Draft Report On

AIR QUALITY MONITORING, EMISSION INVENTORY AND SOURCE APPORTIONMENT STUDIES FOR TEN CITIES IN THE STATE OF MAHARASHTRA

(PUNE CITY)

for

Maharashtra pollution Control Board

By

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Introduction

1.1 Preamble

Pune city is an important urban center in Maharashtra and a rapidly growing metropolis of the country. The rapid growth of the city has transformed from its character as Pensioner's city to Educational - Administrative Center and now to a bustling economic center. The city is famous as the Oxford of the East and the cultural capital of Maharashtra and has now been recognized as the information technology hub and education hub of the country. Pune is also one of the most renowned places among tourists coming to Maharashtra. The educational institutions, presence of a number of industries and branches of virtually every array have made Pune a prosperous city. The Pune Metropolitan Area (PMA) consists of Pune Municipal Corporation (PMC), the Pimpiri-Chinchwad Municipal Corporation (PCMC), Cantonment Boards of Pune and Khadki and some villages. The Government of India has selected Pune, a metropolis, as a "Category B" city.

Pune is situated on Deccan Plateau. It lays on the leeward side of the Sahyadri i.e. the Western Ghats and is hardly 50 Km from the crest of the ghat country. It is 100 Km east from the Konkan the west Coast. City is situated in Latitude of 18.5204° N, 73.8567° E, height of 560 m above the sea level. The highest point within the city is the Vetal hill (800 m) whereas the highest point of the urban area is Sinhagad Fort (1400 m). The height above the sea level and the leeward location relating to Western Ghats have made city climate moderate and salubrious.

With the addition of 23 villages in 2001; the city is spread over an area of 243.84 Sq.Km with a total population of 3,115,431 as per 2011 census. Out of the total area, 36.56% is residential area, 1.70% is commercial area, 5% industrial and public and semi public utility covers 12%. Transport sectors takes 15.90%; recreational area is 9.20% and natural geographical portion i.e. reserved forest & agricultural is 1.70%, water bodies comes around 8.70% and hills and slopes covers 9%. The city is bounded by Thane district to the north-west, Raigad district to the west, Satara district to the south, Solapur district to the south-east and Ahmednagar district to the north and north-east.

Pune has a tropical wet and dry climate, with three distinct seasons- summer, rains and mild winter. Pune has an average temperatures ranging between 20°C to 30°C. Typical summer months are from March to May, with maximum temperatures ranging from 35°C to 38°C. The monsoon lasts from June to October, with moderate temperatures ranging from 25°C to 27°C. Mild winter begins in November; the daytime temperature hovers around 29°C while night temperature is below 13°C for most of December and January, often dropping to 5°C to 6°C. The city receives an annual rainfall of 722 mm (28.4 inches) between June and September as the result of southwest monsoon. July is the wettest month of the year. Linking with this fast urban growth and increasing population from 4.8 Lakhs in 1951 to 3.1 million in 2011, there is grave concern for the issue of environmental degradation in which the growth of the city is linked, increasing urban activities thereby; a sustainable need for improvements in urban infrastructure is expected.

Pune city is the divisional headquarter of Western Maharashtra. Administratively, Pune District is divided into 14 Taluka, 13 Panchayat Samitis (Blocks), and 2 Municipal Corporations, 11 Municipal Councils, 3 Cantonment Boards and 1,844 villages as given below Pune city is divided into 4 main zones and further sub-divided into 14 administrative wards as in **Figure 1.1**. Pune city administration of 14 wards is further divided into 76 'prabhags'.

ZONE 1		ZONE 3	
1	Aundh	8	Bhavani Peth
2	Ghole Road	9	Kasba-Vishram
3	Kothrud (Karve Road)	10	Sahakarnagar
4	Warje Karve Road	11	Tilak Road
ZONE 2		**ZONE 4**	
5	Dhole Patil Road	12	Bibvewadi
6	Nagar Road	13	Dhankawadi
7	Sangamwadi	14	Hadapsar

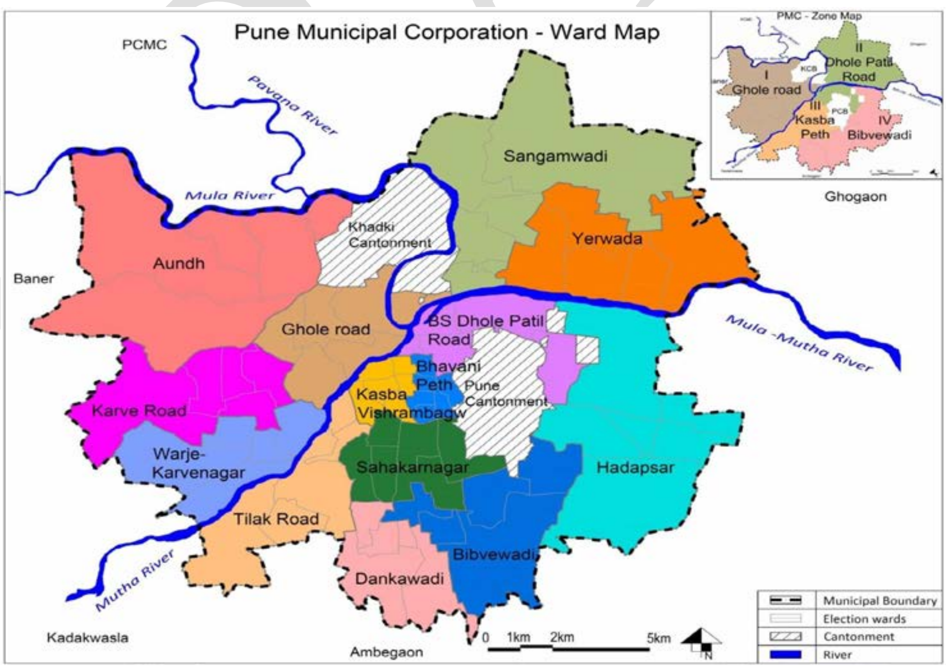


Figure 1.1 : Pune City Map with Administrative Wards

The Pune Municipal Corporation is responsible for administration and managing planned development in Pune city. The PMC, however, has been unable to meet forecasted demands for housing, commercial and industrial space, resulting in large scale unauthorized development, and areas with non- conforming land uses.

Population

The average decadal population growth rate in past 6 decades is 36.54%. Rapid growth of the city is mainly attributed to industrialization of PMC /PCMC after 1960 and expansion of information technology (IT) industry in the last decade. The population density over the years has increased manifold from 3,907 persons per Sq.Km in 1951 to 12,777 persons per Sq.Km as per 2011 census. According to CDP report of Pune, the calculated projected population for Pune City will be 8.59 million for the years 2041. Wardwise population and density with slum population is given in **Table 1.1**. The decadal growth of the Pune city is presented in **Figure 1.2**.

Table 1.1 : Wardwise Population Distribution of Pune City (2011)

Sl.	Wards	Area of the Ward (Ha.)	Ward Wise Population	Density-2011 (persons/Hectare)	Area under slum (Ha.)	Population of Slum
1	Aundh	4075	180264	44	27.3	41475
2	Ghole Road	1275	171756	135	44.9	84405
3	Kothrud	1626	209046	129	47.5	81045
4	Warje, Karve Nagar	1521	232725	153	43.3	52245
5	Dhole Patil Road	1464	155307	106	51.2	72040
6	Sangam Wadi	2935	261307	89	85.9	116390
7	Yerwada (Nagar Rd)	2910	238434	82	20.4	29775
8	Bhawani Peth	290	191787	661	29.4	60615
9	Kasba Vishrambaug	500	222684	445	49.4	8880
10	Sahakar Nagar	920	203321	221	33.4	70900
11	Tilak Road	1471	240740	164	54.22	83595
12	Bibvewadi	1835	295667	161	7.8	15725
13	Dhanakawadi	1084	236621	218	2.3	5260
14	Hadapsar	2478	280215	113	71.9	84465

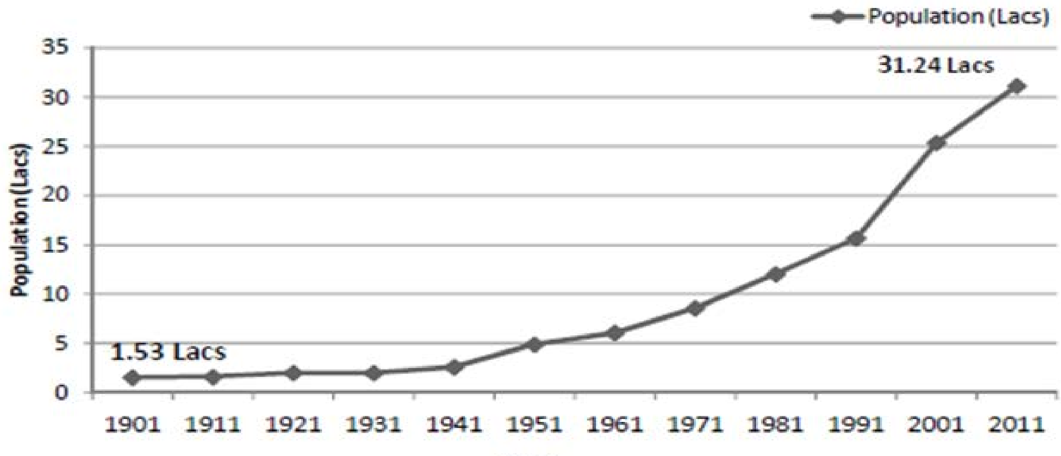
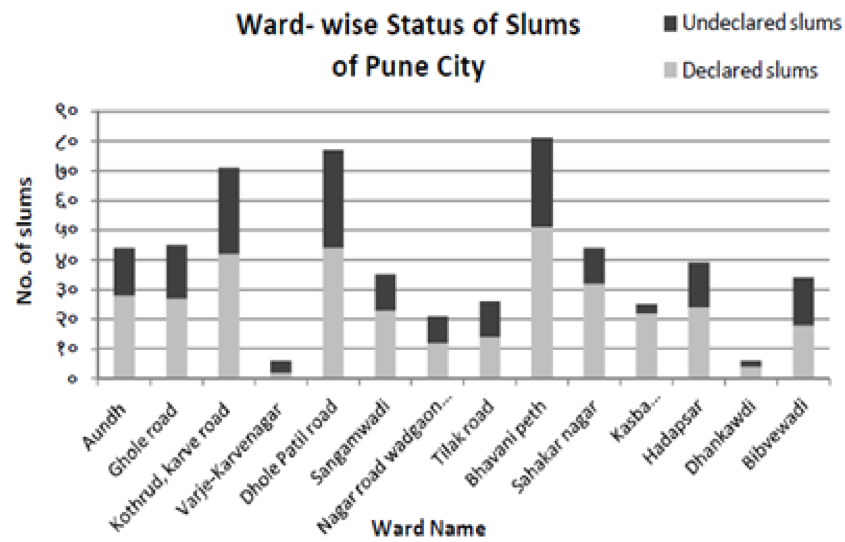


Figure 1.2 : Decadal Growth of Population in Pune City from 1901 to 2011

Predominantly, the wards forming the locus of the city viz. Kasba Vishram Bagh and Bhavani Peth wards comprising the highest population densities that is 445 and 661 respectively, this overcrowding is the consequence of being the old historic city with specialized and intense trade and commerce activities being taken up; the overcrowding indicated by the densities call for decongestion of these areas. The high density is the function of land prices and ease of accessibility to work place and availability of basic services. Population density of Karve road is high due to overcrowding with more than 100 housing projects. Over the decade the population of Warje karve road has increased to almost double, which is mainly due to the increase in residential projects; followed by wards to the eastern side i.e. Hadapsar, BS Dhole Patil Road and Yerwada which is mainly due to the growth of IT industry in this direction.

Substantial growth of the population is noticed from 2001 to 2011 due to urbanization and migrations of people for Jobs so as residential blocks are increased. The migrated population for Pune city has increased from 3.7 Lakhs in 2001 to 6.6 Lakhs migrants in 2011 (the projected in-migration of 2011 as per the Gokhale Demographic Study) accounting to 14% and 21% of the total population. Currently in Pune, additional construction of upto 40% of the plot area is allowed through purchase of TDR and a further 20% is allowed through purchase of slum TDR.

With regards to slums, the City Sanitation plan (CSP 2012, Pune) gives the total number as 564 with 353 declared or notified and 211 undeclared or not notified the slum population in Pune touched a figure of 12,59,216. The total area occupied by the slums in Pune is approx 660.63 hectares. Out of 564 slums, 124 slums are located on non- private land (21.99%) and 440 slums are located on the Private Land (78.01%). Density in slums is approximately 2,399 persons per hectare which is too high. At present the Sangam Wadi shows the maximum percentage of slum population i.e. 14% of the total slum population in Pune city followed by Ghole Road, Kothrud, Tilak Road and Hadapsar areas amongst the all wards.



1.2. Air Quality of Pune City

In Pune district, MPCB is carrying out monitoring at 5 different locations, 3 under NAMP, 2 under SAMP viz. Karve Road (Residential), Pimpari Chichwad, Nalstop (Rural & Other Areas), Bhosari (Industrial) and Swarget (Residential). The annual averages of criteria pollutants with respect to NAAQM Standards are presented in **Figure 1.3 (a to c)**.

(A)

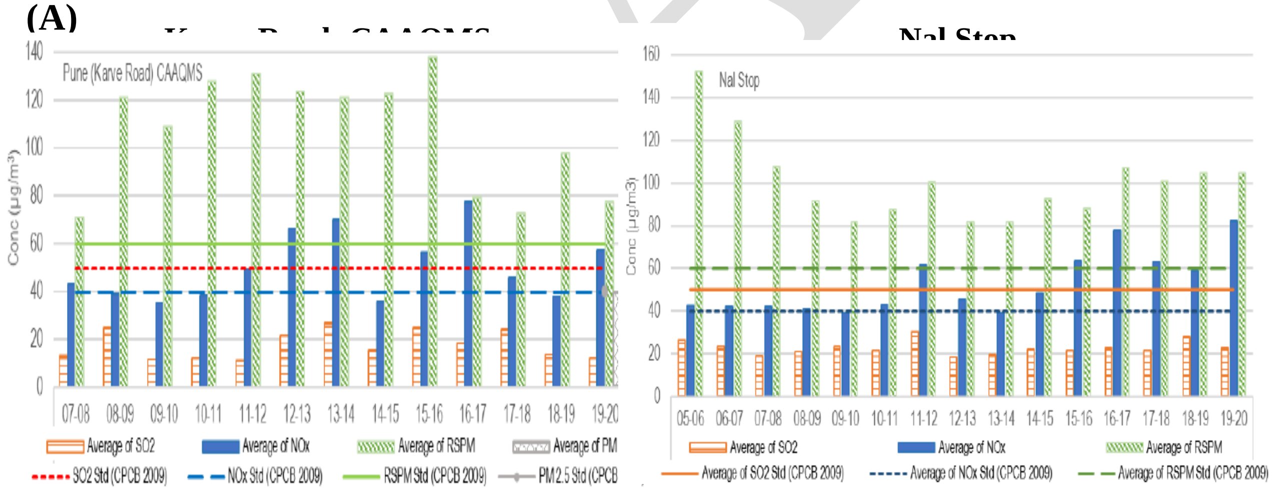
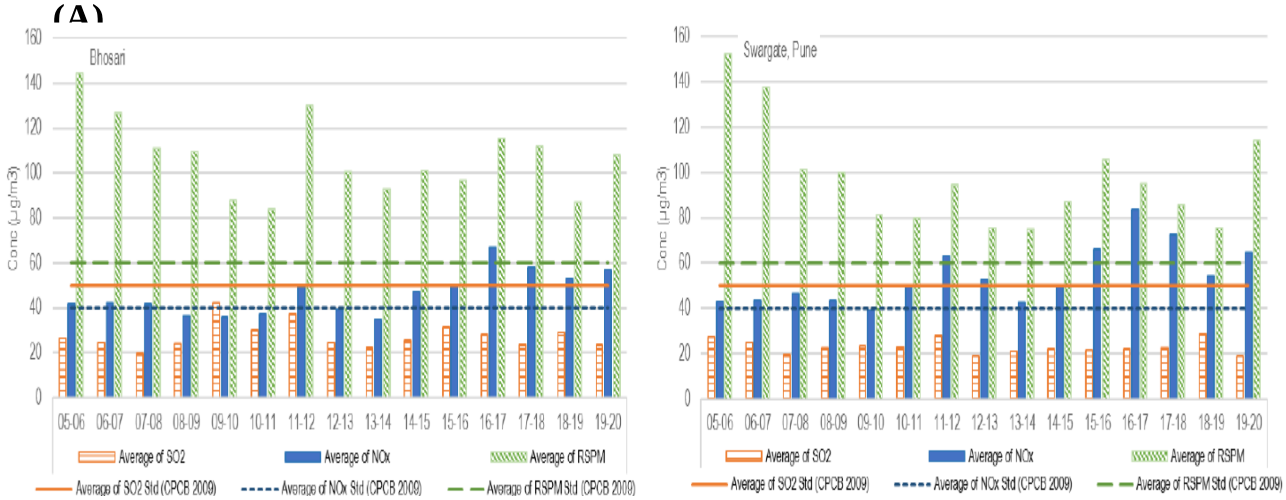


Figure 1.3 : a) The Annual Average Concentrations for Criteria Pollutants of Pune City (2007-2020)

b) Monthly Variation Trends for SOx, NOx and PM_{10} (2018)

(A)



(B)

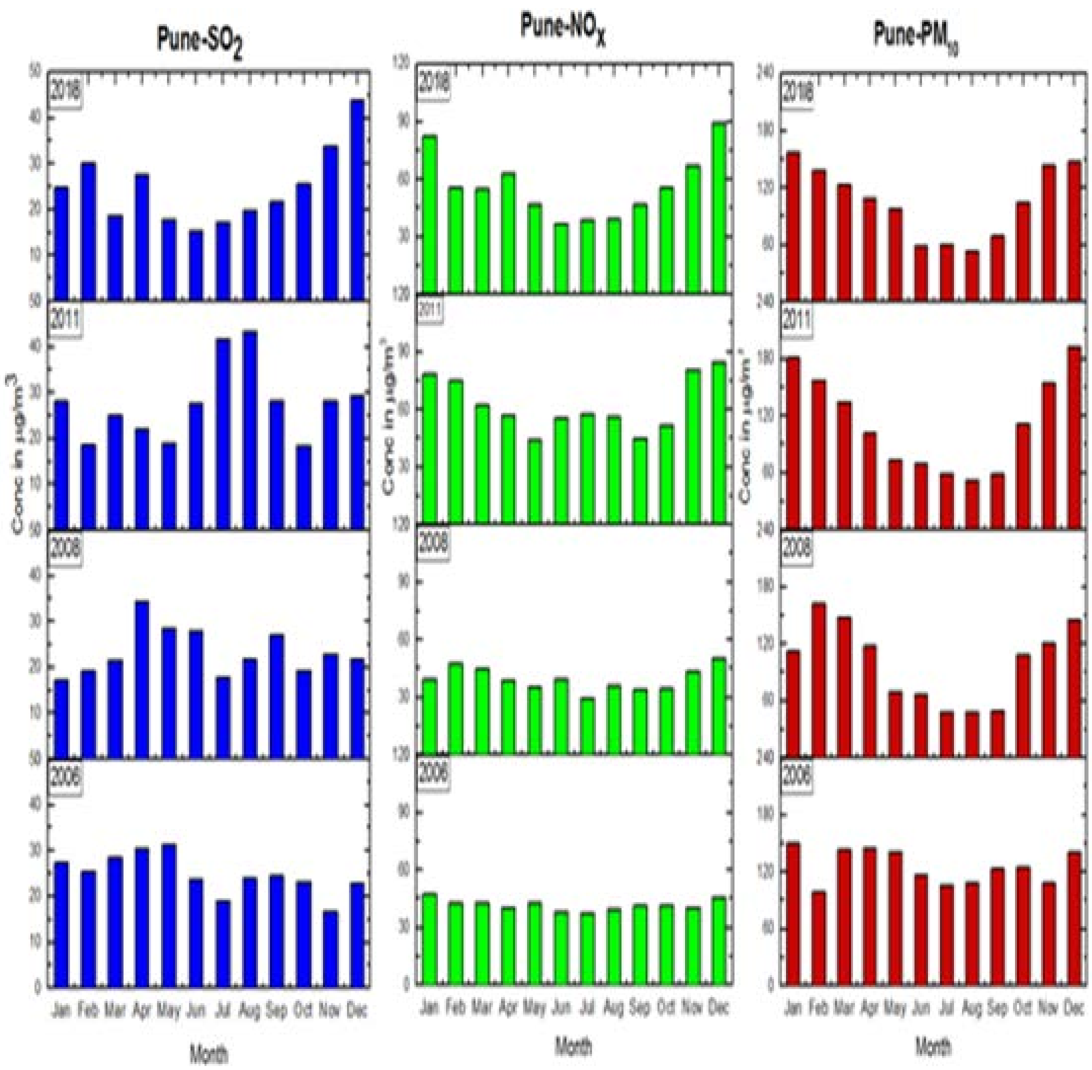


Figure 1.3 : (Contd..)

a) The Annual Average Concentrations for Criteria Pollutants of Pune City (2007-2020)

b) Monthly Variation Trends for SOx, NOx and PM_{10} (2018)

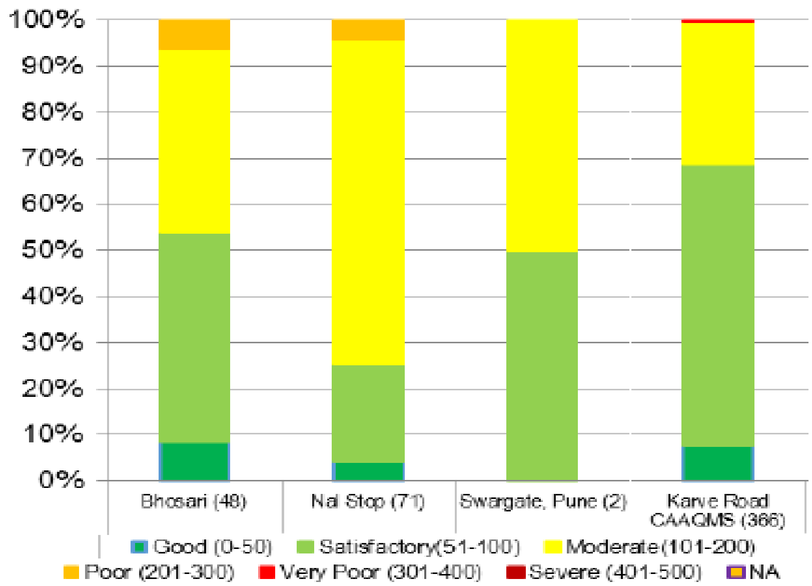


Figure 1.3 c) : Percentage occurrence for classes of AQI across Pune : 2019-20

The study undertaken by MPCB and TERI -'Air Quality Status of Maharashtra' of 2019-2020 shows the trend of air quality parameters from 2007 to 2020

- At Pune Bhosari, RSPM exceeded the annual CPCB standards in all the years; the maximum concentration of 144 µg/m^3 was reported in 2005-06. In other years it ranged between 84 to 144 µg/m^3. AQI varied between Unhealthy to Very Unhealthy during winter, while during monsoon it was good to moderate. The NOx annual concentration is also exceeding the standards from 2014 onwards (50 -60 µg/m^3).
- At Karve Road, RSPM and NO_2 were reported high during 2012-13. The annual concentration of RSPM was ranging from 77 to 138 µg/m^3 and NO_2 was 35 to 77 µg/m^3 with percentage exceedance of 80 to 90% for both the pollutants. AQI was good or moderate during monsoon and in winter it varied between unhealthy for sensitive group to unhealthy.
- At Nal Stop, annual RSPM concentrations exceeded (88 to 152 µg/m^3) the standard for all the years, and for NO_2 concentration increased upto 60 to 80 µg/m^3 from 2015 onwards. The annual exceedance is about 60 to 80% for RSPM and 30 to 87% for NO_2. Normally AQI varied between moderate to Unhealthy for Sensitive Group.
- At Swargate, annual concentration of RSPM ranging from 75 to 152 µg/m^3. AQI for Swargate was reported to be USG to unhealthy during winter, whereas in other months it was good to moderate. NOx annual concentration is increasing from 2015 onwards (75 to 152 µg/m^3).

- Comparison of four year data at Pimpri Chinchwad shows increase in pollution for all the pollutants. The annual concentration of RSPM was 86 to 127 µg/m^3 and for NO_2 it was 40 to 68 µg/m^3. AQI varied between unhealthy for sensitive group to unhealthy and at one or two months during winter it was very unhealthy.
- The overall low concentration of SO_2 is observed at Pune city. Overall air quality in Pune city moves around Unhealthy to Unhealthy for sensitive group. Average AQI represent around 101 to 200 as moderately polluted for Pune City.

The 'Air Quality Monitoring and Emission Source Apportionment' study for city of Pune conducted by Automotive Research Association of India for MoEF and Central Pollution Control Board (CPCB) during 2010 says that SPM was found to exceed the standards (200 µg/m^3 daily averages for residential area) for almost all days at all sites in winter season. At background site 35% of times the PM_{10} concentration exceeded daily average limit value for residential area. While at residential site, exceedence observed was more than 55% of values out of these, 25% of daily average values exceeded 200 µg/m^3. At Kerbside site, 80% times daily average values were exceeding 200 µg/m^3 out of which 35% times they were exceeding 250 µg/m^3. At industrial site, 90% times the daily average values were exceeding 150 µg/m^3 (24 hrly limit for industrial site). For 20% times PM_{10} concentration was exceeding 300 µg/m^3.

NOx was not found to exceed except at kerbside sites in winter season, which is restricted to 50% time which were found to be below 100 µg/m^3. SO_2 was found to be very well below the limits (80 µg/m^3 -24 hrly daily average for residential) at all sites including Industrial location (120 µg/m^3 - 24 hrly daily average for industrial). At industrial site, however, 20% values were between 80 and 105 µg/m^3 8 hrly average concentration of CO was found to exceed the limit (2000 µg/m^3- 8 hrly average) at kerbside site during summer and winter. 1 hrly average CO concentration were found to exceed standards (4000 µg/m^3) during morning peak (9 am to 1 pm) and evening peak (7 pm to 10 pm).

1.3 Objective of the City

CPCB has listed cities in India in which the RSPM levels are non-complaint with the NAAQS and has directed SPCBs to develop action plans and implement these to control air pollution in these cities. Seventeen such cities have been identified for the state of Maharashtra - Akola, Amaravati, Aurangabad, Badlapur, Chandrapur, Kolhapur, Mumbai, Nagpur, Nashik, Navi Mumbai, Pune, Sangli, Solapur and Ulhasnagar.

The main objectives of the projects are :

- To measure baseline air pollutants (Particulate Matter) in different parts of the city which include “hot spots” and kerbside locations.
- To develop emissions inventory various pollutants in the city.
- To conduct source apportionment study of PM.
- Suggest action plan based on various options delineated in the Six City Study of MoEF-CC or any relevant workable options. To prioritize the source categories for evolving city-specific air pollution management strategies/plan.
- To assess the impact of sources on ambient air quality under different management/ interventions/control options and draw a roadmap of short and long term measures as a part of action plan suggested

Among all the criteria air pollutants, particulate matter has emerged as the most critical pollutant in almost all urban areas of the country. Thus the main focus of this study was on characterization and source apportionment of particulate matter.

1.4 Highlights of Previous Study

In past various studies are conducted by different organization to identified the emission load of criteria pollutants in the Pune city. One of the recent studies in 2010 conducted by Central Pollution Control Board (CPCB) and Ministry of Environment and Forests to delineate the status of Particulate Matter Level and to investigate their sources in 6 cites in India, Pune is one them. The study is the outcome of the Auto Fuel Policy document of Government of India recommended for carrying out source apportionment studies to fill the knowledge gap. The findings of the report indicate that total PM emission load (32 T/day). Highest pollution loads of PM was observed at the central part of the city with major commercial activities and high population and road densities. Road dust emerges as the highest contributor towards PM in the city (61%). Prominent area sources other than road dust are construction and Brick Klins (4.5%), domestic and slum fuel usage (including solid fuel burning) (7.5%) and hotels and bakeries (3%). Vehicular emissions contribute to 18% of PM with more than 40% contribution is from 2, 3 wheelers and cars. The high contribution from these vehicles is due to high number of vehicles. (65% -2 Wheelers, 13%- auto rickshaws and 15% cars). Industrial contribution to PM in the city is limited to 1.25% due to confined industrial areas within the city and very low numbers of air polluting industries.

For NOx emissions (41.4 T/day), major contribution is from vehicles (95%). The contribution from industries is limited (2%) due to confined industrial area within the city limits. Domestic and commercial fuel burning for cooking contribute to balance 3%.

The average values of PM_{10} in Pune City at five sites ranged between 94- 68 µg/m and 45-88 µg/m for $PM_{2.5}$ respectively. PM_{10} and $PM_{2.5}$ mass standards are exceeding, indicating that particulates are of serious concern. $PM_{2.5}$ /PM_{10} ratio's shows a mixed trend of fine and coarse particulate dominance. Chemical composition shows abundance of organic matter followed by secondary aerosols and crustal matter.

The chemical speciation of the PM_{10} showed that contribution of earth-crust metals like Silicon, Sodium, Aluminum and Iron is about 40 % in PM_{10} during all seasons indicates re-suspension of soil dust as a major source. Sulphate, Nitrate and Chloride ions were found to contribute major portion among anions. Ammonium and Calcium with Sodium and Potassium were the major contributors to the cations. Presences of higher amount of sulphate and nitrate ions with ammonium ions indicate formation of secondary particles.

$PM_{2.5}$ mass was found to contribute about 35% of the PM_{10}, at all the sites during all the season. Crustal elements are found to comparatively higher in PM_{10} than in $PM_{2.5}$ which indicates major portion of the PM is coming from resuspended dust. The average EC/OC ratio at all the sites was observed to be more than 0.35 during all the seasons of monitoring. At both the Kerbside sites COEP and Hadapsar, average EC/OC ratio was 0.5. Higher EC/OC may be attributed to the predominant vehicle exhaust PM. Higher TC is observed at Kerbside and Residential site. EC/OC ratio is higher at Kerbside and Industrial site. Although, the total carbon concentration in $PM_{2.5}$ is lower ratio of EC/OC was observed to be higher than PM_{10} at respective site suggesting higher contribution of combustion sources to $PM_{2.5}$. Though, controlling the coarser PM and SPM is comparatively easier and control options result into better impact on overall PM concentration reduction, considering health impacts of finer particles.

Molecular Markers-Total 16 PAHs are monitored in PM_{10} and $PM_{2.5}$ samples during monitoring period. Naphthalene, Acenaphthalene, Fluorene + Acenaphthalene and Pyrene are found to be commonly prominent at all the sites. Other PAHs like Dibenz(a,h)anthracene, Benzo(ghi) Perylene and Indeno(1,2,3cd) Pyrene were also observed but found in low concentrations. Highest total PAHs concentrations were observed at Industrial location followed by COEP Kerbside site.

Another study conducted by USEPA and NEERI for Pune city i.e Air Quality Management, Emission Inventory and Source Apportionment study during 2010. The major source contribution to PM as per emission inventory is paved road dust 48%, Unpaved road dust 9%, Vehicle 9%, Street sweeping 3%, trash burning 2%, industrial and non-industrial generator 3%. CO is mainly contributed from area (54.3%) followed by vehicles (45.6%). Industries are the dominant source of SO_2 viz. 84.0%. Vehicular emission accounts for 92.2% of the total NOx.

The major chemical component of PM_{10} is organic matter, accounting for 30 to 60%, probably due to high vehicular movement near the monitoring site and residential area. Anions account for 21 to 27% of the total coarse particulate mass. Amongst the anions, contribution from sulfate is maximum, probably due to secondary aerosol, road dust etc. The contribution from cations and elemental carbon is 8 to 15% and 6.7% respectively. Crustal elements account for 7 to 12% possibly due to resuspension of road dust, whereas Non crustal elements shares 3 to 7% for the total particulate load. Unidentified portion in PM_{10} was 23.1% which may due to volatilization of organic matter and nitrates.

In finer fraction ($PM_{2.5}$), organic matter's contribution is even higher i.e. 40 to 70%, which is due to various combustion activities. Anions account for 30 to 40%, in which sulfate ions have maximum contribution followed nitrate and chloride. The contribution from cations measures up to 16-20%. The crustal element contributes around 8-20%, whereas non-crustal accounts for 4 to 10% for fine particulate matter load. Negative contribution indicates that the sum of identified species exceeded the measured mass, this is due to particle bound water and other analytical uncertainties.

Alkane concentrations were highest among all the markers and cycloalkanes were lowest. Tracer alkanes like n-pentacosane, n-hexacosane, n-heptacosane, n-octacosane indicates gasoline, diesel and fuel oil. Along with alkanes, hopanes and steranes confirm presence of gasoline, diesel and fuel oil combustion. Vegetative detritus source is indicated by presence of n-hentriacontane. Among PAH presence of Benzo (e) pyrene and Indeno (1,2,3-cd) pyrene indicates source such as gasoline, natural gas, coal and fuel oil. Another marker Picene, suggests presence of coal combustion source was also detected. Biomass burning can be attributed to be the cause of Levoglucosan concentration is Pune city.

Chapter 2

Air Quality Monitoring

2.1 Monitoring Sites

Population density, climatology, topography, and other factors all have a role in air quality monitoring design and assessment. The monitoring stations were chosen on the basis of region demography, consideration of activities and standard sampling procedure. Five sampling sites were chosen as representative of the Pune metropolitan area. Of these, one site was selected as control site (New Sangvi Police Station), and others are Rani Mahila Samiti (Residential), APMC Market Yard PMPL Depot (Commercial), Swargate Depot (Kerb) and Bharat Forge (Industrial). The study area is depicted in **Figure 2.1** and site characteristics are presented below.

New Sangvi Police Station: At outskirts of north end of the Pune City, "Background Site" on opposite side of PWD Ground for the study area was selected. The sampling instrument was installed on elevated platform at a height of 2 m above the ground in Police Station premises. Within 5 Km radius of the sampling site, there are many organizations like school and educational institute as well as commercial mall and multispecialty hospitals. The connectivity of New Sangvi allows commuting to other parts of Pune and easy access to all the prime facilities. In the last few years, lots of residential properties have established in Adarsh Nagar, Vedant Nivas, Ganesh Nagar, Vinayak Nagar etc. The Major roads starting from this end of Pune are Aundh Raver BRTS Road, PWD Road, Bhau Patil Road, Khadki Police Station Road, and Ganesh Khind (Pune University) Road. These roads experience traffic during peak office hours as also on holidays. No industrial activities are observed in these areas.

Rani Mahila Samiti (Residential) : The site is situated on south west side of the Pune airport (Viman Nagar) area. At north east, Nagar Road and Samrat Ashok Marg is connected to the site. The residential site is situated between Kelyani Nagar, Yerwada, Akluj Phule Nagar Road and Koregaon Park. The sampling instrument was installed on front porch of a building at a height of 3 m above the ground. These roads are aligned predominantly with residential blocks and societies.. Many commercial shopping malls, upper middle class housing societies and high end hotel establishments exist in the vicinity, because of which there is dense traffic congestions at interjections.

APMC Market Yard PMPL Depot : Shree Shiv Chhatrapati Market Yard, locally called as Market Yard is one of the popular markets in the center of the Pune city. It is located near highly commercial area, Maharshi Nagar and Swargate. Along the road there are numerous shops, hotels & restaurants, open eatouts, traffic interjections, public bus stop and heavy duty goods vehicles, etc. The PMPL minor repairs depot is at the end of the market yard; on the terrace of PMPPL building the sampling instrument was installed at a height of 3 m above the ground. PMPML buses connect Market Yard to various interior parts of the city. The major roads connected to sampling locations are Aaimata chowk, City pride chowk, Gadgill chowk, Padmavati Chowk Road etc.

Swargate Depot : Swargate bus depot (Kerbside), situated opposite Swargate Police Station, is major bus stand for Pune, that operates state as well local public bus service. It serves as a BRTS terminal for Katraj- Swargate, and Hadapsar- Swargate bus routes. The sampling instrument was installed on at a height of 3 m above the ground. The surrounding area has numerous commercial and institutional structure with government offices buildings like Income Tax office, PMC branch (Swargate), and other private organization. Swargate is well connected to the city and nearby villages by PMPML buses. Outside the depot, auto-rickshaws ply their trade from the Swargate bus terminus to nearby residential and slum areas. Some of the major roads from Pune, well connected to Swargate are from distant area like Satara, Shankar Sheth road, Tilak road, Shivajinagar Road and Sinhagad road. Jedhe square which is an important road junction that marks the origin of five roads. The location of Swargate PMPML depot and MSRTC stand is at the Jedhe square. From depot state buses leave for Mumbai, Satara, Baramati, Kolhapur, Belgaum, and other places.

Industrial area: The sampling location to cover industrial sources is located at Mundhwa industrial area. The major industries in the area are automobile parts metal processing units, ceramic and clay products industries etc. The sampling instrument was installed at a height of 1.5 m above the ground. The land use pattern in 2 x 2 Km grid of the sampling location includes 37% agricultural land, 13% bare land and 10% residential area. The location was selected to assess the emission from industrial processes, traffic on surrounding roads and interjections at peak hours and other allied commercial activities in this industrial area.

Figure 2.1 : Air Quality Monitoring Locations at Pune City

New Sangvi Police Station (Background)

Rani Mahila Samiti (Residential)

APMC Mkt Yard PMPL Depot (Commercial)

Swargate Depot (Kerbside)

Industrial Site

2.2 Measurement and Frequencies

Air quality pollutants were monitored as per the CPCB guide lines and chemical speciation methodologies adopted is given in **Table 2.1.** Portable air samplers (Airmetric) were used to sample $PM_{2.5}$ and PM_{10}. Four ARM samplers were collated at every sampling site to sample $PM_{2.5}$ and PM_{10}, each on two filter substrates (Teflon and Quartz). These samplers have been used widely for ambient air monitoring in several studies *(Chow et al., 2002; Ho et al., 2004)* tested MiniVol for its performance against the Federal Reference Method (FRM) sampler, and found that there was no statistical difference in the mass concentrations as measured by both the instruments. The flow rate of 5.0 lpm was found to be suitable as it would collect about 7.2 m^3 of air in 24 hours, and the total mass of sample would be in the range of 720 to 1080 µg (based on the average ambient concentration of PM_{10} and $PM_{2.5}$ is 189 and 80 µg/m^3 respectively reported for Pune). The mass of samples collected over a specified duration includes two main considerations: i) adequate mass collection for gravimetric as well as chemical analysis, and ii) prevention of overloading of the filter that could lead to excessive pressure drop across the filter. The sampling instrument has a constant flow control system, and an elapsed time totalizer. 24 hourly air qualities were monitored at each site for 10 days during winter 2018-19. Mass closures for all sites have been carried out as per protocol given in Data Validation Workbook: Session 4- Particulate Matter.

Table 2.1 : Target Physical and Chemical Components (groups) for Characterization of Particulate Matter for Source Apportionment

	PM_{10}	**$PM_{2.5}$**	**OC/EC**	**Element /Ions**
Sampling Instrument	Air Metric MiniVol Portable Sampler		Particulate collected on Quartz filter paper	Particulate collected on PTFE Filter paper
Sampling Principle	Filtration of aerodynamic sizes with a size cut by impaction			
Flow Rate	5 LPM	5 LPM	5 LPM	5 LPM
Sampling Period	24 Hourly Filter Change			
Sampling Frequency	Total 10 days; using Quartz and PTFT Filter Simultaneously	Total 10 days; using Quartz and PTFT Filter Simultaneously	Total 10 days; using Quartz and PTFT Filter Simultaneously	Total 10 days; using Quartz and PTFT Filter Simultaneously
Analytical Instrument	Electronic Balance	Electronic Balance	OC/EC Analyzer	Ion Chromatography
Minimum Reportable Value	5 µg/m^3	5 µg/m^3	0.2 µg/ 0.5 cm^2 Punch	NA

Components	**Required Filter Matrix**	**Analytical Methods**
PM_{10} / $PM_{2.5}$	Teflon or Nylon 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	ICP- AES or ICP-MS Or ED XRF
Ions (Na^+, NH_4^+, K^+, Mg_2^+, Ca_2^+, F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-})	Teflon filter paper (Same teflon filter paper can be utilized if ED-XRF is used for elements analysis)	Ion chromatography with conductivity detector
Carbon Analysis (OC, EC and Carbonate Carbon)	Quartz filter. Prebaking of quartz filter paper at 600 ºC is essential	TOR/TOT method

2.3 Monitoring Results

The particulate matter concentration compared with NAAQM Standard and $PM_{2.5}$ and PM_{10} ratio is presented in of **Figure 2.2.**

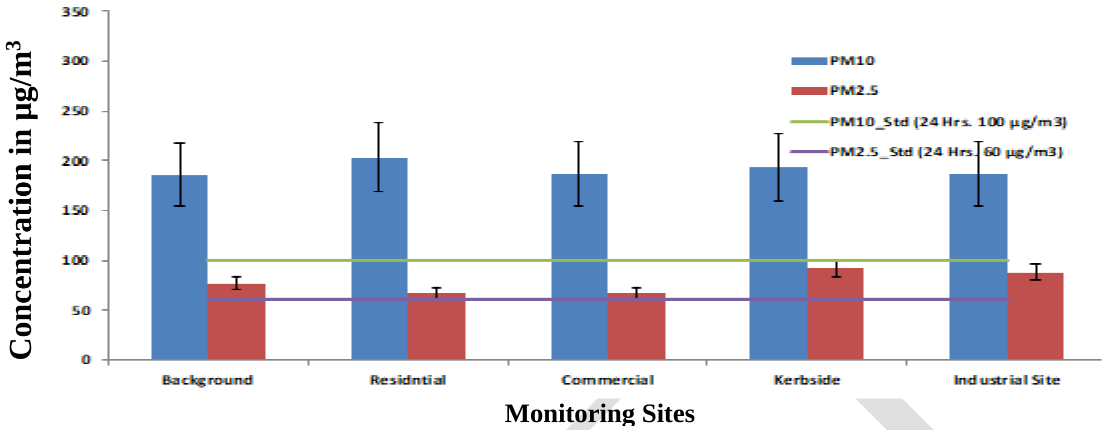
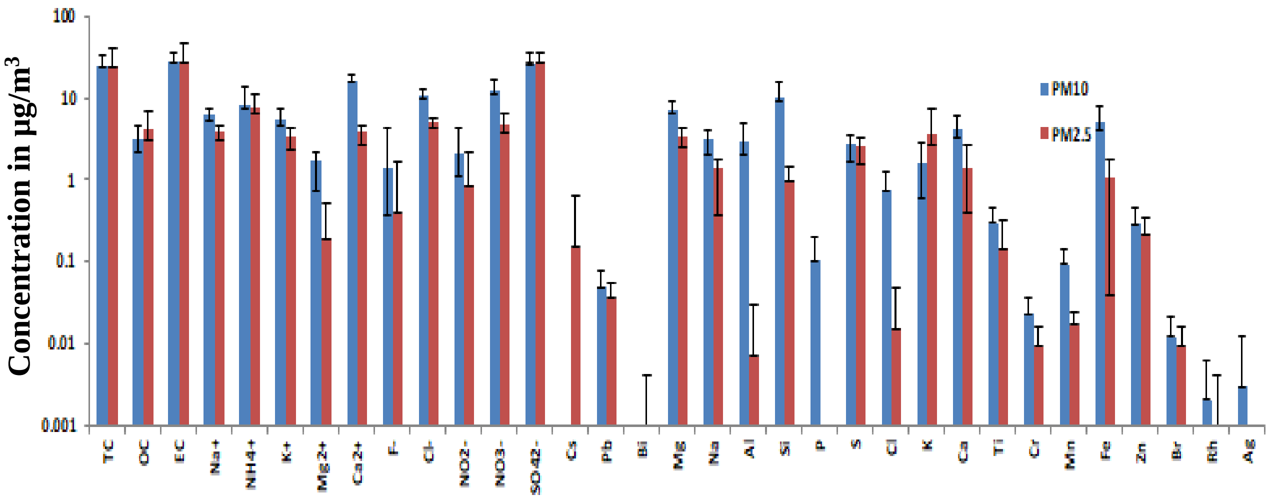


Figure 2.2 : PM_{10} and $PM_{2.5}$ Concentrations with respect to NAAQM Std.

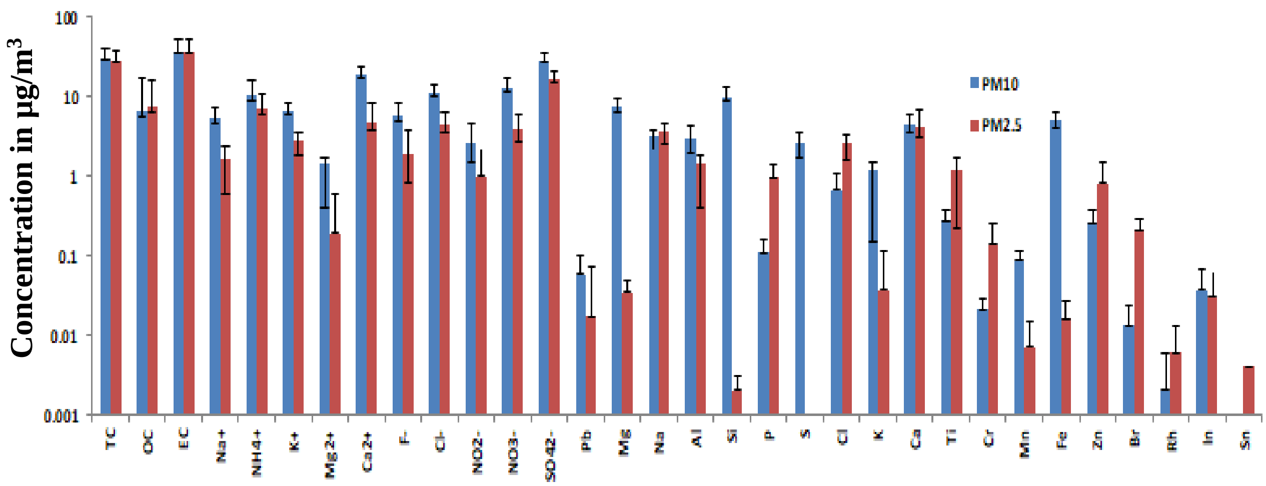
The PM_{10} concentration at New Sangvi (Background site) was observed to be in the range from 92.2 to 312.4 µg/m^3 (Avg. 185.9 µg/m^3), whereas; it was 39.4 to 119.9 for $PM_{2.5}$ (Avg. 77.1 µg/m^3). The $PM_{2.5}$/PM_{10} ratio provides characteristics of particle pollution since fine particles ($PM_{2.5}$) and coarse particles (PM2.5-10) are often created by multiple sources. The ratio can be used to characterize the underlying atmospheric processes and evaluate historical $PM_{2.5}$ pollution in absence of direct measurements. $PM_{2.5}$/PM_{10} ratio is in the range of 0.35 to 0.57. PM_{10} concentration for the residential site (Rani Mahila Samiti) were in the range of 79.8 to 384.4 µg/m^3 (Avg. 203.2 µg/m^3), whereas $PM_{2.5}$ ranged from 26.4 to 154.9 µg/m^3 (Avg. 80.1 µg/m^3). Considering the commercial activity APMC Market PMPL (Commercial site), PM_{10} concentration was in the range of 125 to 239.5 µg/m^3 (Avg. 187.0 µg/m^3) and 43.5 to 93.4 µg/m^3 (Avg. 67.0 µg/m^3) for $PM_{2.5}$. The $PM_{2.5}$/PM_{10} ratio was estimated to be around 0.29 to 0.40.

The Kerbside Swargate Depot, PM_{10} concentration was observed in the range of 88.6 to 284.4 µg/m^3 (Avg. 193.4 µg/m^3) and 31.1 to 168.4 µg/m^3 (Avg. 91.6 µg/m^3) for $PM_{2.5}$. The $PM_{2.5}$/PM_{10} ratio was calculated to be around 0.35 to 0.59. At Industrial site, concentration of PM_{10} observed to be 85.0 to 317.8 µg/m^3 with average of 186.5 µg/m^3 for PM_{10} and 35.4 to 182.4 µg/m^3 (Avg. 87.8 µg/m^3) for $PM_{2.5}$ and there ratio is around 0.32 to 0.57. The 24 hourly average concentrations of PM_{10} and $PM_{2.5}$ exceeded CPCB Standards of 100 µg/m^3 for PM_{10} and 60 µg/m^3 for $PM_{2.5}$ at all the sites of the NAAQM.

The $PM_{2.5}$ concentrations observed at Swargate, Bharat Forge and Rani Laxmi were above the NAAQM CPCB Standards 60 µg/m^3. Overall average PM /PM ratio was found to be 0.4 to 0.5 indicating the predominance of coarse particulate matter, the correlation between PM_{10} and $PM_{2.5}$ showed on R^2 value of 0.76 indicating nearly similar sources for PM_{10} and $PM_{2.5}$. The graphical compositional comparison of $PM_{2.5}$ Vs PM_{10} for all species are shown in **Figure 2.3.**

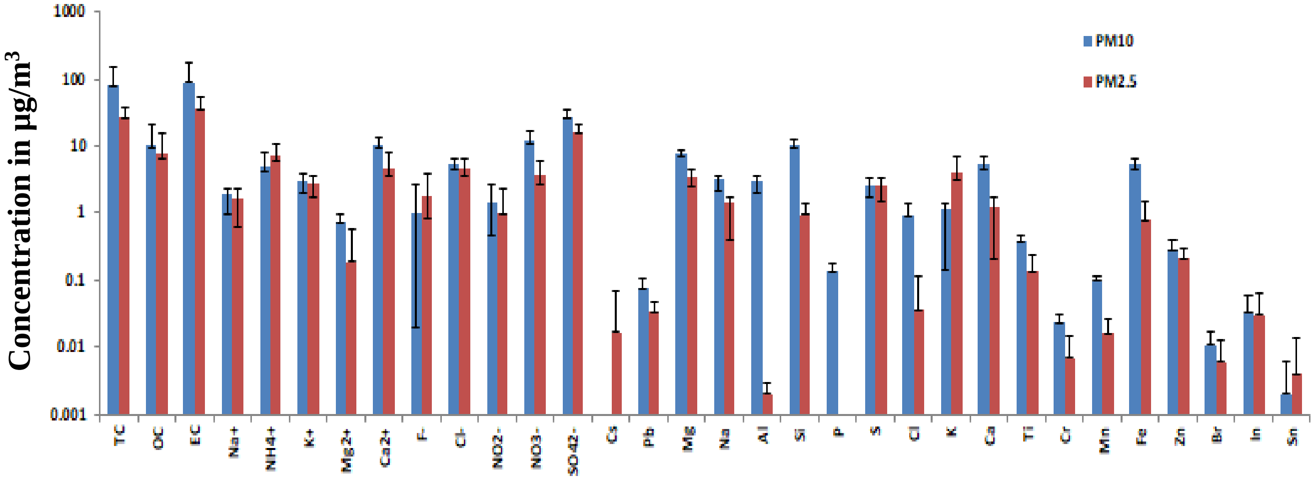


New Sanghvi (Background)

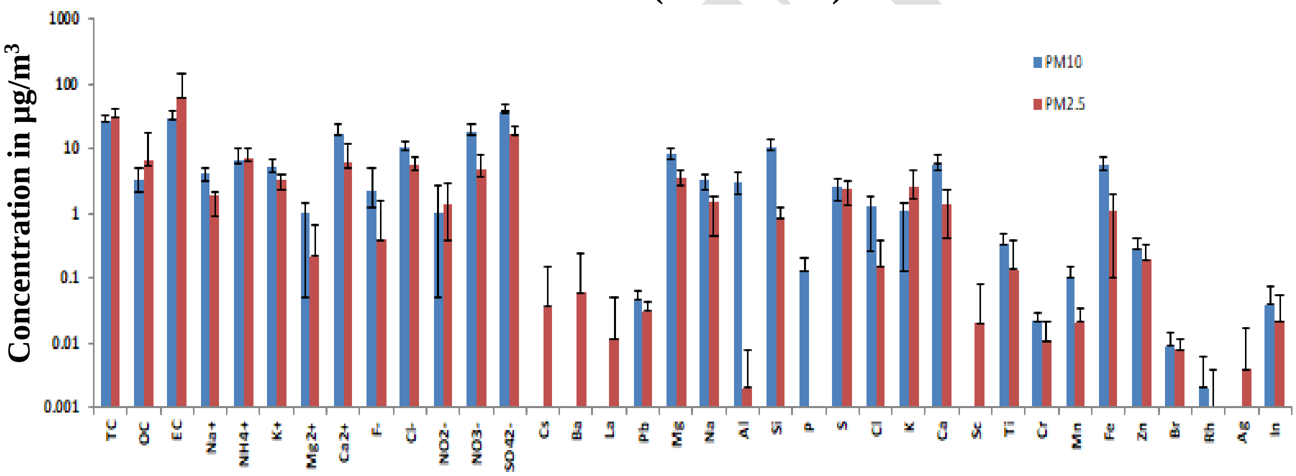


Rani Mahila Samiti (Residential)

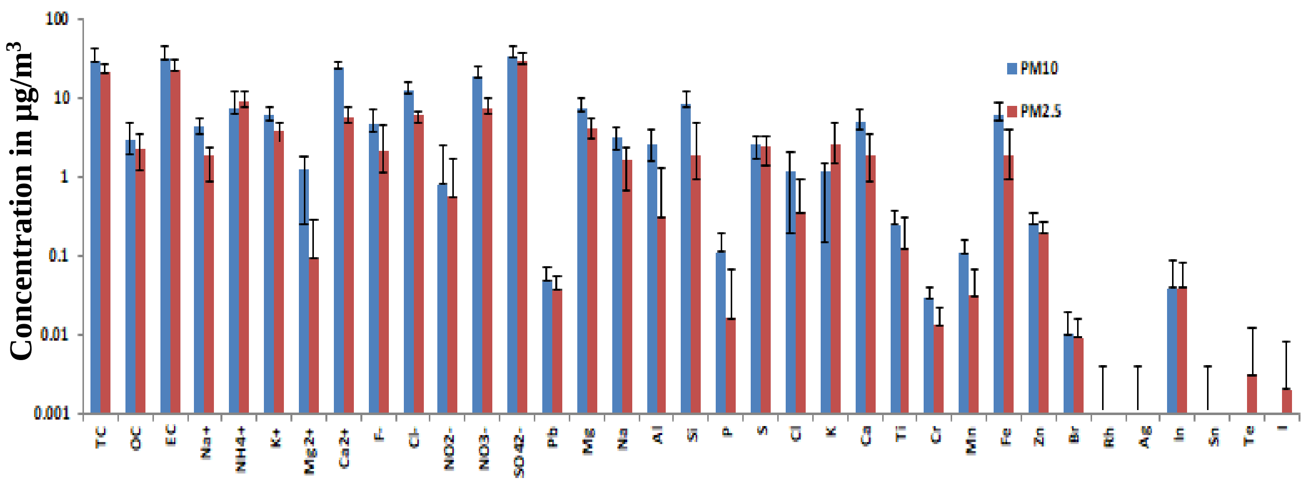
Figure 2.3 : Compositional Comparison of Species Concentrations in PM_{10} and $PM_{2.5}$



APMC Market Yard (Commercial)



Swargate Depot (Kerbside)



Industrial Site

Figure 2.3 (Contd..) : Compositional Comparison of Species Concentrations in PM_{10} and $PM_{2.5}$

2.3.1 Mass Closure of PM_{10} and $PM_{2.5}$

The PM_{10} and $PM_{2.5}$ samples were analyzed for 46 elements and 12 ions species for a total of 50 samples. The mass reconstruction procedure used in the present study was based on PM Data Analysis Workbook, USA.

Material Balance Equation

Geographical [(1.89 x Al) + (2.14 x Si) + (1.4 x Ca) + (1.43 x Fe)]

Organic Carbon (1.4 x OC) + Elemental Carbon

+ Anions (Cl^-, SO_4^{2-}, NO_3^-,…) + Cations (Na^+, K^+, $NH4^+$,…)

+ Trace Elements (Excluding geological) +Unidentified

Interpretation for Mass Closure

New Sangvi (Background) : - The major chemical component of the sample at this site were Crustal and Non-crustal elements, which accounted for 40% and 16.3% of PM_{10}, respectively. Anion accounted for 53.2% of the total coarse particulate mass. Amongst the anions, contribution from sulfate is maximum (26.9%), followed by nitrate (12.3%) and chloride (10.6%), this is probably due to secondary aerosol, road dust etc. Cations make up to 38.4% of the total PM_{10} concentration. The organic matter accounts for 24.5% of the total and elemental carbon is around 3.1%, this is may be due to anthropogenic activities near the monitoring site. Unidentified portion in PM_{10} was 10.3%, which may due to volatilization of organic matter and nitrates **(Figure 2.4)**.

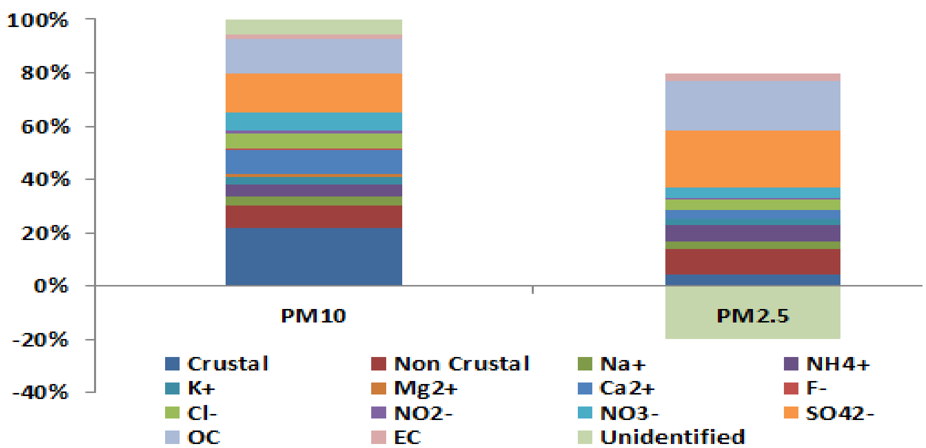


Figure 2.4 : Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at New Sangvi (Background)

Percent contribution of Crustal and Non-crustal elements in $PM_{2.5}$ is found to be around 5.4% and 12.1%, respectively. Anions and cations contribute 38.6% and 18.8% of the total $PM_{2.5}$. Sulfate (27.4%) and chlorides (5.2%) and nitrate (4.8%) form the major proportions in Anions, whereas ammonia (7.6%), calcium (3.7%) and sodium (4%) are the major proportions in Cation. The organic matter accounts for 24% of the total and elemental carbon is around 4%. Negative percent -25.9% in $PM_{2.5}$ indicates that the sum of identified species exceeded the measured mass. This is due to particle bound water and other analytical uncertainties *(Rees et al., 2004)*.

Rani Mahila Samiti (Residential) : The Crustal and Non-crustal elements in the sample of Rani Mahila Samiti (Residential) Site monitoring accounted for 40% and 15.9% in PM_{10}, respectively. The anion contribution in the sample was about 59% of the total coarse PM_{10} mass (sulphate 27.5%, nitrate 12.4% and chloride 10.7%), whereas, 42.3% was cations (calcium 18.5%, ammonia 10.1% and sodium 5.5%). The organic matter accounted for 29.4% of the total mass and elemental carbon is around 6.5%. The emissions from commercial and residential activities in the area and contribution probably due to secondary aerosol, road dust etc are the major source near the sampling point. Unidentified portion in PM_{10} was 10.1% which may due to volatilization of organic matter and nitrates **(Figure 2.5)**.

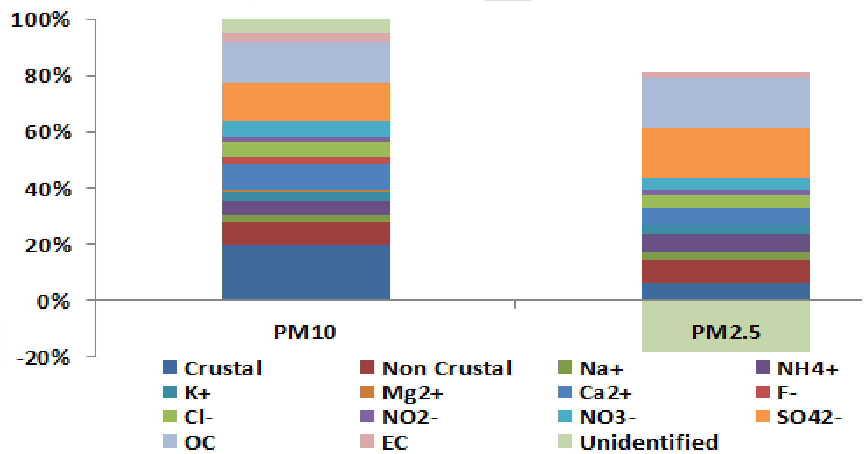


Figure 2.5 : Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at Rani Mahila Samiti (Residential)

$PM_{2.5}$ was composed 7.7% of Crustal elements and 10.9% of Non-crustal elements. Anion and cation contribution in total $PM_{2.5}$ mass was found to be 36.2% and 23.1% , respectively. 22.2% of Sulfate and 6% of chlorides are highest contributing source in Anions, whereas 7.5% of calcium and 8.5% of ammonia are highest in Cation. The organic matter is accounting for about 23.3%, and elemental carbon is around 2.8% of the total mass. The unidentified negative contribution -23.9% of $PM_{2.5}$ indicates that the sum of identified species exceeded the measured mass. This is due to particle bound water and other analytical uncertainties.

APMC Mkt Yard: APMC Market Yard is a busy commercial market area, with loading/unloading of the goods, heavy duty vehicle movements resulted in resuspension of dust contributing 43% for Crustal and 16.8% of Non-crustal elements in PM_{10} mass. Anions in PM_{10} account for 45.9% of the total coarse particulate mass in which sulphate is 26.3%, nitrate is around 11.8% and chloride is 5.4%; whereas Cations make up around 21.3% (calcium 10.5% and ammonia 5.2%) from rest of the total PM_{10}. The organic matter is accounting for 78.9% and elemental carbon is around 10.2%. This contribution is probably due to secondary aerosol, road dust and extensive vehicular movement. Negative discrepancy in PM_{10} mass was -29.1% which due to particle bound water and other analytical uncertainties **(Figure 2.6)**.

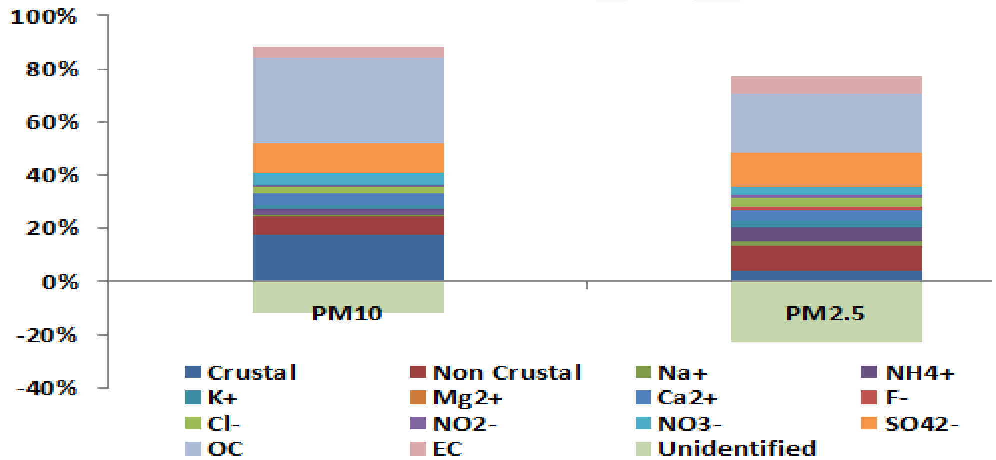


Figure 2.6 : Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at APMC Mkt Yard (Commercial)

In $PM_{2.5}$, Crustal and Non-crustal elements was around 4.9% and 12%, respectively. Anions and cations contribute 16.3% and 27.3% of the total $PM_{2.5}$. Sulfate 16.2% and chlorides 4.5% are the highest portions in Anions, whereas calcium 4.6% and ammonia 7.1% are higher in Cation. The organic matter account for 27.7% of the total and elemental carbon is around 7.5%. The unidentified negative contribution -28.7% of $PM_{2.5}$ indicates that the sum of identified species exceeded the measured mass.

Swargate Depot : Swargate Depot is a major depot of Pune, connected to major traffic intersection that has heavy vehicular movement; resulting in resuspension of road dust in high concentration and is the cause of concern. The 43.8% and 17.4% of PM_{10} mass is composed from Crustal and Non-crustal elements. Anions account for 96.9% of the total coarse particulate mass (sulphate 56.2%, nitrate 26.9% and chloride 10.5%), whereas Cations make up to 34.4% of the total PM_{10} (calcium 17.2% and ammonia 6.8%). The organic matter accounts for 26.8% and elemental carbon is around 3.2%. The high residential activities, commercial activities and vehicular movement in sampling area are reflected from their contribution in sample. Negative percent of -29.2% in PM_{10} indicates that the sum of identified species exceeded the measured mass. This is due to particle bound water and other analytical uncertainties **(Figure 2.7)**.

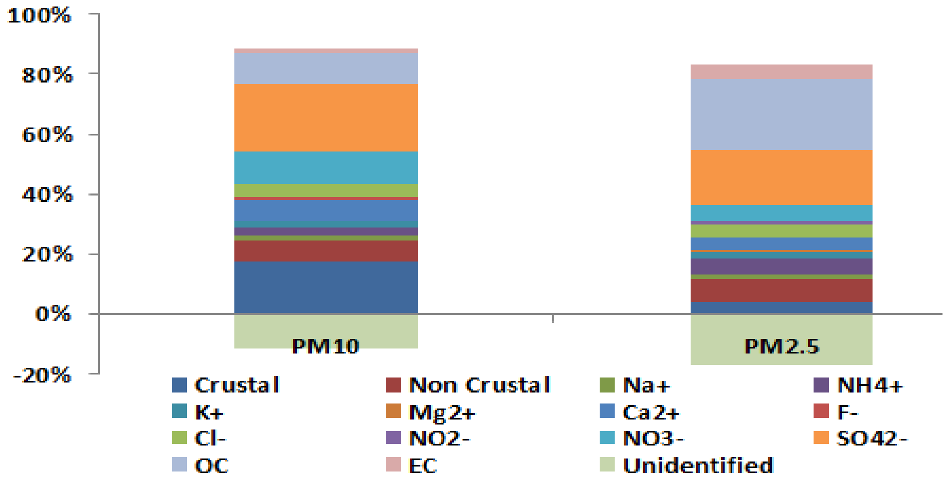


Figure 2.7 : Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ Swargate (Kerb Site)

The Crustal (5.3%) and Non-crustal elements (11%) contributes for $PM_{2.5}$ mass. Anions and cations contribute around 40.9% and 18.8% of the total $PM_{2.5}$, respectively. Sulfate (26.1%), chlorides and nitrate 5 to 7% are some of the highest composition in Anions, whereas calcium (5.9%) and ammonia (7.4%) are highest in Cation. The organic matter account for 32.4% of the total and that of elemental carbon is around 6.6%. Negative discrepancy of -23.6% in $PM_{2.5}$ mass was unidentified, which indicates that the sum of identified species exceeded the measured mass.

Industrial Site: In Mundhawa industrial belt, resuspension of dust, anthropogenic activities and natural wind effect is observed to be the major source. The Crustal and Non-crustal elements contribution is around 38.8% and 16.4% to the PM_{10} mass, respectively. Anions account for 71.3% of the total coarse particulate mass, whereas Cations make up 44% of the total PM_{10}. The sulphate (34.4%), nitrate (18.8%) and chloride (12.7%) in anions, and calcium (25%) and ammonia and potassium sodium (6 to 7%) in cations are the highest contributors; and also the organic matter accounts for 29.1%. The high contribution is probably due to secondary aerosol, road dust. Unidentified negative portion in PM_{10} was -16% which indicates that the sum of identified species exceeded the measured mass **(Figure 2.8).**

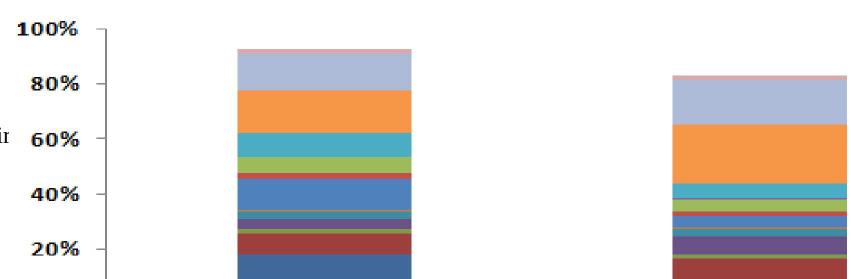


Figure 2.8 : Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ Bharat Forge (Industrial)

Crustal and Non-crustal elements influence on $PM_{2.5}$ mass is around 10% and 11.5%. Anions and cations contribute 44.6% and 20.3% of the total $PM_{2.5}$. Sulfate (28.7%), nitrate (7.4%) and chlorides (5.9%) are highest in Anions, whereas calcium (5.8%) and ammonia (8.8%) is highest in Cation, as also organic matter accounts for 21.1%. Negative unidentified portion (-22%) in $PM_{2.5}$ is identified due to particle bound water and other analytical uncertainties.

Chapter 3

Emission Inventory

3.1 Pune City Emission Inventory

As the city is expanding in terms of population, infrastructure and vehicular growth and being listed as one of the "Non Attainment" city by CPCB, the identification of pollutant loads and to prepare the strategic action for plan for controlling them is the need of the hour. Emissions inventory is the first exercise, under which identification and quantification of various sources are linked with the existing air quality levels and necessary prediction of air quality for the whole region can be made. It helps in assessing the impact of nearly all sources, in and around the region, and also to evaluate the control strategies for certain emission sources. Air pollution sources are broadly categorized as area (domestic and fugitive combustion type emission sources viz. domestic, bakeries, crematoria etc), industrial (point) sources and vehicular (line) sources. Emission inventory of different sources of air pollution has been prepared for 2 km x 2 km sizes for whole of Pune city to accurately identify and quantify emissions from different sources **(Figure 3.1)**. Emission inventory has been prepared in terms of five major pollutants, viz. PM_{10}, SO_2, NOx, CO and HC.

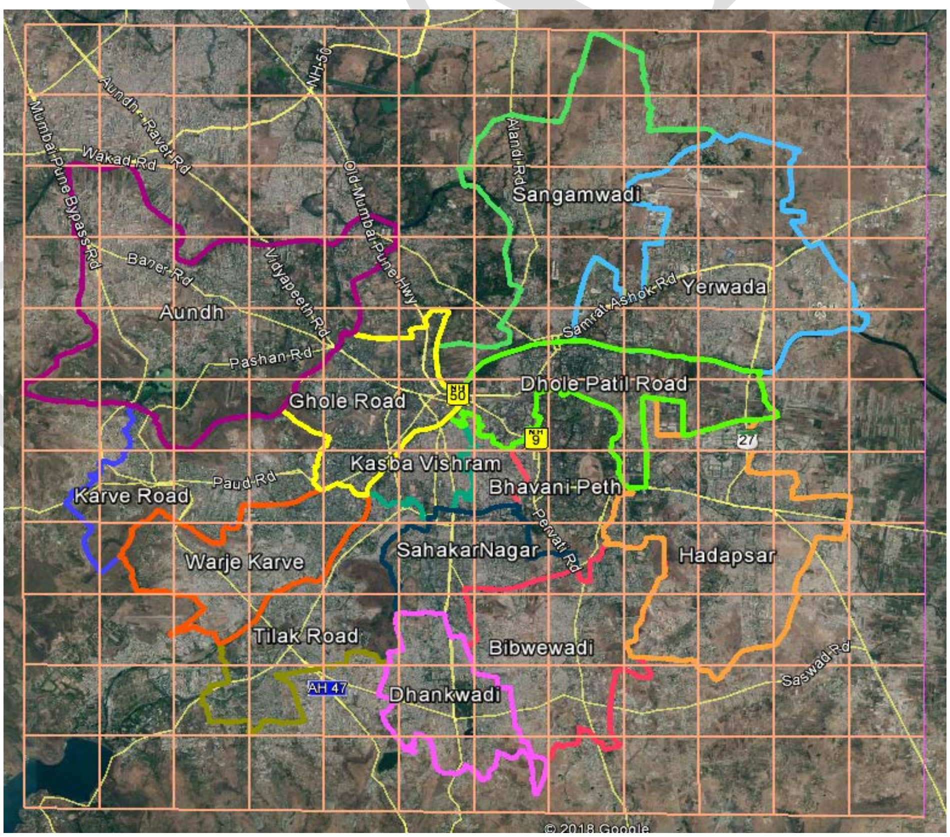


Figure 3.1 : 2 Km X 2 Km Grid Distribution Map of Pune City

3.2. Area Source

Area sources are sources with relatively dispersed emissions over large areas and lead to proportionately constant source contributions over space but can have very large temporal changes in emissions. They are often collection of similar units within a geographic area. Though emissions from individual area sources are relatively small, collectively their emissions can be of concern - particularly where large numbers of sources are located in heavily populated areas. Area sources include the following groups, viz. bakeries, hotels/restaurants, crematories, construction activity, domestic cooking, open eat outs, paved/unpaved road dust, open burning of solid waste. In subsequent sections, these sources have been described along with the methodologies delineated for load estimation. Data on area source activities were collected from various Government and Non-Government departments/agencies. The required information was also collected through interviews with the concerned authorities/ persons in respective activities. In addition, fuel consumption data and related information were obtained through primary surveys of residences, hotels, restaurants, crematoria etc in the study zones (2 km x 2 km area). Area source emissions are calculated by multiplying an established emissions factor referring in the CPCB 6 cities inventory report (emissions per unit of activity) by the appropriate activity or activity surrogate responsible for generating emissions.

3.2.1 Bakery

Bakeries were categorized as the registered and unregistered; the definition for the same remains vague. Bakeries are mostly located in central or outer part of the city, and survey was carried out for various parameters such as fuel type, quantity, hours of baking, ventilation arrangement, area of the bakery, stack details, pollution control equipment. Though most of them use wood as a fuel and their consumption is very high, there is a need for estimations of emissions from this sector. As per survey the fuel consumption pattern reflect as wood is consumed in a day is around 250 (kg/d/oven), commercial cylinder of 19.4 kg (on an average ½ or 1 cylinder) and 10 to 20 kg of Coal is consumed in each bakery. The survey also indicates that diesel and electric operating bakeries are very less in number, so negligible emissions are expected. Distribution of bakeries was done in line with their postal address gathered from the Food and License Department of Pune Municipal Corporation, Cantonment Board and Bakers Association. But the data for the same is not being accounted or managed by any regulatory body. In our study, fuel that came into survey was taken into account for emission load. The number of bakeries operating ward wise as per survey and the fuel consumption in kg/day is given in **Table 3.1.**

Table 3.1 : Ward wise Distribution of Bakeries in Pune (2018-19)

Area	No. of Bakeries	Wood (Kg/day)	LPG	Coal
Aundh	6	750	7	20
Bibwewadi	3	500	20	0
Dhankwadi	3	250	2	2
Dhole patil road	1	0	2	0
Ghole road	2	250	8	20
Hadpsar	5	750	11	0
Karve road	5	1000	23	19
Kasaba vishram baughwada	1	250	0	0
Sahakar nagar	2	500	0	0
Sangam wadi	1	0	5	5
Tilak Road	3	250	31	10
Warje karve road	4	0	20	30
Yerwada	7	0	46	0
Total	**43**	**4500**	**174**	**105**

* Values for fuel consumption in kg/day

Based on the primary survey estimates it was found that most of the bakeries use about 94.15% firewood and remaining 3.64% use LPG and 2.21% coal.

Emission Estimations:

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

Number of bakeries in the PMC area = 43; Wood consumption in a day = 250 (kg/d/oven), +coal consumption 20 (kg/d) + commercial cylinder of 19.4 kg (on an average ½ or 1 cylinder/day) x Emission factor. (The Emission Factor is listed in **Annexure I).**

Emission Factor for Wood Burning = 17.3 (kg/t) (PM_{10})

Emission from wood burning (PM_{10}) = 4500 kg/day x (17.30/1000) = 77.85 (kg/d)

Emission Factor for Coal Burning = 20 (kg/t) (SPM) of 60% is PM_{10}

Emission from coal burning (PM_{10}) = 105 kg/day x (20/1000) x 0.60 = 1.27 (kg/d)

Emission from LPG burning (PM_{10}) = 174 kg/day x (2.10/1000) = 0.37 (kg/d)

Total Emission from all source for PM_{10} = 79.48 Kg/day and 29 (Tons/year)

In similar way emission for pollutants have been estimated as given in **Table 3.2.**

Table 3.2 : Emission Loads from Bakeries for all Wards

Wards	Wood (Kg/day)							LPG (Kg/day)						
	PM10	**PM2.5**	**SO_2**	**NOx**	**CO**	**HC**	**CO2**	**PM10**	**PM2.5**	**SO_2**	**NOx**	**CO**	**HC**	**CO2**
Aundh	13.0	0.5	0.2	1.0	94.7	85.9	1275.0	0.015	0.015	0.003	0.013	0.002	0.001	11.95
Bibwewadi	8.7	0.3	0.1	0.7	63.2	57.3	850.0	0.041	0.041	0.008	0.035	0.005	0.001	33.69
Dhankwadi	4.3	0.2	0.1	0.3	31.6	28.6	425.0	0.004	0.004	0.001	0.003	0.000	0.000	3.26
Dhole Patil								0.004	0.004	0.001	0.003	0.000	0.000	3.26
Ghole Road	4.3	0.2	0.1	0.3	31.6	28.6	425.0	0.017	0.017	0.003	0.015	0.002	0.001	14.13
Hadpsar	13.0	0.5	0.2	1.0	94.7	85.9	1275.0	0.023	0.023	0.004	0.019	0.003	0.001	18.48
Karve Road	17.3	0.7	0.2	1.3	126.3	114.5	1700.0	0.048	0.048	0.009	0.041	0.006	0.002	39.12
Kasaba Vishram	4.3	0.2	0.1	0.3	31.6	28.6	425.0							
Sahakar Nagar	8.7	0.3	0.1	0.7	63.2	57.3	850.0							
Sangam Wadi								0.011	0.011	0.002	0.009	0.001	0.000	8.69
Tilak Road	4.3	0.2	0.1	0.3	31.6	28.6	425.0	0.065	0.065	0.012	0.055	0.008	0.002	52.91
Warje Karve.								0.043	0.043	0.008	0.036	0.005	0.001	34.78
Yerwada								0.096	0.096	0.018	0.082	0.011	0.003	78.25
Total (kg/day)	**77.9**	**3.1**	**0.9**	**5.9**	**568.4**	**515.3**	**7650.0**	**0.37**	**0.37**	**0.07**	**0.31**	**0.04**	**0.01**	**298.5**
Total (Tons/yr)	**28.4**	**1.1**	**0.3**	**2.1**	**207.4**	**188.1**	**2792.3**	**0.13**	**0.13**	**0.03**	**0.11**	**0.02**	**0.00**	**108.96**
	Coal (Kg/day)							**Total Bakery Emission (kg/day)**						
Aundh	0.24	0.16	0.27	0.08	0.50	0.01		13.2	0.7	0.4	1.1	85.9	95.2	1287.0
Bibwewadi								8.7	0.4	0.1	0.7	57.3	63.2	883.7
Dhankwadi	0.02	0.02	0.03	0.01	0.05	0.00		4.4	0.2	0.1	0.3	28.6	31.6	428.3
Dhole Patil								0.0	0.0	0.0	0.0	0.0	0.0	3.3
Ghole Road	0.24	0.16	0.27	0.08	0.50	0.01		4.6	0.4	0.3	0.4	28.6	32.1	439.1
Hadpsar								13.0	0.5	0.2	1.0	85.9	94.7	1293.5
Karve Road	0.23	0.16	0.25	0.08	0.47	0.01		17.6	0.9	0.5	1.4	114.5	126.8	1739.1
Kasaba Vishram								4.3	0.2	0.1	0.3	28.6	31.6	425.0
Sahakar Nagar								8.7	0.3	0.1	0.7	57.3	63.2	850.0
Sangam Wadi	0.06	0.04	0.07	0.02	0.13	0.003		0.1	0.1	0.1	0.0	0.0	0.1	8.7
Tilak Road	0.11	0.08	0.13	0.04	0.24	0.005		4.5	0.3	0.2	0.4	28.6	31.8	477.9
Warje Karve.	0.36	0.24	0.40	0.12	0.75	0.02		0.4	0.3	0.4	0.2	0.0	0.8	34.8
Yerwada								0.1	0.1	0.0	0.1	0.0	0.0	78.2
Total (kg/day)	**1.27**	**0.86**	**1.40**	**0.42**	**2.63**	**0.05**		**79.48**	**4.3**	**2.4**	**6.6**	**515.3**	**571.0**	**7948.5**
Total (Tons/yr)	**0.46**	**0.31**	**0.51**	**0.15**	**0.96**	**0.02**		**29.0**	**1.6**	**0.9**	**2.4**	**208.4**	**188.1**	**2901.2**

Out of the total PM emission load of 79.4 kg/day from bakeries, 94% is contributed by wood. The bakery activities in the region of Karve Road (22.1%), Aundh (16.6%) and Bibwewadi (10.9%) contribute the most towards the final emission loads. Almost 5% of PM load is contributed from Dhankwadi, Ghole Road, Kasaba Vishram and Tilak Road areas and while rest contributes only 0.1 to 2%. The total NOx contribution is around 6.6 kg/day, 88% of this NO_x is from wood combustion in bakery processes of the region, where 1% is contributed from LPG consumption. The major pollutant emission load reflects i.e. HC and CO contribution is around 515.3 kg/d and 571 kg/day respectively. Large numbers of bakeries authorized as well as unauthorized are operating in Pune. The number of bakeries could be more than the licensed ones.

3.2.2 Crematoria

According to Hindu traditions, deaths rites are carried out primarily using wood. Burning of firewood in crematoria is one of the sources of air pollution. The mortality data for Pune City 2018-19 is obtained from Pune Municipal Corporation site around 24360 persons per year and same is distributed according to the percent of population in that particular 14 wards, as the uneven numbers are getting for crematories **(Table 3.3)**. As per PREIS Study 5% increase mortality every year was observed which has been applied to estimate deaths in region. According to PMC there are about 21 Hindu crematoria in Pune city. As per primary survey and discussions with PMC officials it is observed that 40% of bodies are burnt on electricity and remaining 60% on wood. The fuel requirement per body is around 200 kg of wood, 3 liters (2.43 kg) of kerosene, 60 kg of dung cake, or 20 liters of diesel in diesel furnace, or 4 cylinder for LPG burner, electric cremation furnace capacity is around 54 Kw for temperature up to 1200 degree for 60 to 90 minutes. As per data obtained some data constrains are: despite presence of electric crematoria, most of the population prefers using wood based cremation. The proportion of fuel wood & dung cake needed for each body may not be exact. Burning of bodies per day is variable. Hindu cremation processes vary substantially due to the quantity and type of wood used and type of pyres prepared.

Emission Estimations:

Emission (TSP) =No. of Hindu Death /yr (0.8) * **wood** required per body (kg) * emission factor + **kerosene** (liters to kg) * emission factor + **diesel** (liters to kg) * emission factor + **LPG** (kg) * emission factor + **Gobar** (kg) emission factor +Emission from **Body Burnt** *emission factor; + [**electric** cremation body * emission factor] = for Number of Registered death in Mumbai = 24360

Emission factor for wood burning, kerosene, diesel, gobar, LPG and electric crematoria are listed in **Annexure I.**

Table 3.3 : Ward Wise Distribution of Bodies Burnt and Fuel Consumption Pattern

	No. of Deaths during 2018-19	No. of Death Wood Based	No. of Death Electric Based	Wood Qty. (Kg/y)	Diesel Qty (Kg/y)	Kerosene Qty (Kg/y)	Gobar Qty (Kg/y)	LPG Qty (Kg/y)
Aundh	1408	845	563	70376	3.5	144	8445	10922
Bibvewadi	2309	1385	923	115429	5.8	236	13852	17915
Dhanakawadi	1848	1109	739	92377	4.6	189	11085	14337
Dhole Patil	1213	728	485	60632	3.0	124	7276	9410
Ghole Road	1341	805	536	67054	3.4	137	8046	10407
Hadapsar	2188	1313	875	109397	5.5	223	13128	16978
Kothrud	1632	979	653	81612	4.1	167	9793	12666
Kasba	1739	1043	695	86936	4.3	178	10432	13493
Sahakar Nagar	1588	953	635	79377	4.0	162	9525	12319
Sangam Wadi	2040	1224	816	102015	5.1	208	12242	15833
Tilak Road	1880	1128	752	93986	4.7	192	11278	14587
Warje, Karve Nagar	1817	1090	727	90856	4.5	186	10903	14101
Yerwada	1862	1117	745	93085	4.7	190	11170	14447
Bhawani Peth	1497	898	599	74874	3.7	153	8985	11620
Total (Kg/y)	**24360**	**14616**	**9744**	**1218008**	**61**	**2488**	**146161**	**189035**

Emission (PM10) from wood based crematoria = 14616 (death/yr) [wood consumption (1218 (t) + * EF 17.3 (kg/t)] + [kerosene consumption /body =2.5 liters*0.81 (density in kg/l) = 2.04 (kg)= 2488 (kg) * EF 1.95 (SPM) * 0.6 (PM)] + [Diesel consumption 61 (KL) * EF 0.250 (SPM) * 0.6 (PM)] + [LPG Consumption 19.4 capacity * 4 cylinder * density = 189 (t)* EF 2.10 (kg)] + [Gobar 146 (kg) * EF 5.4 (kg)] + [Body burnt (no. of death) * EF 0.000025] + Emission (PM10) from Electric burning = 9744 (deaths/yr) * EF 0.000025 (kg/t)] = 22216.2 kg/year (22.2 t/d).

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

Total emission load from crematoria indicates that Bibvewadi and Hadapsar are the major contributors as the mortality rate of the area period is higher than the rest. 95-99% PM, CO and HC is from Wood used for combustion. 20-25% SOx and NOx is from Wood and Body Burnt, whereas 43-47% is estimated from electric. CO is the major pollutant followed by HC, PM_{10} and NOx, wood burning as the major source. Hindu cremation processes vary substantially due to the quantity and type of wood used and type of pyres prepared.

