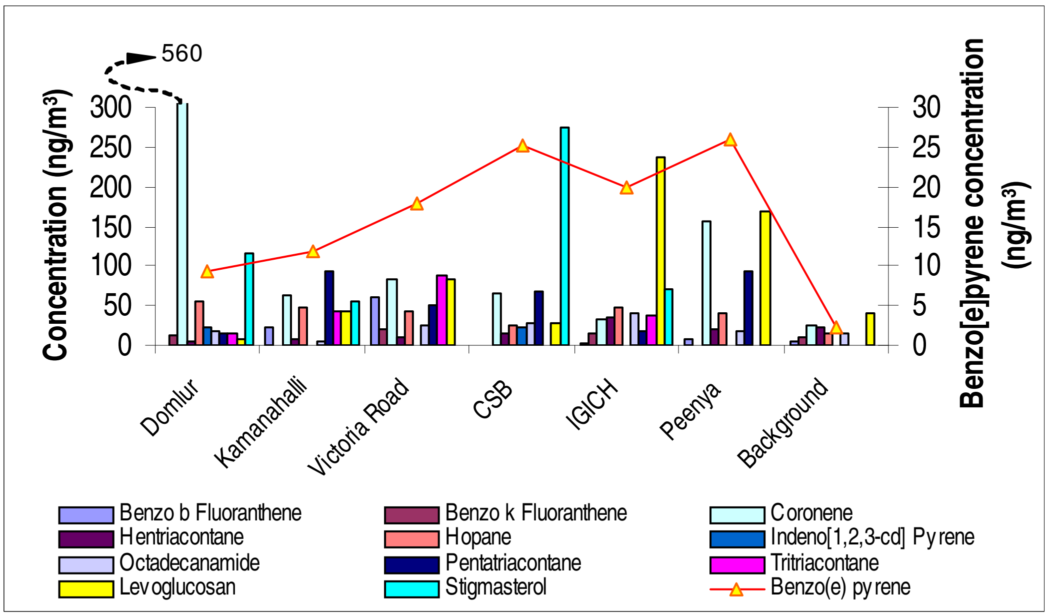


Figure **2.18 (b)** Average concentration of PAHs and other molecular markers in $PM_{2.5}$ samples at 7 monitoring locations during three seasons

Correlation: Particulate matter – 3 seasons

Statistical analysis of particulate matter (SPM, RSPM, PM_{10} and $PM_{2.5}$) for three seasons has been carried out in terms of a correlation matrix (Table 2.5). PM_{10} and $PM_{2.5}$ shows significant +ve correlation at Domlur, CSB and Victoria road location during the first season i.e. winter season. SPM and RSPM also shows +ve correlation at all the locations during the first season.

Table 2.5 Correlation matrix of four dust parameters at all sampling sites during each of the three seasons

Location	Parameters	First season				Second season				Third season			
		SPM	RSPM	PM_{10}	$PM_{2.5}$	SPM	RSPM	PM_{10}	$PM_{2.5}$	SPM	RSPM	PM_{10}	$PM_{2.5}$
Domlur	SPM	1.000				1.000				1.000			
	RSPM	0.704	1.000			0.742	1.000			0.523	1.000		
	PM_{10}	0.635	0.840	1.000		0.561	0.217	1.000		-0.105	0.239	1.000	
	$PM_{2.5}$	0.664	0.355	0.591	1.000	-0.479	-0.492	0.769	1.000	-0.907	0.266	*	1.000
Kammanahalli	SPM	1.000				1.000				1.000			
	RSPM	0.575	1.000			0.679	1.000			0.733	1.000		
	PM_{10}	0.350	0.383	1.000		-0.161	-0.114	1.000		0.361	0.302	1.000	
	$PM_{2.5}$	-0.921	-0.506	-0.410	1.000	-0.995	0.137	-0.651	1.000	0.904	0.999	*	1.000
CSB	SPM	1.000				1.000				1.000			
	RSPM	0.796	1.000			0.645	1.000			0.449	1.000		
	PM_{10}	0.538	0.698	1.000		-0.022	0.242	1.000		0.326	0.333	1.000	
	$PM_{2.5}$	0.467	0.893	0.719	1.000	*	*	*	1.000	-0.881	-0.450	0.201	1.000
Victoria road	SPM	1.000				1.000				1.000			
	RSPM	0.773	1.000			0.350	1.000			0.065	1.000		
	PM_{10}	0.331	0.219	1.000		-0.353	0.109	1.000		0.438	-0.452	1.000	
	$PM_{2.5}$	0.905	0.921	0.776	1.000	*	-0.914	*	1.000	-0.307	-0.954	0.679	1.000
IGICH	SPM	1.000				1.000				1.000			
	RSPM	0.225	1.000			0.327	1.000			0.190	1.000		
	PM_{10}	0.004	0.413	1.000		0.345	0.424	1.000		0.254	0.157	1.000	
	$PM_{2.5}$	0.819	0.006	-0.768	1.000	*	*	*	1.000	*	*	-0.939	1.000
Peenya	SPM	1.000				1.000				1.000			
	RSPM	0.266	1.000			0.218	1.000			0.282	1.000		
	PM_{10}	0.306	0.549	1.000		-0.084	0.453	1.000		0.752	0.019	1.000	
	$PM_{2.5}$	-0.319	0.735	*	1.000	*	*	*	1.000	*	-0.261	-0.398	1.000
Background	SPM	1.000				1.000				1.000			
	RSPM	0.529	1.000			0.613	1.000			0.183	1.000		
	PM_{10}	0.710	0.839	1.000		0.167	0.093	1.000		0.354	-0.086	1.000	
	$PM_{2.5}$	0.183	0.410	-0.832	1.000	0.921	*	*	1.000	0.218	0.591	-0.788	1.000

* Cannot be computed because at least one of the variables is constant

Table 2.6 shows the correlation matrix of various chemical species (PM_{10}, SO_2, NO_2, NO_3^-, SO_4^{2-}, NH_4^+, OC, EC, and TC) in PM_{10} samples at all monitoring sites during each of the three seasons.

Overall, an analysis of the data in Table 2.6 reveals that OC and EC shows +ve correlation in two seasons out of three at all the air quality monitoring stations except Victoria road and CSB where it shows +ve correlation only in one season. Secondary pollutants (NO_3^- and SO_4^{2-} with NH_4^+) have shown +ve correlation at most of the locations (except Peenya and Victoria road) in more than one season.

Table 2.6 Correlation matrix of various chemical species in PM_{10} samples at all monitoring sites during each of the three seasons

Ist Season									
Domlur	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.32	1							
NO2	-0.3	-0.4	1						
NO_3^-	0.59	0.37	-0.7	1					
SO_4^{2-}	0.6	0.49	-0.6	0.93	1				
NH_4^+	0.45	0.33	0.16	0.03	0.22	1			
OC	0.55	0.32	0.03	0.25	0.44	0.79	1		
EC	0.49	-0.01	0.17	0.18	0.32	0.74	0.8	1	
TC	0.55	0.23	0.08	0.24	0.42	0.81	0.98	0.9	1
Kammana-halli	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.01	1							
NO_2	-0.1	-0	1						
NO_3^-	-0.02	*	0.38	1					
SO_4^{2-}	-0.5	*	0.58	0.33	1				
NH_4^+	0.19	*	-0.1	0.26	0.66	1			
OC	0.33	-0.3	0.3	0.46	0.07	0.48	1		
EC	-0.2	-0.3	0.26	0.56	0.55	0.8	0.7	1	
TC	0.22	-0.3	0.32	0.52	0.22	0.61	0.99	0.78	1
CSB	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.4	1							
NO_2	-0.1	-0.3	1						
NO_3^-	0.1	-0.2	0.29	1					
SO_4^{2-}	0.05	-0.2	0.22	0.96	1				
NH_4^+	0.07	-0.1	0.2	0.93	0.93	1			
OC	0.19	-0.3	0.33	0.87	0.82	0.73	1		
EC	-0.1	-0.1	-0.2	0.46	0.51	0.52	0.14	1	
TC	0.17	-0.4	0.26	0.88	0.84	0.72	0.98	0.29	1
Victoria	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM10	1								
SO2	-0.1	1							
NO2	-0.1	0.09	1						
$NO3^-$	0.09	0.3	0.14	1					
$SO4^{2-}$	0.3	-0.1	-0.1	0.84	1				
NH_4^+	-0.6	-0.2	-0.4	0.15	0.1	1			
OC	0.06	-0	0.37	-0.4	-0.4	-0.8	1		
EC	0.12	-0.5	0.11	-0.8	-0.6	-0.3	0.65	1	
TC	0.08	-0.2	0.32	-0.5	-0.5	-0.7	0.98	0.8	1
IGICH	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.48	1							
NO_2	0.46	0.42	1						
NO_3^-	0.44	0.33	0.38	1					
SO_4^{2-}	0.39	0.16	0.34	0.51	1				
NH_4^+	0.1	0.04	0	0.28	0.7	1			
OC	0.67	0.22	0.49	0.35	0.18	0.05	1		
EC	0.66	0.27	0.52	0.38	0.21	0.16	0.87	1	
TC	0.69	0.24	0.51	0.37	0.19	0.08	0.99	0.93	1
Peenya	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.3	1							
NO_2	-0.3	-0.2	1						
NO_3^-	-0	-0.4	-0.3	1					
SO_4^{2-}	0.04	-0.4	-0.1	0.43	1				
NH_4^+	0.11	-0.1	-0.3	-0.4	0.39	1			
OC	-0.1	0.38	0.05	0.32	-0.2	-0.6	1		
EC	0.21	0.14	-0.2	0.15	0.13	-0.4	0.4	1	
TC	-0.01	0.37	0.01	0.32	-0.2	-0.6	0.98	0.56	1
Backgroun	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	*	1							
NO_2	-0.1	-0.2	1						
NO_3^-	0.76	*	0.16	1					
SO_4^{2-}	0.66	*	-0.3	0.58	1				
NH_4^+	0.73	*	-0.2	0.7	0.94	1			
OC	0.56	*	-0.5	0.42	0.49	0.51	1		
EC	0.54	*	-0.5	0.51	0.42	0.53	0.93	1	
TC	0.59	*	-0.5	0.49	0.48	0.54	0.99	0.97	1

IInd Season									
Domlur	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.08	1							
NO_2	-0.6	-0.03	1						
NO_3^-	0.12	-0.3	-0.2	1					
SO_4^{2-}	0.23	0.03	0.02	0.35	1				
NH_4^+	0.14	0.12	0.05	0.49	0.75	1			
OC	0.33	0.06	0.09	0.43	0.44	0.16	1		
EC	-0.1	-0.1	0.42	0.36	0.43	0.3	0.73	1	
TC	0.19	0.05	0.22	0.45	0.52	0.26	0.97	0.86	1
Kammana-halli	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.33	1							
NO_2	0.18	-0.4	1						
NO_3^-	0.12	0.33	0.01	1					
SO_4^{2-}	0.21	0.08	0.17	0.86	1				
NH_4^+	0.21	0.02	0.08	0.29	0.55	1			
OC	0.25	0.57	0.2	0.51	0.4	0.13	1		
EC	0.52	0.59	0.22	0.41	0.31	0.12	0.84	1	
TC	0.21	0.54	0.23	0.55	0.45	0.16	0.98	0.85	1
CSB	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.33	1							
NO_2	-0.01	-0.1	1						
NO_3^-	0.32	0.13	-0.01	1					
SO_4^{2-}	0.07	0.07	-0.2	0.85	1				
NH_4^+	-0.3	-0.3	-0.3	0.51	0.61	1			
OC	0.25	0.12	0.05	0.19	0.2	-0.3	1		
EC	0.32	0.33	0.35	0.22	0.06	-0.1	0.6	1	
TC	0.3	0.19	0.12	0.23	0.21	-0.3	0.98	0.69	1
Victoria	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.07	1							
NO_2	0.17	-0.02	1						
NO_3^-	-0.2	-0.1	-0.03	1					
SO_4^{2-}	0.16	0.05	0.28	0.24	1				
NH_4^+	-0.2	0.16	0.19	0.34	-0	1			
OC	0.49	-0.2	0.45	0.03	0.47	-0.2	1		
EC	0.27	-0.1	0.2	0.03	0.32	-0.3	0.31	1	
TC	0.39	-0.2	0.55	0.02	0.7	-0.2	0.75	0.44	1
IGICH	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.1	1							
NO_2	0.12	0.7	1						
NO_3^-	0.57	-0.1	0.21	1					
SO_4^{2-}	0.57	-0.2	0.1	0.9	1				
NH_4^+	0.76	-0.3	-0.01	0.66	0.64	1			
OC	0.47	-0.2	-0.1	0.59	0.59	0.49	1		
EC	0.79	-0.2	-0.04	0.63	0.63	0.74	0.89	1	
TC	0.6	-0.2	-0.1	0.62	0.62	0.58	0.99	0.94	1
Peenya	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.13	1							
NO_2	-0.1	-0.2	1						
NO_3^-	0.51	0.27	0.21	1					
SO_4^{2-}	0.53	0.2	-0.1	0.88	1				
NH_4^+	-0.4	0.01	0.09	-0.3	-0.3	1			
OC	0.59	-0.02	0.15	0.36	0.27	-0.1	1		
EC	0.58	0.1	0.22	0.5	0.37	-0	0.84	1	
TC	0.61	0.01	0.18	0.42	0.31	-0.1	0.99	0.92	1
Backgroun	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.4	1							
NO_2	-0.2	0.78	1						
NO_3^-	-0.5	0.4	0.45	1					
SO_4^{2-}	-0.5	0.84	0.74	0.76	1				
NH_4^+	-0.4	0.78	0.48	0.93	0.97	1			
OC	-0.5	-0.1	-0.2	0.06	0.65	0.48	1		
EC	-0.5	0.74	0.3	0.88	0.85	0.98	0.11	1	
TC	0.33	0.91	0.68	0.34	0.39	0.38	0.01	0.97	1

IIIrd season									
Domlur	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.15	1							
NO_2	0.45	-0.4	1						
NO_3^-	-0.1	-0.6	0.39	1					
SO_4^{2-}	-0.2	-0.5	0.27	0.79	1				
NH_4^+	0.52	-0.4	0.02	-0.2	0.42	1			
OC	-0.2	0.34	-0.1	-0.2	-0.1	-0.1	1		
EC	0.0	0.65	-0.5	-0.3	-0.2	-0.2	0.28	1	
TC	-0.1	0.46	-0.3	-0.2	-0.1	-0.1	0.97	0.4	1
Kammana-halli	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.5	1							
NO_2	-0.4	0.51	1						
NO_3^-	0.23	-0.1	-0.3	1					
SO_4^{2-}	0.45	-0.2	-0.3	0.91	1				
NH_4^+	-0.2	-0.2	0.01	0.22	0.03	1			
OC	-0.1	0.12	-0.0	0.11	0.19	0.04	1		
EC	-0.4	0.48	0.12	0.15	0.0	0.11	0.11	1	
TC	-0.1	0.2	0.04	0.03	0.11	0.01	0.96	-	1
CSB	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	0.16								
NO_2	0.09	0.14	1						
NO_3^-	-0	0.08	0.78	1					
SO_4^{2-}	0.09	0.19	0.21	0.62	1				
NH_4^+	0.02	0.05	0.81	0.5	-0	1			
OC	0.38	0.02	0.4	0.4	0.22	0.61	1		
EC	0.1	0.39	-0.0	0.12	0.3	0.21	0.27	1	
TC	0.32	0.21	0.35	0.39	0.5	0.52	0.83	0.6	1
Victoria road	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.3	1							
NO_2	-0.5	0.48	1						
NO_3^-	0.84	-0.4	-0.4	1					
SO_4^{2-}	0.75	-0.3	-0.5	0.93	1				
NH_4^+	0.38	-0.3	-0.2	0.61	0.71	1			
OC	0.87	-0.4	-0.5	0.94	0.84	0.41	1		
EC	-0.8	0.33	0.51	-0.7	-0.6	-0.2	-0.7	1	
TC	0.81	-0.4	-0.4	0.91	0.82	0.44	0.99	-	1
IGICH	PM10	SO_2	NO_2	NO_3^-	$SO4^{2-}$	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.1	1							
NO_2	-0.1	-0.5	1						
NO_3^-	0.63	-0.1	0.03	1					
SO_4^{2-}	0.67	0.07	-0.2	0.68	1				
NH_4^+	-0.03	-0.03	0.44	0.27	0.44	1			
OC	0.37	0.01	-0.3	0.61	0.52	-0.01	1		
EC	0.55	-0.03	-0.3	0.72	0.64	0.2	0.84	1	
TC	0.48	0.09	-0.3	0.72	0.62	0.04	0.95	0.8	1
Peenya	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM_{10}	1								
SO_2	-0.2	1							
NO_2	-0.5	0.58	1						
NO_3^-	0.1	0.09	-0.4	1					
SO_4^{2-}	0.3	0.18	-0.5	0.8	1				
NH_4^+	0.07	-0.6	-0.3	0.22	0.28	1			
OC	-0.0	0.01	0.28	-0.4	-0.3	-0.05	1		
EC	0.1	0.02	-0.0	-0.1	0.03	0.1	0.78	1	
TC	0.31	0.17	-0.4	0.13	0.25	0.02	0.01	0.5	1
Background	PM_{10}	SO_2	NO_2	NO_3^-	SO_4^{2-}	NH_4^+	OC	EC	TC
PM10	1								
SO_2	-0.3	1							
NO_2	-0.1	0.12	1						
NO_3^-	0.08	-0.1	0.09	1					
SO_4^{2-}	0	0.32	0.17	0.84	1				
NH_4^+	0.24	0.31	0.34	0.07	0.08	1			
OC	-0.04	0.36	0.08	*	*	*	1		
EC	-0.2	0.64	0.1	*	*	*	0.97	1	
TC	-0.1	0.49	0.1	*	*	*	1	0.9	1

* Cannot be computed because at least one of the variables is constant

Chemical Speciation (PM_{10})

Chemical characterization of carbon, ions, elements and molecular markers of PM_{10} samples have been presented in figures, 2.19 – 2.25, for the seven air quality monitoring stations during three seasons across Bangalore.

First season

Carbon

Total carbon values were highest at Victoria Road, which is a heavy traffic location. The minimum values were observed at Background station.

In terms of EC values, Victoria road and CSB had high values compared to the other locations.

Ions

Sodium and potassium were maximum at industrial sampling site in Peenya Industrial Area. Concentrations of ammonium and calcium were highest at Background and Victoria road station, respectively. Sulphate is abundant at all the locations.

Fluoride and phosphate were in trace quantities during all the 20 days irrespective of the monitoring sites. Twenty days average SO_4^{-2} was maximum at Victoria road. The average values for NO_3^- was maximum at Peenya followed by Victoria road station. Chloride was maximum at Peenya station.

Elements

Higher levels were observed for elements such as Na, Mg, Fe, Si, Al, Ca and Zn.

Molecular Markers

Coronene and Hopane were relatively higher, followed by Pentriacontane. Hentriacontane, Tritriacontane, and Benzo b Fluoranthene were also found in smaller quantities.

Second season

Carbon

Highest carbon content in the PM_{10} samples was observed at kerbside locations i.e. Victoria road and CSB. However, lower carbon concentrations were observed at IGICH and background location. In terms of EC values, CSB and Victoria road had high values compared to the other locations.

Ions

Calcium ion concentration was observed to be dominant in the cations at all the locations. However, sodium, and ammonium were also present in significant quantities at certain locations. High concentrations of sulphate is measured at all the locations, except IGICH and Kammanahalli where chloride was dominating. Significant concentrations of chloride and nitrates were also observed at all the locations.

Elements

Higher levels were observed for elements such as Na, Fe, Ca, Al, Mg, Si and Zn.

Molecular Markers

Coronene, Hentriacontane, and Tritriacontane were found in higher quantities. Pentriacontane, Octadecanamide and Hopane were also found in smaller quantities.

Third Season

Carbon

Highest carbon content in the PM_{10} samples was observed at kerbside locations i.e. Victoria road and CSB. However, lower carbon concentrations were observed at IGICH, Kammanhalli and background location. In terms of EC values, CSB and Victoria road had high values compared to the other locations. Highest EC/OC ratio was observed at CSB location.

Ions

Calcium ion concentration was observed to be dominant in the cations at all the locations. However, sodium, and potassium were also present in significant quantities at certain locations. High concentrations of sulphate and chloride were measured at all the locations. Significant concentrations of nitrate were also observed at all the locations.

Elements

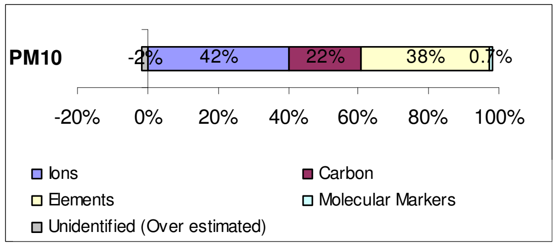
Higher levels were observed for elements such as Ca, Fe, Mg and Na.

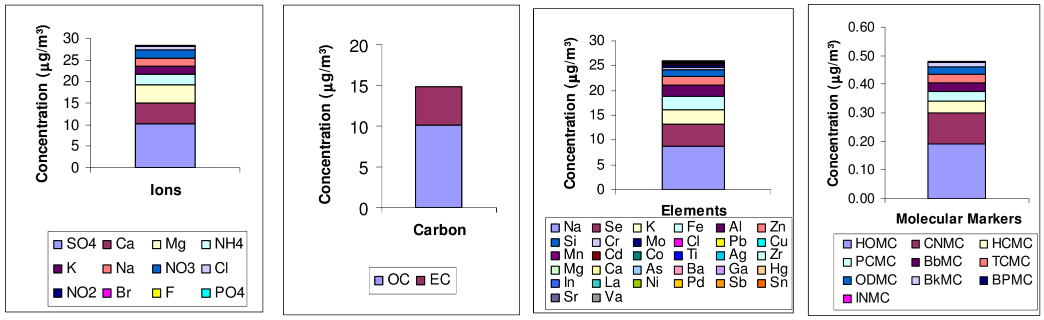
Molecular Markers

Coronene, Hentriacontane, and Tritriacontane were found in higher quantities. Benzo k Fluoranthene, Octadecanamide and Hopane were also found in smaller quantities.

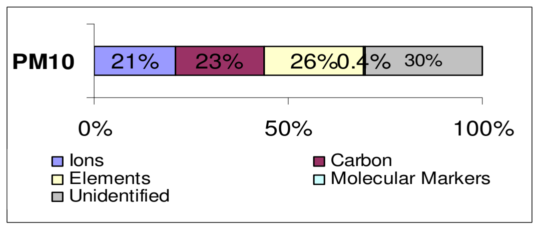
Figure:2.19 Chemical characterization – PM10 (Domlur)

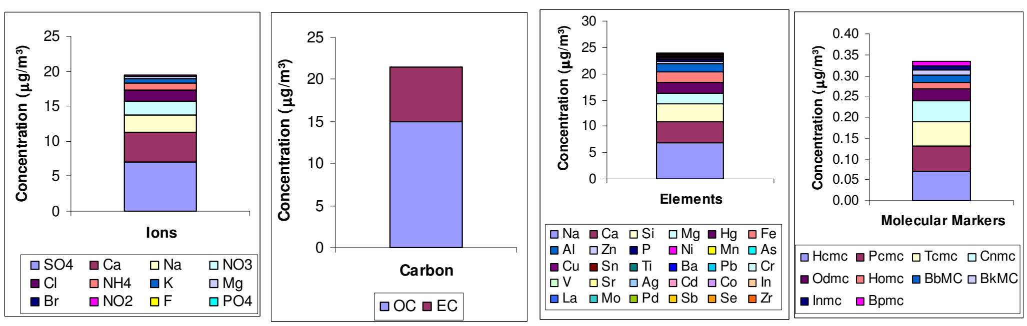
First Season



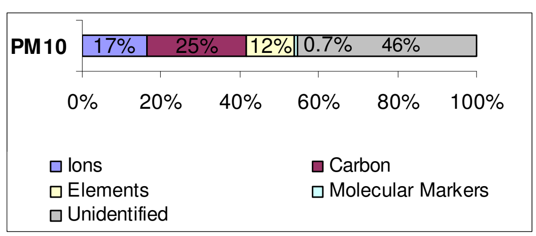


Second Season





Third Season



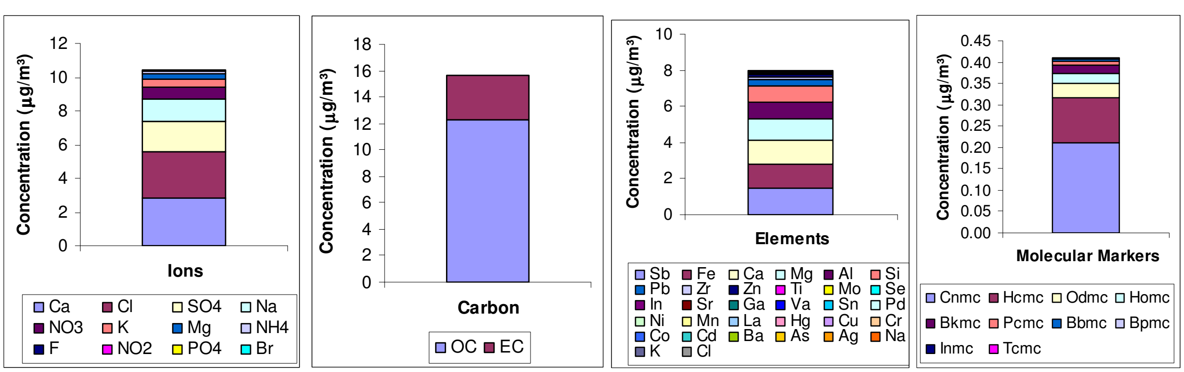
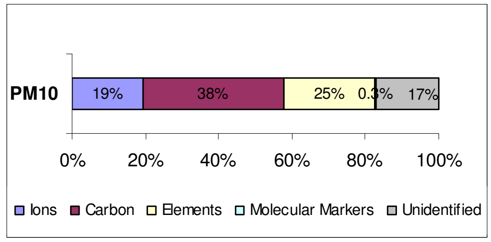
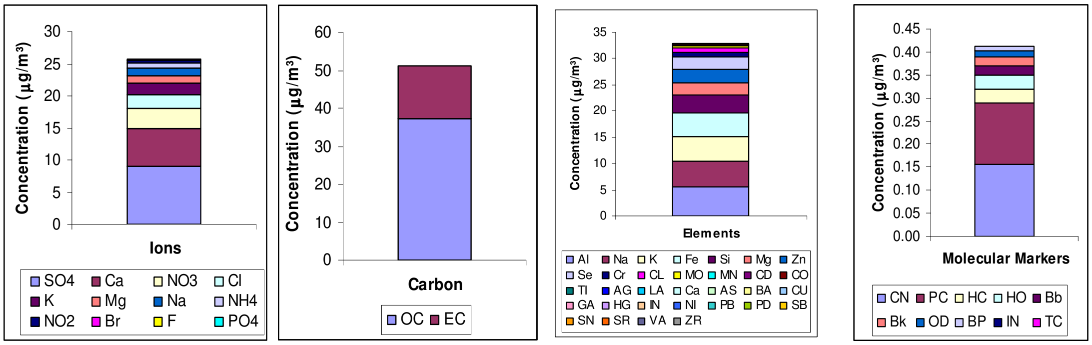


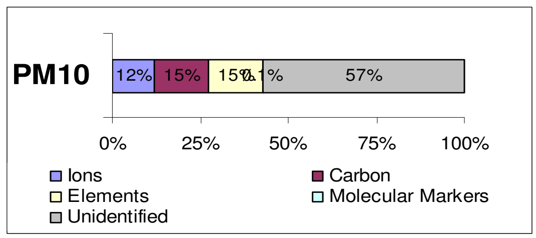
Figure :2.20 Chemical characterization – PM10 Kammanhalli

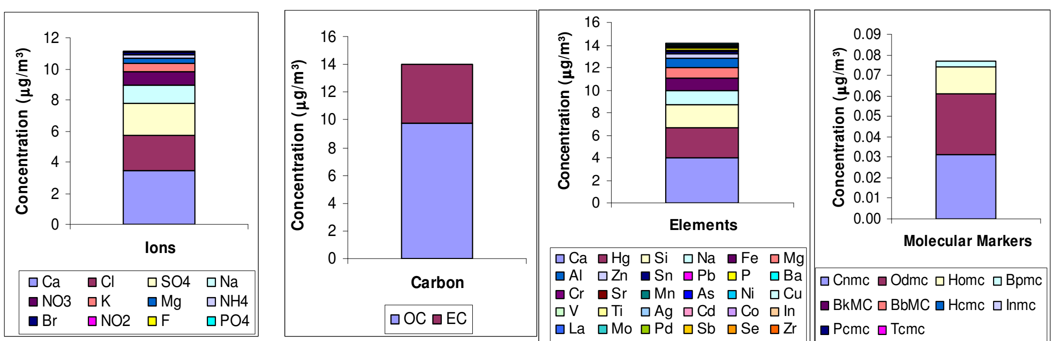
First Season



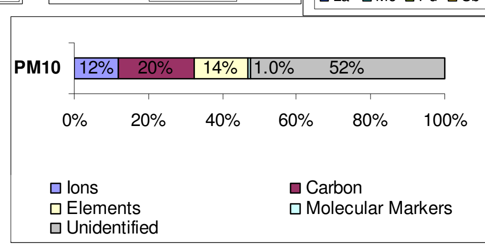


Second Season





Third Season



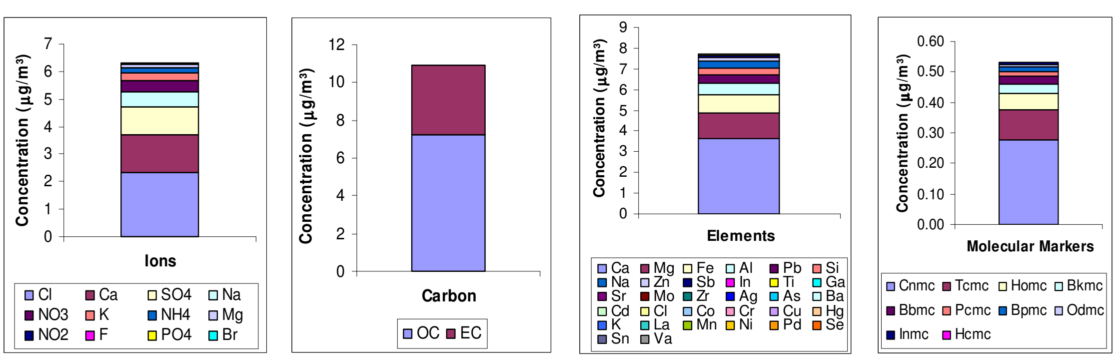
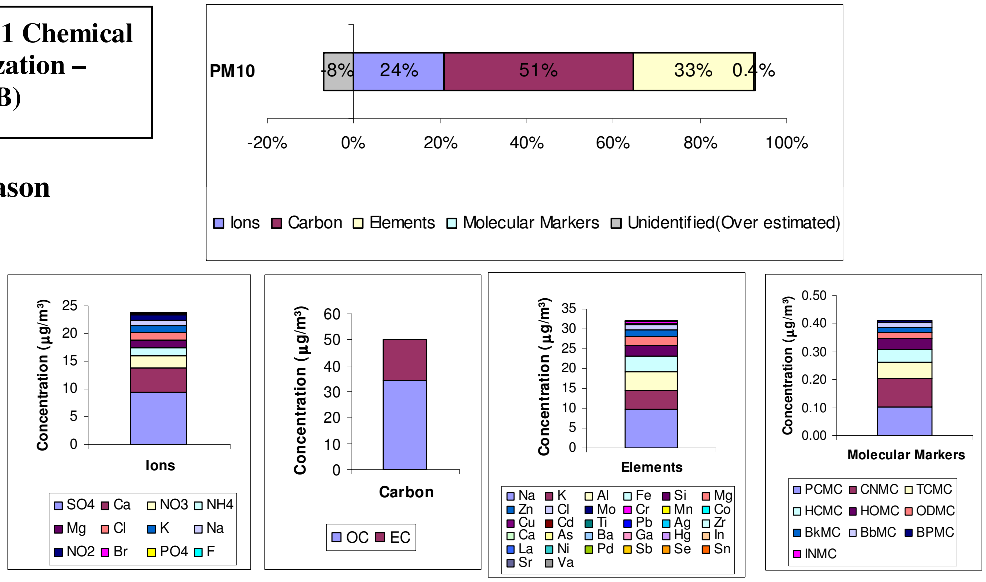
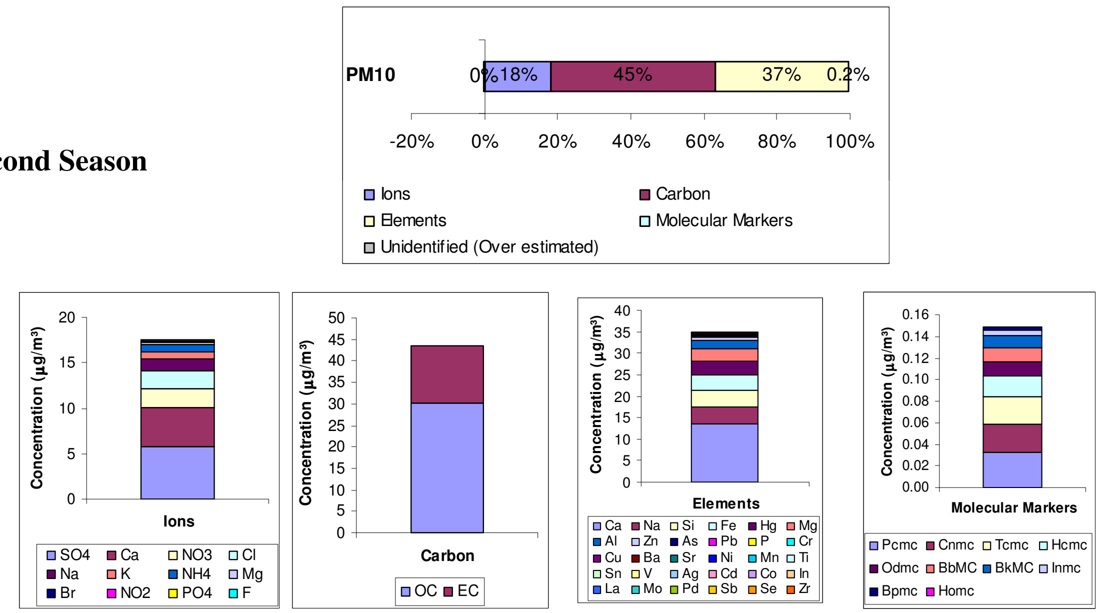


Figure :2.21 Chemical characterization – PM10 (CSB)

First Season



Second Season



Third Season

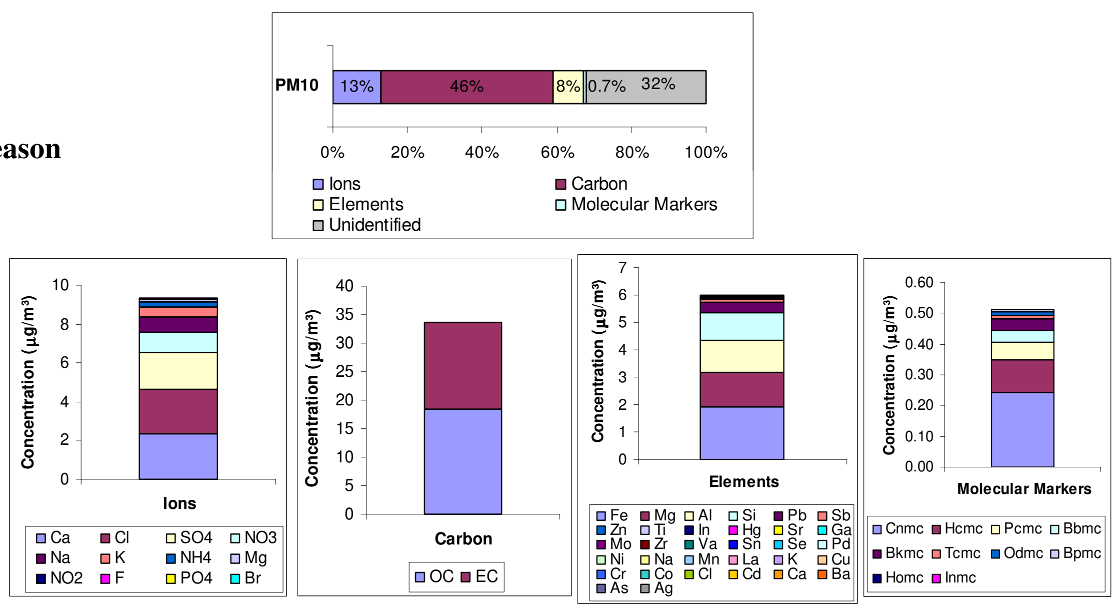
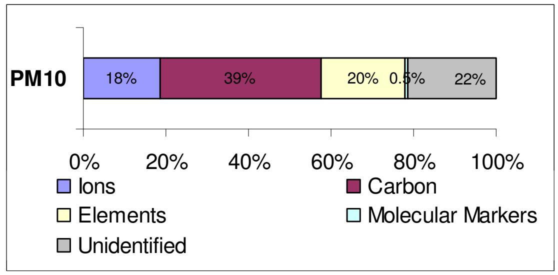
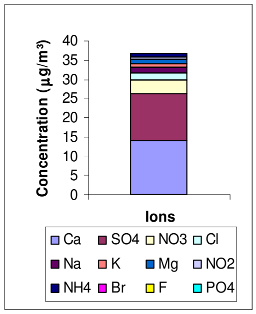
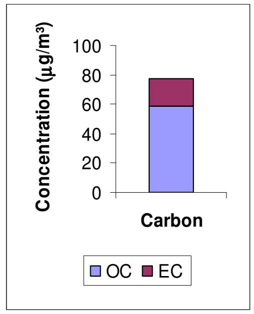


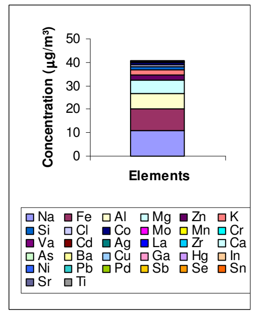
Figure :2.22 Chemical characterization – PM10 (Victoria Road)

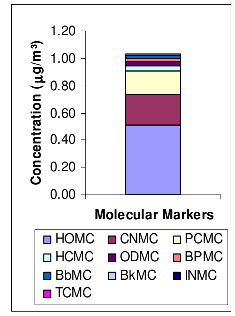
First Season



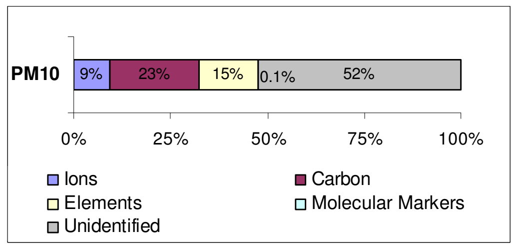


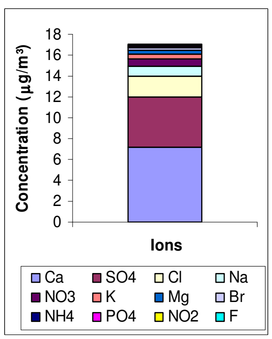


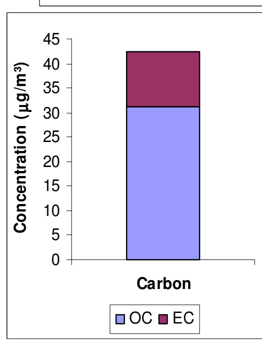


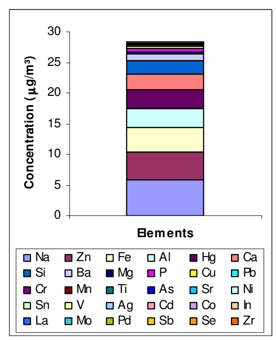


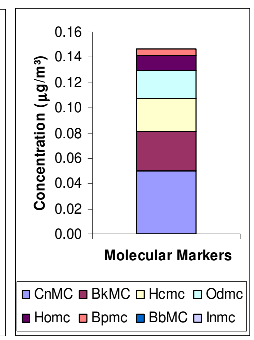
Second Season



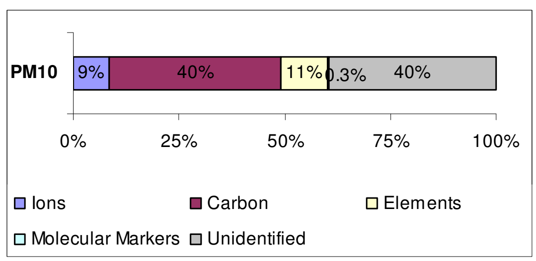


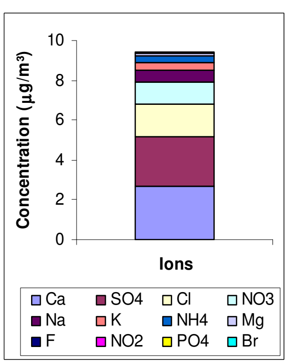


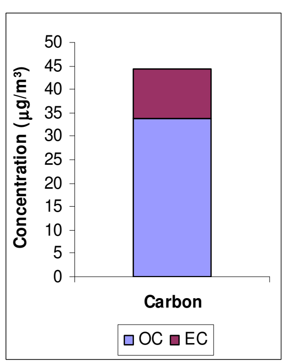


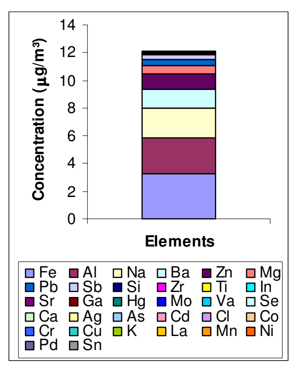


Third Season









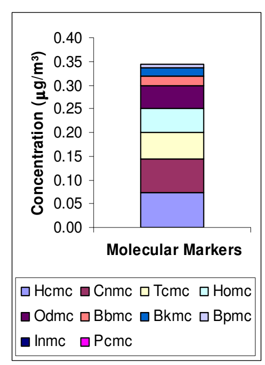
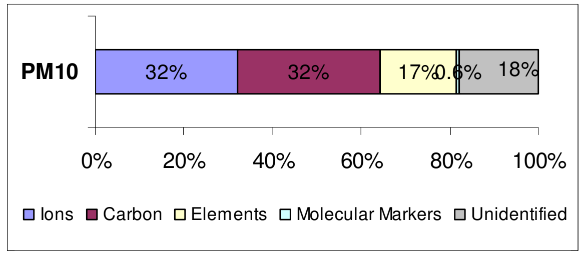
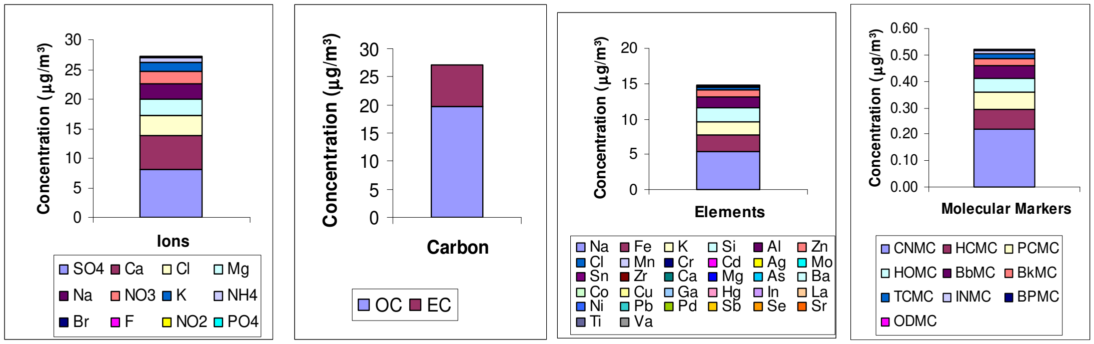


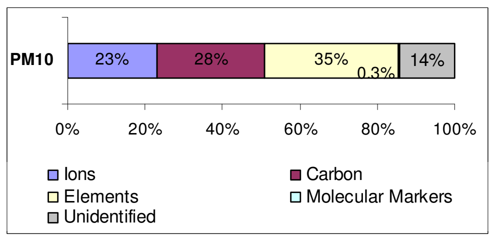
Figure :2.23 Chemical characterization – PM10 (IGICH)

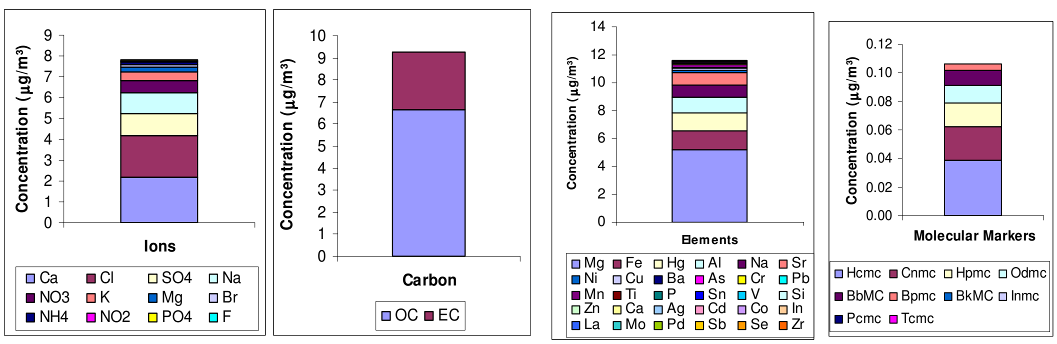
First Season



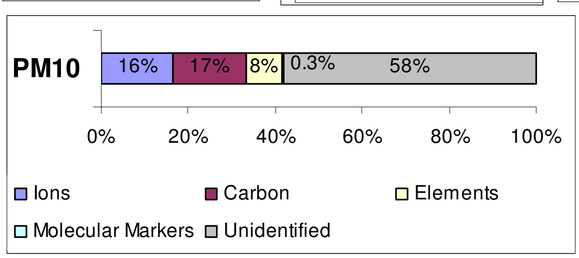


Second Season





Third Season



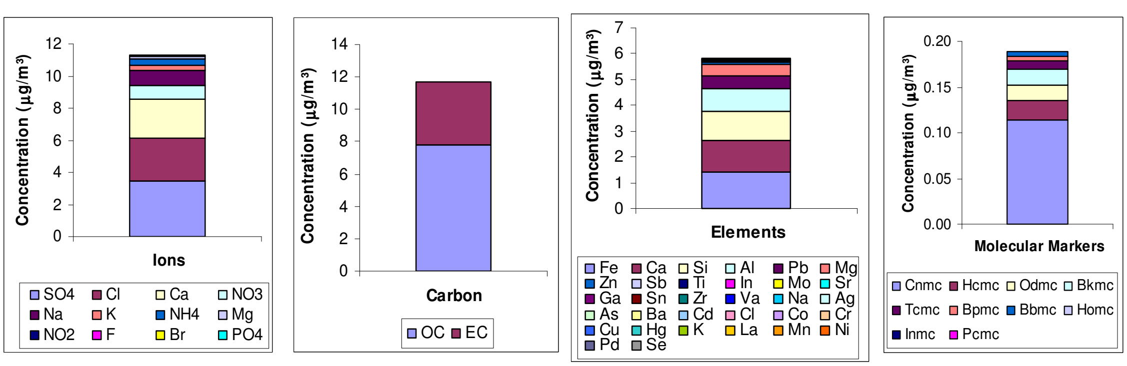
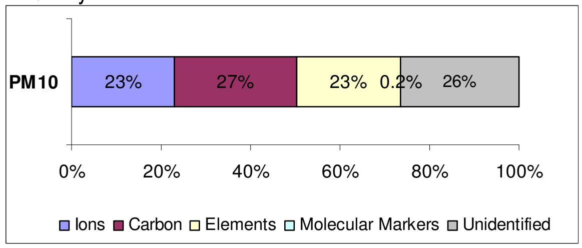
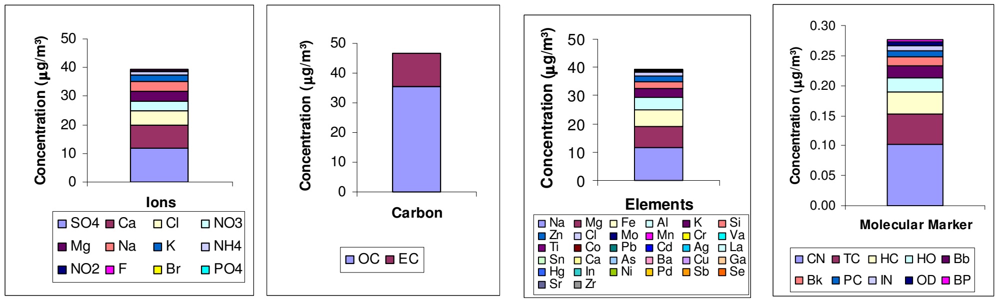


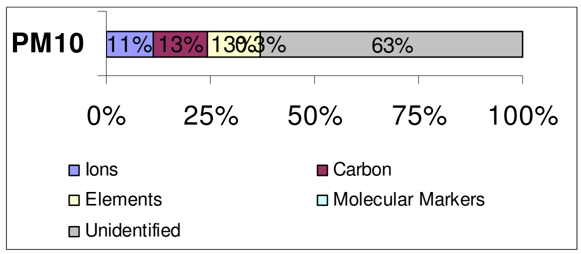
Figure :2.24 Chemical characterization – PM10 Peenya

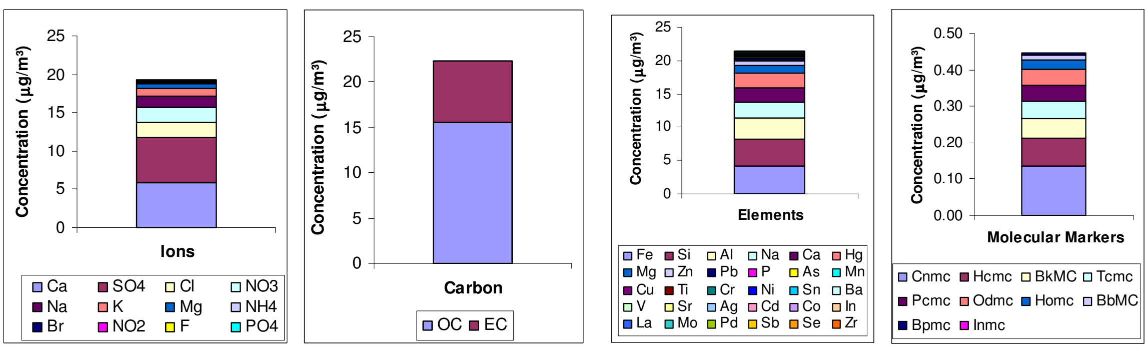
First season



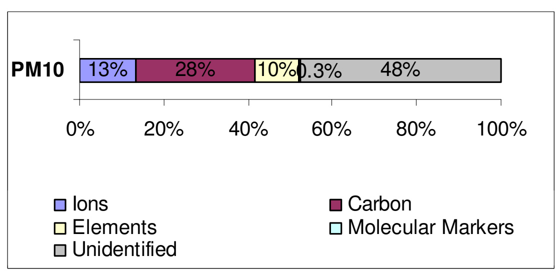


Second season





Third Season



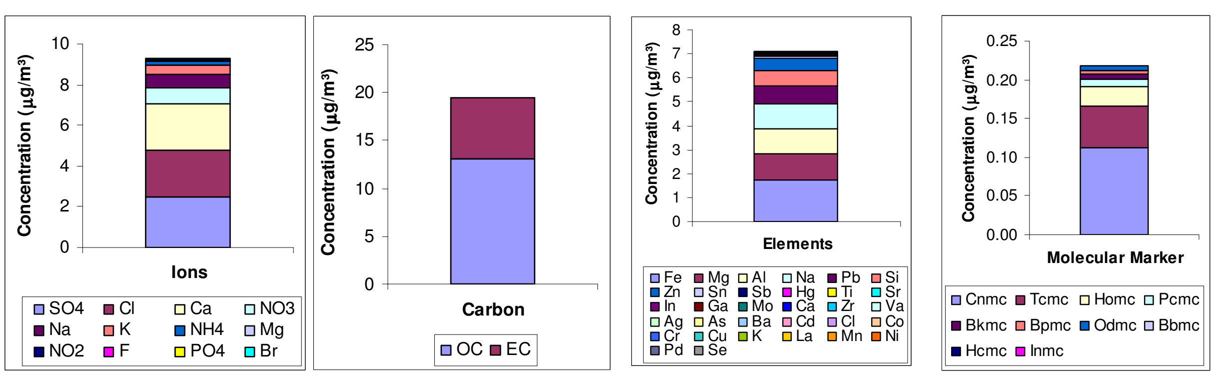
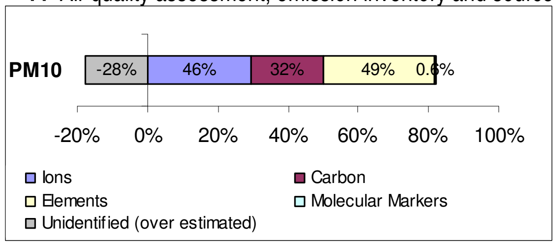
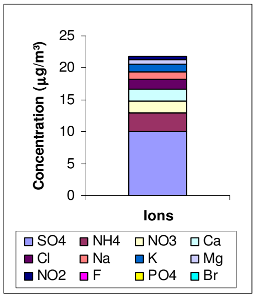
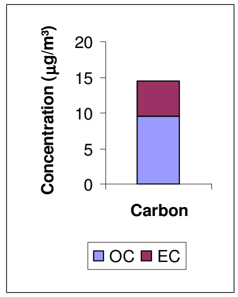


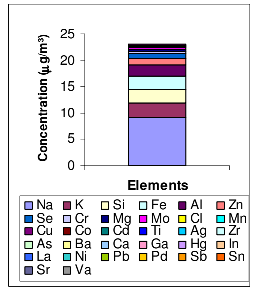
Figure:2.25 Chemical characterization – PM10 Background

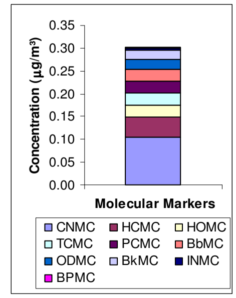
First season



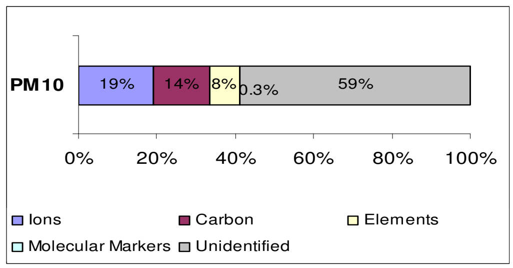


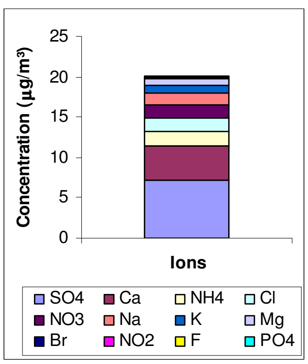


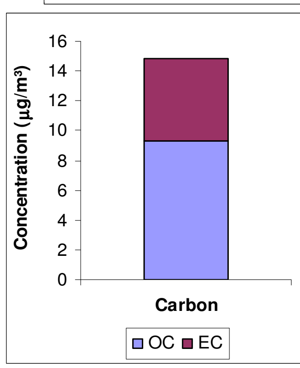


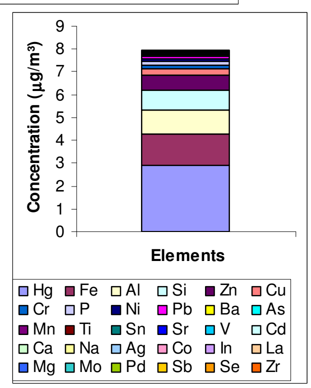


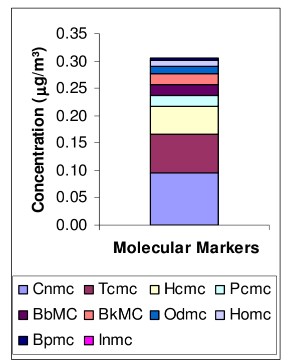
Second season



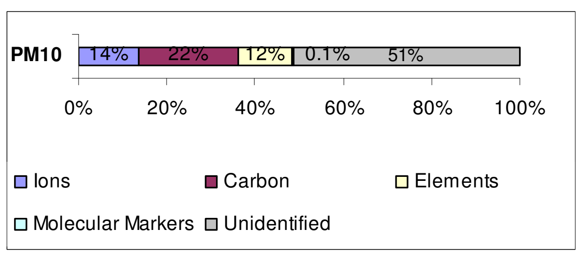


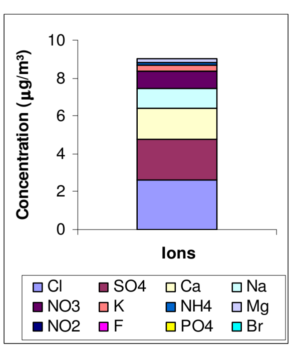


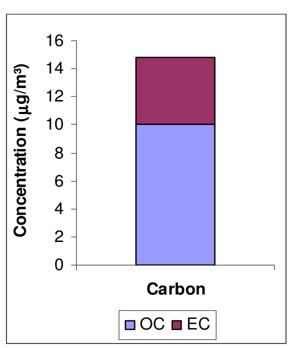


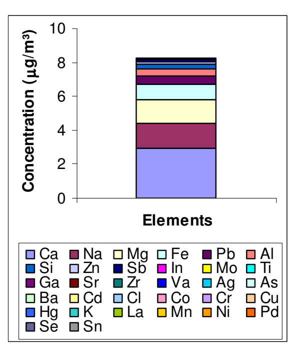


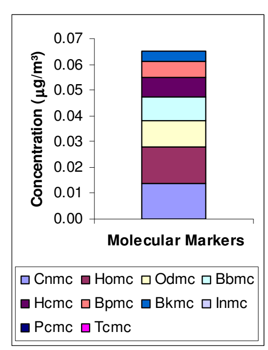
Third Season











Total carbon and EC/ OC ratio for 3 seasons for PM_{10} samples

Summary of total carbon concentrations (average for three seasons) and EC/OC ratios for PM_{10} samples at different locations in Bangalore are shown in Figure 2.26 .Being kerbside locations, Victoria road and CSB show high carbon concentration, followed by Peenya (industrial location). Moreover, the EC/OC ratio is higher at CSB probably due to greater number of diesel vehicles.

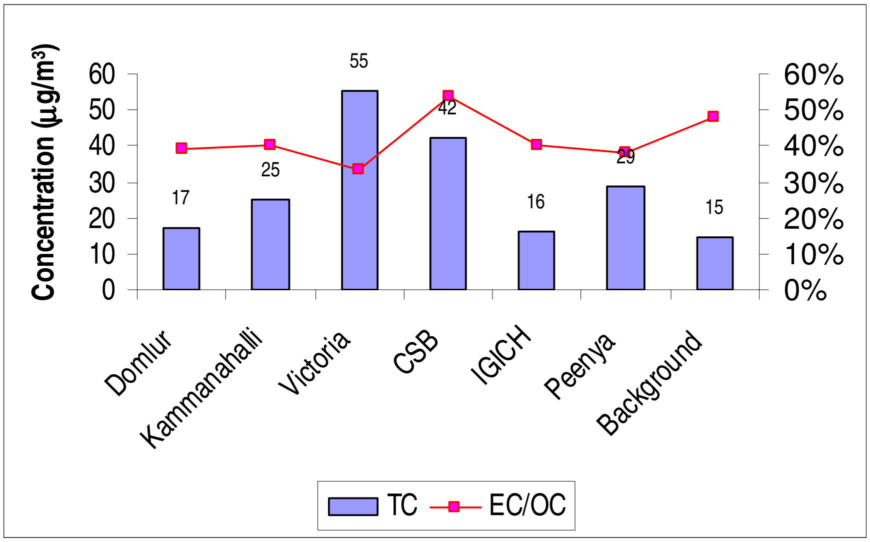


Figure **2.26** Total carbon content (µg/m³) and EC/OC ratios in PM_{10} samples at various locations in Bangalore during three seasons

Chemical Speciation (PM2.5)

Chemical characterization of carbon, ions, elements and molecular markers of PM2.5 samples have been carried out for the seven air quality monitoring stations during three seasons across Bangalore. The results are presented in figures, 2.27 – 2.33, for the seven air quality monitoring stations during three seasons across Bangalore.

First season

Carbon

In case of PM2.5, total carbon content was highest at traffic locations (CSB and Victoria Road). The minimum values were observed at Background station. In terms of EC values, traffic location such as CSB and Victoria road had high values compared to the other locations.

Ions

High calcium and sodium concentration is observed at Peenya location. High sulphate content is observed amongst the anions at all the locations.

Elements[1]

Higher levels were observed for elements such as Ca, Fe, Mg, Na, Si and Al.

Molecular Markers

Coronene and Hopane were found to be relatively higher, followed by Pentriacontane.

Second season

Carbon

Highest carbon content in the PM2.5 samples was observed at kerbside locations i.e. CSB and Victoria road. Lower carbon concentrations were observed at background location, depicting less combustion sources. EC values were also highest at kerbside locations (CSB and Victoria road). Highest EC/OC ratio was observed at CSB location, followed by Victoria road and Peenya.

Ions

Calcium ion was found to be the dominant one among all the cations analysed, followed by ammonium and sodium ions. High sulphate and chloride contribution is observed amongst the anions at all the locations.

Elements1

Higher levels were observed for elements such as Na, Fe, Ca, Al, Mg, Si and Zn.

Molecular Markers

Coronene, Hentriacontane, and Tritriacontane were found in relatively higher quantities.

Third season

Carbon

Highest carbon content in the PM2.5 samples was observed at kerbside locations i.e. CSB and Victoria road. Lower carbon concentrations were observed at background and Domlur locations, depicting less combustion sources. EC values were also highest at kerbside locations (CSB and Victoria road). Highest EC/OC ratio was observed at CSB location, followed by Peenya and Victoria road.

Ions

Calcium ion is found to be the dominant one amongst all the cations analysed, followed by sodium and potassium ions. High sulphate and chloride contribution exists amongst the anions at all the locations.

Elements

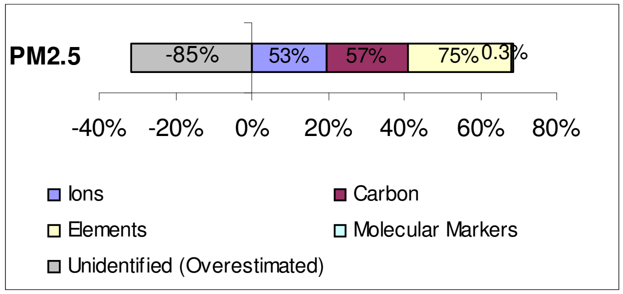
Higher levels were observed for elements such as Ca, Fe, Mg and Na.

Molecular Markers

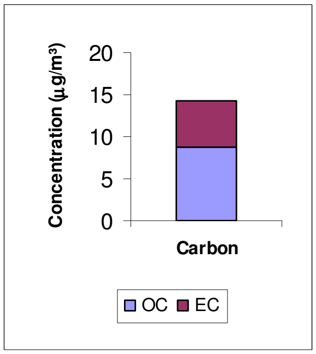
Coronene and Hentriacontane,Tritriacontane were found in relatively higher quantities.

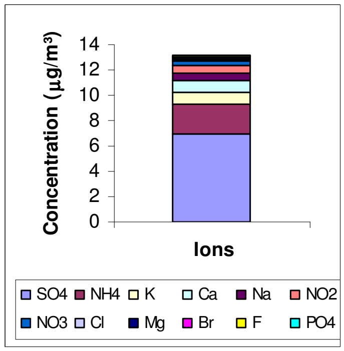
[1] Elements values for first and second season are based on their distribution in PM2.5 mass observed during the 3rd season.

