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

MUMBAI CITY
(Final Report)

for

Maharashtra Pollution Control Board

by

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&

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Executive Summary

This study was initiated by Maharashtra Pollution Control Board (MPCB) as a part of a State-wide effort in ten cities for managing the air quality. Several aspects of the air pollution status in these ten cities have been investigated with an intent to identify the key sources of pollutants, where Particulate Matter (PM) have been used to represent air pollution. An overview of the organization of the work presented in this report is shown in Figure 1.2.

Analyses have been carried by using the results from source apportionment, and also the results of dispersion model where an inventory of air pollution sources were used as an input (Table 7.1). The results and suggestions for Mumbai are summarized in the following sections.

Inventory

- The inventory for the point, line and area sources were compiled from secondary data made available by the offices of MPCB, MCGM and RTO.
- The results of the inventory-based dispersion model are included in Section 7.2. In the inventory, about 60% of the PM10 results from road dust while 10% of the PM2.5 is sourced from uncontrolled biomass/ garbage burning. These are ground level sources, and have a direct impact on the ground level ambient PM concentrations.
- The source apportionment results indicate that the contribution from industries is of the order of 12 to 20%, while that from the dispersion model indicates less than1% of contribution from the point source (industries). This difference is largely due to the fact that several sources that are associated with unorganized/unauthorized sector (such as small scale industries, for example “Bhatties”) could not be included in the inventory for dispersion model. In order to be able to include such sources, which are indicated in the results of the source apportionment analysis, a ward-wise inventory is recommended.
- There is a large uncertainty in the quantities, emission factors and the chemical profiles of garbage (wet and dry, often mixed), and biomass (shed leaves from trees etc.) that are burnt in the open. Burning of plastics and anthropogenic dry wastes in an uncontrolled manner is a serious matter of health concern, and requires immediate attention. Measurements and quantification of the emissions from such uncontrolled burning for inventory development is tedious, if not impossible. From a pragmatic perspective, therefore it is best to implement common sense actions required to strictly enforce ban on such uncontrolled burning.

Source Apportionment

- Sampling for the source apportionment component of the work were carried out at six locations in Mumbai to quantify the sources of air pollution that influence the respective locations.

- The chemical analyses were carried out as per CPCB guidelines. The source apportionment analysis was conducted employing the EPA Positive Matrix Factorization (PMF) method and the results for likely sources of PM_{10} and $PM_{2.5}$are summarized as Figure ES-1.

- The findings revealed that resuspended road dust emerged as the predominant contributor for PM_{10} pollution. This occurrence is attributed to the high dust loadings on the roads, and the possibly the ongoing construction activities (Metro as well as real-estate developments) near roadways, within, and around the city.

- $PM_{2.5}$ pollution was prominently influenced by secondary aerosols (22%) and marine sources (26%) adding to 48% of the total contribution in Mumbai.Research efforts to study secondary aerosols in India has been limited thus far, and need to be strengthened to improve the understanding, and therefore control of this significant component of ambient $PM_{2.5}$ through control of precursor gases.

- Dispersion modelling was carried out using AERMOD dispersion model (Chapter 5). The inputs for sources were taken from the inventory developed in this study, and the datasets shared by MPCB. MM5 data were used for the meteorological inputs.

- Results of the delineated sources indicate that the dominant source for PM is road-dust resuspension. Similarly, the NOx emissions were dominated by vehicular sources. "Hot-spots' in three seasons were identified.

- The results of the source apportionment confirm the contribution from "smoke" that results from biomass combustion, including that of other uncontrolled open burning of garbage (extremely toxic emissions).

Suggested Action Plans

- An assessment of impact of various control measures has been carried out in Chapter 6. The action plans include interventions required for point, line and area sources. The scenarios are set up as Priority I which is immediately implementable, and Priority II which are expected to take a little longer to implement (5-year time frame).

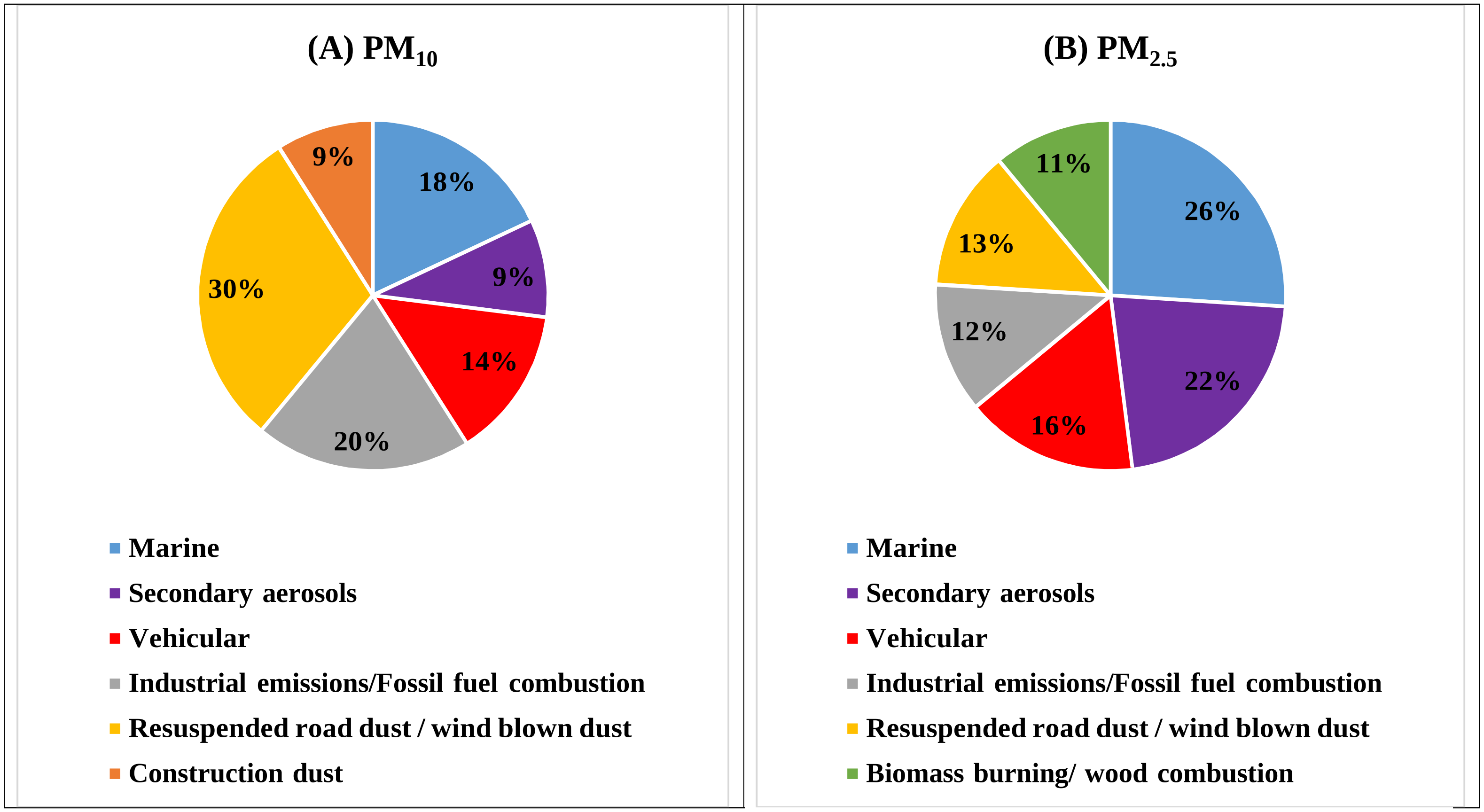

Figure ES-1: Percentage Contribution of Sources for (A) PM_{10} and (B) $PM_{2.5}$ for Mumbai

- The analysis indicates that sustained and concerted efforts in all sectors is the key to reaching a point of acceptable air quality. Further, while the focus has largely been on primary sources of PM, the control of gaseous pollutants at source, across all sectors, would lead to a natural outfall of control on the pre-cursors which lead to the formation of secondary aerosols.

- The parameters measured in CAAQMS are a rich data resource, and need to be assessed based on sources of each pf the pollutant being measured, Along with temperature, rainfall and other meteorological conditions. Triangulation of data such as CO, NOx, PM and ozone could help in quality assurance efforts, as well as an indication of the immediate impact of actions being taken locally.

- Mumbai is a part of the larger MMR airshed, and requires to be treated as such. The influence on meteorology (wind directions, wind speeds, mixing heights etc.) need to be included for the entire region with all sources in MMR included. Diurnal land-sea breezes have a significant impact on hourly air pollution levels and the meteorology needs to be assessed as a finer temporal scale for the entire region.

- The linkage between an identified problem and implementation of it solutions needs to be strengthened. As an example, the design of roads needs to have them be amenable for mechanical sweeping, where dust from the unpaved shoulders is prevented from “drifting” onto the road by design. Biomass from trees can be removed from the roads by vacuum trucks. Another example is the strengthening of the collection efforts for solid wastes (which are often put to fire if left to pile up).

- The effort requires a sector-wise cost analysis for a time-bound implementation by the industry, transport department and the urban local bodies. The cost of public health due to air pollution is well established in previous studies and outweighs the cost of control of air pollution at source itself.

- The timeframe for a sustainable system is typically about 10 years, and requires programme based approach, which would become mainstream with time.

- Management of air quality is a new emerging problem for the MMR, and therefore requires for a new vertical in the administrative structure. The work is of a nature that would require day-to-day data collection, analysis and ground level control of sources through coordination with multiple agencies.

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Chapter 1

Introduction

1.1 Preamble

Greater Mumbai, an area of 603 km^2 consisting of the Mumbai City and Mumbai Suburban districts, extending from Colaba in the south, to Mulund and Dahisar in the north, and Mankhurd in the east. Of this, the island city spans 68 km^2 while the suburban district spans 370 km^2 under the administration of Municipal Corporation of Greater Mumbai (MCGM).

Mumbai, the capital city of Maharashtra is second most populous metropolitan city in India and fifth most populous city in the World, with an estimated city population of 12.44 million according to 2011 census. The population density of Mumbai is 27461 people per sq. km (excluding the no development area). The living space is 4.5 square meters per person. The estimated projected population of 2016, 2020, and 2030 is around 12.91, 13.18 and 13.42 million respectively. During the last decade, 2001-2011, Island City has shown a population decline of 262,620 whereas the western and eastern have shown an increase of 321,841 and 394,702 respectively. Ward P/N in the Western Suburbs has the highest population of nearly one million among all 24 wards, holding 7.5% of the total population. Whereas, Ward B in the island City has the lowest population of 140,633 among 24 wards **(Figure 1.1)**

Greater Mumbai region is along the seacoast that experiences a tropical wet and dry climate. The region experiences three seasons, Summer (March to May), Monsoon (June to September) and Winter (October to February). The mean minimum temperature is 16.3°C and the mean maximum temperature is 32.2°C. The normal annual rainfall over the region varies from about 1800 mm to about 2400 mm. Rest of year remains dry with average relative humidity around 75%. The average wind speed in the region is in the order of 25 kmph and gusts up to 45 kmph.

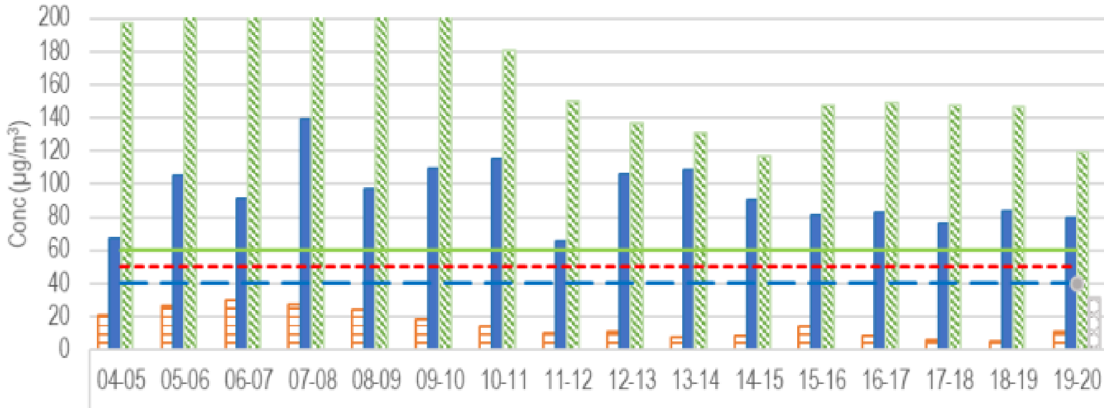
1.2 Air Quality

Mumbai's ambient air quality is monitored under the National Ambient Air Monitoring Program (NAMP), coordinated by Central Pollution Control Board (CPCB) and SAMP (State Ambient Air Monitoring Program) stations. The annual averages trend of important pollutant is monitored continuously at air quality station operated by MPCB in Sion and Bandra and one NAMP station at Worli operated by NEERI are given in **Figure 1.2 (a).**

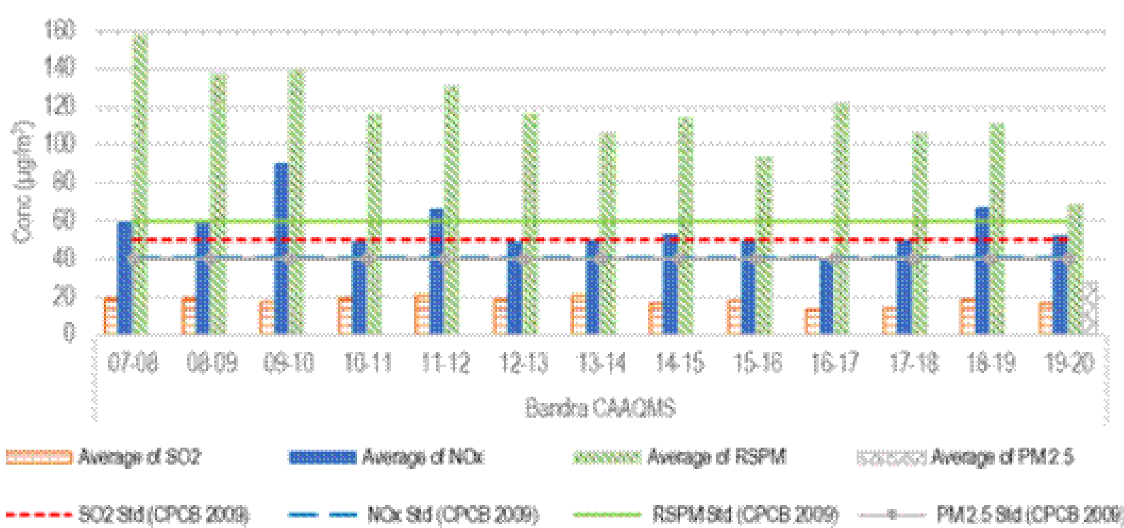
LIST OF 24 Wards in Mumbai

Ward A
Ward B
Ward C
Ward D
Ward E
Ward F North
Ward F South
Ward G North
Ward G South
Ward H East (Andheri Taluka)
Ward H West (Andheri Taluka)
Ward K East (Andheri Taluka)
Ward K West (Andheri Taluka)
Ward L (Kurla Taluka)
Ward M East (Kurla Taluka)
Ward M West (Kurla Taluka)
Ward N (Kurla Taluka)
Ward P North (Borivali Taluka)
Ward P South (Borivali Taluka)
Ward R North (Borivali Taluka)
Ward R South (Borivali Taluka)
Ward R Central (Borivali Taluka)
Ward S (Kurla Taluka)
Ward T (Kurla Taluka)

Figure 1.1 Administrative ward map of Mumbai (URL 1) (www.mcgm.gov.in)



Sion



Bandra

Figure 1.2(a): Trends of Annual Averages at two locations for PM, NOx and SOx over period 2007-08 to 2019-20 in Mumbai (SAMP Station Operated by MPCB)

Figure 1.2 (b) shows the historical data for PM_{10}, SO_2 and NOx on a monthly average basis for the year 2006, 2008, 2011 and 2018

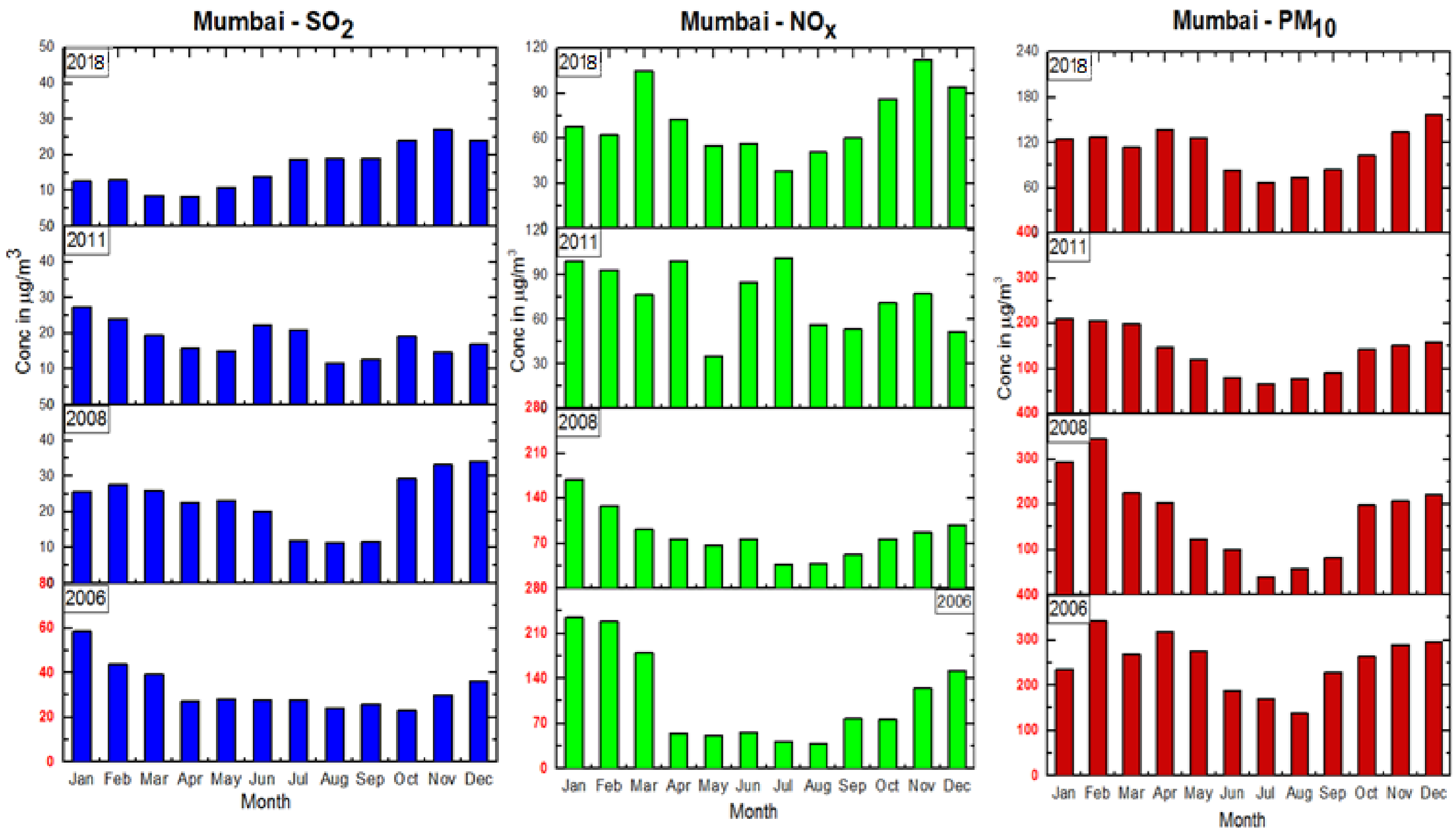


Figure 1.2(b): Monthly Trends of Annual Averages for PM_{10}, NOx and SOx (2006 - 2018) in Mumbai.

1.3 Objectives of the Study

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. Nineteen such cities have been identified for the state of Maharashtra - Akola, Amaravati, Aurangabad, Badlapur, Chandrapur, Kolhapur, Jalna, Jalgaon, Latur, Mumbai, Nagpur, Nashik, Navi Mumbai, Pune, Sangli, Solapur, Ulhasnagar, Vasai-Virar and Thane.

The main objectives of the study 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 for 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

1.4 Organisation of the report

The report organization is shown Figure 1.3. Chapter 7 highlights the outcomes and the recommendations from this study

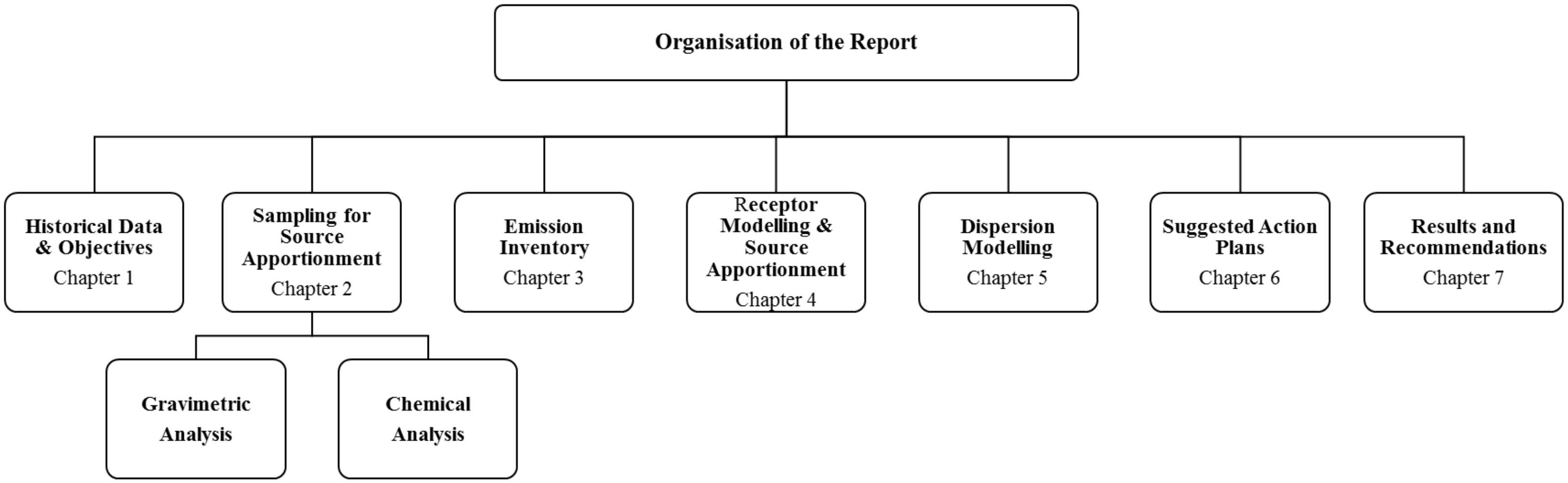


Figure 1.3: Flow Chart for the organisation of the present study

Chapter 2

Sampling for Source Apportionment

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. Six sampling sites were selected which were representative of Greater Mumbai Region. Of these, one site was selected as control site, one as industrial and commercial, two as kerbsides, and one as a residential site. The study area is depicted in **Figure 2.1(a)** and site characteristics have been presented below.

Colaba: This sampling location was selected as "Background Site" for the study region and sampling instrument was installed in the campus of Municipal Sewage Pumping Station at a height of 2 to 3 meter from ground level. It has Arabian Sea on one side and residential area on the other side. The southern side is occupied by a military cantonment, including the Navy Nagar. There are number of restaurants and some big hotels like Taj President Hotel, Diplomat and Kailash Parbat. In the vicinity of Colaba, Backbay Bus Depot contributes to transport related emissions. Major roads starting from this end of Mumbai are Bhagat Singh Marg and Jaganath Bhosle Marg which goes to Churchgate and C.S.T Terminal respectively. These roads experience heavy traffic during office hours as also on holidays. No industries are located in these areas.

Kalbadevi: The site is represented as Commercial site. The site is mainly a wholesale market area viz. Kalbadevi, Bhuleshwar market, enormous movement of merchant and dealers are observed in Mulji Jetha Market and Mangaldas Market, which are main cloth markets. The sampling instrument was installed on elevated surface of Municipal School located at interjection, at a height of 2 to 3 m from ground. Zaveri Bazaar is one of the oldest gold jewellery market in the area, gold smelting fumes are emitted from their small workshops. The area also has residential block on Abdul Rehman Street, Princess Street, and Bhuleshwar Road. The Kalbadevi is area of commercial activities of shops, petrol pump, hotels & restaurants and open eat-outs; along with heavy traffic of public transport buses and vehicles at junctions, and also ongoing construction activities. The sampling location is well connected to main roads like Metro Road, Marine Lines, Masjid Bunder, CST and Churchgate.

Mulund: Mulund is a north-eastern suburb of Mumbai, mainly comprising of upper income group residential building and blocks. Air quality monitoring station was installed at a fire-department station at a height of 2m from the ground. The fires station is located on crossing of two major arterial roads viz., L.B.S. Road and the Eastern Express Highway. There are few cosmetic, pharmaceuticals, paints, and textile industrial units located in this area. Many of these establishments are being developed into commercial shopping malls and luxurious apartment complexes altering the landscape. Solapur area around Mulund has many marbles granite shops, scrap dealers, timber marts and many garages. Major residential colonies are Tata Colony, Mhada Colony, Vina Nagar, Vaishali Nagar, Gamdevi (slum), Mulund has become crowded over the years leading to the sharp increase in vehicles.

Bandra: The location was selected as "Kerbside" as it is in vicinity of Western Express Highway. The monitoring was carried out at a height of 1.5 m from ground level at Kalanagar interjunction. Bandra roads are stressed with traffic, particularly around the railway station and exiting towards S.V. Road. The establishment of a business center, Bandra-Kurla Complex, has only exacerbated the traffic problems, unlike any other commercial hubs. The major connected roads are 90ft Dharavi Sion Junction, Kalanagar Junction, South Mumbai Mahim area and north Mumbai Khar Santacruz Airport Road. The vehicular traffic from corporate office at BKC, Bandra Court area and residential MHADA colonies contribute to peak hour traffic in the area. Towards south of the sampling site, Mithi River and Mahim Creek is situated. The Dharavi Slum area near the sampling location has many small-scale industrial units of glassworks, leathers, plastic pellets, jewelry, small scale food packing, welding etc.

Powai (Gandhi Nagar Junction): The second "Kerbside" sampling location was selected at Gandhinagar Junction, which is well connected to Eastern Express Highway, LBS Marg from Mulund and Vikhroli and also JVLR. The sampling instrument was installed near police kiosk at a height of 1.5m from ground. The sampling location covers activity at interjection from traffic movement of nearby commercial and institutional organizations as well as from public and private vehicles.

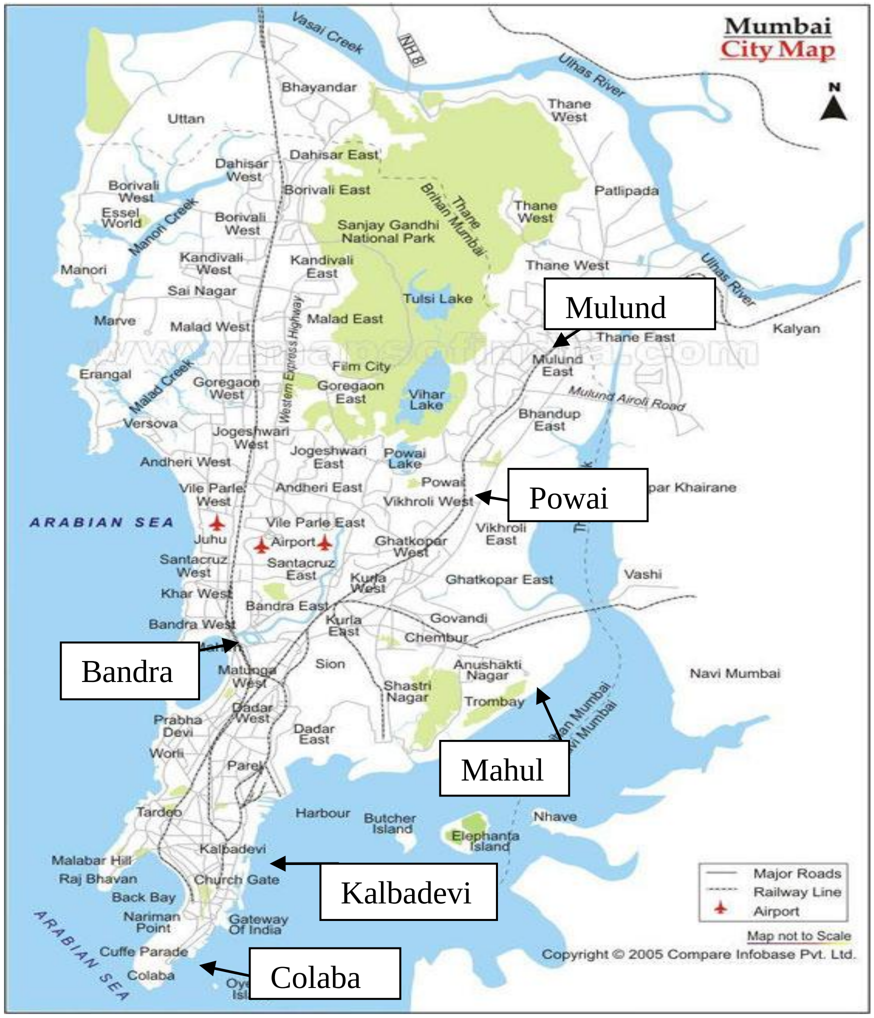


Figure 2.1(a): Air Quality Monitoring Locations at Mumbai City

Mahul: The “Industrial Site” was selected at Chembur area. The sampling instrument was installed on terrace of an industrial unit at a height of 3 meter from ground. The location was near Mahul Creek and salt pans. Containers and heavy-duty vehicles from the surrounding area use Port Trust Road, Mahul Road, and Ramakrishna Chemburkar Marg. Heavy duty vehicles use on Eastern Express Highway to go towards Wadala Truck Terminal. The traffic from roads connected to city by Eastern Express Highway and roads towards Panvel also contribute towards final load. Anushakti Nagar Colony, Tata Colony, BPCL colony, RCF Colony, Mhada Colony and Chembur Colony are some of the residential complexes in area. The area has few restaurants and open eat outs; however, it has many other commercial shops. Wadavali is in the vicinity of Mahul, which is a slum, where garages, scraps and other auxiliary’s industries works are carried out.

Figure 2.1(b): Photographs of six sampling sites for the study

2.2 Sample Collection

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 samplers were collocated 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), and meet the requirements of a Federal Reference Method (FRM). The commercially available samplers available from Airmetrics are designed for ~ 16.7 lpm flow. However, 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} reported for Mumbai 66 to 345 $\mu g/m^3$). 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 PM samples were collected on Teflon and Quartz filters for both PM_{10} and $PM_{2.5}$ at each site during summer of 2019.

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 (Summer 2019)			
Sample Type	Quartz and PTFE filter simultaneously for both PM_{10} and $PM_{2.5}$	Quartz and PTFE filter simultaneously for both PM_{10} and $PM_{2.5}$	Quartz filter simultaneously for both PM_{10} and $PM_{2.5}$	PTFE Filter simultaneously for both PM_{10} and $PM_{2.5}$
Analytical Instrument	Electronic Balance	Electronic Balance	OC/EC Analyzer	Ion Chromatography
Minimum Reportable Value	5 $\mu g/m^3$	5 $\mu g/m^3$	0.2 µg/ 0.5 cm^2 Punch	Element specific LDL

Components	Required Filter Matrix	Analytical Methods
PM_{10} and $PM_{2.5}$	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	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 Total Carbon)	Quartz filter. Prebaking of quartz filter paper at 600 ºC is essential	TOR/TOT method

2.3 Sampling Results

2.3.1 Gravimetric Results

The particulate matter concentration compared with NAAQM Standard is presented in of **Figure 2.2**.

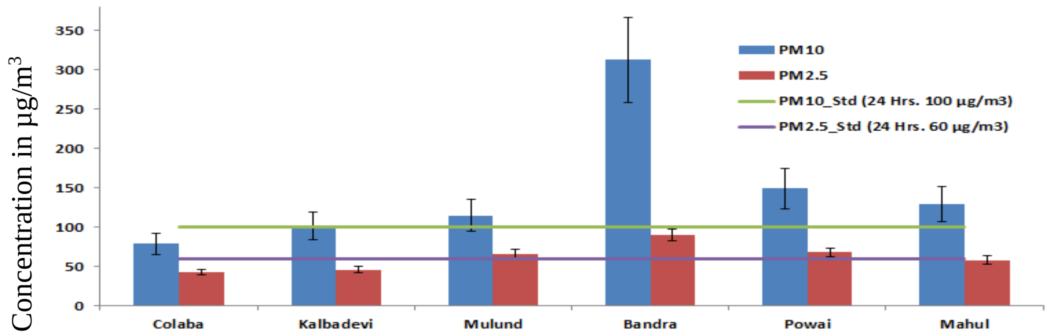


Figure 2.2: PM_{10} and $PM_{2.5}$ Concentrations at the six sampling sites during May-June 2019

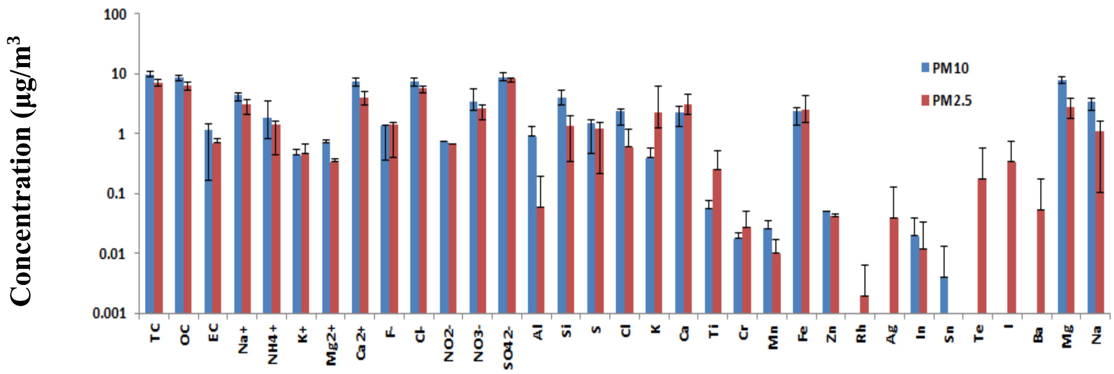
The PM_{10} concentration at Colaba (Background) site ranges from 66.22 to 91.96 µg/m^3, whereas it was 26.11 to 56.87 µg/m^3 for $PM_{2.5}$. $PM_{2.5}/PM_{10}$ ratio is in the range of 0.39 to 0.61. Kalbadevi (Commercial) site concentration ranges from 89.96 to 111.82 µg/m^3 and 39.71 to 53.3 µg/m^3 for PM_{10} and $PM_{2.5}$, respectively. The $PM_{2.5}/PM_{10}$ ratio is around 0.44 to 0.52. The Mulund (residential) site concentrations was in the range of 101.64 to 128.61 µg/m^3 for PM_{10} and 59.13 to 76.21 µg/m^3 for $PM_{2.5}$, their $PM_{2.5}/PM_{10}$ ratio is 0.5 to 0.65.

Both the kerbside PM_{10} concentration was in the range of 232.0.5 to 345.47 µg/m^3 at Bandra and 126.58 to 185.40 µg/m^3 at Powai (Gandhi Nagar), whereas it was 77.92 to 99.85 µg/m^3 at Bandra and 57.34 to 79.56 µg/m^3 at Powai for $PM_{2.5}$. The $PM_{2.5}/PM_{10}$ ratio for both sites was calculate to be around 0.23 to 0.52. At Mahul (Industrial) site, PM_{10} was observed in the range of 123.42 to 138.67 µg/m^3 for PM_{10} and 43.39 to 69.68 µg/m^3 for $PM_{2.5}$ and ratio is around 0.34 to 0.5.