Table 3.4 : Emission Loads from Crematoria for all Wards

Wards	Wood (Kg/Year)							Diesel (Kg/Year)						
	PM10	PM2.5	SO_2	NOx	CO	HC	CO2	PM10	PM2.5	SO_2	NOx	CO	HC	CO2
Aundh	1217.5	827.9	14.1	91.5	8888.4	8058.0	119638.5	0.53	0.36	0.03	9.68	2.22	0.42	
Bibvewadi	1996.9	1357.9	23.1	150.1	14578.7	13216.6	196229.7	0.87	0.59	0.04	15.87	3.64	0.69	
Dhanakawadi	1598.1	1086.7	18.5	120.1	11667.3	10577.2	157041.7	0.69	0.47	0.03	12.70	2.91	0.55	
Dhole Patil	1048.9	713.3	12.1	78.8	7657.9	6942.4	103074.9	0.45	0.31	0.02	8.34	1.91	0.36	
Ghole Road	1160.0	788.8	13.4	87.2	8468.9	7677.7	113991.8	0.50	0.34	0.02	9.22	2.11	0.40	
Hadapsar	1892.6	1286.9	21.9	142.2	13816.8	12525.9	185974.4	0.82	0.56	0.04	15.04	3.45	0.66	
Kothrud	1411.9	960.1	16.3	106.1	10307.6	9344.6	138740.6	0.61	0.42	0.03	11.22	2.57	0.49	
Kasba Vishram	1504.0	1022.7	17.4	113.0	10980.1	9954.2	147792.0	0.65	0.44	0.03	11.95	2.74	0.52	
Sahakar Nagar	1373.2	933.8	15.9	103.2	10025.3	9088.7	134941.0	0.60	0.40	0.03	10.91	2.50	0.48	
Sangam Wadi	1764.9	1200.1	20.4	132.6	12884.5	11680.7	173425.5	0.77	0.52	0.04	14.03	3.21	0.61	
Tilak Road	1626.0	1105.6	18.8	122.2	11870.4	10761.3	159775.5	0.70	0.48	0.03	12.92	2.96	0.56	
Warje Karve	1571.8	1068.8	18.2	118.1	11475.2	10403.1	154456.0	0.68	0.46	0.03	12.49	2.86	0.55	
Yerwada	1610.4	1095.1	18.6	121.0	11756.7	10658.3	158245.0	0.70	0.47	0.03	12.80	2.93	0.56	
Bhawani Peth	1295.3	880.8	15.0	97.3	9456.6	8573.1	127286.1	0.56	0.38	0.03	10.30	2.36	0.45	
Total (kg/day)	**57.7**	**39.3**	**0.7**	**4.3**	**421.5**	**382.1**	**5672.9**	**0.03**	**0.02**	**0.00**	**0.46**	**0.11**	**0.02**	
Total (T/yr)	**21.1**	**14.3**	**0.2**	**1.6**	**153.8**	**139.5**	**2070.6**	**0.01**	**0.01**	**0.00**	**0.17**	**0.04**	**0.01**	
	Kerosene (Kg/Year)							LPG Emission (kg/year)						
Aundh	0.09	0.06	0.58	0.36	8.91	2.73		1.4	22.9	4.4	19.7	2.8	0.8	18742.6
Bibvewadi	0.14	0.10	0.94	0.59	14.62	4.48		2.3	37.6	7.2	32.2	4.5	1.3	30741.5
Dhanakawadi	0.12	0.08	0.75	0.47	11.70	3.59		1.8	30.1	5.7	25.8	3.6	1.0	24602.3
Dhole Patil	0.08	0.05	0.50	0.31	7.68	2.35		1.2	19.8	3.8	16.9	2.4	0.7	16147.8
Ghole Road	0.08	0.06	0.55	0.34	8.49	2.60		1.3	21.9	4.2	18.7	2.6	0.7	17858.0
Hadapsar	0.14	0.09	0.89	0.56	13.86	4.25		2.2	35.7	6.8	30.6	4.3	1.2	29134.9
Kothrud	0.10	0.07	0.67	0.42	10.34	3.17		1.6	26.6	5.1	22.8	3.2	0.9	21735.2
Kasba Vishram	0.11	0.07	0.71	0.44	11.01	3.37		1.7	28.3	5.4	24.3	3.4	1.0	23153.2
Sahakar Nagar	0.10	0.07	0.65	0.41	10.05	3.08		1.6	25.9	4.9	22.2	3.1	0.9	21140.0
Sangam Wadi	0.13	0.09	0.83	0.52	12.92	3.96		2.0	33.2	6.3	28.5	4.0	1.1	27169.0
Tilak Road	0.12	0.08	0.77	0.48	11.90	3.65		1.9	30.6	5.8	26.3	3.7	1.1	25030.5
Warje Karve	0.11	0.08	0.74	0.46	11.51	3.53		1.8	29.6	5.6	25.4	3.6	1.0	24197.2
Yerwada	0.12	0.08	0.76	0.48	11.79	3.61		1.8	30.3	5.8	26.0	3.6	1.0	24790.8
Bhawani Peth	0.09	0.06	0.61	0.38	9.48	2.91		1.5	24.4	4.6	20.9	2.9	0.8	19940.7
Total (kg/day)	**0.004**	**0.003**	**0.027**	**0.017**	**0.423**	**0.130**		**1.1**	**1.1**	**0.2**	**0.9**	**0.1**	**0.0**	**888.7**
Total (T/yr)	**0.002**	**0.001**	**0.010**	**0.006**	**0.154**	**0.047**		**0.4**	**0.4**	**0.1**	**0.3**	**0.0**	**0.0**	**324.4**

Table 3.4 (Contd..) : Emission Loads from Crematoria for all Wards

Wards	Gobar (Kg/Year)							Body Burnt (Kg/Year)						
	PM10	PM2.5	SO_2	NOx	CO	HC		PM10	PM2.5	SO_2	NOx	CO	HC	CO2
Aundh	42.6							0.01	0.01	19.14	108.38	49.61	4.57	
Bibvewadi	69.8							0.01	0.01	31.40	177.76	81.38	7.50	
Dhanakawadi	55.9							0.01	0.01	25.13	142.26	65.13	6.00	
Dhole Patil	36.7							0.01	0.01	16.49	93.37	42.75	3.94	
Ghole Road	40.6							0.01	0.01	18.24	103.26	47.27	4.36	
Hadapsar	66.2							0.01	0.01	29.76	168.47	77.12	7.11	
Kothrud	49.4							0.01	0.01	22.20	125.68	57.54	5.30	
Kasba Vishram	52.6							0.01	0.01	23.65	133.88	61.29	5.65	
Sahakar Nagar	48.0							0.01	0.01	21.59	122.24	55.96	5.16	
Sangam Wadi	61.7							0.01	0.01	27.75	157.10	71.92	6.63	
Tilak Road	56.8							0.01	0.01	25.56	144.74	66.26	6.11	
Warje Karve	55.0							0.01	0.01	24.71	139.92	64.05	5.91	
Yerwada	56.3							0.01	0.01	25.32	143.35	65.63	6.05	
Bhawani Peth	45.3							0.01	0.01	20.37	115.31	52.79	4.87	
Total (kg/day)	**2.0**							**0.0004**	**0.0003**	**0.9077**	**5.1390**	**2.3526**	**0.2169**	
Total (T/yr)	**0.74**							**0.0002**	**0.0001**	**0.3313**	**1.8757**	**0.8587**	**0.0792**	
	Electrical Crematoria (Kg/Year)							**Total (kg/Year)**						
Aundh	0.014	0.01	30.6	173.4	79.4	7.3		1283.6	851.3	68.8	403.0	9031.3	8073.8	138381.1
Bibvewadi	0.023	0.02	50.2	284.4	130.2	12.0		2105.4	1396.2	112.9	660.9	14813.1	13242.6	226971.2
Dhanakawadi	0.018	0.01	40.2	227.6	104.2	9.6		1684.9	1117.4	90.3	529.0	11854.8	10598.0	181644.0
Dhole Patil	0.012	0.01	26.4	149.4	68.4	6.3		1105.9	733.4	59.3	347.2	7781.0	6956.0	119222.7
Ghole Road	0.013	0.01	29.2	165.2	75.6	7.0		1223.1	811.1	65.6	383.9	8605.1	7692.8	131849.9
Hadapsar	0.022	0.01	47.6	269.6	123.4	11.4		1995.4	1323.3	107.0	626.4	14038.9	12550.5	215109.3
Kothrud	0.016	0.01	35.5	201.1	92.1	8.5		1488.6	987.2	79.8	467.3	10473.3	9363.0	160475.8
Kasba Vishram	0.017	0.01	37.8	214.2	98.1	9.0		1585.7	1051.6	85.0	497.8	11156.6	9973.8	170945.2
Sahakar Nagar	0.016	0.01	34.5	195.6	89.5	8.3		1447.8	960.2	77.6	454.5	10186.5	9106.5	156081.0
Sangam Wadi	0.020	0.01	44.4	251.4	115.1	10.6		1860.7	1234.0	99.8	584.1	13091.6	11703.7	200594.4
Tilak Road	0.019	0.01	40.9	231.6	106.0	9.8		1714.3	1136.9	91.9	538.2	12061.2	10782.5	184806.0
Warje Karve	0.018	0.01	39.5	223.9	102.5	9.4		1657.2	1099.0	88.8	520.2	11659.6	10423.5	178653.2
Yerwada	0.019	0.01	40.5	229.4	105.0	9.7		1697.9	1126.0	91.0	533.0	11945.7	10679.2	183035.8
Bhawani Peth	0.015	0.01	32.6	184.5	84.5	7.8		1365.7	905.7	73.2	428.7	9608.6	8589.9	147226.8
Total (kg/day)	**0.001**	**0.0005**	**1.452**	**8.222**	**3.764**	**0.347**		**60.9**	**40.4**	**3.3**	**19.1**	**428.2**	**382.8**	**6561.6**
Total (T/yr)	**0.0002**	**0.0002**	**0.53**	**3.00**	**1.37**	**0.13**		**22.2**	**14.7**	**1.2**	**7.0**	**156.3**	**139.7**	**2395.0**

3.2.3 Open Eatouts

In India, the national policy for urban street vendors /hawkers notes that street vendors constitute approximate 2% of the population of a metropolis. Pune is surrounded by a large number of street vendors catering to a large population of people all across the city. The street vendors provide sort of fast food which varied from simple tea/coffee to groundnut and maize roasting. Some of them are seasonal depending up on the type of food item sold where as others are usually found all the year round. A large portion of these street vendors are authorized by Municipal Corporation and located at permanent places, whereas equally significant fraction of them are unauthorized and keep shifting from one place to other. On the basis of primary survey, 40% of the vendors use LPG as fuel followed by 28% of Kerosene and coal. The average consumption of kerosene per day is approximately 2.5 liters, 1 ½ cylinder (14.6 kg/day LPG) and 4 kg/day of coal for cooking purpose. Average operating hours of street vendors is 8-10 hours. Data regarding number of street vendors is not available since it is considered as illegal operation within the corporation limit. PMC regularly takes action on unauthorized street vendors and the data is documented. These number have been verified and fuel use pattern was estimated on the basis of primary survey (**Table 3.5).**

Table 3.5 : The Ward wise Distribution of Open Eat outs and Their Fuel Consumption

	Street Vendor No.			Fuel Consumption (kg/day)		
Wards	**LPG**	**Kerosene**	**Coal**	**LPG**	**Kerosene**	**Coal**
Aundh	9	6	4	192	39	24
Bhavani Peth	7	5	4	149	33	24
Bibwewadi	8	6	3	170	39	18
Dhankawdi	9	5	5	192	33	30
Dhole Patil	6	5	4	128	33	24
Ghole road	8	4	3	170	26	18
Hadapsar	11	8	10	234	52	60
Karve road	6	4	5	128	26	30
Kasba Vishram Bagh	7	4	4	149	26	24
Sahakar nagar	7	4	4	149	26	24
Sangam Wadi	8	6	6	170	39	36
Tilak road	10	7	8	213	46	48
Warje karve nagar	6	3	5	128	20	30
Yerawada	6	3	4	128	20	24
Total	**108**	**70**	**69**	**2300**	**458**	**414**

Emission Estimation

Per capita consumption for each type of fuel is taken as : For Kerosene – 8 lits/day * density i.e. (6.53 kg), for LPG = 1.5 cylinder *14.2 capacity * density i.e. (21.3 kg) and for Coal – 6 kg/day; Total emissions = emissions from kerosene burning + LPG burning + Coal burning.

Emission from kerosene burning (PM) per day
= Number of street vendors operating on kerosene x fuel consumption per day x emission factor
= (70 x 6.53 x 0.06 (EF SPM))/ 1000 x 0.61 (EF PM) =0.0028 kg/d
Emission from LPG burning (PM) per day
= Number of street vendors operating on LPG x fuel consumption per day x emission factor
= 108 x 21.3 / 1000 x 2.10 = 4.83 kg/d
Emission from Coal burning (PM) per day
= Number of street vendors operating on Coal x fuel consumption per day x emission factor
= 69 x 6 /1000 x 20 (EF SPM) x 0.6 (PM) = 4.97 kg/d

Emission factors for LPG, Kerosene and Coal burning are listed in **Annexure I**. Emission for others pollutants have been also estimated similarly as given in **Table 3.6.**

Table 3.6 : Emission Loads from Open Eatouts for all Wards

	Kerosene (Kg/day)					
	PM10	**PM2.5**	**SOx**	**NOx**	**CO**	**HC**
Aundh	0.001	0.03	0.16	0.10	2.43	0.75
Bhavani Peth	0.001	0.02	0.13	0.08	2.03	0.62
Bibwewadi	0.001	0.03	0.16	0.10	2.43	0.75
Dhankawdi	0.001	0.02	0.13	0.08	2.03	0.62
Dhole Patil	0.001	0.02	0.13	0.08	2.03	0.62
Ghole Road	0.001	0.02	0.10	0.07	1.62	0.50
Hadapsar	0.002	0.04	0.21	0.13	3.24	0.99
Karve Road	0.001	0.02	0.10	0.07	1.62	0.50
Kasba Vishram Bagh	0.001	0.02	0.10	0.07	1.62	0.50
Sahakar Nagar	0.001	0.02	0.10	0.07	1.62	0.50
Sangam Wadi	0.001	0.03	0.16	0.10	2.43	0.75
Tilak Road	0.002	0.03	0.18	0.11	2.84	0.87
Warje Karve Nagar	0.001	0.01	0.08	0.05	1.22	0.37
Yerawada	0.001	0.01	0.08	0.05	1.22	0.37
Total (Kg/day)	**0.02**	**0.3**	**1.8**	**1.1**	**28.4**	**8.7**
Total (Tons/Year)	**0.006**	**0.11**	**0.67**	**0.42**	**10.36**	**3.17**

Site-specific emission distribution shows that some areas are commercial, and mixed (industrial estates, shopping malls) spots, where likelihood of floating population is high. 72% of CO from Kerosene and 26% from Coal are the major pollutant estimated in this category. LPG and Coal each contribute almost 50% of PM. The 67% of SO_2 is emitted from Coal burning. NOx is contributed highest form LPG i.e. 60%, where as 96% HC is from kerosene. The actual number of street vendors could be high /low than the estimated depending upon time, season and locations.

Table 3.6 (Contd..) : Emission Loads from Open Eatouts for all Wards

Wards	LPG (Kg/day)							Coal (Kg/day)					
	PM10	PM2.5	SO_2	NOx	CO	HC	CO2	PM10	PM2.5	SO_2	NOx	CO	HC
Aundh	0.4	0.4	0.1	0.3	0.05	0.01	329.0	0.29	0.20	0.32	0.10	0.60	0.01
Bhavani Peth	0.3	0.3	0.1	0.3	0.04	0.01	255.9	0.29	0.20	0.32	0.10	0.60	0.01
Bibwewadi	0.4	0.4	0.1	0.3	0.04	0.01	292.4	0.22	0.20	0.24	0.07	0.45	0.01
Dhankawdi	0.4	0.4	0.1	0.3	0.05	0.01	329.0	0.36	0.20	0.40	0.12	0.75	0.02
Dhole Patil	0.3	0.3	0.1	0.2	0.03	0.01	219.3	0.29	0.20	0.32	0.10	0.60	0.01
Ghole Road	0.4	0.4	0.1	0.3	0.04	0.01	292.4	0.22	0.20	0.24	0.07	0.45	0.01
Hadapsar	0.5	0.5	0.1	0.4	0.06	0.02	402.1	0.72	0.39	0.80	0.24	1.50	0.03
Karve Road	0.3	0.3	0.1	0.2	0.03	0.01	219.3	0.36	0.20	0.40	0.12	0.75	0.02
Kasba Vishram	0.3	0.3	0.1	0.3	0.04	0.01	255.9	0.29	0.20	0.32	0.10	0.60	0.01
Sahakar Nagar	0.3	0.3	0.1	0.3	0.04	0.01	255.9	0.29	0.20	0.32	0.10	0.60	0.01
Sangam Wadi	0.4	0.4	0.1	0.3	0.04	0.01	292.4	0.43	0.20	0.48	0.14	0.90	0.02
Tilak Road	0.4	0.4	0.1	0.4	0.05	0.02	365.5	0.58	0.39	0.64	0.19	1.20	0.02
Warje KarveN.	0.3	0.3	0.1	0.2	0.03	0.01	219.3	0.36	0.20	0.40	0.12	0.75	0.02
Yerawada	0.3	0.3	0.1	0.2	0.03	0.01	219.3	0.29	0.20	0.32	0.10	0.60	0.01
Total (Kg/d)	**4.8**	**4.8**	**0.9**	**4.1**	**0.6**	**0.2**	**3947.5**	**5.0**	**3.1**	**5.5**	**1.7**	**10.3**	**0.2**
Total (T/yr)	**1.8**	**1.8**	**0.3**	**1.5**	**0.2**	**0.1**	**1440.8**	**1.8**	**1.1**	**2.0**	**0.6**	**3.8**	**0.1**

Wards	Total Open Eatouts (Kg/day)						
	PM10	PM2.5	SO_2	NOx	CO	HC	CO2
Aundh	0.7	0.6	0.6	0.5	3.1	0.8	329.0
Bhavani Peth	0.6	0.5	0.5	0.4	2.7	0.6	255.9
Bibwewadi	0.6	0.6	0.5	0.5	2.9	0.8	292.4
Dhankawdi	0.8	0.6	0.6	0.5	2.8	0.6	329.0
Dhole Patil	0.6	0.5	0.5	0.4	2.7	0.6	219.3
Ghole Road	0.6	0.6	0.4	0.4	2.1	0.5	292.4
Hadapsar	1.2	0.9	1.1	0.8	4.8	1.0	402.1
Karve Road	0.6	0.5	0.6	0.4	2.4	0.5	219.3
Kasba Vishram	0.6	0.5	0.5	0.4	2.3	0.5	255.9
Sahakar Nagar	0.6	0.5	0.5	0.4	2.3	0.5	255.9
Sangam Wadi	0.8	0.6	0.7	0.5	3.4	0.8	292.4
Tilak Road	1.0	0.9	0.9	0.7	4.1	0.9	365.5
Warje KarveN.	0.6	0.5	0.5	0.4	2.0	0.4	219.3
Yerawada	0.6	0.5	0.4	0.4	1.8	0.4	219.3
Total (Kg/d)	**9.8**	**8.3**	**8.3**	**6.9**	**39.3**	**9.1**	**3947.5**
Total (T/yr)	**3.6**	**3.0**	**3.0**	**2.5**	**14.3**	**3.3**	**1440.8**

3.2.4 Hotels and Restaurants

There are in all more than 30,000 shops and around 93,000 trading establishments in the Pune city. Currently, Central Business District (CBD) comprises areas of Camp (MG Road, East Road), Swargate, Laxmi Road (Tilak Road, Bajirao Road), Kalyani Nagar, Shivajinagar, Wakad Wadi, Deccan, FC Road, JM Road, and Ahmednagar Road, have commercial activities area, corporate offices, shopping malls where major hotels and restaurants activities are observed. The total number of hotels are 1349 *(City Development Plan, PMC)* which add to emissions to the overall Pune air. Though most of them use clean fuel like LPG the consumption is very high, necessitating an attempt to estimate the emissions from this sector. Survey of about 50 hotels in the central part of the Pune city was carried out for various parameters such as fuel type, quantity, hours of cooking, ventilation arrangement, area of the hotel, stack details (if available). The survey also revealed that 70% of the hotels are large in terms of daily operations, consuming more than 3 cylinders per day on an average, whereas 30% of the smaller hotels consume 1 ½ cylinder per day each of 19.2 kg capacity and 8 kg of coal per day in big hotels. The fuel quality and number of hotels presented in **Table 3.7**.

Table 3.7 : Ward wise Fuel Consumption from Hotel & Restaurants

Wards	No.of Hotels	LPG (Kg/day) Consumption	Coal (Kg/day) Consumption
Aundh	72	2872.8	615.6
Bhavani Peth	108	3810.2	699.8
Bibwewadi	45	2381.4	437.4
Dhankawdi	90	1984.5	364.5
Dhole Patil	171	7541.1	1385.1
Ghole road	215	18014.9	3308.9
Hadapsar	52	5478.2	1006.2
Karve road	110	2802.8	514.8
Kasba Vishram Bagh	130	7007.0	1287.0
Sahakar nagar	94	5987.8	1099.8
Sangam Wadi	20	921.2	169.2
Tilak road	42	411.6	75.6
Warje karve nagar	84	1728.7	317.5
Yerawada	116	4774.6	877.0
Total	**1349**	**65716.8**	**12158.4**

Emission Estimations

Total $PM_{2.5}$ is considered as PM10 emissions due to LPG burning in Hotels

= No. of Hotels x LPG consumption (kg/day) x Emission Factor (Kg/MT)

= 1349 x (70% - 3x19.2/1000 T/d + 30% - 1.5 x19.2/1000 T/d) x EF 2.1 Kg/MT = 164 Kg/Day

Emission Load from Coal
Total emissions (PM) due to coal burning in Hotels
= No. of Hotels x Coal consumption (kg/day) x Emission Factor (Kg/MT)
= 1349 x 8/1000 Tons/day x EF 20 kg/MT (SPM) x 0.60 (PM) = 215.8 Kg/Day

Emission factors for LPG and Coal burning are listed in **Annexure I**. Emission for others pollutants have been also estimated similarly as given in **Table 3.8.**

Table 3.8 : Emission Loads from Hotel & Restaurants for all Wards

Wards	**Emission from LPG (kg/day)**						
	PM10	**pm2.5**	**SO2**	**NO2**	**CO**	**HC**	**CO2**
Aundh	7.3	7.3	1.4	6.3	0.9	0.3	5986.1
Bhavani Peth	9.5	9.5	1.8	8.1	1.1	0.3	7739.3
Bibwewadi	5.9	5.9	1.1	5.1	0.7	0.2	4837.1
Dhankawdi	4.9	4.9	0.9	4.2	0.6	0.2	4030.9
Dhole Patil	18.7	18.7	3.6	16.1	2.2	0.6	15317.4
Ghole road	44.8	44.8	8.5	38.4	5.4	1.5	36591.5
Hadapsar	13.6	13.6	2.6	11.7	1.6	0.5	11127.2
Karve road	7.0	7.0	1.3	6.0	0.8	0.2	5693.0
Kasba Vishram Bagh	17.4	17.4	3.3	14.9	2.1	0.6	14232.5
Sahakar nagar	14.9	14.9	2.8	12.8	1.8	0.5	12162.3
Sangam Wadi	2.3	2.3	0.4	2.0	0.3	0.1	1871.1
Tilak road	1.0	1.0	0.2	0.9	0.1	0.0	836.0
Warje karve nagar	4.3	4.3	0.8	3.7	0.5	0.1	3511.3
Yerawada	11.9	11.9	2.3	10.2	1.4	0.4	9698.0
Total Kg/day	**163.5**	**163.5**	**31.2**	**140.2**	**19.6**	**5.6**	**133633.7**
Total Tons/Yr	**59.7**	**59.7**	**11.4**	**51.2**	**7.2**	**2.0**	**48776.3**
	Emission from Coal (kg/day)						
Aundh	6.9	4.7	7.7	2.3	14.4	0.3	
Bhavani Peth	10.4	7.1	11.5	3.4	21.5	0.4	
Bibwewadi	4.3	2.9	4.8	1.4	9.0	0.2	
Dhankawdi	8.6	5.9	9.6	2.9	17.9	0.4	
Dhole Patil	16.4	11.2	18.2	5.5	34.1	0.7	
Ghole road	20.6	14.0	22.9	6.9	42.9	0.9	
Hadapsar	5.0	3.4	5.5	1.7	10.4	0.2	
Karve road	10.6	7.2	11.7	3.5	21.9	0.4	
Kasba Vishram Bagh	12.5	8.5	13.8	4.1	25.9	0.5	
Sahakar nagar	9.0	6.1	10.0	3.0	18.7	0.4	
Sangam Wadi	1.9	1.3	2.1	0.6	4.0	0.1	
Tilak road	4.0	2.7	4.5	1.3	8.4	0.2	
Warje karve nagar	8.1	5.5	8.9	2.7	16.7	0.3	
Yerawada	11.1	7.6	12.3	3.7	23.1	0.5	
Total Kg/day	**129.5**	**88.1**	**143.5**	**43.1**	**268.9**	**5.4**	
Total Tons/Yr	**47.3**	**32.1**	**52.4**	**15.7**	**98.2**	**2.0**	

Table 3.8 (Contd..) : Emission Loads from Hotel & Restaurants for all Wards

Wards	Total Emission from Hotel & Restaurants (kg/day)						
	PM10	**pm2.5**	**SO2**	**NO2**	**CO**	**HC**	**CO2**
Aundh	14.2	12.0	9.1	8.6	15.2	0.5	5986.1
Bhavani Peth	19.8	16.5	13.3	11.6	22.7	0.8	7739.3
Bibwewadi	10.2	8.9	5.9	6.5	9.7	0.4	4837.1
Dhankawdi	13.6	10.8	10.5	7.1	18.5	0.5	4030.9
Dhole Patil	35.2	29.9	21.8	21.5	36.3	1.3	15317.4
Ghole road	65.4	58.8	31.4	45.2	48.2	2.4	36591.5
Hadapsar	18.6	17.0	8.1	13.3	12.0	0.7	11127.2
Karve road	17.5	14.1	13.0	9.5	22.8	0.7	5693.0
Kasba Vishram Bagh	29.9	25.9	17.1	19.1	28.0	1.1	14232.5
Sahakar nagar	23.9	21.0	12.8	15.8	20.5	0.9	12162.3
Sangam Wadi	4.2	3.6	2.6	2.6	4.3	0.2	1871.1
Tilak road	5.1	3.8	4.7	2.2	8.5	0.2	836.0
Warje karve nagar	12.4	9.8	9.8	6.4	17.3	0.5	3511.3
Yerawada	23.0	19.4	14.6	13.9	24.5	0.9	9698.0
Total Kg/day	**293.0**	**251.6**	**174.7**	**183.2**	**288.6**	**11.0**	**133633.7**
Total Tons/Yr	**107.0**	**91.8**	**63.8**	**66.9**	**105.3**	**4.0**	**48776.3**

Site-specific major contributions of PM from hotel and restaurant category are higher from Ghole Road, Dhole Patil Road, Kasba Vishrambaug and Yerwada, where the sites are predominantly commercial. Next highest emissions load are for CO, NOx and SO_2, which are majorly from Ghole Road and Dhole Patil Road. LPG and Coal contribute 56% and 44% of PM emission load. 77% NOx is estimated from LPG and 82% of SOx from Coal. LPG and Coal contribute 51% and 49% of the total HC emission load. There is prevalent unauthorized use of Domestic cylinders as source of fuel in the commercial sector for which data is not available.

3.2.5 Domestic Cooking

Pune population is around 31.24 lakhs as per Census, 2011 which reflect average density about 12,777; for which more and more residential blocks are being developed. During 2016-17, there were 3095 construction activities were being carried out in the city. The major proportion of Pune's population lives in slums. With regards to slums, the City Sanitation plan (CSP 2012, Pune) gives the total number as 564 with 353 declared or notified and 211 undeclared or not notified. The slum population in Pune is around 12,59,216. The total area occupied by the slums in Pune is approximately 661 hectares. Out of 564 slums, 124 slums are located on non- private land (21.99%) and 440 slums are located on the Private Land (78.01%). Density in slums is approximately 2,399 persons per hectare which is too high for area. Emission load of different pollutants caused by domestic cooking in the slum areas as well as the non-slum areas was calculated on the basis of various types of fuels used.

One of the most differentiating factors that came out of the survey is that most of the houses used mixed fuels i.e. a combination of different fuel options available within the area of Pune city. The overall emissions calculations and distribution is on the basis of three basic types of fuel i.e. Fuel Wood, Kerosene and LPG in the ratio of 0.196: 0.317: 0.405 has been considered. Percentage of LPG and Kerosene consumption by household was estimated on the basis of questionnaire survey. LPG is the major fuel used (75-85%), besides; about 15-20% of kerosene and 5-10% wood is used as fuel by domestic. One family consumes 1 ½ cylinder in a month of 14.6 Kg, wood of 1 to 1.5 kg/day (traditional domestic water heaters for bathing boiling water in non-slum areas) and average kerosene consumption by a slum household is about 25 Liters/month and non-slum household consumption is 3 Liters/month. The number of members in a slum household and non-slum household is assumed to be 6 and 5 respectively. The total consumption is converted into kilogram for per day emission calculation which is shown in **Table 3.9**.

Table 3.9 : Ward wise Fuel Consumption from Domestic Sector

Wards	LPG Consumption (Kg/day)		Wood Consumption (Kg/day)		Kerosene Consumption (Kg/day)	
	Slum	**Non Slum**	**Slum**	**Non Slum**	**Slum**	**Non Slum**
Aundh	2633	34611	3005	4827	2044	1086
Ghole Road	5358	21783	6116	3038	4159	684
Karve Road	5145	31921	5873	4452	3994	1002
Wajare Karve Nagar	3316	45008	3786	6278	2574	1412
Dhole Patil Road	4573	20765	5220	2896	3550	652
Sangam Wadi	7388	36139	8434	5041	5735	1134
Nagar Rodvadgav Sheri	1890	52035	2158	7258	1467	1633
Tilak Road	5306	39189	6058	5466	4119	1230
Bhavani Peth	3848	32712	4392	4563	2987	1027
Sahakar Nagar	4501	33023	5138	4606	3494	1036
Kasab Vishram	564	53318	643	7437	438	1673
Hadpsar	5362	48816	6121	6809	4162	1532
Dhamakwadi	334	57697	381	8047	259	1811
Bibavewadi	998	69812	1139	9737	775	2191
Total (kg/day)	**51215**	**576828**	**58465**	**80454**	**39756**	**18102**

Emission Estimation

- Emission Load from LPG

= Number of LPG cylinders consumed (Slum and Non Slum areas) x Capacity of the cylinder (14.6 Kg * density) x Em. Factor (Kg/MT) = 628043 Cylinder x (capacity 14.6*density) x 2.1/1000 kg/d= 1318.9 Kg/Day. PM_{10} emission are considered as PM2.5

(Dr.D.P.Singh, Slum Population in Mumbai: Part I, Population – ENVIS Centre IIPS, Vol.3, No.1, March, 2006). Number of Household was calculated on the assumption that there are 6 members from one slum-household and 5 members in non -slum household

Kerosene consumption per slum household = 25 liters/month = 0.68 Liters/Day
Kerosene consumption per non-slum household = 3liters/month = 0.1 Liters/Day

Total emissions (PM) from kerosene burning per day =
= (Slum Pop./6 x No.of Household x 0.68L/d) +(NonSlum Pop./5 x No.of Household x 0.1L/d) = 57858 (kg/day) x (EF 0.61/1000) Kg/Ton = 35.3 Kg/day

Total emissions (PM) from wood burning per day =
= (Wood consumption Slum & non Slum /day approx 1.5 kg = 138919 (kg/day) x (EF 17.3/1000) Kg/Ton = 2403.3 Kg/day

Emission factors for LPG, Wood and Kerosene burning are listed in **Annexure I**. Emission for others pollutants have been also estimated similarly as given in **Table 3.10.**

Table 3.10 : Domestic Sector LPG Usages Emission Load (kg/day) from Slum and Non Slum Areas

Wards	**Emission from LPG (kg/day)**						
	PM10	**pm2.5**	**SO2**	**NO2**	**CO**	**HC**	**CO2**
Aundh	78.2	78.2	14.9	67.0	9.4	2.7	63910.4
Ghole Road	57.0	57.0	10.9	48.9	6.8	2.0	46574.6
Karve Road	77.8	77.8	14.8	66.7	9.3	2.7	63604.1
Wajare Karve Nagar	101.5	101.5	19.3	87.0	12.2	3.5	82924.5
Dhole Patil Road	53.2	53.2	10.1	45.6	6.4	1.8	43480.0
Sangam Wadi	91.4	91.4	17.4	78.3	11.0	3.1	74693.1
Yerwada	113.2	113.2	21.6	97.1	13.6	3.9	92535.7
Tilak Road	93.4	93.4	17.8	80.1	11.2	3.2	76353.6
Bhavani Peth	76.8	76.8	14.6	65.8	9.2	2.6	62735.7
Sahakar Nagar	78.8	78.8	15.0	67.5	9.5	2.7	64390.5
Kasab Vishram Bagh	113.2	113.2	21.6	97.0	13.6	3.9	92461.3
Hadpsar	113.8	113.8	21.7	97.5	13.7	3.9	92968.8
Dhamakwadi	121.9	121.9	23.2	104.5	14.6	4.2	99580.2
Bibavewadi	148.7	148.7	28.3	127.5	17.8	5.1	121509.6
Total (Kg /day)	**1318.9**	**1318.9**	**251.2**	**1130.5**	**158.3**	**45.2**	**1077722.3**
Total (Ton/Yr)	**481.4**	**481.4**	**91.7**	**412.6**	**57.8**	**16.5**	**393368.6**

Table 3.10 (Contd..) : Domestic Sector Fuel Consumption Emission Load (kg/day) from Slum and Non Slum Areas

Wards	Domestic Wood (Kg/d) [Slum & Non Slum Areas]							Domestic Kerosene (Kg/d) [Slum & Non Slum Areas]					
	PM10	PM2.5	SO_x	NOx	CO	HC	CO2	PM10	PM2.5	SO_2	NOx	CO	HC
Aundh	135.5	92.1	1.6	10.2	989.3	896.9	13315.9	1.9	1.3	12.5	7.8	194.1	59.5
Bibvewadi	158.4	107.7	1.8	11.9	1156.2	1048.2	15562.8	3.0	2.0	19.4	12.1	300.2	92.0
Dhanakawadi	178.6	121.5	2.1	13.4	1304.1	1182.2	17552.6	3.0	2.1	20.0	12.5	309.7	94.9
Dhole Patil	174.1	118.4	2.0	13.1	1271.0	1152.3	17107.8	2.4	1.7	15.9	10.0	247.2	75.8
Ghole Road	140.4	95.5	1.6	10.6	1025.1	929.3	13798.1	2.6	1.7	16.8	10.5	260.5	79.8
Hadapsar	233.1	158.5	2.7	17.5	1701.8	1542.8	22906.9	4.2	2.8	27.5	17.2	425.9	130.5
Kothrud	162.9	110.8	1.9	12.2	1189.2	1078.1	16006.0	1.9	1.3	12.4	7.8	192.2	58.9
Kasba Vishram	199.4	135.6	2.3	15.0	1455.4	1319.4	19590.0	3.3	2.2	21.4	13.4	331.6	101.6
Sahakar Nagar	154.9	105.3	1.8	11.6	1131.0	1025.3	15223.3	2.4	1.7	16.1	10.0	248.8	76.3
Sangam Wadi	168.6	114.6	1.9	12.7	1230.6	1115.6	16564.2	2.8	1.9	18.1	11.3	280.9	86.1
Tilak Road	139.8	95.1	1.6	10.5	1020.5	925.2	13736.2	1.3	0.9	8.4	5.3	130.9	40.1
Warje Karve	223.7	152.1	2.6	16.8	1633.0	1480.4	21979.9	3.5	2.4	22.8	14.2	353.0	108.2
Yerwada	145.8	99.2	1.7	11.0	1064.5	965.1	14328.4	1.3	0.9	8.3	5.2	128.3	39.3
Bhawani Peth	188.2	128.0	2.2	14.1	1373.7	1245.4	18490.2	1.8	1.2	11.9	7.4	183.9	56.3
Total (kg/day)	**2403.3**	**1634.2**	**27.8**	**180.6**	**17545.5**	**15906.2**	**236162.4**	**35.3**	**24.0**	**231.4**	**144.6**	**3587.2**	**1099.3**
Total (T/yr)	**877.2**	**596.5**	**10.1**	**65.9**	**6404.1**	**5805.8**	**86199.3**	**12.9**	**8.8**	**84.5**	**52.8**	**1309.3**	**401.2**

Table 3.10 (Contd..) : Domestic Sector Fuel Consumption Emission Load (kg/day) from Slum and Non Slum Areas

Wards	Total Emission Domestic Sector (Kg/d) [Slum & Non Slum Areas]						
	PM10	**PM2.5**	**SO_x**	**NOx**	**CO**	**HC**	**CO2**
Aundh	215.6	171.7	29.0	85.0	1192.7	959.0	77226.3
Bibvewadi	218.3	166.7	32.1	72.9	1463.3	1142.2	62137.4
Dhanakawadi	259.5	201.4	36.9	92.6	1623.1	1279.8	81156.7
Dhole Patil	278.0	221.5	37.3	110.0	1530.4	1231.5	100032.4
Ghole Road	196.2	150.4	28.6	66.7	1292.0	1011.0	57278.1
Hadapsar	328.7	252.8	47.6	113.0	2138.7	1676.5	97600.0
Kothrud	278.0	225.3	35.9	117.1	1395.0	1140.8	108541.7
Kasba Vishram	296.1	231.2	41.5	108.4	1798.3	1424.3	95943.6
Sahakar Nagar	234.1	183.8	32.5	87.5	1389.0	1104.2	77959.0
Sangam Wadi	250.1	195.3	35.1	91.5	1520.9	1204.4	80954.7
Tilak Road	254.2	209.1	31.6	112.8	1165.0	969.2	106197.6
Warje Karve	340.9	268.2	47.0	128.6	1999.7	1592.5	114948.7
Yerwada	268.9	221.9	33.2	120.6	1207.5	1008.6	113908.7
Bhawani Peth	338.7	277.9	42.4	149.0	1575.4	1306.8	139999.9
Total (kg/day)	**3757.5**	**2977.1**	**510.4**	**1455.7**	**21291.0**	**17050.8**	**1313884.7**
Total (T/yr)	**1371.5**	**1086.7**	**186.3**	**531.3**	**7771.2**	**6223.5**	**479567.9**

Domestic sector maximum emission of PM is from Hadpsar, Warje Karve, and Bhawani Peth, as residential population density of slums and non slums are more in these areas. Amongst the pollutants, CO and HC is the major pollutant followed by PM and NOx. 63% of PM is estimated from wood combustion and 34% is from LPG. The percent contribution from SOx and NOx is around 83% and 74% from LPG, respectively; whereas 80-90% CO and HC is from wood combustion. Exact estimation of LPG consumption quantity in slum area is not possible, due to availability multiple option as fuel.

3.2.6 Building Construction

Real estate sector in Pune is growing; converting open lands to row houses, residential complexes and malls is recent phenomena observed in the city. Slum rehabilitation programme have also lead to large scale construction of new building society and towers. Data source for construction was obtained from list of RERA Registered Projects in Pune and Building department in Pune Municipal Corporation. The numbers of construction projects within the city are increasing year on year due to rapid urbanization and demand for built up space. During 2016-17 there were 3095 construction activities being carried on in the city. **Table 3.11** gives the construction area under each ward. The building construction dust source category provides estimates of the fugitive dust particulate matter caused due to construction and demolition activities.

- The activity is assumed to occur 6 days a week with 8 hours duration of working hours in total of 8 months in a year.
- The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction. The area of influence of each construction activity was taken as (sq meters 1 to acres 0.000247) acres for building.
- Emission due to vehicle movement during construction activity is not calculated

Table 3.11 : Construction works at Different Wards of Pune

Ward	Total Construction Area (Sq. Mt)	Area in acres		Ward	Total Construction Area (Sq. Mt)	Area in acres
Aundh	77994.7	19.3		Kasba Vishram Baugh	10219.6	2.5
Bhavani Peth	15474.5	3.8		Sahakar Nagar	9032.8	2.2
Bibwewadi	68358.0	16.9		Sangamwadi	840.0	0.2
Dhankwadi	1600.3	0.4		Tilak Road	11962.6	3.0
Dhole Patil Road	895.0	0.2		Warje Karve Road	4909.1	1.2
Ghole Road	63590.3	15.7		Yerwada	67959.6	16.8
Hadapsar	19917.2	4.9		**Total**	**368506.6**	**91.1**
Karve Road	15752.9	3.9				

Emission Estimation

For the purpose of estimating emissions, it is assumed that the fugitive dust emission is related to the acreage affected by construction.

Total area of Building construction in Pune 368506.6 (sq.meters) x 0.000247 (acres) x

8 months x EF (AP42, Section 13.2.3.3– PM10 - 1.2 tones/ acres months) = **3618.9 kg/day**.

Ward wise emission load of PM during construction activity is presented in **Table 3.12.**

Table 3.12 : PM Emission Load Due Construction works at Different Wards of Pune

Ward	PM Emission Load		Ward	PM Emission Load
Aundh	770.9		Kasba VishramBag	77.6
Bhavani Peth	153.0		Sahakar Nagar	89.3
Bibwewadi	675.7		Sangamwadi	8.3
Dhankwadi	15.8		Tilak Road	118.2
Dhole Patil Road	8.8		Warje Karve Road	48.5
Ghole Road	628.5		Yerwada	671.7
Hadapsar	196.9		**Total (kg/d)**	**3618.9**
Karve Road	155.7		**Total (Tones/yr)**	**1320.9**

Total Emission Load = 3618.9 kg/day and 1320.9 tones /year. Aundh, Bibwewadi, Yerwada and Ghole Road are the areas where some of the maximum particulate emission load due to construction activity is notice.

3.2.7 Open Burning

Open burning is the burning of any matter in such a manner that products resulting from the burning are emitted directly into the ambient (surrounding outside) air without passing through an adequate stack, duct or chimney. Open burning is an illegal method of burning solid waste; materials commonly disposed of in this manner include municipal waste, auto body components, wood refuse, small scale industrial refuse and leaves. Pune has large tree cover of about 33% of total municipal area, which is also surrounded by agricultural area. The trash of leaves is normally burnt in un-collectively manner which significant impact in total PM emissions. During the survey, discussions were carried out for understanding the generation and burning pattern of waste however estimates for hourly variations in emission loads have not been computed due to higher variability to the total PM_{10} emissions in the city. The data have been collected by Solid Waste Management Dept. of Pune. Municipal Corporation and discussions with NGO and local survey.

The quantity of waste generated was 1586 MT per day the maximum share of waste that is 40% comes from households followed by waste generated from hotels and restaurants (25%) and vegetables market waste 5%, construction 5% and commercial area 25%. The bio-medical waste is 0.1 percent and Construction and Demolition Waste is 5 percent. The waste collection efficiency of municipality is 100%; which is collected from door to door for 52% of households and rest of the waste is collected from the community bins and containers. There are 7 garbage collection centers, 412 compactor buckets and 936 containers placed in various parts of the city. 4% of the garbage from collected and uncollected trash is expected to be burnt throughout Pune city. The ward wise solid waste generation and dry waste likely to burnt as open burning for dry waste is given in **Table 3.13**.

Table 3.13 : Solid Waste and Open Burning Quantity at Different Wards of Pune City

	Total Waste Generation in MTD	Dry Waste	Open Burnt (4% Dry waste)
Aundh (Banner)	80.3	51.9	2.1
Bhavani Peth + (Kondva Yevlewadi)	69.3	64.3	2.6
Bibwewadi	133.3	124.1	5.0
Dhankawdi + (Katraj Ramp)	169.4	80.1	3.2
Dhole Patil	109.6	77.5	3.1
Ghole Road	116.9	79.3	3.2
Hadapsar (Mundhava V- Ramtekwadi)	242.5	125.1	5.0
Karve road +(Kothrud- Bavdhan)	115.2	68.8	2.8
Kasba Vishram Bagh	48.6	37.8	1.5
Sahakar Nagar	99.6	83.3	3.3
Tilak road + (Shihngad Road)	85.9	78.4	3.1
Warje Karve Nagar	95.8	59.9	2.4
Yerawada (Kalas-Dhanori Nagar Rd - Vadgao)	220.4	123.1	4.9
Total (MT)	**1586.7**	**1053.6**	**42.1**

Emission Estimation

Total emissions (PM) from open burning of solid waste
= Amount of solid waste generated (tons) x percentage of solid waste burnt x emission factor (Kg/MT) = [1053 (tons of dry waste) x 4% of open burning] x PM EF 8 (Kg/MT) = **337.2 Kg/Day.**

Emission factors are given in **Annexure I.** In similar way emission for others pollutants have been estimated and their ward wise distribution is presented in **Table 3.14**.

Table 3.14 : Ward Emission Load from Open Burning (kg/d)

	PM10	PM2.5	SOx	NOx	CO	HC
Aundh	16.6	11.3	1.0	6.2	87.1	44.6
Bhavani Peth	20.6	14.0	1.3	7.7	108.0	55.3
Bibwewadi	39.7	27.0	2.5	14.9	208.5	106.7
Dhankawdi	25.6	17.4	1.6	9.6	134.6	68.9
Dhole Patil	24.8	16.9	1.6	9.3	130.2	66.7
Ghole Road	25.4	17.3	1.6	9.5	133.2	68.2
Hadapsar	40.0	27.2	2.5	15.0	210.2	107.6
Karve Road	22.0	15.0	1.4	8.3	115.6	59.2
Kasba Vishram Bagh	12.1	8.2	0.8	4.5	63.6	32.5
Sahakar Nagar	26.7	18.1	1.7	10.0	139.9	71.6
Tilak Road	25.1	17.1	1.6	9.4	131.7	67.4
Warje Karve Nagar	19.2	13.0	1.2	7.2	100.6	51.5
Yerawada	39.4	26.8	2.5	14.8	206.8	105.9
Total (Kg/day)	**337.2**	**229.3**	**21.1**	**126.4**	**1770.1**	**906.1**
Total (Ton/day)	**123.1**	**83.7**	**7.7**	**46.1**	**646.1**	**330.7**

PM contribution is highest at Hadpsar, Bibwewadi and Yerwada. CO and HC are major pollutants from this sector. Refuse burning refers to common burning of street litter and leaves, although little is known about the magnitude of the practice. No documented data on rate of burning, area of dump, unauthorized activity of the rag pickers are available.

3.2.8 Paved & Unpaved Road Dust

Paved Road: As motor vehicle moves over road surface, it leads to resuspension of dust from unpaved roads or settled dust from the paved surface by the turbulent wake of the vehicle and emitted as particulate matter. Emissions are estimated as a function of the silt loading of the paved surface and mean weight of the vehicles traveling over the surface. Data source such as road length, vehicle km traveled and depot, truck terminal was obtained from Transport Dept. (RTO), Pune and primary survey of some roads for vehicle counting. As per survey observations 98% roads are paved and 2% roads are unpaved.

- **Emission Estimates for Paved Road Dust**

Vehicle Count 2005		**%Vehicle Count (A)**	**Avg.Weight (kg) (B)**	**Veh. Weight by % (A*B) (kg)**
2 W	2197442	0.51	175	89.3
3 W	634588	0.15	450	67.5
HDDV	428150	0.10	20000	2000.0
Cars	1065570	0.25	1425	356.3
Total	4325750			**2.51**

** Strengthening Environmental Management at the State Level (Cluster) Component E- Strengthening, Environmental Management at West Bengal Pollution Control Board, TA No. 3423-IND, Asian Development Bank, Nov. 2005*

Annual /Long Term Avg. E. Factor E = (k (sL/2)^0.91 (W/3^1.02)) (1-P/4N)

E= particulate emission factor (having units matching the units of k)

k= particle size multiplier for particle size range and units of interest

sL= road surface silt loading (grams per square meter) (g/m^2)

W= average weight (tons) of the vehicles traveling on the road

P= No. of wet days with at least 0.254 mm of precipitation during avg. period

N = No. of days in averaging period (365 /year, 30/monthly, 91/seasonal);

Values of k (g/vkt) = PM2.5 -0.15, PM10-0.62

EF (PM10) = (k (sL/2)^0.91 (W/3)^1.02) (1-P/4N)
=(0.62*((5/2)^0.91)*((1.0125^1.02))*(1-120/(4*365))) = **1.326 g/vkt**

EF (PM2.5) = (k (sL/2)^0.91 (W/3)^1.02) (1-P/4N)
=(0.15*((5/2)^0.91)*((1.0125^1.02))*(1-120/(4*365))) **= 0.320 g/vkt**

For VKT – calculate: lb/vmt to gms/vkt =0.98 (VKT * 0.98)
VKT from all shifts * $PM_{2.5}$ (EF) AND VKT from all shifts * PM_{10} (EF) =
Emission load for paved Road Dust

Emission Estimation for Unpaved Dust

Annual /Long Term Avg. E. Factor, E = {([k (s/12)^a (S/30) ^d] /(m/0.5) ^c-C)} *(365-P)/ 365

E = size specific emission factor, (lb/vmt),
s = surface material silt content (%),
m= surface material moisture content (%),
S= mean vehicle speed (mph);
k = particle size multiplier (lb/vmt),
P= No. of wet days with at least 0.254 mm of precipitation during avg. period
C= Break and tire wear correction ($PM_{2.5}$=0.00036, PM_{10}=0.00047) - lb/VMT
Public Roads- Constant k (lb/vmt) - $PM_{2.5}$= 0.27, PM_{10}=1.8;
a. $PM_{2.5}$=1, PM_{10}=1, b. $PM_{2.5}$=0.2, PM_{10}=0.2;
c. $PM_{2.5}$=0.5, PM_{10}=0.5

EF (PM_{10}) = {([k (s/12)a (S/30)d] /(m/0.5)c-C)} *(365-P)/ 365
=(((1.8*(18/12)^1*(12.5/30)^0.5)/(6.65/0.5)^0.2-0.00047))*(365-120)/365
0.69689 lb/vmt = **196.4534 g/vkt**

EF ($PM_{2.5}$) = {([k (s/12)^a (S/30) ^d] /(m/0.5) ^c-C)} *(365-P)/ 365
=(((0.27*(18/12)^1*(12.5/30)^0.5)/(6.65/0.5)^0.2-0.00036))*(365-120)/365
0.104339 lb/vmt = **29.41 g/vkt**

Emission Load

- Total **Paved** Dust Emission Load for Whole City =
  PM10= 7479.2 Kg/d and **PM2.5= 1809.5 Kg/d**
- Total **Unpaved** Dust Emission Load for Whole City =
  PM10= 22601.9 Kg/d and **PM2.5 = 3384.0 kg/d**

Wardwise contribution of the pollutant emission load is given in **Table 3.15.**

Table 3.15 : Wardwise Concentration of Paved and Unpaved Roads

Wards	Paved		Unpaved		Total
	PM2.5	PM10	PM2.5	PM10	
Aundh	177.3	732.7	331.5	2214.3	3455.8
Ghole Road	213.6	883.0	399.5	2668.4	4164.6
Dhole Patil	78.1	322.8	146.1	975.5	1522.5
Warje Karve Nagar	143.3	592.4	268.0	1790.2	2793.9
Karve Road	139.6	577.0	261.1	1743.7	2721.4
Bhavani Peth	32.9	136.0	61.5	411.0	641.5
Sangamwadi	83.5	345.0	156.1	1042.7	1627.3
Yerawada	157.8	652.2	295.1	1970.8	3075.8
Tilak Road	226.2	934.9	423.0	2825.2	4409.3

Table 3.15 (Contd..) : Wardwise Concentration of Paved and Unpaved Roads

Wards	Paved		Unpaved		Total
	PM2.5	PM10	PM2.5	PM10	
Kasba Vishram Bagh	37.2	153.7	69.6	464.5	725.0
Sahakar Nagar	82.8	342.3	154.9	1034.5	1614.6
Bibwewadi	175.8	726.8	328.8	2196.3	3427.8
Dhankawdi	139.7	577.6	261.3	1745.5	2724.2
Hadapsar	121.6	502.7	227.4	1519.1	2370.8
Total Kg/day	**1809.5**	**7479.2**	**3384.0**	**22601.9**	**35274.5**
Total Tons/ Yr.	**660.5**	**2729.9**	**1235.2**	**8249.7**	**12875.2**

3.2.9 Brick Kilns

Coal burnt daily in brick kilns on the outskirt of city is one of the sources of air pollution. The second and third generation members of traditional brick kiln makers in the Pune city, have diversified to other businesses and this is manifested in the dwindling numbers of brick kilns. Sinhagad road, which was once the epicenter of the brick kiln business, barely has one or two major units today as against the 42 units it had a few years ago. According to the manufacturing capacity of brick kilns has come down substantially to nearly 200 loads annually (one load is equivalent to 1,000 bricks) and this was directly linked with the investment and marketing capabilities of the brick kiln owner.

No. of bricks produced per lot may vary at different units and time and duration of production process is also different. Due to data constraints, the primary survey and secondary data collection was undertook in the city area, and found very few number of brick kilns activities were observed at the outskirt of the city.

Brick produced by each unit = 10000 bricks/day Weight of each brick = 2.2 kg

EF for PM 10 = 1.4 lb/T of Brick Production = 0.7 kg/ T of Brick Production
Emission Estimation = EF* Total Brick Production

Total Emission = 0.6 tones/day of PM10 = 241.4 T/Yr

3.2.10 Non Industrial Generators

As far as non-Industrial generators, these are most commonly found in apartments and shopping malls also commercial area. However, the both generator types use diesel as fuel, so are known to be polluting. Through local survey the non industrial generators were quantified around 1276 around city in household sector as well as stores and shops. As per discussions with NGO around

4% annual growth were observed. In case of Non-Industrial generators time of usage here is fixing for 4 hrs every day as load shedding in some areas. However estimates for hourly variations in emission loads have not been computed due to higher variability and their insignificant contribution to the total PM10 emissions in the city. Normally 3 HP/5 HP generators were used consuming around 4 to 5 liters of diesel per day (density diesel 860).

Emission factor for non industrial generator = 0.002lbs i.e. 0.0009 Kg/hr (Diesel generator)
Exact fuel used for generator runs and capacity may vary at different sites and purpose.

Emission of PM in Non industrial area is around = **1.2 tones/day of PM10 = 450.6 T/Yr**

3.2.11 Agricultural Pumps

Pune is surrounded by a large agricultural area with large population of people being farmers all across the rural Pune. 5.32% of the agricultural area is forest and 1.7% is hills and Hill Slopes. As far as Agricultural pumps are concern these are most commonly used since olden days, but now as power is reached all pockets of city the usage of pumps are minimized. However, the pumps mainly use diesel as fuel, so are known to be polluting. Diesel pump are emission are mostly working during watering at agricultural fields 80% of the total pumps are of capacity 3-5 HP with usage of 4 hours average. 20% of the total pumps are of capacity 5-10 HP.

Average HP is 4 for 3 - 5 HP and 7.5 for 5 - 10 HP. Assuming the pumps are used for 180 days and an average of 4 hrs in a day. Although there are pumps between 20 to 400 HP but since the engine powers are variable we are clubbing the 20% of this group of Agricultural Pumps in the second group (5 -10 HP). It is considered that only 2% of the agricultural pumps are diesel operated.

Emission Factor =0.002lbs i.e. 0.0009 Kg/hr

Data Constraints :Use of Pump in Agricultural land distribution is not known correctly. Exact time of operation and actual usage of pump is a limitation. Survey was carried out to quantify the agricultural pump used in the city vicinity. Few farmers were interview to collect the information regarding the pump capacity in nearby fields. As few data is available detail estimation of emission load is not possible, so the agricultural pump emission was taken from recent study conducted by NEERI for USEPA study, 2010 'Air Quality Management Emission Inventory and Source Apportionment Studies' and reduction of 40% is estimated as more and more land are converted to residential blocks.

Emission of PM in Non industrial area is around = **0.5 tones/day of PM10 = 201.1 T/Yr**

3.3 Line Source (Transport)

Pune rapid population growth increase travel demand and population pressure, which in turn leads to spatial expansion of urban areas and increased journey lengths. Parallel growth in city economies and personal income leads to increased travel demand, increased cars and two wheelers ownership. Increase in ownership of two wheeler and cars works as a catalyst for air quality deterioration, road congestion and reduced journey speeds, wastage of scarce fuels, besides sub optimal utilization of infrastructure and other resources.

Out of the total 1,922 Km road network spread across city limits, 1,872 Km road are municipal roads and 50 Km roads come under national highway, state highway and PWD roads. Pune is connected to Mumbai by NH-4 as well by a new expressway, railways and airways. NH-50 connects Pune to Nashik, NH-9 to Solapur and NH-4 to Kolhapur-Bangalore, whereas state Highways are SH-27 connects to Ahmednagar, SH-60 to Kolad, SH-64 to Sasvad and SH-57 to Pirangut. As per Comprehensive Mobility Plan for Pune city, 42% of the roads in Pune city are four lanes divided and 35% roads constituted with two lanes. In addition to four lanes and two lanes 10% roads are six lanes, 1% road intermediate lane and 12% roads are four lanes undivided. Over the years, the total number of vehicles on Pune roads has increased with almost 10% annual growth in vehicular traffic. In Pune city around 2 lakh vehicles are added to the traffic every year. Two-wheelers are the major mode of transport in the city with 73% of motorized vehicles contributed by Motor Cycle, Scooter and Mopeds. Likewise, the number of vehicle registration has also increased considerably over the years. Such large number of vehicles within a city limits contribute to emission levels on large extents. The decadal vehicular growth and registered vehicles in Pune region and city limits is given in **Table 3.16 a&b and Figure 3.2a&b.**

Table 3.16a : Decadal Registered Vehicle Growth of Pune City

Name of the Office/Region	2012-13	2013-14	Growth %	2014-15	Growth %	2015-16	Growth %	2016-17	Growth %
Pune	202556	197028	**-2.73**	233596	**18.56**	249478	**6.80**	268775	**7.73**
Solapur	47727	54807	**14.83**	59168	**7.96**	58266	**-1.52**	64145	**10.09**
Pimpri Chinchwad	118070	120420	**1.99**	133743	**11.06**	142835	**6.80**	137410	**-3.80**
Baramati	23099	30008	**29.91**	28279	**-5.76**	23781	**-15.91**	23665	**-0.49**
Akluj	17595	15640	**-11.11**	19981	**27.76**	25006	**25.15**	25668	**2.65**
Pune Region Total	**409047**	**417903**	**2.17**	**474767**	**13.61**	**499366**	**5.18**	**519663**	**4.06**

Table 3.16b : Category wise Vehicle Distribution in Pune City (2018-19)

Sr.	Category	Pune	Pune Region
1	Motor Cycles	109269	251446
2	Scooters	68794	119223
3	Moped	406	655
	Total --Two Wheelers	**178469**	**371324**
4	Cars	49543	82201
5	Jeeps	10	3534
6	Stn. Wagons	0	0
7 a)	Taxis meter fitted	0	21
7 b)	Luxury /Tourist Cabs/	12617	16634
8	Auto-rickshaws	4937	6365
9	Stage carriages	0	7
10	Contract carriages /Mini Bus	4921	5578
11	School Buses	113	334
12	Private Service Vehicles	10	73
13	Ambulances	28	143
14	Articulated/Multi.	3038	3151
15	Trucks & Lorries	7188	8519
16	Tanker	37	188
17	Delivery Van (4wheelers)	4074	9842
18	Delivery Van (3wheelers)	1869	3842
19	Tractors	1249	5814
20	Trailors	190	1238
21	Others	482	855
	Total	**268775**	**519663**

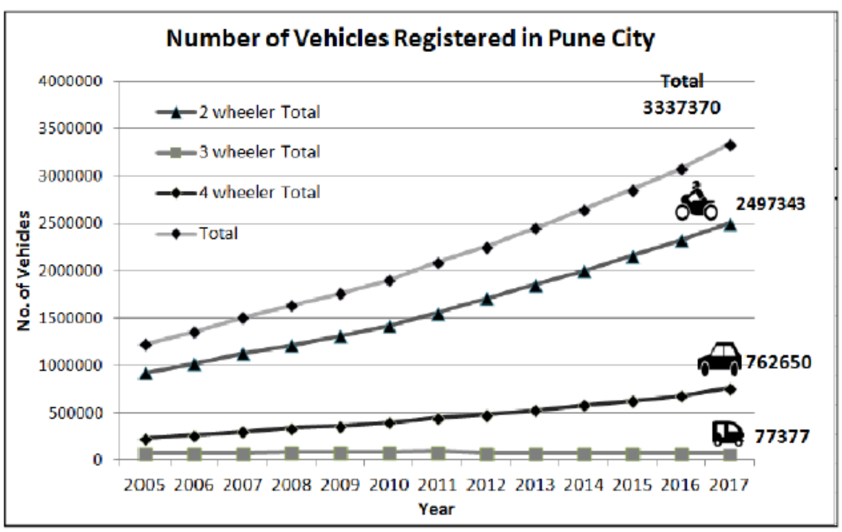


Figure 3.2a : Growth of Number of Registered Vehicles in Pune

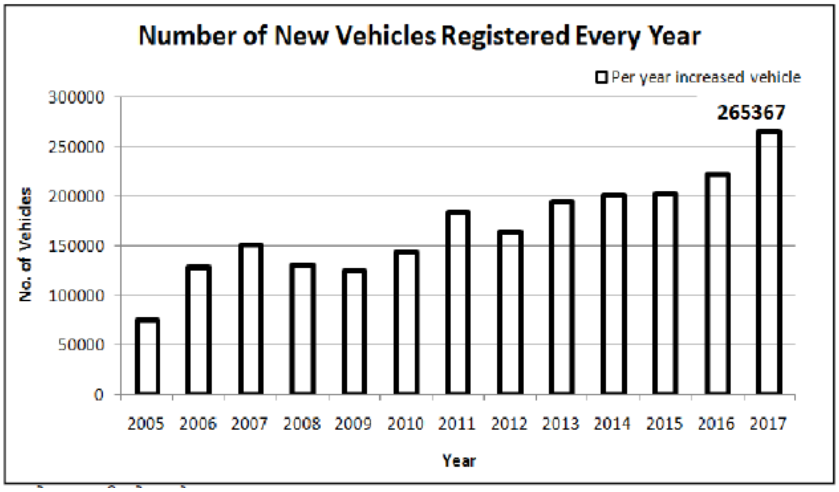


Figure 3.2b : Growth of New Vehicles Registered Vehicles in Pune

PMC is internally well- connected through an extensive road network comprising 11 major intercity roads. Pune has two main railway stations namely, Pune Junction and Shivajinagar Station; most trains halt at Pune Junction. Pune suburban trains run from Pune Junction to the industrial towns of Khadki, Pimpri and Chinchwad etc. The city has an international airport at Lohegaon operated by the Airport Authority of India. It shares its runways with the neighboring Indian Air Force base.

The road network in the city is divided into different categories based on the types of surface. It is found that majority of the roads in the city i.e. 71% are having Tar Road surface. Of the remaining roads, 3 % are having concrete surface, 16% WBM surface and 10% earthen surface. As per the land use study 13.05% of the total land is under transportation *(Source: DP cell, and CSP-2012, PMC)*, of the entire road length only about 25 percent in the city has a road width greater than 24 m and majority of them are the highways.

Congestion indicator on other major intersections is also greater than 1.5 (against the standard of 0.8) for the free flow of traffic movement. The average speed of vehicles in Pune city varies between 23 kilometer per hour to 13 kilometer per hours in peak hours, with clear start -stop and obstructed flow on many corridors. High volume capacity ratio in various corridors in Pune involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants. However, these measures are for traffic management but are not the permanent solution to the problem of congestion, moreover due to one way traffic flow the traffic moves through the inner roads and riders have to take longer routes, which adds to pollution, more fuel consumption and more wear-tear of vehicles.

Pune Mahanagar Parivahan Mahamandal Ltd. (PMPML) is the service provider of the public transport system of Pune. PMPML has about 1,745 buses in operation, including around 327 buses hired from private operators. PMPML operates 334 intercity routes with average route length of 18 Kms. As per PMPML records, 12.3 lakh passenger are daily travelling in PMPML buses. As of 2012, about 65,592 three wheelers are running on the streets of Pune. Six-seater autos are becoming increasingly popular, however, are causing higher level of pollution. According to Pune Traffic Control Branch, three wheelers wait for commuters at 500 designated stands on the streets. About 11% of the total trips in the city are made by cycles in the form of Non-Motorized Transport. Two-wheelers shared the majority of the total vehicles parked, which share 63% of the total vehicles followed by Car/ Van. Thus it can be seen that 89% of the vehicles parked on the streets are private vehicles. Two-wheelers shared the majority of the total vehicles parked, which shared 65% of the total vehicles. Cars and auto shared 25% and 3% respectively; Cycles shared 7% of the Total vehicle parked.

Pune is the Pioneer to introduce the first BRTS in India with a Pilot Project named Swargate-Katraj- Hadpsar, BRTS in 2006 The project consists of 16.5 kms of bus lanes along the Pune Satara Road using air conditioned, low-floor more than 500 Volvo B7RLE buses. BRTS route is comprised of 27 bus stops, 29 Junctions and 6 terminals. BRTS project also improve the PMPML performance, increase the ridership, reduce the accidents and save the travel time. After the completion of subway on westerly by-pass at Baner junction traffic congestion and travel time reduce considerably. Sangamwadi Bridge approach road increase the accessibility between Defense areas, Yerwada, Shivajinagar and Airport.

As Pune is having over wheeling growth it has some proposed developmental plan suggested in CMP such as :

Feeder Road Links:

- Development of feeder road linkages connecting the identified industrial area with NHDP, Hinterlands, inter alia, includes following development proposals:
- Provision of connectivity to NH-50 (Pune- Nashik/ Sinnar), NH-4 (Chennai) and NH-9 (Hyderabad/ Vijayawada).
- Widening and Strengthening of NH-50 to four-lane dual carriageway.
- Augmentation of Pune-Ahmed Nagar Link.
- Development of requisite grade separators/flyovers/interchanges and underpasses along the National Highways/ State Highways and access roads for uninterrupted freight and passenger movement to the region would also be included in the development of feeder links.

Feeder Rail Links:

- A high speed rail link is already available between Mumbai and Pune
- It is further recommended that Vasai Road-Karjat-Pune BG Link be upgraded to the standards of Dedicated Freight Corridor so as to enable movement of double stacked high speed container trains between JN Port, Pune and to cater to other traffic to/from Ahmedabad and Delhi side. These developments are expected to contribute enormous benefits to the Port / Hinterland Traffic from Pune Region.

The facilitation and management of roads and transportation in Pune is at present done by a multiplicity of agencies/departments like Municipal Corporation, PWD, NHAI, State Highways, RTO, Railways, Interstate bus operators, PMPML Board etc. No single agency is solely accountable for providing transport services as well as transport infrastructure resulting in overlapping functions, functional and spatial fragmentation. Pune Municipal Corporation is responsible for maintenance, construction of road network (city roads) and traffic management.

3.3.1 Primary Survey and Methodology

Grid wise emission inventory preparation includes the following procedural steps:

- Division of study area into grids of 2 Km X 2 Km size
- Identification of major nodes which represent major traffic junctions
- Calculation of road length between the nodes and estimation of grid-wise road length
- Collection of data on number and type of vehicles traveling between nodes through field studies
- Estimation of vehicle kilometers (Km) traveled by each type of vehicle in each grid

$$VKTI = RLj * NI$$

Where, VKTI = Vehicle Km traveled by vehicle type I,
RLj = Road length in grid j
NI = Number of vehicles travelling between nodes for vehicle type I per day,

- Selection of appropriate emission factors from the ARAI vehicle emission study.
- Estimation of emissions from each grid m

$$PMj = N * \sum_{j=1}^{m} VKTI * Ef_I$$

Where, PMj = Pollutant load in tones/year for grid j
N = Number of activity days in a year
Ef_I = Emission factor for a vehicle type I

3.3.2 Vehicle Counts

The assessment of the number of vehicle plying on the roads and emissions from them was important. For which, the vehicular count survey was carried out at the actual grid-wise within city limits. 40 major junctions were identified covering whole city (Mumbai NH-4, new expressway, NH-50 : Pune to Nashik : NH-9 : Solapur and NH-4 to Kolhapur) and inner traffic hotspots for vehicular survey. Road map of the city as given in Figure 5was used to determine the locations of the vehicle counting survey.

For this purpose, the 14 administrative wards Pune transportation network was divided into grids for vehicular survey. Manual counting of the traffic movement covering internal road and major traffic junctions was undertaken for continuous monitoring for whole day covering different types of vehicles categories viz. Cars, Taxis, 2 Wheelers, Three Wheelers, Heavy Duty Diesel Vehicles (HDDV) + Buses. It is important to note that these junctions have been selected after reconnaissance survey of the various inlets to the city and also designed to include multimodal and multi-functional characteristic of the vehicular population in the city. A vehicle counting programme specific to the need for developing emissions inventory was planned and executed in the month of April 2018 for different shifts of the day.

Shift	Traffic	Duration	No. of Hrs
I	Morning Peak	0700 to 1100	4
II	Afternoon Average	1100 to 1700	6
III	Evening Peak	1700 to 2200	5
IV	Night Average	2200 to 0700	9

The locations of major & minor road traffic junctions in 2 x 2 Kms grids are presented in **Table 3.17 and Figure 3.3.**

Table 3.17 : Vehicular Counting Locations for Estimating Vehicular Emission in Pune City

Wards	Grid No.	Major and Minor Road Traffic Roads (Connecting Interal Roads and Intersections)
Aundh	28,36,50, 52,61,63	Old Mumbai Pune Highway, Bapodi Road, Balewadi Road, Mumbai Pune Bypass Road, Pashan Road Circle, Pune Vidyapeeth Baner Road, Pune-Solapur Highway,Kothrud Road Near Bus Stop
Ghole Road	52,53,63, 64,65,75, 76	Pune Vidyapeeth Baner Road, Old Mumbai Pune Highway, Kothrud Road Near Bus Stop, F.C. Road, Shivaji Maharaj Chowk Road, Nyaymurti Ranade Path, Karve Road, Paud Phata, Tilak Road
Dhole Patil Rd	55,57, 65,66	Band Garden Road, Mundhwa Road, Shivaji Maharaj Chowk Road, Nyaymurti Ranade Path, Sasoon Road, Pune Station Road, Ramabai Ambedkar Road
Karve Road	61,63,73, 74,75	Pune-Solapur Highway, Kothrud Road Near Bus Stop,Chandani Chowk, Mumbai Pune Bypass Road, Kothrud Stand, Karve Road, Paud Phata
Kasba Vishram Bag	65,76,77	Shivaji Maharaj Chowk Road, Nyaymurti Ranade Path, Tilak Road, Mirza Galib Road ,Shukrawar Peth Pune
Bhavani Peth	65,66, 77,78	Shivaji Maharaj Chowk Road, Nyaymurti Ranade Path, Sasoon Road, Pune Station Road, Ramabai Ambedkar Road, Mirza Galib Road , Shukrawar Peth Pune Mumbai Highway

Table 3.17 (Contd..) : Vehicular Counting Locations for Estimating Vehicular Emission in Pune

Bibwewadi	103,115, 127	Kondhwa Kharda Jyoti Chowk, Saswad Bopdev Pune Road , Saswad Bopdev Road
Sangamwadi	20,42,53, 55, 65	Lohegaon Road, Alandi Road, Old Mumbai Pune Highway, Band Garden Road, Shivaji Maharaj Chowk Road,Nyaymurti Ranade Path
Warje Karve Nagar	73,74,75, 76,87,88, 98,99	Chandani Chowk, Mumbai Pune Bypass Road, Kothrud Stand Karve Road, Paud Phata, Tilak Road, Maharshi Karve Road, NDA Road Symbiosis Law College Road, Warje - Sinhgad Road, Shree Sant Mamasaheb Deshpande Path
Dhanakwadi	101,112, 113,125	Pune Satara Road, Padmavati Temple, Mumbai Pune Bypass Road, Dattanagar Katraj Ghat Road
Tilak Road	76,77,87, 88,98,99, 100,110, 111	Tilak Road, Mirza Galib Road ,Shukrawar Peth, Maharshi Karve Road, NDA Road, Symbiosis Law College Road, Warje Sinhgad Road, Shree Sant Mamasaheb Deshpande Path, Trimurti Chawk, Sinhagad Road, Dhairy Phata
Sahakar Nagar	77,78, 101	Mirza Galib Road ,Shukrawar Peth Pune, Mumbai Highway, Pune Satara Road, Padmavati Temple
Hadapsar	81,82	Pune Hadapsar Road, Pune-Solapur Highway
Yerwada	20,45, 55,57	Lohegaon Road, Samrat Ashok Road /Old Mundhwa Road, Band Garden Road, Mundhwa Road

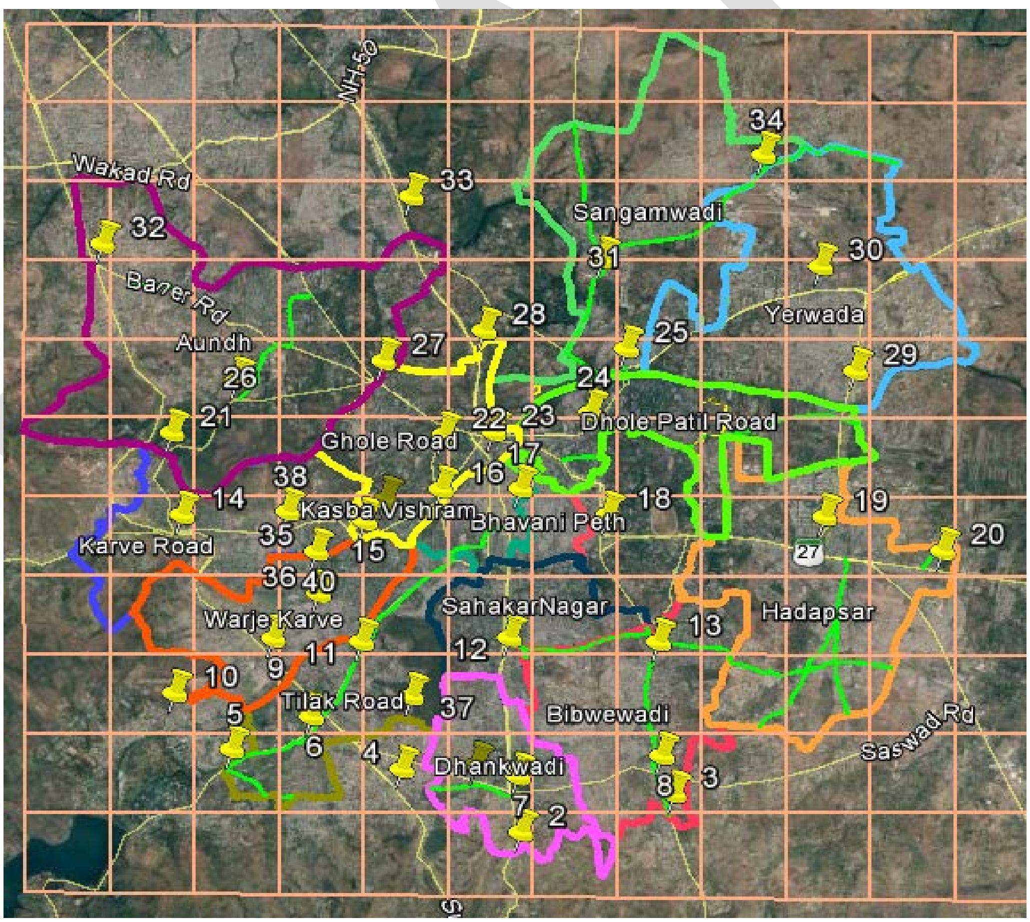


Figure 3.3 : Gridwise Vehicular Counting Locations in Pune City

The vehicular counting of different vehicles and at different Shifts is shown in **Figure 3.4**.

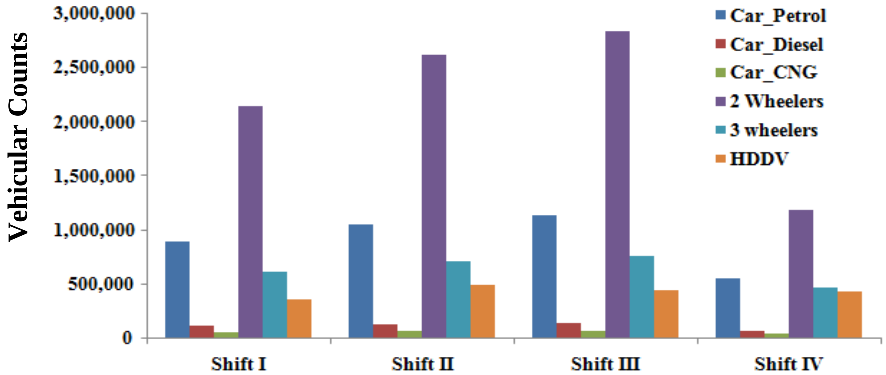


Figure 3.4 : Shift wise Vehicular Counts for Different Categories of Vehicles

Vehicular count data of each traffic junction/road has been extrapolated /distributed/ allocated to all the adjacent/nearby grids taking into account (in relation to and in proportion to) the road network, traffic in up and down directions, intensity of traffic etc. The vehicles count shows around 27.46 lakhs (2 wheelers), 7.93 lakhs (3 wheelers), 11.32 lakhs (car petrol), 1.33 lakhs (car diesel), vehicles are running on the road every day on whole of Pune. CNG Cars are around 0.66 lakhs, whereas 5.35 lakhs Heavy Duty Diesel vehicles respectively are plying on the roads. The evening peak (Shift III 1134560 car petrol and 2835512 two wheelers) shows the maximum counts of vehicles. On an average Shift I and Shift II counts (890346, 1046357 for Car Petrol), (2152336, 2618320 for 2 wheelers) moves similar way which is also remarkable, whereas shift IV counts (551664 for Car Petrol) and (1183600 for 2 wheelers) observed decrease in trend. The HDDV counts observed around (353328 to 490032) in a day. The vehicular kilometer travelled was calculated based on number vehicles multiply by road length for different types of vehicles in shifts which is shown in **Figure 3.5**.

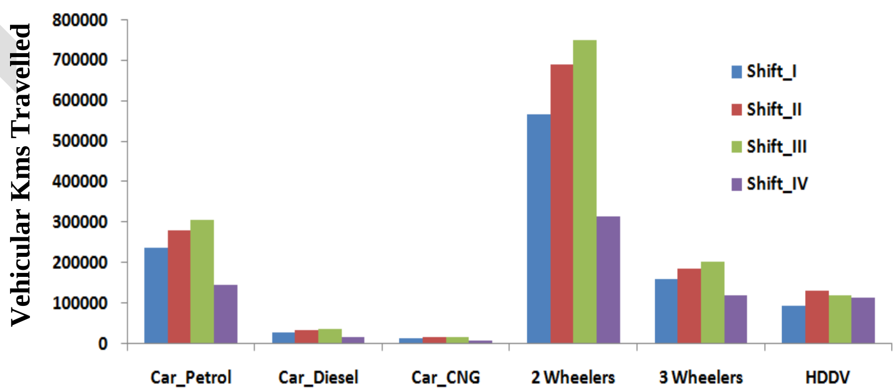
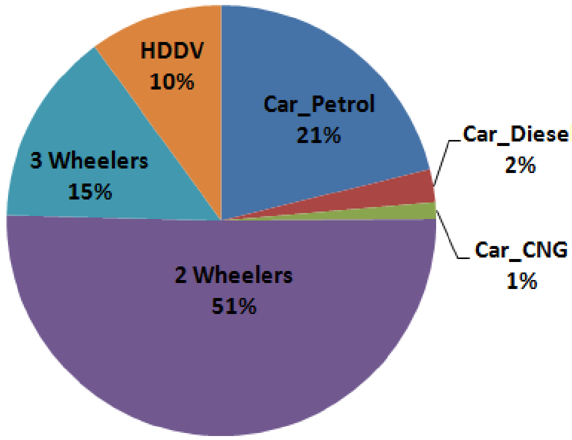


Figure 3.5 : Shift wise Vehicle Kms Travelled (VKT) for Different Categories of Vehicles



Almost 51 percent contributes by 2 Wheelers, All types of cars viz. petrol, diesel and CNG powered vehicles contribute around 24%. Whereas, 3 wheelers contribution is around 15% and heavy duty diesel vehicles around 10%. On an average 1.7 to 2.2 Kms roads are observed including internal road, highways major and minor roads in each grid which was used for calculations.

3.3.3 Emission Estimation

ARAI developed emissions factors for vehicles, post 2005 emission factors of different categories of vehicles are considered for calculations **(Table 3.18)**.

Table 3.18 : Emission Factors Calculated by Automotive Research Association of India (ARAI)

Vehicular Emission Factors (Gm/Km)	Car Petrol Post 2005 Fuel BSII	Car Diesel Post 2005 Fuel BSII	Car CNG Post 2000, Fuel BSII	Two Wheeler Post 2005 4 Stroke Fuel BS II	Three Wheeler CNG Retro 25 Post 2000 Fuel BS II	CNG Buses Post 2000 Fuel BS II	Trucks Diesel Post 2000 Fuel BSII
PM	0.002	0.015	0.006	0.013	0.118	0.044	1.240
NOx	0.090	0.280	0.740	0.150	0.190	6.210	9.300
CO	0.840	0.060	0.060	0.720	0.690	3.720	6.000
HC	0.12	0.080	0.460	0.520	2.06	3.750	0.370

Factors used for emission load calculation Source: Air Quality Monitoring Project-Indian Clean Air Programme (ICAP), The Automotive Research Association of India, 08, 2007

3.3.4 Whole City Vehicular Emission Inventory

The emission estimates were made from 2 Km x 2 Km grids with respect to the entire city taking ARAI emission factor for PM, NOx, CO and HC. SO_2 emissions are calculated based on VKT and sulphur content (Diesel 300 ppm and Gasoline 30 ppm) as SO_2 emission factor was not available. These estimates have been further used for grid wise projections, input to dispersion modeling and scenario generation. The shift wise pollutant loads from different category of vehicles area presented in **Table 3.19**.

Table 3.19 : Vehicular Emission Load from Line Sources for Pune City

	Cars			2 Wheeler	3 Wheeler	HD Diesel	Total Emission
	Petrol	Diese	CNG				
PM Emission Load							
Shift I (4 Hrs.)	4.8	4.2	0.8	74.0	189.3	1182.7	
Shift II (6 Hrs.)	5.6	5.0	1.0	89.8	220.8	1628.2	
Shift III (5 Hrs.)	6.1	5.4	1.1	97.6	238.9	1478.9	
Shift IV (9 Hrs.)	2.9	2.6	0.5	40.9	142.9	1425.2	
Kg/day	**19.5**	**17.2**	**3.4**	**302.3**	**791.9**	**5714.9**	**6849.2**
Tons/Yr	**7.1**	**6.3**	**1.3**	**110.3**	**289.1**	**2086.0**	**2500.0**
NOx Emission Load							
Shift I (4 Hrs.)	214.6	5.2	2.2	853.6	304.8	8870.0	
Shift II (6 Hrs.)	253.6	92.8	122.6	1035.8	355.5	12211.7	
Shift III (5 Hrs.)	275.0	100.7	133.0	1126.2	384.6	11091.6	
Shift IV (9 Hrs.)	132.6	48.5	64.1	471.9	230.2	10688.8	
Kg/day	**875.8**	**247.2**	**322.0**	**3487.5**	**1275.2**	**42862.0**	**49069.8**
Tons/Yr	**319.7**	**90.2**	**117.5**	**1273.0**	**465.4**	**15644.6**	**17910.5**
SO_2 Emission Load							
Shift I (4 Hrs.)	11.9	14.0		7.6		163.5	
Shift II (6 Hrs.)	14.1	16.6		9.2		225.1	
Shift III (5 Hrs.)	15.3	18.0		10.0		204.5	
Shift IV (9 Hrs.)	7.4	8.7		4.2		197.0	
Kg/day	**48.7**	**57.3**		**31.0**		**790.1**	**927.0**
Tons/Yr	**17.8**	**20.9**		**11.3**		**288.4**	**338.4**
CO Emission Load							
Shift I (4 Hrs.)	2003.3	16.9	8.4	4097.2	1107.0	5722.6	
Shift II (6 Hrs.)	2366.7	19.9	9.9	4971.7	1291.2	7878.5	
Shift III (5 Hrs.)	2567.0	21.6	10.8	5405.9	1396.8	7155.9	
Shift IV (9 Hrs.)	1237.5	10.4	5.2	2265.3	835.8	6896.0	
Kg/day	**8174.5**	**68.7**	**34.4**	**16740.2**	**4630.8**	**27652.9**	**57301.5**
Tons/Yr	**2983.7**	**25.1**	**12.5**	**6110.2**	**1690.2**	**10093.3**	**20915.0**
HC Emission Load							
Shift I (4 Hrs.)	286.2	22.5	64.6	2959.1	3305.0	352.9	
Shift II (6 Hrs.)	338.1	26.5	76.2	3590.7	3854.8	485.8	
Shift III (5 Hrs.)	366.7	28.8	82.7	3904.3	4170.1	441.3	
Shift IV (9 Hrs.)	176.8	13.9	39.9	1636.1	2495.4	425.3	
Kg/day	**1167.8**	**91.6**	**263.4**	**12090.1**	**13825.3**	**1705.3**	**29143.6**
Tons/Yr	**426.2**	**33.4**	**96.1**	**4412.9**	**5046.3**	**622.4**	**10637.4**

The percent contribution of different pollutant and there category wise distribution is show in **Figure 3.6**.

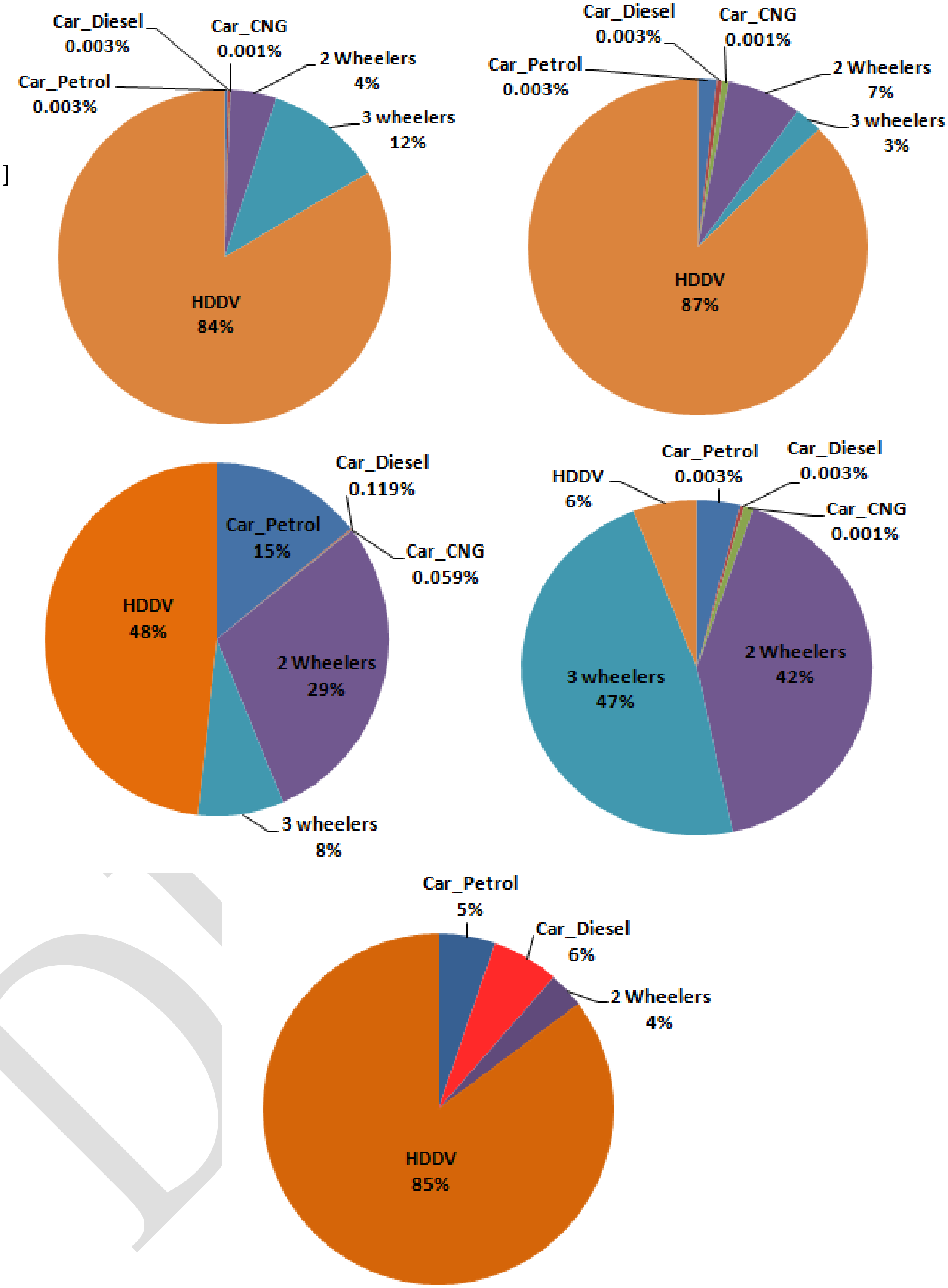


Figure 3.6 : Percent Contribution Pollutants from Different Categories of Vehicles

Total PM contribution from all types of vehicles in all shifts per day is around 6849.2 kg/day and 2500 tonnes/year. Maximum contribution of contribute 83.5% (i.e. 1628.2 kg) from Heavy Duty vehicles is in shift II; followed by 3 wheelers 12% (238.9 kg) in shift III and remaining types of vehicles contributes around 0.1% to 4% (i.e 342.4 kg/day). Even though, the heavy duty diesel vehicle kilometer travelled distribution is very less i.e. 10 percent, the maximum emission load is from heavy duty vehicles in all shifts is around 5714.9 kg/day,

The 49069.8 kg/day and 17910.5 tonnes/year emission load was observed for NOx pollutant. Considering all shifts, the highest emission of 42862 kg/day was observed for heavy duty diesel vehicles which are around 87% of the total. Even in shift II the emission load of 12211.7 kg from HDDV is highest; followed by 1126.2 kg from 2 Wheelers (7%) and 384.6 kg from 3 wheelers (3%) in shift III.