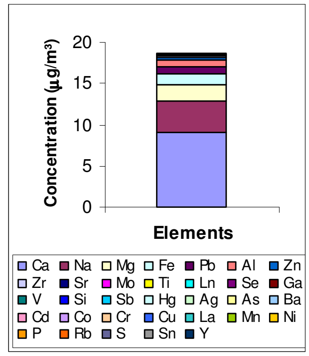
Figure:2.27 Chemical characterization – PM2.5 Domlur

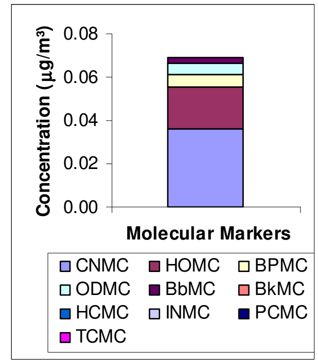


First Season

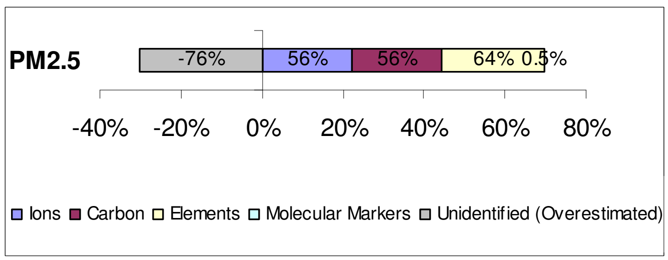


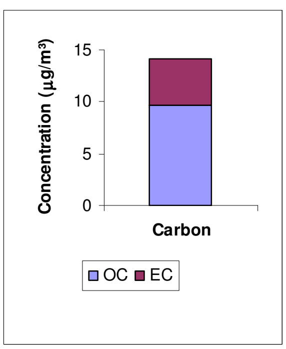


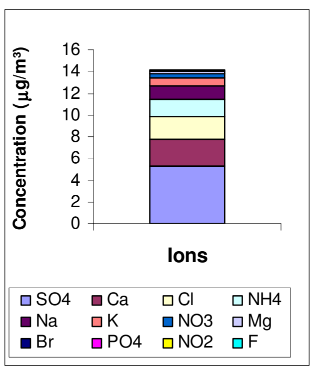


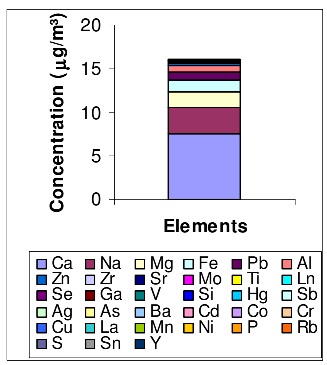


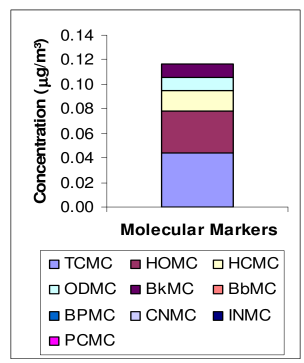
Second Season



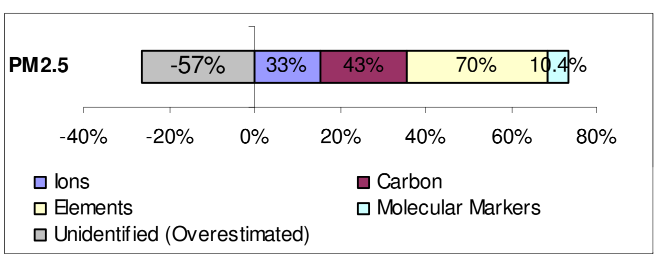








Third Season



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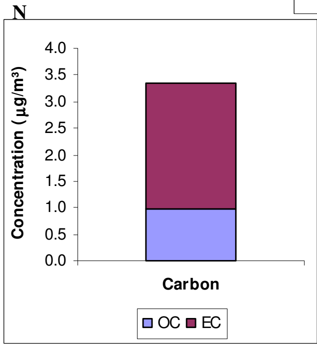
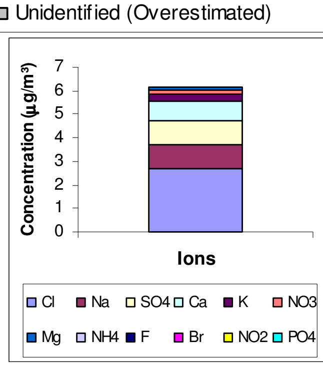
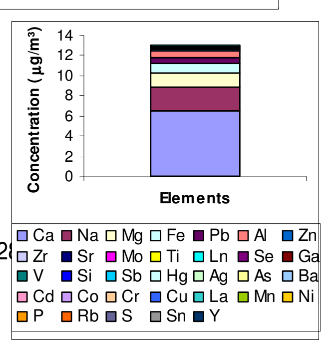






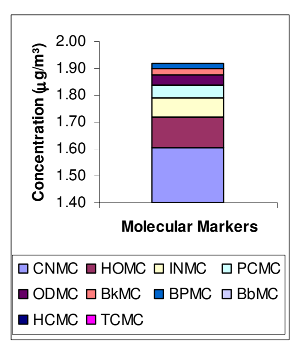
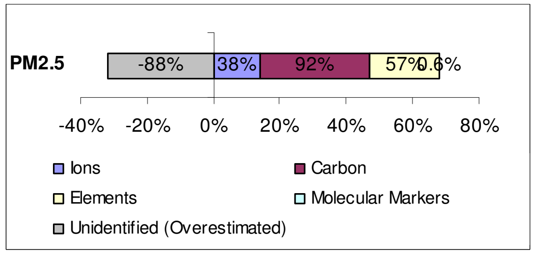
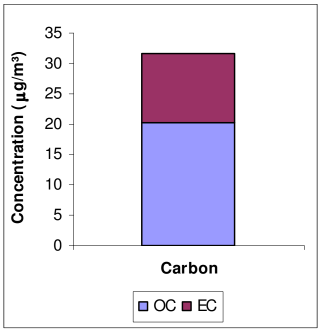
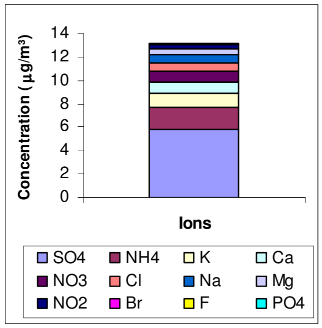


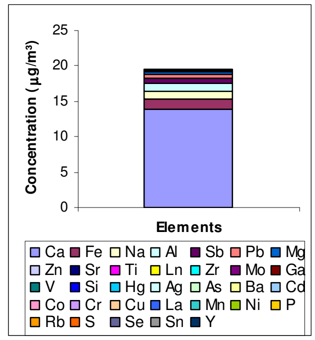
Figure:2.28 Chemical characterization – PM2.5 Kammanhalli

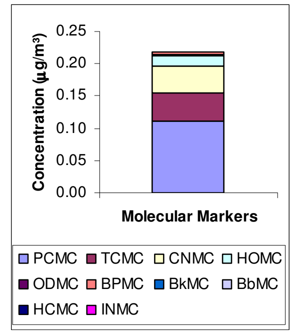
First Season



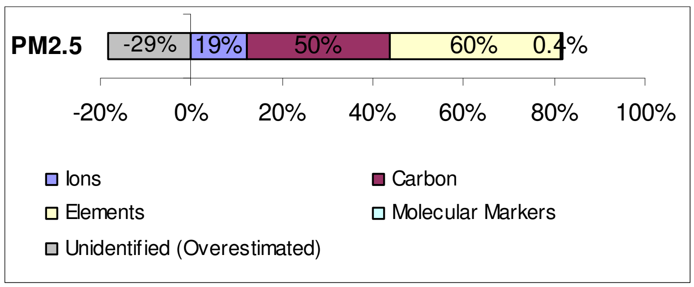


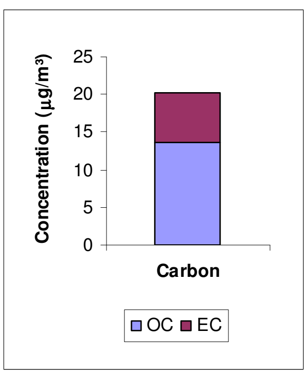


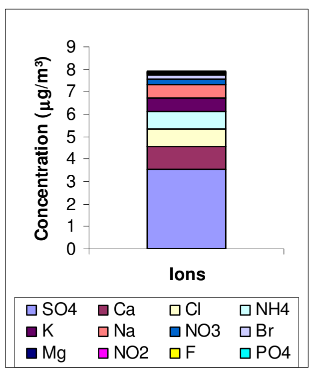


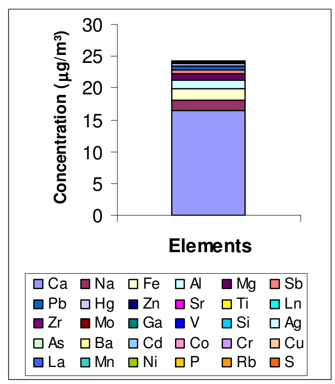


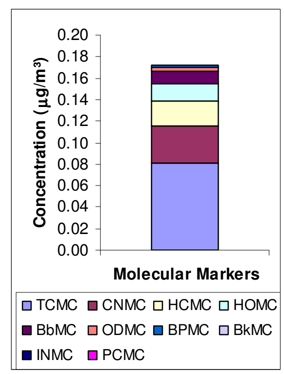
Second Season



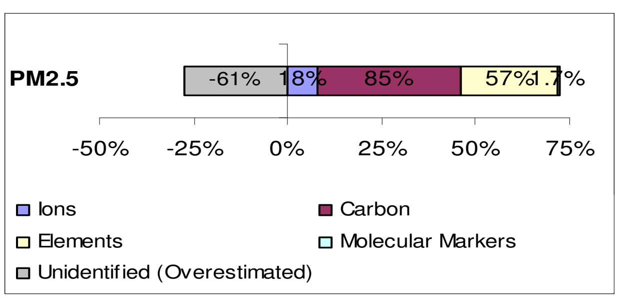


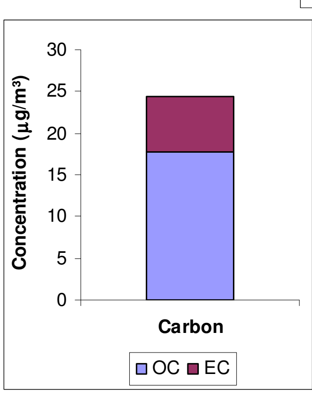


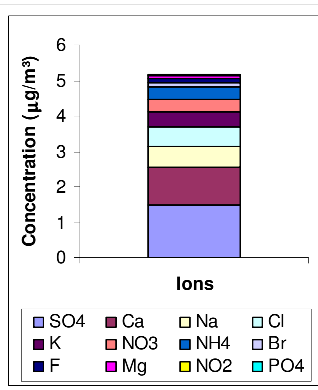


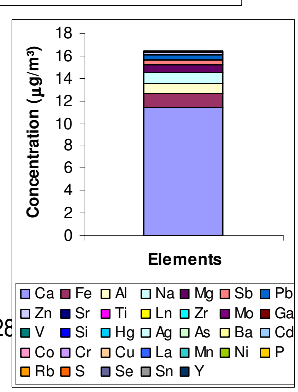


Third Season









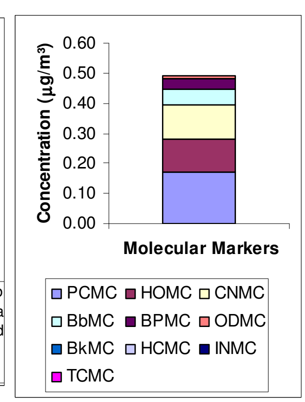
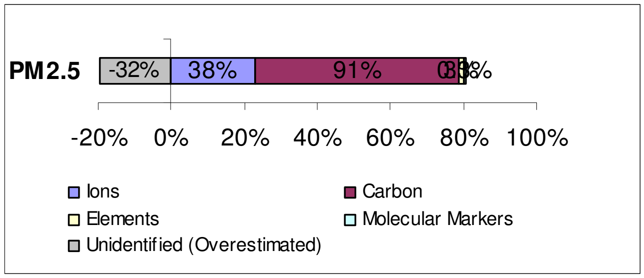
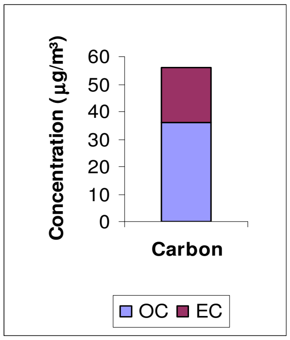
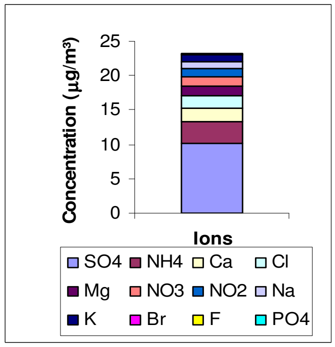


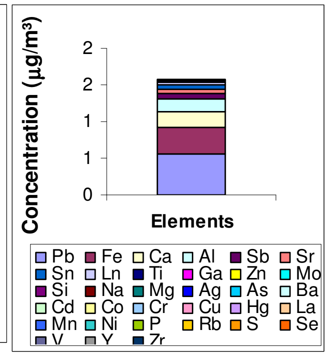
Figure:2.29 Chemical characterization – PM2.5 CSB

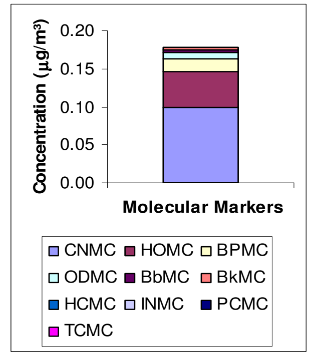
First Season



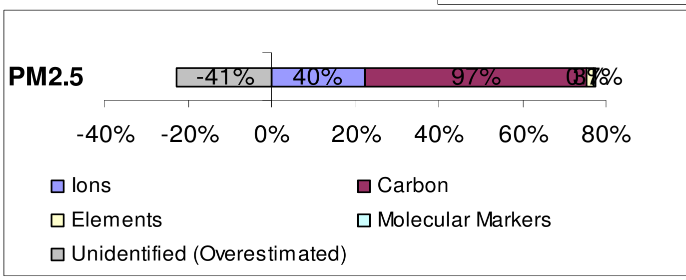


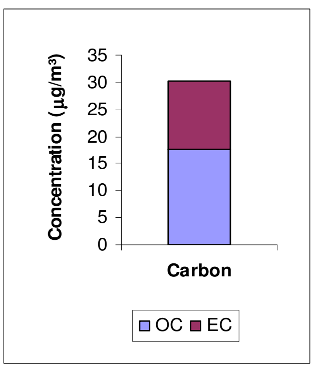


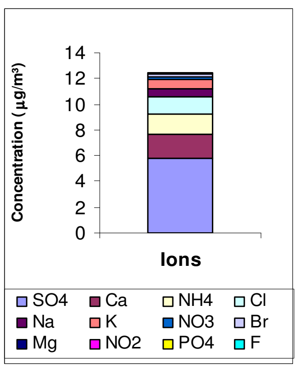


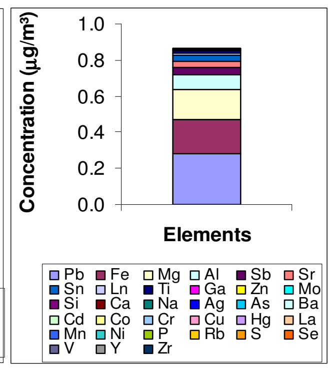


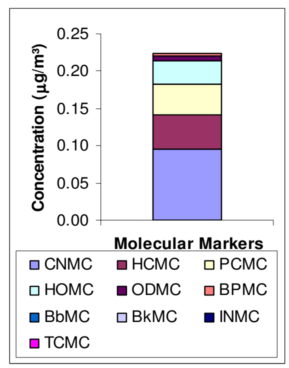
Second Season



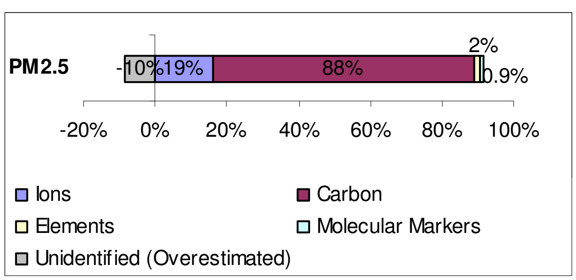


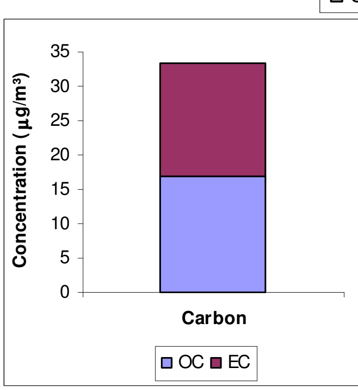


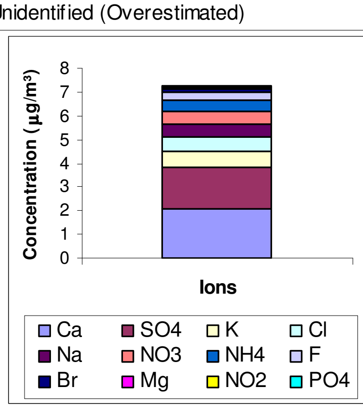


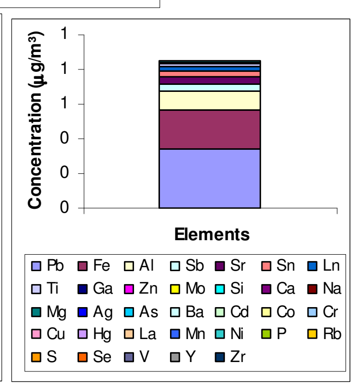


Third Season









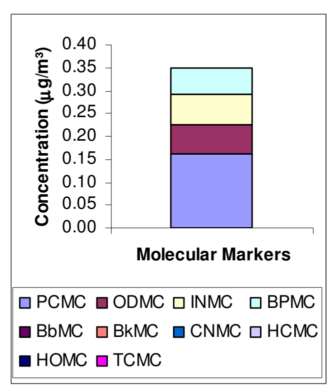
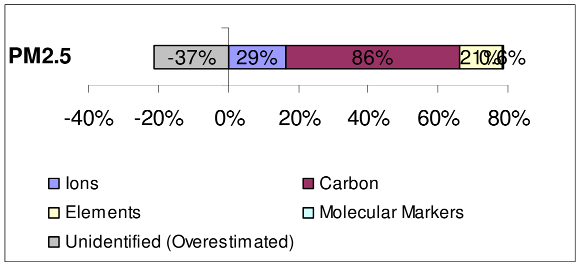
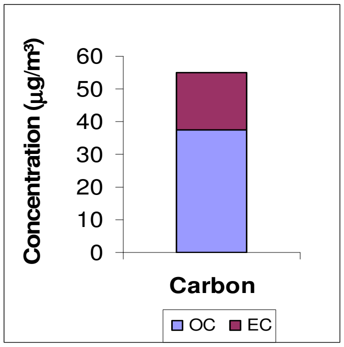
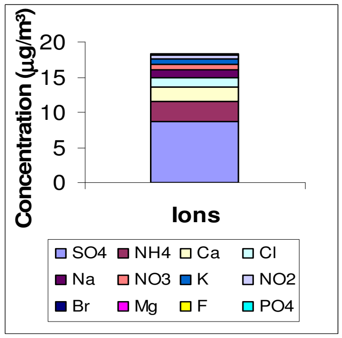


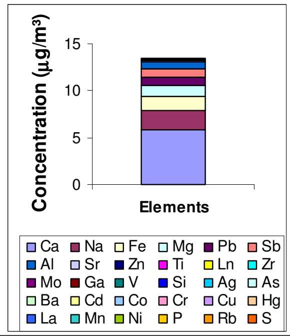
Figure:2.30 Chemical characterization – PM2.5 Victoria Road

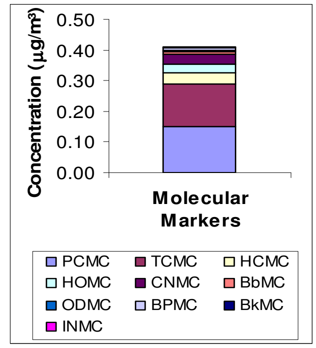


First Season

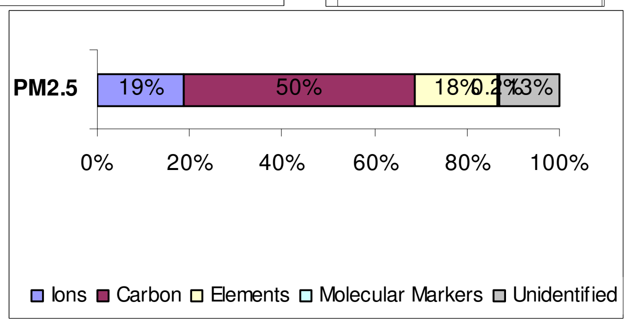


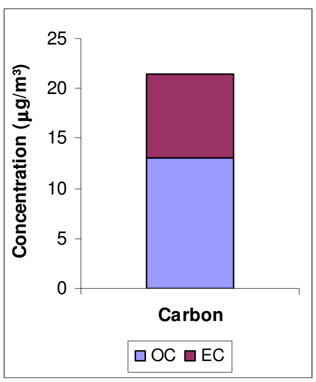


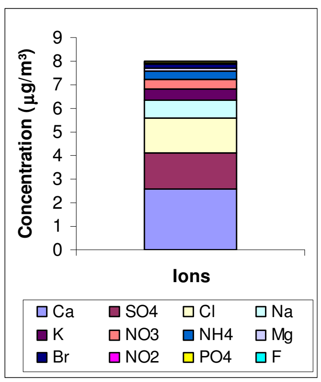


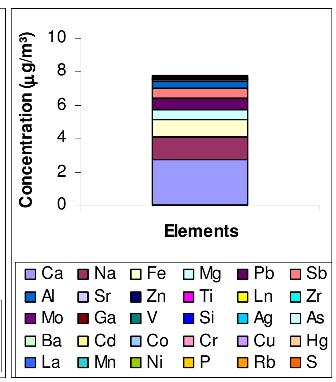


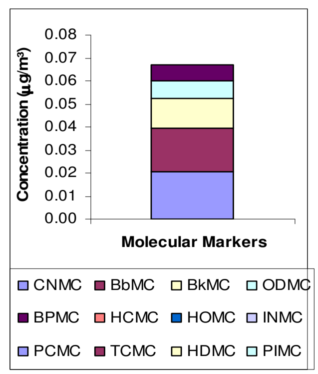
Second Season



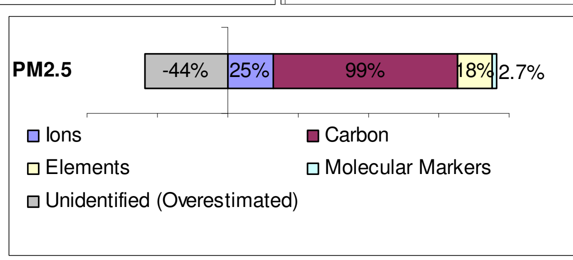


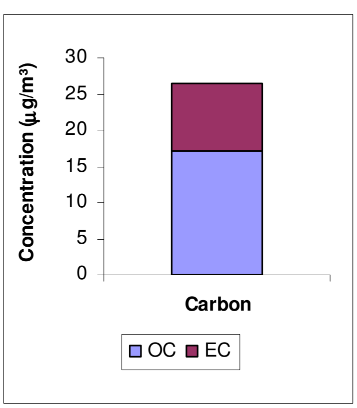


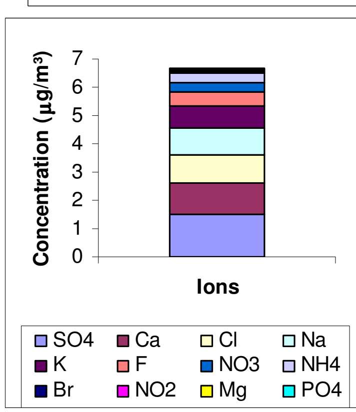


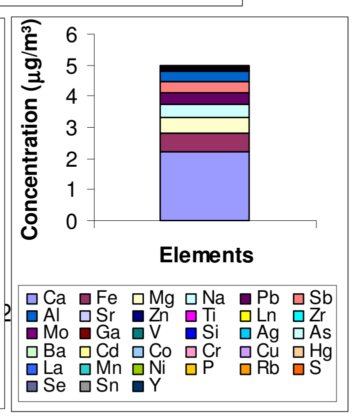


Third Season









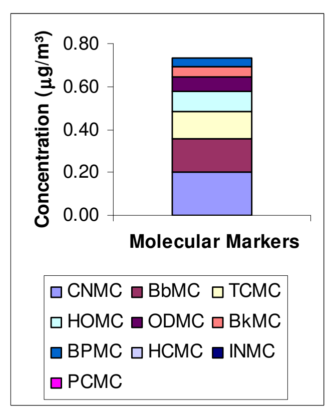
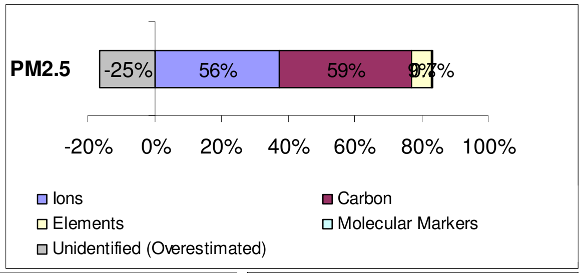
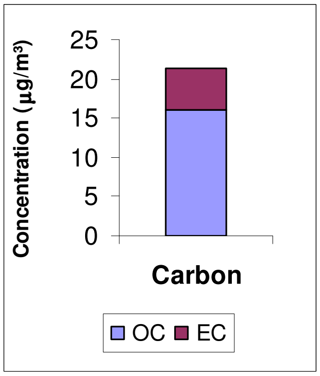
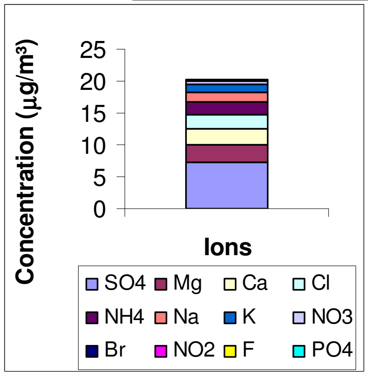


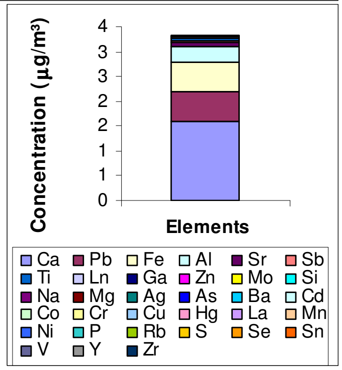
Figure:2.31 Chemical characterization – PM2.5 IGICH

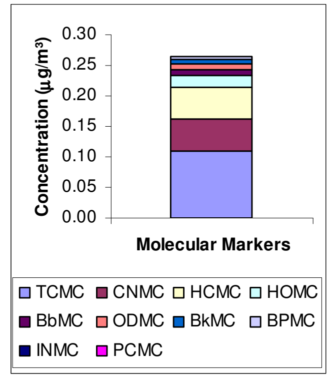
First Season



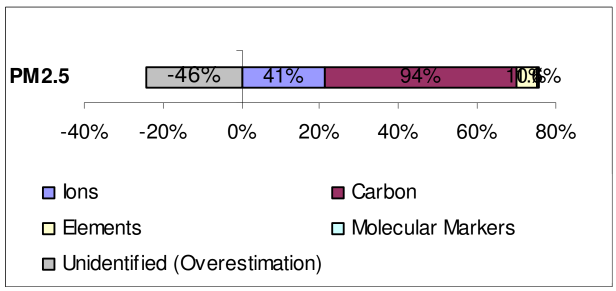


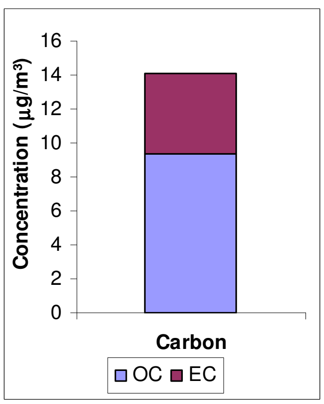


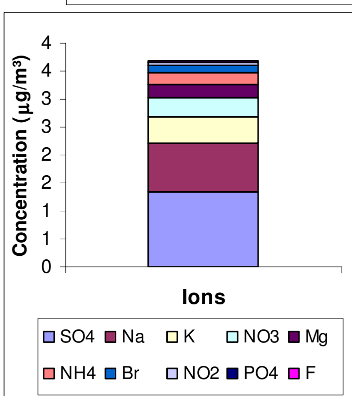


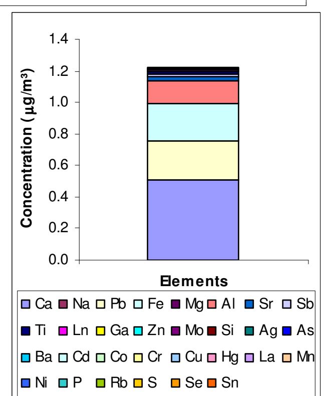


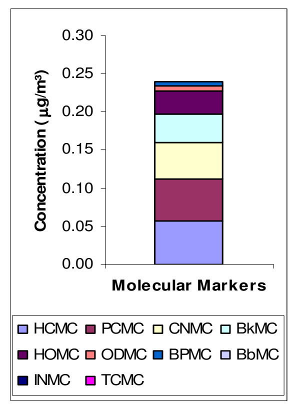
Second Season



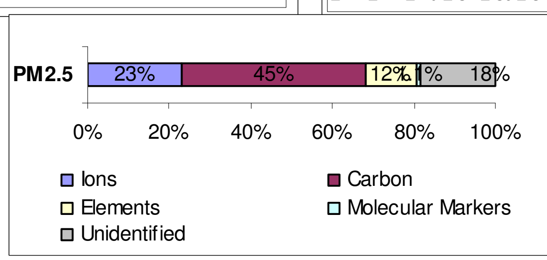


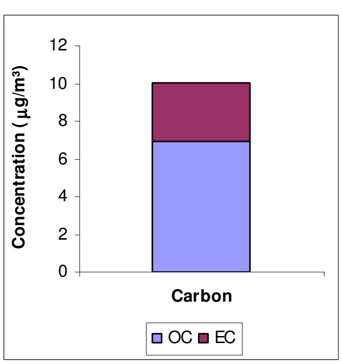


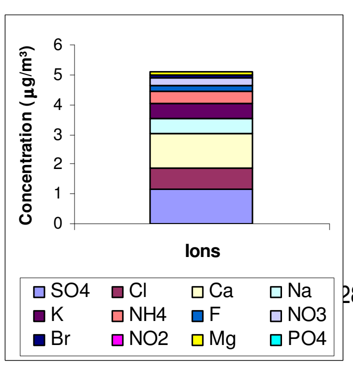


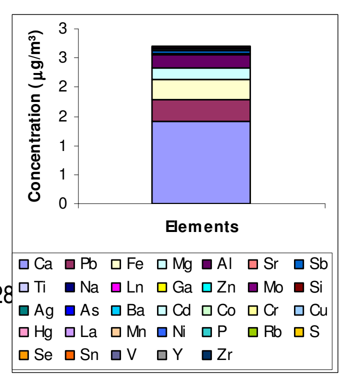


Third Season









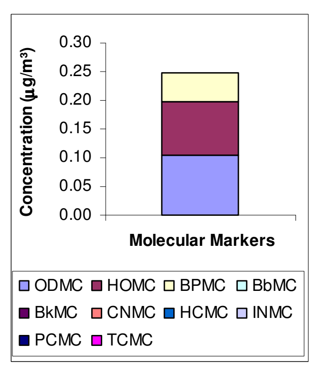
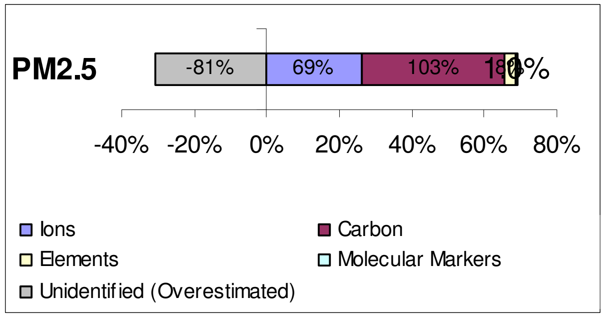
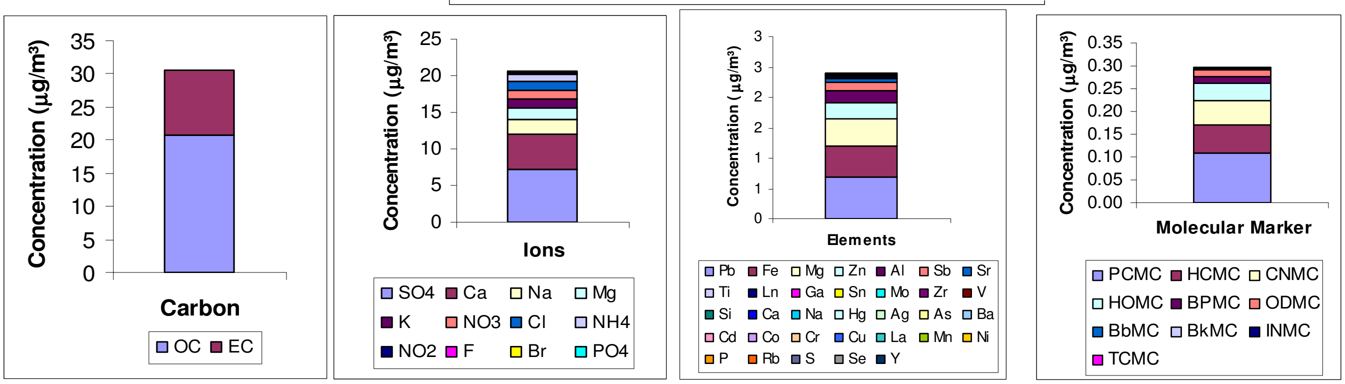


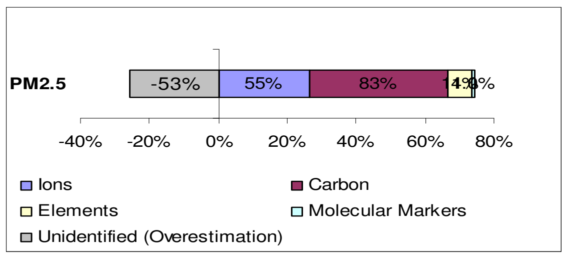
Figure:2.32 Chemical characterization – PM2.5 Peenya

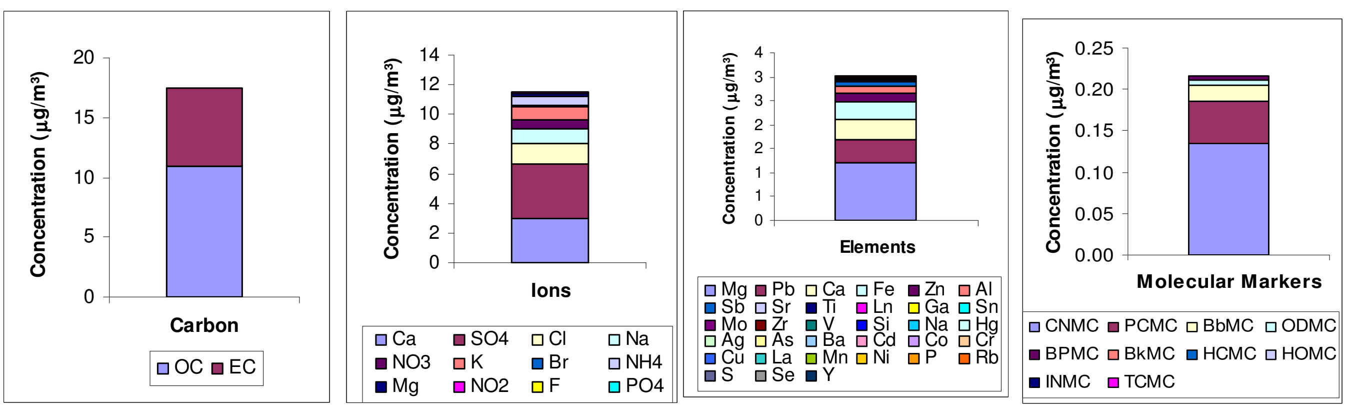
First season



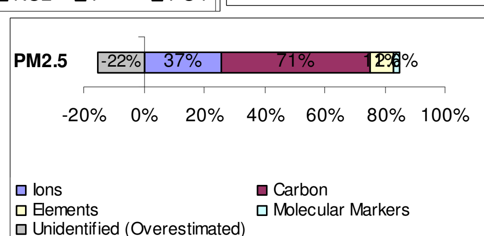


Second season





Third Season



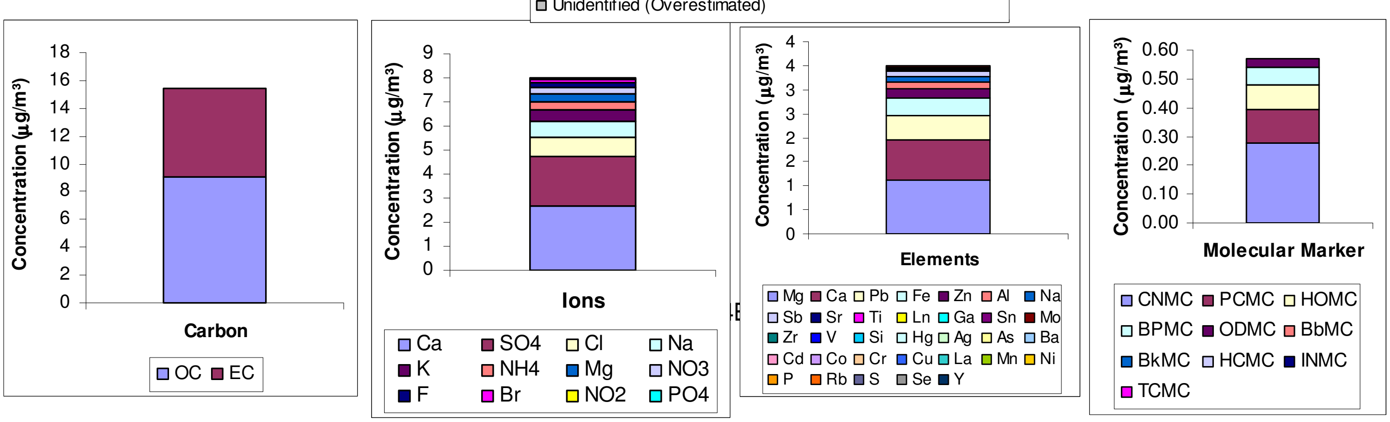
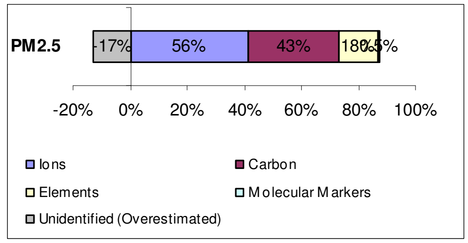
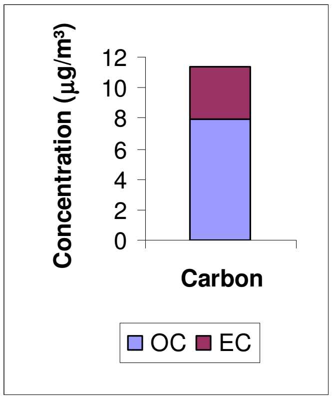
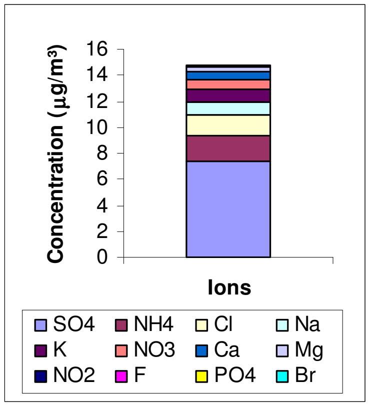


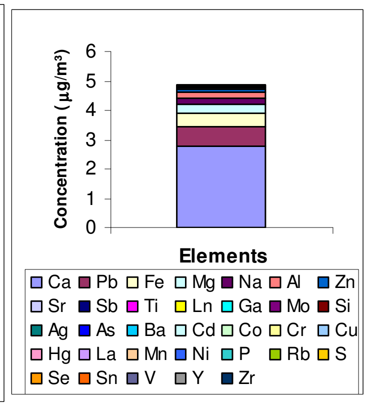
Figure:2.33 Chemical characterization – PM2.5 Background

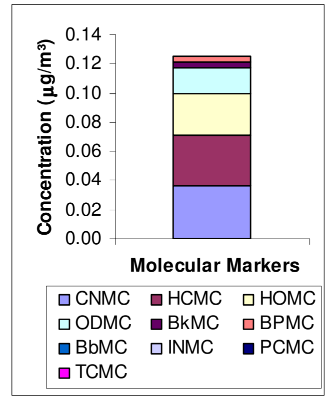
First season



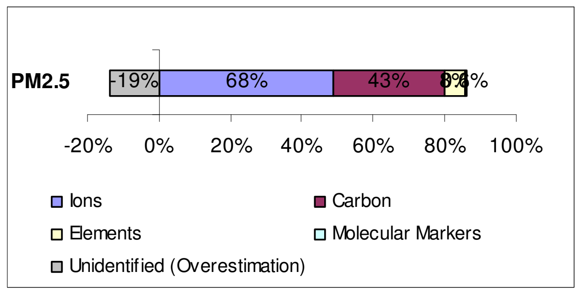


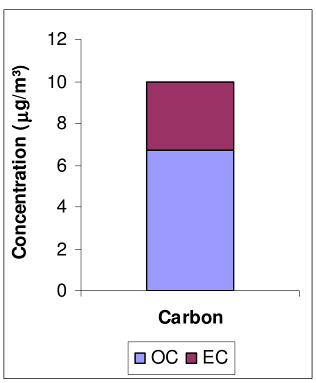


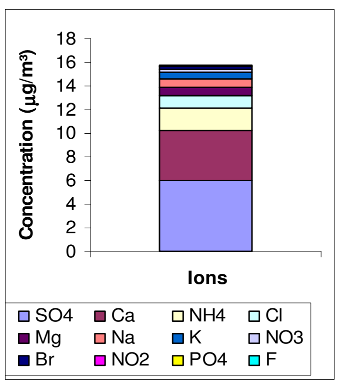


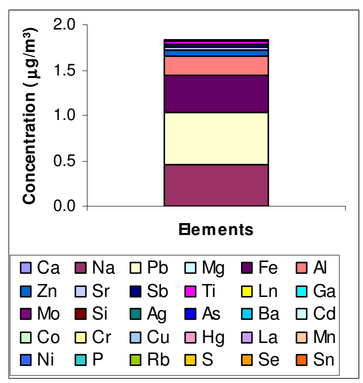


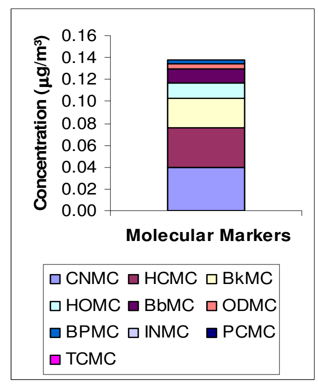
Second season



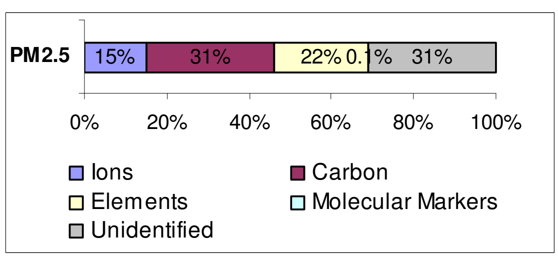


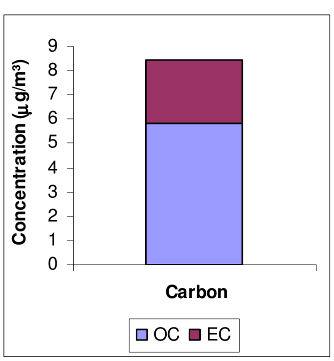


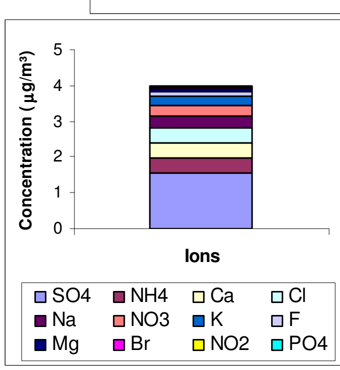


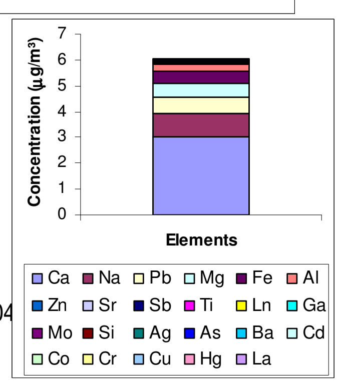


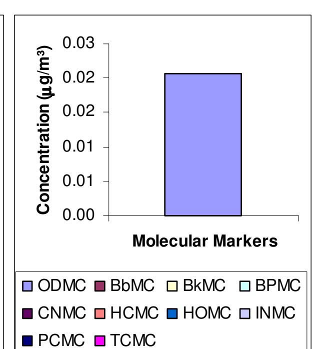
Third season











Total carbon and EC/ OC ratio for 3 seasons for $PM_{2.5}$ samples

Summary of total carbon concentrations (average for three seasons) and EC/OC ratios for $PM_{2.5}$ samples at different locations in Bangalore are shown in Figure 2.34 .Being kerbside locations, CSB and Victoria road show high carbon concentration. Background and Domlur residential locations have minimum carbon concentrations indicating lesser combustion activities. Moreover, as observed in the case of PM_{10} samples, here again, the EC/OC ratio is higher at CSB probably due to greater number of diesel vehicles.

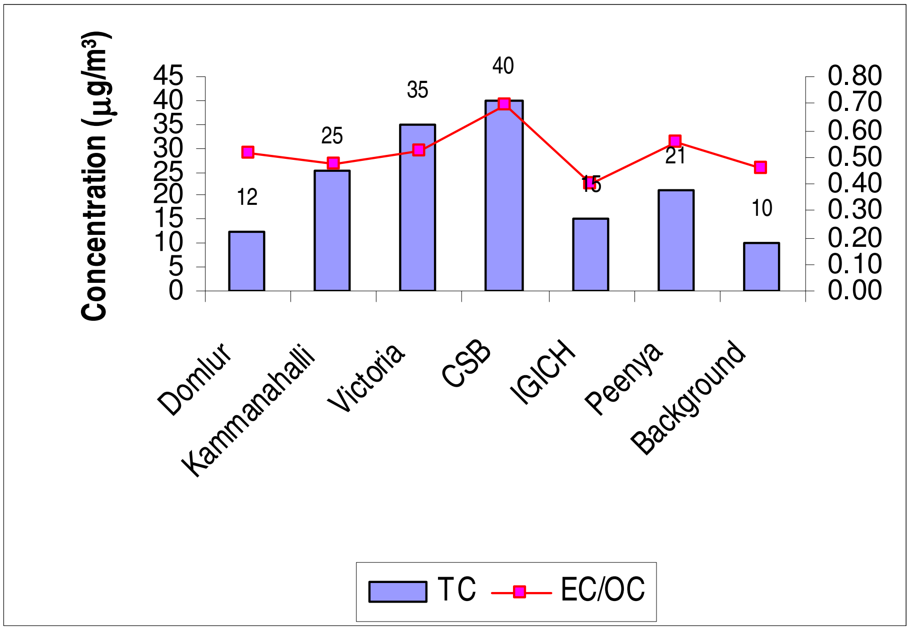


Figure **2.34** Total carbon content (µg/m³) and EC/OC ratios in $PM_{2.5}$ samples at various locations in Bangalore during three seasons

Mass distribution of chemical species in PM_{10} and $PM_{2.5}$ samples

Figures 2.35 and 2.36 show the mass distribution of chemical species (carbon, elements, ions, and molecular markers) in PM_{10} and $PM_{2.5}$ samples averaged across the three seasons. The share of carbon in the total PM_{10} and $PM_{2.5}$ mass is highest at kerbside locations (CSB and Victoria road) and lowest at background and Domlur residential location. Kerbside locations show a significant increase in the carbon content in $PM_{2.5}$ samples as compared to PM_{10} samples indicating enhanced contribution in the finer particle range by sources such as vehicles. The share of ions in the total mass is maximum at background location showing enhanced contribution by secondary particles and also indicating lesser influence of combustion sources. Also, the share of ions increases in $PM_{2.5}$ as compared to PM_{10}. The share of elements decreases at most of the locations in the case of $PM_{2.5}$ as compared to PM_{10} probably depicts lesser influence of coarser elements.

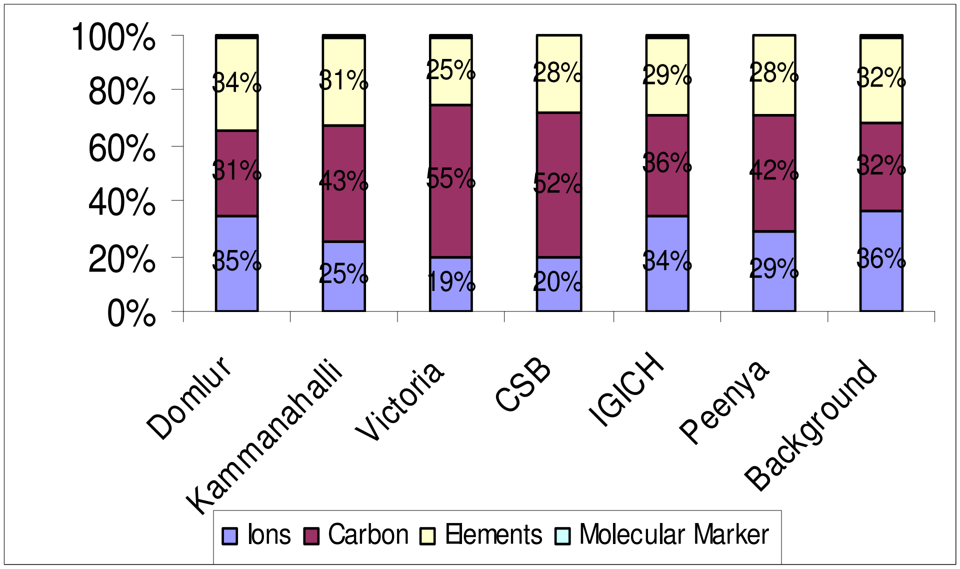


Figure **2.35** Mass distribution of chemical species in PM_{10} samples averaged across the three seasons

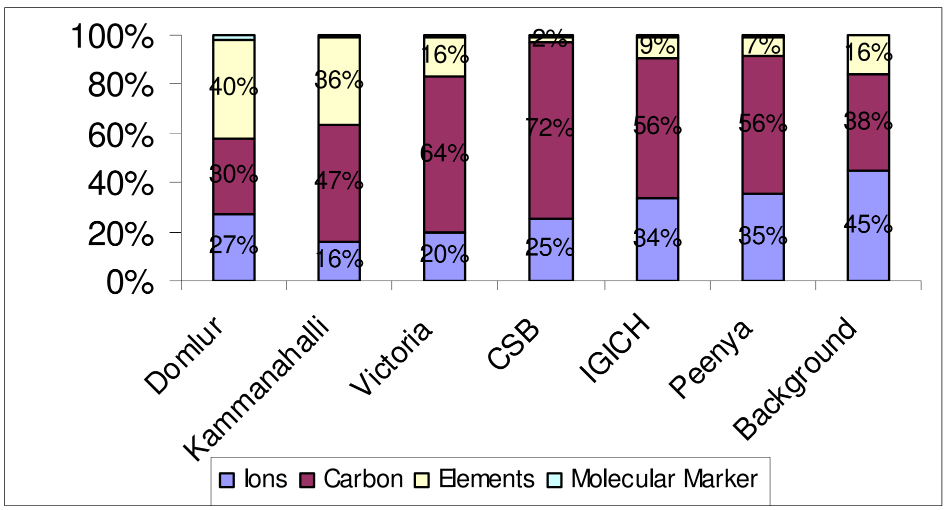


Figure **2.36** Mass distribution of chemical species in PM2.5 samples averaged across the three seasons

2.5 Conclusions

Air quality monitoring was carried out for three seasons at seven air quality monitoring stations. SPM concentrations have violated the standards at kerbside locations (CSB and Victoria road) as well as at industrial location (Peenya) and one residential location (Kammanahalli). RSPM values are also exceeding the standard at a traffic location (Victoria road) and are close to the standard at the other traffic location (CSB), industrial (Peenya) and residential location (Kammanahalli). $PM_{2.5}$ values show daily exceedences at traffic location (CSB and Victoria road) and on an average are close to the CPCB standard (proposed). For Domlur and Background location, particulate matter concentrations remained under the standards in all the three seasons.

In case of gaseous pollutants, SO_2 concentrations are well within limits for three seasons at all the seven air quality monitoring locations, while NO_2 concentrations violate the standards at kerbside locations, CSB and Victoria road in some seasons. On an average the NO_2 values are close to the standards at the traffic locations. O_3 concentrations are observed to be relatively higher at the background location and Domlur (residential) and IGICH (hospital) locations. CO concentrations generally violate the prescribed CPCB standards at all locations except at Background and Domlur. CO and O_3 show consistent diurnal variation during many days.

Chemical characterization of carbon, ions, elements and molecular markers of PM_{10} and $PM_{2.5}$ samples have been carried for each site for three seasons. Total carbon values were high at kerbside locations (CSB and Victoria road). Also, the EC/OC ratio is highest at CSB showing higher diesel consumption. Calcium ion concentration was observed to be dominant at all the locations. Also, sodium, and potassium were present in significant quantities at certain locations.

High concentrations of sulphate are measured at all the locations. Also, significant concentrations of chloride were also observed at most of the locations. Higher levels were observed for elements such as Na, Fe, Ca, and Mg, in all the three seasons. Al, Si and Zn were also observed at certain locations in different seasons.

Amongst the molecular marker, in general, Coronene, Hentriacontane, Tritriacontane and Hopane were found to be relatively higher.

CHAPTER 3 Emission Inventory

3.0 Introduction

An air emission inventory is an essential planning tool in environmental management of the airshed. Emission inventory is the record of the estimated amount of pollutants emitted from mobile and stationary sources present in a region, over a specific period of time. The major sources identified in the city are transport, industries, power plants, Diesel Generator (DG) sets, domestic, road dust emissions and construction activities. Sector-wise description of activity levels, methodology and emission factors used, and emission loads are presented in subsequent sections.

General methodology

Overall approach for the preparation of emission inventory has been presented in Figure 3.1. Prominent sources in the whole city as well as in the zones of influence around the monitoring stations were identified as per the Point, Line and Area source categorisation. Information has been collected from secondary sources to establish a baseline profile for the city. Primary surveys were conducted for each sector i.e. Transport, Domestic, Industries, and others to estimate activity levels across various sectors. Data collected from secondary sources and primary surveys were complied to convert them into usable forms for preparation of emission inventory. Emission factors for transport sector were adopted from ARAI report. However, for other sources CPCB's suggested emissions factors were used. Emission inventory has been prepared for the base year 2007.

Emission inventory has been prepared for the city as a whole as well as for the 2x2 km^2 zone of influence around the monitoring sites. Bangalore city (as per survey of India map, 2002) has been divided into grids of 2x2 km^2. Emissions are allocated to each of the grid using GIS tools (ArcInfo) for further input to the air quality models.

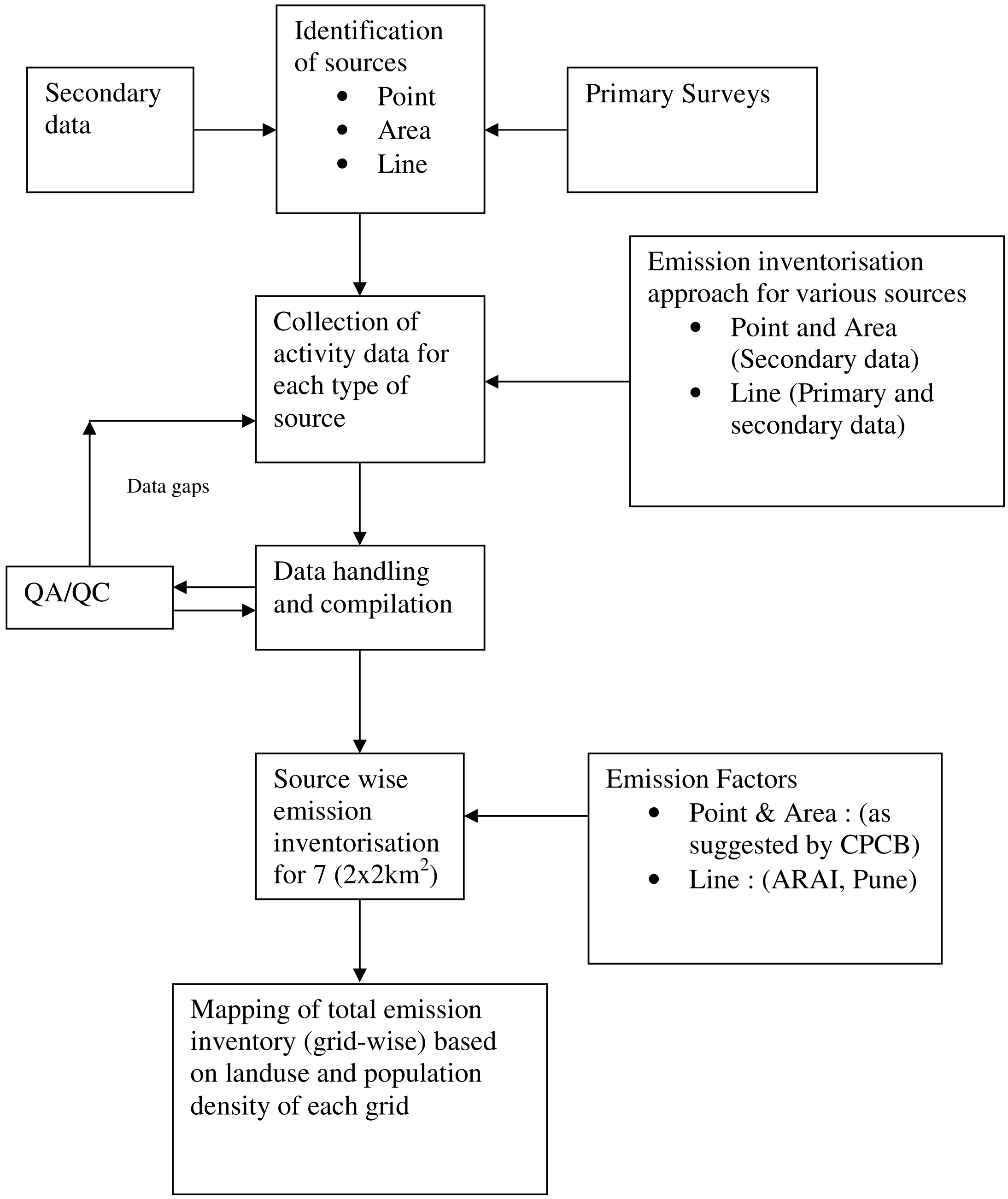


Figure **3.1** Overall approach for emission inventorisation

Detailed emission inventory is prepared for 7 zones of influence around the monitoring locations using the information collected during extensive primary surveys. However, for rest of the city, the following approach is adopted:

a) Land use patterns and population densities have been identified for all of the 156 grids

b) Each grid is compared (in terms of land use and population density) with 7 monitoring locations, to ascertain its resemblance with one of them.
c) Detailed information (such as fuel consumption patterns, traffic counts, construction activities, DG sets) of the resembling monitoring location is applied to the corresponding grid to estimate its emission loads. However, basic information of the grid such as population, road length etc has been used in calculation to keep its local identity.

Source wise emissions inventory is presented in subsequent sections.

3.1 Area sources

3.1.1 Bakery, hotel & restaurants

The approach towards emission inventorisation of cooking centres (bakery, hotel and restaurants) is based on the fuel consumption data collected in primary survey and use of emission factors. Emission factors from CPCB document on non-vehicular emission factors compiled under Air Quality Monitoring, Emission Inventory and Source Apportionment Studies for Indian Cities were used.

Data was collected in 2x2 sq km zone on the number of cooking centers and the fuel usage pattern. Analysis of the pattern of fuel consumption data reveals that LPG is the major fuel type used for cooking purposes in above mentioned cooking centers. In addition, secondary data on the number of cooking centers at the city level was collected from Bruhat Bengaluru Mahanagara Palike (BBMP) authorities.

The methodology followed for emission inventorisation is based on activity level data i.e., fuel consumption per month per cooking center and the number of cooking center.

Emissions = Fuel consumption x emissions factor

Emission estimations

Based on the data collected during primary survey at the various sampling sites, emissions for cooking centres falling in 2 x 2 sq km area of 7 sampling locations have been estimated

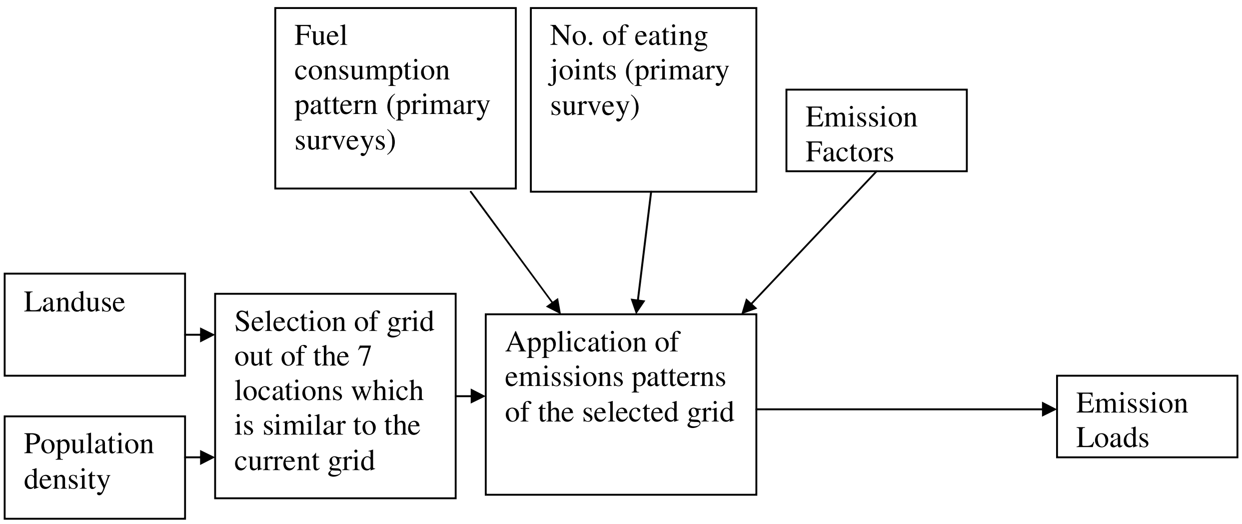
The estimated emission load is shown in Table 3.1 for the 2x2 sq Km area of seven sampling locations.