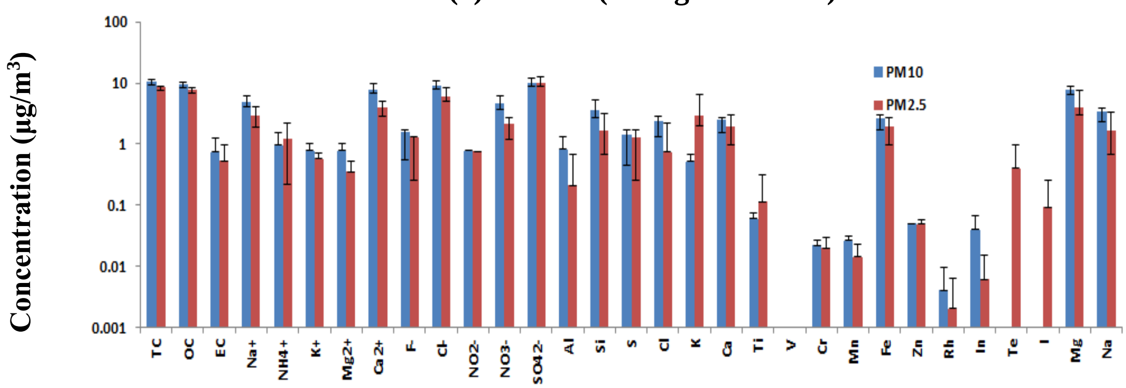
The 24-hourly average concentration of PM_{10} exceeded beyond of NAAQ Standards of 100 µg/m^3 at Bandra, Mulund, Powai (kerbside) and Mahul (industrial) area. The $PM_{2.5}$ concentration at Bandra was observed higher as compared to NAAQ CPCB Standards of 60 µg/m^3. Overall average $PM_{2.5}$ /PM_{10} ratio was 0.46, indicating the predominance of coarse particulate matter.

2.3.2 Chemical Compositions

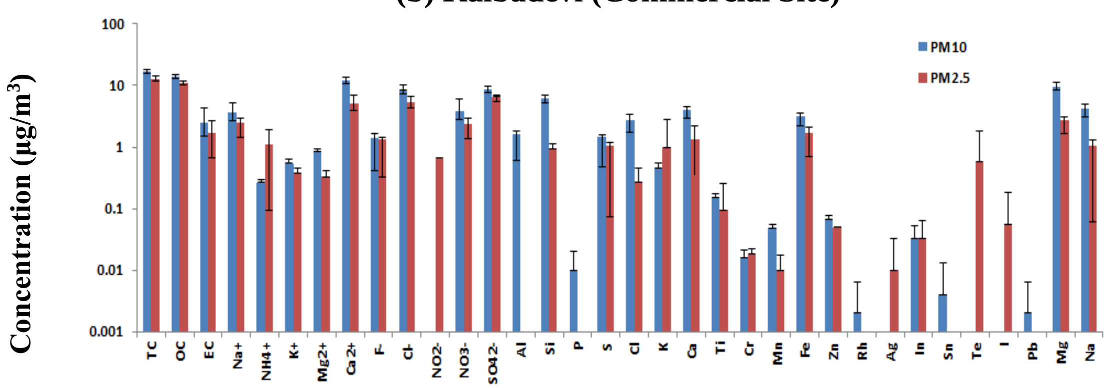
Chemical compositions (as per Table 2.1) were carried out for the PM_{10} and $PM_{2.5}$ samples collected from six sites, are shown in Figure 2.3



(a) Colaba (Background Site)

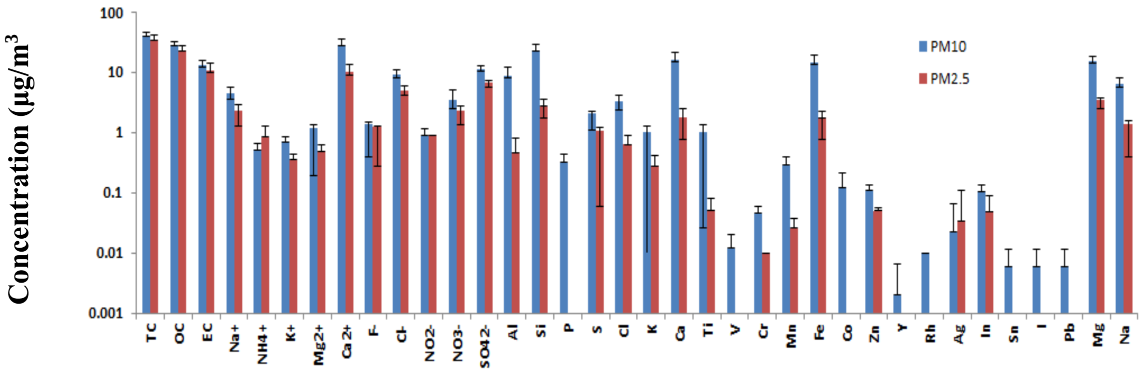


(b) Kalbadevi (Commercial Site)

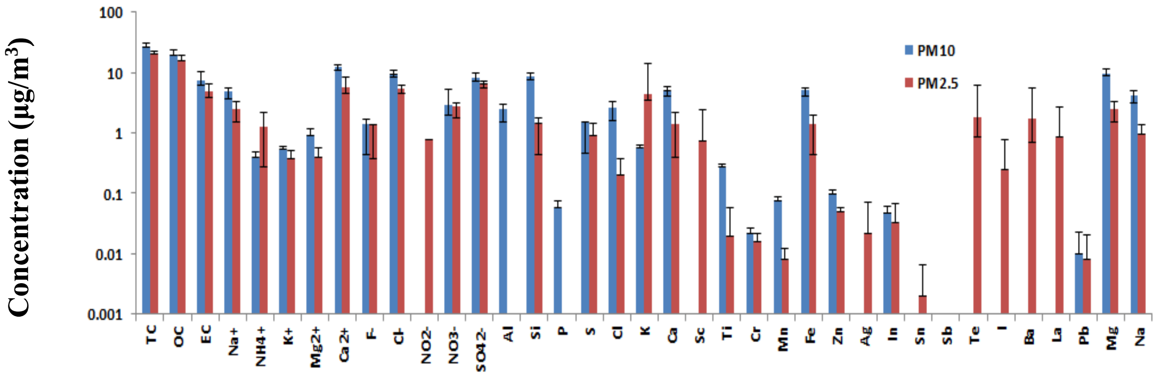


(f) Mulund (Residential Site)

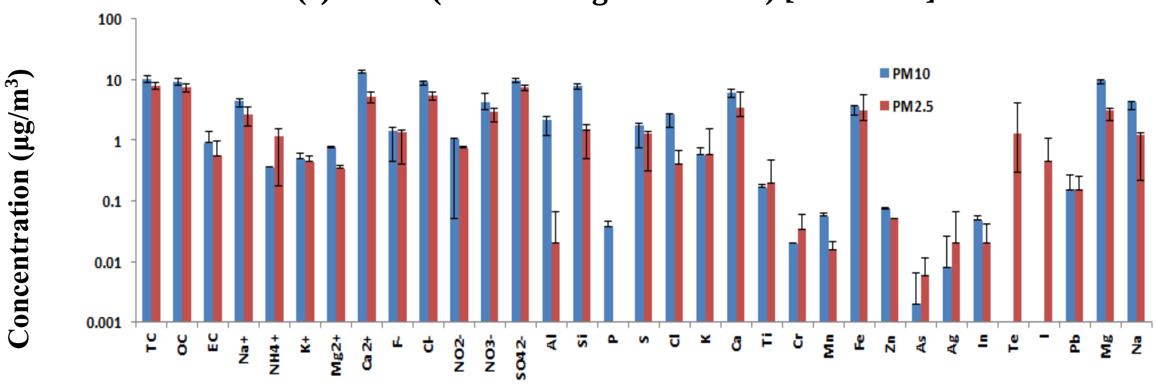
Figure 2.3: Compositional Comparison of Species Concentrations in PM_{10} and $PM_{2.5}$ at the six sampling sites (Some elements were found to be below detectable limits and are not reported here (Contd...)



(d) Bandra (Kerb Site)



(e) Powai (Gandhi Nagar Junction) [Kerb Site]



(f) Mahul (Industrial Site)

Figure 2.3: (Contd...)

2.4 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 60 samples collected at 6 sites for 10 days. 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

Colaba: - The major chemical component of PM_{10}, Crustal and Non-crustal elements account for 21.5% and 19.9% of the total, respectively. Anions account for 27.2% of the total coarse particulate mass. Amongst the anions, contribution from sulfate is maximum, probably due to secondary aerosol, road dust etc. Cations constitute 18.9% of the total PM_{10} mass. The organic matter, accounting for 15.4%, and elemental carbon of around 1.5% is probably due to anthropogenic activities near the monitoring site **(Figure 2.4)**.

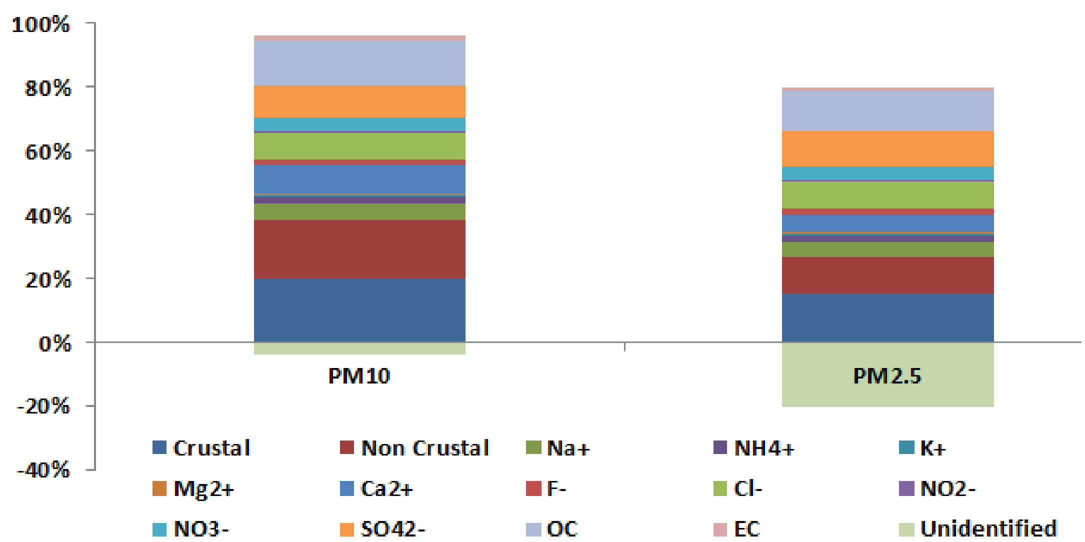


Figure 2.4: Percent Contribution to Mass in PM10 and PM2.5 at Colaba

Similar contribution is observed for $PM_{2.5}$, where Crustal elements were in the range of 25.8% and Non-crustal elements were around 19.5%. Anions and cations contribute 43.9% and 22.0% of the total $PM_{2.5}$. Sulfate (19%) and Chlorides (13.7%) are highest in Anions, whereas Calcium (9.4%) and Sodium (7.3%) are highest contributor in Cation. The organic matter accounts for 21%, and elemental carbon is around 1.7% of the total mass. The unidentified negative contribution in PM_{10} is -4.3% and -33.8% in $PM_{2.5}$ indicates that the sum of identified species exceeded the measured mass. This is due to particle bound water (Rees et al., 2004).

Kalbadevi: The Crustal and Non-crustal elements account for 16.5% and 15.3% of the total PM mass, respectively. Anions account for 25.5% of the total coarse particulate mass, whereas Cations make up to 15.1% of the total PM_{10}. The organic matter account for 13.3% and elemental carbon is around 0.7%. The highly commercial and residential activities are the major sources in the area and maximum contribution is probably due to secondary aerosol, road dust etc. Unidentified portion in PM_{10} was 13.6%, which may due to volatilization of organic matter and nitrates **(Figure 2.5)**.

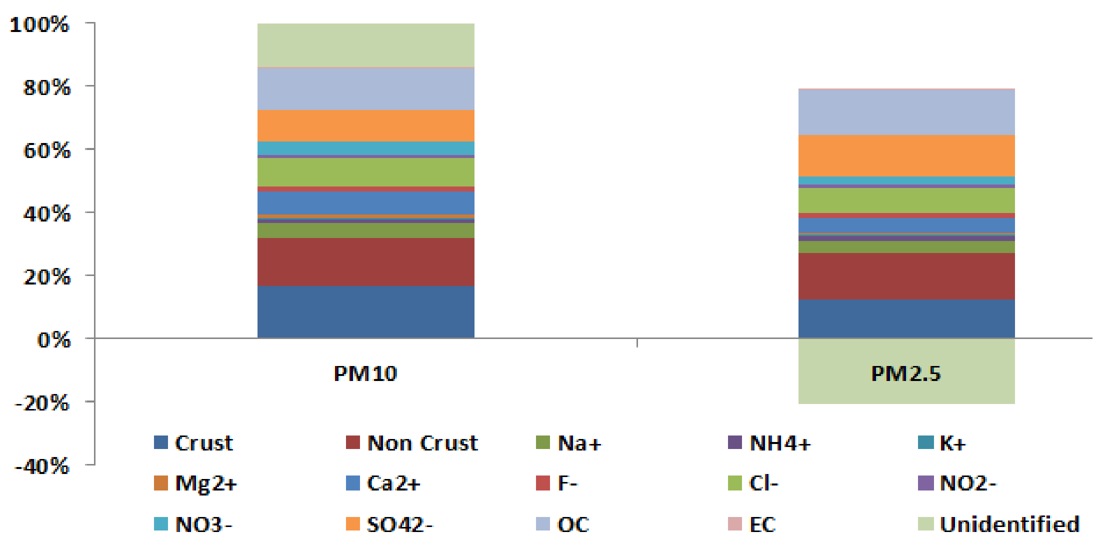


Figure 2.5: Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at Kalbadevi

Similar trend is observed for $PM_{2.5}$, where Crustal and Non-crustal elements are around 21.0% and 25.1%, respectively. Anions and cations contribute 44.4% and 19.5% of the total $PM_{2.5}$. Sulfate (21.9%) and chlorides (13.2%) are highest in Anions, whereas

Calcium (8.5%) and Sodium (6.3%) are highest in Cation. The organic matter account for 24.1%, and elemental carbon is around 1.2% of the total. The unidentified negative contribution of 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.

Mulund: The 23.09% and 16.17% are the Crustal and Non-crustal element proportion in PM_{10} mass. Anions account for 19.3% of the total coarse particulate mass, whereas Cations make up 15.1% of the total PM_{10}. The organic matter account for 17.08% and elemental carbon is around .2% of the total. The residential, commercial activities and vehicular movement are the source of emission loads.

The Crustal and Non-crustal elements contribution for $PM_{2.5}$ is around 10% for both. Anions and cations contribute 24.6% and 13.9% of the total $PM_{2.5}$, respectively. Sulfate (9.95%) and chlorides (8.03%) are highest in Anions, whereas Calcium (7.55%) and Sodium (3.67%) are highest in Cation. The organic matter account for 23.4% of the total mass and elemental carbon is around 2.54%. Unidentified portion in PM_{10} is around 7.08% and 15.03% in $PM_{2.5}$, probably due to volatilization of organic carbon and nitrates **(Figure 2.6)**.

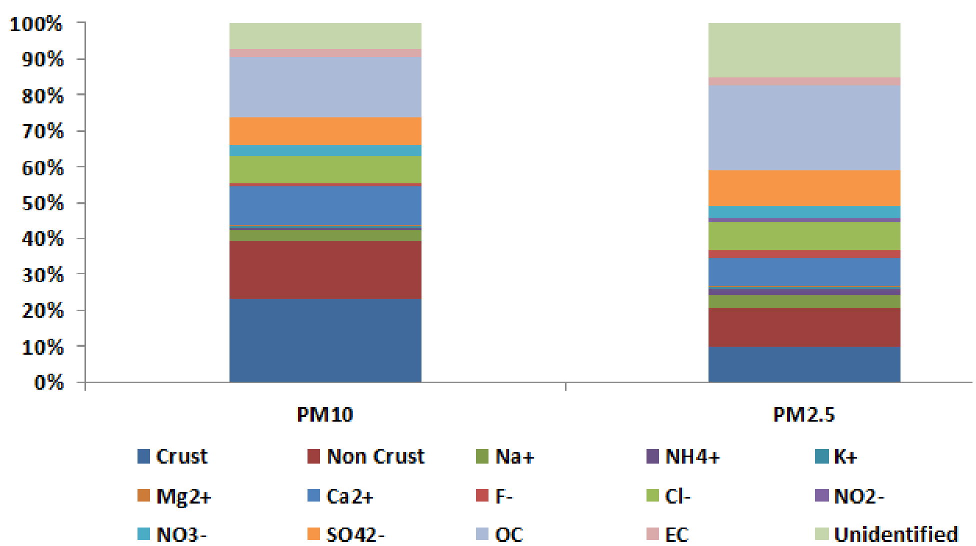


Figure 2.6: Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at Mulund

Bandra: The sampling location was near traffic intersection which resulted in heavy deposition of resuspension of road dust that contributes 35.6% for Crustal and 9.8% of

Non-crustal elements in PM_{10} mass. Anions account for 8.6% of the total coarse particulate mass, whereas Cations make up 11.6% of the total PM_{10}. The organic matter account for 13% of the total and elemental carbon is around 4.3%. This contribution is probably due to secondary aerosol, road dust and extensive vehicular movement. Unidentified portion in PM_{10} was 17.1% which may due to volatilization of organic matter and nitrates.

Crustal and Non-crustal elements influence for $PM_{2.5}$ is around 13.2% and 7.9% of the total mass, respectively. Anions and cations contribute 18.4% and 15.8% of the total $PM_{2.5}$. Sulfate (7.6%) and chlorides (5.7%) are highest in Anions, whereas Calcium (11.3%) is highest in Cation. The organic matter account for 37.4% of the total and elemental carbon is around 12.1%, indicting influence of vehicular movement. The negative unidentified portion (-4.7%) 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 **(Figure 2.7)**.

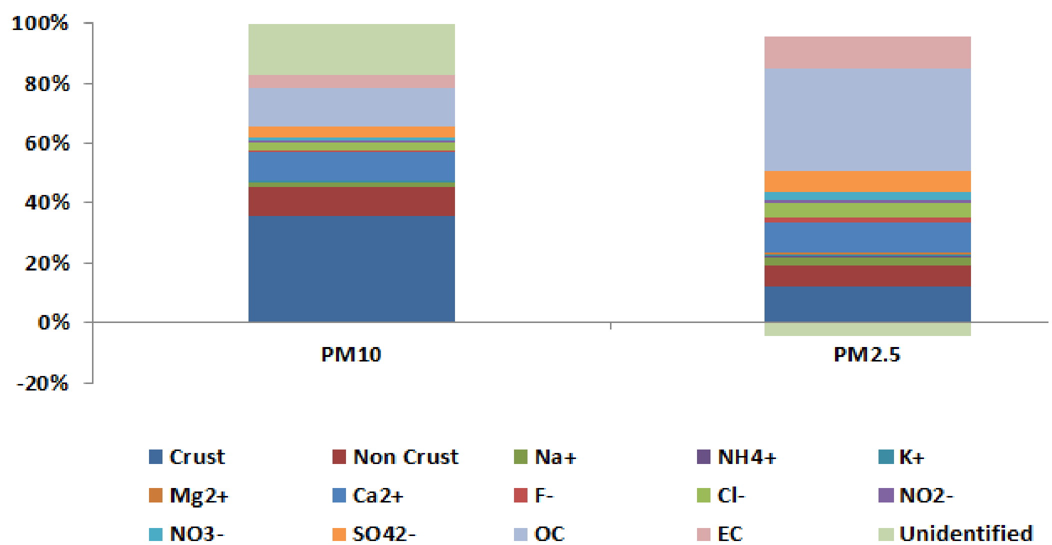


Figure 2.7 : Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at Bandra

Powai (Gandhi Nagar): The major sources near the sampling location is heavy vehicular movement and resuspension of road dust. The contribution of 25.10% for Crustal and 12.75% of Non-crustal elements is observed in PM_{10} mass. Anions account for 14.8% of the total coarse particulate mass, whereas Cations make up 12.5% of the total PM_{10}. The sulphate, chloride, calcium and sodium are the tracers. The organic matter is around

18.79%, and elemental carbon is around 4.88% of the total. The high contribution is probably due to secondary aerosol, road dust and extensive vehicular movement. Unidentified portion in PM_{10} was 11.13% which may due to volatilization of organic matter and nitrates **(Figure 2.8)**.

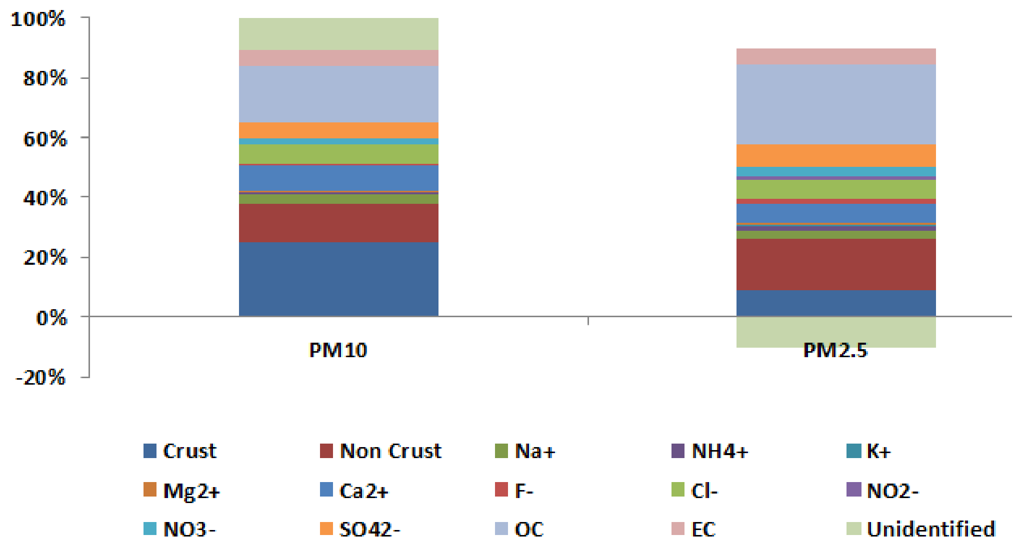


Figure 2.8: Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at Powai (Gandhinagar)

Crustal and Non-crustal elements influence for $PM_{2.5}$ is around 11.0% and 21.57%, respectively. Anions and cations contribute 24.8% and 15.0% of the total $PM_{2.5}$. Sulfate (9.55%) and chlorides (8.05%) are highest in Anions, whereas Calcium (8.24%) and sodium (3.73%) is highest in Cation. The organic matter of $PM_{2.5}$ is around 33.54% and elemental carbon is around 7.05%, indicating influence of the vehicular movement. The negative unidentified portion (-12.99%) 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.

Mahul: The Crustal and Non-crustal elements contribution is around 24.95% and 14.88% to the PM_{10} mass, respectively. Anions account for 19.8% of the total coarse particulate mass, whereas Cations make up 15.2% of the total PM_{10}. The sulphate (7.62%), chloride (7.06%) in anions, and calcium (10.43%) and sodium (3.51%) in cations are the highest contributors. The organic matter, accounts for 9.85% of the total mass. The high contribution is probably due to secondary aerosol, road dust and extensive vehicular movement near the sampling location. Unidentified portion in PM_{10} was 14.61% which may due to volatilization of organic matter and nitrates **(Figure 2.9)**.

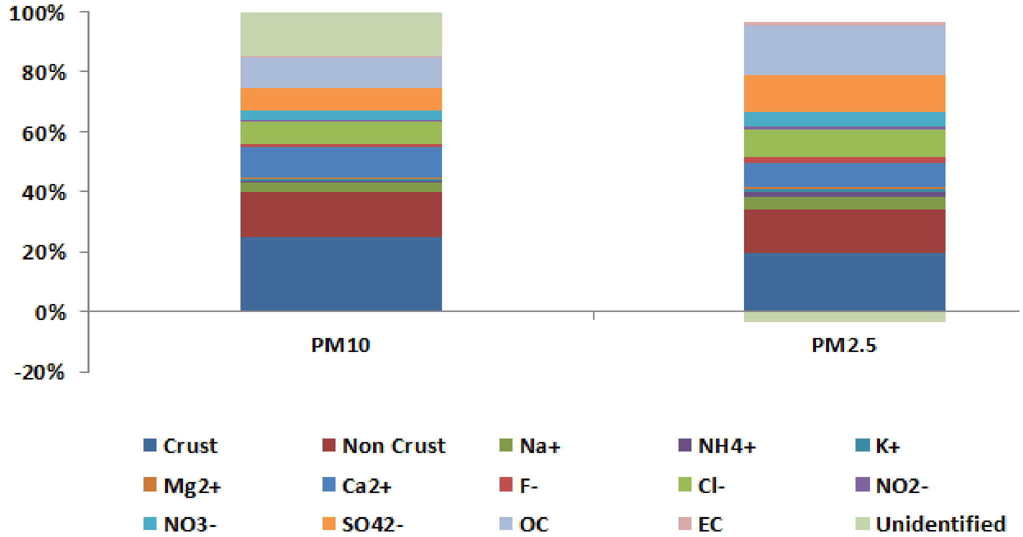


Figure 2.9: Percent Contribution to Mass in PM_{10} and $PM_{2.5}$ at Mahul

Crustal and Non-crustal elements influence for $PM_{2.5}$ is around 21.15% and 15.16%, respectively. Anions and cations contribute 31.6% and 17% of the total $PM_{2.5}$. Sulfate (13.12%) and chlorides (9.64%) are highest in Anions, whereas Calcium (8.92%) and sodium (4.70%) is highest in Cation. The organic matter accounts for 17.84% of the total. Unidentified portion of -3.70% in $PM_{2.5}$ is due to particle bound water and other analytical uncertainties.

2.4.1 Summary of the Mass Closure

This exercise served two important functions

1. Source characteristics
2. Accounting for total mass

An often-used practice of comparing the elemental, ions and EC/OC in terms of quality of contribution was used (Chow et al., 2015; Herlekar et al., 2012). The results are summarized in Table 2.2 and Figure 2.10.

a) The average values for crustal components in PM_{10} (24%) and $PM_{2.5}$ (17%) suggest a significant influence of natural sources like soil, road dust and possibly construction dust.

b) Conversely, the higher concentration of non-crustal components in $PM_{2.5}$ (17%) compared to PM_{10} (14%) implies a more prominent impact of anthropogenic sources, possibly from industrial emissions or combustion activities.

c) The anion and cation levels in $PM_{2.5}$ (31% and 17%, respectively) surpass those in PM10 (19% and 14%), indicating potential sources of air pollution releasing ions into the atmosphere such as marine and secondary aerosols.

d) Elevated levels of Organic Carbon (OC) and Elemental Carbon (EC) in $PM_{2.5}$ (26% and 4%, respectively) suggest a notable contribution from combustion-related sources like vehicular emissions and/or biomass burning.

For accounting of the total mass, as much as ~90% was accounted for. While 10% remained unidentified. These are consistent with similar studies reported previously (Chow et al., 2015; Herlekar et al., 2012).

Table 2.2: Mass closure for PM_{10} and $PM_{2.5}$ at six sampling locations in Mumbai

Location	Sample	Crustal	Non-crustal	Anions	Cation	OC	EC	Unidentified
Colaba	**PM_{10}**	22	20	27	19	15	2	0
	$PM_{2.5}$	26	20	44	22	21	2	-4
Kalbadevi	**PM_{10}**	17	15	26	15	13	1	14
	$PM_{2.5}$	21	25	44	20	24	1	0
Mulund	**PM_{10}**	23	16	19	15	17	2	0
	$PM_{2.5}$	10	10	25	14	23	3	7
Bandra	**PM_{10}**	36	10	9	12	13	4	17
	$PM_{2.5}$	13	8	18	16	37	12	-5
Powai	**PM_{10}**	25	13	15	13	19	5	11
	$PM_{2.5}$	11	22	25	15	34	7	-13
Mahul	**PM_{10}**	25	15	20	15	10	0	15
	$PM_{2.5}$	21	15	32	17	18	0	-4
Average	**PM_{10}**	24	15	19	15	15	2	9
	$PM_{2.5}$	17	17	31	17	26	4	-3

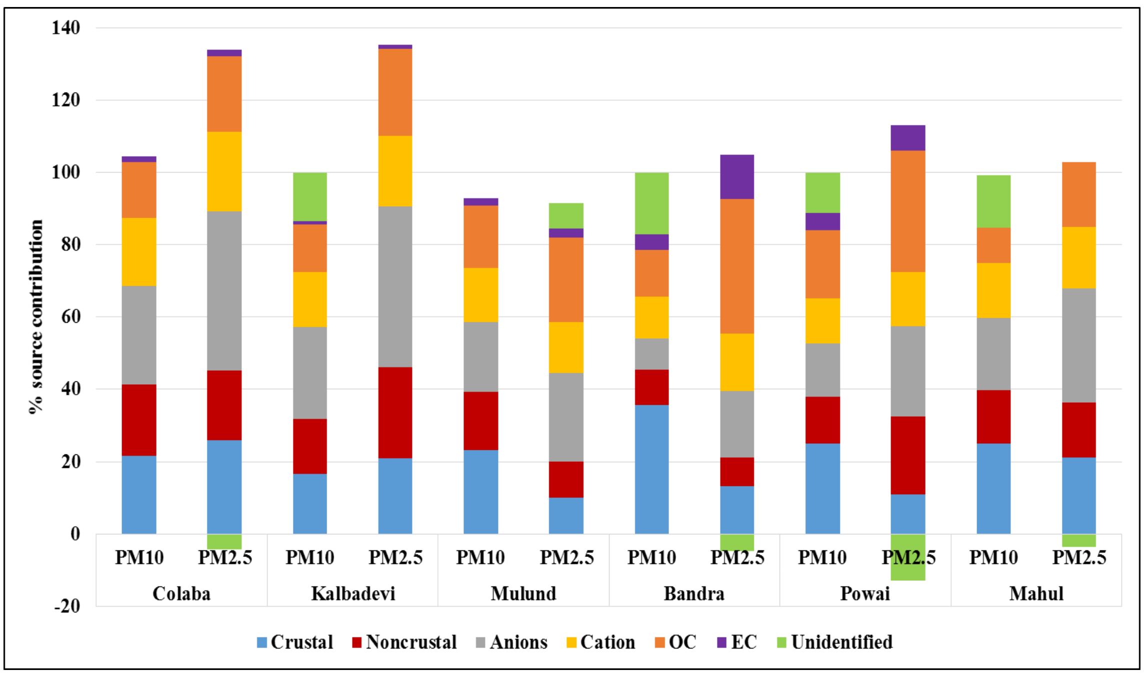


Figure 2.10: Mass closure for PM_{10} and $PM_{2.5}$ at six sampling locations in Mumbai

Chapter 3

Emission Inventory

3.1 Preamble

As the city is expanding and the population and vehicular growth are increasing day by day, with periodic updates to the emissions inventory, it is possible to determine emission trends over time. The identification of pollutant loads and preparation of strategic action plan for controlling these is necessary for air quality management.

Emissions inventory is the first exercise, under that identification and quantification of various sources are necessary to link them with the existing air quality levels measured at certain locations as well as predict air quality for whole region. An emissions factor is a representative variable that attempts to link the amount of a pollutant emitted to the level of activity associated with that pollutant's emission. Emissions data with geographic and temporal information can be utilized as input data for atmospheric transport and dispersion models. After verification using ground monitoring data, the resulting air concentration and dispersion estimations derived by modeling will be critical information for air quality management decision-making. It helps in assessing the impact of additional nearby sources in and around the region, and also to evaluate the control strategies for certain emission sources. The key emission sources can be identified and emission reduction priorities can be established. An emission inventory can be used to forecast future emissions based on expected socio-economic indicators (e.g. population increase, economic growth, changes in energy usage per unit activity), lower emission factors (e.g. better control methods), fuel switching, and so on. 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.

One of the most important dimensions that characterize emission inventories is the spatial resolution of emission data. Inventory with high spatial resolution is required for micro scale or local scale assessments. Low spatial resolution inventories are sufficient for estimating background concentration. Emission inventory of different sources of air pollution has been prepared for 2 km x 2 km sizes for whole of Mumbai city for accurately identifying and quantifying emissions from different sources **(Figure 3.1)**. Emission inventory has been prepared in terms of five major pollutants, viz. PM_{10}, SOx, NOx, CO and HC.

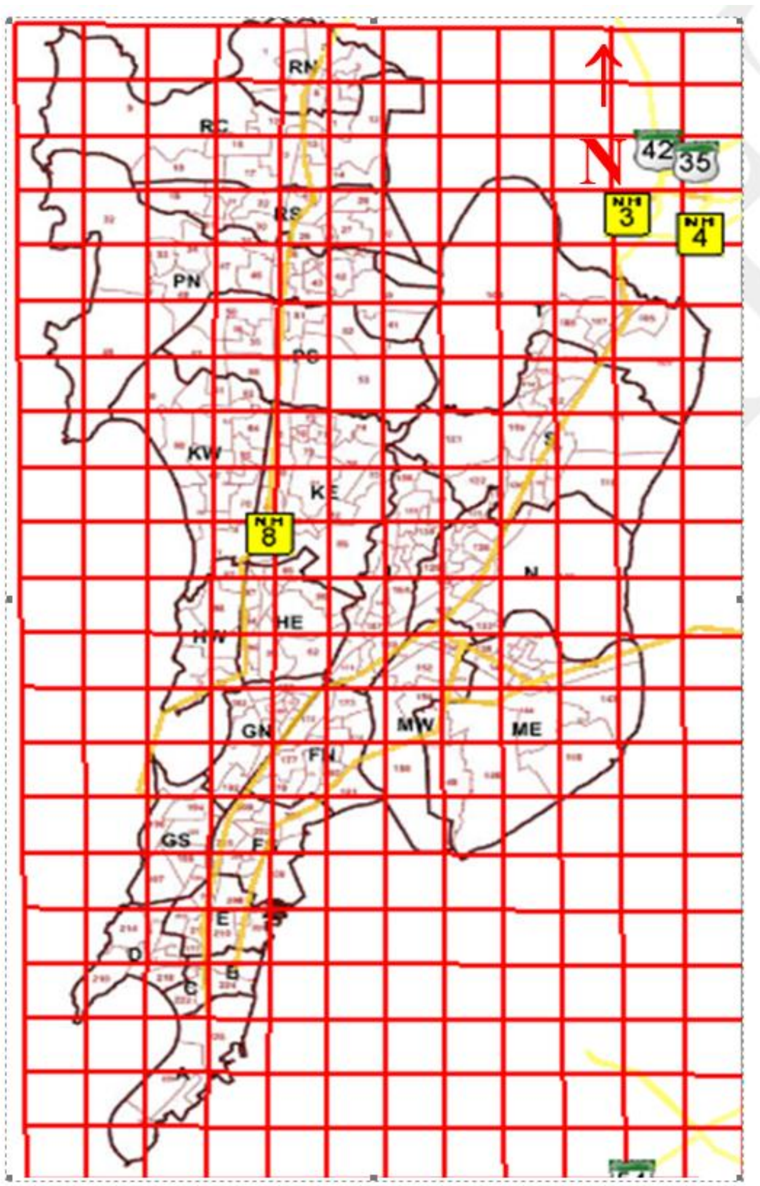


Figure 3.1: Study Area: Mumbai City CPCB Report, 2010 [URL 02]

3.2 Area Sources

An area source may be defined as a collection of similar units within a geographic area. Area sources collectively represent individual sources that are small and numerous and that cannot be inventoried as specific point or mobile sources. Area sources include the following groups, viz. bakeries, hotels/restaurants, crematoria, construction activities, domestic cooking, open eat outs, solid waste dumping ground, refuse burning and ports. In subsequent sections, these sources have been described along with the methodologies delineated for load estimations. Data on area source activities were collected from various

Government and non-Government departments/ agencies. The required information was 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). The emissions from various activities were estimated by applying emission factors used in CPCB Report, 2010 [URL 02] for various sources.