As SO_2 emissions are calculated based on sulphur content (Diesel 300 ppm and Gasoline 30 ppm), the maximum emission load is observed for heavy duty diesel vehicle 85% (i.e. 790.1 kg/day) and it was highest at shift II (225.1 kg), whereas 6% (57.3 kg/day) for car diesel and 5% (48.7 kg/day) for car petrol and 4% (31 kg/day) for 2 wheelers. The total emission of SOx in the city is around 927 kg/day and 338.4 tones /year.

Total CO emission load of 57301.5 kg/day and 20915 tonnes/year was observed in Pune. The highest shift II load of 48% (7878.5 kg) is from heavy duty diesel veichle emission, followed by 2 wheeler 29% (5405.9 kg), car petrol 15% (2567 kg) and 3 wheelers 8% (1396.8 kg) in shift III.

The HC is mainly contributed from 3 wheelers i.e. 47% (13825.3 kg/day) as against the total emission of 29143.6 kg/day. 2 Wheelers (12090.1 kg/day) and HDDV (1705.3 kg/day) contribution are around 42% and 6%, respectively.

If we considered all pollutants than the major load is observed from Heavy duty diesel vehicles i.e. around 48% to 88% (from average 428150 vehicles in all shifts) even though their number and VKT is around 10% (HD); followed by 2 wheelers ranging from 29% to 42% (from average 2197442 vehicles in all shifts) and 3wheelers in the range of 12% to 47% (from average 634588 vehicles in all shifts) and the number of vehicle percent in total is around 15% (3W) and 51% (2W). The 21% of Petrol Car (average 905731 Car Petrol vehicles) contributes 15% of CO and 5% of SO2. Traffic congestion reduces average traffic speed. Traffic locks the roads in all most every part of the city. The average trip speed is less than 20 kilometers per hour; a 10 kilometer trip can take 30 minutes, or more. At such speeds, vehicles in India emit air pollutants 4 to 8 times more than they would with less traffic congestion.

Ward wise vehicular emission load for different pollutant is presented in **Table 3.20** and **Figure 3.7**.

Table 3.20 : Ward wise Distribution of Pollutant from Different Categories of Vehicles

	Car_P	Car_D	Car_C	2 Wheelers	3 Wheelers	HDDV	Total
PM (kg/day)							
Aundh	2.0	1.8	0.4	30.7	67.4	481.4	583.6
Ghole Road	2.3	2.1	0.4	34.8	111.2	543.2	694.1
Dhole Patil Rd	0.9	0.8	0.2	11.9	42.0	227.8	283.6
Warje Karve Nagar	1.4	1.2	0.2	26.1	53.2	440.8	523.0
Karve Road	1.7	1.5	0.3	22.3	61.7	390.2	477.7
Bhavani Peth	0.3	0.3	0.1	6.1	15.6	64.0	86.3
Sangamwadi	0.8	0.7	0.1	15.8	28.0	249.3	294.7
Yerwada	1.4	1.3	0.3	28.2	52.5	685.9	769.6
Tilak Road	2.3	2.0	0.4	38.8	87.2	823.8	954.5
Kasba Vishram Bag	0.2	0.2	0.0	6.3	31.7	63.0	101.4
Sahakar Nagar	1.1	1.0	0.2	11.8	38.0	287.9	340.0
Bibwewadi	1.9	1.7	0.3	28.3	85.5	586.7	704.3
Dhanakwadi	1.8	1.5	0.3	21.6	63.4	399.6	488.2
Hadapsar	1.3	1.1	0.2	19.6	54.5	471.4	548.1
Total PM (kg/day)	**19.5**	**17.2**	**3.4**	**302.3**	**791.9**	**5714.9**	**6849.2**
NOx (kg/day)							
Aundh	90.8	25.3	33.0	354.3	108.5	3610.4	4222.3
Ghole Road	105.1	30.5	39.7	401.7	179.1	4074.2	4830.3
Dhole Patil Rd	40.7	11.8	15.3	137.2	67.7	1708.7	1981.3
Warje Karve Nagar	63.7	17.3	22.5	301.0	85.6	3306.3	3796.5
Karve Road	76.4	20.2	26.2	257.0	99.4	2926.3	3405.4
Bhavani Peth	14.1	4.1	5.4	70.3	25.1	479.8	598.8
Sangamwadi	36.2	11.0	14.4	181.8	45.0	1869.7	2158.1
Yerwada	64.5	18.9	24.7	325.8	84.5	5144.3	5662.7
Tilak Road	104.4	28.5	37.1	447.7	140.4	6178.2	6936.3
Kasba Vishram Bag	11.1	3.2	4.2	72.1	51.0	472.3	614.1
Sahakar Nagar	49.1	14.4	18.8	136.4	61.2	2159.3	2439.3
Bibwewadi	84.2	24.7	32.2	326.0	137.6	4400.5	5005.2
Dhanakwadi	78.9	21.1	27.4	249.5	102.2	2996.7	3475.7
Hadapsar	56.6	16.3	21.2	226.7	87.8	3535.3	3943.9
Total NOx (kg/day)	**875.8**	**247.2**	**322.0**	**3487.5**	**1275.2**	**42862.0**	**49069.8**

- C_P – Car Petrol, C_D – Car Diesel, C_C – Car CNG, HDDV – Heavy Duty Diesel Vehicle

PM concentration is mainly from HDDV, 2 and 3 wheelers and highest total concentration is observed in Tilak Road (954.5 kg/d), Yerwada (769.6 kg/d), Bibwewadi (704.3 kg/d) and Ghole Road (694.1 kg/d), the other contributing areas are Aundh, Warje Karve and Hadpsar. The HDDV and 2 wheelers contribute significantly to NOx concentration and total highest load was observed at Yerwada (5662.7 kg/d), Tilak Road (6936.3 kg/d), Bibwewadi (5005.2 kg/d) and Ghole Road (4830.3 kg/d).

Table 3.20 (Contd..) : Ward wise Distribution of Pollutant from Different Categories of Vehicles

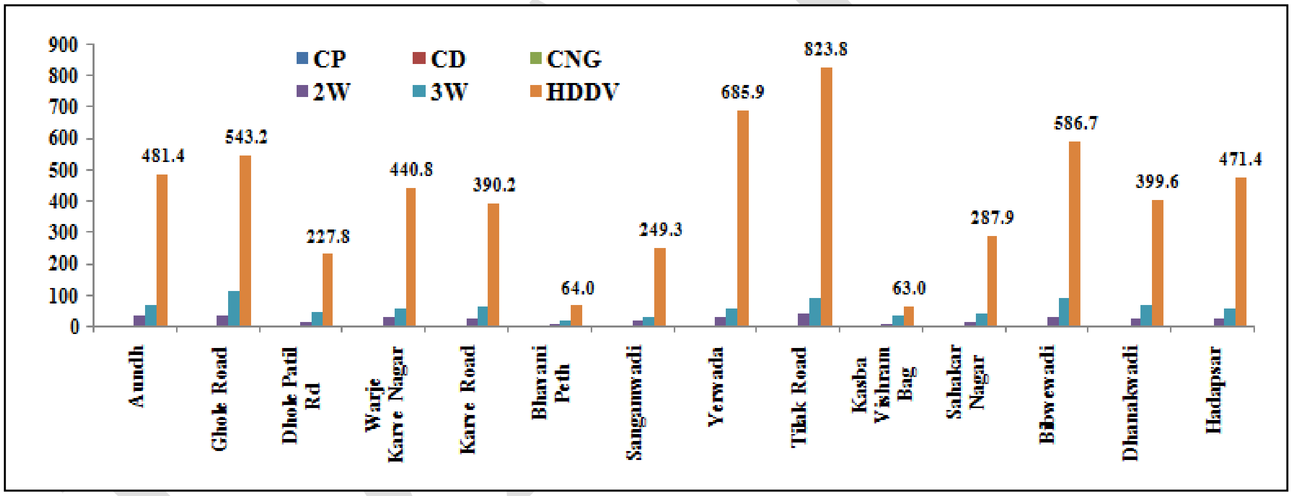
	Car_P	Car_D	Car_C	2 Wheelers	3 Wheelers	HDDV	Total
SOx (kg/day)							
Aundh	5.0	6.0		3.1		66.6	80.7
Ghole Road	5.8	6.9		3.6		75.1	91.4
Dhole Patil Rd	2.3	2.7		1.2		31.5	37.6
Warje Karve Nagar	3.5	4.2		2.7		60.9	71.3
Karve Road	4.2	5.0		2.3		53.9	65.5
Bhavani Peth	0.8	0.9		0.6		8.8	11.2
Sangamwadi	2.0	2.4		1.6		34.5	40.5
Yerwada	3.6	4.2		2.9		94.8	105.5
Tilak Road	5.8	6.8		4.0		113.9	130.5
Kasba Vishram Bag	0.6	0.7		0.6		8.7	10.7
Sahakar Nagar	2.7	3.2		1.2		39.8	47.0
Bibwewadi	4.7	5.5		2.9		81.1	94.2
Dhanakwadi	4.4	5.2		2.2		55.2	67.0
Hadapsar	3.1	3.7		2.0		65.2	74.0
Total SOx (kg/day)	**48.7**	**57.3**		**31.0**		**790.1**	**927.0**
HC (kg/day)							
Aundh	121.0	9.5	27.4	1228.4	1176.1	143.6	2706.0
Ghole Road	140.2	11.0	31.6	1392.6	1942.0	162.1	3679.5
Dhole Patil Rd	54.2	4.3	12.2	475.6	733.5	68.0	1347.9
Warje Karve Nagar	84.9	6.7	19.1	1043.4	928.1	131.5	2213.7
Karve Road	101.9	8.0	23.0	890.9	1077.8	116.4	2218.0
Bhavani Peth	18.8	1.5	4.2	243.8	272.2	19.1	559.6
Sangamwadi	48.2	3.8	10.9	630.3	488.0	74.4	1255.6
Yerwada	86.0	6.7	19.4	1129.4	916.6	204.7	2362.7
Tilak Road	139.2	10.9	31.4	1551.9	1522.4	245.8	3501.6
Kasba Vishram Bag	14.9	1.2	3.4	250.1	553.0	18.8	841.2
Sahakar Nagar	65.5	5.1	14.8	473.0	663.9	85.9	1308.2
Bibwewadi	112.3	8.8	25.3	1130.1	1492.1	175.1	2943.8
Dhanakwadi	105.1	8.2	23.7	864.9	1107.7	119.2	2228.9
Hadapsar	75.4	5.9	17.0	785.9	952.1	140.7	1976.9
Total HC(kg/day)	1167.8	91.6	263.4	12090.1	13825.3	1705.3	29143.6

- C_P – Car Petrol, C_D – Car Diesel, C_C – Car CNG, HDDV – Heavy Duty Diesel Vehicle

The highest SOx concentration is observed at Yerwada (105.5 kg/d), Tilak Road (130.5 kg/d), Ghole Road (91.4 kg/d) and Bibwewadi (94.2 kg/d) is mainly from HDDV. The CO is mainly from 2 wheelers, where concentration ranges from (1400 to 2000 kg/d) and also from HDDV vehicles emission load ranges from (2000 to 3000 kg/d). These loads are mainly from Tilak Road, Ghole Road, Aundh, Yerwada and at Bibwewadi. The HC concentration is mainly from 2 and 3 wheelers and the concentration ranges from 1000 to 1551.9 kg/d for 2 wheelers and 1500 to 1942.0 kg/d for 3 wheelers and the source area is similar to PM and NOx.

Table 3.20 (Contd..) : Ward wise Distribution of Pollutant from Different Categories of Vehicles

	Car_P	Car_D	Car_C	2 Wheelers	3 Wheelers	HDDV	Total
CO (kg/day)							
Aundh	847.2	7.1	3.6	1700.8	393.9	2329.3	5282.0
Ghole Road	981.3	8.2	4.1	1928.2	650.5	2628.5	6200.8
Dhole Patil Rd	379.7	3.2	1.6	658.6	245.7	1102.4	2391.1
Warje Karve Nagar	594.3	5.0	2.5	1444.7	310.9	2133.1	4490.5
Karve Road	713.5	6.0	3.0	1233.5	361.0	1887.9	4204.9
Bhavani Peth	131.5	1.1	0.6	337.6	91.2	309.6	871.5
Sangamwadi	337.7	2.8	1.4	872.7	163.5	1206.2	2584.4
Yerwada	601.8	5.1	2.5	1563.7	307.0	3318.9	5799.0
Tilak Road	974.4	8.2	4.1	2148.8	509.9	3985.9	7631.3
Kasba Vishram Bag	104.1	0.9	0.4	346.2	185.2	304.7	941.6
Sahakar Nagar	458.7	3.9	1.9	654.9	222.4	1393.1	2734.8
Bibwewadi	786.2	6.6	3.3	1564.8	499.8	2839.1	5699.8
Dhanakwadi	736.0	6.2	3.1	1197.5	371.0	1933.4	4247.2
Hadapsar	527.9	4.4	2.2	1088.1	318.9	2280.8	4222.4
Total SOx (kg/day)	8174.5	68.7	34.4	16740.2	4630.8	27652.9	57301.5



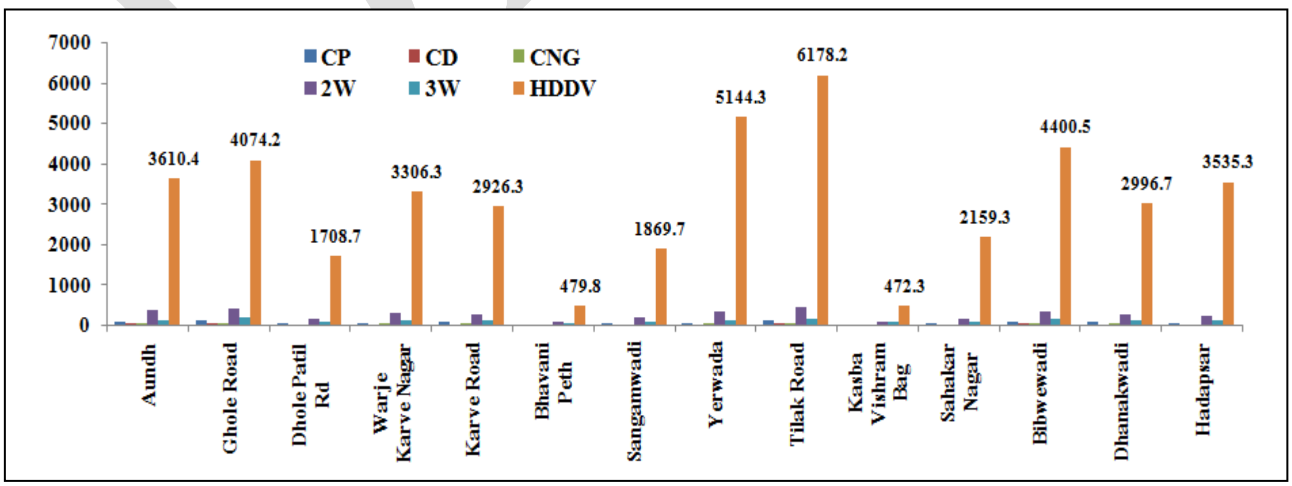


Figure 3.7 : Ward wise Distribution of Pollutant from Different Categories of Vehicles

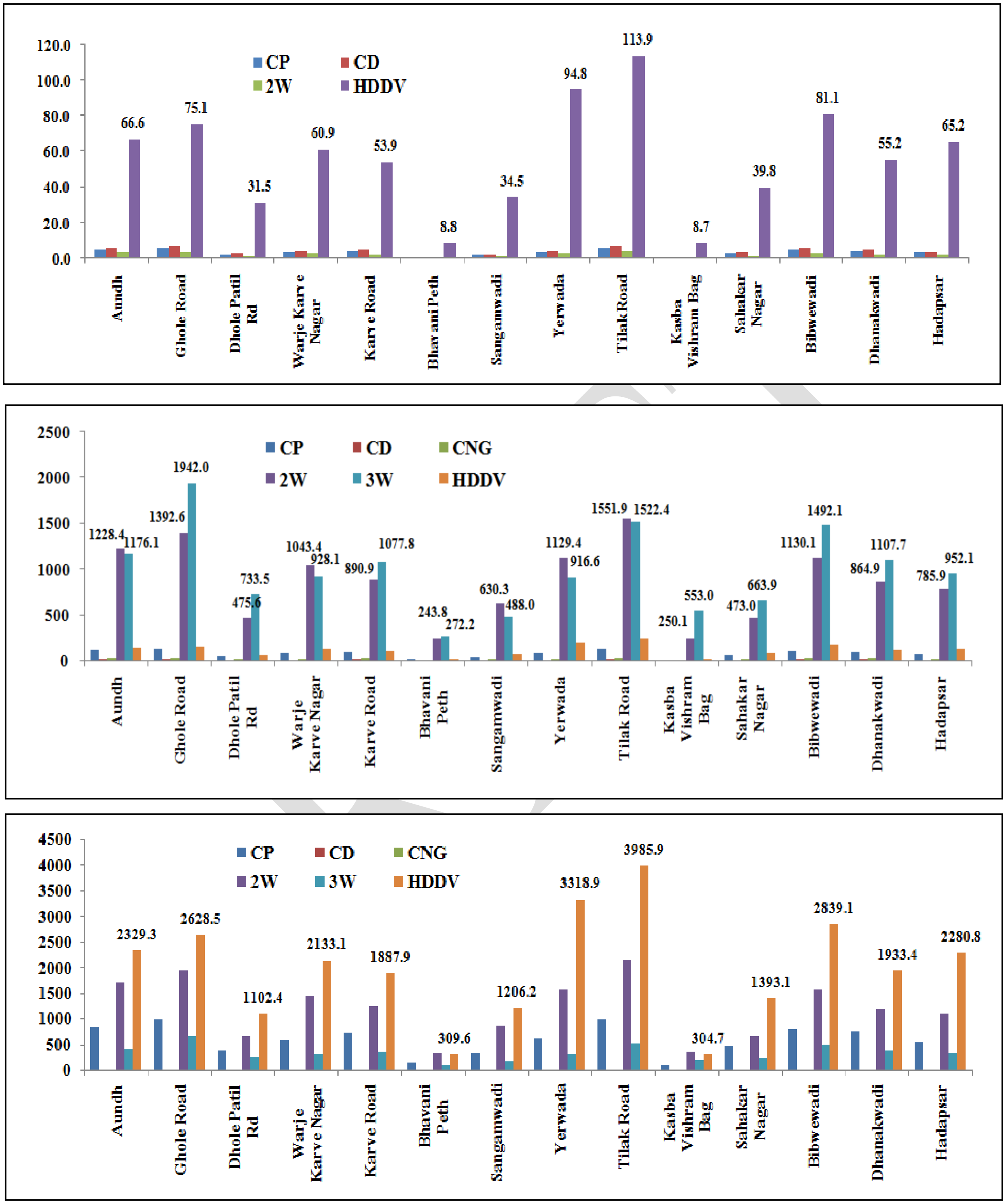


Figure 3.7 (Contd..): Ward wise Distribution of Pollutant from Different Categories of Vehicles

3.4 Point Source

The Pune city is surrounded by 7 Nos. of Talukas including Pimpri-Chinchwad Municipal Corporation (PCMC) area. The average decadal growth rate of industries from 1951 to 2011 is 36.54%. Rapid growth of the city is mainly attributed to industrialization of PMC/ PCMC after 1960 and expansion of Information Technology (IT) industry in the last decade. Major industries are situated at Warje Karve Road, Hadapsar, Dhole Patil Road and Yerwada. However, within city area polluting industries are limited and dominated by forging and automotive engines industry. The contribution of point sources is limited due to confined industrial areas. The growth of PMC is driven by various industrial segments. Presently, except Kharadi Knowledge Park, which is located within PMC limits, all other industries are located outside PMC in PMR or close to PMR towards North-West, North and North-East. The recent industrial growth is seen in a radius of 60-65 Kms from the main city of Pune.

In 1957, PMC set up an industrial township at Hadapsar followed by Maharashtra Industrial Development Corporation (MIDC) which established an industrial estate of engineering-ancillary industries on 4000 acres of land at Bhosari in 1960. In mid-sixties, Pune reached its peak in economy and boasted with the reputation as the Detroit of India. From 1970 to 1990, the government policies inclined towards industrial concentration by encouraging smaller units which triggers the industrial opportunities provided by automobile industries, as a consequence, the percentage of in-migration rose rapidly. Ultimately, the city became one of the top investment destinations for automobile and auto components makers.

The food processing units in the city operate in various segments like milk and milk products, fruit and vegetable processed products, bakeries, ready-to-eat foods etc. Pune contributes 13% of Maharashtra biotech revenues and 6% of overall India Biotech Industry.

Large scales IT parks are established at Hingewadi, Talawade, Kharadi and Hadapsar in 1999, Infotech Park was set up at Hingewadi - IT city. With an addition of educational facilities, many leading software companies and some foreign players established in Pune as they considered the city as best destination for IT establishment. The study done by MIDC in 2010, confirms that Pune city with its region is the most preferred investment destination after Mumbai in the state, having 35 registered IT Parks (2010) and 16 notified Special Economic Zones (SEZ). Pune also functions as a distributing centre for agricultural implements, fertilizers, drugs and medicines, iron and steel, cement and minerals, petroleum products and forest products such as timber, and readymade garments and textiles. Pune is surrounded by a large number of industries catering to employment of a large population of people all across the city. Most of the industries within the Pune City limits of study are engineering type and may not be responsible for air pollution as direct sources. However, some of the industries such as those including forging, auto components, etc having furnace and DG sets are known to be polluting.

As per Maharashtra Pollution Control Board (MPCB), Regional Office of Pune there were more than 1000 different types of industries (i.e. Small, Medium & Large depending up on their production capacities as received from MPCB, consent including location, type, height of stack, capacity, & temperature, fuel type and usage timings, etc.) with a view of identifying the grossly air polluting industries in the vicinity of Pune Municipal Corporation area.

There are no thermal power plants within Pune city limits and therefore the pollution load contribution from this source is nil. However, the industries in Pune and Pimpri-Chinchwad have set up D.G. sets to meet the power requirements of their respective industries particularly during the load shedding and weekly power holidays. Data obtained from MPCB and local survey for operating generators in industrial area is about 1059 approx. MPCB, Inspector of Generators, Pune through actual surveys of each of these industrial and non-industrial generators were obtained. Not much variation in time of usage was observed with respect to Industrial generators because the hours of weekdays are fix as load shedding and these do have weekly off where in power supply is been restricted for a specified day.

Point sources are generally large emitters with one or more emission points at a permitted facility with an identified location. Examples include oil processing units, steam generators, boilers, process heaters, manufacturing, etc. The emissions from point sources are generally calculated using emission factors obtained from direct measurements (e.g., source testing). EPA’s document entitled, *Compilation of Air Pollutant Emissions Factors* (AP-42), or California Air Resource Board’s material balance formulas are the major resources for emission factors of point sources. The simplest method of calculating emissions is to multiply the process rate (how much or how often an activity occurs) by an emissions factor (mass of air pollutant emitted per unit time of activity) and a control factor (percent of emissions not allowed to reach the atmosphere).
Fossil fuel used by the industries for boilers or manufacturing process remains the single potential source of discharging emissions into the atmosphere from their stacks. For proper estimate of emissions, the effectiveness of an existing control device must be applied in the emission

calculation. Emissions are estimated for pollutants such as PM_{10}, NOx, SO_2, CO and HC. In order to workout emission loads from industries due to burning of fossil fuel, information on fuel consumption in industries and the information on industries typology capacity etc. was obtained from Maharashtra Pollution Control Board (MPCB) for classification of industries viz. large, medium and small as well as red, orange and green categories.

According to MPCB, the polluting industries are classified as red (highly polluting), orange (moderately polluting) and green (low polluting) in nature. There are 1650 different categories of industries operates in Pune, out of that about 394 are the air polluting industries in Pune City.

MPCB Consent : Pune Industries 1650

Red	813		Orange	531		Green	306	
LSI	MSI	SSI	LSI	MSI	SSI	LSI	MSI	SSI
378	110	325	190	88	253	67	40	199

Air Polluting Industries : 394

Red	191		Orange	123		Green	80	
LSI	MSI	SSI	LSI	MSI	SSI	LSI	MSI	SSI
94	21	76	50	24	49	17	11	52

Emission inventory from industries has considered working hours considered: for industries, MSI =16 hrs, LSI = 22 hrs, SSI = 12 hrs. 1 Barrel–159 lit, LSHS, FO is assumed to be residual oil. LDO and HSD are assumed to be distilled oil.

3.4.1 Approach/Methodology

The gross emissions are estimated for all types of industries and information relating to consumption of fuels such as Furnace Oil (FO), Light Diesel Oil (LDO), Low Sulphur Heavy Stock (LSHS), Bagasse and others is obtained from MPCB consent forms **(Table 3.21)**.

Table 3.21 : Fuel Consumption from Industries of Pune (TPD)

	FO	LDO	HSD	Coal	Kerosene	LPG	Wood	Diesel	CNG/ PNG	Bagasse
Red_LSI	6	1	23	25	3	3	3	3	0	445
Red_MSI	34	0	23	50	0	1	4	8	1	4
Red_SSI	9	4	12	6	0	0	1	1	0	11
Orange_LSI	7	0	50	0	0	2	16	13	0	9
Orange _MSI	2	0	27	0	0	0	5	10	0	0
Orange _SSI	1	0	1	0	0	0	9	4	0	1
Green_LSI	0	0	1	0	0	0	0	1	0	75
Green _MSI	0	0	1	0	0	0	0	2	0	1
Green _SSI	1	0	4	0	0	0	3	5	0	9
Total	**60**	**5**	**142**	**81**	**3**	**6**	**41**	**47**	**1**	**555**

The percent fuel consumption shows use of 57% of Fuel Oil is from Red MSI, followed by remaining Red categories and Orange LSI which is around 10 to 14%. LDO consumption is more from Red SSI 67% and 9 to 15% is from LSI and MSI of Red and all Orange categories. Consumption of 35% of HSD is from Orange LSI and 15 to 18% is from majors Red and MSI and SSI Orange type of industries. Coal consumption in percent is 62% from Red MSI, and other 31% major consumer of coke is Red LSI. Similarly Orange LSI consumes 38% of wood and other Orange categories uses around 13 to 21% of the total quantity. LPG is mostly coming from Red LSI 40%, whereas Orange MSI and Red MSI contribute around 15 to 28%. The 27% of diesel as fuel is majorly consumed in Orange LSI and MSI and other categories shows consumption is 5 to 17% among them Red MSI and Green SSI is higher. CNG /PNG is mainly coming from Red MSI 64%. Being an agricultural region, there is easy availability of bagasse as fuel almost 80% for Red Category. The average daily consumption of bagasse in heavy industry is around 445 TPD. The most significant pollutant emitted by bagasse -fired boilers is particulate matter, caused by the turbulent movement of combustion gases with respect to the burning bagasse and resultant ash. Emissions of sulfur dioxide (SO_2) and nitrogen oxides (NOx) are lower than conventional fossil fuels due to the characteristically low levels of sulfur and nitrogen associated with bagasse.

Emission factors published by TERI, New Delhi are used because the data on type of combustion equipment used for firing and other operating parameters like fuel quality, efficiency of boilers were not readily available with the industries in the region which are essential **(Table 23)**. The emission load was calculated based on 90% reduction due to control equipments in industries for PM and SOx viz. bag filters, industrial scrubbers, electro static precipitator, use of low sulphur fuel oil, cylinder lubrication and for NOx 30% reduction was assumed by way of different technologies for reduction of NOx viz. Flue-gas recirculation, Hybrid SNCR/SCR technologies, reagents to reduce these emissions, humid air method, water injection and water emulsion, high scavenge pressure and compression ratio and selective catalytic reduction. The sulfur and ash content was taken from the consent of respective industry, for those industries without any ash and sulfur contain is calculated based on **Table 3.22**.

Table 3.22 : Emission Factors applied for Industrial Emissions

S. No.	Type of Fuel	Unit	S	Emission Factors (Kg/Unit)					
				TSP	SO_2	NO_x	HC	CO	Ash
1.	LSHS	KL	0.45	1.25*S + 0.38	19.25*S	7.5	0.12	0.63	
2.	FO	KL	4.0	1.25*S + 0.38	19.25*S	7.5	0.12	0.63	
3.	LDO	KL	1.8	0.25	17.25*S	2.75	0.12	0.63	
4.	HSD	KL	1.0	0.25	17.25*S	2.75	0.12	0.63	
5.	LPG/FG[$$]	KL	0.02	0.072	0.01*S	2.52	0.07	0.43	
6.	NG	m^3	-	160 E-06	9.6 E-06	2800 E-06	48 E-06	272 E-06	
7.	Coal /Coke	MT	0.5*	6.5*A	19S	7.5	0.5	1.0	45
8.	Kerosene[##]	Kg/t	0.25	0.06	17S	2.5	--	--	--
*For Power Plant** *									
1.	LSHS	KL	0.45	1.25*S + 0.38	19.25*S	6.25	0.12	0.63	
2.	NG	m^3	-	160 E-06	9.6 E-06	2800 E-06	48 E-06	272 E-06	
3.	Coal	MT	0.15	6.5*A	19*S	7.5	0.5	1	6

Source: URBAIR Report, Bombay, 1992
A: Percentage ash in coal = 45% and S: Percentage Sulphur
Other than Power Plant, efficiency of Cyclone considered as 75%
* *Power plant
[$$]Emission Factors for LPG from Revised AP-42 (Ref. PMRAP, NEERI, 2003 (Tabl
Π Coal
A - % Ash: 2- 10% Avg. 6%, S - % Sulphur: 0.1 – 0.2%, Avg. 0.15%
ESP Eff. : 99.5%, FGD Eff. : 99%
Π LSHS Sulphur: 0.45%
Source:
a. Environmental effects of energy production, transformation and consumption in the National Capital Region submitted to the Ministry of Environment & Forest, by Tata Energy Research Institute (TERI), New Delhi, February 1992
b. Indian Oil Corporation Ltd, Vadodara

Density[b] of Fuels (Kg/m^3)

LSHS	943
FO	943
LDO	
LPG	860
HSD	504

Baggase : Emission Factor Documentation for AP-42 Section 1.8, Bagasse Combustion in Sugar Mills, April, 1993 [PM10- 4.6, SO2-0.18, NO2-0.275, HC-0.0002515, CO -390 (g/km)]

3.4.2 Point Source Emission Load

The industrial emission load from different pollutants and whole of Pune city is given in **Table 3.23**. The percent distribution of pollutant from source category is presented in **Figure 3.8**.

Table 3.23 : Industrial Emission Load from Different Categories of Fuel

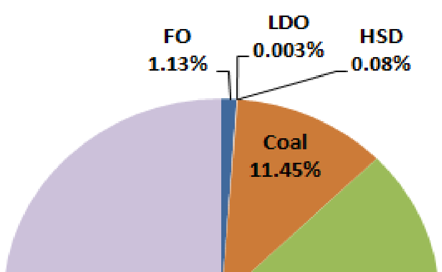
	Red			Orange			Green		
	LSI	**MSI**	**SSI**	**LSI**	**MSI**	**SSI**	**LSI**	**MSI**	**SSI**
PM (Kg/Day)									
FO	3.0	16.6	4.3	3.5	1.2	0.4	0.0	0.0	0.3
LDO	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
HSD	0.3	0.3	0.2	0.7	0.4	0.0	0.0	0.0	0.1
Coal	92.8	184.6	20.6	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	47.6	73.5	15.8	276.8	92.9	152.2	0.0	0.0	58.1
Diesel	1.3	4.1	0.5	6.4	5.0	1.9	0.5	1.1	2.6
CNG/PNG	0.1	0.6	0.0	0.0	0.2	0.1	0.0	0.0	0.0
Bagasse	1024.1	16.9	51.6	42.9	0.0	5.4	345.0	4.3	40.8
Total (Kg/day)	**1169.1**	**296.6**	**93.0**	**330.4**	**99.7**	**159.9**	**345.6**	**5.3**	**102.0**
Total (Tons/Yr)	**426.7**	**108.3**	**33.9**	**120.6**	**36.4**	**58.4**	**126.1**	**1.9**	**37.2**
NOx (Kg/Day)									
FO	48.4	273.0	70.4	57.4	19.1	6.3	0.0	0.0	5.7
LDO	2.4	0.4	10.4	0.0	1.5	0.3	0.0	0.0	0.5
HSD	74.2	72.7	39.2	161.3	84.8	3.6	3.4	4.6	13.8
Coal	187.8	373.7	41.7	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	14.1	5.5	0.0	10.1	2.3	0.6	0.8	0.0	1.8
Wood	3.6	5.5	1.2	20.8	7.0	11.4	0.0	0.0	4.4
Diesel	20.6	66.6	8.4	105.1	82.3	31.2	8.8	17.4	42.2
CNG/PNG	12.1	107.9	0.0	0.0	32.7	14.3	0.0	0.0	0.0
Bagasse	61.2	1.0	3.1	2.6	0.0	0.3	20.6	0.3	2.4
Total (Kg/day)	**429.6**	**906.3**	**174.3**	**357.2**	**229.7**	**68.0**	**33.5**	**22.3**	**70.9**
Total (Tons/Yr)	**156.8**	**330.8**	**63.6**	**130.4**	**83.8**	**24.8**	**12.2**	**8.1**	**25.9**
SOx (Kg/Day)									
FO	49.7	280.2	72.2	59.0	19.6	6.5	0.0	0.0	5.9
LDO	2.7	0.4	11.7	0.0	1.7	0.3	0.0	0.0	0.6
HSD	46.6	45.6	24.6	101.2	53.2	2.3	2.1	2.9	8.6
Coal	7.1	14.2	1.6	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wood	0.6	0.8	0.2	3.2	1.1	1.8	0.0	0.0	0.7
Diesel	21.2	68.4	8.6	107.9	84.5	32.0	9.0	17.9	43.3
CNG/PNG	0.0	0.4	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Bagasse	40.1	0.7	2.0	1.7	0.0	0.2	13.5	0.2	1.6
Total (Kg/day)	**176.2**	**410.7**	**121.0**	**272.9**	**160.2**	**43.1**	**24.6**	**20.9**	**60.7**
Total (Tons/Yr)	**64.3**	**149.9**	**44.2**	**99.6**	**58.5**	**15.7**	**9.0**	**7.6**	**22.2**

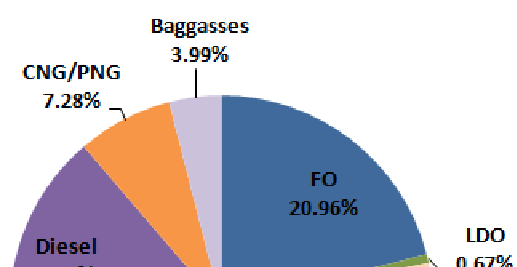
Table 3.23 (Contd..) : The Industrial Emission Load from Different Categories of Fuel

	Red			Orange			Green		
	LSI	MSI	SSI	LSI	MSI	SSI	LSI	MSI	SSI
HC (Kg/Day)									
FO	0.8	4.4	1.1	0.9	0.3	0.1	0.0	0.0	0.1
LDO	0.1	0.0	0.5	0.0	0.1	0.0	0.0	0.0	0.0
HSD	3.2	3.2	1.7	7.0	3.7	0.2	0.1	0.2	0.6
Coal	12.5	24.9	2.8	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	39.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	0.4	0.2	0.0	0.3	0.1	0.0	0.0	0.0	0.1
Wood	315.0	486.2	104.4	1832.0	615.0	1007.1	0.0	0.0	384.7
Diesel	0.3	1.1	0.1	1.7	1.3	0.5	0.1	0.3	0.7
CNG/PNG	0.2	1.8	0.0	0.0	0.6	0.2	0.0	0.0	0.0
Bagasse	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (Kg/d)	**371.9**	**521.7**	**110.6**	**1841.9**	**621.0**	**1008.1**	**0.3**	**0.5**	**386.2**
Total (T/Yr)	**135.8**	**190.4**	**40.4**	**672.3**	**226.7**	**368.0**	**0.1**	**0.2**	**140.9**
CO (Kg/Day)									
FO	4.1	22.9	5.9	4.8	1.6	0.5	0.0	0.0	0.5
LDO	0.5	0.1	2.4	0.0	0.3	0.1	0.0	0.0	0.1
HSD	17.0	16.7	9.0	37.0	19.4	0.8	0.8	1.0	3.2
Coal	25.0	49.8	5.6	0.0	0.0	0.0	0.0	0.0	0.0
Kerosene	128.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
LPG	2.4	0.9	0.0	1.7	0.4	0.1	0.1	0.0	0.3
Wood	4676.9	7218.2	1550.5	27200.0	9131.4	14951.8	0.0	0.0	5712.0
Diesel	1.7	5.6	0.7	8.8	6.9	2.6	0.7	1.5	3.5
CNG/PNG	1.2	10.5	0.0	0.0	3.2	1.4	0.0	0.0	0.0
Bagasse	86821.7	1430.0	4373.7	3640.0	0.0	454.3	29250.0	360.4	3463.2
Total (Kg/d)	**91678.8**	**8754.7**	**5947.7**	**30892.3**	**9163.3**	**15411.6**	**29251.6**	**362.9**	**9182.8**
Total (T/Yr)	**33462.8**	**3195.5**	**2170.9**	**11275.7**	**3344.6**	**5625.3**	**10676.8**	**132.4**	**3351.7**

Table 3.23 (Contd..) : Industrial Emission Load for Whole of Pune City

Industries	TSP	PM10	SOx	NOx	HC	CO
Red LSI	103.6	1169.1	176.2	429.6	371.9	91678.8
Red MSI	220.0	296.6	410.7	906.3	521.7	8754.7
Red SSI	27.8	93.0	121.0	174.3	110.6	5947.7
Orange LSI	13.2	330.4	272.9	357.2	1841.9	30892.3
Orange MSI	8.3	99.7	160.2	229.7	621.0	9163.3
Orange SSI	2.8	159.9	43.1	68.0	1008.1	15411.6
Green LSI	0.7	345.6	24.6	33.5	0.3	29251.6
Green MSI	1.3	5.3	20.9	22.3	0.5	362.9
Green SSI	3.6	102.0	60.7	70.9	386.2	9182.8
Total Kg/day	**381.1**	**2601.6**	**1290.4**	**2291.9**	**4862.3**	**200645.8**
Total Ton/Yr	[illegible]	[illegible]	**471.0**	**836.5**	**1774.7**	**73235.7**





HC

Figure 3.8 : Percent Distribution of Pollutant from Different Source Category (Pune Industries)

The Red category of 191 industries contributing 60% to 66% of PM and NOx; 55% of SOx, and CO and HC is around 53% and 21% respectively. The fuel consumption is more for Red category i.e. Bagasse (460 TPD), HSD (58 TPD), coal (81 TPD) and FO (49 TPD) which reflecting the higher PM emission load. 123 Orange category of industries contributes around 22% to 28% of PM and NOx respectively, whereas, SOx gives 37% and HC gives 71% to the total Orange category. The fuel consumption pattern shows less emission as compared to Red category i.e. (HSD 78 TPD, Wood & Diesel 30 TPD and Bagasse & FO 10 TPD). Similarly, 80 Green category of industries contribution around 17% of PM and 5 to 8% of SOx and NOx respectively. The only contribution is from Bagasse i.e. 85 TPD and 6 to 8 TPD of HSD & Diesel shows lesser contribution as compared to Red.

From all LSI categories pollution load is contributing around 71- 75% for PM and CO; NOx and SOx is around 35- 36% and HC is 45%. The MSI and SSI only contribute 13 to 15% of PM, 45 to 50% of SOx and NOx for MSI, whereas as it was 17% to 13% for SSI. The HC contribution for MSI and SSI is approximately 23-31%, whereas 9% to 15% is for CO. It is noticeable here that Red LSI is the major contributors and fossil fuel Bagasse and Wood needs to be control. **Figure 3.8** shows the percent contribution of fuel consumption for different pollutants.

The percent TSP and PM_{10} are showing similar trend of contributions for fuel consumption. Total TSP and PM i.e. 381.1 and 2601.6 kg/day respectively where Bagassee and wood are the major source sharing percent of 59% and 28% respectively, other one is coal gives 11%. The category wise contribution shows it is mainly from Bagasse 87.6% (from 445 TPD) and Coal 7.9% (from 25 TPD) i.e. as of Red Category, whereas MSI shows maximum contribution is from Coal 62% (from 50 TPD) and Wood 25% from (16 TPD). The Red SSI percent contribution to PM load is 55% for Bagasse (11 TPD) and 22% and 17% for coal and wood. The percent maximum input from Orange category is for wood i.e. around 80-90% (from 30 TPD). Whereas, it is showing 40-90% for Green category from Bagasse (85 TPD) and it’s mainly from Green LSI. The major PM is reflected by all Red (LSI, MSI and SSI) and Green LSI categories of industries. Total emission from all Red categories (1558.7 kg/day), all Orange (590 kg/day) and all Green (452.9 kg/day) contributing 60%, 23% and 17% respectively.

The total NOx emission from industries is 2291.9 Kg/day major share is from Coal (26%) and other fuel such as FO, Diesel and HSD contributes around 16-20%. The category wise percent contribution from NOx is coming from Coal 20-40% (from 81 TPD); FO 11-40% (from 49 TPD) and HSD 17-22% (from 58 TPD) for Red category. The Orange category reflected by 20-40% for HSD from (78 TPD) and Diesel (from 27 TPD) major is from LSI industries. Similarly percent NOx gives 60-70% Green from MSI and SSI for Diesel (i.e. 7 TPD) and 62% for Bagasse from LSI (i.e. 75 TPD) category. Total emission of NOx from all Red categories (1510 kg/day), all Orange (655 kg/day) and all Green (126.6 kg/day) contributing 58%, 25% and 5% respectively.

The total emissions of SOx is 1290.4 Kg /day, the major contributors are FO (38%), Diesel (30%) and HSD (22%). The category wise distribution split in the form of 20-60% for FO (from 49 TPD), 20-26% for HSD (from 58 TPD) and 7-125 for Diesel (from 12 TPD) for Red Category. Similarly Orange FO, HSD and Diesel is the major fuel and their percent contribution is around 15-21% (from 10 TPD), 33-37% (from 78 TPD) and 40-75% (from 27 TPD) respectively. The Green category signifies the diesel 36-71%; HSD 8-14% and as Bagasse quantity is more in LSI i.e. 75 TPD the contribution is also more for SOx around 55%. The other fuel consumption is around 1 to 4% each from Coal, Kerosene and LDO. Very Minor contribution is from Wood and NG i.e. 0.02%. As the emission factor for NG (9.6 E-06 m^3) is very less the load also reflect the less contribution.

The total CO emission from 200645.8 Kg/day is mainly coming from Baggasse around 64% and from wood 35%. The percent category wise distribution shows around 94 -99% for Bagasse (i.e. 555 TPD) which is mainly coming from LSI, as also 60-80% for Wood (41 TPD) from MSI and SSI of all the categories. Whereas, total emission from HC is around 4862.3 kg/day maximum contribution is from wood i.e 80-98% from 41 TPD for all categories and other very minor percent contributors are HSD and Diesel.

Data Constraints / Assumptions

- Emissions have been worked on the basis of fuel consumption only. The estimation of DG sets emission while load shading time is not worked out
- A wide variation in the data on fuel supplied to the industries as per survey and the data obtained from the consent forms of MPCB on fuel consumption is observed. This indicates some other source of fuel supply and consumption whose details are not available for estimating the point source emissions. It necessarily does not mean that the fuel supplied goes to industries alone.
- The surrounding industrial areas like Pimpri Chinchwad, Hinjiwadi and in the vicinity of Pune city (Pune region) is not taking for estimation as whole emission inventory is developed on the basis of city level.

3.5 Whole City Total Emission Load

Emission loads from vehicles, area and industries categories for the whole city is presented in **Table 3.24.**

Table 3.24 : Emission Load for Pune City from All Sources

	PM Load	% PM	NOx Load	% NOx	SOx Load	% SOx	HC Load	% HC	CO Load	% CO
Bakery	79.5	0.2	6.6	0.01	2.4	0.1	571.0	1.1	515.3	0.2
Open Eatout	9.8	0.02	6.9	0.01	8.3	0.3	9.1	0.02	39.3	0.01
Hotels	293.0	0.6	183.2	0.3	174.7	5.9	11.0	0.02	288.6	0.1
Domestic Fuel	3757.5	7.5	1455.7	2.7	510.4	17.4	17050.8	32.2	21291.0	7.5
Crematorium	60.9	0.1	19.1	0.04	3.3	0.1	382.8	0.7	428.2	0.2
Bldg.Construction	3618.9	7.2	--	--	--	--	--	--	--	--
Open Burning	337.2	0.7	126.4	0.2	21.1	0.7	906.1	1.7	1770.1	0.6
Bricks Klin	600.0	1.2	--	--	--	--	--	--	--	--
Non Ind. Generator	1234.0	2.5	--	--	--	--	--	--	--	--
Agri. Pump	500.0	1.0	--	--	--	--	--	--	--	--
Total Area Source (A)	**10490.8**	**21.0**	**1798.0**	**3.4**	**720.2**	**24.5**	**18930.8**	**35.8**	**24332.4**	**8.6**
Red_LSI	1169.1	2.3	429.6	0.8	176.2	6.0	371.9	0.7	91678.8	32.5
Red_MSI	296.6	0.6	906.3	1.7	410.7	14.0	521.7	1.0	8754.7	3.1
Red_SSI	93.0	0.2	174.3	0.3	121.0	4.1	110.7	0.2	5947.7	2.1
Orange LSI	330.4	0.7	357.2	0.7	272.9	9.3	1841.9	3.5	30892.3	10.9
Orange MSI	99.7	0.2	229.7	0.4	160.2	5.5	621.1	1.2	9163.3	3.2
Orange SSI	159.9	0.3	68.0	0.1	43.1	1.5	1008.1	1.9	15411.6	5.5
Green LSI	345.6	0.7	33.5	0.1	24.6	0.8	0.3	0.001	29251.6	10.4
Green MSI	5.3	0.01	22.3	0.04	20.9	0.7	0.5	0.001	362.9	0.1
Green SSI	102.0	0.2	70.9	0.1	60.7	2.1	386.2	0.7	9182.8	3.3
Total Point Source (B)	**2601.5**	**5.2**	**2292.0**	**4.3**	**1290.3**	**43.9**	**4862.4**	**9.2**	**200645.8**	**71.1**
Car Petrol	19.5	0.04	875.8	1.6	48.7	1.7	1167.8	2.2	8174.5	2.9
Car Diesel	17.2	0.03	247.2	0.5	57.3	2.0	91.6	0.2	68.7	0.0
Car CNG	3.4	0.01	322.0	0.6			263.4	0.5	34.4	0.0
2 Wheelers	302.3	0.6	3487.5	6.6	31.0	1.1	12090.1	22.8	16740.2	5.9
3 Wheelers	791.9	1.6	1275.2	2.4			13825.3	26.1	4630.8	1.6
HDDV	5714.9	11.4	42862.0	80.6	790.1	26.9	1705.3	3.2	27652.9	9.8
Paved Rd.	7479.2	15.0	--	--	--	--	--	--	--	--
Unpaved Rd.	22601.9	45.2	--	--	--	--	--	--	--	--
Total Line Source (C)	**36930.2**	**73.8**	**49069.8**	**92.3**	**927.1**	**31.6**	**29143.6**	**55.1**	**57301.5**	**20.3**
* Line Source contribute - 13.7% (6849.2 Kg/d)										
Total A+B+C (Kg/day)	**50022.6**		**53159.7**		**2937.6**		**52936.7**		**282279.7**	
Total (Tones/Yr.)	**18258.3**		**19403.3**		**1072.2**		**19321.9**		**103032.1**	

Percent contribution of pollutant due to different source categories for PM and NOx is presented in **Figure 3.9 and 3.10**.

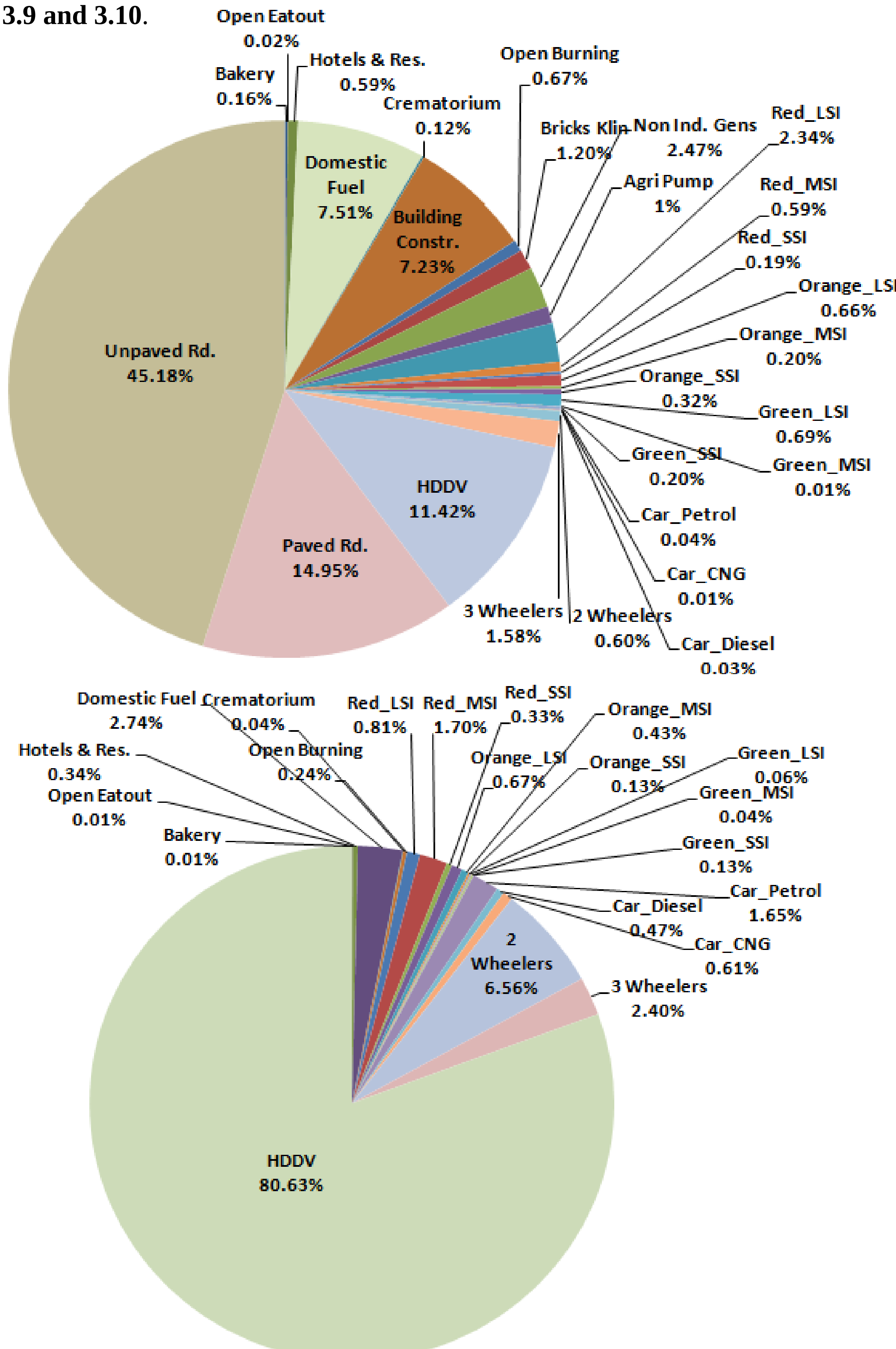


Figure 3.9 : Percent Contribution of PM and NOx from Different Sector in Pune City

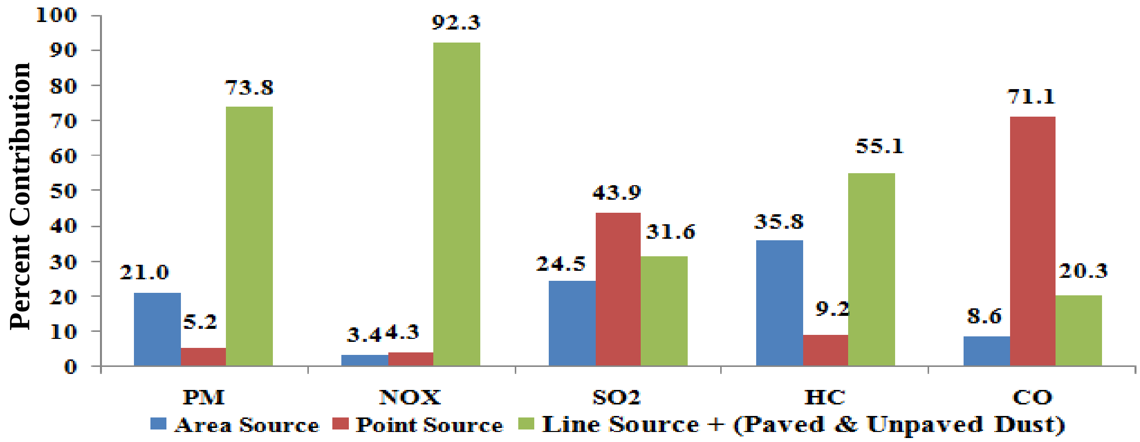


Figure 3.10 :Percent Contribution from All Sources for Whole of Pune City

In Pune city, PM is mainly contributed from road dust (60.1%) and tailpipe emissions of vehicular sources contribute 13.7%; followed by area sources (21%); whereas industrial sources contribution is around 5.2%.

Among the total area source i.e. 10490.8 kg/day construction activities contribute 7.2% followed by domestic fuel 7.5%, and other sources viz. open burning, non industrial generator, brick kilns and agricultural pumps percentage is negligible i.e. around 0.7 to 2.5%. The point source contribution is around 5.2% (i.e. 2601.5 kg/d) to the total PM; the major source is from Red LSI i.e. 2.3% (1169.1 kg/d) and others are Orange- Green LSI and Red MSI giving 0.7% each share to the total point source emission. The baggasse and wood are the major fuel to the industrial sector. The fuel consumption is more for Red category i.e. Bagasse (460 TPD), HSD (58 TPD), coal (81 TPD) and FO (49 TPD) which reflecting the higher PM emission load. In vehicular sector percent contribution from heavy duty is more 5714.9 kg/d gives 11.4%, 3 wheelers 791.9 kg/d shares 1.6%. The overall line source contributes 13.7% (6849.2 kg/d), but if we considered vehicular dust the percentages goes upto 60.1% (paved 7479.2 kg/d -15% and Unpaved 22601.9 kg/d – 45.2%).

The NOx contribution mainly reflects by line source i.e 92.3% (49069.8 kg/d) followed by point source 4.3% (2292.0 kg/d) and area source 3.4% (1798.0 kg/d). The domestic sector add 2.7% to the total NOx and minute percentage 0.2-0.3% is from hotel and open burning in Area source. Among industries Red MSI gives 1.7%. The fossil fuel i.e. Diesel, FO and HSD are the major source of fuel to the industries. The vehicular sector major NOx is coming from HDDV vehicles 80.6% (5714.9 kg/d) second highest is from 6.6% (3487.5 kg/d) and 3 wheelers 2.4% (1275.2 kg/d).

The total 2937.6 kg/d of SOx emission is mainly from industries i.e. around 43.9% (1290.3 kg/d) next is coming from line source i.e 31.6% (927.1 kg/d) and 24.5% (720.2 kg/d) is from area source. Among area source major 17.4% is domestic sector followed by hotels 5.9% to the total SOx emission. Industrial SOx is mainly from Red_MSI 14% and other categories Red and Orange, LSI and MSI gives 5 to 9% to the total emission. The fossil fuel i.e. Diesel, FO and HSD are the major source of fuel to the industries. For vehicles SOx emissions are calculated based on sulphur content (Diesel 300 ppm and Gasoline 30 ppm), higher emission of line source is from HDDV i.e. 26.9% (790.1 kg/d) and other vehicles sources i.e car petrol- diesel and 2 wheelers gives 1-2% emission load.

The hydrocarbon emission from domestic sector -32.2% and open burning -1.7% collectively reflect the area source contribution around 35.8% (18930.8 kg/d). The industrial hydrocarbon contribution is around 9.2% (i.e. 4862.4 kg/d). The orange categories industries (LSI, MSI and SSI) shares 1 to 3.5% to the total HC emission, as wood are the major source of fuel i.e 97.5%. Total vehicular source contribution for hydrocarbon is 55.1% (29143.6 kg/d), among 2 and 3 wheelers share is around 22.8% to 26.1% and HDDV contribution is 3.2% to the total emission of HC.

The 71.1% (200645.8 kg/d) CO is coming from industries, among them Red LSI is the major and others are Orange and Green LSI. The Bagasses 64.6% and wood 35.1% is the major source of fuel in industries. Area source gives 8.6% which is mainly reflected by domestic fuel 7.5%. The total vehicular emission Load for CO is 20.3% (57301.5 kg/d) and HDDV and 2 W contributes 9.8% and 5.9% respectively.

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

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study Using EPA PMF v5.0

Positive matrix factorization (PMF) is a receptor modeling tool used for identification and quantification of sources and their contribution *(Norris et al., 2014)*. It is a multivariate statistical approach to factor analysis used for the source apportionment of atmospheric particulate matter *(Paatero and Hopke, 2003; Gupta et al., 2012; Das et al., 2015; Cesari et al., 2016; Habil et al., 2016; Sharma et al., 2016; Zong et al., 2016; Gadi et al., 2019)*. It requires concentration dataset of samples and associated uncertainty as inputs and gives several variables such as factor profiles, their contribution and error in modeling as output *(Polissar, 1998; Paatero and Hopke, 2003; Pakbin et al., 2011)*. The chemically speciated air samples can be assembled as a data matrix 'X' of i x j dimensions, in which i is the number of samples and j is the number of chemical species measured during analysis. It is based on chemical characterization of collected particles, are aimed to solve Eq 1.1.

$$x_{ij} = \sum_{k-1}^{p} g_{ik} f_{jk} + e_{ij} \qquad \text{...... Eq 1.1}$$

where p is the number of factors contributing to the atmospheric particulate matter, x_{ij} is the j^{th} compound concentration measured in the i^{th} sample, g_{ik} is the gravimetric concentration of the j^{th} element in material from the k^{th} source, and f_{kj} is the airborne mass concentration (mg/m^3) of material from the k^{th} source contributing to the i^{th} sample and e_{ij} is the residual for each species, difference between the measured and calculated amount.

PMF is a weighted least square problem in which a certain number of factors have to be determined in order to minimize an 'object function' as shown in Eq 1.2. Factor contributions and profiles are calculated by minimizing the object function 'Q' in the PMF model.

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{x_{ij} - \sum_{k-1}^{p} g_{ik} \, f_{kj}}{u_{ij}} \right)^2 \qquad \text{........ Eq 1.2}$$

Where, u_{ij} is an estimate of uncertainty in the j^{th} variable in ith sample. Q is a significant parameter in the PMF model for which two values, Q (true) and Q (robust), are calculated in the model results. The apportionment technique relies on many trial attempts to arrive at an acceptable solution *(Reff et al., 2007; Jiang et al., 2015)*. More description with results analysis of the apportionment approach is included in Section 4.2; technical details can be found elsewhere *(Paatero and Hopke, 2003; Pakbin et al.,2011; Jiang et al., 2015)*.

4.2 Methodology

For the present study EPA PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for identification of sources and their positive contributions to ambient air pollution.

The study was carries out for representative samples of $PM_{2.5}$ and PM_{10} collected during winter, 2020 sampling campaign at 5 locations: Sanghvi Police Station (Background); Rani Mahila Samiti (Residential); APMC Mkt PMPL (Commercial); Swargate Department (Kerb Site) and Bharat Forge (Industrial). The concentration and uncertainty data were obtained from the gravimetric analysis ($PM_{2.5}$ and PM_{10}); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (46 elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb, Bi, Th and In); and Ionic Analysis (12 ions: Na^+, NH_4^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, NO_2^-, Br^-, NO_3^{2-}, PO_4^{3-} and SO_4^{2-}) for both PM_{10} and $PM_{2.5}$ for all sources as listed above.

EPA PMF requires 2 input files : 'Concentration' file and 'Uncertainty' file. The input file is prepared using concentration data set of samples and associated uncertainty and both these data sets should be in same format (csv or xls) with all the elements analysed for the study in same units ($\mu g/m^3$). The Concentration file is prepared by multiplying the concentration data as well as the uncertainty (i.e., standard deviation of analysis) obtained in $\mu g/cm^2$ with area of Filter paper (i.e., 11.9 cm^2 @ 39mm ϕ deposit area) from the ED -XRF and ionic analysis and then dividing the mass by the flow rate of Mini volume samplers (7.2 m^3, taking the sampling time as 24 hours @ 5 lpm. Here note that PMF works on non-negative aspect so if the concentration of any species is below detection limit or zero then that value needs to be replaced by 0.5 x Minimum Detection Limit (MDL) of that species. The MDL of all the elements is given in **Table 4.1**.

The uncertainty for measured values of elemental, ionic, gravimetric and EC-OC Analysis are calculated with Eq. 1.3 *(Norris et al., 2014)*. This calculation includes field as well as analytical uncertainty. If the value of uncertainty is missing it can be replaced by 5/6 x MDL *(Norris et al., 2014)*.

$$\text{Unc} = \sqrt{(conc\ of\ ion\ X\ 0.05)^2 + (Mdl * 0.5)^2)} \qquad \text{....Eq 1.3}$$

Where, Conc of ion = Concentration of ion, $\mu g/m^3$; Del relativity = Delta Relativity ~ 5%, Smp Unc = Sampling uncertainty ~5%; MDL = Minimum Detection Limit, $\mu g/m^3$

These two files are then used as input for EPA PMF v5.0 software. The model uses input files to display the summary of concentration data species in the form of minimum value, 25^{th}, 50^{th} and 75^{th} percentile value, maximum value and 'Signal to Noise' (S/N) ratio. Based on this ratio the species are assigned as strong, weak or bad, as error is minimum in strongest variable and maximum in weakest variable, those labelled bad are excluded from the analysis *(Paatero and Hopke, 2003; Jiang et al., 2015)*. The Species having S/N ratio more than 3 are assigned Strong, ratio between 1 to 3 are assigned as weak and species with ratio less than 1 are assigned as bad species for running of the model. Species with 80% values below MDL are considered Bad species.

The model requires many trial and error attempts to arrive at the solutions. Thus, a wide range of factors (3-8 in number) were tried, and trial runs of 100 with a random start were attempted each time. The ratio Q_{true}/Q_{robust} has also been used to assess the modelled results. Q_{true} is estimated by considering entire data whereas Q_{robust} is estimated excluding outliers *(Waked et al., 2014)*. This ratio when close to 1.0, signifies good solution and negligible influence of outlier whereas if ratio is greater than 1.5 indicates, non-negligible influence *(Waked et al., 2014; Jiang et al., 2015)*. Hence for the present study the recommended protocol of convergence of all the runs and factors were selected for the cases where $Q_{robust} < 1.5\ Q_{true}$ *(Jiang et al., 2015: Zong et al., 2016; Gadi et al., 2019)*. Also, the correlation coefficients (R^2) between measured and modelled metal concentration were checked for >0.80, which indicate better fit of the model to the measured data.

Table 4.1 : Minimum Detection Limit (MDL) of Target Analytes

Elements (a)	µg/cm^2	µg/m^3#	Elements (a)	µg/cm^2	µg/m^3#
Na	0.0876	0.211	Ag	0.0192	0.046
Mg	0.0414	0.1	Cd	0.0260	0.063
Al	0.0128	0.031	Sn	0.0488	0.118
Si	0.0050	0.012	Sb	0.0700	0.169
P	0.0134	0.032	Te	0.0866	0.209
S	0.0090	0.022	I	0.1176	0.283
Cl	0.0100	0.024	Cs	0.0040	0.01
K	0.0162	0.039	Ba	0.0092	0.022
Ca	0.0048	0.012	La	0.0054	0.013
Sc	0.0074	0.018	W	0.0060	0.014
Ti	0.0020	0.005	Au	0.0022	0.005
V	0.0042	0.01	Hg	0.0020	0.005
Cr	0.0020	0.005	Pb	0.0056	0.013
Mn	0.0110	0.026	In	0.0274	0.066
Fe	0.0102	0.025	Br	0.0010	0.002
Co	0.0044	0.011	Rb	0.0102	0.025
Ni	0.0030	0.007	Sr	0.0086	0.021
Cu	0.0050	0.012	Y	0.0090	0.022
Zn	0.0020	0.005	Zr	0.0100	0.024
Ga	0.0020	0.005	Mo	0.0104	0.025
Ge	0.0010	0.002	Rh	0.0108	0.026
As	0.0092	0.022	Pd	0.0126	0.03
Se	0.0010	0.002	**Ions (b)**	**PPM**	**µg/m^3#**
Ions (b)	**PPM**	**µg/m^3#**	NO_2^-	0.01	0.001
Na^+	0.008	0.001	Br^-	0.02	0.003
NH_4^+	0.009	0.001	NO_3^{2-}	0.02	0.003
K^+	0.02	0.003	NO_3^{2-}	0.06	0.008
Mg^{2+}	0.02	0.003	PO_4^{3-}	0.02	0.003
Ca^{2+}	0.03	0.004	SO_4^{2-}	0.02	0.008
F^-	0.002	0.0002	**EC-OC (c)**	**PPM**	**µg/m^3#**
Cl^-	0.005	0.001	EC	0.06	0.063
			OC	0.45	0.013

#Based on nominal air sampled @ 5LPM per sampling day

ED- XRF; (b) IC; (c)Based on DRI SOP for EC/OC (URL 2)

PMF can produce non-unique solutions because of many possible rotations of the solutions *(Paatero et al., 2002; Norris et al., 2014)*, also referred to as rotation ambiguity. Rotating a given solution and investigating how rotated solution fill the solution space is one way to minimize the number of solutions. F-peak, a parameter for rotation of solution, is controlled to ensure minimum change in Q to produce unique solution. F-peak values were varied between −3 and 3 and Q-values were monitored. The lowest Q-value indicated negligible presence of rotational ambiguity and thus solution at that F-peak was considered. The results are then check for mapping of the factors with respect to base model. Near to 100% mapping indicates that model is showing the efficiency of model results. If unmapped factors are more then, base factors and other parameters may need to be revised for getting better results. For the present work mapping of factors above 95% were accepted for all the cases.

Bootstrapping is a technique to estimate uncertainty in the solution by using series of dataset that are modified version of the original data *(Norris et al., 2014)*. Bootstrap runs indicated less than 5% variability in percentage of species. Minimum correlation value of 0.8 was selected with the default block size for every case. The above criteria, with reasonable control over numerous statistical parameters, substantiate that the solutions arrived were acceptable.

After matching all the criteria as described above, the model runs were considered for further analysis. The factor fingerprints, factor profiles and contribution obtained from these optimized runs were matched with the standard factor fingerprints and previous studies *(Maykut et al., 2003; Gupta et al., 2012; Patil et al., 2013; Sharma et al., 2016; Zong et al., 2016; Police et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Taghvaee et al., 2018; Garaga et al., 2020)* to identify the sources. Also, all the results from various run and error estimation were obtained in the form of datasheets which were used for further analysis to obtain percentage contributions of each source at receptor locations and percentage of elemental contribution from that source.

4.3 Results

The results of both cases for $PM_{2.5}$ & PM_{10} mentioned in Section 4.2 are presented in this section.

4.3.1 PM_{10}

After the EPA PMF run analysis, 6 factors were identified in the study location for PM_{10} Samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and b)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for $PM_{2.5}$ and PM_{10} is presented in **Figure 4.2 (a to d).**

Factor 1: Biomass Burning/Wood Combustion

Factor 1 is identified as Biomass burning which accounted for contributions of 8.84%. Major proportions of EC, OC, F^-, Ca^{2+}, SO_4^{2-} and NO_3^{2-} (~10.95%, 7.19%, 12.97%, 13.73%, 16% and 11.57%) and K^+ and K as minor indicators contributed to this source. There have been many studies in the past suggesting that OC, K^+ and SO_4^{2-} are clear indicator of biomass burning. *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020).*

Factor 2: Vehicular Emissions

Factor 2 vehicular emission, accounted for 13.98%, with indicators of OC, Ca^{2+}, SO_4^{2-} and NO_3^{2+} (~6.15%, 17.70%, 17.36% and 21.46%) and minor indicators such as Zn, Cr, Pb, EC and Br contributed to this factor. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017; Mukherjee et at., 2018, Pawar et al., 2020).* Also, EC, Br and OC were present in this factor indicating emissions from burning of fossil fuel from vehicles *(Jain et al., 2018; Keerthi et al., 2018)*. The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018; Jain et al., 2017; Pawar et al., 2020.*

Factor 3: Construction Dust/Road Dust

Factor 3 is identified as Construction dust which accounted for contributions of 11.49%. Major proportions of Mg, Ca^{2+}, Ca, Fe, Si, NO_3^{2-} and SO_4^{2-}(~11.25%, 8.70%, 9.65%, 6.91%, 15.03%, 6.37% and 11.33%) and minor species such as Cl and Na also contributed to this factor. Ca^{2+}, Mg, Si, Cl^- are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al., 2020)*. Several Construction activities like infrastructure development projects and renovation of old structures was observed in and around the city contributing to this source.

Factor 4: Secondary Aerosols

Factor 4 is represented by the significant levels NH_4^{3-}, NO_2^-, SO_4^3, S, Si and Mg (~5.16%, 4.83%, 26.02%, 8.01%, 8.78% and 12.35%) contributing to about 13.54% of total PM_{10} Pollution indicating secondary aerosols. The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols *(Patil et al., 2013; Police et al.,2016; Sharma et al., 2016; Jain et al., 2017, Mukherjee et at., 2018; Garaga et al., 2020).* This is a background source which is contributing at all locations of the study area.

Factor 5: Resuspended Road dust/ wind-blown dust

Factor 5 is represented by the significant levels of Al, Si, Ca, Fe, Mg and SO_4^{2-} (~7.90%, 24.95%, 11.38%, 12.56%, 11.98% and 9.27%) and minor indicators such as Zn, Ti, S and Na contributing to 25.63% of total PM_{10} Pollution. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor. K, Mg, Si and Ca are good tracer of crustal dust *(Kothai et al., 2008; Patil et al., 2013; Jain et al., 2017; Keerthi et al., 2018; Garaga et al., 2020)* whereas substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as Fe, Zn and Al are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*. Road dust gets re-suspended due to natural gust of winds or moving objects like vehicles *(Zhang, 2008; Kothai, 2011; Banerjee et al., 2015; Ashrafi et al., 2018)*. Since the study was done in dry conditions wind-blown dust has large influence on this source.

Factor 6: Fossil fuel Combustion/ Industrial emissions

Factor 6 was identified as fossil fuel combustion the presence of tracers, such as Al, Ca^{2+}, Fe, Mg (~6.50%, 3.08%, 11.62 and 15.56%) with minor indicators such as OC, Cl^-, Cl, Na, Cr, Mn, Zn and Pb suggest the source of fossil fuel combustion contributed to about 26.49% of total PM_{10} Pollution. Cl^- along with SO_4^{2-} have been widely used as a marker of coal combustion in power plants *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. Earlier studies reported that Fe, Cr and Al are the indicators of the industrial emissions as these elements are greatly used in various industries like machinery, battery and electroplating purposes *(Taghvaee et al., 2018)*. Location of industrial regions in some of this study area could be the possible reason of this source. Ca, Ti and Fe are major indicators of crustal dust/ soil as per previous studies *(Kothai et al., 2008; Sharma et al., 2016; Jain et al., 2017; Mukherjee et al., 2018; Pawar et al., 2020)*.The modal could not differentiate these sources as there were many overlapping species.

4.3.2 $PM_{2.5}$

After the EPA PMF run analysis, 7 factors were identified in the study location for $PM_{2.5}$ samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and c)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for $PM_{2.5}$ and PM_{10} is presented in **Figure 4.2 (a to d)**.

Factor 1: Construction Dust/Road Dust

Factor 1 is identified as Construction dust which accounted for contributions of 11.42%. Major proportions of Mg, Ca, NO_3^{2-}, SO_4^{2-} and Cl^- (~8.2%, 19.60%, 19.64%, 16.28% and 9.33%) and minor species such as Al, Si and Na^+ contributed to this factor. Ca^{2+}, Mg, Cl^- are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al., 2020)*. Several Construction activities like infrastructure development projects and renovation of old structures was observed in and around the city contributing to this source.

Factor 2: Biomass Burning/ Wood Combustion

Factor 2 is identified as Biomass burning which accounted for contributions of 26.50%. Major proportions of OC, NH_4^{2-}, SO_4^{2-}, S, K^+ and K (~5.36%, 7.19%, 27.95%, 9.43%, 3.08% and 7.83%) were contributed to this factor. There have been many studies in the past suggesting that K^+ and SO_4^{2-} are clear indicator of biomass burning. *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020)*. It is a known fact that biomass is a widely used energy source as well as there is issue of illegal litter burning in India which has resulted in the nominal contributions of biomass burning in this location.

Factor 3: Crustal Dust/Road Dust

Factor 3 is identified as Crustal dust/Soil which accounted for contributions of 7.56% of total $PM_{2.5}$ pollution. Major proportions of K, Ca, Ti and Fe (~ 35.95%, 16.12%, 4.24% and 6.19%) and minor species such as OC and Cr contributed to this factor. Ca, Ti and Fe are major indicators of crustal dust/ soil as per previous studies *(Kothai et al., 2008; Sharma et al., 2016; Jain et al., 2017; Mukherjee et al., 2018; Pawar et al., 2020)*.

Factor 4: Fossil Fuel Combustion/Industrial Emissions

Factor 4 was identified by the significant levels of S, Fe, SO_4^{2-} Mg and Na (~6.26%, 11.64%, 21.56% 17.97% and 7.38%) contributed to 13.58% of total $PM_{2.5}$ emissions. S, Fe, Cl^- along with SO_4^{2-} have been widely used as a marker of Fossil fuel combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*.

Factor 5: Resuspended Road Dust/ Wind Blown Dust

Factor 5 was identified by the significant levels of Ca, SO_4^{2-}, Fe, OC, NO_3^{2-} and Mg (~13.07%, 8.94%, 19.39%, 8.93%, 8.13% and 8.71%) contributed to 14.03% of total $PM_{2.5}$ emissions.Ca, Mg, OC and Mg are major indicators of Resuspended Road dust *(Buyan, 2018; Rai et al., 2016)*. The wind-driven airborne dust from surface soils and paved roads by vehicular movements would have resulted in the considerable emissions of this factor.

Factor 6: Secondary aerosols

Factor 6 was identified by the significant levels of NH_4^{3-}, NO_2^-, SO_4^{2-}, S, Mg (~6.10%, 14.04%, 31.63%, 10.43% and 11.3%) contributed to 8.83% to the total $PM_{2.5}$ emissions. The studies indicated that NH_4^{3-}, $NO_3^{2-}$and SO_4^{2-} are major indicators for secondary aerosols *(Patil et al., 2013; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017, Mukherjee et at., 2018; Garaga et al., 2020).*

Factor 7: Vehicular Emissions

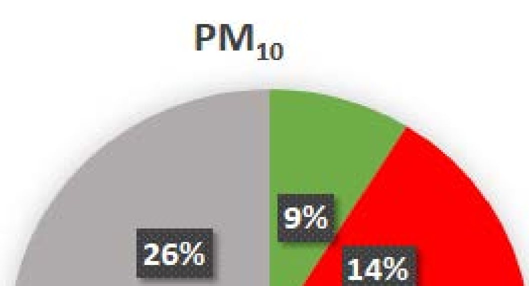
Vehicular factor accounted for 18.1%, with indicators of EC, OC, K, Mg^{2+}, S and SO_4^{3} (~3.5%, 16.09%, 7.49%, 14.77%, 6.61%, and 19.92%) and minor indicators such as Zn, EC, Pb and Br contributed to this factor. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017; Mukherjee et at., 2018, Pawar et al., 2020)* Also, EC, SO_4^{2-}, S, & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles *(Jain et al., 2018; Keerthi et al., 2018).* The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018; Jain et al., 2017; Pawar et al., 2020).*

Table 4.2: Percentage Source Contribution for Pune

Most likely source(s)	%Contribution	
	PM_{10}	$PM_{2.5}$
Construction Dust/Road Dust	11.49	11.42
Biomass Burning/ Wood Combustion	8.84	26.50
Crustal Dust/Road Dust	--	7.56
Fossil Fuel Combustion/Industrial Emission	26.49	13.58
Resuspended Road Dust	25.63	14.03
Secondary Aerosols	13.54	8.83
Vehicular Emissions	13.98	18.06

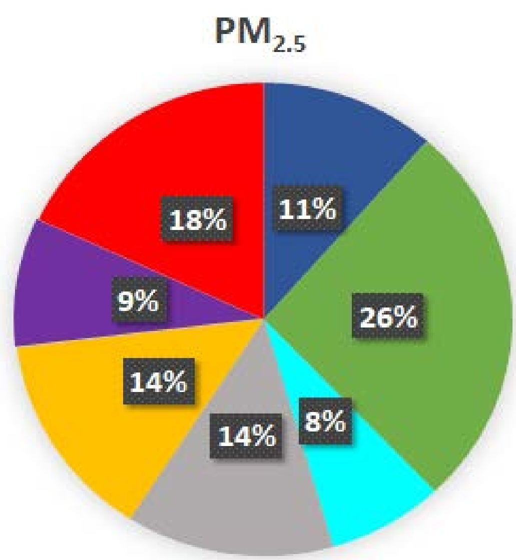
4.4 Positive Matrix Factor Analysis Conclusion

After PMF analysis seven factors were identified contributing to $PM_{2.5}$ Pollution whereas for PM_{10} six major sources were identified. The contribution of vehicular pollution (18.06%) & Biomass Burning (26.5%) dominated in $PM_{2.5}$ size range; whereas fossil fuel combustion/ Industrial emissions (26.49%) and Road dust resuspension/ windblown dust (25.63%) contributions dominated in PM_{10} size range. Secondary aerosols (9-14%) and construction dust (11%) was found to be contributing alm



■ Construction Dust ■ Biomass Burning / Wood Combustion ■ Vehicular Emission

■ Fossil Fuel Combustion ■ Resuspended Road Dust ■ Secondary Aerosols



A)

■ Construction Dust ■ Biomass Burning / Wood Combustion ■ Vehicular Emission

■ Fossil Fuel Combustion ■ Resuspended Road Dust ■ Secondary Aerosols

■ Crustal Dust

Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Pune

B) PM_{10}

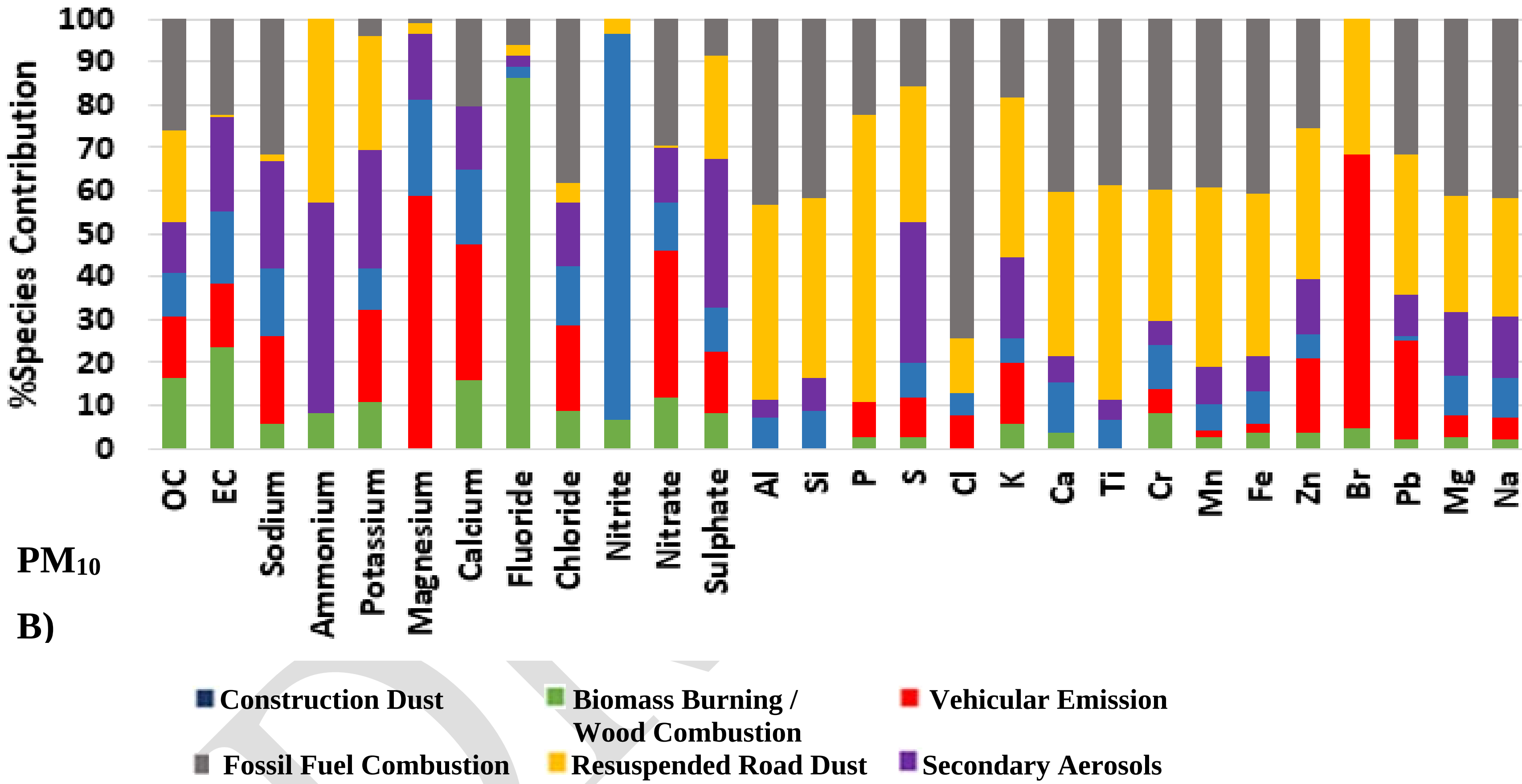


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Pune

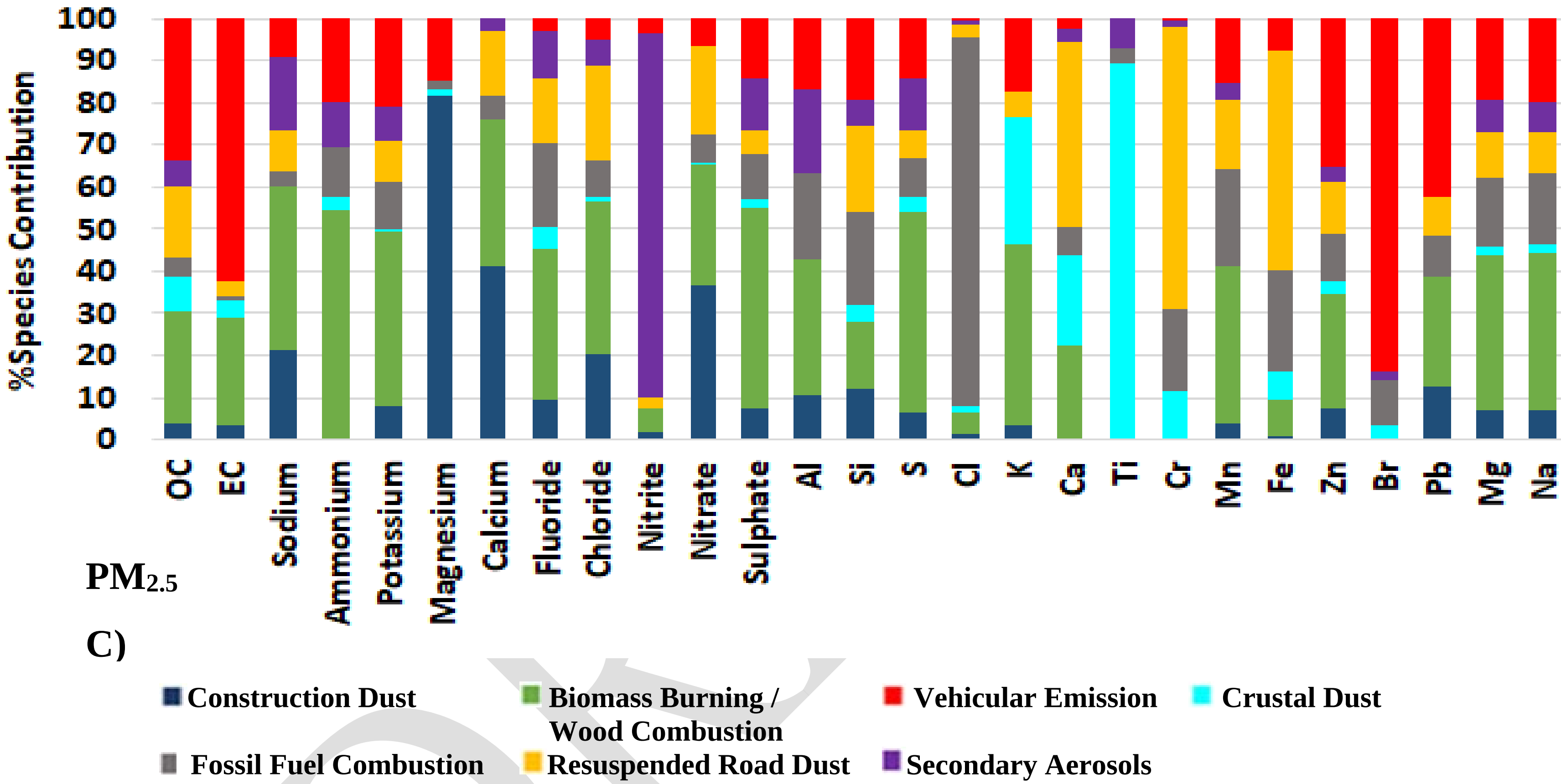


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Pune

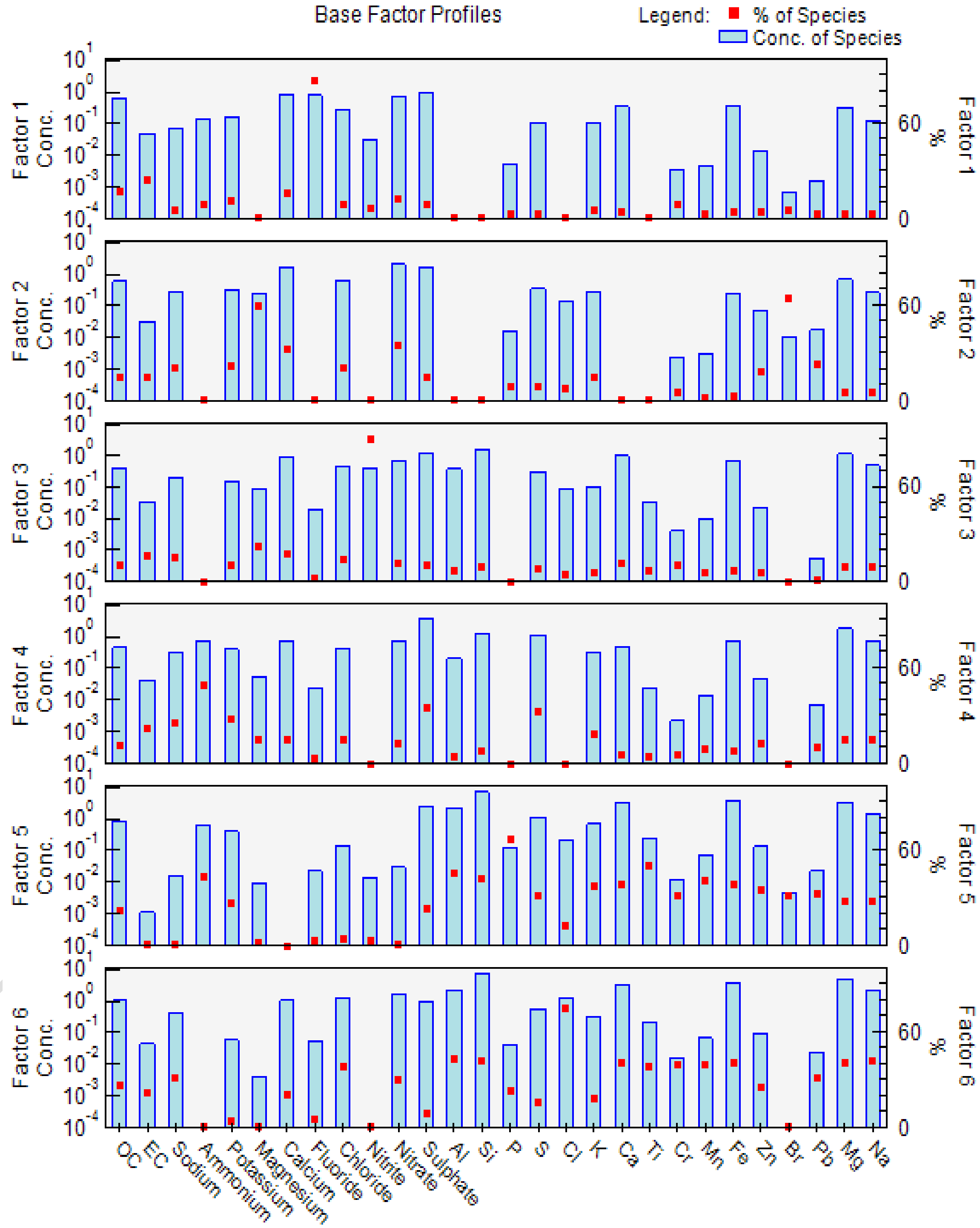


Figure 4.2 a : PM_{10} Base Factor Profiles

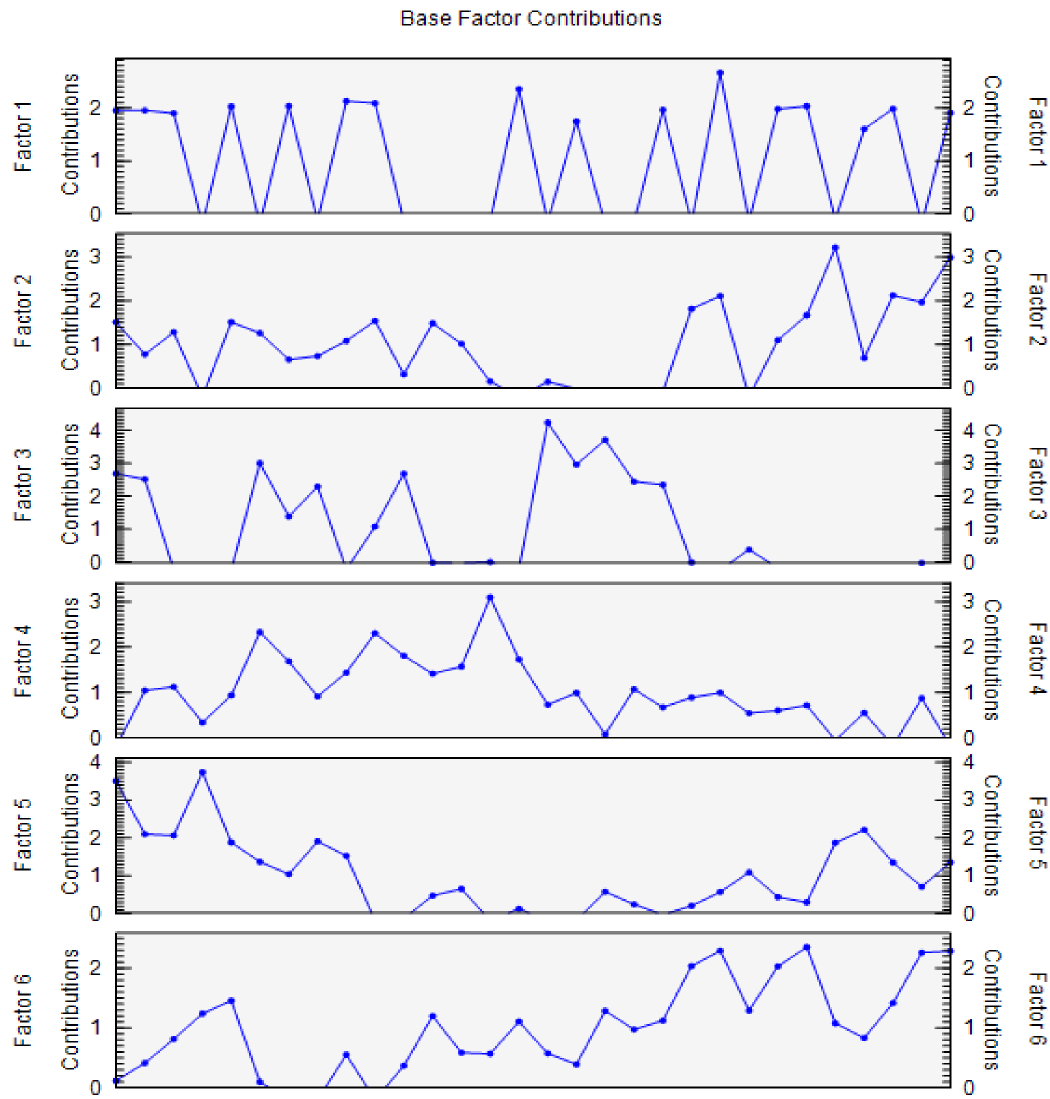


Figure 4.2 b : PM_{10} Base Factor Contributions

	Predominant Factors	% Contribution	Factor Name
Factor 1	EC, OC, Cl, K^+, OC, F^-, Ca^{2+}, NO_3^{2-}, SO_4^{2-}	8.84	Biomass Burning
Factor 2	EC, OC, Br, K, Mg^{2+},Ca^{2+}, Pb, Zn SO_4^{2-} and NO_3^{2+}	13.98	Vehicular
Factor 3	Mg, Ca^{2+}, Ca, Fe, Si, NO_3^{2-}, SO_4^{2-}	11.49	Construction Dust
Factor 4	NH_4^{3-}, NO_2^-, SO_4^{2-}, S, Si, Mg	13.54	Secondary Aerosols
Factor 5	Al, Si, Ca, Fe, Mg, SO_4^{2-}	25.63	Road Dust Resuspension/ Wind Blown Dust
Factor 6	Al, Ca, Fe, Mg, OC, Cl^-, Cl, Na, Cr, Mn, Zn and Pb	26.49	Fossil Fuel Combustion/ Industrial Emissions