Table 3.1 Emission load (Kg/D) from cooking centers (bakery, hotel and restaurants) in 2x2 Km^2 area around each sampling location

Location	Background Kannamangala	Central Silk Board	Domlur	Kammanahalli	Peenya	Victoria Road	IGICH (HOSPITAL)
PM_{10}	0.003	1.35	1.98	1.16	0.614	2.84	2.09
SO_2	0.001	0.26	0.38	0.27	0.12	0.54	0.60

NO_X	0.005	2.31	3.39	1.85	1.05	4.87	2.67

City level inventory for 156 (2x2) grids have been prepared using the information of 7 zones of influence around the monitoring locations. Each grid is identified in terms of its resemblance to one of the monitoring grid and information of that monitoring grid is applied to it. Overall approach followed is



Based on the approach the estimated city level emission loads from the sector shown in Table 3.2 .

Table 3.2 Emission load (Kg/D) from cooking centers (bakery, hotel and restaurants) at the City level

Location	PM_{10}	SO_2	NO_X
City level	121.8	24.9	202.2

3.1.2 Crematoria

In Bangalore out of total seven crematoria which are electrically operated none of this is falling in 2 x 2 sq Km area of the seven sampling locations.

3.1.3 & 3.1.4 Open eat outs and hotel & restaurants

Covered under the section 3.1.1.

3.1.5 Domestic sector

Population and study area

Bangalore, the capital city of Karnataka, is the fifth biggest city in India with a population of about 5.7 million as in 2001 (Census of India, 2001). The population has increased from 2.4

million in 1980 to 5.7 million in 2001 due to urbanization of rural areas around the city and further growth of the core city itself owing to the incorporation of the surrounding areas on a continuous basis over the years.

It is worth mentioning here that the concept of urban agglomeration for Bangalore was introduced in 1971 Census. The major constituent units of BUA as in 2001 include Bangalore Municipal Corporation (including its outgrowths), 7 CMCs and their outgrowths (Dasarahalli, Pattanagere, Bommanahalli, Mahadevapura, Krishnarajapura, Byatarayanapura, and Yelahanka), 6 Census Towns (Herohalli, Uttarahalli, Konanakunte, Gottikere, Kothnur, Hunasamaranahalli) and 1 Town Municipal Corporation (TMC) namely Kengeri.

Domestic sector in Bangalore

Within Bangalore Municipal Corporation area, Bangalore city's population is divided in 100 wards as of 2006-07 and is shown in the Table 3.3 below.

Table 3.3 Distribution of ward-wise population (estimated for 2007)

Name	Population	Name	Population	Name	Population	Name	Population
Ward No.1	36827	Ward No.26	49979	Ward No.51	52613	Ward No.76	48590
Ward No.2	48137	Ward No.27	43718	Ward No.52	47517	Ward No.77	43241
Ward No.3	62198	Ward No.28	42442	Ward No.53	82833	Ward No.78	49340
Ward No.4	72894	Ward No.29	54239	Ward No.54	110106	Ward No.79	46622
Ward No.5	48353	Ward No.30	52662	Ward No.55	149784	Ward No.80	47545
Ward No.6	51599	Ward No.31	37402	Ward No.56	116338	Ward No.81	52859
Ward No.7	50316	Ward No.32	53363	Ward No.57	85156	Ward No.82	44451
Ward No.8	54197	Ward No.33	54456	Ward No.58	53874	Ward No.83	66967
Ward No.9	51841	Ward No.34	59121	Ward No.59	46122	Ward No.84	42620
Ward No.10	46241	Ward No.35	53475	Ward No.60	52378	Ward No.85	46562
Ward No.11	47175	Ward No.36	75074	Ward No.61	52641	Ward No.86	52749
Ward No.12	57891	Ward No.37	29177	Ward No.62	71868	Ward No.87	75327
Ward No.13	51626	Ward No.38	20783	Ward No.63	65265	Ward No.88	34783
Ward No.14	49194	Ward No.39	53937	Ward No.64	84096	Ward No.89	43825
Ward No.15	49310	Ward No.40	34138	Ward No.65	68684	Ward No.90	57874
Ward No.16	81702	Ward No.41	68952	Ward No.66	87706	Ward No.91	56070
Ward No.17	39009	Ward No.42	57595	Ward No.67	61201	Ward No.92	52852
Ward No.18	34302	Ward No.43	79862	Ward No.68	54614	Ward No.93	68728
Ward No.19	30952	Ward No.44	58487	Ward No.69	69396	Ward No.94	81145
Ward No.20	37472	Ward No.45	54395	Ward No.70	46214	Ward No.95	112545
Ward No.21	63537	Ward No.46	54267	Ward No.71	53021	Ward No.96	98774
Ward No.22	55261	Ward No.47	43890	Ward No.72	59106	Ward No.97	50691
Ward No.23	47258	Ward No.48	57190	Ward No.73	56349	Ward No.98	70018
Ward No.24	46098	Ward No.49	54733	Ward No.74	53061	Ward No.99	43387
Ward No.25	47186	Ward No.50	42498	Ward No.75	48017	Ward No.100	69641
Outside BMP*	1865679					Total	7597256

* Outside BMP is the area in the study domain outside the BMP limits

Apart from this, using GIS, population has also been estimated, for the 2 x 2 sq km area of the 6 zones of influence around the monitoring stations in the city. Estimated population is presented Table 3.4.

Table 3.4 Population estimates for 2x2 km² zones of influence around the monitoring stations

Location	Population
CSB	68794
IGICH	110794
Domlur	59429
Victoria	105222
Kammanahalli	112180
Peenya	23109

Secondary data collected from the Census of India 2001 show the mix of different types of fuels used for the cooking purposes in the household sector in Bangalore Urban Agglomeration area. The comparison of results for the BMP region and the broader BUA region is presented in Figure 3.2.

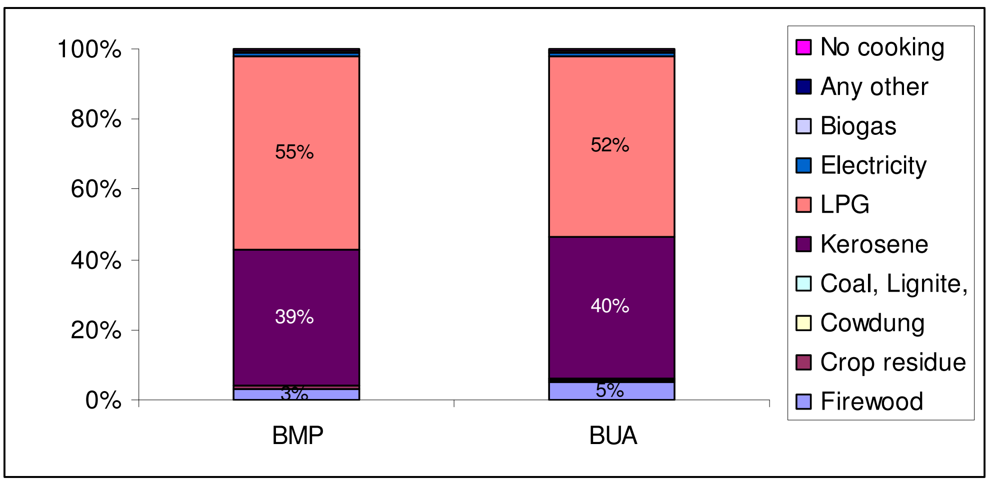


Figure **3.2** Percentage distribution of households by type of fuel used for cooking in Bangalore (BMP and BUA)
SOURCE Census, 2001

It shows that LPG is the most prominent fuel used for cooking with 52-55% share, followed by kerosene that is used by 39-40% of the households, and then firewood that is used by about 3-5% of the household. Rest of the people use crop residue, biogas and other fuels in small quantities.

Primary survey

In this study, analysis for domestic sector is carried out using both secondary data and the data collected during the primary surveys. Primary data is collected from 2X2 sq. km area of all 7 sites and door-to-door sample surveys conducted in these sites in order to collect data on fuel consumption, pattern of fuel usage and other details related with fuels used in domestic sector.

Based on property sizes (as surrogate to income classes), housing societies/bungalows are randomly selected for the surveys. Three broad categories (High, middle and low income categories) covering maximum of 650 houses per category were surveyed. This implies that total of around 1950 samples in residential sector were selected. The information on the use of DG sets was also collected.

Data on parameters such as fuel consumption, price of fuel, etc. from various households is collected to understand the use of fuel for various purposes such as cooking, heating, lighting, etc.

Primary data has been analysed by way of calculating the averages for various parameters collected from 3 income groups at different locations. It is seen that kerosene consumption is mainly in low-income houses. Figure 3.3 presents the average fuel consumption (kerosene or LPG) in Bangalore city.

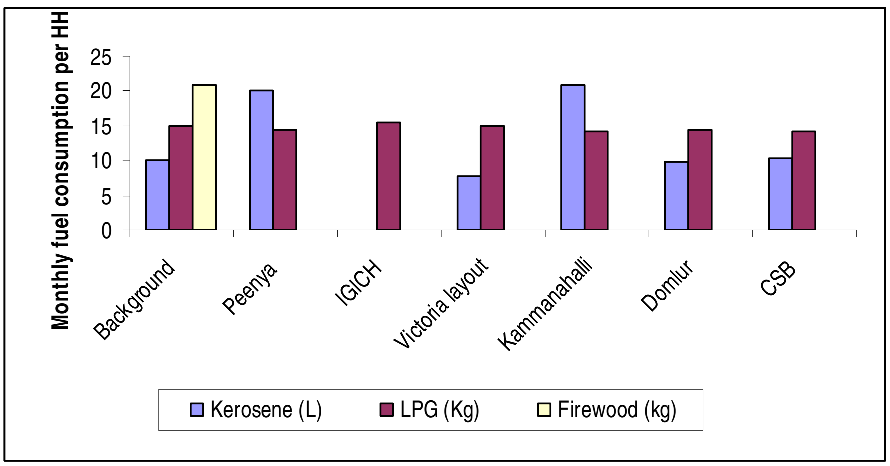


Figure **3.3** Average consumption of different fuels across different locations in Bangalore city

Figure 3.3 shows that LPG consumption varies from 14-16 kgs per month per household, while kerosene consumption varies from nil at IGICH to 21 litres in Kammanhalli. Firewood is used only in background location and not in the BMP region and therefore considered to be used only outside the BMP limits.

On the basis of fuel consumption patterns generated from the primary surveys and the census information about percentage of population using particular fuel , total fuel consumption is estimated

Total fuel consumption is estimated using :-
Fuel consumption (t) = Population x % Population using (t) fuel x per capita fuel consumption

Different fuel used estimated for the study domain is presented in Figure 3.4.

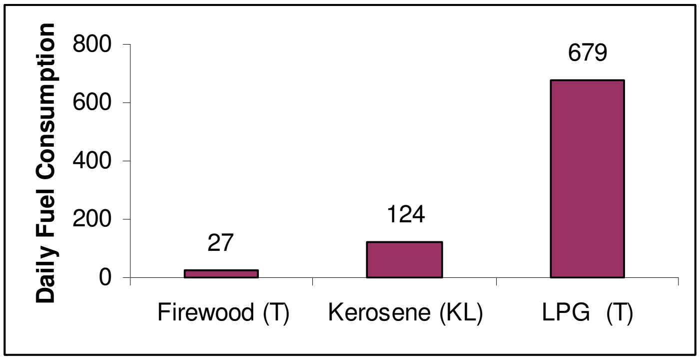


Figure **3.4** Total domestic fuel consumption in the study domain

Emission factors

Emission factors used in the current study are based on the fuel consumed and are presented in Table 3.5.

Table 3.5 Fuel based emission factors for domestic sector

Pollutant	Firewood(g/ kg)	Kerosene	LPG (kg/ t)
PM_{10}	6.3	1.95 (g/ litre)	2.1
NO_X	1.4	2.5 (g/ kg)	3.6
SO_2	0.48	4 (g/ litre)	0.4

SOURCE Reddy and Venkatraman, AP-42, USEPA 2000 (as suggested by CPCB)

Domestic emissions

Emission from domestic sector are estimated using: -

Emissions = Population X % households using fuel X per capita fuel consumption X Emission Factor

Emissions in the 7 zones of influence have been estimated (Table 3.6).

Table 3.6 Domestic emissions (T/d) from six zones of influences around the monitoring stations in Bangalore

	CSB	Domlur	IGICH	Kammanahalli	Peenya	Victoria	Background
PM_{10}	0.014	0.014	0.027	0.028	0.004	0.020	0.002
NO_X	0.023	0.024	0.046	0.045	0.007	0.035	
SO_2	0.004	0.003	0.005	0.018	0.001	0.004	

Emission inventory has been prepared for the seven monitoring grid locations. Grids of similar landuse were identified as discussed in section 3 , and fuel consumption patterns observed during the primary survey at the 7 locations were applied to the corresponding grids.

Population of each grid has been estimated using the GIS technique by allocation of population of different wards in proportion to their area falling in the grid as depicted in Figure 3.5.

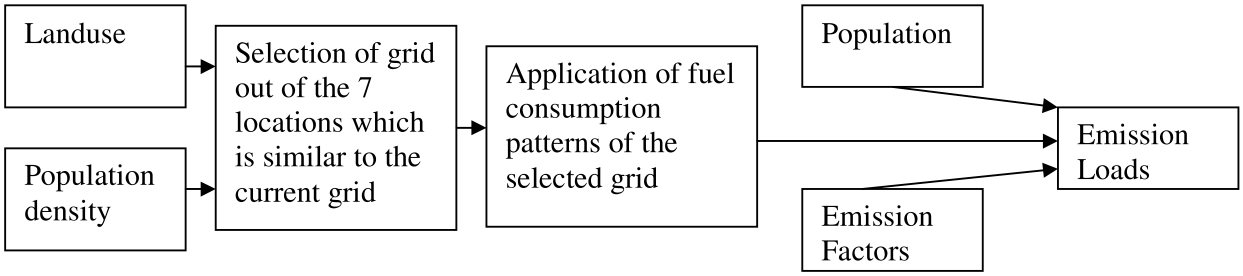


Figure **3.5** Landuse and population density approach for domestic emissions estimation

Based on above approach , total emission from the domestic sector in Bangalore city are shown in Table 3.7 .

Table 3.7 Fuel-wise emissions (T/d) of different pollutant from domestic sector

	Firewood	Kerosene	LPG	Total
PM_{10}	0.17	0.19	1.43	1.79
NO_X	0.04	0.25	2.45	2.73
SO_2	0.01	0.40	0.27	0.68

Grid-wise emission inventory for domestic sector is presented in Figure 3.6.

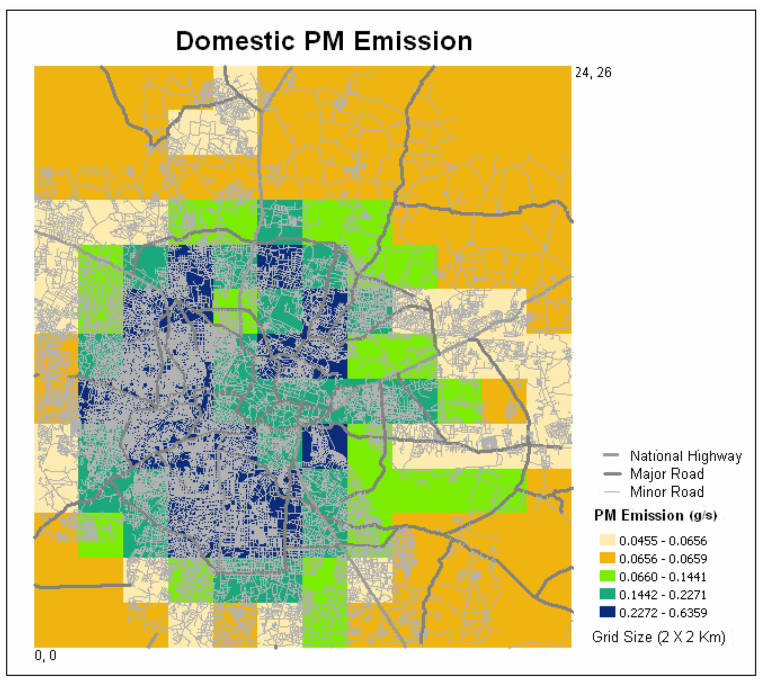


Figure **3.6** PM_{10} emissions (g/s) from domestic sector in various grids (2x2 km^2) across the study domain

Figure 3.6 reveals the presence of high domestic sector emissions in the centre of the study domain corresponding to Bangalore city.

3.1.6 Open burning

Not found significant

3.1.7 Paved road dust

Emissions from road dust resuspension due to movement of vehicles were calculated using the USEPA procedure (AP-42):-

Emission loads =VKT x EF
where

$$EF = \{ K\,(SL/2)^{0.65} .\,(W/3)^{1.5} - C\}\,(1 - P/4N)$$

EF= 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 travelling the road, and
C = emission factor for vehicle fleet exhaust, brake wear and tire wear.
P = number of "wet" days
N = number of days in the averaging.

Dust samples were collected from various roads of Bangalore city as per the USEPA procedure. Samples were tested for their silt content and then converted into the silt loadings (g/m^2). The average value of silt loading for different roads in Bangalore emerges out to be 0.36 g/m^2.

Two separate emission factors were developed separately for major and minor category of roads. Vehicle mix for Bangalore vehicles is studied and average weight ('W') of vehicles is calculated for both. Value of K for PM_{10} is 4.6. Number of wet days is adopted from the meteorological data i.e. 59.8 days in a year.

Emission inventory has been prepared for the seven monitoring grid locations and is presented in Table 3.8.

Table 3.8 Road dust emissions (T/d) for different locations

	CSB	Domlur	IGICH	Kammanahalli	Peenya	Victoria	Background
Road dust	0.42	0.06	0.07	0.05	0.07	0.08	0.012

Road dust emission intensities (g/s/km) were estimated for the 7 zones of influence. Grids of similar landuse were identified as discussed in section 3 , and the same emission intensities were applied to the corresponding grids

Road length (Major and minor) in each grid has been estimated using the GIS technique.

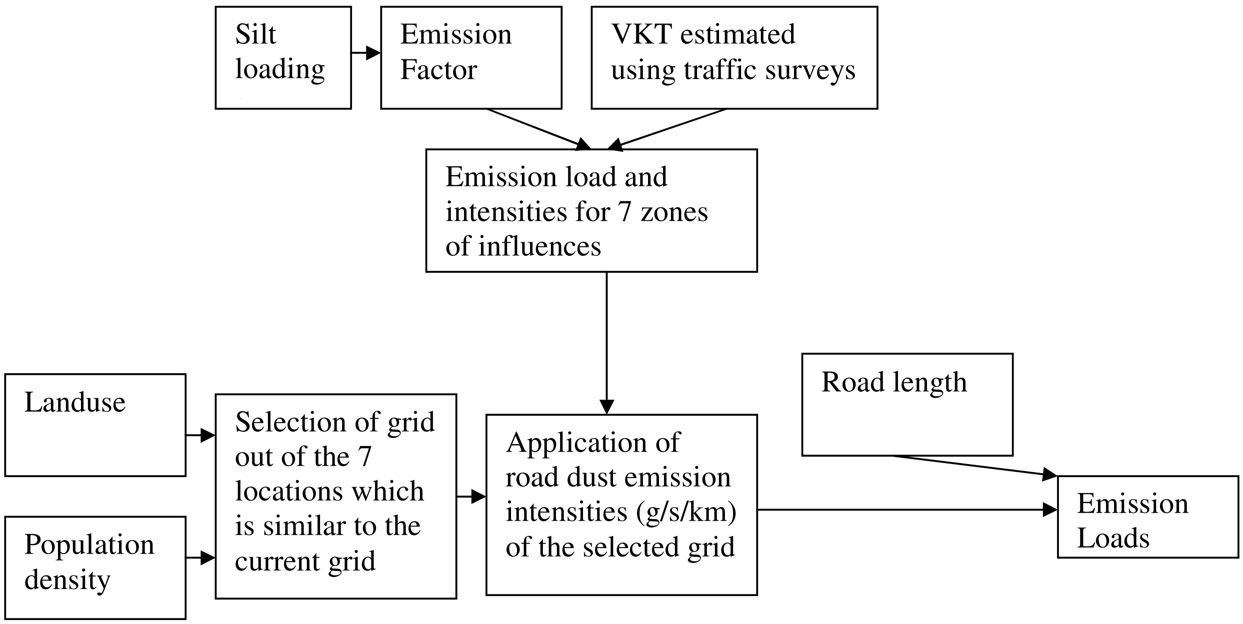


Figure **3.7** Landuse and population density approach for road dust emissions estimation

The emission estimated using the above approach are presented in Figure 3.8 .

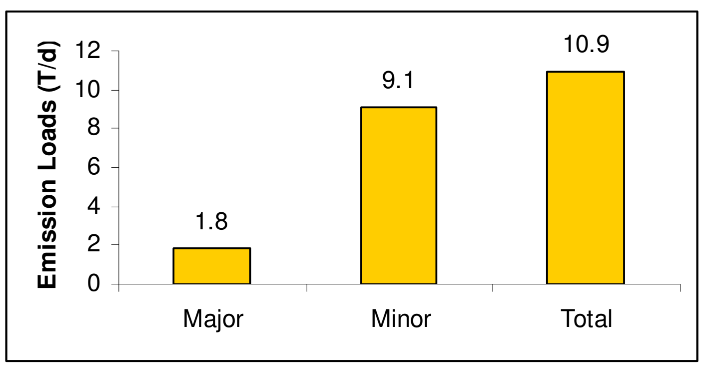


Figure 3.8 Road dust emission loads (T/d) for the study domain

Figure3.8 shows that a total of 10.9 tonnes of PM_{10} load is emitted daily due to movement of vehicles on paved roads. Out of total, 83% is the share of minor roads (which have more length), and 17% of major roads. Road dust emissions are allocated based on the road lengths in each grid in the study domain.

3.1.8 Construction activities

Bangalore is one of the major cities in India which has seen unprecedented growth in industries and services sector. Therefore, many construction activities are ongoing in this city. Thus, consideration of construction activities towards estimation of air pollution load becomes significant.

The approach towards emission inventorisation of construction activities is based on the area of the construction activity and use of emission factors. Emission factors from CPCB document on non-vehicular emission factors compiled under Air Quality Monitoring, Emission Inventory and Source Apportionment Studies for Indian Cities were used. Emission factors listed under the heading 'construction' were used.

Surveys were conducted in the 7 zones of influence and few high construction zones to collect information related to the area of the construction activities and duration of completion of this activity.

The methodology followed for emission inventorisation is based on the area and duration of construction activity and the emission factor.

Emissions (Tons of PM) = Area of construction activity x duration of activity x emissions factor

Emission estimations

Based on the data collected during primary survey at various sampling sites, emissions have been estimated for ongoing construction activities in 2 x 2 sq km area of each sampling location. Table 3.9 shows the emission load of PM_{10} around each sampling location.

Table 3.9 PM_{10} emission load (T/D) due to construction activities in 2x2 Km^2 area around each sampling location

Location	PM_{10}
Kammanahalli	0.05
IGICH	0.04
Victoria	0.04
CSB	0.05
Domlur	0.03
Peenya	0.02
BG	0.01
Whitefield	0.31

Three high construction zones were identified in the city from the vision document (on the basis of highest increase in residential+commercial area between existing and proposed landuse patterns). The areas are Whitefield, Tanasandra, and Anjanapura. Also, three commercial zones namely Petta, Majestic, Vastanagar were identified in the heart of the city where construction activities were found to be high.

For city level projections, emissions estimated for Whitefield are projected in grids identified in high construction zones. However, for other grids, landuse and population densities were used to identify the monitoring location resembling to the grid and same emissions were applied.

The total city level load from the construction sector is 7.73 T/d.

Grid-wise distribution of the load is presented in Figure 3.9 .

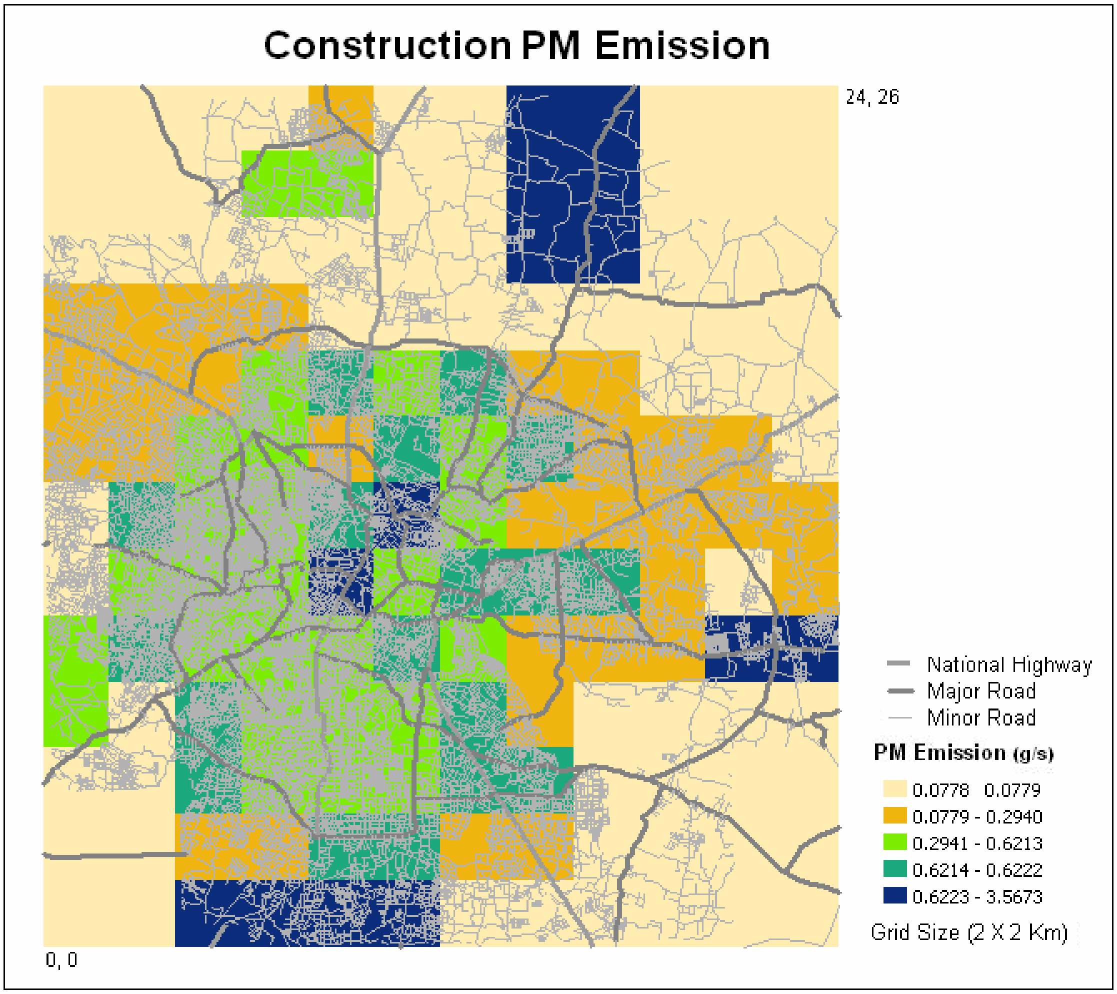


Figure **3.9** Grid-wise distribution of the PM_{10} load from construction activities

3.1.9,10 & 11 Locomotive, aircraft

Aircraft emissions for PM_{10} were estimated to be 0.05 T/d. Since these were just 0.09% of the total PM_{10} emissions, and also due to the fact that the new airport lies outside the study domain, these were not considered for further analysis. Likewise, locomotive emissions for PM_{10} worked out to be low, i.e., 0.17 T/d (0.3% of total) and hence were not considered for further analysis.

3.1.12 Other sources as per local inventory

DG sets (Domestic)

Information on the use of back-up power during power failures from the grid was also collected from the 7 sites. On an average, the percentage of households having DG sets was estimated to be 6%. The information collected during the primary surveys are tabulated in Table 3.10.

Table 3.10 DG sets information collected during primary survey at seven sampling locations

	Kammanhalli	IGICH	Victoria	CSB	Domlur	Peenya	BG	Average
% DG sets	5%	6%	4%	18%	6%	0%	0%	6%
Capacity (KVA)	1.08	1.27	1.20	1.15	1.10			1.16
Working Hours	1.00	1.00	1.00	1.16	1.00			1.03

Total number of DG sets is estimated for each ward based on the survey results and total installed capacity is evaluated using the working hour data. Therefore total daily energy consumption is estimated based on:-

Energy (Kw-hr) = Installed capacity x Working Hours

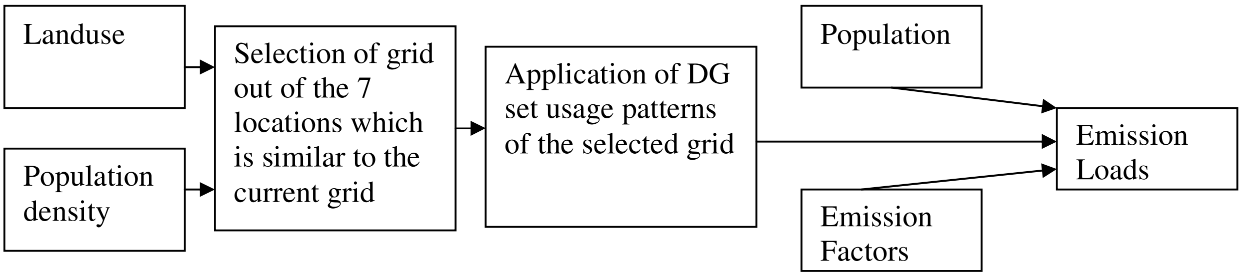
Emissions = Energy (Kw-hr) x Emission Factors (Kg/Kw-hr)

Emissions from DG sets (table 3.11) are estimated using emissions factors suggested by CPCB.

Table 3.11 Emission (Kg/d) of domestic DG sets in zones of influences around the 7 monitoring grids

Location	PM_{10}	NO_X	SO_2
Domlur	0.38	5.73	0.31
Kammanahalli	0.58	8.85	0.48
Victoria Road	0.48	7.38	0.40
CSB	1.58	24.13	1.30
IGICH	0.81	12.33	0.66
Peenya	0.00	0.00	0.00
Background	0.00	0.00	0.00

Following methodology is applied to estimate the city level emissions (i.e. for all 156 2x2 grids across the city)



* DG set usage patterns include a) % households using DG sets, b) capacity of DG sets , and c) working hours

Emissions from DG sets for city level are tabulated below (Table 3.12).

Table 3.12 Estimated total emissions (Kg/d) for various pollutants from domestic DG sets for city level

	Emission Factor Kg/Kwhr	Emissions (Kg/d)
PM_{10}	0.000438	58.5
NO_X	0.006688	892.6
SO_2	0.000359	48.0

DG sets (Commercial)

Data for DG sets more than 12 KVA has been collected from chief electrical inspectorate. DG sets are manually marked in each of the 156 grids. Total installed capacity is estimated to be about 3200 MVA. Similar working hours i.e. 1 hrs/day has been assumed for this case also (as taken for domestic sets). Emission factors for large stationary DG sets (suggested by CPCB) were used to estimate the emissions.

Energy (Kw-hr/d) = Installed capacity (Kw) x Working Hours (hr/d)

Emissions (Kg/d) = Energy (Kw-hr/d) x Emission Factors (Kg/Kw-hr)

Estimated emissions from commercial DG sets are presented in Table 3.13.

Table 3.13 Estimated total emissions (T/d) for various pollutants from commercial DG sets for city level

PM_{10}	NO_X	SO_2
3.54	50.07	3.30

Emission (Kg/d) of commercial DG sets in zones of influences around the 7 monitoring grids is presented in Table 3.14.

Table 3.14 Emission (Kg/d) of commercial DG sets in zones of influences around the 7 monitoring grids

	CSB	IGICH	Domlur	Victoria	Kammanahalli	Peenya	Whitefield
PM_{10}	20.4	136.0	217.7	82.8	12.9	59.9	0.0
SO_2	19.0	126.8	202.9	77.2	12.0	55.8	0.0
NO_X	287.8	1922.5	3076.8	1170.5	181.9	846.1	0.0

Grid-wise DG set emissions are presented in Figure 3.10.

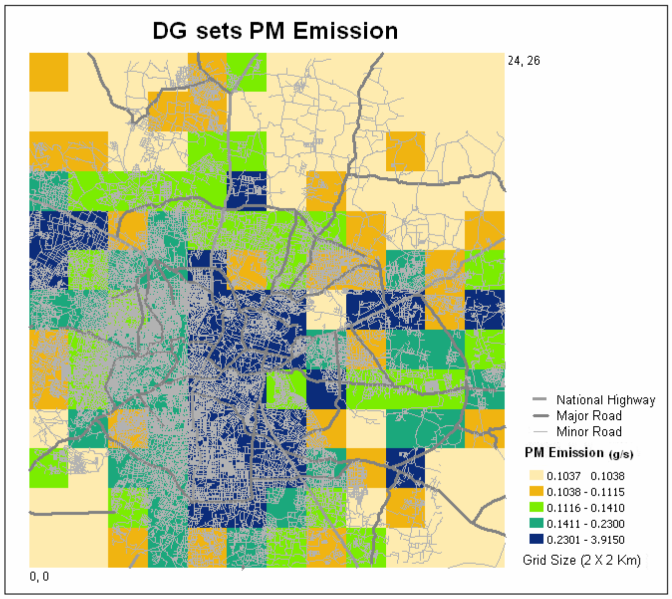


Figure **3.10** Grid-wise distribution of the PM_{10} emission load from DG Sets

3.1.13 Percentage distribution of area sources

See Section 3.4

3.2 Point sources

Information regarding industrial activities was collected from regional offices of Karnataka State Pollution Control Board (KSPCB) with respect to their jurisdictional areas falling in the study domain.

Accordingly, the quantitative data of industries was collected from eleven regional KSPCB offices for Bangalore Urban and Rural district. The jurisdiction area of nine offices out of total eleven KSPCB regional offices that fall in present study domain is shown in Figure 3.11.

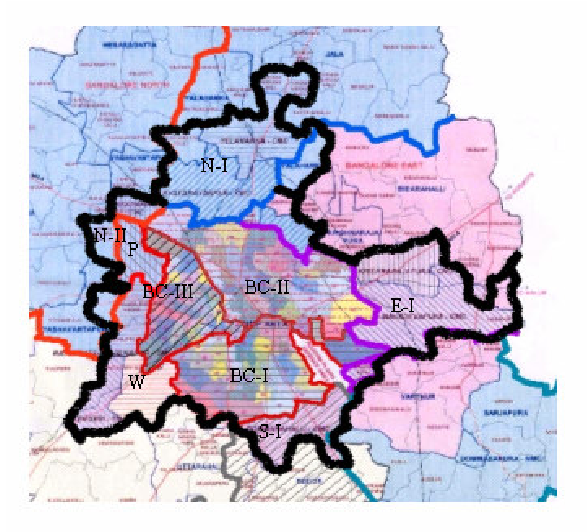


Figure **3.11** Map indicating jurisdiction of KSPCB regional offices* within Bangalore agglomeration area in 2001

*KSPCB regional offices: BC-I- Bangalore City 1, BC-II- Bangalore city-2, BC-III- Bangalore city-3, P- Peenya, N-I- North-1, E-I- East-1, W- West, N-II- North-2, S-I- South-1

3.2.1 Methodology

The approach towards emission inventorisation of point sources adopted in the study is based on the activity data (stack monitoring (characteristics) report/ fuel consumption estimates / product manufactured) compiled from KSPCB records and use of appropriate emission factors.

Further based upon discussions with KSPCB, large & medium industries under the red and orange category were selected for secondary data collection. In total, data was collected for more than 200 industries falling in jurisdictional area of KSPCB regional offices in Bangalore urban and rural district. The secondary data compiled from eleven KSPCB regional offices has been sorted to consider the industries falling in study domain. Consequently, total 168 industries were considered for emission inventory at city level. The distribution of these 168 industries is shown in Figure 3.12.

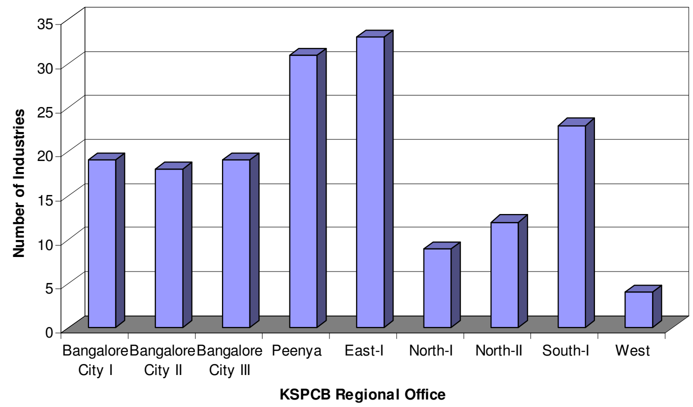


Figure **3.12** Distribution of industries from nine KSPCB regional offices

The methodology followed for emission inventorisation of point sources adopted in the study is based on the following approaches.

1) Actual emissions : Stack monitoring analysis of different industries conducted by KSPCB

Emissions = Flow Rate x Pollutant concentration x operating hrs

2) Fuel Consumption: The industries, for which actual emissions were not reported, were estimated on the basis of fuel consumed by them.

Emissions = Fuel consumption x emissions factor

For DG Sets (Kg/Kw-Hr) = DG set Capacity x Power Factor x Working Hours x Emission factor

3) Production: The industries for which actual emissions or fuel consumption were not reported, were estimated on the basis of their production capacities.

Emissions = Production x emissions factor per unit of production

3.2.2 Data analysis

Emission factors from CPCB document on non-vehicular emission factors compiled under Air Quality Monitoring, Emission Inventory and Source Apportionment Studies for Indian Cities were used. In a few cases, for estimation with product manufactured details, WHO (1993) emission factors were used where emission factors were not given in CPCB document.

3.2.3 Total emission estimation

City level

Emission loads have been estimated for the industries falling in the study area. Amongst these industries, the one having stack emissions greater than 15Kg/Day are considered as point sources for modelling purposes. Rest of the industrial emissions are considered to be distributed as an area source, since emissions are very low and in certain cases, the source characteristics are not available. The total PM_{10} emissions at the city level are 7.78 T/day (Table 3.15).

2x2 Sq Km Area

Based on the industrial data compiled during secondary data collection through file records of 9 KSPCB regional offices and extensive survey of zone of influence for seven sampling sites, it is found that the manufacturing units are located mainly in 2x2 sq Km zone of Peenya industrial area.

In Peenya Industrial Area, primary survey was carried out both for large & medium and small scale industries falling in the red and orange categories. On the basis of the survey, data was compiled for a total of 148 industries in 2 x 2 sq Km zone. The emission loading is then estimated based on the approach explained earlier. The PM_{10} emissions are 0.29 T/day (Table 3.16).

Table 3.15 Emission load (T/D) from industries at City level

Pollutant		SO_2	PM_{10}	NO_X
Number of Industries	Source Type			
168	City Level considering all industries	8.21	7.78	17.18
26	Point Source	2.71	2.48	13.43
142	Area Source	5.50	5.30	3.76

Table 3.16 Emission load (Kg/D) from industries in 2x2 Km^2 zone of influence at Peenya

Pollutant	SO_2	PM_{10}	NO_X
Total Emissions (Kg/D)	123.72	289.86	819.13

3.2.4 Percentage distribution of pollutants

The estimated load from point and area sources at the city level is further represented in terms of percentage distribution of pollutants. (Figure 3.13).

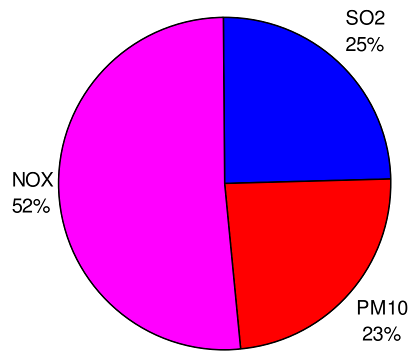


Figure **3.13** Percentage distribution of pollutants from industries at city level

The estimated load from large, medium and small scale industries falling in 2x2 sq Km area of Peenya Industrial Area are shown in Figure 3.14.

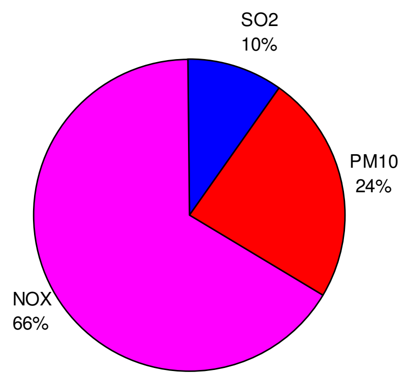


Figure **3.14** Percentage distribution of pollutants from industries falling in 2 x2 sq Km zone of influence

Spatial distribution of industrial emission presented in Figure 3.15.

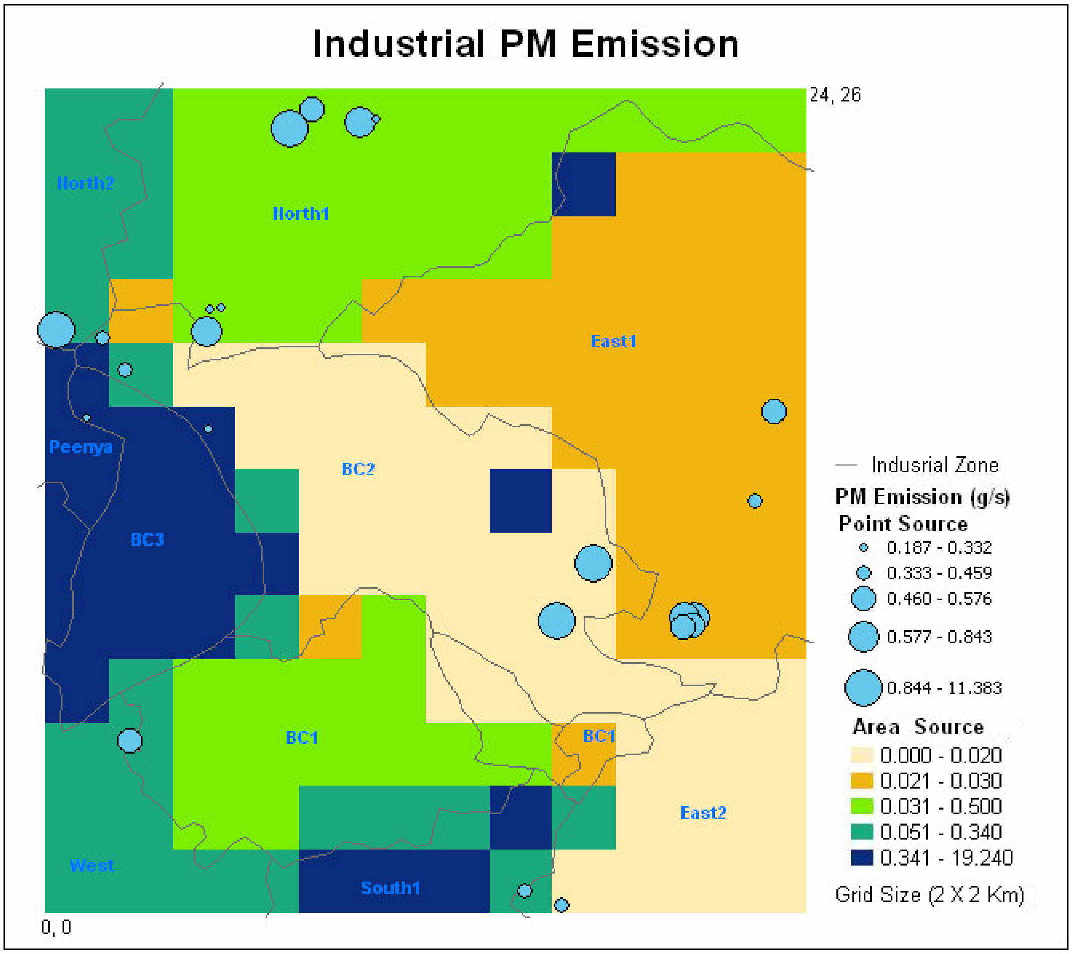


Figure **3.15** Spatial distribution of emissions (g/s) from industrial sector

3.2.5 Data constraints

1) Information on all the pollutants was not given in consent for operation form.
2) Appropriate distinction of industries falling in Bangalore urban district and rural district were not readily available.
3) Type of products manufactured details were not reported in KSPCB file records for small scale industries.

3.3 Line sources

Vehicular emissions are one of the major sources of air pollution affecting the urban population. Unlike industrial -emissions, vehicular pollutants are released at ground level and hence the impact on recipient population will be more. Vehicles are the major source of emissions of carbon monoxide, oxides of nitrogen, hydrocarbons and particulate matter.

The data on vehicle statistics is compiled by the Transport Department of the Government of Karnataka based on data collected from the Regional Transport Offices (RTOs) in Bangalore Urban District. The increase in vehicular fleet during 1980 to 2005 has been depicted in Table 3.17.

Table 3.17 Number of registered vehicles in Bangalore during various years

(Figures in lakhs, as on 31 March each year)

Year	2-Wheelers	M/Cars	3-Wheelers/Cabs	Others	Total
1980	0.97	0.3	0.1	0.31	1.68
1985	1.89	0.47	0.11	0.3	2.77
1990	4.01	0.71	0.15	1.41	6.28
1995	5.94	1.07	0.34	0.62	7.97
1996	6.69	1.21	0.39	0.71	9.00
1997	7.58	1.38	0.47	0.8	10.23
1998	8.39	1.52	0.54	0.84	11.29
1999	9.1	1.64	0.55	0.94	12.23
2000	9.94	1.84	0.58	1.01	13.37
2001	10.92	2.07	0.62	1.12	14.73
2002	11.83	2.26	0.64	1.23	15.96
2003	13.23	2.53	0.69	1.37	17.83
2004	14.44	2.77	0.76	1.53	19.5
2005	15.7	3.18	0.75	1.67	21.3

SOURCE http://rto.kar.nic.in/bng-veh-stat.htm

Category of roads

The three categories of roads are identified in the 7 zones of influence (2x2) around the monitoring stations i.e a) arterial roads, b) sub-arterial roads, c) other roads. Traffic count survey has been conducted at 25 locations in the city including locations around the six monitoring sites. Total lengths of the different category of roads in the zone of influence have been measured on map.

3.3.1 Primary data collection elements and methodology

During primary surveys, traffic count survey was undertaken at 25 locations across the city. Further, parking lot surveys and fuel pump surveys were carried out for ascertaining the vintage of the vehicles, distances travelled per day, fuel-wise distribution, technological mix etc.

3.3.2 Vehicle counts & parking lot surveys

Traffic count survey has been conducted at 25 locations in Bangalore city in the year 2007. The summary of the results is presented in Figure 3.16.

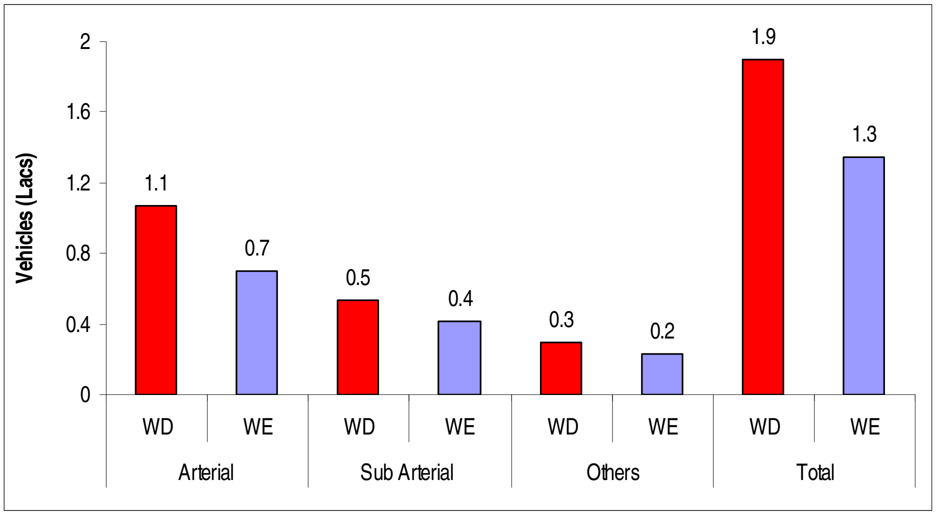


Figure **3.16** Average number of vehicles passing through different categories of roads during a typical weekday and weekend.

WD: weekday
WE: weekend

Figure 3.16 depicts the average vehicles count during 24 hours at different category of roads in Bangalore city. There has been a decrease of about 30% vehicular movement during a weekend as compared to the weekdays. As expected, arterial roads are the most busy roads with almost 0.7-1 lakh vehicle pass daily through them, followed by sub-arterial roads with nearly 0.4-0.5 lakh vehicles passing through them. About 0.2-0.3 lakh vehicles pass through the other category roads.

However, for the entire study domain, arterial & sub-arterial roads are clubbed because of unavailability of information.

Distribution of vehicles

Percentage break-up of total vehicles: - a) based on registered vehicles data, and b) based on vehicle count at 25 locations, is provided in Figure 3.17, which clearly shows the dominance of private vehicles, i.e. two wheelers and cars. As per registration data, more than 75% are two-wheelers, while the figure is 50% as per the primary survey results. Primary survey however shows increased percentage of cars on road in Banglore city.

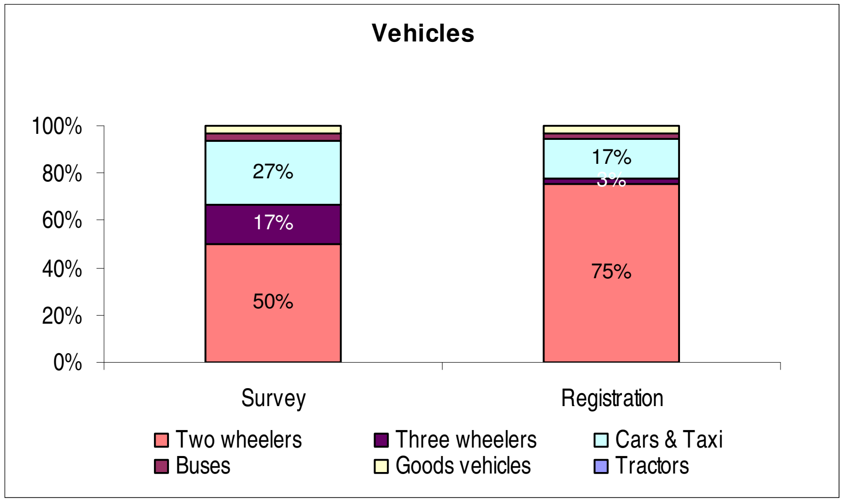


Figure **3.17** Percentage break-up of surveyed vehicles and registered vehicles in the study domain

Parking lot survey

Survey are carried out at parking lots and fuel pumps to know the:-

a) Vintage of vehicles on road
b) Technological mix of vehicles on road
c) Fuel-wise distribution
d) Daily vehicle kilometer travelled
e) Mileage of her vehicle
f) Occupancy of the vehicle

The results of the survey were used to divide vehicles into sub-categories based on their technology and vintages. The vehicle-wise results of the survey are presented below.

Two-wheelers

Survey covering more than 5000 two-wheelers, reveals the fact that 4-stroke vehicles are dominant and constitute about 78% of the total two-wheelers on road. Vintage distribution shows that out of the total on road two-wheelers, about 72% are post-2000, while 28% are pre-2000 vehicles (Table 3.18). This shows the dominance of new vehicles in the on-road vehicular fleet of Bangalore city.

Table 3.18 Vintage distribution of various vehicles on road in Bangalore

	2w	Car	3w	Bus	Truck	LCV
<1995	6%	4%	12%	5%	14%	13%
1995-2000	22%	20%	40%	41%	46%	27%
2000-2005	50%	53%	38%	47%	30%	38%
>2005	22%	23%	10%	7%	9%	22%

Table 3.19 shows the technological distribution of 2-wheelers both 4-stroke and 2-stroke. In the 4-stroke category about 47% are motor cycles between 100-200 CC. However, in 2-stroke category, majority is of scooters (>80 cc) i.e. 34%.

Table 3.19 Technological distribution of 2-wheelers

2-stroke	Percentage share	4-Stroke	Percentage share
Moped <80cc	28%	Scooter >100cc	10%
Scooter <80cc	8%	M.cycle <100cc	38%
Scooter >80cc	34%	M.cycle 100-200cc	47%
M.Cycle <80cc	1%	M.cycle >200cc	5%
M.Cycle >80cc	29%		
Total	100%	Total	100%

Cars & Taxis

Survey of more than 1200 cars reveals the fact that petrol cars are about 67% of the total personal use cars, while diesel cars are 29%. However, diesel cars are more popular (51%) under the commercial category, followed by about 38% petrol and 12% LPG cars. Vintage distribution shows that out of the total on road cars, about 76% are post-2000, while 24% are pre-2000 vehicles.

Table 3.20 shows the technological distribution of petrol, diesel and LPG cars.

Table 3.20 Technological distribution of petrol, diesel and LPG cars

Petrol	Percentage share	Diesel	Percentage share	LPG	Percentage share
<1000 CC	36%	<1600 cc	50%	<1000 CC	83%
1000-1400 CC	38%	>1600 CC	50%	1000-1400 CC	11%
>1400 cc	26%			>1400 cc	6%
Total	100%	Total	100%	Total	100%

Three-wheelers

Survey of about 500 auto-rickshaws reveals that 78% autos run on LPG, while 11% each on petrol and diesel. Vintage distribution shows that out of the total on road autos, about 48% are post-2000, while 52% are pre-2000 vehicles.

Bus, Truck & LCV

About 85 buses, 190 trucks and 190 LCVs were surveyed. Vintage distribution shows that 46% buses, 60% trucks, and 40% LCVs are older than the year 2000. Overall parking lot/fuel pump surveys of about 10000 vehicles was carried out to estimate daily vehicle kilometre travelled and fuel efficiency of different vehicles types plying in Bangalore city. The results are presented in Figures 3.18a, b, c.

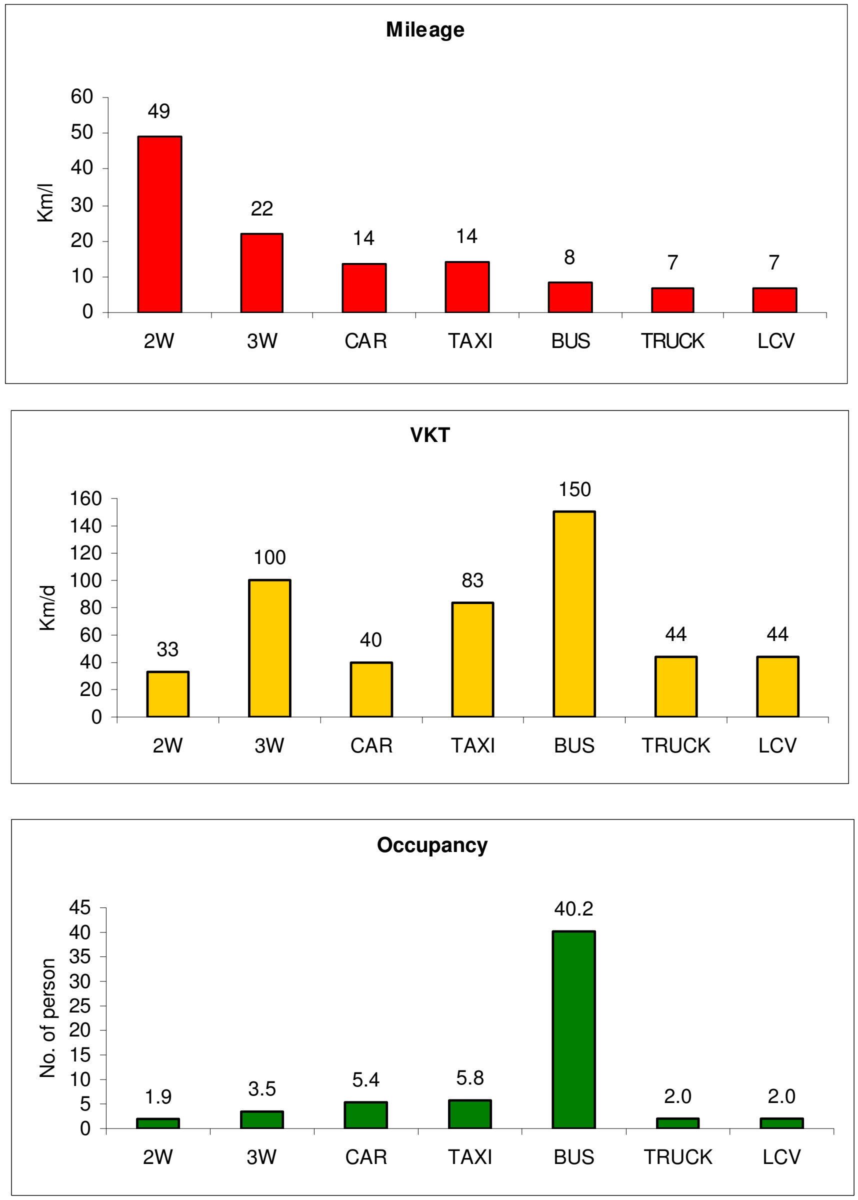


Figure **3.18a,b,c** Fuel efficiency, VKT, and occupancy estimated based on parking lot/fuel pump survey for different vehicles

3.3.3 Vehicle kilometer travelled

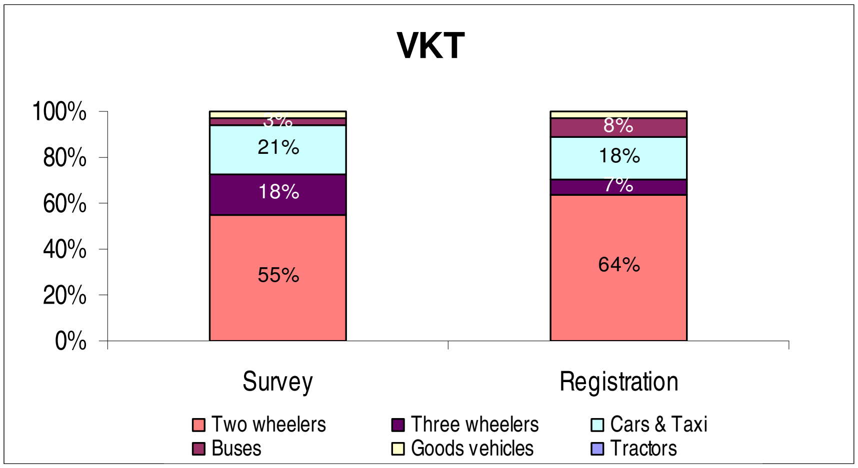
Vehicle kilometre travelled by different categories of vehicles have been estimated using following two approaches:-

a) based on registered vehicles data and VKT from parking lot survey
b) based on vehicle count at 25 locations and road length in Bangalore city

There has been a overall difference of 34% in the total VKT estimated for Bangalore city using the above two approaches.

Approach using the traffic counts survey and road length estimates 34% more vehicles than the other. The difference may be attributed to additional on-road vehicles from outside Bangalore city and also the difference in approach of these two methodologies.

Percentage break-up of daily vehicle kilometre travelled by different vehicles is provided in Figure 3.19.



Figures **3.19** Percentage share of different vehicles in total VKT for Bangalore city (based on two methodologies)

Percentage share of different vehicles in VKT is presented in Figures 3.19, which shows the dominance of private vehicles in daily vehicle kilometre travelled. Share of two-wheelers is 55-64% using both the approaches. Cars also have a substantial share of 18-21%, followed by three wheelers 7-18%. Survey results reveals less share of VKT of buses as compared to the registered data values.

3.3.4 Emission factors

Emission factors are adopted from ARAI, which are based on different technologies and vintages of the various categories of the vehicles.

3.3.5 Vehicle emission inventory

Transport sector emissions have been estimated using the VKT estimated from primary traffic count surveys at 25 locations in Bangalore city. The approach used in the present study is:-

Emissions (a) = Traffic count (t) X Road length(t) X emission factor (a)

t : type of road
a: type of vehicles

Emission factors are adopted from ARAI, which are based on different technologies and vintages of the various categories of the vehicles. Vehicles were divided into sub categories based on the primary survey results of technology and vintages.

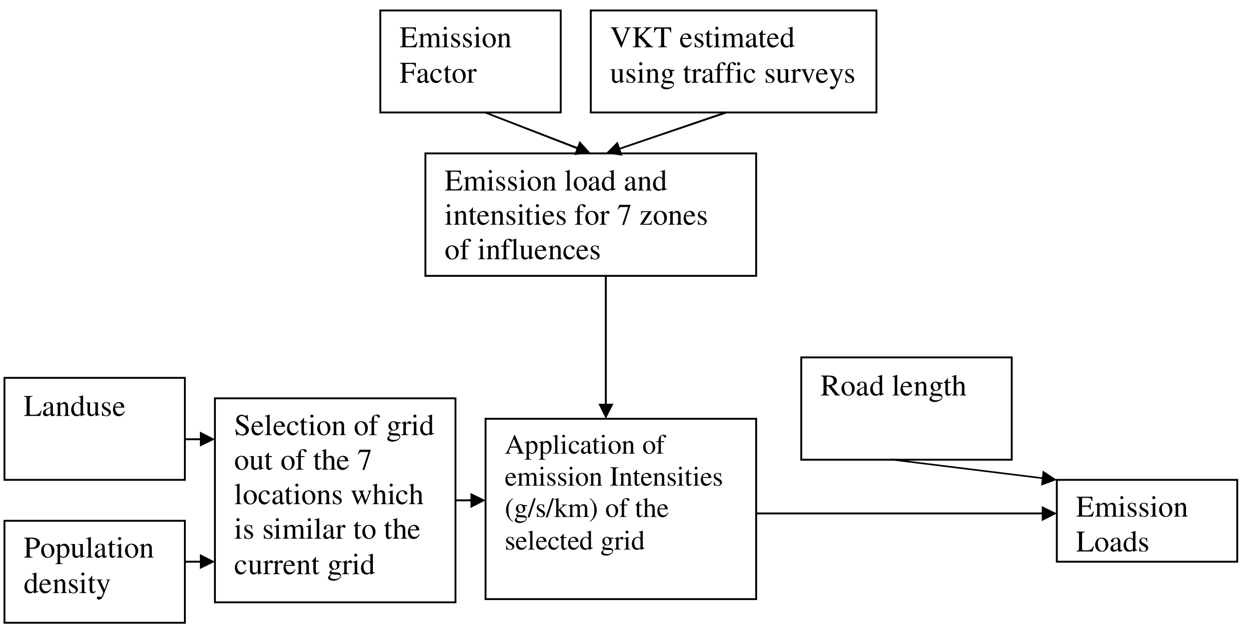
Emission loads estimated for various pollutants are presented in Table 3.21.

Table 3.21 Emission loads (T/d) from transport sector in Bangalore city for the year 2007

Pollutants	CSB	IGICH	Domlur	Victoria	Kammanahalli	Peenya	BG
PM_{10}	0.56	0.29	0.11	0.17	0.27	0.09	0.01
NO_X	4.36	1.66	0.70	1.09	1.76	0.65	0.07
SO_2	0.06	0.03	0.02	0.02	0.03	0.01	0.00

CSB location shows the maximum loads because of large fleet of vehicles and length of roads in the (2x2) grid.

Following approach is followed to estimate grid-wise emissions for the whole city.