3.2.1 Bakeries

Description: Bakeries operate across Mumbai city, and their major influence is noticed in the central part of the city. According to MCGM, there are about 560 bakeries operating in Mumbai, while the Bakers' Association reports that there are about 1500 bakeries. Wood burning is the main source of pollution from bakeries. Mostly bakeries operate for 16 hours in a day and the peak season of business is December and January. Discussion with Bakers' Association pointed out that on an average, bakeries have 2 ovens operating and the average amount of wood consumed per oven is 250 kg/day. Diesel consumption for oven operating is about 60 liters/day. Electric and LPG consumption is based on the per unit of electric consumption and per cylinder of respective bakeries in a day. Data regarding bakeries in each ward were obtained from MCGM, Public Health Department and MPCB. On the basis of discussions with Bakers' Association and other MCGM officials and also after conducting primary survey for 2 km x 2 km around the city, average wood and diesel consumption per oven was quantified. The number of bakeries operating ward wise as per MCGM is given in **Table 3.1**.

Based on the primary survey estimates it was found that most of the bakeries use about 67% firewood and remaining 33% use electric, diesel and LPG. Some of the bakeries also use electric ovens and PNG. The ward-wise fuel consumption data are presented in **Table 3.2**.

Emission Estimations:

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

Number of registered bakeries with MCGM = 560
Wood consumption in a day = 250 (kg/d/oven) x 2 Ovens = 500 kg/d
Diesel consumption in a day = 60 (l/d)
Emission factor used are listed **Annexure I**
Emission Factor for Wood Burning = 17.3 (kg/t) (PM_{10})

Emission from wood burning (PM_{10}) = 378 x 500 x (17.30/1000) = 3269.70 (kg/d)

Emission Factor for Wood Burning = 17.3 (kg/t) (PM_{10})
Emission from wood burning (PM_{10}) = 378 x 500 x (17.30/1000) = 3269.70 (kg/d)
Emission Factor for Diesel Burning = 0.25 (kg/kl) (SPM) -60% PM_{10}
Emission from diesel burning (PM_{10}) = 52 x (60/1000) x 0.25 = 0.78 (kg/d)
Emission from LPG burning (PM) per day = 28 x (19/1000) x 2.10 = 1.1172 kg/d
Emission (PM_{10}) from Electric heating = 102 * 0.000025 (kg/per Unit) = 0.0026 (kg/d)

In similar way emission for others pollutants have been estimated as given in **Table 3.3.** Major pollutants from bakeries are CO, HC and PM_{10} due to wood burning, highest PM_{10} concentration was found at wards A, E, G/N and S. Large numbers of bakeries authorized as well as unauthorized are operating in Dharavi, Bandra and Khar. There is some level of uncertainty in the emission estimation of bakeries due to gap between number of bakeries registered with MCGM and as reported by Baker's Association. The number of bakeries could be more than registered with MCGM. Finally, the overall estimates for this sector have been based on bakeries registered with MCGM as they are more realistic and verifiable.

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

Wards	No. of Bakeries	Wood Based	Electric	Diesel Based	LPG Based
A	77	58	10	9	
B	21	17	4		
C	18	13	2	1	2
D	11	10	1		
E	48	38	4	6	
F/N	16	12	4		
F/S	14	10	4		
G/N	35	24	5	4	2
G/S	12	10	2		
H/E	22	18	4		
H/W	14	12	2		
K/E	39	18	8	9	4
K/W	40	19	9	8	4
P/N	20	7	5		8
P/S	19	6	5		8
R/C	6	4	2		
R/N	8	3	5		
R/S	18	9	5	4	
L	19	15	4		
M/E	19	18	1		
M/W	13	11	2		
N	25	17	5	3	
S	34	25	4	5	
T	12	4	5	3	
Total	**560**	**378**	**102**	**52**	**28**

Table 3.2: Ward-wise Wood and Diesel Consumption in Bakeries

Wards	Wood Consumption Total (kg/day)	Diesel Consumption Total (Kiloliter/day)
A	29000	0.54
B	8500	
C	6500	0.06
D	5000	
E	19000	0.36
F/N	6000	
F/S	5000	
G/N	12000	0.24
G/S	5000	
H/E	9000	
H/W	6000	
K/E	9000	0.54
K/W	9500	0.48
P/N	3500	
P/S	3000	
R/C	2000	
R/N	1500	
R/S	4500	0.24
L	7500	
M/E	9000	
M/W	5500	
N	8500	0.18
S	12500	0.3
T	2000	0.18
Total	189000	3.1200

Source: MCGM

Table 3.3: Emission Loads from Bakeries for all Wards

Wards	Wood Emissions (kg/day)						Diesel Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	501.7	341.2	5.8	37.7	3662.7	3320.5	0.08	0.06	0.05	1.49	0.34	0.06
B	147.1	100.0	1.7	11.1	1073.6	973.3						
C	112.5	76.5	1.3	8.5	821.0	744.3	0.01	0.01	0.01	0.17	0.04	0.01
D	86.5	58.8	1.0	6.5	631.5	572.5						
E	328.7	223.5	3.8	24.7	2399.7	2175.5	0.05	0.04	0.03	0.99	0.23	0.04
FN	103.8	70.6	1.2	7.8	757.8	687.0						
FS	86.5	58.8	1.0	6.5	631.5	572.5						
GN	207.6	141.2	2.4	15.6	1515.6	1374.0	0.04	0.02	0.02	0.66	0.15	0.03
GS	86.5	58.8	1.0	6.5	631.5	572.5						
HE	155.7	105.9	1.8	11.7	1136.7	1030.5						
HW	103.8	70.6	1.2	7.8	757.8	687.0						
KE	155.7	105.9	1.8	11.7	1136.7	1030.5	0.08	0.06	0.05	1.49	0.34	0.06
KW	164.4	111.8	1.9	12.4	1199.9	1087.8	0.07	0.05	0.04	1.32	0.30	0.06
PN	60.6	41.2	0.7	4.6	442.1	400.8						
PS	51.9	35.3	0.6	3.9	378.9	343.5						
RC	34.6	23.5	0.4	2.6	252.6	229.0						
RN	26.0	17.6	0.3	2.0	189.5	171.8						
RS	77.9	52.9	0.9	5.9	568.4	515.3	0.04	0.02	0.02	0.66	0.15	0.03
L	129.8	88.2	1.5	9.8	947.3	858.8						
ME	155.7	105.9	1.8	11.7	1136.7	1030.5						
MW	95.2	64.7	1.1	7.2	694.7	629.8						
N	147.1	100.0	1.7	11.1	1073.6	973.3	0.03	0.02	0.02	0.50	0.11	0.02
S	216.3	147.1	2.5	16.3	1578.8	1431.3	0.05	0.03	0.03	0.83	0.19	0.04
T	34.6	23.5	0.4	2.6	252.6	229.0	0.03	0.02	0.02	0.50	0.11	0.02
kg/day	**3269.7**	**2223.4**	**37.8**	**245.7**	**23870.7**	**21640.5**	**0.47**	**0.32**	**0.27**	**8.58**	**1.97**	**0.37**
Ton/year	**1193.4**	**811.5**	**13.8**	**89.7**	**8712.8**	**7898.8**	**0.17**	**0.12**	**0.10**	**3.13**	**0.72**	**0.14**

Table 3.3 (Cont..): Emission Loads from Bakeries for all Wards

Wards	Electric Emissions (kg/day)						LPG Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	0.0003	0.0002	0.5440	3.0800	1.4100	0.1300						
B	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
C	0.0001	0.0000	0.1088	0.6160	0.2820	0.0260	0.080	0.080	0.015	0.068	0.010	0.003
D	0.0000	0.0000	0.0544	0.3080	0.1410	0.0130						
E	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
FN	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
FS	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
GN	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650	0.080	0.080	0.015	0.068	0.010	0.003
GS	0.0001	0.0000	0.1088	0.6160	0.2820	0.0260						
HE	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
HW	0.0001	0.0000	0.1088	0.6160	0.2820	0.0260						
KE	0.0002	0.0001	0.4352	2.4640	1.1280	0.1040	0.160	0.160	0.030	0.137	0.019	0.005
KW	0.0002	0.0002	0.4896	2.7720	1.2690	0.1170	0.160	0.160	0.030	0.137	0.019	0.005
PN	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650	0.319	0.319	0.061	0.274	0.038	0.011
PS	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650	0.319	0.319	0.061	0.274	0.038	0.011
RC	0.0001	0.0000	0.1088	0.6160	0.2820	0.0260						
RN	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650						
RS	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650						
L	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
ME	0.0000	0.0000	0.0544	0.3080	0.1410	0.0130						
MW	0.0001	0.0000	0.1088	0.6160	0.2820	0.0260						
N	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650						
S	0.0001	0.0001	0.2176	1.2320	0.5640	0.0520						
T	0.0001	0.0001	0.2720	1.5400	0.7050	0.0650						
kg/day	**0.0026**	**0.0017**	**5.5488**	**31.4160**	**14.3820**	**1.3260**	**1.117**	**1.117**	**0.213**	**0.958**	**0.134**	**0.038**
Ton/year	**0.0009**	**0.0006**	**2.0253**	**11.4668**	**5.24943**	**0.4840**	**0.408**	**0.408**	**0.078**	**0.350**	**0.049**	**0.014**

Table 3.3 (Cont..): Emission Loads from Bakeries for all Wards

Wards	Total Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	501.8	341.2	6.4	42.3	3664.5	3320.7
B	147.1	100.0	1.9	12.3	1074.1	973.3
C	112.5	76.6	1.4	9.3	821.3	744.3
D	86.5	58.8	1.1	6.8	631.6	572.5
E	328.8	223.6	4.0	26.9	2400.5	2175.6
FN	103.8	70.6	1.4	9.0	758.4	687.1
FS	86.5	58.8	1.2	7.7	632.1	572.6
GN	207.7	141.3	2.7	17.9	1516.5	1374.1
GS	86.5	58.8	1.1	7.1	631.8	572.5
HE	155.7	105.9	2.0	12.9	1137.3	1030.6
HW	103.8	70.6	1.3	8.4	758.1	687.0
KE	155.9	106.1	2.3	15.8	1138.2	1030.7
KW	164.6	112.0	2.5	16.6	1201.4	1087.9
PN	60.9	41.5	1.0	6.4	442.8	400.8
PS	52.2	35.6	0.9	5.7	379.6	343.6
RC	34.6	23.5	0.5	3.2	252.9	229.0
RN	26.0	17.6	0.6	3.5	190.2	171.8
RS	77.9	53.0	1.2	8.1	569.2	515.3
L	129.8	88.2	1.7	11.0	947.8	858.8
ME	155.7	105.9	1.9	12.0	1136.8	1030.5
MW	95.2	64.7	1.2	7.8	694.9	629.8
N	147.1	100.0	2.0	13.1	1074.4	973.3
S	216.3	147.1	2.7	18.3	1579.5	1431.3
T	34.6	23.5	0.7	4.6	253.4	229.1
kg/day	**3271.3**	**2224.8**	**43.8**	**286.7**	**23887.2**	**21642.2**
Ton/year	**1194.0**	**812.1**	**16.0**	**104.6**	**8718.8**	**7899.4**

3.2.2 Crematoria

Description: As per Hindu tradition, deaths rites are carried out primarily using wood. According to MCGM there are about 88 Hindu crematoria in Mumbai city. Of these, 42 are wood based and 11 are electrically operated by MCGM, whereas 35 wood based crematoria are operated by private agencies. Average wood requirement for burning the dead bodies, on the basis of primary survey and consultation with MCGM officials, is about 300 kg and 3 liters (2.43 kg) of kerosene. Data regarding crematoria in each ward was obtained from MCGM's Public Health Department. The number of crematoria operating ward-wise and number of Hindu deaths in each ward as per MCGM is given in **Table 3.4**.

Table 3.4: Ward-wise Distribution of Crematoria and Registered Hindu Deaths (2018-19)

Wards	Total Crematoria	Wood Based	Electric Based	Pvt. Crematoria	No. of Bodies	Electric Burning Deaths
A	--	--	--	--	--	--
B	--	--	--	--	--	--
C	3	1	1	1	1701	1600
D	--	--	--	--	198	98
E	2	1	1	--	725	637
F/N	5	2	1	2	1888	1115
F/S	2	1	1	--	2053	615
G/N	3	2	1	--	2292	832
G/S	4	1	1	2	1082	197
H/E	3	2	--	1	1645	--
H/W	4	2	--	2	1477	--
K/E	1	1	--	--	3761	435
K/W	9	4	1	4	2723	1182
P/N	11	3	--	8	2259	--
P/S	1	1	--	--	989	--
R/C	4	3	1	--	3571	1241
R/N	6	1	--	5	172	--
R/S	5	2	1	2	3896	1114
L	4	2	--	2	1289	--
M/E	8	4	--	4	1359	--
M/W	6	4	1	1	120	--
N	3	2	--	1	3268	--
S	3	2	1	--	2835	541
T	1	1	--	--	727	--
Total	**88**	**42**	**11**	**35**	**40030**	**9607**

-- Crematoria is not present in the respective wards. * *Source: MCGM by personal communication*

Assumptions

Based on the consultation and visits, it appears that about 20% of bodies are burnt in electric crematoria in respective wards where electric crematoria exist, and remaining 80% are burnt in wood crematoria. Despite presence of electric crematoria, most of the population prefers using wood-based cremation. Since there are no crematoria in Ward A and B, it is assumed that cremation from A and B wards will be in neighboring wards, accordingly deaths have been distributed in ward C, D and E. Similarly, deaths from ward T are distributed in the respective neighboring wards. Ward-wise wood consumption, kerosene consumption in each crematorium is given in **Table 3.5.**

Table 3.5: Ward-wise Distribution of Bodies Burnt and Wood and Kerosene Consumption

Wards	Total Wood Consumption (kg)	Total Kerosene Consumption (kg)	Ward	Total Wood Consumption (kg)	Total Kerosene Consumption (kg)
C	510300	4133	**P/N**	677700	5489
D	59400	481	**P/S**	296700	2403
E	217500	1762	**R/C**	1071300	8678
F/N	566400	4588	**R/N**	51600	418
F/S	615900	4989	**R/S**	1168800	9467
G/N	687600	5570	**L**	386700	3132
G/S	324600	2629	**M/E**	407700	3302
H/E	493500	3997	**M/W**	36000	292
H/W	443100	3589	**N**	980400	7941
K/E	1128300	9139	**S**	850500	6889
K/W	816900	6617	T	218100	1767

Emission Estimations:

Emission (TSP) =No. of Hindu Death /yr. (0.8) * wood required per body (kg) * emission factor

+ fuel used (kerosene –liters) * emission factor +Emission from Body Burnt *emission factor

Number of Registered deaths in Mumbai = 49637

Taking 80% of total dead bodies in fire wood crematoria = 40030 (deaths/yr.)

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

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

Emission Factor (SPM) Kerosene = 1.95 (kg/t)

Emission Factor (PM_{10}) Kerosene = 0.61 (kg/t)

Emission Factor Electric crematoria = 0.000025 (kg/body)

Emission (PM_{10}) from wood burning = 40030 (deaths/yr.) * 17.3 (kg/t) = 207755.7 (kg/yr.)

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

Emission (PM) from Kerosene burning = 40030 (deaths/yr.) * 0.00243 (T) * 1.95 (SPM) (kg/t) + 0.61 (PM) (kg/t) = 59.3 (kg/year)

Emission (PM_{10}) from Electric burning = 9607 (deaths/yr.) * 0.000025 (kg/t) = 0.24 (kg/yr.)

In similar way emission for others pollutants have been estimated as given **Table 3.6.** Total emission load from crematoria indicates that G/N, K/E, K/W, P/N, R/C, R/S and N are the major contributors as they are reporting more death during particular year. CO is the major pollutant followed by HC, PM_{10} and NOx as the major source in wood burning. Hindu cremation processes vary substantially due to the quantity and type of wood used and type of pyres prepared.

Table 3.6: Ward-wise Emission Estimates for Crematoria

Wards	Wood Emissions (kg/year)						Kerosene Emissions (kg/year)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
C	8828.2	6003.2	102.1	663.4	64450.9	58429.4	2.5	1.7	16.5	10.3	256.3	78.5
D	1027.6	698.8	11.9	77.2	7502.2	6801.3	0.3	0.2	1.9	1.2	29.8	9.1
E	3762.8	2558.7	43.5	282.8	27470.3	24903.8	1.1	0.7	7.0	4.4	109.2	33.5
F/N	9798.7	6663.1	113.3	736.3	71536.3	64852.8	2.8	1.9	18.4	11.5	284.4	87.2
F/S	10655.1	7245.4	123.2	800.7	77788.2	70520.6	3.0	2.1	20.0	12.5	309.3	94.8
G/N	11895.5	8088.9	137.5	893.9	86843.9	78730.2	3.4	2.3	22.3	13.9	345.3	105.8
G/S	5615.6	3818.6	64.9	422.0	40997.0	37166.7	1.6	1.1	10.5	6.6	163.0	50.0
H/E	8537.6	5805.5	98.7	641.6	62329.1	56505.8	2.4	1.7	16.0	10.0	247.8	75.9
H/W	7665.6	5212.6	88.6	576.0	55963.5	50735.0	2.2	1.5	14.4	9.0	222.5	68.2
K/E	19519.6	13273.3	225.7	1466.8	142504.3	129190.4	5.6	3.8	36.6	22.8	566.6	173.6
K/W	14132.4	9610.0	163.4	1062.0	103174.5	93535.1	4.0	2.7	26.5	16.5	410.2	125.7
P/N	11724.2	7972.5	135.5	881.0	85593.5	77596.7	3.3	2.3	22.0	13.7	340.3	104.3
P/S	5132.9	3490.4	59.3	385.7	37473.2	33972.2	1.5	1.0	9.6	6.0	149.0	45.7
R/C	18533.5	12602.8	214.3	1392.7	135305.2	122663.9	5.3	3.6	34.7	21.7	538.0	164.9
R/N	892.7	607.0	10.3	67.1	6517.1	5908.2	0.3	0.2	1.7	1.0	25.9	7.9
R/S	20220.2	13749.8	233.8	1519.4	147619.4	133827.6	5.8	3.9	37.9	23.7	587.0	179.9
L	6689.9	4549.1	77.3	502.7	48840.2	44277.2	1.9	1.3	12.5	7.8	194.2	59.5
M/E	7053.2	4796.2	81.5	530.0	51492.5	46681.7	2.0	1.4	13.2	8.3	204.7	62.7
M/W	622.8	423.5	7.2	46.8	4546.8	4122.0	0.2	0.1	1.2	0.7	18.1	5.5
N	16960.9	11533.4	196.1	1274.5	123824.5	112255.8	4.8	3.3	31.8	19.9	492.4	150.9
S	14713.7	10005.3	170.1	1105.7	107418.2	97382.3	4.2	2.9	27.6	17.2	427.1	130.9
T	3773.1	2565.7	43.6	283.5	27546.0	24972.5	1.1	0.7	7.1	4.4	109.5	33.6
3.2.2.1 k	**569.2**	**387.1**	**6.6**	**42.8**	**4155.4**	**3767.2**	**0.2**	**0.1**	**1.1**	**0.7**	**16.5**	**5.1**
Ton/year	**207.8**	**141.3**	**2.4**	**15.6**	**1516.7**	**1375.0**	**0.1**	**0.0**	**0.4**	**0.2**	**6.0**	**1.8**

--- Crematoria is not present in the ward which are not listed.

Table 3.6 (Contd..): Ward wise Emission Estimates for Crematoria

Wards	Electric Emissions (kg/year)						Body Burnt Emissions (kg/year)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
C	0.040	0.027	87.040	492.800	225.600	20.800	0.043	0.029	92.534	523.908	239.841	22.113
D	0.002	0.002	5.331	30.184	13.818	1.274	0.005	0.003	10.771	60.984	27.918	2.574
E	0.016	0.011	34.653	196.196	89.817	8.281	0.018	0.012	39.440	223.300	102.225	9.425
F/N	0.028	0.019	60.656	343.420	157.215	14.495	0.047	0.032	102.707	581.504	266.208	24.544
F/S	0.015	0.010	33.456	189.420	86.715	7.995	0.051	0.035	111.683	632.324	289.473	26.689
G/N	0.021	0.014	45.261	256.256	117.312	10.816	0.057	0.039	124.685	705.936	323.172	29.796
G/S	0.005	0.003	10.717	60.676	27.777	2.561	0.027	0.018	58.861	333.256	152.562	14.066
H/E							0.041	0.028	89.488	506.660	231.945	21.385
H/W							0.037	0.025	80.349	454.916	208.257	19.201
K/E	0.011	0.007	23.664	133.980	61.335	5.655	0.094	0.064	204.598	1158.388	530.301	48.893
K/W	0.030	0.020	64.301	364.056	166.662	15.366	0.068	0.046	148.131	838.684	383.943	35.399
P/N							0.056	0.038	122.890	695.772	318.519	29.367
P/S							0.025	0.017	53.802	304.612	139.449	12.857
R/C	0.031	0.021	67.510	382.228	174.981	16.133	0.089	0.061	194.262	1099.868	503.511	46.423
R/N							0.004	0.003	9.357	52.976	24.252	2.236
R/S	0.028	0.019	60.602	343.112	157.074	14.482	0.097	0.066	211.942	1199.968	549.336	50.648
L							0.032	0.022	70.122	397.012	181.749	16.757
M/E							0.034	0.023	73.930	418.572	191.619	17.667
M/W							0.003	0.002	6.528	36.960	16.920	1.560
N							0.082	0.056	177.779	1006.544	460.788	42.484
S	0.014	0.009	29.430	166.628	76.281	7.033	0.071	0.048	154.224	873.180	399.735	36.855
T							0.018	0.012	39.549	223.916	102.507	9.451
3.2.2.2 kg/da	**0.001**	**0.0004**	**1.432**	**8.107**	**3.711**	**0.342**	**0.003**	**0.002**	**5.966**	**33.779**	**15.464**	**1.426**
Ton/year	**0.0002**	**0.0002**	**0.523**	**2.959**	**1.355**	**0.125**	**0.001**	**0.001**	**2.178**	**12.329**	**5.644**	**0.520**

Table 3.6 (Contd.): Ward wise Emission Estimates for Crematoria

Wards	Total Emissions (kg/year)					
	PM_{10}	**$PM_{2.5}$**	**SO_2**	**NOx**	**CO**	**HC**
C	8830.8	6004.9	298.2	1690.4	65172.6	58550.8
D	1027.9	699.0	29.9	169.6	7573.8	6814.3
E	3763.9	2559.4	124.6	706.7	27771.5	24954.9
F/N	9801.6	6665.1	295.0	1672.7	72244.2	64979.0
F/S	10658.2	7247.6	288.3	1634.9	78473.7	70650.0
G/N	11899.0	8091.3	329.7	1870.0	87629.7	78876.6
G/S	5617.2	3819.7	145.0	822.5	41340.3	37233.3
H/E	8540.0	5807.2	204.2	1158.2	62808.8	56603.1
H/W	7667.9	5214.1	183.3	1039.9	56394.3	50822.3
K/E	19525.3	13277.2	490.5	2782.0	143662.6	129418.5
K/W	14136.5	9612.8	402.3	2281.3	104135.3	93711.5
P/N	11727.6	7974.8	280.4	1590.5	86252.4	77730.3
P/S	5134.4	3491.4	122.8	696.3	37761.7	34030.7
R/C	18538.9	12606.5	510.7	2896.5	136521.7	122891.3
R/N	892.9	607.2	21.3	121.1	6567.2	5918.4
R/S	20226.1	13753.8	544.2	3086.2	148912.8	134072.6
L	6691.9	4550.5	160.0	907.6	49216.2	44353.4
M/E	7055.3	4797.6	168.7	956.8	51888.9	46762.1
M/W	623.0	423.6	14.9	84.5	4581.8	4129.1
N	16965.8	11536.8	405.6	2300.9	124777.7	112449.2
S	14717.9	10008.2	381.3	2162.7	108321.3	97557.0
T	3774.2	2566.5	90.2	511.9	27758.1	25015.5
3.2.2.3 kg/day	**569.4**	**387.2**	**15.0**	**85.3**	**4191.1**	**3774.0**
Ton/year	**207.8**	**141.3**	**5.5**	**31.1**	**1529.8**	**1377.5**

3.2.3 Open Eat-outs

Description: In India, the national policy for urban street vendors /hawkers notes that street vendors constitute approximately 2% population of a metropolis. In Mumbai, around commercial centers, mainly street hawkers / open eat outs operate providing meals /snacks and tea. Municipal Corporation /government consider street vendors as encroachers, but this forms an important unorganized sector of business. On the basis of primary survey, 40% of the vendors use kerosene as fuel followed by LPG -50% and coal about 10%. The average consumption of kerosene per day is approximately 8 liters, 1 cylinder (4 kg/day LPG) and 10 kg/day of coal for cooking purpose. Average operating hours of street vendors is 12 hours. Data regarding number of street vendors is not available since it is not authorized. Therefore, MCGM regularly takes action on street vendors and the data are documented. Based on the data of areas of such action taken on number of street vendors by MCGM (License Department), surveys were carried out. These numbers have been checked and fuel use pattern was estimated on the basis of primary survey which involved consultations with operators. Distribution of open eat outs is presented in **Table 3.7**.

Emission Estimates

Per Vendor/ Stall consumption for each type of fuel is taken as
For Kerosene - 8 l/stall/day, For LPG - 4 kg /day, For Coal - 10 kg/day
Total emissions = Emissions from kerosene burning + LPG burning + Coal burning

Emission from kerosene burning (PM) per day
= Number of street vendors operating on kerosene x fuel consumption per day x emission factor
= (533 x 8 x 0.8172 (density) x 0.06 (EF SPM))/ 1000 x 0.61 (EF PM) =0.13 kg/d

Emission from LPG burning (PM) per day
= Number of street vendors operating on LPG x fuel consumption per day x emission factor
= 666 x 4 /1000 x 2.10 = 5.60 kg/d

Emission from Coal burning (PM) per day
= Number of street vendors operating on Coal x fuel consumption per day x emission factor
= 133 x 10 /1000 x 20 (EF SPM) x 0.6 (PM) = 15.99 kg/d

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

Site-specific emission distribution shows that A, F/N, F/S, G/N, K/E and K/W areas have larger emissions, as these areas are commercial, and mixed (industrial estates, shopping malls) spots, where likelihood of floating population is high. CO is the major contributor followed by SO_2, PM_{10}, and NOx. The actual number of street vendors could be higher /lower than the estimated depending upon time, season and locations.

Table 3.7: Ward-wise Distribution of Open Eat outs

Wards	Street Vendors	S. Vendors Operated on Kerosene	S. Vendors Operated on LPG	S. Vendors Operated on Coal	Kerosene Consumption (Liters)	LPG Consumption (Converted to kg)	Coal Consumption (kg)
A	166	67	83	17	135	84	42
B	42	17	21	4	107	67	33
C	33	13	17	3	66	41	21
D	21	8	10	2	35	22	11
E	11	4	5	1	463	289	145
FN	145	58	72	14	266	166	83
FS	83	33	42	8	187	117	58
GN	58	23	29	6	124	78	39
GS	39	16	19	4	135	84	42
HE	32	13	16	3	104	65	32
HW	46	19	23	5	149	93	46
KE	77	31	38	8	245	153	77
KW	230	92	115	23	736	460	230
PN	17	7	9	2	55	35	17
PS	50	20	25	5	159	99	50
RC	19	8	10	2	62	39	19
RN	6	3	3	1	21	13	6
RS	31	13	16	3	100	63	31
L	42	17	21	4	135	84	42
ME	32	13	16	3	104	65	32
MW	48	19	24	5	152	95	48
N	56	22	28	6	180	112	56
S	12	5	6	1	38	24	12
T	35	14	17	3	111	69	35
Total	**1333**	**533**	**666**	**133**	**4265**	**2665**	**1333**

** Source: MCGM by personal communication*

Table 3.8: Emission Load from Open Eat Out

Wards	Kerosene Emissions (kg/day)							LPG Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC		PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	0.016	0.011	1.74	1.09	26.96	8.26		0.70	0.70	0.13	0.60	0.08	0.024
B	0.004	0.003	0.44	0.28	6.83	2.09		0.18	0.18	0.03	0.15	0.02	0.006
C	0.003	0.002	0.35	0.22	5.43	1.66		0.14	0.14	0.03	0.12	0.02	0.005
D	0.002	0.001	0.21	0.13	3.33	1.02		0.09	0.09	0.02	0.07	0.01	0.003
E	0.001	0.001	0.11	0.07	1.75	0.54		0.05	0.05	0.01	0.04	0.01	0.002
FN	0.014	0.009	1.51	0.95	23.46	7.19		0.61	0.61	0.12	0.52	0.07	0.021
FS	0.008	0.005	0.87	0.54	13.48	4.13		0.35	0.35	0.07	0.30	0.04	0.012
GN	0.006	0.004	0.61	0.38	9.45	2.90		0.24	0.24	0.05	0.21	0.03	0.008
GS	0.004	0.003	0.41	0.25	6.30	1.93		0.16	0.16	0.03	0.14	0.02	0.006
HE	0.003	0.002	0.34	0.21	5.25	1.61		0.14	0.14	0.03	0.12	0.02	0.005
HW	0.004	0.003	0.49	0.30	7.53	2.31		0.20	0.20	0.04	0.17	0.02	0.007
KE	0.007	0.005	0.80	0.50	12.43	3.81		0.32	0.32	0.06	0.28	0.04	0.011
KW	0.022	0.015	2.41	1.50	37.29	11.43		0.97	0.97	0.18	0.83	0.12	0.033
PN	0.002	0.001	0.18	0.11	2.80	0.86		0.07	0.07	0.01	0.06	0.01	0.002
PS	0.005	0.003	0.52	0.32	8.05	2.47		0.21	0.21	0.04	0.18	0.03	0.007
RC	0.002	0.001	0.20	0.13	3.15	0.97		0.08	0.08	0.02	0.07	0.01	0.003
RN	0.001	0.000	0.07	0.04	1.05	0.32		0.03	0.03	0.01	0.02	0.00	0.001
RS	0.003	0.002	0.33	0.20	5.08	1.56		0.13	0.13	0.03	0.11	0.02	0.005
L	0.004	0.003	0.44	0.28	6.83	2.09		0.18	0.18	0.03	0.15	0.02	0.006
ME	0.003	0.002	0.34	0.21	5.25	1.61		0.14	0.14	0.03	0.12	0.02	0.005
MW	0.005	0.003	0.50	0.31	7.70	2.36		0.20	0.20	0.04	0.17	0.02	0.007
N	0.005	0.004	0.59	0.37	9.10	2.79		0.24	0.24	0.04	0.20	0.03	0.008
S	0.001	0.001	0.12	0.08	1.93	0.59		0.05	0.05	0.01	0.04	0.01	0.002
T	0.003	0.002	0.36	0.23	5.60	1.72		0.15	0.15	0.03	0.12	0.02	0.005
kg/day	**0.128**	**0.087**	**13.94**	**8.71**	**216.06**	**66.21**		**5.60**	**5.60**	**1.07**	**4.80**	**0.67**	**0.192**
Ton/year	**0.047**	**0.032**	**5.09**	**3.18**	**78.86**	**24.17**		**2.04**	**2.04**	**0.39**	**1.75**	**0.25**	**0.070**

Table 3.8 (Contd..): Emission Load from Open Eat Outs

Wards	Coal Emissions (kg/day)							Total Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC		PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	2.0	1.4	2.2	0.7	4.1	0.08		2.71	2.07	4.08	2.35	31.19	8.37
B	0.5	0.3	0.6	0.2	1.0	0.02		0.69	0.52	1.03	0.60	7.90	2.12
C	0.4	0.3	0.4	0.1	0.8	0.02		0.55	0.42	0.82	0.47	6.28	1.68
D	0.2	0.2	0.3	0.1	0.5	0.01		0.33	0.25	0.50	0.29	3.85	1.03
E	0.1	0.1	0.1	0.0	0.3	0.01		0.18	0.13	0.27	0.15	2.03	0.54
FN	1.7	1.2	1.9	0.6	3.6	0.07		2.36	1.80	3.55	2.04	27.14	7.28
FS	1.0	0.7	1.1	0.3	2.1	0.04		1.36	1.03	2.04	1.17	15.60	4.19
GN	0.7	0.5	0.8	0.2	1.5	0.03		0.95	0.72	1.43	0.82	10.94	2.94
GS	0.5	0.3	0.5	0.2	1.0	0.02		0.63	0.48	0.95	0.55	7.29	1.96
HE	0.4	0.3	0.4	0.1	0.8	0.02		0.53	0.40	0.80	0.46	6.08	1.63
HW	0.6	0.4	0.6	0.2	1.2	0.02		0.76	0.58	1.14	0.66	8.71	2.34
KE	0.9	0.6	1.0	0.3	1.9	0.04		1.25	0.95	1.88	1.08	14.38	3.86
KW	2.8	1.9	3.1	0.9	5.7	0.12		3.75	2.86	5.65	3.25	43.14	11.58
PN	0.2	0.1	0.2	0.1	0.4	0.01		0.28	0.21	0.42	0.24	3.24	0.87
PS	0.6	0.4	0.7	0.2	1.2	0.02		0.81	0.62	1.22	0.70	9.32	2.50
RC	0.2	0.2	0.3	0.1	0.5	0.01		0.32	0.24	0.48	0.27	3.65	0.98
RN	0.1	0.1	0.1	0.0	0.2	0.00		0.11	0.08	0.16	0.09	1.22	0.33
RS	0.4	0.3	0.4	0.1	0.8	0.02		0.51	0.39	0.77	0.44	5.87	1.58
L	0.5	0.3	0.6	0.2	1.0	0.02		0.69	0.52	1.03	0.60	7.90	2.12
ME	0.4	0.3	0.4	0.1	0.8	0.02		0.53	0.40	0.80	0.46	6.08	1.63
MW	0.6	0.4	0.6	0.2	1.2	0.02		0.77	0.59	1.17	0.67	8.91	2.39
N	0.7	0.5	0.7	0.2	1.4	0.03		0.92	0.70	1.38	0.79	10.53	2.83
S	0.1	0.1	0.2	0.0	0.3	0.01		0.19	0.15	0.29	0.17	2.23	0.60
T	0.4	0.3	0.5	0.1	0.9	0.02		0.56	0.43	0.85	0.49	6.48	1.74
kg/day	**16.0**	**10.9**	**17.7**	**5.3**	**33.2**	**0.67**		**21.72**	**16.56**	**32.73**	**18.83**	**249.95**	**67.07**
Ton/year	**5.8**	**4.0**	**6.5**	**1.9**	**12.1**	**0.24**		**7.93**	**6.04**	**11.95**	**6.87**	**91.23**	**24.48**

3.2.4 Hotel & Restaurants

Description: Information on hotels and restaurants was obtained by consulting the members of Hotel and Restaurant Owners Association of Mumbai and MCGM Ward Offices. There were 5504 hotels and restaurants registered with BMC up to March 2016, ward-wise break up is presented in **Table 3.9**. During the discussions with the concerned people, it was revealed that the actual number of tea stalls/snack bars/fast food centers could be more than twice the registered number. In addition, there are a number of staff canteens of various establishments in Mumbai. Hotels and Restaurants use LPG cylinders and coal for their operation. LPG commercial cylinders are used for cooking and coal is used in the tandoor Bhatti's. The primary survey of hotels and restaurants gave an average LPG consumption of 3 Cylinders (19 kg capacity) per day and coal consumption of 8 kg per day per hotel/restaurant as per the survey.

Table 3.9: Ward-wise Number of Hotels & Restaurants: (2018-19)

Wards	No. o Hotel	LPG (kg) Consumptio	Coal (kg) Consumptio		Ward	No. of Hotel	LPG (kg) Consumptio	Coal (kg) Consumptio
A	414	23598	3312		**P/N**	215	12255	1720
B	385	21945	3080		**P/S**	187	10659	1496
C	296	16872	2368		**R/C**	117	6669	936
D	198	11286	1584		**R/N**	87	4959	696
E	311	17727	2488		**R/S**	144	8208	1152
F/N	169	9633	1352		**L**	256	14592	2048
F/S	333	18981	2664		**M/E**	65	3705	520
G/N	398	22686	3184		**M/W**	182	10374	1456
G/S	247	14079	1976		**N**	209	11913	1672
H/E	159	9063	1272		**S**	159	9063	1272
H/W	217	12369	1736		**T**	179	10203	1432
K/E	294	16758	2352					
K/W	283	16131	2264		**Total**	**5504**	**313728**	**44032**

** Source: MCGM*

Emission Estimations

Emission Load from LPG

Since LPG burning doesn't comprise of coarse particles, an assumption that only $PM_{2.5}$ particles are present in the LPG emissions is made and considered as PM.