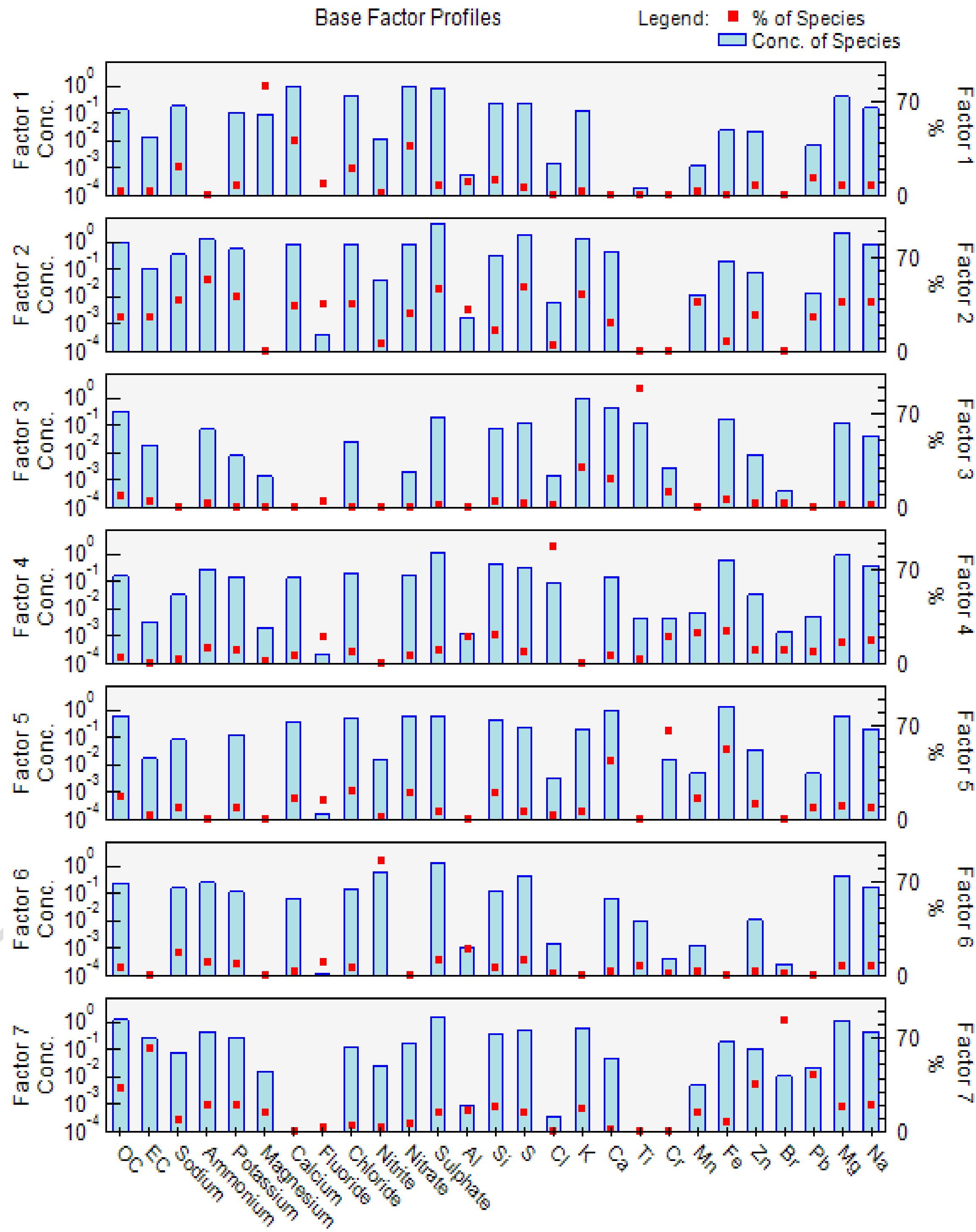


Figure 4.2 c : $PM_{2.5}$ Base Factor Profiles

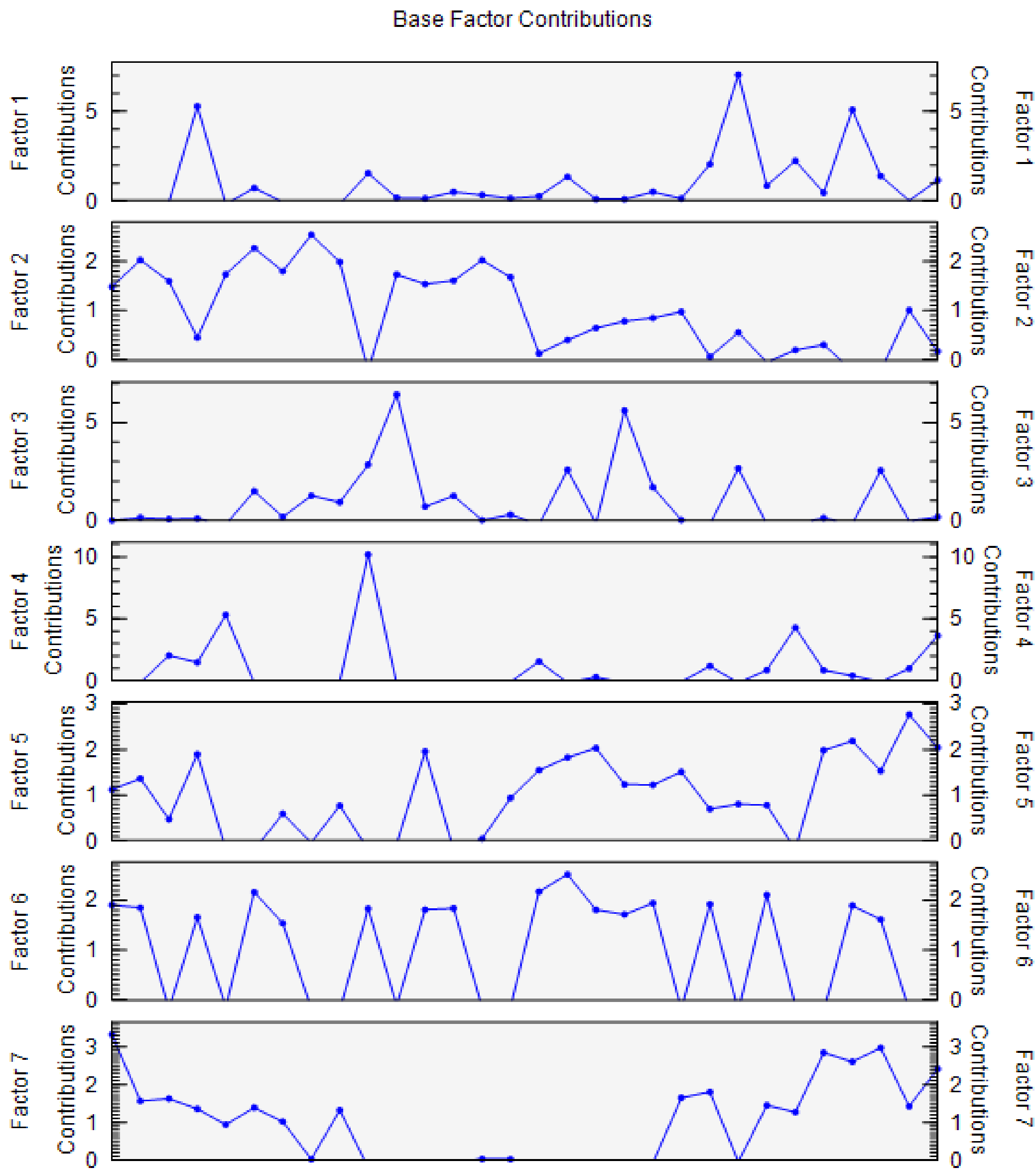


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Contribution	Factor Name
Factor 1	Mg, Ca, NO_3^{2-}, Na^+, Cl^- Al, Si, Mg	11.42	Construction Dust/ Road Dust
Factor 2	OC, NH_4^{2-}, SO_4^{2-}, S, K^+, K	26.50	Biomass Burning/ wood Combustion
Factor 3	K, Ca, Ti, Fe	7.56	Crustal Dust/ Road Dust
Factor 4	F^-, S, Mn, Fe, Cl, Mg, Na, SO_4^{2-}	13.58	Fossil Fuel Combustion
Factor 5	Ca, SO_4^{2-}, Fe, OC, NO_3^{2-}, Mg	14.03	Resuspended Road Dust
Factor 6	NH_4^{3-}, NO_2^-, SO_4^{2-}, S, Mg	8.83	Secondary aerosols
Factor 7	EC, OC, K, Mg^{2+}, S and SO_4^{2-} Zn, Pb, Br, Al	18.06	Vehicular

4.5 Emission Inventory and Source Apportionment

Emission inventory is a comprehensive listing by sources of air pollutant emissions and amount of air pollutants released into air as a result of a specific process in a particular geographic region during a specific time period. Source apportionment (SA) is the technique which relates a source emission (an activity sector or an area) to the ambient air concentration of a pollutant.

Industrial Source: The point source contribution is around 5.2% (i.e. 2601.5 kg/d) to the total overall city PM load. Total emission from industries of all Red categories (1558.7 kg/day), all Orange (590 kg/day) and all Green (452.9 kg/day) categories contribute around 60%, 23% and 17%, respectively. Contribution of TSP and PM were 381.1 and 2601.6 kg/day, respectively; where Bagassee and wood contribute around 59% and 28% respectively, while that from coal is 11%. The contribution from Red Category is mainly from Bagasse 87.6% (from 445 TPD) and Coal 7.9% (from 25 TPD). MSI has maximum contribution from Coal (62%) from combustion of 50 TPD and Wood (25%) from combustion of 16 TPD. The Red SSI contribution to PM load is 55%, which is mainly from Bagasse (11 TPD), while 22% and 17% is from coal and wood. The maximum contribution from Orange category is from wood (80-90%) from 30 TPD. Whereas, 40-90% of emission load from Green category is due to use of Bagasse (85 TPD) and it's mainly from Green LSI. Overall NOx contribution from all industries is around 4.3% (2292.0 kg/d) which is due to fossil fuel consumption i.e. Diesel, FO and HSD; being the major source of fuel to the industries. SOx emission from industries is around 43.9% (1290.3 kg/d) of the total emission load.

The results are well corroborated with apportionment of particulate matter; the overall factor emphases fossil fuel combustion/ industrial emissions as source contribution. The total emission from this factor is around 26.49% in PM_{10}, as compared to 13.58% in $PM_{2.5}$. In PM_{10} significant indicators such as Al, Ca^{2+}, Fe and Mg were found, which were ranging from 6 to 16%. In $PM_{2.5}$ the indicators of S, Fe, SO_4^{2-}, Mg and Na are the dominant tracers, with 6 to 22% of contribution. The minor indicators are OC, Cl^-, Cl, Na, Cr, Mn, Zn and Pb, suggests source of fossil fuel combustion. Earlier studies reported that As, S, Mg, Cl, K, Zn, Na, Pb and Cr is the source of smelting /incinerator /furnaces and coal combustion industries. S, Fe, Cl^- along with SO_4^{2-} has been widely used as a marker of Fossil fuel combustion. Other research suggests that Fe, Cr, and Al are indications of industrial emissions because these elements are widely employed in industries such as machinery, batteries, and electroplating.

Vehicular Source: The overall city emission inventory shows vehicular sources contribution for PM is about 13.68% (6849.2 kg/d). The maximum load of 5714.9 kg/day (11.4%), is from heavy duty vehicles emissions across all shifts; although, the heavy duty diesel vehicle distribution is very less in total number of vehicles in the study area i.e. 10 percent. 3 wheelers and 2 wheelers give around 791.9 kg/d (1.6%) and 302.3 (0.6%) of the total load, respectively. If we consider emission load from line and resuspension of road dust, the percent contribution of PM is around 73.8% of the total. The NOx contribution is mainly from line source i.e 92.3% (49069.8 kg/d). In vehicular sector, major NOx load is from HDDV vehicles 80.6% (42862 kg/d). Following the emission load is from 2 wheelers i.e. 6.6% (3487.5 kg/d) and 3 wheelers 2.4% (1275.2 kg/d). For vehicles, SOx emissions are calculated based on sulphur content of the fuel (Diesel 300 ppm and Gasoline 30 ppm). Sox load from line source is 31.6% (927.1 kg/d) of the total load

The vehicular source factor have dominant species like OC, Ca^{2+}, SO_4^{2-} and NO_3^{2+} in PM_{10}, contributing around (6 to 21%) in the total, whereas EC, OC, K, Mg^{2+}, S and SO_4^{3} were found around 6 to 20% in $PM_{2.5}$. The noticeable tracers found are Zn, EC, Cr, Pb, EC and Br. The overall source contribution of vehicular emission factor is around 13.98% and 18.1% in PM_{10} and $PM_{2.5}$, respectively. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles. Also, EC, Br, SO_4^{2-}, S and OC were present, indicating emissions from burning of fossil fuel from vehicles. The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies.

The resuspended road dust and wind blowing dust contributes 25.63% in PM_{10} and 14.03% in $PM_{2.5}$. The major indicators Al, Si, Ca, Fe, Mg and SO_4^{2-} were contribute around (7 to 25%) in PM_{10}, whereas in $PM_{2.5}$ dominant species were Ca, SO_4^{2-}, Fe, OC, NO_3^{2-} and Mg which were in the range of 8 to 19%. The minor trace indictors found were Zn, Ti, S, Na and Mg. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor. As earlier studies indicated tracer like Al, Si and SO_4^{2-} which are the major indicators of resuspended road dust. Ca, Mg, Si and Ti are prominent tracer of crustal dust, whereas substantial amount of paved road dust is being resuspended by vehicular movements; indicated by minor markers such as EC, OC, Zn, Al, S Fe and Pb; are indicators of road dust re-suspension. The Unpaved and Paved road dusts get resuspended and act as source due to vehicles movement and friction of tires with roads. The percent contribution of this source in overall city estimated emission load from unpaved road is observed to be 45.2% (22601.9 kg/d), while that from paved road is around 15% (7479.2 kg/d).

Area Source : The estimated emission of the city shows total area source contribution of around 10490.8 kg/day (21%), among which emission from domestic fuel and construction activities is around 3757.5 kg/d and 3618.9 kg/d, i.e. (7 to 8%), respectively; followed by Non Ind. Generator 2.5% (1234 kg/d), Agricultural Pumps 1% (500 kg/d) and Open Burning 0.7% (337.2 kg/d). The overall NOx contribution is around 1798 kg/d (i.e. 3.4%) and SOx is 720 kg/d (i.e. 24.5%). As per the study, unorganized and illegal open eat outs uses 10 kg/d of coal and wood as a fuel source and which is also adding 21.7 kg/d to the total mass.

As per the PMF matrix factorization, biomass burning/wood combustion, construction/crustal dust and secondary aerosols are the prominent sources. Biomass burning accounted for 8.84% and 26.50% in PM_{10} and $PM_{2.5}$, respectively. The tracers identified are EC, OC, F^-, Ca^{2+}, SO_4^{2-} and NO_3^{2-} in PM_{10} are around (7 to 14%), whereas OC, NH_4^{2-}, SO_4^{2-}, S, K^+ and K is around (5 to 9%) in $PM_{2.5}$. There have been many studies in the past suggesting that OC, K^+ and SO_4^{2-} are clear indicator of biomass burning. It is a known fact that biomass is a widely used energy source as well as there is issue of illegal litter burning in India. The significant biomass burning was observed in the study area.

The construction dust tracer contributes around 11% in both PM_{10} and $PM_{2.5}$. The major indicators are Mg, Ca^{2+}, Ca, Fe, Si, Al, NO_3^{2-} and SO_4^{2} , ranging around 8 to 20% of the total. Studies suggest Ca, Si, Ca^{2+}, Mg, Cl^- are the major indicators of construction dust from cement and aggregate mixing plants. Construction dust is mainly contributed from emerging infrastructure development projects and renovation of old structures around the city which contributes around 3618.9 kg/d (7.2% city emission load). Another identified tracer was crustal dust. In $PM_{2.5}$ crustal dust/ soil tracers accounted for 7.56%. Significant indicators are K, Ca, Ti, Fe, OC and Cr sharing their part around (6 to 36%). Ca, Ti and Fe are major indicators of crustal dust/ soil as per previous studies. The overall percent share of secondary aerosol tracer is around 13.54% for PM_{10} and 8.83% for $PM_{2.5}$. The fraction in PM_{10} where NH_4^{3-}, NO_2^-, SO_4^{3}, S, Si and Mg contributing (8 to 26%), whereas NH_4^{3-}, NO_2^-, SO_4^{2-}, S, Mg are the indicators for $PM_{2.5}$ sharing (6 to 32%). The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols. The formation of secondary aerosols is due to the chemical transformation. These secondary ions are derived from gas to particle conversion processes involving photo-chemical reaction of gaseous precursors such as SO_2 and NOx which are largely emitted from local and regional sources. Since these are background pollutant sources, they are found in all samples for entire study duration.

4.6 Past Studies

- **Seasonal Variation of Chemical Composition and Source Apportionment of $PM_{2.5}$ in Pune, India.** *Gawhane R.D.et al., Environ Sci Pollut Res., 2017, 24:21065-21072*

Particulate matter with size less than or equal to 2.5 μm ($PM_{2.5}$) samples were collected from an urban site Pune, India, during April 2015 to April 2016. The samples were analysed for various chemical constituents, including water soluble inorganic ions, organic carbon (OC), and elemental carbon (EC). The yearly mean total mass concentration of $PM_{2.5}$ at Pune was 37.3 $\mu g/m^3$, which is almost four times higher than the annual WHO standard (10 $\mu g/m^3$), and almost equal to that recommended by the Central Pollution Control Board, India (40 $\mu g/m^3$). Measured (OC, EC) and estimated organic matter (OM) were the dominant component (56 ± 11%) in the total particulate matter which play major role in the regional atmospheric chemistry. Total measured inorganic components formed about 35% of $PM_{2.5}$. Major chemical contributors to $PM_{2.5}$ mass were OC (30%), SO_4^{2-} (13%), and Cl^- and EC (9% each). The high ratios of OC/EC demonstrated the existence of secondary organic carbon. The air mass origin and correlations between the various components indicate that long range transport of pollutants from Indo-Gangetic Plain (IGP) and Southern part of the Arabian Peninsula might have contributed to the high aerosol mass during the dry and winter seasons. To our knowledge, this is the first systematic study that comprehensively explores the chemical characterization and source apportionment of $PM_{2.5}$ aerosol speciation in Pune by applying multiple approaches based on a seasonal perspective. This study is broadly applicable to understanding the differences in anthropogenic and natural sources in the urban environment of particle air pollution over this region.

- **Anthropogenic fine aerosols dominate over the Pune region, Southwest India**
  Gawhane R.D.et al., Meteorology and Atmospheric Physics, 2019, 131, 1497-1508

The major water-soluble ions, organic carbon (OC), elemental carbon (EC) and mass concentration of fine- ($PM_{2.5}$) and coarse-mode ($PM_{10-2.5}$) aerosols were measured at Pune during January–December 2016. The mass closure approach was used by comparing the sum of the masses of the individual chemical species to the gravimetric PM obtained by weighting the filter samples. The 1 year mean total mass concentration of fine and coarse mode was 40 $\mu g m^{-3}$ (64%) and 23 $\mu g\ m^{-3}$ (36%), respectively. The $PM_{2.5}/PM_{10}$ ratio was 0.64 ± 0.9 indicating an abundance of fine-mode particles over Pune during the study period. A principal component analysis identified three components, where the one with highest explanatory power (59%) displayed clear impact of anthropogenic sources on the measured mass concentration of a majority of the compounds. The strong linear relationships between EC, OC, nss-SO_4^{2-} and nss-K^+ suggest a predominance of a common primary source, with a contribution from biofuel as well as biomass burning sources. Keeping the strong correlation and sources of individual chemical species as the base, it was noticed that (1) major contributors to fine- and coarse-mode particles over the Pune regions are carbonaceous aerosols and secondary inorganic aerosols (non-sea-salt SO_4^{2-}, NO_3^-, and NH_4^+), (2) anthropogenic aerosols contribute mostly to the fine-mode, and (3) meteorological parameters play an important role in controlling levels of fine- and coarse-mode particles. Taken together, the study clearly indicates the dominance of anthropogenic sources during the entire year with more significance in the winter season.

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URL

- URL 1: EPA PMF v5.0 Software link: https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses
- URL 2: DRI EC-OC Manual : https://www.epa.gov/sites/production/files/2018-10/documents/csn_improvea_ model2015_2-231r0_053118_508comp-dri.pdf
- URL 3 : US EPA Speciates : https://www.epa.gov/air-emissions-modeling/speciate-0

Chapter 5

Dispersion Modelling of Pune

Air quality dispersion modeling exercise was undertaken with a view to delineate the immediate sources and their impact on measurement locations. Dispersion modeling tool (AERMOD model) was also used for the whole city air quality scenario generation for different emission loads of PM and NOx. The existing scenario model runs were undertaken to establish the dispersion pattern of pollutants due to local meteorology and emission from all possible sources. Model runs also provide an idea about missing sources or additional sources which may have been accounted for earlier. The scenarios for different seasons, locations and sources have been generated to bring out the contributions and their variability. The comparison of concentrations for the scenario has been carried out by considering the highest ten concentrations.

5.1 Description of AERMOD Model

The AMS/ EPA Regularity Model (AERMOD, EPA 2004) are a steady-state plume model. AERMOD was developed in collaboration between the USEPA and the American Meteorological Society (AMS). Air quality model provides a mathematical prediction of ambient concentration of pollutants using simulation of physical and chemical processes of atmosphere, affecting air pollutants and determining the dispersion, reaction and behaviour of pollutants. The model is capable to assess the pollutant concentrations from number of sources and considers the dispersion of pollutants from stationary sources for a short-range (up to 50 Km). In the stable boundary layer (SBL), it assumes the concentration distribution to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is also assumed to be Gaussian, but the vertical distribution is described with a bi- Gaussian probability density function. The convective boundary layer is the lower troposphere layer in contact with the ground heated by the sun and moves by the wind. The convective phenomena and wind causes significant air mixing with horizontal and vertical turbulences. The model is capable of accepting single station data assuming that the weather status is horizontally homogenous over the study area.

Additionally, in the CBL, AERMOD treats “plume lofting,” whereby a portion of plume mass, released from a buoyant source, rises to and remains near the top of the boundary layer before becoming mixed into the CBL. AERMOD also tracks any plume mass that penetrates into the elevated stable layer, and then allows it to re-enter the boundary layer when and if appropriate. The

AERMOD model is applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including, point, area and volume sources).

The modelling system of AERMOD contains an air dispersion model processor, a meteorological data pre-processor called AERMET, and a terrain data pre-processor called AERMAP. The AERMET meteorological pre-processor program provides the meteorological data as the basic input data in AERMOD. AERMET presents two types of meteorological data files consisting of surface scalar parameters and vertical profiles of meteorological data. AERMET uses the steady hourly surface and upper air meteorological observations to develop the meteorological inputs for AERMOD through calculating the hourly boundary layer parameters such as the Monin-Obukhov length, sensible heat flux, surface friction velocity, convective velocity scale, temperature scale and mixing height. AERMAP facilitates the generation of hill heights scales for AERMOD. The details of AERMOD model and its application guide have been presented in EPA, 2004.

5.2 Application of AERMOD for Air Quality Management

Air quality management studies have been done across the World using AERMOD. In China, it was applied for near future air quality simulation using change in emissions based on proposed development plan to predict the concentration for the industrial city, Xuanwei of Yunan province (Ma *et al.*, 2013). The impact of emission control policy was studied for the five year (2011-2015) plan for Xuanwei. Emission reduction scenarios were prepared for the emission control policy for SO_2, NOx and PM_{10}. Emission inventory was built based on general investigation of pollution sources and pollutant source monitoring report (2008). This included the industrial plant and six important factories around the city. In this case, average meteorological data in same time period was to be used to predict the future air quality. One way ANOVA test was used to show effectiveness of the emission control policy. Spatial contour plots helped to identify the high concentration regions, which required the attention of the special environmental supervisors. Gulia *et al.*, 2015 used AERMOD to appraise the air quality surrounding the heritage site of Amritsar. Amritsar is a tourist place and religious heritage complex which is crowded during festivals. Free open kitchens operate next to the heritage structure to provide free meals to the visitors. Apart from this, coal based tandoor, diesel generators, local industries and vehicle movement are main source of emission. In this study conducted to predict concentration from June to September 2012, AERMOD was used. Various management options were discussed to decrease pollution levels at the heritage site. Recently in 2010, air quality monitoring, emission inventory and source apportionment study for Indian Cities were conducted by CPCB and MoEF-CC. Dispersion modelling is an important component of the study that was used for projecting air quality profiles (iso-concentrations plots) of the city, under different scenarios viz. business as usual, future projections with implementations of control options, etc. It was also used to evaluate efficacy of various control options for evolving city-specific action plans for air quality improvements.

Meteorological data required for AERMET includes upper air and onsite data. The requirement of meteorological data for air quality modelling can be accomplished by either onsite monitoring or meteorological modelling. The onsite meteorological measurement in Pune is limited to surface measurement and limited upper air data is available at IMD station. Therefore, meteorological model can help to generate onsite meteorological data to use in air quality models. Meteorological and air quality models have been applied in many studies with several objectives and addressed various scientific research questions across the world.

Meteorological models calculate three-dimensional gridded meteorology using mathematical equations to simulate atmospheric processes like the variation in temperature, wind direction and speed over time. The main purpose of the meteorological model is to forecast and simulate the weather parameters.

In the early nineties, mesoscale meteorological models were developed. Mesoscale is an intermediate scale between those of weather systems and of microclimates, on which storms and other phenomena occur. The mesoscale meteorological modelling system was upgraded to the fifth generation of mesoscales meteorological model by Penn State University and National Center for Atmospheric Research which is commonly referred to as MM5 (1994).

Weather Research and Forecasting Model (WRF) was developed as an evolutionary successor to the MM5 model and incorporates current state-of-the-science atmospheric physics improvements. WRF use 1 Km by 1 Km gridded land use to estimate surface properties (surface boundary conditions). It also uses the pre-processed wind field for the global weather simulations to obtain the initial time boundary condition at t=0 and at other times as well.

Regarding low wind conditions, the majority of meteorological data is collected from airport met stations. An airports primary concern is high wind speeds which may affect aircraft. Therefore, low wind speeds are often not recorded with sufficient accuracy for air dispersion modelling purposes. This is of particular concern for air dispersion modelling because low wind speeds often result in higher concentrations. The WRF models avoid this issue as all wind speeds are calculated with equal accuracy.

The uncertainties of meteorological model create negative impact to air quality model simulation (Sistla *et al.*, 1996). Significant errors have still been observed during the routine assessment of the performance of the next generation air quality models despite having made use of the advanced techniques for data collection and numerical modelling with high computational abilities *(Russell and Dennis, 2000).*

Hourly meteorological data has been collected from Lakes Environmental for 2016 which includes both surface and upper air data and considered as representative for whole Pune city. The Albedo, Bowen ratio and Surface roughness length were set to default, as 0.2075, 1.625 and 1 respectively. Wind roses of December to January (winter season) and March to April (summer season) of Mumbai are presented in **Figure 5.1**.

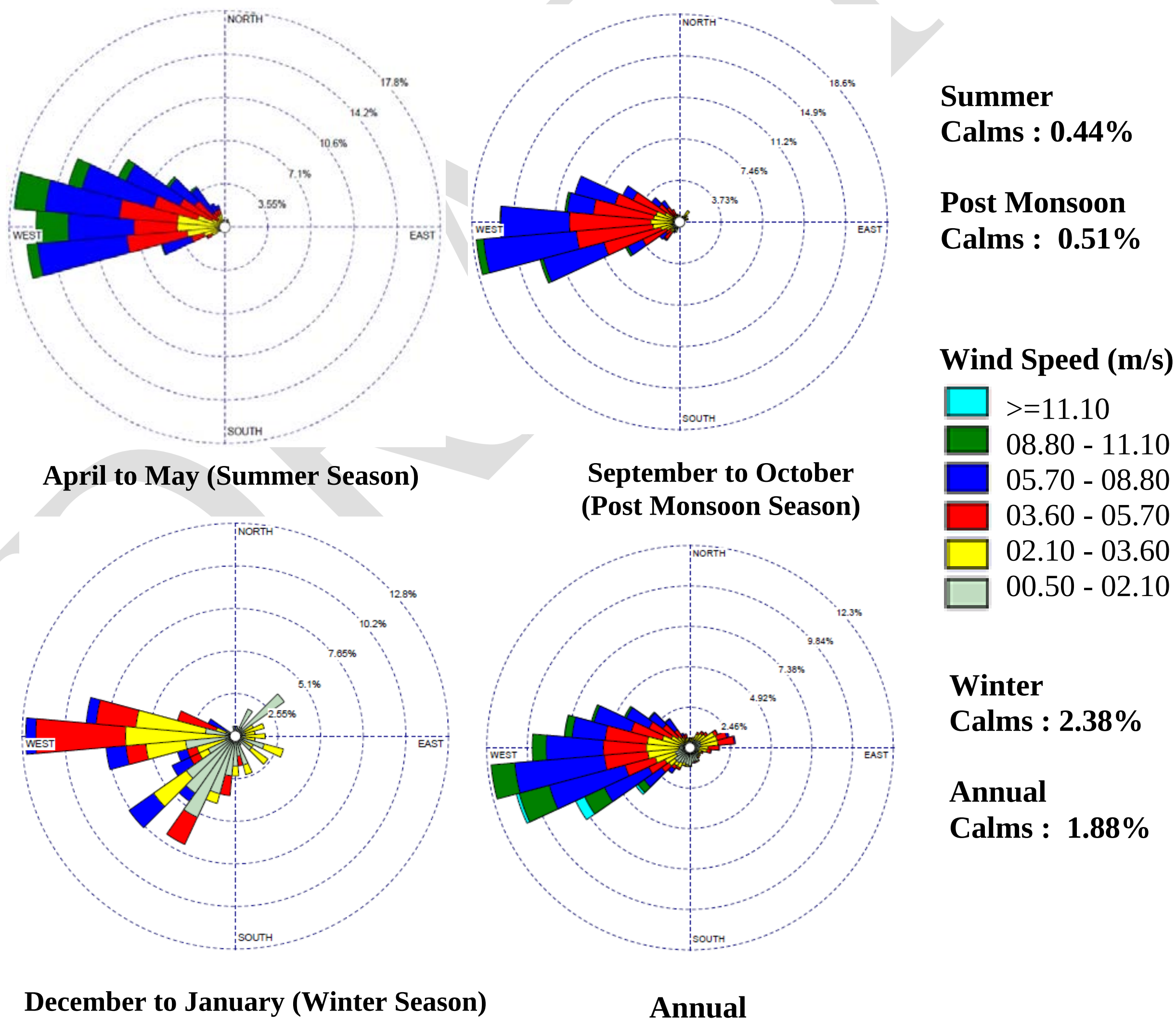

Figure 5.1 : Wind Rose of the Winter and Summer for the Study Area (Pune)

Annual windrose shows, the predominant direction is from WSW (11%), W (9%); in WSW direction wind speed mostly is in the range 8.8 to 11.10 m/s or less. In W direction predominant wind speed is in the ramge of 5.7 to 8.8 m/s. Calm condition is around 1.88%. During December to January (winter season) the predominant directions are blowing from W (11%), WSW (10%) or less and WNW (11%). The predominant wind speeds are 5.7 to 8.8 m/s in W direction, whereas WSW and WNW direction shows, it is around 3.6 to 5.7 m/s or less. Calm condition is around 2.38%. During Post Monson and Summer seasons the predominant wind directions are blowing from mostly the same way i.e. W, WSW and WNW. The wind speed moves around 5.7- 8.8 m/s to 8.8 -11.1 m/s. Calm condition for both the seasons are around 0.44 to 0.51%.

5.3 Terrain Data

The terrain is characterized by the AERMIC terrain pre-processor (AERMAP) which also generates elevations for receptor grids. Gridded terrain data are used to model the area, where the gridded elevation data is made available to AERMAP in the form of a Digital Elevation Model (DEM) data and all sources (Area–wards, Line –vehicular and Point -industry, are presented in **(Figure 5.2)**.

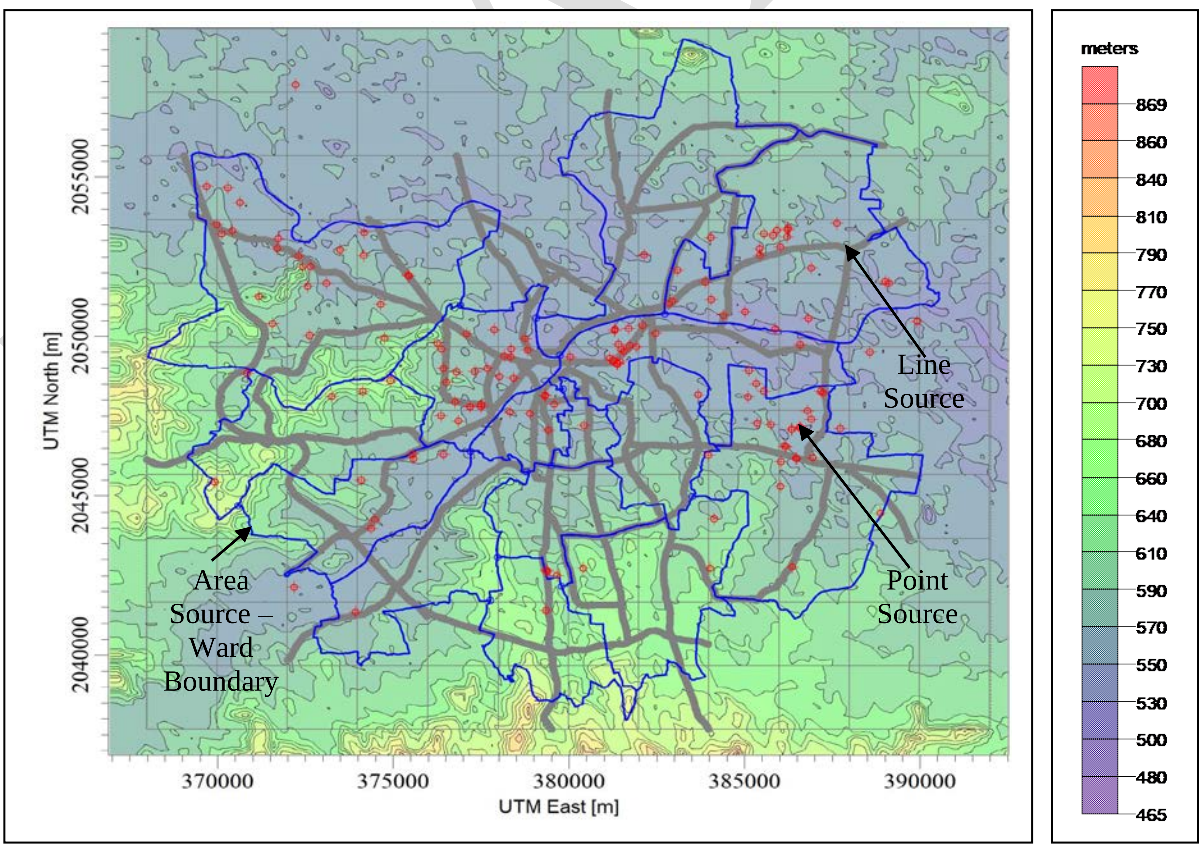

Figure 5.2 : AERMAP Digital Elevation Model (DEM) Data for Pune City

This data also proves useful when the associated representative terrain influence height has to be calculated for each receptor location. Thus, elevations for all sources viz. line sources, point sources, area sources, both discrete receptors and receptor grids are computed by the terrain pre-processor.SRTM3 - Shuttle Radar Topography Mission (SRTM) 3 with resolution of 90 m was used as Terrain Data for running the model.

A uniform Cartesian grid receptor covering 22 x 24 Km^2 of the study area was considered as input in the AERMOD model. The model was set to simulate the 24-h ground level concentrations (GLC) of at the selected receptor network. The number sources as a input to the model was considered for different source category i.e. Area, Line, Industry and Resupension Dust is given in **Table 5.1 and Figure 5.2.**

Table 5.1 : Summary of Type and Number of Sources

Emission Source	Modelled Source Type	Number of Sources
Area sources	Area sources including bakery, crematoria, building construction, hotels and Restaurants, domestic sector, open burning, open eatouts	14 Pune Municipal Wards
Vehicles	Line Volume (Major & Arterial Roads, connecting State & National Highways	111 Roads
Major Industries with stack heights more than 10m	Point	161 Stacks
Industries which include Medium and small scale industries with less than 15m stacks	Area (MSI 24 and SSI 36)	60 Stacks
Road dust	Line Volume on each road	111 Roads

5.4 Model Simulations

The modelling exercise was carried out for PM_{10} and NOx for three seasons as well as for annual, by making use of meteorological data and emission loads and other related inputs for area, line and point sources. Meteorological inputs were put in AERMET. Based on the emission load discussed eelier, the future estimation were worked out.

5.4.1 Model Performance for PM

Table 5.2 has the average PM_{10} concentration observed at 4 monitoring locations, which are in the range of 114 to 236 µg/m^3 during the winter season. The predicted concentrations at these sites varied between 35 to 237 µg/m^3. During summer season, the average concentrations observed at 4 ambient air quality monitoring sites were in the range of 80 to 127 µg/m^3. The predicted average PM_{10} concentrations at these sites during summer varied from 14 to 130 µg/m^3. The annual concentration differs from 79 to 115 µg/m^3 for observed, whereas it is 19 to 147 µg/m^3 for predicted. 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 varied between 0.1 to 1.6. All the predicted values were lying within FAC2. Variations in are presented in **Figure 5.3**.

Table 5.2 : Seasonal PM_{10} Average Concentrations (µg/m^3) of the 24 Hourly Model Simulations

	Observed Concentration (µg/m^3) #				Predicted Concentration (µg/m^3)			
	Summer	**Post Monsoon**	**Winter**	**Annual**	**Summer**	**Post Monsoon**	**Winter**	**Annual**
Karve Rd.	91	79	114	79	14	11	35	19
Nal Stop	106	118	153	107	41	34	84	50
Bhosari	127	109	236	115	127	100	237	147
Swargate	80	123	204	95	130	98	224	142
Ratio of Predicted to Observed Concentration								
Karve Rd.	0.2	0.1	0.3	0.2				
Nal Stop	0.4	0.3	0.5	0.5				
Bhosari	1.0	0.9	1.0	1.3				
Swargate	1.6	0.8	1.1	1.5				

 # Observed Concentration (Air Quality Status of Maharashtra 2018-19, MPCB

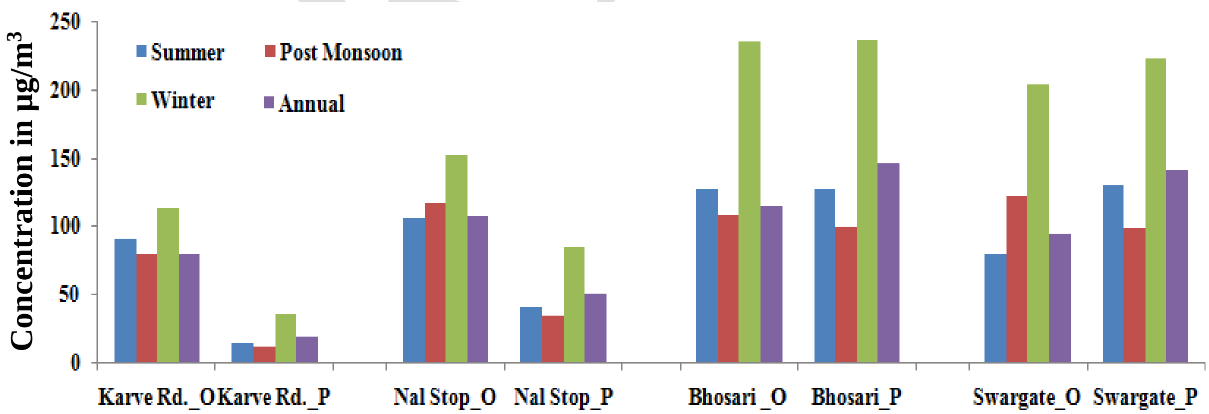

Figure 5.3 : Observed and Predicted Concentration for All Seasons (PM - µg/m^3)

From modeling results, discrete cartesian location where identified based on pollution control sampling points and the difference where match for observed and predicted concentrations. It has been observed that less prediction is reflected at Karve Road and Nal Stop in all seasons, whereas over prediction indicated in Bhosari and Swargat areas.

5.4.2 Existing Scenario Concentration Contours for PM_{10}

The models were run for the period of annual as well as for all seasons separately for different source group combinations **(Table 5.1)**. The iteration for different source groups were estimated and presented in **Table 5.3** for PM concentrations. The annual and seasonal 24 hourly average concentrations at grid points were plotted for all the source group is presented in **Figures 5.4 through 5.7**. The sector wise distribution (area, line, point, resuspended dust) of all the seasons for PM is depicted in **Annexure 2** and highest 10^{th} concentrations at ground level is presented in **Annexure 3.**

Table 5.3 : Predicted PM Concentrations for Different Source Group for Pune City

Sources Group	Summer	Post Monsoon	Winter	Annual
All Group	130.0	100.4	237.0	147.0
Area Source	10.7	8.3	22.9	12.9
Line Source	19.2	15.6	33.5	22.1
Point Source (LSI)	3.48	1.9	1.73	1.68
Point Source (MSI)	0.739	0.362	1.410	0.636
Point Source (SSI)	0.00049	0.418	1.10	0.623
Resuspension Dust	113.0	90.4	213.0	131.0

- Concentrations in $\mu g/m^3$

Observations

- The annual average of PM concentrations from all sources exceeds the CPCB standard, which turns worse post monsoon, in winter.
- The maximum 24 hourly predicted concentration due to all sources in winter was 237 $\mu g/m^3$. The pockets of high concentration are observed close to major traffic junctions in central part of the city viz. Ghole Road, Dhole Patil Road, Bhavani Peth, Kasbavishram Baugh where major vehicle movements were observed. Whereas, the predicted concentration due to re-suspended dust is 213 $\mu g/m^3$ and tailpipe emission contribution from Vehicles is around 33.5 $\mu g/m^3$.
- The maximum 24 hourly predicted concentration due to area sources was 22.9 $\mu g/m^3$ in winter. The overall impact of areas source is due to domestic cooking and domestic DG sets, spread across administrative wards of the study area. Building construction activities are also one of the prominent sources in study area.
- Industries are located mainly at Warje Karve Road, Hadapsar, Dhole Patil Road and Yerwada wards where dispersion impact is predicted. The maximum 24 hourly predicted concentration

due to Industries was 3.48 μg/m^3 from LSI category in summer, annually it was 1.68 μg/m^3 from all categories.

- The PM concentration in Winter season are almost double the CPCB standard of 100 μg/m^3 for.

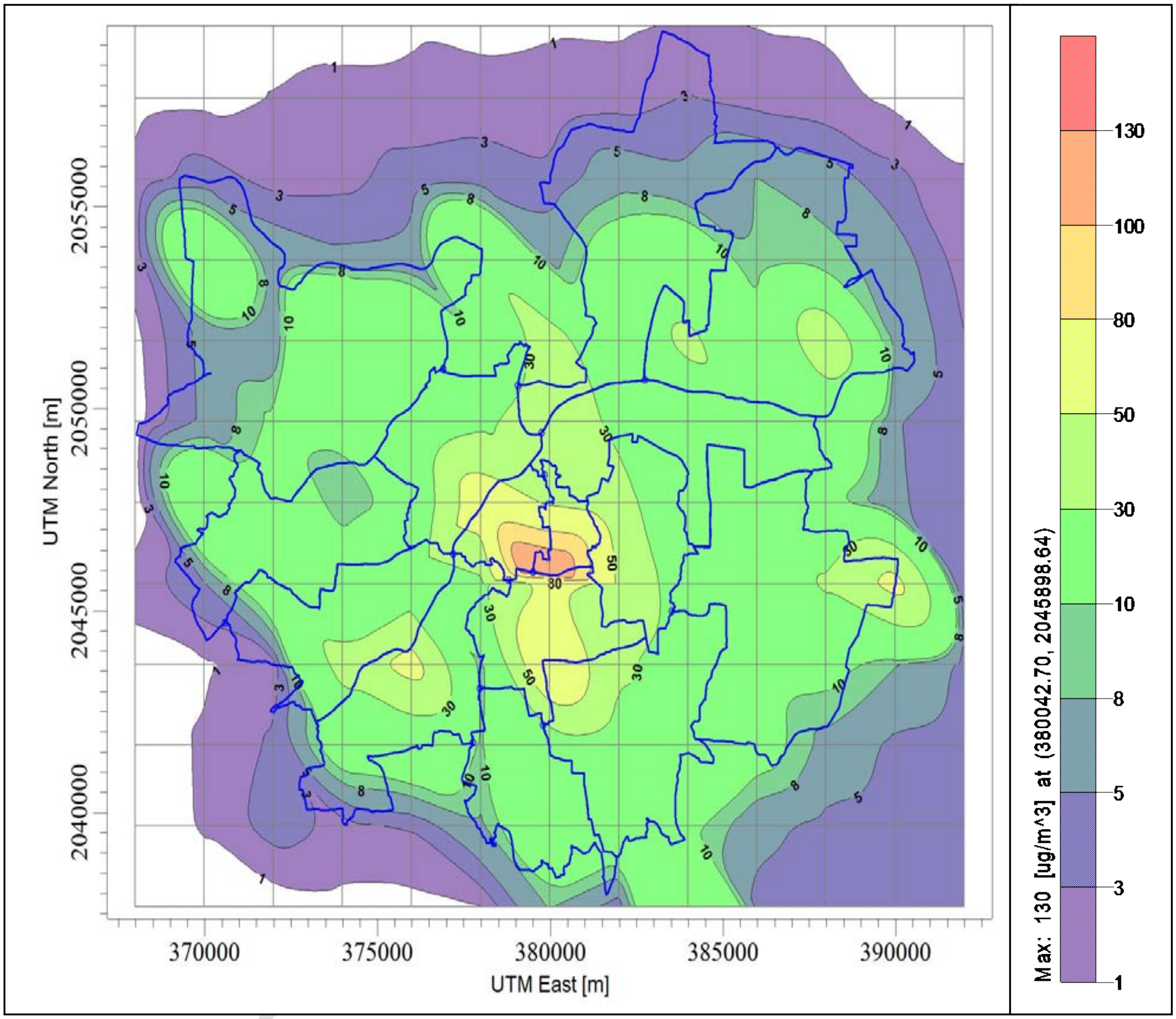

Figure 5.4 : Isopleths of PM Due to All Sources – Summer Season (Pune City)

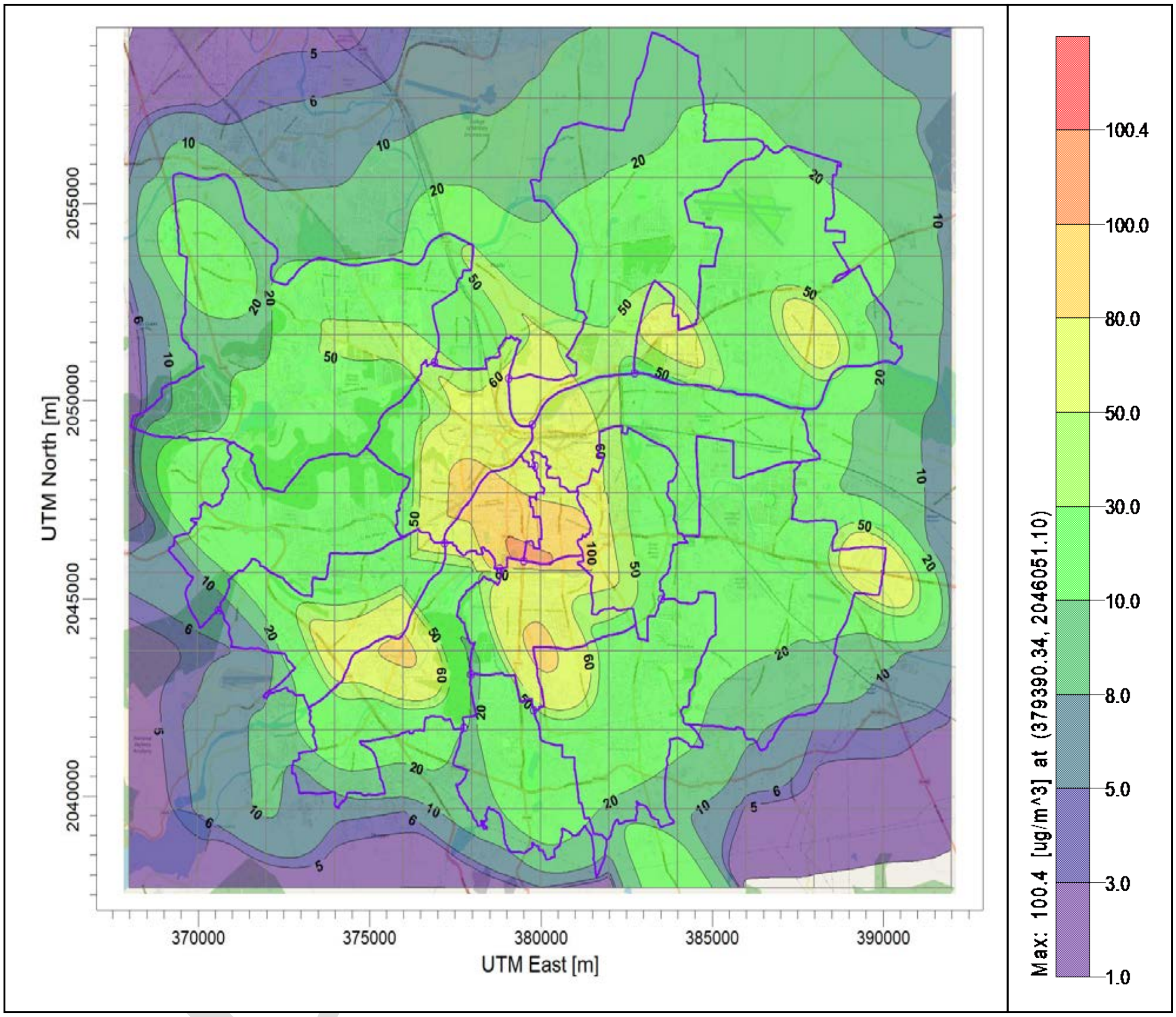

Figure 5.5 : Isopleths of PM Due to All Sources – Post Monsoon Season (Pune City)

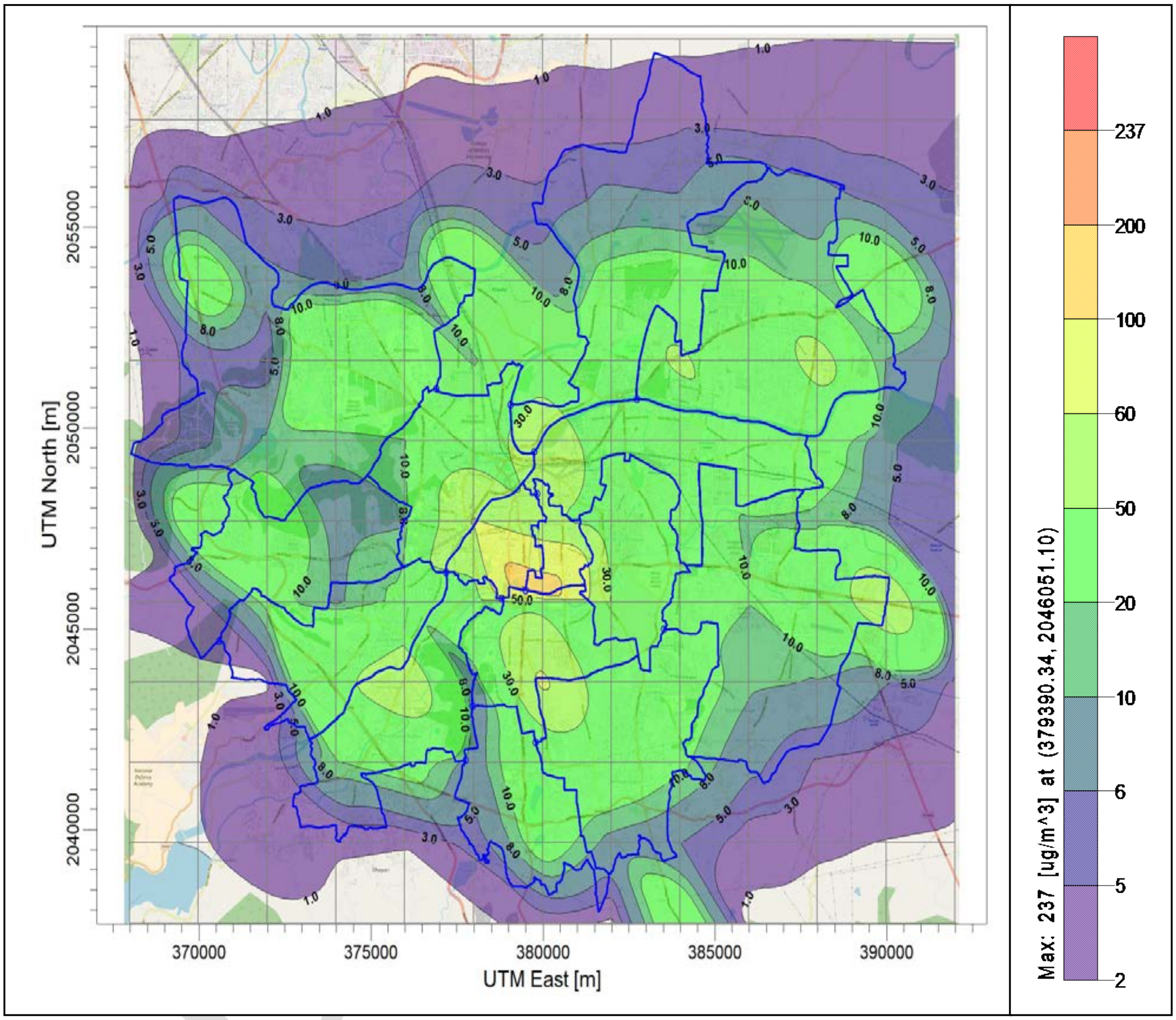

Figure 5.6 : Isopleths of PM Due to All Sources – Winter Season (Pune City)

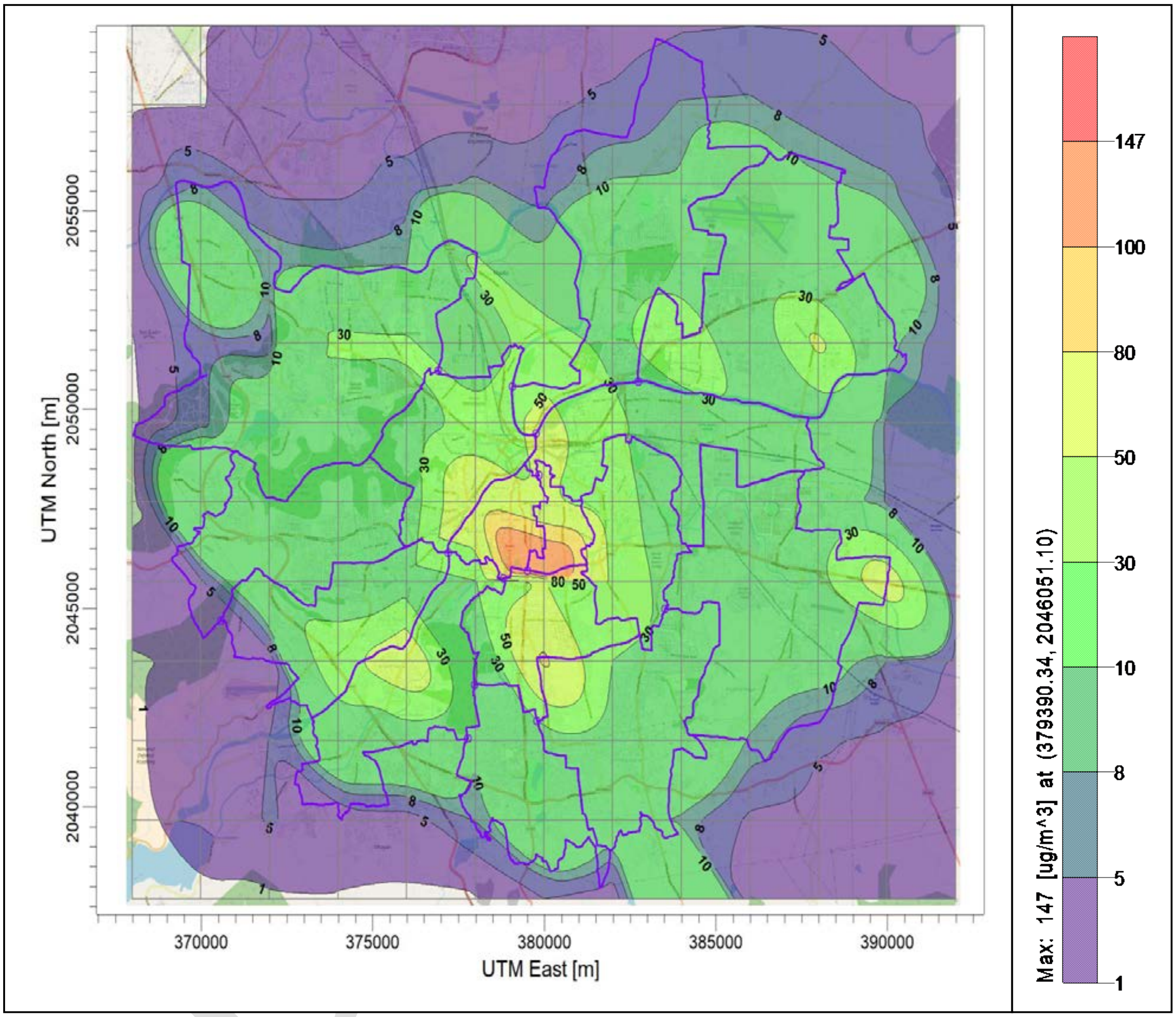

Figure 5.7 : Isopleths of PM Due to All Sources – Annual (Pune City)

5.4.3 Model Performance for NOx

Similar to PM_{10}, the modeling exercise was carried out for NOx for all seasons and source group. **Table 5.4** shows the average NOx concentration observed at 4 monitoring locations, which ranged from 77 to 155 µg/m^3 during the winter season. The predicted concentrations at these sites ranged from 60 to 84 µg/m^3. During summer season, the average concentrations observed at 4 ambient air quality monitoring sites were in the range of 48 to 68 µg/m^3. The predicted average PM_{10} concentrations at these sites during summer were about 37 to 46 µg/m^3. The annual concentration differs from 67 to 83 µg/m^3 for observed, whereas it differed 33 to 63 µg/m^3 for predicted. 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 varied between 0.3 to 1.0. All the predicted values were lying within FAC2. Variations in are presented in **Figure 5.8**.

Table 5.4 : Seasonal NOx Average Concentrations (µg/m^3) of the 24 Hourly Model Simulations

	Observed Concentration (µg/m^3) #				Predicted Concentration (µg/m^3)			
	Summer	**Post Monsoon**	**Winter**	**Annual**	**Summer**	**Post Monsoon**	**Winter**	**Annual**
Karve Rd.	68	99	77	77	37	34	60	33
Nal Stop	56	62	107	78	40	43	71	43
Bhosari	48	45	95	67	43	44	79	63
Swargate	55	68	155	83	46	45	84	60
Ratio of Predicted to Observed Concentration								
Karve Rd.	0.5	0.3	0.8	0.4				
Nal Stop	0.7	0.7	0.7	0.6				
Bhosari	0.9	1.0	0.8	0.9				
Swargate	0.8	0.7	0.5	0.7				

 # Observed Concentration (Air Quality Status of Maharashtra 2018-19, MPCB

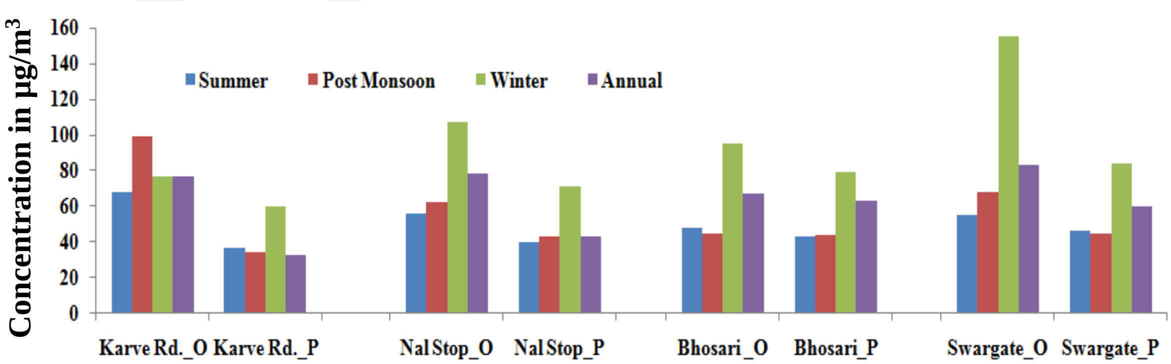

Figure 5.8 : Observed and Predicted Concentration for All Seasons (NOx - µg/m^3)

From predicted modeling results discrete cartesian location where identified, which where match with observed concentrations. It has been observed that less prediction of NOx is reflected at all the locations and seasons.

5.4.4 Existing Scenario Concentration Contours for NOx

The models were run for annually and all seasons for different source group combinations **(Table 5.1)**. The iteration for different source groups were estimated and presented in **Table 5.5** for NOx concentrations. The annual and seasonal 24 hourly average concentrations at grid points were plotted for all the source group is presented in **Figures 5.9 through 5.12.** The sector wise distribution (area, line, point, resuspended dust) of all the seasons for NOx is presented in **Annexure 4** and highest 10th concentrations at ground level is presented in **Annexure 5**.

Table 5.5 : Predicted NOx Concentrations for Different Source Group for Pune City

Sources Group	Summer	Post Monsoon	Winter	Annual
All Group	148.0	106.0	250.0	165.0
Area Source	2.8	2.2	5.9	3.5
Line Source	147.0	105.0	247.0	163.0
Point Source (LSI)	0.892	0.590	0.863	0.773
Point Source (MSI)	1.18	0.736	2.76	1.50
Point Source (SSI)	0.045	0.273	0.945	0.508

- Concentrations in µg/m^3

Observations

- The dispersed NOx concentrations from all the sources of the city exceed the CPCB standard, which is also observed in summer and tunrs worst in winter. The observed and predicted concentration is coherent to MPCB monitoring site, the concentrations are observed to be within the standards and ratio varied between 0.3 to 1.0.
- The maximum 24 hourly predicted concentration from all sources in winter was 250 µg/m^{3,} and that from vehicular source is predicted to be around 247 µg/m^3. The concentrations are predicted in central part of the city; Ghole Road, Dhole Patil Road, Bhavani Peth, Kasbavishram Baugh, where heavy vehicular traffic movements was observed.
- The maximum 24 hourly predicted concentration due to area sources was 5.9 µg/m^3 in winter. The overall impact of areas source is due to domestic cooking, hotels and open burning; spread across every administrative ward of the study area.
- Industries are located mainly at Warje Karve Road, Hadapsar, Dhole Patil Road and Yerwada wards where impact is predicted concentrations were observed. The maximum 24 hourly predicted concentration from Industries was around 1.18 µg/m^3 for MSI category in summer and annually it was found to be around 1.50 µg/m^3.

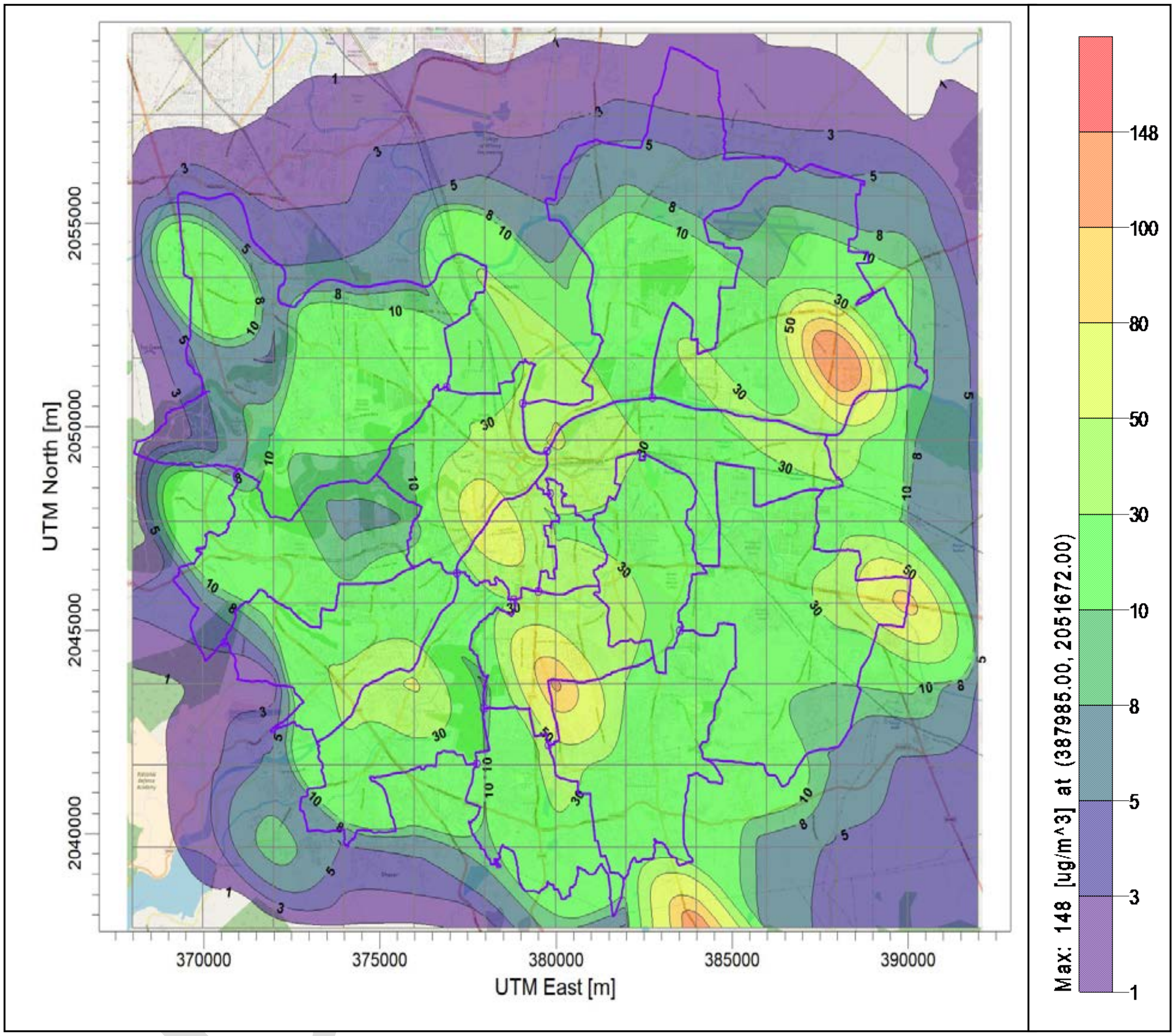

Figure 5.9 : Isopleths of NOx Due to All Sources – Summer Season (Pune City)

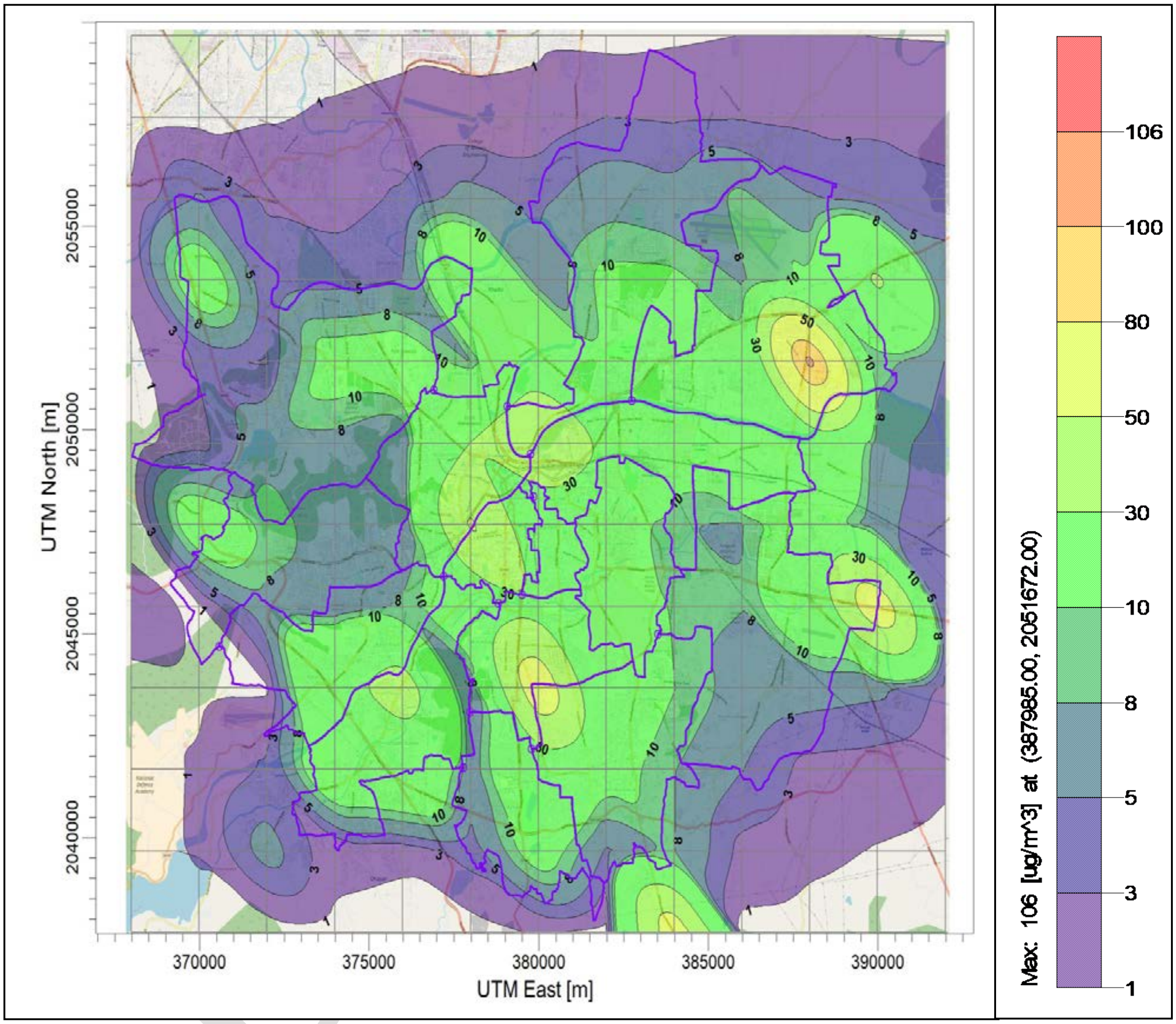

Figure 5.10 : Isopleths of NOx Due to All Sources – Post Monsoon Season (Pune City)

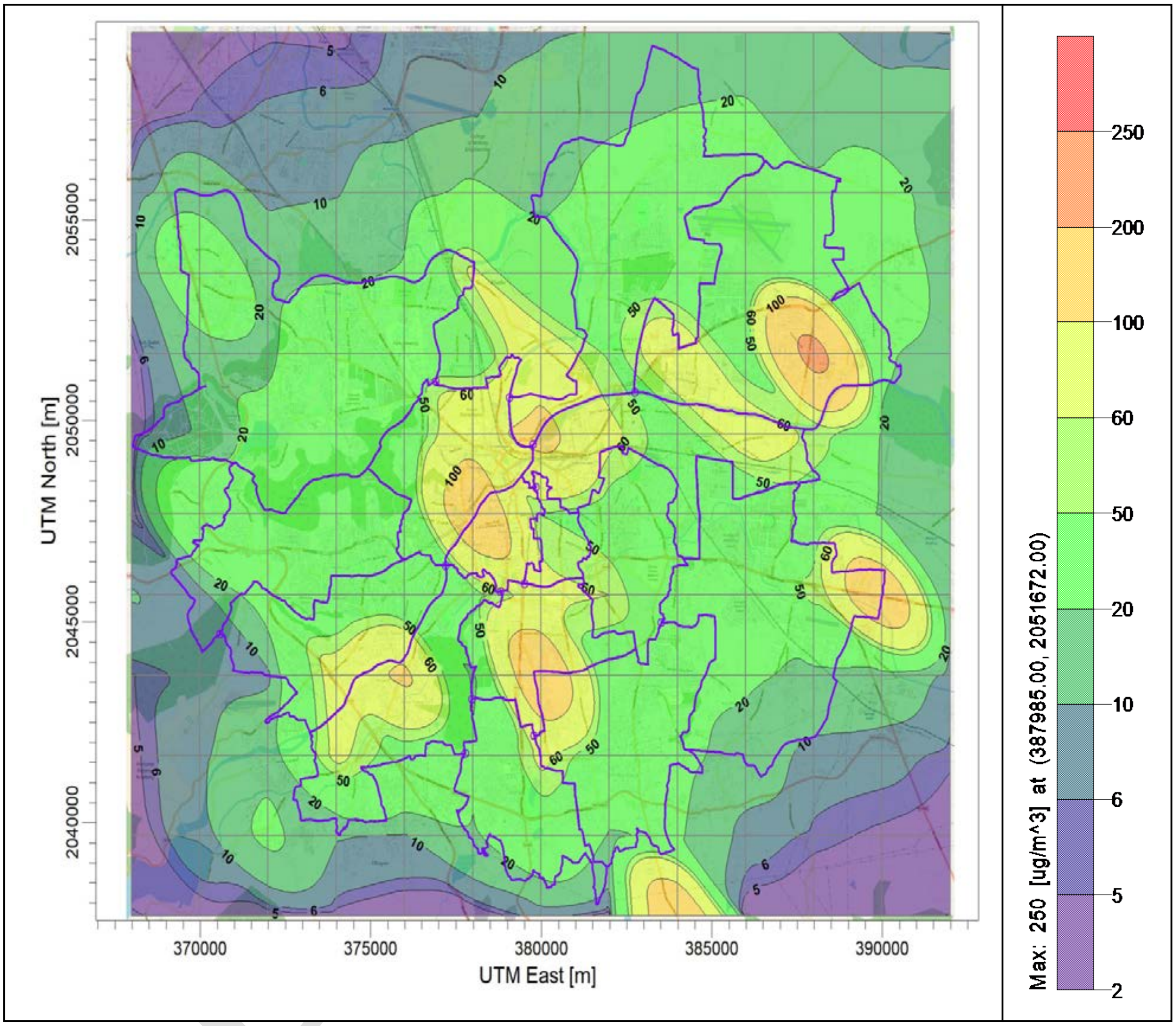

Figure 5.11 : Isopleths of NOx Due to All Sources – Winter Season (Pune City)

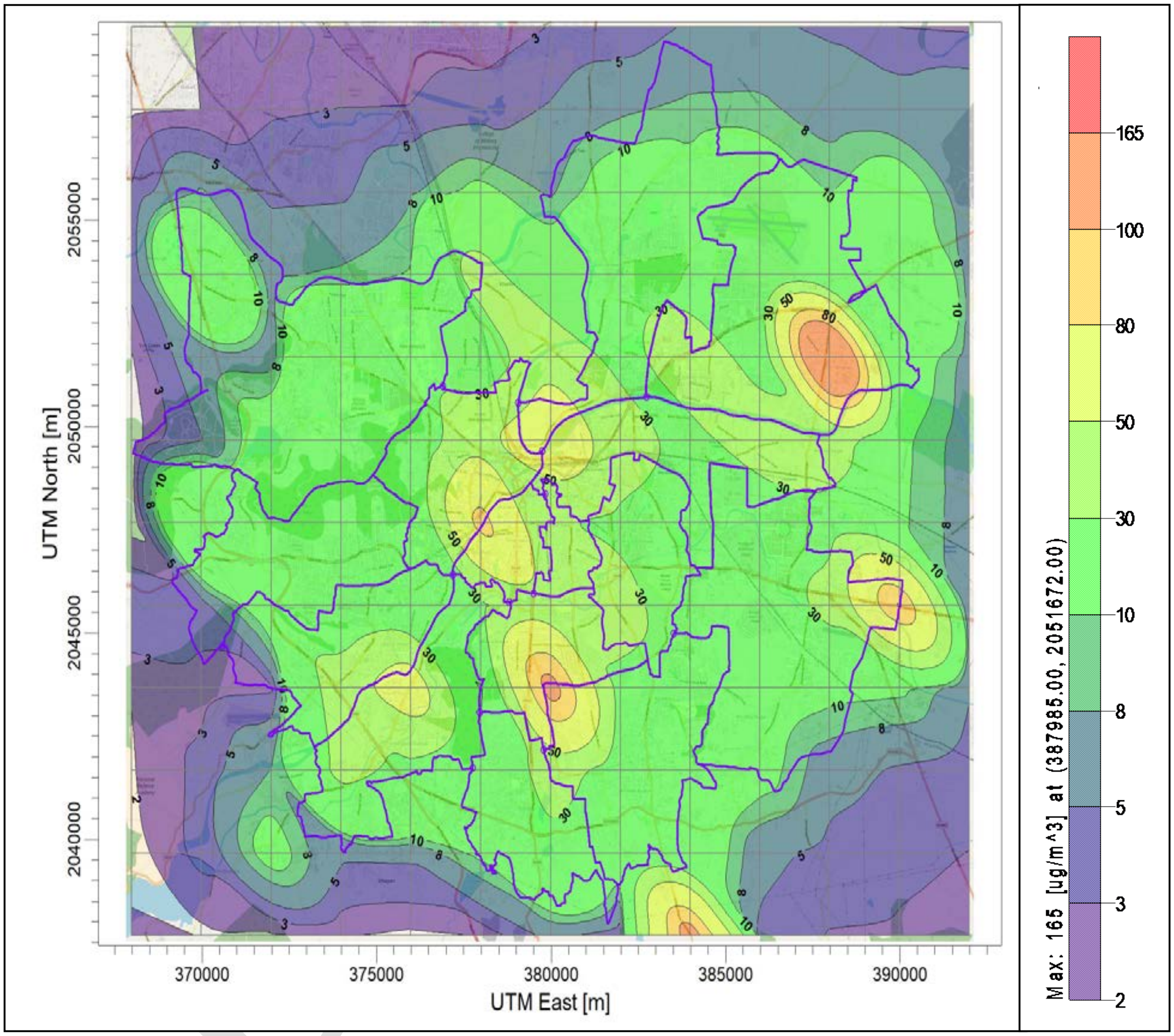

Figure 5.12 : Isopleths of NOx Due to All Sources – Annual (Pune City)

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Chapter 6

Emission Reduction Action Plan for Pune

Linking with this fast urban growth and increasing population from 4.8 Lakhs in 1951 to 3.1 million in 2011, there is an issue of grave concern of environmental degradation in which the growth of the city is linked with increasing urban activities thereby; a substantial need for improvements in urban infrastructure is expected. Based on the statistical methods of population projection, the projected population for Pune City for the years 2041 is 8.59 million. The Pune Municipal Corporation is responsible for administration and managing planned development in Pune city. The PMC, however, has been unable to meet forecasted demands for housing, commercial and industrial space, resulting in large scale unauthorized development, and areas with non- conforming land uses.

There are many sources of particulate matter emission impacting the ambient air quality of the city of Pune; however the major ones are resuspended dusts and vehicles. The impact of the industrial sector is less as major industries are located at the outskirts of Pune city and less used of traditional fuel pattern viz. bricks and briquette. Still some orange and small scale industries are using fuel like bagasse because of its easy availability. Even small-scale industrial units are changing into commercial offices. The industrial emission inventory shows impact on the ambient air quality is low due to emissions at a higher elevation, providing high dilution and dispersion.

Vehicle activity in the city has shown tremendous increase over a period of last 10 years. The mobile (line) source emissions are not only dependent upon the number of vehicles registered but also on the actual number plying on the roads, speed of movement and the conditions of vehicles besides many other factors. Vehicle kilometer travelled for the city has been showing consistent increase; however, at some junctions the traffic congestion is so high that VKT rise is ironically not so high but emission is high. Saturation traffic situation where average speed goes on decreasing, the VKT may not increase as vehicles are not crossing a point for a long time. Increased levels of vehicular activity and resulting high levels of air pollution have led to active anti air pollution campaign by the nongovernmental organization (NGO) and judiciary.

The area sources which emit at ground level also have significant impact on the PM levels in the atmosphere; however it could be more localized, particularly from the sources such as bakeries, crematories, construction, garbage burning etc. Some of these sources can have significant local impact on the ambient air quality for a shorter duration. Overall a city growth pattern indicates that domestic fuel has become cleaner, bakeries /crematoria situation have not changed so much. Construction/ demolition related emission has gone up; refuse burning has increase and road dust related emissions have also shown increase.

The action plan presented later therefore, makes an attempt to delineate strategies on the basis of understanding of the PM and NOx sources and their possible contribution to the ambient and kerb side air quality. Each of the strategies will have to be looked at from the point of view of its impact level in terms of reduction in PM and NOx emissions (low, medium, high); its feasibility from implementation and administrative point of view (easy, moderately difficult and difficult); financial viability (low, medium and high costs) besides issues relating to their long and short term impacts.

6.1 Area Sources - Reduction Strategy

Area sources are mainly domestic sources of fuel (coal, wood, kerosene, LPG) burning, trash/MSW combustion, bakeries, hotels/restaurants etc. and resuspension of dust. The main source of area based emission in Pune city is DG set and building/construction resuspension. With the implementation of the short and long term scenarios, the total reduction in particulate matter from area sources would be around 60%. **(Table 6.1)**.

Based on the survey and assessment, following recommendations emerge to curb area source emissions:

- Switch over of fuel from wood to LPG/ NG and electric be implemented for combustion operations in bakeries.
- Awareness about use of electric crematoria and its benefits instead of conventional wood based crematorium should be initiated.
- LPG cylinders consumption of 143.53 TMD from April 17- February 18 out of which 103 TPD was consumed in the Slum and 350 TPD in Non Slums. Whereas 40 TPD of Wood, 12 TPD of Coal and 106 Kl/d of Kerosene is being consumed in Slums on daily basis while 78 TPD of wood in Non Slum areas. ULB should take initiative to sensitize people from the slum & non slum to make the shift from conventional domestic fuel (Kerosene, wood) to Liquefied /Piped Natural Gas (LPG/PNG). Inventorization of LPG quantity from supply agencies should be maintained with the administration. Mandatory licensing of open eat-outs should be put in place. Inventorization of fuel use and operating hours of these should be maintained, as the data is missing with the administration. Regulation to encourage use of LPG (more in slum population regions) as fuel.