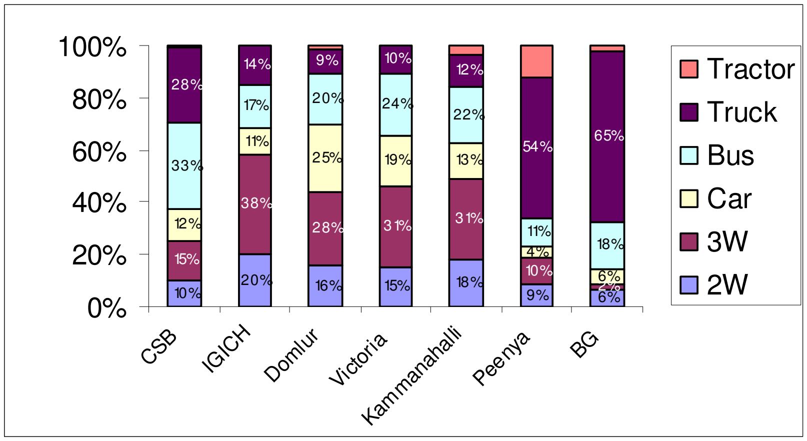
The estimated total emissions from the transport sector for the Bangalore city are depicted in table 3.22.,

Table 3.22 Emissions (T/d) from the transport sector in Bangalore city

PM	NO_X	SO_2
22.4	146.4	2.3

Table 3.22 shows that 22.4 tonnes/day of PM load is emitted from Bangalore city.

Figure 3.20 presents the percentage distribution of vehicular PM emissions from various monitoring locations. CSB, Peenya and Background locations clearly shows higher percentage of PM emissions from Trucks (Figure 3.20).



Figures **3.20** Percentage distribution of vehicular PM emissions from various monitoring locations

Vehicle-wise distribution of PM and NO_X at the city level in Bangalore is presented in Figures 3.21.

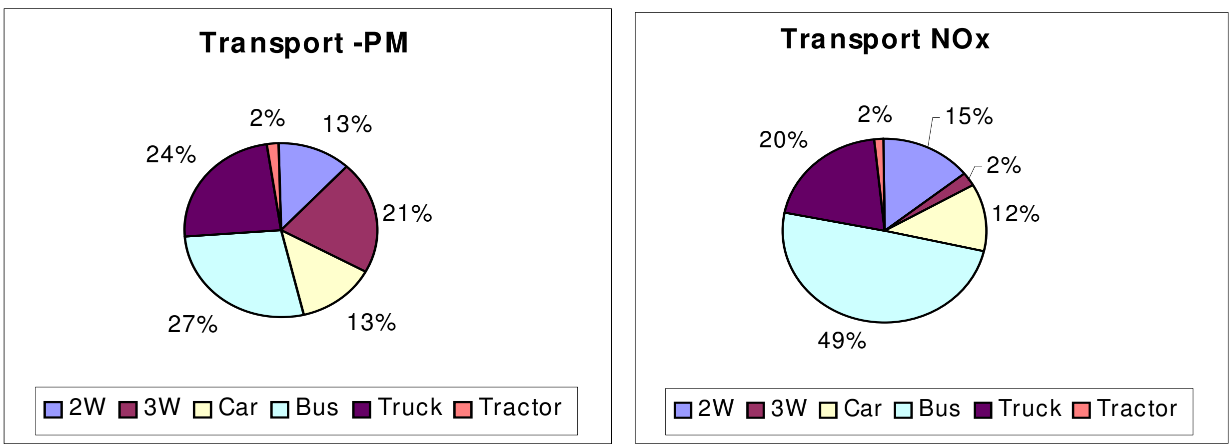


Figure **3.21** Vehicle-wise distribution of PM and NO_X emission loads in Bangalore city

Note: High PM emissions from 3-Wheelers because of high emission factor for LPG autos. Presently, emissions factor is used for post 2000 retrofication of LPG autos

Figure 3.21 suggests that heavy vehicles such as buses and trucks contribute about 51% of the total PM emissions. Three-wheelers have a share of 21% and two wheelers also have a substantial share of 13%, in Bangalore city. The share of cars towards the total PM emission load is 13%. Likewise, in the case of NO_X emissions, heavy vehicles such as buses and trucks have the largest share i.e. 69%.

Grid-wise emission inventory for transport sector is presented in Figure 3.22.

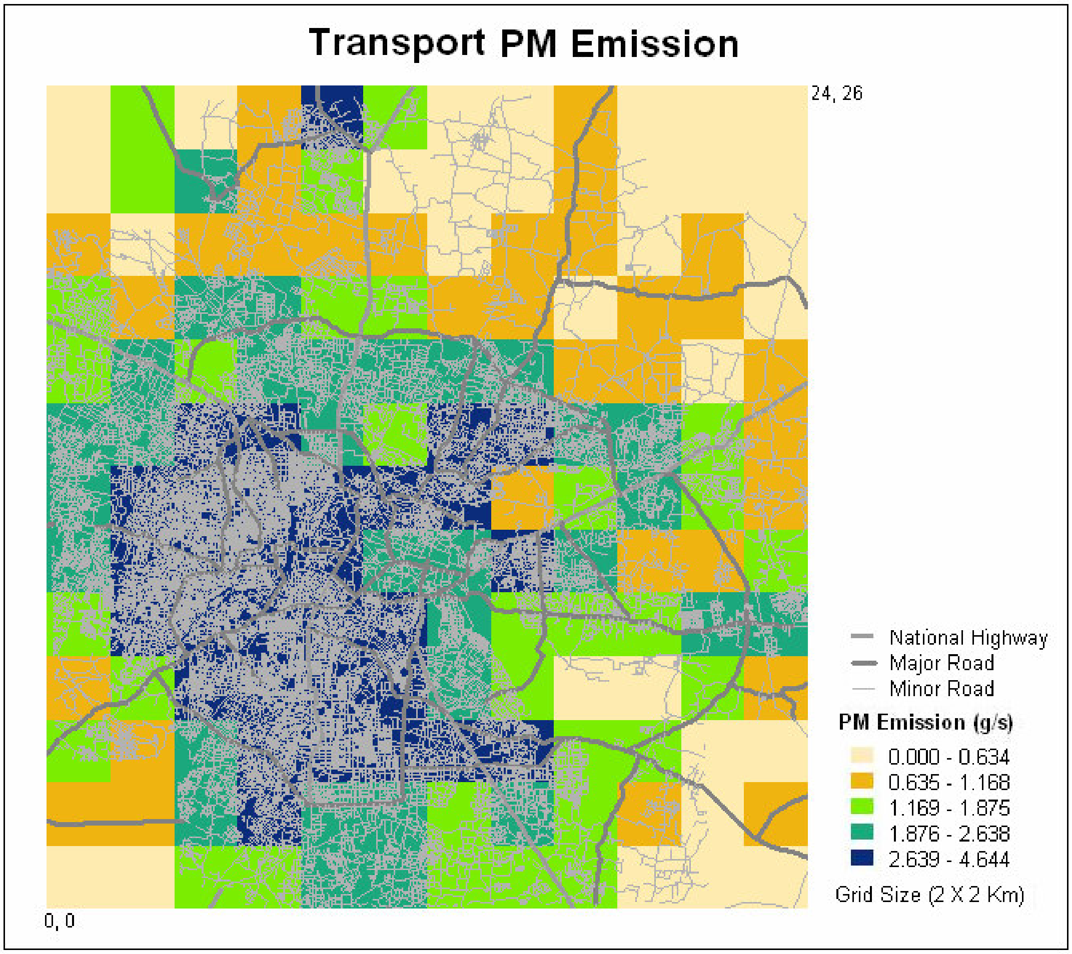


Figure **3.22** Spatial distribution of PM emissions (g/s) from transport sector across the study domain

Figure 3.22 reveals the presence of high transport sector emissions in the centre of the study domain corresponding to Bangalore city road map.

3.4 Emission inventory summary

City Level

In the current study, emission inventory is prepared for various sectors and for various pollutants. Pollutant wise sectoral breakup of emission loads are presented in Table 3.23 and Figure 3.23.

Table 3.23 Total emission loads (T/d) in Bangalore

	PM_{10}	NO_X	SO_2
Transport	22.4	146.36	2.31
Road Dust	10.9	0.00	0.00
Domestic	1.8	2.73	0.68
DG Set	3.6	50.96	3.35
Industry	7.8	17.19	8.21
Hotel	0.1	0.20	0.02
Construction	7.7	0.00	0.00
Total	54.4	217.4	14.6

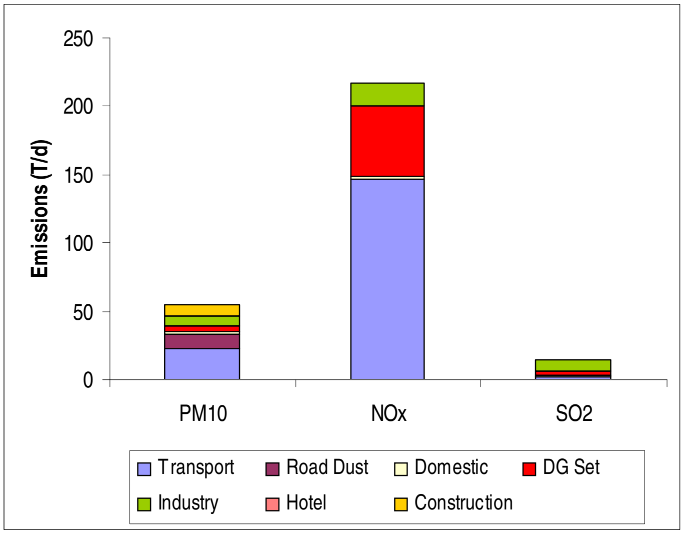


Figure **3.23** Total emission loads (T/d) in Bangalore

Its evident from the Table 3.23 and Figure 3.24 that transport (42%) and road dust resuspension (20%) have major share in PM emission loads. However, construction activities (14%), DG sets (7%) and Industries (14%) also have substantial shares in the total PM loads.

NO_X emissions are primarily from Transport and DG sets with a small share from industries (Figure 3.25). SO_2 emissions are emitted mainly from DG sets and industries (Fugure 3.26).

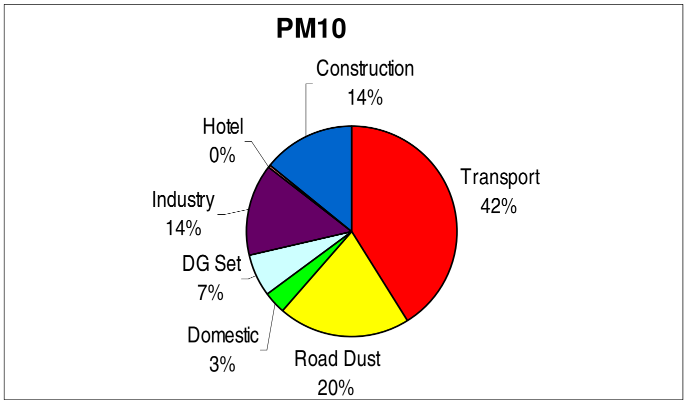


Figure **3.24** Percentage share of different sources in total PM_{10} emission loads

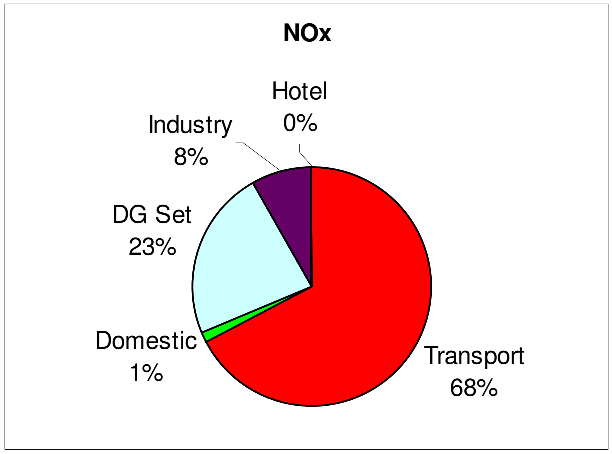


Figure 3.25 Percentage share of different sources in total NO_X emission loads

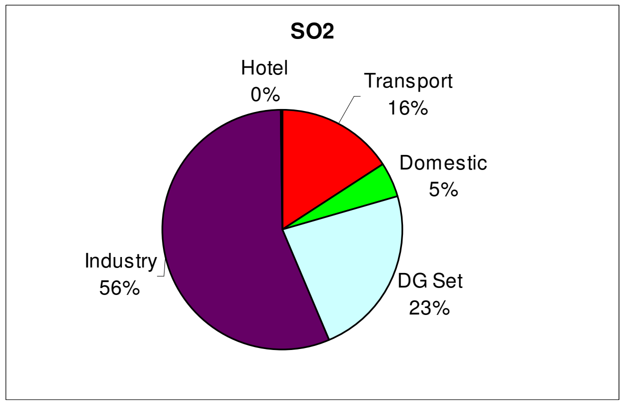


Figure 3.26 Percentage share of different sources in total SO_2 emission loads

Grid-wise PM emission inventory for all the sector is presented in Figure 3.27.

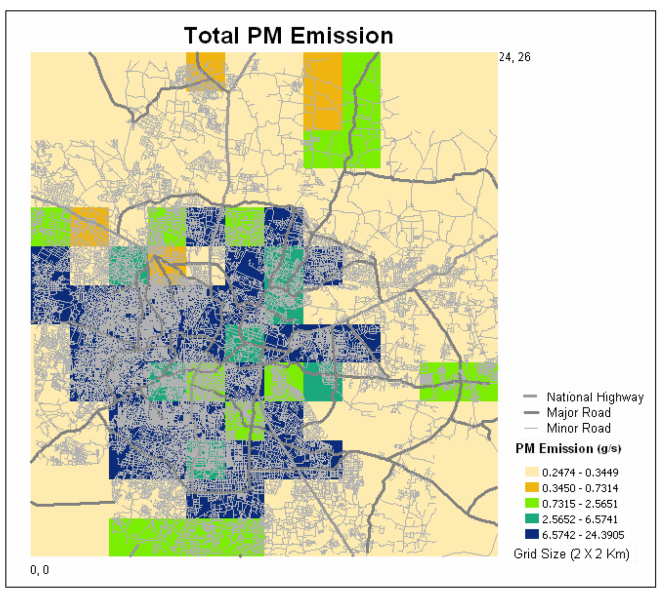


Figure 3.27 Grid-wise PM emission inventory (g/s) for the whole study domain

Total emission inventory for the 2 x 2 km² zones of influence

Sector-wise emission inventory prepared for the six 2x2 zones of influence around the monitoring stations is presented in Table 3.24 and 3.25; and Figures 3.28 and 3.29 .

Table 3.24 Sector-wise PM_{10} emission inventory (T/d) for the six 2x2 km² zones of influence

	CSB	Domlur	IGICH	Kammanahalli	Peenya	Victoria	Background
Transport	0.56	0.11	0.29	0.27	0.09	0.17	0.010
Industries	0.00	0.00	0.00	0.00	0.29	0.00	0.00
Domestic	0.01	0.01	0.03	0.03	0.00	0.02	0.002
DG sets	0.02	0.22	0.14	0.01	0.06	0.08	0.00
Road dust	0.42	0.06	0.07	0.05	0.07	0.08	0.012
Hotels	0.00	0.00	0.00	0.00	0.00	0.00	0.000003
Constructlon	0.05	0.03	0.04	0.05	0.02	0.04	0.0067
Total	**1.07**	**0.43**	**0.56**	**0.42**	**0.54**	**0.40**	**0.031**

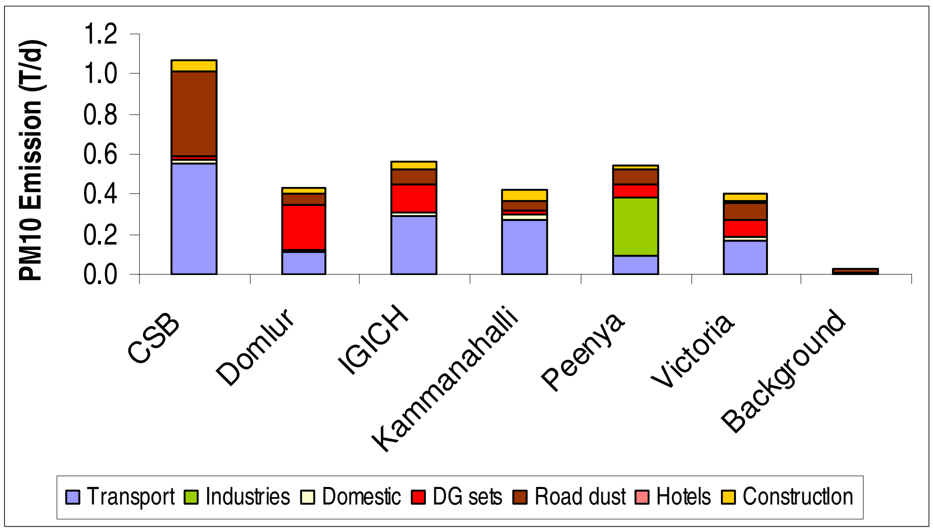


Figure **3.28** Sector-wise PM_{10} emission inventory for the six 2x2 km² zones of influence

Table 3.25 Sector-wise NO_X emission inventory (T/d) for the six 2x2 km² zones of influence

	CSB	Domlur	IGICH	Kamman	Peenya	Victoria	BG
Transport	4.34	0.71	1.66	1.76	0.66	1.11	0.07
Industries	0.00	0.00	0.00	0.00	0.82	0.00	0
Domestic	0.0231	0.024	0.046	0.045	0.007	0.035	0.0020718
DG sets	0.31	3.08	1.93	0.19	0.85	1.18	0
Road dust	0.00	0.00	0.00	0.00	0.00	0.00	**0**
Hotels	0.0023	0.0034	0.0027	0.0018	0.0011	0.0049	0.0000048
Construction	0.00	0.00	0.00	0.00	0.00	0.00	0
Total	**4.68**	**3.82**	**3.64**	**2.00**	**2.33**	**2.33**	0.07

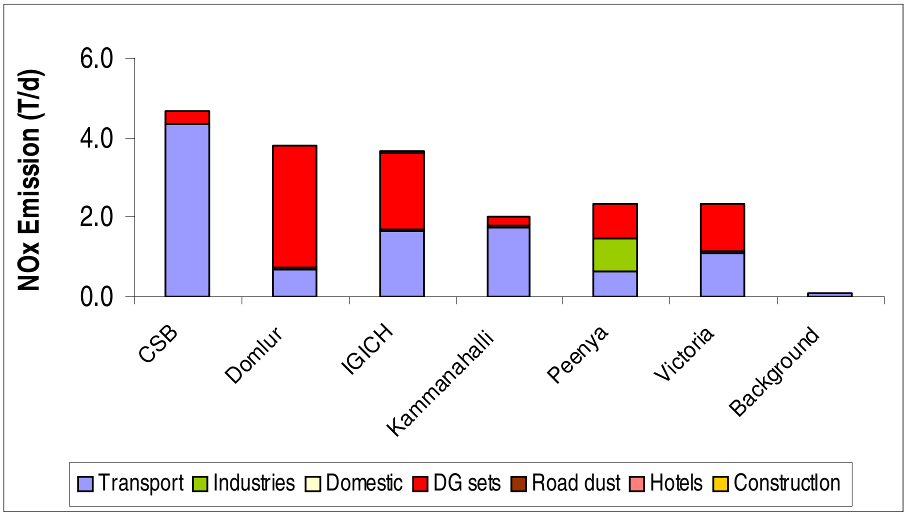


Figure **3.29** Sector-wise NO_X emission inventory for the six 2x2 km^2 zones of influence

Spatial distribution of PM emisons in 6 monitoring grids falling in the city are presented in Figure 3.30.

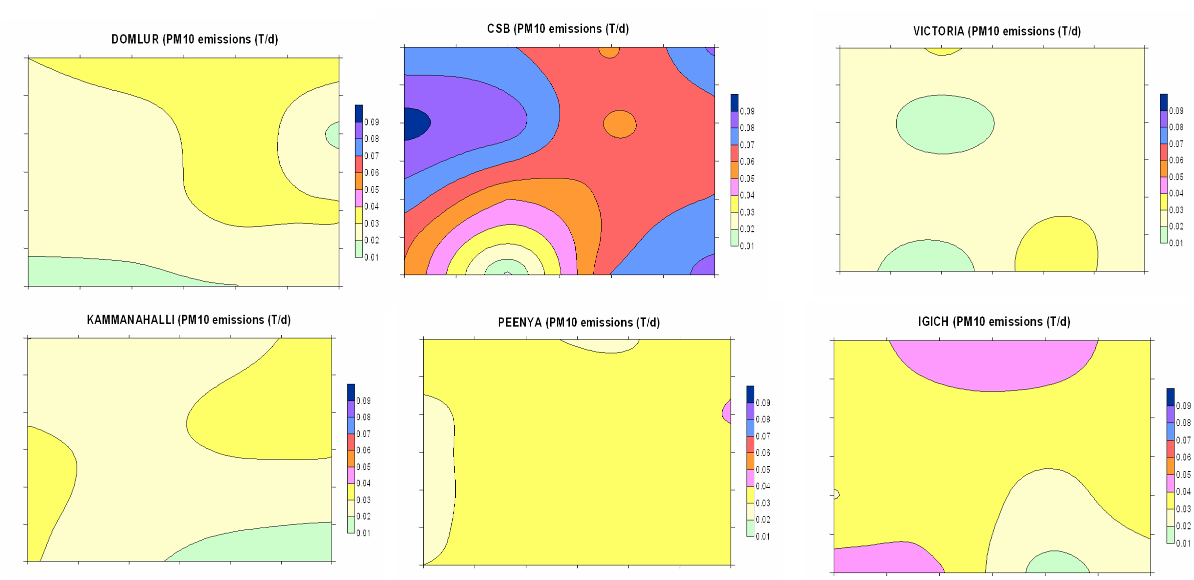


Figure **3.30** Spatial distribution of PM emissions in 6 monitoring grids falling in the city

Percentage distribution of different sources contributing to the PM and NO_X emission inventory of six 2x2 km^2 zones of influence is presented in Figure 3.31a,b, respectively.

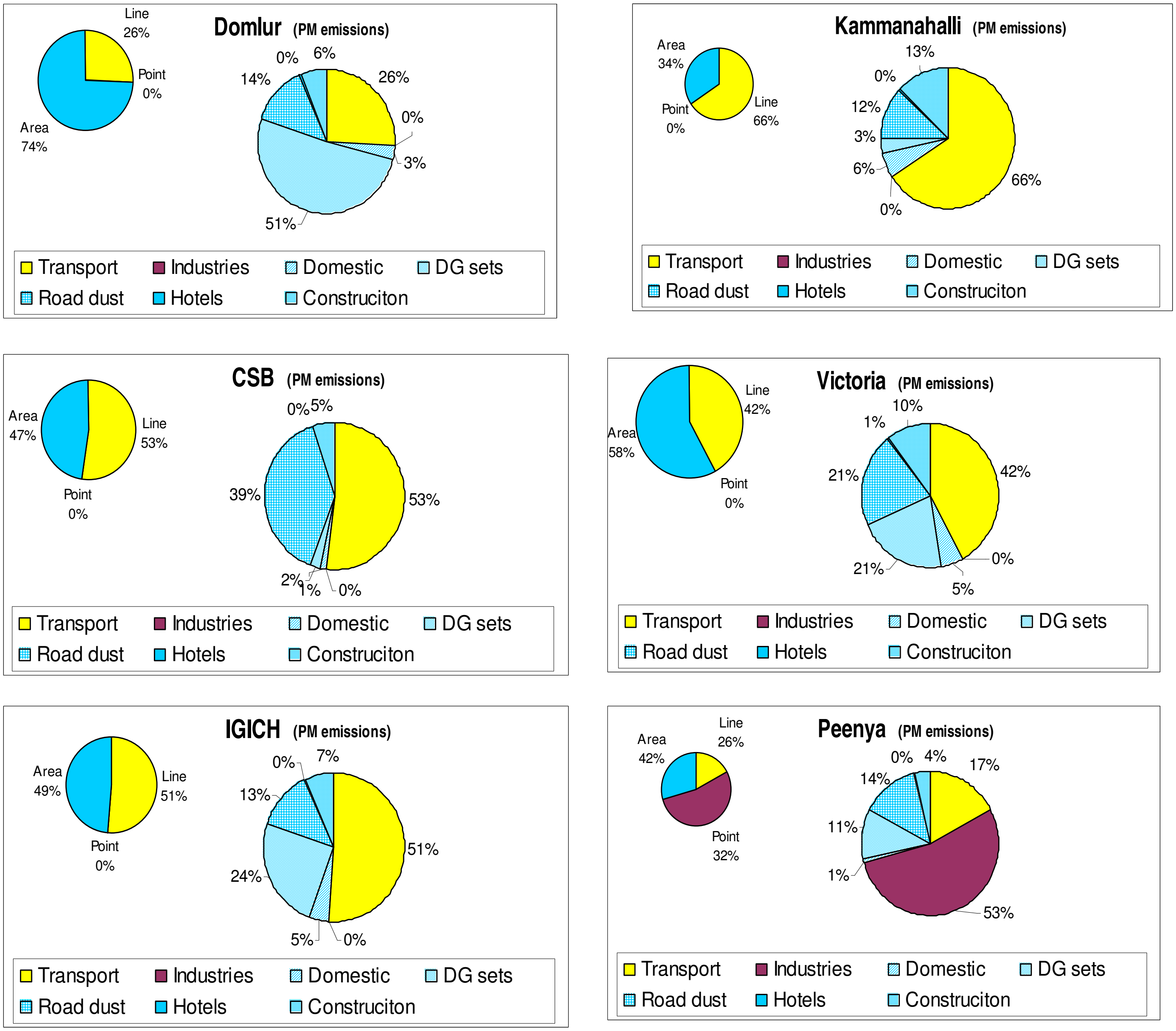


Figure 3.31a Percentage distribution of different sources contributing to the PM emission inventory of six 2x2 km^2 zones of influence

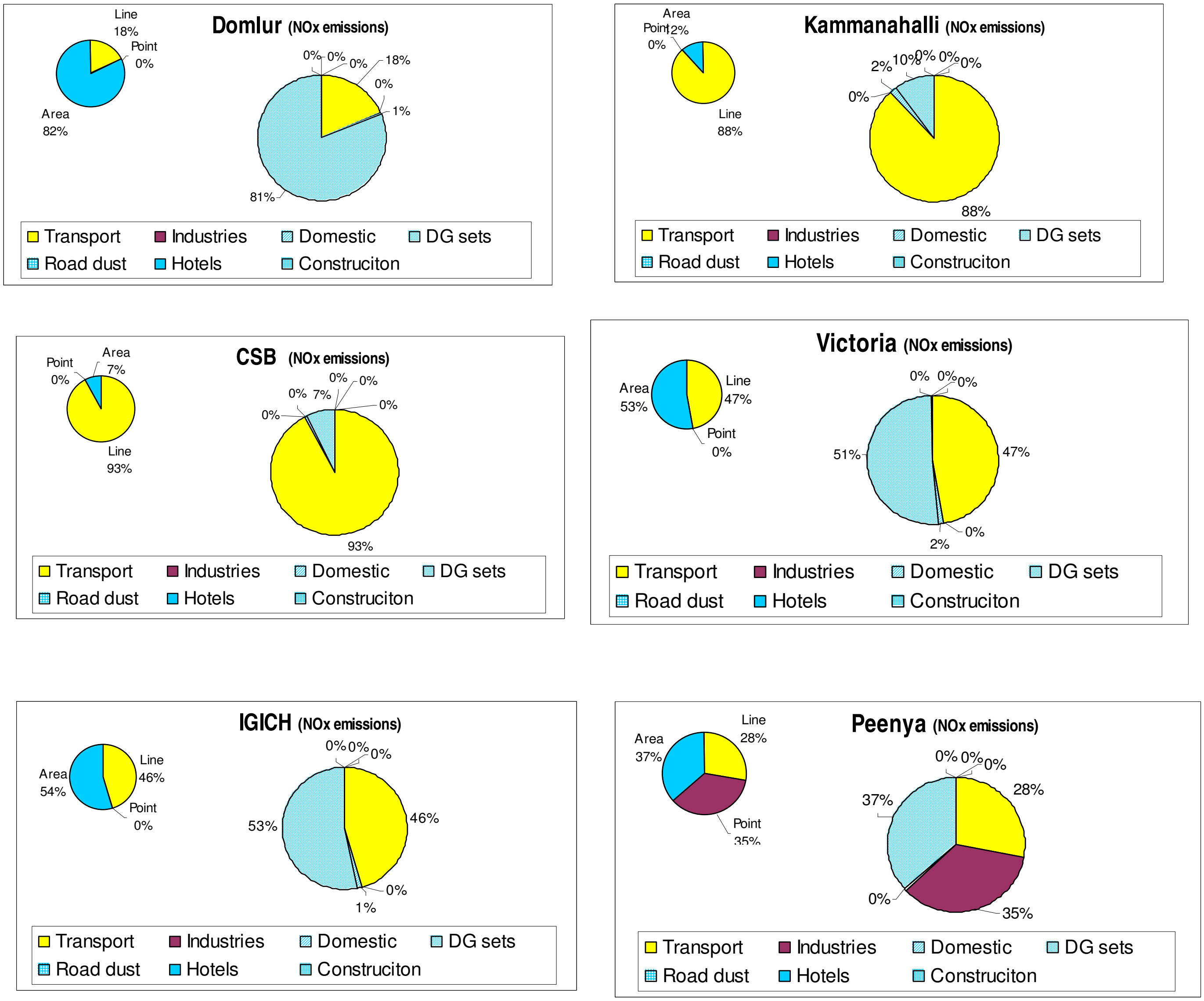


Figure 3.31b Percentage distribution of different sources contributing to the NO_x emission inventory of six 2x2km² zones of influence

Five sites (corresponding to residential/kerbside) lie in the core zone of the city . As such the number of vehicles and the road density in these areas is much more than the rest of the city. This obviously leads to high contribution of vehicular emission to the total PM_{10} load (varying from 26-66%). Likewise, the road dust emissions are also higher (12-39%)

At Peenya, PM_{10} emissions from the industrial sector are the most significant source (53%).

It may be noted that at the city level, the share of transport sector to the total PM load has been less as compared to the majority of the six (2x2 km²) zones. Major reason for this is the relative lower road density in the rest of the city compared to the 2x2 sites, which were in the core of the city.

Also, domestic bio-fuel combustion has been observed to be used mainly in the areas outside the BMP and thereby having a relatively higher contribution in the PM_{10} emissions load. Finally, industrial contribution is also significant at the city level because the city has industries located in eight other industrial zones besides the Peenya industrial zone, which was chosen as one of the seven 2x2 km^2 zone.

3.5 Emission inventory QA/QC

Following QA/QC measures were taken during the preparation of emission inventory: -

1) Reconnaissance survey was carried out initially at all the 2x2 locations so that no major emission source is missed out during actual primary surveys. Pilot testing of questionnaires were carried out before actual implementation of the primary surveys.
2) Representativeness of samples: Three different kinds of roads were selected for primary survey to have better representation of traffic flow in zone of influence. Sample size of each category of vehicle is carefully selected to represent each category effectively. Moreover, different kinds (in view of technology, vintage, fuel) of vehicles were surveyed for better representation of vehicular fleet in the city. In domestic sector, different categories of households were surveyed to represent various sections of the society.
3) Data cross checks: Random survey checks has been made between the hard data sheets prepared during the surveys and the data in soft form.
   Also, crosschecks have been made between the manual vehicular count surveys and selected video recording.
4) Emission Factors : The emissions factors as provided by CPCB are being used. Further, the emission factors in certain cases have been cross-checked with the original sources. However, there still remains multiple category of sources from which one could choose the emission factor e.g. residential wood stove and Chulha (wood & dung). Also, there is scope for further improvement of emissions factors by using test results from significant number of samples (e.g. vehicular sector). Moreover, India specific emission factors for other sectors would also be helpful.
5) Spatial analysis using GIS : This allows for detection of missing or incorrectly mapped emissions across the modelling domain.
6) Quantitative analysis includes the generation of emission totals for each pollutant in each sectoral emission file. The emissions totals are matched to total of the grid-wise emissions to ensure data consistency and cross check.

3.6 Conclusions

The total pollution load in Bangalore in 2007 is estimated to be 54.4 T/d for PM_{10}, 217.4 T/d for NO_X and 14.6 for SO_2. At the city level, the major sources of PM_{10} emissions are transport (42%), road dust resuspension (20%), construction (14%), industry (14%), DG set (7%) and domestic (3%). Like wise, at the city level, the major sources of NO_X are transport (68%), DG set (23%), industry (8%), and domestic (1%). In the case of SO_2, at the city level, industry (56%), DG set (23%) and transport (16%) are the major sources.

CHAPTER 4 Receptor modelling & Source Apportionment

4.1 Receptor modelling

Emission of pollutants from the sources and its effect i.e., pollutant levels in ambient air can be related using modelling techniques. The two widely used modelling techniques are receptor modelling and dispersion modelling.

Receptor models use 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. Receptor models are generally contrasted with dispersion models that use pollutant emissions rate estimates, meteorological transport, and chemical transformation mechanisms, to estimate the contribution of each source to receptor concentrations. The two type of models are complementary, with each type having strengths that compensate for the weaknesses of the other.

Receptor models are retrospective as they can only assess the impacts of air pollution source categories on pollutant concentrations that have already been monitored. Receptor modelling involves sampling of the pollutants (for example PM_{10}) and analyzing its chemical composition.

In the current study, the particulate matter samples collected during the three seasons have been analysed for anions, cations, elements, organic carbon and elemental carbon, and molecular markers. This information is used for receptor modelling.

CMB (Chemical Mass Balance) will be used in this study for receptor modelling for source apportionment of particulate matter. In addition, factor analysis method is also being used for ascertaining the likely sources that contribute to pollution at the various monitoring sites.

4.1.1 Factor analysis: methodology & results

One of the methods for source apportionment is based on Multi-Variate Analysis (MVA) methods. This does not require source composition libraries in the receptor model solutions. These methods are Factor Analysis (FA), Principal Component Analysis (PCA), Multiple Regression (MR), Positive Matrix Factorization (PMF) etc.

Factor Analysis is the major and most extensively used technique of Multivariate Analysis for source identification. Advantage of this method is that it does not require *a priori* knowledge of the source profiles. In this, the set of variables is first normalised and each of these variables is then represented as a linear combination of a smaller set of common factors plus a factor unique to each variable. First step in FA is the selection of adequate number of samples. Subsequently, the correlations and other statistical parameters between different variables are examined. Henery et al. (1984) suggested that minimum number of samples (N) for FA should be such that $N>30+(V+3)/2$, where V represents the number of variables.

In this study Factor Analysis is done to identify the number of significant source types based on analyzed concentration levels of source signature species. However the number of samples is very less as compared to number of variables. Thus, appropriate selection of variables has been resorted to based on the chemical abundance of significant species of various sources, concentration levels at given location and comparing correlation matrix with reference to Kaiser-Mayer-Olkin (KMO) index.

Results of varimax rotated factor analysis carried out on different inorganic and organic marker species using SPSS software at different locations are depicted in following section. Factors were selected based on the criteria of cumulative % variance of >80% and Eigen value of >1.0. Varimax rotated factor analysis showed four to seven possible groups/factors (based on factor loading greater than 0.5). Based on the preliminary data analysis, it is difficult to assign distinct source categories to the various factors at different sites.

It is important to note that the results quoted here are just indicative. Receptor modelling using CMB model would provide quantitative information on the contribution of various sources to the pollution load at various monitoring locations.

Domlur

Factor Analysis of the Domlur PM_{10} data revealed six factors (Table 4.1). For factor 1, the association with Al, Mn and K is strongly suggestive of a road dust. Factor 2 shows particularly high factor loading values relating to NO_3 and SO_4 strongly indicating secondary aerosol. There is also a significant factor loading for Br, and motor vehicles may well contribute to primary and secondary particulate matter associated with this factor. Factor 3 is easier to attribute due to the high loadings on OC, EC and Zn which are strongly associated with exhaust emissions from petrol and diesel vehicles. The high factor loading values for Ca and Si lead us to associate Factor 4 with crustal source, presumably re-suspended soil and or road dust. The high factor loading of NH4 in this factor could possibly be due to the storm water drain in this area. Factor 5 has very high factor loading values on K which is indicating biomass burning in the vicinity of sampling site. The high loadings on Cl, Na and Mg also indicate natural soil contribution in case of factor 6. Though Cl and Na also linked to marine aerosols, but due to large distance of Bangalore from the sea, this is likely to be modest.

Table 4.1 Factor loadings of different variables at Domlur

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
PM_{10}	0.30	0.25	-0.26	**0.67**	0.02	-0.14	0.69
Na Ions	-0.08	-0.27	-0.27	0.21	-0.49	**0.60**	0.79
NH4 Ions	-0.06	0.08	-0.23	**0.86**	0.04	0.08	0.81
K Ions	0.29	0.23	-0.53	0.12	**0.67**	-0.04	0.88
Ca Ions	0.02	-0.07	0.09	**0.82**	-0.18	0.41	0.88
Mg Ions	0.29	0.01	-0.21	0.20	0.57	**0.64**	0.90
Cl Ions	-0.12	0.29	-0.11	0.07	0.00	**0.86**	0.86
Br Ions	-0.26	**0.79**	-0.02	0.07	0.34	0.13	0.84
NO_3 Ions	-0.10	**0.97**	0.01	0.02	-0.13	-0.01	0.96
SO_4 Ions	-0.05	**0.94**	-0.11	0.11	0.02	0.09	0.91
OC	0.12	-0.01	**0.84**	-0.22	-0.03	-0.17	0.79
EC	0.27	-0.25	**0.85**	0.08	0.03	-0.22	0.92
Fe	0.34	0.06	-0.05	0.09	-0.83	0.02	0.81
Cr	**0.82**	-0.24	0.09	0.05	-0.03	-0.08	0.75
Zn	0.44	0.29	**0.66**	-0.18	-0.16	0.05	0.78
Si	-0.41	0.02	0.38	**0.52**	0.30	0.04	0.67
Al	**0.92**	-0.16	0.15	0.18	-0.05	-0.05	0.92
Mn	**0.67**	0.30	-0.23	0.23	-0.02	-0.17	0.68
K	**0.90**	-0.08	0.22	-0.12	-0.01	0.14	0.90
Na	-0.81	0.20	-0.32	0.26	0.01	-0.01	0.87
Total	**5.18**	**3.53**	**2.67**	**2.01**	**1.77**	**1.46**	
% of Variance	**25.92**	**17.66**	**13.35**	**10.07**	**8.83**	**7.29**	
Cumulative %	**25.92**	**43.59**	**56.93**	**67.00**	**75.84**	**83.12**	

Silk board

Factor Analysis of the Silk Board PM_{10} data also revealed six factors (Table 4.2). Factor 1, the association with NO_3, SO_4 and NH_4 is suggestive of secondary particulate matter. Again, there is significant factor loading on Ca and K which indicates to paved road dust. However, factor loading values on Br, NO_2, NO_3, SO_4 and NH_4 lead us to motor vehicle contribution. Factor 2 shows particularly high factor loading values relating to Cr, Zn, Si and K which strongly indicating urban dust such as from construction activities. The high loadings on Cl, Na and Mg indicate natural soil contribution in case of Factor 3. Factor 4 has high factor loadings on Al and Mn indicating contribution of paved and unpaved road dust. Factor 5 is easier to attribute due to the high loadings on OC and EC which are strongly associated with exhaust emissions from petrol and diesel vehicles. Factor 6 has very high factor loading values on Fe which is again indicating paved road dust and construction activities in the vicinity of sampling site.

Table 4.2 Factor loadings of different variables at Silk Board

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
PM_{10}	0.12	0.21	0.08	-0.27	-0.82	0.20	0.85
Na Ions	-0.10	-0.30	**0.86**	-0.11	0.28	-0.10	0.93
NH4 Ions	**0.95**	0.05	0.03	-0.02	0.01	0.07	0.92
K Ions	**0.75**	-0.18	0.43	-0.03	-0.01	-0.21	0.82
Ca Ions	**0.72**	-0.24	0.34	0.27	-0.27	-0.20	0.87
Mg Ions	0.42	-0.41	**0.76**	-0.13	-0.03	0.01	0.94
Cl Ions	0.04	-0.33	**0.75**	-0.07	-0.10	-0.16	0.71
NO_2 Ions	**0.77**	-0.22	-0.28	-0.06	-0.09	-0.14	0.75
Br Ions	**0.84**	0.06	-0.29	0.22	0.00	-0.21	0.89
NO_3 Ions	**0.95**	-0.05	0.19	0.06	-0.02	0.03	0.94
SO_4 Ions	**0.96**	0.05	0.18	0.08	0.07	-0.03	0.96
OC	-0.42	-0.09	0.23	-0.13	**0.69**	0.20	0.77
EC	0.30	0.15	0.05	-0.04	**0.81**	0.29	0.85
Fe	-0.22	0.11	-0.37	0.20	-0.12	**0.80**	0.89
Cr	-0.16	**0.65**	-0.41	0.19	-0.10	0.54	0.94
Zn	0.06	**0.92**	-0.25	0.08	0.08	-0.16	0.95
Mo	0.04	-0.08	-0.06	0.02	-0.36	-0.77	0.74
Si	-0.10	**0.59**	-0.17	0.56	-0.09	0.19	0.74
Al	0.44	0.29	-0.20	**0.78**	-0.08	0.08	0.95
Mn	0.06	0.05	-0.02	**0.96**	0.17	0.02	0.96
K	-0.24	**0.73**	-0.36	-0.09	-0.07	0.41	0.91
Na	0.04	-0.73	0.42	-0.37	0.18	-0.20	0.92
Total	**7.34**	**5.46**	**2.39**	**1.65**	**1.34**	**1.02**	
% of Variance	**33.38**	**24.80**	**10.88**	**7.48**	**6.11**	**4.62**	
Cumulative %	**33.38**	**58.18**	**69.06**	**76.54**	**82.65**	**87.27**	

Peenya

Factor Analysis of the Peenya PM_{10} data revealed seven factors (Table 4.3). For Factor 1, the association with Ca and Mg is suggestive of soil dust. However, NO_3 presence also indicates unpaved road dust. Factor 2 has very high factor loading values on F, Cl and Na which is indicating residual oil burning in this industrial area. The high factor loading values for Fe, Al, Mn and K lead us to associate Factor 3 with crustal source, presumably resuspended soil and or paved road dust. Factor 4 shows particularly high factor loading values relating to Co, Pb and Si which possibly indicate industrial sources. Factor 5 has high loadings on Cr and Zn which are associated with many sources such as metal industries, motor vehicles, construction and road dust. Factor 6 indicates diesel combustion from diesel driven vehicles and industrial process emissions with high factor loading values on EC and Cd. The high factor loading values for OC lead us to fuel combustion in petrol driven motor vehicles.

Table 4.3 Factor loadings of different variables at Peenya

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Communalities
PM_{10}	0.33	-0.06	0.01	-0.02	**0.90**	0.10	-0.02	0.93
Na Ions	0.09	**0.96**	-0.01	0.02	0.04	0.03	-0.12	0.96
K Ions	0.55	0.34	0.32	0.45	0.11	0.26	0.03	0.80
Ca Ions	**0.91**	0.04	0.13	-0.01	0.16	-0.16	-0.10	0.90
Mg Ions	**0.87**	0.20	0.21	-0.06	-0.19	-0.02	-0.09	0.89
F Ions	0.04	**0.90**	-0.02	0.03	0.18	-0.10	0.16	0.89
Cl Ions	0.49	**0.74**	0.30	0.20	0.08	-0.05	-0.13	0.95
NO_3 Ions	**0.94**	0.05	-0.08	-0.02	0.25	-0.10	-0.02	0.96
SO_4 Ions	0.37	0.45	-0.71	-0.09	0.03	0.29	0.05	0.94
OC	-0.14	-0.07	0.08	0.05	-0.09	0.06	**0.89**	0.83
EC	-0.11	0.11	0.07	-0.34	0.27	**0.67**	0.46	0.88
Fe	0.37	0.17	**0.83**	0.07	0.02	0.25	0.24	0.98
Cr	-0.33	0.50	0.00	-0.16	**0.70**	-0.18	-0.11	0.91
Cd	-0.16	-0.14	0.05	0.19	-0.01	**0.86**	-0.05	0.83
Co	-0.43	0.04	-0.03	**0.54**	-0.34	-0.01	-0.04	0.60
Pb	0.00	-0.34	-0.24	**0.58**	0.17	0.02	-0.35	0.66
Zn	0.11	0.47	0.11	-0.14	**0.67**	0.17	-0.04	0.75
Si	0.38	-0.13	0.32	**0.67**	-0.08	-0.11	0.36	0.86
Al	0.13	0.19	**0.74**	0.49	0.14	0.08	0.22	0.90
Mn	0.25	0.15	**0.78**	0.02	0.28	0.28	0.20	0.88
K	0.00	-0.06	**0.72**	-0.08	-0.23	-0.21	-0.36	0.77
Na	0.11	-0.23	-0.18	-0.88	0.18	-0.11	-0.03	0.91
Total	**5.81**	**3.65**	**2.81**	**2.34**	**1.82**	**1.52**	**1.04**	
% of Variance	**26.40**	**16.60**	**12.76**	**10.64**	**8.26**	**6.89**	**4.74**	
Cumulative %	**26.40**	**43.00**	**55.76**	**66.40**	**74.66**	**81.54**	**86.29**	

Background

Factor Analysis of the Background PM_{10} data revealed four factors (Table 4.4). Factor 1, the association with Cr, Al, Mn and K is suggestive of road dust or natural soil. Factor 2 shows particularly high factor loading values relating to Fe and Si which strongly indicates crustal source and natural soil. The high loadings on EC, OC and Zn lead us to vehicular sources and K leads to biomass burning for Factor 3. Factor 4 is easier to attribute due to the high loadings on NO_3, SO_4 and NH_4 which are suggestive of secondary particulate matter.

Table 4.4 Factor loadings of different variables at Background

	Factor 1	Factor 2	Factor 3	Factor 4	Communalities
PM_{10}	-0.65	0.41	0.16	0.22	0.66
Na Ions	0.14	-0.83	-0.22	-0.22	0.80
NH4 Ions	-0.33	0.15	0.18	**0.84**	0.87
K Ions	-0.08	0.00	**0.77**	0.35	0.72
Ca Ions	-0.18	-0.81	0.12	-0.03	0.71
Mg Ions	0.07	-0.85	-0.23	-0.13	0.80
Cl Ions	0.18	-0.81	0.43	0.04	0.87
NO_3 Ions	0.05	0.04	0.14	**0.89**	0.82
SO_4 Ions	-0.52	0.15	0.23	**0.72**	0.87
OC	0.06	0.42	**0.70**	0.32	0.77

EC	0.01	0.50	**0.68**	0.35	0.84
Fe	0.36	**0.55**	0.39	-0.35	0.70
Cr	**0.88**	-0.15	-0.11	0.04	0.82
Zn	0.48	0.05	**0.75**	-0.37	0.92
Mo	0.21	0.11	-0.78	-0.08	0.67
Si	-0.34	**0.49**	0.17	0.02	0.39
Al	**0.79**	0.19	0.25	-0.36	0.85
Mn	**0.69**	0.12	0.41	0.16	0.68
K	**0.81**	0.04	-0.07	-0.48	0.89
Na	-0.65	0.25	0.24	0.54	0.83
Total	**6.64**	**4.55**	**2.88**	**1.42**	
% of Variance	**33.18**	**22.77**	**14.38**	**7.10**	
Cumulative %	**33.18**	**55.95**	**70.33**	**77.43**	

Victoria road

Factor Analysis of the Victoria Road PM_{10} data revealed six factors (Table 4.5). Factor 1, the association with Ca, Si, Na, NO_3 and SO_4 is strongly suggestive of a soil and road dust. The high loadings on Cl, Na and Mg indicate natural soil contribution for Factor 2. Factor 3 shows particularly high factor loading values relating to NO_2, OC and EC which strongly indicating motor vehicles. Again, there is a significant factor loading on Al, K and paved road dust may well contribute along with motor vehicle exhaust. Factor 4 is easier to attribute due to the high loadings on Fe, Zn, Mn and Br which are associated with motor vehicles. Factor 5 has very high factor loading values on NH_4 and K which is indicative of biomass burning. Factor 6 indicates high factor loading value for PM_{10} which is giving insight to inclusion of more molecular marker species for source identification. Since it has relatively higher value of NH4, it is indicative of secondary particle formation.

Table 4.5 Factor loadings of different variables at Victoria Road

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
PM_{10}	0.12	0.11	0.10	0.17	-0.03	**0.82**	0.74
Na Ions	-0.01	**0.81**	-0.17	-0.08	0.29	0.36	0.90
NH4 Ions	0.08	-0.09	-0.34	-0.16	**0.59**	0.51	0.77
K Ions	0.46	0.30	-0.12	0.23	**0.59**	0.07	0.72
Ca Ions	**0.71**	0.41	0.33	0.28	-0.14	-0.24	0.93
Mg Ions	0.12	**0.71**	-0.59	0.14	-0.06	0.02	0.88
Cl Ions	0.07	**0.88**	0.16	0.09	0.05	-0.01	0.81
NO_2 Ions	0.40	-0.21	**0.69**	-0.08	-0.30	-0.04	0.79
Br Ions	0.15	0.61	-0.05	**0.64**	0.18	-0.09	0.85
NO_3 Ions	**0.90**	0.25	-0.08	0.06	0.20	0.22	0.97
SO_4 Ions	**0.81**	0.04	0.18	-0.12	0.14	0.15	0.74
OC	-0.19	-0.54	**0.57**	-0.01	-0.02	0.33	0.76
EC	-0.23	-0.54	**0.41**	0.30	-0.09	0.39	0.76
Fe	0.11	-0.17	0.09	**0.85**	0.11	0.12	0.80
Cr	-0.57	-0.32	-0.10	-0.28	0.41	0.18	0.72
Zn	-0.13	0.12	-0.20	**0.88**	-0.06	0.21	0.90

Mo	0.29	-0.21	-0.02	-0.08	-0.81	0.13	0.81
Si	**0.80**	-0.12	0.07	-0.02	-0.28	-0.12	0.75
Al	0.07	0.07	**0.91**	-0.05	0.01	-0.11	0.85
Mn	0.28	0.19	0.04	**0.71**	-0.17	-0.51	0.90
K	0.22	-0.03	**0.77**	0.05	-0.09	0.11	0.66
Na	**0.61**	-0.01	0.23	0.32	-0.43	-0.03	0.72
Total	**5.48**	**4.68**	**2.49**	**2.25**	**1.72**	**1.12**	
% of Variance	**24.90**	**21.29**	**11.31**	**10.25**	**7.80**	**5.08**	
Cumulative %	**24.90**	**46.19**	**57.50**	**67.75**	**75.55**	**80.64**	

Kammanahalli

Factor Analysis of the Kammanahalli PM_{10} data revealed six factors (Table 4.6). Factor 1, the association with NO_3, Ca and Cl is suggestive of unpaved road dust. Factor 2 is to attribute due to the high loadings on Se which is associated with coal combustion. The high loadings on K lead us clearly for vegetative burning in case of Factor 3 at this sampling location. Factor 4 has very high factor loading values on NH_4 which is indicating secondary particulate matter. For Factor 5, the association with Na and Mg is strongly suggestive of a crustal source, presumably re-suspended soil. Factor 6 is easier to attribute due to the high loadings on OC, EC and SO_4 which are strongly associated with exhaust emissions from petrol and diesel vehicles.

Table 4.6 Factor loadings of different variables at Kammanahalli

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
PM_{10}	0.26	0.45	**0.64**	-0.16	0.42	-0.31	0.98
Na Ions	0.40	0.41	0.18	0.19	**0.73**	-0.09	0.94
NH4 Ions	0.39	-0.33	-0.11	**0.74**	0.35	0.01	0.94
K Ions	0.32	0.15	**0.64**	0.51	-0.19	0.24	0.89
Ca Ions	**0.97**	-0.07	0.06	-0.02	-0.11	-0.08	0.96
Mg Ions	-0.07	0.07	0.04	0.17	**0.90**	0.18	0.89
Cl Ions	**0.82**	0.09	-0.03	-0.11	0.36	-0.20	0.86
NO_3 Ions	**0.75**	0.42	0.16	0.15	0.07	0.12	0.81
SO_4 Ions	0.42	-0.21	-0.50	0.45	0.11	**0.53**	0.97
OC	0.04	-0.45	0.44	-0.08	-0.48	**0.56**	0.95
EC	-0.38	0.27	0.12	0.18	-0.55	**0.59**	0.92
Fe	0.11	-0.81	0.09	-0.39	-0.02	0.21	0.87
Cr	-0.45	0.22	-0.74	0.34	-0.07	0.12	0.94
Zn	0.36	0.39	-0.13	0.48	0.33	-0.41	0.80
Se	0.18	**0.75**	0.21	-0.22	0.05	0.50	0.94
Si	0.11	0.06	-0.03	0.02	-0.12	-0.87	0.79
Al	-0.11	-0.86	0.12	0.12	-0.14	0.08	0.81
Mn	0.18	0.12	-0.91	0.00	-0.04	-0.20	0.92
K	-0.27	0.10	-0.04	**0.92**	0.07	-0.01	0.93
Total	**5.06**	**3.37**	**2.77**	**2.66**	**1.79**	**1.44**	
% of Variance	**26.65**	**17.72**	**14.60**	**14.00**	**9.44**	**7.58**	
Cumulative %	**26.65**	**44.37**	**58.97**	**72.97**	**82.42**	**89.99**	

IGICH

Factor Analysis of the Indira Gandhi Institute of Child Health PM_{10} data revealed six factors (Table 4.7). For factor 1, the association with OC, EC, NO_3 and Al is strongly suggestive of a motor vehicle source. And, there is significant factor loading on Na and K which indicates to road dust. Factor 2 shows particularly high factor loading values relating to ions of Na, K, Ca, Mg and Cl indicate natural soil and road dust. Factor 3 has very high factor loading values on NH_4 and SO_4 which is indicating secondary particulate matter. Again, there is a significant factor loading on Mn, and road dust or motor vehicles may also associate with this factor. Factor 4 has high loadings on Si and Cr which are associated with soil dust as well as construction activities. The high factor loading value for Zn at this sampling site lead us to associate Factor 5 with incinerator combustion. Factor 6 has very high factor loading values on Fe which could be from multiple sources like construction, incinerator, soil dust and road dust.

Table 4.7 Factor loadings of different variables at IGICH

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Communalities
PM_{10}	**0.81**	0.25	0.10	-0.12	-0.05	0.05	0.74
Na Ions	-0.06	**0.96**	0.08	0.09	0.13	-0.01	0.95
NH4 Ions	0.15	-0.04	**0.87**	0.29	-0.11	-0.22	0.92
K Ions	0.24	**0.66**	0.60	-0.03	-0.29	-0.14	0.94
Ca Ions	0.40	**0.82**	0.18	-0.11	0.02	0.14	0.90
Mg Ions	0.04	**0.94**	0.04	0.02	-0.03	-0.05	0.90
Cl Ions	-0.03	**0.95**	0.04	0.12	0.11	-0.09	0.94
NO_3 Ions	**0.57**	0.45	0.42	-0.13	0.03	0.15	0.75
SO_4 Ions	0.18	0.26	**0.87**	-0.14	-0.18	0.17	0.94
OC	**0.85**	0.01	0.04	-0.03	-0.21	0.17	0.80
EC	**0.85**	0.01	0.00	0.19	-0.27	0.20	0.87
Fe	0.20	-0.03	0.01	-0.06	0.05	**0.81**	0.71
Cr	-0.43	0.03	0.40	**0.64**	-0.04	0.23	0.81
Zn	-0.12	0.14	-0.10	0.14	**0.83**	0.08	0.76
Si	0.24	0.13	-0.12	**0.79**	0.18	-0.24	0.81
Al	**0.60**	0.00	-0.26	0.42	0.10	0.13	0.63
Mn	-0.28	0.11	**0.70**	-0.19	0.39	0.02	0.77
K	**0.74**	-0.22	0.05	0.09	0.42	-0.21	0.83
Na	**0.63**	0.29	0.24	0.01	-0.04	-0.42	0.71
Total	**5.84**	**3.63**	**2.30**	**1.65**	**1.19**	**1.09**	
% of Variance	**30.73**	**19.12**	**12.11**	**8.67**	**6.28**	**5.75**	
Cumulative %	**30.73**	**49.85**	**61.96**	**70.63**	**76.91**	**82.66**	

The indicative sources based on Factor Analysis for the different sites are presented in Table 4.8.

Table 4.8 Indicative sources based on Factor Analysis for the different sites

S. No.	*Site*	*Site description*	*Indicative sources*
1	Silk Board	Traffic location	Motor vehicle exhaust, secondary particulate matter, construction activities, natural soil, road dust
2	Victoria road	Traffic location	Motor vehicle exhaust, natural soil, road dust, biomass burning, secondary particle formation
3	Peenya	Industrial	Road dust, residual oil burning, crustal soil dust, industrial sources, metal industries, motor vehicle exhaust, construction activities
4	Domlur	Residential	Soil and road dust, secondary particle formation, motor vehicle exhaust, storm water drain, biomass burning
5	Kammanahalli	Residential	Road dust, coal combustion, vegetative burning, secondary particle formation, re-suspended soil, motor vehicle exhaust
6	IGICH	Hospital/ Residential	Road dust, natural soil, secondary particle formation, construction activities, motor vehicle exhaust, incinerator combustion
7	Kanamangala/ Background	Background	Natural soil, crustal source, road dust, vehicular sources, biomass burning, secondary particle formation

It may however be noted that the results of Factor Analysis have to be analysed keeping into consideration the limitations due to less sample size with respect to number of variables. Factor analysis and emission inventory results were used for identification of the major sources. These major sources were included for CMB analysis

4.1.2 CMB model 8.2 : methodology & results

The Chemical Mass Balance (CMB) air quality model is one of several receptor models that have been applied to air resources management.The CMB (Chemical Mass Balance) model is used in this study for receptor modelling for source apportionment

The source profile abundances (i.e. the mass fraction of a chemical from each source type) and the receptor concentrations, with appropriate uncertainty estimates, served 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 the values for the contributions for each source. The methodology followed to run CMB8.2 model is as follows:

- *Preparation of Input data*

CMB 8.2 compatible files are prepared containing ambient PM_{10} data for each of the 7 sites. Files include daily PM_{10} concentration and its constituents in the form of ions (cations/anions), carbon (OC/EC), elements and molecular markers.

Also, a CMB compatible files is prepared containing source profile data for various sources including wood burning, FO burning, DG sets (diesel and kerosene), LPG combustion, road dust, soil dust, petrol vehicles, diesel vehicles, secondary particulates (sodium nitrate, ammonium sulphate ammonium nitrate).

- *CMB run*

With the selection of ambient data files and the source profile file, CMB8.2 is run for all the days during which the monitoring was carried out in the three seasons.

- *Selection of sources & species*

Initially, all the major sources are selected including those identified based on emission inventory of the (2x2) grid and results of factor analysis. To start with all the species were selected for the initial CMB run. The results of the initial run were analysed in terms of model performance measures like :-

$$\% \text{ Mass : } \frac{\text{Total Source contribution estimates}}{\text{Total measured concentration}}$$

R Square : It is the fraction of the variance in the measured concentrations that is explained by the variance in the calculated species concentrations. It is determined by a linear regression of measured versus model calculated values for the fitting species.

Chi-square: Chi-square is the weighted sum of squares of the differences between the calculated and measured fitting species concentrations.

T-stat : It is the ratio of the source contribution estimate to the standard error.

Sources showing negative contribution (which are physically not meaningful) were removed sequentially discarding first the source whose T-stat is low because of higher uncertainty associated with them.

Species showing high residual uncertainty are sequentially removed in the order of their magnitude.

Continuous, CMB runs were carried out for the same sample till the fitting statistical parameters like % Mass, R Square, and Chi-square come within the desired ranges.

It may however be noted that the results of the CMB modelling have to be analysed keeping into consideration the limitations due to the existence of co-linearity amongst the source profiles. The contribution of paved road dust re-suspension and soil dust is shown together due to the co-linearity issue. Also, there was not a clear distinction between diesel usage in transport and DG sets and accordingly, the combined share of these two sources was finally split in the ratio of their contribution in the emission inventory.

The results of CMB8.2 receptor modelling are presented in subsequent sections:

4.1.3 Receptor modelling PM_{10}

Domlur (residential)

Source apportionment of PM_{10} at Domlur location using the CMB8.2 model suggests a significant contribution from diesel burning in DG sets and transport sector. DG sets contribute 38%, 21% and 35% in the first, second and third seasons. Transport sector (both diesel and petrol) contributes 7%, 6%, and 8% in the three corresponding seasons. Dust originating from road dust re-suspension and from crustal sources has a significant share of 35-62 % during different seasons. Secondary particulates also have a share of 9-19% in the PM_{10} concentrations observed in different seasons at Domlur location. (Figure 4.1).

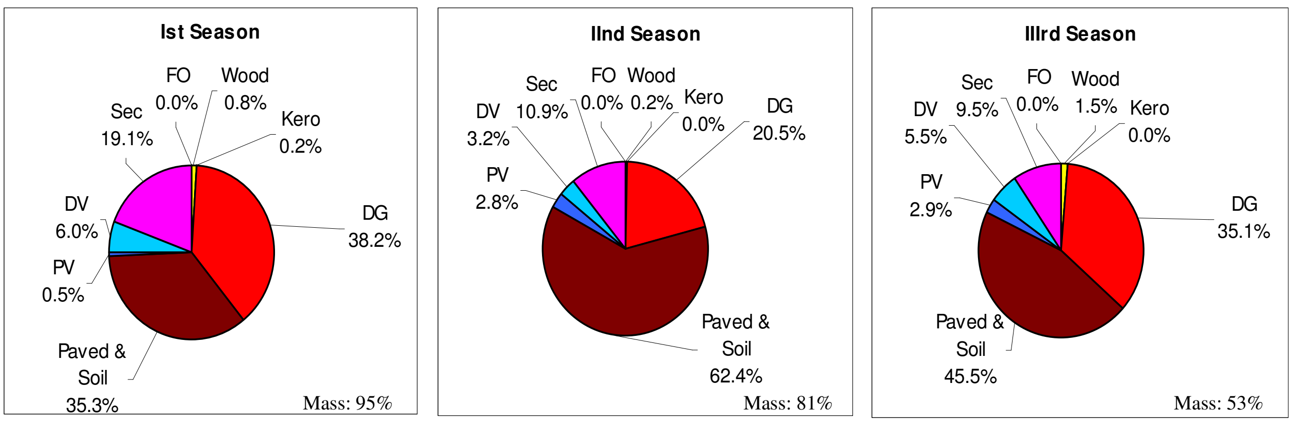


Figure **4.1** PM_{10} source contribution at Domlur

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Kammanahalli (residential)

Source apportionment of PM_{10} at Kammanahalli location using the CMB8.2 model suggests substantial contribution from the transport sector (Figure 4.2). Transport sector (petrol & diesel) have a significant share of 38%, 41%, and 26% in the three corresponding seasons. DG sets contribution varies between 3-5%. Dust originating from road dust re-suspension and from crustal origin has a significant share of 38-62%.