Total emissions ($PM_{2.5}$) due to LPG burning in hotels

= Number of Hotels x LPG consumption (Tons/day) x Emission Factor (kg/mt) **(Annexure I)**

Total $PM_{2.5}$ emissions due to LPG burning in hotels

= 5504 x (3x19/1000 Tons/day) x 2.1 kg/mt = 658.8 kg/day

However, for calculation purposes, it has been referred to as PM_{10}.

Emission Load from Coal

Total emissions (PM) due to coal burning in hotels

= No. of Hotels x Coal consumption (Tons/day) x Emission Factor (kg/mt)

= 5504 x 8/1000 Tons/day x 20 kg/mt (SPM) x 0.60 (PM) = 528.38 kg/day

In similar way emission for others pollutants have been estimated and their ward-wise distribution is presented in **Table 3.10**. Site-specific major contributions of PM from hotel and restaurant are higher from wards B, C, E, F/S, G/N, K/E, K/W and L area as the sites are predominantly commercial in nature. CO is the major pollutant followed by PM, NOx, SO_2 and HC emissions.

Table 3.10: Ward-wise Distribution of Emission Load from Hotel and Restaurants

Wards	LPG Emissions (kg/day)							Coal Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC		PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	49.6	49.6	9.4	42.5	5.9	1.7		39.7	27.0	44.0	13.2	82.5	1.7
B	46.1	46.1	8.8	39.5	5.5	1.6		37.0	25.1	41.0	12.3	76.8	1.5
C	35.4	35.4	6.7	30.4	4.3	1.2		28.4	19.3	31.5	9.4	59.0	1.2
D	23.7	23.7	4.5	20.3	2.8	0.8		19.0	12.9	21.1	6.3	39.5	0.8
E	37.2	37.2	7.1	31.9	4.5	1.3		29.9	20.3	33.1	9.9	62.0	1.2
F/N	20.2	20.2	3.9	17.3	2.4	0.7		16.2	11.0	18.0	5.4	33.7	0.7
F/S	39.9	39.9	7.6	34.2	4.8	1.4		32.0	21.7	35.4	10.6	66.4	1.3
G/N	47.6	47.6	9.1	40.8	5.7	1.6		38.2	26.0	42.3	12.7	79.3	1.6
G/S	29.6	29.6	5.6	25.3	3.5	1.0		23.7	16.1	26.3	7.9	49.2	1.0
H/E	19.0	19.0	3.6	16.3	2.3	0.7		15.3	10.4	16.9	5.1	31.7	0.6
H/W	26.0	26.0	4.9	22.3	3.1	0.9		20.8	14.2	23.1	6.9	43.3	0.9
K/E	35.2	35.2	6.7	30.2	4.2	1.2		28.2	19.2	31.3	9.4	58.6	1.2
K/W	33.9	33.9	6.5	29.0	4.1	1.2		27.2	18.5	30.1	9.0	56.4	1.1
P/N	25.7	25.7	4.9	22.1	3.1	0.9		20.6	14.0	22.9	6.9	42.9	0.9
P/S	22.4	22.4	4.3	19.2	2.7	0.8		18.0	12.2	19.9	6.0	37.3	0.7
R/C	14.0	14.0	2.7	12.0	1.7	0.5		11.2	7.6	12.4	3.7	23.3	0.5
R/N	10.4	10.4	2.0	8.9	1.2	0.4		8.4	5.7	9.3	2.8	17.3	0.3
R/S	17.2	17.2	3.3	14.8	2.1	0.6		13.8	9.4	15.3	4.6	28.7	0.6
L	30.6	30.6	5.8	26.3	3.7	1.1		24.6	16.7	27.2	8.2	51.0	1.0
M/E	7.8	7.8	1.5	6.7	0.9	0.3		6.2	4.2	6.9	2.1	13.0	0.3
M/W	21.8	21.8	4.1	18.7	2.6	0.7		17.5	11.9	19.4	5.8	36.3	0.7
N	25.0	25.0	4.8	21.4	3.0	0.9		20.1	13.6	22.2	6.7	41.7	0.8
S	19.0	19.0	3.6	16.3	2.3	0.7		15.3	10.4	16.9	5.1	31.7	0.6
T	21.4	21.4	4.1	18.4	2.6	0.7		17.2	11.7	19.0	5.7	35.7	0.7
kg/day	**658.8**	**658.8**	**125.5**	**564.7**	**79.1**	**22.6**		**528.4**	**359.3**	**585.6**	**175.7**	**1097.3**	**22.0**
Ton/year	**240.5**	**240.5**	**45.8**	**206.1**	**28.9**	**8.2**		**192.9**	**131.1**	**213.8**	**64.1**	**400.5**	**8.0**

Table 3.10 (Contd..): Ward-wise Distribution of Emission Load from Hotel and Restaurants

Wards	Total Emissions (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	89.3	76.6	53.5	55.7	88.5	3.4
B	83.0	71.2	49.7	51.8	82.3	3.1
C	63.8	54.8	38.2	39.8	63.3	2.4
D	42.7	36.6	25.6	26.6	42.3	1.6
E	67.1	57.5	40.2	41.8	66.5	2.5
F/N	36.5	31.3	21.8	22.7	36.1	1.4
F/S	71.8	61.6	43.0	44.8	71.2	2.7
G/N	85.8	73.6	51.4	53.5	85.1	3.2
G/S	53.3	45.7	31.9	33.2	52.8	2.0
H/E	34.3	29.4	20.5	21.4	34.0	1.3
H/W	46.8	40.1	28.0	29.2	46.4	1.8
K/E	63.4	54.4	38.0	39.5	62.8	2.4
K/W	61.0	52.3	36.6	38.1	60.5	2.3
P/N	46.4	39.8	27.8	28.9	46.0	1.7
P/S	40.3	34.6	24.2	25.2	40.0	1.5
R/C	25.2	21.6	15.1	15.7	25.0	0.9
R/N	18.8	16.1	11.2	11.7	18.6	0.7
R/S	31.1	26.6	18.6	19.4	30.8	1.2
L	55.2	47.4	33.1	34.4	54.7	2.1
M/E	14.0	12.0	8.4	8.7	13.9	0.5
M/W	39.3	33.7	23.5	24.5	38.9	1.5
N	45.1	38.7	27.0	28.1	44.7	1.7
S	34.3	29.4	20.5	21.4	34.0	1.3
T	38.6	33.1	23.1	24.1	38.3	1.5
kg/day	**1187.2**	**1018.1**	**711.1**	**740.4**	**1176.3**	**44.6**
Ton/year	**433.3**	**371.6**	**259.6**	**270.2**	**429.4**	**16.3**

3.2.5 Domestic Sector

Description: The total numbers of cylinder LPG consumption during the year 2018-19 in domestic sector were reported to be 1,22,87,862 of 14.6 kg each. BPCL and HPCL respectively shared 65% and 35% of the total supply. LPG is the major fuel used (80-85%) in Greater Mumbai. Mahanagar Gas Pvt. Ltd. is also supplying the PNG connections (6,64,805 approx.) in most parts of the city. On an average 1.62 scmd (1 scm = 0.814 kg) i.e. 1.32 kg/d consumption is observed per registered. Besides, about 15-20% Kerosene is used as fuel by domestic use. Based on primary survey it is estimated that most of the slum population (88%) use kerosene as the major cooking fuel. Average kerosene consumption by a slum household is about 25 liters/month and average kerosene consumption by a non-slum household is 3 liters/month. The number of members in a slum household and non-slum household is assumed to be 6 and 5 respectively. Ward-wise fuel consumption viz. LPG-Cylinder and PNG consumption and Slum and Non-slum kerosene consumption is presented in **Table 3.11**. The total consumption is converted into kilogram for per day emission calculation which is shown in **Table 3.12.** The estimated consumption of LPG and Kerosene were obtained from State Level Oil Coordination Committee (SLOC) which was again calculated based on population of each ward of 2018.

Table 3.11: Ward-wise Fuel Consumption in Domestic Sector

Wards	Area	LPG Consum- -ption (No. of Cylinders /Yr)	PNG Consum- -ption (No. of Connections/year	Kerosene Consumption (lit/day)	Kerosene Consumption (lit/day)
A	Colaba	248942	14271	8629	2384
B	Wadi Bunder/ Dongri	113050	6481	1960	2213
C	Marine Lines/Girgaon	270338	15498	0	3258
D	Tardev/ M. Central	528859	30319	4491	6154
E	Byculla	117946	6762	10589	6185
FN	Matunga Rd, (W)	102292	5864	41973	4326
FS	Wadala/Parel	482943	27686	12957	5211
GN	Mahim /Sion, Dadar	880494	50477	25805	8028
GS	Worli/ Prabhadevi	488495	28005	10657	5871
HE	Bandra E/Khar, SantCrz	591545	31318	34460	6948
HW	Bandra (W)	124921	6614	17391	3866
KE	Andheri, Santacruz	1199981	63531	59263	8882
KW	Jogeshwari, Andheri (W)	1191536	63083	15968	13529
PN	Malad (E/W)	943827	49969	74042	9236
PS	Goregaon	763150	40403	38745	4218
RC	Kandivali, Borivali	429904	22760	15307	9680
RN	Dahisar, Borivali	728363	38562	32508	4437
RS	Malad, Kandivali	205223	10865	58588	6174

Table 3.11 (Contd..): Ward-wise Fuel Consumption in Domestic Sector

Ward	Area	LPG Consum- -ption (No. of Cylinders /year)	PNG Consum- -ption (No. of Connections/year)	Slum Kerosene Consumption (lit/day)	Non Slum Kerosene Consumption (lit/day)
L	Kurla (W), Ghatkopar	490315	25971	71941	8703
ME	Govandi/ Mankhurd	491435	26030	35985	11886
MW	Sion/ Trombay Rd, Chembur	556004	29450	31863	4114
N	Ghatkopar (E/W)	448890	23776	56567	5014
S	Bhandup (W), Vikroli	625655	33139	78909	4351
T	Mulund	263756	13970	16401	4853
Total		**12287862**	**664805**	**754997**	**149522**

Table 3.12: Ward-wise Fuel Consumption in kg/day for Domestic Sector

Ward	Area	LPG Consumption	PNG Consumption	Slum Kerosene Consumption	Non Slum Kerosene Consumption
A	Colaba	9958	52	7051	1948
B	Wadi Bunder/ Dongri	4522	23	1601	1809
C	Marine Lines/Girgaon	10814	56	0	2662
D	Tardev/ M. Central	21154	110	3670	5029
E	Byculla	4718	24	8652	5054
FN	Matunga Rd, (W)	4092	21	34298	3535
FS	Wadala/Parel	19318	100	10588	4258
GN	Mahim /Sion, Dadar	35220	183	21086	6560
GS	Worli/ Prabhadevi	19540	101	8708	4798
HE	Bandra (E)/Khar, Santacruz	23662	113	28159	5678
HW	Bandra (W)	4997	24	14211	3159
KE	Andheri, Santacruz	47999	230	48426	7258
KW	Jogeshwari, Andheri (W	47661	228	13048	11055
PN	Malad (E/W)	37753	181	60503	7547
PS	Goregaon	30526	146	31661	3447
RC	Kandivali, Borivali	17196	82	12508	7910
RN	Dahisar, Borivali	29135	139	26564	3626
RS	Malad, Kandivali	8209	39	47875	5045
L	Kurla (W), Ghatkopar	19613	94	58787	7112
ME	Govandi/ Mankhurd	19657	94	29405	9712
MW	Sion/ Trombay Rd, Chembur	22240	107	26037	3362
N	Ghatkopar (E/W)	17956	86	46224	4097
S	Bhandup (W), Vikroli	25026	120	64481	3555
T	Mulund	10550	51	13402	3966
Total (kg/day)		**491514**	**2404**	**616946**	**122182**

Emission Estimation

Emission Load from LPG

Total emissions (PM) from LPG burning for domestic cooking

= Number of LPG cylinders consumed x Capacity of the cylinder (14.6 kg) x Em. Factor (kg/mt)

= 12287862/365 x 14.6 x 2.1/1000 kg/day= 1032.18 kg/day

Census data was obtained from Census 2011, Percentage of Slum population from each ward is calculated according to *(Dr.D.P.Singh, Slum Population in Mumbai: Part I, Population – ENVIS Centre IIPS, Vol.3, No.1, March, 2006).*

Number of Household was calculated on the assumption that there are 6 members from one slum-household and 5 members in non-slum household

Kerosene consumption per slum household = 25 liters/month = 0.833liters/day

Kerosene consumption per non-slum household = 3 liters/month = 0.1 liters/day

Total emissions (PM) from kerosene burning per day in a household = number of households x kerosene consumption (tons/day) x emission factor (kg/mt)

Total emissions (PM) from kerosene burning per day in a slum household

= (Slum Pop. /6) = No. of Household x 0.833l/day = 754997 l/day x 0.8175 x (0.61/1000) kg/ton = 376.34 kg/day

Total emissions (PM) from kerosene burning per day in a non-slum household

= (Non-Slum Pop. /5) = No. of Household x 0.1l/day = 149522 l/day x 0.8175 x (0.61/1000) kg/ton

= 74.53 kg/day

All $PM_{2.5}$ emissions are estimated to be in terms of PM_{10}. Domestic emission load from LPG and kerosene with respect to their pollutants have been estimated and their ward-wise distribution is presented in **Table 3.13.** All emission factors used are given in **Annexure I.** Domestic sector maximum emission of PM is from Mahim, Andheri, Jogeshwari, Malad, Borivali, Dahisar and Bhandup where residential blocks are more. Amongst the pollutants, CO is the major pollutant followed by NOx, SO_2, PM, HC respectively.

Table 3.13: Ward-wise Distribution of Emission Load from Domestic Sector

Wards	LPG Emission (kg/day)						PNG Emission (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	**20.9**	20.9	4.0	501.9	70.3	20.1	0.0000050	0.0000034	0.0000005	0.0001445	0.0000140	0.0000025
B	**9.5**	9.5	1.8	227.9	31.9	9.1	0.0000023	0.0000016	0.0000002	0.0000656	0.0000064	0.0000011
C	**22.7**	22.7	4.3	545.0	76.3	21.8	0.0000055	0.0000037	0.0000005	0.0001569	0.0000152	0.0000027
D	**44.4**	44.4	8.5	1066.2	149.3	42.6	0.0000107	0.0000073	0.0000011	0.0003070	0.0000298	0.0000053
E	**9.9**	9.9	1.9	237.8	33.3	9.5	0.0000024	0.0000016	0.0000002	0.0000685	0.0000067	0.0000012
FN	**8.6**	8.6	1.6	206.2	28.9	8.2	0.0000021	0.0000014	0.0000002	0.0000594	0.0000058	0.0000010
FS	**40.6**	40.6	7.7	973.6	136.3	38.9	0.0000098	0.0000066	0.0000010	0.0002804	0.0000272	0.0000048
GN	**74.0**	74.0	14.1	1775.1	248.5	71.0	0.0000178	0.0000121	0.0000018	0.0005111	0.0000497	0.0000088
GS	**41.0**	41.0	7.8	984.8	137.9	39.4	0.0000099	0.0000067	0.0000010	0.0002836	0.0000275	0.0000049
HE	**49.7**	49.7	9.5	1192.6	167.0	47.7	0.0000111	0.0000075	0.0000011	0.0003171	0.0000308	0.0000054
HW	**10.5**	10.5	2.0	251.8	35.3	10.1	0.0000023	0.0000016	0.0000002	0.0000670	0.0000065	0.0000011
KE	**100.8**	100.8	19.2	2419.2	338.7	96.8	0.0000224	0.0000152	0.0000022	0.0006433	0.0000625	0.0000110
KW	**100.1**	100.1	19.1	2402.1	336.3	96.1	0.0000223	0.0000151	0.0000022	0.0006388	0.0000621	0.0000110
PN	**79.3**	79.3	15.1	1902.8	266.4	76.1	0.0000176	0.0000120	0.0000017	0.0005060	0.0000492	0.0000087
PS	**64.1**	64.1	12.2	1538.5	215.4	61.5	0.0000143	0.0000097	0.0000014	0.0004091	0.0000397	0.0000070
RC	**36.1**	36.1	6.9	866.7	121.3	34.7	0.0000080	0.0000055	0.0000008	0.0002305	0.0000224	0.0000040
RN	**61.2**	61.2	11.7	1468.4	205.6	58.7	0.0000136	0.0000093	0.0000013	0.0003905	0.0000379	0.0000067
RS	**17.2**	17.2	3.3	413.7	57.9	16.5	0.0000038	0.0000026	0.0000004	0.0001100	0.0000107	0.0000019
L	**41.2**	41.2	7.8	988.5	138.4	39.5	0.0000092	0.0000062	0.0000009	0.0002630	0.0000255	0.0000045
ME	**41.3**	41.3	7.9	990.7	138.7	39.6	0.0000092	0.0000062	0.0000009	0.0002636	0.0000256	0.0000045
MW	**46.7**	46.7	8.9	1120.9	156.9	44.8	0.0000104	0.0000071	0.0000010	0.0002982	0.0000290	0.0000051
N	**37.7**	37.7	7.2	905.0	126.7	36.2	0.0000084	0.0000057	0.0000008	0.0002408	0.0000234	0.0000041
S	**52.6**	52.6	10.0	1261.3	176.6	50.5	0.0000117	0.0000080	0.0000012	0.0003356	0.0000326	0.0000058
T	**22.2**	22.2	4.2	531.7	74.4	21.3	0.0000049	0.0000034	0.0000005	0.0001415	0.0000137	0.0000024
kg/day	**1032.2**	**1032.2**	**196.6**	**24772.3**	**3468.1**	**990.9**	**0.0002347**	**0.0001596**	**0.0000231**	**0.0067318**	**0.0006539**	**0.0001154**
Ton/year	**376.75**	**376.75**	**71.76**	**9041.90**	**1265.87**	**361.68**	**0.0000856**	**0.0000582**	**0.0000084**	**0.0024571**	**0.0002387**	**0.0000421**

Table 3.13 (Contd..): Ward-wise Distribution of Emission Load from Domestic Sector

Wards	Slum Kerosene Emission (kg/day)						Non-Slum Kerosene Emission (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	4.3	2.9	28.2	17.6	437.2	134.0	1.2	0.8	7.8	4.9	120.8	37.0
B	1.0	0.7	6.4	4.0	99.3	30.4	1.1	0.8	7.2	4.5	112.1	34.4
C	0.0	0.0	0.0	0.0	0.0	0.0	1.6	1.1	10.6	6.7	165.1	50.6
D	2.2	1.5	14.7	9.2	227.5	69.7	3.1	2.1	20.1	12.6	311.8	95.5
E	5.3	3.6	34.6	21.6	536.5	164.4	3.1	2.1	20.2	12.6	313.4	96.0
FN	20.9	14.2	137.2	85.7	2126.5	651.7	2.2	1.5	14.1	8.8	219.2	67.2
FS	6.5	4.4	42.4	26.5	656.4	201.2	2.6	1.8	17.0	10.6	264.0	80.9
GN	12.9	8.7	84.3	52.7	1307.3	400.6	4.0	2.7	26.2	16.4	406.7	124.6
GS	5.3	3.6	34.8	21.8	539.9	165.5	2.9	2.0	19.2	12.0	297.4	91.2
HE	17.2	11.7	112.6	70.4	1745.8	535.0	3.5	2.4	22.7	14.2	352.0	107.9
HW	8.7	5.9	56.8	35.5	881.1	270.0	1.9	1.3	12.6	7.9	195.9	60.0
KE	29.5	20.1	193.7	121.1	3002.4	920.1	4.4	3.0	29.0	18.1	450.0	137.9
KW	8.0	5.4	52.2	32.6	809.0	247.9	6.7	4.6	44.2	27.6	685.4	210.0
PN	36.9	25.1	242.0	151.3	3751.2	1149.6	4.6	3.1	30.2	18.9	467.9	143.4
PS	19.3	13.1	126.6	79.2	1963.0	601.6	2.1	1.4	13.8	8.6	213.7	65.5
RC	7.6	5.2	50.0	31.3	775.5	237.7	4.8	3.3	31.6	19.8	490.4	150.3
RN	16.2	11.0	106.3	66.4	1647.0	504.7	2.2	1.5	14.5	9.1	224.8	68.9
RS	29.2	19.9	191.5	119.7	2968.2	909.6	3.1	2.1	20.2	12.6	312.8	95.9
L	35.9	24.4	235.1	147.0	3644.8	1116.9	4.3	2.9	28.4	17.8	440.9	135.1
ME	17.9	12.2	117.6	73.5	1823.1	558.7	5.9	4.0	38.8	24.3	602.2	184.5
MW	15.9	10.8	104.1	65.1	1614.3	494.7	2.1	1.4	13.4	8.4	208.5	63.9
N	28.2	19.2	184.9	115.6	2865.9	878.3	2.5	1.7	16.4	10.2	254.0	77.8
S	39.3	26.7	257.9	161.2	3997.8	1225.1	2.2	1.5	14.2	8.9	220.4	67.6
T	8.2	5.6	53.6	33.5	830.9	254.6	2.4	1.6	15.9	9.9	245.9	75.4
kg/day	**376.3**	**255.9**	**2467.8**	**1542.4**	**38250.7**	**11722.0**	**74.5**	**50.7**	**488.7**	**305.5**	**7575.3**	**2321.5**
Ton/year	**137.4**	**93.4**	**900.7**	**563.0**	**13961.5**	**4278.5**	**27.2**	**18.5**	**178.4**	**111.5**	**2765.0**	**847.3**

Table 3.13 (Contd..): Ward-wise Distribution of Emission Load from Domestic Sector

Wards	Total Emission (kg/day)					
	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	26.4	24.6	40.0	524.4	628.2	191.1
B	11.6	10.9	15.4	236.4	243.3	73.9
C	24.3	23.8	15.0	551.7	241.4	72.4
D	49.7	48.0	43.3	1087.9	688.6	207.9
E	18.3	15.6	56.7	272.0	883.1	269.9
FN	31.7	24.3	153.0	300.8	2374.5	727.1
FS	49.6	46.7	67.1	1010.7	1056.7	321.0
GN	90.8	85.4	124.7	1844.2	1962.6	596.3
GS	49.3	46.6	61.8	1018.6	975.2	296.0
HE	70.3	63.7	144.8	1277.1	2264.8	377.7
HW	21.1	17.7	71.5	295.3	1112.2	1068.1
KE	134.8	123.9	241.9	2558.4	3791.1	554.7
KW	114.8	110.1	115.5	2462.4	1830.7	1389.0
PN	120.8	107.5	287.3	2072.9	4485.5	743.2
PS	85.5	78.7	152.6	1626.3	2392.1	449.5
RC	48.6	44.6	88.6	917.7	1387.3	608.3
RN	79.6	73.7	132.4	1543.9	2077.3	1064.2
RS	49.5	39.2	215.0	546.0	3339.0	16.5
L	81.4	68.5	271.4	1153.2	4224.1	598.1
ME	65.1	57.5	164.3	1088.5	2564.0	995.7
MW	64.6	58.9	126.5	1194.4	1979.7	1337.5
N	68.4	58.6	208.5	1030.8	3246.6	366.2
S	94.1	80.8	282.2	1431.4	4394.8	50.5
T	32.8	29.4	73.7	575.2	1151.3	21.3
kg/day	**1483.0**	**1338.8**	**3153.1**	**26620.2**	**49294.1**	**12396.1**
Ton/year	**541.3**	**488.7**	**1150.9**	**9716.4**	**17992.3**	**4524.6**

3.2.6 Open Burning

Description: Open burning is the burning of any matter in such a manner that products resulting from the burning are emitted directly into the ambient air untreated, without passing through an adequate stack, duct or chimney. Open burning is an illegal method of burning solid waste; materials commonly disposed of in this manner include municipal waste, auto body components, wood refuse, small scale industrial refuse and leaves. As per the discussions with MCGM officials, it was found that about 1% of the total solid waste generated in each ward is openly burnt and about 4% of the total solid waste is burnt in the wards containing solid waste landfill sites as given in **Table 3.14**. The quantity of ward wise solid waste generated was obtained from MCGM, Solid Waste Management Division.

Table 3.14: Ward-wise & Landfill Site, Solid Waste Generation and Open Burning Percent (2018-19)

Wards	Solid waste Generation in Tonnes	Open Burning (1%)	Wards	Solid waste Generation in Tonnes	Open Burning (1%)
A	534.2	5.3	**PN**	444.1	4.4
B	176.4	1.8	**PS**	270.1	2.7
C	345.2	3.5	**RC**	402.2	4.0
D	696.3	7.0	**RN**	201.1	2.0
E	672.3	6.7	**RS**	214.4	2.1
FN	420.1	4.2	**L**	557.1	5.6
FS	390.1	3.9	**ME**	375.3	3.8
GN	708.3	7.1	**MW**	399.3	4.0
GS	498.2	5.0	**N**	306.2	3.1
HE	338.5	3.4	**S**	348.1	3.5
HW	432.2	4.3	**T**	240.8	2.4
KE	450.2	4.5			
KW	549.3	5.5	**Total**	9970	

Landfill Sites	Solid Waste at Landfill Site (Tonnes)	Open Burning (4%)
Deonar (M/E)	2435	97
Mulund (T)	4058	162
Kanjurmarg (S)	3478	139

** Source : MCGM, SWM Dept.*

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) = [9970 (tons) x 1% (non dumping site) + 9970 (Landfill site) x 4%] x PM EF 8 (kg/mt)
= 3426.6 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 3.15**.

Table 3.15: Ward Emission Load from Open Burning (kg/day)

Wards	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
A	36.9	25.1	2.3	13.8	193.5	99.1
B	12.2	8.3	0.8	4.6	63.9	32.7
C	23.8	16.2	1.5	8.9	125.1	64.0
D	48.0	32.7	3.0	18.0	252.3	129.1
E	46.4	31.5	2.9	17.4	243.6	124.7
FN	29.0	19.7	1.8	10.9	152.2	77.9
FS	26.9	18.3	1.7	10.1	141.4	72.4
GN	48.9	33.2	3.1	18.3	256.6	131.4
GS	34.4	23.4	2.1	12.9	180.5	92.4
HE	23.4	15.9	1.5	8.8	122.6	62.8
HW	29.8	20.3	1.9	11.2	156.6	80.2
KE	31.1	21.1	1.9	11.6	163.1	83.5
KW	37.9	25.8	2.4	14.2	199.0	101.9
PN	30.7	20.8	1.9	11.5	160.9	82.4
PS	18.6	12.7	1.2	7.0	97.9	50.1
RC	27.8	18.9	1.7	10.4	145.7	74.6
RN	13.9	9.4	0.9	5.2	72.9	37.3
RS	14.8	10.1	0.9	5.5	77.7	39.8
L	38.4	26.1	2.4	14.4	201.8	103.3
ME	25.9	17.6	1.6	9.7	135.9	69.6
MW	27.5	18.7	1.7	10.3	144.6	74.0
N	21.1	14.4	1.3	7.9	110.9	56.8
S	24.0	16.3	1.5	9.0	126.1	64.6
T	16.6	11.3	1.0	6.2	87.2	44.7
kg/day	**688.0**	**467.8**	**43.0**	**258.0**	**3612.0**	**1849.0**
Ton/year	**251.1**	**170.8**	**15.7**	**94.2**	**1318.4**	**674.9**

Emission Load from Landfill Open Burning

Wards	PM_{10}	$PM_{2.5}$	SO_2	NOx	CO	HC
Deonar (ME)	671.2	456.4	42.0	252.0	3528.0	1806.0
Mulund (T)	1118.6	760.6	70.0	420.0	5880.0	3010.0
Kanjurmarg (S)	958.8	652.0	60.0	360.0	5040.0	2580.0
kg/day	**2748.6**	**1869.0**	**172.0**	**1032.0**	**14448.0**	**7396.0**
Ton/year	**1003.2**	**682.2**	**62.8**	**376.7**	**5273.5**	**2699.5**

PM contribution due to open burning is highest at wards viz. A, D, E, G/N, K/W and L, whereas at Mulund dump site the concentration is higher than others. 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. The documented data for such cases of burning, area of dump, unauthorized activity of the rag pickers is not available.

3.2.7 Paved and Unpaved Road Dust

Paved Road: As motor vehicles moves over road surface, resuspension of dust from unpaved roads and/or from the paved surface takes place, including that caused by the turbulent wake of the vehicles. Such fugitive emissions are estimated as a function of the silt loading of the paved surface vehicle speed and mean weight of the vehicles traveling over the surface. Data source such as road length, vehicle km traveled and depot, truck terminal was obtained from MMRDA, MCGM and RTO, Mumbai and primary survey of some roads for vehicle counting.

Emission Estimates for Paved Road Dust (Vehicle Weight –Mumbai *)

Vehicle Count 2017-18		%Vehicle Count (A)	Avg.Weight (kg) (B)	Veh. Weight by % (A*B) (kg)
2 W	4667314	27	175	47.3
3 W	3336176	19	450	85.5
HDDV	1405189	8	20000	160.0
Taxi	1321688	8	1425	114.0
Cars	6708110	38	1425	541.5
Total	17438477			0.9483

* *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^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
C= Break and tire wear correction ($PM_{2.5}$=0.1005, PM_{10}=0.1317)
N = No. of days in averaging period (365 /year, 30/monthly, 91/seasonal);
Values of k (g/vkt) = $PM_{2.5}$ -0.15, PM_{10}-0.62

EF (PM_{10}) = (k (sL/2) ^0.91 (W^1.02) (1-P/4N)
= (0.62*((3/2) ^0.91) *((0.9483^1.02)) *(1-120/ (4*365))) = 0.781192
EF (PM2.5) = (k (sL/2) ^0.91 (W^1.02) (1-P/4N)
= (0.15*((3/2) ^0.91) *((0.9483^1.02)) *(1-120/ (4*365))) = 0.188998

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*(12/12) ^1*(12.5/30) ^0.5)/ (6.65/0.5) ^0.2-0.00047)) *(365-120)/365
0.464488434 lb./vmt = **130.93 g/vkt**

EF ($PM_{2.5}$) = {([k (s/12) ^a (S/30) ^d] /(m/0.5) ^c-C)} *(365-P)/ 365
= (((0.27*(12/12) ^1*(12.5/30) ^0.5)/ (6.65/0.5) ^0.2-0.00036)) *(365-120)/365
= 0.069478943 lb/vmt = **19.58 g/vkt**

Emission Load

- Total Paved Dust Emission Load for Whole City =
  PM_{10}= 24771 kg/day $PM_{2.5}$= 5993 kg/day

Total Unpaved Dust Emission Load for Whole City =

PM_{10}= 41939 kg/day $PM_{2.5}$ = 6273 kg/day

Ward-wise contribution of the pollutant emission load is given in **Table 3.16.**

Table 3.16: Ward-wise Emission Load from Paved & Unpaved Dust

Wards	Paved Emission		Unpaved Emission		Wards	Paved Emission		Unpaved Emission	
	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}		$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
A	116.5	481.5	121.9	815.2	P/N	285.5	1179.9	298.8	1997.7
B	44.6	184.5	46.7	312.4	P/S	265.1	1095.8	277.5	1855.3
C	32.6	134.6	34.1	227.9	R/C	348.2	1439.3	364.5	2436.8
D	131.8	544.6	137.9	922.1	R/N	183.4	757.9	191.9	1283.1
E	106.3	439.4	111.3	743.9	R/S	362.6	1498.9	379.6	2537.7
F/N	182.6	754.6	191.1	1277.6	L	294.7	1217.9	308.4	2062.1
F/S	154.3	637.7	161.5	1079.7	M/E	200.0	826.8	209.4	1399.9
G/N	176.3	728.7	184.6	1233.8	M/W	226.0	934.0	236.6	1581.4
G/S	221.0	913.3	231.3	1546.3	N	326.3	1348.6	341.5	2283.3
H/E	407.2	1683.2	426.3	2849.9	S	471.8	1950.0	493.8	3301.5
H/W	190.0	785.4	198.9	1329.7	T	356.1	1472.5	372.7	2492.6
K/E	434.5	1795.9	454.8	3040.6					
K/W	475.6	1966.0	497.9	3328.5					

Total	Paved Emission			Unpaved Emission		
	$PM_{2.5}$	PM_{10}	Total	$PM_{2.5}$	PM_{10}	Total
kg/day	5993.2	24771.6	30764.8	6273.5	41939.7	48213.2
Ton/year	2187.5	9041.6	11229.1	2289.8	15307.9	17597.8

PM emission load is highest at K/E, K/W and S wards. Uncertainty with respect to all sites all across the whole city is high as silt loadings can vary from place to place. The paved and unpaved road dusts get resuspended and act as a line source due to vehicles; however, they also act as area source.

3.2.8 Building Construction

Description: Real estate sector is a booming business in Mumbai. Slum rehabilitation programmes have also led to large scale construction of new buildings and towers. The building construction dust source category provides estimates of the fugitive dust particulate matter due to cause by construction and demolition activities while building residential, commercial, industrial and institutional or governmental structures. Particulate emissions are predominantly due to site preparation work, which may include scrapping, grading, loading, digging, compacting, light-duty vehicle travel and other operations. Data for construction were obtained from Building Construction Department of MCGM. The number of construction activities ward-wise are given in **Table 3.17**.

Assumptions

- The project duration was estimated as 18 months for new buildings, 6 months for addition /alteration.
- The area of influence of each construction activity was taken as 0.5 acres for new building and 0.2 acres for addition /alteration

Table 3.17: Ward-Wise distribution of Construction Activities (MCGM)

Wards	Build Construction	New Building	Alteration/ Addition		Wards	Build Construction	New Building	Alteration/ Addition
A	**5**	2	**3**		P/N	**27**	11	16
B	**5**	2	3		P/S	**25**	7	18
C	**13**	4	9		R/C	**25**	11	14
D	**13**	4	9		R/S	**35**	14	21
E	**13**	4	9		R/N	**31**	14	17
F/N	**22**	9	13		L	**29**	14	15
F/S	**23**	9	14		M/E	**23**	14	9
G/N	**23**	9	14		M/W	**29**	16	13
G/S	**23**	9	14		N	**20**	11	9
H/E	**27**	11	16		S	**43**	16	27
H/W	**29**	11	18		T	**38**	16	22
K/E	**25**	13	12					
K/W	**25**	9	16		Total	**571**	**240**	**331**

Emissions Estimation

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

Step 1 –Total No. of construction activities in each region.

Step 2 – Acres disturbed

For new buildings, = 0.5 acres are disturbed per activity

For addition / alteration = 0.2 acres per activity are disturbed

Step 3 – Months of activity
New buildings = 18 months, Addition / alteration = 6 months
Step 4 – Acre –months of activity
For new building = 18 x total number of acres disturbed
For addition / alteration = 6 x total number of acres disturbed
Step 5 – PM_{10} Tons /years = 1.2 x total number of acres – months
(AP42, Section 13.2.3.3– PM_{10} - 1.2 tonnes/ acres months)

Ward-wise emission loads of PM during construction activity are presented in **Table 3.18**.

Table 3.18: Ward-wise Emission Load of PM in Acre Months due to Construction Activities

Wards	New Building	Alteration/ Addition		Wards	New Building	Alteration/ Addition
A	40	24		P/N	220	128
B	40	24		P/S	140	144
C	80	72		R/C	220	112
D	80	72		R/S	280	168
E	80	72		R/N	280	136
F/N	180	104		L	280	120
F/S	180	112		M/E	280	72
G/N	180	112		M/W	320	104
G/S	180	112		N	220	72
H/E	220	128		S	320	216
H/W	220	144		T	320	176
K/E	260	96		**kg/day**	**4800.0**	**2648.0**
K/W	180	128		**Ton/year**	**1752.0**	**966.5**

Total Emission Load = 7448.0 kg/day and 2718.5 tones /year, the maximum particulate emission load due to construction activity is observed in the suburban areas.