- Use of solid fuel is high in Pune, especially in winter season. Similarly, banning of open burning (trash/ wood) has to be strictly implemented. Some of the places, it contains all mix of plastics and thermocol. Helpline contacts/ or a mechanism should be efficient to ensure accountability in reporting and action on waste burning.
- Building construction / demolition codes need to be formulated with specific reference to PM control. Operational measures to be made compulsory and building permissions should be revoked if the norms are not met by the organization. In addition to this, environmental conditions are made compulsory to the new building construction projects. Due to such initiatives, considerable increase in public participations can be observed.
- Development of roads - Total length of roads in city is 2065 km. PMC has been providing UTWT- Ultra Thin White Topping treatment for internal roads in the city. Urban Street Design Guidelines for Pune aim to design guidelines for streets in Pune which prioritize streets for people and not for vehicles, thereby reinstating the position of streets of Pune as dominant and most vibrant urban public realm. 4 special built Road Maintenance vans are being operated under PMC and it even act against complaint made by general public through mobile app. After success of the 4 RMVs, more 8 RMVs are now in stage of being introduced bringing the total number of RMVs to 12.

Table 6.1 : Emission Reduction Action Plan for Area Source

<table>
<tr><th>Area Sources</th><th>Short Term-2019</th><th>Long Term-2022</th><th>Action required</th></tr>
<tr><td>Bakeries</td><td>25% LPG /NG
25% Electric</td><td>50% LPG /NG
75% Electric</td><td>The illegal and unaccounted small and mid-scale bakeries should be inventoried with fuel a consumption practice which requires change in current baking practices for which a separate study involving techno-economic feasibility is recommended. In Pune, Bakeries have wood consumption of 4500 kg/day, coal 105 kg/d and LPG around 174 kg/d. Clean fuels like LPG/NG or electricity can be attempted for bakery operations. Initial incentives and rebate should be provided for the conversion from traditional fuel.</td></tr>
<tr><td colspan="4">If consumption of wood in a bakery is considered to be 500 kg/day, then emission load of pollutants are PM - 9 kg/d, CO - 63 kg/d, NOx -0.65 kg/d, HC-57 kg/d and if we manage to replace the wood quantity by other fuel i.e only 100 kg/days of wood is being used, there will be 80% reduction in load, with final emission per 100 kg will be PM - 2 kg/d, CO -13 kg/day, NOx- 0.13 kg/d and HC - 11 kg/d. This conversion can be towards natural gas, as emissions from them are relatively much less than solid fuels.</td></tr>
<tr><td>Crematoria</td><td>50% Electric</td><td>75% Electric</td><td>There are sentiments involved in the activities that are carried out in crematorium. Still all crematoria should be provided with efficient pyres and chimneys with bag filters or cyclones filters for release of emissions through stacks at appropriate height. Further, a study involving usage of NG burners in a closed furnace like electrical crematoria may be explored as substitute to existing practices. This will require participation of social organizations for increasing the awareness about need to change from the traditional methods. Concept like Green Crematoria should be explored.</td></tr>
<tr><td colspan="4">Similarly, for wood consumption of 300kg/body cremation at crematoria is replaced by electric or gas cremation, an overall PM-5.19, CO-37.89, NOx -0.39, HC -34.35 and CO2 – 510 kg/yr of emission load reduction can be achieved per unit cremation</td></tr>
<tr><td>Domestic</td><td>-25% of slums to use LPG/ PNG
-50% of non slum to use LPG/PNG</td><td>-50% of slum to use LPG/ PNG
-100% same</td><td>Increase the infrastructure and availability of LPG/PNG to whole of Pune region. Proper dispensing and easy availability of cylinder to the consumer of slum population should be made. Ensure proper ventilation reforms to be implemented in kitchens through periodic information dissemination of indoor air quality via awareness programme and street acts.</td></tr>
<tr><td>Hotel & Restaurants</td><td>-50% of coal to replace by LPG</td><td>-75% of coal to replace by LPG</td><td>Hotels & Restaurants should be regulated for their operation and maintenance of chimneys. Around 1349 hotels consumes around LPG of 65716.8 (2 Cylinder /day) and coal around 12158.4 kg/d. Wood is mainly used in tandoors in restaurant, LPG/ electrically operated tandoors should be used. Designated areas should be designed for the coal and wood based operations within the premises. Options of fuel shift should be implanted in phase wise.</td></tr>
</table>

Table 6.1 (Contd..) : Emission Reduction Action Plan for Area Source

Area Sources	Short Term-2019	Long Term-2022	Action required
Open Eatouts	Since these operation is illegal, difficult to quantify, proper licensing and hawker zones should be developed		From current survey 247 Open Eat-outs were identified with fuel consumption - 458 kg/d of Kerosene, 1 LPG cylinder per day - 2300 Kg/day and 414 Kg/day of coal. If we restrict the activities with proper rehabilitation or their conversion from traditional fuels to clean fuels, then per unit /day reduction of PM- 0.12, and NOx – 0.039 kg/day can be achieved, considering the large number of vendors and eat outs.
Open & Landfill Burning	-50% control on open burning -100% control of Landfill burning	-100% control of Landfill burning -100% control on open burning	It has been observed that the unaccounted or mismanaged waste from SWM system, often are reported into road side open burning cases. Solid Waste generation is around 1586 T/d (only 973 T/d is Dry waste). Proper collection and disposal practices should be adopted on daily basis so that opening burning cases are not reported. Fast track steps for scientific SW management. Treated water from STP can be used effectively for any accidental fire for landfill sites. Strict vigilance by sensor base monitoring of the incidences and immediate attention is required for frequent fire movement at landfills.
If we restrict the activities of open and landfill burning we can reduce pollutant load per Tonne by PM -8, CO- 42, HC -21.5 kg/t			
Bldg. & Road Construction	50% control on dust emission	50% control on dust emission	Around 422 new building constructions and 122 alteration works were going on in the city emitting PM load of around 20414.6 kg/day Building construction/demolition codes need to be used with specific reference to PM control. UTTIPEC design manual has been recently created by Delhi Development authority for uniform roadside, drains, footpath and related design. The same should be adopted for all future design for roads and pathways. Road construction/repair uses wood for melting tar; this technology needs to be abolished as over a large period of time, emissions are high. Water spraying on the tires of trucks and vehicles at the entry/exit point of construction site. Constructing a water pit at the entry/exit points of the construction site to avoid dispersion of particulate matter through movement of trucks while entering and exiting the site. Appropriate barricading of the under construction site to avoid dispersion of the dust and particulate matter in the ambient air

Table 6.1 (Contd..) : Emission Reduction Action Plan for Area Source

Area Sources	Short Term-2019	Long Term-2022	Action required
Paved & Unpaved Road Dust	-Paving : 75% control on dust -Unpaving: 15% of remaining road if any	-Paving : 25% control on dust -Unpaved : 100% of remaining road if any	98% of roads were considered to be paved. As per current emission inventory 7.4 ton/ day of paved and 22.6 ton/day for unpaved road dust is resuspended. Need for better construction practices and codes for roads and pavement construction. UTTIPEC design manual has been recently created by Delhi Development authority for uniform roadside, drains, footpath and related design. The same should be adopted for all future design for roads and pathways. Pavement of road should be made wall to wall, especially the shoulders. The silt on partially paved shoulders of road are re-entrained, or resuspended, into air through vehicle-induced turbulence and shearing stress of the tires. A Road dust suspension is an increasing concern in terms of being a source of atmospheric PM. Vehicle speed and volume and road condition should frequently monitor by Traffic department, potholes and repair digging activities should be properly managed. Better sweeping management system should be implemented. Use of mechanical sweepers should be initiated for large coverage. Standards for road construction specified in terms of guaranteed life of the road. Financial incentives to contractors using better technology for road construction. Treated sewage for road side bioswale system, which will not only keep the kerb-side green but also help in arresting air pollution

6.2 Line Sources - Reduction Strategy

High volume capacity ratio in various corridors in Pune involves queuing, slower speeds and increased travel times, which impose costs on the economy and generate multiple impacts on urban regions and their inhabitants. The problem of congestion, moreover due to one way traffic flow the traffic moves through the inner roads and riders have to take longer routes, which adds to pollution, more fuel consumption and more wear-tear of vehicles. One of the major contributors to Particulate Matter (PM) and NOx emissions in Pune region is vehicular exhaust. Particulates present in vehicular emissions are especially harmful due to their small size (under PM_{10}) and even larger number below $PM_{2.5}$. The fine particles are also important due to their harmful chemical composition. The most prominent sources of vehicle particulate emissions are diesel driven and two-stroke petrol driven vehicles. Reduction strategies addressing both technical and non-technical issues presented here take into consideration the current ambient air quality standards; exhaust emission standards, emission inventory, vehicular population composition, infrastructure availability and the techno-economic feasibility in Greater Mumbai Region.

The discussion has been presented in following order:

- Improvement in fuel quality and alternate fuels
- Improvement in vehicle related components/technologies (After-exhaust treatment techniques and retrofitment)
- Synchronization of traffic signals
- Inspection & Maintenance programme
- Transport planning and traffic management
- Other options including phasing out old vehicles, revision of emission standards
- Encourage public transport, encourage non motorized transport and
- Reduce dust resuspension

Many potential emission reduction options have been considered based on viability in the city and the major issues are pertaining to the overall vehicular sector emission reduction have been discussed in **Table 6.2**.

Table 6.2 : Emission Reduction Action Plan for Line Source

Area Sources	Short Term-2019	Mid Term-2022	Long Term-2025	Action required
Reduction Emission per Unit of Fuel				
Sulphur reduction	S Reduction - 10%	S Reduction -30%	S Reduction -50%	Low S level in the metro cities used as diesel in HDDV and LDDV. Delineating tighter diesel fuel standards. Phasing out fuel subsidies, uniform pricing all over the state Measures which can dissuade truck operators from buying high S fuel should be stricter, reliable and reproducible inspection for smoke levels.
Fuel Adulteration	Strict Banning of Fuel Adulteration-50%	Strict Banning of Fuel Adulteration-80%	Strict Banning of Fuel Adulteration-100%	At petrol pumps facility should be provided for identification of fuel adulteration by way of marker Oil companies should used colour codes on the tanker transporting the fuel, regular testing of the fuel before it is filled in the bunks and after. Show pro-activeness in promoting the better lubricants. Oil companies should also put their own manpower and machineries in checking effectively their products being sold from their outlets. (e.g. BPCL's Pure for Sure; HPCL's Club HP and IOC's Q & Q etc., which are being carried out in, limited way. Economic measures such as removing the disparity in petrol, diesel and kerosene prices will be required to remove incentives for such large scale malpractices, Fines and cancellation of license are the tools Ministry of petroleum has constituted anti adulteration cell for preventing the malpractices of fuel adulteration
CNG/PNG	Privately operated Vehicles should be converted - 30%	Privately operated Vehicles should be converted - 50%	Privately operated Vehicles should be converted - 75%	The contract buses and intra city buses should be encouraged for shifting of fuel through administrative orders and tax exemption. Incentive for new owners to buy CNG/LPG vehicles. Developed infrastructure for easy availability of fuel station for CNG refuelling and availability of kits for such conversion to the older vehicles

Table 6.2 (Contd..) : Emission Reduction Action Plan for Line Source

Area Sources	Short Term-2019	Mid Term-2022	Long Term-2025	Action required
Reduction Emission per Unit of Fuel				
Banning of 15 year Old Commercial Vehicle	50% banning Encouragement by provision of incentives in form of scrap value	70% banning	100% banning	All vehicles should go through inspection and certification every two years. Incentive for an owner to phase out his vehicle after 15 years given in the form of low registration cost or direct subsidy Corporation and metropolitan authority should demark designated places for scrapped vehicles as such there is no provision in the city
Synchronization of traffic signals Sensor Based - Real time tracking	Major & minor roads, excluding feeder roads (or about 35% of the all arterial roads)	Major & minor roads, excluding feeder roads (or about 65% of the all arterial roads)	Major & minor roads, excluding feeder roads (or about 80% of the all arterial roads)	Pre feasibility study should undertake for some hotspots. Detail study should be worked out on signalling network with sensor based monitoring and apply fuzzy logic, mathematical model gives the real time picture.
New Vehicle Standards	Currently BS-IV standards are in operation	Implement BS- VI from 2020 -50% (adopt progressive increment)	Implement BS- VI from 2020 -75% (adopt progressive increment)	The government of India is planning to implement BS VI norm across all country in 2020, but due to recent events it has been implemented in some regions like Delhi. Regulatory bodies can undertake prior feasibility studies for its successful implementation across region. This is major measure considering 90% reduction in fuel sulphur.
In-Use vehicle	Marginal improvement from newer vehicles except when implementation is for Euro V & VI. -25%	Newer vehicles implementation of standards -50%	Newer vehicles implementation of standards -75%	Improvement and compliance system in existing PUC. In-use vehicles emission reduction can be substantial. Inspection and identification of highly polluting vehicles. Augmentation of manpower and related infrastructure for Inspection and Certification Vehicle manufacturer should be asked to get the emission warranty for the complete period of the operation of the vehicle. The same may also be included in the MoRTH guidelines to be developed asking manufacturer to be proactive even when vehicles have been sold

Table 6.2 (Contd..) : Emission Reduction Action Plan for Line Source

Area Sources	Short Term-2019	Mid Term-2022	Long Term-2025	Action required
Reducing Fuel Consumption Per Unit Distance				
Share of Electric vehicles in Total City Fleet	Two wheeler: 5%, 3 wheeler and Taxi: 5% Public transport buses -5%	Two wheeler: 10%, 3 wheeler and Taxi: 10% Public transport buses -10%	Two wheeler: 10%, 3 wheeler and Taxi: 10% Public transport buses -20%	Encouragement to public participation for taking share of electric vehicles. Easily availability of engine testing and repairs workshop. Incentive for buying and providing exchange offers mostly young generation and women.
Share of Hybrid vehicles in Total City Fleet	(Gasoline powered four-wheelers only) – 10%	(Gasoline powered four-wheelers only) – 20%	Gasoline powered four-wheelers only) – 30%	Hybrid vehicle particularly efficient for city traffic where there are frequent stops and idling periods also reduce noise emissions in comparison to conventional engine vehicles. Hybrid vehicles can reduce air emissions of smog-forming pollutants by up to 90% and cut carbon dioxide emissions in half
Retrofitment of Diesel Oxidation Catalyst (DOC) and Diesel Particulate Filter in HDDV	Retrofitting devices- 50% conversion for HDDV in city registered vehicles	Retrofitting devices- 75% conversion for HDDV in city registered vehicles	Retrofitting devices- 100% (Excluding the heavy duty city outside vehicles)	As per current emission inventory 6.8 Tons/day emits from vehicular sector out of which 83% of PM, 85% of SO_2 and 87% of NOx only from HDDV. The retrofitment of vehicles helps to minimize the emission. A pilot study is required to test the need and efficacy of emission control device and retrofitting it in the older vehicles As retrofitment of emission control devices also needs a certain levels of fitness of the vehicle, it would be desirable to follow the norm after developing the same through the inspection and certification procedures It will be helpful to Maharashtra State Transport Corporation, Old PMT buses, Contract carriers Impose restriction of truck movement in the city for plying without retrofitment to HDDV vehicles (base on age and engine type). Tighter diesel fuel standards particularly for Sulphur to bring down its level up to 50 ppm. Differential taxation to those with and without after treatment devices.

Table 6.2 (Contd..) : Emission Reduction Action Plan for Line Source

Area Sources	Short Term-2019	Mid Term-2022	Long Term-2025	Action required
Inspection and Maintenance	New I&M regulations (30% population of vehicles of a RTO region)	New I&M regulations (50% population of vehicles of a RTO region)	Full compliance - 100%	The test design should have the basis of engine and overall vehicles fitness (road worthiness). The Vahan-nagari area should be developed for I&M which is equipped with state-of-the-art testing set-up for all the types of emission as well as fitness testing Strict compliance for I&M programs that are difficult to cheat; computerized data capture of control of tests, strict enforcement with socially acceptable failure rates and penalties
Ban of odd /even vehicles	It is feasible to take trail for commercial / office areas – 20%	Identified the interlinking roads and traffic hotspots and implement for trail road - 20%	Identified the interlinking roads and traffic hotspots and implement for trail road - 50%	Odd and even number vehicles will run on alternate days. Alternate arrangements should be made to bolster public transport. All private vehicles even having registration numbers issued by neighbouring states will have to follow the odd-even number formula
Reduce Vehicle Distance Travelled				
Regulating Road Site Parking	Road site parking to be reduced by 50% (On street parking spaces as per IRC: SP: 12:2015.)	Road site parking to be reduced by 75%	Road site parking to be reduced by 100%	Parking on roads should be regulated along with a rule to allow purchase of vehicles only if parking place is available. All road side shop, commercial premises, busy lanes are parking their vehicles indiscriminately near the approach movement. Municipal corporation should define designated space in the localities and develop elevated pay and park zones. Higher parking fee for longer period of time. The commercial vehicles for good transport should not be allowed in peak hours

Table 6.2 (Contd..) : Emission Reduction Action Plan for Line Source

Area Sources	Short Term-2019	Mid Term-2022	Long Term-2025	Action required
Reduce Vehicle Distance Travelled				
Encourage Public Transport	Increase Public Transport - 20% Which reflect 10% VKT reduction from private vehicles.	Increase Public Transport - 50% Which reflect 40% VKT reduction from private vehicles	Increase Public Transport - 75% Which reflect 60% VKT reduction from private vehicles	Incorporate city specific proposals on public transport with respect to Metro/mono rail, BRT, large buses contingent etc with integration of sustainable development and management. It can be achieved by way of providing better frequency to reduce congestion during peak period, better bus quality in terms of sitting as well as standing space The public transport should be cross-supported directly from the personalized vehicles either being purchased newly or older one running on the road. Funds generated from measures such as higher car user charges, higher parking charges, high registration fees, higher taxes on private mode of transport etc. should be directly transferred to them to achieve the low cost, better comfort, better frequency and faster travel. Diesel or any fuel used for public transport should be sold at lower price to keep the bus fare lower. An exclusive lane has been designated for BRT buses, but is being operated inefficiently. A strategic approach should be made to use the lane at its full potential for efficient public transport.

For example, for one km of travel, a car consumes nearly five times more energy than a 52-seater bus with an average load factor of 82 percent. The corresponding consumption factor for two-wheeler is 2.6. The comparative fuel costs of a car and two-wheeler are 11.8 and 6.8 times respectively for the same distance. Besides, the major issue is that a car occupies 38 times more road space compared to a bus for a kilometer of a travel. Two wheelers space requirement is even higher at 54 times that of a bus*.
Further, the emission from a two-wheeler equivalent to a bus could add 27 percent higher, whereas the cars would cause 17 percent more pollution. The age of the bus can be of no major concern, when we compare the benefits that it could give in terms of fuel savings, emission and safety.

* Report on the Expert Committee on Auto Fuel Policy, Chapter 15, Government of India, 2002.

Every stakeholders consulted during the process, have agreed the major focus of any future transport initiative should be based on low cost public transport. Some of these initiatives are discussed hereunder:

Table 6.2 (Contd..) : Emission Reduction Action Plan for Line Source

Area Sources	Short Term-2019	Mid Term-2022	Long Term-2025	Action required
Road and Traffic Control	Interlinkage & accessibility of road to Station, Residential Blocks & Offices. Identify 10% area	Identify 50% area covering feeder and service roads	Identify 75% area covering service roads and arterial roads highways	Prepare plan for widening of road and improvement of infrastructure for decongestion zones. Interlinkage of Road should be designed as per traffic flow in peak hours. Encouragement of car pooling results in reduction of private occupancy of vehicles and generates open space, less congestion with easy traffic flow.
Encourage non motorized Transport	Define in every ward at least 2% are for walking and cycling track	Define in every ward at least 10% are for walking and cycling track	Every road should at least 3m road for walking - 100% removal of road encroachment	Pedestrian friendly walkways /Subways Introduce and define walking and cycle tracks during city development plan. Cycling should be promoted with safety, free parking lots for users, and free bicycle ride facilities stops outside all railway stations

6.2.1 Demography Based Control Measures

Regional Transport officer in collaboration with ULB and private and PPP entity should be directed to give information about the time bound strategy to control the vehicular pollution and traffic management for:

- Promotion of CNG fuel: Subsidy to three wheeler autorickshaw operating on CNG. PMC has given subsidy for CNG conversion to 15350 autorickshaws in the last 5 years. Each rickshaw is given subsidy of Rs 12,000/-. The scope should be to cover entire jurisdiction as well as other intermediate public transport category.
- Encouraging more CNG stations within city. The total CNG consumption has gone upto 80,000 MT per year in 2017. The CNG consumption was 20,000 MT in 2012. There are 31 CNG stations operational in city. Proposed are 23 new daughter booster stations and 17 new online stations. Increasing technical infrastructure for dispensing of CNG/LPG is recommended. More than 90% reduction in PM can be achieved with the change in fuel pattern.
- Encouraging registration of CNG based vehicles. March 2017, the CNG based registered vehicles were: 30670 three wheelers, 36,888 four wheelers and 1226 Pubic Transport buses. Also CNG two wheelers are on trial basis in the region.
- Purchasing of new CNG buses for public transport. Out of 2055 public transport fleet, there are 1226 CNG buses in operation. The administration has proposed 800 BRT buses, 200 midi buses and 550 AC buses to be purchased. Emphasis should be on conversion of all public transit into CNG based fuel.
- Phasing out old bus fleet of more than 12 years. Out of 2055 bus fleet, there are 197 buses more than 12 years old. These buses are to be phased out from service. Phasing out should also be considered for private vehicles. The move can be encouraged by provision of incentives in the form of scrap value, direct transfer of percentage of cost of basic model as well as cash discounts for the original equipment manufacturers.
- Promoting Electric buses. Electric buses will be introduced under Smart city program. The trial and test to understand the feasibility will be taken by PMC.
- Steps for Promoting Battery operated vehicles. Promote the scheme in consultation with RTO, Transport. Operation of Electric vehicles instead of grossly pollution from high VKT vehicles is a good option. It needs to be introduced and requires a regulatory push.

- Hybrid buses can be introduced in PMCs fleet of buses. Biodiesel (B5/B10:5 – 10% blends) should be considered as a fuel option for public transport. Promotion of electric public transport. Battery Operated transport vehicles providing point to point service can also be initiated.
- Promoting Bicycles in Pune. Pune Cycle Plan is being prepared by PMC 2017 through a project supported by the Ministry of Urban Development, Govt. of India. It consists of: Identification of a city-wide cycle track network and cycle-safe streets. Factors such as city-wide Public Bicycle Scheme, Bicycle Parking Facilities and integration with Public Transit as well as Design Guidelines for planning and implementing cycle-friendly infrastructure and Recommendations for Institutional Mechanisms, Capacity-building and Financial Planning for implementing the plan are considered for the plan.
- Launch extensive drives against polluting vehicles for ensuring strict compliance. With involvement of Colleges & NGOs this process should be considered as continuous & mandatory activity at Toll Plaza & Extensive during winter months in coordination with traffic department. Estimate suggests that 25% of this vehicle may contribute 75% of total emission. Regular check-up of polluting vehicles by PUC and better compliance will lead to reduction of PM and other pollutants as well. It will also lead to less pressure on complying vehicles.
- Prevent parking of Vehicles at Non designated areas. As per City Development plan, Two-wheelers shared the majority of the total vehicles parked, which share 63% of the total vehicles followed by Car / Van. Thus it can be seen that 89% of the vehicles parked on the streets are private vehicles.
- On street parking spaces should be designed as per IRC:SP:12:2015. While designing streets, priority should be given to the movement of pedestrians, cyclists, public transport, public spaces and then motor vehicles. Parking can be accommodated in the remaining street space. However, opinion of traffic police and local stakeholders are necessary while designating parking spaces. Parallel parking configuration should be adopted for all three-wheeled and four-wheeled vehicles including motor cars, light commercial vehicles (LCV), buses and trucks. Perpendicular parking configuration should be adopted for motorized two wheelers as well as bicycles. Only single lane parking should be allowed for any on street parking lots.
- Off street parking spaces should be designed to comply with design standards, including dimensional and circulation requirements. IRC:SP:12:2015, NBCC,BSI standards should be adopted. Private sector's investment should be encouraged for creating multi story parking

structures. Cost of land, construction of built space, operation and maintenance should be recovered from the users using such facility. The capacity of off street parking block shall be dependent on the carrying capacity of the adjoining street and not on FSI permissibility or availability of built up space.

- Initiate steps for retrofitting of particulate filters in Diesel vehicles, when BS-V fuels are available. Retrofit with either type of diesel particulate filter or an oxidation catalyst is expected to provide net benefits to society, beginning immediately. RTO should coordinate for proper implementation of replacement of existing diesel particulate filters for heavy duty vehicles registered in PMC city limits. Involvement of R & D units of engine manufacturing organization can provide with technical insights for such measures. A pilot retrofit programme to value the efficiency needs to be undertaken. Frame work policy for legislation should to be explored.
- As per Auto fuel Policy, the GoI plans to implement BS VI nationwide in 2020, excluding BS V. Adoption of BIS VI norms before its implementation will be beneficial in terms of future compliance.
- Prepare action plan to check fuel adulteration and random monitoring of fuel quality data. An action plan regarding fuel adulteration and random monitoring of the fuel quality data should be drafted in coordination with anti-adulteration cell and maintained as a continuous process. Success of marker system shall be highly dependent upon the joint working of Oil Companies and Anti Adulteration Cell. Fiscal Measures for development of alternative fuel technology should be made available from concerned organizations. Fuel dispensing system should be regularly and strictly monitored.
- Prepare action plan for widening of road and improvement of Infrastructure for decongestion of Roads. Previous CDP 2006-2012, suggested increase in the carrying capacity through road widening and also to improve riding quality through strengthening of existing roads to cater to the missing links and developing areas by providing efficient, safe and accessible mass transportation system for entire region. Pune Municipal Corporation successfully completed 3 projects under Road & Transportation sector i.e. Pune Pilot BRTS, Baner Sub-way and New Alandi road. Other measures such as implementation of Special projects Like Tunnels, High Capacity Mass Transport Road (HCMTR) and Flyovers as per CMP should be adopted as soon as possible.

- Synchronize Traffic movements/Introduce Intelligent Traffic systems for Lane Driving Intelligent traffic system with installation of CCTV and Surveillance System should be implemented city vide. Using information from transmitters built into or along a road to the cars on it, the system works to help avoidance from dangers like a missed stop sign or signal or a dangerous intersections.Under Smart city initiative of GoI, appropriate funds can be utilized for the development such technology
- Installation of Remote Sensor based PUC systems. With the involvement of MSRAC, a feasibility study to understand the effectiveness of Remote Sensor based PUC system should be done. Adapting required measures concerning to city demography, the systems can be initiated with 2 wheelers.
- Provide good public transport system. According to JNURM guidelines for provision of buses 40 buses per lakh population are required, a city of the size of Pune, with a population of around 45 lakhs including Pimpri-Chinchwad, should have about 2,500 buses.
- Public transport should serve the needs of urban poor and should be affordable. PMPML operated on road public transport buses are around 916, in additional to 308 contract buses carries 1236176 passengers on 334 routes for 18 km. Increase the public transport modes coverage and quality including the expansion and improvement of bus system Establishment of newer and higher quality bus system to cater the need of all sections
- Strengthening the passenger information system: The BRTS already uses an Information system for displaying advertisement messages transmitted via satellite; this system could be used to show current status of the bus in terms of timing and location as well as the status of buses available from the next stop.
- Introduction of new Modes of public transport such as Metro-rail, Light Rail Transport System (LRTS) and Monorail System – Special Projects. Feeder service system of buses should be proposed to the metro-lines. Feeder services for metro rail should also be comprehended.
- Restricting entry of polluting trucks and heavy duty goods vehicles and passenger travel buses in the cities by providing circumferential roads/by-passes.
- Promotion of non-motorized transport (NMT). Bicycle sharing schemes should be introduced in the city. Provision of cycle parking facilities at mass transit (BRT/Metro) stations should be made. Provision of City E rickshaw can be initiated. Allocation of designated space for idling/ parking of cycle rickshaws will curb traffic congestion. Safety concern of cyclist and pedestrian has to be addressed by encouraging the construction of segregated right of way for

bicycle and pedestrian. Continuity of cycle track should be maintained. Introduction of rental based cycles (Rent-a-Cycle Scheme) as point to point service. Provision of cycle parking should be made especially at metro stations. Barricading of footpath –foot path opening only the strategic location to regulate the pedestrian movement, to improve traffic safety and pedestrian safety also.

- With the routine upgradation of roads from the administrations, the traffic movement is free flowing whereby increase in per km speed and decrease in travel time has been observed. For better management of traffic, some of the roads have been declared as a one way, that contributed to increase in per km speed and the increase in capacity of the road in one direction has brought the VC ration down. However, these measures not the permanent solution to the problem of congestion, moreover due to one way traffic flow the traffic moves through the inner roads and riders have to take longer routes, which adds to pollution, more fuel consumption and wear-tear of vehicle.
- 4 special built Road Maintenance vans in operation and connected by mobile app. After success of the 4 RMVs, more 8 RMVs are now in stage of being introduced bringing the total number of RMVs to 12
- Besides the direct exhaust emissions, a major source of PM is the fugitive dust due to vehicular activity on the road. This re-suspended dust includes (a) windblown dust which settles on the road (b) wear and tear of tires and (c) dry deposits of other pollutants. The control measure to control resuspension:
- Total length of roads in city is 2065 km. PMC has been providing UTWT- Ultra Thin White Topping treatment for internal roads in the city. Urban Street Design Guidelines for Pune. Aim to design guidelines for streets in Pune which prioritize streets for people and not for vehicles, thereby reinstating the position of streets of Pune as dominant and most vibrant urban public realm.
- Road design improvement. The new roads are constructed as per the Urban Street design guidelines which takes into consideration the latest technologies used in road development as well as the specifications given under Indian Road Congress guidelines and National Urban Transport Policy.
- Prepare plan for creation of green buffers along the Traffic corridors. There are 36 road medians and traffic islands which are maintained by Private agencies on PPP basis. The greenery maintenance is done by these agencies. Greenery should also be maintained at open

areas, garden, community places, schools and housing societies. Pune city has total 181 gardens developed and maintained by PMC. Along with Forest Department, PMC has Joint Forest Management Committee in which 550 Hecate of land on hills is maintained green.

6.2.2 Clean Air Fund

Prioritization of Public Transport on Roads: Once, more and more people get used to personalized transport, it would be very difficult to bring them back into the fold of public transport users. The fact that personal vehicles are occupying more and more space on the road; it is felt necessary that disincentive mechanism should be developed for personal vehicle owners. There are many methods of carrying out this task, however, financial and space constraints can achieve the balance. The efficiency of the public transport can be maintained only if priority is given to the public transport vehicles. Some of the suggestions are:

As city having BRT Bus lane, there is need to find out gaps and exclusive bus lanes should be introduce base on point to point service.

If one wishes to see higher bus utilization, it also has to see correspondingly higher service levels. This could be achieved by way of providing better frequency to reduce congestion during peak period, better bus quality in terms of sitting as well as standing space. Those vehicles which may travel in bus lanes will need to pay a sum to get the benefits

Cost of Bus Ride: The cost of the bus fare has been increasing at a steady pace. This is seen as a very common practice when there is an increase in the diesel cost announced by the Government. What it leads to is that the bus fare for two-four persons becomes almost equivalent to either the taxi fare or attractive enough to own a private two or four wheeler. In such a situation, it shows that increasing bus fare and purchasing power is becoming the main responsible agent for higher private vehicles purchase. The other reason, such as better roads with flyovers (faster travel) makes it attractive for private vehicle ownership.

Public transport fare pricing, therefore, should not only be dependent upon the actual cost, but on some other sources of income. Modalities and options which can be adopted for no increase in bus fares are presented below:

- The public transport should be cross-supported directly from the personalized vehicles either being purchased newly or older one running on the road.
- An Air Quality Fund could be created which will have sources of funds coming from measures such as higher car user charges, higher parking charges, high registration fees, higher taxes on private mode of transport etc. should be directly transferred to them to achieve the low cost, better comfort, better frequency and faster travel.
- Diesel or any fuel used for public transport should be sold at lower price to keep the bus fare lower. The losses can be recovered from car-users.
- Certain areas of business district or identified regions of high congestion, free bus services can be provided. The cost can be recovered from parking, congestion and high fuel costs charged to personal vehicles. (For example Pilot feasibility study may be carried out in Hotspots)
- All malls must be asked to provide their own free service to nearest train and bus routes so that congestion due to their activities is reduced further. Alternately, all cars must pay an additional fee besides parking charges as congestion fee when they enter the mall. All such charges should be pooled and shared with the public transport company.
- All malls and institutions attracting outside car visitors levy a Rs. 10 per hour charges. This can either go to PMT or the fund

- Administration : Insurance cost should be inclusive of congestion charge every six months, buy sticker worth congestion charges. Annual insurance time each vehicle can pay a sum of Rs.500 extra, which can go to the fund. Collection responsibility will be with the insurance company.
- Vehicle manufacturers selling vehicles in state of Maharashtra must pay a ONE TIME air pollution tax towards the CAF

The key is that all such charges thus collected should be managed as Clean Air Fund and should be passed on the public transport company, which could not only take care of its operational costs but also addresses other issues such as: Lower cost to passenger, Better bus quality, Faster services and Adequate growth in bus population for more people.

Emission reduction from transport sector can also be achieved by forming a ‘Clean Air Fund’ in co-operation with public private partnership which can operate on following guidelines:

Example of how a small levy can bring additional revenue as part of Clean Air Fund :

Vehicle Km Travel in a Day for Pune City (2017)

	2 Wheeler	3 Wheeler	Car Diesel	Car Petrol	HDDV
VKT	23250250	6711334	1145294	9731519	4608821
Cost (Rs.)	1,16,25,125	33,55,667	11,45,294	97,31,519	46,08,821
Rate Rs./Km	0.5	0.5	1.0	1.0	1.0

Total Collection : 3,04,66,426 about 3 Crores per day

The current VKT growth of the city ranges between 2-5% depending upon the region of the city. Awareness programmes for policy makers, people, drivers-mechanic, traffic police, health professionals, academicians etc. will bring the importance of better air quality. Land use and transport planning need to be looked at seriously for future sustainability of the cities. In dense cities conglomerate of PMC, public transport saves valuable space and energy compared to private transport, and can make a healthy profit at the same time. But cities need to nurture their public transport by giving then some priority on the road over cars. If buses are always caught in traffic then a vicious cycle begins, with bus riders abandoning public transport and adding to the traffic jams. Various case studies from other places also indicate the importance of sustainable transportation. Strong leadership and governance brings radical change in achieving sustainable development of the city. The authorities responsible for the development of transport need to develop Integrated Environment Management Systems (IEMS). The goal of achieving a balanced development of the region through proper land use planning, strengthening of infrastructure facilities and formulates policies and programmes that help in preserving the environment for sustainable development.

6.3 Point Source - Reduction Strategy

The average decadal growth rate of industries from 1951 to 2011 is 36.54%. Rapid growth of the city is mainly attributed to industrialization of PMC/ PCMC after 1960 and expansion of Information Technology (IT) industry in the last decade. As per MPCB consent there are about 394 air polluting industries among them 191 is Red, 123 orange and 80 green categories.

The Pune city is surrounded by 7 Nos. of Talukas including Pimpri-Chinchwad Municipal Corporation (PCMC) area. There are no thermal power plants within Pune city limits and therefore the pollution load contribution from this source is nil. However, the industries in Pune and Pimpri-Chinchwad have set up D.G. sets to meet the power requirements of the respective industries particularly during the load shedding and weekly power holidays. However, within city area polluting industries are limited and dominated by forging and automotive engines industry. The contribution of point sources is limited due to confined industrial areas. With the implementation of the short and long term scenarios, the total reduction in particulate matter from point sources would be 55% and 98% respectively **(Table 6.3)**.

Based on the survey and assessment, following recommendations emerge:

- Inventorisation of prominent industries with inclusion of technological gaps.
- Identification of low cost and advanced cleaner technology for air pollution control. Use of air pollution monitoring devices (Continuous Environment Monitoring System) and other in-situ emission reduction devices.
- Continuous power supply must be ensured to avoid use of non-industrial generators, as it has remarkable benefits in terms of emission reduction. Reduction in use of non-industrial generators by ensuring continuous power supply can give benefits as reduction in PM and NOx emissions
- Use of FO, LSHS, LDO, and Bagasse should be regulated.
- Pune, Pimpri-Chinchwad and circumferential area earmarked for development and industrialization should be grouped under a Pune Metropolitan Development Authority for better planning and administration. The fuel (vehicular and industry) of corresponding quality in this area should be ensured. Similarly, national level decision of controlling sulfur content of these industrial fuels will yield good results (present sulfur content: FO 4%, LDO 1.8%)
- Industries should adopt stack emission norms beyond those prescribed by CPCB, which should be regulated& maintained by regular QA/QC & performance audit and industries should be encouraged for use of air pollution control devices like Bag filter. ESP, etc.
- Reduction in use of DG sets by ensuring adequate power supply, and have stricter norms for DG set emissions.
- Some units having coal fired boilers are proposed to improve efficiency of the wet scrubber and to stick for eco-friendly fuels.
- All the bulk drug manufacturing units should be proposed to improve efficiency of their VOC scrubbers.

Table 6.3 : Emission Reduction Action Plan for Point Source

Point Sources	Short Term-2020	Long Term-2025	Action Plan
Red (LSI, MSI and SSI) FO (49), HSD (58), Coal (81), Diesel (12) and Bagasse (460) TPD are the major contributors towards PM emissions	Shift to cleaner fuels - 50% FO, LSHS, HSD to LDO Coal & Others to NG	Shift to cleaner fuels - 100% Low Fuel i.e LDO Nearly all to NG	Emission load from Red (LMS) industries shows 1558.7 kg/d of PM; 1510.2 kg/d, 707.9 kg/d, 1004.2 kg/d and 106381.2 kg/d of NOx, SO2, HC and CO respectively. PM emission load across all categories is due to consumption of Bagasse as fuel. It must be shifted to clean fuel. Shift to cleaner fuels from FO and Coal to Natural Gas (NG) as per the availability from M/s. Mahanagar Gas P.Ltd. Requisition should be made towards establishment of such facilities. Feasibility of changing combustion technology to facilitate usage of gaseous fuels may be undertaken with financial incentives. Identification of low cost and advanced cleaner technology for air pollution control with policy intervention at specific zones. Use of continuous air pollution monitoring devices. Industries should adopt stack emission norms beyond those prescribed by CPCB Industries with QA/QC Inventorisation of prominent industries with technological gaps and detailed feasibility study is required as dispersion pollution with modeling and formulate land use based policy. Industries should take lead for plantation around industrial zone and premises and green belt development. One tree will offset on average about 10 kg CO_2 each year. According to this we will need 500 million additional trees in 2020 and 1200 million trees in 2051.

Table 6.3 (Contd..) : Emission Reduction Action Plan for Point Source

Point Sources	Short Term-2020	Long Term-2025	Action Plan
MSI, LSI & SSI (All Categories Orange and Green) FO (11), HSD (84) Wood (33) Diesel (35), and Bagasse (95) TPD are the major contributors towards PM emissions	Shift to cleaner fuels – 50% FO, LSHS, HSD to LDO Coal & Others to NG Shift to cleaner fuels (from FO to LDO)	Shift to cleaner fuels – 100% Low Fuel i.e LDO Nearly all to NG .	Emission load from Orange and Green (LMS) industries shows 1042.9 kg/d of PM; 781.6 kg/d, 582.4 kg/d, 3858.0 kg/d and 94264.5 kg/d of NOx, SO2, HC and CO respectively. Shift to cleaner fuels from FO and Coal to Natural Gas (NG) as per the availability from M/s. Mahanagar Gas P.Ltd. Inventorisation of prominent industries with technological gaps and make them available to change combustion technology to facilitate usage of gaseous fuels may be undertaken with financial incentives. Reduction in use of DG sets by ensuring adequate power supply, and have stricter norms for DG set emissions. Hazardous Air Pollutant emitting units. They have been directed to install Leak detection & repair system (LDAR) within months. All the bulk drug and pesticides manufacturing units are being proposed to improve efficiency of their VOC scrubbers. Energy Conservation Scheme should be encouraged in the industries that are not economically capable towards shifting to eco friendly fuel use or advanced clean technology. Identification of Illegal SSI, MPCB should survey their levels of operation and their contribution of emission in each of the city grid.

- Energy Conservation Scheme should be encouraged in the industries that are not economically capable towards shifting cleaner fuel use or advanced cleaner technologies. Air polluting industries can improve their ECS by increasing efficiency of their scrubbers and changing to eco-friendly fuels.
- PMC, MIDC & MPCB should survey for the identification of illegal SSI and their levels of operation /contribution in each of the grids in the city. Need for regulations for such units.
- PMC, MIDC, Industries should be take lead for plantation in and around their industrial zone and green belt development with the help of local NGOs, School & Colleges.

All reductions planned will only reduce emissions from manmade sources; however, natural background and dust would continue to remain in the atmosphere. The benefits computed in the process described above will not only yield PM and NOx related pollution reduction but also co benefits of other pollutants (SOx, VOCs, HC, CO etc.) reductions as well. One of the other major co-benefits of these options (adoption of mass transport, use of cleaner fuel, efficient combustion etc) will provide large scale green house gas reduction. Pune as a big metro city will provide the impetus of overall mitigation of GHG.

6.4 Management

The dominant parameter are PM and NOx, attributed to growing vehicular traffic and construction projects as well as commercial and infrastructure development including road construction etc. Hierarchical and structured managerial system for efficient implementation should be introduced with data linkage to SPCB/CPCB (of monitoring devices). Inclusion of IT will be beneficial at all the levels. Continuous updation of emission inventory considering not only PMC but complete area of Pune, Pimpri-Chinchwad and circumferential area earmarked for development and industrialization to be grouped under a Metropolitan Development Authority. The objectives of clean air cannot be kept limited to the political boundary.

There is a lack of collaborative policy initiative among the administrations and organization with regard to air quality improvement. These policy initiatives can be sustained and kept up-to-date only if there is an apex body, which from time to time gets feedback from various sources down their hierarchy. These sources could be State Pollution Control Board, Regional transport office, Pune Municipal Corporation, MIDC, Oil Companies, Anti-Adulteration cell, and representative from ULB and NGOs, school and colleges. Regulatory framework, if needs can be communicated to the apex body for starting the initiative for policy formation.

Chapter 7

Reduction Strategies for Emission Control

Based on emission inventory results of all the sources viz. industrial, area and vehicular obtained under the present study, the subsequent sections will discuss the possible strategies for pollution reduction. The focus on reduction discussed will be mainly for PM and NOx as these pollutants are cause of concern. Other pollutants will also reduce with the adoption of strategies discussed here. Additional benefits should be taken as co benefits.

7.1 Area Source Pollution Reduction Strategies

Attributing to the population, currently the domestic fuel (i.e. LPG kerosene and Wood) consumption emits the highest emission load across all the sectors of the total area source emission load. The other major sources considered under area source emissions are construction, non industrial generators, agricultural pumps, brick kilns, hotels and restaurants, bakeries, crematoria, open /landfill burning etc. Area source emissions are high particularly for PM when compared with emissions from vehicular emissions. The area sources though called area sources, are limited to small regions and therefore, their impact does not seem to be wide ranging and across the city. It is observed that the total particulate matter emissions from area sources, particularly due to burning of wood and fossil fuel in slum population. Hence, the efforts should focus on finding out appropriate technology/management options, particularly on conversion to natural gas in much more cost effective way. Other sectors also need large scale adoption of cleaner practices. The brief control scenarios which were discussed earlier in **Table 7.1.**

Table 7.1 : Area Source Emission Scenario with Control Options (Emission Load in kg/day)

Source	Present Emissions	PM Control Options	
		2020	**2025**
Domestic	3757.5	• 25% of Slums to use LPG/ PNG • 50% of Non Slum to use LPG/PNG	• 50% of Slum to use LPG • 100% same
Hotel & Res.	293.0	50% of coal to LPG	75% of coal to LPG
Open Eat outs	9.8	Since these operation is illegal, difficult to quantify	
Bakeries	79.48	• 25% LPG • 25% Electric	• 50% LPG • 75% Electric
Crematoria	60.9	50% Electric	75% Electric
Open /Landfill Bu.	337.2	50% Open burning	100%
Building Constr.	3618.9	50%	50%
Brick Kiln	600.0	Awareness and Management	
Non Ind. Generator	1234.0	Awareness and Better Inventory	
Agricultural Pump	500.0	Awareness and Better Inventory	

As part of management plans the anticipated sector-wise particulate matter emission loads reduction is presented in **Table 7.2**.

Table 7.2 : Anticipated Reduction in Particulate Matter (Area Sources)

Area Source /Sectors	Existing	% Contri-bution	BaU 2020 (5.5% Growth)	BaU 2025 (7.0% Growth)	Expected Emissions (Short Term), 2020	Expected Emissions (Long Term), 2025
Bakeries	79.48	0.8	83.85	89.72	63.6	34.9
Crematoria	60.90	0.6	64.25	67.78	32.1	17.2
Open Eat-outs	9.80	0.1	10.36	11.08	9.5	10.3
Hotel Restaurants	293.00	2.8	297.4	304.9	221.1	228.3
Domestic Sector	3757.50	35.8	4020.5	4623.6	3429.7	2728.9
Open Burning	337.20	3.2	360.8	387.7	180.4	96.9
Construction Activity	3618.90	34.5	3980.8	4523.7	1990.4	2261.8
Brick Kiln	600.00	5.7	600.00#	600.00#	300.0	150.0
Non Industrial Generator	1234.00	11.7	1234.00#	1234.00#	617.0	308.5
Agricultural Pump	500.00	4.8	500.00#	500.00#	250.0	120.0
Total	**10490.78**		**11151.96**	**12342.48**	**7093.8**	**5956.7**
Reduction w.r.t BaU 2018					**67.6%**	**56.8%**

As BaU 2018 (Assumption No Possible Change)

With the implementation of the short and long term scenarios, the total reduction in particulate matter from area sources would be more than 68% in short term and 57% as long term goals. The major emission load from domestic sector will be reducing by 8.7% in 2020 and 27% in 2025, as population increasing residential sector consumption of LPG is also increase only effect of kerosene and wood burning will reduce. As also open burning and construction sector it is around 45 to 46% in 2020, whereas the reduction will be 71% and 37% in 2025. The non industrial DG sets, crematories, agriculture pumps, brick klins emission also reduce by 50% in 2020 and 75% in 2025.

7.2 Point Source Pollution Reduction Strategies

The strategies for abatement of emissions from point sources include cleaner fuel substitution, change in basic production processes, and pollution abatement through flue gas treatment modifications of exit gas characteristics besides shifting of industries outside the city premises. The strategies mainly considered are based on cleaner fuel substitution as well as closing/shifting of industries outside the city region. The strategies are recommended for the following two broad sectors i.e. all Red groups (LSI, MSI and SSI); another all Orange and Green (LSI, MSI and SSI); for short term 2 yrs. (upto 2020) and long term 5 yrs. (upto 2025).

Point Source Control Options and Analysis

Total PM Emission load from RED, Orange and Green category was calculated to be 1558.7 kg/day, 590 kg/day and 452.9 kg/day, respectively. Whereas, NOx total emission load was 1510.2 kg/d, 654.9 kg/d and 126.7 kg/d for Red, Orange and Green categories of industries respectively. This emission load is mainly coming from FO (49), HSD (58), Coal (81), Diesel (12) and Bagasse (460) TPD from Red Category of industries and FO (11), HSD (84), Wood (33), Diesel (35), and Bagasse (95) TPD from Orange and Green categories respectively. **Table 7.3** presents the fuel switch options and emission loads in each case. It has been calculated to align the use of clean fuel in the city for improving the air quality.

The control options were derived on the basis of emission inventory estimated for all categories of industries. The replacement with alternative fuel was suggested on the basis of respective calorific value of each fuel. The calorific value is energy contained in a fuel, determined by measuring the heat produced by the complete combustion of a specified quantity of it. The calorific value considered for the inter conversion of fuel for reduction strategies were: 45.00 MJ/kg (FO), 44.38 MJ/kg (LSHS), and 49.57 MJ/kg (HSD), 43.96 MJ/kg (LDO), 30.20 MJ/kg (Coal), 50.03 MJ/kg (Natural Gas), 16.0 MJ/kg (Wood) and 46.1 MJ/kg (LPG), respectively. After implementing short and long term control options, the reduction emission load is depicted in **Table 7.4 a to c** (for PM) and **Table 7.5 a to c** for NOx.

Table 7.3 : Point Source Strategies for Short and Long Term

Point Sources Category	Major PM Emission Contributor	Control Strategies	
		Short Term (2020)	**Long Term (2025)**
Red, Orange and Green Category (LSI/MSI/SSI)	FO, HSD & Coal major contributors towards PM emissions	• Shift to cleaner fuels i.e. LSHS to Light Diesel Oil (LDO) Combustion technology up gradation for fuel change.	• Shift in cleaner fuels from LSHS & coal to Natural Gas (NG) • Combustion technology improvement with fuel change • Feasibility of conversion of thermal power production to gas based system. • Industrial development (expansion) should be based on cleaner gaseous fuel with no net increase in emissions.

Table 7.4 : Point Source Emission Scenario Before & After Control Strategies : Short & Long Term Scenarios for PM

A. For Red (LSI/MSI/SSI)

Sr.	Present PM Emissions			PM Emissions After Control Strategies					
				Short Term (2020)			Long Term (2025)		
	Fuel Type	**Qty. (TPD)**	**Emissions (Kg/day)**	**Fuel Type**	**Qty. (TPD)**	**Emissions (Kg/day)**	**Fuel Type**	**Qty. (TPD)**	**Emissions (Kg/day)**
1.	FO	49	23.89	LDO (50%)	29	0.4	LDO	242	3.5
2.	LDO	4	0.06	LDO	4	0.1	NG (m^3/d)	138	2.8
3.	HSD	58	0.85	LDO (50%)	34	0.5	LPG	6	0.08
4.	Coal	81	298.0	NG (m^3/d) (50%)	67	1.34	CNG/ PNG	1.2	23.65
5.	Kerosene	3	0.08	Kerosene (-50%)	1	0.04			
6.	LPG	4	0.06	LPG	5	0.07			
7.	Wood	8	136.86	Wood (-50%)	4	68.41			
8.	Diesel	12	5.83	LDO (50%)	7	0.1			
9.	CNG/ PNG	0.76	15.16	CNG /PNG	0.91	18.19			
10.	Bagasse	460	1092.50	LDO (50%)	52	0.7			
				FO (50%)	25	11.94			
				HSD (50%)	29	0.4			
				Coal (50%)	40	149.0			
				Diesel (50%)	6	2.92			
				Bagasse (50%)	230	529.14			
		Total (kg/d)	**1573.29**		**Total (kg/d)**	**783.25**		**Total (kg/d)**	**30.03**
					Reduction (%) wrt BaU 2018	**50.21%**		**Reduction (%) wrt BaU 2018**	**98.09%**

Shift in cleaner fuel based on equivalent heat input estimation.

Table 7.4 (Contd..) : Point Source Emission Scenario Before & After Control Strategies : Short & Long Term Scenarios for PM

B. For Orange & Green (LSI/MSI/SSI)

Sr.	Present PM Emissions			PM Emissions After Control Strategies					
				Short Term (2020)			Long Term (2025)		
	Fuel Type	**Qty. (TPD)**	**Emissions (Kg/day)**	**Fuel Type**	**Qty. (TPD)**	**Emissions (Kg/day)**	**Fuel Type**	**Qty. (TPD)**	**Emissions (Kg/day)**
1.	FO	11	4.8	LDO (50%)	6	0.1	LDO	164	2.4
2.	LDO	1	0.01	LDO	1	0.01	NG	1	0.016
3.	HSD	85	1.1	LDO (50%)	44	0.6	LPG	4	0.1
3.	LPG	3	0.041	LPG	3.3	0.05	CNG/ PNG	0.40	8.1
3.	Wood	34	524.5	Wood (-50%)	15	262.2			
3.	Diesel	36	16.5	LDO (50%)	20	0.3			
4.	CNG/ PNG	0.29	5.2	CNG/ PNG	0.31	6.2			
5.	Bagasse	95	497.4	LDO (50%)	12	0.2			
				FO (50%)	5	2.4			
				HSD (50%)	38	0.6			
				Diesel (50%)	17	9.4			
				Bagasse (50%)	54	124.3			
		Total (kg/d)	**1049.5**		**Total (kg/d)**	**406.3**		**Total (kg/d)**	**10.61**
					Reduction % wrt BaU 2018	**61.28%**		**Reduction % wrt BaU 2018**	**98.98%**

Shift in cleaner fuel based on equivalent heat input estimation.

C. Total Industrial Emissions in Mumbai Before & After Control Strategies for PM

	Sector	Present PM Emissions (kg/d)	Emissions After Control Strategies (kg/d)	
			Short Term	**Long Term**
A.	RED	1573.29	783.25	30.03
B.	ORANGE & GREEN	1049.5	406.3	10.61
	Total (kg/d)	**2622.79**	**1189.55**	**40.64**
		% Reduction	**54.64%**	**98.45%**

Shift in cleaner fuel based on equivalent heat input estimation.

Table 7.5 : Point Source Emission Scenario Before & After Control Strategies : Short & Long Term Scenarios for NOx

A. For Red (LSI/MSI/SSI)

Sr.	Present NOx Emissions			PM Emissions After Control Strategies					
				Short Term (2020)			Long Term (2025)		
	Fuel Type	Qty. (TPD)	Emissions (Kg/day)	Fuel Type	Qty. (TPD)	Emissions (Kg/day)	Fuel Type	Qty. (TPD)	Emissions (Kg/day)
1.	FO	49	391.76	LDO (50%)	29	91.6	LDO	242	3.5
2.	LDO	4	13.12	LDO	4	13.1	NG (m^3/d)	138	309.6
3.	HSD	58	186.16	LDO (50%)	34	108.2	LPG	6	29.29
4.	Coal	81	603.24	NG (m^3/d) (50%)	67	149.54	CNG/ PNG	1.2	4138.85
5.	Kerosene	3	5.17	Kerosene (-50%)	1	2.59			
6.	LPG	4	19.59	LPG	5	22.53			
7.	Wood	8	10.28	Wood (-50%)	4	5.14			
8.	Diesel	12	95.65	LDO (50%)	7	22.4			
9.	CNG/ PNG	0.76	2653.11	CNG/ PNG	0.91	3183.73			
10.	Bagasse	460	65.31	LDO (50%)	52	164.8			
				FO (50%)	25	195.88			
				HSD (50%)	29	93.1			
				Coal (50%)	40	301.62			
				Diesel (50%)	6	47.82			
				Bagasse (50%)	230	31.63			
		Total (kg/d)	**4043.39**		**Total (kg/d)**	**4433.68**		**Total (kg/d)**	**4481.24**
					Reduction (%) wrt BaU 2018	**-9.65%**		**Reduction (%) wrt BaU 2018**	**-1.07%**

Table 7.5 (Contd..) : Point Source Emission Scenario Before & After Control Strategies : Short & Long Term Scenarios for NOx

B. For Orange & Green (LSI/MSI/SSI)

Sr.	Present NOx Emissions			PM Emissions After Control Strategies					
				Short Term (2020)			Long Term (2025)		
	Fuel Type	Qty. (TPD)	Emissions (Kg/day)	Fuel Type	Qty. (TPD)	Emissions (Kg/day)	Fuel Type	Qty. (TPD)	Emissions (Kg/day)
1.	FO	11	79.2	LDO (50%)	6	18.5	LDO	164	524.7
2.	LDO	1	2.2	LDO	1	2.2	NG	1	2.754
3.	HSD	85	243.8	LDO (50%)	44	141.8	LPG	4	21.4
4.	LPG	3	14.3	LPG	3.3	16.4	CNG /PNG	0.40	1410.9
5.	Wood	34	39.4	Wood (-50%)	15	19.7			
6.	Diesel	36	271.1	LDO (50%)	20	63.4			
7.	CNG/ PNG	0.29	904.4	CNG/ PNG	0.31	1085.3			
8.	Bagasse	95	29.7	LDO (50%)	12	38.7			
				FO (50%)	5	39.6			
				HSD (50%)	38	139.3			
				Diesel (50%)	17	154.9			
				Bagasse (50%)	54	7.4			
		Total (kg/d)	**1584.1**		**Total (kg/d)**	**1727.2**		**Total (kg/d)**	**1959.75**
					Reduction % wrt BaU 2018	**-9.03%**		**Reduction % wrt BaU 2018**	**-23.71%**

Shift in cleaner fuel based on equivalent heat input estimation.

C. Total Industrial Emissions in Mumbai Before & After Control Strategies for NOx

	Sector	Present NOx Emissions (kg/d)	Emissions After Control Strategies (kg/d)	
			Short Term	Long Term
A.	RED	4043.39	4433.68	4481.24
B.	ORANGE & GREEN	1584.1	1727.2	1959.75
	Total (kg/d)	**5627.49**	**6160.88**	**6440.99**
		% Reduction	**-9.47%**	**-14.45%**

Shift in cleaner fuel based on equivalent heat input estimation.

The above short and long term strategies for different sectors, if implemented effectively would reduce the overall PM emissions from 2622.79 to 1189.55 kg/d (i.e. about 55%) in short term and 40.64 kg/d (i.e. about 98.45%) in long term, respectively for all category industries. The Red category short term reduction is upto 50.21% whereas in long term it will be 98.09%,similary the Orange and Green categories short term reduction is upto 61.28% whereas long term 98.98% for PM. The use of Natural gas as fuel is lower in industries of Pune region. Conversion of heavy sulphur fuel to natural gas, will probably increase the overall NOx emission load upto 9.47% in short term and 14% in long respectively.

7.3 Vehicular Sources Reduction Strategies

One of the major contributors to Particulate Matter (PM) and NOx emissions in Pune region is vehicular exhaust. Till March 31, 2018, the RTO has notched an increase of over 280,000 vehicles, with two-wheelers still enjoying the lion's share. This takes the figure of registered vehicles in the city to 36.27 lakh, from 33.37 lakh the previous year (2016-2017). The most prominent sources of vehicle particulate emissions are diesel driven and two-stroke petrol driven vehicles. The present number of four-wheelers in Pune is 645,683, two-wheelers 273,147, autorickshaws 53,227, taxi-cabs 28,344, and other heavy vehicles like trucks, buses, tempos, etc., at 38,598. Based on the results of emission inventory, specific strategies need to be ranked out of wide variety of reduction options available. Reduction strategies presented here take into consideration the current ambient air quality standards; exhaust emission standards, vehicular emission inventory, vehicular population composition, infrastructure availability and the techno-economic feasibility in Pune Region.

The discussion has been presented in following order:

- Improvement in vehicle related components/technologies
- Improvement in fuel quality and alternate fuels
- After-exhaust treatment techniques and retrofitment
- Transport planning and traffic management
- Inspection & Maintenance programme
- Other options including phasing out old vehicles, revision of emission standards, anti-smoke campaign, upgraded PUC

As there are considerable differences in emission control options required for diesel and petrol driven vehicles, for new and in-use vehicles; it will be appropriate to address them separately. This approach will also help in planning and implementing the specific control options and also assessing their contributions towards emission reduction.

Factors Effecting Vehicle Emissions

1. Vehicle/Fuel Characteristics

- Engine type and technology-two stroke, four stroke; diesel, otto, wankel, other engines; fuel injection, turbo charging, and other engine design features; type of transmission system
- Exhaust, crankcase, and evaporative emission control systems in place-catalytic converters, exhaust gas recirculation, air injection, stage II and other vapor recovery systems
- Engine mechanical condition and adequacy of maintenance
- Air conditioning, trailer towing, and other vehicle appurtenances
- Fuel properties and quality-contamination, deposits, sulfur, distillation characteristics, composition (e.g., aromatics, olefin content) additives, oxygen content, gasoline octane, diesel cetane
- Alternative fuels such as CNG, LPG, Bio Diesel
- Deterioration characteristics of emission control equipment
- Deployment and effectiveness of inspection/maintenance (I/M) and anti-tampering (ATP) program

2. Fleet Characteristics

- Vehicle mix (number and type of vehicles in use)
- Vehicle utilization (kilometres per vehicle per year) by vehicle type
- Age profile of the vehicle fleet
- Traffic mix and choice of mode for passenger/goods movements
- Emission standards in effect and incentives/disincentives for purchase of cleaner vehicles
- Adequacy and coverage of fleet inspection maintenance programs

3. Operating Characteristics

- Vehicle use patterns-number and length of trips, number of cold starts, speed, loading, aggressiveness of driving behaviour
- Degree of traffic congestion, capacity and quality of road infrastructure, and traffic control systems
- Transport demand management programs

Source: Faiz and others 1995; Faiz and Aloisi de Larderal 1993

As per recent emission standards for BS IV and BS VI norms across all category of vehicles, and its implementation will yield the maximum reduction of PM and NO_x emission **(Table 7.6)**. The stipulated CO emission for diesel vehicles is 0.50 g/km and for petrol it is 1.0 g/km, whereas NO_x is regulated at 0.08 g/km for diesel and 0.06 g/km for petrol, while particulate matter (PM) is set at 0.005 g/km for both. We should see a substantial drop in air pollutants, especially for diesel car vehicles, as current BS IV figures are 0.25 g/km for NO_x and 0.025 g/km for PM. Similarly HDDV reduction will possible from 3.5 g/km to 0.4 g/km in BS VI for NOx and 0.02 to 0.01 g/km for PM.

Table 7.6 : Emission Factors for BS IV and BS VI

BS IV fuel	PM	NO_x	CO	HC
Car Petrol Car	0.002	0.08	1	0.1
Car Diesel Car	0.025	0.25	0.5	0.3
CNG Car/Taxi (LMV)	0.006	0.08	1	0.1
Two wheeler	0.013	0.79	1.403	0.39
Three wheeler	0.0425	0.38	0.38	2.06
Heavy Duty Diesel Vehicles	0.02	3.5	1.5	0.46

BS VI fuel	PM	NO_x	CO	HC
Car Petrol Car	0.005	0.06	1	0.1
Car Diesel Car	0.005	0.08	0.5	0.17
CNG Car/Taxi (LMV)	0.005	0.06	1	0.1
Two wheeler	0.0045	0.06	1	0.1
Three wheeler	0.025	0.1	0.22	0.1
CNG Buses	0.01	0.46	4	0.16
Heavy Duty Diesel Vehicles	0.01	0.4	1.5	0.13

* Values in g/km Source: *https://www.transportpolicy.net/region/asia/india/*

TransportPolicy.net is collaboration between the International Council on Clean Transportation and DieselNet. On 19 Feb 2016, the Ministry of Road Transport and Highways (MoRTH) issued a draft notification of Bharat Stage (BS) VI emission standards. The standards, as proposed, will take effect throughout the country for all light-duty and heavy-duty vehicles as well as two and three wheelers manufactured on or after 1 Apr 2020. The draft proposal specifies mass emission standards, type approval requirements, and on-board diagnostic (OBD) system and durability levels for each vehicle category.

Additional provisions in the draft proposal include:

- Adoption of more stringent WHSC and WHTC test cycles
- Off-cycle emissions testing requirements and in-service conformity testing for type approval
- Specifications for Portable Emissions Measurement System (PEMS) demonstration testing at type approval. The proposed BS VI regulation establishes an important precedent for leap frogging from Euro IV-equivalent directly to Euro VI-equivalent motor vehicle emissions standards.

The World Harmonized Transient Cycle (WHTC) test is a transient engine dynamometer schedule defined by the proposed global technical regulation (GTR) developed by the UN ECE GRPE group. The GTR is covering a world-wide harmonized heavy-duty certification (WHDC) procedure for engine exhaust emissions. The proposed regulation is based on the world-wide pattern of real heavy commercial vehicle use.

a. test is performed on an engine dynamometer operated through a sequence of 13 speed and load conditions
b. a hot start steady state test cycle
c. transient test cycle with both cold and hot start requirements

Prior to 2010, emissions were tested using the ECE R49[a] test cycle. After 2010, for Bharat III and IV, the ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles were used. BS VI will require the application of WHSC[b] (World Harmonized Stationary Cycle) and WHTC[c] (World Harmonized Transient Cycle) test cycles.

The option selection was based on much iteration with a view to achieve significant change in load and consequent reduced emission contribution. For calculation of BaU scenario for vehicle projections the average decadal registered vehicle growth was considered as 5.5% in 2020 and 6.2% in 2025. The estimation of emission loads for new emission standards i.e. BS- IV and BS- VI was also calculated for comparison with BaU scenario. **Table 7.7** presents options which are likely to achieve desired results based on earlier discuss action plan **(Table 6.3)** for line source as also those which are relevant to Pune city.

Table 7.7 : Vehicular Source Control Options

Scenario	PM		NOx	
BAU 2018	**6849.2**		**49069.8**	
BAU 2020 (5.5% growth)	7219.1		51719.5	
BAU 2025 (6.2% growth)	7277.3		52136.6	
Complete implementation of BS – IV norms by 2020	**770.7**		**40143.6**	
Complete Implementation of BS – VI norms by 2025	**394.1**		**4878.1**	
	PM	**NOx**	**PM**	**NOx**
Conversion vehicles to CNG/LPG ▪ 2020- Privately operated Vehicles viz. OLA, Uber and other contract buses, public transport should be converted -50% ▪ 2025-Privately operated Vehicles viz. OLA, Uber and other contract buses, public transport should be converted -75%	4800.7 **(29.9%)**	33437.0 **(31.9%)**	3620.3 **(47.1%)**	24456.6 **(50.2%)**
Banning of 15 year Old Commercial Vehicle ▪ 2020-70% banning ▪ 2025-100% banning Encouragement by provision of incentives in form of scrap value.	4148.3 **(39.4%)**	28962.9 **(41.0%)**	2846.6 **(58.4%)**	19320.2 **(60.6%)**
Synchronization of traffic signals ▪ 2020-Major & minor roads, excluding feeder roads (or about 65% of the all arterial roads) ▪ 2025-Major & minor roads, excluding feeder roads (or about 80% of the all arterial roads)	3607.2 **(47.3%)**	25236.7 **(48.6%)**	2543.8 **(62.9%)**	17368.5 **(64.6%)**
Share of Electric vehicles in Total City Fleet ▪ 2020-Two wheeler: 10%; 3 wheeler and Taxi: 10% and Public transport buses -10% ▪ 2025-Two wheeler: 10%; 3 wheeler and Taxi: 10% and Public transport buses -20%	4694.3 **(31.4%)**	33146.9 **(32.4%)**	3821.4 **(44.2%)**	26583.1 **(45.8%)**
Encourage Public Transport ▪ 2020-Increase Public Transport -50%	4894.4 **(28.5%)**	34114.9 **(30.5%)**	3732.6 **(45.5%)**	25526.2 **(48.0%)**

▪ 2025-Increase Public Transport -75%				

* Emission load in kg/day

Table 7.7 (Contd..) : Vehicular Source Control Options

Scenario	PM		NOx	
BAU 2018	**6849.2**		**49069.8**	
BAU 2020 (5.5% growth)	7219.1		51719.5	
BAU 2025 (6.2% growth)	7277.3		52136.6	
Complete implementation of BS – IV norms by 2020	**770.7**		**40143.6**	
Complete Implementation of BS – VI norms by 2025	**394.1**		**4878.1**	
<u>Retrofitment of Diesel Oxidation Catalyst (DOC) 4wheeler public transport (BSII)</u> ▪ 2020-50% conversion ▪ 2025-100% conversion	3026.8 **(55.8%)**	20258.0 **(58.7%)**	3002.6 **(56.2%)**	20095.9 **(59.0%)**
<u>Retrofitment of Diesel particulate filter in 4 Wheelers Public Transport (BS II)</u> ▪ 2020 -50% conversion ▪ 2025-100% conversion	4809.7 **(29.8%)**	33649.2 **(31.4%)**	3634.0 **(46.9%)**	24812.4 **(49.4%)**
<u>Reduce Dust Resuspension</u> (Unpaved Dust as on 2018- 22601.9 kg/day) ▪ 2020-Paving of all road 45% wrt BaU 2018 ▪ 2025-Paving of all road 90% wrt BaU 2020	10193.46 **(45.10%)**		5643.3 **(90.0%)**	
Banning Odd/Even Vehicles on Particular Day	3558.59 **(48.0%)**	25129.84 **(48.8%)**	3378.53 **(50.7%)**	24566.76 **(49.9%)**

* Emission load in kg/day

- If we start to implement the BS IV by 2020 and BS VI by 2025 then reduction with projected vehicles growth is around 90 to 95% for PM and for NOx it is around 22% in 2020 and 90% reduction in 2025. It can be observed that the BS IV and VI norms can reduces the PM and NOx emission load considerably.
- About 55-56 % of PM reduction and 58-59 % of NOx reduction can be achieved on short and long term basis with the retro fitment of Diesel Oxidation Catalyst (DOC) of 4 wheelers on BS II operating public transport.
- Followed by retrofitment, synchronization of traffic with strategic and technology based management can achieve the reduction of 40-60% of PM and NOx loads.
- The conversion of CNG/LPG, share of electric vehicles, use of public transport, retrofitment of particulate filter and banning of old vehicles will give reduction of 30-40% in 2020 (short term) and 45-55% in 2025 (long term). Banning of Odd/Even vehicles reduce the emission load almost half of the current.
- The PM emissions load from the resuspension of road dust is maximum than all other categories of line sources, which can be effectively controlled by the pavement and widening of unpaved roads. Reduction can be possible upto 50% in 2020 and 90% in 2025.

Chapter 8

Prioritization of Management/Control Options

Management options for each sectors need to be prioritized with a view to understand the issue of implementation. Implementations are highly influenced not only by the idea of the improvement alone but also by the nature of the recommendations, fiscal and administrative barriers, effectiveness, implementing agencies and acceptance from large group of stakeholders. Prioritization issues are also driven by the comparative account of short term and long term implementation dilemma. Low cost with high effectiveness, low cost with shorter implementation period shall be a better option when compared with high effectiveness with high costs or long implementation period. Some of these considerations have been used here to prioritize the options in each case of vehicular, industrial and area sources.

8.1 City wise Dispersion Modeling for Selected Options for Future Scenario

A very comprehensive set of options have been examined for the purpose of understanding the issue of urban air pollution reduction and are given in **Table 8.1.** The dispersion run was carried out for many scenarios and based on options, where the effectiveness of PM and NOx reductions were significant, those were selected and included for the model run. For the successful implementation of the control measures, it is very important to categories them according to need of mitigation required. In order to achieve maximum reduction in emission loads, it is essential to prioritize selected control option, taking into account their respective sources and demography of the region. Out of the all devised control measures, few were selected according to the sources, their fuel consumption and feasibility. The implementation of these control measures were considered to be applied in stages, cumulatively across all the identified sources of the region. 2020 is considered short term measures, where for industrial and area sources the listed control measures were implemented and that for vehicles, 1 to 6 were selected **(Priority I)**. The selected control measures for point and area sources for short term 2020 are further aggressively implemented during the long term stage 2025 **(Priority II)**, so as to cover the aspects which weren't possible in short term stage. Considering their tremendous number growth, for vehicles sources, option 1 to 11 were applied with point and line source measures. The control options were compared with the Business as Usual Scenario considering the growth of vehicles and activities within the area sources, no changes will be assumed for industrial growth in Pune city. The annual predicted concentrations for different sources in BaU and control option scenario are presented in **Table 8.2** and **Table 8.3** for PM and NOx.

Table 8.1 : Summary of Options used for City Based Model Run

Category		**Control Options**	**Scenario 2020**	**Scenario 2025**
Vehicle Sources	1	New Vehicle Standards	Complete implementation of BS - IV	Complete Implementation of BS - VI
	2	CNG/ LPG	Privately operated Vehicles viz. OLA, Uber, contract buses, public transport converted -50%	Privately operated Vehicles viz. OLA, Uber, contract buses, public transport converted-75%
	3	Electric vehicles	Two wheeler: 10%; 3 wheeler and Taxi: 10% and Public transport buses -10%	Two wheeler: 10%; 3 wheeler and Taxi: 10% and Public transport buses -20%
	4	Synchronization of traffic	Major & minor roads, excluding feeder roads (or about 65% of the all arterial roads)	Major & minor roads, excluding feeder roads (or about 80% of the all arterial roads)
	5	Public Transport	Increase Public Transport-50%	Increase Public Transport -75%
	6	Ban or scrapping -15 year old Veh.	70% banning	100% banning
	7	Ban of odd / even vehicles	50% reduction private vehicles	50% reduction private vehicles
	8	Retrofitment of DOC- 4 wheeler Public Transport	50% conversion (BSII)	100% conversion
	9	Retrofitment of DPF-4 wheelers public transport	50% conversion (BSII)	100% conversion
	10	Share of Hybrid vehicles in Total City Fleet	Gasoline powered four-wheelers only -20%	Gasoline powered four-wheelers only- 30%
	11	Inspection and Maintenance	New I&M regulations (50% population)	Full compliance -100%
Industrial Sources		Shifting of Fuel	Red, Orange & Green Industries (LSI, MSI & SSI) 50% fuel FO, LSHS, HSD to LDO; Coal & Others to NG	100% [Low Fuel i.e LDO to Nearly all to NG]
Area Sources		Domestic	25% of slums to use LPG/ PNG 50% of non slum to use LPG/PNG	50% of slum to use LPG 100% same
		Hotel & Rest.	50% of coal use to LPG	75% of coal use to LPG
		Open Eat outs	Since these operation is illegal, difficult to quantify	
		Bakeries	25% LPG, 25% Electric	50% LPG, 25% Electric
		Crematoria	50% Electric	75% Electric
		Open Burning	50% control on open burning	100% control on open burning
		Landfill Burning	100% control of Landfill burning	100% control of Landfill burning
		Bldg. Constr.	50% control on dust emission	50% control on dust emission
		Unpaved Rd.Dust	Paving of all road 75%	Paving of all road 100%

Though some of the options were selected on the basis of PM reduction potential, their possible co-benefits in reducing NOx and other pollutants were also considered during the process of prioritizing. The options considered are based on the discussion presented earlier in action plan, describing the city specific situation and its possible impacts on air quality. Model runs for the whole city included the major control options from all the three sources (Area, Line and Point). The model run's iso-contours maps for PM and NOx in BaU 2020, BaU 2022 and after implementation of Preferred Option I (i.e. options 1 to 6 for vehicles, and all options for industries and area) scenario's in 2020 and Preferred Option II (i.e. options 1 to 11 for vehicles and all options for industries and area) 2025 are given in **Figures 8.1 through 8.8.**

Table 8.2 : Comparison of PM_{10} Concentrations BaU With Preferred Option I (2020) & Preferred Option II (2025)

Sources Group	BaU 2018	BaU 2020	BaU 2025	Preferred Option I -2020	Preferred Option II -2025
All Group	146.69	164.29	177.62	82.64	55.24
Area Source	12.87	14.43	15.44	7.26	4.80
Line Source	22.12	22.50	23.6	9.81	6.56
Point Source (LSI)	1.68	1.73	1.73	0.87	0.54
Point Source (MSI)	0.64	0.66	0.66	0.33	0.20
Point Source (SSI)	0.62	0.69	0.69	0.35	0.22
Resuspension Dust	131.40	144.46	156.32	72.67	48.62

- Concentrations in $\mu g/m^3$

Table 8.3 : Comparison of NOx Concentrations BaU With Preferred Option I (2020) & Preferred Option II (2025)

Sources Group	BaU 2018	BaU 2020	BaU 2025	Preferred Option I -2020	Preferred Option I -2025
All Group	164.55	178.53	193.08	93.73	60.05
Area Source	3.48	3.67	3.92	1.93	1.22
Line Source	162.87	176.81	191.33	92.83	59.50
Point Source (LSI)	0.77	0.77	0.77	0.41	0.24
Point Source (MSI)	1.50	1.50	1.50	0.79	0.47
Point Source (SSI)	0.51	0.51	0.51	0.27	0.16

- Concentrations in $\mu g/m^3$

The annual predicted 24 hourly average concentrations were compared with the BaU scenarios considering the future growth and after implementation of preferred option for 2020 and 2025 for both PM and NOx is presented in **Figure 8.9 and 8.10** respectively.