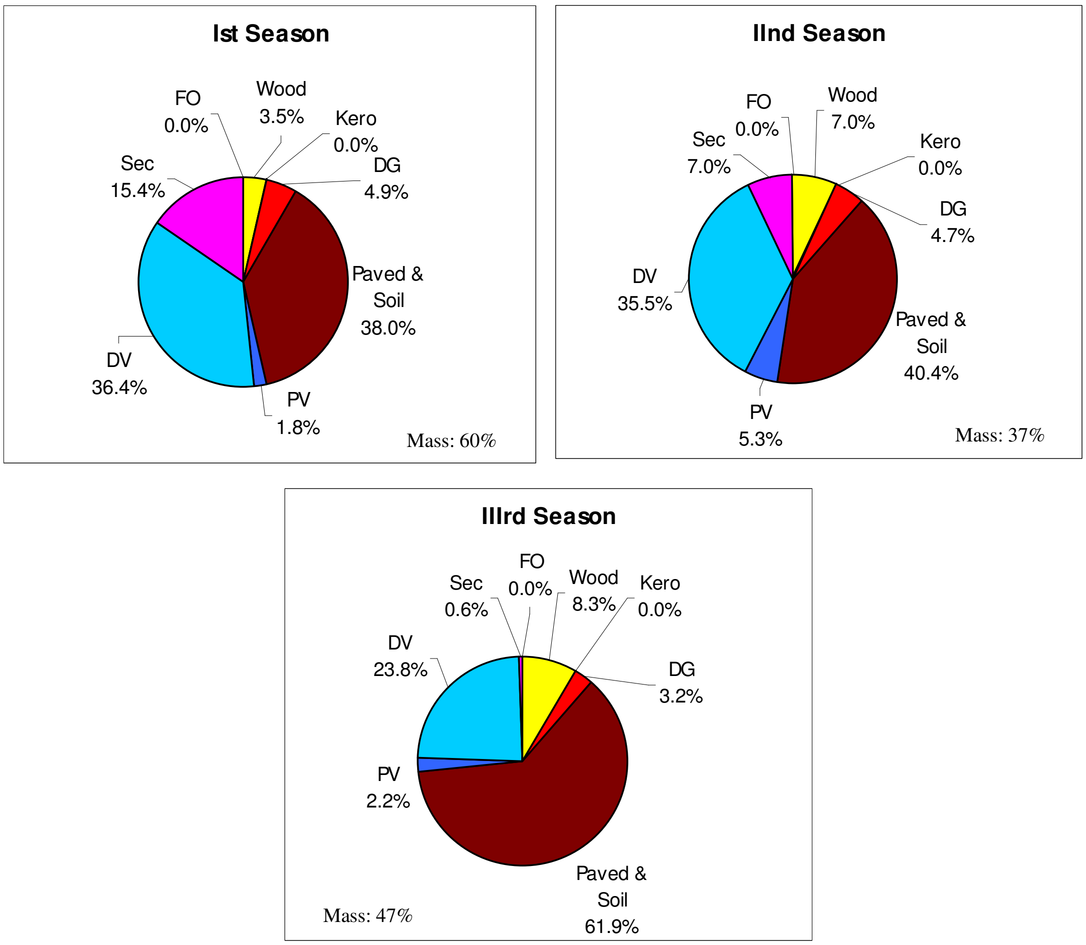


Figure **4.2** PM_{10} source contribution at Kammanahalli

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

CSB (kerbside)

Figure 4.3 shows the source apportionment of PM_{10} at CSB location using the CMB8.2 model which suggests substantial contribution from transport sector (14-54%). Dust originating from road dust re-suspension and from crustal origin has a significant share of 26-72%. DG sets contribute minimally (1-3%) in the three seasons. Share of secondary particulate varies from 7- 17%.

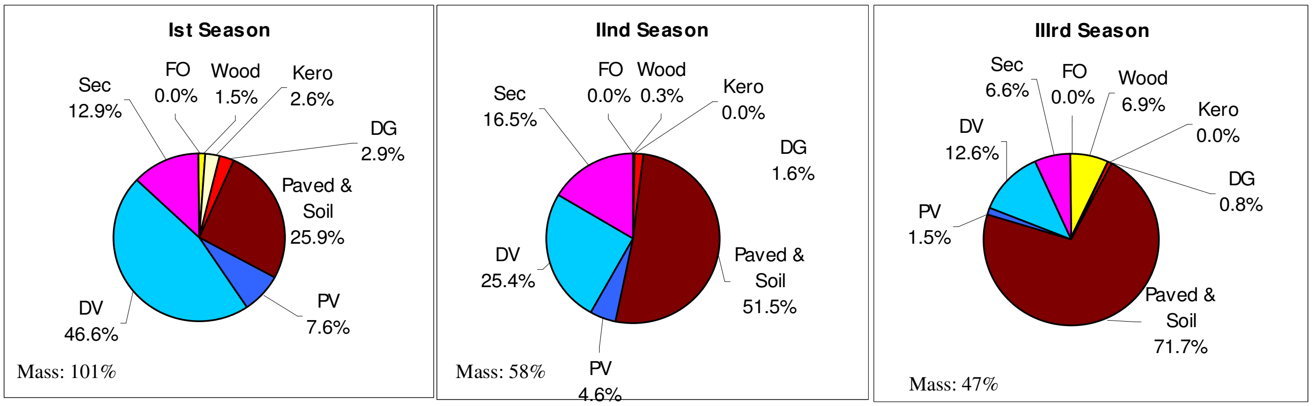


Figure **4.3** PM_{10} source contribution at CSB

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Victoria Road (kerbside)

Source apportionment of PM_{10} at Victoria road location using the CMB8.2 model suggests significant contribution from transport sector (8-15%). DG sets contribute 8-19% while secondary particles contribute 6-16% in different seasons. However, dust originating from road dust re-suspension and from crustal origin has a maximum share of 52-73%..(Figure 4.4).

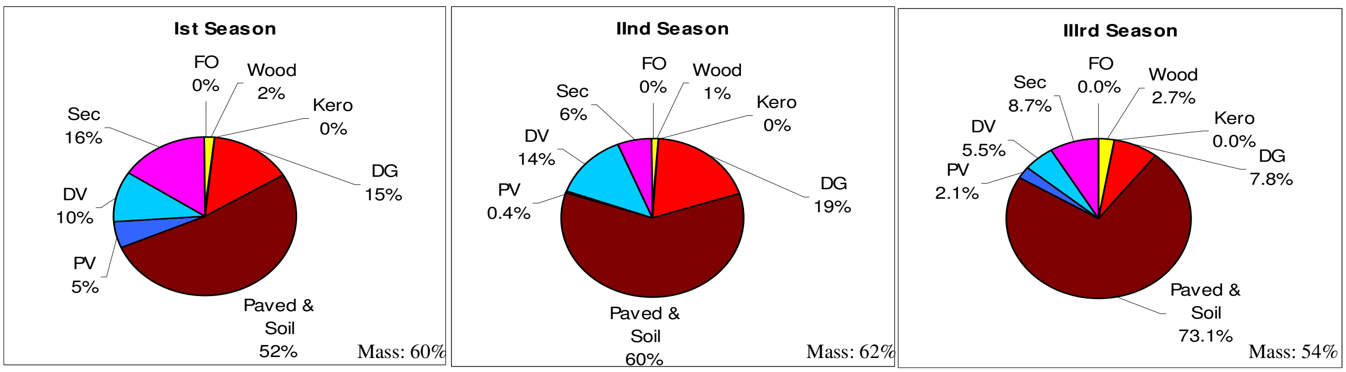


Figure **4.4** PM_{10} source contribution at Victoria road

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

IGICH (Hospital/Residential)

Source apportionment of PM_{10} at IGICH location using the CMB8.2 model suggests significant contribution from transport sector (7-22%). Wood burning has also been detected varying from 2-9% in different seasons. Share of dust from road re-suspension and crustal origin have eclipsed the share of other sectors and has contributed 64%, 48%, and 44% in first, second and third season, respectively. Secondary particulates have a share of 1-14% in the PM_{10} concentrations observed in different seasons at IGICH location (Figure 4.5).

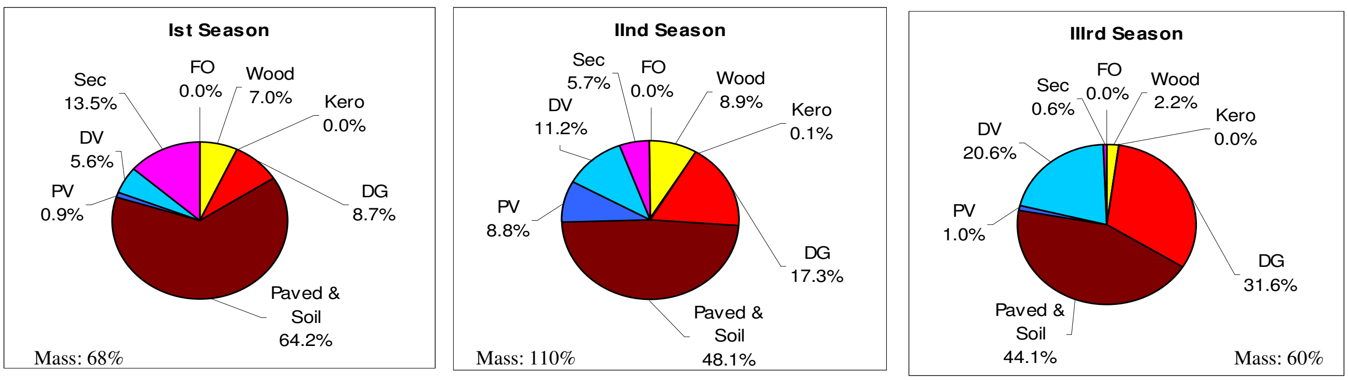


Figure **4.5** PM_{10} source contribution at IGICH

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Peenya (Industrial)

Source apportionment of PM_{10} at Peenya location using the CMB8.2 model suggests significant contribution from industrial sector i.e. FO burning (17%-42%) in different seasons. Transport sector has a considerable share of 4-18% in different seasons. Wood burning has also been detected varying from 1-16% in different seasons. Dust originated from road dust re-suspension and from crustal origin has the maximum share of 31-56%. (Figure 4.6).

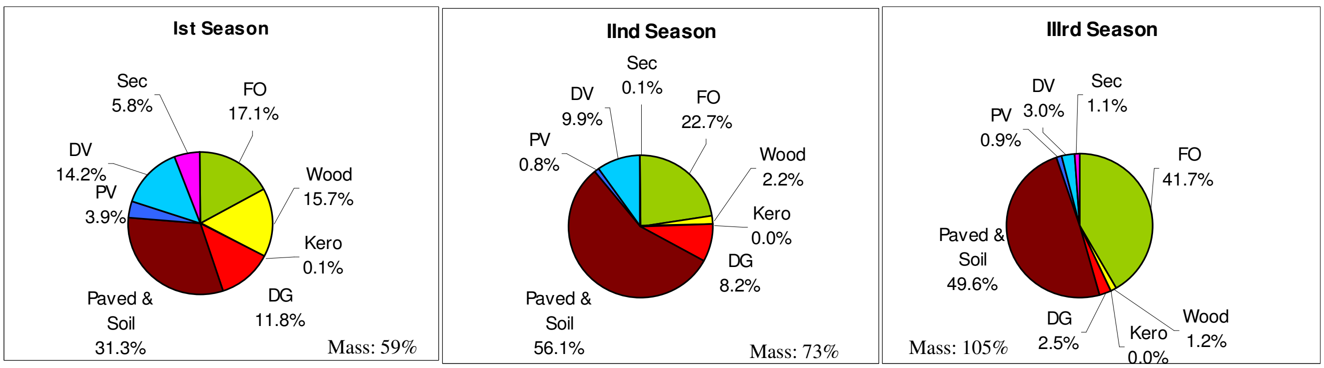


Figure **4.6** PM_{10} source contribution at Peenya

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Kanamangla (Background)

Source apportionment of PM_{10} at Kanamangla location using the CMB8.2 model suggests major contribution from secondary particulates and soil dust, which clearly shows the characteristics of a background location. Secondary particulates contribute 13-40%, while dust (from road dust re-suspension and soil) contributes 24-55%.
Transport sector also have a share of 16-25% in different seasons. Wood burning has also been detected varying from 5-11% in different seasons (Figure 4.7).

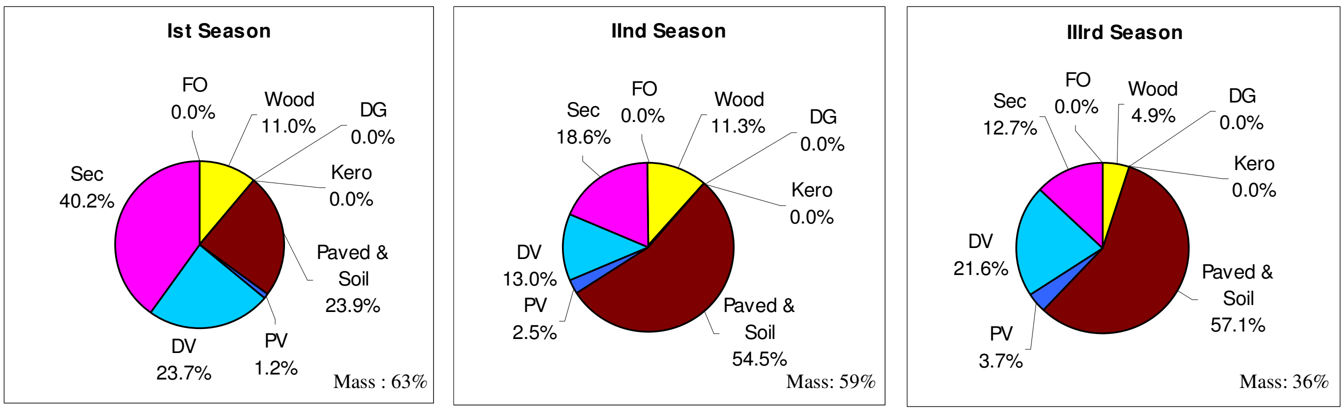


Figure **4.7** PM_{10} source contribution at Kanamangala (Background)

* Third season results are obtained using average of all the samples during the season

Note Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

PV: Petrol vehicles, DV : Diesel vehicles, Sec : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

4.1.4 Receptor modelling $PM_{2.5}$

Domlur (Residential)

Source apportionment of $PM_{2.5}$ at Domlur location using the CMB8.2 model suggests substantial contribution from DG sets (37-49%). Transport sector also contributes in a considerable manner (13-48%). Secondary particulates have substantial share of 39%, 15%, and 4%, in first, second, and third seasons, respectively. Being coarse, dust doesn't feature much in the $PM_{2.5}$ distribution. (Figure 4.8).

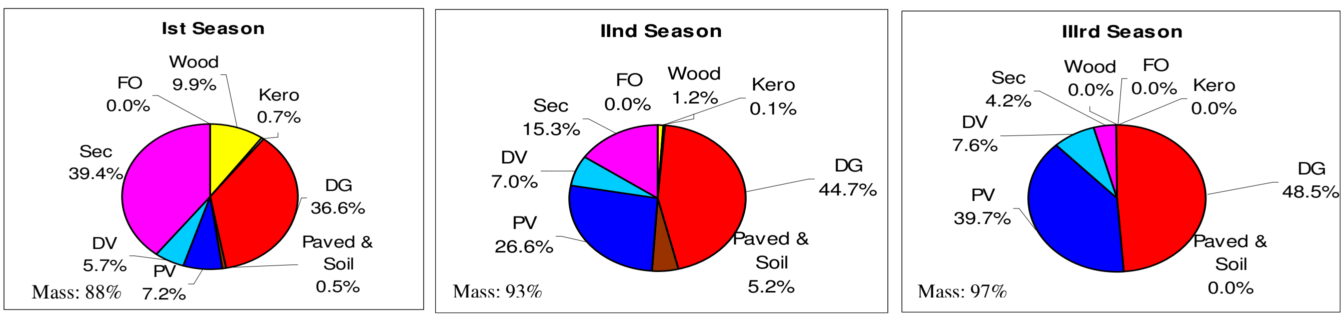


Figure **4.8** $PM_{2.5}$ source contribution at Domlur

Note: Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Kammanahalli (Residential)

Source apportionment of $PM_{2.5}$ at Kammanahalli location using the CMB8.2 model suggests major contribution from transport sector . Transport sector (diesel + petrol vehicles) contributes 57%, 80% and 80% in the first, second and third seasons, respectively. Share of secondary particulates varies in between 7-23%. 7-9% of $PM_{2.5}$ emissions are contributed by DG sets while wood burning contributes about 2-3%.. Being coarse, dust doesn't feature much in the $PM_{2.5}$ distribution. (Figure 4.9).

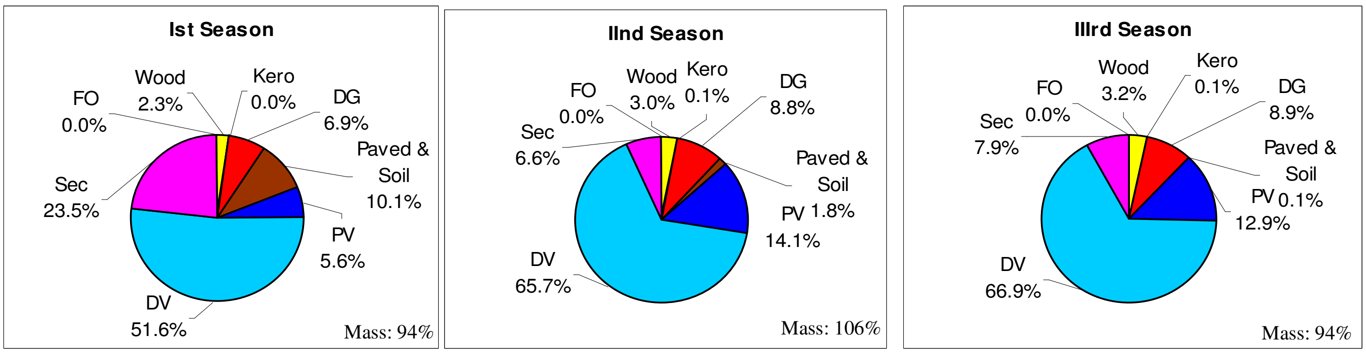


Figure **4.9** $PM_{2.5}$ source contribution at Kammanahalli

Note: Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

CSB (Kerbside)

Source apportionment of $PM_{2.5}$ at CSB location (kerbside location) using the CMB8.2 model suggests major contribution from transport (petrol+diesel) sector (60-84%).
Secondary particulates contribute 12%, 28% and 5% in the first second and third seasons, respectively. DG sets have small contribution of 3-5%. Dust being coarse doesn't feature much in the $PM_{2.5}$ distribution. (Figure 4.10).

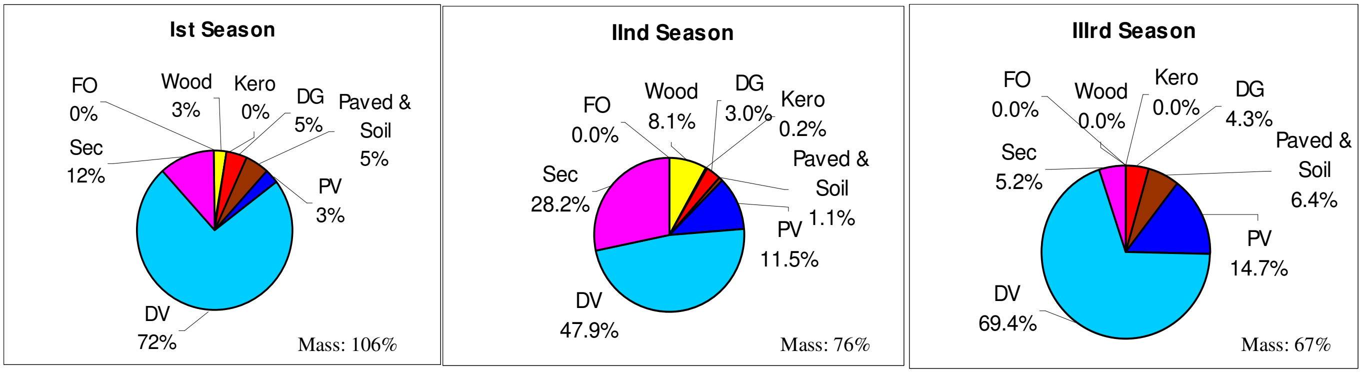


Figure **4.10** $PM_{2.5}$ source contribution at CSB

Note: Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Victoria Road (Kerbside)

Source apportionment of $PM_{2.5}$ at Victoria road location using the CMB8.2 model suggests significant contribution from transport sector (40-55%). This clearly shows representativeness of the kerbside location. DG sets contribute 35-47% to the PM_{10} concentrations. Share of secondary particulates varies between 4-13% in different seasons. Dust being coarse doesn't feature much in the $PM_{2.5}$ distribution (Figure 4.11).

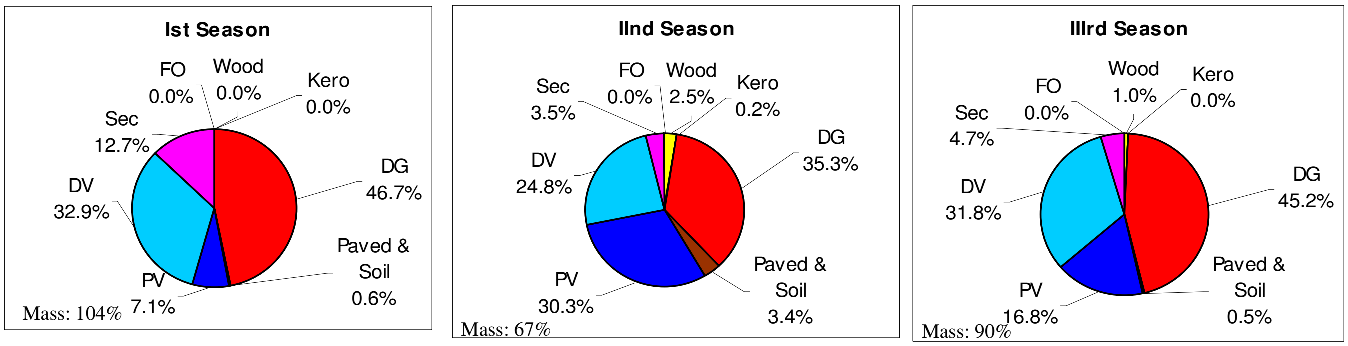


Figure **4.11** $PM_{2.5}$ source contribution at Victoria road

Note: Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

IGICH (Hospital/Residential)

Source apportionment of $PM_{2.5}$ at IGICH location using the CMB8.2 model suggests that the share of transport sector varies between 37-43% in various seasons. DG sets also contribute substantially (25-38%). Dust (from road dust resuspension and soil) has contributions upto18%.. Wood burning has also been detected varying from 9-13%. Secondary particulates have a considerable share of 10%, 7% and 9% in the first, second and third seasons (Figure 4.12).

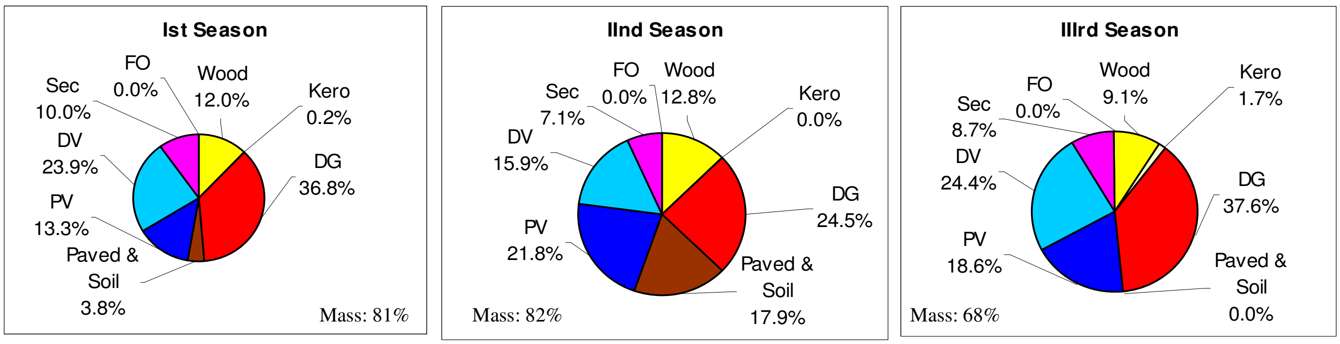


Figure **4.12** $PM_{2.5}$ source contribution at IGICH

Note: Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Peenya (Industrial)

Peenya truly represents the industrial location and source apportionment of $PM_{2.5}$ suggests significant contribution from industrial sector i.e. FO burning (14%-25%) in different seasons. Transport sector (diesel & petrol) also has a substantial share of 20%, 41% and 44% in first, second, and third season, respectively. DG sets also has a significant contribution of 13-23%. Wood burning has also been detected varying from 7-15% in different seasons. Share of secondary particulates has been 8-23% (Figure 4.13).

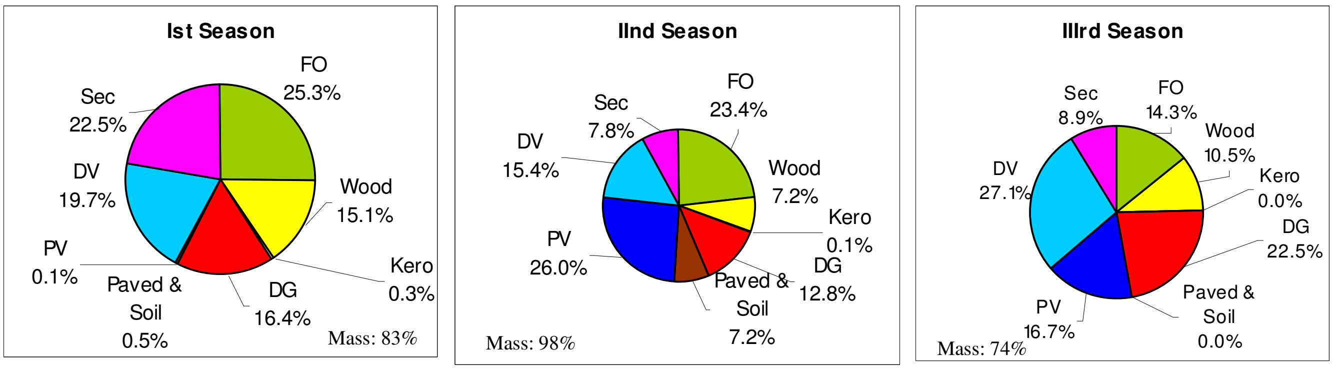


Figure **4.13** $PM_{2.5}$ source contribution at Peenya

Note: Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

Kanamangla (Background)

Source apportionment of $PM_{2.5}$ at Kanamangla location using the CMB8.2 model suggests significant contribution from secondary particulates. They contribute 33%, 30% and 9% in first, second and third season, respectively. In absence of any other major antropogenic sources, transport sector (diesel +petrol vehicles) have a share of 51-70% in the different seasons. Being a location in a village, wood burning has also been detected in varying proportions (2-14%). Also, dust (from road dust resuspension and soil) contributes 2-19% (Figure 4.14).

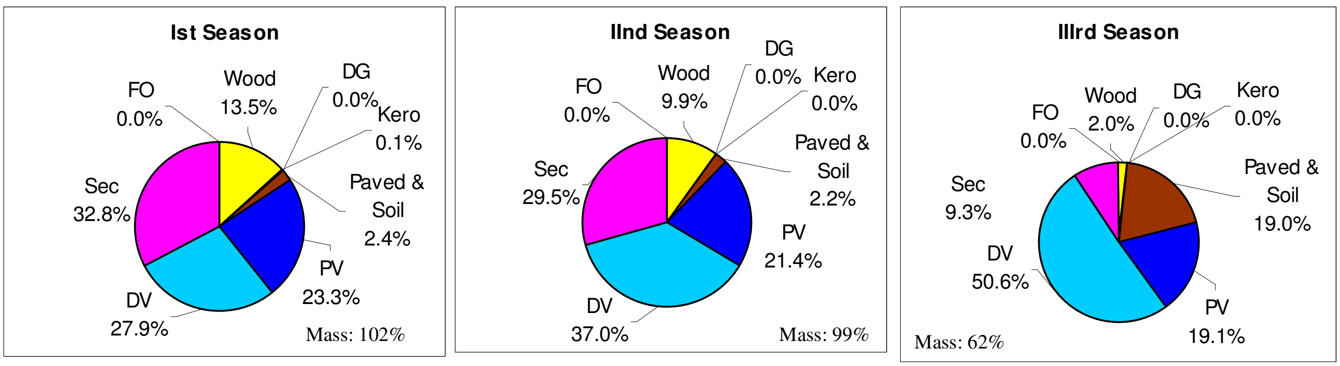


Figure **4.14** $PM_{2.5}$ source contribution at Kanamangala (Background)

Note : Above analysis does not include the unaccounted mass fraction which includes both the unaccounted mass fraction in the source profiles and unidentified sources itself.

Petrol: Petrol vehicles, Diesel : Diesel vehicles, Secondary : Secondary particulates, FO : Fuel oil burning, Wood : Domestic wood burning, DG: Diesel generator set, Kero: Kerosene generator set, Paved: Paved road dust re-suspension, Soil : Soil dust

4.1.5 Conclusions : Receptor modelling

Receptor modelling using CMB8.2 model has been carried out for PM_{10} and $PM_{2.5}$ concentrations at all the 7 ambient air quality monitoring locations in Bangalore for all the three seasons.

PM_{10}

CMB8.2 modelling of PM_{10} for 7 locations in Bangalore suggests that there is a wide variation in the contribution of various sources to PM_{10} concentrations at various sites as well as in different seasons. Table 4.9 presents the summary of results of receptor modelling for PM_{10} concentrations in three seasons at 7 locations in Bangalore. It is seen that major sectoral contributors to the PM_{10} concentration are dust from paved road and soil; transport; DG sets; and secondary particle formation. Domestic and industrial sectors have small contributions.

Broadly, some of the key features that emerge are as follows:

i) The contribution of paved road dust re-suspension and soil dust is significant at all sites (contributing sectors road dust re-suspension and natural soil/ construction);
ii) At the kerbside locations (CSB), vehicles have a substantial contribution..
iii) At the industrial location (Peenya), the share of fuel oil (FO) combustion is clearly significant.
iv) At the background location (Kanamangala), the contribution due to secondary particulates is maximum.

Table 4.9 Quantification of PM_{10} sources at 7 monitoring locations in Bangalore

	Domlur			Kammanhalli			CSB			Victoria road			IGICH			Peenya			Background		
Sector	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd
Transport	6%	6%	8%	38%	41%	26%	54%	30%	14%	16%	14%	8%	7%	20%	22%	18%	11%	4%	25%	15%	25%
DG sets	38%	20%	35%	5%	5%	3%	3%	2%	1%	15%	19%	8%	9%	17%	32%	12%	8%	2%	0%	0%	0%
Industrial	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	23%	42%	0%	0%	0%
Domestic	1%	0%	2%	4%	7%	8%	4%	0%	7%	2%	1%	3%	7%	9%	2%	16%	2%	1%	11%	11%	5%
Paved road & Soil dust	35%	62%	45%	38%	40%	62%	26%	52%	72%	52%	60%	73%	64%	48%	44%	31%	56%	50%	24%	55%	57%
Secondary particulates	19%	11%	9%	15%	7%	1%	13%	17%	7%	16%	6%	9%	14%	6%	1%	6%	0%	1%	40%	19%	13%

The average sectoral share to PM_{10} concentration in Bangalore based on receptor modelling (average of 6 monitoring sites and three seasons) are presented in Table 4.10.

Table 4.10 Average sectoral share to PM_{10} concentration in Bangalore based on receptor modelling

Sector/	Seasonal average of 6 sites			Average of all seasons
	Ist	IInd	IIIrd	
Transport (Fuel combustion Petrol & Diesel vehicles)	23.2%	20.3%	13.6%	19.0%
DG sets	13.5%	11.9%	13.5%	13.0%
Industrial (FO combustion)	2.9%	3.8%	7.0%	4.5%
Domestic (Wood, LPG, Kerosene)	5.6%	3.3%	3.8%	4.2%
Paved road & Soil dust	41.1%	53.0%	57.6%	50.6%
Secondary Particulates	13.8%	7.7%	4.5%	8.7%

Table 4.10 shows that average share of transport sector to the PM_{10} concentrations in the city across various seasons varies from 14-23%. DG sets contribute 12-14% and industries contribute 3-7%. Paved road and soil dust are the major contributors having a share of 41-58%. Secondary particulates also have a share of 5-14%.

$PM_{2.5}$

Table 4.11 presents the results of receptor modelling using CMB8.2 for $PM_{2.5}$ concentrations in different season at all the 7 monitoring locations in Bangalore. It emerges out that the transport sector has a major contribution to the $PM_{2.5}$ concentrations, followed by other sectors like DG sets, and secondary particulates. However, domestic sector, and industries have small contribution.

Some of the key features that emerge out are as follows:

i) The contribution of transport sector (petrol and diesel vehicles) is significant at all sites, with kerbside locations showing the higher contribution.
ii) Secondary particulates also have substantial share in the $PM_{2.5}$ concentrations. Background location shows highest contribution from them.
iii) At the industrial location (Peenya) the share of fuel oil (FO) combustion is clearly significant.
iv) Dust being coarse, does not contribute much to the $PM_{2.5}$ concentrations

Table 4.11 Quantification of $PM_{2.5}$ sources at 7 monitoring locations in Bangalore

	Domlur			Kammanhalli			Victoria road			CSB			IGICH			Peenya			Background		
Sector	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd	Ist	IInd	IIIrd
Transport (Fuel combustion Petrol & Diesel vehicles)	13%	34%	47%	57%	80%	80%	40%	55%	49%	76%	59%	84%	37%	38%	43%	20%	41%	44%	51%	58%	70%
DG sets	37%	45%	49%	7%	9%	9%	47%	35%	45%	5%	3%	4%	37%	24%	38%	16%	13%	22%	0%	0%	0%
Industrial (FO combustion)	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	23%	14%	0%	0%	0%
Domestic (Wood, LPG, Kerosene)	11%	1%	0%	2%	3%	3%	0%	3%	1%	3%	8%	0%	12%	13%	11%	15%	7%	10%	14%	10%	2%
Paved road & Soil dust	1%	5%	0%	10%	2%	0%	1%	3%	1%	5%	1%	6%	4%	18%	0%	0%	7%	0%	2%	2%	19%
Secondary Particulates	39%	15%	4%	23%	7%	8%	13%	3%	5%	12%	28%	5%	10%	7%	9%	23%	8%	9%	33%	30%	9%

The average sectoral share to $PM_{2.5}$ concentration in Bangalore based on receptor modelling (average of 6 monitoring sites and three seasons) are presented in Table 4.12 .

Table 4.12 Average sectoral share to $PM_{2.5}$ concentration in Bangalore based on receptor modelling

Sector	Seasonal average of 6 sites			Average of all seasons
	Ist	IInd	IIIrd	
Transport (Fuel combustion Petrol & Diesel vehicles)	40.6%	51.2%	57.8%	49.9%
DG sets	24.6%	21.5%	27.8%	24.7%
Industrial (FO combustion)	4.2%	3.9%	2.4%	3.5%
Domestic (Wood, LPG, Kerosene)	7.2%	5.9%	4.2%	5.8%
Paved road & Soil dust	3.4%	6.1%	1.2%	3.5%
Secondary Particulates	20.0%	11.4%	6.6%	12.7%

Table 4.12 shows that average share of transport sector to the $PM_{2.5}$ concentrations in the city varies from 41-58%, during different seasons. Secondary particulates also have a significant share of 7-20%. Domestic sectors have a small share of 4-7%, followed by industries 2-4%. Being course in size, dust doesn’t feature much in the $PM_{2.5}$ sources.

Conclusions of PM_{10} & $PM_{2.5}$ receptor modelling

Figure 4.15 shows the contribution of various sources to PM_{10} and $PM_{2.5}$ based on the CMB8.2 modelling results. Some of the key points are :

- Share of transport sector increase from 19% in PM_{10} to 50% in $PM_{2.5}$, depicting dominance of finer particles in the vehicular exhaust.
- Share of anthropogenic sources has been eclipsed by dust contributions, in case of PM_{10}. However, $PM_{2.5}$ clearly shows the significant contribution of anthropogenic sources.
- DG sets have emerged out as an important source of air pollution. Their contribution is 13% & 25% in PM_{10} and $PM_{2.5}$, respectively.
- Contribution of industries to the particulate matter is low in Bangalore, primarily due to absence of any large scale air polluting units. However, their contribution in the industrial zone (Peenya) is high.
- Overall, domestic sector has a small contribution in both PM_{10} and $PM_{2.5}$. However, few locations have shown substantial contribution which is attributable to wood burning in the region.
- Share of secondary particulates is higher in $PM_{2.5}$ than in PM_{10}, depicting their finer size.

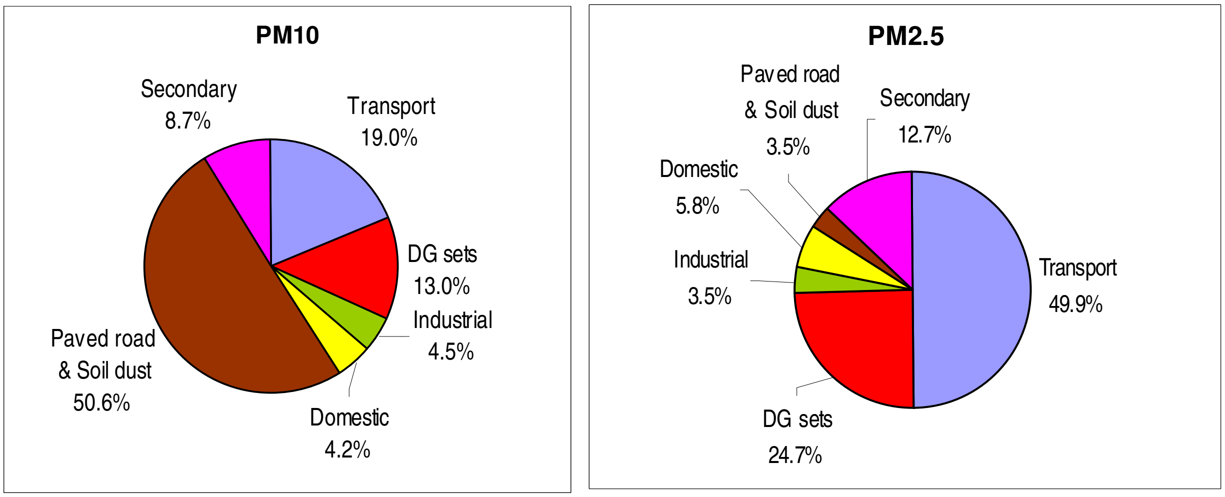


Figure **4.15** Comparison of PM_{10} and $PM_{2.5}$ source contribution in Bangalore city (average of 3 seasons)

CHAPTER 5 Dispersion modelling: Existing scenario

5.1 Dispersion modelling - ISCST3 : Methodology

Dispersion modelling is used to predict concentrations at selected receptor locations. Industrial Source Complex Short-term (ISCST3) model has been used in this study. The field data collected during the primary monitoring as well as from secondary sources were used as inputs to the model. The preparation of input data files was undertaken as per the specified format. This included appropriate estimation of emissions from the various sources based on the activity data and the relevant emission factors. The emission data were input to the model along with the onsite meteorological data to get the predicted PM_{10} and NO_X concentration values, which were then compared against the observed PM_{10} and NO_X concentrations obtained at various sites in the city.

ISCST3 model is a steady-state Gaussian plum model which is used to assess pollutant concentrations from a wide variety of sources. Emission sources are categorised into two basic types of sources, i.e., Point, Area and Line as Area. The ISCST3 model estimates the concentrations for each source and receptor combination for each hour of input meteorology, and calculates a user-selected short-term average e.g., 24-hourly average concentration.

Salient features of adopted methodology for simulation of ISCST3 model:

1) Total city area of 624 sq Km divided into 2*2 sq km area grids. Further 2*2 sq Km area grids around the six air quality monitoring stations are divided into 0.5*0.5 sq area and adjacent grids were also accounted as separate partial grids. Eventually, total numbers of grids for city level analysis are 180 and for 0.5*0.5 sq Km area of sampling stations are 96 grids (16*6 grids). Grid wise map is shown in Figure 5.1.
2) Site-specific micro-meteorology has been taken for modeling of the respective six air quality monitoring stations that lie within the modelling domain. This includes (0.5x0.5 km^2) emissions for all the six air quality monitoring stations and the (2 x 2 km2) emissions for rest of the grids. Concentration values so obtained are used for comparison against observed values at each site.
3) For City level runs, using the same emission inventory (i.e. detailed (0.5x0.5 Km^2) for six air quality monitoring stations and (2x2 Km^2) for rest of the city), but with the

dominant meteorology (which in this case is background station meteorology).

4) Concentration values obtained at six air quality monitoring stations has been taken for the individual site meteorology while for the rest of grids it is based on dominant meteorology (background station meteorology)

5) Total number of sources taken for area, point and line sources at city level and 0.5x0.5 km2 are depicted in Table 5.1.

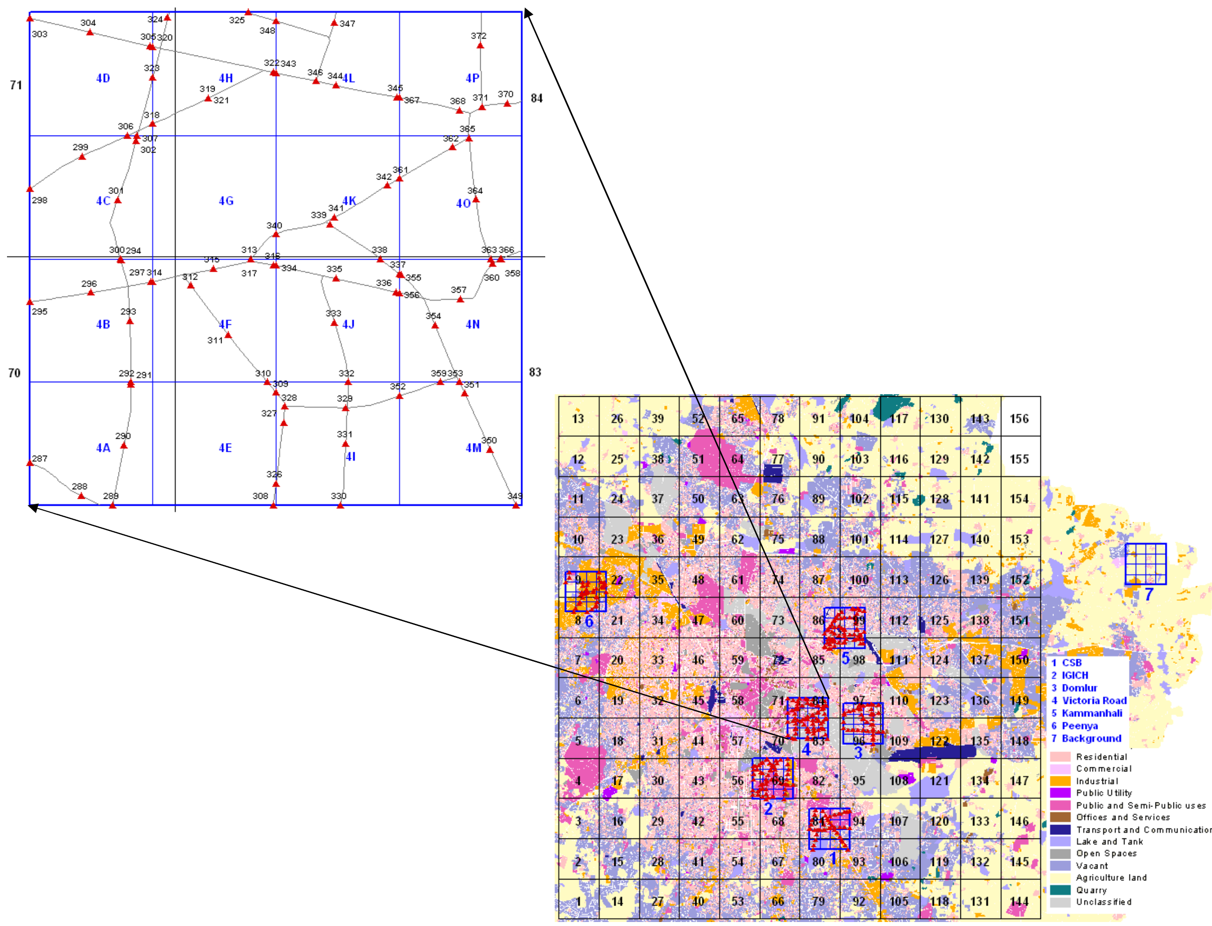


Figure **5.1** City level map of 2*2 sq Km and 0.5*0.5 sq Km grids with illustration of line sources at one 0.5*0.5 sq km level

Table 5.1 Summary of type and number of sources

	Emission Sources	Modelled Source Type	Number of Sources
1	Transport	**AREA** (line sources on major roads at 0.5*0.5 sq Km resolution that are within 2*2 sq Km area around each monitoring site)	372
		AREA (on minor roads within 2*2 sq Km area around each monitoring site)	96
		AREA (on major and minor roads in rest of the city)	180
2	Road Dust	**AREA** (line sources on major roads at 0.5*0.5 sq Km resolution that are within 2*2 sq Km area around each monitoring site)	372
		AREA (on minor roads within 2*2 sq Km area around each monitoring site)	96
		AREA (on major and minor roads in rest of the city)	180
3	Industries	**POINT** (City level including those located at Peenya)	158
		AREA (at 0.5*0.5 sq Km resolution of 2*2 sq Km area in Peenya)	16
		AREA (rest of the city at resolution of 2*2 sq Km)	180
4	Domestic	**AREA** (at 0.5*0.5 sq Km resolution of 2*2 sq Km area)	96
		AREA (rest of the city at resolution of 2*2 sq Km)	180
5	DG sets (Domestic and Commercial)	**AREA** (at 0.5*0.5 sq Km resolution of 2*2 sq Km area)	96
		AREA (rest of the city at resolution of 2*2 sq Km)	180
6	Construction	**AREA** (at 0.5*0.5 sq Km resolution of 2*2 sq Km area)	96
		AREA (rest of the city at resolution of 2*2 sq Km)	180
7	Eating joints	**AREA** (at 0.5*0.5 sq Km resolution of 2*2 sq Km area)	96
		AREA (rest of the city at resolution of 2*2 sq Km)	180
		Total	2754

5.2 Emission loads

City level

In the current study, emission inventory is prepared for various sectors and for various pollutants. Pollutant wise sectoral breakup of emission loads in Bangalore are presented in Table 5.2.

Table 5.2 Total emission loads (T/d) in Bangalore

	PM_{10}	NO_X	SO_2
Transport	22.4	146.36	2.31
Road Dust	10.9	0.00	0.00
Domestic	1.8	2.73	0.68
DG Set	3.6	50.96	3.35
Industry	7.8	17.19	8.21
Hotel	0.1	0.20	0.02
Construction	7.7	0.00	0.00
Total	54.4	217.4	14.6

Total emission inventory for the 2 x 2 km² zones of influence

Sector-wise emission inventory prepared for the six 2x2 km² zones of influence around the monitoring stations in the modeling domain is presented in Tables 5.3 and 5.4.

Table 5.3 Sector-wise PM_{10} emission inventory (T/d) for the six 2x2 km² zones of influence

	CSB	Domlur	IGICH	Kammanahalli	Peenya	Victoria
Transport	0.56	0.11	0.29	0.27	0.09	0.17
Industries	0.00	0.00	0.00	0.00	0.29	0.00
Domestic	0.01	0.01	0.03	0.03	0.00	0.02
DG sets	0.02	0.22	0.14	0.01	0.06	0.08
Road dust	0.42	0.06	0.07	0.05	0.07	0.08
Hotels	0.00	0.00	0.00	0.00	0.00	0.00
Constructlon	0.05	0.03	0.04	0.05	0.02	0.04
Total	**1.07**	**0.43**	**0.56**	**0.42**	**0.54**	**0.40**

Table 5.4 Sector-wise NO_X emission inventory (T/d) for the six 2x2 km² zones of influence

	CSB	Domlur	IGICH	Kammanahalli	Peenya	Victoria
Transport	4.34	0.71	1.66	1.76	0.66	1.11
Industries	0.00	0.00	0.00	0.00	0.82	0.00
Domestic	0.0231	0.024	0.046	0.045	0.007	0.035
DG sets	0.31	3.08	1.93	0.19	0.85	1.18
Road dust	0.00	0.00	0.00	0.00	0.00	0.00
Hotels	0.0023	0.0034	0.0027	0.0018	0.0011	0.0049
Construction	0.00	0.00	0.00	0.00	0.00	0.00
Total	**4.68**	**3.82**	**3.64**	**2.00**	**2.33**	**2.33**

5.3 Meteorological data

5.3.1 First season

During the 1st monitoring season the 24-h average temperature varied from 18.7 °C to 27.6 °C and average relative humidity was in the range of 41.6 percent to 63.5 percent. Wind speed was in the range of 1.8 to 4.3 km/h. The maximum was observed at Domlur and Victoria road sampling sites. The prominent wind direction (blowing from) observed at most of the sampling stations was in the sector ENE to SSE. Table 5.5 presents the summary of weather parameters recorded at various monitoring location. Wind rose diagram (Figure 5.2) of background location depicts the wind direction and frequency at this site during first season. The average wind speed at this location was 2.8 Km/hr and the calm percentage was 34.8% (below 1.8 Km/hr). There was no rain during this period.

Table 5.5 Summary of 24 hours* average, maximum and minimum values of primary meteorological parameters at various locations during the first season

Location	Sampling Dates	Wind Direction (degrees)			Wind Speed (Km/h)			Temp (^{o}C)			Relative Humidity (%RH)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average
Domlur	18 Dec 2006 to 07 Jan 2007	97.4	196.8	147.9	0.0	10.5	4.3	10.5	28.2	18.7	26.9	99.0	63.5
Kammanahalli	14 Jan to 02 Feb 2007	0.7	359.3	233.0	0.0	6.4	2.6	9.8	32.4	20.1	18.0	99.0	59.6
Victoria Road	6 to 26 March 2007	13.2	356.5	131.8	0.0	10.1	4.3	18.5	34.6	25.7	28.9	80.0	51.8
Central Silk Board	18 Dec 2006 to 07 Jan 2007	126.1	166.5	148.2	0.0	10.5	4.1	12.8	25.5	18.6	40.6	88.1	63.5
Peenya	15 Feb to 6 March 2007	1.4	359.8	162.9	0.0	5.0	1.8	9.7	34.6	23.3	13.4	91.0	48.8
IGICH	16 March to 4 April 2007	4.8	356.9	140.9	0.0	5.4	2.8	15.0	38.8	27.6	16.9	88.2	41.6
Background	6 to 8 Jan, 17 Jan & 29 Jan to 13 Feb 2007	0.0	359.5	138.4	0.0	13.6	2.8	11.5	30.0	21.4	17.8	92.6	57.4

*Meteorological parameters recorded as 60min average values for 24 hours

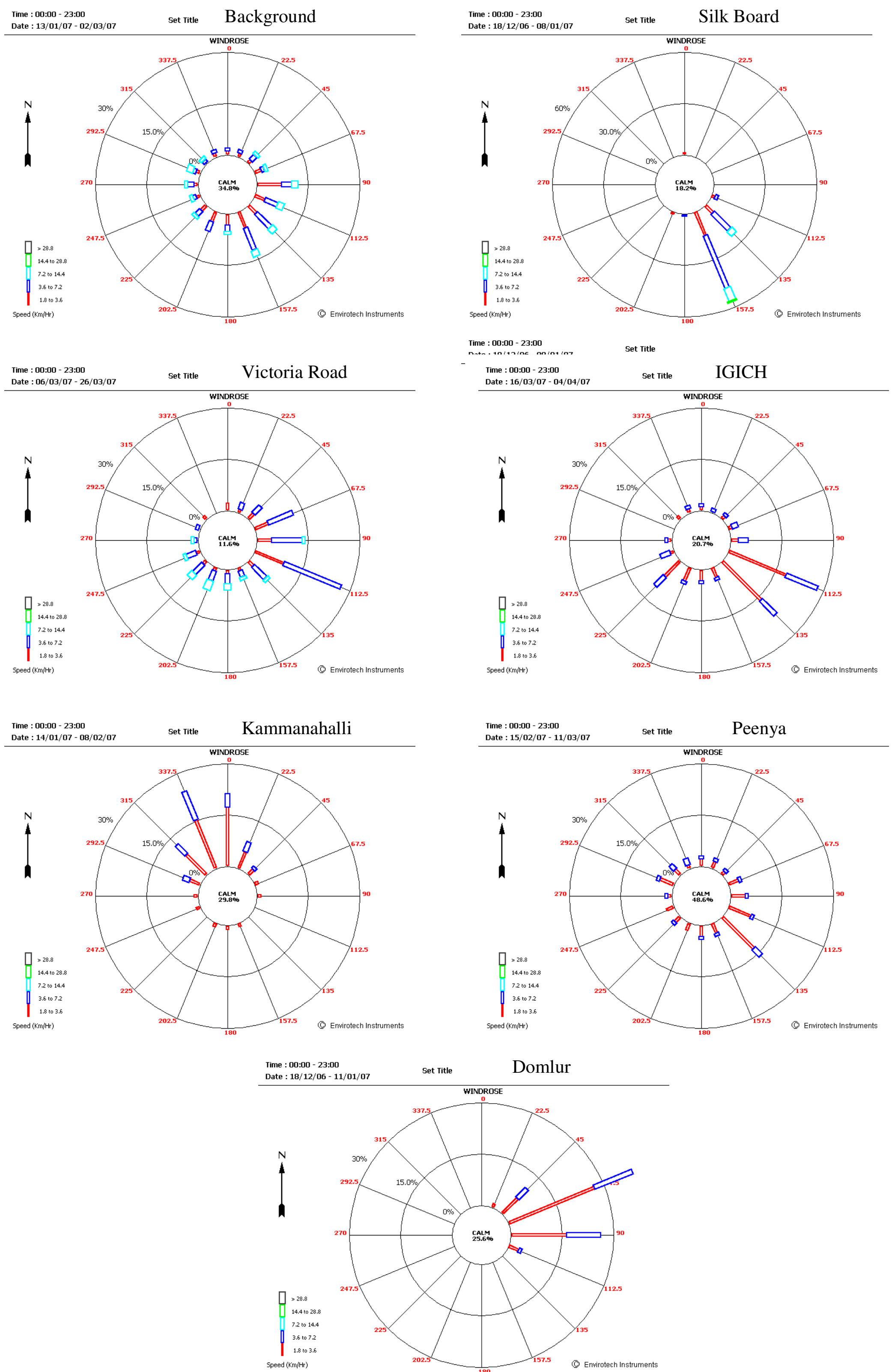


Figure **5.2** Wind rose diagram at various locations during the first season

5.3.2 Second season

During the 2nd monitoring season, the 24-hr average temperature varied from 24 °C to 27 °C and average relative humidity was in the range of 58-78%. Wind speed varies in between 2 to 4 km/h. The maximum wind speed was observed at IGICH and Silk Board sampling sites. The prominent wind direction sector at Silk Board and Kammanhalli was ESE-SSE, while Background and Peenya sampling stations showed SSW-WSW and SW-W as the prominent sectors (blowing from), respectively. Wind direction was quite varied at Domlur location. Wind rose diagram (Figure 5.3) of different locations depicted the prominent wind direction and wind speed frequency for the monitoring period. There was rain on few days during the second season monitoring. Table 5.6 presents the summary of weather parameters recorded at various monitoring locations.

Table 5.6 Summary of 24-hr average, maximum and minimum values of primary meteorological parameters at various locations during the second season

Location	Sampling Dates	Wind Speed (Km/h)			Temp (°C)			Relative Humidity (%RH)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
Domlur*	13 April to 4th May 2007	0.00	7.10	2.30	14.60	37.40	26.84	28.80	99.00	58.72
Kammanhalli*	5 May to 27 May 2007	0.00	7.00	2.25	18.00	38.00	27.29	24.70	96.00	58.62
Victoria Road	Data not available due to instrument failure									
Central Silk Board*	11 April to 27 April 2007	0.20	14.30	4.17	18.00	34.00	26.13	41.00	82.00	65.21
Peenya*	6 May to 25 May 2007	0.00	5.60	2.98	20.50	35.00	26.34	47.50	99.00	78.58
IGICH*	29 May to 8 June and 12 June to 20 June 2007	0.00	8.70	4.44	17.20	36.90	24.63	34.40	99.00	70.56
Background**	4 May to 28 June 2007	0.00	33.48	3.97	19.00	35.10	25.76	20.20	95.00	67.95

*Meteorological parameters recorded as 60min average values for 24 hours
**Meteorological parameters recorded as 10min average values

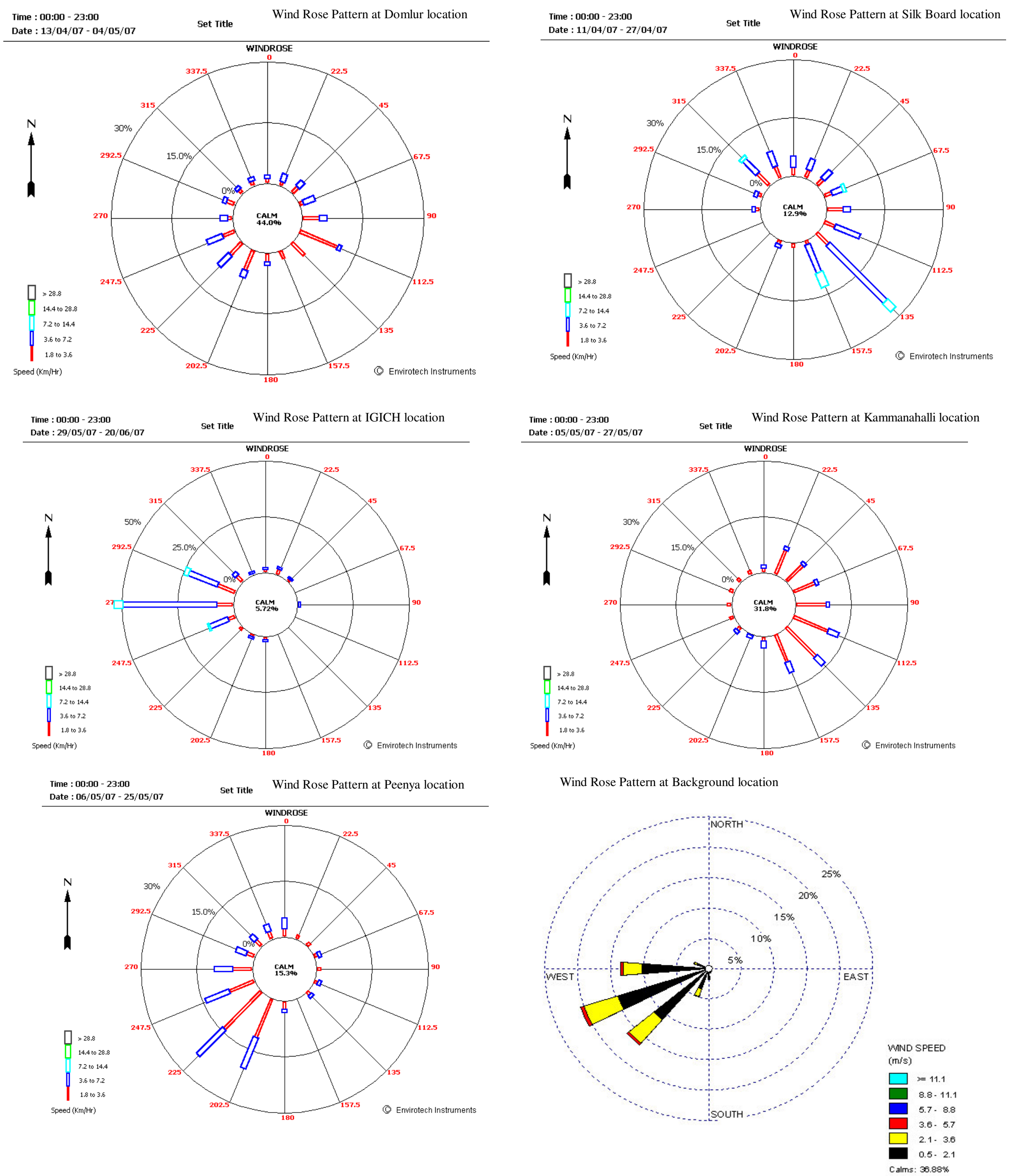


Figure **5.3** Wind rose pattern at various locations during the second season

5.3.3 Third season

24-hr average temperature varied from 21.0 °C to 22.9 °C and average relative humidity was in the range of 63.9-83.7%. Wind speed varied in between 2.0 to 8.0 km/h. The average wind speed was observed to be highest at Domlur and CSB sampling sites. The prominent wind direction (blowing from) sector at Domlur, Victoria road and background locations was W-SW. N-NW directions were prominent at Kammanhalli and CSB locations. Wind rose diagram (Figure 5.4) of different locations depicted the prominent wind direction and wind speed frequency for the monitoring period. Table 5.7 presents the summary of weather parameters recorded at various monitoring locations.

Table 5.7 Summary of 24-hr average, maximum and minimum values of primary meteorological parameters at various locations during the third season

Location	Sampling Dates	Wind Speed (Km/h)			Temp (^{O}C)			Relative Humidity (%RH)		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
Domlur*	27 June to 17 July 2007	2.9	13.3	8.0	17.4	28.7	21.7	51.8	99.0	77.8
Kammanahalli*	12 August to 1 September 2007	0.0	5.2	2.0	16.9	32.2	22.9	37.3	99.0	74.9
Victoria road*	4 September to 27 September 2007	0.0	10.4	4.9	16.2	31.7	22.2	45.9	99.0	80.6
CSB*	20 July to 5 August 2007	1.4	10.3	5.7	16.8	28.9	21.0	55.0	99.0	83.7
IGICH		NA, due to instrument failure								
Peenya		NA, due to instrument failure								
Background**	8 July to 1 September 2007	0.0	19.4	2.8	18.8	30.7	23.3	43.4	95.0	79.1

Meteorological parameters recorded as 60min average values for 24 hours
**Meteorological parameters recorded as 10min average values

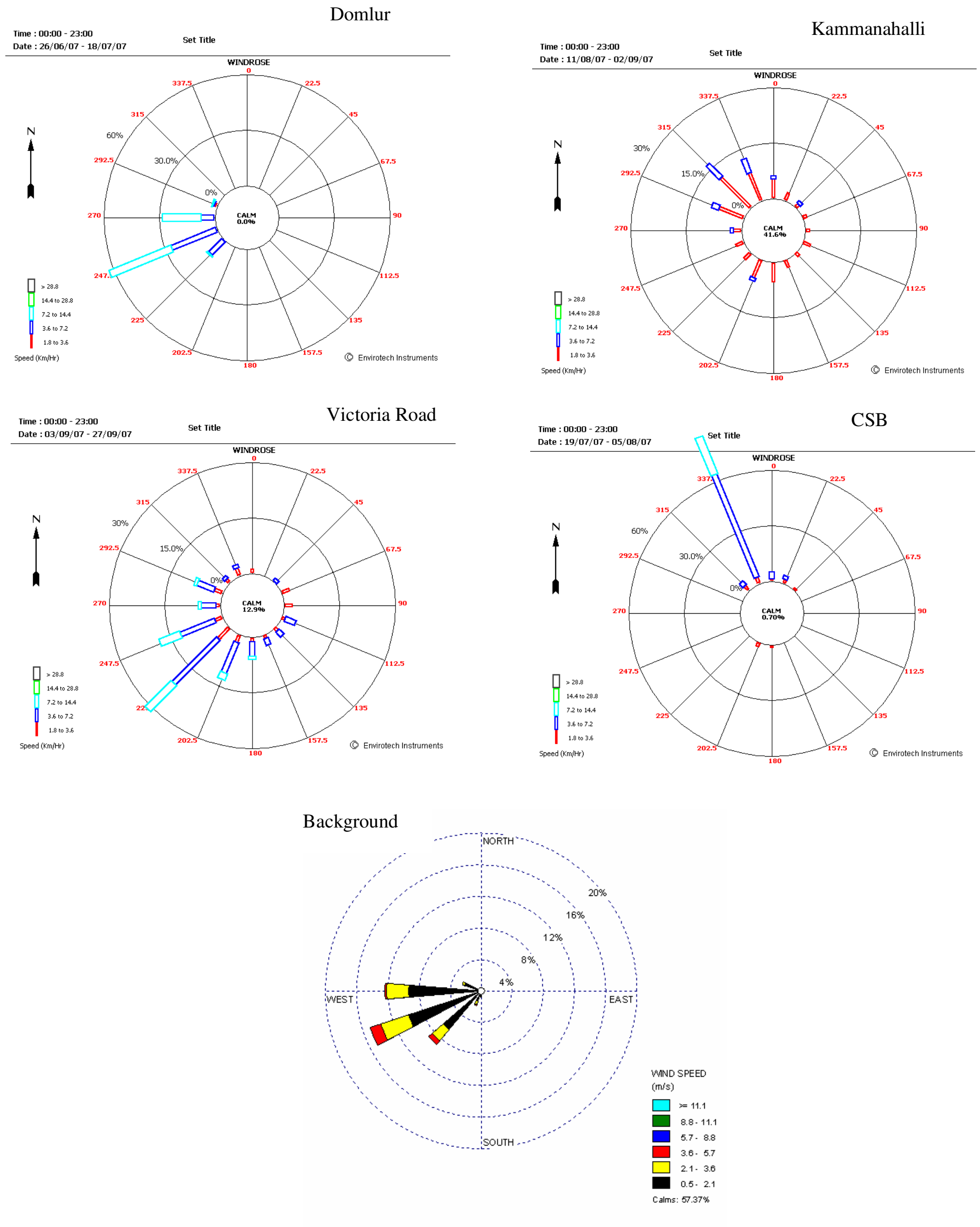


Figure **5.4** Wind rose pattern at various locations during the third season

5.4 Concentration profiles

5.4.1 Existing Scenario 2007

5.4.1.1 Existing Scenario: PM_{10}

Model simulations

As mentioned, the modelling exercise was carried out for PM_{10} for all the three seasons by making use of inputs such as onsite meteorological data and emission rates and other related inputs for area, line and point sources. Meteorological inputs in terms of wind speed, wind direction, mixing height and stability class were incorporated. The atmospheric stability categories (in terms of A-E) were determined on the basis of Turner's classification based on wind speed, insolation and cloud cover (Turner, 1969 as cited in Wark and Warner,1976). The mixing height values of three seasons for Bangalore are based on the CPCB entitled "spatial distribution of hourly mixing depth over Indian region, 2002-03".