Assumptions:

- The activity is assumed to occur 6 days a week with 8 hours duration of working hours
- The current methodology assumes that all construction operations emit the same levels of PM on per acre basis.
- The methodology assumes that construction dust emissions are directly proportional to the number of acres disturbed during construction. The estimates of acreage disturbed are limited in their accuracy, as explained above
- Emission due to vehicle movement during construction activity are not included

3.2.9 Construction Work of Mumbai Metro

Mumbai Metro will be a rapid transit system serving the city of Mumbai and the wider MMR. The system is designed to reduce traffic congestion in the city, and supplement the overcrowded Mumbai Suburban Railway (local trains) network. Under different phase of construction Metro Lines 2 to 10 will be worked out. The construction activities of metro line are primarily temporary activity for 2 to 5 years, the emission load is therefore a matter for the years of construction.

Currently three major works are in progress i.e., Metro Line 3 (Colaba-Bandra-SEEPZ), Metro Line 2A (Dahisar East to D.N. Nagar Corridor) and Metro Line 7 (Andheri East - Dahisar East Corridor) covering major part of City area. The heavy construction and excavation work is in progress which has added the particulate emission load to the city.

A) Metro Line 3 is a 33.5 kms long underground corridor running along Colaba-Bandra-SEEPZ. Length of the corridor is marked with 27 key stations out of which 26 will be underground and 1 at surface. MMRCL's contractors plan to deploy a total of 17 (Tunnel Boring Machines) TBMs. There are 7 packages:

- Package UGC-07 : CSIA T2 – Sariput Nagar Ramp with 3 stations at Marol Naka, MIDC & SEEPZ
- Package UGC-05/06 : Dharavi – CSIA T2 with 7 stations at Dharavi, BKC, Vidyanagari, Santa Cruz, CSIA T1, Sahar Road and CSIA T2
- Package UGC-04: Worli – Dharavi with 3 stations at Siddhivinayak, Dadar & Shitladevi
- Package UGC-03: Mumbai Central – Worli with 5 stations at Mumbai Central, Mahalaxmi, Science
- Package UGC-02: CST to Mumbai Central with 4 stations at CST, Kalbadevi, Girgaon & Grant Road
- Package UGC-01: Cuffe Parade to CST with 4 stations at Cuffe Parade, Vidhan Bhavan, Churchgate & Hutatma Chowk

Metro Rail Corporation Limited (MMRCL) has suggested that the muck may be used for reclamation in the coastal road project or be transported to quarries in Thane and Raigad districts. Deep-sea dumping, 100 km from Mumbai's coast, or dumping into the Rohini creek at Shrivardhan village on the Raigad coast were the other options. The consultants have also suggested using the muck for reclamation for the proposed Terminal 4 at Jawaharlal Nehru Port Trust.

The emission load was calculated based on the chainage between the stations for Metro Line 3 which is given below. The designated zones from where the tunneling activities are undertaken which is defined in the package UGC are CST Metro, Science Museum, Siddhivinayak, BKC, Sahar Airport, Marol Naka, SEEPZ are covering an area about 400 to 900 m^2 each.

Sr.	Stations	Chainage (m)	Distance Between Chainage (m)	Sr.	Stations	Chainage (m)	Distance Between Chainage (m)
1	Cuffe Parade	0	0	15	Dadar	15,683	1,397
2	Vidhan Bhavan	1,438	1,438	16	Sitaladevi	17,364	1,681
3	Churchgate	2,216	778	17	Dharavi	19,095	1,731
4	Hutatma chowk	3,087	871	18	BKC	20,925	1,830
5	CST Metro	3,902	815	19	Vidyanagari	22,138	1,213
6	Kalabadevi	4,754	852	20	Santacruz	23,155	1,017
7	Girgaon	5,452	698	21	Domestic Airport	25,510	2,355
8	Grant Road	7,035	1,583	22	Sahar Road	27,220	1,710
9	Mumbai Central Metro	7,951	916	23	International Airport	28,202	982
10	Mahalaxmi	9,047	1,096	24	Marol Naka	29,200	998
11	Science Museum	10,208	1,161	25	MIDC	30,380	1,180
12	Acharya Atre Chowk	11,256	1,048	26	SEEPZ	31,697	1,317
13	Worli	12,723	1,467	27	Aarey Depot	33,000	1,303
14	Siddhivinayak	14,286	1,563	**Total 33.5 Kms**			

** Source : Metro 3, EIA Report*

B) Metro Line 2A: The elevated Metro 2A (between Dahisar and D.N. Road), began in November 2016. This section shall be 18.589 Km long, and comprise of 17 stations. The proposed metro corridor will basically serve the western parts of Mumbai and the route where the corridor is suggested is heavily loaded. The capacity of the road is much less than the demand. The elevation construction work and piling of the pillars add to the particulate load during operation as also the traffic congestion affecting the air quality of the region. The emission load was calculated based on the chainage between the station for Metro Line 2A which is given below:

Sr.	Stations	Chainage (m)	Distance Between Chainage (m)	Sr.	Stations	Chainage (m)	Distance Between Chainage (m)
1	Dahisar (E)	0		10	Charkop	9535.5	1,335
2	Dahisar (W)	711	711	11	Malad Metro	10846	1,311
3	Rushi Sankul	2422.7	1,712	12	Kasturi Park	12243.4	1,397
4	IC Colony	3383.1	960	13	Bangur Nagar	13183.1	940
5	LIC Colony	4468.4	1,085	14	Oshiwara Metro	14455.5	1,272
6	Don Bosco	5537.5	1,069	15	Samartha Nagar	15468.7	1,013
7	Kasturi Park	6465.9	928	16	Sashtri Nagar	16433	964
8	Ekata Nagar	7571.8	1,106	17	D N Nagar	17578.6	1,146
9	Kandivali Nagar	8200.3	628	**Total 18.58 Kms**			

** Source : Metro 2A, EIA Report*

C) Metro Line 7: Andheri (E) to Dahisar (E) is 16.475 km. long elevated corridor with 16 stations. It shall provide interconnectivity among the existing Western Express Highway, Western Railway, Metro Line 1 (Ghatkopar to Versova), the ongoing Metro Line 2A (Dahisar to D N Nagar) and the proposed Metro Line 6 (Swami Samarth Nagar to Vikhroli). It shall facilitate smooth and efficient interchange with the suburban rail system and MRT system at Andheri, JVLR and Dahisar. It shall provide connectivity between the Central Mumbai and the Northern suburban Mumbai. It shall provide rail-based access to the Mumbai International Airport (CSIA), SEEPZ, National Park and other commercial and geographical landmarks. It shall reduce the current travel time by anything between 50% and 75% depending on road conditions. During construction and piling activities the dust emits in the vicinity which contributes to the particulate matter emission load in the area and also affects the traffic flow.

The emission load was calculated based on the chainage between the station for Metro Line 7 which is given below:

Sr.	Stations	Chainage (m)	Distance Between Chainage (m)	Sr.	Stations	Chainage (m)	Distance Between Chainage (m)
1	Andheri	0		10	Bandongri	9075.7	1,008
2	Shankarwadi	1229.8	1,230	11	Mahindra & Mahindra	9700	624
3	JVLR Jn.	2413.9	1,184	12	Thakur Complex	11427.7	1,728
4	Bombay Exhibition	3781.5	1,368	13	Borivali Bus Stop	12250	822
5	HUB Mall	4580	799	14	Borivali Omkareshwar	13376.5	1,127
6	Vishveshwar Nagar	5559.7	980	15	Shrinath Nagar	14384.5	1,008
7	Aarey Road Jn	6100	540	16	Dahisar (E)	15524.9	1,140
8	Vitt Bhatti Jn	7180	1,080	**Total 16.47 Kms**			
9	Kurar Village	8068	888				

** Source: Metro 7, EIA Report*

Emission Estimation Assumptions

As the project activities is yearly the approximate total working days i.e., 8 months was assumed for a year. The area acre is calculated based on distance of the chainage. However, some places sizes vary more than the above-mentioned values. The standard metro gauge is around 1.43 m was assumed and the width was calculated around 6 m for elevated route considering both side and additional space for construction. For Metro line 3, underground work is mainly going from designated area where the total tunneling and excavation work is going on, the designated area is calculated based on google image. The main road where piling and digging activities are going on the width of road is assumed as 3 m. Particulate emissions are predominantly due to site preparation work, which may include scrapping, grading, loading, digging, compacting, light–duty vehicle travel and other operations.

The emission estimation is calculated based on emission factor from AP42, Section 13.2.3.3 for heavy construction work i.e. (PM_{10} - 1.2 tones/ acres months)

$$PM_{10} \text{ Tons /years} = 1.2 \times \text{total number of acre} \times \text{months}$$

The emission load of PM for Metro lines is presented in **Table 3.19 a to c.**

Table 3.19 (a): Total PM Emission Load from Metro Construction Activity: Metro Line 3 (Between Colaba to SEEPZ - Aarey Depot]

Sr.	Metro Line 3 (Colaba –SEEPZ)	PM (kg/day)	Sr.	Metro Line 3 (Colaba –SEEPZ)	PM (kg/day)	Sr.	Metro Line 3 (Colaba –SEEPZ	PM (kg/day)
1-2	Cuffe Parade to Vidhan Bhavan	42.6	11	Science Museum	43.3	20	Santacruz	30.2
3	Churchgate	23.1	12	Acharya Atre Chowk	31.1	21	Domestic Airport	69.8
4	Hutatma chowk	25.8	13	Worli	43.5	22	Sahar Road	58.6
5	CST Metro	33.1	14	Siddhivinayak	53.2	23	International Airport	29.1
6	Kalabadevi	25.3	15	Dadar	41.4	24	Marol Naka	33.4
7	Girgaon	20.7	16	Sitaladevi	49.8	25	MIDC	35.0
8	Grant Road	46.9	17	Dharavi	51.3	26	SEEPZ	43.0
9	Mumbai Central Metro	27.2	18	BKC	58.7	27	Aarey Depot	38.6
10	Mahalaxmi	32.5	19	Vidyanagari	36.0		**Total kg/day**	**980.6**
							Total Ton/year	**235.4**

Table 3.19 (b): Total PM Emission Load from Metro Construction Activity: Metro 2A [Between Dahisar and D.N. Road]

Sr.	Metro Line 2A (Dahisar – DN Ng.)	PM (kg/day)	Sr.	Metro Line 2A (Dahisar – DN Ng.)	PM (kg/day)	Sr.	Metro Line 2A (Dahisar – DN Ng.)	PM (kg/day)
1-2	Dahisar (E to W)	42.2	8	Ekata Nagar	65.6	14	Oshiwara Metro	75.5
3	Rushi Sankul	101.5	9	Kandivali Nagar	37.3	15	Samartha Nagar	60.1
4	IC Colony	57.0	10	Charkop	79.2	16	Sashtri Nagar	57.2
5	LIC Colony	64.4	11	Malad Metro	77.7	17	D N Nagar	67.9
6	Don Bosco	63.4	12	Kasturi Park	82.9			
7	Kasturi Pk.	55.1	13	Bangur Nagar	55.7		**Total kg/day**	**1,042.5**
							Total Ton/year	**250.2**

Table 3.19 (c): Total PM Emission Load from Metro Construction Activity: Metro 7 [Between Andheri (E) to Dahisar (E)]

Sr.	Metro Line 7 Andheri (E) to Dahisar (E)	PM (kg/day)	Sr.	Metro Line 7 Andheri (E) to Dahisar (E)	PM (kg/day)	Sr.	Metro Line 7 Andheri (E) to Dahisar (E)	PM (kg/day)
1-2	And.- ShankarW	70.2	8	Vitt Bhatti Jn	52.7	14	Borivali Omkareshw	59.8
3	JVLR Jn.	81.1	9	Kurar Village	59.8	15	Shrinath Nagar	67.6
4	Bombay Ex.	47.4	10	Bandongri	37.0	16	Dahisar (E)	72.9
5	HUB Mall	58.1	11	Mahindra & Mahindra	102.5			
6	Vishveshwar Naga	32.0	12	Thakur Complex	48.8		**Total kg/day**	**920.7**
7	Aarey Road Jn	64.0	13	Borivali Bus Stop	66.8		**Total Ton/year**	**221.0**

The total PM emission load from all these metro projects is around 2943.8 kg/day and 706.6 Ton/year

3.2.10 Aircrafts

Description: Emission estimates from aircrafts have been made for the domestic and international airports. These two airport terminals are spread over two different locations about 4 km apart in the west of Mumbai at Andheri. Terminal 1 at Santacruz is dedicated for domestic travel. Terminal 2 at Sahar is an integrated terminal catering to both international and domestic passengers. Mumbai handles over 900 flights per day. 46 movements, that is landing and takeoff, is the hourly capacity. The aircraft movement details were obtained from the report given at the website *(https://www.aai.aero/sites/default/files/.../Mumbai%20-%20CSI%20REPORTS.pdf).*

The annual Traffic handled for last 4-5 years are given below.

Aircraft Movement	2015-16	2016-17	2017-18	2018-19
International	186466	189513	196577	232247
Domestic	71247	72359	74086	76381

Emissions from aircraft originate from fuel burned in aircraft engines. Emissions from aircrafts are calculated from the aircraft movements in an LTO (Landing /Takeoff) cycle. 1 LTO =2 aircraft movements (http://www.aeat.co.uk/netcen/airqual/ naei/annreport/annrep99/app1_210.html).

Emission Estimation

Total emissions from aircrafts = Number of LTO cycles x Emission Factor **(Annexure I)**

Total annual emissions (PM_{10}) from aircrafts

= Number of LTO cycles x Emission factor (Kg/ LTO)

= 308628/2 LTO x 0.99 Kg/LTO = 152771 Kg/year

Emission load due to Aircraft Movement from international and domestic is presented in **Table 3.20.**

Table 3.20: Emission Load due to Aircraft

	PM	$PM_{2.5}$	SOx	NOx	VOC	CO
International	315	290	509	8272	64	1941
Domestic	104	95	84	868	52	1235
Total kg/day	**419**	**385**	**593**	**9140**	**116**	**3175**
Ton/year	**153**	**141**	**216**	**3336**	**42**	**1159**

Assumptions

- Aircraft emissions calculations have been based on aircraft movements only
- Other details of vehicle's movement for cargo, passenger, crew etc. could not be obtained
- Aircraft types and capacities-based variations for emissions have not been accounted

3.2.11 Marine Vessels

Description: Marine vessels include boats and ships which are used for transport of people and goods. Air pollutants are also emitted when ships/ vessels are waiting in the bay for docking space. A survey was carried out to established average fuel consumption. Fishing vessels consume about 20 liters/d diesel, and other vessels consume about 60-70 liters/d of diesel. Activity information such as type and number of vessels – (fishing, govt., commercial), average duration of stay, vessel, transit, waiting in the bay for dock space etc. were obtained from Mumbai Port Trust *(Administrative Report 2016-17)*, fishing community and Central Marine Fisheries Research Institute, Mumbai.

Type of vessels operated annually in the Mumbai Coast:
Bulk & Container = 1911, Gen. Cargo = 3078, Passenger = 180, Fishing Vessels (Trawlers =2258, Gillnetters= 386, Dolnetters = 1037, Liners= 44, Others =87) = 3812

Emission Estimation
Emission load = Vessel type x time spent x fuel consumed x emission factor **(Annexure I)**

Emission loads due to marine vessel are presented in **Table 3.21.**

Table 3.21: Emission Load from Marine Vessels

	PM	$PM_{2.5}$	SOx	NOx	HC	CO
Bulk & Container	1.7	1.1	17.9	16.3	1.3	3.0
Gen. Cargo	1.9	1.3	20.8	18.9	1.6	3.5
Passenger	0.05	0.03	0.50	0.45	0.04	0.08
Fishing Vessels	0.09	0.1	0.99	0.90	0.07	0.17
kg/day	**3.74**	**2.6**	**40.19**	**36.55**	**3.01**	**6.75**
Ton. /Year	**1.37**	**0.93**	**14.65**	**13.32**	**1.11**	**2.46**

Assumptions:
- Naval and Coast Guard Vessel data are not available since it is of classified nature.
- Repairs works related activity in Dockyard and BPT areas have not been accounted.

3.3 Line Sources

Mumbai has been a natural shipping and trading center because of its harbor constructed on a wide bay between the city and the mainland, facing Africa and East Asia. The mainland of Greater Mumbai now connected together by bridges is of 458.28 Sq. km (10.5% of MMR area of 4,355 Sq. km). As with the further infrastructure's development, the city is spreading over these bridges into the mainland. Transition towards service-based economy from manufacturing, jobs are slowly moving out of the congested island city. From an overall planning, economic and transportation perspective, all the urbanized areas of the region are functioning as a single entity with people travelling between municipal jurisdictions for work, education, shopping and personal needs.

a. *Roads*: The road length in Mumbai is about 2,000 km (about 525 km in Island city, 950 km in western suburbs and about 525 km in Eastern suburbs), comprising of about 1,950 km of MCGM maintained roads and about 50 km of State Highways (23.55 km of Eastern Express Highway from Sion to Thane and 25.33 km of Western Express Highway from Bandra to Dahisar). All the roads in the city are surfaced, with about 17.5 per cent concretized and the rest black-topped. MCGM carries routine pre-monsoon works in order to reduce the damage due to rains. A key issue though is the digging of roads by ULBs utility agencies/companies for laying utility lines or water/sewerage pipeline repairs throughout the year, which after road restoration leaves the road in an uneven condition.

b. *Flyovers and Bridges*: Currently MCGM maintains 11 flyovers, 47 ROBs (Road over Bridges) and 104 bridges. In addition, for pedestrian facilitation MCGM has constructed 68 foot-over-bridges (FOB) and 28 pedestrian subways. As a measure to improve the road infrastructure to facilitate smooth traffic flow, a committee appointed by the Government of Maharashtra had recommended the construction of 55 flyovers in the past.

Mumbai's public transport consists primarily of rapid transit on railway lines serving across suburbs, central and eastern part of the region, the bus services of the three municipalities making up the metropolitan area, public taxis and auto rickshaws, as well as ferry services. Over the past five years, the number of vehicles has grown from about two million to three million, an increase of 50% in Mumbai. However, the road length in

Mumbai, at around 2,000 km, has not changed significantly during the same period. Vehicle density has thus increased to approximately 1,500 vehicles per km in 2018-19 from 935 in 2011-12. The number of private cars on the road has also crossed the 9 lakh marks i.e., 45% increase in five years. As for two-wheelers, the population now stands at over 17 lakhs with the density up to 855 two-wheelers per km *(RTO, Mumbai, TOI, Jan 3, 2017).*

Vehicular pollution is one of the major sources of air pollution. The method used to estimate emissions includes data collection on vehicle counts, vehicle kilometer traveled, secondary data on vehicle registered, types of vehicles, age of vehicles, fuel used etc. The registered vehicle population within the city limit is given in **Table 3.22** and the year on percentage growth of vehicles is presented in **Figure 3.2**. Category wise distribution of vehicle population in Mumbai is given in **Table 3.23.**

Table 3.22: Registered Motor Vehicle Population in Mumbai (2008-2018)

Year	**2008-09**	**2009-10**	**2010-11**	**2011-12**	**2012-13**
No. of Vehicles	1674366	1767798	1870311	2028500	2187398
Year	**2013-14**	**2014-15**	**2015-16**	**2016-17**	**2017-18**
No. of Vehicles	2332806	2571204	2819652	3069756	3352640

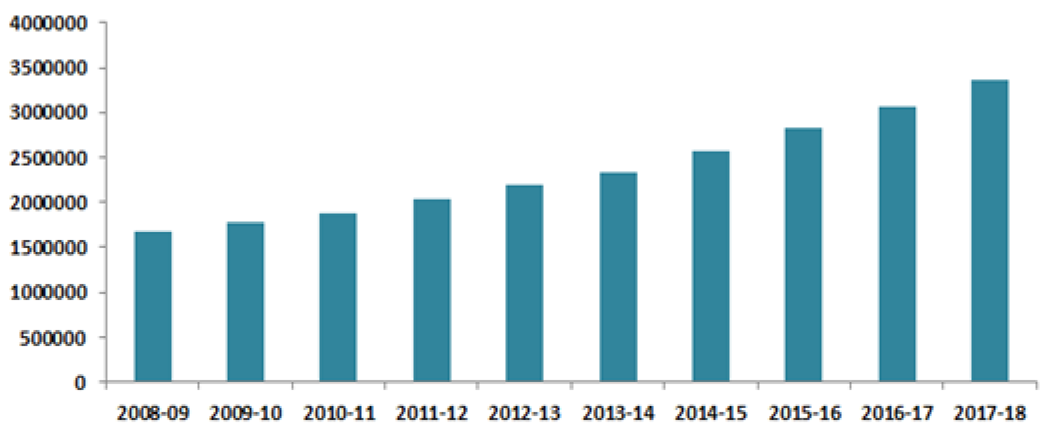


Figure 3.2: Growth of Registered Vehicles in Mumbai

Table 3.23: Category wise Distribution of Vehicle Population in Mumbai (2008-2018)

Category	2008-09	2015-16	2016-17	2017-2018
Motor Cycles	575442	1024668	1114049	1304624
Scooters	301078	569737	623806	617103
Moped	33473	33915	34143	31228
Total 2 Wheelers	**909993**	**1628320**	**1771998**	**1952955**
Cars	484473	857708	911814	978639
Jeeps	24773	32310	32708	29513
Stn. Wagons	3611	3868	3870	3726
Taxi's meter fitted	48992	50584	55343	60252
Luxury/Tourist Cabs	7966	37229	59917	67640
Auto Rickshaws	104716	119245	139065	182069
Stage carriages	4081	4450	4457	4953
Contract Carriages / Mini Bus	4670	5201	5298	4630
School Buses	986	3323	3573	2869
Pvt. Service Vehicles	1688	1103	1168	1091
Ambulances	11	1631	1730	1296
Trucks & Lorries	16012	8171	8307	4650
Tanker	1773	355	358	895
Delivery Van (4 wheelers)	19979	27611	30476	34066
Delivery Van (3 wheelers)	31339	36998	37872	21415
Tractors	1433	203	223	194
Trailor's	1029	96	113	110
Others	5205	**1246**	1356	1663
Total Vehicles	**1674366**	**2819652**	**3069756**	**3352640**

3.3.1 Primary Vehicle 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

$VKTI = RL_j * N_I$

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 database.
- Estimation of emissions from each grid

$$PM_j = N * \sum_{J=1}^{m} VKT_I * Ef_I$$

Where, PM_j = Pollutant load in tones/year for grid j

N = Number of activity days in a year EfI = Emission factor for a vehicle type I

3.3.2 Vehicle Counts

The assessment of the number of vehicle plying on the roads is required to estimate the emissions. A vehicular count survey was carried out at the actual grid-wise cells within the city limits. The location selected for the vehicular count consisted of major and minor junctions, highways, congestion zones spread over the city. Road map of the city as given in **Figure 3.3** was used to determine the locations of the vehicle counting survey. For this purpose, the Greater Mumbai transportation network was divided into three parts (I) Western Corridor transportation network (ii) Eastern Corridor transportation network and (iii) South Mumbai transportation network. 60 major junctions were identified covering whole city from Dahisar Check Naka (West) Mulund Check Naka (East) to Colaba (South) 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.

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

Following categories of vehicles were covered in these counts:

1. Cars
2. Taxis
3. 2-Wheelers
4. Three-Wheelers
5. Heavy Duty Diesel Vehicles (HDDV)
6. Buses

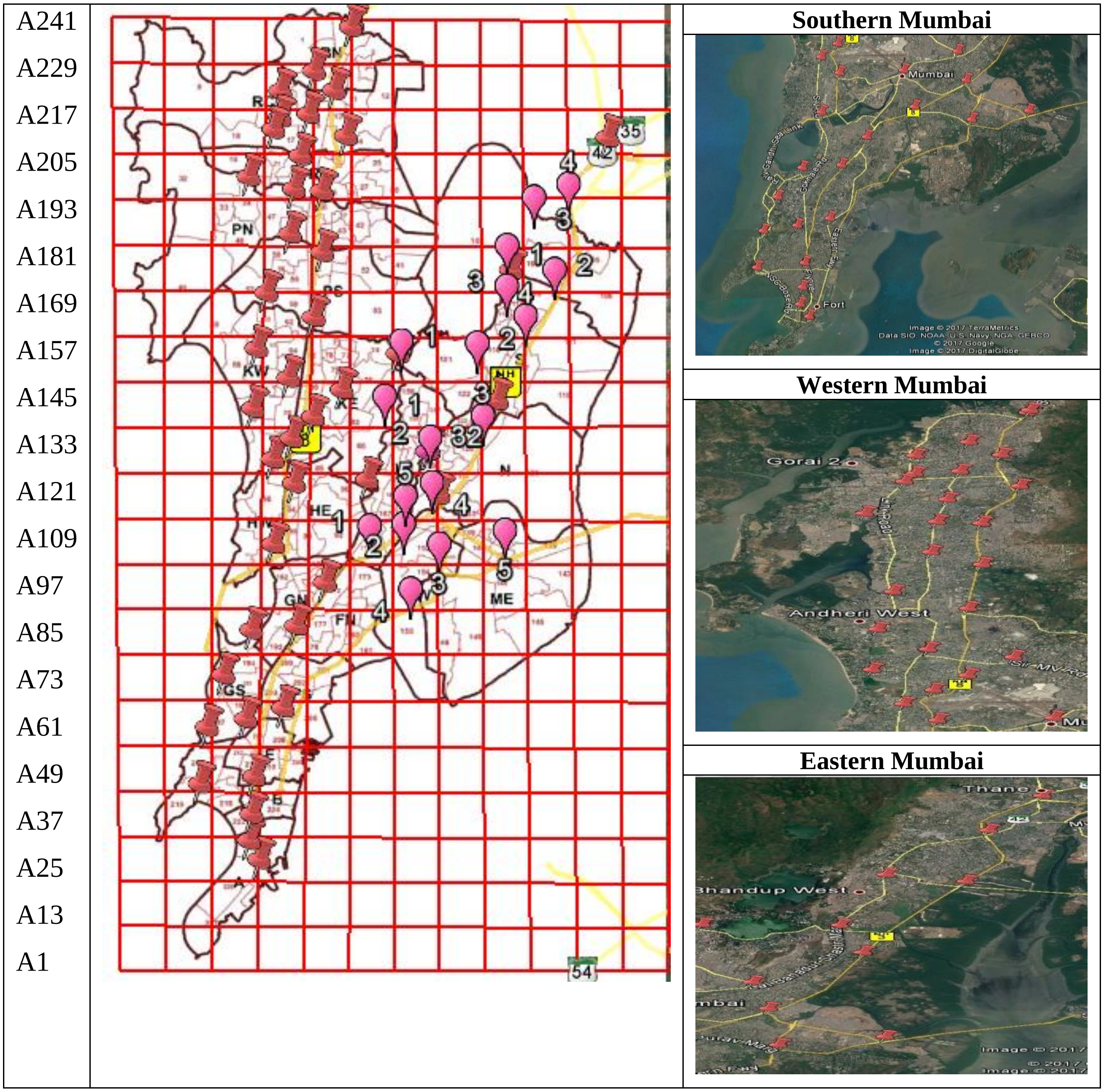


Figure 3.3: Vehicular Count Locations across Mumbai City (2km x 2 km Grid)

The locations of major and minor road traffic junctions in 2km x 2 km grid are presented in **Table 3.24.**

Table 3.24: Grid wise Traffic Junctions of Major and Minor Around the Mumbai City

Wards	Grid No.	Major and Minor Road Traffic Roads (Connecting Interal Roads and Intersections)
A	15,27, 28,39, 40	Colaba Causeway, Cuffe Parade Rd., Madam Cama Rd, M.G.Road, Marine Drive, Karmavir Bhaurao Patil Marg, Old Custom House Rd. (Shahid Bhagat Singh Rd.), Dadabhai Naorji Rd. Ferer Rd. Maharashi Karve Rd., LT Road, Mahapalika Marg, Veer Nariman Road,
B	39, 40, 52	Ferer Rd., Easter Free Way, J.J.Flyover Bridge, Sardar Vallabhbhai Patel Marg, Carnac Bridge, Dr. Maheshwari Road
C	39,51	LT Road, J.J.Flyover Bridge, Marine Lines Flyover, Kalbadevi Rd., Sardar Vallabhbhai Patel Rd, Maulana Shaukat Ali Rd., Maharashi Karve Rd., NS Bose Rd.
D	37 to 39, 50, 51,62	Neapean Sea Rd., Walkeshwar Rd., Babulnath Rd., NS Bose Rd., Sardar Vallabhbhai Patel Rd., Maulana Shaukat Ali Rd. (Frere Bridge), August Kranti Rd., Javiji Dadaji Marg, Bellasis Rd., Gopalrao Deshmukh Marg, Bhulabhai Desai Rd., Tardeo Rd., Anandrao Nair Marg
E	51,52, 62,63	Anandrao Nair Marg, Bellasis Rd. (Clare Rd., N.M.Joshi Marg, Lalbaug Flyover, Balasaheb Nath Pai Marg, BPT Rd., Easter Free Way (BPT Rd.), Hay Bunder Rd., Nasbit Rd (Dockyard Rd.), Keshavrao Khadye Marg
F/N	88, 89, 90, 101, 102	Dadar TT Flyover (Sion Hospital Flyover), Kartak Rd., Rafi Ahmed Kidwai Marg, Sewri Chembu Rd., Eastern Free Way, BPT Rd.
F/S	64,65, 76,77	Dr. Babasaheb Ambedkar Marg (Lalbaug Flyover), G.D.Ambedkar Mag, Barister Nath Pai Rd., Rafi Ahmed Kidwai Marg, BPT Road, Haji Bunder Rd., Kartak Rd., Kind Edward Rd.,
G/N	76,87,88, 100, 101, 112, 113	Veer Savarkar Road, Gokhale Rd., (Elephinstone Flyover) Senapati Bapat Marg, Dadar Flyover (TT Bridge), Lakhamsi Nappu Rd., L.J. Rd. (S.V.Rd. Starting), TH Khatari Marg, 90 Feet Rd., Mahim Sion Link Rd., S.V.Road, Sion Bandra Link Rd.
G/S	62,63, 74,75, 76, 87	Dr. Lalalajpathrai Rd., Dr. A. Besant Rd., Dr. E. Moses Rd., Worli Seaface Rd. (Khan Abdul Gafarkhan Rd., Tulsi Pipe Rd., Ganpatrao Kadam Rd., N.M. Joshi Marg, G.D. Ambedkar Mag, Gokhale Rd., Elephinstone Flyover, Shankar Ghanekar Marg, Narayan Haldikar Marg, S.K. Bole Rd., Sane Guruji Marg, Veer Savarkar Road
M/W	79,90,91, 102, 103, 115, 116, 127, 128	BPT Rd., RCF Rd., Ghatkopar Mahul Rd. (Ramkrishna Chemburkar Marg, Eastern Free Way (Sewri Chembur Rd.), Sion Panvel Ex.Wy. (Dr. Choturam Gidwai Marg, Eastern Express Highway, Chembur Trombay Road, Chembur Govandi Road, Central Avenue Rd., P.L. Lokhande Marg, Ghatkopar Mankhurd Link Rd.
M/E	80,81, 91 to 94 103 to 106, 116 to 118	Eastern Express Highway, Sion Panvel Ex.Wy., Chembur Govandi Road , Ghatkopar Mankhurd Link Rd.

Wards	Grid No.	Major and Minor Road Traffic Roads (Connecting Interal Roads and Intersections)
H/W	99, 110, 112, 123, 124, 136	Raji Gandhi Sealink Ending Rd., Ali Yavar Jung Rd. (Western Express Highway), S.V.Rd. Starting, KC Rd., Perry Rd. (Datta Ram Lad Path), Hill Rd., Station Rd. (Jayprakash Rd.), Linking Rd. (Gurunanak Marg), Chitrakar Dhurandar Rd., Juhu Rd., J.Nehru Rd., Milan Bridge
H/E	112, 113, 114, 124, 125, 126, 136, 137	L.B.S Marg, Bandra Kurla Complex Rd., Ali Yavar Jung Rd. (Western Express Highway), Hans Bhugra Marg, S.G.Barve Rd. (Santacruz Chembur Link Rd., CST Rd)., J.Nehru Rd. (Air India Rd),
K/W	135, 136, 147, 148, 159, 160, 171, 172	Juhu Tara Rd., S.V.Road, Vaikunthlal Marg, Shahaji Raje Rd.,Gulmohar Rd., Jai Prakash Marg, K.L. Walawalkar Marg, CD Barfiwala Rd., Best Colony Rd. Swami Nityanand Marg
K/E	126, 137, 138, 148, 149, 150, 151, 160, to 162	Ali Yavar Jung Rd. (Western Express Highway), N. Nathuram Rd., Airport Rd., M.V. Road (Andheri Ghatkopar Rd.), Sakhi Vihar Road, MIDC Central Rd., Jogeshwari Vikhroli Link Rd., Airey Road
L	114,115, 126, 127, 138, 139, 151, 152, 163	L.B.S. Road, Eastern Express Highway, Sion Tromba Road (V N Pura Marg), Santacruz Chamber Link Rd., Andheri Ghatkopar Road., Khorana Road., Yogeshwar Vikhroli Link Rd., Chandivali Farm Rd.,
N	116, 127, 128, 140, 141, 152	Eastern Express Highway, Vasant Dada Patil Marg, L.B.S Road, Andheri Ghatkopar Road., Ghatkopar Mehul Road, Barista Nath Pai Marg
S	152, 153, 163 to 166, 177, 178, 189, 190	Eastern Express Highway, L.B.S Road, Yogeshwar Vikhroli Link Rd., Mulund Airol Bridge Rd., JN Road, Park Site Rd.
T	189 to 191, 202, 203	Eastern Express Highway, L.B.S Road, Mulund Airol Bridge Rd., JN Road, Namghar Road
P/S	170 to 174 183 to 187	Andheri Dahisar Link Road, Svoboda, Ali Yavari Jung Rd. (Western Express Highway), Goregaon Mulund Link Road, Airey Road
P/N	187, 194 to 199, 206 to 208	Andheri Dahisar Link Road, Svoboda, Ali Yavari Jung Rd. (Western Express Highway), Dutta Mandir Road, Madhu and Malady Marva Road
R/S	207 to 210, 219 to 220	Bandar Phakia Link Rd., Andheri Dahisar Link Rd., Mahatma Gandhi Rd., Svoboda, Ali Yavari Jung Rd. (Western Express Highway), Karli Road, Poiser Gymkhana Road, RDP No.6 Rd.
R/C	219 to 222 231 to 234	Andheri Dahisar Link Rd., Ali Yavari Jung Rd. (Western Express Highway), Svoboda, L.T. Road, Gori Link Road, Kora Kendra Road., Devadas Rd.
R/N	244 to 246	Ali Yavari Jung Rd. (Western Express Highway), Svoboda, CS Link Road

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

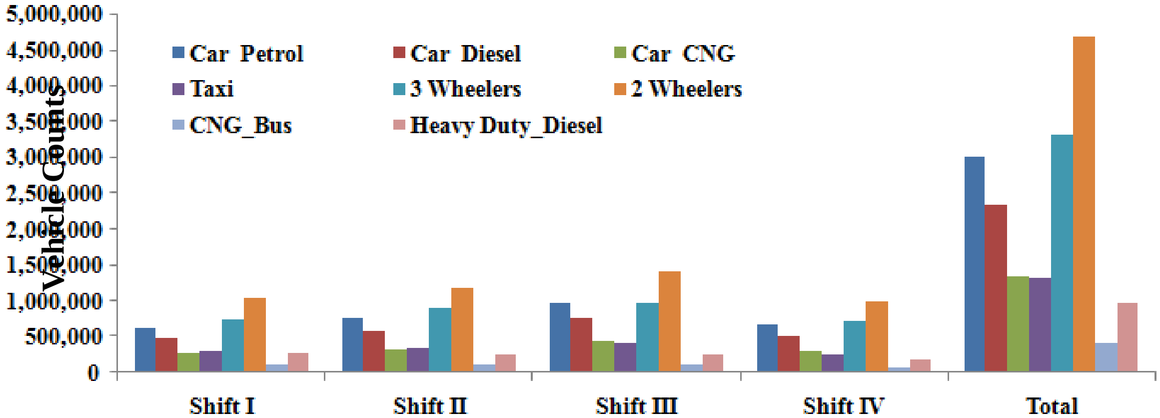


Figure 3.4: Vehicular Counting Survey of Whole of Mumbai City

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 total vehicles count shows around 46 lakhs (2 wheelers), 33 lakhs (3 wheelers), 30 lakhs (car petrol), 23 lakhs (car diesel) vehicles are running on the road every day on whole of Mumbai. Taxis and CNG Cars are around 13 lakhs, whereas 4 lakhs and 9 lakhs are CNG Buses and Heavy-Duty Diesel vehicles respectively. As against registered vehicles actual vehicle plying movement is very high. The evening peak (Shift III 1700 to 2200 Hours) shows the maximum counts of vehicles. On an average Shift I and Shift II counts moves similar way whereas shift IV counts observed decrease in trend. The percent distribution of different types of vehicles is shown in **Figure 3.5**. \

Almost 46 percent contributes by 2 Wheelers and 3 Wheelers. All types of cars viz. petrol, diesel and CNG vehicles contribute around 38%. Rest 16% is contributed by Taxis, CNG Buses and Heavy-duty Diesel vehicles. On an average 1.7 to 2.2 km roads length are observed including internal road, highways major and minor roads in each grid which were used for calculations.