A) Predicted Scenario for PM

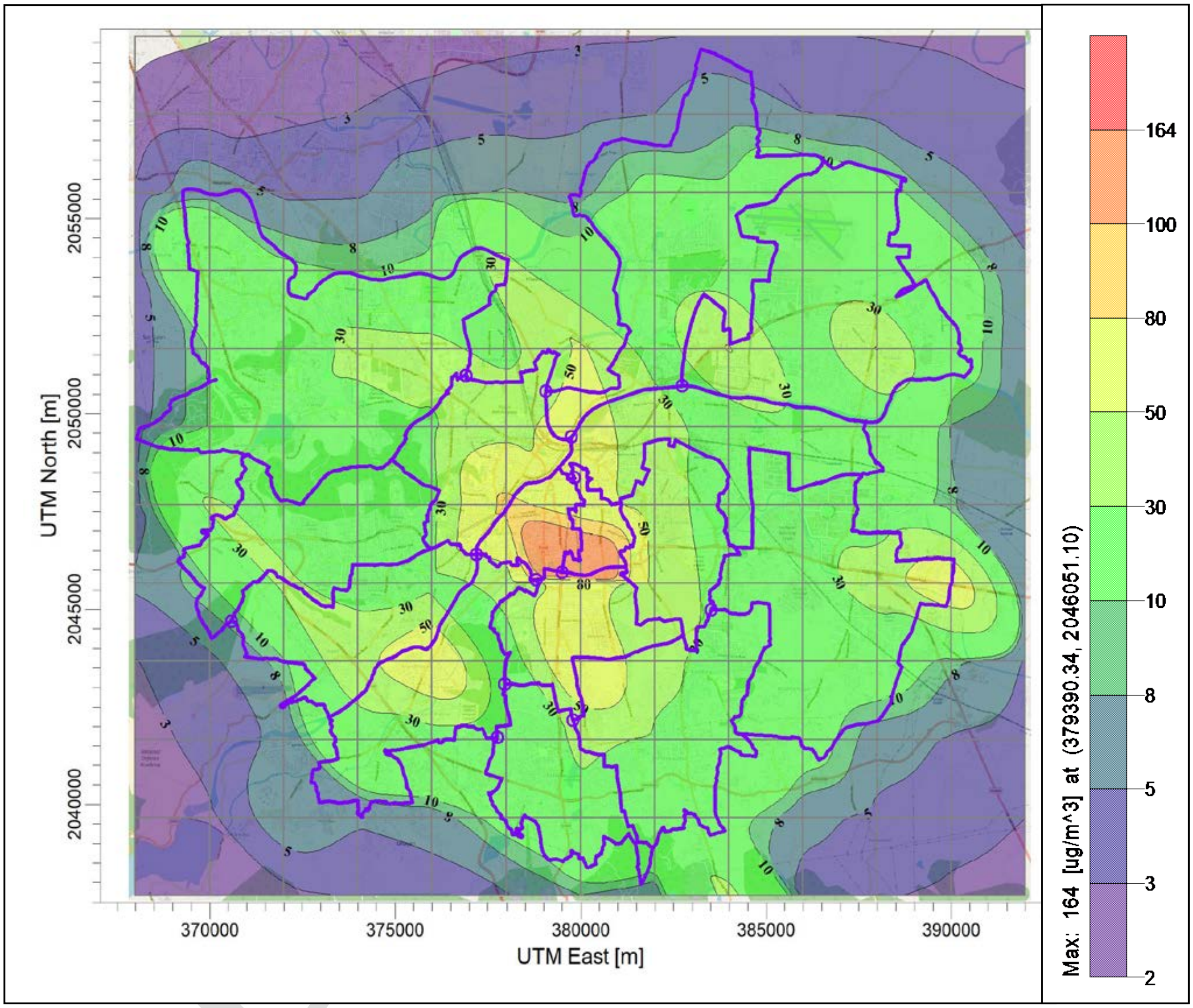

Figure 8.1 : Isopleths of PM Due to All Source– BaU 2020 (Pune City)

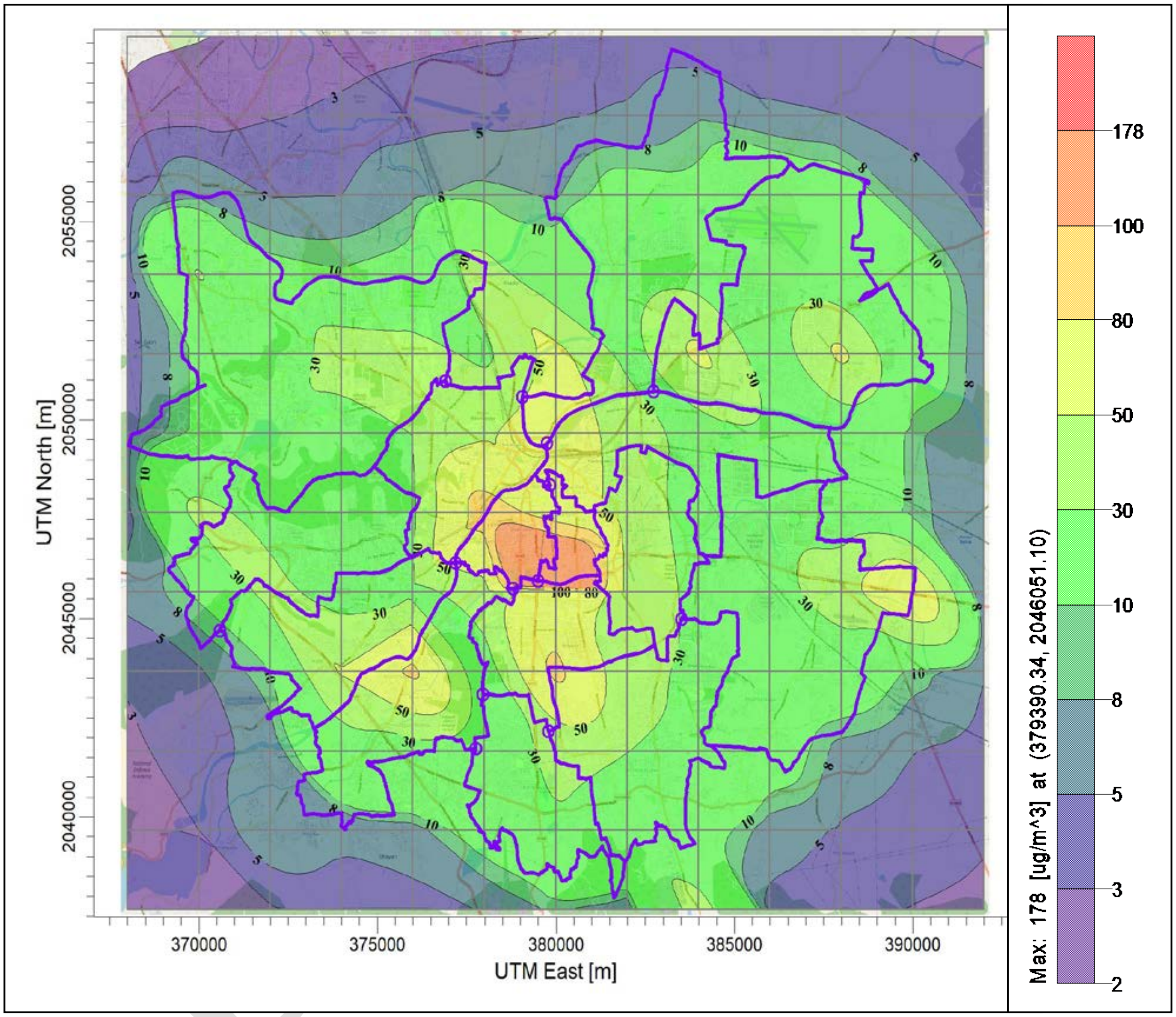

Figure 8.2 : Isopleths of PM Due to All Source– BaU 2025 (Pune City)

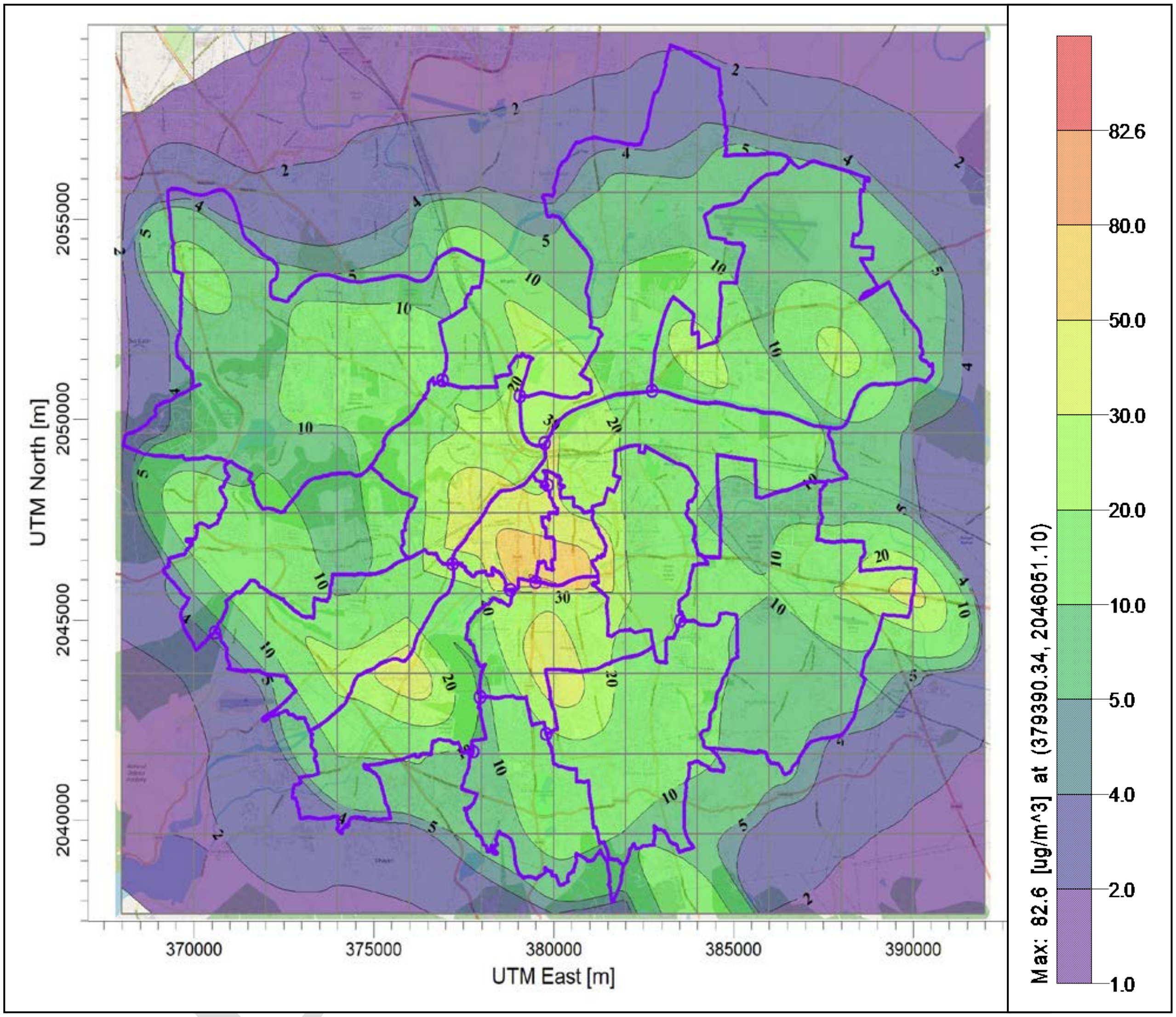

Figure 8.3 : Isopleths of PM Due to All Source– Preferred Options I - 2020 (Pune City)

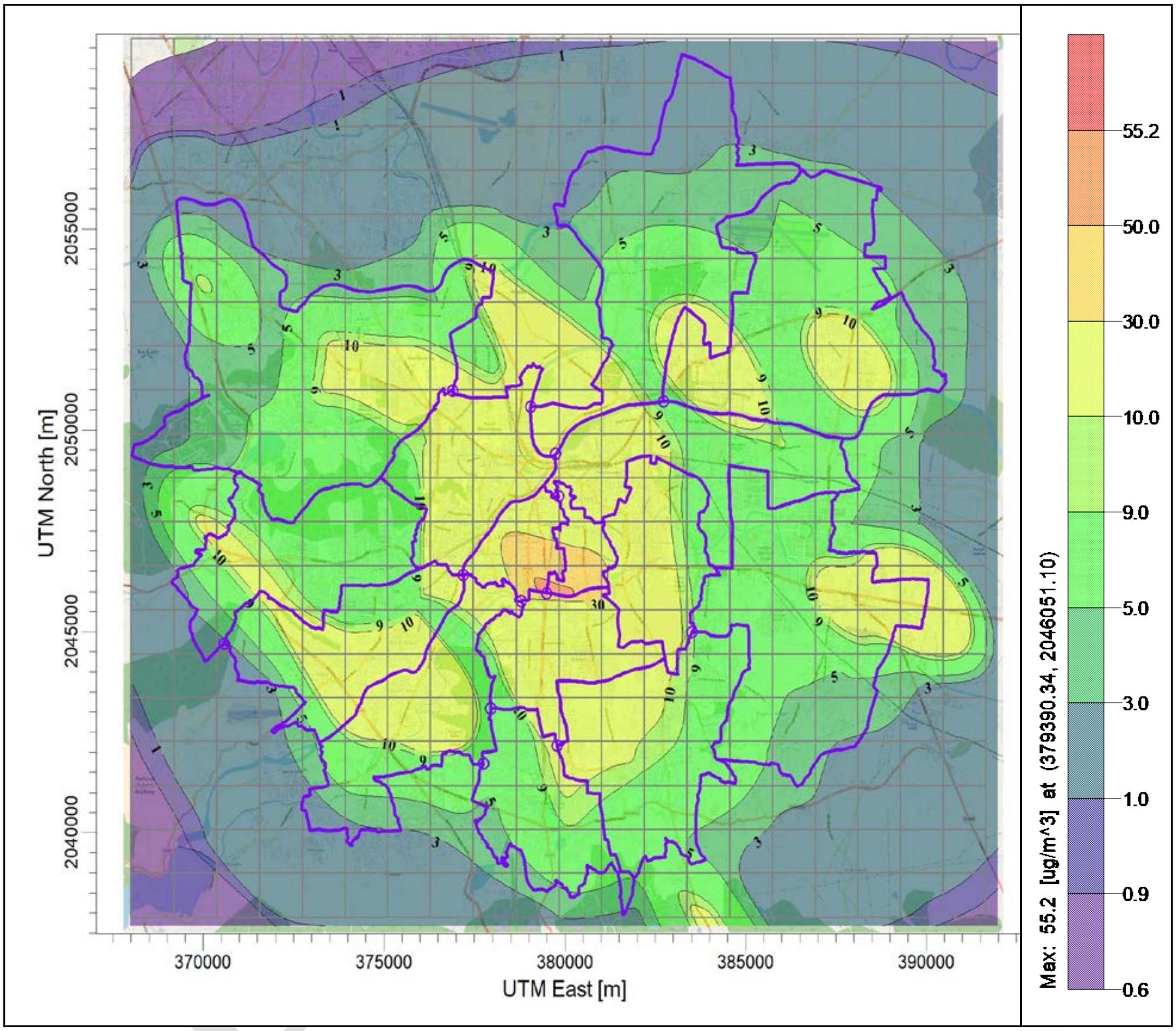

Figure 8.4 : Isopleths of PM Due to All Source– Preferred Options II - 2025 (Pune City)

A) Predicted Scenario for NOx

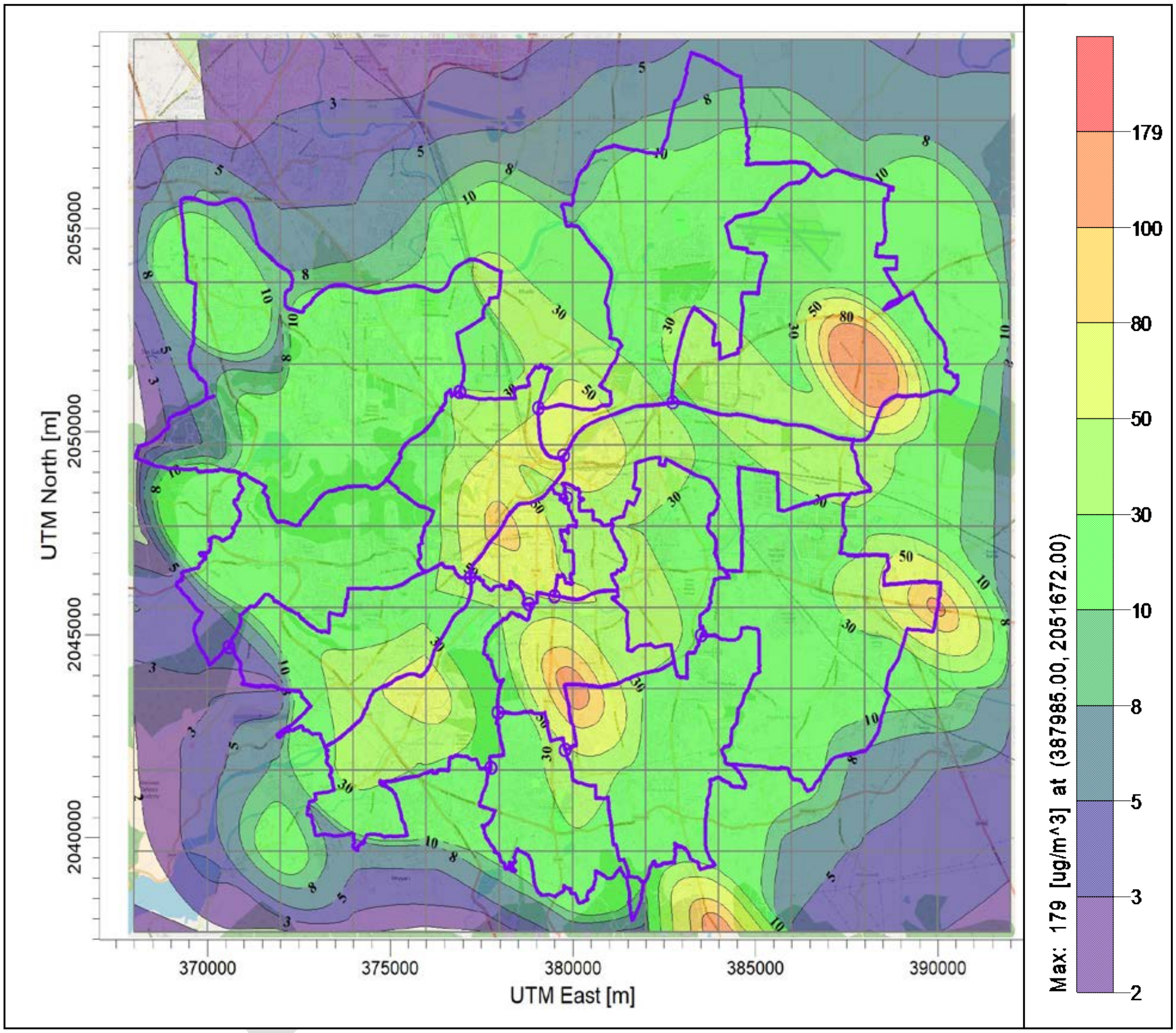

Figure 8.5 : Isopleths of NOx Due to All Source– BaU 2020 (Pune City)

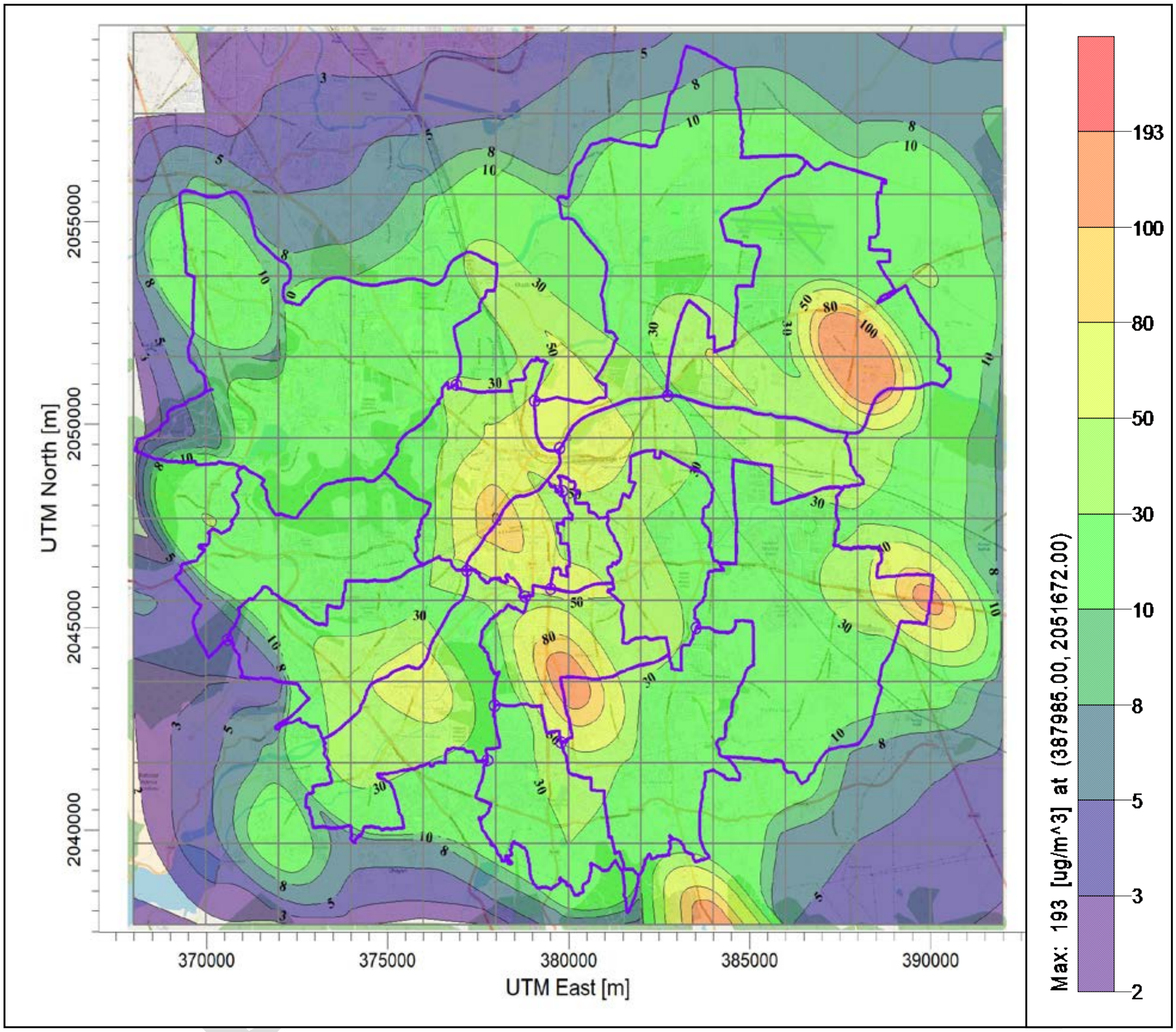

Figure 8.6 : Isopleths of NOx Due to All Source– BaU 2025 (Pune City)

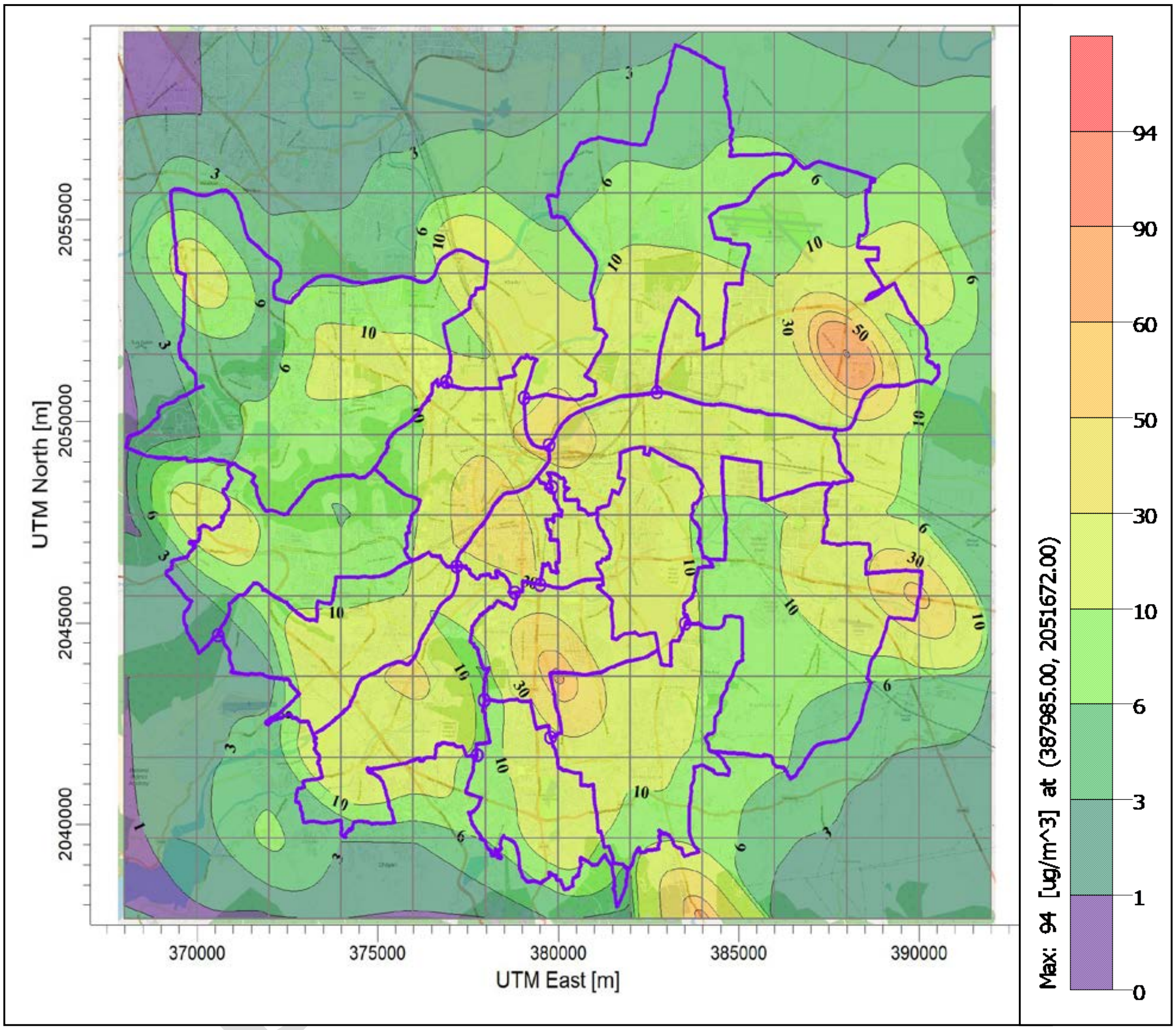

Figure 8.7 : Isopleths of NOx Due to All Source– Preferred Options I - 2020 (Pune City)

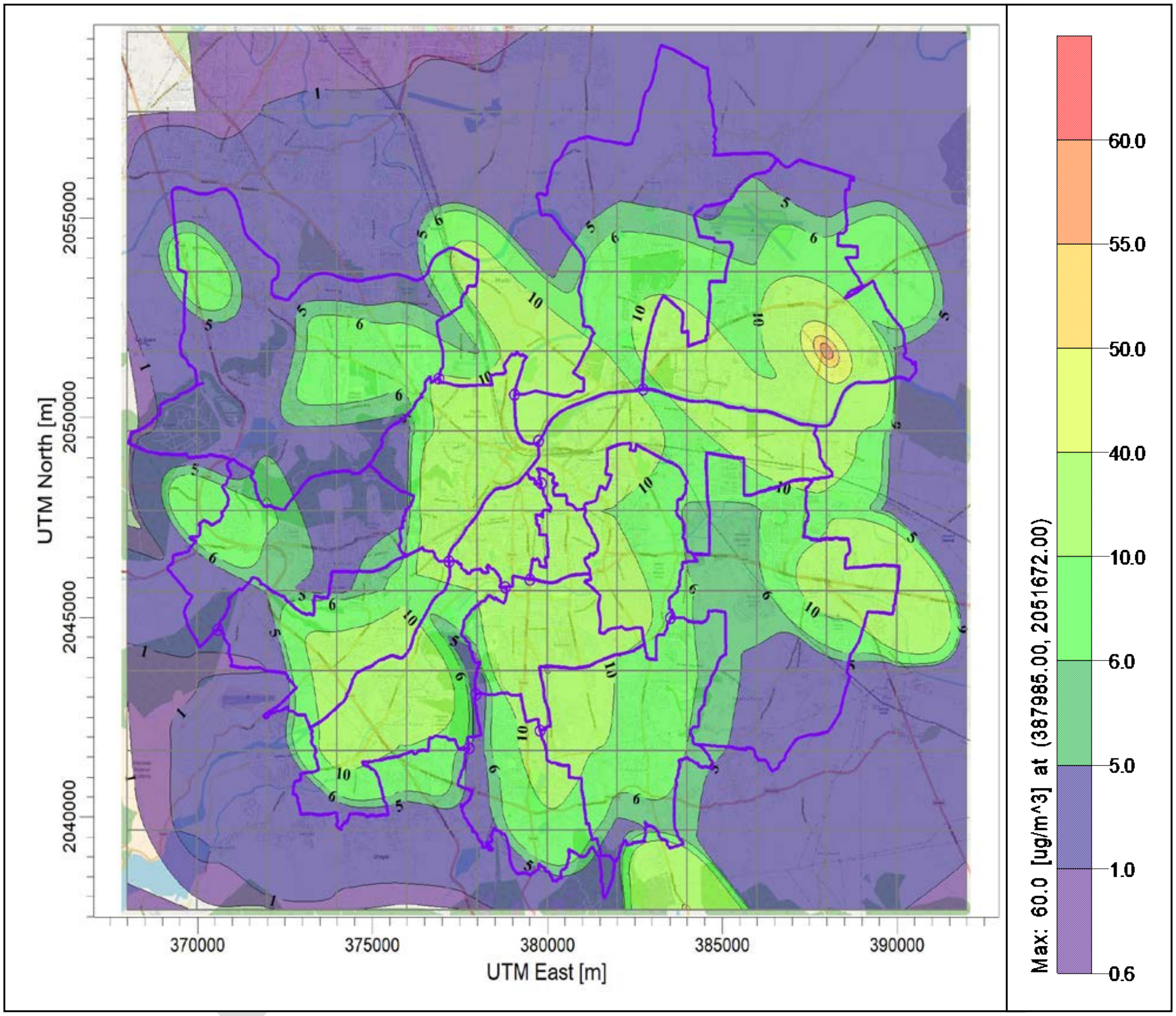

Figure 8.8 : Isopleths of NOx Due to All Source– Preferred Options II - 2025 (Pune City)

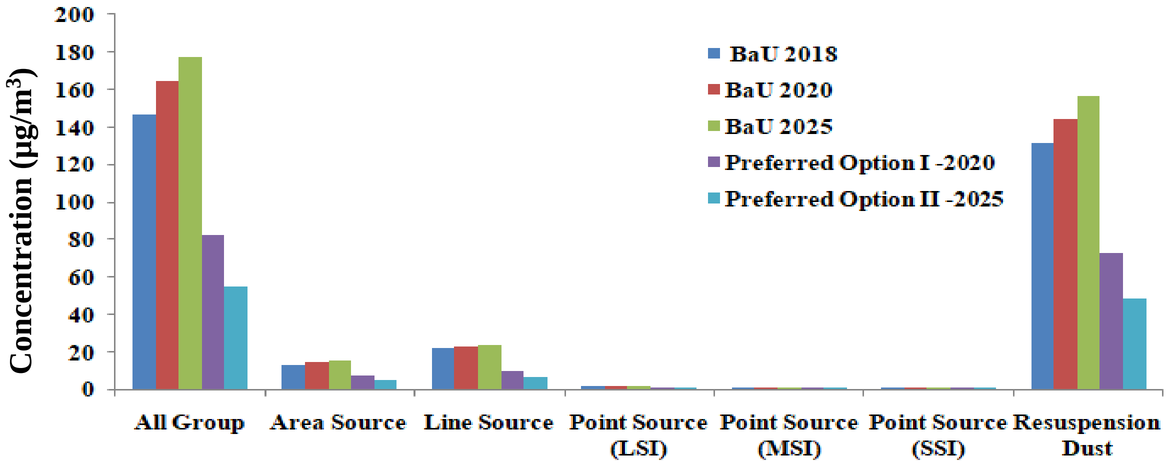

Figure 8.9 : PM Scenario Compared with BaU of 2018 for Preferred Option I (2020) and Preferred Option II (2025)

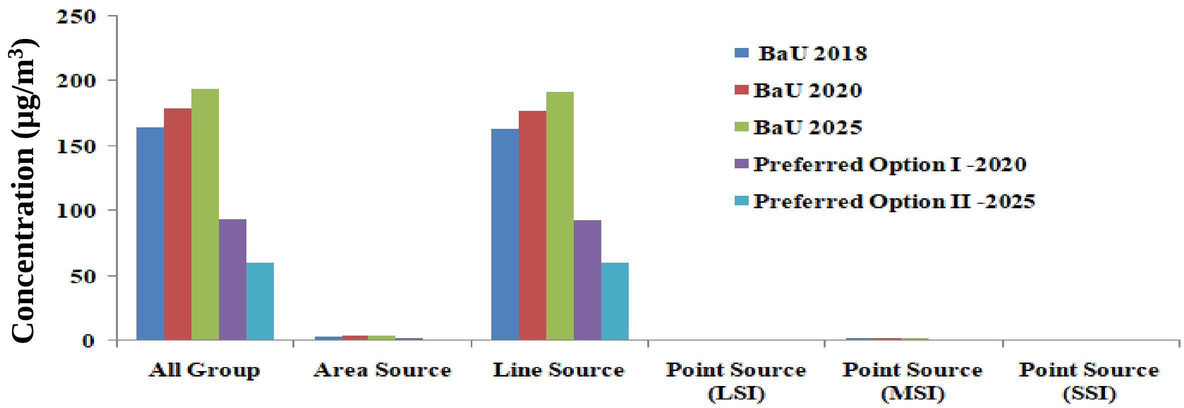

Figure 8.10 : NOx Scenario Compared with BaU of 2018 for Preferred Option I (2020) and Preferred Option II (2025)

If we compared with the all source group for BaU 2018, the concentrations of PM range around 146.6 µg/m^3 and that will increase upto 164.2 µg/m^3 in 2020 and 177.6 µg/m^3 in 2025, if the growth factor is liner. However, the Preferred Option I is applied (control measures for area, industrial source and vehicles 1 to 6 scenarios) the predicted concentrations will be coming down to 82.6 µg/m^3, whereas for Preferred Option II (all vehicles scenarios 1 to 11; industrial and area sources) it is coming around 55.2 µg/m^3. That means the reduction can be observed upto 43% in short term and 62% in long term as per dispersion modeling, which is also coming line with reduction option calculation without modeling upto 40% in short term and 50% long term as discussed earlier in reduction strategies for control option chapter.

The other source contributions such as area source increases from 12.87 to 15.44 µg/m^3 from 2018 to 2025 as liner growth, after control option implementation, as preferred option I (2020) and II (2025) it will decreases upto 7.26 µg/m^3 to 4.80 µg/m^3 in 2020 and 2025 respectively. As compared to preferred options, line source also decreases from 22.50 µg/m^3 to 9.81 µg/m^3 in 2020 and 6.56 μg/m^3 in 2025, and if we not considered any preferred option the BaU 2025 concentration may reaches upto 23.6 μg/m^3 for line source. The both dispersion modeling and reduction control option for line source gives the reduction upto 55% to 70% in short and long term respectively. The pockets of high concentration are observed close to major traffic junctions in city. The major impacted areas are Ghole Road, Tilak Road, Yerwada, Bibwewadi, and outer boundary areas are viz. Aundh, Warje Karve and Hadpsar. Among the total emission load of PM (i.e. 50022.6 kg/d), area sources contributes around 21% and the overall line source contributes 13.7% (6849.2 kg/d). In vehicular sector percent contribution from heavy duty is more 5714.9 kg/d gives 11.4% and 3 wheelers 791.9 kg/d shares 1.6%. At discrete cartesian location at highest concentrations is also reported at central part of the city i.e. Ghole Road, Swargat areas.

The industrial source will not give any impact as there is no growth scenario in the city of Pune, the percentage contribution is very less i.e. 5.2% of the total load, among industries LSI gives 1.68 μg/m^3 in BaU 2018 and considering linear growth it will increase upto 1.73 μg/m^3 in BaU 2020 & 2025. If implement the shifting fuel quality from fossil fuel to NG in preferred options the reduction observed as 0.87 μg/m^3 in 2020 and 0.54 μg/m^3 in 2025. The dispersion modeling for preferred options gives reduction upto 48% in 2020 and 67% in 2025, whereas without dispersion modeling reduction option calculations gives 54% in short term and 94% in long term for industrial source.

As we are observed from emission inventory 60.1% contribution is from resuspension of dust i.e. (paved 7479.2 kg/d -15% and Unpaved 22601.9 kg/d– 45.1%), which is also reflected in dispersion modeling for BaU 2018 and gives concentration of 131.4 μg/m^3 out of 146.69 μg/m^3 from all source group. If we considered the preferred options I and II (i.e. pavement and widening of unpaved roads, vehicular resupension, controlling road constructions and building activities) it will bring down the concentrations upto 72.67 μg/m^3 in short term and 48.62 μg/m^3 in long term, which will reduce the concentrations upto 44% to 66% as per dispersion modeling, similar percent is noticed without the dispersion modeling calculations in 2020.

In current scenario, the concentrations of emission is exceeding the CPCB standard i.e. 100 μg/m^3 for PM, is mainly due to resuspension of dust. We compare the standard with individual sources (area, point and line) then preferred option will definitely reduce the emission below the CPCB standard, as also the respension of dust will be reduce. Anthropogenic activities like construction, vehicular resupension will be managed, but natural dust remains and concentrations will be noticed above the standard.

In case of NOx the predicted ground level concentrations for all source group for BaU 2018, the concentrations of NOx range around 164.55 µg/m^3 and that will increase upto 178.53 µg/m^3 in 2020 and 193.08 µg/m^3 in 2025, if the growth factor is liner. After running the Preferred Option I and II the predicted concentrations goes down upto 93.73 µg/m^3 and 60.05 µg/m^3 in short and long term respectively. The reduction is coming upto 43 -63% in both the cases.

The other source contributions for NOx will also decrease viz. area source i.e. 3.48 µg/m^3 (2018) to 3.67 to 3.92 µg/m^3 in 2020 and 2025. Vehicular source is the major contributor, out of 164.55 µg/m^3 from all sources, the line source share approx 95% i.e. 162.87 µg/m^3. Predicted line source also decreases upto 92.83 µg/m^3 in 2020 and 59.50 µg/m^3 in 2025; and if we not considered any preferred option the concentration may reaches upto 176.81 to 191.33 µg/m^3 for line source in BaU 2020 and BaU 2025 respectively. The both dispersion modeling and reduction control option for line source gives the reduction upto 40% to 60% in short and long term respectively. If rigorous BS-VI scenario will be implemented then NOx reduction can be achieved upto 91%. The hotspot for major traffic junctions will not change the concentrations range which is in between 36 to 165 µg/m^3.

The industry share is very negligible overall NOx is coming around 4.3% (i.e. 2292.0 kg/d) of the total NOx (53159.7 kg/d), As per BaU concentration comes around 0.77 to 1.50 µg/m^3, which is further reduces upto 0.16 to 0.41 µg/m^3, if we implement conversion of fuels to NG. The dispersion modeling for preferred options gives the reduction upto 40-45% in short term and long term, whereas without dispersion modeling reduction will not observed for the both the years in industrial source. The all group annual impact of NOx concentrations shows that, it is exceeding the CPCB 24 hourly standard of 80 µg/m^3 among all the sources vehicular source is highest.

8.2 Prioritizing Technical Measures

Based on the framework of each sector delineated in possible action plan has been discussed in respect to their effectiveness, barriers to implementation and administrative issues. These options have also been considered for their co-benefits with regard to other pollutants adding values to the action planned. Pune city specific measures at national as well as local levels have also been finalized after interactions in various meetings. Implementing agencies roles and responsibilities finally take the process further. These agencies are likely to have direct and indirect role in implementation. **Table 8.4** presents the considerations in prioritizing various measures for vehicular, industrial and area sources, respectively.

Table 8.4 : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers (Co-Benefit)	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit Fuel Used						
S reduction in diesel	Technically feasible and being implemented	Moderate. Reported elsewhere 2000 to 300 ppm reduction in S leads to 2.5- 13% reduction in PM #	High cost. Being planned by Refineries as per the Auto Fuel Policy. The cost is in the range of 15000/35000 crores based on the levels of S	Improvement in emission standards as well as legislation for stringent fuel standards for S, Phasing out the subsidies on diesel. Bringing diesel cost at par in a state/centre	The S reduction will not only reduce the PM but also lead to correspondingly lower SO_2 emission leading to lower ambient SO_2 and sulphate. It will also allow better functioning of exhaust after treatment devices.	Oil companies, Ministry of Petroleum, vehicle manufacturer
Reduce fuel adulteration	Better quality fuel by adopting stricter fuel supply and dispensing system (e.g. Pure for Sure etc.) Chemical marker system	Reduced adulteration will lead to reduced PM (difficult to quantify). Effectiveness is moderate as marker system has not been seen as a primary means to reduce PM	Present system of Anti Adulteration cell function needs major improvement in terms of higher manpower and spread. Presently one office at Mumbai looks after three states of western region. Success of marker system shall be highly dependent upon the joint working relation of Oil companies and AAC.	The current fuel specifications are too broad and therefore checking of conventional parameters such as density etc. does not reflect the adulteration. Finer fuel specifications are needed for implementation. Oil companies themselves can be proactive in proposing these values, which can be checked easily in any laboratory. They also need to be more accountable.	One of biggest advantage of non-adulteration shall be longer engine life besides the emission reduction for PM as well as CO and HC. The catalytic converter shall be active for its entire lifetime.	Anti-Adulteration Cell, Oil Companies, Vehicle owners

 # Source (Air Quality Monitoring, Emission Inventory and Source Apportionment Studies for Indian Cities, February, 2011, CPCB, and Air pollution from motor vehicles, Faiz Asif, Weaver C.S. and Walsh M.P., The World Bank, Washington, D.C., 1996)

Table 8.4 (Contd..) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	**Technical Issue**	**Effectiveness for Pollution reduction**	**Barriers to implementation**	**Administrative /regulatory**	**Qualifiers (Co-Benefit)**	**Local/ National Stakeholders**
Strategy : Vehicles: Emission Reduction per unit Fuel Used						
Alternative fuels	Technical infrastructure in Pune for dispensing CNG/LPG is not effective its need to be improve	High, more than 90% reduction in PM can be achieved compared to diesel #	Can be applicable mainly for vehicles, which are supposed to ply within the city. Applicable to only local public transport, Buses /taxies, auto etc.	Incentive by the government authorities to private vehicle owners to shift to CNG/LPG.	Will lead to substantial reduction in CO and HC emission, however, NOx values may go up	Mahanagar Gas, Oil Companies marketing LPG, Local Government
Phase out of grossly polluting vehicles	No major technical problem	High, Estimate suggest 25% of these vehicle may contribute 75% of total emission $	Poor Inspection system both for emission as well as vehicle. New legislation may require changes in Motor Vehicles Act	New legislation needed for improved Inspection certification system, better testing facility.	Better compliance will lead to reduction of other pollutants as well. It will also lead to less pressure on complying vehicles	Transport Commissioner Office, Ministry of Road Transport and Highway

Source (Air pollution from motor vehicles, Faiz Asif, Weaver C.S. and Walsh M.P., The World Bank, Washington, D.C., 1996)
$ Source (Impact of Better Traffic Management, South Asia Urban Air Quality Management, Briefing Note No. 5, ESMAP, The World Bank, 2002)

Table 8.4 (Contd...) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	**Technical Issue**	**Effectiveness for Pollution reduction**	**Barriers to implementation**	**Administrative /regulatory**	**Qualifiers (Co-Benefit)**	**Local/ National Stakeholders**
Strategy : Vehicles: Emission Reduction per unit distance travelled						
Congestion reduction	Improvement of roads, new roads, scientifically planned traffic management Connectivity of nodes to major highways, intercity transport	High emission due to fuel burning at idle or slow moving traffic	Road quality improvement is a matter of technology and quality of work carried out. Inter disciplinary approach within nodal agencies for future expansion of city.	Better planning and training in traffic management Road construction norms to be evolved and implemented	It will reduce traffic junction hotspot of all the pollutants It will also reduce continuous source of dust	PMC, Pune Metropolitan Region, MSRDC, State Government Transport police, other agencies.
Standards for new and In-use vehicles	No technical issue with new vehicles. For in-use old vehicles, technical feasibility needs to be established	Implementation of BSIV- BSVI norms- vehicles emission reduction can be substantial	The process of in-use vehicles standards may take time as they need to be revised at central level. Inadequate infrastructure and manpower at local levels could be other major barriers.	After the legislation is in place, provision of strict penalty leading to cancellation of vehicle registration.	As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types	MoRTH, Transport Office Govt. Maharashtra, Automobile Companies & Fuel Suppliers
Introduction of new technology vehicles	New technology based vehicles emit less per unit distance travelled Electric and Hybrid vehicles	High compared to grossly polluting, moderate with respect to in-use vehicles. It can be mostly use for Public transport	Emphasis to allow only a type of technology to be permitted may meet with resistance from manufacturer as well as buyer. (e.g. rule to allow only 4 stroke vehicle to be registered)	This needs to be backed with proper legislation. Else charge higher registration fee or subject them to carry out more frequent I&C test. Electric vehicles for grossly polluting high VKT vehicles are a good option. It needs regulatory push	It will lead to better compliance from on-road emission test and overall improvement in emission of all the pollutants. Electric vehicles provide localized benefits of no air pollution	MNRE, MoRTH, Transport Office Govt. Maharashtra, Automobile Companies

Table 8.4 (Contd...) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers (Co-Benefit)	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit distance travelled						
Retrofitment of new engine/ Emission control device	Experience of other countries suggests that it can be feasible. However, in Indian scenario, a pilot retrofit programme to evaluate the efficacy needs to be undertaken. A pilot project was conducted in Pune with USEPA, USTDA and NEERI	Engine replacement could lead to major reduction of PM. Emission control devices available (DPF, DOC) can remove PM upto 90%	Availability of new engines for retrofit. Vehicle manufacturers need to come forward. For Emission control devices, there are innumerable agencies. Govt initiative for cost sharing for its implementation.	Presently no legislation. Need to frame one including a mechanism by which the system can be evaluated by an appropriate agency.	All the heavy duty in-use vehicles. Truck and heavy tourist vehicles entering into the city boundary will be restricted. High levels of compliance expected.	Truck Association, Transport Office Govt. Maharashtra, vehicle manufacturer, MoRTH, MSRDC
Higher usage of Public Transport	Dedicated bus lane, better buses, low cost of travel, faster travel etc. Inter-linkages of nodes development with surrounding cities.	Effectiveness is high as less and less road space will be occupied by private vehicles, faster movement of public transport in comfort shall lead to low emissions	Feasibility to be established for bus lane. Finances for better buses Measures to reduce the cost of travel by way of cross financing.	Local level planning in coordination with all the authorities involved in Pune Mahanagar Parivahan Mahamandal Limited (PMPML), Urban Planners, and City Development Planers	Future growth of the city will entirely depend upon the levels of public transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency.	Rainbow Bus Rapid Transit System, PMPML and MSRTC Pune Suburban Railway, Pune Metro, Pimpri-Chinchwad Municipal Corporation, MSRDC Transport Office Govt. Maharashtra,

Table 8.4 (Contd...) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Vehicles

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers (Co-Benefit)	Local/ National Stakeholders
Strategy : Vehicles: Emission Reduction per unit distance travelled						
Decrease Private vehicles on Road	Vehicle manufactures and holding of private ownership vehicle is the major issue	Less private vehicles on road, high road space utilization	Awareness matched with better public transport. Need for barriers for buying a car	Higher parking charges, high registration fees, higher car user charges, sale linked with parking availability.	Private vehicles owners should must own their own garages, less parking on the roads, less congestion	Transport Office Govt. Maharashtra, RTO, PMC, Pune Metropolitan Region Development Authority
Strategy : Vehicles: Emission Reduction -Awareness						
Training and Awareness programme for car owners, public transport operators, drivers and mechanics	On use of alternative fuel, Inspection and certification, adulteration of fuels, use of public transport, less usage of private vehicles	May lead to 5-10% reduction of emission.	Resources for awareness and training, bringing the different groups together	Structure for such programme should be developed and integrated into legislation.	Savings by way of improved vehicle maintenance and operation	RTO, Transport Commissioner Off., PMC, Pune Metropolitan Region Development Authority, Other institutions/ NGO involved in awareness campaign

Table 8.4 (Contd..) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Industries

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers] (Co-Benefit)	Local/ National Stakeholders
Strategy : Industries: Emission Reduction per unit Fuel Used						
S reduction in fuel	This process is currently on, however, the fuel S reduction is mainly for Medium and Small Scale industries	Many industries are shifting fuel from fossil fuel to NG, PNG, CNG Bigger industries needs to take care for Coal, HSD, LSHS, and FO	Industrial growth is not progressive in Pune, the Medium and Small Scale LSI, Orange industries need to be pressed upon	MPCB can specify the S levels for the fuel being used	Implementation of barriers viz. bag filters, industrial scrubbers, electro static precipitator, use of low sulphur fuel oil will leads to control PM, SOx and pollutants	MPCB, Industries
Combustion Processes	Change in combustion technology will be needed for shifting from coal/oil to natural gas	Moderate	Finances to change the process technology.	Administrative and regulatory incentive and tax rebate for changing technology.	It will lead to lower emission of CO and HC	MPCB, Industries
Alternate Fuel	Large no of small scale industries are using Bagasse /Wood, FO and HSD	Industry should get cleaner fuel viz. NG, PNG. Shifting of heavy fuel ie. FO, HSD, Diesel to LDO and low sulphur and ash. The higher percentage of use of cleaner fuel will resulted in better air quality in the city	Easy availability and infrastructural improvement	More allocation of NG/LPG to the industrial sector through MGL/GAIL/ Govt. of India	Better air quality in terms of SO_2, CO and HC will be achieved.	Mahanagar Gas, MPCB

Table 8.4 (Contd..) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution - Industries

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers (Co-Benefit)	Local/ National Stakeholders
Strategy : Industries: Emission Reduction by Industrial Policy and Standards						
Promoting Cleaner Industries	Use of cleaner production processes	Large scale shift shall result in major PM reduction	Finances to carry out these changes	State as well as central government can provide incentives to carry out the necessary change	It will lead to sustainable existence of industries within the city. Also lead to other pollutants reduction High level emission shall have lower PM and other gaseous pollutants	MoEF, CPCB, MPCB, MNRE Electrical and auxiliary industries
Fugitive Emission control	Industrial process improvement better operation and maintenance	For localized region, very effective, particularly for industries with fine particles raw material or products. Brick Kilns, DG Sets, Agriculture Pumps needs to be controlled	Monitored data is scarce and therefore how and where to undertake the action will be limited	MPCB can work on the identification of hotspots, standards and compliance system should be developed for fugitive emission	Local area air quality improvement could be highly effective.	MPCB, Industries, CPCB

Table 8.4 (Contd..) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution – Area Source

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers (Co-Benefit)	Local/ National Stakeholders
Strategy : Area Sources: Mixed sources and varied strategies						
Improve fuel used for domestic purposes	LPG/PNG major domestic fuel, however kerosene is still a major source in low income group/ better stoves or change in fuel to LPG	Likely to improve indoor air quality	Lack of finance to low income group, particularly in slums	Administrative mechanism to be evolved to provide low cost clean fuel to slum dwellers	It would alleviate large section of population with high indoor pollution of other sources leading to lower disease burden and better quality of life	Central and State Govt., MoPNG, Mahanagar Gas
Bakeries /crematoria	Electric/LPG source based bakeries needing changes in design. Many crematoria have electric system, but need to convert all the other into electric system	Local grid based PM can be reduced.	Awareness to bakeries that the quality can still be maintained with electric or LPG ovens. Similarly, despite electric crematoria being available, people prefer using wood based pyres	Strict monitoring of emissions from bakeries and crematoria, Stack monitoring	Reduction in PM as well as odour will take place and is likely to improve the local air quality	PMC and Pune Metropolitan Region Development Authority, MPCB
Biomass/trash burning, landfill waste burning	Better control on collection and disposal at the respective sites. Trash burning and Landfill waste burning needs proper technology driven site management	Local area can have substantial reduction in PM. Very high effectiveness to adjoining grids (city connecting with agriculture field)	Awareness and local control. Apathy to take urgent action. No burning day vow to be taken by PMC and	Pune Metropolitan Region Development Authority and Pune Municipal Regional Wards offices needs to address this issues	High level improvement in local area ambient air quality not only for PM but other pollutants	PMC, MPCB, Pune Metropolitan Region Development Authority

Table 8.4 (Contd..) : Considerations in Prioritizing Technical Measures for Addressing Urban Air Pollution – Area Source

Actions	Technical Issue	Effectiveness for Pollution reduction	Barriers to implementation	Administrative /regulatory	Qualifiers (Co-Benefit)	Local/ National Stakeholders
Strategy : Area Sources: Mixed sources and varied strategies						
Resuspension	Vehicle movement related resuspension can be reduced by having better paved roads, regular sweeping and spray of water.	Highly effective for kerb-side air quality	Awareness and will to implement	Norms for road construction to be framed and implemented	Roadside as well population within the distance of about 200-300 m from the road will have low exposure of PM leading to better sense of well being	PMC, Pune Metropolitan Region Development Authority, MSRDC, MSRTC
Illegal SSI	Level of problem not well known. Need to understand what are the levels of operation and their contribution in each of the grids in the city	Local area improvement can be moderately good	Knowledge of the problem	Need for strict rules of such units and identification by MPCB/DIC and PMC & PCMC	It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem	MPCB, DIC, NMMC
Construction	Construction activities which involve demolition, digging, construction, vehicle movement etc. need information on how to minimize the dust	Large scale improvement in local area is expected.	Emphasis on better construction practices and management plan for air emission and its control by the implementing agencies	Penalty system to be employed by the local authorities for violating the best construction practices for air pollution control.	Spillage on road and further re-suspension of dust can be minimized	PMC, Pune Metropolitan Region Development Authority, Builders Association

The options discussed are also detailed with regard to action to be taken up at city, state or central levels. The **Table 8.5** delineate the prioritize action plan components with ranking for vehicles, industries and area sources.

Table 8.5 : Prioritization of Action Components for Ranking

Types	Components
Vehicular Sector	
Fuel Related	1. Alternative Fuel CNG/LPG 2. Prevent fuel adulteration 3. Sulphur reduction
Vehicle Technology related	1. Replacement of commercial diesel vehicles to CNG/LPG 2. Conversion of private diesel cars to CNG/LPG 3. Electric vehicles for high VKT vehicles 4. Phase out of older vehicles 5. Stringent Emission standards for new vehicles (Bharat IV and VI) 6. Retrofitment of catalytic converter & diesel oxidation catalyst -older vehicles 7. Retrofitment of older vehicles with Bharat Stage III engines with DOC
In-Use vehicle	1. Improvement and compliance system in existing PUC 2. Inspection and identification of highly polluting vehicles 3. Augmentation of manpower and related infrastructure for Inspection and Certification
Policy and Public Processes	1. Prioritization of public transport on roads (bus lanes, better buses, low cost of travel, faster travel, accessibility of transport viz. BRTS, Metro Rail). 2. Affordable public transport (cross-support from charges collected for higher car use charges, higher parking charges, higher registration costs, higher taxes on private mode of transport, low fuel cost for public transport 3. Incentive/subsidy for voluntary inspection and maintenance of vehicles 4. Incentive/subsidy to phase out grossly polluting vehicles 5. Drivers and Mechanics Training programmes 6. Public awareness on use of alternate fuel (CNG/LPG), adulteration of fuels, benefits of various maintenance measures.
Road and Traffic Control	1. Improvement of roads, (Inter linkages and Bypass Roads etc.) 2. Interstate transport vehicles viz. tourist and goods vehicles needs to be ply outside the city area, restricted entry into the city 3. Transportation planning and better road maintenance 4. Pavement improvement and better sweeping for less resuspension 5. Road Congestion –encroachment etc. 6. Traffic Management: signal synchronization, one way, pedestrian plaza

Table 8.5 (Contd..) : Prioritization of Action Components for Ranking

Types	Components
Industrial Sector	
Fuel Related	1. Change of FO, HSD, LSHS, Coal to NG 2. Change of fuel such as Bagasse and Wood to Alternative Fuel
Technology related	1. Clean combustion technology 2. High efficiency control technology 3. Clean process technology
Fugitive and other emissions	1. Industry specific plans 2. Compliance monitoring design for fugitive emissions
Area Sector	
Fuel Related	1. LPG/ CNG & Low sulfur fuel for bakeries, crematoria 2. PNG/ LPG for domestic fuel in place of kerosene
Biomass /landfill burning	1. Open burning viz. biomass, trash burning need to urgently managed in big organizations premises landscape areas 2. Landfill burning management 3. Open eatout burning of coal /kerosene to be regulated
Construction / demolition of buildings	1. Norms for building construction / demolitions 2. Regulation and compliance monitoring 3. Material movement control 4. Construction machineries use and its management
Road Construction/ Repairs	1. Road quality norms to be revisited (Refer : UTTIPEC design manual created by Delhi Development Authority for uniform roadside, drains, footpath and related design) 2. Use road repair technologies and consider life of road warranties 3. Stoppage of wood burning for tar melting or re-surfacing of the road
Public Awareness	1. Public awareness programme to empower citizens to report small sources but highly prevalent 2. Dissemination of information to public addressing system

All the above actions have been rated on the basis four criteria viz.

- Effectiveness - Ease of implementation - Cost implications - Time frame

These criteria should not be considered as firm numbers as many of these cannot be easily quantified. The ranking carried out here therefore is of subjective in nature; however, these are based on relevant facts and analysis of their effectiveness. For example an action plan with “low cost” in Fuel Related category may not be same as in Technology Related “low cost”.

The prioritization of various options in all three categories have addressed mostly all the major reduction in the overall pollutants load reduction combined with ambient air quality improvement. However, many of these measures still may not lead to resolving very small area high concentration points which could be due to short term but high emission or high activity for a limited period and limited area. Such hot spots in the city of Pune could exist when a local road is dug up and/or being repaired, construction and demolition of buildings, biomass and refuse burning, industries short term emissions etc. All of such activities can be controlled and regulated through local efforts and constant vigil on the part of citizen, pollution control agency and respective responsible implementing agency.

One of the biggest issues for large metro city is land use pattern, which indirectly drives the growth pattern of the city and consequent vehicle increase. Migration of people within the state from nearby districts, due to climate conditions, searching for the jobs, development of city as a IT hub had changed the city growth profile and living structure. Frequent change in floor space index (allowing more built up per unit area) leads to large scale increase in vehicle ownership and their presence on road. Better air quality planning for the city also needs appropriate transport planning which is linked with land use.

All reductions planned will only reduce emissions from manmade sources; however, natural background and dust would continue to remain in the atmosphere.

The benefits computed in the process described above will not only yield PM and NOx related pollution reduction but also co benefit of other pollutants (SO_2, VOCs, HC, CO etc) reductions as well. One of the other major co-benefits of these options (adoption of mass transport, use of cleaner fuel, efficient combustion etc) will provide large scale green house gas reduction. Pune as growing metro city will provide the impetus of overall mitigation of GHG. The benefits of air quality improvement plan suggested and delineated above again will not yield desired results if the adjoining urban centers do not adopt measures suggested, as the objectives of clean air cannot be kept limited to the political boundary of Pune City, when it is in close proximity of major urban centers viz. Pimpri-Chinchwad, Hadpsar, Saswad etc..

ANNEXURE - 1

Emission Factors

(Area, Line and Point Sources)

Annexure 1

Emission Factors

A) Area Source

Bakery

Emission Factor for Wood Burning (kg/t)
PM_{10} = 17.3, SO_2 = 0.2, NOx = 1.3, CO =126.3, HC = 114.5 (VOC as HC)
*$PM_{2.5}$ /PM_{10} ratio considered was =0.68
http://www.epa.gov/ttn/chief/ap42/index.html (Sec. 1.9, pp. 1.10.4, Table 1.9.1)
(Rakesh Kumar and Abba Elizabeth., 2003), VOC to HC - lb/ton - kg/ton*
Emission Factor for Diesel Burning (kg/kiloliters)
SPM= 0.25, PM_{10} =60% of SPM, $PM_{2.5}$ =40% of SPM, CO= 0.63, SO_2 =17.25S, NOx = 2.75, HC = 0.12, (Sulfur content = 0.35%) - automobile euro norms
(TERI, Environmental Effects of Energy Production Transportation and Consumption in NCR, New Delhi, 1992)

Crematoria

Emission factors for wood burning (kg/t)
PM_{10}=17.3, SO_2 = 0.2, NOx 1.3, CO =126.3, HC =114.5 (VOC as HC)
*$PM_{2.5}$ /PM_{10} ratio considered was =0.68
http://www.epa.gov/ttn/chief/ap42/index.html (Sec. 1.9, pp. 1.10.4, Table 1.9.1)
Emission Factor Kerosene (kg/t)
SPM =1.95, PM_{10} =0.61, SO_2 =4, NOx =2.5, CO=62, HC =19
URBAIR, Working Group 1992 - Kerosene, Residential Emission Factor - Electric (kg/ body)
Emission Factor Electric (kg/body)
PM_{10} =0.000025, SO_2 = 0.0544, NOx =0.308, CO =0.141, NVOC =0.013
*$PM_{2.5}$ /PM_{10} ratio considered was =0.68
http://www.naei.org.uk/emissions/selection.php
Body burning was separately calculated based on emission factor electric crematoria

Open Eat Outs

Emission factor for LPG
PM_{10} =2.10, SO_2 = 0.40, NOx = 1.8, CO= 0.25, HC as VOC=0.07
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 one – Rapid Inventory Techniques in Environmental Pollution by A.P. Economopolous, WHO, Geneva, 1993
Particulate emission LPG considered as $PM_{2.5}$
Emission factor for Kerosene : SPM=0.06, PM_{10}=0.61, SO_2 =4, NOx =2.5, CO = 62
Urban Air Quality Management Strategy in Asia – Greater Mumbai Report edited by Jitendra J. Shah and Tanvi Nagpal, World Bank Technical Paper No. 381, 1997
Emission factor for Coal : SPM =20, SO_2 = 13.3, NOx =3.99, CO=24.92, HC =0.5
Environmental effects of energy production, transformation and consumption in the National Capital Region submitted to the Ministry of Environment & Forest, by Tata Energy Research Institute (TERI), New Delhi, February 1992

Domestic Cooking
Emission Factor for LPG : PM=2.1, CO =0.252, SO_2 = 0.4, NOx = 1.8, VOC = 0.072
Emission Factor for Kerosene : PM_{10}=0.61, SO_2 =4, NOx =2.5, CO = 62
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 one – Rapid Inventory Techniques in Environmental Pollution by A.P. Economopolous, WHO, Geneva, 1993

Hotels & Restaurants
Emission factor for LPG
PM_{10} =2.10, SO_2 = 0.40, NOx = 1.8, CO= 0.25, HC as VOC=0.07
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 one – Rapid Inventory Techniques in Environmental Pollution by A.P. Economopolous, WHO, Geneva, 1993
Particulate emission LPG considered as PM2.5
Emission factor for Coal : SPM =20, SO_2 = 13.3, NOx =3.99, CO=24.92, HC =0.5
Environmental effects of energy production, transformation and consumption in the National Capital Region submitted to the Ministry of Environment & Forest, by Tata Energy Research Institute (TERI), New Delhi, February 1992

Open Burning
Emission Factor (kg/MT) PM_{10} = 8, $PM_{2.5}$ =5.44, CO=42, SO_2=0.5000,NOx= 3, VOC= 21.5
A Guide to Rapid Source Inventory Techniques and their Use in Formulating Environmental Control Strategies – Part one – Rapid Inventory Techniques in Environmental Pollution by A.P. Economopolous, WHO, Geneva, 1993

Aircrafts
Emission factor domestic flight
PM10=0.99*, CO =11.8, SOx =0.8, NOx =8.3, VOC=0.5
Emission factor international flight
PM10=0.99*, CO =6.1, SOx =1.6, NOx =26, VOC=0.2
** A Guide to Rapid Source Inventory Techniques and their Use in Formulating Environmental Control Strategies – Part one – Rapid Inventory Techniques in Environmental Pollution by A.P. Economopolous, WHO, Geneva, 1993*
Other emission factors are taken from
www.ecotourism.org/onlineLib/Uploaded/ … Airplanes emissions. PDF
PM2.5/PM10 = 0.92
Preparation of Fine Particulate Emission Inventories -Student Manual, APTI Course 419B, Sec. 4.2.1, pg-4.7

Marine Vessels
Emission factors *(kg/t fuel consumed)*: PM_{10} =1.03, CO =1.85, SO_2 =11, NOx= 10, VOC as HC = 0.83, Density of diesel = 0.86 (HSD) *UK-Shipping international-Fuel oil*

Paved & Unpaved Dust
Paved Road Dust : $PM_{2.5}$ = 0.39, PM_{10}= 1.93
** Strengthening Environmental Management at the State Level (Cluster) Component E- Strengthening Environmental Management at West Bengal Pollution Control Board, TA No. 3423-IND, Asian Development Bank, Nov. 2005 (Table 12, Page 23) USEPA AP42 Paved, Section 13.2.1.4 Motor Transport Statistics, Transport Commissioner Office, Mumbai* Silt loading estimate -0.531 gm/m2 (*Kolkata ADB report –Table 13, page 23) Break and tire wear correction – (USEPA AP42 Paved, Section 13.2.1.4, Table 13.2.1.2) Wet days = 120, (IMD, Mumbai)

Emission factor for industrial and vehicular sources are given in respective chapters

B) Line (Vehicular) Source

Emission Factors Calculated by Automotive Research Association of India (ARAI)

Vehicular Emission Factors (Gm/Km)	Car Petrol Post 2005 Fuel BSII	Car Diesel Post 2005 Fuel BSII	Car CNG Post 2000, Fuel BSII	Two Wheeler Post 2005 4 Stroke Fuel BS II	Three Wheeler CNG Retro 25 Post 2000 Fuel BS II	CNG Buses Post 2000 Fuel BS II	Trucks Diesel Post 2000 Fuel BSII
PM	0.002	0.015	0.006	0.013	0.118	0.044	1.240
NOx	0.090	0.280	0.740	0.150	0.190	6.210	9.300
CO	0.840	0.060	0.060	0.720	0.690	3.720	6.000
HC	0.12	0.080	0.460	0.520	2.06	3.750	0.370

Factors used for emission load calculation Source: Air Quality Monitoring Project-Indian Clean Air Programme (ICAP), The Automotive Research Association of India, 08, 2007

* Emission Factors for BS IV and BS VI are given below :

Emission Factors for BS IV and BS VI

Emission Factor for BS IV fuel	PM	NO_x	CO	HC
Car Petrol Car	0.002	0.08	1	0.1
Car Diesel Car	0.025	0.25	0.5	0.3
CNG Car/Taxi (LMV)	0.006	0.08	1	0.1
Two wheeler	0.013	0.79	1.403	0.39
Three wheeler	0.0425	0.38	0.38	2.06
Heavy Duty Diesel Vehicles	0.02	3.5	1.5	0.46

Emission Factor for BS VI fuel	PM	NO_x	CO	HC
Car Petrol Car	0.005	0.06	1	0.1
Car Diesel Car	0.005	0.08	0.5	0.17
CNG Car/Taxi (LMV)	0.005	0.06	1	0.1
Two wheeler	0.0045	0.06	1	0.1
Three wheeler	0.025	0.1	0.22	0.1
CNG Buses	0.01	0.46	4	0.16
Heavy Duty Diesel Vehicles	0.01	0.4	1.5	0.13

* Values in g/km Source: *https://www.transportpolicy.net/region/asia/india/*

TransportPolicy.net is collaboration between the International Council on Clean Transportation and DieselNet. On 19 Feb 2016, the Ministry of Road Transport and Highways (MoRTH) issued a draft notification of Bharat Stage (BS) VI emission standards. The standards, as proposed, will take effect throughout the country for all light-duty and heavy-duty vehicles as well as two and three wheelers manufactured on or after 1 Apr 2020. The draft proposal specifies mass emission standards, type approval requirements, and on-board diagnostic (OBD) system and durability levels for each vehicle category.

Additional provisions in the draft proposal include:

- Adoption of more stringent WHSC and WHTC test cycles
- Off-cycle emissions testing requirements and in-service conformity testing for type approval
- Specifications for Portable Emissions Measurement System (PEMS) demonstration testing at type approval. The proposed BS VI regulation establishes an important precedent for leap frogging from Euro IV-equivalent directly to Euro VI-equivalent motor vehicle emissions standards.

The World Harmonized Transient Cycle (WHTC) test is a transient engine dynamometer schedule defined by the proposed global technical regulation (GTR) developed by the UN ECE GRPE group. The GTR is covering a world-wide harmonized heavy-duty certification (WHDC) procedure for engine exhaust emissions. The proposed regulation is based on the world-wide pattern of real heavy commercial vehicle use.

a. test is performed on an engine dynamometer operated through a sequence of 13 speed and load conditions
b. a hot start steady state test cycle
c. transient test cycle with both cold and hot start requirements

Prior to 2010, emissions were tested using the ECE R49[a] test cycle. After 2010, for Bharat III and IV, the ESC (European Stationary Cycle) and ETC (European Transient Cycle) test cycles were used. BS VI will require the application of WHSC[b] (World Harmonized Stationary Cycle) and WHTC[c] (World Harmonized Transient Cycle) test cycles.

C) Point (Industry) Source

Emission Factors applied for Industrial Emissions

S. No.	Type of Fuel	Unit	S	Emission Factors (Kg/Unit)					
				TSP	SO_2	NO_x	HC	CO	Ash
1.	LSHS	KL	0.45	1.25*S + 0.38	19.25* S	7.5	0.12	0.63	
2.	FO	KL	4.0	1.25*S + 0.38	19.25* S	7.5	0.12	0.63	
3.	LDO	KL	1.8	0.25	17.25* S	2.75	0.12	0.63	
4.	HSD	KL	1.0	0.25	17.25* S	2.75	0.12	0.63	
5.	LPG/FG$$	KL	0.02	0.072	0.01*S	2.52	0.07	0.43	
6.	NG	m^3	-	160 E-06	9.6 E-06	2800 E-06	48 E-06	272 E-06	
7.	Coal /Coke	MT	0.5*	6.5*A	19S	7.5	0.5	1.0	45
8.	Kerosene##	Kg/t	0.25	0.06	17S	2.5	--	--	--
For Power Plant**									
1.	LSHS	KL	0.45	1.25*S + 0.38	19.25* S	6.25	0.12	0.63	
2.	NG	m^3	-	160 E-06	9.6 E-06	2800 E-06	48 E-06	272 E-06	
3.	Coal	MT	0.15	6.5*A	19*S	7.5	0.5	1	6

Source: URBAIR Report, Bombay, 1992
A: Percentage ash in coal = 45% and S: Percentage Sulphur
Other than Power Plant, efficiency of Cyclone considered as 75%
* *Power plant
$$Emission Factors for LPG from Revised AP-42 (Ref. PMRAP, NEERI, 2003 (Table 3.2)
Π Coal
A - % Ash: 2- 10% Avg. 6%, S - % Sulphur: 0.1 – 0.2%, Avg. 0.15%
ESP Eff. : 99.5%, FGD Eff. : 99%
Π LSHS Sulphur: 0.45%
Source:
a. Environmental effects of energy production, transformation and consumption in the National Capital Region submitted to the Ministry of Environment & Forest, by Tata Energy Research Institute (TERI), New Delhi, February 1992
b. Indian Oil Corporation Ltd, Vadodara

Density[b] of Fuels (Kg/m^3)

LSHS	943
FO	943
LDO	860
LPG	504
HSD	860

Baggase : Emission Factor Documentation for AP-42 Section 1.8, Bagasse Combustion in Sugar Mills, April, 1993 [PM10- 4.6, SO2-0.18, NO2-0.275, HC-0.0002515, CO - 390 (g/km)]

ANNEXURE - 2

ISOPLETS OF PM :

All Categories- (a)Area, (b) Line, (c) Resuspension of Dust,
(d) Point –LSI, MSI & SSI

&

For All Season (Summer, Post Monsoon, Winter and Annual)

(Pune City)

A) AREA SOURCE – ALL PM

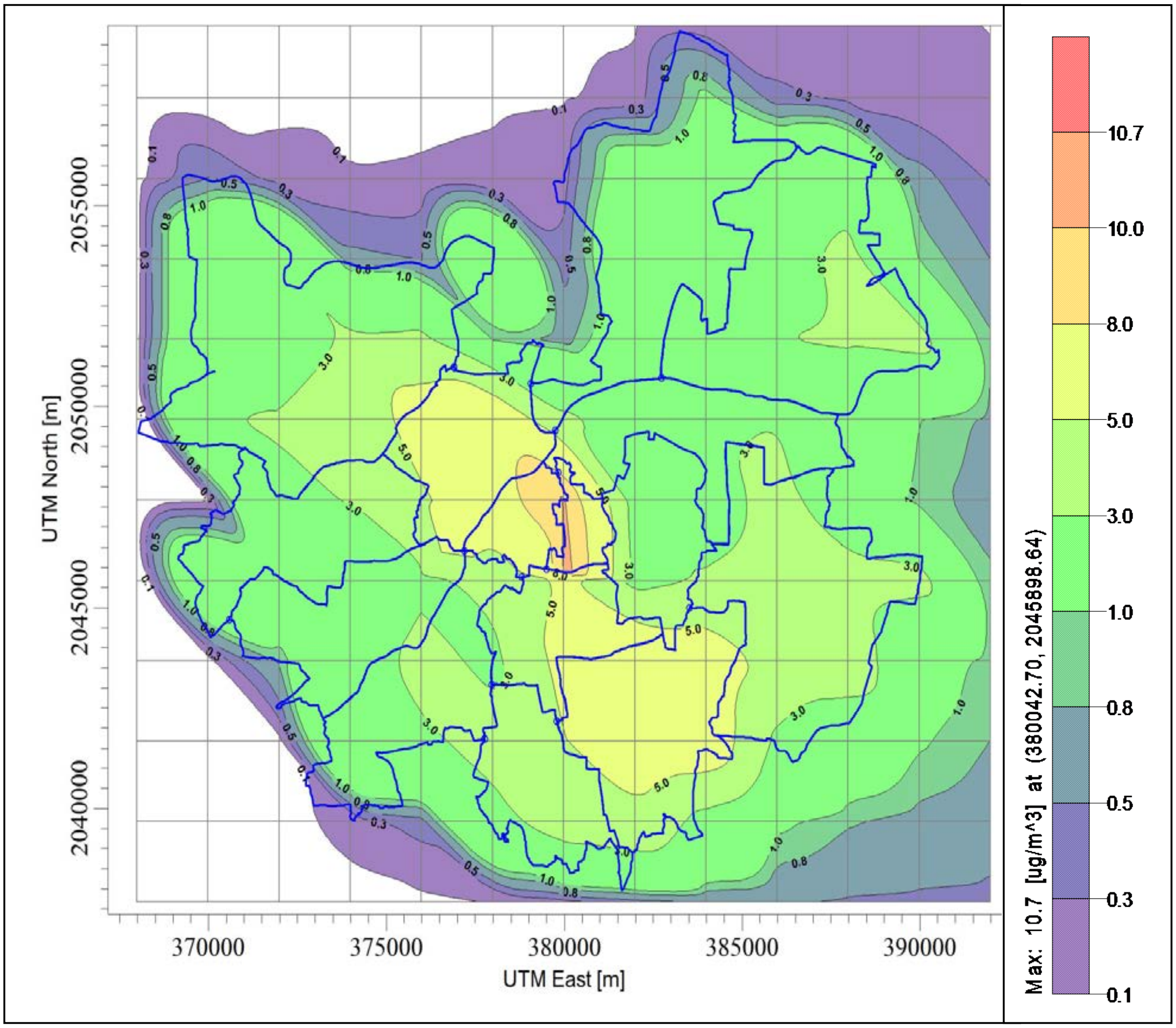

Figure P1: Isopleths of PM Due to Area Sources – Summer Season (Pune City)

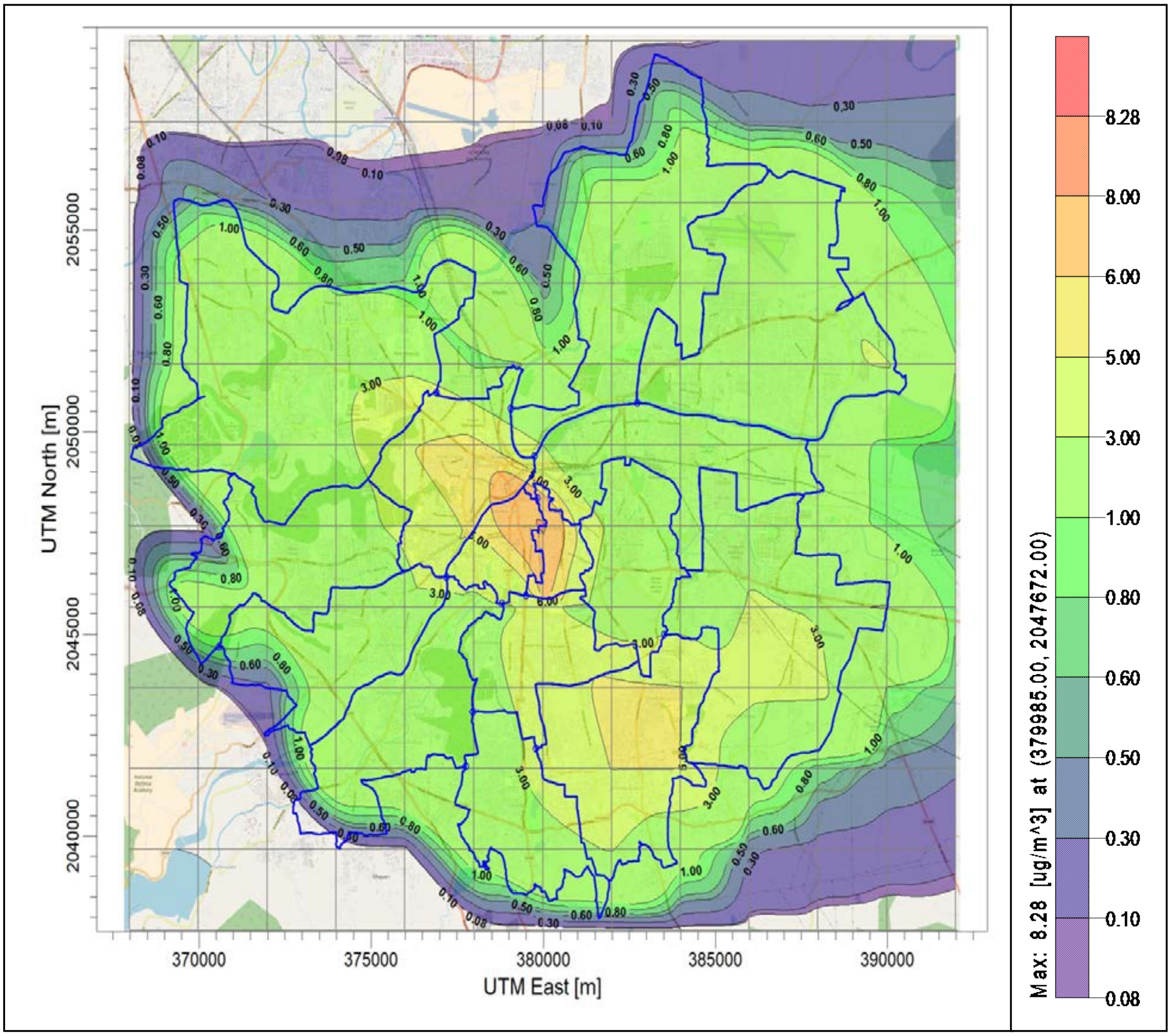

Figure P2 : Isopleths of PM Due to Area Sources – Post Monsoon Season (Pune City)

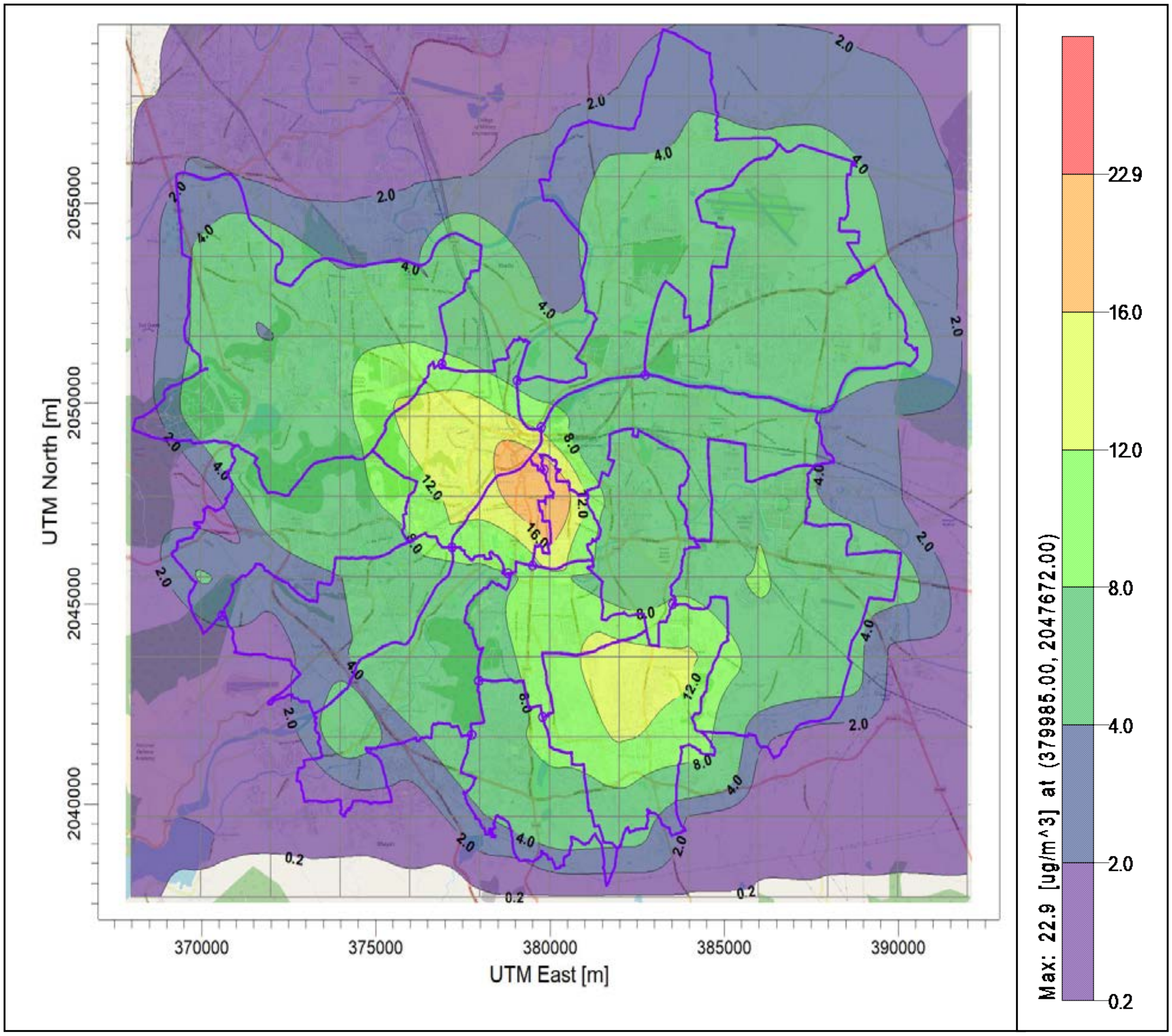

Figure P3 : Isopleths of PM Due to Area Sources – Winter Season (Pune City)

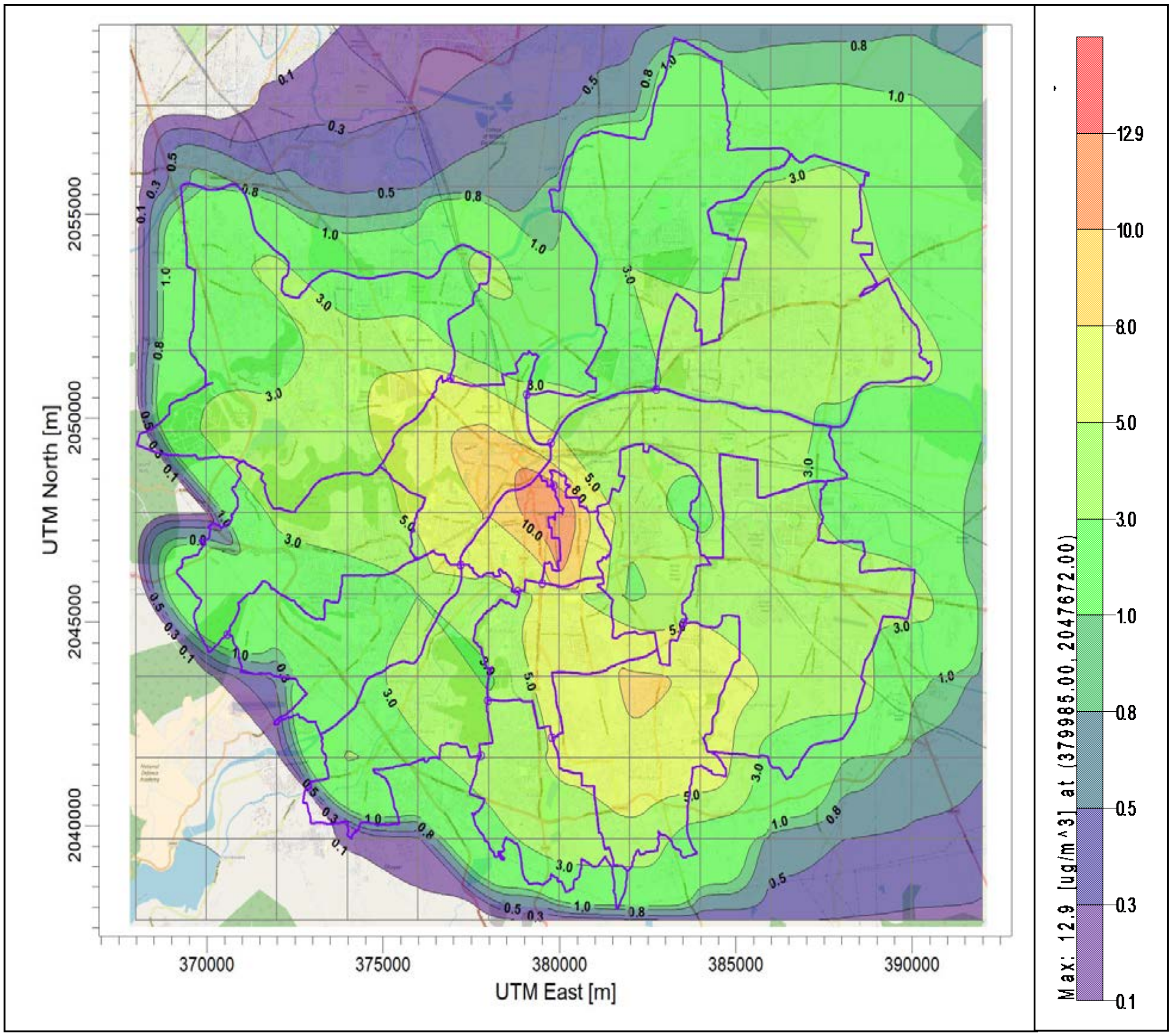

Figure P4 : Isopleths of PM Due to Area Sources – Annual (Pune City)

B) LINE SOURCE – ALL PM

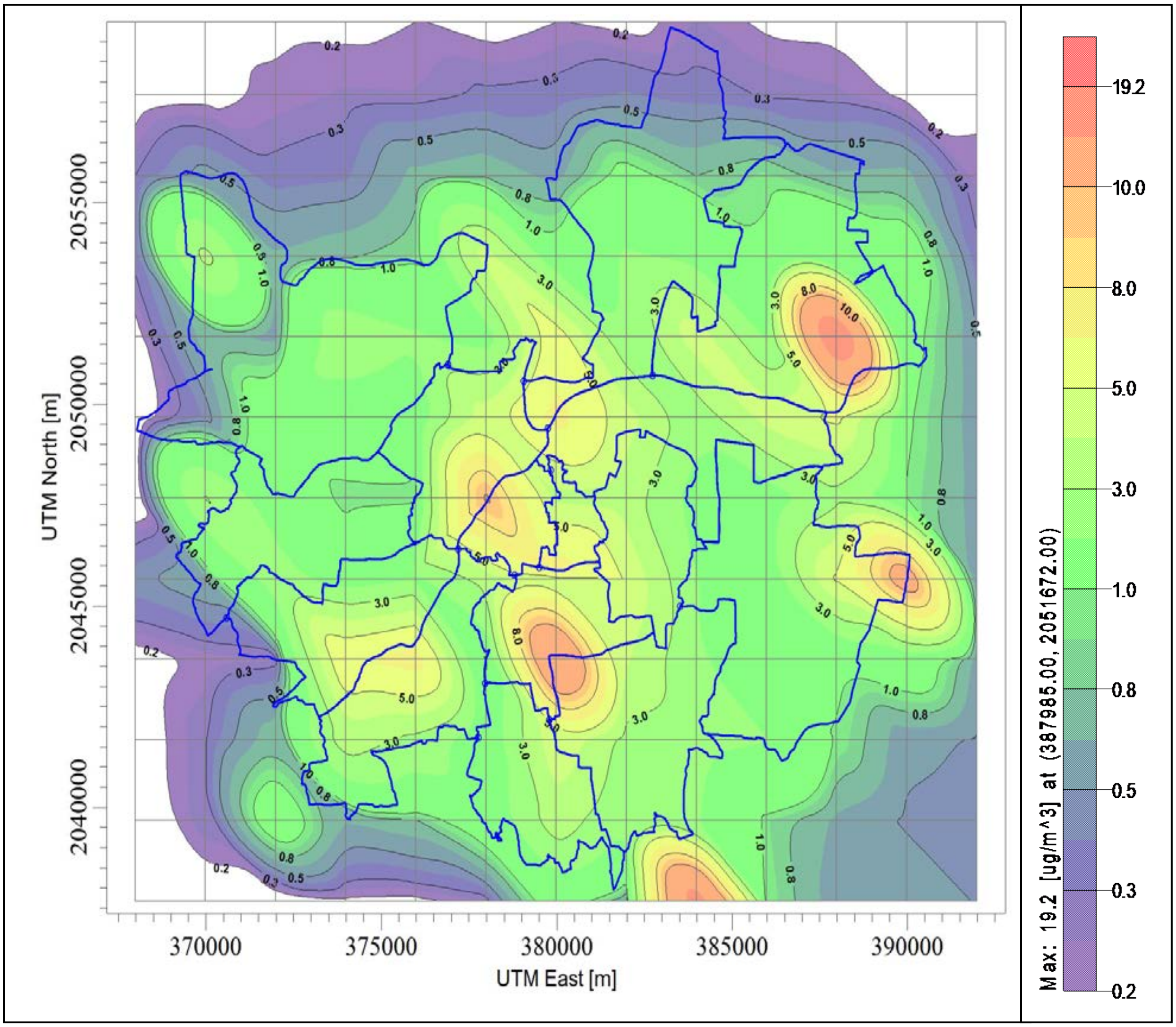

Figure P5 : Isopleths of PM Due to Line Sources – Summer Season (Pune City)

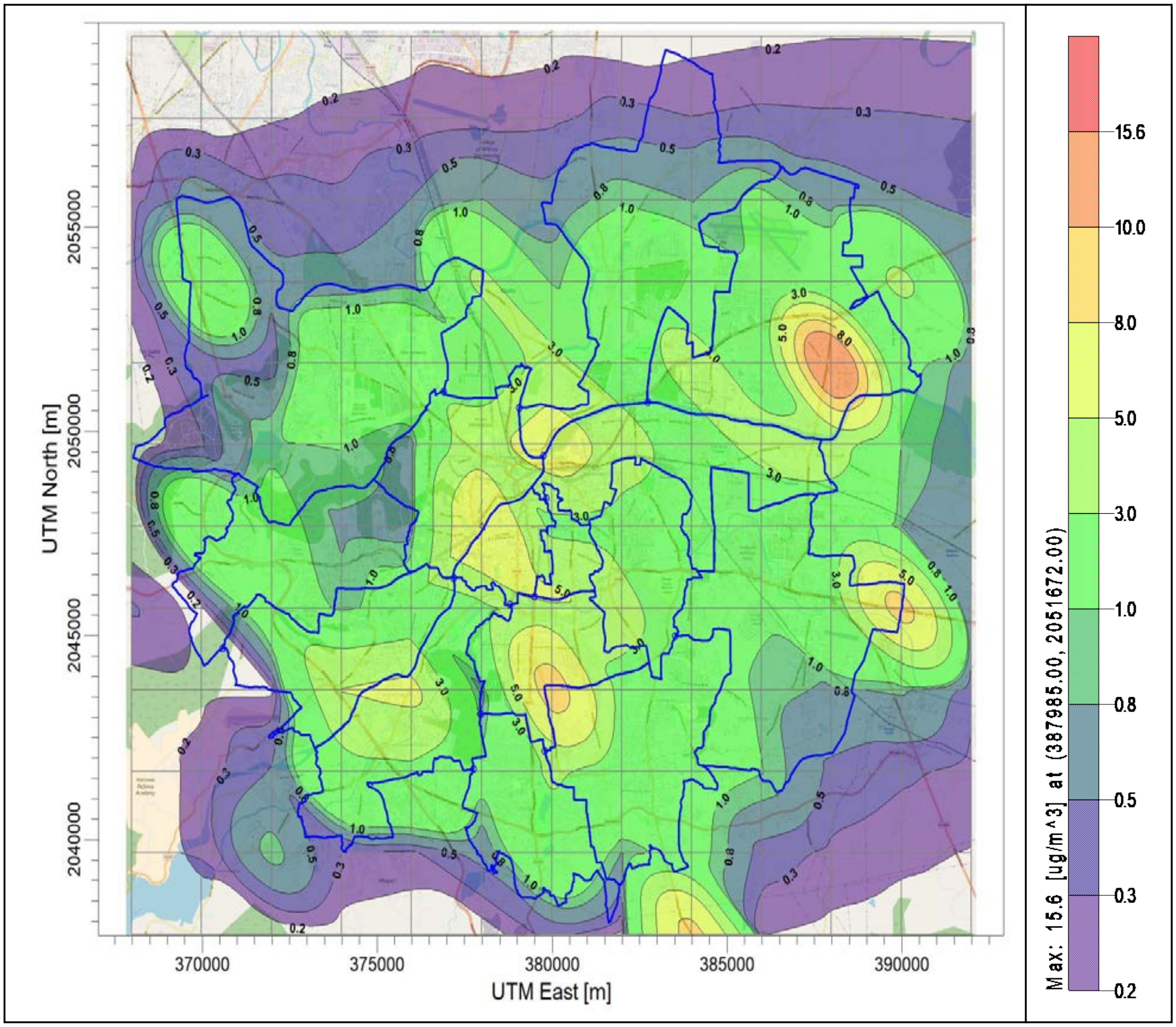

Figure P6 : Isopleths of PM Due to Line Sources – Post Monsoon Season (Pune City)

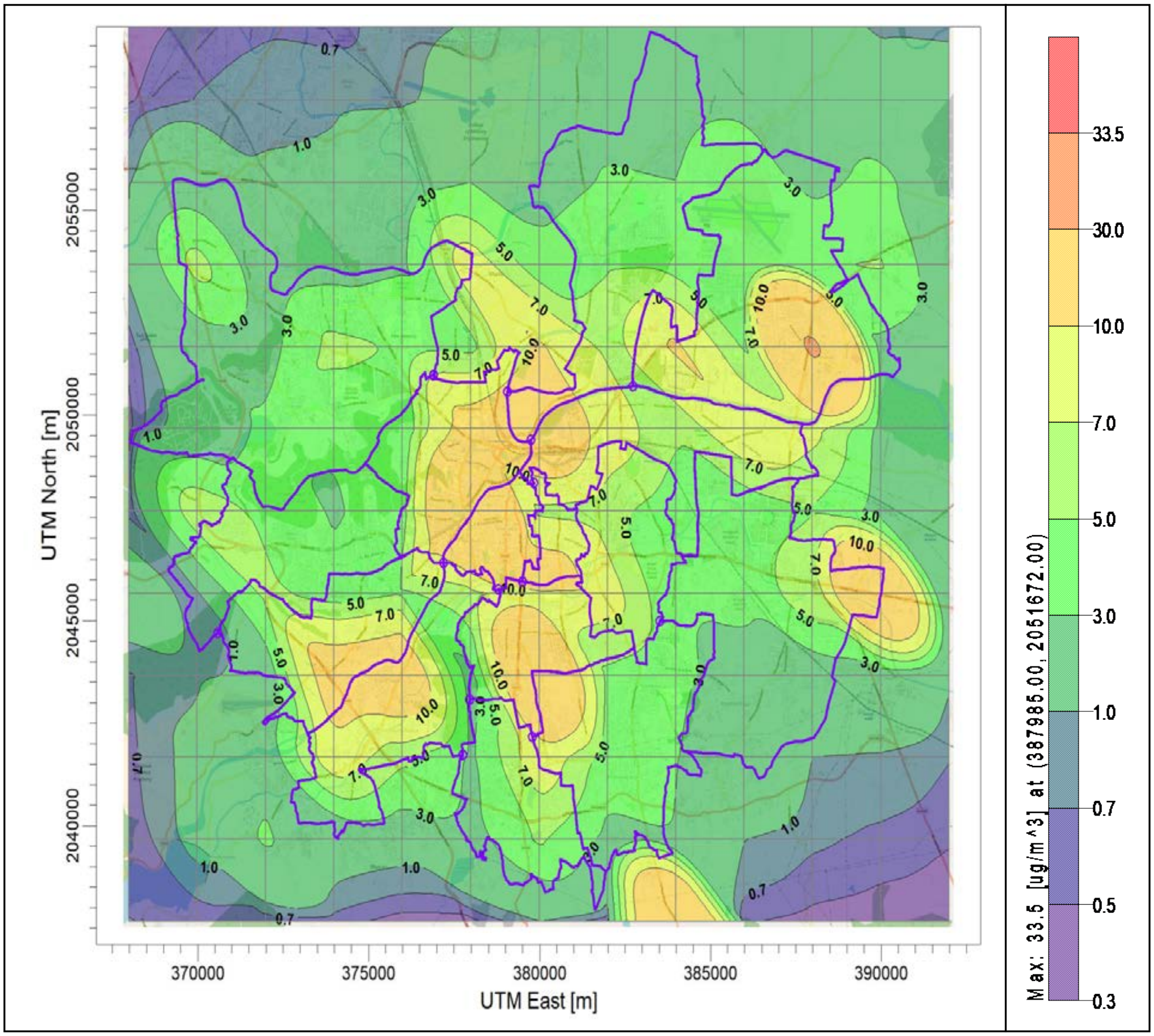

Figure P7 : Isopleths of PM Due to Line Sources – Winter Season (Pune City)

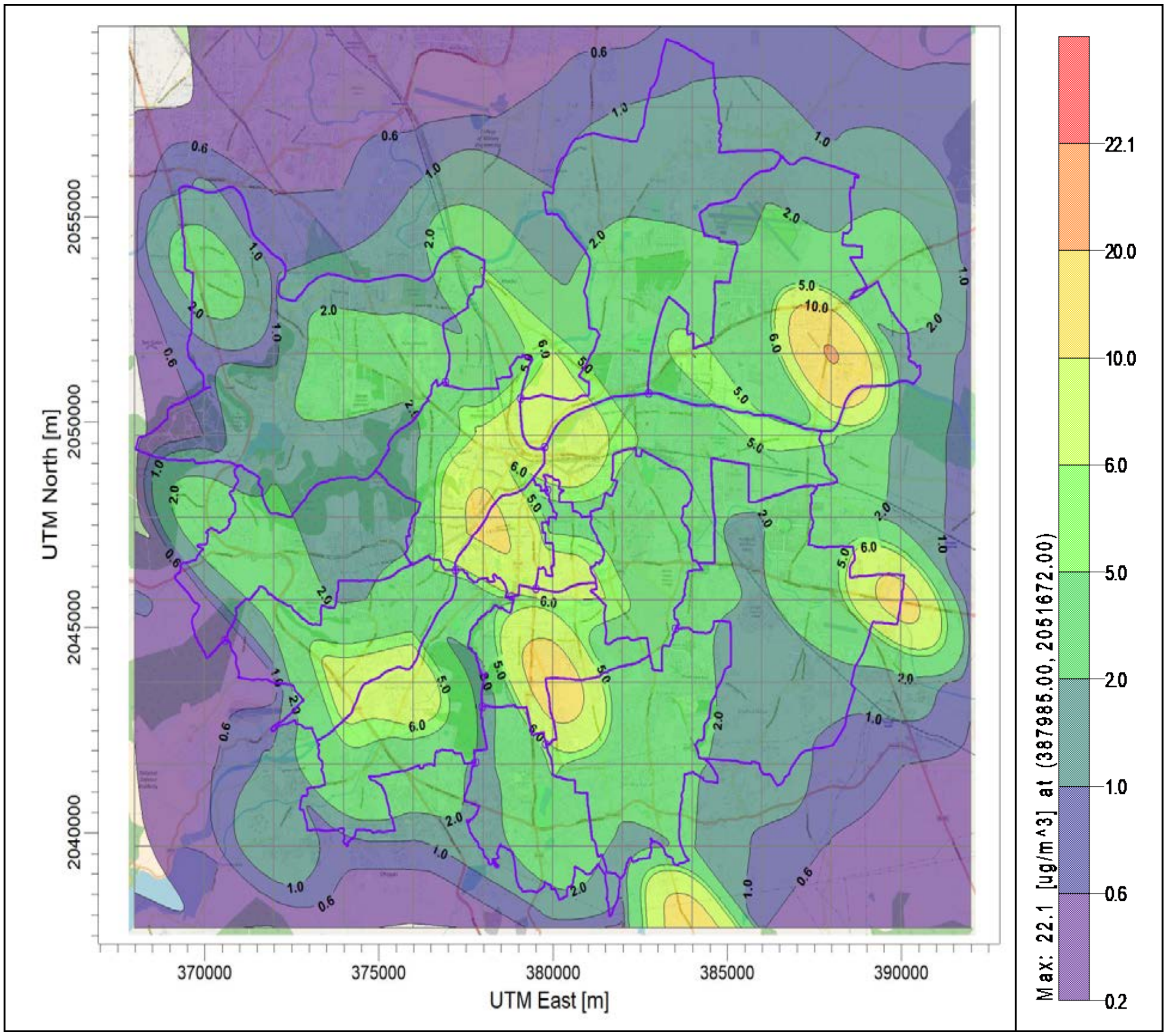

Figure P8 : Isopleths of PM Due to Line Sources – Annual (Pune City)