Based on the emission load estimations discussed in chapter 3, the emission rates for the area, point and line sources were input as per the model format.

Model simulations were carried out for the field monitoring days at six air quality monitoring stations during each of the three seasons. 12-hourly model simulations were done for day and night period separately to arrive at 24-hourly averaged concentrations.

Model performance

Table 5.8 indicates that the average PM_{10} concentrations observed at six air quality monitoring stations ranged from 69 – 199 $\mu g/m^3$ during the first season (winter season). The predicted average concentrations at these sites ranged from 56 – 231 $\mu g/m^3$. Likewise, during the second season, the average concentrations observed at six ambient air quality monitoring stations ranged from 39- 181 $\mu g/m^3$. The predicted average concentrations at these sites during second season ranged from 61 – 233 $\mu g/m^3$. Further, during the third season, the average concentrations observed at these six air quality monitoring stations ranged from 54- 109 $\mu g/m^3$. The predicted average concentrations at these sites during third season ranged from 34 – 167 $\mu g/m^3$.

Thus, relatively lower ambient concentrations are observed during the third season as compared to first season and second season. Table 5.8 shows that considering the average values at each of the monitoring stations, 14 out of 18 (78%) values lie within a factor of 2 during all the three seasons. The factor of 2 (FAC2) value is most commonly used to assess the performance of the air quality models. It is defined as the ratio of predicted to observed concentration and varies between 0.5 – 2.0.

In addition to simulations with onsite meteorological input, simulations were also carried out for six air quality monitoring stations using background station meteorology for all three seasons. The response was mixed in terms of FAC2 while using onsite meteorology and background station meteorology., i.e., at few air quality monitoring stations FAC2 results are better with background meteorology while at others, they were better with onsite meteorology. Overall, the predicted values using background meteorology lying within FAC2 were 11 out of 18 which is close to the FAC2 value of 14 out of 18 obtained using site specific meteorology. Also, the worst season in terms of air quality concentration is winter season. Thus, it was decided to carry out simulations of BAU and alternate options scenarios using background station meteorology (dominant meteorology) of the first season i.e. winter season. As shown in Figure 5.5, across all the three seasons, the predicted concentrations were high for the first season using background meteorology, which is broadly in agreement with the observed concentration values also being high during the first season at most of the sites.

Table 5.8 Seasonal PM_{10} average concentration ($\mu g/m^3$) of the 24-hourly model simulations at each of the air quality stations

Season	Location	Observed Conc.	ISCST3 Predicted Conc.
FIRST	CSB	98	108
	IGICH	85	61
	Domlur	69	80
	Victoria Road	199	72
	Kammanhalli	133	56
	Peenya	171	231
SECOND	CSB	96	130
	IGICH	39	62
	Domlur	94	128
	Victoria Road*	181	61
	Kammanhalli	91	62
	Peenya	171	233
THIRD	CSB	73	167
	IGICH*	69	34
	Domlur	64	77
	Victoria Road	109	87
	Kammanhalli	54	75
	Peenya*	69	69

*Predicted values using Background meteorology as onsite meteorology was not available due to instrument failure

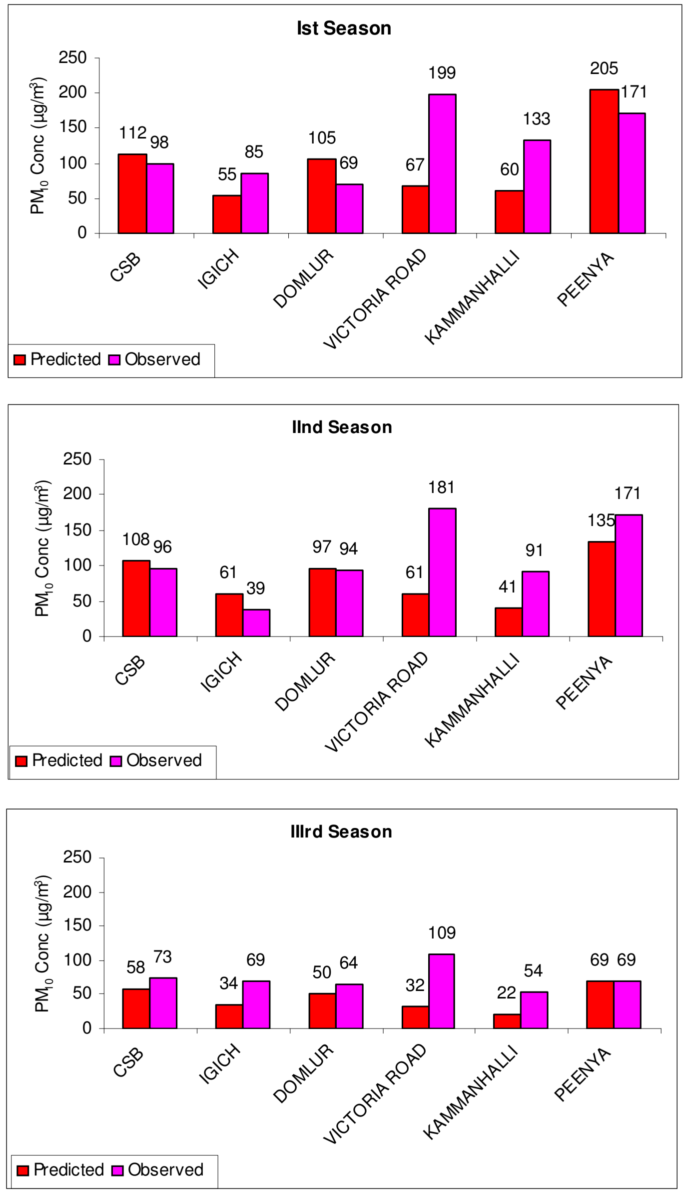


Figure **5.5** Observed and predicted concentrations of PM_{10} during different seasons

Concentration contours

The model output in terms of predicted average concentration values of PM_{10} at all the grid points in the entire study area could be depicted in terms of concentration contours for easy interpretation. As an illustration, during the winter season using background station meteorology, the PM_{10} predicted concentration values for January and February months of year 2007 are shown in Figure 5.6. These concentration contours have been plotted using Surfer (version 7) software. The pockets of highest concentration are observed close to Peenya industrial area followed by high traffic locations close to the central hub of the city. Further, PM_{10} concentration contours were also plotted for second and third season as shown in Figures 5.7 and 5.8, respectively. It is clearly evident from these contours that the highest concentration is observed during the winter (first) season, while the lowest concentration is observed in the pre-monsoon (third) season.

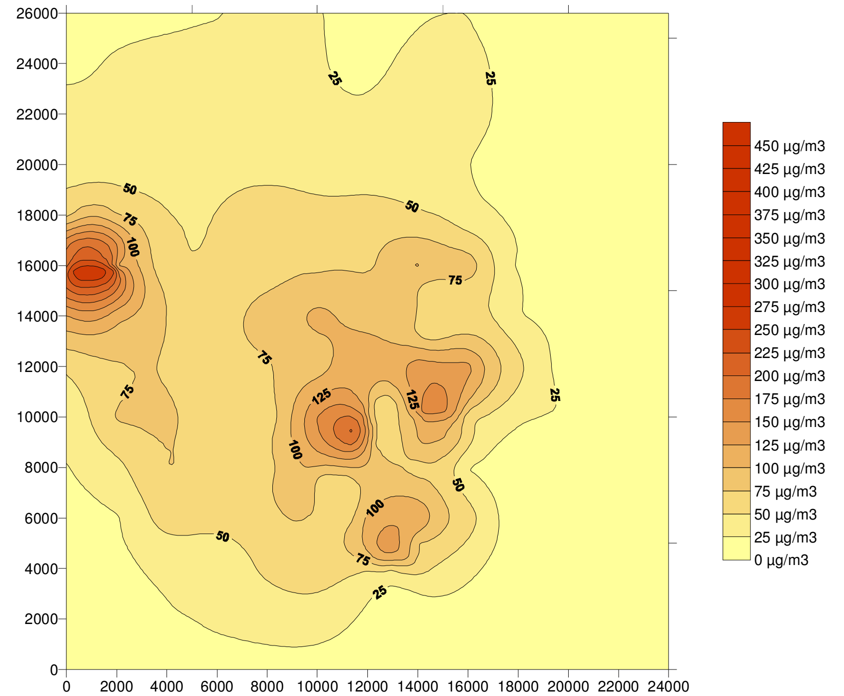


Figure **5.6** Contours for 24-hourly average PM_{10} concentration (µg/m^3) for first season, year 2007

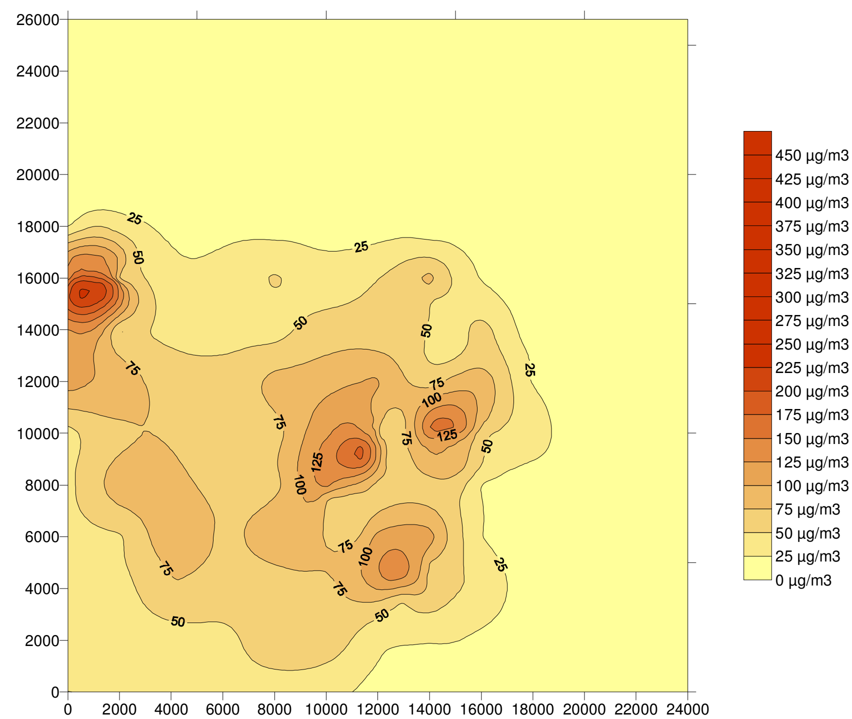


Figure **5.7** Contours for 24-hourly average PM_{10} concentration (µg/m^3) for second season, year 2007

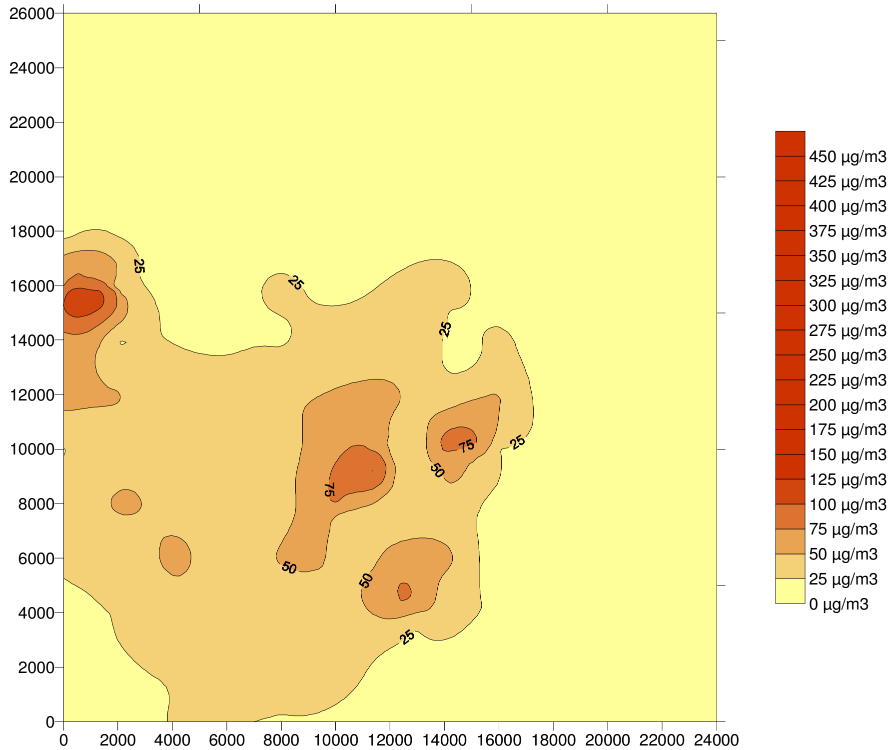


Figure **5.8** Contours for 24-hourly average PM_{10} concentration (µ g/m^3) for third season, year 2007

5.4.1.2 Existing Scenario :NO_X

Model simulations

As in the case of PM_{10}, the modelling exercise was carried out for NO_X as well for all the three seasons by making use of inputs such as onsite meteorological data and emission rates and other related inputs for area, line and point sources.

Based on the emission load estimations discussed in chapter 3, the emission rates for the area, point and line sources were calculated for NO_X.

Model simulations were carried out for the field monitoring days at six air quality monitoring stations during each of the three seasons. 12-hourly model simulations were done for day and night period separately to arrive at 24-hourly averaged concentrations.

Model performance

Table 5.9 indicates that the average NO_X concentrations observed at six air quality monitoring stations ranged from 23 – 94 µg/m^3, 17-105 µg/m^3, and 23- 90 µg/m^3 during the first (winter), second and third seasons, respectively. Model simulations were carried out using onsite meteorology and a comparison was made against the observed values at the six air quality monitoring stations for model calibration. The predicted average concentrations using the calibrated model at these six sites ranged from 25-88 µg/m^3, 29-121 µg/m^3 and 14-96 µg/m^3

during the three seasons, respectively. Table 5.9 shows that most of the predicted values lie within a factor of two (FAC2) during all the three seasons.

In addition to simulations with onsite meteorological input, simulations were also carried out using background station meteorology for all three seasons. Figure 5.9 shows the predicted and observed concentrations at six air quality monitoring stations for the three seasons using background station meteorology. Here again, model performance in terms of factor of two (FAC2) is satisfactory. Also, the worst season in terms of air quality concentration is winter season. Hence, as in the case of PM_{10}, it was decided to carry out simulation of BAU and alternate scenarios using background station meteorology (dominant meteorology) of the first season (winter season). The calibrated model for NO_X is used for modelling the future scenarios subsequently.

Table 5.9 Seasonal NO_X average concentration (μg/m^3) of the 24-hourly model simulations at each of the air quality stations

Season	Location	Observed Conc.	ISCST3 predicted Conc.
FIRST	CSB	94	64
	IGICH	23	41
	Domlur	46	88
	Victoria Road	60	42
	Kammanhalli	26	25
	Peenya	53	51
SECOND	CSB	58	73
	IGICH	17	30
	Domlur	29	121
	Victoria Road*	105	36
	Kammanhalli	19	29
	Peenya	30	32
THIRD	CSB	47	96
	IGICH*	90	21
	Domlur	23	66
	Victoria Road	66	48
	Kammanhalli	49	36
	Peenya*	90	14

* Predicted values using background meteorology as onsite meteorology was not available

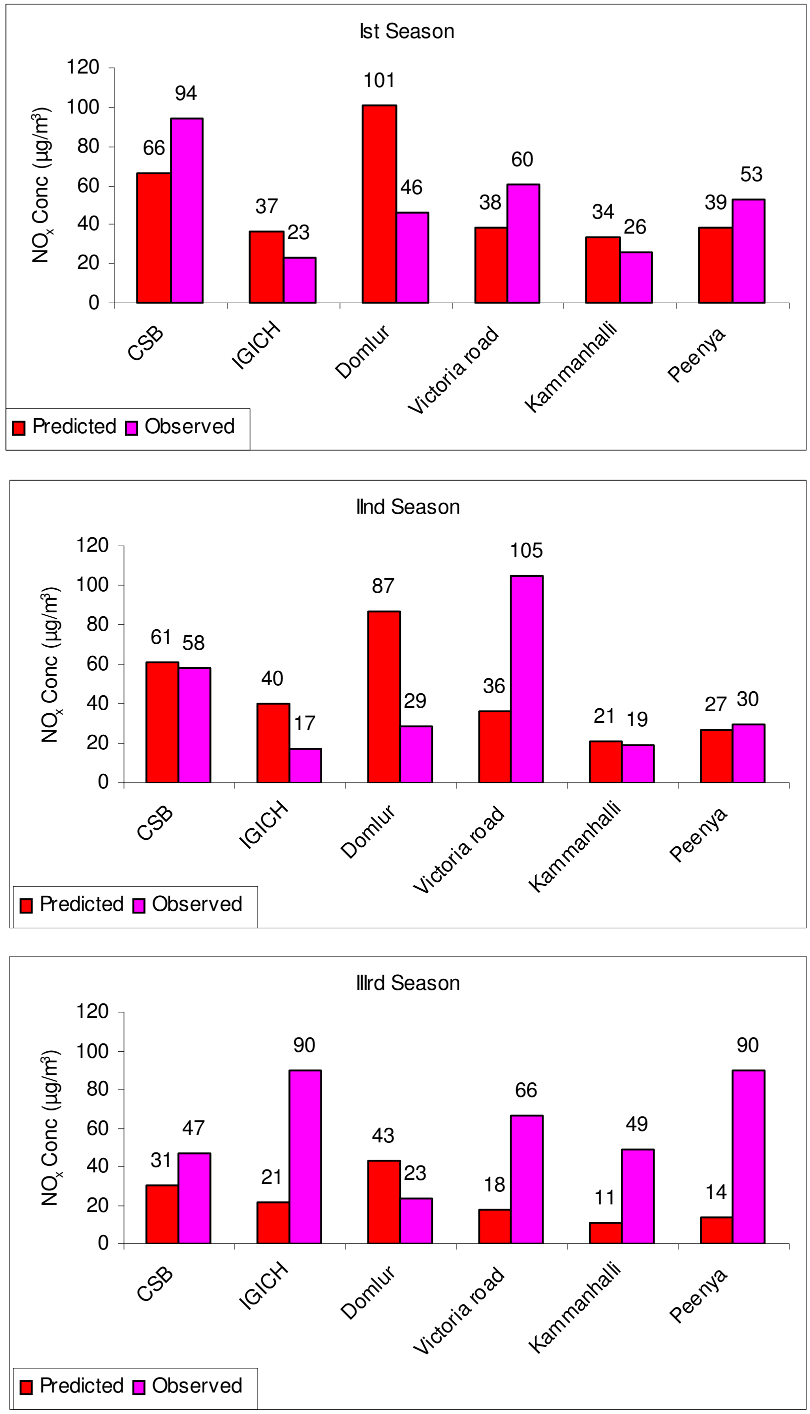


Figure **5.9** Observed and predicted concentrations of NO_X during different seasons

Concentration contours

The model output in terms of predicted 24-hourly average concentration values of NO_X at all the grid points in the entire study area could be depicted in terms of concentration contours for easy interpretation. As an illustration, during the winter season using background station meteorology, the predicted NO_X concentration values for January and February months of year 2007 are shown in Figure 5.10. The pockets of high NO_X values are observed at three zones that are close to the central hub of the city which also happen to be high traffic zones and commercial areas having high DG set operations. In addition concentration contours were also plotted for second and third season NO_X concentrations as shown in Figures 5.11 and 5.12, respectively. It is clearly evident from these contours that the highest concentration is observed during the winter (first) season, while the lowest concentration is observed in the pre-monsoon (third) season.

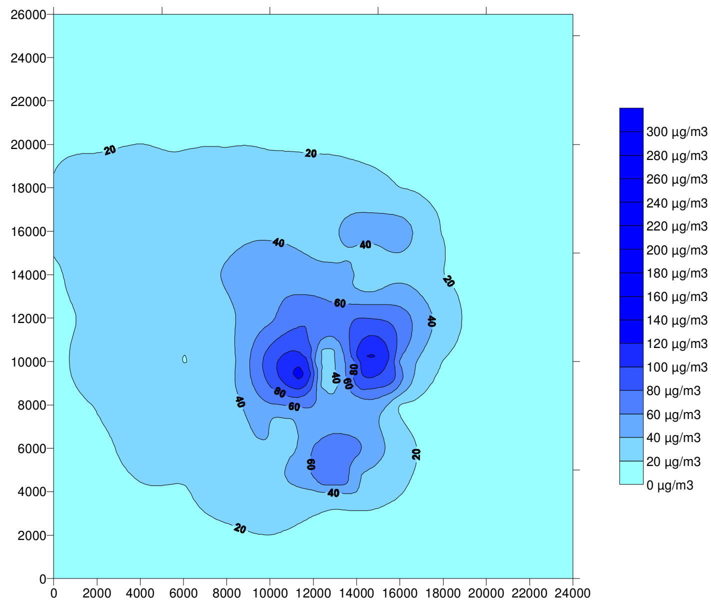


Figure **5.10** Contours for 24-hourly averaged NO_X concentration (µg/m³) for first season, year 2007

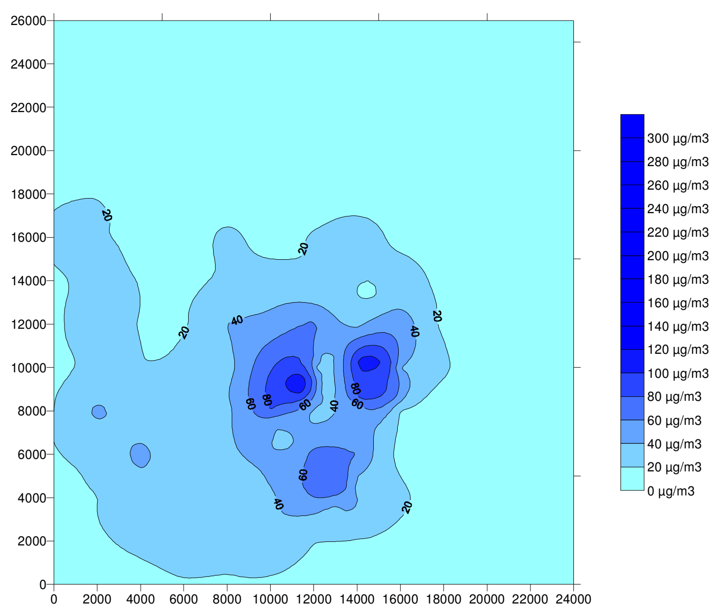


Figure **5.11** Contours for 24-hourly averaged NO_X concentration (µg/m³) for second season, year 2007

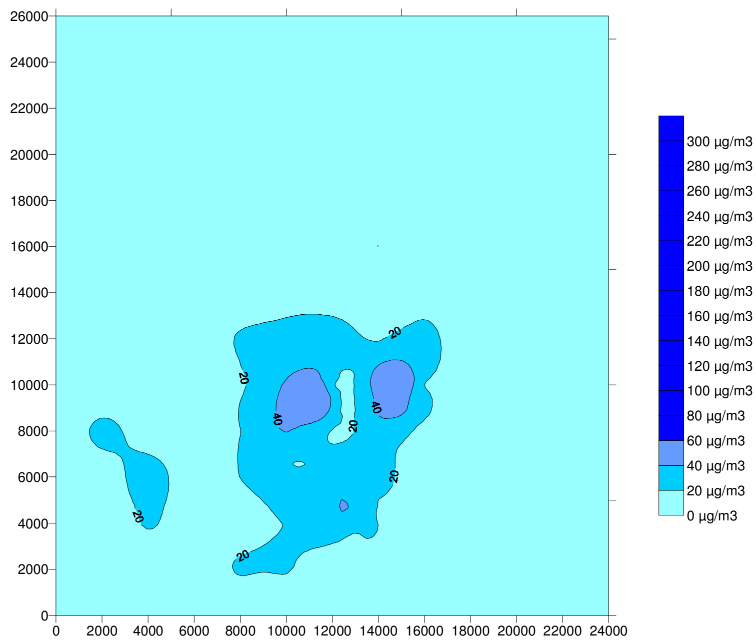


Figure **5.12** Contours for 24-hourly averaged NO_X concentration (µg/m^3) for third season, year 2007

5.4.1.3 Sectoral contribution: PM_{10} and NO_X

The sectoral contribution to ambient air quality (PM_{10} and NO_X) based on dispersion modelling approach has been estimated.

During the winter season (worst season), as shown in Figure 5.13, the contribution of different sectors to predicted PM10 air quality at the 6 monitoring locations within the city indicates maximum contribution by the transport sector (average 44%; range 13-54%) followed by road dust re-suspension (average 22%; range 7-29%), other area sources, including domestic, construction activities, hotels and Diesel Generator (DG) sets (average 20%; range 6-35%), and industries(average 14%; range 1-74%).

Likewise, in the case of NOx (Figure 5.14), the contribution of different sectors at the 6 monitoring locations indicates maximum contribution by transport sector (average 50%; range 23-73%), followed by other area sources (average 46%; range 26-77%) and industries (average 4%; range 0-19%).

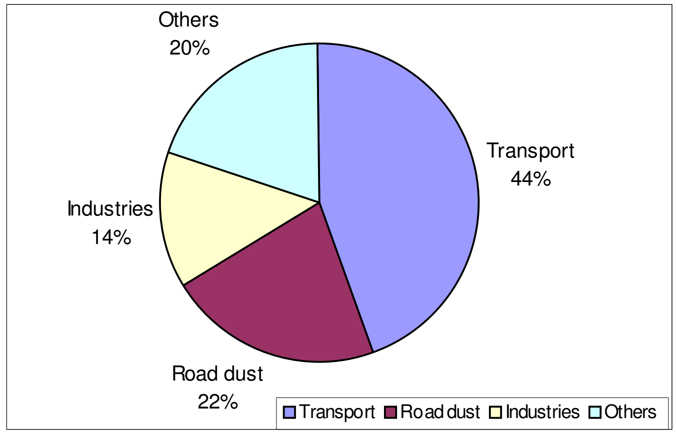


Figure **5.13** Sectoral distribution of PM10 based on dispersion modelling in the year 2007

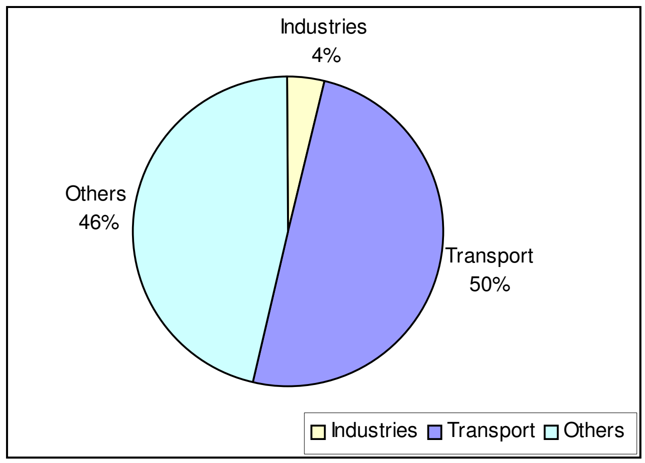


Figure **5.14** Sectoral distribution of NOx based on dispersion modelling in the year 2007

5.5 Conclusions: Dispersion modelling

Dispersion modelling of PM_{10} and NO_X is carried out both for the city level as well as for the six air quality monitoring stations. In general, the predicted concentrations of PM_{10} lie within a FAC2 as compared against observed concentrations. The pockets of highest concentration of PM_{10} are also well captured by the contours at the city level whereby they correspond to high industrial and traffic activities. Likewise, the contours at the city level for predicted 24-hourly average NO_X concentration again capture well the pockets of high concentration in terms of activity levels corresponding to high traffic and DG set usage. The framework developed for modelling the base scenario for 2007 is subsequently used for modelling the BAU and alternative scenarios in future.

CHAPTER 6 Emission control options and analysis

6.1 Summary of prominent Sources

The emission inventory developed for the base year 2007 indicates total emissions of PM_{10} and NO_X to be 54.4 T/d and 217.4 T/d, respectively. The prominent sources of PM_{10} are transport (42%), road dust re-suspension (20%), construction (14%), industry (14%) and DG sets (7%). The prominent sources for NO_X emission are transport (68%), Diesel Generator (DG) sets (23%) and industry (8%).

6.2 Future growth scenario

Scenario analysis is carried out for 2012 and 2017 to evaluate:-

a) Business as usual scenario (BAU) and
b) Alternate scenarios (with interventions to abate air pollution levels)

BAU - Business as usual scenario

BAU scenario depicts growth in different sectors such growth in population, vehicles, industries, construction activities, DG sets etc. The scenario does not account for any intervention to abate air pollution levels except BS-IV norms for vehicles which are already in the current road map.

Growth patterns

Sector specific growth rates are applied to project current (2007) data to 2012 and 2017. The details are presented in Table 6.1.

Table 6.1 Growth rates of different sectors

S.No	Sector	Description of growth
1	Domestic	Population growth rate of 3.1% as listed in Master Plan - 2015
2	Transport	Vehicle-wise growth rates were calculate using the last five years data (2002-2007). BS-IV norms are taken into account from 2010.
3	Industrial	5.85% as depicted in Industrial development plan
4	DG sets	Based on population growth rates for domestic and based on energy consumption for commercial DG sets.
5	Construction	Based on population growth rates
6	Road dust	Based on increase in VKT (from transport sector)
7	Eating joints	Based on population growth rates

Based on above, BAU scenario is developed and emissions loads for PM_{10} and NO_X are presented in Figures 6.1and 6.2. The total emissions of PM_{10} increased from 54.4 T/d in 2007 to 95.8 T/d in 2017. Likewise, NO_X emissions during the same period increase from 217 T/d to 460 T/d.

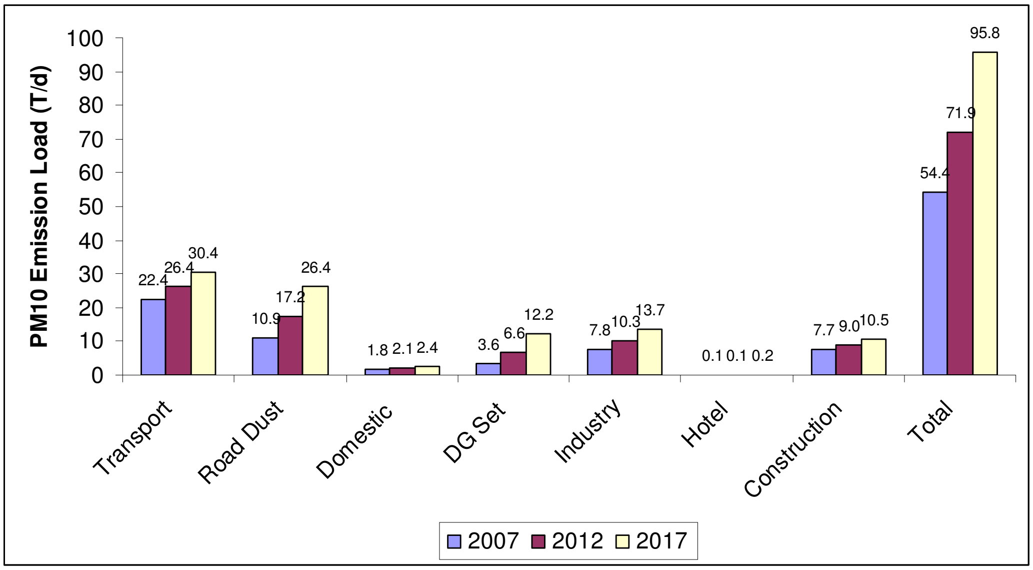


Figure **6.1** Sectoral and total PM_{10} emission load under BAU scenario during 2007-2017

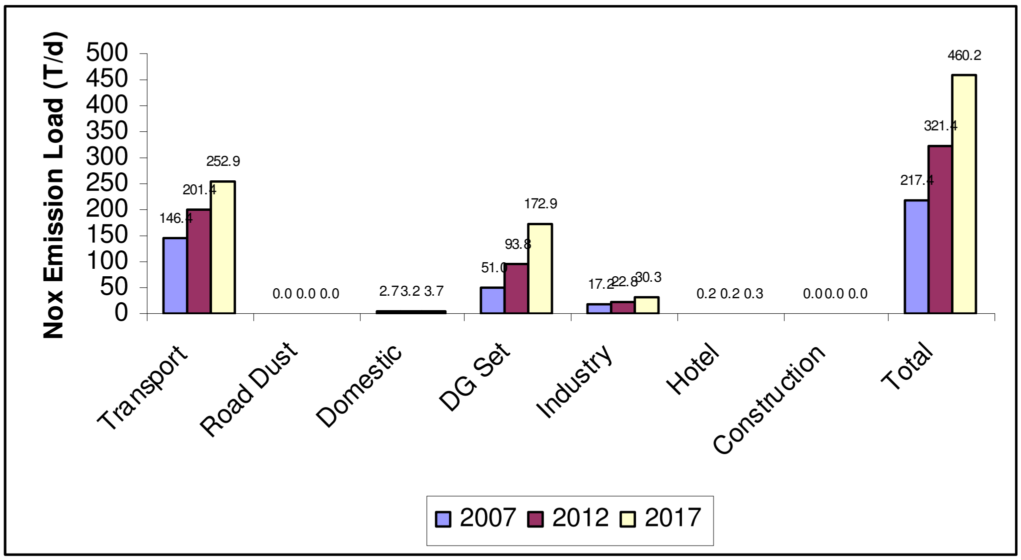


Figure **6.2** Sectoral and total NO_X emission load under BAU scenario during 2007-2017

Alternate scenarios

Alternate scenarios are developed accounting for different combinations of abatement measures in various sectors in Bangalore.

6.2.1 Line source control options & analysis

Transport sector contributes substantially to the air pollution loads in Bangalore. Therefore, emission estimates of PM_{10} and NO_X are made for various technical interventions in the transport sector. The technical strategies for the reduction of emissions are as follows:

- Implementation of BS – V norms
- Implementation of BS – VI norms

- Introduction of Electric Vehicles
- Introduction of Hybrid vehicles
- Conversion of commercial (all 3 and 4-wheelers) vehicles to CNG
- Ethanol blending (E10 – 10% blend)
- Bio-diesel (B5/B10: 5 – 10% blend)
- Hydrogen – CNG blend (H10/H20: 10 – 20% blend)
- Retrofitment of Diesel Oxidation Catalyst (DOC) in 4-wheeler public transport
- Retrofitment of Diesel Particulate Filter in 4-wheeler public transport

Reductions have been made as per the chart provided by CPCB.

PM_{10} Emission estimates made for various technical strategies in the transport sector are presented in Table 6.2.

Table 6.2 Reduction in PM_{10} emission loads due to various technological interventions in transport sector in Bangalore

S.No	Strategy	2007	2012	2017	% reduction 2012	% reduction 2017	Remarks
1	BAU	22.4	26.4	30.4			CAGR 2002-2007, BS-IV from 2010, No BD,Ethanol, ban or attrition
2	BS-V	22.4	26.4	30.1	0%	-1%	BAU + BS -V has been applied from 2015
3	BS-VI	22.4	26.4	30.0	0%	-1%	BAU + BS -VI has been applied from 2015
4	ELECTRIC	22.4	25.8	29.1	-2%	-4%	BAU + Introduction of EV as per chart provided by CPCB
5	Hybrid	22.4	26.4	30.4	0%	0%	BAU + 1% hybrid cars in 2012 & 2% in 2017
6	CNG	22.4	25.4	26.6	-4%	-12%	BAU+ commercial vehicles (Bus/Car/3w)-25% conversion in 2012 and 100% in 2017
7	Ethanol	22.4	26.4	30.4	0%	0%	BAU + 10% Ethanol introduced in 2012-2017
8	Bio-diesel	22.4	26.3	30.2	-0.4%	-1%	BAU + 5-10% Biodiesel introduced in 2012-2017
9	H2/CNG	22.4	26.4	30.4	0%	0%	10% Vehicles in 2017
10	DOC	22.4	26.1	29.9	-1.0%	-1.7%	50% conversion of BS-II buses in 2012, and 100% in 2017
11	DPF	22.4	26.2	30.1	-0.6%	-1.2%	50% conversion of BS-III buses in 2012, and 100% in 2017

Percentage reduction achieved by implementing various strategies in the transport sector are shown in Figure 6.3.

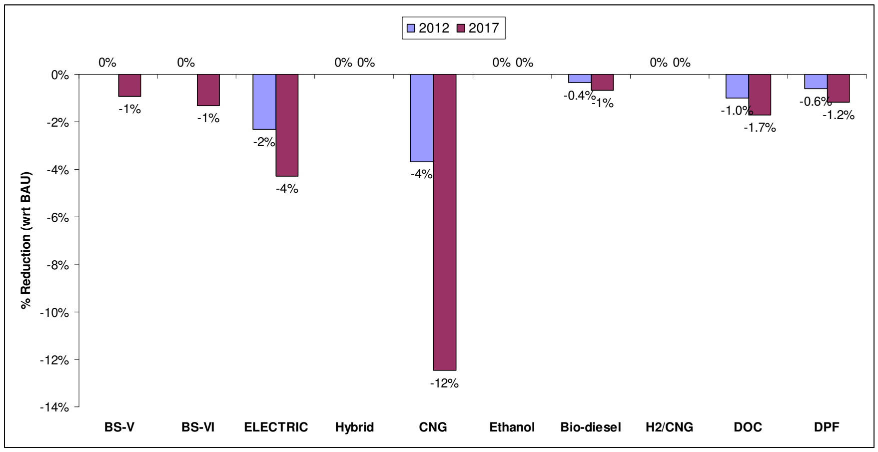


Figure **6.3** Percentage reduction achieved in PM_{10} emissions by implementing various strategies in the transport sector

Introduction of BS-V and BS-VI have minimal impact on PM_{10} emission loads because of their introduction in 2015.

Introduction of electric vehicle can reduce the load to some extent and the strategy can be useful in some specific areas.

Introduction of Hybrid vehicles and ethanol blending does not have any impact on PM_{10} emission loads. However, blending of bio-diesel reduces the load marginally by 0.4-1% in 2012 and 2017, respectively. Likewise, introduction of DOC in BS-II buses and DPF in BS-III buses reduces the load only marginally.

Introduction of CNG in 3 & 4-wheeler commercial vehicles can reduce the PM_{10} emissions load by 4% in 2012 and 12% in 2017.

NO_X emission estimates made for various technical strategies in the transport sector are presented in Table 6.3 .

Table 6.3 Reduction in NO_X emission loads due to various technological interventions in transport sector in Bangalore

S.No	Strategy	2007	2012	2017	% reduction 2012	% reduction 2017	Description
1	BAU	146.4	201.4	252.9			CAGR 2002-2007, BS-IV from 2010, No BD,Ethanol, ban or attrition
2	BS-V	146.4	201.4	248.0	0%	-1.9%	BAU + BS -V has been applied from 2015
3	BS-VI	146.4	201.4	243.5	0%	-3.7%	BAU + BS -VI has been applied from 2015
4	ELECTRIC	146.4	196.3	241.4	-2.5%	-5%	BAU + Introduction of EV as per chart provided by CPCB.
5	Hybrid	146.4	201.3	252.8	-0.02%	-0.04%	BAU + 1% hybrid cars in 2012 & 2% in 2017
6	CNG	146.4	199.0	241.5	-1%	-4%	BAU+ commercial vehicles (Bus/Car/3w) - 25% conversion in 2012 and 100% in 2017
7	Ethanol	146.4	201.1	252.6	-0.1%	-0.1%	BAU + 10% Ethanol introduced in 2012-2017
8	Bio-diesel	146.4	201.6	253.4	0.1%	0.2%	BAU + 5-10% Biodiesel introduced in 2012-2017
9	H2/CNG	146.4	201.4	240.6	0.0%	-4.9%	10% Vehicles in 2017
10	DOC	146.4	201.4	252.9	0.0%	0.0%	50% conversion of BS-II buses in 2012, and 100% in 2017
11	DPF	146.4	201.4	252.9	0.0%	0.0%	50% conversion of BS-III buses in 2012, and 100% in 2017

Percentage reduction achieved in NO_X emissions by implementing various strategies in the transport sector are shown in Figure 6.4.

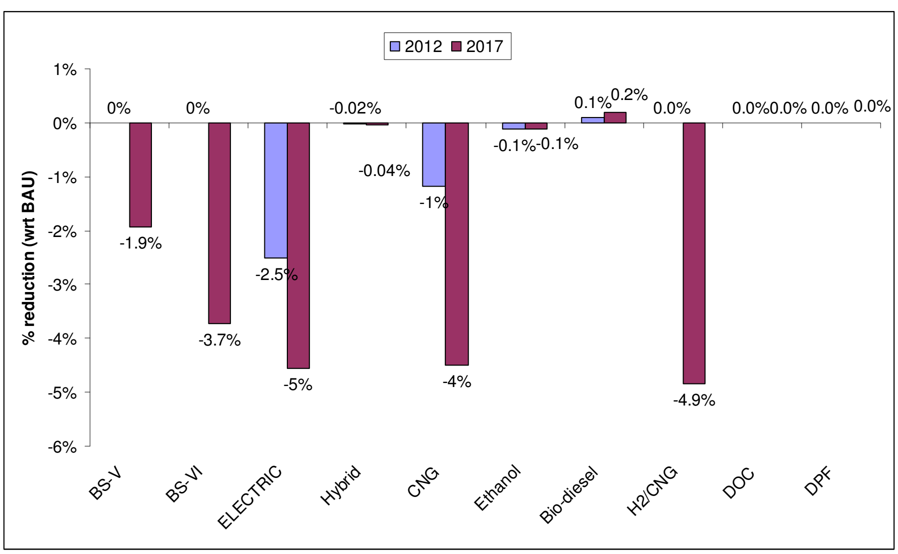


Figure **6.4** Percentage reduction achieved in NO_X emissions by implementing various strategies in the transport sector

Introduction of BS-V and BS-VI have minimal impact on NO_X emission loads because of their introduction in 2015. However, the impact is more than that seen in the case of PM_{10}.

Introduction of electric vehicles can reduce the load up to 5 % in 2017 and the strategy can be useful in some specific areas.

Introduction of Hybrid vehicles and ethanol blending have very small impact on the NO_X emission loads. Blending of bio-diesel increases the load marginally by 0.1-0.2% in 2012 and 2017, respectively.

Introduction of DOC in BS-II buses and DPF in BS-III buses does not have any impact on NO_X emissions.

Introduction of CNG in commercial vehicles (bus, car, 3w), reduces the NO_X emission loads by 1% in 2012 and 4% in 2017. The impact is lower in case of NO_X than in the case of PM_{10}.

6.2.2 Area Source Control Options & Analysis

Domestic

Scenario has been developed to see the impact of usage of natural gas/ LPG in the domestic sector. In 2012, 50% of solid fuel and kerosene for domestic use is assumed to be shifted to LPG, while in 2017, 75% shift is envisaged. However, there is a increase in emission loads as the emission factors for LPG for PM_{10} and NO_X are more than that for kerosene (figure 6.5) .

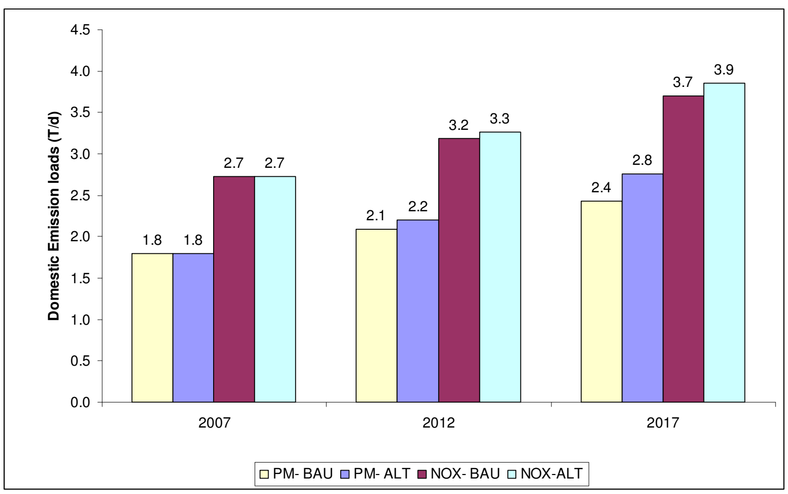


Figure **6.5** PM_{10} & NO_X emission loads from domestic sector in BAU and ALT scenarios

DG sets

Scenario simulating better inspection and maintenance of DG sets was evaluated which resulted in 15% reduction of PM_{10} and NO_X emissions loads, figure 6.6.

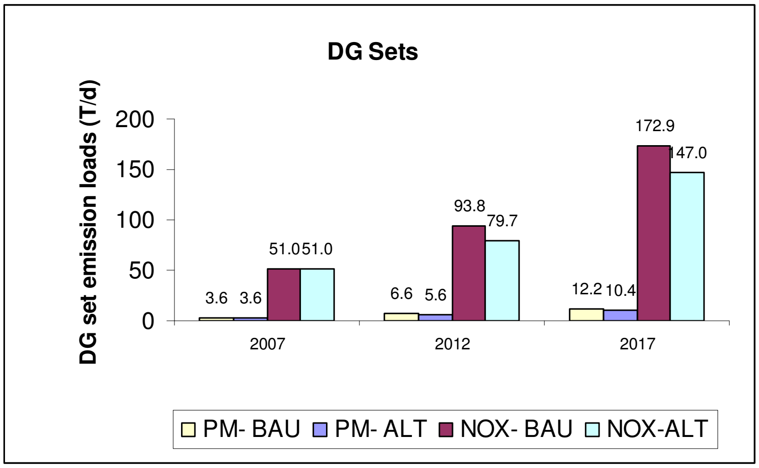


Figure **6.6** PM_{10} & NO_X emission loads from DG sets in BAU and ALT scenarios

Road dust re-suspension

Strategy of wall to wall paving is evaluated to estimate reduction in road dust emissions. As per the strategy, wall to wall paving leads to 15% reduction in silt loading on paved roads. The strategy is applied to all major roads in 2012 and to all roads in 2017. The reduction in PM_{10} emissions are presented in Figure 6.7.

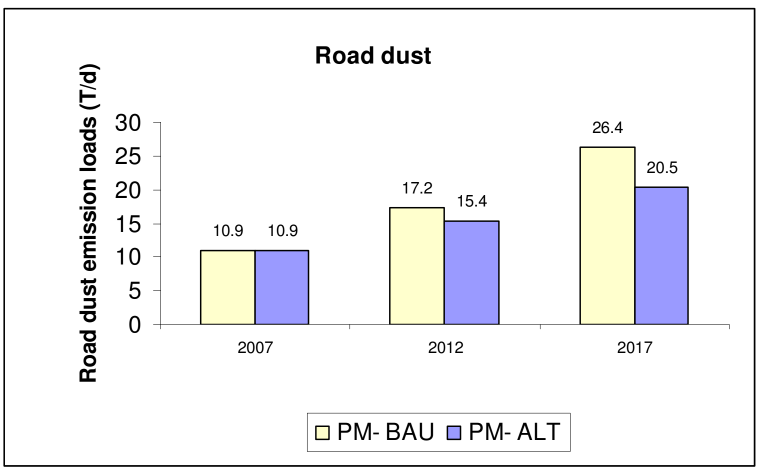


Figure **6.7** PM_{10} emission loads from road dust re-suspension in BAU and ALT scenarios

The strategy shows substantial reduction i.e. 11% in 2012 and 22% in 2017.

Construction

50% reduction in PM_{10} emission loads has been envisaged in view of better construction practices including proper loading/unloading of material, water spraying, etc.

Hotels

Primary surveys revealed that most of the eating joints, hotels etc are already functioning on LPG, therefore, there is little scope of any further intervention in the sector in the city.

6.2.3 Point Source Control Options & Analysis

Industries

Two strategies were evaluated for industrial sector:

a) Ban on new air polluting industries in the city limits , which means no further addition of emission loads in 2012 and 2017
b) Fuel shift : All solid fuel fired combustion converted to LSHS in 2012 and all solid fuel or HSD/LSHS fired combustion converted to NG in 2017.

The effect of these two strategies has been shown in Figure 6.8.

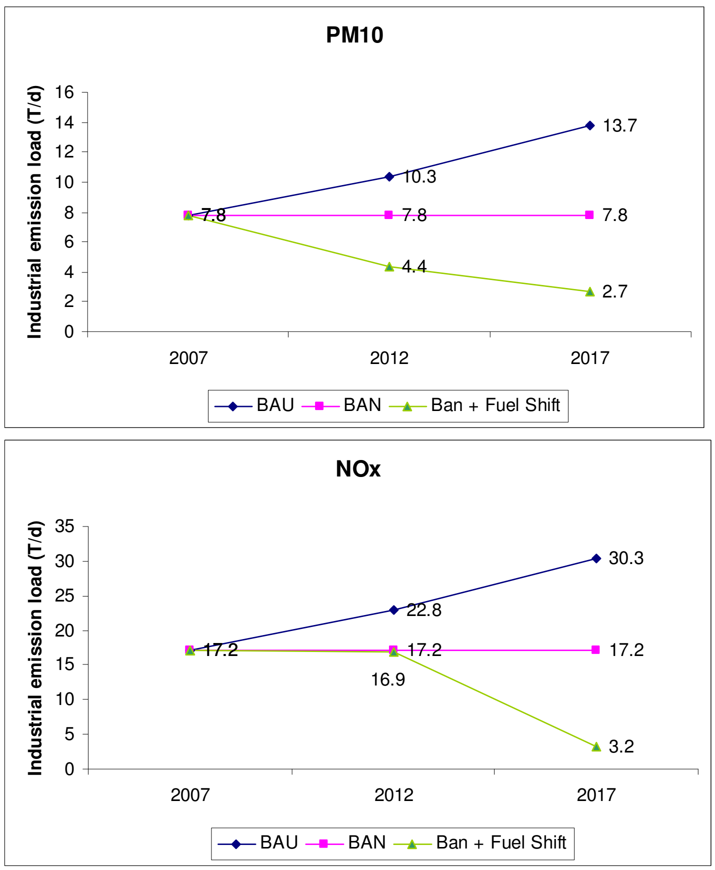


Figure **6.8** PM_{10} & NO_X emission loads from industrial sector in BAU and ALT scenarios

The strategy of banning new air polluting industries results in reduction of 24% and 43% of PM_{10} emission loads compared to BAU in years 2012 and 2017, respectively. Likewise, this strategy for NO_X results in similar reductions in the years 2012 and 2017. The combined effect of ban and fuel shift strategies results in significant reductions for both the pollutants compared to BAU. PM_{10} reduced 57% and 80% and NO_X reduced 25% and 89% in the years 2012 and 2017, respectively.

6.3 Scenario Analysis

Four alternate scenarios (Alternate – I, Alternate – II, Alternate-III, and Alternate-IV) are developed. These include the measures that are implemented under BAU scenario (including introduction of BS-IV norms in 2010) and in addition the following technical and management options (Refer Table 6.4):-

Table 6.4 Description of alternate scenarios for future air quality management in Bangalore

Sectors	**Alternate-I**	**Alternate-II**	**Alternate-III**	**Alternate-IV**
Description	Scenario with certain strategies to reduce the air pollution loads across various sectors.	Stringent scenario with many more strategies to reduce the air pollution load across various sectors as compared to Alternate- I scenario.	Scenario that contains additional set of measures that are not a part of the common control options as per the chart suggested by CPCB (for example, introduction of fuel efficiency standards, installation of control devices (DOC/DPF) on all diesel vehicles and DG sets).	Scenario with measures that are more oriented towards meeting the air quality standards in future
Transport	• Introduction of BS-V in 2015 • Ban on 10 year old commercial vehicles in 2012 and 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017) • Improvement in inspection and maintenance • Introduction of DOC in BS-II buses and DPF in BS-III buses	• Introduction of BS-VI in 2015 • Ban on 10-yr old commercial vehicles and 15-yr old private vehicles both in 2012 and 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on CNG (shift of PKT from private vehicles to public transport i.e. 10 % in 2012 and 20% in 2017) • Introduction of electric vehicles (1–2% 2w, 5-10% 3w and taxis, 5–10% buses in 2012 and 2017, respectively) • Improvement in inspection and maintenance • Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017)	• Introduction of BS-VI in 2015 • Ban on 15 yr old commercial vehicles in 2012 and 10 yr old commercial vehicles in 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10 % in 2012 and 20% in 2017) • Introduction of electric vehicles (1 – 2% 2w, 5 - 10% 3w and taxis, 5 – 10% buses in 2012 and 2017, respectively) • Improvement in inspection and maintenance • Application of DOC/DPF after introduction of BS- IV fuel in 2010 to: *Old Buses and Trucks (pre BS-IV):reduction in PM_{10} - DOC : 22.5%, DPF : 70%* *Old Diesel Cars – pre BS-IV (about half of PM reduction is assumed as compared to that for buses/trucks) : reduction in PM_{10}-DOC: 10%, DPF : 35%* • Introduction of fuel efficiency standards (considering reduction of fuel consumption) *Light passenger vehicles : 10% between (2012-15) and 15% between (2015-17), Light duty Passenger cars : 20% between (2012-15) and 30% between (2015-17), Heavy duty vehicles : 20% between (2012-15) and 30% between (2015-17)*	• Introduction of BS-V in 2015 • Ban on 10 yr old commercial vehicles in 2012 and 2017 • Introduction of Metro in 2011 • Enhancement of public transport system based on CNG (shift of PKT from private vehicles to public transport i.e. 10 % in 2012 and 20% in 2017) • Introduction of electric vehicles (1 – 2% 2w, 5 - 10% 3w and taxis, 5 – 10% buses in 2012 and 2017, respectively) • Improvement in inspection and maintenance • Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017) • By-passing of trucks on the proposed peripheral ring road around Bangalore (which is broadly outside the study domain- assumed only 10% truck traffic within the city)
Industries	Ban on any new air polluting industries in city limits	• Ban on any new air polluting industries in city limits • Shift from solid fuel to liquid fuel (LSHS) in 2012 & NG in 2017 in existing industries	• Ban on any new air polluting industries in city limits • Shift from solid fuel to liquid fuel (LSHS) in existing industries in both 2012 and 2017	• Ban on any new air polluting industries in city limits • Shift from solid fuel to liquid fuel (LSHS) in 2012 and to NG in 2017 in existing industries
DG sets		• Inspection and maintenance	• Inspection and maintenance • DOC and DPF applied to commercial DG sets (>12 kVA) in 2010. Reduction in PM_{10} :DOC : 22.5%, DPF : 70% (reductions taken same as those in the case of buses)	• No power cuts i.e. no usage of DG sets in the city
Road dust re-suspension		• Wall to wall paving	• Wall to wall paving	• Wall to wall paving • Reduction of road dust re-suspension due to by-passing of trucks
Construction		• Better construction practices	• Better construction practices	• Better construction practices

The estimated emission loads for PM_{10} and NO_X under BAU and four alternate scenarios are presented in Figure 6.9.

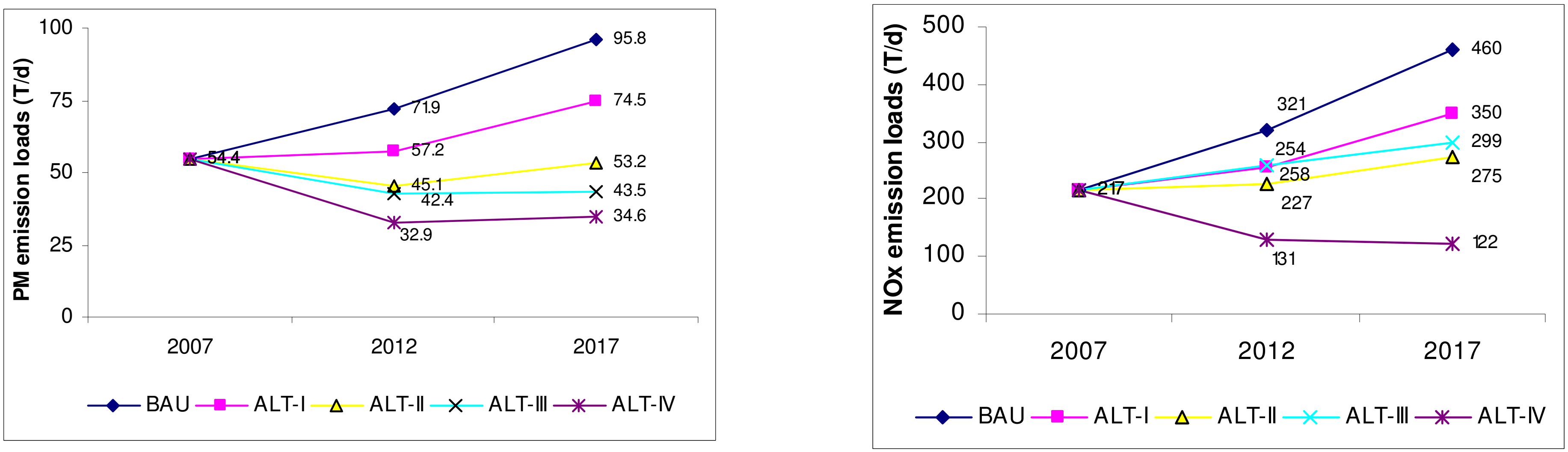


Figure **6.9** Estimated emissions loads for PM_{10} and NO_X under the BAU and four alternate scenarios

PM_{10} emission load

%PM reduction w.r.t. BAU

Scenario	2012	2017
ALT-I	-20%	-22%
ALT-II	-37%	-44%
ALT-III	-41%	-55%
ALT-IV	-54%	-64%

ALT-I scenario with less stringent measures shows a reduction of 20% in 2012 and 22% in 2017, respectively. However, ALT-II scenario with more stringent measures show reduction of 37% and 44%, in 2012 and 2017, respectively. ALT-III scenario that includes additional measures including installation of DOC/DPF control devices in all diesel vehicles as well as DG sets amounts to substantial reduction of 41% and 55% in the years 2012 and 2017, respectively. ALT-IV emerges out to be the best showing reductions of 54% and 64% in the above mentioned years mainly because of no power cuts (and thus no emissions from DG sets) and by-passing of the truck traffic.

Overall, it is seen that in 2017, the PM_{10} emission loads in Alternate-IV, Alternate-III and Alternate – II are lower (36%, 19% & 2.1 %, respectively) than in 2007, while those in Alternate – I are 37 % higher than in 2007. However, under the BAU scenario, the emission loads in 2017 show an increase of 76 % as compared to 2007.

NO_X emission load

% NOx reduction wrt BAU

Scenario	2012	2017
ALT-I	-21%	-24%
ALT-II	-29%	-40%
ALT-III	-20%	-35%
ALT-IV	-59%	-73%

ALT-I scenario with less stringent measures shows a reduction of 21% in 2012 and 24% in 2017, respectively. However, ALT-II scenario with more stringent measures show reduction of 29% and 40%, in 2012 and 2017, respectively. ALT-III scenario shows reductions of 17% and 33%, in 2012 and 2017, respectively. Here again, ALT-IV scenario shows the maximum reduction in NO_X emissions loads w.r.t. BAU i.e. 59% and 73%, respectively. The reduction is mainly because of no usage of DG sets and by-passing of trucks which are a significant source of NO_X emissions.

Overall, it is seen that in 2017, under the BAU scenarios, the emission loads in 2017 show an increase of 112 % as compared to 2007. Alternate-I, Alternate – II and Alternate – III scenarios, show that the NO_X emission loads are 61%, 26% and 38% more than in 2007, respectively. Only Alternate-IV scenario show a decrease of 44% NO_X emissions from the 2007 levels.

CHAPTER 7 Prioritization of management/ Control options

7.1 Citywise Dispersion modelling for Select Options for future scenarios

7.1.1 PM_{10} BAU Scenarios for 2012 and 2017

PM_{10} emission load have been estimated for the years 2012 and 2017 under business as usual scenario as mentioned in Chapter 6. Further, emission rate input files for the area, point and line sources of the years 2012 and 2017 were prepared for ISCST3 model simulations.

Model simulations were carried out for BAU and alternate scenarios using the worst meteorology season i.e., first (winter) season in the case of Bangalore. The background meteorology was used for the scenarios simulation. 12-hourly model simulations were done for day and night period separately to arrive at 24-hourly averaged concentrations.

Model performance

Figure 7.1 indicates that the predicted 24-hourly averaged PM_{10} concentrations in base year 2007 at six air quality monitoring stations ranged from 55 – 205 µg/m^3. The predicted 24 hourly average concentrations at these six sites for BAU 2012 and 2017 ranged from 72 – 276 µg/m^3 and 96 - 374 µg/m^3, respectively. Further, 150 highest concentration points with details on receptor co-ordinates and day of occurrence during the winter season in the entire modelling domain at the city level were noted for the base year 2007. The predicted 150 highest concentration values ranged from 236 – 351 µg/m^3 at city level in 2007. The predicted highest concentrations at city level for the same receptor locations and dates under BAU 2012 and 2017 ranged from 323 – 469 µg/m^3 and 437 - 629 µg/m^3, respectively as shown in Figure 7.2.

Moreover, highest concentrations predicted at six ambient air quality monitoring stations were also calculated. These are subsequently used to assess the effectiveness of different technological control options in the transport sector. Figure 7.3 indicates that the predicted 24-hourly highest PM_{10} concentrations in base year 2007 at six air quality monitoring stations ranged from 95 – 260 µg/m^3. The predicted highest concentrations at these sites for BAU 2012 and 2017 ranged from 125 – 349 µg/m^3 and 167 - 470 µg/m^3, respectively.