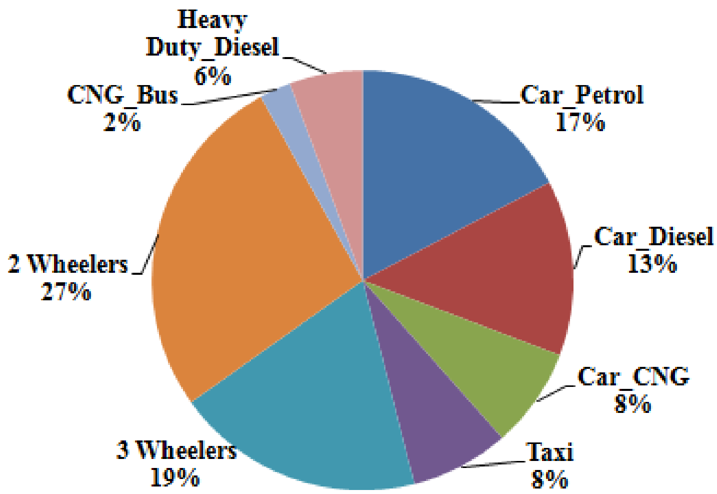


Figure 3.5 Percent Distributions of Different Types of Vehicles

3.3.3 Vehicle Kilometers Traveled (VKT) Estimation

Vehicle Kilometers Traveled (VKT) by each category of vehicles in each grid per day was estimated by multiplying the road length and the number of vehicles **(Figure 3.6)**.

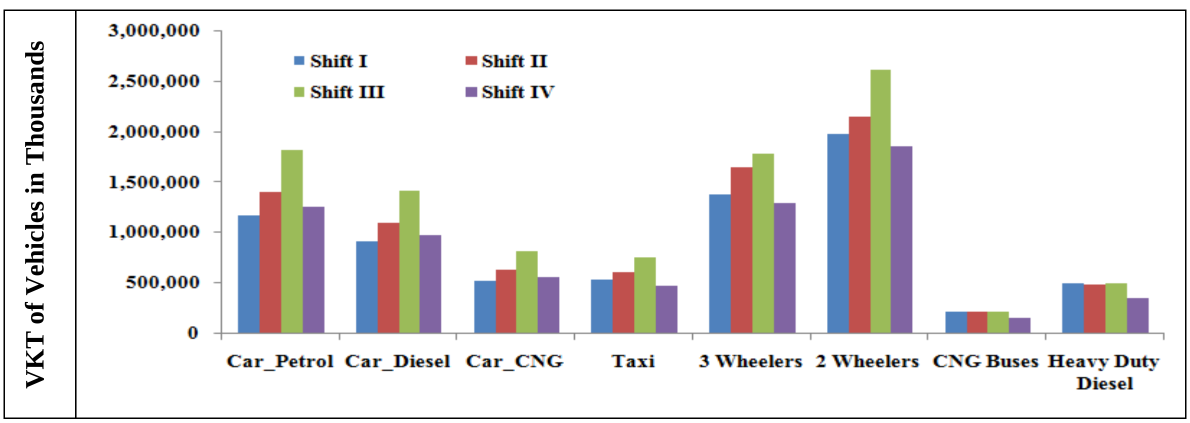


Figure 3.6: Vehicle Kilometer Travel (VKT) of Different Types of Vehicles in Whole of Mumbai City

The 2 wheelers are observed maximum VKT followed by Car Petrol and Diesel. Around 26 lakhs kms and 14 to 18 lakhs kms cars petrol and diesel are plying on Mumbai 2,000 km road length, which is more than its vehicular density and observed mostly in Shift III.

3.3.4 Vehicular Emission Factors

ARAI developed emissions factors for vehicles, post 2005 emission factors of different categories of vehicles are considered for calculations (**Table 3.25).**

Table 3.25: 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 BSI, 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

3.3.5 Whole City Vehicular Emission Inventory

The emission estimates were made for 2 km x 2 km grid 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 were 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 3.26.**

Table 3.26: Vehicular Emission Load from Line Sources for Mumbai City

	Cars			Taxi	3 Wheelers	2 Wheelers	CNG Bus	HD Diesel	Total Emission
	Petrol	Diesel	CNG						
PM Emission Load									
Shift I (4 Hrs.)	3.2	18.8	4.3	4.2	225.9	35.3	12.8	839.4	----
Shift II (6 Hrs.)	3.9	22.6	5.2	4.9	271.8	38.3	12.5	824.4	----
Shift III (5 Hrs.)	5.0	29.2	6.7	6.1	292.8	46.7	12.7	836.3	----
Shift IV (9 Hrs.)	3.5	20.3	4.6	3.8	212.1	33.1	9.0	592.0	----
kg/day	**15.6**	**91.0**	**20.8**	**19.1**	**1002.7**	**153.4**	**47.0**	**3092.1**	**4441.6**
Tons/Year	**5.7**	**33.2**	**7.6**	**7.0**	**366.0**	**56.0**	**17.2**	**1128.6**	**1621.2**
NOx Emission Load									
Shift I (4 Hrs.)	145.1	351.2	530.4	522.9	363.7	407.2	1801.6	6295.3	----
Shift II (6 Hrs.)	174.6	422.6	638.2	603.5	437.7	441.4	1769.5	6183.1	----
Shift III (5 Hrs.)	225.6	545.9	824.4	750.9	471.5	538.9	1795.0	6272.4	----
Shift IV (9 Hrs.)	156.3	378.2	571.1	474.0	341.6	382.0	1270.6	4439.9	----
kg/day	**701.6**	**1697.8**	**2564.0**	**2351.4**	**1614.5**	**1769.5**	**6636.6**	**23190.7**	**40526.1**
Tons/Year	**256.1**	**619.7**	**935.9**	**858.2**	**589.3**	**645.9**	**2422.4**	**8464.6**	**14792.0**
SOx Emission Load									
Shift I (4 Hrs.)	8.1	63.1	----	----	----	3.7	----	117.3	----
Shift II (6 Hrs.)	9.8	76.0	----	----	----	4.0	----	114.4	----
Shift III (5 Hrs.)	12.6	98.0	----	----	----	4.9	----	116.2	----
Shift IV (9 Hrs.)	8.7	67.9	----	----	----	3.5	----	82.2	----
kg/day	**39.2**	**304.9**	----	----	----	**16.0**	----	**430.1**	**790.3**
Tons/Year	**14.3**	**111.3**	----	----	----	**5.8**	----	**157.0**	**288.5**

Table 3.26 (Contd..: Vehicular Emission Load from Line Sources for Mumbai City

CO Emission Load									
Shift I (4 Hrs.)	1354.6	75.3	43.0	84.8	1321.0	1954.7	1079.2	4061.5	----
Shift II (6 Hrs.)	1629.9	90.5	51.7	48.9	1589.4	2118.9	1060.0	3989.1	----
Shift III (5 Hrs.)	2105.5	117.0	66.8	60.9	1712.4	2586.7	1075.3	4046.7	----
Shift IV (9 Hrs.)	1458.6	81.0	46.3	38.4	1240.4	1833.5	761.1	2864.4	----
kg/day	**6548.6**	**363.8**	**207.9**	**233.1**	**5863.2**	**8493.8**	**3975.5**	**14961.7**	**40647.7**
Tons/Year	**2390.2**	**132.8**	**75.9**	**85.1**	**2140.1**	**3100.2**	**1451.1**	**5461.0**	**14836.4**

	Cars			**Taxi**	**3 Wheelers**	**2 Wheelers**	**CNG Bus**	**HD Diesel**	**Total Emission**
	Petrol	**Diesel**	**CNG**						
HC Emission Load									
Shift I (4 Hrs.)	197.5	102.4	336.5	325.1	3943.8	1411.7	1087.9	250.5	----
Shift II (6 Hrs.)	238.2	123.5	405.8	375.2	4745.2	1530.3	1068.5	246.0	----
Shift III (5 Hrs.)	300.8	156.0	512.5	466.8	5112.3	1868.2	1083.9	249.5	----
Shift IV (9 Hrs.)	208.2	108.0	354.8	294.6	3703.3	1324.2	767.3	176.6	----
kg/day	**944.7**	**489.8**	**1609.5**	**1461.7**	**17504.6**	**6134.4**	**4007.6**	**922.6**	**33074.9**
Tons/year	**344.8**	**178.8**	**587.5**	**533.5**	**6389.2**	**2239.1**	**1462.8**	**336.8**	**12072.3**

The percent contribution of different pollutant and their category-wise distribution is show in Figure **3.7**.

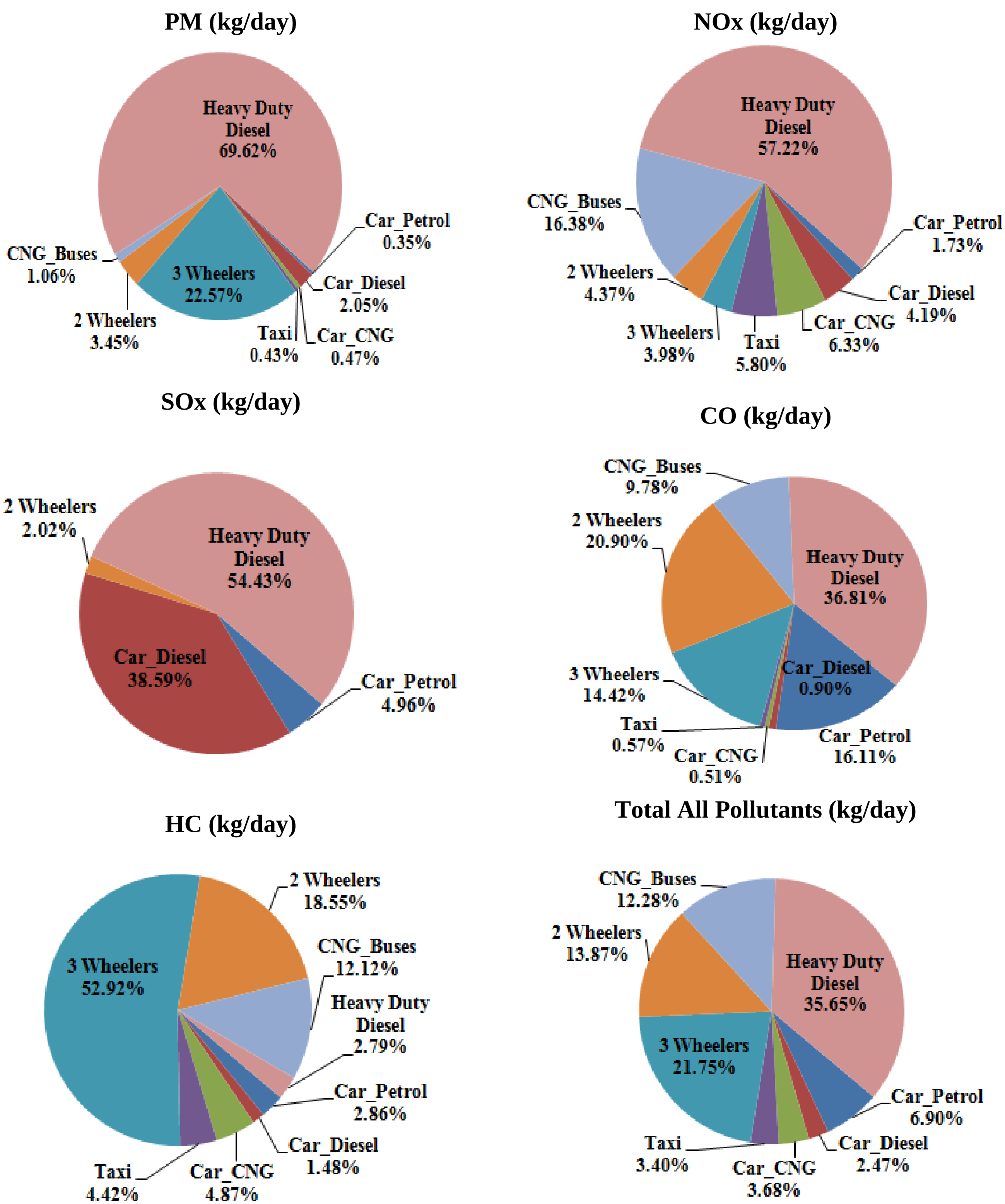


Figure 3.7: Pollutant Load from Different Categories of Vehicles

Total PM contribution from all types of vehicles in all shifts per day is around 4441.6 kg/day and 1621.2 tonnes/year. Heavy Duty vehicles contribute 69.62% (i.e. 3092.1 kg/day) followed by 3 wheelers 22.57% (1002.7 kg/day) and reset types of vehicles contribute 7.8% (i.e 346.8 kg/day). Shift III shows the maximum load and alone heavy duty vehicles emissions in shift III is 836.3 kg/day is observed. Although, the heavy duty diesel vehicle percent distribution is 6%, but the maximum emission of PM is observed from that type of vehicles.

The 40526.1 kg/day and 14792.0 tonnes/year emission load was observed for NOx pollutant. The highest emission of 23190.7 kg/day was observed for heavy duty diesel vehicles which is 57.22%, followed by 6636.6 kg/day for CNG buses (16.38%) and 2564.0 kg/day for CNG Cars (6.33%) and rest shares about 20.07% for 2 and 3 Wheelers, Taxis, Car Petrol and Car Diesel.

As SOx 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 54.43% (i.e., 430.1 kg/day) and 38.59% (304.9 kg/day) for car diesel. The total emission of SOx in the city is around 790.3 kg/day and 288.5 tones /year.

Total CO 40647.7 kg/day and 14836.4 tones/year were observed Mumbai. The heavy-duty diesel emission around 36.81% (14961.7 kg/day) followed by 2-wheeler (8493.8 kg/day), car petrol (6548.6 kg/day) and 3 wheelers (5863.2 kg/day).

The HC mainly contribute from 3 wheelers i.e., 52.92% (17504 kg/day) emission load as against the total emission of 33074.9 kg/day and 12072.3 ton/years for Mumbai city. CNG Buses (4007.6 kg/day) and CNG Cars (1609.5 kg/day) contribute around 16.99%. 2 Wheelers (6134.4 kg/day) contribute is 18.55%.

If we considered all pollutants then the noticeable pollution is observed from Heavy duty diesel vehicles i.e., 35.7% (983633 vehicles) followed by 3 wheelers (21.7%) (3336176 vehicles) and 2 wheelers (4667314 vehicles) and CNG Buses (421557 vehicles) contributes 13.9% and 12.3%, even though their percent contribution is around 6% (HD), 19% (3W), 27% (2W) and 2% CNG Buses respectively. The rest of vehicles shows; 17% car petrol vehicles contribute 6.9% emission, 13% car diesel contribute 2.5%, 8% Car CNG gives 3.7% and 8% taxis shares 3.4% emission load in the city.

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 emit air pollutants 4 to 8 times more than they would with less traffic congestion.

3.3.6 Ward-wise Emission Load

The city is divided into three major parts viz. Island City, Western Suburbs and Eastern Suburbs and accordingly the MCGM wards are distributed as follows:

- Island City (9 wards): Ward A, B, C, D, E, F/N, F/S, G/N and G/S.
- Western Suburbs (9 wards): H/E, H/W, K/E, K/W, P/N, P/S, R/C, R/N and R/S
- Eastern Suburbs (6 wards): L, M/E, M/W, N, S and T

The grid wise emission load was estimated for whole city **(Figure 3.3),** and forward emission calculations the grid was identified, which are passing through the respective wards and their major, minor and internal roads. Based on road length and different types of vehicles counts the emission was estimated. Within Greater Mumbai, Auto rickshaws are allowed to operate only in the suburban areas, while taxis are allowed to operate throughout Mumbai, but generally operate in South Mumbai. Taxis and Auto rickshaws in Greater Mumbai are required by law to run on compressed natural gas (CNG).

Greater Mumbai is connected to rest of MMR by six major roads i.e. Goroutine Road, Western Express Highway, LBS Marg, Eastern Express Highway, Airol Bridge, Vashi Creek bridge on Sion-Panvel Highway. The Worli-Bandra Sea Link bridge, along with Mahim Causeway, Bandra-Sion Link Road, LBS Marg, Wadala Truck Terminal Road, Eastern Express Highway, Eastern Freeway, etc. links the Island City to the suburbs.

The four major road arteries of the Greater Mumbai are the Eastern Express Highway from Sion to Thane, the Sion Panvel Expressway from Sion to Panvel, Eastern Freeway connecting Mankhurd to D' Mello Road and the Western Express Highway from Bandra to Borivali. These are considered as backbones of the MMR's road transport system.

The main arterial roads/ sub-arterial roads in Island City are Western Corridor (Netaji Subhash Marg, Peddar Road, Anne Besant Road), Central Corridor (Babasaheb Ambedkar Road, Senapati Bapat Marg and Maulana Azad Marg) and eastern Corridor (PD' Mello Road and Rafi Ahmed Kidwai Marg). The main arterial roads/ sub- arterial roads in Suburbs are S V Road, Linking

Road, New Link Road (Western Relief Road) and LBS Marg. Major east-west connecting roads in Suburbs are Jogeshwari Vikhroli Link Road (JVLR), Andheri-Ghatkopar Link Road (AGLR), Santacruz Chembur Link Road (SCLR) and Sion-Mahim Link Road.

Street networks in most parts of the Greater Mumbai are old, narrow and their capacity is reduced considerably due to encroachments, on-street parking, pedestrian walking on the carriageway due to inadequate footpaths, and hawkers, there are lack of appropriate management and traffic and parking.

Suburban station areas, inter-city rail terminal areas, inter-city bus terminal areas throughout the study area are typically congested. Located in close proximity to commercial areas and markets, and surrounded by informal markets; they experience increasing number of vehicles and pedestrians, all competing for limited available road space. The suburban railway station areas in Greater Mumbai are well served by bus services and with increasing population pressure they usually experience traffic congestion during peak periods. Bazar areas in the Island City experience conflicts due to their narrow streets, activity and high pedestrian movements. The vehicle count distributions along the wards for different types of vehicles are presented in **Figure 3.8.** The major car movement was observed at K/E, K/W, H/E, S and N wards representing areas viz. Eastern Express Highway, L.B.S Road, Jogeshwari Vikhroli Link Rd., Mulund Airoli Bridge Rd., Andheri Ghatkopar Road., Ghatkopar Mahul Road, Juhu Tara Rd., Gulmohar Rd., S.V.Road, Jai Prakash Marg, K.L. Walawalkar Marg, CD Barfiwala Rd., Western Express Highway, Sakhi Vihar Rd, Aarey Road, Bandra Kurla Complex Rd., Santacruz Chembur Link Rd.

The Taxi counts mainly represent island city (A, D, F/N, F/S, G/N and G/S) i.e. Colaba, Fort, Marine Drive, Kalbadevi, Mahapalika Marg, Neapean Sea Rd., Walkeshwar Rd., Babulnath Rd., Tardeo, Haji Ali, Worli, Dadar, Parel, Byculla Matunga and Mahim.

Three-wheelers and 2-wheelers are dominated in Wards of K/E, K/W, R/C, R/S, S and T and the impacted area mainly Eastern and Western Express Highway, S.V. Roads, LBS Marg and link roads of western side and Kurla, Ghatkopar, Vikhroli, Bhandup, Mulund in eastern side. Jogeshwari Vikhroli Link Rd., Aarey Road and santacruz chamber link road are also congested which are the linkages for other parts of the city. The residential blocks are more in these wards and people use 2 and 3 wheelers mostly for their internal transport for market, schools, approach to station etc.

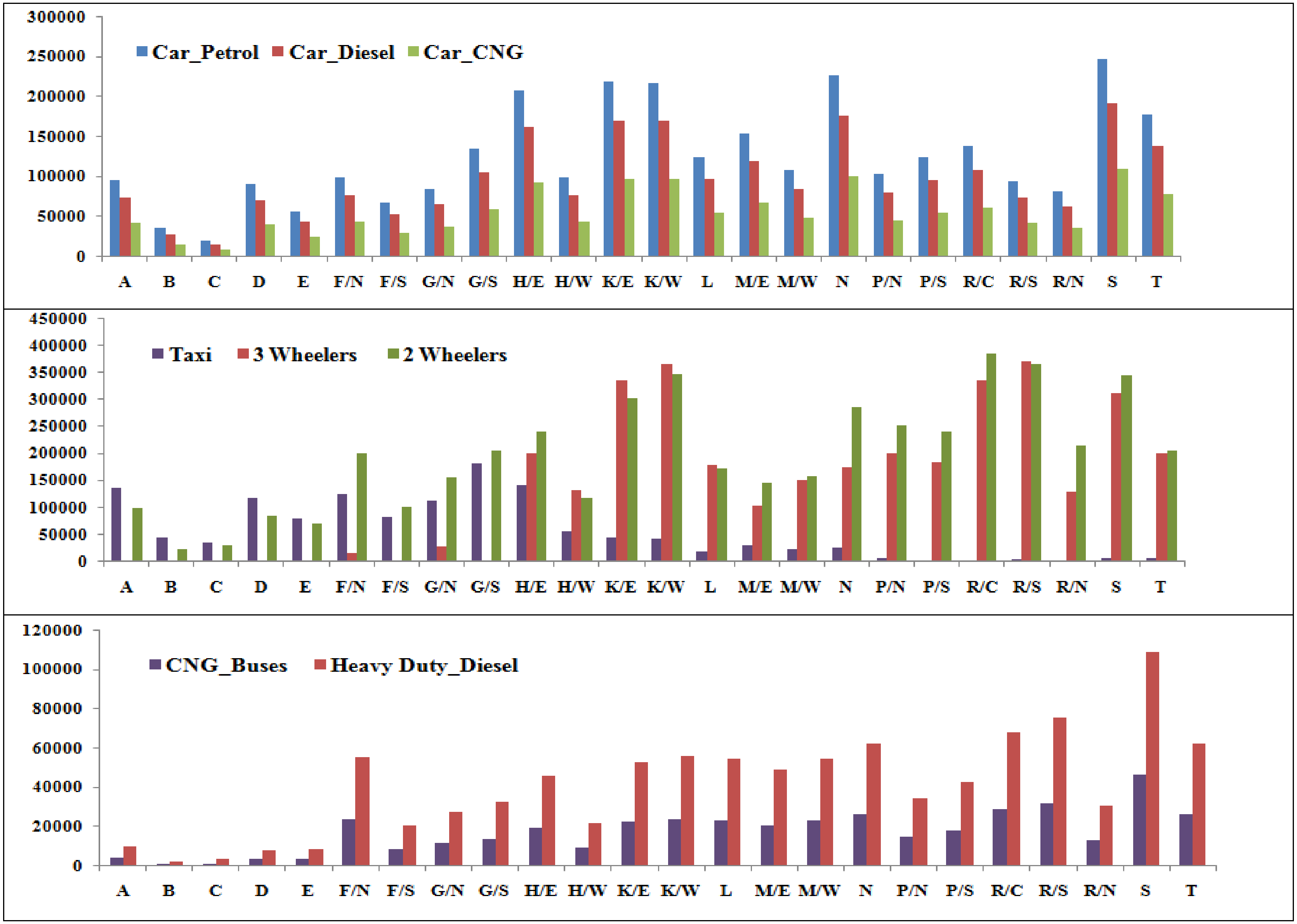


Figure 3.8: Vehicle Count of Different Categories of Vehicles in Respective Wards

The BEST's major bus depot is located in this ward's R/C, R/S, N, L, S and T showing the CNG Buses impact. The heavy-duty vehicles are mainly observed at ward R/C, R/S (Western Express Highways –NH8 (Mumbai Agra Road) and S and T wards (Eastern Express Highways –NH3, Mumbai Thane & Airoli Road) as also at Sion Panvel Highway.

The ward wise emission loads of pollutants from different categories of vehicles are presented in **Table 3.27 through 3.31 and Figure 3.9**. The highest PM load was observed at S ward (466.8 kg/day) and R/S (353.6), then followed by R/C, K/E, K/W and L. The highest contribution is from heavy duty diesel vehicles representing wards S (343.4 kg), R/C (223.1) and R/S (231.2) and 3 wheelers also contributes substantial to the PM emission load from wards K/W (114.2 kg/day), R/C and R/S (100.2 and 103 kg/day).

The S ward dominates the NOx contribution (4030 kg/day) and others R/C, R/S, K/E, K/W and L wards ranging between 2500 to 2650 kg/day. Heavy duty diesel vehicles also show the highest emission load at S (2575.2 kg/day) and at ward R/C, R/S and L ranging from (1600 to 1700 kg/day). NOx from CNG Buses also contributes significantly ranging from 460 to 730 kg/day. Similarly, 2 and 3 Wheelers emission load observed around 130 to 170 kg/day.

Highest emission load of SOx is observed at S (77.2), K/E (54.9), K/W (55.4) and H/E (50.0) kg/day. Diesel soot vehicles i.e., Car Diesel and Heavy-duty diesel vehicles show the load around 20 to 47 kg/day. The highest CO emission contribute at S ward (3915.5 kg/day) followed by R/N, R/C and K/E and values ranges from 2800 to 3100 kg/d. Emission load of Car petrol, 2 and 3 Wheelers are also observed in the range from 400 to 600 kg/day. Heavy duty diesel vehicles values were observed to be between 1000 to 1600 kg/day.

The hydrocarbon emission is mostly observed in the range of 1000 to 3000 kg/d, amongst 3 wheelers ranging from 1600 to 1900 kg/day, whereas 2 wheelers and CNG Buses ranging from 200 to 400 kg/day at Ward S, R/S, R/C K/E and K/W.

Overall ward-wise observations shows that the entry points of Mumbai i.e., Mulund-Thane, Borivali- Dahisar and Mulund -Airoli Link Road, Sion Panvel Highways are influenced by Heavy duty diesel vehicles and Cars where to and for movements are more. The inner part of the city was mostly influenced by 3 wheelers, 2 wheelers and cars impacted area is mostly suburban, LBS, SV Road, Jogeshwari Vikhroli Link Rd. and Santacruz Chembur Link Road. The island city i.e., Colaba to Sion and Bandra mostly influenced by taxi and cars.

Table 3.27: Ward-wise Emission Load of PM (Values in kg/day)

Wards	Cards			Taxi	3 Wheelers	2 Wheelers	CNG Buses	Heavy Duty Diesel	Total PM (kg/d)
	Petrol	Diesel	CNG						
A	0.4	2.4	0.5	1.7	--	2.6	0.4	25.0	**33.0**
B	0.2	0.9	0.2	0.5	--	0.6	0.1	6.2	**8.7**
C	0.1	0.5	0.1	0.4	--	0.8	0.1	9.6	**11.6**
D	0.4	2.4	0.6	1.6	--	2.5	0.4	23.8	**31.7**
E	0.3	1.7	0.4	1.1	--	2.3	0.4	27.9	**34.1**
F/N	0.4	2.5	0.6	1.6	2.2	5.7	2.1	140.8	**156.0**
F/S	0.4	2.5	0.6	1.5	--	3.9	1.1	72.3	**82.2**
G/N	0.5	2.7	0.6	1.8	7.2	5.4	1.5	95.8	**115.4**
G/S	0.6	3.2	0.7	2.4	--	6.2	1.5	101.7	**116.4**
H/E	1.2	7.0	1.6	2.2	56.2	8.3	2.1	140.5	**219.0**
H/W	0.5	3.1	0.7	0.9	34.3	3.9	1.0	68.8	**113.2**
K/E	1.3	7.4	1.7	0.7	105.7	11.0	2.7	179.9	**310.5**
K/W	1.2	7.3	1.7	0.8	114.2	12.5	2.9	193.0	**333.5**
L	0.8	4.8	1.1	0.3	65.2	7.0	3.3	215.4	**297.9**
M/E	0.7	4.1	0.9	0.4	27.3	4.1	2.0	132.0	**171.4**
M/W	0.6	3.4	0.8	0.4	49.1	5.6	2.8	183.9	**246.5**
N	1.0	5.6	1.3	0.3	46.1	7.7	2.5	162.3	**226.7**
P/N	0.6	3.4	0.8	0.1	64.4	9.1	1.8	115.1	**195.3**
P/S	0.7	3.9	0.9	0.0	55.5	8.2	2.2	141.9	**213.3**
R/C	0.7	4.3	1.0	0.0	100.2	11.4	3.4	223.1	**344.2**
R/S	0.5	2.9	0.7	0.1	103.0	11.7	3.5	231.2	**353.6**
R/N	0.4	2.4	0.6	0.0	36.1	7.2	1.5	99.1	**147.3**
S	1.3	7.6	1.7	0.1	95.6	11.9	5.2	343.4	**466.8**
T	0.9	5.0	1.1	0.1	63.7	7.1	2.8	184.1	**264.7**

Table 3.28: Ward-wise Emission Load of NOx (Values in kg/day)

Wards	Cards			Taxi	3 Wheelers	2 Wheelers	CNG Buses	Heavy Duty Diesel	Total NOx (kg/d)
	Petrol	Diesel	CNG						
A	18.1	43.9	66.3	209.2	--	29.7	53.8	187.8	**608.8**
B	7.3	17.7	26.7	65.8	--	6.7	13.3	46.5	**184.1**
C	4.0	9.6	14.5	50.5	--	9.0	20.6	71.9	**180.1**
D	18.8	45.4	68.6	201.4	--	28.5	51.1	178.5	**592.2**
E	13.0	31.5	47.6	141.7	--	26.7	59.9	209.2	**529.7**
F/N	19.7	47.5	71.8	199.1	3.6	65.5	302.1	1055.7	**1765.0**
F/S	19.0	46.0	69.5	180.0	--	44.8	155.2	542.3	**1056.7**
G/N	20.6	49.8	75.3	222.5	11.6	62.5	205.7	718.7	**1366.7**
G/S	24.9	60.2	90.9	300.3	0.0	71.8	218.2	762.6	**1528.9**
H/E	53.7	129.9	196.2	265.2	90.4	96.0	301.5	1053.5	**2186.5**
H/W	24.0	58.2	87.8	109.3	55.2	45.2	147.6	515.8	**1043.1**
K/E	57.4	138.9	209.7	91.1	170.3	126.5	386.1	1349.3	**2529.4**
K/W	56.2	135.9	205.3	93.6	183.9	143.9	414.2	1447.3	**2680.2**
L	36.7	88.7	134.0	41.8	104.9	80.9	462.4	1615.9	**2565.3**
M/E	31.3	75.7	114.3	50.6	43.9	46.9	283.3	989.8	**1635.7**
M/W	26.4	63.8	96.4	45.8	79.0	64.3	394.7	1379.3	**2149.7**
N	43.0	103.9	157.0	38.3	74.2	89.1	348.3	1217.0	**2070.7**
P/N	26.2	63.4	95.7	13.6	103.7	105.4	247.1	863.4	**1518.4**
P/S	29.9	72.3	109.2	4.3	89.4	95.2	304.6	1064.4	**1769.2**
R/C	33.3	80.6	121.7	4.7	161.4	131.2	478.9	1673.6	**2685.5**
R/S	22.2	53.8	81.2	10.2	165.8	135.0	496.3	1734.4	**2699.0**
R/N	18.7	45.4	68.5	3.4	58.1	82.6	212.8	743.5	**1233.0**
S	58.4	141.4	213.5	13.4	153.9	137.4	737.0	2575.2	**4030.2**
T	38.7	93.6	141.4	9.7	102.6	81.5	395.0	1380.4	**2242.9**

Table 3.29: Ward-wise Emission Load of SOx (Values in kg/day)

Wards	Cards		2 Wheelers	Heavy Duty Diesel	Total SOx (kg/d)
	Petrol	Diesel			
A	1.0	7.8	0.3	3.5	**12.6**
B	0.4	3.2	0.1	0.9	**4.5**
C	0.2	1.7	0.1	1.3	**3.3**
D	1.0	8.1	0.3	3.3	**12.7**
E	0.7	5.6	0.2	3.9	**10.5**
F/N	1.1	8.5	0.6	19.5	**29.6**
F/S	1.1	8.2	0.4	10.0	**19.7**
G/N	1.1	8.9	0.6	13.2	**23.8**
G/S	1.4	10.8	0.6	14.1	**26.8**
H/E	3.2	24.5	0.9	21.4	**50.0**
H/W	1.3	10.4	0.4	9.5	**21.6**
K/E	3.2	25.1	1.1	25.4	**54.9**
K/W	3.1	24.3	1.3	26.7	**55.4**
L	2.0	15.8	0.7	29.8	**48.4**
M/E	1.7	13.5	0.4	18.2	**33.9**
M/W	1.5	11.4	0.6	25.4	**38.9**
N	2.4	18.6	0.8	22.4	**44.2**
P/N	1.5	11.3	0.9	15.9	**29.6**
P/S	1.7	12.9	0.8	19.6	**35.0**
R/C	1.9	14.4	1.4	30.9	**48.5**
R/S	1.2	9.6	1.2	32.0	**44.0**
R/N	1.0	8.1	0.7	13.7	**23.6**
S	3.2	25.3	1.2	47.5	**77.2**
T	2.1	16.7	0.7	25.4	**45.0**

Table 3.30: Ward-wise Emission Load of CO (Values in kg/day)

Wards	Cards			Taxi	3 Wheelers	2 Wheelers	CNG Buses	Heavy Duty Diesel	Total CO (kg/d)
	Petrol	Diesel	CNG						
A	169.2	9.4	5.4	20.5	0.0	142.4	32.2	121.2	**500.2**
B	68.2	3.8	2.2	6.3	0.0	32.3	8.0	30.0	**150.8**
C	37.1	2.1	1.2	5.0	0.0	43.1	12.3	46.4	**147.1**
D	175.1	9.7	5.6	19.8	0.0	137.0	30.6	115.2	**492.9**
E	121.7	6.8	3.9	13.7	0.0	128.1	35.9	135.0	**444.9**
F/N	183.4	10.2	5.8	19.3	13.0	314.5	181.0	681.1	**1408.4**
F/S	177.5	9.9	5.6	17.5	0.0	215.0	93.0	349.9	**868.2**
G/N	192.2	10.7	6.1	21.6	42.0	299.9	123.2	463.7	**1159.5**
G/S	232.2	12.9	7.4	29.6	0.0	344.6	130.7	492.0	**1249.4**
H/E	501.1	27.8	15.9	27.9	328.4	460.8	180.6	679.7	**2222.2**
H/W	224.3	12.5	7.1	11.4	200.3	217.0	88.4	332.8	**1093.8**
K/E	535.6	29.8	17.0	9.3	618.4	607.3	231.3	870.5	**2919.2**
K/W	524.3	29.1	16.6	9.5	667.8	690.6	248.1	933.7	**3119.8**
L	342.2	19.0	10.9	4.0	381.1	388.4	277.0	1042.5	**2465.1**
M/E	291.8	16.2	9.3	5.1	159.4	225.3	169.7	638.6	**1515.4**
M/W	246.1	13.7	7.8	4.4	286.9	308.4	236.5	889.9	**1993.7**
N	400.9	22.3	12.7	3.6	269.6	427.7	208.6	785.1	**2130.6**
P/N	244.4	13.6	7.8	1.4	376.7	505.8	148.0	557.0	**1854.8**
P/S	278.9	15.5	8.9	0.4	324.7	456.8	182.5	686.7	**1954.3**
R/C	310.8	17.3	9.9	0.5	586.2	629.9	286.9	1079.8	**2921.2**
R/S	207.5	11.5	6.6	1.0	602.3	648.0	297.3	1118.9	**2893.2**
R/N	175.0	9.7	5.6	0.4	211.1	396.3	127.5	479.7	**1405.2**
S	545.4	30.3	17.3	1.3	558.9	659.4	441.5	1661.4	**3915.5**
T	361.1	20.1	11.5	1.0	372.6	391.0	236.6	890.6	**2284.5**