C) RESUSPENSION DUST– ALL PM

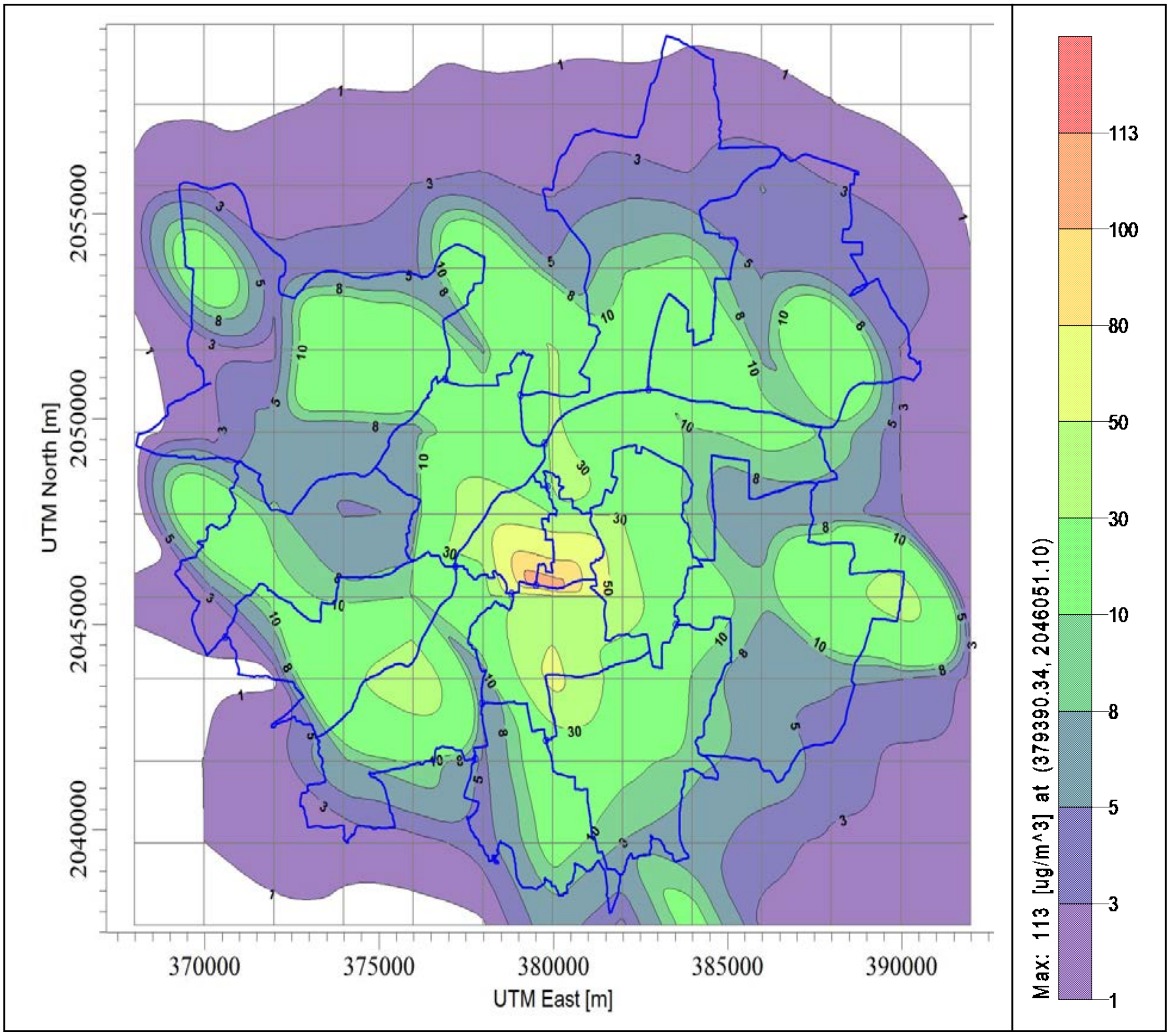

Figure P9 : Isopleths of PM Due to Resuspension Dust– Summer Season (Pune City)

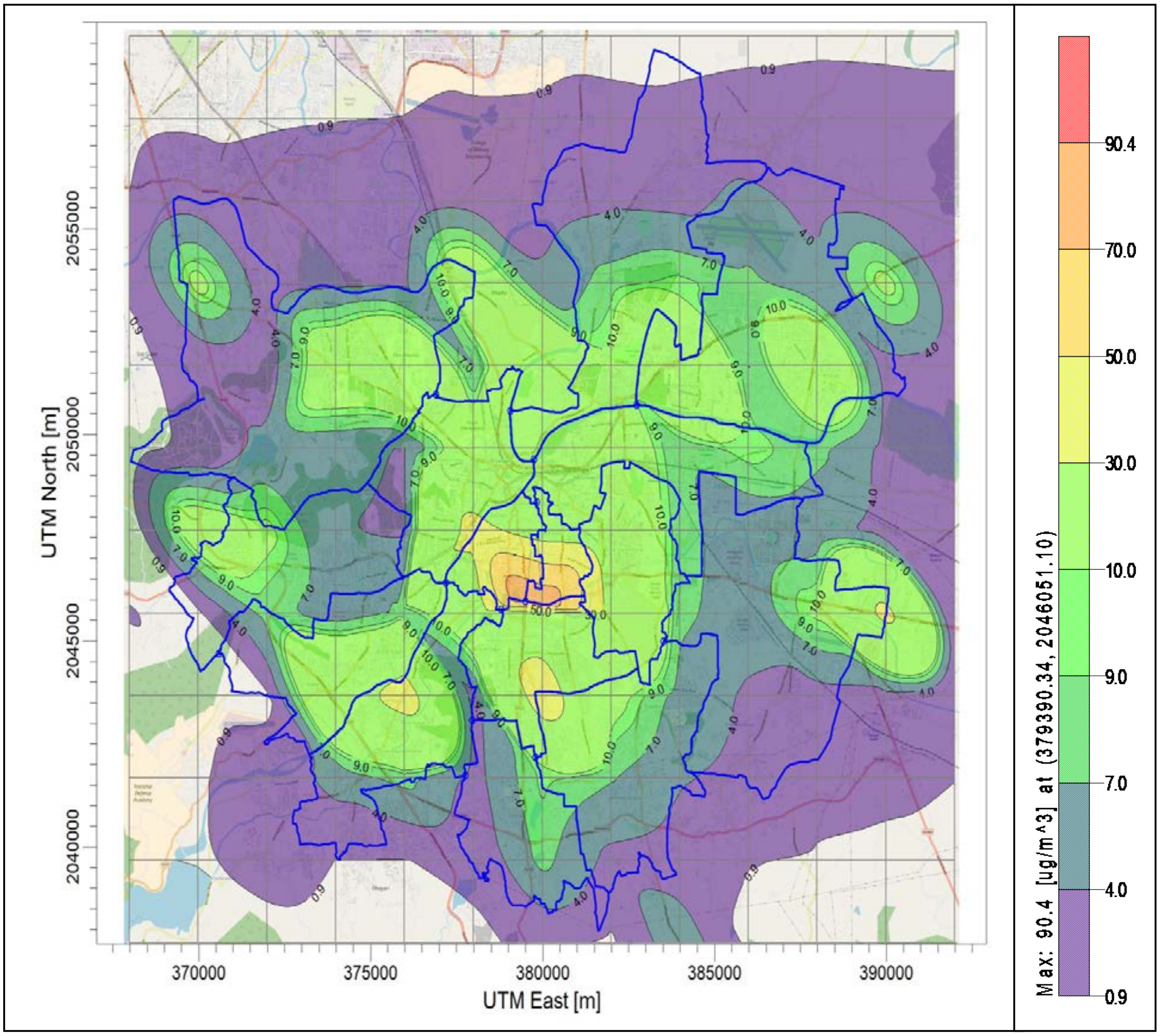

Figure P10 : Isopleths of PM Due to Resuspension Dust– Post Monsoon Season (Pune City)

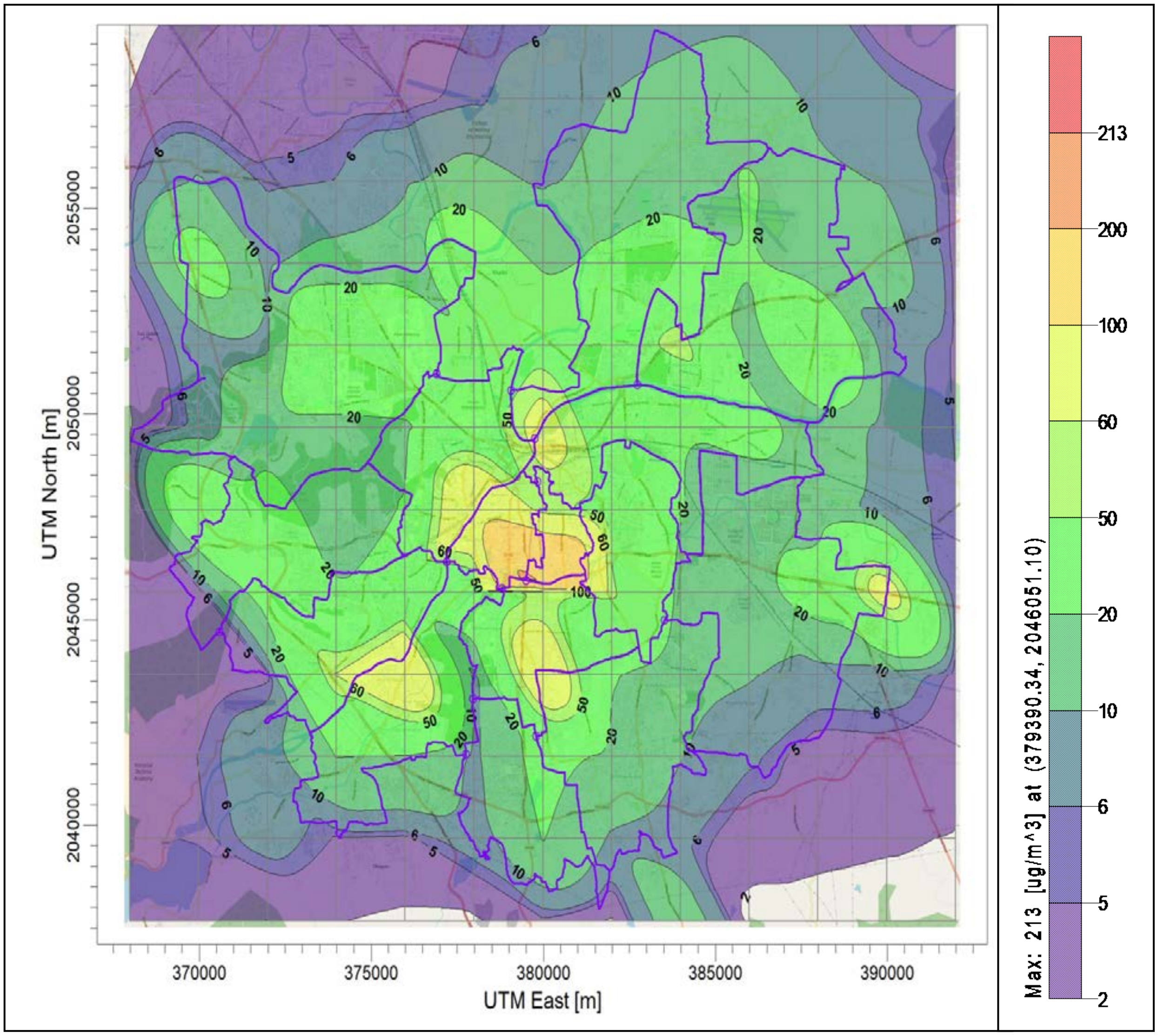

Figure P11 : Isopleths of PM Due to Resuspension Dust– Winter Season (Pune City)

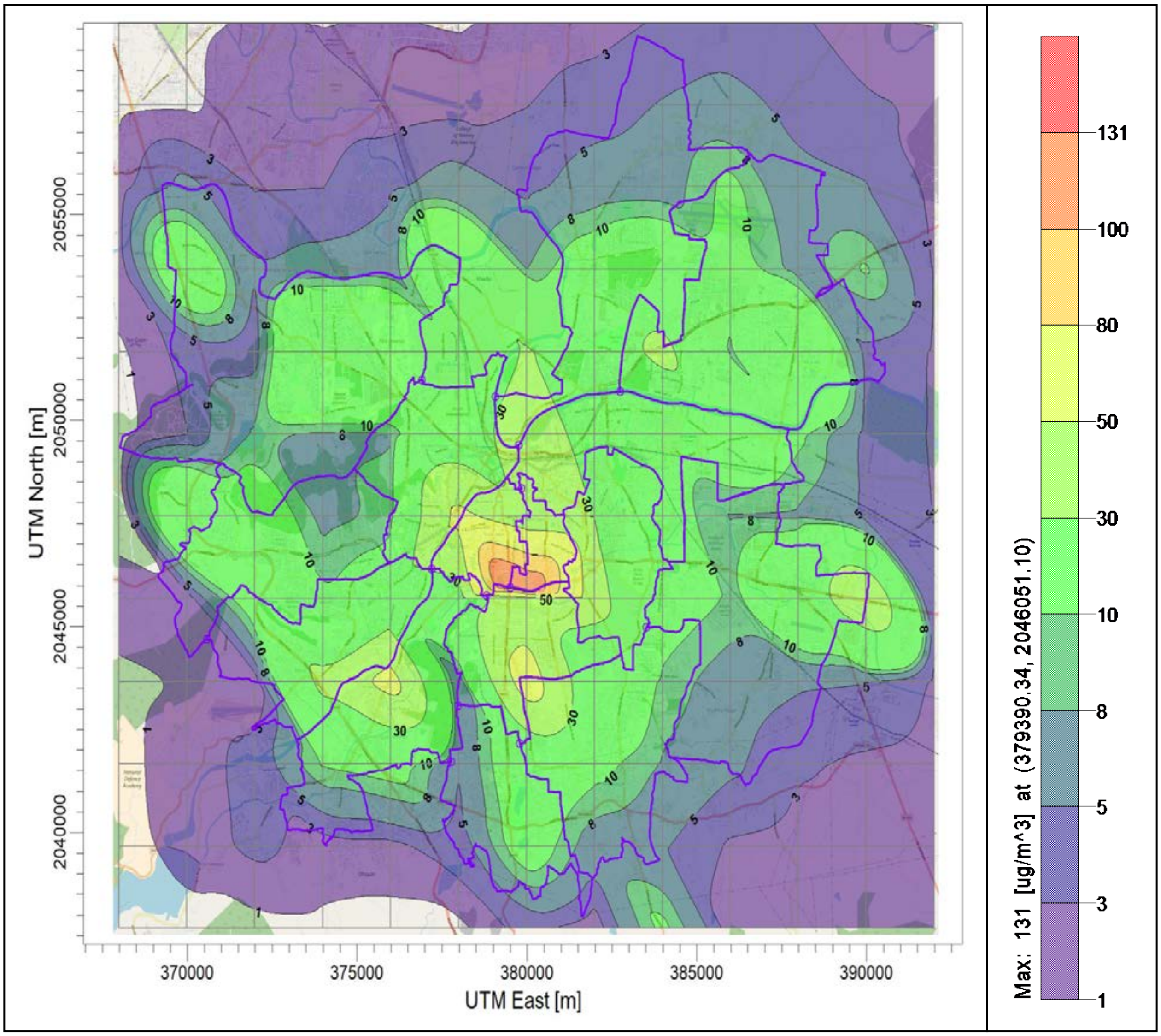

Figure P12 : Isopleths of PM Due to Resuspension Dust– Annual (Pune City)

D) POINT SOURCE – LSI PM

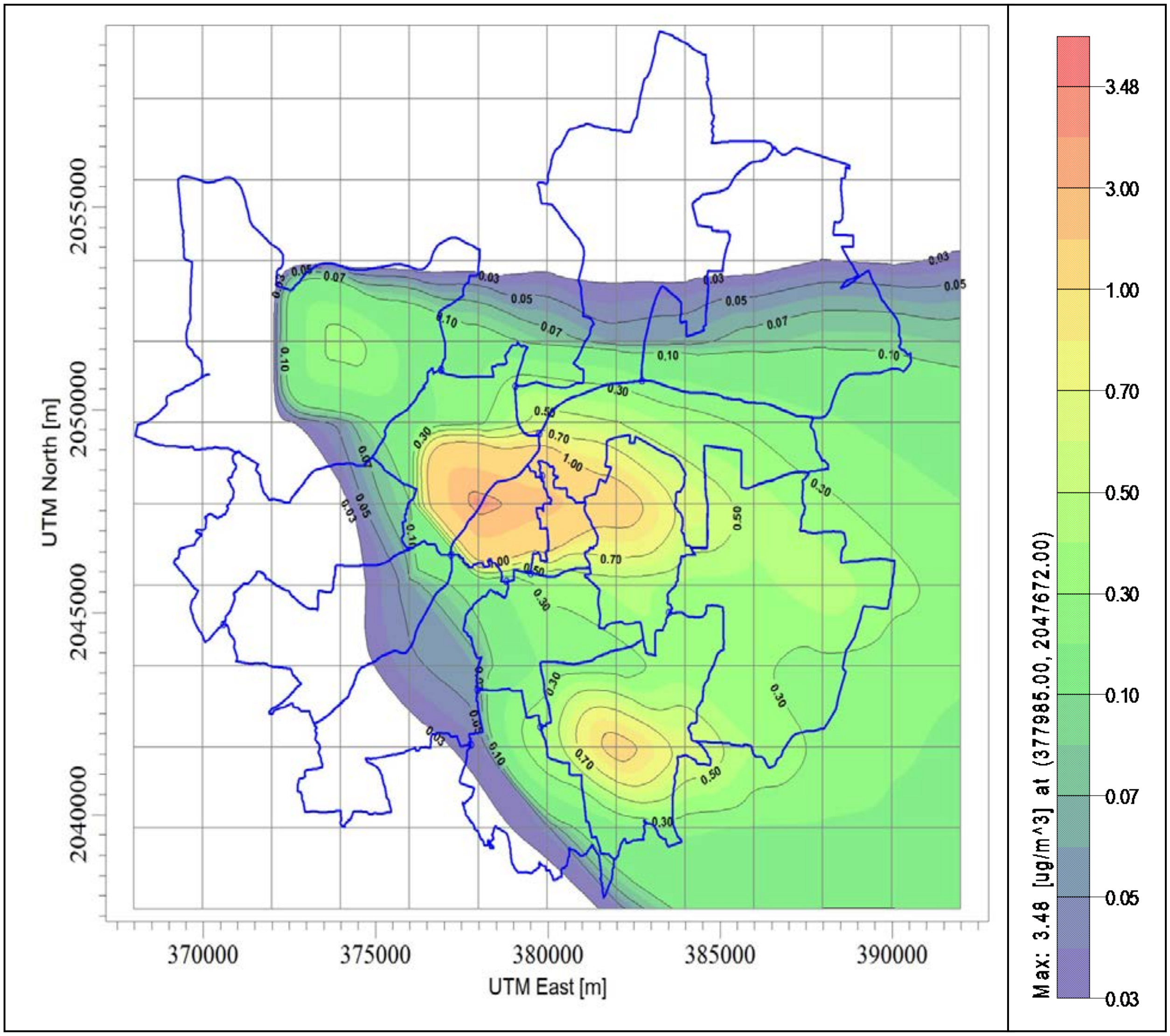

Figure P13 : Isopleths of PM Due to Point Sources (LSI) – Summer Season (Pune City)

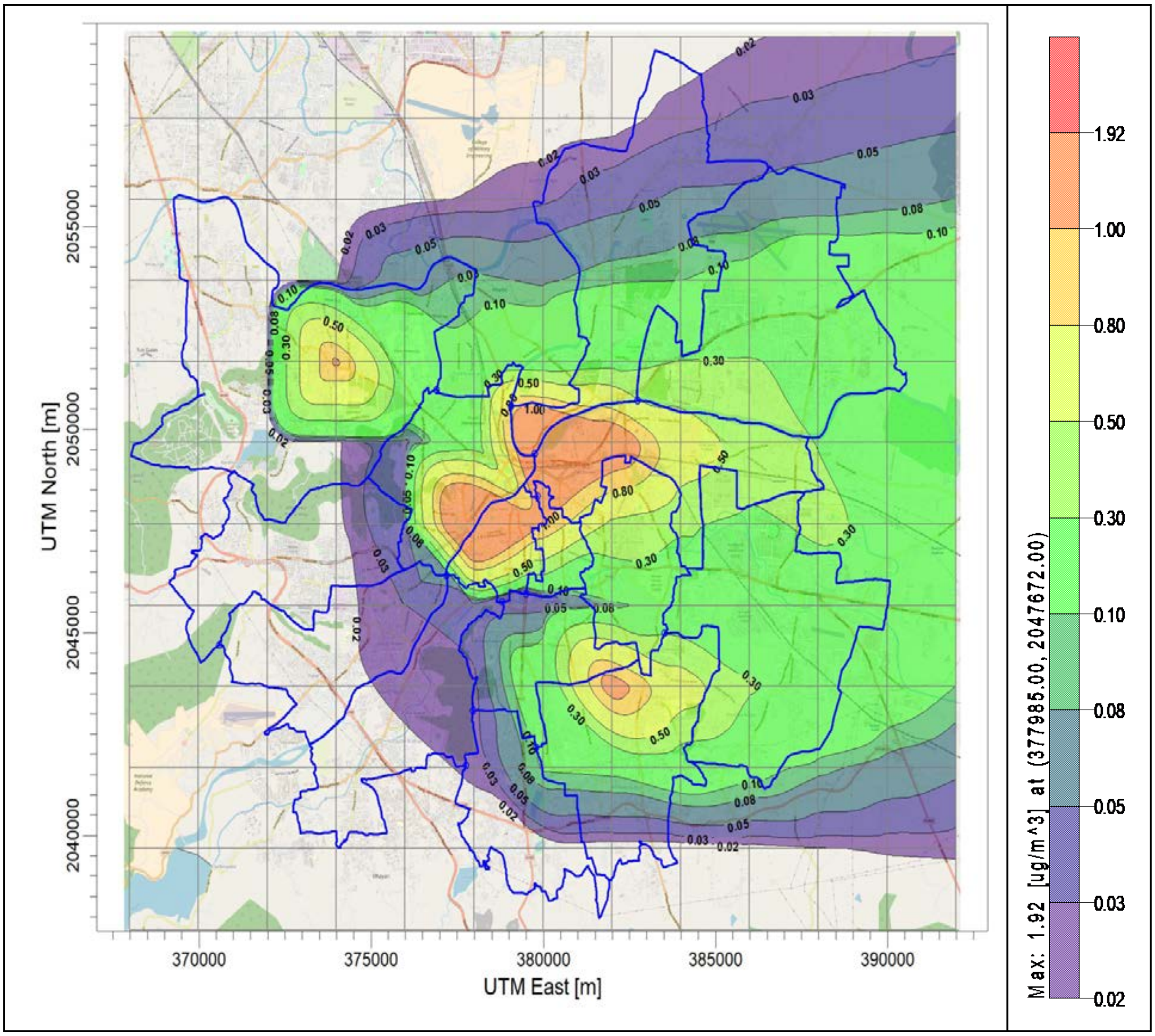

Figure P14 : Isopleths of PM Due to Point Sources (LSI) – Post Monsoon Season (Pune City)

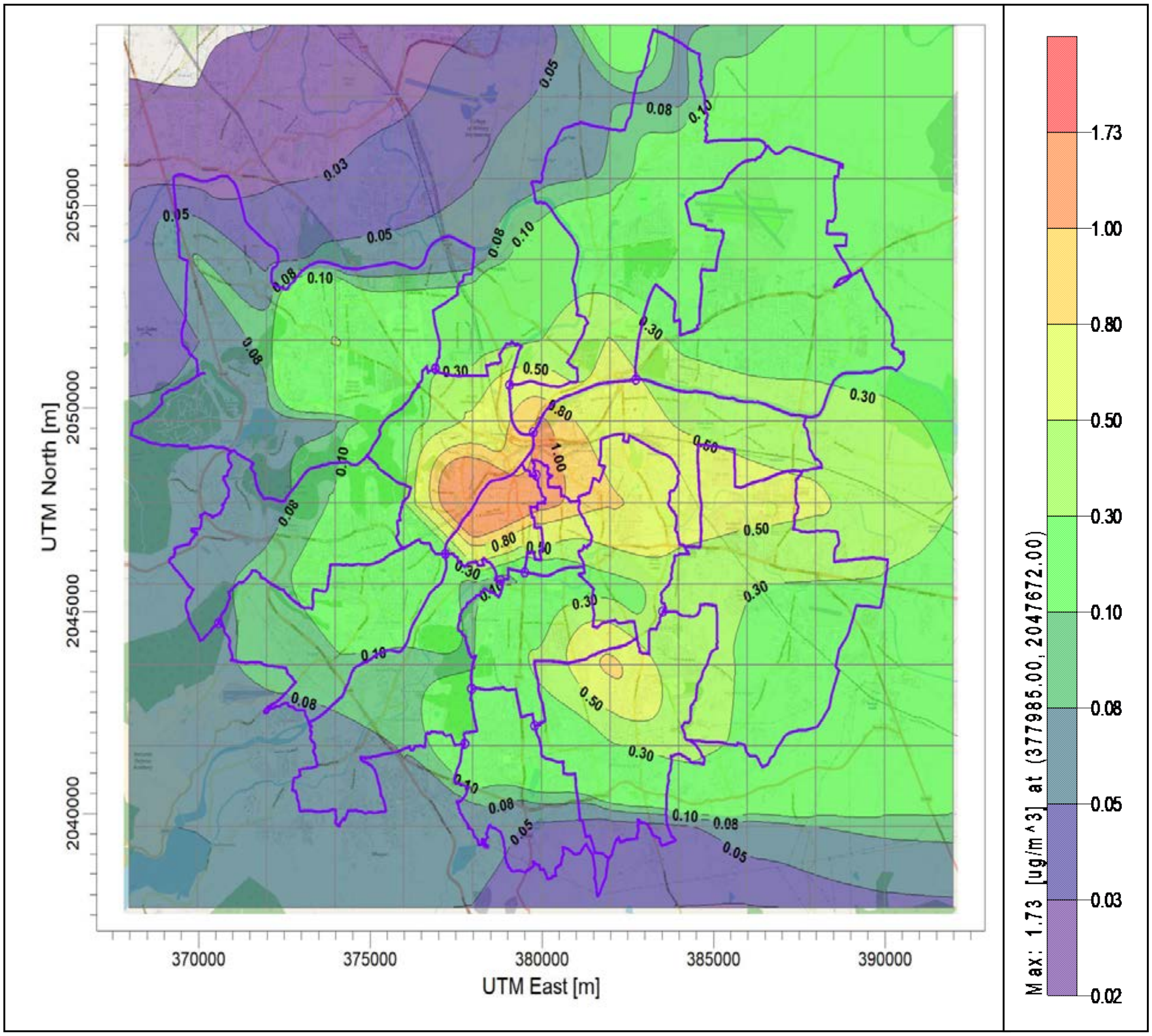

Figure P15 : Isopleths of PM Due to Point Sources (LSI) – Winter Season (Pune City)

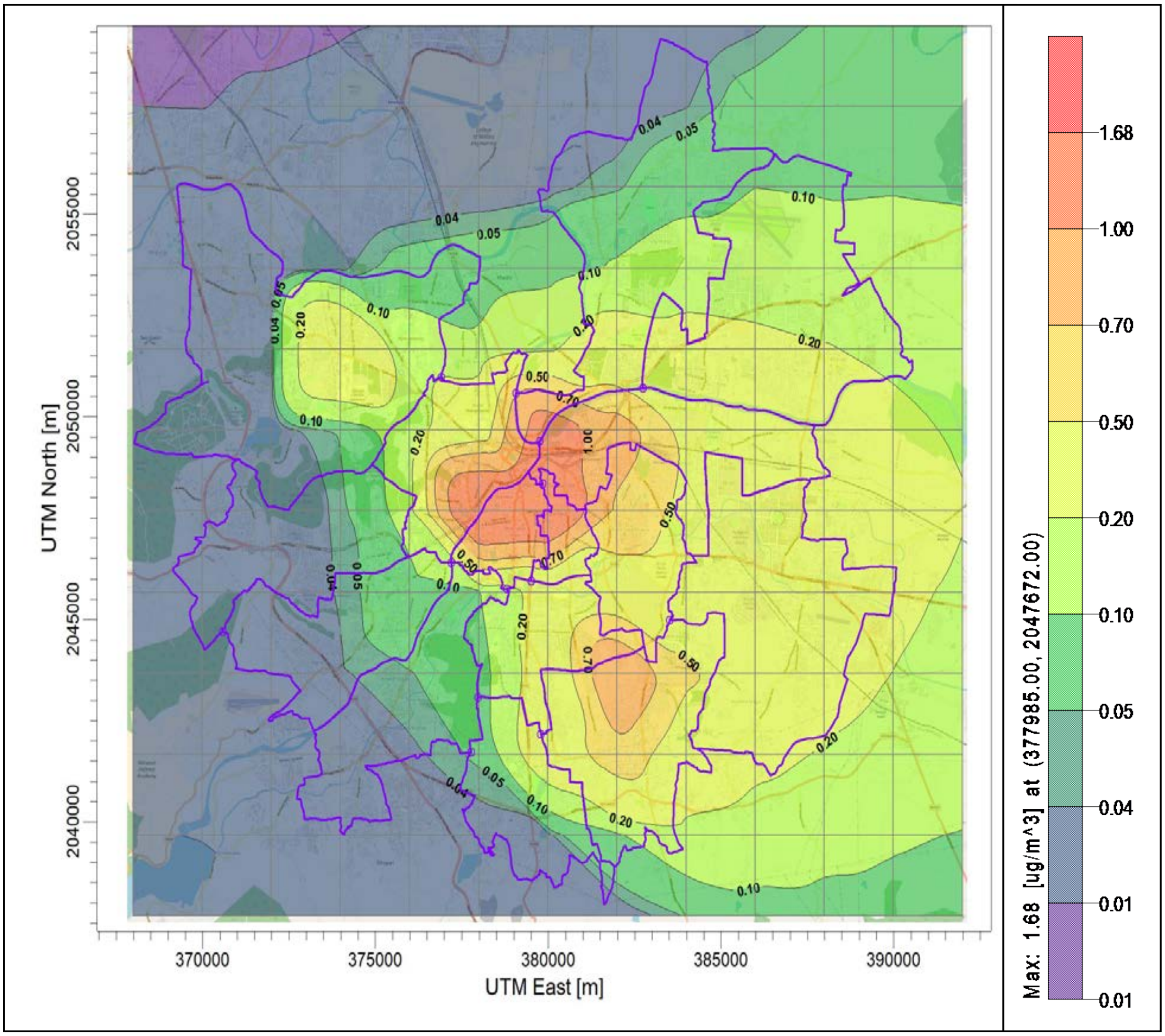

Figure P16 : Isopleths of PM Due to Point Sources (LSI) – Annual (Pune City)

E) POINT SOURCE – MSI PM

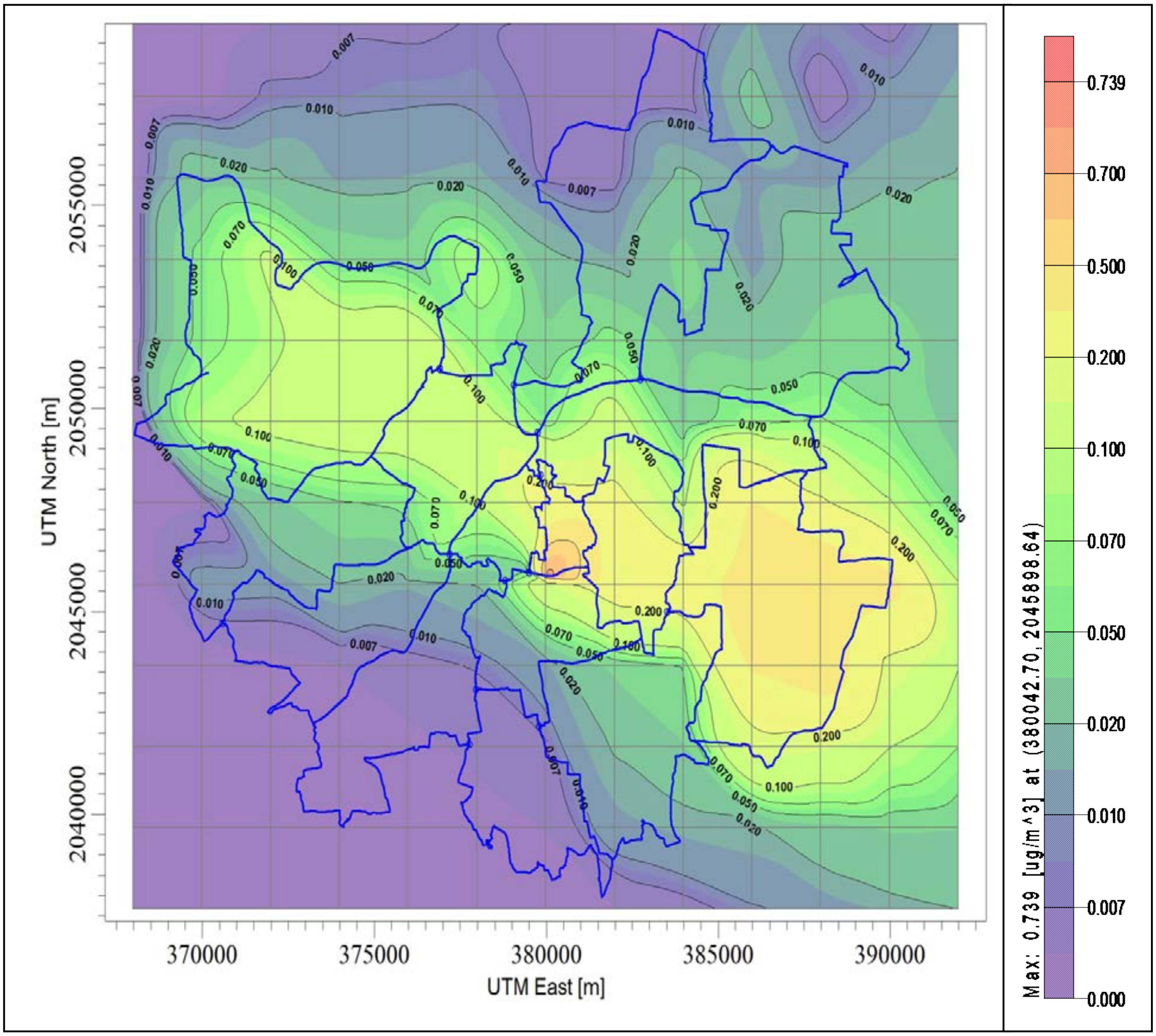

Figure P17 : Isopleths of PM Due to Point Sources (MSI)– Summer Season (Pune City)

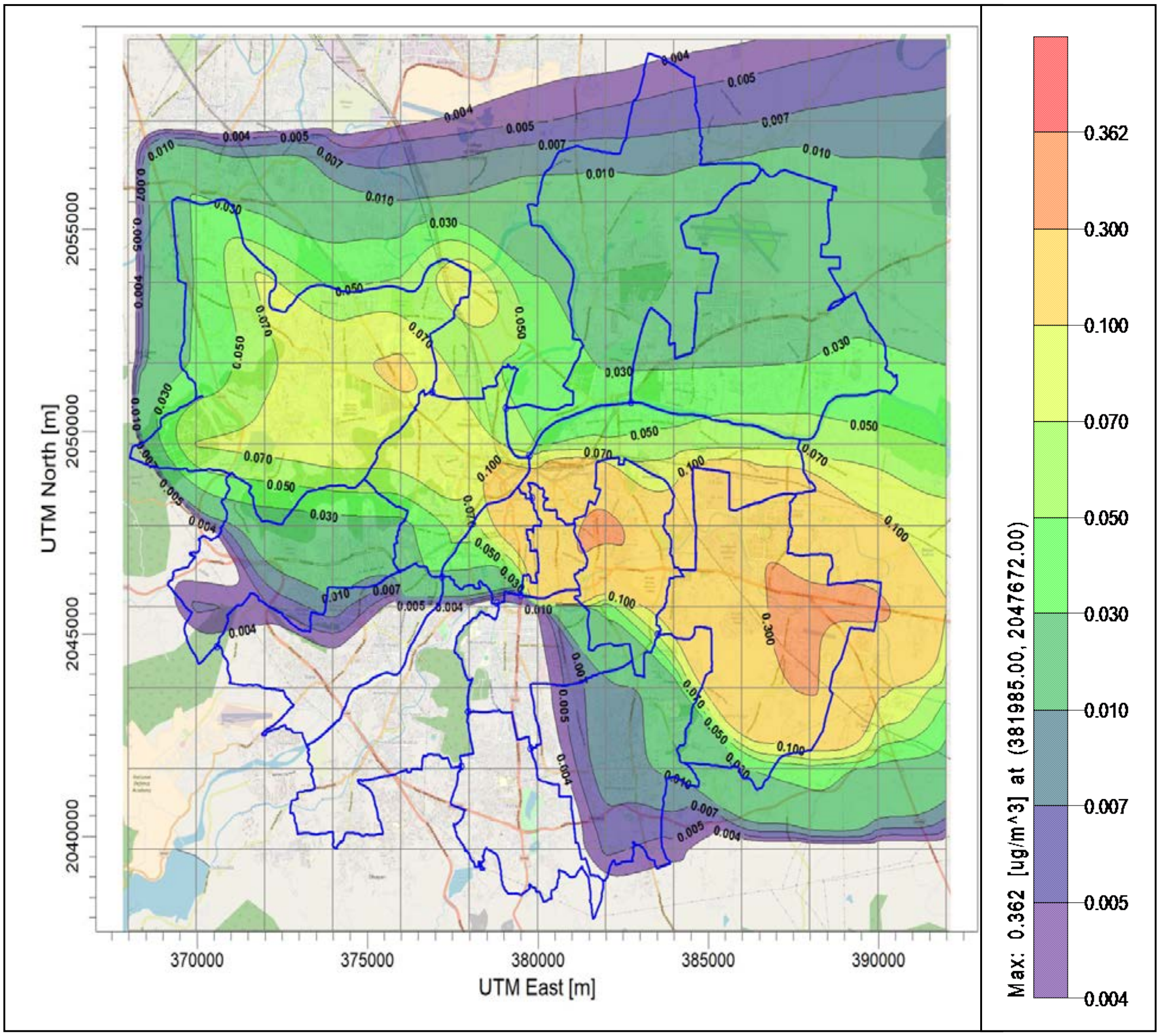

Figure P18 : Isopleths of PM Due to Point Sources (MSI)– Post Monsoon Season (Pune City)

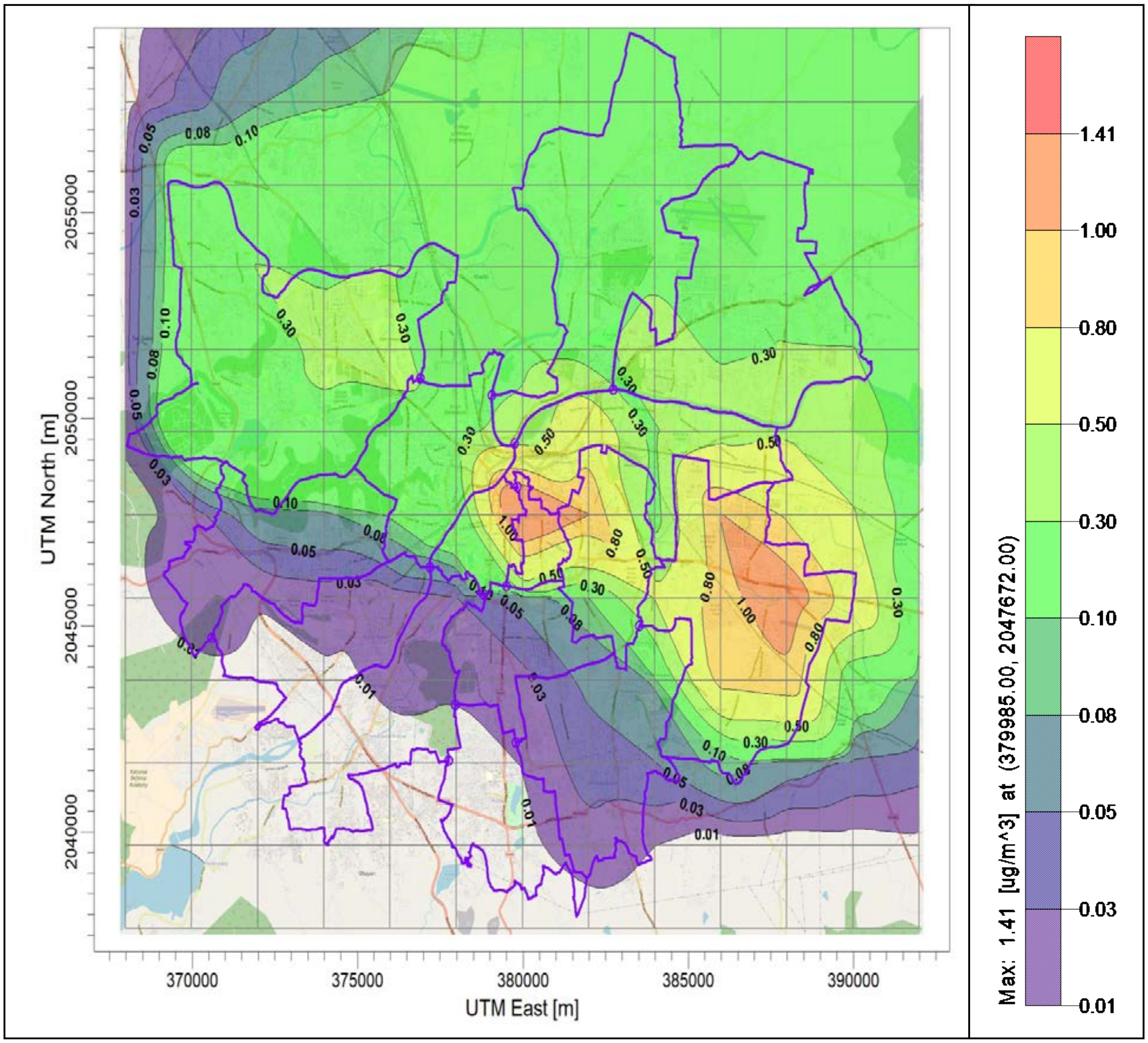

Figure P19 : Isopleths of PM Due to Point Sources (MSI) – Winter Season (Pune City)

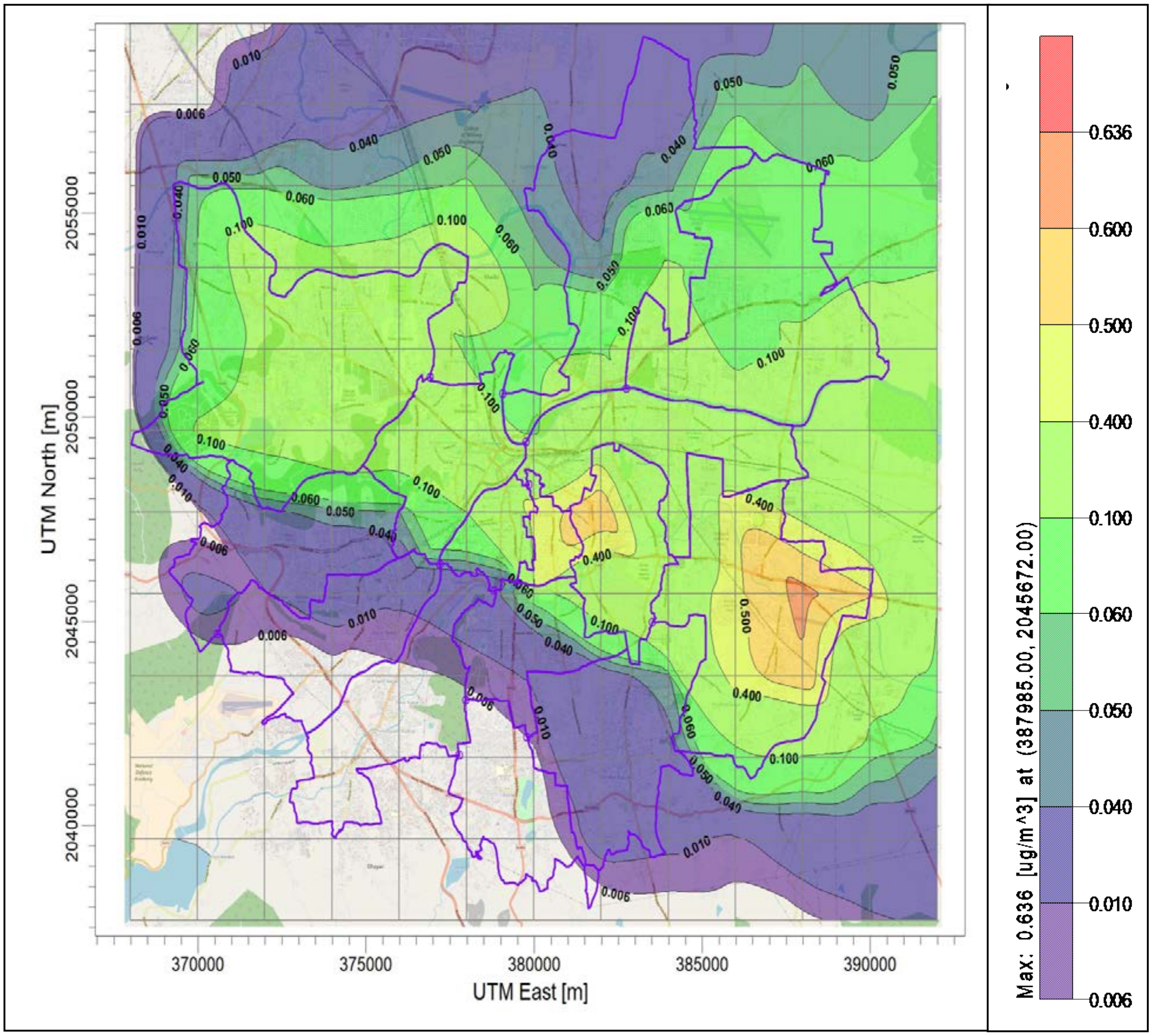

Figure P20 : Isopleths of PM Due to Point Sources (MSI) – Annual (Pune City)

F) POINT SOURCE – SSI PM

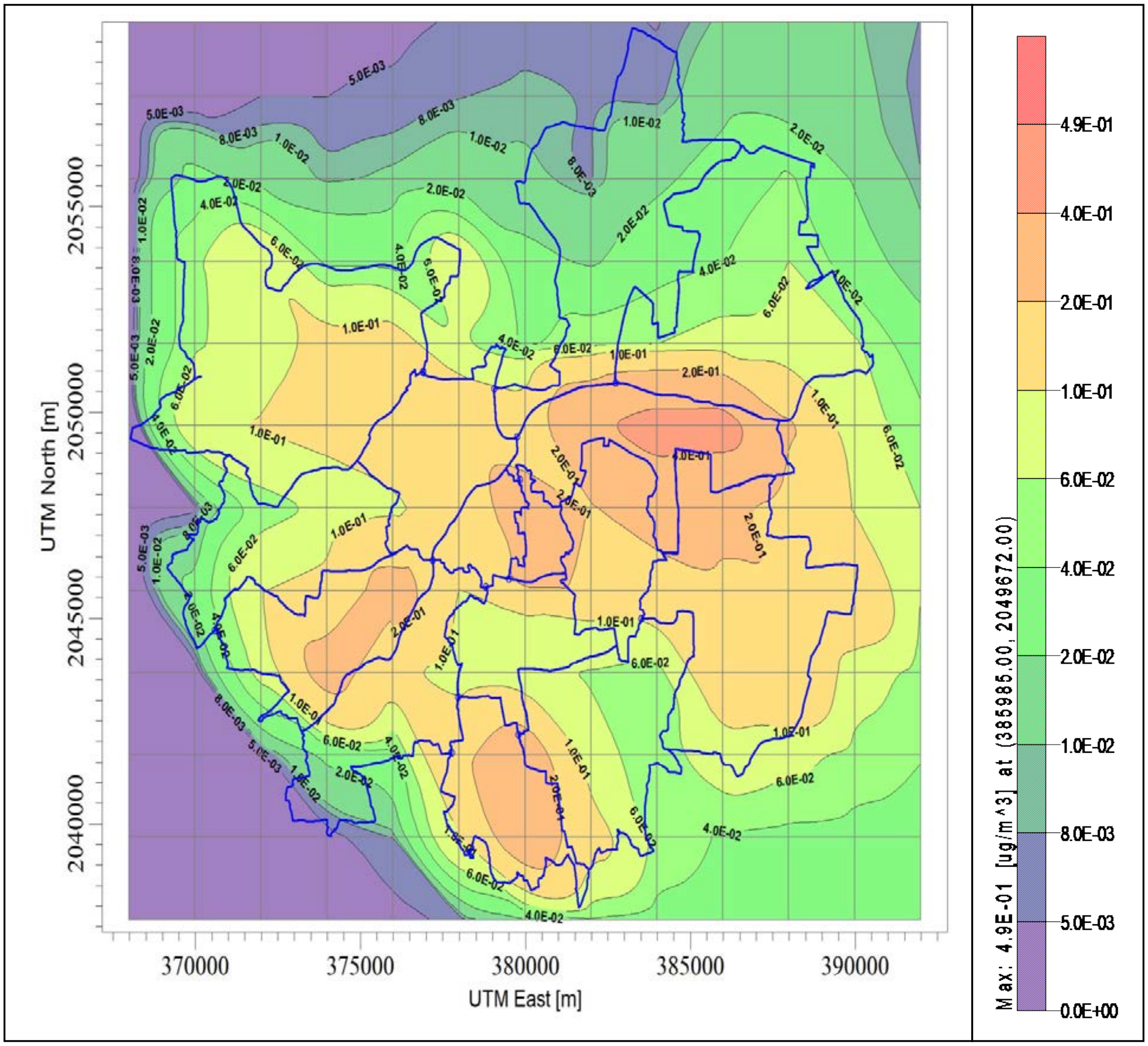

Figure P21 : Isopleths of PM Due to Point Sources (SSI) – Summer Season (Pune City)

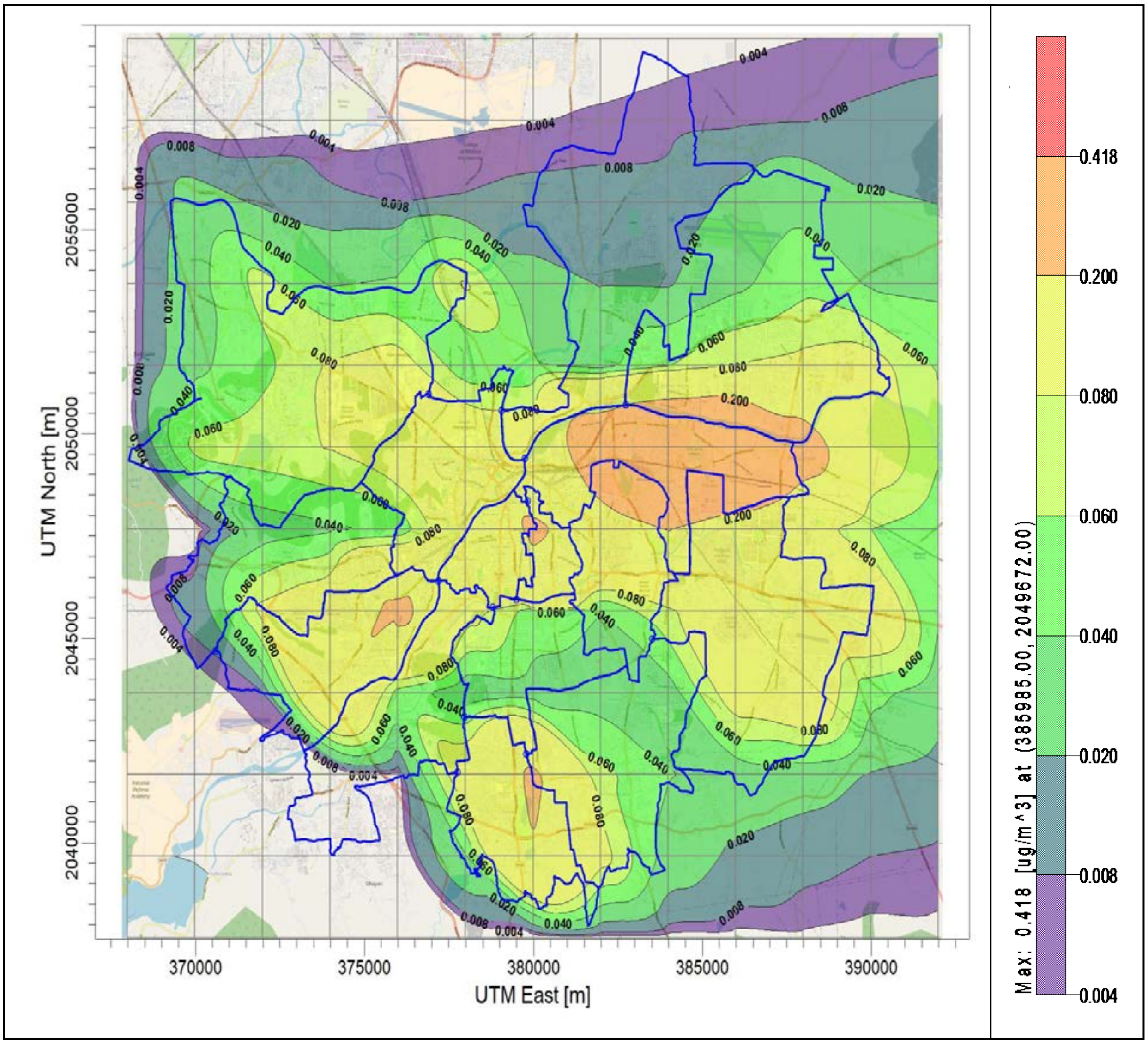

Figure P22 : Isopleths of PM Due to Point Sources (SSI) – Post Monsoon Season (Pune City)

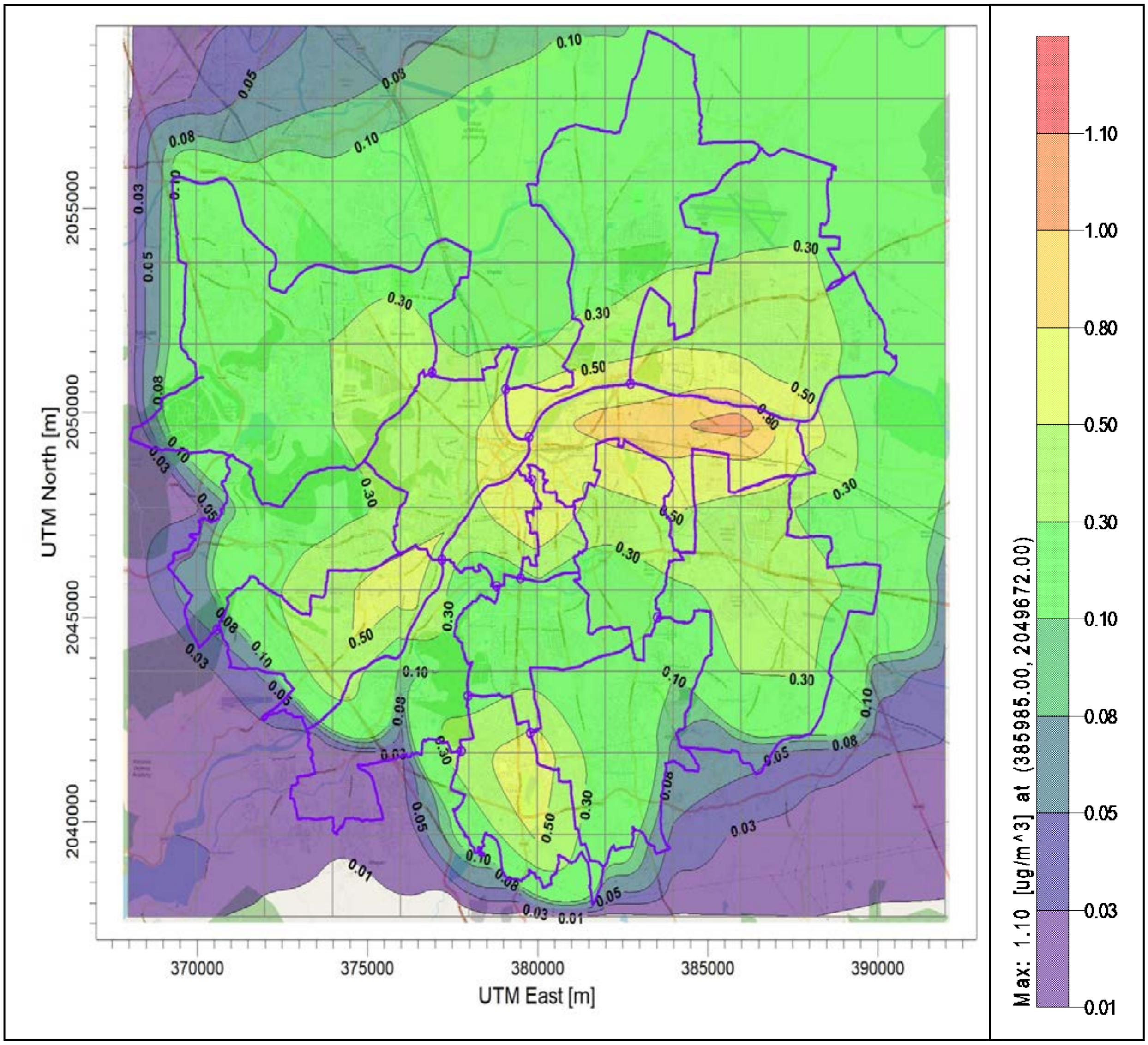

Figure P23 : Isopleths of PM Due to Point Sources (SSI) – Winter Season (Pune City)

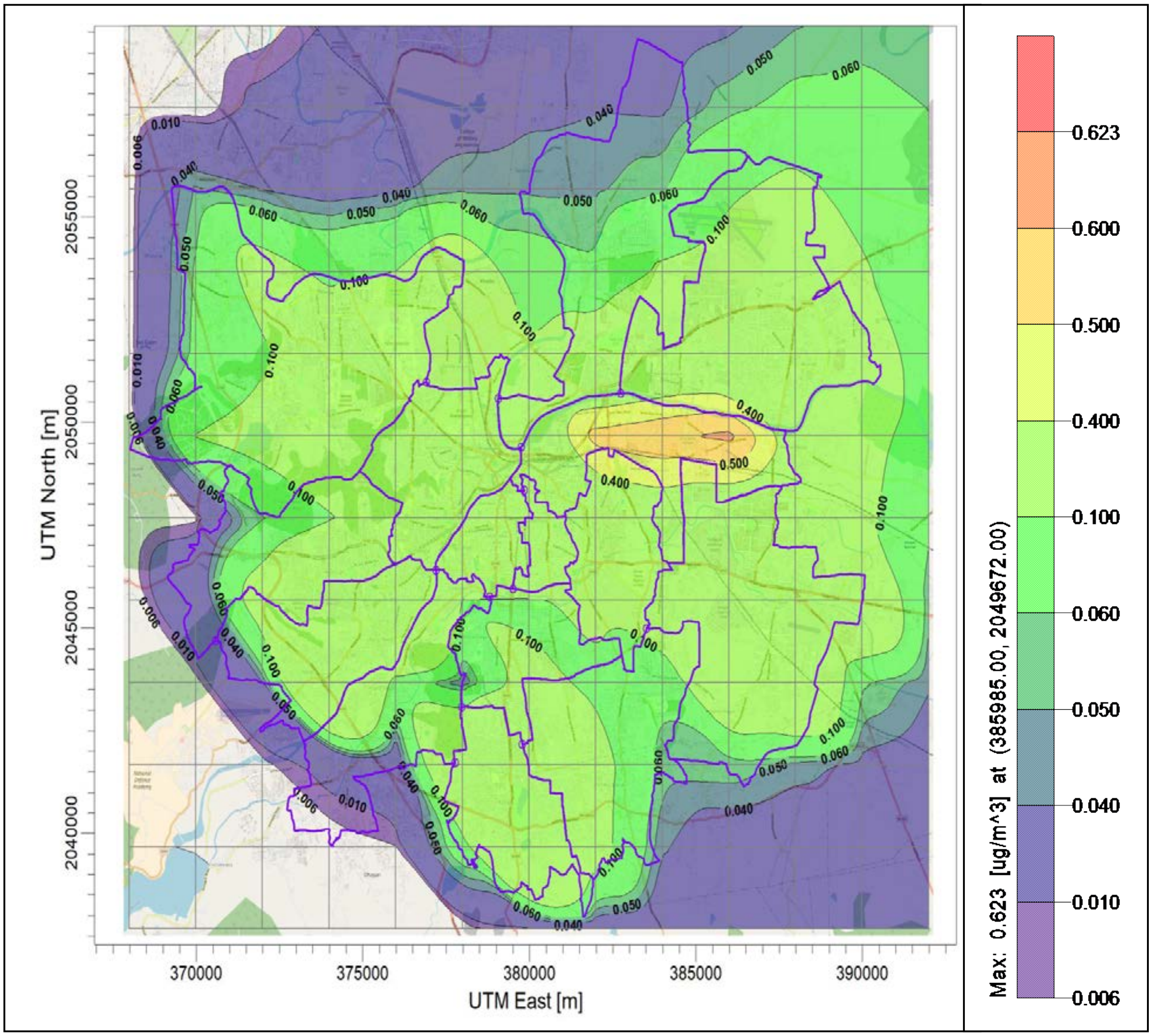

Figure P24 : Isopleths of PM Due to Point Sources (SSI) – Annual (Pune City)

ANNEXURE – 3

Maximum Ten Concentrations of PM_{10} (Annual) BaU 2018, 2020, 2025 and Preferred Option I -2020, Preferred Option II – 2025

Pune City

Annexure 3

A) Maximum Ten Occurrences of PM_{10} Concentrations in BaU 2018 at Pune City (Annual)

Annual - All Source – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	379390.34	2046051.10	245.14
2nd	379390.34	2046051.10	239.79
3rd	379390.34	2046051.10	198.76
4th	379390.34	2046051.10	130.99
5th	379390.34	2046051.10	115.93
6th	379390.34	2046051.10	113.24
7th	379390.34	2046051.10	94.59
8th	379390.34	2046051.10	92.95
9th	379390.34	2046051.10	90.98
10th	379390.34	2046051.10	89.78
Avg.	379390.34	2046051.10	146.69

Annual - Area Source – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	23.79
2nd	379985.00	2047672.00	22.55
3rd	379985.00	2047672.00	18.53
4th	380042.70	2045898.64	11.37
5th	380042.70	2045898.64	10.39
6th	380042.70	2045898.64	10.18
7th	379985.00	2047672.00	8.02
8th	379985.00	2047672.00	7.67
9th	379985.00	2047672.00	7.67
10th	381985.00	2047672.00	7.12
Avg.	379985.00	2047672.00	12.87

Annual – Point Source (LSI) – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	3.08
2nd	379985.00	2047672.00	2.93
3rd	379985.00	2047672.00	2.87
4th	377985.00	2047672.00	1.77
5th	377985.00	2047672.00	1.75
6th	377985.00	2047672.00	1.61
7th	377985.00	2047672.00	1.42
8th	377985.00	2047672.00	1.17
9th	377985.00	2047672.00	0.56
10th	377985.00	2047672.00	0.51
All Avg.	377985.00	2047672.00	1.68

Annual – Point Source (MSI) – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2047672.00	1.59
2nd	381985.00	2047672.00	1.22
3rd	387985.00	2045672.00	0.96
4th	387985.00	2043672.00	0.49
5th	387985.00	2043672.00	0.44
6th	387985.00	2043672.00	0.42
7th	389985.00	2045672.00	0.32
8th	389985.00	2045672.00	0.31
9th	389985.00	2045672.00	0.30
10th	389985.00	2045672.00	0.29
Avg.	387985.00	2045672.00	0.64

Annual – Point Source (SSI) – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	385985.00	2049672.00	1.17
2nd	385985.00	2049672.00	1.14
3rd	385985.00	2049672.00	0.92
4th	383985.00	2049672.00	0.47
5th	383985.00	2049672.00	0.43
6th	383985.00	2049672.00	0.40
7th	385985.00	2049672.00	0.38
8th	385985.00	2049672.00	0.38
9th	385985.00	2049672.00	0.37
10th	385985.00	2049672.00	0.31
Avg.	385985.00	2049672.00	0.62

A) Maximum Ten Occurrences of PM_{10} Concentrations in BaU 2018 at Pune City (Annual) (Contd..)

Annual – Line Source – BaU 2018			
	X length,m	Y length,m	Concentration µg/m^3
1st	387985.00	2051672.00	39.58
2nd	387985.00	2051672.00	36.01
3rd	387985.00	2051672.00	28.17
4th	387985.00	2051672.00	17.27
5th	387985.00	2051672.00	16.57
6th	387985.00	2051672.00	16.47
7th	387985.00	2051672.00	14.68
8th	387985.00	2051672.00	14.31
9th	387985.00	2051672.00	14.00
10th	387985.00	2051672.00	13.59
Avg.	387985.00	2051672.00	22.12

Annual – Resuspended Dust– BaU 2018			
	X length,m	Y length,m	Concentration µg/m^3
1st	379390.34	2046051.10	220.46
2nd	379390.34	2046051.10	215.73
3rd	379390.34	2046051.10	178.71
4th	379390.34	2046051.10	116.03
5th	379390.34	2046051.10	102.49
6th	379390.34	2046051.10	99.97
7th	379390.34	2046051.10	85.41
8th	379390.34	2046051.10	83.70
9th	379390.34	2046051.10	82.03
10th	379390.34	2046051.10	81.86
Avg.	379390.34	2046051.10	131.40

B) Maximum Ten Occurrences of PM_{10} Concentrations in BaU 2020 at Pune City (Annual)

Annual - All Source – BaU 2020			
	X length,m	Y length,m	Concentration μg/m^3
1st	379390.34	2046051.10	280.49
2nd	379390.34	2046051.10	274.87
3rd	379390.34	2046051.10	224.78
4th	379390.34	2046051.10	144.89
5th	379390.34	2046051.10	127.11
6th	379390.34	2046051.10	125.16
7th	379390.34	2046051.10	103.22
8th	379390.34	2046051.10	101.36
9th	379390.34	2046051.10	99.28
10th	379390.34	2046051.10	98.69
Avg.	379390.34	2046051.10	164.29

Annual - Area Source – BaU 2020			
	X length,m	Y length,m	Concentration μg/m^3
1st	379985.00	2047672.00	27.00
2nd	379985.00	2047672.00	25.52
3rd	379985.00	2047672.00	20.93
4th	380042.70	2045898.64	14.53
5th	380042.70	2045898.64	12.87
6th	380042.70	2045898.64	12.81
7th	379985.00	2047672.00	8.98
8th	379985.00	2047672.00	8.62
9th	379985.00	2047672.00	8.62
10th	379985.00	2047672.00	8.14
Avg.	379985.00	2047672.00	14.43

Annual – Point Source (LSI) – BaU 2020			
	X length,m	Y length,m	Concentration μg/m^3
1st	379985.00	2047672.00	3.09
2nd	379985.00	2047672.00	2.93
3rd	379985.00	2047672.00	2.86
4th	377985.00	2047672.00	1.82
5th	377985.00	2047672.00	1.81
6th	377985.00	2047672.00	1.67
7th	377985.00	2047672.00	1.48
8th	377985.00	2047672.00	1.21
9th	377985.00	2047672.00	0.58
10th	377985.00	2047672.00	0.54
All Avg.	377985.00	2047672.00	1.73

Annual – Point Source (MSI) – BaU 2020			
	X length,m	Y length,m	Concentration μg/m^3
1st	381985.00	2047672.00	1.60
2nd	387985.00	2045672.00	1.26
3rd	387985.00	2045672.00	0.99
4th	380042.70	2045898.64	0.50
5th	387985.00	2043672.00	0.44
6th	387985.00	2043672.00	0.41
7th	389985.00	2045672.00	0.34
8th	389985.00	2045672.00	0.33
9th	389985.00	2045672.00	0.32
10th	391985.00	2045672.00	0.31
Avg.	387985.00	2045672.00	0.66

Annual – Point Source (SSI) – BaU 2020			
	X length,m	Y length,m	Concentration μg/m^3
1st	381985.00	2049672.00	1.45
2nd	381985.00	2049672.00	1.38
3rd	381985.00	2049672.00	1.06
4th	383985.00	2049672.00	0.49
5th	383985.00	2049672.00	0.44
6th	383985.00	2049672.00	0.42
7th	385985.00	2049672.00	0.40
8th	385985.00	2049672.00	0.40
9th	385985.00	2049672.00	0.39
10th	385985.00	2049672.00	0.31
Avg.	381985.00	2049672.00	0.69

B) Maximum Ten Occurrences of PM_{10} Concentrations in BaU 2020 at Pune City (Annual) (Contd..)

Annual – Line Source – BaU 2020			
	X length,m	Y length,m	Concentration µg/m^3
1st	387985.00	2051672.00	33.92
2nd	387985.00	2051672.00	33.20
3rd	387985.00	2051672.00	26.57
4th	383985.00	2037672.00	18.61
5th	383985.00	2037672.00	15.93
6th	383985.00	2037672.00	15.76
7th	383985.00	2037672.00	11.85
8th	383985.00	2037672.00	11.67
9th	383985.00	2037672.00	11.46
10th	383985.00	2037672.00	10.95
Avg.	383985.00	2037672.00	19.50

Annual – Resuspended Dust– BaU 2020			
	X length,m	Y length,m	Concentration µg/m^3
1st	379390.34	2046051.10	247.16
2nd	379390.34	2046051.10	242.22
3rd	379390.34	2046051.10	198.17
4th	379390.34	2046051.10	126.31
5th	379390.34	2046051.10	110.79
6th	379390.34	2046051.10	108.89
7th	379390.34	2046051.10	91.42
8th	379390.34	2046051.10	89.61
9th	379390.34	2046051.10	87.84
10th	379390.34	2046051.10	87.12
Avg.	379390.34	2046051.10	144.46

C) Maximum Ten Occurrences of PM_{10} Concentrations in BaU 2025 at Pune City (Annual)

Annual - All Source – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379390.34	2046051.10	303.28
2nd	379390.34	2046051.10	297.22
3rd	379390.34	2046051.10	243.04
4th	379390.34	2046051.10	156.58
5th	379390.34	2046051.10	137.37
6th	379390.34	2046051.10	135.25
7th	379390.34	2046051.10	111.62
8th	379390.34	2046051.10	109.59
9th	379390.34	2046051.10	107.35
10th	379390.34	2046051.10	106.84
Avg.	379390.34	2046051.10	177.62

Annual - Area Source – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	28.89
2nd	379985.00	2047672.00	27.31
3rd	379985.00	2047672.00	22.39
4th	380042.70	2045898.64	15.55
5th	380042.70	2045898.64	13.78
6th	380042.70	2045898.64	13.71
7th	379985.00	2047672.00	9.60
8th	379985.00	2047672.00	9.22
9th	379985.00	2047672.00	9.22
10th	379985.00	2047672.00	9.08
Avg.	379985.00	2047672.00	15.44

Annual – Point Source (LSI) – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	3.09
2nd	379985.00	2047672.00	2.93
3rd	379985.00	2047672.00	2.86
4th	377985.00	2047672.00	1.82
5th	377985.00	2047672.00	1.81
6th	377985.00	2047672.00	1.67
7th	377985.00	2047672.00	1.48
8th	377985.00	2047672.00	1.21
9th	377985.00	2047672.00	0.58
10th	377985.00	2047672.00	0.57
All Avg.	377985.00	2047672.00	1.73

Annual – Point Source (MSI) – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2047672.00	1.60
2nd	387985.00	2045672.00	1.26
3rd	387985.00	2045672.00	0.99
4th	380042.70	2045898.64	0.50
5th	387985.00	2043672.00	0.44
6th	387985.00	2043672.00	0.41
7th	389985.00	2045672.00	0.34
8th	389985.00	2045672.00	0.33
9th	389985.00	2045672.00	0.32
10th	389985.00	2045672.00	0.31
Avg.	387985.00	2045672.00	0.66

Annual – Point Source (SSI) – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	1.45
2nd	381985.00	2049672.00	1.38
3rd	381985.00	2049672.00	1.06
4th	383985.00	2049672.00	0.49
5th	383985.00	2049672.00	0.44
6th	383985.00	2049672.00	0.42
7th	385985.00	2049672.00	0.40
8th	385985.00	2049672.00	0.40
9th	385985.00	2049672.00	0.39
10th	385985.00	2049672.00	0.38
Avg.	381985.00	2049672.00	0.69

C) Maximum Ten Occurrences of PM_{10} Concentrations in BaU 2025 at Pune City (Annual) (Contd..)

Annual – Line Source – BaU 2025			
	X length,m	Y length,m	Concentration µg/m^3
1st	387985.00	2051672.00	36.70
2nd	387985.00	2051672.00	35.93
3rd	387985.00	2051672.00	28.75
4th	383985.00	2037672.00	20.14
5th	383985.00	2037672.00	17.24
6th	383985.00	2037672.00	17.05
7th	383985.00	2037672.00	12.83
8th	383985.00	2037672.00	12.63
9th	383985.00	2037672.00	12.40
10th	383985.00	2037672.00	12.06
Avg.	383985.00	2037672.00	21.10

Annual – Resuspended Dust– BaU 2025			
	X length,m	Y length,m	Concentration µg/m^3
1st	379390.34	2046051.10	267.45
2nd	379390.34	2046051.10	262.11
3rd	379390.34	2046051.10	214.44
4th	379390.34	2046051.10	136.68
5th	379390.34	2046051.10	119.89
6th	379390.34	2046051.10	117.83
7th	379390.34	2046051.10	98.92
8th	379390.34	2046051.10	96.97
9th	379390.34	2046051.10	95.05
10th	379390.34	2046051.10	94.64
Avg.	379390.34	2046051.10	156.32

D) Maximum Ten Occurrences of PM_{10} Concentrations after Implementation of Control Options (Preferred Option I -2020) at Pune City (Annual)

Annual All Source Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	379390.34	2046051.10	141.09
2nd	379390.34	2046051.10	138.26
3rd	379390.34	2046051.10	113.06
4th	379390.34	2046051.10	72.88
5th	379390.34	2046051.10	63.94
6th	379390.34	2046051.10	62.95
7th	379390.34	2046051.10	51.92
8th	379390.34	2046051.10	50.98
9th	379390.34	2046051.10	49.94
10th	379390.34	2046051.10	48.55
Avg.	379390.34	2046051.10	82.64

Annual Area Source Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	13.58
2nd	379985.00	2047672.00	12.84
3rd	379985.00	2047672.00	10.53
4th	380042.70	2045898.64	7.31
5th	380042.70	2045898.64	6.48
6th	380042.70	2045898.64	6.44
7th	379985.00	2047672.00	4.51
8th	379985.00	2047672.00	4.34
9th	379985.00	2047672.00	4.34
10th	381985.00	2047672.00	4.12
Avg.	379985.00	2047672.00	7.26

Annual Point Source (LSI) Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	1.55
2nd	379985.00	2047672.00	1.47
3rd	379985.00	2047672.00	1.44
4th	377985.00	2047672.00	0.91
5th	377985.00	2047672.00	0.91
6th	377985.00	2047672.00	0.84
7th	377985.00	2047672.00	0.74
8th	377985.00	2047672.00	0.61
9th	377985.00	2047672.00	0.29
10th	377985.00	2047672.00	0.28
All Avg.	377985.00	2047672.00	0.87

Annual Point Source (MSI) Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2047672.00	0.80
2nd	387985.00	2045672.00	0.63
3rd	387985.00	2045672.00	0.50
4th	380042.70	2045898.64	0.25
5th	387985.00	2043672.00	0.22
6th	387985.00	2043672.00	0.21
7th	389985.00	2045672.00	0.17
8th	389985.00	2045672.00	0.16
9th	389985.00	2045672.00	0.16
10th	389985.00	2045672.00	0.13
Avg.	387985.00	2045672.00	0.33

Annual Point Source (SSI) Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.73
2nd	381985.00	2049672.00	0.69
3rd	381985.00	2049672.00	0.53
4th	383985.00	2049672.00	0.25
5th	383985.00	2049672.00	0.22
6th	383985.00	2049672.00	0.21
7th	385985.00	2049672.00	0.20
8th	385985.00	2049672.00	0.20
9th	385985.00	2049672.00	0.20
10th	385985.00	2049672.00	0.19
Avg.	381985.00	2049672.00	0.35

D) Maximum Ten Occurrences of PM_{10} Concentrations after Implementation of Control Options (Preferred Option I -2020) at Pune City (Annual) (Contd..)

Annual Line Source Preferred Option I -2020			
	X length,m	**Y length,m**	**Concentration µg/m^3**
1st	387985.00	2051672.00	17.06
2nd	387985.00	2051672.00	16.70
3rd	387985.00	2051672.00	13.36
4th	383985.00	2037672.00	9.36
5th	383985.00	2037672.00	8.01
6th	383985.00	2037672.00	7.93
7th	383985.00	2037672.00	5.96
8th	383985.00	2037672.00	5.87
9th	383985.00	2037672.00	5.76
10th	383985.00	2037672.00	5.51
Avg.	383985.00	2037672.00	9.81

Annual Resuspended Dust Preferred Option I -2020			
	X length,m	**Y length,m**	**Concentration µg/m^3**
1st	379390.34	2046051.10	124.32
2nd	379390.34	2046051.10	121.84
3rd	379390.34	2046051.10	99.68
4th	379390.34	2046051.10	63.53
5th	379390.34	2046051.10	55.73
6th	379390.34	2046051.10	54.77
7th	379390.34	2046051.10	45.98
8th	379390.34	2046051.10	45.08
9th	379390.34	2046051.10	44.18
10th	379390.34	2046051.10	43.68
Avg.	379390.34	2046051.10	72.67

E) Maximum Ten Occurrences of PM_{10} Concentrations after Implementation of Control Options (Preferred Option II -2025) at Pune City (Annual)

Annual All Source Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379390.34	2046051.10	94.32
2nd	379390.34	2046051.10	92.44
3rd	379390.34	2046051.10	75.58
4th	379390.34	2046051.10	48.70
5th	379390.34	2046051.10	42.72
6th	379390.34	2046051.10	42.06
7th	379390.34	2046051.10	34.71
8th	379390.34	2046051.10	34.08
9th	379390.34	2046051.10	33.39
10th	379390.34	2046051.10	32.87
Avg.	379390.34	2046051.10	55.24

Annual Area Source Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	8.98
2nd	379985.00	2047672.00	8.49
3rd	379985.00	2047672.00	6.96
4th	380042.70	2045898.64	4.84
5th	380042.70	2045898.64	4.28
6th	380042.70	2045898.64	4.26
7th	379985.00	2047672.00	2.99
8th	379985.00	2047672.00	2.87
9th	379985.00	2047672.00	2.87
10th	379985.00	2047672.00	2.65
Avg.	379985.00	2047672.00	4.80

Annual Point Source (LSI) Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	0.96
2nd	379985.00	2047672.00	0.91
3rd	379985.00	2047672.00	0.89
4th	377985.00	2047672.00	0.56
5th	377985.00	2047672.00	0.56
6th	377985.00	2047672.00	0.52
7th	377985.00	2047672.00	0.46
8th	377985.00	2047672.00	0.38
9th	377985.00	2047672.00	0.18
10th	379985.00	2047672.00	0.17
All Avg.	377985.00	2047672.00	0.54

Annual Point Source (MSI) Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2047672.00	0.50
2nd	387985.00	2045672.00	0.39
3rd	387985.00	2045672.00	0.31
4th	380042.70	2045898.64	0.15
5th	387985.00	2043672.00	0.14
6th	387985.00	2043672.00	0.13
7th	389985.00	2045672.00	0.10
8th	389985.00	2045672.00	0.10
9th	389985.00	2045672.00	0.10
10th	389985.00	2045672.00	0.09
Avg.	387985.00	2045672.00	0.20

Annual Point Source (SSI) Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.45
2nd	381985.00	2049672.00	0.43
3rd	381985.00	2049672.00	0.33
4th	383985.00	2049672.00	0.15
5th	383985.00	2049672.00	0.14
6th	383985.00	2049672.00	0.13
7th	385985.00	2049672.00	0.13
8th	385985.00	2049672.00	0.12
9th	385985.00	2049672.00	0.12
10th	387985.00	2049672.00	0.11
Avg.	381985.00	2049672.00	0.22

E) Maximum Ten Occurrences of PM_{10} Concentrations after Implementation of Control Options (Preferred Option II -2025) at Pune City (Annual) (Contd..)