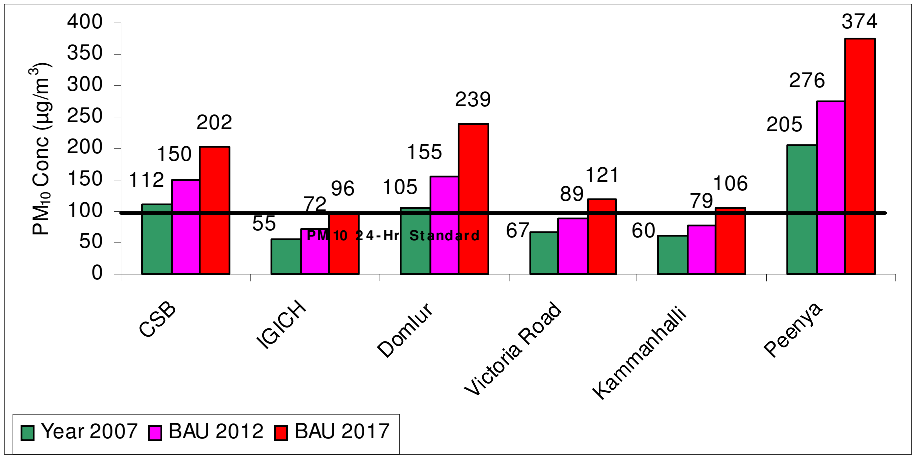


Figure **7.1** Predicted 24-hourly average PM_{10} concentrations (µ g/m³) for base year (2007) and BAU **(**2012, 2017)

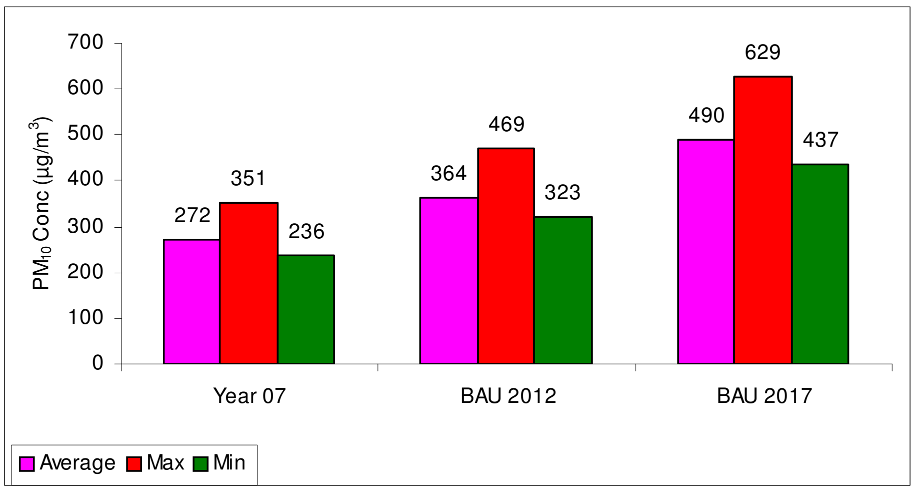


Figure **7.2** Predicted average, maximum and minimum PM_{10} concentrations (µ g/m³) for base year (2007) and BAU (2012, 2017) at city level (considering the highest 150 concentration values in the study domain)

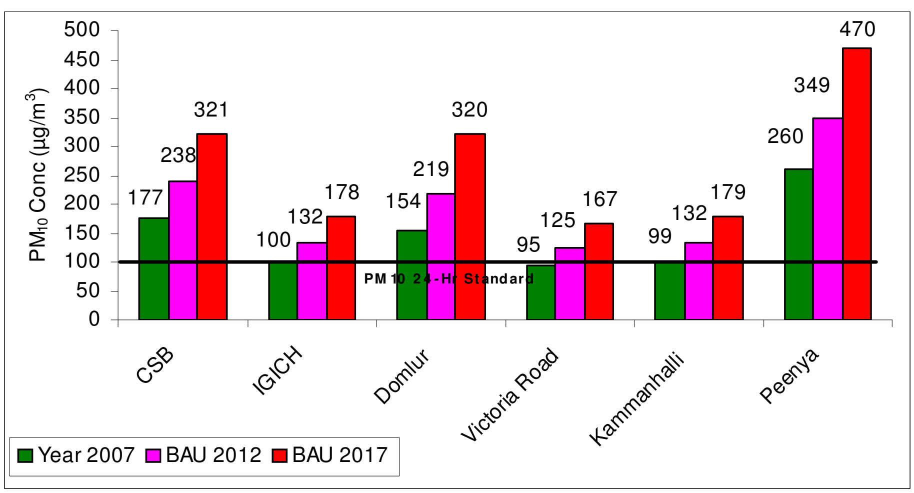


Figure **7.3** Predicted 24-hourly highest PM_{10} concentrations (µ g/m³) for base year (2007) and BAU (2012, 2017) at six air quality monitoring stations

Concentration contours for BAU 2012 and 2017

As an illustration, the PM_{10} predicted 24 hourly average concentration values during the winter season for year 2012 and 2017 under BAU scenario are shown in Figure 7.4 and 7.5, respectively.

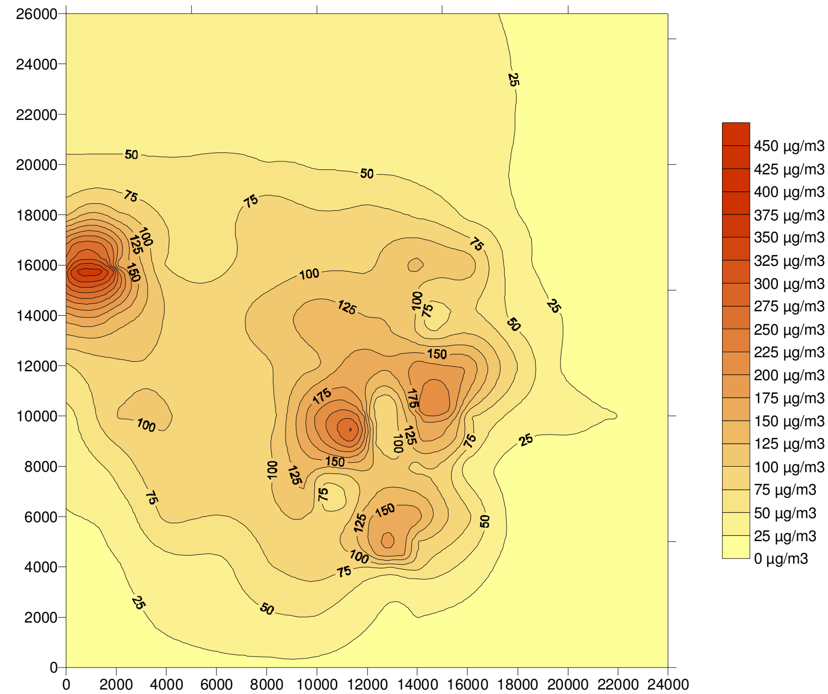


Figure **7.4** Contours for 24-hourly average PM_{10} concentration ($\mu g/m^3$) for BAU 2012

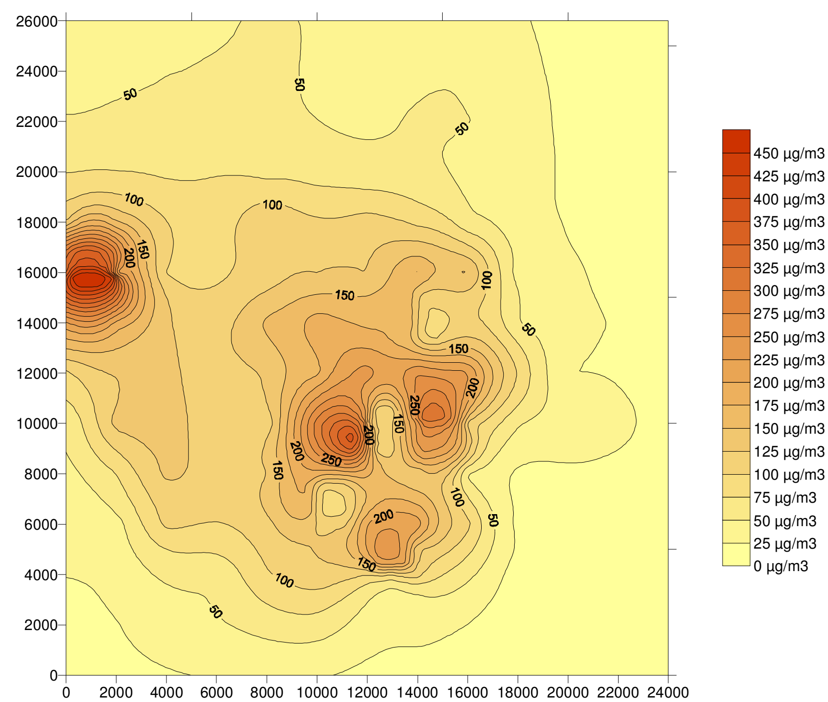


Figure **7.5** Contours for 24-hourly average PM_{10} concentration ($\mu g/m^3$) for BAU 2017

As in the base year 2007, it is noted that the maximum concentration is observed close to Peenya industrial area and high traffic locations close to the central hub of the city. Also, compared to the base year 2007, the concentration values increase in BAU 2012 and show a further increase in 2017, which is in accordance with the increasing trend of the pollutant emissions.

7.1.1.1 Transport control options

Chapter 6 had discussed various technical options for the reduction of emissions from the transport sector. It was evident that the reduction in emission loads due to different control options is limited, though in some cases, a marginal impact was seen. Modelling exercise has been carried out for each of these technical control options in the transport sector to quantify the impact on ambient air quality. The percentage reduction in ambient air quality (highest 24 hourly PM_{10} concentrations) at each of the six monitoring locations has been calculated under different technical control options in the transport sector as compared to BAU for the years 2012 and 2017 (Table 7.1)

It is seen that most of the control options do not have much impact on the ambient air quality except for electric vehicles and CNG introduction in the commercial fleet of vehicles. In the year 2017, the impact due to electric vehicles varies from 0.2-1.7 % while impact due to CNG vehicles varies from 0.7-5.6 % at these six air quality monitoring sites.

Table 7.1 Percent change in PM_{10} concentrations due to different control options in the transport sector w.r.t. BAU 2012 and BAU 2017

	Euro V	Euro VI	Electric Vehicle	Bio diesel	CNG	DOC	DPF
w.r.t. BAU 2012							
CSB	NA	NA	-1.06	-0.20	-1.91	-0.53	-0.40
IGICH			-1.02	-0.14	-1.50	-0.41	-0.31
Domlur			-0.68	-0.09	-1.23	-0.31	-0.25
Victoria Road			-1.08	-0.14	-1.62	-0.44	-0.31
Kammanhalli			-1.05	-0.13	-1.74	-0.46	-0.39
Peenya			-0.14	-0.03	-0.24	-0.06	-0.03
w.r.t. BAU 2017							
CSB	-0.35	-0.46	-1.64	-0.26	-5.58	-0.93	-0.44
IGICH	-0.34	-0.43	-1.63	-0.23	-4.34	-0.72	-0.36
Domlur	-0.23	-0.30	-1.03	-0.12	-3.28	-0.43	-0.26
Victoria Road	-0.36	-0.49	-1.70	-0.25	-4.72	-0.78	-0.43
Kammanhalli	-0.37	-0.45	-1.67	-0.19	-4.97	-0.83	-0.36
Peenya	-0.05	-0.08	-0.22	-0.05	-0.71	-0.11	-0.06

7.1.2 PM_{10} alternate scenarios for 2012 and 2017

As discussed in chapter 6, Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios have been developed that comprise of a mix of control options across various sectors and the emission loads have been estimated accordingly. Emission rate input files for the area, point and line sources for the four alternate scenarios were prepared for ISCST3 model simulations for the years 2012 and 2017. Model simulations were carried out using the worst (winter) season meteorology.

12-hourly model simulations were done for day and night period separately to arrive at 24-hourly concentrations for the Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios.

Model performance

Figure 7.6 indicates that the predicted 24-hourly average PM_{10} concentrations for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios at the six air quality monitoring stations in year 2012 ranged from 59 – 213 µg/m³, 51 – 119 µg/m³, 42 – 100 µg/m³, and 30 -81 µg/m³ , respectively. Likewise in the year 2017, it ranged from 79 – 241 µg/m³, 65 – 182 µg/m³, 42 – 104 µg/m³ , and 32 – 75 µg/m³ for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios, respectively.

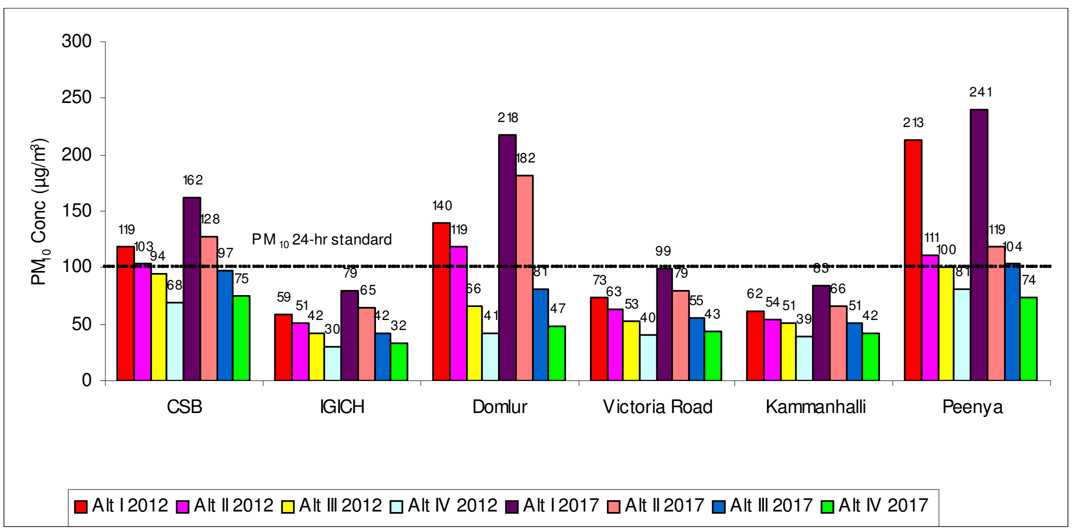


Figure **7.6** 24-hourly average PM_{10} concentrations (µg/m³) for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the year 2012 and 2017

The predicted 24-hourly highest PM_{10} concentrations for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios at the six air quality monitoring stations in year 2012 ranged from 100 – 267 µg/m³, 87 – 162 µg/m³, 77 – 148 µg/m³ and 55 – 107 µg/m³, respectively. Likewise, in the year 2017, it ranged from 135 – 294 µg/m³, 107 – 229 µg/m³ , 78 – 153 µg/m³ and 60 – 119 µg/m³ for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios, respectively.

Figure 7.7 indicates the percent reduction of 24-hourly highest PM_{10} concentration at different sites in Bangalore under the Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios w.r.t. BAU scenario for the years 2012 and 2017. It is evident that the PM_{10} ambient concentration reduces by 14-23 % in 2012 and 13-37 % in 2017 under the Alternate – I scenario as compared to BAU of the respective years. The reduction in PM_{10} ambient concentration under the Alternate – II scenario is 27-63 % in 2012 and 28-72 % in 2017 as compared to BAU of the respective years. Likewise, the reduction in PM_{10} ambient concentration under the Alternate – III scenario is 38-66 % in 2012 and 52-74 % in 2017 as compared to BAU of the respective years. Under Alternate –IV scenario, the reduction in PM_{10} ambient concentration is 55 - 72 % in 2012 and 62 - 81 % in 2017 as compared to BAU of the respective years.

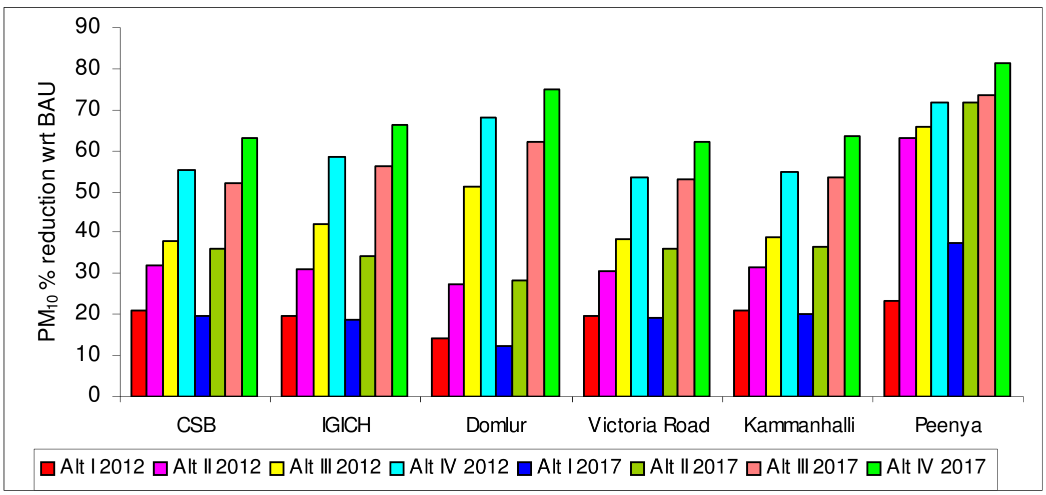


Figure **7.7** Percent reduction of predicted 24-hourly highest PM_{10} concentration (µg/m³) for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the years 2012 and 2017

Concentration contours for alternate scenarios

As an illustration, the PM_{10} predicted 24 hourly average concentration values during the winter season for Alternate – I, Alternate – II , Alternate – III and Alternate – IV scenarios for the years 2012 and 2017 are shown in Figure 7.8, 7.9, 7.10, 7.11 and 7.12, 7.13, 7.14 and 7.15, respectively. It is again seen from the contours that Alternate – I, Alternate – II , Alternate – III and Alternate – IV scenarios do show a significant decrease compared to BAU scenario in both the years 2012 and 2017. Alternate – III scenario shows more reduction in comparison to Alternate-I, and Alternate-II, due to the introduction of fuel efficiency standards in all the vehicles, DOC/DPF installation in all diesel vehicles (buses, trucks and cars) and commercial DG sets. The reduction is highest in Alternate – IV scenario which has additional control options that are more oriented towards meeting the air quality standards e.g., no power cuts and by-passing of trucks.

It is seen that there would be certain localised areas under Alternate-I and Alternate –II scenarios where the ambient air quality would still exceed the 24-hourly residential area standards for PM_{10}. However, in Alternate-III scenario, there is a substantial reduction in the area showing exceedence, and only small pockets in the central hub of the city and Peenya industrial area show exceedence. Finally, in Alternate –IV, the overall air quality in Bangalore improves tremendously and broadly all areas across the city conform to the ambient air quality standards in 2012 and 2017. Only a very small region (about 1.5 km^2 near the central city areas such as Richmond town and Brigade road) shows marginal exceedence and thus, in this specific region, measures such as restriction of vehicular traffic could be implemented.

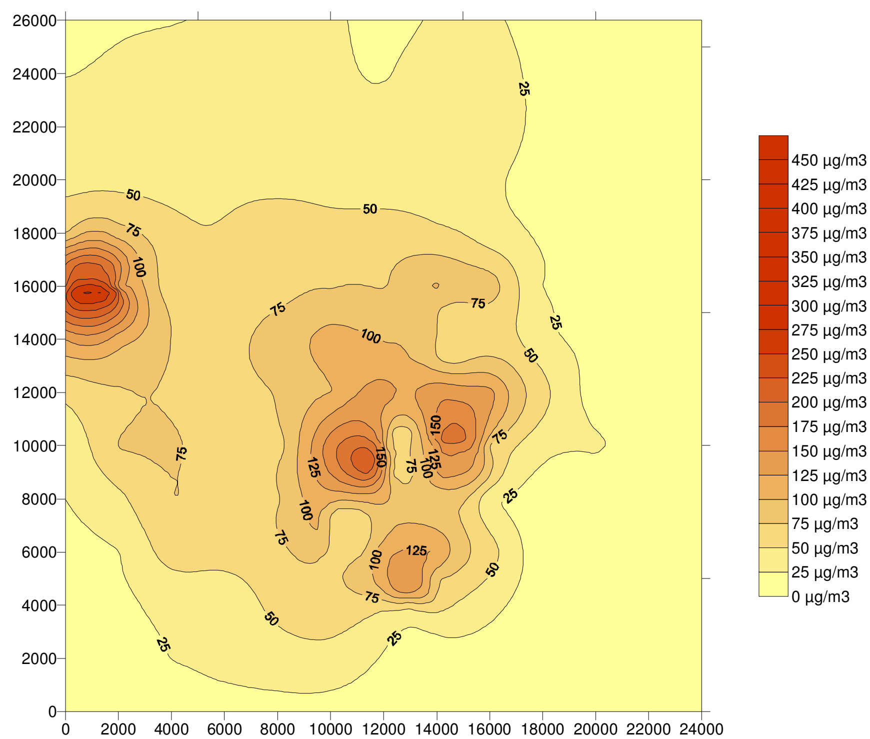


Figure **7.8** Contours for 24-hourly average PM_{10} concentration (µg/m^3) for Alternate - I scenario in 2012

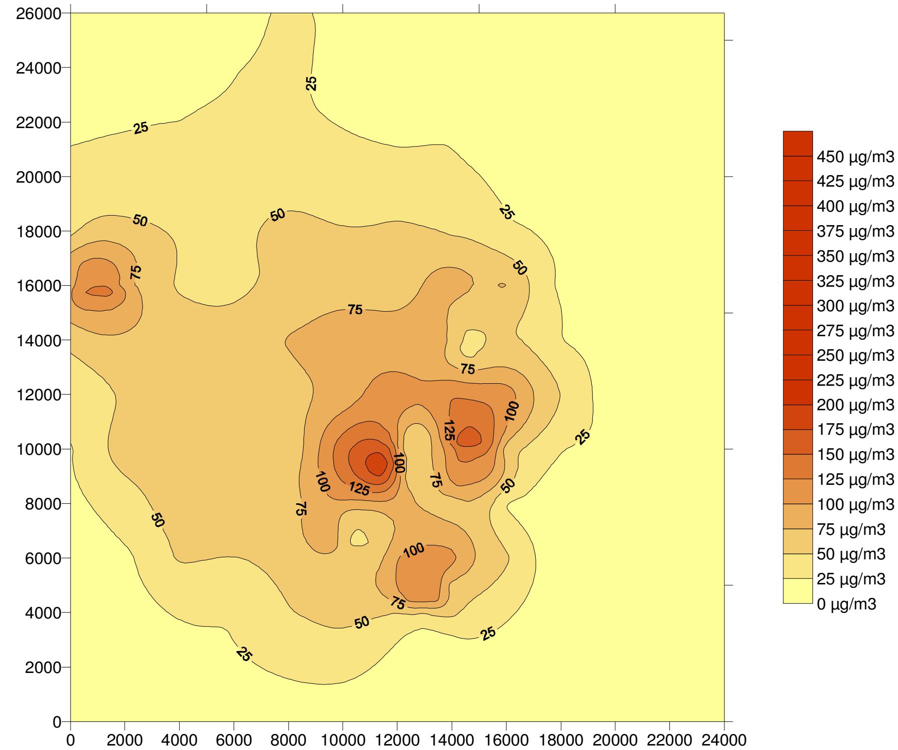


Figure 7.9 Contours for 24-hourly average PM_{10} concentration (µg/m³) for Alternate – II scenario in 2012

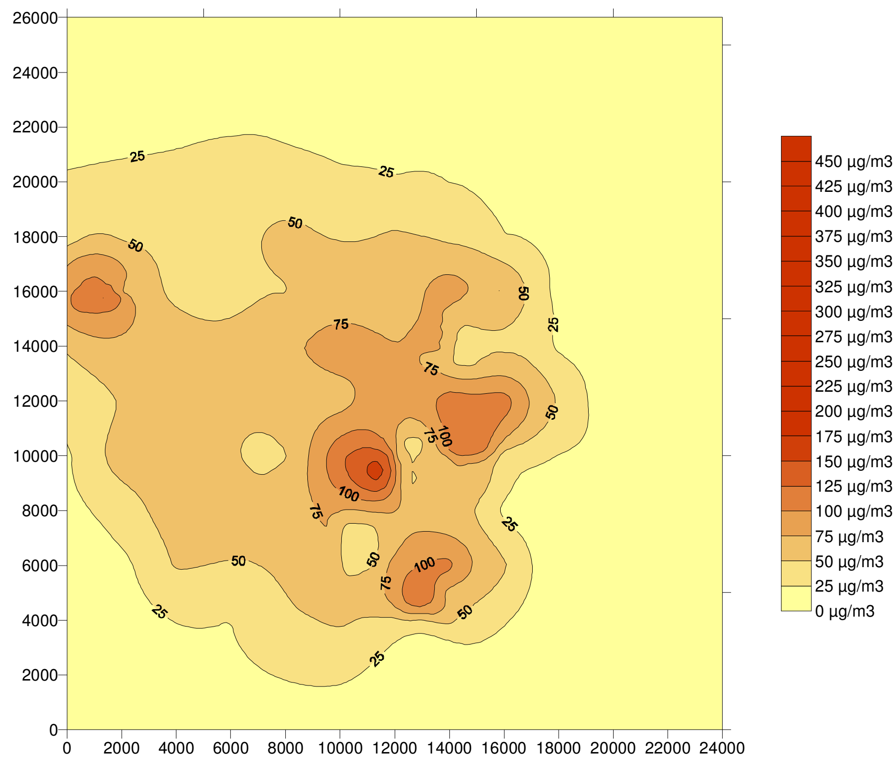


Figure 7.10 Contours for 24-hourly average PM_{10} concentration (µg/m³) for Alternate – III scenario in 2012

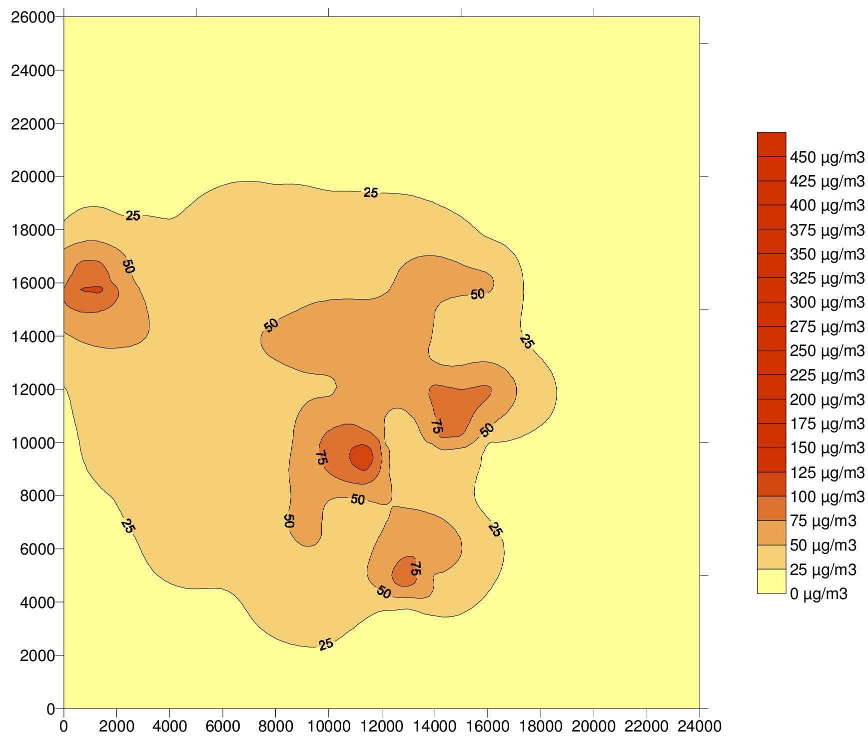


Figure 7.11 Contours for 24-hourly average PM_{10} concentration (µg/m³) for Alternate – IV scenario in 2012

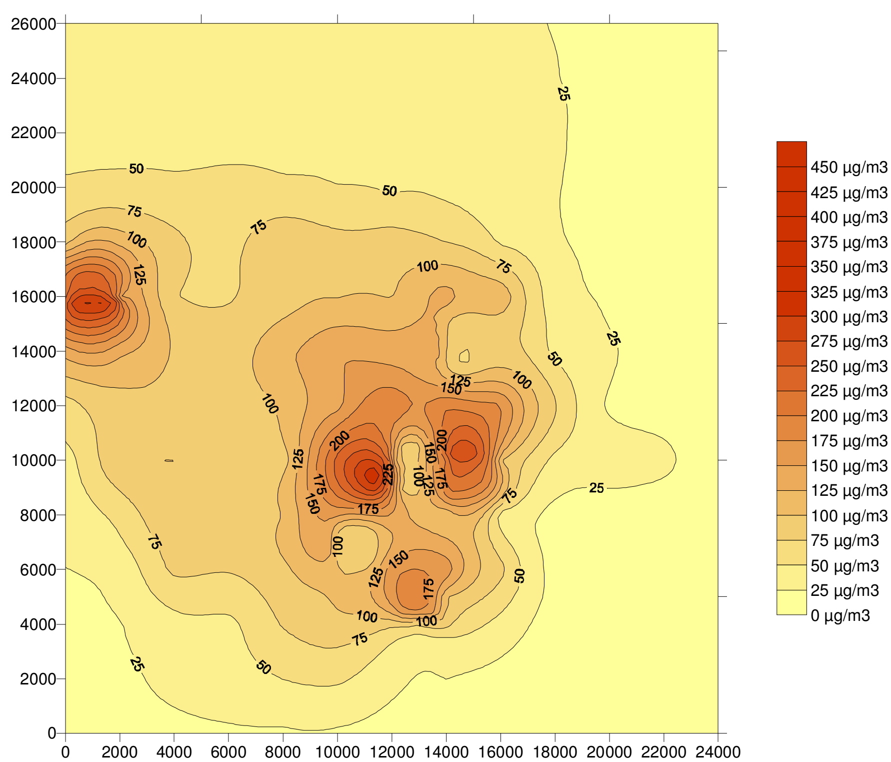


Figure **7.12** Contours for 24-hourly average PM_{10} concentration (µg/m³) for Alternate – I scenario in 2017

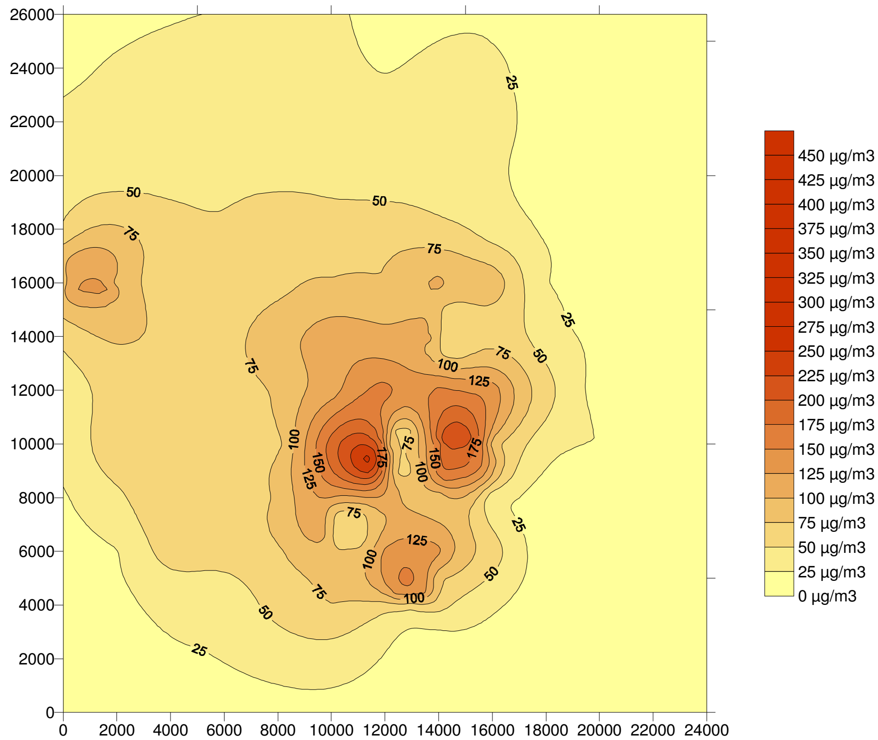


Figure **7.13** Contours for 24-hourly average PM_{10} concentration (µg/m³) for Alternate - II scenario in 2017

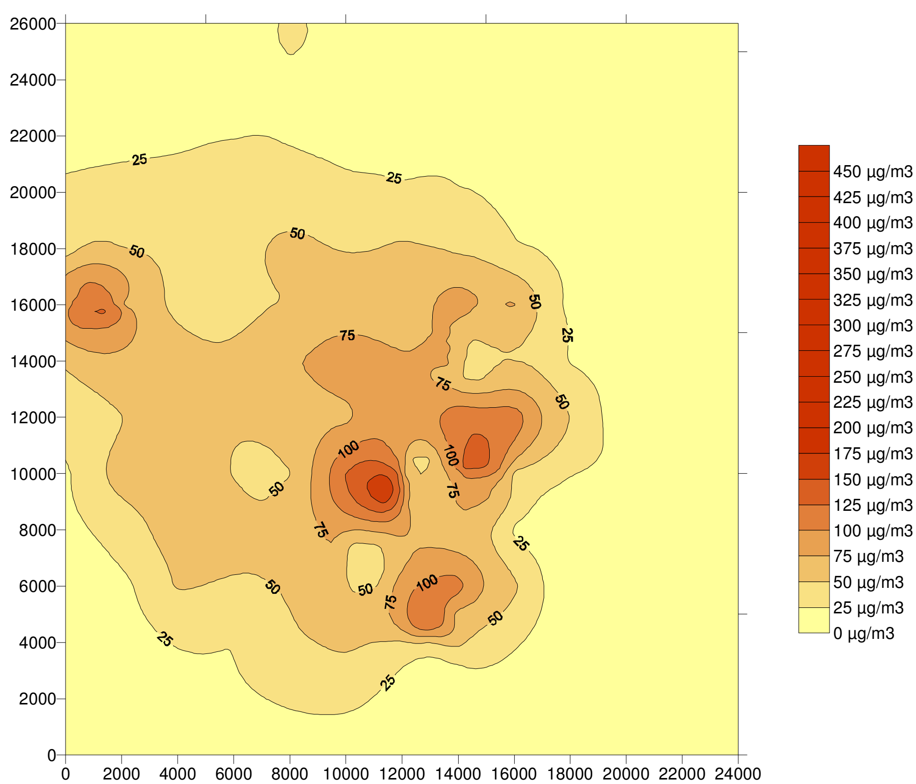


Figure **7.14** Contours for 24-hourly average PM_{10} concentration (µg/m³) for Alternate - III scenario in 2017

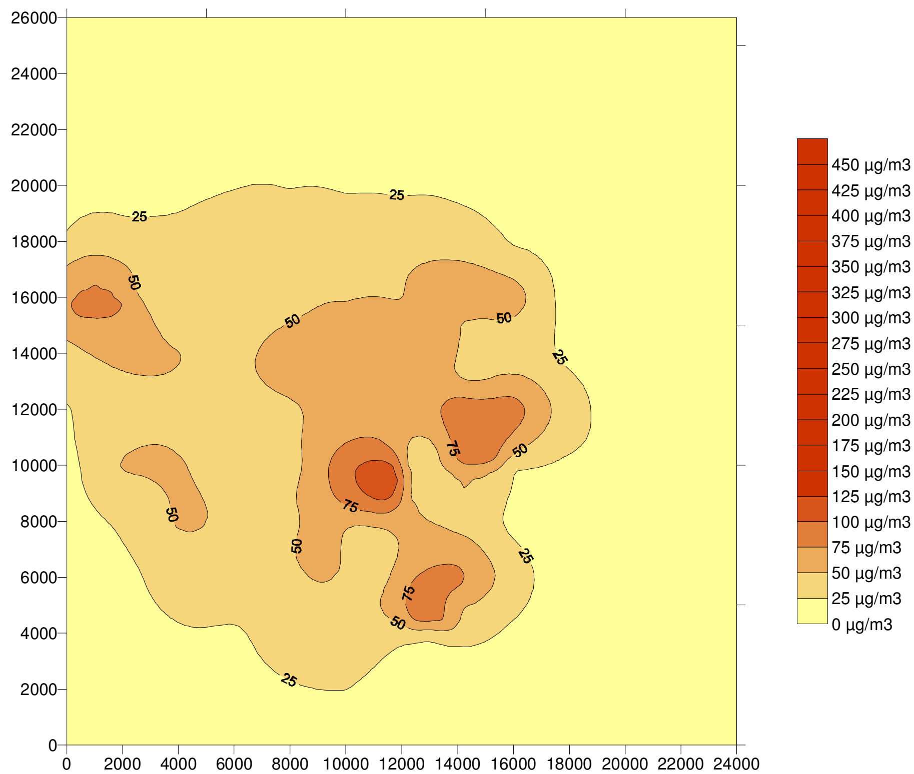


Figure **7.15** Contours for 24-hourly average PM_{10} concentration (µ g/m^3) for Alternate - IV scenario in 2017

7.1.3 NO_X BAU Scenarios for 2012 and 2017

NO_X emission load have been estimated for the years 2012 and 2017 under business as usual scenario as mentioned in Chapter 6. Further, emission rate input files for the area, point and line sources of the years 2012 and 2017 were prepared for ISCST3 model simulations.

Model simulations were carried out for BAU and alternate scenarios using the worst meteorology season i.e., first (winter) season in the case of Bangalore. The background station meteorology was used for the scenarios simulations. 12-hourly model simulations were done for day and night period separately to arrive at 24-hourly averaged concentrations. The framework developed for modelling the base scenario for 2007 is again used for modelling the BAU and alternative scenarios in future.

Model performance

Figure 7.16 indicates that the predicted 24-hourly averaged NO_X concentrations in base year 2007 at six air quality monitoring stations ranged from 34 – 101 µg/m^3. The predicted 24 hourly average concentrations at these six sites for BAU 2012 and 2017 ranged from 46 - 161 µg/m^3 and 65 - 265 µg/m^3, respectively. Further, 150 highest concentration points with details on receptor co-ordinates and day of occurrence during the winter season in the entire modelling domain at the city level were noted for the base year

2007. The predicted 150 highest concentration values ranged from 116 – 150 µg/m³ at city level in 2007. The predicted highest concentrations at city level for the same receptor locations and dates under BAU 2012 and 2017 ranged from 170 – 236 µg/m³ and 272 - 358 µg/m³, respectively as shown in Figure 7.17.

Moreover, highest concentrations predicted at six ambient air quality monitoring stations were also calculated. These are subsequently used to assess the effectiveness of different technological control options in the transport sector. Figure 7.18 indicates that the predicted 24-hourly highest NO_X concentrations in base year 2007 at six air quality monitoring stations ranged from 48 – 126 µg/m³. The predicted highest concentrations at these sites for BAU 2012 and 2017 ranged from 79 – 195 µg/m³ and 113 - 319 µg/m³, respectively.

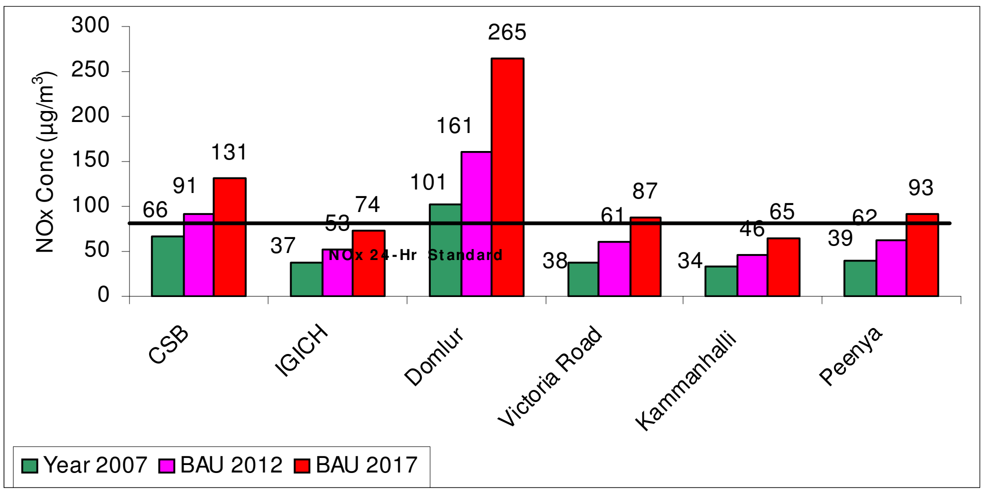


Figure **7.16** Predicted 24-hourly average NO_X concentrations (µg/m³) for base year (2007) and BAU (2012, 2017)

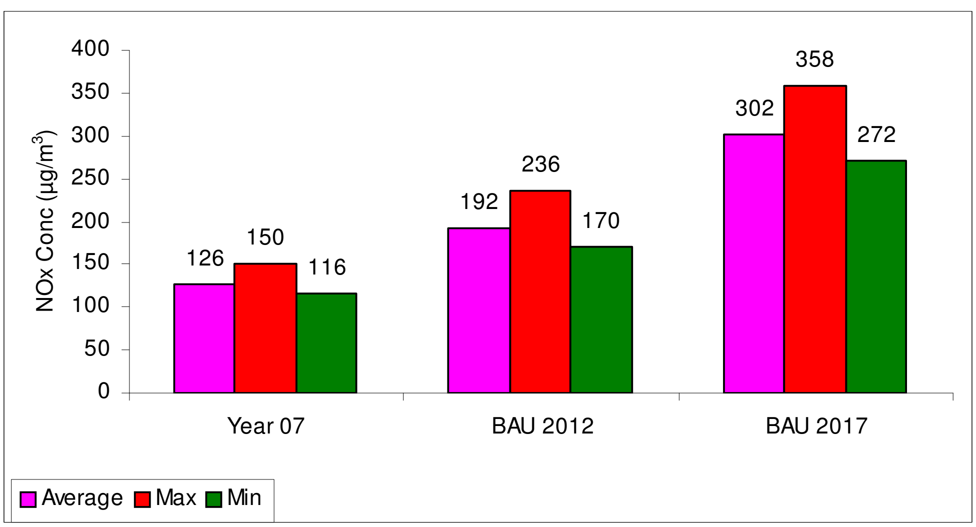


Figure **7.17** Predicted average, maximum and minimum NO_X concentrations (µg/m³) for base year (2007) and BAU (2012, 2017) at city level (considering the highest 150 concentration values in the study domain)

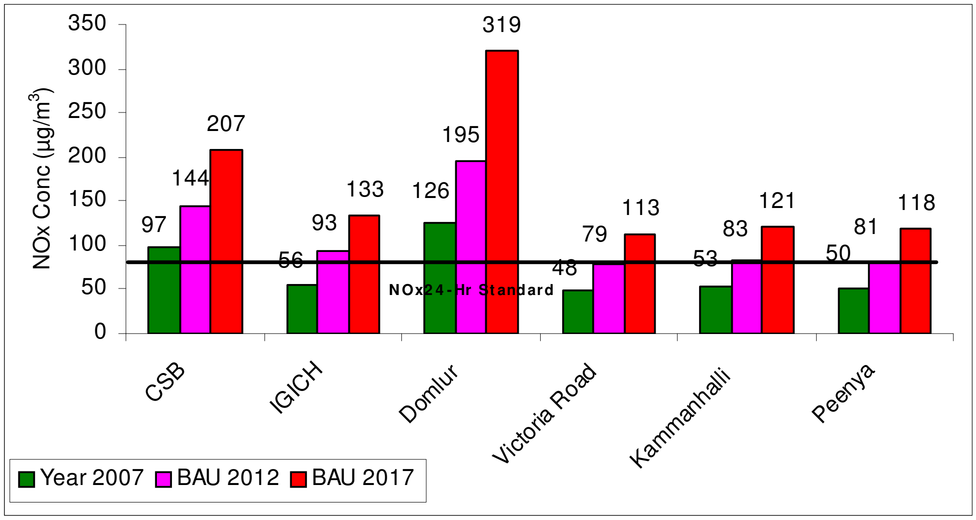


Figure **7.18** Predicted 24-hourly highest NO_X concentrations (µg/m³) for base year (2007) and BAU (2012, 2017) at six air quality monitoring stations

Concentration contours for BAU 2012 and 2017

As an illustration, the NO_X predicted 24 hourly average concentration values during the winter season for year 2012 and 2017 under BAU scenario are shown in Figure 7.19 and 7.20, respectively.

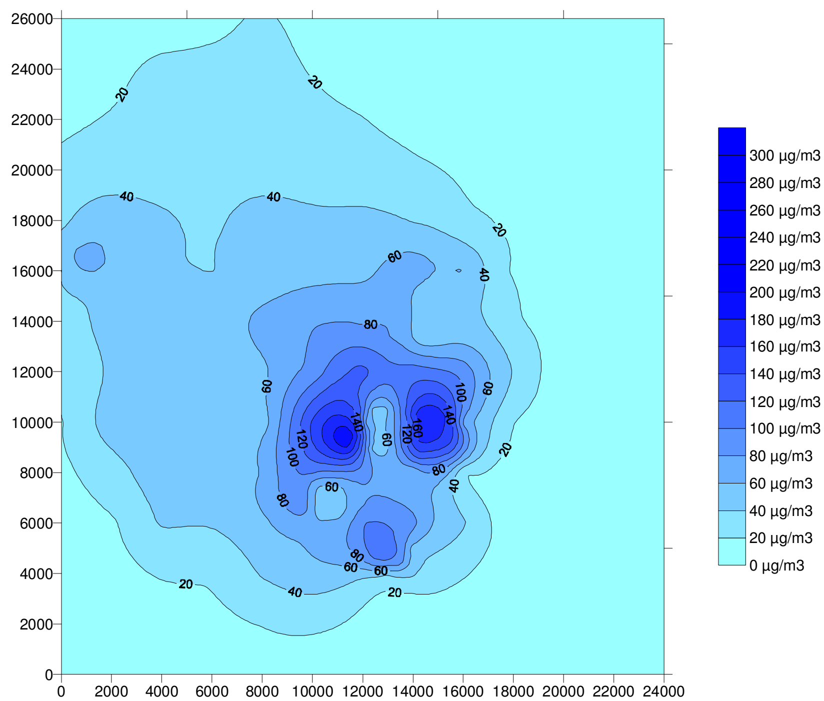


Figure **7.19** Contours for 24-hourly average NO_X concentration (µg/m³) for BAU 2012

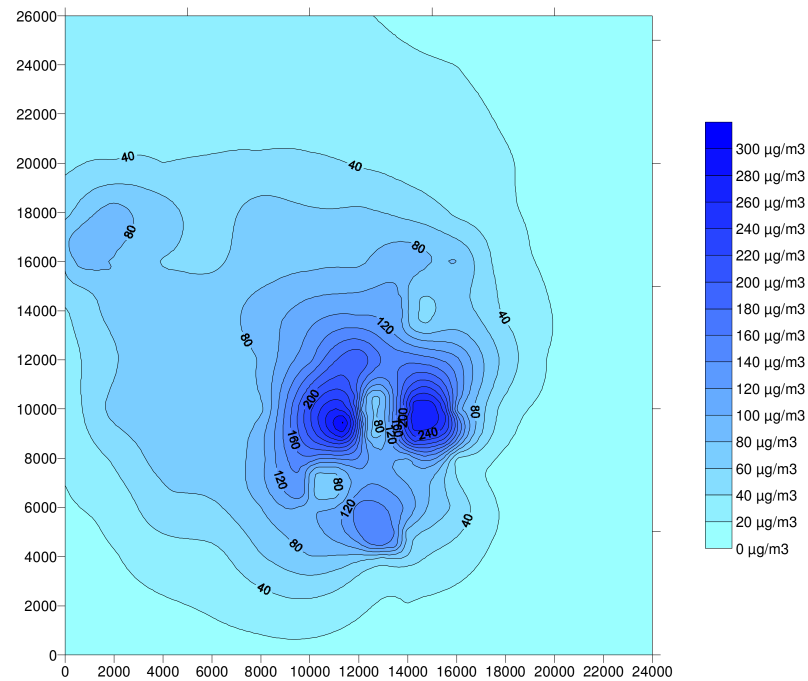


Figure **7.20** Contours for 24-hourly average NO_X concentration (µg/m³) for BAU 2017

As in the base year 2007, it is noted that the maximum concentration zones are observed close to the central hub of the city which also happen to be high traffic zones and commercial areas having high DG set operations. Also, compared to the base year 2007, the concentration values increase in BAU 2012 and show a further increase in 2017, which is in accordance with the increasing trend of the pollutant emissions.

7.1.3.1 Transport control options

Chapter 6 had discussed various technical options for the reduction of emissions from the transport sector. It was evident that the reduction in emission loads due to different control options was limited, though in some cases, a marginal impact was seen. Modelling exercise has been carried out for each of these technical control options in the transport sector to quantify the impact on ambient air quality. The percentage reduction in ambient air quality (highest 24 hourly NO_X concentrations) at each of the six monitoring locations has been calculated under different technical control options in the transport sector as compared to BAU for the years 2012 and 2017 (Table 7.2).

It is seen that most of the control options do not have much impact on the ambient air quality except for electric vehicles and CNG introduction in the commercial fleet of vehicles. In the year 2017, the impact due to H2-CNG varies from 0.8 – 2.9 % , electric vehicles varies from 0.8-2.7 % and CNG vehicles varies from 0.7-2.7 % at these six air quality monitoring sites.

Table 7.2 Percent change in NO_X concentrations due to different control options in the transport sector w.r.t. BAU 2012 and BAU 2017

NO_X w.r.t. BAU 2012	Euro V	Euro VI	Bio diesel	Ethanol	CNG	Hybrid	Electric Vehicle	H_2-CNG
CSB	NA	NA	0.07	-0.04	-0.91	-0.02	-1.73	NA
IGICH			0.04	-0.05	-0.66	0.00	-1.25	
Domlur			0.01	-0.02	-0.27	0.00	-0.56	
Victoria Road			0.05	-0.05	-0.77	-0.01	-1.51	
Kammanhalli			0.05	-0.08	-0.81	-0.01	-1.61	
Peenya			0.05	-0.04	-0.51	-0.01	-1.04	
NO_X w.r.t. BAU 2017								
CSB	-1.04	-2.09	0.09	-0.05	-2.71	-0.01	-2.68	-2.96
IGICH	-0.88	-1.60	0.04	-0.08	-2.05	-0.01	-2.09	-2.22
Domlur	-0.29	-0.57	0.02	-0.03	-0.71	-0.01	-0.76	-0.78
Victoria Road	-0.82	-1.54	0.05	-0.07	-1.97	-0.03	-2.05	-2.16
Kammanhalli	-0.91	-1.67	0.08	-0.07	-2.16	-0.03	-2.28	-2.41
Peenya	-0.82	-1.55	0.06	-0.07	-1.58	-0.01	-1.61	-1.72

7.1.4 NO_X alternate scenarios for 2012 and 2017

As discussed in chapter 6, Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios have been developed that comprise of a mix of control options across various sectors and the emission loads have been estimated accordingly. Emission rate input files for the area, point and line sources for the four alternate scenarios were prepared for ISCST3 model simulations for the years 2012 and 2017. Model simulations were carried out using the worst (winter) season meteorology.

12-hourly model simulations were done for day and night period separately to arrive at 24-hourly concentrations for the Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios.

Model performance

Figure 7.21 indicates that the predicted 24-hourly average NO_X concentrations for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios at the six air quality monitoring stations in year 2012 ranged from 37 – 156 µg/m³, 33 – 134 µg/m³, 38 – 138 µg/m³, and 14 – 33 µg/m³ respectively. Likewise in the year 2017, it ranged from 50 – 256 µg/m³, 41 – 215 µg/m³, 43 – 217 µg/m³ and 14 – 33 µg/m³ for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios, respectively.

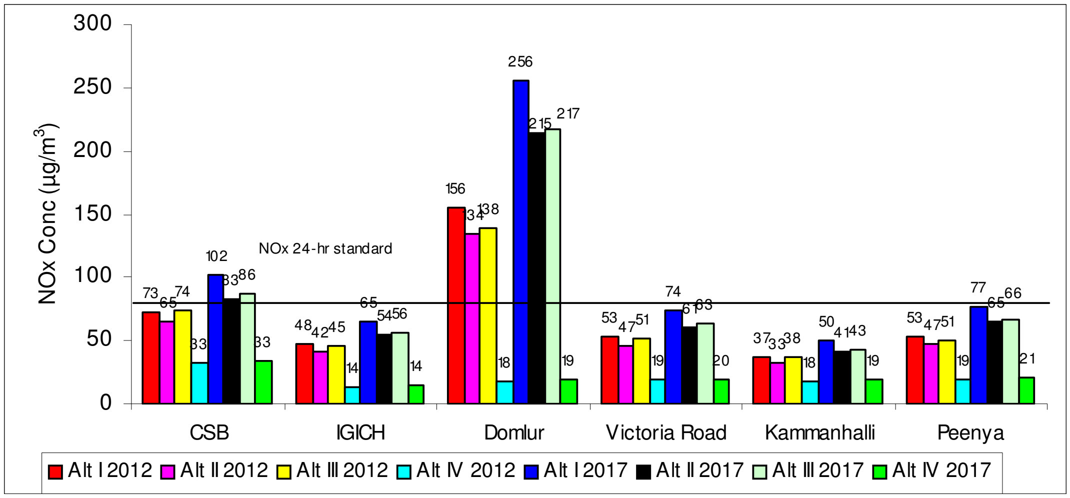


Figure **7.21** 24-hourly average NO_X concentrations (µg/m3) for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the year 2012 and 2017

The predicted 24-hourly highest NO_X concentrations for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios at the six air quality monitoring stations in year 2012 ranged from 68 – 186 µg/m3, 59 – 161 µg/m3, 65 – 167 µg/m3 and 27 – 52 µg/m3 respectively. Likewise, in the year 2017, it ranged from 96 – 305 µg/m3, 79 – 256 µg/m3, 82 – 259 µg/m3 and 27 – 53 µg/m3 for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios, respectively.

Figure 7.22 indicates the percent reduction of 24-hourly highest NO_X concentration at different sites in Bangalore under the Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios w.r.t. BAU scenario for the years 2012 and 2017. It is evident that the NO_X ambient concentration reduces by 4 - 20 % in 2012 and 5 - 22 % in 2017 under the Alternate – I scenario as compared to BAU of the respective years. The reduction in NO_X ambient concentration under the Alternate – II scenario is 18 -29 % in 2012 and 20 - 36 % in 2017 as compared to BAU of the respective years. Likewise, the reduction in NO_X ambient concentration under the Alternate – III scenario is 14 - 19 % in 2012 and 19 - 34 % in 2017 as compared to BAU of the respective years. Under Alternate –IV scenario, the reduction in NO_X ambient concentration is 64 - 84 % in 2012 and 74 - 90 % in 2017 as compared to BAU of the respective years.

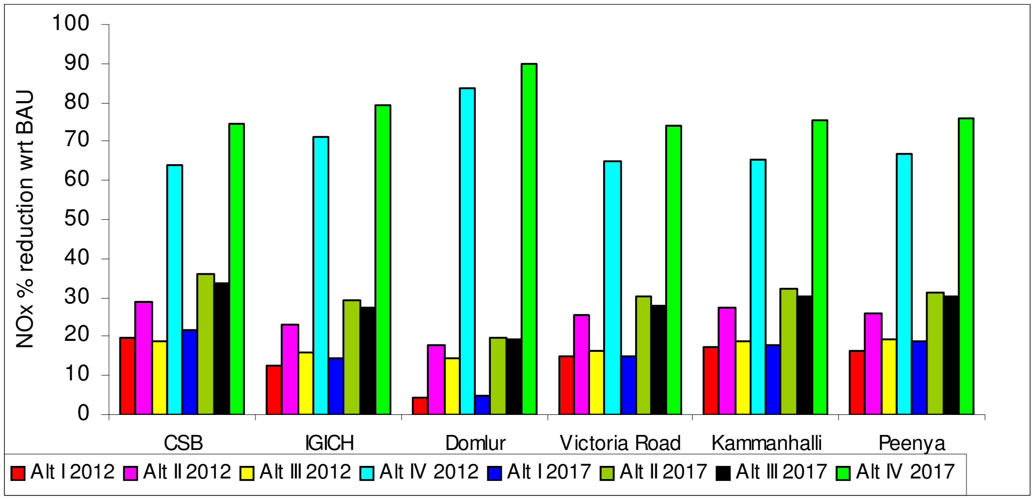


Figure **7.22** Percent reduction of predicted 24-hourly highest NO_X concentration (µg/m³) for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the years 2012 and 2017

Concentration contours for alternate scenarios

As an illustration, the NO_X predicted 24 hourly average concentration values during the winter season for Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios for the years 2012 and 2017 are shown in Figure 7.23, 7.24, 7.25, 7.26, and 7.27, 7.28, 7.29 and 7.30, respectively. It is again seen from the contours that Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios do show a significant decrease compared to BAU scenario in both the years 2012 and 2017. The reduction is highest in Alternate – IV scenario which has additional control options that are more oriented towards meeting the air quality standards, e.g., no power cuts, by-passing of trucks. It is seen that while in alternate scenarios I-III, there are certain localised regions showing exceedence against the standards, however, in alternate IV scenario, all the areas in the study domain comply against the residential area ambient air quality standards for NO_X.