Table 3.31: Ward-wise Emission Load of HC (Values in kg/day)

Wards	Cards			Taxi	3 Wheelers	2 Wheelers	CNG Buses	Heavy Duty Diesel	Total HC (kg/d)
	Petrol	Diesel	CNG						
A	24.2	12.5	41.2	130.1	0.0	102.8	32.5	7.5	**350.7**
B	9.7	5.1	16.6	40.9	0.0	23.4	8.0	1.8	**105.6**
C	5.3	2.7	9.0	31.4	0.0	31.1	12.4	2.9	**94.9**
D	25.0	13.0	42.6	125.2	0.0	99.0	30.8	7.1	**342.7**
E	17.4	9.0	29.6	88.1	0.0	92.5	36.2	8.3	**281.1**
F/N	26.2	13.6	44.6	123.7	38.9	227.2	182.4	42.0	**698.7**
F/S	25.4	13.1	43.2	111.9	0.0	155.3	93.7	21.6	**464.1**
G/N	27.5	14.2	46.8	138.3	125.5	216.6	124.2	28.6	**721.8**
G/S	33.2	17.2	56.5	186.7	0.0	248.9	131.8	30.3	**704.6**
H/E	71.6	37.1	122.0	164.8	980.3	332.8	182.1	41.9	**1932.6**
H/W	32.0	16.6	54.6	67.9	598.1	156.7	89.1	20.5	**1035.7**
K/E	76.5	39.7	130.4	56.6	1846.1	438.6	233.2	53.7	**2874.8**
K/W	74.9	38.8	127.6	58.2	1993.8	498.8	250.1	57.6	**3099.8**
L	48.9	25.3	83.3	26.0	1137.7	280.5	279.2	64.3	**1945.2**
M/E	43.1	22.3	73.4	31.4	475.8	162.7	171.1	39.4	**1019.2**
M/W	35.2	18.2	59.9	28.5	856.5	222.7	238.4	54.9	**1514.2**
N	65.1	33.7	110.9	23.8	804.9	308.9	210.3	48.4	**1606.0**
P/N	34.9	18.1	59.5	8.4	1124.8	365.3	149.2	34.4	**1794.6**
P/S	39.8	20.7	67.9	2.6	969.5	329.9	183.9	42.3	**1656.7**
R/C	44.4	23.0	75.7	2.9	1750.1	454.9	289.2	66.6	**2706.8**
R/S	29.6	15.4	50.5	6.4	1798.0	468.0	299.7	69.0	**2736.7**
R/N	25.0	13.0	42.6	2.1	630.3	286.3	128.5	29.6	**1157.3**
S	77.9	40.4	132.7	8.3	1668.6	476.2	445.0	102.5	**2951.7**
T	51.6	26.8	87.9	6.0	1112.4	282.4	238.5	54.9	**1860.5**

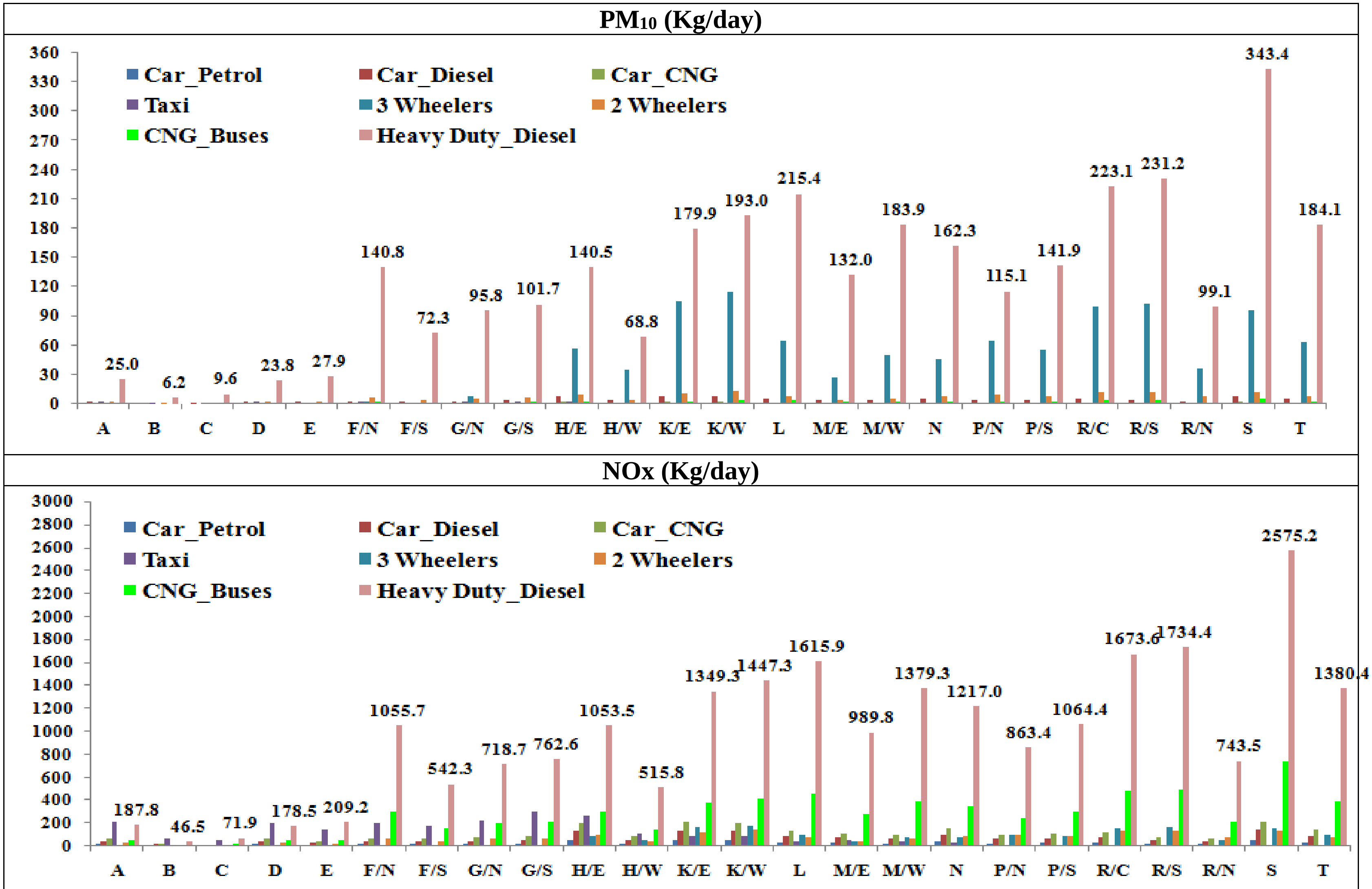


Figure 3.9 : Ward-wise Emission Loads of Pollutants from Different Categories of Vehicles in Mumbai City

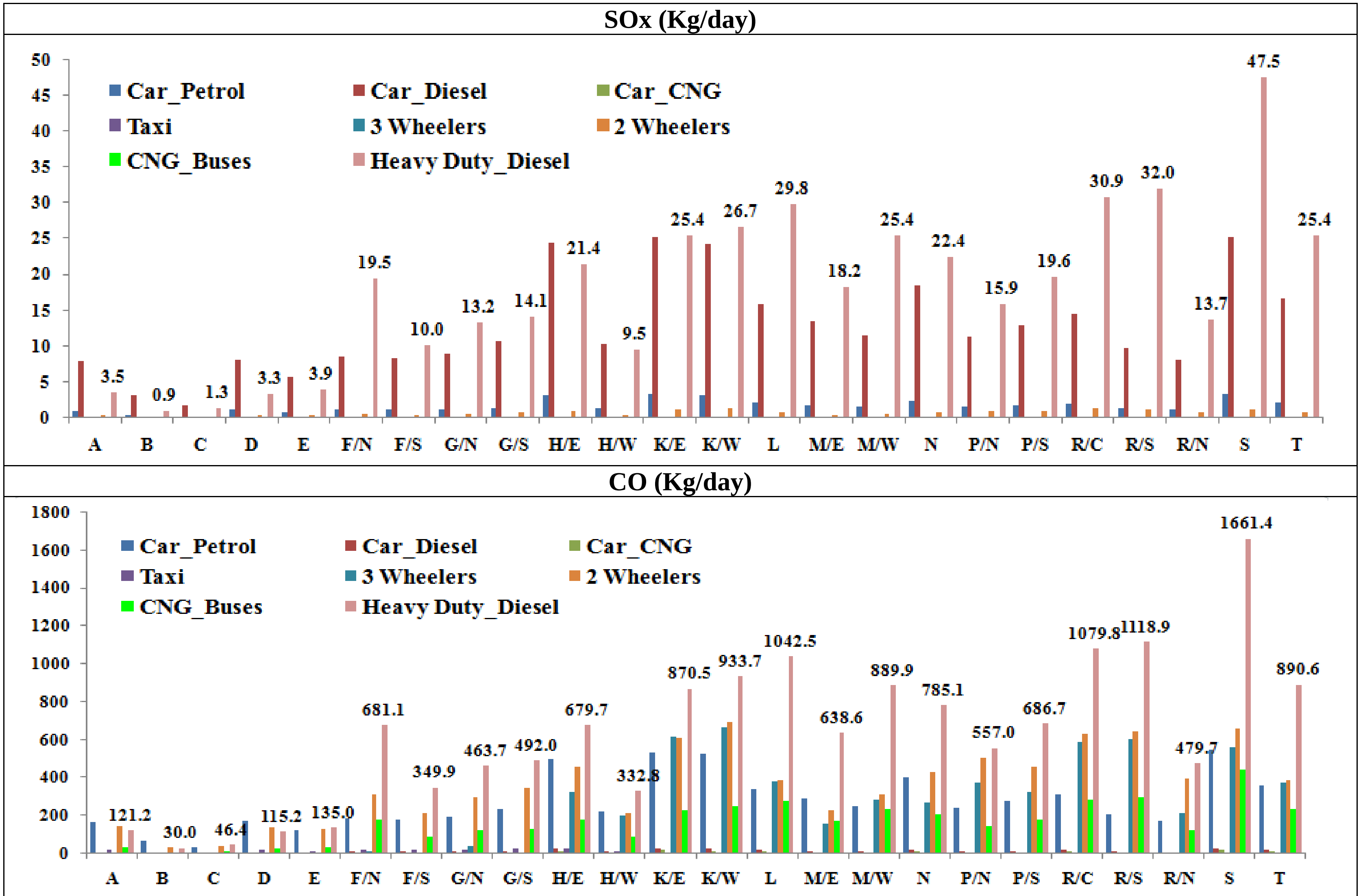


Figure 3.9 (Contd..): Ward wise Emission Loads of Pollutants from Different Categories of Vehicles in Mumbai City

HC (Kg/day)

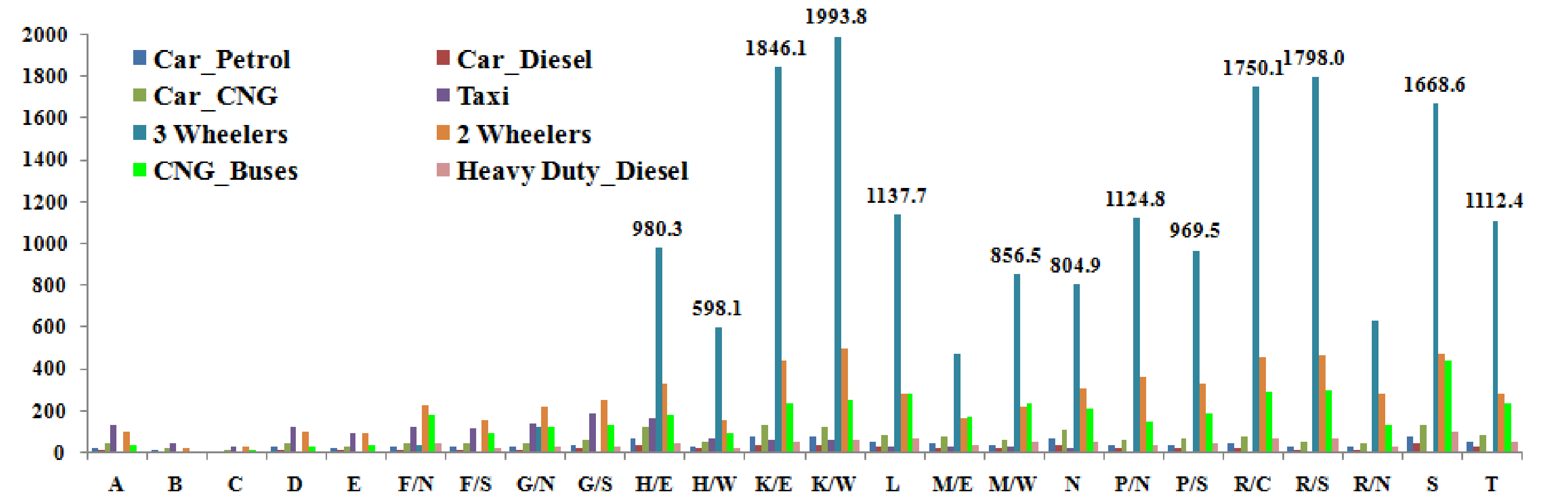


Figure 3.9 (Contd..): Ward wise Emission Loads of Pollutants from Different Categories of Vehicles in Mumbai City

3.4 Point (Industrial) Sources

Point sources are generally large emitters with one or more emission points at a permitted facility with an identified location. Examples include oil production and refinery facilities, steam generators, boilers, process heaters, glass manufacturing, etc. The emissions from point sources are generally calculated using emission factors obtained from direct measurements (e.g., source testing). EPA's document entitled, *Compilation of Air Pollutant Emissions Factors* (AP-42), or California Air Resource Board's material balance 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).

Oil refinery/ petrochemical, fuel-based power plant, fertilizer and other industries are the major point sources of emissions in Mumbai region. These industries are located mainly in the eastern and northeastern parts of the region. Large industrial areas are mainly concentrated in Chembur, Andheri and along LBS Marg starting from Kanjur Marg to Mulund. In Western region viz. Kandivali, Goregaon also has some industries, with potential sources of air pollution. Chembur has chemical industries, a power plant and refineries. **Figure 3.10** shows locations of these industries in the city. Fossil fuel used by the industries for boilers or manufacturing process remains the single potential source of emissions into the atmospheres 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).

The information also included MPCB classification viz. large, medium and small as well as red, orange and green categories based on labour employed and consumption of water, fuel and power. According to MPCB, the polluting industries are classified as red (highly polluting), orange (moderately polluting) and green (low polluting) in nature. There are 4305 different categories of industries operating in Mumbai, of where about 197 are air polluting industries.

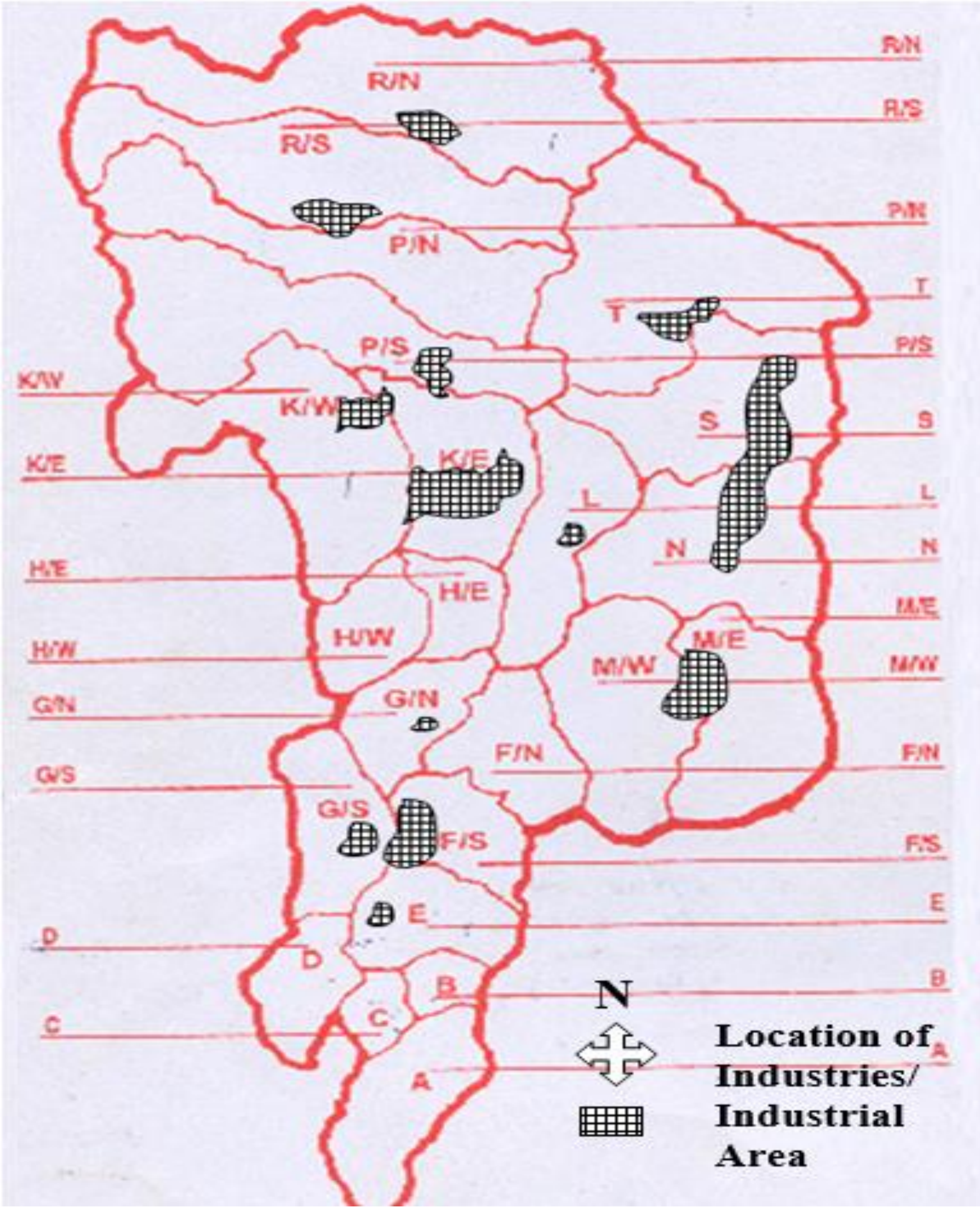


Figure 3.10: Location of Industries in Mumbai

LSI	MSI	SSI	Red Total	LSI	MSI	SSI	Orange Total	LSI	MSI	SSI	Green Total	Grand Total
175	56	573	804	514	315	689	1518	10	27	1946	1983	4305

Air Polluting Industries in Mumbai (Approx.197 industries)

LSI	MSI	SSI	**Red**	LSI	MSI	SSI	**Orange**	LSI	MSI	SSI	**Green**	**Grand Total**
51	1	23	**75**	54	12	32	**98**	4	1	19	**24**	**197**

Emission inventory from industries has considered working hours for industries as MSI=16 hrs., LSI=22 hrs., SSI=12 hrs.

3.4.1 Approach/Methodology (Point Source)

The gross emissions are estimated for all types of industries viz. power plant, chemicals, refineries and information relating to consumption of fuels such as Furnace Oil (FO), Light Diesel Oil (LDO), Low Sulphur Heavy Stock (LSHS), and Compressed Natural Gas (CNG), is obtained by MPCB **(Table 3.32)**. The major Red LSI i.e., industries like refinery, fertilizer plant are calculated separately and other remaining like MSI, SSI from Red, Orange and Green are combining and calculated. Only Power Plant was separately calculated as the fuel quantity is huge.

Table 3.32: Fuel Consumption from Industries (TPD)

Industries	**FO**	**LSHS**	**LDO**	**HSD**	**NG (m^3/day)**	**Coal**	**LPG**
Red (LSI)	1134	378	20	280	3469396	1	0.4
Power Plant	--	--	--	--	3000	8400	--
Other R, O, G (LSI, MSI, SSI)	82	1	52	630	70	0.8	3
Total	**1216**	**380**	**73**	**909**	**3472467**	**8401**	**3**

Almost 99% of coal consumption is from Power Plant, whereas NG's input is more from Red (LSI) 99% as also for FO and LSHS i.e., 94% and 99% respectively. The other fuel LDO and HSD are around 72-87% from MSI & SSI industries. HSD and LDO are the less used fuel.

Emission factors published by TERI, New Delhi were 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 **(Table 3.33)**. The emission load was calculated based on 90% reduction due to control equipment's 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 were taken from the consent of respective industry, for those industries without any ash and sulfur contain is calculated based on **Table 3.33**. The industrial emission load from different pollutants and whole Mumbai city is given in **Table 3.34 and Table 3.35**.

Table 3.33: Emission Factors Applied for Industrial Emissions

S. No				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

Coal A - % Ash: 2- 10% Avg. 6%, S - % Sulphur: 0.1 – 0.2%, Avg. 0.15%
ESP Eff. : 99.5%, FGD Eff. : 99%

LSHS Sulphur: 0.45%

Data:
Density of Fuels (Kg/m^3)

LSHS	943
FO	943
LDO	860
LPG	504
HSD	860

Sources:

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

Table 3.34 : The Industrial Emission Load from Different Categories of Fuel

	TSP	PM10	SO2	NO2	CO	HC
Coal (kg/day)						
Red (LSI)	1.1	1.1	0.1	1.5	0.3	0.1
Power Plant	819.0	778.1	239.4	44100.0	8400.0	4200.0
MSI & SSI	3.0	2.8	0.2	4.0	0.8	0.4
Total	**823.1**	**781.9**	**239.7**	**44105.5**	**8401.0**	**4200.5**
NG (kg/day)						
Red (LSI)	109.0	109.0	65.4	13350.2	1852.7	326.9
Power Plant	48.0	48.0	28.8	5880.0	816.0	144.0
MSI & SSI	1.4	1.4	0.8	172.4	23.9	4.2
Total	**158.4**	**158.4**	**95.0**	**19402.6**	**2692.6**	**475.2**
FO (kg/day) (FO is not in consent of Power Plant)						
Red (LSI)	104.3	88.7	1452.0	6121.5	734.6	139.9
MSI & SSI	46.9	39.9	671.3	457.7	54.9	10.5
Total	**151.2**	**128.5**	**2123.4**	**6579.3**	**789.5**	**150.4**
LDO (kg/day) (LDO is not in consent of Power Plant)						
Red (LSI)	0.3	0.2	38.1	25.6	8.4	1.6
MSI & SSI	1.5	0.8	188.7	117.0	38.3	7.3
Total	**1.9**	**0.9**	**230.0**	**142.6**	**46.7**	**8.9**
LSHS (kg/day) (FO is not in consent of Power Plant)						
Red (LSI)	5.4	2.7	51.0	2079.3	249.5	47.5
MSI & SSI	0.143	0.071	1.314	7.961	0.955	0.182
Total	**5.6**	**2.8**	**52.4**	**2087.3**	**250.5**	**47.7**
HSD (kg/day) (HSD is not in consent of Power Plant)						
Red (LSI)	5.4	2.7	369.5	422.2	138.2	26.3
MSI & SSI	18.3	9.1	1262.7	1409.1	461.2	87.8
Total	**23.7**	**11.8**	**1632.1**	**1831.2**	**599.3**	**114.2**
LPG (kg/day) (LPG is not in consent of Power Plant)						
Red (LSI)	0.006	0.006	0.000	13.073	3.187	0.519
MSI & SSI	0.039	0.039	0.000	9.540	2.326	0.379
Total	**0.045**	**0.045**	**0.000**	**22.614**	**5.512**	**0.897**

Table 3.35: Industrial Emission Load for Whole of Mumbai City

Industries	TSP	PM10	SO2	NOx	CO	HC
Red (LSI)	225.5	204.2	1976.1	22013.4	2986.8	543
Power Plant	867	826.1	268.2	49980	9216	4344
Other R, O, G (LSI, MSI, SSI)	71.3	54.1	2125.1	2177.7	582.3	110.8
Total kg/day	**1163.8**	**1084.4**	**4369.4**	**74171.1**	**12785.1**	**4997.7**
Total Ton/year	**424.8**	**395.8**	**1594.8**	**27072.5**	**4666.6**	**1824.2**

The percent contribution of pollutant in kg/day was 18 to 19% for TSP and PM, 45% of SO_2, 29% of NOx, 23% (CO) and 11% of HC from Red (LSI) industries. Whereas, 8400 TPD of coal and 3000 NG (m^3/day) fuel burning at Power Plant gives percent contribution is around 74 to 76% for TSP and PM, 6.1% (SO_2), 67.4% (NOx), 72.1% (CO) and 86.9% of HC. Highest emissions from all categories of pollutants are represents M/E and M/W wards the major large-scale industries are refineries; power plant and fertilizer industry are located in this area. The MSI & SSI from all categories i.e., red, orange and green industries share of pollutant is 5 to 6% for TSP and PM, SO_2 (48.64%), NOx (2.9%) and HC and CO (2.2 – 4.6%). Figure 3.11 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., 1163.8 and 1084.4 kg/day contributes mainly from Coal 70-72%, FO and NG share around 11-13% and 13-14% respectively. The major contribution of PM to the inventory is reflected Power Plant 826.1 kg/day and all other LSI and MSI & SSI categories of industries from Red, Orange and Green, collectively they are contributing around 258.3 kg/day.

The total SO_2 emission from industries is 4369.4 kg/day, the FO contributes 48% (i.e., 2123 kg/d, from 1216 TPD), HSD contributes 37% from (i.e., 1632 kg/d, 909 TPD) and Coal contributes is around 6% (i.e., 240 kg/d, from 8401 TPD), respectively of the total SO_2 emissions. As the emission factor for NG (9.6 E-06 m^3) is very less the load also reflect the less contribution.

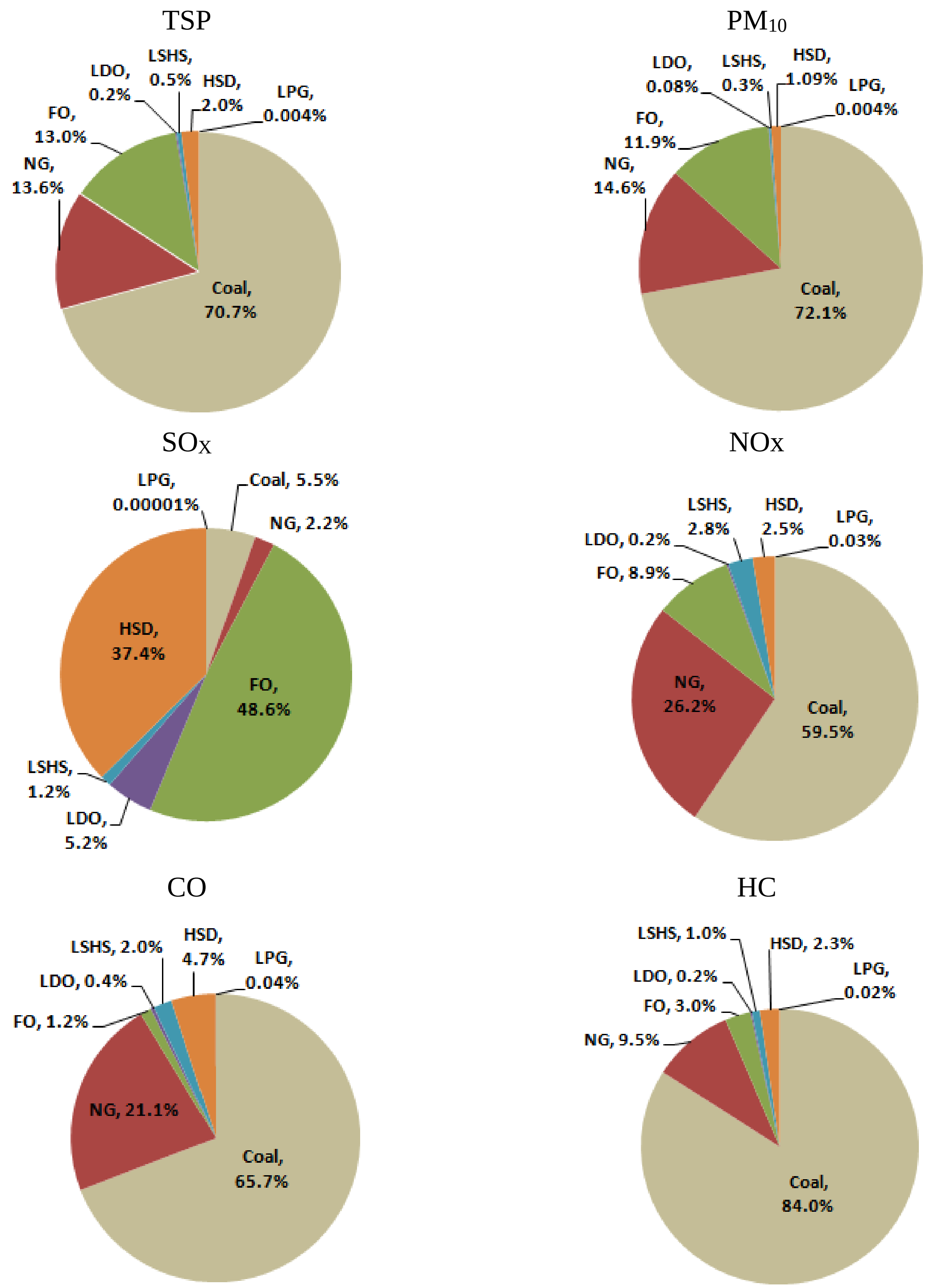


Figure 3.11: Percent Emission Load of Pollutants from Different Sources

The total emission of 74171.1 Kg /day of NOx split in the form of Coal 59% (i.e., 44106 kg/d, from 8401 TPD), Natural Gas 26% (i.e., 19403 kg/d, from 3472467 M^3/day) and other fuel consumption is around FO - 9% and LSHS and HSD 2-3%. The Red LSI and Power Plant are the major contributors to the inventory.

The total CO emission is around 12785 Kg/day, the percent share from coal is 65% followed by NG- 21% and LSHS and HSD ranges from 2 to 4%. Whereas in case of HC, the percent share of pollutant is 84% of Coal (4201 kg/d), 10% of Natural Gas and 2.3% of HSD and 3% from FO, to total load HC emission i.e., 4998 Kg/day, as the combustion of coal is more (8401 TPD) it reflect the higher percent share of HC.

Data Constraints / Assumptions

- Emissions have been worked on the basis of fuel consumption only.
- A wide variation in the data on fuel supplied by the refineries to the industries and the data obtained from the consent forms of MPCB on fuel consumption is observed. This indicates some other source of fuel supply and consumption whose details are not available for estimating the point source emissions.

3.5 Whole City Total Emission Load

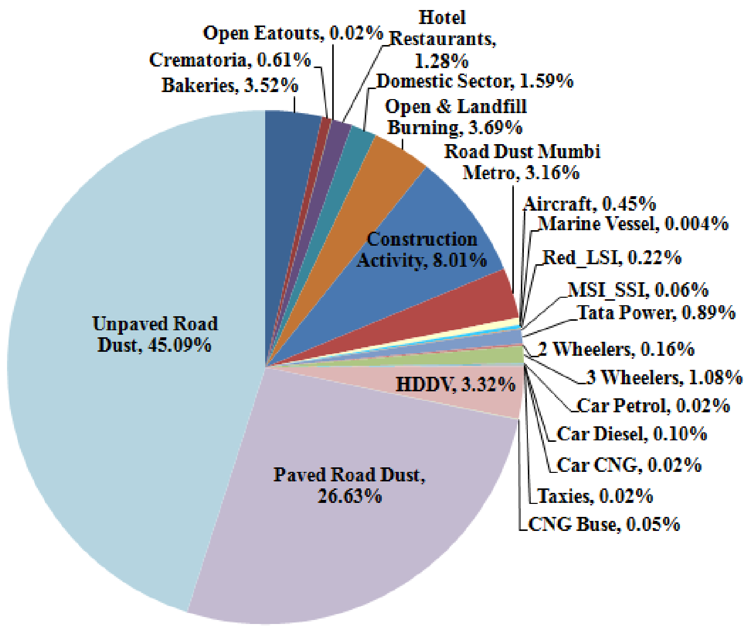
Emission loads from vehicles, area and industries for the city are presented in **Table 3.36.**

Table 3.36: Emission Load for Mumbai City from All Sources (Values are in kg/day)

	PM Load	% PM	SOx Load	% SOx	NOx Load	% NOx	CO Load	% CO	HC Load	% HC
Bakeries	3271.3	3.5	43.8	0.5	286.7	0.2	23887.2	15.9	21642.2	25.4
Crematoria	569.4	0.6	15.0	0.2	85.3	0.1	4191.1	2.8	3774.0	4.4
Open Eat outs	21.7	0.02	32.7	0.4	18.8	0.01	250.0	0.2	67.1	0.1
Hotel Restaurants	1187.2	1.3	711.1	7.6	740.4	0.5	1176.3	0.8	44.6	0.1
Domestic Sector	1483.0	1.6	3153.1	33.8	26620.2	18.5	49294.1	32.8	12396.1	14.5
Open & Landfill B.	3436.6	3.7	215.0	2.3	1290.0	0.9	18060.0	12.0	9245.0	10.8
Construction Act.	7448.0	8.0								
Rd. Dust Mumbai Metro	2943.8	3.2								
Aircraft	419.0	0.5								
Marine Vessel	3.7	0.004								
Total (Area Sources) [A]	**20783.7**	**22.3**	**4170.7**	**44.7**	**29041.4**	**20.2**	**96858.7**	**64.4**	**47169.0**	**55.3**
Eat outs	204.2	0.2	1976.1	21.2	22013.4	15.3	2986.8	2.0	543.0	0.6
Power Plant	826.1	0.9	268.2	2.9	49980.0	34.8	9216.0	6.1	4344.0	5.1
MSI & SSI (All Categories Red, Orange, Green)	54.1	0.1	2125.1	22.8	2177.7	1.5	582.3	0.4	110.8	0.1
Total (Point Sources) [B]	**1084.4**	**1.2**	**4369.4**	**46.8**	**74171.1**	**51.6**	**12785.1**	**8.5**	**4997.7**	**5.9**
2 Wheelers	153.4	0.2	16.0	0.2	1769.5	1.2	8493.8	5.7	6134.4	7.2
3 Wheelers	1002.7	1.1			1614.5	1.1	5863.2	3.9	17504.6	20.5
Car Petrol	15.6	0.02	39.2	0.4	701.6	0.5	6548.6	4.4	944.7	1.1
Car Diesel	91.0	0.10	304.9	3.3	1697.8	1.2	363.8	0.2	489.8	0.6
Car CNG	20.8	0.02			2564.0	1.8	207.9	0.1	1609.5	1.9
Taxies	19.1	0.02			2351.4	1.6	233.1	0.2	1461.7	1.7
HDDV	3092.1	3.3	430.1	4.6	23190.7	16.1	14961.7	10.0	922.6	1.1
CNG Buses	47.0	0.05			6636.6	4.6	3975.5	2.6	4007.6	4.7
Paved Rd. Dust	24771.0	26.6								
Unpaved Rd. Dust	41939.0	45.1								
Total (Line Sources) [C]	**71151.7**	**76.5**	**790.2**	**8.5**	**40526.1**	**28.2**	**40647.6**	**27.0**	**33074.9**	**38.8**
Total [A+B+C] Kg/day	**93019.9**		**9330.3**		**143738.6**		**150291.4**		**85241.6**	
Total [A+B+C] Tons/Yr.	**33952.2**		**3405.6**		**52464.6**		**54856.4**		**31113.2**	

Percent contribution of pollutant from different source categories for Mumbai city is presented in **Figure 3.12 and Figure 3.13**.