Annual Line Source Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m^3
1st	387985.00	2051672.00	11.41
2nd	387985.00	2051672.00	11.17
3rd	387985.00	2051672.00	8.94
4th	383985.00	2037672.00	6.26
5th	383985.00	2037672.00	5.36
6th	383985.00	2037672.00	5.30
7th	383985.00	2037672.00	3.99
8th	383985.00	2037672.00	3.93
9th	383985.00	2037672.00	3.86
10th	383985.00	2037672.00	3.78
Avg.	383985.00	2037672.00	6.56

Annual Resuspended Dust Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m^3
1st	379390.34	2046051.10	83.18
2nd	379390.34	2046051.10	81.52
3rd	379390.34	2046051.10	66.69
4th	379390.34	2046051.10	42.51
5th	379390.34	2046051.10	37.28
6th	379390.34	2046051.10	36.65
7th	379390.34	2046051.10	30.76
8th	379390.34	2046051.10	30.16
9th	379390.34	2046051.10	29.56
10th	379390.34	2046051.10	28.95
Avg.	379390.34	2046051.10	48.62

ANNEXURE - 4

ISOPLETS OF NOx:

All Categories- (a)Area, (b) Line, (c) Resuspension of Dust, (d) Point –LSI, MSI & SSI

&

For All Seasons (Summer, Post Monsoon, Winter and Annual)

(Pune City)

A) AREA SOURCE – ALL NOX

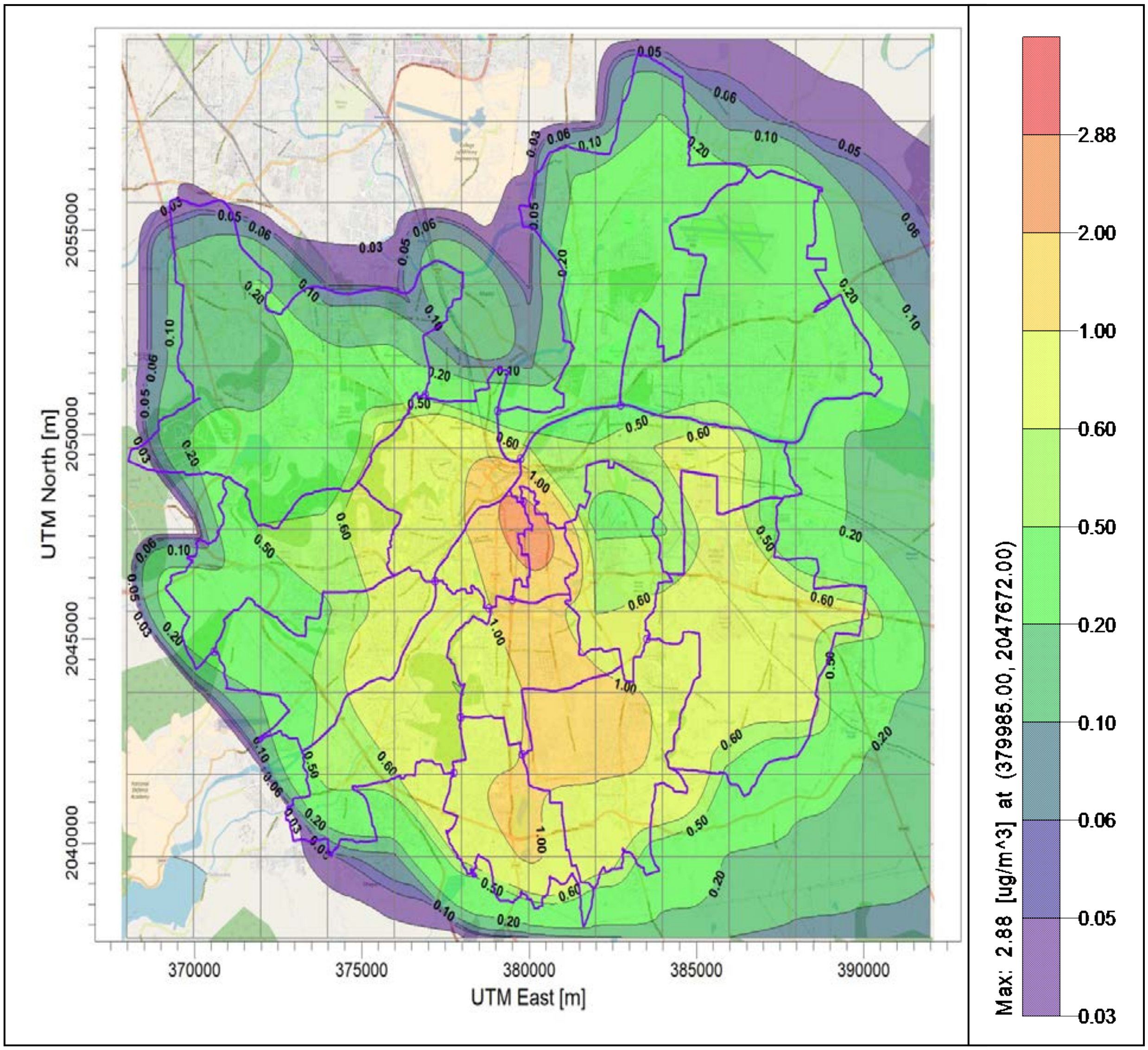

Figure N1 : Isopleths of NOx Due to Area Sources– Summer Season (Pune City)

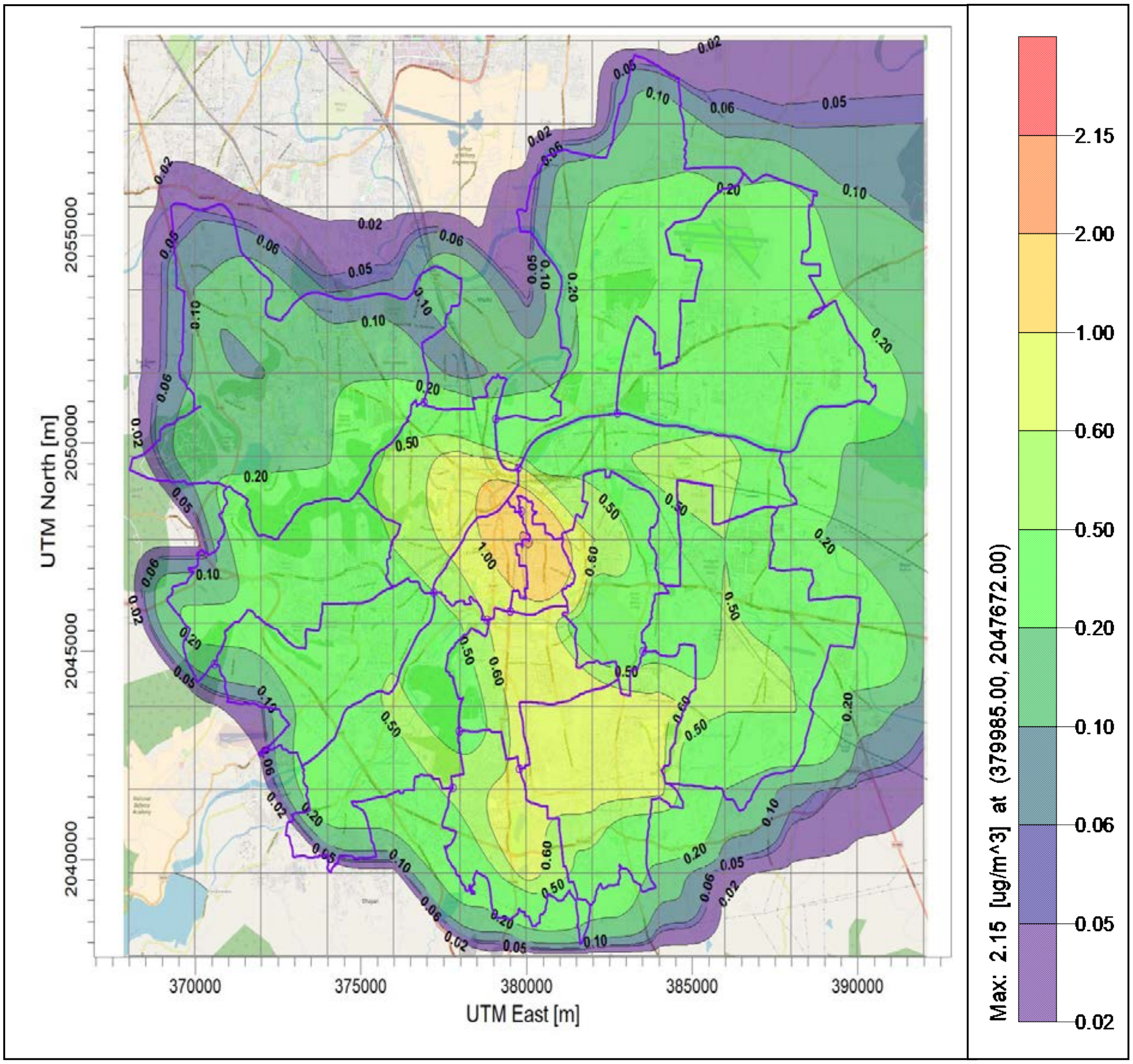

Figure N2 : Isopleths of NOx Due to Area Sources– Post Monsoon Season (Pune City)

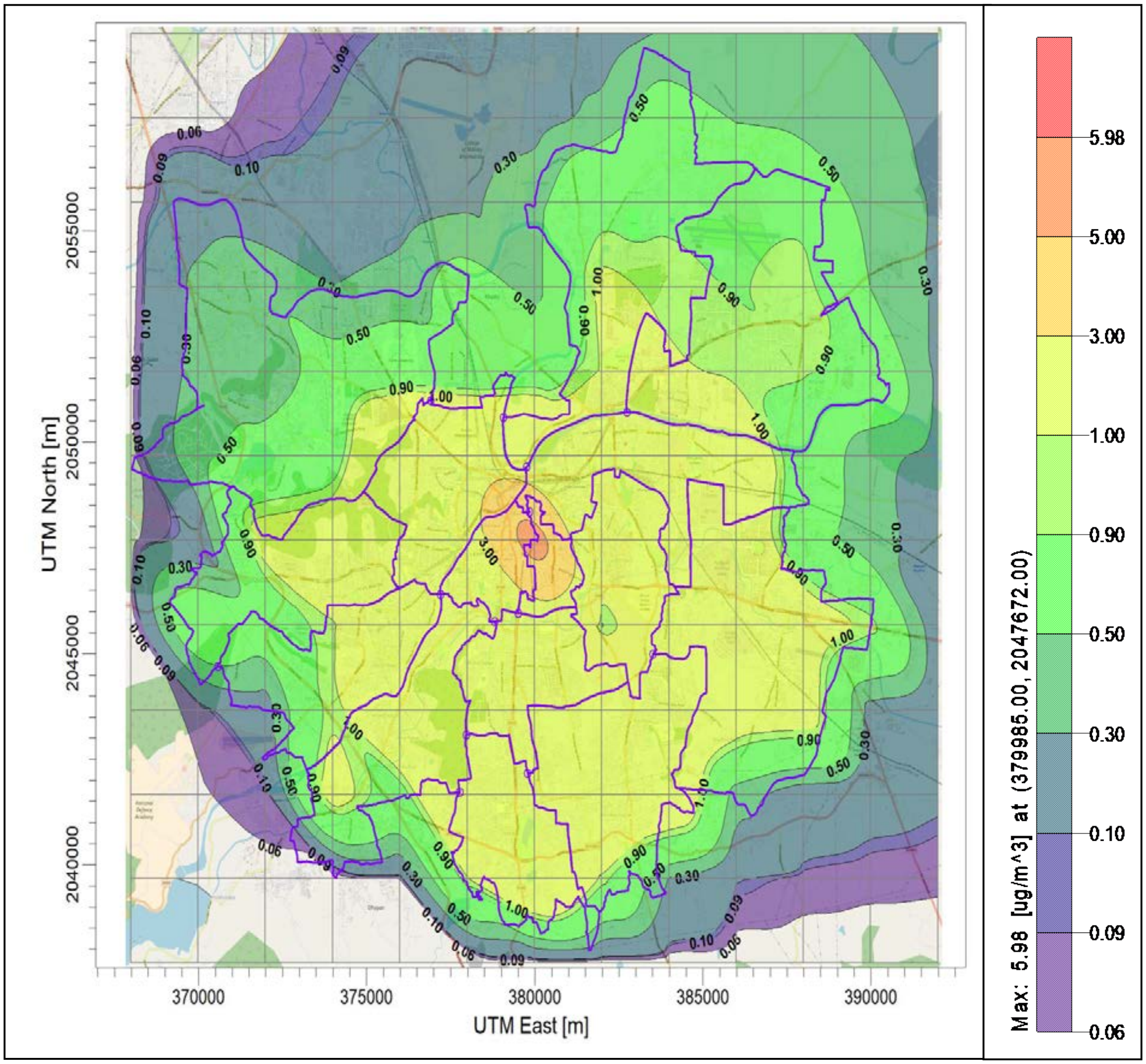

Figure N3 : Isopleths of NOx Due to Area Sources– Winter Season (Pune City)

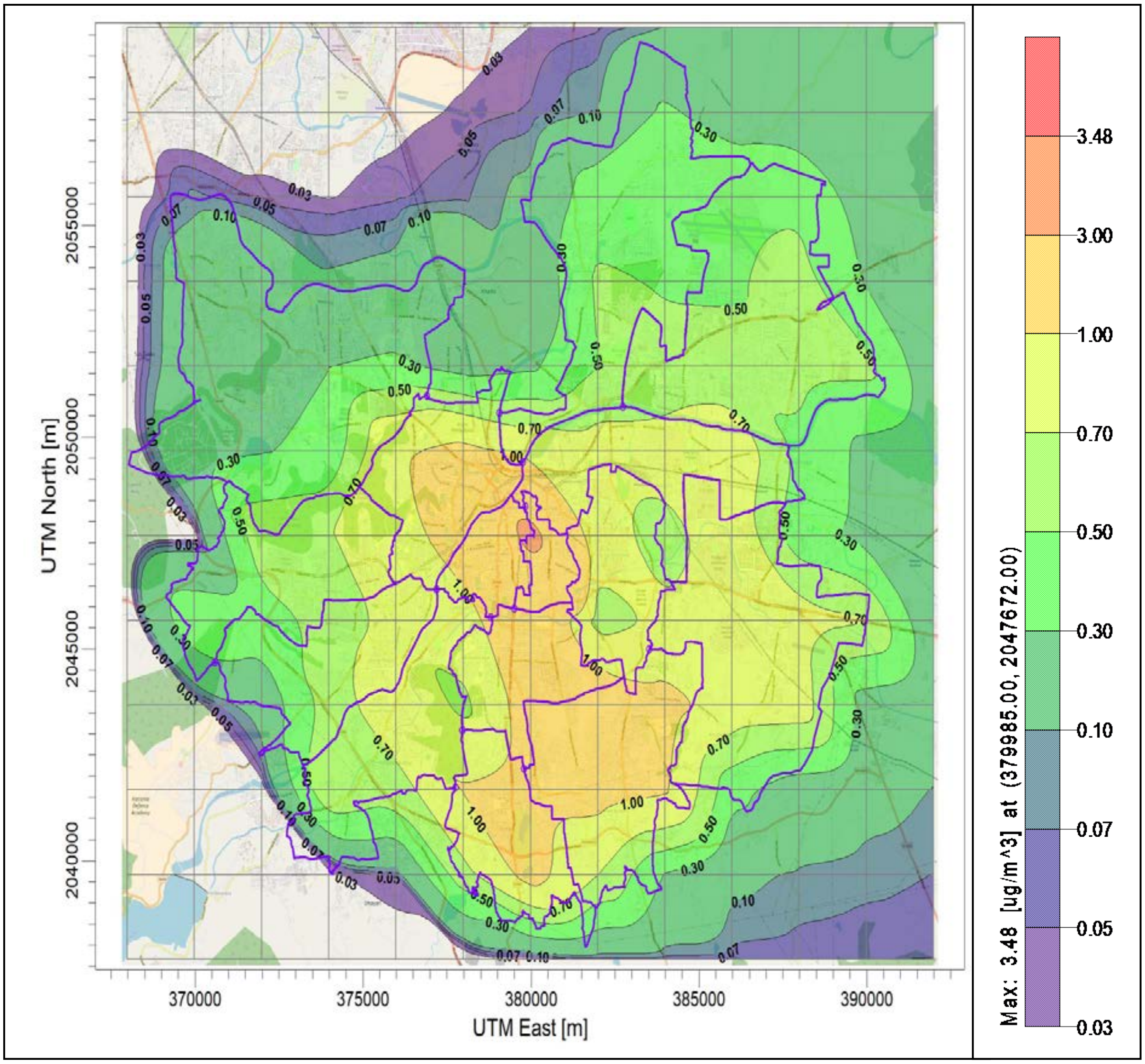

Figure N4 : Isopleths of NOx Due to Area Sources– Annual (Pune City)

B) LINE SOURCE – ALL NOX

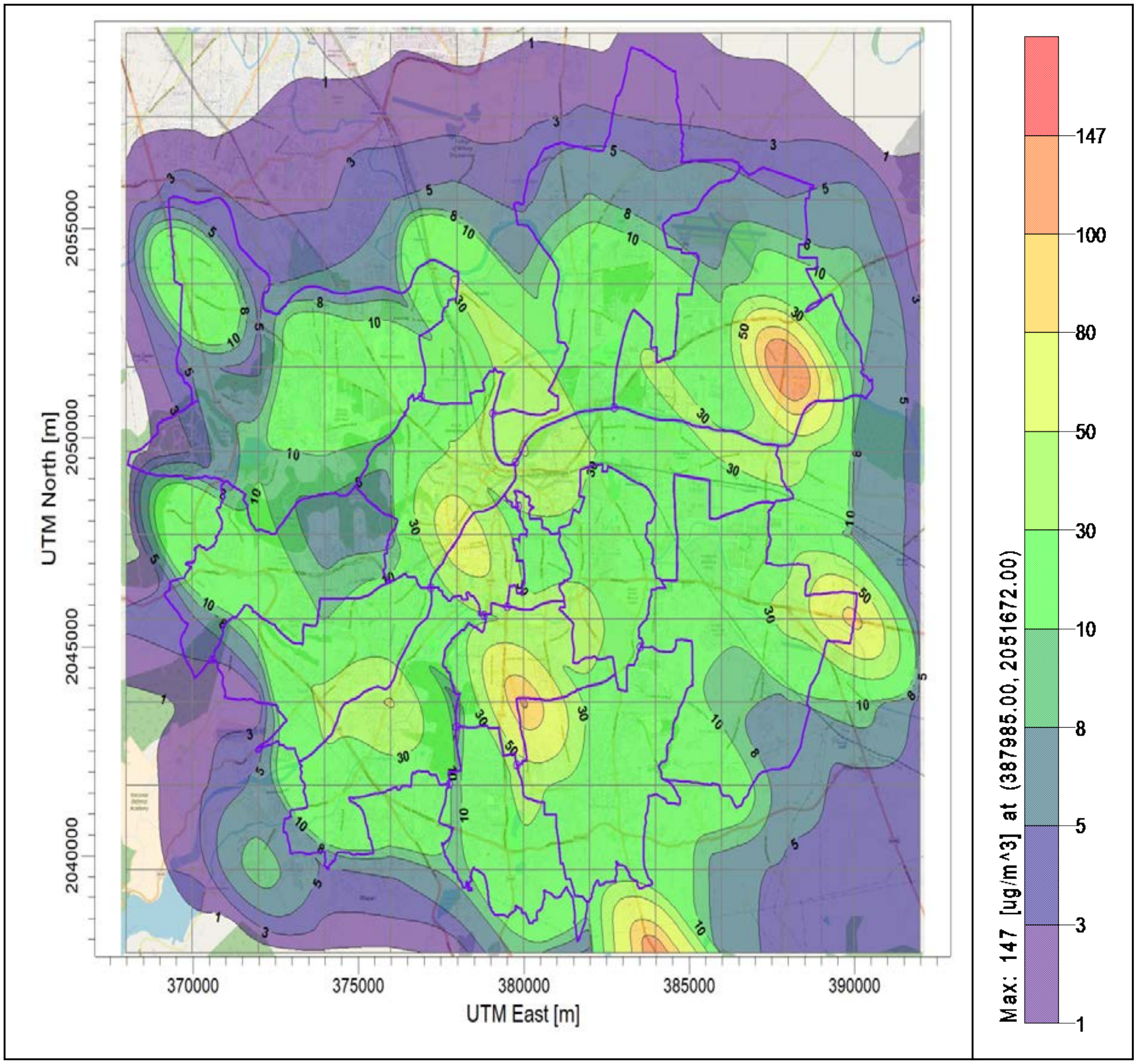

Figure N5 : Isopleths of NOx Due to Line Sources– Summer Season (Pune City)

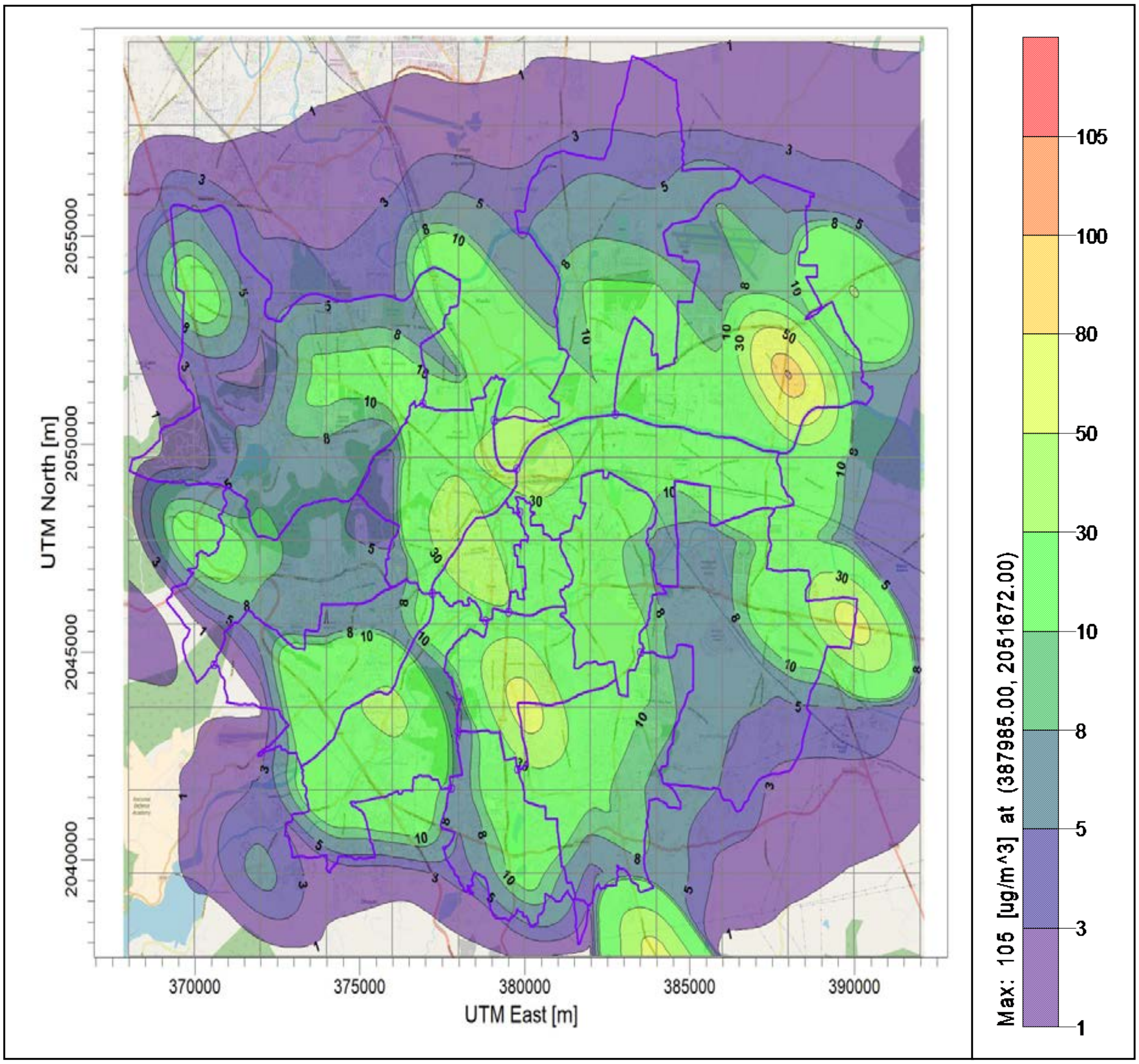

Figure N6 : Isopleths of NOx Due to Line Sources– Post Monsoon Season (Pune City)

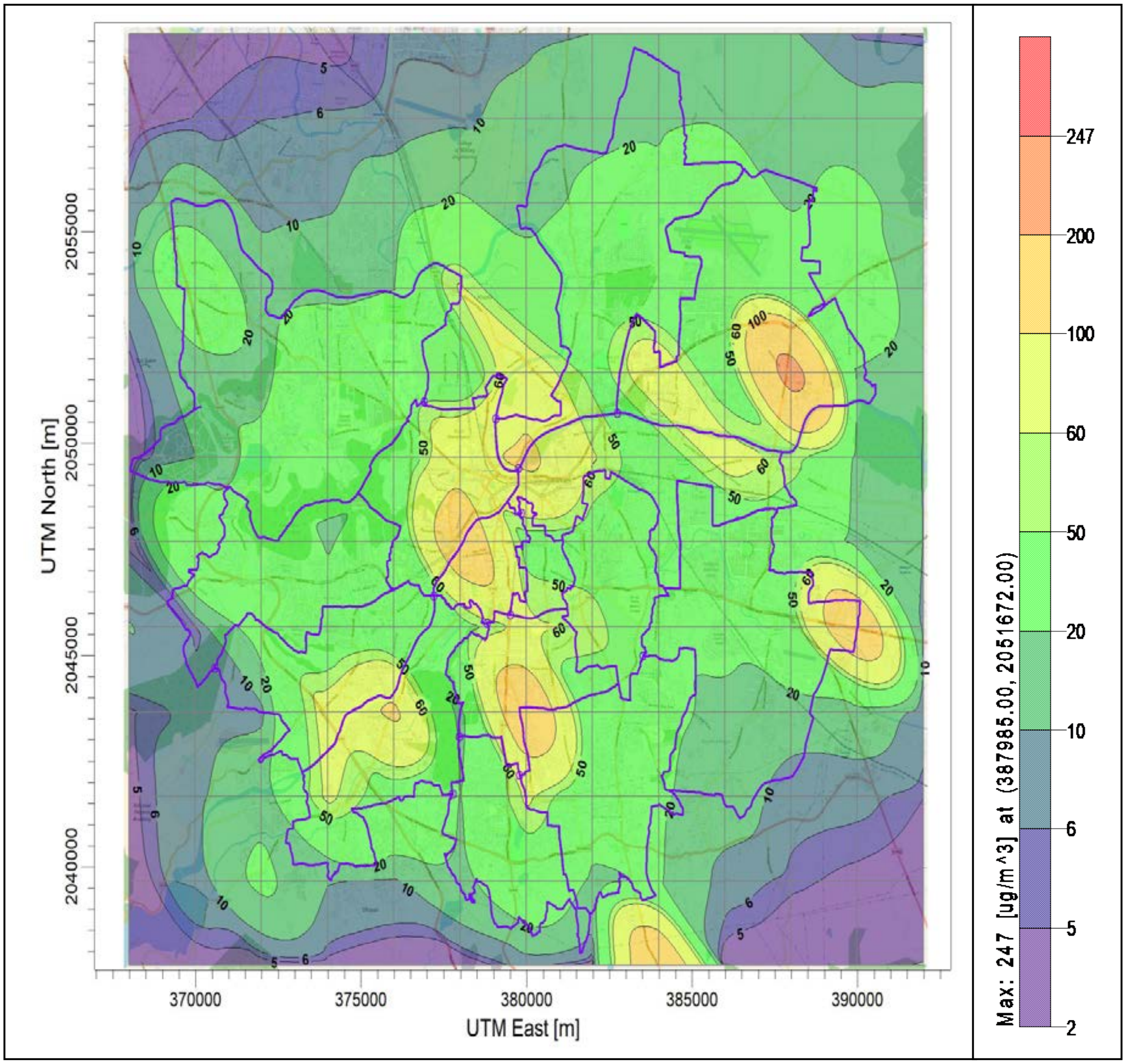

Figure N7 : Isopleths of NOx Due to Line Sources– Winter Season (Pune City)

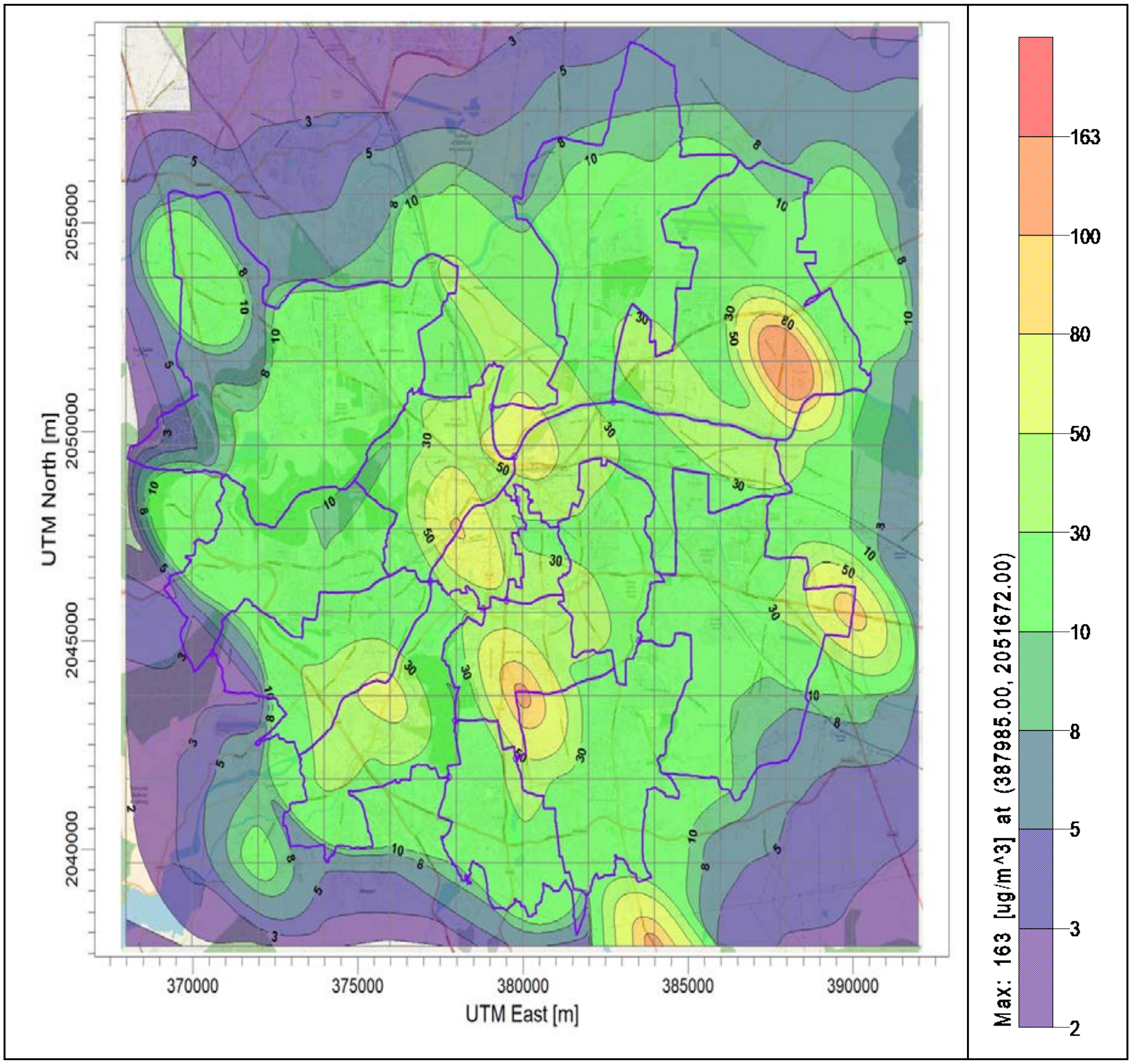

Figure N8 : Isopleths of NOx Due to Line Sources– Annual (Pune City)

C) POINT SOURCE (LSI) – ALL NOX

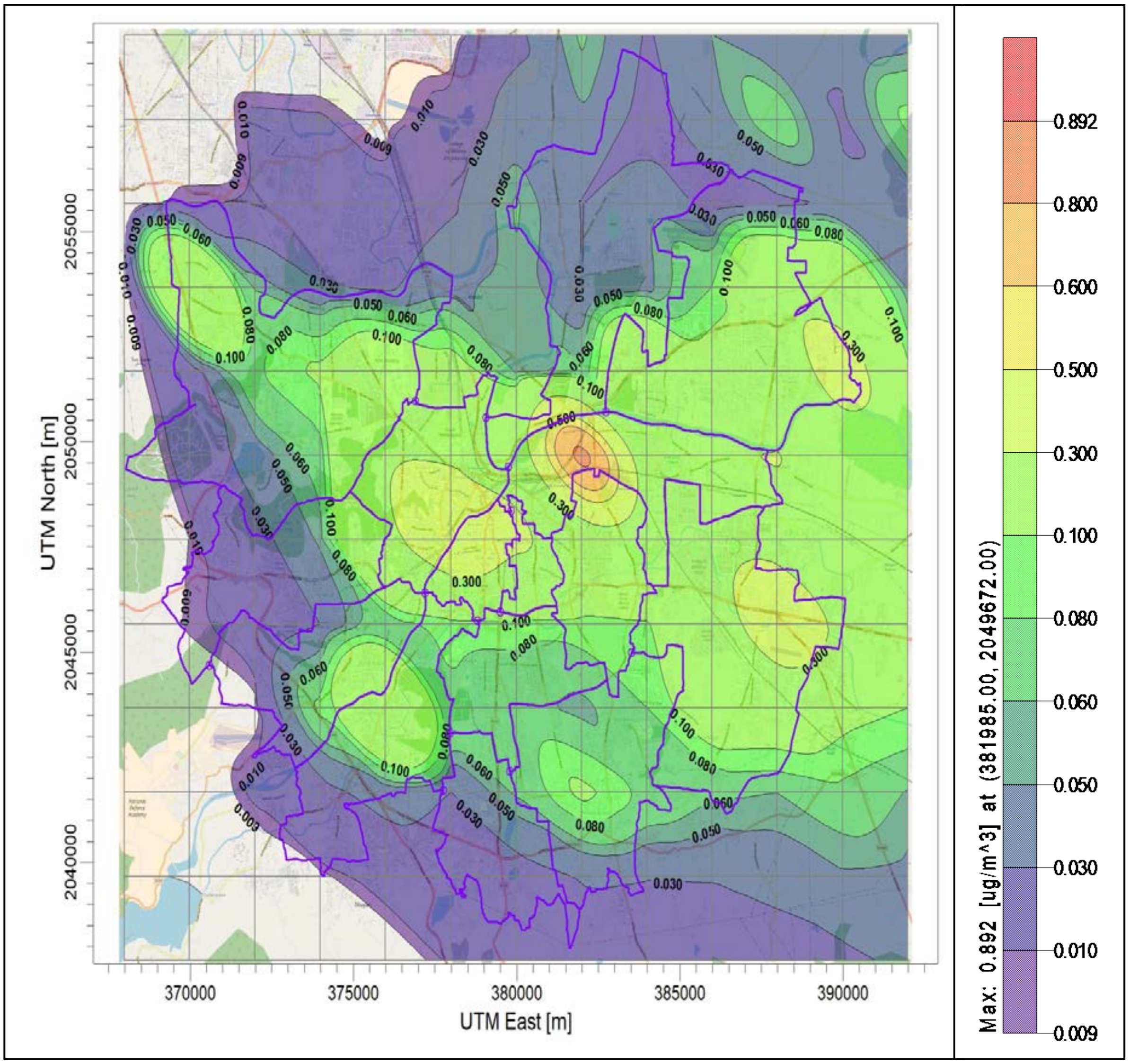

Figure N9 : Isopleths of NOx Due to Point Sources (LSI)– Summer Season (Pune City)

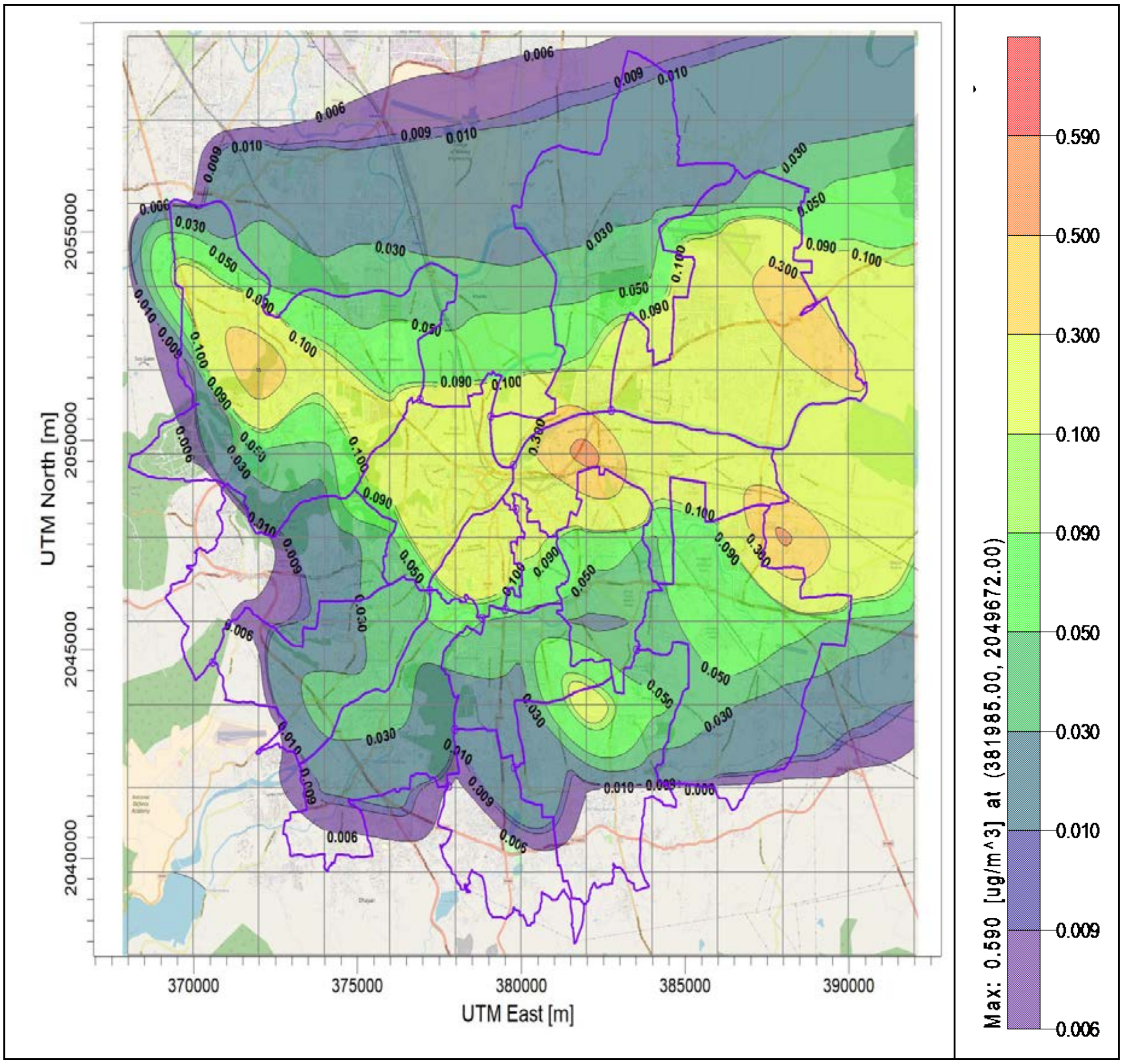

Figure N10 : Isopleths of NOx Due to Point Sources (LSI)– Post Monsoon Season (Pune City)

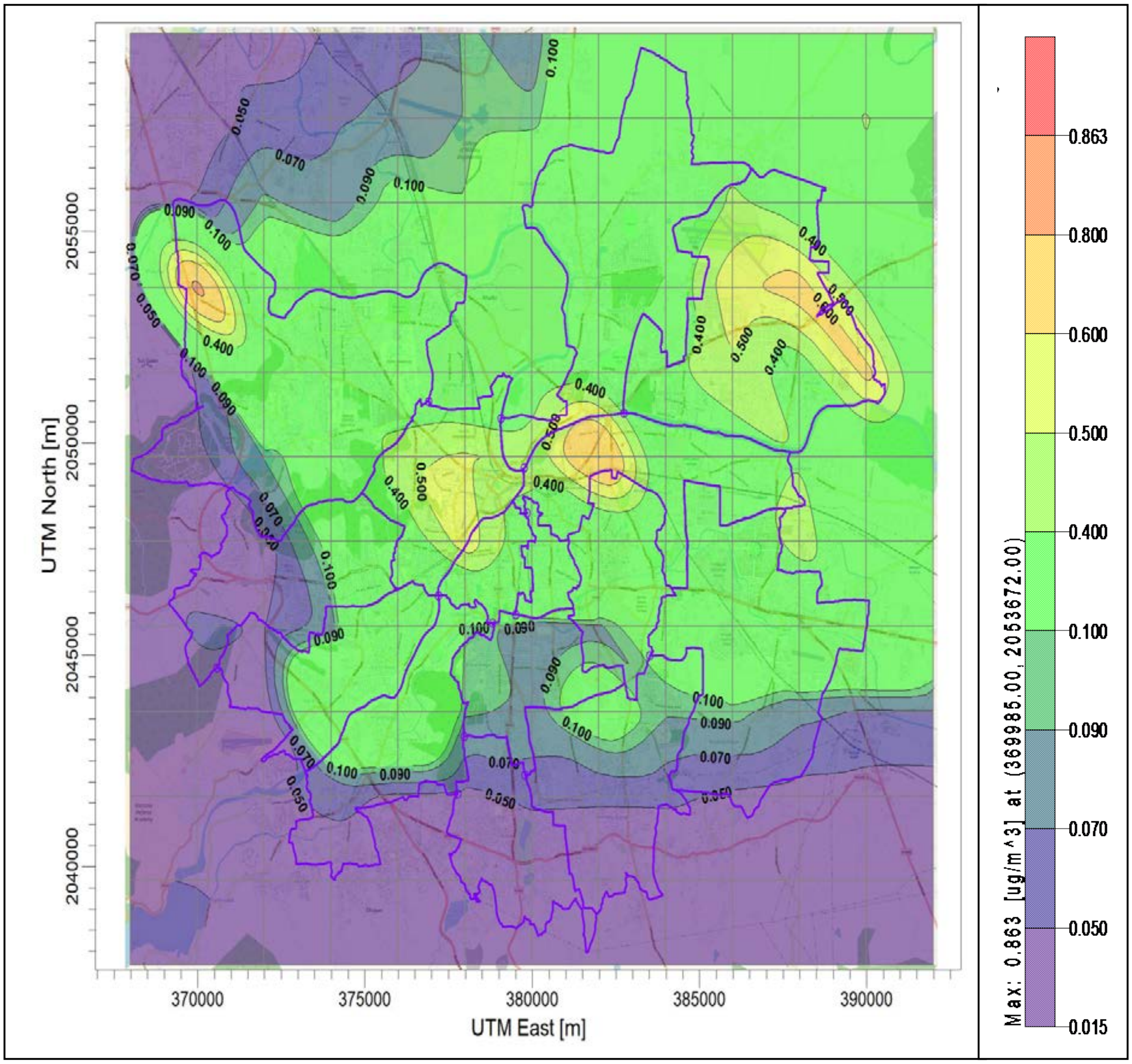

Figure N11 : Isopleths of NOx Due to Point Sources (LSI)– Winter Season (Pune City)

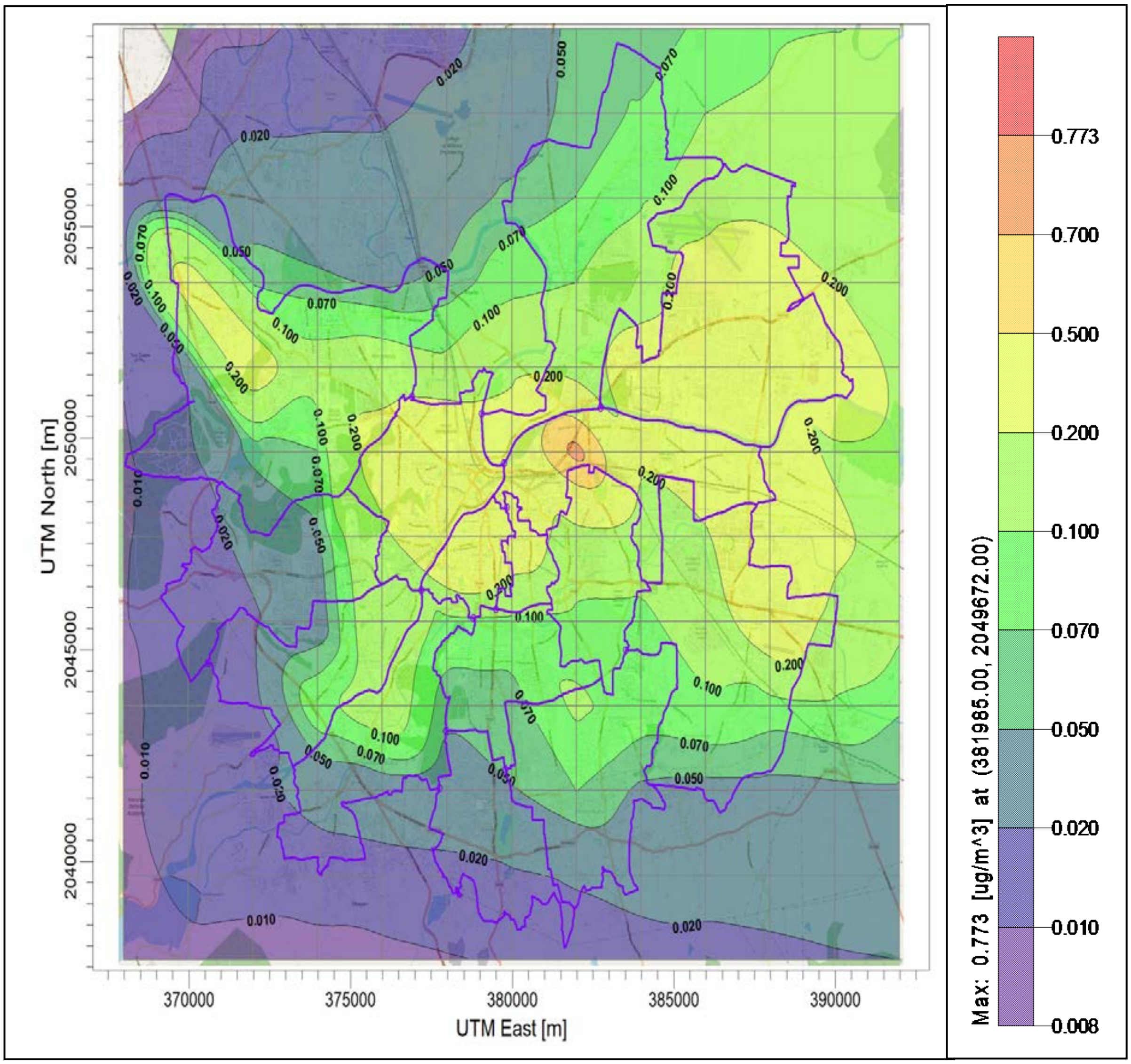

Figure N12 : Isopleths of NOx Due to Point Sources (LSI)– Annual (Pune City)

D) POINT SOURCE (MSI) – ALL NOX

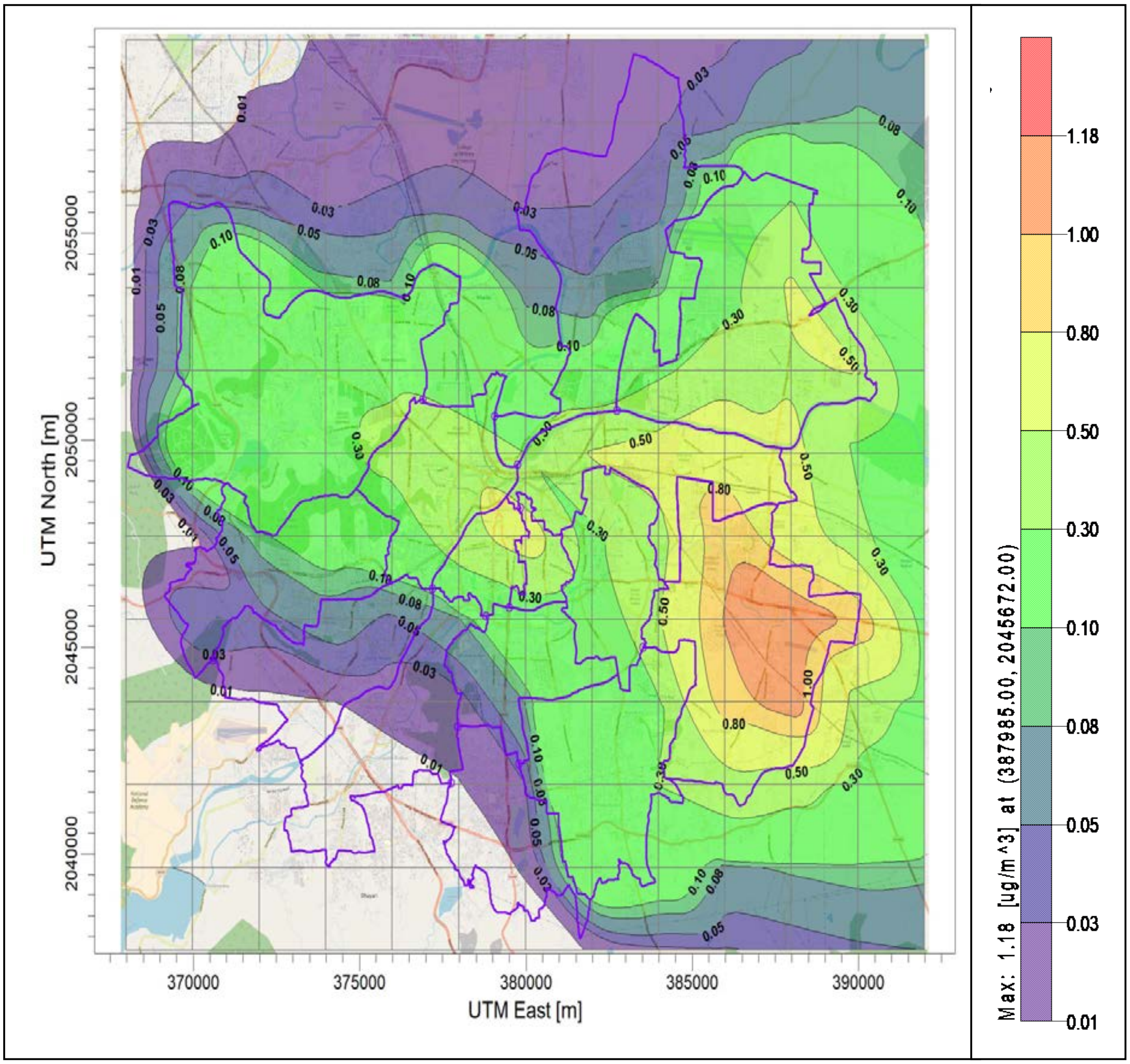

Figure N13 : Isopleths of NOx Due to Point Sources (MSI)– Summer Season (Pune City)

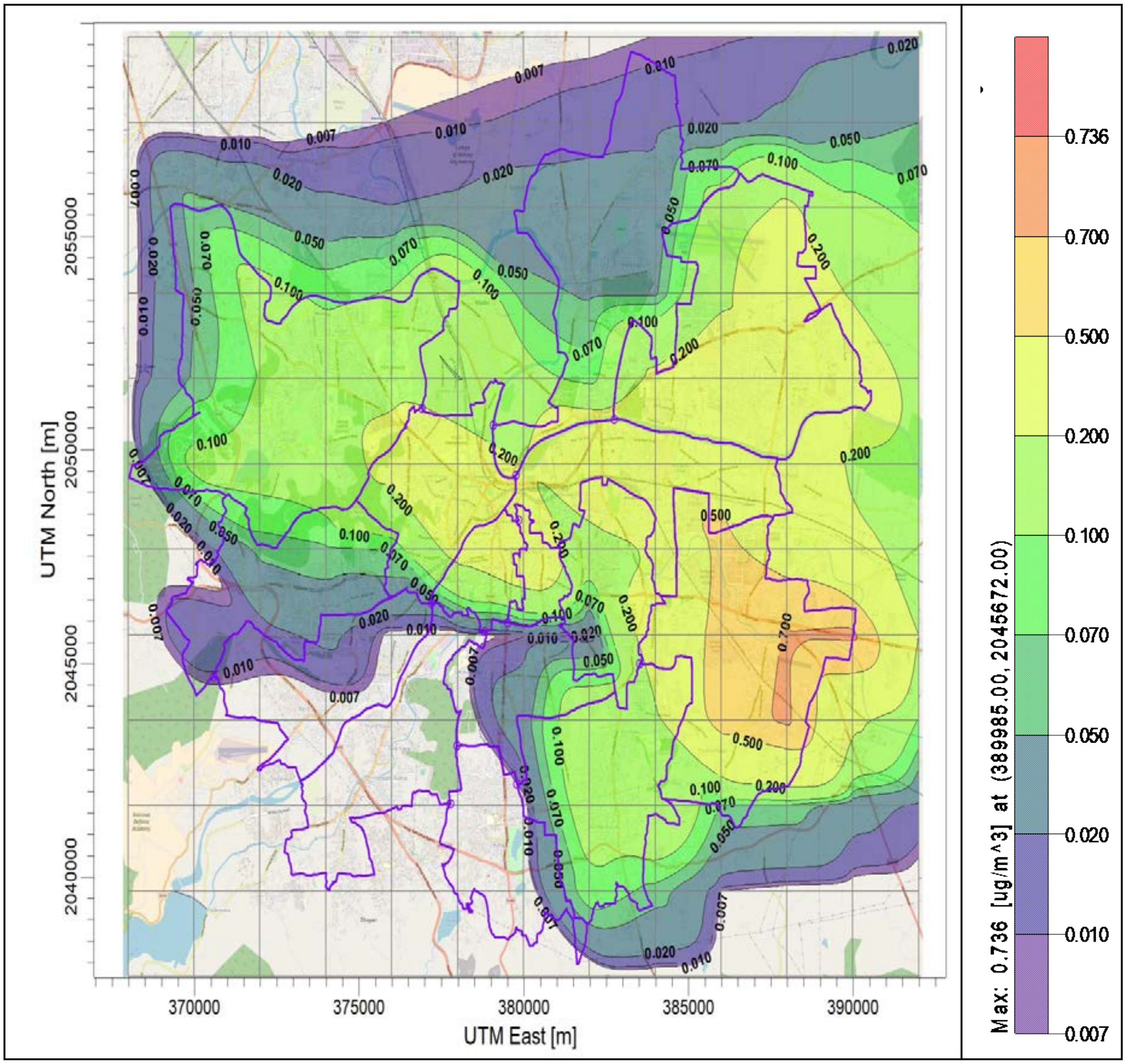

Figure N14 : Isopleths of NOx Due to Point Sources (MSI)– Post Monsoon Season (Pune City)

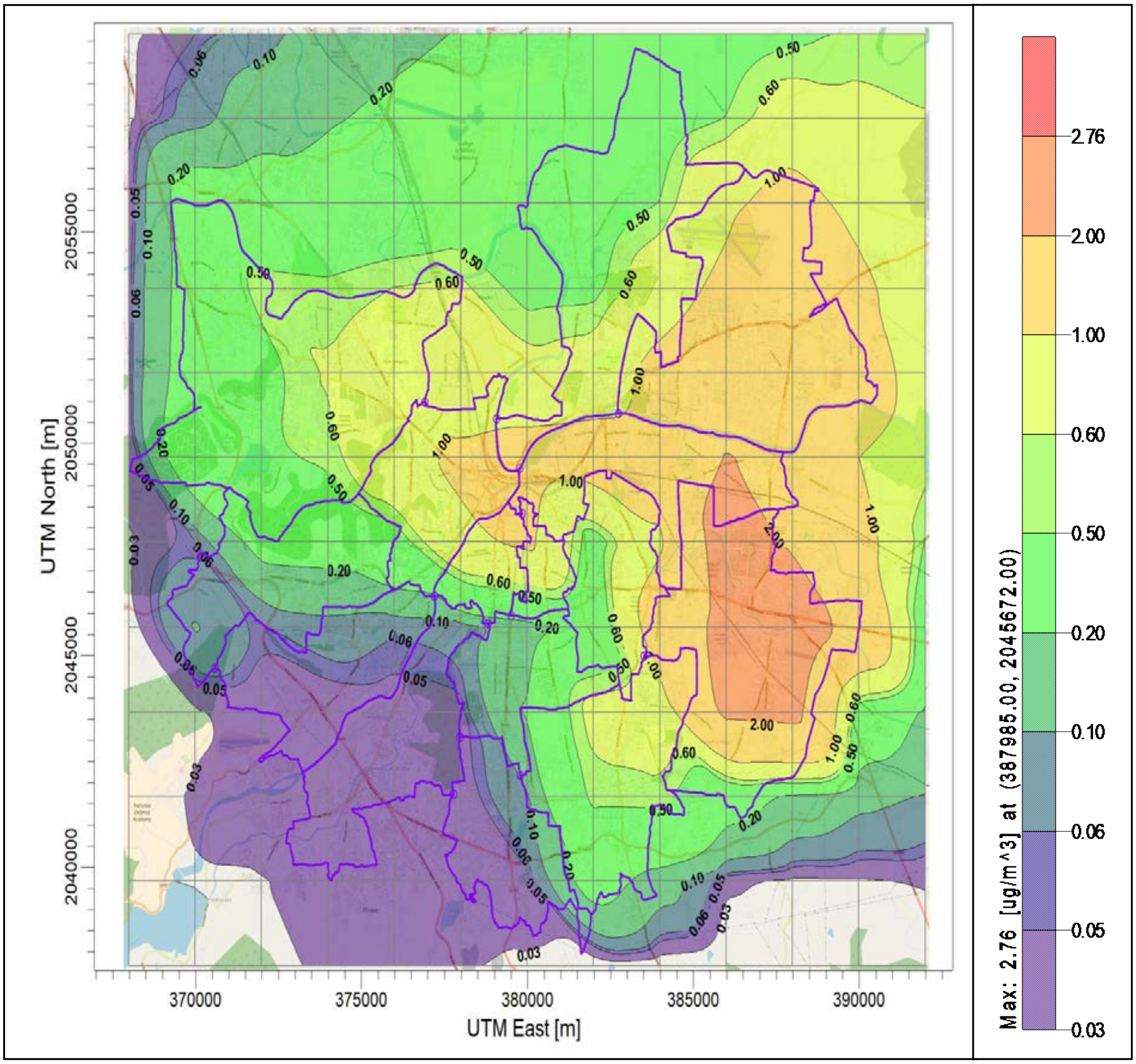

Figure N15 : Isopleths of NOx Due to Point Sources (MSI)– Winter Season (Pune City)

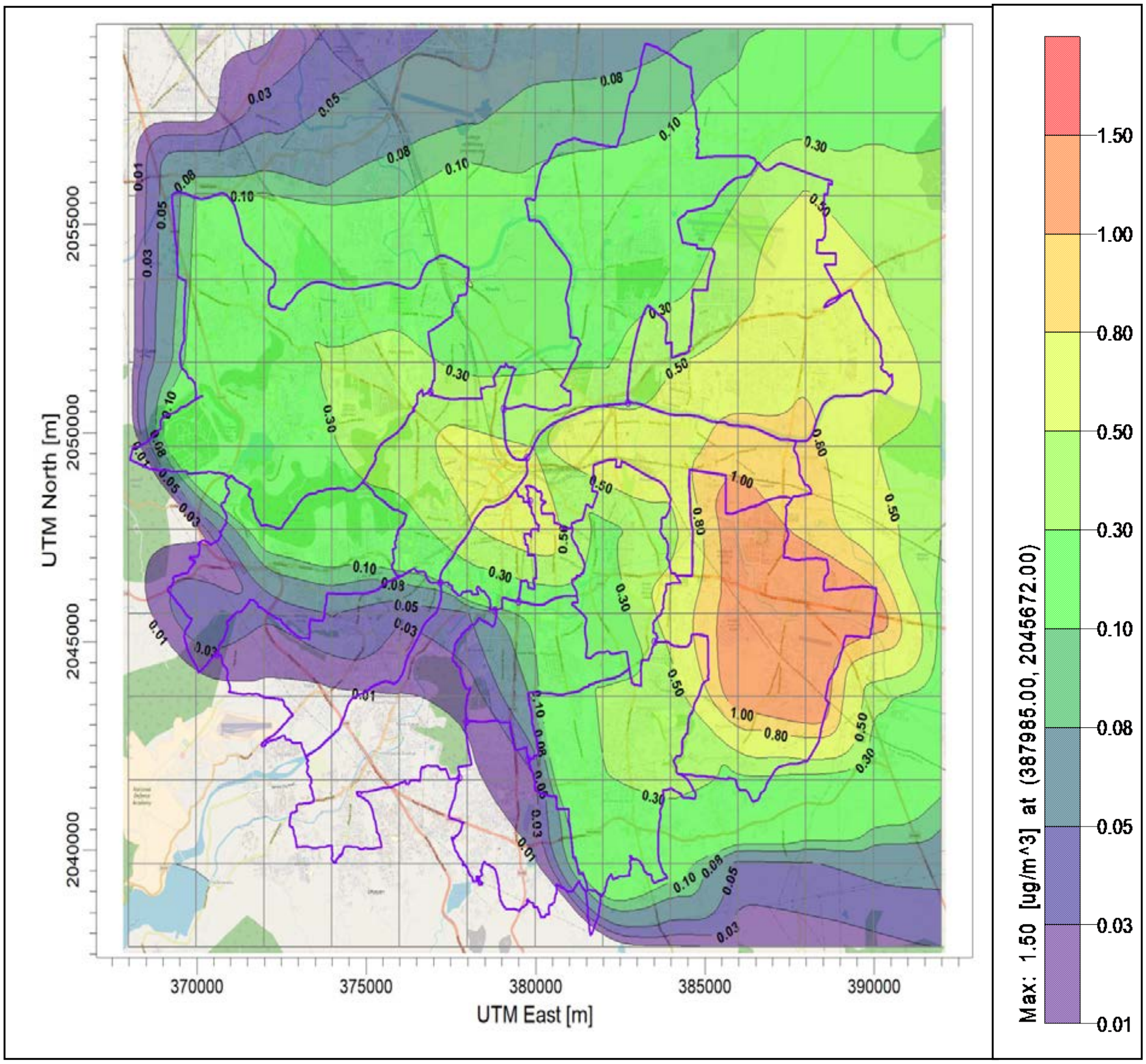

Figure N16 : Isopleths of NOx Due to Point Sources (MSI)– Annual Season (Pune City)

E) POINT SOURCE (SSI) – ALL NOX

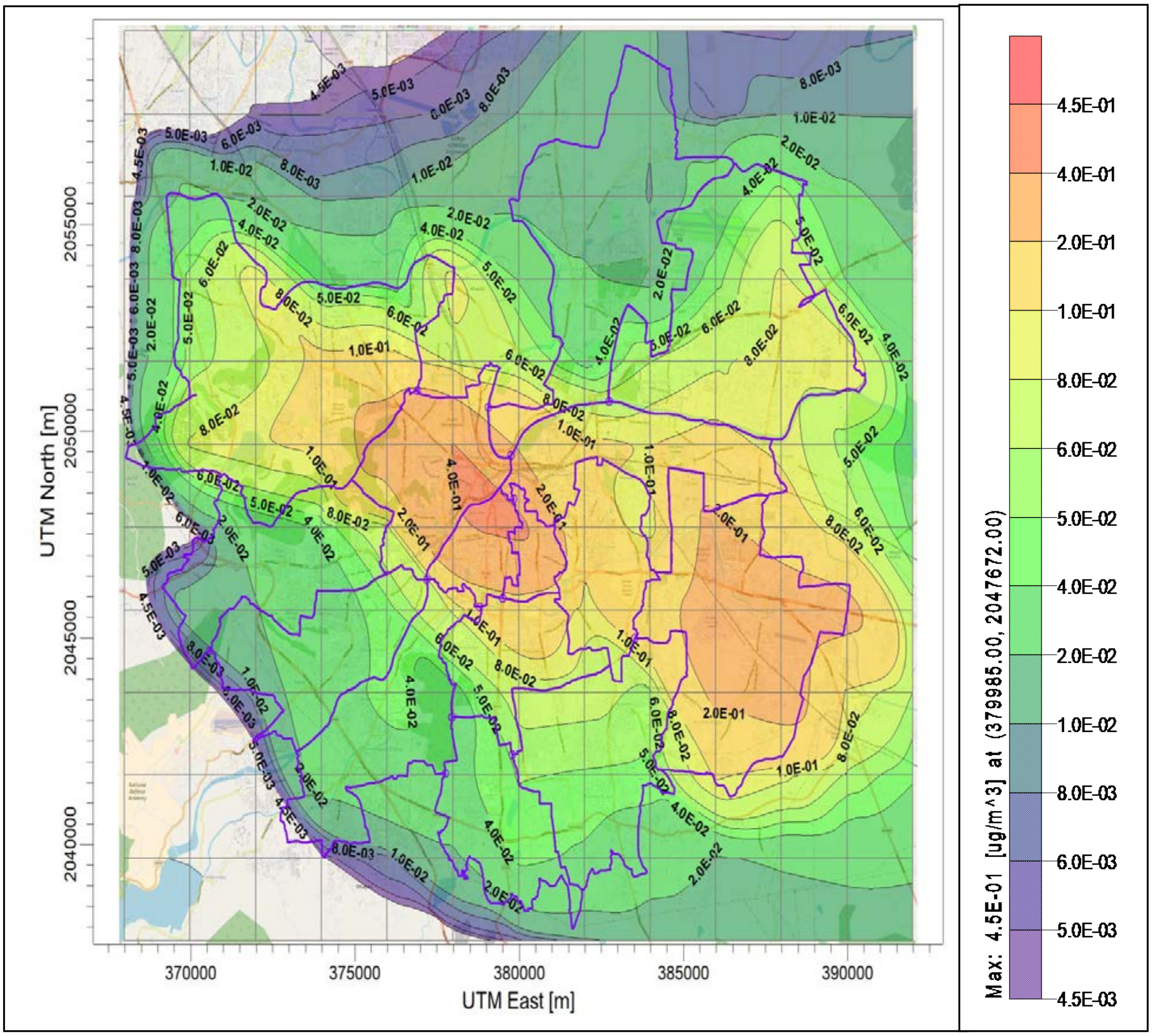

Figure N17 : Isopleths of NOx Due to Point Sources (SSI)– Summer Season (Pune City)

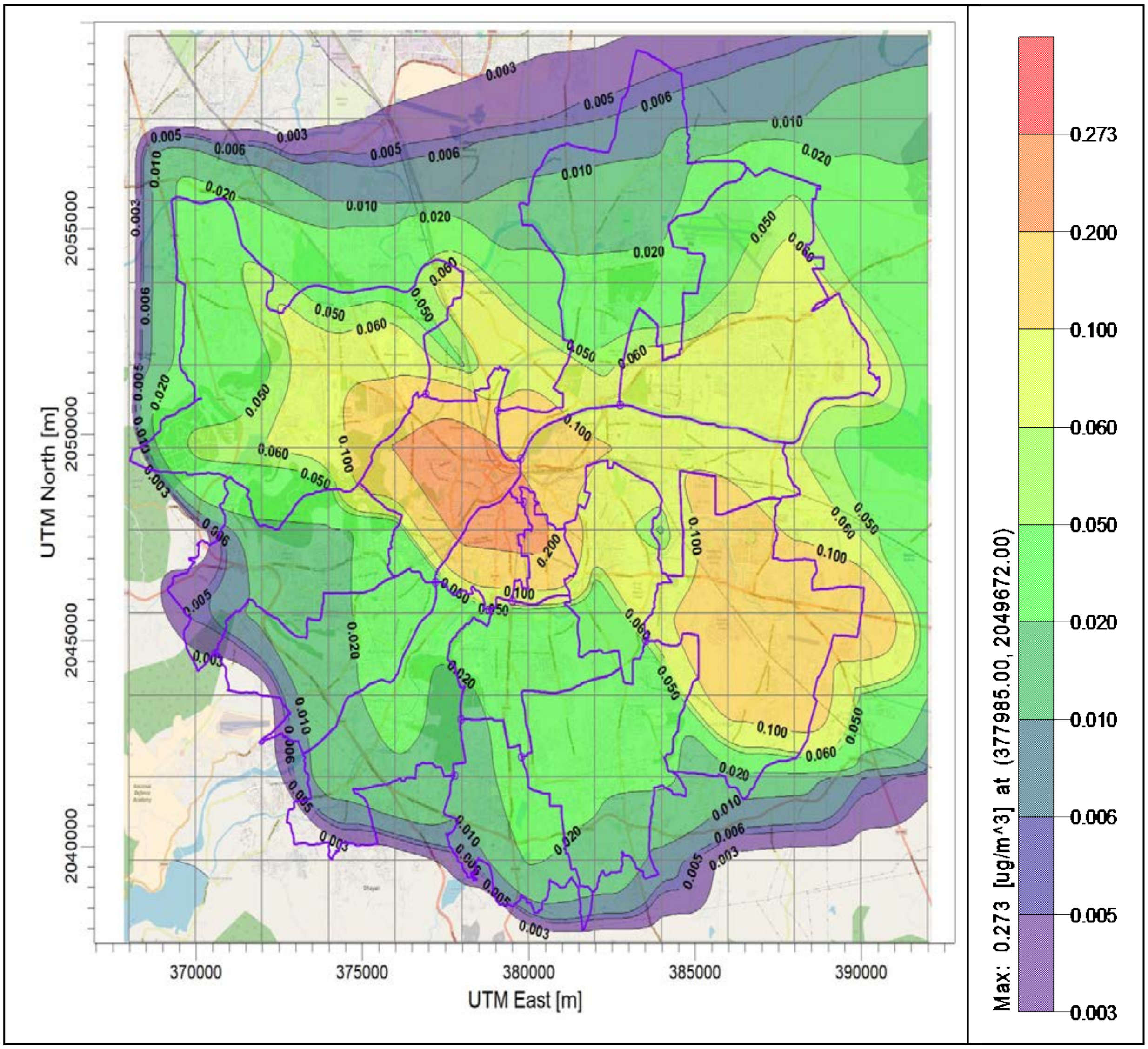

Figure N18 : Isopleths of NOx Due to Point Sources (SSI)– Post Monsoon Season (Pune City)

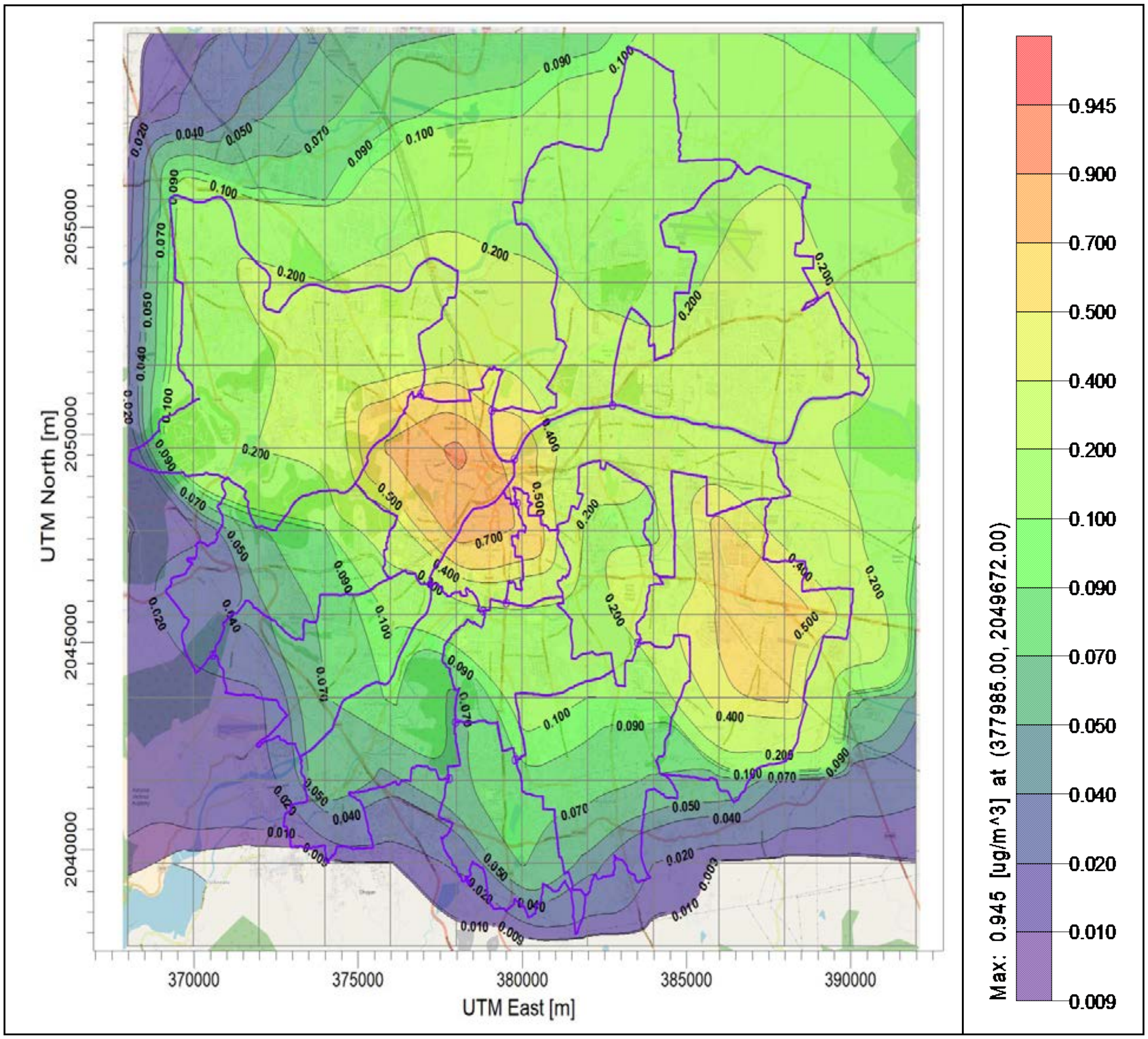

Figure N19 : Isopleths of NOx Due to Point Sources (SSI)– Winter Season (Pune City)

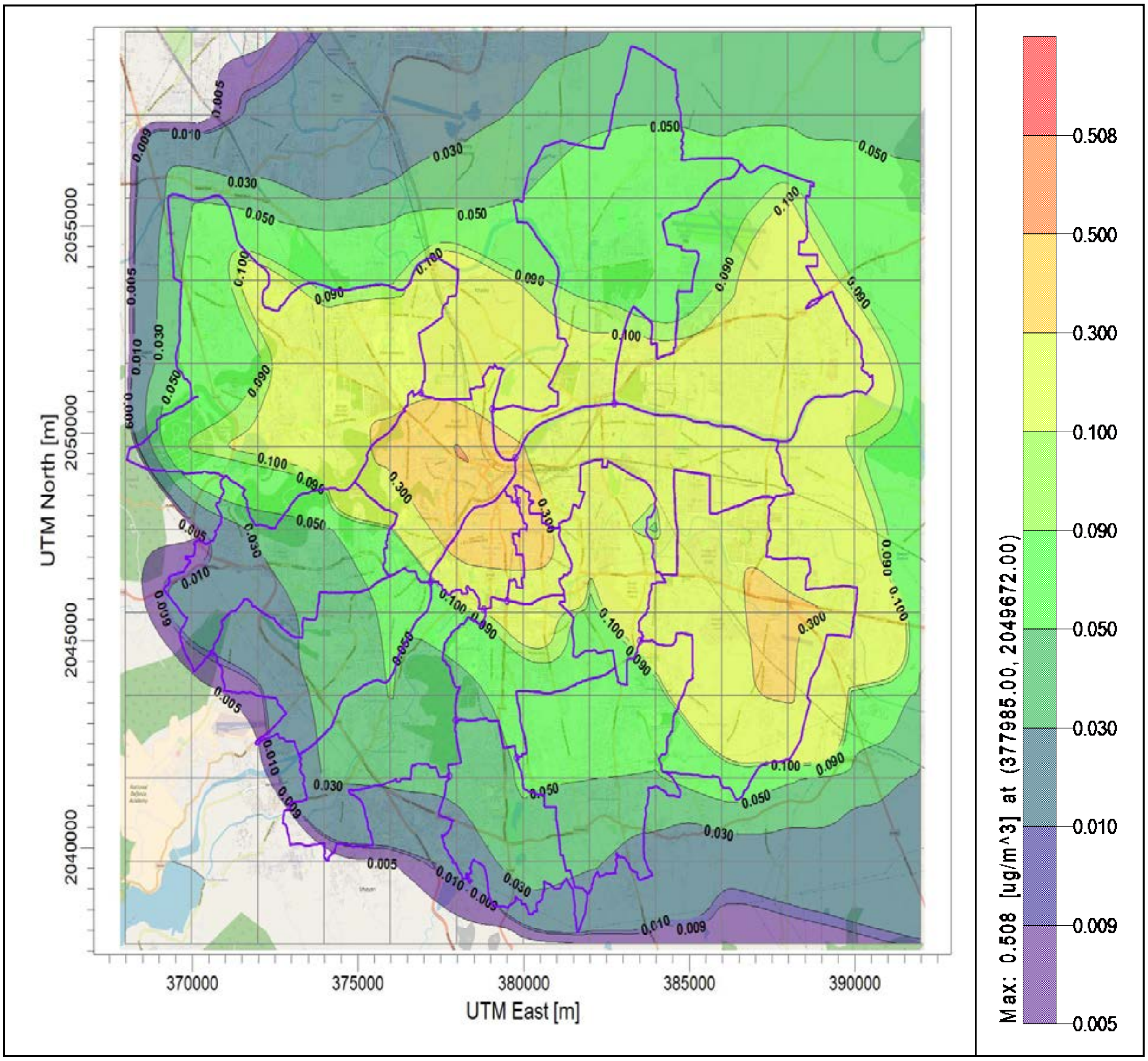

Figure N20 : Isopleths of NOx Due to Point Sources (SSI)– Annual (Pune City)

ANNEXURE – 5

Maximum Ten Concentrations of NOx (Annual) BaU 2018, 2020, 2025 and Preferred Option I -2020, Preferred Option II – 2025

Pune City

Annexure 5

A) Maximum Ten Occurrences of NO_X Concentrations in BaU 2018 at Pune City (Annual)

Annual - All Source – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	294.19
2nd	387985.00	2051672.00	268.29
3rd	387985.00	2051672.00	209.89
4th	387985.00	2051672.00	145.38
5th	387985.00	2051672.00	123.26
6th	387985.00	2051672.00	122.56
7th	387985.00	2051672.00	108.96
8th	387985.00	2051672.00	106.36
9th	387985.00	2051672.00	103.98
10th	387985.00	2051672.00	102.55
Avg.	387985.00	2051672.00	164.55

Annual - Area Source – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	6.26
2nd	379985.00	2047672.00	6.01
3rd	379985.00	2047672.00	4.92
4th	379985.00	2047672.00	2.84
5th	380042.70	2045898.64	2.53
6th	380042.70	2045898.64	2.48
7th	379985.00	2047672.00	2.22
8th	379985.00	2047672.00	2.12
9th	379985.00	2047672.00	2.11
10th	379985.00	2047672.00	2.10
Avg.	379985.00	2047672.00	3.48

Annual – Line Source – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	290.76
2nd	387985.00	2051672.00	264.89
3rd	387985.00	2051672.00	207.24
4th	387985.00	2051672.00	144.30
5th	387985.00	2051672.00	122.45
6th	387985.00	2051672.00	121.72
7th	387985.00	2051672.00	107.90
8th	387985.00	2051672.00	105.43
9th	387985.00	2051672.00	103.01
10th	387985.00	2051672.00	102.62
Avg.	387985.00	2051672.00	162.87

Annual - Point Source (LSI)– BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.99
2nd	381985.00	2049672.00	0.90
3rd	381985.00	2049672.00	0.86
4th	381985.00	2049672.00	0.81
5th	381985.00	2049672.00	0.79
6th	381985.00	2049672.00	0.79
7th	381985.00	2049672.00	0.64
8th	381985.00	2049672.00	0.59
9th	381985.00	2049672.00	0.57
10th	381985.00	2049672.00	0.56
Avg.	381985.00	2049672.00	0.77

Annual – Point Source (MSI) – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2045672.00	3.32
2nd	387985.00	2045672.00	2.83
3rd	387985.00	2045672.00	2.23
4th	387985.00	2043672.00	1.14
5th	387985.00	2043672.00	1.00
6th	387985.00	2043672.00	0.97
7th	389985.00	2045672.00	0.76
8th	387985.00	2043672.00	0.72
9th	387985.00	2043672.00	0.72
10th	387985.00	2043672.00	0.71
Avg.	387985.00	2045672.00	1.50

Annual – Point Source (SSI) – BaU 2018			
	X length,m	Y length,m	Concentration µg/m³
1st	377985.00	2049672.00	1.02
2nd	377985.00	2049672.00	0.94
3rd	377985.00	2049672.00	0.76
4th	379985.00	2047672.00	0.45
5th	379985.00	2047672.00	0.42
6th	379985.00	2047672.00	0.40
7th	377985.00	2049672.00	0.28
8th	377985.00	2049672.00	0.28
9th	377985.00	2049672.00	0.27
10th	377985.00	2049672.00	0.26
Avg.	377985.00	2049672.00	0.51

B) Maximum Ten Occurrences of NO_X Concentrations in BaU 2020 at Pune City (Annual)

Annual - All Source – BaU 2020			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	319.14
2nd	387985.00	2051672.00	291.02
3rd	387985.00	2051672.00	227.68
4th	387985.00	2051672.00	157.76
5th	387985.00	2051672.00	133.76
6th	387985.00	2051672.00	133.00
7th	387985.00	2051672.00	118.22
8th	387985.00	2051672.00	115.40
9th	387985.00	2051672.00	112.81
10th	387985.00	2051672.00	111.62
Avg.	387985.00	2051672.00	178.53

Annual - Area Source – BaU 2020			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	6.61
2nd	379985.00	2047672.00	6.34
3rd	379985.00	2047672.00	5.19
4th	379985.00	2047672.00	2.99
5th	380042.70	2045898.64	2.67
6th	380042.70	2045898.64	2.61
7th	379985.00	2047672.00	2.35
8th	379985.00	2047672.00	2.23
9th	379985.00	2047672.00	2.23
10th	379985.00	2047672.00	2.20
Avg.	379985.00	2047672.00	3.67

Annual – Line Source – BaU 2020			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	315.65
2nd	387985.00	2051672.00	287.56
3rd	387985.00	2051672.00	224.97
4th	387985.00	2051672.00	156.65
5th	387985.00	2051672.00	132.93
6th	387985.00	2051672.00	132.14
7th	387985.00	2051672.00	117.14
8th	387985.00	2051672.00	114.46
9th	387985.00	2051672.00	111.83
10th	387985.00	2051672.00	110.78
Avg.	387985.00	2051672.00	176.81

Annual - Point Source (LSI)– BaU 2020			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.99
2nd	381985.00	2049672.00	0.90
3rd	381985.00	2049672.00	0.86
4th	381985.00	2049672.00	0.81
5th	381985.00	2049672.00	0.79
6th	381985.00	2049672.00	0.79
7th	381985.00	2049672.00	0.64
8th	381985.00	2049672.00	0.59
9th	381985.00	2049672.00	0.57
10th	381985.00	2049672.00	0.56
Avg.	381985.00	2049672.00	0.77

Annual – Point Source (MSI) – BaU 2020			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2045672.00	3.32
2nd	387985.00	2045672.00	2.83
3rd	387985.00	2045672.00	2.23
4th	387985.00	2043672.00	1.14
5th	387985.00	2043672.00	1.00
6th	387985.00	2043672.00	0.97
7th	389985.00	2045672.00	0.76
8th	387985.00	2043672.00	0.72
9th	387985.00	2043672.00	0.72
10th	389985.00	2043672.00	0.71
Avg.	387985.00	2045672.00	1.50

Annual – Point Source (SSI) – BaU 2020			
	X length,m	Y length,m	Concentration µg/m³
1st	377985.00	2049672.00	1.02
2nd	377985.00	2049672.00	0.94
3rd	377985.00	2049672.00	0.76
4th	379985.00	2047672.00	0.45
5th	379985.00	2047672.00	0.42
6th	379985.00	2047672.00	0.40
7th	377985.00	2049672.00	0.28
8th	377985.00	2049672.00	0.28
9th	377985.00	2049672.00	0.27
10th	377985.00	2049672.00	0.26
Avg.	377985.00	2049672.00	0.51

C) Maximum Ten Occurrences of NO_X Concentrations in BaU 2025 at Pune City (Annual)

Annual - All Source – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	345.14
2nd	387985.00	2051672.00	314.70
3rd	387985.00	2051672.00	246.21
4th	387985.00	2051672.00	170.65
5th	387985.00	2051672.00	144.69
6th	387985.00	2051672.00	143.87
7th	387985.00	2051672.00	127.86
8th	387985.00	2051672.00	124.82
9th	387985.00	2051672.00	122.02
10th	387985.00	2051672.00	121.45
Avg.	387985.00	2051672.00	193.08

Annual - Area Source – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	7.07
2nd	379985.00	2047672.00	6.79
3rd	379985.00	2047672.00	5.56
4th	379985.00	2047672.00	3.20
5th	380042.70	2045898.64	2.86
6th	380042.70	2045898.64	2.80
7th	379985.00	2047672.00	2.51
8th	379985.00	2047672.00	2.39
9th	379985.00	2047672.00	2.39
10th	379985.00	2047672.00	2.38
Avg.	379985.00	2047672.00	3.92

Annual – Line Source – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	341.56
2nd	387985.00	2051672.00	311.17
3rd	387985.00	2051672.00	243.45
4th	387985.00	2051672.00	169.51
5th	387985.00	2051672.00	143.84
6th	387985.00	2051672.00	142.99
7th	387985.00	2051672.00	126.76
8th	387985.00	2051672.00	123.85
9th	387985.00	2051672.00	121.01
10th	387985.00	2051672.00	120.68
Avg.	387985.00	2051672.00	191.33

Annual - Point Source (LSI)– BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.99
2nd	381985.00	2049672.00	0.90
3rd	381985.00	2049672.00	0.86
4th	381985.00	2049672.00	0.81
5th	381985.00	2049672.00	0.79
6th	381985.00	2049672.00	0.79
7th	381985.00	2049672.00	0.64
8th	381985.00	2049672.00	0.59
9th	381985.00	2049672.00	0.57
10th	381985.00	2049672.00	0.56
Avg.	381985.00	2049672.00	0.77

Annual – Point Source (MSI) – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2045672.00	3.32
2nd	387985.00	2045672.00	2.83
3rd	387985.00	2045672.00	2.23
4th	387985.00	2043672.00	1.14
5th	387985.00	2043672.00	1.00
6th	387985.00	2043672.00	0.97
7th	389985.00	2045672.00	0.76
8th	387985.00	2043672.00	0.72
9th	387985.00	2043672.00	0.72
10th	387985.00	2043672.00	0.71
Avg.	387985.00	2045672.00	1.50

Annual – Point Source (SSI) – BaU 2025			
	X length,m	Y length,m	Concentration µg/m³
1st	377985.00	2049672.00	1.02
2nd	377985.00	2049672.00	0.94
3rd	377985.00	2049672.00	0.76
4th	379985.00	2047672.00	0.45
5th	379985.00	2047672.00	0.42
6th	379985.00	2047672.00	0.40
7th	377985.00	2049672.00	0.28
8th	377985.00	2049672.00	0.28
9th	377985.00	2049672.00	0.27
10th	377985.00	2049672.00	0.26
Avg.	377985.00	2049672.00	0.51

D) Maximum Ten Occurrences of NO_X Concentrations after Implementation of Control Options (Preferred Option I -2020) at Pune City (Annual)

Annual - All Source Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	167.55
2nd	387985.00	2051672.00	152.79
3rd	387985.00	2051672.00	119.53
4th	387985.00	2051672.00	82.82
5th	387985.00	2051672.00	70.22
6th	387985.00	2051672.00	69.82
7th	387985.00	2051672.00	62.07
8th	387985.00	2051672.00	60.59
9th	387985.00	2051672.00	59.23
10th	387985.00	2051672.00	58.32
Avg.	387985.00	2051672.00	93.73

Annual - Area Source Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	3.47
2nd	379985.00	2047672.00	3.33
3rd	379985.00	2047672.00	2.73
4th	379985.00	2047672.00	1.57
5th	380042.70	2045898.64	1.40
6th	380042.70	2045898.64	1.37
7th	379985.00	2047672.00	1.23
8th	379985.00	2047672.00	1.17
9th	379985.00	2047672.00	1.17
10th	379985.00	2047672.00	1.16
Avg.	379985.00	2047672.00	1.93

Annual – Line Source Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	165.72
2nd	387985.00	2051672.00	150.97
3rd	387985.00	2051672.00	118.11
4th	387985.00	2051672.00	82.24
5th	387985.00	2051672.00	69.79
6th	387985.00	2051672.00	69.37
7th	387985.00	2051672.00	61.50
8th	387985.00	2051672.00	60.09
9th	387985.00	2051672.00	58.71
10th	387985.00	2051672.00	57.69
Avg.	387985.00	2051672.00	92.83

Annual Point Source (LSI) Preferred Option I -2020			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.52
2nd	381985.00	2049672.00	0.47
3rd	381985.00	2049672.00	0.45
4th	381985.00	2049672.00	0.43
5th	381985.00	2049672.00	0.42
6th	381985.00	2049672.00	0.41
7th	381985.00	2049672.00	0.34
8th	381985.00	2049672.00	0.31
9th	381985.00	2049672.00	0.30
10th	381985.00	2049672.00	0.29
Avg.	381985.00	2049672.00	0.41

Annual Point Source (MSI) Preferred Option I-2020			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2045672.00	1.74
2nd	387985.00	2045672.00	1.48
3rd	387985.00	2045672.00	1.17
4th	387985.00	2043672.00	0.60
5th	387985.00	2043672.00	0.52
6th	387985.00	2043672.00	0.51
7th	389985.00	2045672.00	0.40
8th	387985.00	2043672.00	0.38
9th	387985.00	2043672.00	0.38
10th	389985.00	2043672.00	0.37
Avg.	387985.00	2045672.00	0.79

Annual Point Source (SSI) Preferred Option I-2020			
	X length,m	Y length,m	Concentration µg/m³
1st	377985.00	2049672.00	0.54
2nd	377985.00	2049672.00	0.49
3rd	377985.00	2049672.00	0.40
4th	379985.00	2047672.00	0.24
5th	379985.00	2047672.00	0.22
6th	379985.00	2047672.00	0.21
7th	377985.00	2049672.00	0.15
8th	377985.00	2049672.00	0.14
9th	377985.00	2049672.00	0.14
10th	377985.00	2049672.00	0.13
Avg.	377985.00	2049672.00	0.27

E) Maximum Ten Occurrences of NO_X Concentrations after Implementation of Control Options (Preferred Option II -2025) at Pune City (Annual)

Annual - All Source Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	107.34
2nd	387985.00	2051672.00	97.87
3rd	387985.00	2051672.00	76.57
4th	387985.00	2051672.00	53.07
5th	387985.00	2051672.00	45.00
6th	387985.00	2051672.00	44.74
7th	387985.00	2051672.00	39.77
8th	387985.00	2051672.00	38.82
9th	387985.00	2051672.00	37.95
10th	387985.00	2051672.00	36.85
Avg.	387985.00	2051672.00	60.05

Annual - Area Source Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	379985.00	2047672.00	2.20
2nd	379985.00	2047672.00	2.11
3rd	379985.00	2047672.00	1.73
4th	379985.00	2047672.00	1.00
5th	380042.70	2045898.64	0.89
6th	380042.70	2045898.64	0.87
7th	379985.00	2047672.00	0.78
8th	379985.00	2047672.00	0.74
9th	379985.00	2047672.00	0.74
10th	379985.00	2047672.00	0.73
Avg.	379985.00	2047672.00	1.22

Annual – Line Source Preferred Option II -2025			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2051672.00	106.23
2nd	387985.00	2051672.00	96.77
3rd	387985.00	2051672.00	75.71
4th	387985.00	2051672.00	52.72
5th	387985.00	2051672.00	44.74
6th	387985.00	2051672.00	44.47
7th	387985.00	2051672.00	39.42
8th	387985.00	2051672.00	38.52
9th	387985.00	2051672.00	37.63
10th	389985.00	2051672.00	36.85
Avg.	387985.00	2051672.00	59.50

Annual Point Source (LSI) Preferred Option II-2025			
	X length,m	Y length,m	Concentration µg/m³
1st	381985.00	2049672.00	0.31
2nd	381985.00	2049672.00	0.28
3rd	381985.00	2049672.00	0.27
4th	381985.00	2049672.00	0.25
5th	381985.00	2049672.00	0.25
6th	381985.00	2049672.00	0.24
7th	381985.00	2049672.00	0.20
8th	381985.00	2049672.00	0.18
9th	381985.00	2049672.00	0.18
10th	381985.00	2049672.00	0.17
Avg.	381985.00	2049672.00	0.24

Annual Point Source (MSI) Preferred Option II-2025			
	X length,m	Y length,m	Concentration µg/m³
1st	387985.00	2045672.00	1.03
2nd	387985.00	2045672.00	0.88
3rd	387985.00	2045672.00	0.69
4th	387985.00	2043672.00	0.35
5th	387985.00	2043672.00	0.31
6th	387985.00	2043672.00	0.30
7th	389985.00	2045672.00	0.24
8th	387985.00	2043672.00	0.22
9th	387985.00	2043672.00	0.22
10th	387985.00	2043672.00	0.21
Avg.	387985.00	2045672.00	0.47

Annual Point Source (SSI) Preferred Option II-2025			
	X length,m	Y length,m	Concentration µg/m³
1st	377985.00	2049672.00	0.32
2nd	377985.00	2049672.00	0.29
3rd	377985.00	2049672.00	0.24
4th	379985.00	2047672.00	0.14
5th	379985.00	2047672.00	0.13
6th	379985.00	2047672.00	0.13
7th	377985.00	2049672.00	0.09
8th	377985.00	2049672.00	0.09
9th	377985.00	2049672.00	0.08
10th	377985.00	2049672.00	0.07
Avg.	377985.00	2049672.00	0.16