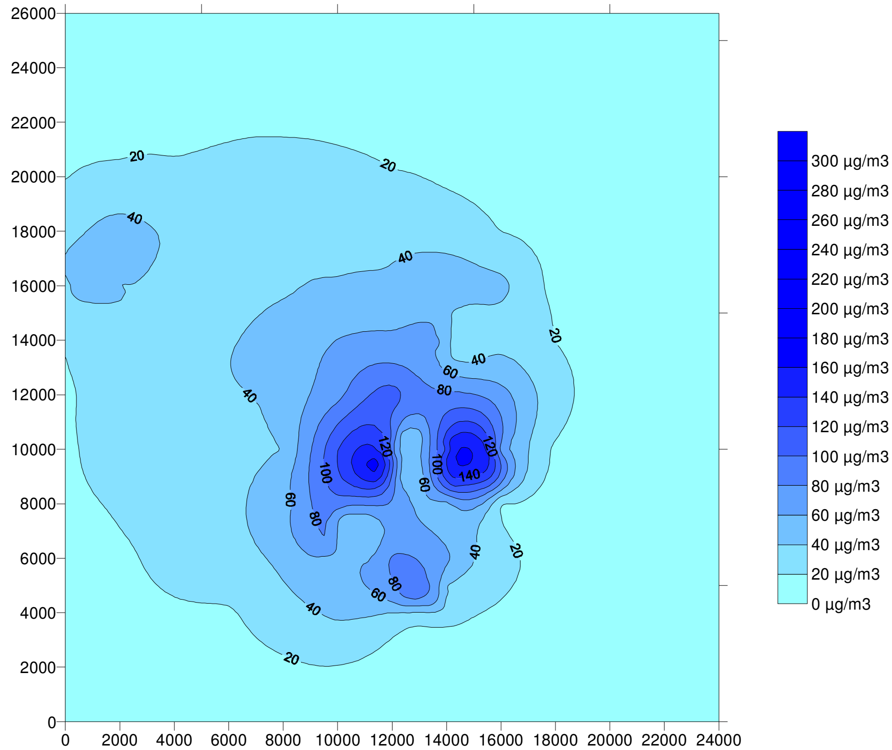


Figure **7.23** Contours for 24-hourly average NO_X concentration ($\mu g/m^3$) for Alternate - I scenario in 2012

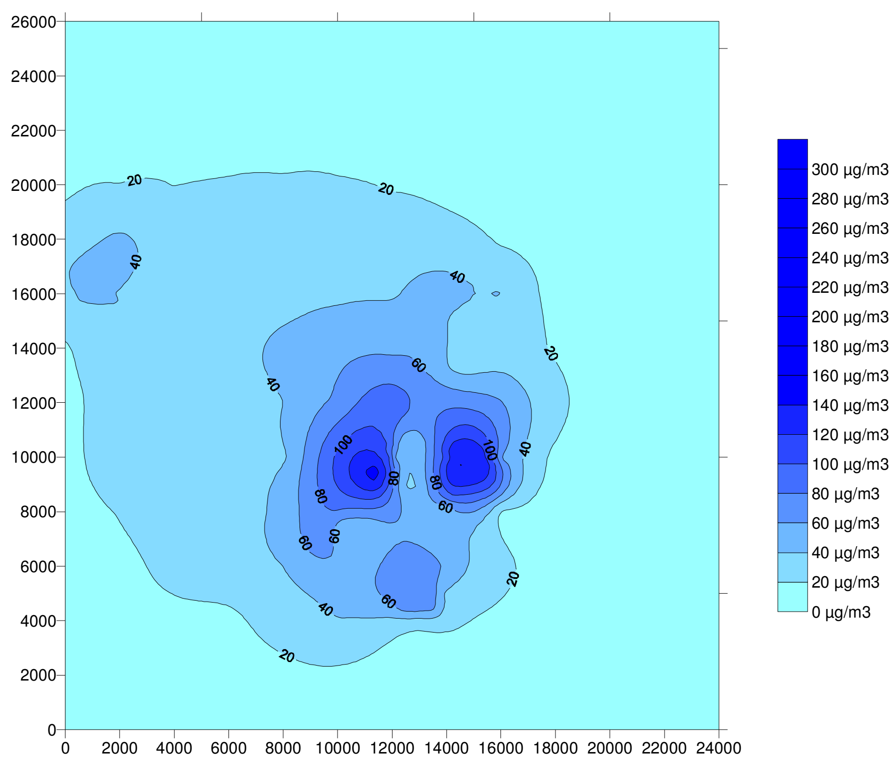


Figure **7.24** Contours for 24-hourly average NO_X concentration ($\mu g/m^3$) for Alternate – II scenario in 2012

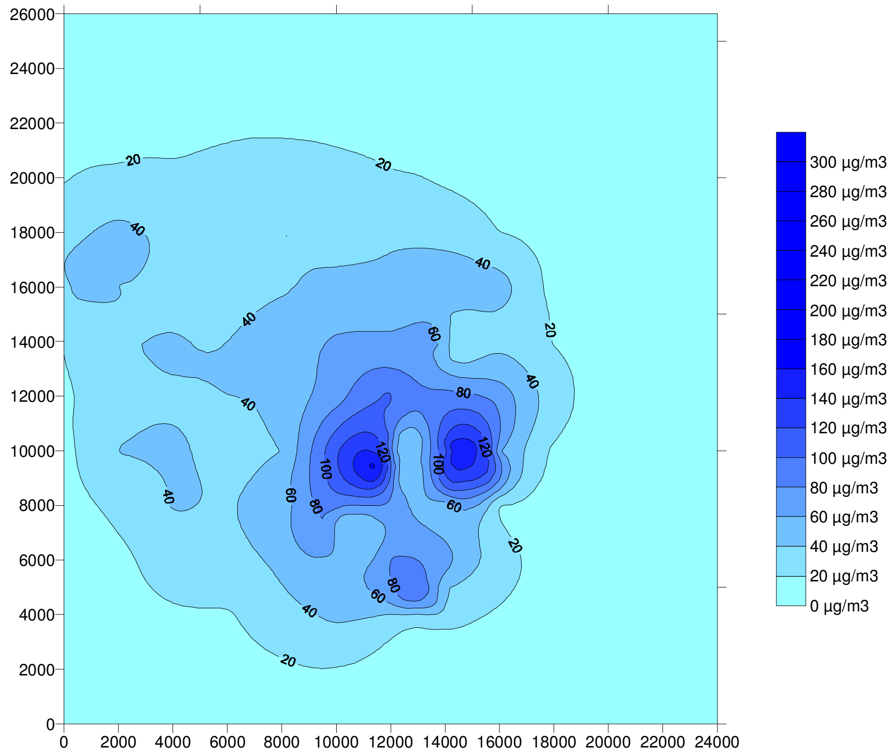


Figure **7.25** Contours for 24-hourly average NO_X concentration (µg/m³) for Alternate – III scenario in 2012

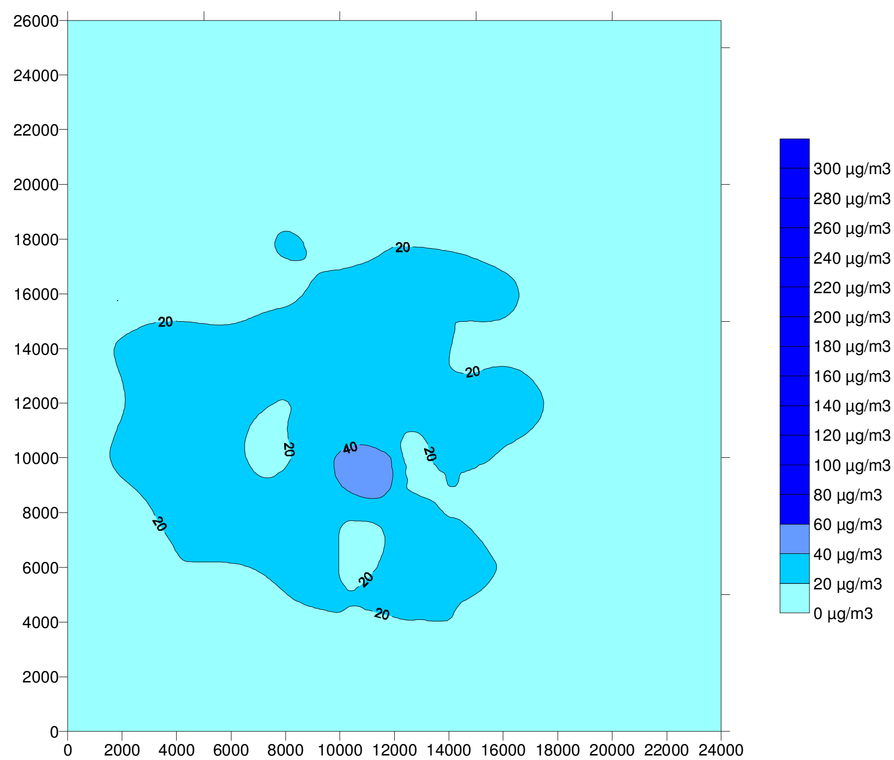


Figure **7.26** Contours for 24-hourly average NO_X concentration (µg/m³) for Alternate – IV scenario in 2012

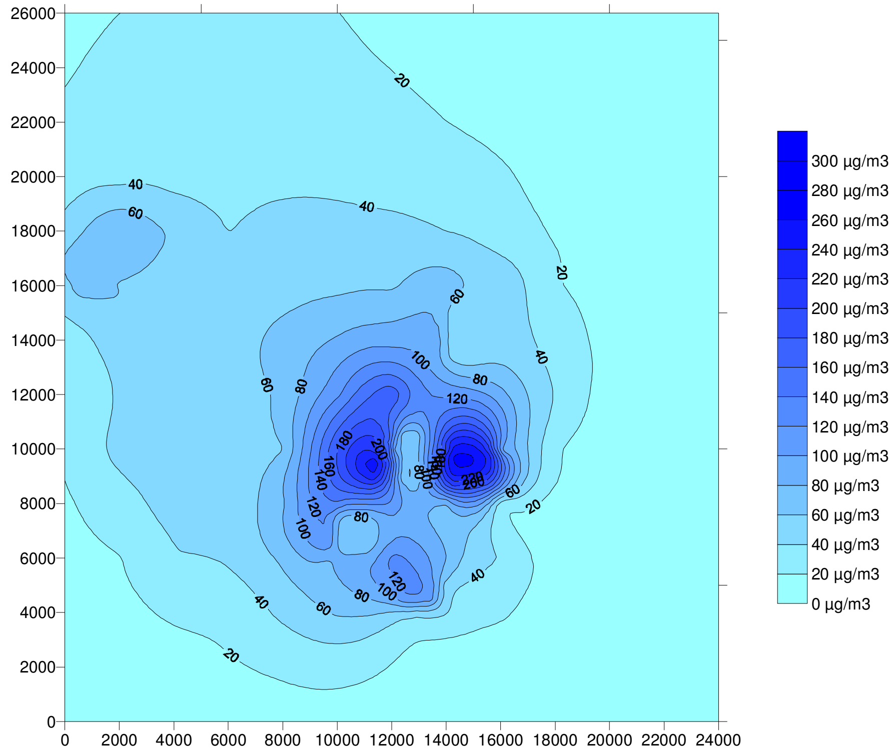


Figure **7.27** Contours for 24-hourly average NO_X concentration (µg/m³) for Alternate – I scenario in 2017

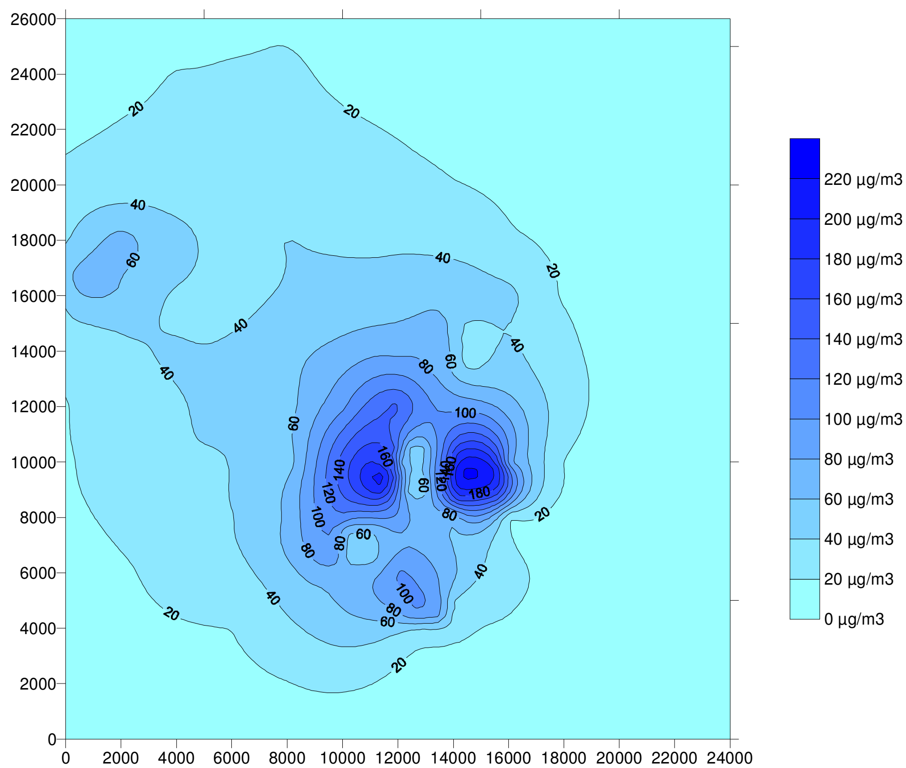


Figure **7.28** Contours for 24-hourly average NO_X concentration (µg/m³) for Alternate - II scenario in 2017

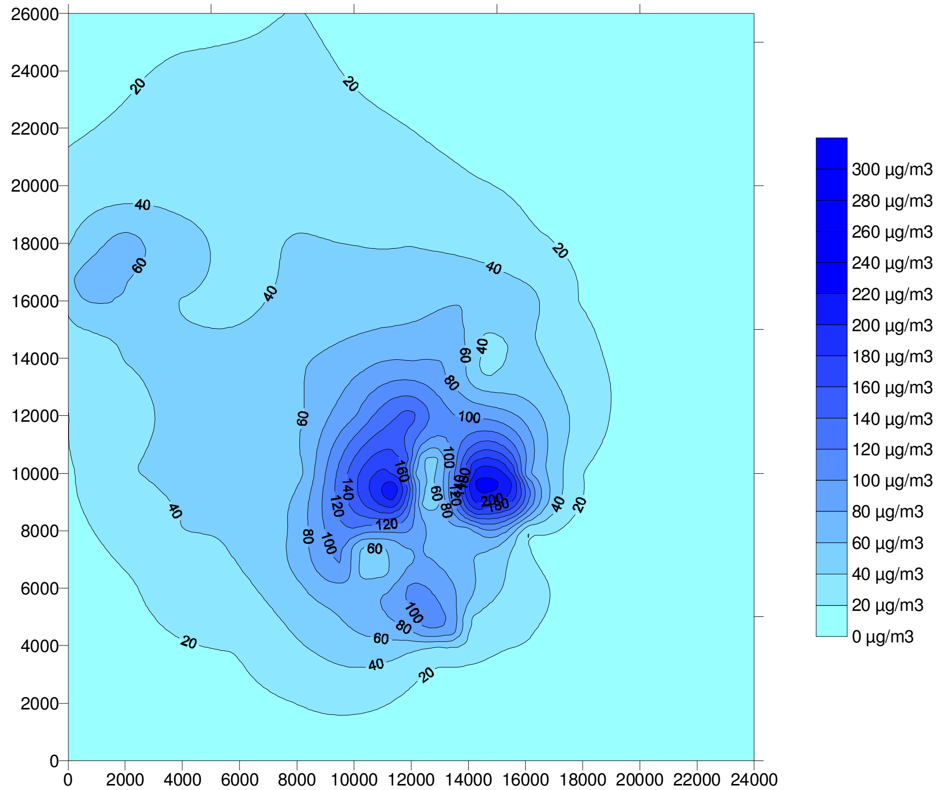


Figure **7.29** Contours for 24-hourly average NO_X concentration (µg/m³) for Alternate - III scenario in 2017

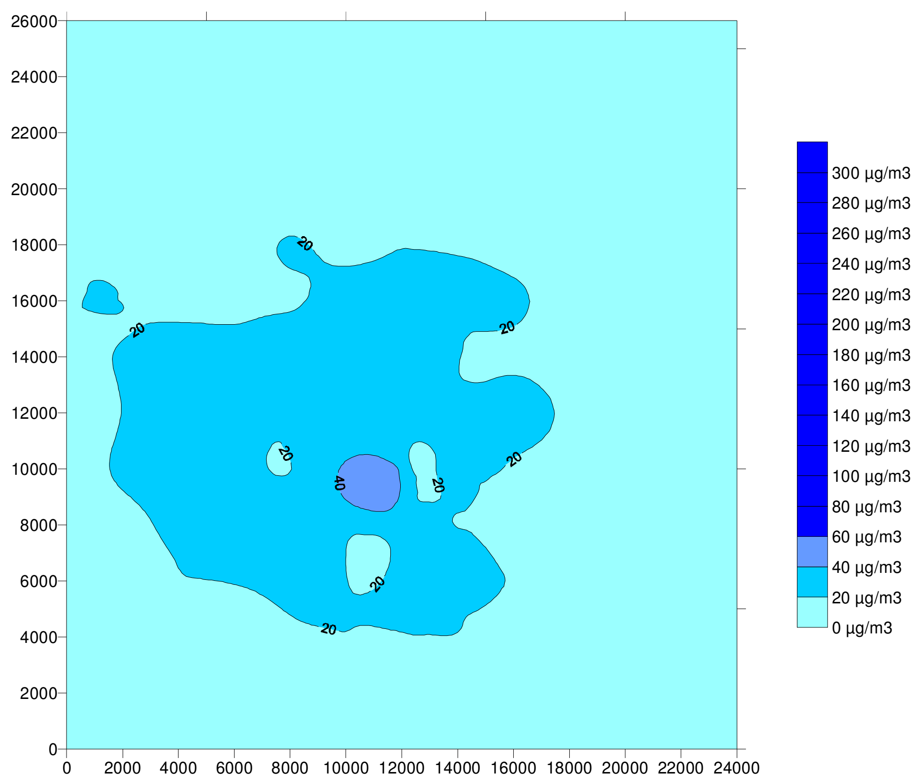


Figure **7.30** Contours for 24-hourly average NO_X concentration (µg/m³) for Alternate - IV scenario in 2017

7.2 Prioritized list of management/control options

Based on emission inventory and receptor modelling approach, the major common sources of PM_{10} are transport and road dust re-suspension. DG sets and industry show significant contributions in different approaches. In addition, due to major construction activities ongoing in Bangalore, construction sector also contributes to the emission load. Therefore, in the case of Bangalore, control strategies need to be devised for transport, road dust re-suspension, industry, DG sets, and soil dust/construction. In addition, CMB8.2 quantification shows secondary particulates as an additional source. The control strategies for primary pollutant like SO_2 and NO_X would results in the reduction of the secondary particulates as well.

7.2.1 Sectoral control options

Since transport sector is an important contributor to the air pollution load in Bangalore, thus various control options are explored. Different technical and management strategies for the reduction of PM_{10} and NO_X emissions are selected as per the control options chart provided by CPCB.

As discussed earlier in chapter 6, it is seen that the introduction of BS-V and BS-VI have minimal impact on PM_{10} emission loads because of their introduction in 2015. Introduction of electric vehicles can reduce the load significantly and the strategy can be useful in some specific areas. Introduction of Hybrid vehicles and ethanol blending does not have any impact on PM_{10} emission loads. However, blending of bio-diesel reduces the load marginally by 0.4-1% in 2012 and 2017, respectively. Likewise, introduction of DOC in BS-II buses and DPF in BS-III buses reduces the load only marginally. Introduction of CNG in 3 & 4-wheeler commercial vehicles can reduce the PM_{10} emissions load by 4% in 2012 and 12% in 2017. In case of NO_X emission loads, introduction of BS-V and BS-VI have minimal impact because of their introduction in 2015. Introduction of electric vehicles can reduce the load up to 5 % in 2017 and the strategy can be useful in some specific areas. Introduction of Hybrid vehicles and ethanol blending have very small impact on the NO_X emission loads. Blending of bio-diesel increases the load marginally by 0.1-0.2% in 2012 and 2017, respectively. Introduction of DOC in BS-II buses and DPF in BS-III buses does not have any impact on NO_X emissions.

Introduction of CNG in commercial vehicles (bus, car, 3w), reduces the NO_X emission loads by 1% in 2012 and 4% in 2017. The impact is lower in case of NO_X than in the case of PM_{10}.

Two strategies were evaluated for industrial sector i.e., ban on new air polluting industries in the city limits, which means no further addition of emission loads in 2012 and 2017 and fuel shift in terms of conversion of all solid fuel fired combustion to

LSHS in 2012 and all solid fuel or HSD fired combustion to natural gas in 2017. The strategy of banning new air polluting industries results in reduction of 24% and 43% of PM_{10} emission loads compared to BAU in years 2012 and 2017, respectively. Likewise, this strategy for NO_X results in similar reductions in the years 2012 and 2017. The combined effect of ban and fuel shift strategies results in significant reductions for both the pollutants compared to BAU. PM_{10} reduced 57% and 80% and NO_X reduced 25% and 89% in the years 2012 and 2017, respectively.

Inspection and maintenance of DG sets results in 15% reduction of PM_{10} and NO_X emissions loads.

Strategy of wall to wall paving is considered for reduction of emissions due to road dust re-suspension. The strategy shows substantial reduction i.e. 11% in 2012 and 22% in 2017.
50% reduction in PM_{10} emission loads has been envisaged in view of better construction practices including proper loading/unloading of material, water spraying etc.

7.2.2 Prioritization of control options

As discussed in chapter 6, four alternate scenarios (Alternate – I, Alternate – II, Alternate-III, and Alternate-IV) are developed. These include the measures that are implemented under BAU scenario and in addition various combinations of control options under different sectors.

For prioritizing the list of management/ control options, an analysis is made of the percentage reduction in the overall emission load as compared to the BAU total emission load in the respective years i.e. 2012 and 2017. (Figure 7.31).

Under the Alternate-I scenario, the percentage reductions in the various sectors are as follows:

- 2012 : Transport (16.8%), industry (3.6%)
- 2017 : Transport (16.1%), industry (6.2%).

Under the Alternate-II scenario the percentage reductions in the various sectors are as follows:

- 2012 : Transport (18.7%), industry (8.3%), construction (6.3%), road dust (2.6%) and DG sets (1.4%).
- 2017 : Transport (19.4%), industry (11.5%), road dust (6.2%), construction (5.5%) and DG sets (1.9%).

Under the Alternate-III scenario the percentage reductions in the various sectors are as follows:

- 2012 : Transport (16.4%), industry (8.3%), DG sets (7.4%), construction (6.3%), and road dust (2.6%)
- 2017 : Transport (23.0%), DG sets (10.2%), industry (9.8%), road dust (6.2%), and construction (5.5%)

Under the Alternate-IV scenario the percentage reductions in the various sectors are as follows:

- 2012 : Transport (19.6%), road dust (10.8%), DG sets (9.2%), industry (8.3%), and construction (6.3%),
- 2017 : Transport (19.4%), DG sets (12.8%), industry (11.5%), road dust (14.7%), and construction (5.5%)

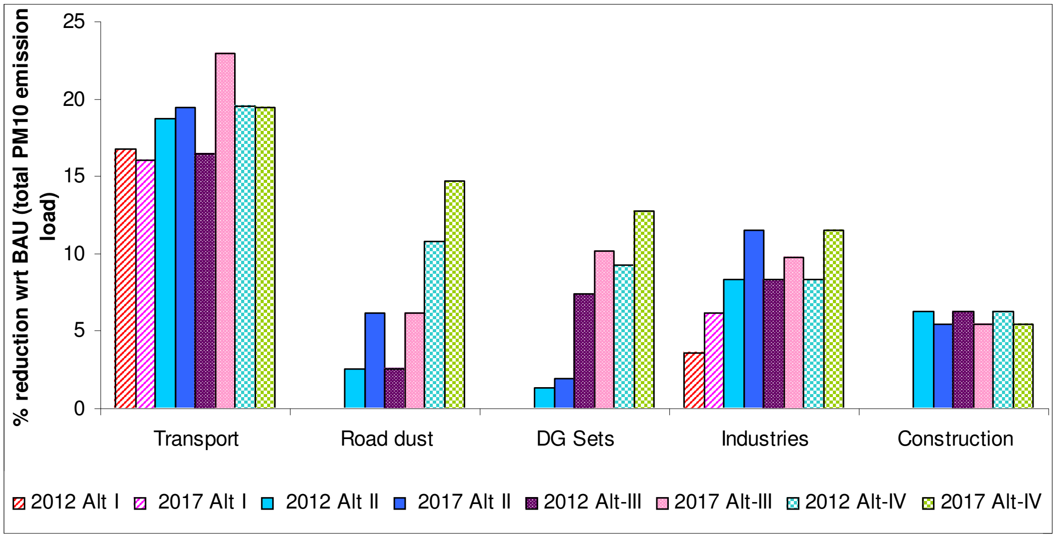


Figure **7.31** Percent PM_{10} emission load reduction in different sectors under Alternate scenarios as compared to the total pollution load under BAU scenario

Further, within the transport sector, the percentage reduction in the emission load in 2012 by various individual measures as compared to the total load in BAU is as follows:

- 2012 : by-passing of trucks -leading to reduction of exhaust emissions as well as re-suspended road dust (15%), banning of old commercial vehicles (12.2%), installation of DOC-DPF in half of the pre-2010 diesel vehicles (9.1%), inspection /maintenance programme (1.5%), enhancement of public transport based on CNG (1.4%), introduction of CNG in commercial vehicles (1.4%), enhancement of public transport based on diesel (1.2%), introduction of electric vehicles (0.9%), retrofitment of DOC-DPF in public transport buses (0.4%).

Likewise, for the year 2017, the percentage reductions are as follows:

- 2017 : by-passing of trucks -leading to reduction of exhaust emissions as well as re-suspended road dust (13.8%), installation of DOC-DPF to all pre-2010 diesel vehicles (13%), banning of old commercial vehicles (12.5%), introduction of CNG in commercial vehicles (4%), inspection /maintenance programme (2.5%), enhancement of public transport based on CNG (1.7%), enhancement of public transport based on diesel (1.5%), introduction of electric vehicles (1.4%), and synchronisation of traffic signals (1.3%).

Strategies in other sectors have also resulted in significant reduction of PM_{10} emissions.

- No DG set usage (due to no power cuts) leads to reduction of 12.8% in PM_{10} emissions in 2017.
- Installation of DOC & DPF devices in DG sets lead to a reduction of 8.3% in 2017. In addition, I&M programme for DG sets also shows a reduction of 1.9%.
- Wall to wall paving reduces the road dust emissions by 6.2 %, and better construction practices show a reduction of 5.5% in 2017.
- Banning new air polluting industries in the city limits reduces the emissions by 6.2% in 2017. Further, shift of industrial fuel to natural gas shows a reduction of 5.3% while in case of LSHS it is 3.6% in the year 2017.

The prioritised list of key interventions in terms of reduction in total PM_{10} emission loads in 2017 are given in Table 7.3 and also represented graphically in Figure 7.32.

Table 7.3 Prioritised list of key interventions in terms of reduction in total PM_{10} emission loads in 2017

S.No	Strategy	% reduction in total PM_{10} emission loads in 2017
1	By-passing of trucks through the proposed peripheral ring road around Bangalore	13.8%
2	Installation of DOC and DPF devices in all pre-2010 diesel vehicles	13.0%
3	No power cuts leading to zero usage of DG sets	12.8%
4	Ban on 10 year old commercial vehicles in 2012 and 2017	12.5%
5	Ban on any new industries in city limits(6.2%) and fuel shift towards cleaner fuel natural gas(5.3%) in existing industries	11.5 %
6	Installation of DOC and DPF devices in DG sets	8.3%
7	Wall to wall paving for reduction of road dust	6.2%
8	Better construction practices	5.5%
9	Conversion of public transport (commercial 3 & 4 w) to CNG (25% in 2012 and 100 % in 2017)	4.0%
10	Improvement in inspection and maintenance for vehicles	2.5%
11	Inspection and maintenance for DG sets	1.9%
12	Enhancement of public transport system based on CNG (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017)	1.7%
13	Enhancement of public transport system based on diesel (shift of PKT from private vehicles to public transport i.e. 10% in 2012 and 20% in 2017)	1.5%

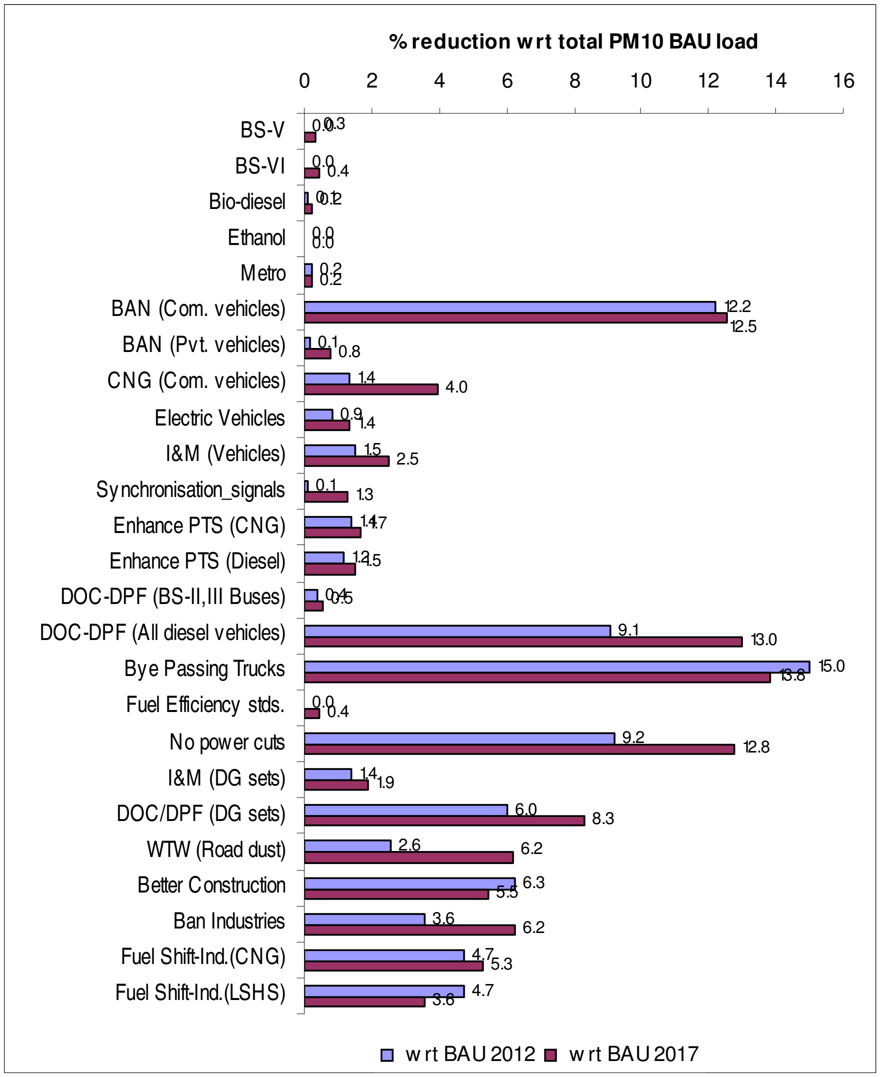


Figure **7.32** Percent PM_{10} emission load reduction due to various individual interventions as compared to the total pollution load under BAU scenario in the years 2012 & 2017

7.3 Benefits anticipated from prioritized management/control options

Selection of various control options shows an impact in terms of reduction in emission loads eventually translating into reduction of PM_{10} ambient concentrations. The benefits are anticipated in terms of improvements in the ambient air quality at the six ambient air quality stations as well as at the city level thereby leading to improved health and ecological benefits (in terms of impacts on crops/ materials, visibility, etc.).

In terms of ambient air quality , the percent reduction of 24-hourly highest PM_{10} concentration at different ambient air quality monitoring sites in Bangalore under the Alternate – I, Alternate – II, Alternate – III and Alternate – IV scenarios w.r.t. BAU scenario for the years 2012 and 2017 have been estimated. The PM_{10} ambient concentration reduces by 14-23 % in 2012 and 13-37 % in 2017 under the Alternate – I scenario as compared to BAU of the respective years. The reduction in PM_{10} ambient concentration under the Alternate – II scenario is 27-63 % in 2012 and 28-72 % in 2017 as compared to BAU of the respective years. Likewise, the reduction in PM_{10} ambient concentration under the Alternate – III scenario is 38-66 % in 2012 and 52-74 % in 2017 as compared to BAU of the respective years. Under Alternate –IV scenario, the reduction in PM_{10} ambient concentration is maximum, i.e., 55 - 72 % in 2012 and 62 - 81 % in 2017 as compared to BAU of the respective years.

Similarly, the NO_X ambient concentration reduces by 4 - 20 % in 2012 and 5 - 22 % in 2017 under the Alternate – I scenario as compared to BAU of the respective years. The reduction in NO_X ambient concentration under the Alternate – II scenario is 18 -29 % in 2012 and 20 - 36 % in 2017 as compared to BAU of the respective years. Likewise, the reduction in NO_X ambient concentration under the Alternate – III scenario is 14 - 19 % in 2012 and 19 - 34 % in 2017 as compared to BAU of the respective years. Under Alternate –IV scenario, the reduction in NO_X ambient concentration is 64 - 84 % in 2012 and 74 - 90 % in 2017 as compared to BAU of the respective years.

Besides the above strategies, other options such as staggered business timings and no vehicle zones in hot spots would also be helpful in improving the air quality. Fiscal measures such as congestion charges, enhanced parking charges etc. would be helpful in reducing the usage of private vehicles. More importantly, rationalisation of excise duty on vehicles and appropriate fuel pricing policies could play an important role in curbing the growth of more polluting private vehicles. Other measures such as appropriate landuse planning to curb travel demand, enhancing virtual mobility, car pooling etc would contribute to air quality improvements. However, in order to implement many of these strategies, the basic requirement is to have an efficient mass public transport system in place.

7.4 Action plan

S.No	Sector	Strategy	Impact*	Responsible Agency / agencies	Time frame	Remarks
1	Transport	Strengthening of Public transport system - Metro implementation on schedule - Enhance share of public mass transport system on diesel - Conversion/ enhancement of public transport to CNG	High	Govt of India, State Government, BMRCL (Bangalore Metro rail Corporation Ltd.), Transport Department- Bangalore, BMTC (Bangalore Metropolitan Transport Corporation), GAIL	Medium term	Leveraging the JNNURM funding mechanism for public transportation improvement Public-private partnership models to be explored The metro network needs to be progressively expanded. Bangalore currently does not have a CNG network. There are plans to set up such a network in future. ULSD would also be available by April 2010 in Bangalore. Retro-fitted 2-stroke three wheelers on LPG in Bangalore have higher PM emissions compared to OE 2-stroke/ 4-stroke LPG/Petrol. Thus retro-fitment of 2-stroke 3-wheelers is not an effective control option.
		Ban on old commercial vehicles (10 year) in the city	High	Transport department - Bangalore	Short-term	Fiscal incentives/ subsidies for new vehicle buyers A plan should be devised for gradual phase out with due advance notice. Careful evaluation of socio-economic impact of banning required. In the long run, a ban/ higher tax on private vehicles (> 15 years) could be looked into.
		By-passing of trucks through the proposed peripheral ring road around Bangalore	High	Traffic Police, Transport department	Short-term	Has high potential in reducing the pollutant load in the city
		Progressive improvement of vehicular emissions norms (BS-V, BS-VI)	Low	MoRTH, MoPNG, Ministry of Heavy Industry and Public Enterprises, MoEF, Oil companies, Automobile manufacturers	Medium to Long term	Auto-fuel road map should be developed well in advance to plan the progressive improvement of emissions norms and corresponding fuel quality norms. Though the impact is low, its potential is high in the long term when gradually fleet renewal takes place.
		Installation of pollution control devices (DOC/DPF) in all pre-2010 diesel vehicles	High	Transport department	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction. Retro-fitment of DOC in BS-II buses and DPF in BS-III buses is technically feasible.
		Introduction of fuel efficiency standards	Low	BEE, Ministry of Power, Ministry of Heavy Industry and Public Enterprises, MoRTH, Automobile manufacturers	Medium	Impact is low since it is applied only to new vehicles registered after 2012. However, its potential is high in the long term when gradually fleet renewal takes place.
		Introduction of hybrid vehicles/ electric vehicles	Low - medium	Ministry of Finance, Ministry of Heavy Industry and Public Enterprises,	Short-Medium	Appropriate fiscal incentives need to provided; Electric vehicles would be especially effective in high pollution zones. Impact determined by the extent

				Automobile manufacturers, State government,		of switchover to hybrid/ electric vehicles.
		Effective Inspection and maintenance regime for vehicles	Medium	Transport Department, Traffic police	Short to Medium	Initial focus could be on commercial vehicles; Capacity development in terms of infrastructure for fully computerized testing/certification and training of personnel. Linkage of all PUC centres for better data capture.
		Alternative fuels such as ethanol, bio-diesel	Low	MNRE, MoRD, MoPNG, MoA, Oil companies,	ongoing	There are operational issues regarding availability and pricing that need to be sorted.
		Reduction in private vehicle usage/ ownership		Min. of Finance, State Government NGOs General public	Medium term	A pre-requisite for curbing the growth of private vehicles is the provision of an effective mass based transport system. Strategies such as costlier parking, higher excise duties/sales tax on private vehicles, car pooling would be helpful.
		Improve traffic flow	Medium	Traffic police, Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP),	Short	Synchronization of signals, one way roads, flyovers, widening of roads, removal of encroachments, staggering of office timings to reduce peak flow and congestion. Application of IT tools for traffic management (Intelligent transport system)
		Fuel adulteration	n.a	Govt. of India, Oil companies, Food and civil supplies department- Bangalore	Short	Re-assess subsidy on kerosene, strict vigilance and surveillance actions, better infrastructure in terms of testing laboratories
2	Road dust	-Construction of better quality roads -Regular maintenance and cleaning/sweeping of roads -Reduction in vehicular fleet and trips	n.a	Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP), NHAI	Short - Mediumterm	Effective enforcement of road quality norms is required. Landscaping/ greening of areas adjacent to roads
		Wall to wall paving for reduction of road dust	High	Bangalore Development Authority (BDA), Bruhat Bengaluru Mahanagara Palike (BBMP)	Short term	Interlocking tiles may be used so that water percolation takes place.
3	Industries	Fuel shift towards cleaner fuels	High	KSPCB, Directorate of Industries and Commerce, Industry associations, GAIL, Oil companies	Short-Medium term	Shift from solid fuels to liquid fuels (LSHS) and subsequently to gaseous fuels (CNG)
		Ban on any new air polluting industry in city limits	High	KSPCB, Department of Forest, Ecology and Environment, Department of Industries and Commerce, Karnataka Industrial Area Development Board	Short term	Industrial estates/zones may be developed well outside the city
		Strengthening of enforcement mechanism for pollution control	n.a	KSPCB, Industry associations,	Short term	This would ensure greater compliance with standards. In addition, cleaner technology options need to be promoted and appropriate incentives to be defined. Voluntary measures such as ISO certifications to be encouraged.

4	Power/ DG sets	No power cuts leading to zero usage of DG sets	High	Bangalore Electricity Supply Company, Karnataka Power Corporation Ltd.	Medium term	Adequate tie-ups need to be ensured
		Installation of pollution control devices (DOC/DPF) in DG sets	High	KSPCB, DG set manufacturers	Medium	Technical feasibility and implementation plan of this strategy needs to be carefully evaluated, though it has potential for emission load reduction
		Effective Inspection and maintenance regime for large DG sets	Medium	KSPCB, Chief Electrical inspectorate	Short to Medium	
5	Construction	Better enforcement of construction guidelines (which should reflect Green Building concepts)	High	KSPCB, SEAC (State expert appraisal committee), Bruhat Bengaluru Mahanagara Palike (BBMP),	Short term	
6	Other sectors	Integrated land-use development of Bangalore taking environmental factors into consideration	n.a.	Bangalore Metropolitan Region Development Authority, Bangalore Development Authority, Bruhat Bengaluru Mahanagara Palike (BBMP)	Medium term	Holistic development of the entire region including peripheral areas.
		Open burning/ Waste burning to be discouraged	n.a	Bruhat Bengaluru Mahanagara Palike (BBMP), KSPCB	Short term	Organic matter could be used for compost formation and methane gas generation
		Domestic sector – biomass burning to be reduced	Low	Food and civil supplies department, Oil companies	Medium	Rural areas should be encouraged to shift to cleaner fuels
		Virtual mobility- using ICT information and communication technology	n.a	Department of Information Technology& Biotechnology, Government of Karnataka;	Short-Medium term	Reduced number of trips.
		Strengthening of air quality monitoring mechanism in terms of number of stations as well as pollutants monitored. Capacity building of KSPCB staff.	n.a	KSPCB	Short	Good quality data is an important input in assessing the change in air quality and the impact of policy interventions. Continuous monitoring stations to be promoted.
		Environmental education and awareness activities	n.a	Education department, Schools/Colleges, CBOs, NGOs	Short	Also, sensitization programmes for policy makers.

* Impact is determined in terms of percent reduction in total emission load for PM_{10} for the study period upto 2017 subject to the assumptions listed in chapter 6 (High impact > 5% reduction; medium impact 1-5% reduction; low impact < 1% reduction; n.a = not quantified or not quantifiable). Time frame: Short (upto 2012), Medium (2012-2017)

Bibliography

ARAI.2007
Emission Factor development for Indian Vehicles
Automotive Research Association of India, Pune

BBMP. 2007
http://www.bmponline.org
last accessed, Dec 2007

BDA. 2007
Revised master plan – 2015, vision document Bangalore, vol 1&2
Bangalore, Bangalore Development Authority

BMRC.2007
http:// www.bmrc.co.in
last accessed, Dec 2007

CPCB.2000b
Transport Fuel Quality 2005
Central Pollution Control Board, New Delhi

CPCB. 2003
Spatial distribution of hourly mixing depth over Indian region.
PROGRAMME OBJECTIVE SERIES:PROBES/98/2002-03
Central Pollution Control Board, New Delhi

CPCB.2006
National air quality status 2004, National Ambient Air Quality Monitoring Series: NAAQMS/27/2006-2007, 131 pp.
Central Pollution Control Board, New Delhi

CPCB.2007
Non-Vehicular Emission Factors
Central Pollution Control Board, New Delhi

Henry, R.C., Lewis, C.W., Hopke, P.K. and Williamson, H.J.1984
Review of receptor model fundamentals.
Atmospheric Environment 18:1507-1515

IMD.1999
Climatological Tables of observations in India, 1951-1980, 5th Edition, Controller of Publication, 782 pp.
India Meteorological Department, New Delhi

b

JNURM. 2006
City development plan for Bangalore
Jawaharlal Nehru National Renewal Mission

NSSO.2001
Consumption of Some Important Commodities in India, 1999-2000, Report No. 461(55/1.0/4. 675 pp.
National Sample Survey Organisation, Ministry of Statistics & Programme Implementation, Government of India

Potential investment opportunities in Bangalore Urban District. ***Highlights of district development plan***, (Tiny and SSI Units)-2006-2011, pp 15-25

Potential investment opportunities in Bangalore Urban District. ***Highlights of district development plan***, (Medium and Large Industries)-2006-2011, pp 26-30

Reddy, M.S. and Venkataraman, C.2002
Inventory of Aerosol and Sulphur Dioxide Emissions from India: II – Biomass Combustion,
Atmospheric Environment, 36 (4), 699-712

Report of the Expert Committee on Auto Fuel Policy, August 2002, R.A. Mashelkar, 298 pp.
Ministry of Petroleum and Natural Gas, Govt. of India, New Delhi

RGCC.1991
Census of India 1991: Provisional population totals
Registrar General and Census Commissioner, India, New Delhi

RGCC.2001
Census of India 2001: Provisional population totals
Registrar General & Census Commissioner, India, New Delhi

SPECIATE 3.2
U.S. Environmental Protection Agency, NC

USEPA.1995
Compilation of air pollutant emissions factors AP 42, Office of air quality planning and standards , Office of air and radiation
United States Environmental Protection Agency, NC

USEPA.1995
User's Guide for the Industrial Source Complex (ISC3) Dispersion Models, Volume I and II (EPA-454/B-95-003 a & b)
United States Environmental Protection Agency, NC

USEPA. 2000
Greenhouse Gases From Small-Scale Combustion Devices In Developing Countries: Phase IIA, Household Stoves In India Prepared By National Risk Management Research Laboratory Research Triangle Park, Nc 27711
United States Environmental Protection Agency

USEPA. 2003
Compilation of Air Pollutant Emission Factors, AP 42, Fifth Edition, Volume I, Chapter 13: Miscellaneous Sources, Section 13.2.1 Paved Roads
United States Environmental Protection Agency
http://www.epa.gov/ttn/chief/ap42/ch13/index.html

USEPA.2004
Chemical mass balance – CMB8.2
Air Quality Modeling Group
U.S. Environmental Protection Agency, NC

Wark K and Warner C F. 1976
Air pollution:Its origin and control
New York: Harper and Row publishers Inc.

WHO.1993
Assessment of Sources of Air , Water and Land Pollution – A guide to rapid source inventory techniques and their use in formulating environmental control strategies Part I, Rapid Inventory Techniques in Environmental Pollution by Alexender P.Economopoulos
World Health Organisation, Geneva

Annexure – I Emission Factors for Area source

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
1	Fuel Oil Combustion	TSP = {9.19(S) + 3.22} * 0.120 SO_2 = 18.84S NOx = 6.6 CO = 0.6 CH_4 = 0.0336 TOC = 0.1248 NMTOC = 0.091 **(Unit: Kg/10^3 L)**	TSP May Be Considered As PM_{10}. TOC Is Total Organic Compound Including VOC. EPA-42: Table 1.3 – 1 And Table 1.3 – 3; S – Sulphur Content In Fuel (For 1% Sulphur S=1); Gm/Lit Oil, Fuel Oil Combustion, Normal Firing.
2	Natural Gas Combustion	TSP = 121.6 SO2 = 9.6 NOx = 1600 CO = 1344 CO2 =1,920,000 CH4 = 36.8 VOC =88 TOC = 176 NMTOC = 0.091 **(Unit: Kg/10^6 m^3)**	TSP May Be Considered As PM_{10}. http://www.epa.gov/ttn/chief/ap42/ch01/Final/C01s04.Pdf
3	Liquified Petroleum Gas Combustion	PM= 2.1 SO_2 = 0.4 **(Unit: Gm/Kg)** NO_x = 1.8 CO = 0.252 CO_2 =1716 CH4 = 0.024 VOC =88 TOC = 0.072 NMTOC = 0.091	Reddy And Venkatraman Http://Www.Epa.Gov/Ttn/Chief/Ap42/Ch01/Final/C01s05.Pdf (Commercial Boilers) we have used 3.6 Kg/T for NOx and 0.504 Kg/T for CO

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
		(Unit: Kg/10^6 M^3)	
6	Kerosene Combustion Domestic	PM=1.95 SO_2=4 **(Unit: G/Lit)** TSP=0.61 CO=62 NOx=2.5 CH_4=1 TNMOC=19 **(Unit: G/Kg)**	PM & SO_2 – Reddy And Venkatraman TSP May Be Considered As PM_{10}. USEPA 2000
8	Coal Combustion Boilers	**Stoker Fired Boilers** CO=0.3 CO_2=2840 Sox=19.5S Nox=4.5 PM= 5.0 **FBC Boilers** CO=0.3 CO_2=ND Sox=1.45 Nox=0.9 PM= **Pulverized Coal Boilers** Sox=19.5S Nox=9.0 PM= **(Unit: Kg/Mg)**	 S= Weight Percent Sulphur. AP-42 1.2-1,2,3 Use suitable EF pertinent to the city & 2x2 grid Alternative PM E.F. = 0.8A where A is ash content of fuel, weight %
9	Chulha (Dung, Wood)	PM=6.3 PM_{10}=5.04 SO_2= 0.48 **(Unit: G/Kg)** TSP=1.9 CO=31 NOx=1.4	Reddy And Venkatraman - (PM_{10}, SO_2, PM) TSP May Be Considered As PM_{10}. USEPA 2000 Use suitable EF pertinent to the city & 2x2 grid

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
		TNMOC=29.8 CH_4=3 **(Unit: G/Kg)**	
14	Kerosene Generators Domestic	Apply same EF as for item no. 6: domestic Kerosene combustions	
15	Diesel Industrial Generators Large Stationary Diesel And All Stationary Dual - Fuel Engines(Film Shooting)	PM_{10} = 1.33 E-03 CO_2= 0.69 CO=4.06 E-03 Sox= 1.24 E-03 NOx=0.0188 Aldehydes= 2.81 E-04 TOC Exhaust = 1.50 E-03 Evaporative =0 Crankcase = 2.68 E-03 Refueling =0 **(Unit: Kg/Kw-Hr)**	AP-42 (Table 3.3-1) EF For Uncontrolled Gasoline & Diesel Industrial Engines.
18	Secondary Metal Smelting (Lead) And Other Operations (Foundries)	**Lead** **Sweating** PM=16-35 Pb=4-8 SO_2=ND **Reverberatory Smelting** PM=162 Pb=32 SO_2=40 **Blast Smelting Cupola** PM=153 Pb=52 SO_2=27 **Kettle Refining** PM=0.02 Pb=0.006 SO_2=ND **Kettle Oxidation** PM=$\leq$ 20 Pb=ND SO_2=ND	AP-42 12.11 For Lead; 12.13 For Steel Foundries; 12.4 For Zinc

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
		Casting PM=0.02 Pb=0.007 SO_2=ND **(Unit: Kg/Mg)** **Steel Foundries** **Melting** Electric Arc TSP=6.5 (2 To 20) Nox=0.1 PM_{10}=ND Open Hearth TSP =5.5 (1 To 10) Nox=0.005 PM_{10}=ND Open Hearth Oxygen Lanced TSP =5.5 (1 To 10) Nox=0.005 PM_{10}=ND Electric Induction TSP =0.05 Nox=ND PM_{10}=0.045 Sand Grinding/Handling In Mold And Core Making TSP =ND Nox=NA PM_{10}=0.27 3.0 Core Ovens TSP =ND Nox=ND PM_{10}=1.11 0.45 Pouring And Casting TSP =ND Nox=NA PM_{10}=1.4 Casting Cleaning TSP =ND Nox=NA PM_{10}=0.85	

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
		Charge Handling TSP =ND Nox=NA PM_{10}=0.18 Casting Cooling TSP =ND Nox=NA PM_{10}=0.7 **(Unit: Kg/Mg)** **Zinc** Reverberatory Sweating Clean Metallic Scrap PM= Neglliible General Metallic Scrap PM=6.5 Residual Scrap PM=16 **(Unit: Mg/Mg Of Feed)** Rotary Sweating PM=5.5-12.5 Muffle Seating PM=5.4-16 Kettle Sweating Clean Metallic Scrap PM= Negligible General Metallic Scrap PM=5.5 Residual Scrap PM=12.5 Electric Resistance Sweating PM=<5 Sodium Carbonate Leaching Calcining PM=44.5 **(Unit: Kg/Mg Of Zinc Used)** **Kettle Pot**	

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
		PM=0.05 **(Unit: Mg/Mg)** <u>Crucible Melting</u> PM=ND <u>Reverberatory Melting</u> PM=ND <u>Electric Induction Melting</u> PM=ND <u>Alloying</u> PM=ND <u>Retort And Muffle Distillation</u> <u>Pouring</u> PM=0.2 – 0.4 <u>Casting</u> PM=0.1-0.2 <u>Muffle Distillation</u> PM=22.5 **(Unit: Kg/Mg Of Product)** <u>Graphite Rod Distillation</u> PM-Neg <u>Retort Distillation/Oxidation</u> PM=10-20 <u>Muffle Distillation/Oxidation</u> PM=10-20 <u>Retort Reduction</u> PM=23.5 <u>Galvanizing</u> PM=2.5 **(Unit: Kg/Mg Of Zinc Used)**	
19	Cast Iron Furnace	<u>Cupola</u> <u>Uncontrolled</u> PM=6.9 <u>Electric Arc Furnace</u> <u>Uncontrolled</u>	AP-42 (Table 12.10-2) Use suitable EF pertinent to the city & 2x2 grid

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
		PM=6.3 **(Unit: Kg Of Pollutant/Mg Of Grey Iron Produced)**	
21	Wood Residue Combustion In Boilers / Bakeries	PM_{10}=17.3 CO=126.3 Sox=0.2 Nox=1.3 CO_2=1700 Total VOC=114.5 **(Unit: Kg /Mg)**	*AP42 (Sec. 1.9, Pp. 1.10.4, Table 1.9.1)* Use suitable EF pertinent to the city & 2x2 grid
25	Cupolla Cast Iron	TSP=6.9 SO2=0.6S Nox=NA CO=73 VOC=NA Pb=0.32 **(Unit: Kg /Tons)**	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos
27	Manufacture Of Rubber Products / Plastics Small Scale	PM=17.5 Gases=8.5 **(Unit: Kg /Mg)**	AP-42 (Table 6.6.1-1) Use suitable EF pertinent to the city & 2x2 grid
30	Glass Manufacturing	TSP=0.7 SO_2=1.7 NO_X=3.1 CO=0.1 VOC=0.1 **(Unit: Kg /Ton)**	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos
31	Lead Oxide And Pigment Production	TSP=7 SO_2=NA NO_X= NA CO= NA VOC= NA Pb=7 **(Unit: Kg /Ton)**	WHO 1993, Rapid Techniques In Environmental Pollution Part 1 By Alexander P. Economopoulos

S. No. (as per list given by CPCB)	Source/Activity	Common Emission Factor	Reference/Remarks
32	Construction (Building)	TSP=1.2 **(Unit: Tons/Acre/ Month Of Activity)**	For Details Refer AP-42 Section 13.2.3.3 Use suitable EF pertinent to the city & 2x2 grid depending upon construction activity
33	Construction Roads (A) Aggregate Laying And (B) Asphalt	TSP=1.2 **(Unit: Tons/Acre/ Month Of Activity)**	For Details Refer AP-42 Section 13.2.3.3 Use suitable EF pertinent to the city & 2x2 grid depending upon construction activity
34	Construction Of Flyovers	TSP=1.2 **(Unit: Tons/Acre/ Month Of Activity)**	For Details Refer AP-42 Section 13.2.3.3 Use suitable EF pertinent to the city & 2x2 grid depending upon construction activity
37	Paved Roads	Refer Section 13.2.1.3 Of AP-42	AP 42 (13.2.1.3) Given equation has to be used and respective parameters shall vary for each city and/or grid

Appendix –I : Climatological Data for Bangalore (IMD)

जलवायवी सारणी
CLIMATOLOGICAL TABLE

स्टेशन : बंगलोर
STATION : Bangalore

अक्षांश LAT 12°58′ N देशांतर LONG 77°35′ E समुद्री तल माध्य से ऊँचाई HEIGHT ABOVE M. S. L. 921 मीटर METRES

1951 से 1980 तक के प्रेक्षणों पर आधारित
BASED ON OBSERVATIONS FROM 1951 TO 1980

माह MONTH		स्टेशन का सतह दाब STATION LEVEL PRESSURE (एच. पी. ए. hPa)	वायु तापमान AIR TEMPERATURE — माध्य MEAN: शुष्क बल्ब DRY BULB (डि.सें. °C)	नम बल्ब WET BULB (डि.सें. °C)	दैनिक अधिक तम DAILY MAX (डि.सें. °C)	दैनिक न्यून तम DAILY MIN (डि.सें. °C)	माह में उच्चतम HIGHEST IN THE MONTH (डि.सें. °C)	माह में निम्नतम LOWEST IN THE MONTH (डि.सें. °C)	चरम EXTREMES: उच्चतम HIGHEST (डि.सें. °C)	दिनांक और वर्ष DATE AND YEAR	निम्नतम LOWEST (डि.सें. °C)	दिनांक और वर्ष DATE AND YEAR	आर्द्रता HUMIDITY: सापेक्ष आर्द्रता RELATIVE HUMIDITY (प्रतिशत %)	वाष्प दाब VAPOUR PRESSURE (एच.पी.ए. hPa)	मेघ की मात्रा CLOUD AMOUNT: समस्त मेघ ALL CLOUDS (आकाश के अष्टमांश Oktas of sky)	निम्न मेघ LOW CLOUDS	वर्षा RAINFALL: मासिक योग MONTHLY TOTAL (मि.मि. mm)	वर्षा के दिनोंकी संख्या NO. OF RAINY DAYS	वर्षसहित सबसे नम महीने का योग TOTAL IN WETTEST MONTH WITH YEAR (मि.मि. mm)	वर्षसहित शुष्कतम महीने का योग TOTAL IN DRIEST MONTH WITH YEAR (मि.मि. mm)	24 घंटोंकी सबसे भारी वर्षा HEAVIEST FALL IN 24 HOURS (मि.मि. mm)	दिनांक और वर्ष DATE AND YEAR	माध्य पवन गति MEAN WIND SPEED (कि.मी. प्र. घं. Kmph)
जनवरी JAN	I	913.1	17.7	15.4	27.0	15.1	29.7	12.3	32.2	30 1925	7.8	13 1884	78	15.8	3.5	2.1	2.7	0.2	101.9 1908	0.0	65.8	16 1908	9.5
	II	910.0	24.9	16.4									40	12.5	2.7	1.1							
फरवरी FEB	I	912.4	19.7	16.0	29.6	16.6	32.3	13.5	34.5	23 1969	9.4	06 1884	68	15.5	2.6	1.2	7.2	0.5	89.9 1932	0.0	67.3	22 1901	9.2
	II	909.1	27.7	16.9									31	11.4	2.7	1.3							
मार्च MAR	I	911.7	22.8	18.0	32.4	19.2	34.6	15.6	37.2	30 1925	11.1	05 1884	63	17.2	1.7	0.6	4.4	0.4	71.9 1944	0.0	50.8	10 1911	8.5
	II	908.1	30.6	17.8									26	11.0	2.7	1.5							
अप्रैल APR	I	910.3	24.6	20.8	33.6	21.5	35.8	18.6	38.3	30 1931	14.4	26 1894	71	21.7	3.4	1.1	46.3	3.0	165.6 1929	1.0 1913	90.7	15 1939	7.5
	II	906.4	31.2	19.9									34	14.9	5.0	2.9							
मई MAY	I	908.4	23.9	20.9	32.7	21.2	35.8	18.6	38.9	22 1931	16.7	06 1945	77	22.6	5.0	2.0	119.6	7.0	287.1 1957	1.3 1891	153.9	06 1909	9.4
	II	905.0	29.8	21.3									48	19.0	5.8	3.3							
जून JUN	I	907.4	22.0	20.0	29.2	19.9	32.8	18.6	37.8	02 1926	16.7	22 @ 1967	84	22.0	6.6	4.2	80.8	6.4	218.9 1891	4.6 1945	101.6	16 1891	13.6
	II	904.9	26.6	21.0									61	20.7	6.6	3.9							
जुलाई JUL	I	907.3	20.9	19.9	27.5	19.5	30.7	18.3	33.3	01 1914	16.1	31 1882	88	21.7	7.4	5.5	110.2	8.3	350.3 1949	5.6 1881	111.4	30 1964	13.8
	II	905.0	25.1	20.6									67	21.0	7.1	4.5							
अगस्त AUG	I	907.9	20.7	19.5	27.4	19.4	30.0	18.3	33.3	06 1899	14.4	04 1882	89	21.9	7.3	5.6	137.0	10.0	357.1 1965	20.6 1885	162.1	27 1890	12.3
	II	905.3	25.1	20.6									67	21.1	7.0	4.4							
सितम्बर SEP	I	909.1	21.0	19.5	28.0	19.3	30.6	17.7	33.3	16 1951	15.0	25 1883	87	21.6	6.5	4.6	194.8	9.3	490.7 1897	8.4 1934	136.0	13 1979	9.5
	II	905.8	25.7	20.6									64	20.5	6.5	3.8							
अक्तूबर OCT	I	910.4	21.4	19.6	27.7	19.1	30.0	16.6	32.2	04 @ 1976	13.2	31 1974	84	21.4	5.7	3.3	180.4	9.0	522.3 1956	3.2 1965	116.8	19 1935	7.1
	II	907.4	24.8	20.1									66	20.2	6.2	3.4							
नवम्बर NOV	I	911.9	20.3	17.9	26.6	17.2	28.9	13.7	31.1	20 1923	9.6	15 1967	79	18.8	4.6	2.8	64.5	4.0	252.2 1916	0.0	114.5	09 1916	7.7
	II	909.2	23.7	18.5									61	17.6	5.2	2.8							
दिसम्बर DEC	I	913.0	18.3	16.2	25.9	15.6	28.4	12.4	31.1	18 1926	8.9	29 1883	80	16.8	4.2	2.6	22.1	1.7	119.2 1969	0.0	68.0	15 1969	9.0
	II	910.2	23.3	17.1									53	15.0	4.1	1.9							
वार्षिक योग या माध्य ANNUAL TOTAL OR MEAN	I	910.2	21.1	18.6	29.0	18.6	36.2	11.5	38.9		7.8		79	19.8	4.9	3.0	970.0	59.8	1348.5	544.3	162.1		9.8
	II	907.2	26.5	19.2									52	17.1	5.1	2.9			1916	1913			
वर्षोंकी सं. NUMBER OF YEARS	I	30	30	30	30	30	30	30	100		100		30	30	30	22	30	30	100	100	100		30
	II	30	30	30									30	30	30	22							

जलवायवी सारणी
CLIMATOLOGICAL TABLE

स्टेशन : बंगलोर
STATION : **Bangalore**

माह / MONTH		मौसम परिघटना के साथ दिनों की संख्या / WEATHER PHENOMENA — No. OF DAYS WITH: वर्षण 0.3 मि.मि. या अधिक / PPT 0.3mm or more	ओले / HAIL	गर्जन / THUNDER	कुहरा / FOG	धूल भरी आंधी / DUST STORM	चंड वात / SQUALL	पवन की गति के साथ दिनों की संख्या (कि. मी. प्र. घं.) / WIND — No. OF DAYS WITH WIND SPEED (Km. p. h.): 62 या अधिक / 62 or more	20-61	1-19	0
जनवरी JAN	I	0.5	0.0	0.0	2.5	0.0	0.0	0	0	29	2
	II							0	0	28	3
फरवरी FEB	I	0.9	0.0	0.3	0.7	0.0	0.0	0	0	26	2
	II							0	0	26	2
मार्च MAR	I	0.8	0.0	1.1	0.2	0.0	0.2	0	0	28	3
	II							0	1	28	2
अप्रैल APR	I	5.0	0.1	6.7	0.1	0.0	1.4	0	0	26	4
	II							0	0	27	3
मई MAY	I	10.3	0.2	10.6	0.0	0.0	2.5	0	0	29	2
	II							0	1	27	3
जून JUN	I	11.7	0.0	4.0	0.0	0.0	1.5	0	2	28	0
	II							0	6	24	0
जुलाई JUL	I	16.8	0.0	2.3	0.1	0.0	0.8	0	2	29	0
	II							0	7	24	0
अगस्त AUG	I	16.4	0.0	2.4	0.2	0.0	0.6	0	1	29	1
	II							0	3	27	1
सितम्बर SEP	I	13.6	0.0	5.9	0.3	0.0	0.1	0	1	28	1
	II							0	1	27	2
अक्तूबर OCT	I	12.7	0.0	5.9	1.2	0.0	0.2	0	0	27	4
	II							0	0	27	4
नवम्बर NOV	I	7.2	0.0	1.0	1.1	0.0	0.1	0	0	28	2
	II							0	0	27	3
दिसम्बर DEC	I	3.3	0.0	0.1	1.7	0.0	0.0	0	0	30	1
	II							0	0	29	2
वार्षिक योग या माध्य ANNUAL TOTAL OR MEAN	I	99.2	0.3	40.3	8.1	0.0	7.4	0	6	337	22
	II							0	19	321	25
वर्षों की सं. NUMBER OF YEARS	I	27						24			
	II							24			

माह / MONTH		पवन की दिशा के दिनों की संख्या का प्रतिशत / WIND — PERCENTAGE No. OF DAYS WIND FROM: उ / N	उपू / NE	पू / E	दपू / SE	द / S	दप / SW	प / W	उप / NW	शांत / CALM
जनवरी JAN	I	0	8	66	18	1	0	0	0	7
	II	1	12	59	17	1	1	1	0	8
फरवरी FEB	I	0	5	47	26	4	6	3	1	8
	II	1	11	54	21	1	2	1	1	8
मार्च MAR	I	0	1	24	26	9	19	9	1	11
	II	2	11	46	27	2	3	2	2	5
अप्रैल APR	I	1	1	6	12	10	29	22	6	13
	II	5	10	36	27	2	4	4	4	8
मई MAY	I	1	1	1	3	2	20	52	14	6
	II	7	7	9	7	3	13	26	21	7
जून JUN	I	0	0	0	0	0	33	59	8	0
	II	1	1	0	0	1	26	59	12	0
जुलाई JUL	I	0	0	0	0	0	34	60	5	1
	II	0	0	0	0	1	25	62	9	3
अगस्त AUG	I	0	0	0	0	0	25	64	8	3
	II	1	0	1	0	1	16	61	18	2
सितम्बर SEP	I	2	1	1	2	1	17	53	18	5
	II	4	2	3	3	1	17	40	23	7
अक्तूबर OCT	I	2	8	24	7	2	12	23	10	12
	II	8	17	19	7	2	8	14	13	12
नवम्बर NOV	I	3	26	46	9	0	1	2	3	10
	II	7	28	38	11	1	1	2	4	8
दिसम्बर DEC	I	1	25	61	8	0	0	0	0	5
	II	2	24	56	10	0	1	0	0	7
वार्षिक योग या माध्य ANNUAL TOTAL OR MEAN	I	1	6	23	9	2	16	29	6	8
	II	3	10	27	11	1	10	23	9	6
वर्षों की सं. NUMBER OF YEARS	I	30								
	II	30								

माह / MONTH		मेघ मात्रा (सभी मेघ) सहित दिनों की संख्या - अष्टांश / CLOUD — No. OF DAYS WITH CLOUD AMOUNT (ALL CLOUDS) OKTAS: 0	से-2 / T-2	3-5	6-7	8	निम्न स्तरी मेघ मात्रा सहित दिनों की संख्या - अष्टांश / No. OF DAYS WITH LOW CLOUD AMOUNT OKTAS: 0	से-2 / T-2	3-5	6-7	8	कुहरा / FOG 8
जनवरी JAN	I	8	6	8	6	3	16	4	5	4	2	0
	II	9	8	8	5	1	18	6	6	1	0	0
फरवरी FEB	I	9	6	7	5	1	19	4	3	2	0	0
	II	8	7	9	4	0	15	6	6	1	0	0
मार्च MAR	I	15	7	5	3	1	25	3	2	1	0	0
	II	10	6	9	5	1	15	7	8	1	0	0
अप्रैल APR	I	4	7	10	7	2	18	6	5	1	0	0
	II	2	4	9	12	3	4	9	14	3	0	0
मई MAY	I	1	5	9	11	5	13	7	7	3	1	0
	II	1	2	8	13	7	2	8	16	4	1	0
जून JUN	I	0	1	4	14	11	2	4	12	8	4	0
	II	0	0	5	14	11	1	5	18	5	1	0
जुलाई JUL	I	0	0	1	12	18	0	2	11	11	7	0
	II	0	0	2	14	15	0	3	18	8	2	0
अगस्त AUG	I	1	0	2	11	17	0	2	10	12	7	0
	II	0	0	4	15	12	0	4	18	8	1	0
सितम्बर SEP	I	0	1	5	12	12	2	4	11	8	5	0
	II	0	1	4	16	9	1	6	17	5	1	0
अक्तूबर OCT	I	1	3	6	12	9	7	5	10	6	3	0
	II	0	2	6	14	9	3	8	14	5	1	0
नवम्बर NOV	I	3	6	7	9	5	12	5	6	5	2	0
	II	1	4	8	11	6	8	8	10	3	1	0
दिसम्बर DEC	I	3	7	8	8	5	14	5	5	5	2	0
	II	4	7	8	8	4	12	8	8	2	1	0
वार्षिक योग या माध्य ANNUAL TOTAL OR MEAN	I	45	49	72	110	89	128	51	87	66	33	0
	II	35	41	80	131	78	79	78	153	46	9	0
वर्षों की सं. NUMBER OF YEARS	I	28					28					
	II	28					28					

माह / MONTH		दृश्यता सहित दिनों की संख्या / VISIBILITY — No. OF DAYS WITH VISIBILITY: 1 कि.मी. तक / UP TO 1Km	1-4 कि.मी. / 1-4 Kms	4-10 कि.मी. / 4-10 Kms	10-20 कि.मी. / 10-20 Kms	20 कि.मी. से अधिक / OVER 20 Kms
जनवरी JAN	I	0.7	2.2	8.5	12.4	7.2
	II	0.0	0.0	0.3	4.2	26.5
फरवरी FEB	I	0.0	1.2	8.3	12.1	6.4
	II	0.0	0.0	0.2	4.1	23.7
मार्च MAR	I	0.0	2.8	8.8	8.9	10.5
	II	0.0	0.0	0.7	6.3	24.0
अप्रैल APR	I	0.0	0.4	8.0	10.3	11.3
	II	0.0	0.2	1.2	7.3	21.3
मई MAY	I	0.0	0.4	5.7	13.5	11.4
	II	0.0	0.1	1.8	9.9	19.2
जून JUN	I	0.0	0.4	6.4	15.0	8.2
	II	0.0	0.1	1.1	11.4	17.4
जुलाई JUL	I	0.0	0.7	7.5	18.5	4.3
	II	0.0	0.4	2.1	14.3	14.2
अगस्त AUG	I	0.0	1.0	7.6	18.9	3.5
	II	0.0	0.2	2.5	13.5	14.8
सितम्बर SEP	I	0.0	0.8	7.2	16.0	6.0
	II	0.0	0.3	1.4	11.3	17.0
अक्तूबर OCT	I	0.1	1.5	6.9	15.0	7.5
	II	0.0	0.1	1.9	11.0	18.0
नवम्बर NOV	I	0.1	1.6	7.0	15.4	5.9
	II	0.0	0.2	1.0	11.1	17.7
दिसम्बर DEC	I	0.1	1.7	7.8	16.4	5.0
	II	0.0	0.1	0.4	9.5	21.0
वार्षिक योग या माध्य ANNUAL TOTAL OR MEAN	I	1.0	14.7	89.7	172.4	87.2
	II	0.0	1.7.	14.6	113.9	234.8
वर्षों की सं. NUMBER OF YEARS	I	28				
	II	28				