PM



NO_x

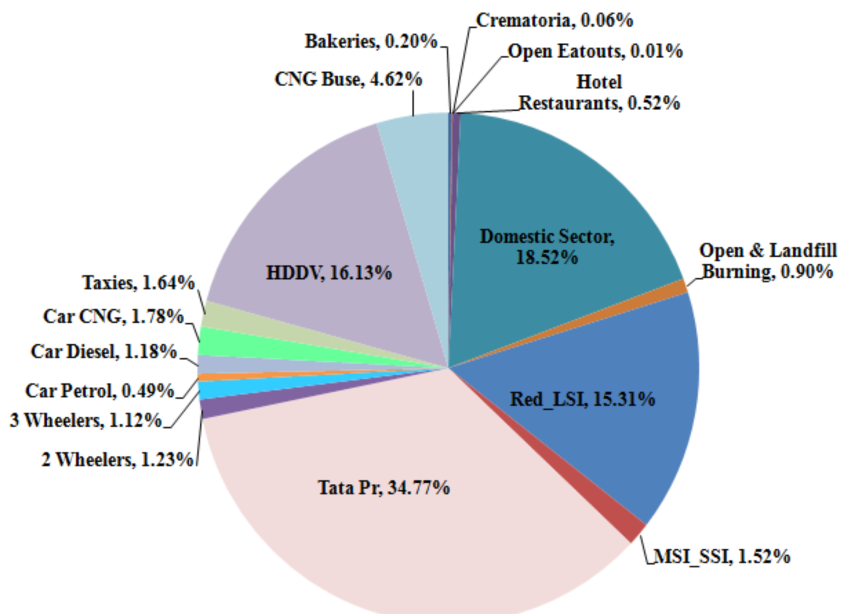


Figure 3.12: Percent of Inventory of PM and NOx in Mumbai City

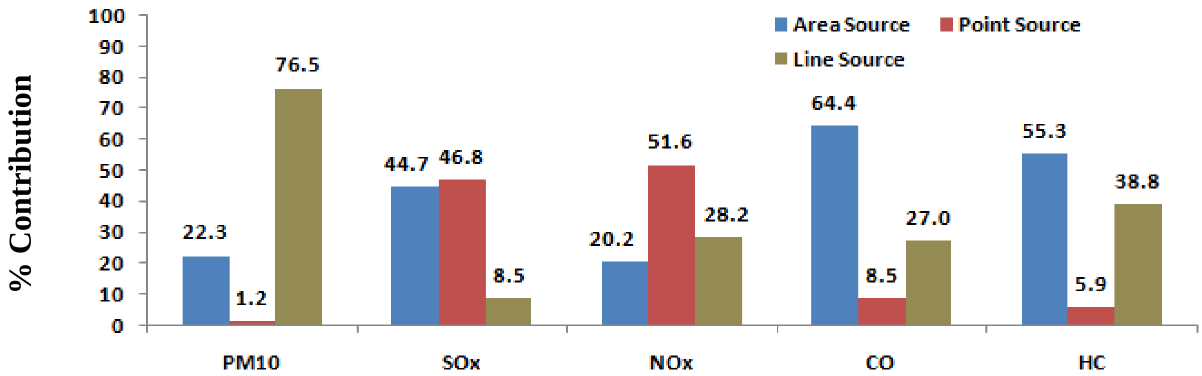


Figure 3.13: Percent Contribution from All Sources for Whole of Mumbai Line Source also includes Paved + Unpaved Rd. Dust for PM

In Mumbai city, PM is mainly contributed from road dust (Paved Rd. Dust 26.6%, Unpaved Rd. Dust 45.1%) followed by area sources (22.3%) and tailpipe emissions of vehicular sources contribute 4.78% and industrial sources (1.2%). Among the total area source i.e., 20784 kg/day, construction activities contribute 8% (7448 kg/d) followed by open burning and bakeries (3.7 to 3.5%). During the study period Mumbai metro work is in progress which contributes 3.2% and very negligible sources i.e., 0.5 to 1.6% is shares from crematoria, hotels & restaurants and domestic sectors, aircrafts etc. Among the industries Power Plant fuel share is higher i.e., Coal - 8400 (TPD) and NG -3000 (m^3/day) which contribute PM emission load around 826.1 kg/d (0.9%) to the total PM emission. The Red LSI i.e., refineries, chemical and fertilizers companies are emitting the PM around 204.2 kg/day shares the 0.2% of the total PM. As per consent and industrial survey most of them use control options and shifted to cleaner fuel, which reflect less emissions from industrial source. The contribution of 54.1 kg/day from all MSI & SSI (All Categories R, O, G) share only 0.1% percent of PM. The vehicular sources percent contribution from heavy duty vehicles is more 3092.1 kg/day (3.3%) and 3 wheelers 1002.7 kg/day (1.1%). The overall line source contributes 4441.7 kg/d (4.78%), amongst them 2 wheelers give 153.4 kg/d, car diesel 91 kg/d, CNG Buses 47 kg/d are the major contributors. If we consider the line and resuspension road dust the percent contribution of PM reaches up to 76.5%.

The NOx contribution is mainly reflected by industries i.e., 51.6% (74171.1 kg/d). Among industries power plant contribute to 49980 kg/d (34.8%) (Collectively from 3000 NG-m^3/d and 8400 TPD of coal); and Red LSI contributes (22013.4 kg/day) i.e., 15.3% (mostly from 3469396 NG-m^3/d); and MSI & SSI (All Categories R, O, G) adds 2177.7 kg/day shares around 1.5% to the total NOx load. The area source and line source give 20.2% (29041.4 kg/d) and 28.2% (40526.1 kg/d) NOx contributions respectively. The domestic sector alone gives 18.5% of the total NOx (consumption of LPG cylinder -i.e., 491514 kg/d) and other area sources share only about 1.68%. The HDDV and CNG Buses shares 16.1% (23190.7 kg/d) and 4.6% (6636.6 kg/d) respectively and other vehicles categories contribute around 7.44%. The overall NOx percent contribution is mainly reflected by Coal 59.5% and NG 26.2% in industries as well as from line source and domestic sector.

The total 9330.3 kg/day of SOx emission is mainly from industries i.e., around 46.8% (4369.4 kg/d) followed by area source 44.7 (4170.7 kg/d). Out of the industries, 21-22% comes from Red LSI and MSI /SSI respectively. The Red LSI industries contributing around 1976.1 kg/d, whereas MSI-SSI shares 2125.1 kg/d. Power Plant gives less contribution as 2.9% (268.2 kg/d) to the total SOx emission load. The major 33.8% shares come from area source domestic sector which is higher 3153.1 kg/d, as kerosene consumption from slums area is prominent i.e., 754997 liters/d. For vehicles SOx emissions are calculated based on Sulphur content (Diesel 300 ppm and Gasoline 30 ppm) which reflect 4.6% from HDDV, 3.3% from Car Diesel.

The 64.4% (96858.7 kg/d) and 27% (40647.6 kg/d) of CO comes from area and line source respectively. Out of total area sources major contributes are domestic sector 32.8% followed by bakeries 15.9%, and 12% from Open burning. The Power Plant gives 6.1% of their contribution to total CO, whereas Red LSI gives 2% and very minute share from MSI & SSI only 0.4% of total CO percent. The HDDV gives significant percent i.e., 10%, followed by 2 wheelers 5.7% and all other vehicles contribute around 2-4% to the total CO load. The total load of hydrocarbon in Mumbai city is around 85241.6 kg/d. The hydrocarbon emission from bakeries 25.4% (21642.2 kg/d), domestic sector 14.5% and open burning -10.8% collectively reflect the area source contribution around 55.3%. The emission load from industry is about, MSI & SSI (0.1%), Red LSI (0.6%) and Power Plant (5.1%), and overall industrial HC load is around 5.9%. The line source contributes 38.8% (33074.9 kg/d) to the total HC load, amongst them 3 wheelers share is maximum 20.5%; followed by 2 wheelers 7.2% and CNG Buses 4.7%.

It is important to note that high emission load from a source contribution does not necessarily lead to high ambient air pollution contribution 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.

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study using EPA PMF v5.0

Positive Matrix Factorization (PMF) was used in the present study as the receptor model to identify and quantify sources of pollution and their contribution (USEPA, 2014). This multivariate statistical approach for source identification relies on observed data, operating independently of any prior knowledge regarding emission profiles. PMF takes into consideration uncertainties within the measured data and deduces source contributions based on observations at the receptor site. The method involves the utilization of two user input files: one containing species concentration and the associated uncertainties. The chemical mass balance, involving species concentrations and source profiles, is subsequently resolved using Equation 4.1. The air particulate matter samples, featuring chemical speciation, are portrayed as a data matrix 'X' with dimensions i x j, where 'i' represents the number of samples and 'j' denotes the number of chemical species analyzed during the assessment.

$$x_{ij} = \sum_{k-1}^{p} g_{ik} f_{jk} + e_{ij} \qquad \textbf{Eq. 4.1}$$

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 presents a weighted least squares problem wherein the determination of a specific number of factors is imperative for the minimization of an 'objective function,' as illustrated in Equation 4.2. The calculations of factor contributions and profiles are executed through the minimization of the said 'objective function' denoted as 'Q' within the PMF model.

$$Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left(\frac{x_{ij} - \sum_{k-1}^{p} g_{ik} \; f_{kj}}{u_{ij}} \right)^2$$ **Eq. 4.2**

Where, u_{ij} is an estimate of uncertainty in the j^{th} variable in i^{th} sample. The uncertainties (uij) are computed using Equation 4.3, as specified by (Norris et al., 2014). This calculation encompasses both field and analytical uncertainties. In instances where the uncertainty value is absent, it is admissible to substitute it with 5/6 times the Method Detection Limit (MDL) (Norris et al., 2014)

Unc = $\sqrt{(conc\ of\ ion\ X\ 0.05)^2 + (Mdl * 0.5)^2)}$ **Eq. 4.3**

Where, Conc of ion = Concentration of ion, $\mu g/m^3$; MDL = Minimum Detection Limit, $\mu g/m^3$

4.2 Methodology

The present study was carried out for representative samples of $PM_{2.5}$ and PM_{10} collected during the sampling campaign at the end of summer season from 6 locations: Colaba; Kalbadevi; Mulund; Bandra; Powai and Mahul. PM_{10} and $PM_{2.5}$ were collected on 47 mm Whatman quartz and PTFE filters using samplers with 5 LPM flow rate (Air Metrics - Minivol Sampler) for 24-hour sampling period at all locations concurrently. The gravimetric analyses were carried out for all the collected samples to obtain total PM_{10} and $PM_{2.5}$ concentration levels.

To carry out source apportionment, Elemental carbon and Organic carbon analysis (DRI); Elemental analysis (ED-XRF) and Ionic Analysis (IC) were conducted for all samples. The preparation of the input file involved compiling concentration datasets of the samples and their associated uncertainties. The model processes input files, computing the 'Signal to Noise' (S/N) ratio for each species to categorize them as strong, weak, or bad. This classification, guided by the principle of minimizing errors in strong variables and maximizing errors in weak variables (Paatero & Hopke, 2003), informs subsequent analysis. Species with an S/N ratio above 3 are labelled strong, those between 1 and 3 as weak, and those below 1 as bad for model execution. Additionally, species with 80% of values below the Minimum Detection Limit (MDL) are considered bad and excluded from the model analysis.

The modelling process necessitates multiple trial-and-error iterations to attain optimal solutions. Accordingly, a broad spectrum of factors ranging from 3 to 8 was explored, conducting 100 trial runs with a random start on each occasion. The evaluation of modelled results employed the Q_{true}/Q_{robust} ratio. Q_{true} is computed by considering the entire dataset, while Q_{robust} is derived by excluding outliers. A ratio close to 1.0 signifies a favourable solution with negligible outlier influence, whereas a ratio exceeding 1.5 indicates a noteworthy impact of outliers. Additionally, the correlation coefficients (R^2) between measured and modelled metal concentrations were scrutinized, aiming for values exceeding 0.80. Such correlations indicate a robust fit of the model to the measured data.

In addressing the challenge of non-unique solutions in Positive Matrix Factorization (PMF), known as rotation ambiguity, various rotations were systematically explored using the F-peak parameter. This parameter, ranging from -3 to 3, aimed to minimize changes in the objective function (Q) to identify a unique solution. Monitoring Q-values during this exploration revealed the solution with the lowest Q-value, indicative of minimal rotational ambiguity, as the optimal solution at that specific F-peak. Implementation of bootstrapping, altering the dataset for uncertainty estimation, demonstrated less than 5% variability in species percentages. Criteria, including a minimum correlation value of 0.8 and default block size, ensured robustness in results. Following these considerations, comparing factor fingerprints and contributions to standard profiles. The results were subsequently utilized for determining the percentage contribution of sources at receptor locations with their source profiles.

4.3 Results

The results of both cases for PM_{10} and $PM_{2.5}$ are presented in this section. The source contributions are shown in **Table 4.1** and **Figure 4.1.** The base profiles are given in Annexure II.

Table 4.1: Percentage Source Contribution for PM_{10} and $PM_{2.5}$

Most likely source(s)	% Contribution	
	PM_{10}	**$PM_{2.5}$**
Marine Aerosols	18	26
Secondary Aerosols	9	22
Vehicular Emissions	14	16
Industrial Emission/ Fossil fuel combustion	20	12
Resuspended road dust/wind-blown dust	30	13
Construction Dust	9	--
Biomass Burning/ Wood Combustion	--	11

4.3.1 Factors of PM_{10}

EPA PMF run analysis identified 6 factors in the study location for PM_{10} samples with factor finger prints as shown in Figure 4.2

Factor 1 (PM_{10}): Marine Aerosols

First factor was identified as marine with 18.12% of total PM_{10} emissions which was indicated by high levels of elements such as Na^+, Cl^-, SO_4^{2-}, OC, Mg, Na and Ca^{2+} (~7.58%, 11.80%, 8.35%, 9.56%, 17.87%, 8.02% and 9.42%) as major species markers along with Ca, Fe, Cl and Si as minor markers which indicated the source to be Marine aerosols *(*Gupta et al., 2012; Sharma et al., 2016; Taghvaee et al., 2018; Zong et al., 2016). Sea spray is a source of sulphates (Kothai et al., 2008) .As Mumbai is a coastal city the presence of marine aerosols as a major source contributor is well justified and it was found to be well distributed in all sources across the study area.

Factor 2 (PM_{10}): Secondary Aerosols

Second Factor is represented by the significant levels of OC (14.35%), Na^+ (7.1%), Cl^- (10.63%) NO_3^{2-}(4.8%), Na (6.39%), SO_4^{2-}(9.80%), Fe (7.19%), Mg (14.29%) and NH_4^{2-} (2.57%) contributing to about 9.1% of total PM_{10} Pollution. The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols (Garaga et al., 2020; Jain et al., 2019; Mukherjee et al., 2018; Patil et al., 2013; Police et al., 2016; Sharma et al., 2016). The formation of secondary aerosols is due to the chemical transformation (Panda et al., 2022). 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.

Factor 3 (PM_{10}): Vehicular Emissions

Third factor accounted for 13.58%, with indicators of OC (24.35%), EC (14.89%), Ca^{2+} (8.13%), Si (14.16%) and Fe (8.81%) and minor indicators such as Zn, Cr, Pb, Ca and Mg 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 (Jain et al., 2017; Mukherjee et al., 2018; Panwar et al., 2020; Shukla & Sharma, 2008) Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles (Jain et al., 2019; Keerthi et al., 2018).

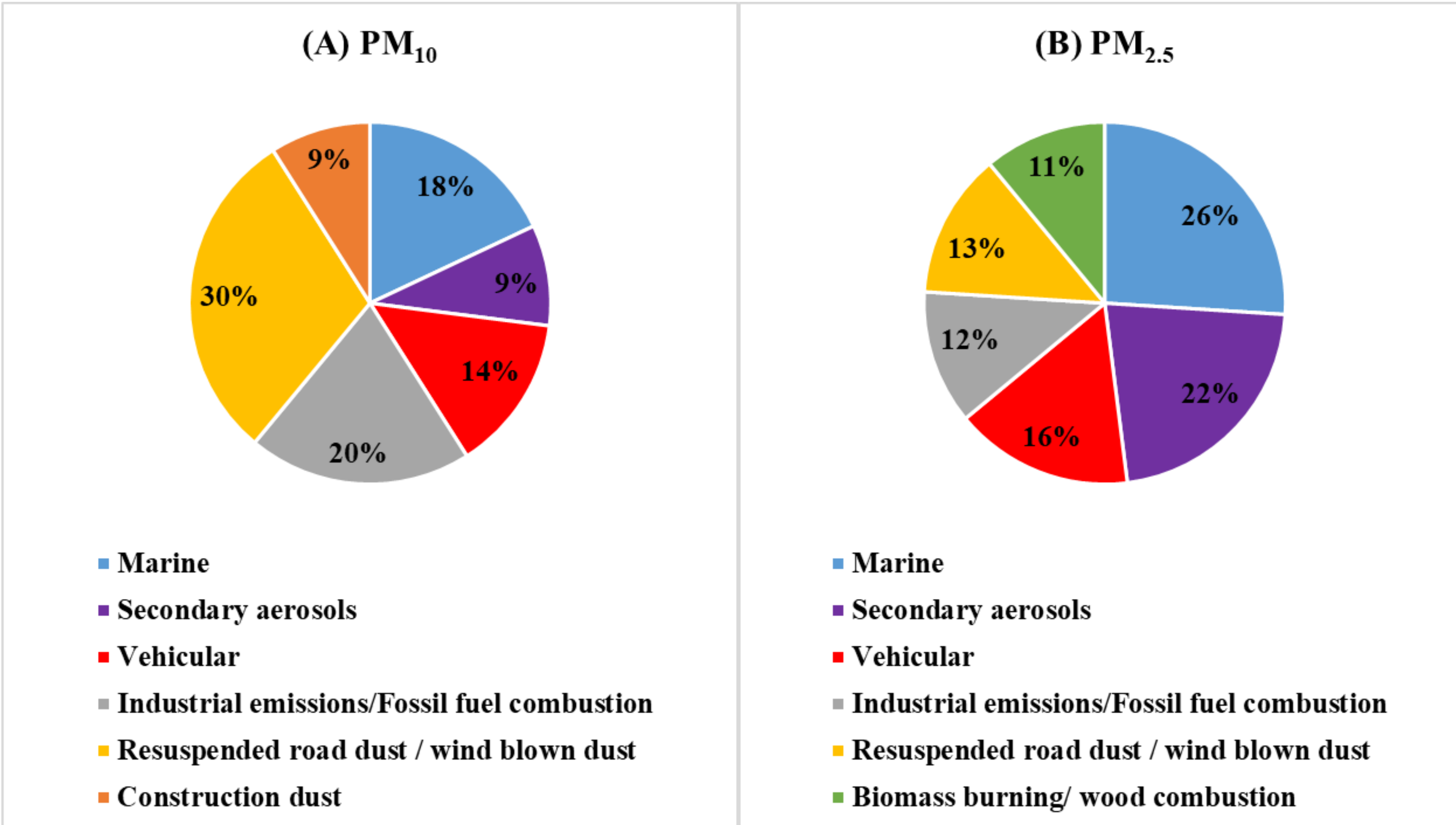


Figure 4.1: Percentage Contribution of Sources for (A) PM_{10} and (B) $PM_{2.5}$ for Mumbai

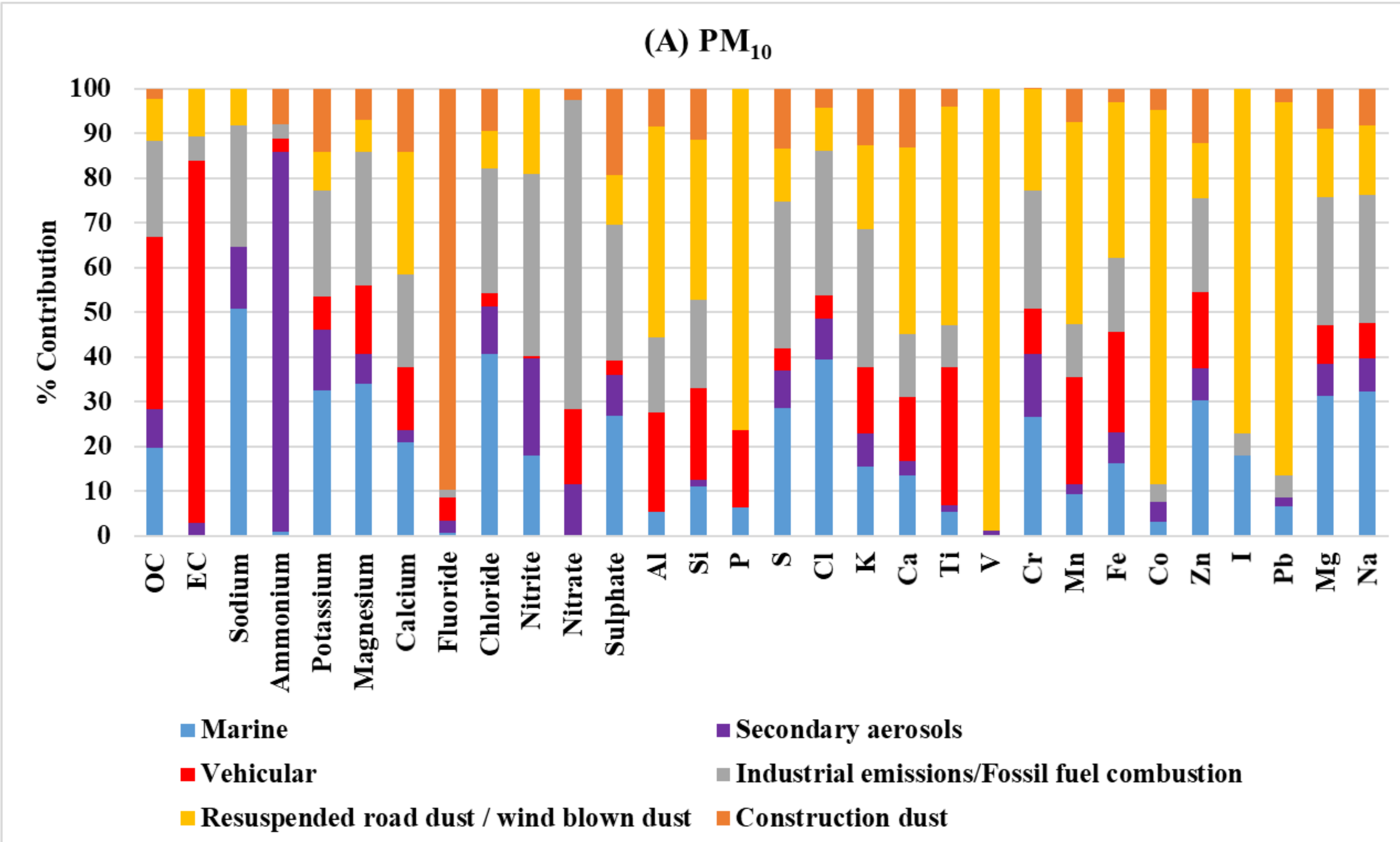


Figure 4.2: Factor Fingerprints of PM_{10} for Mumbai

Factor 4 (PM_{10}): Industrial Emissions/ Fossil Fuel Combustion

Fourth factor was identified as Industrial emissions/ fossil fuel combustion the presence of tracers, such as OC, Ca^{2+}, Cl^- SO_4^{2-}, NO_3^{2-}, Si and Mg (~9.67%, 8.73%, 7.56%, 8.70%, 7.72%, 9.59% and 15.31%) with minor indicators such as Zn, S, Fe, Na, K^+ Cl suggest the source of Industrial emissions/fossil fuel combustion contributed to about 20.12%. of total PM_{10} Pollution. S, Cl^- along with SO_4^{2-} have been widely used as a marker of coal combustion in power plants (Jain et al., 2019; Kumar et al., 2001; Mehta et al., 2022; Pathak et al., 2013; Patil et al., 2013; Rai et al., 2016; Sharma et al., 2016)*)*. Earlier studies reported that Fe, Cr are the indicators of the industrial emissions as these elements are greatly used in various industries like machinery, battery and electroplating purposes (Mehta et al., 2022; Taghvaee et al., 2018). Location of industrial regions in some of this study area could be the possible reason of this source (Figure 3.10).

Factor 5 (PM_{10}): Resuspended Road Dust/ Wind-Blown Dust

Fifth Factor is represented by the significant levels of Si (19.88%), Ca^{2+}(13%), Fe (11.42%), Mg (9.19%), Ca (15.19%) and Al (8.36%) and minor indicators such as OC, Na and SO_4^{2-} contributing to 29.62% 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 (Garaga et al., 2020; Jain et al., 2017; Keerthi et al., 2018; Patil et al., 2013) whereas substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as Fe, OC and Al are indicators of road dust re-suspension (Jain et al., 2017; Panwar et al., 2020). Road dust gets re-suspended due to natural gust of winds or moving objects like vehicles (Ashrafi et al., 2018; Banerjee et al., 2015; Kothai et al., 2008) Since the study was done in dry summer conditions wind-blown dust has large influence on this source. Also, the traces of salts such as Na and Mg is also seen in wind-blown dust due to coastal locations.

Factor 6 (PM_{10}): Construction Dust

Sixth factor is identified as construction dust which accounted for contributions of 9.43%. Major proportions of Ca^{2+}, F^-, Ca, Mg, SO_4^{2-} and Si (~14.81%, 7.66%, 10.64%, 12%, 13.92% and 14.01%) and minor species such as Fe and Cl^- contributed to this factor. Ca, Si, Ca^{2+}, Mg, Cl^- are major indicators of construction dust from cement and aggregate mixing (Bhuyan et al., 2018; Garaga et al., 2020; Jain et al., 2019; Keerthi et al., 2018; Patil et al., 2013). Construction dust is mainly contributed from all infrastructure development projects going in and around the city like metro.

4.3.2 Factors of $PM_{2.5}$

EPA PMF run analysis identified 6 factors in the study location for $PM_{2.5}$ samples with factor finger prints as shown in Figure 4.3

Factor 1 ($PM_{2.5}$): Marine Aerosols

First factor was identified as marine with 26.40% of total $PM_{2.5}$ emissions which was indicated by high levels of elements such as Na^+, Cl^-, SO_4^{2-}, OC and Ca^{2+}(~8.37%, 16.02%, 16.27%, 18.73% and 8.73%) as major species markers along with Na, NO_3^- as minor markers which indicated the source to be Marine aerosols (Gupta et al., 2012; Sharma et al., 2016; Taghvaee et al., 2018; Zong et al., 2016). Sea spray is a source of sulphates (Kothai et al., 2008) As Mumbai is a coastal city the presence of marine aerosols as a major source contributor is well justified and it was found to be well distributed in all sources across the study area.

Factor 2 ($PM_{2.5}$): Secondary Aerosols

Second Factor is represented by the significant levels of OC (15.96%), EC (12.34%), NO_3^{2-}13.38%), NH_4^{2-}(7.65%), SO_4^{2-}(13.42%), Ca^{2+} (18.81%) and Mg (8%) contributing to about 22.18% of total $PM_{2.5}$ Pollution. The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols (Garaga et al., 2020; Jain et al., 2019; Mukherjee et al., 2018; Patil et al., 2013; Police et al., 2016; Sharma et al., 2016). The formation of secondary aerosols is due to the chemical transformation (Panda et al., 2022). 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 (Garaga et al., 2020).

Factor 3 ($PM_{2.5}$): Vehicular Emission

Third factor accounted for 15.88%, with indicators of OC (40.41%), EC (20.81%), Ca^{2+} (11.81%) and Mg (5.15%) and minor indicators such as Zn, Pb, Mn, Fe 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 (Jain et al., 2017; Mukherjee et al., 2018; Shukla & Sharma, 2008) Panwar et al., 2020) Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles (Jain et al., 2019; Keerthi et al., 2018).

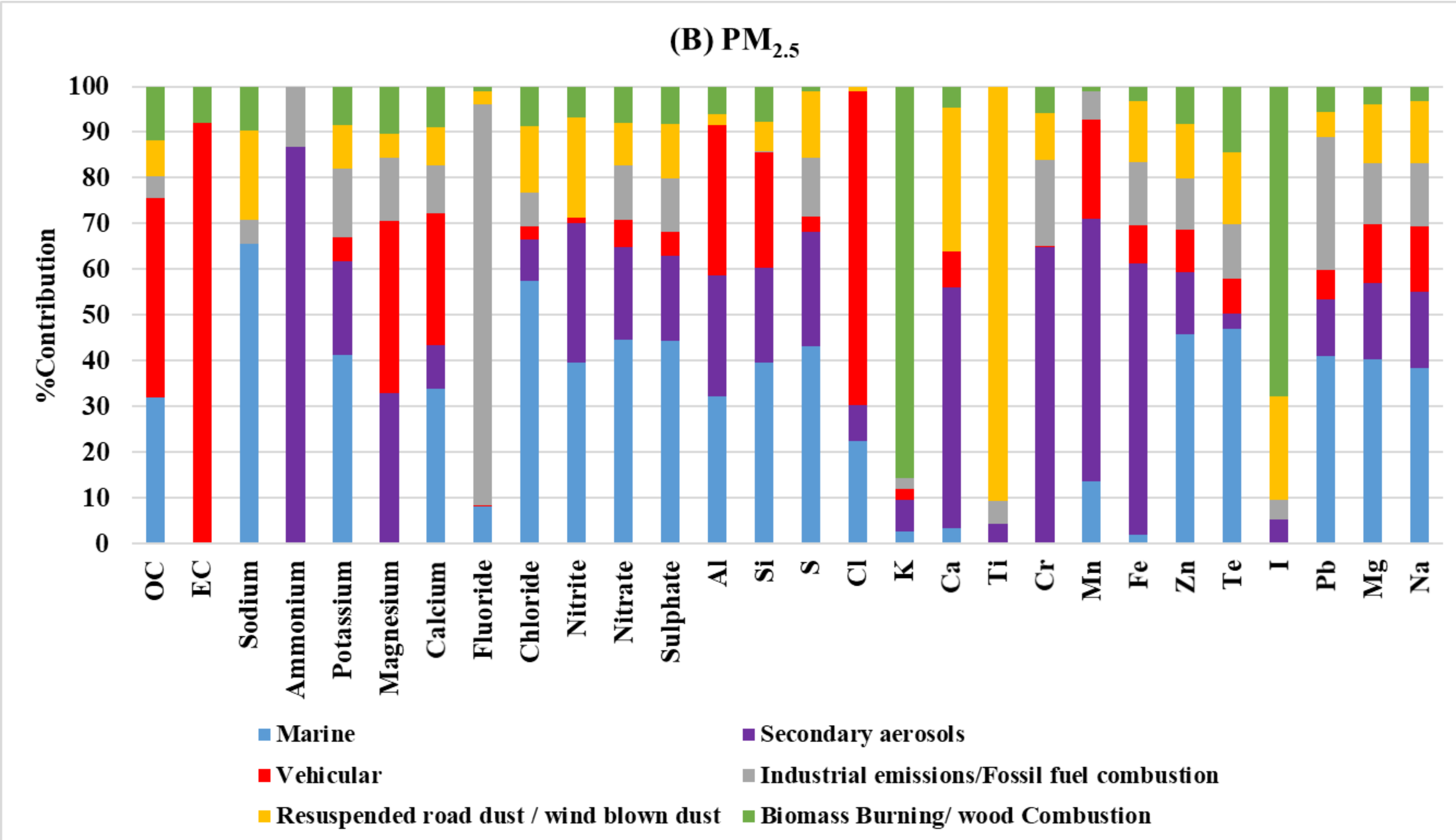


Figure 4.3: Factor Fingerprints of $PM_{2.5}$ for Mumbai

Factor 4 ($PM_{2.5}$): Fossil Fuel Combustion/ Industrial Emissions

Fourth factor was identified by the significant levels of OC (9.78%), Ca^{2+} (10.16%), F^-(11.82%), SO_4^{2-}(15.79%), Mg (12.30%) and Fe (8.70%) contributed to 11.55% of total $PM_{2.5}$ emissions. S, Cl^-, K^+, Zn and Cr are indicators of Industrial emissions from various previous studies (Basha et al., 2010; Patil et al., 2013; Jain et al., 2017; Garaga et al., 2020; Panwar et al., 2020*)*. S, Cl^- along with SO_4^{2-} have been widely used as a marker of coal combustion in power plants *(*Jain et al., 2019; Kumar et al., 2001; Mehta et al., 2022; Pathak et al., 2013; Patil et al., 2013; Rai et al., 2016; Sharma et al., 2016). Earlier studies reported that Fe, Cr are the indicators of the industrial emissions as these elements are greatly used in various industries like machinery, battery and electroplating purposes (Mehta et al., 2022; Taghvaee et al., 2018). Location of industrial regions in some of this study area could be the possible reason of this source (Figure 3.10)

Factor 5 ($PM_{2.5}$): Resuspended Road Dust/ Wind-Blown Dust

Fifth factor is represented by the significant levels of OC (13.36%), Na^+(7.15%), Ca (16.42%), Cl^- (11.49%), SO_4^{2-}(12.40%) and Mg (9.16%) and minor indicators such as Fe, S, Si, Ti and Ca^{2+} contributing to 12.94% of total $PM_{2.5}$ 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 (Garaga et al., 2020; Jain et al., 2017; Keerthi et al., 2018; Patil et al., 2013) whereas substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as Fe, OC and Al are indicators of road dust re-suspension (Jain et al., 2017), Panwar 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. Also, the traces of salts such as Na and Mg is also seen in wind-blown dust due to coastal locations.

Factor 6 ($PM_{2.5}$): Biomass Burning/ Wood Combustion

Sixth factor is identified as Biomass burning which accounted for contributions of 11.04%. Major proportions of K^+, OC, SO_4^{2-} and Mg^{2+} (~40%, 18.51%, 8.16% and 2.6%) 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. (Jain et al., 2017; Mehta et al., 2022; Mukherjee et al., 2018; Police et al., 2016; Sharma et al., 2016; Shukla & Sharma, 2008; Srivastava & Ramanathan, 2018). It is a known fact that biomass is a widely used as an energy source, as well as the issue of illegal garbage burning which has resulted in the contributions of biomass burning in these locations.

4.4 Conclusions

In conclusion, the Positive Matrix Factorization (PMF) analysis has provided an estimate of the contributing factors to both PM_{10} and $PM_{2.5}$ concentrations in Mumbai. The study identified six distinct factors, shedding light on the sources influencing particulate matter in the city. Notably, marine aerosols and secondary aerosols were found to exert a substantial influence on PM2.5, constituting 26% and 22% of its composition, respectively. Vehicular emissions emerged as another significant contributor at 16%. The identification of marine aerosols as a background source underscores the role of regional and atmospheric factors in $PM_{2.5}$ composition. While direct mitigation for marine aerosols is not possible due to location of Mumbai, the study emphasizes the potential for effective control measures targeting secondary aerosols.

In contrast, the prominence of road dust resuspension (30%) in PM_{10} underscores the necessity for robust dust control measures, particularly on unpaved roads and construction sites, to enhance overall air quality in the city. These findings offer insights to help in targeted mitigation strategies, recognizing the need for source specific interventions.

Chapter 5

Dispersion Modelling

Air quality dispersion modeling exercise was undertaken with a view to delineate and estimate the spatial impact of sources on ground level concentrations. 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. The scenarios for different seasons have been generated to the highlight the variability.

5.1 Description of AERMOD Model

The AMS/ EPA Regularity Model (AERMOD, EPA 2004) is 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^2).

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

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. 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 (isopleths) 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.

5.3 Meteorological Data

Meteorological data required for AERMET includes upper air and surface 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 Mumbai is limited to surface measurement and limited upper air data are available at the 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).

Regarding low wind conditions, the majority of meteorological data are collected from airport met stations. Primary concern of Airports is about 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 used from commercially available MM5 data. 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), April to May (summer season) and September to October (Post Monsoon) of Mumbai are presented in **Figure 5.1**

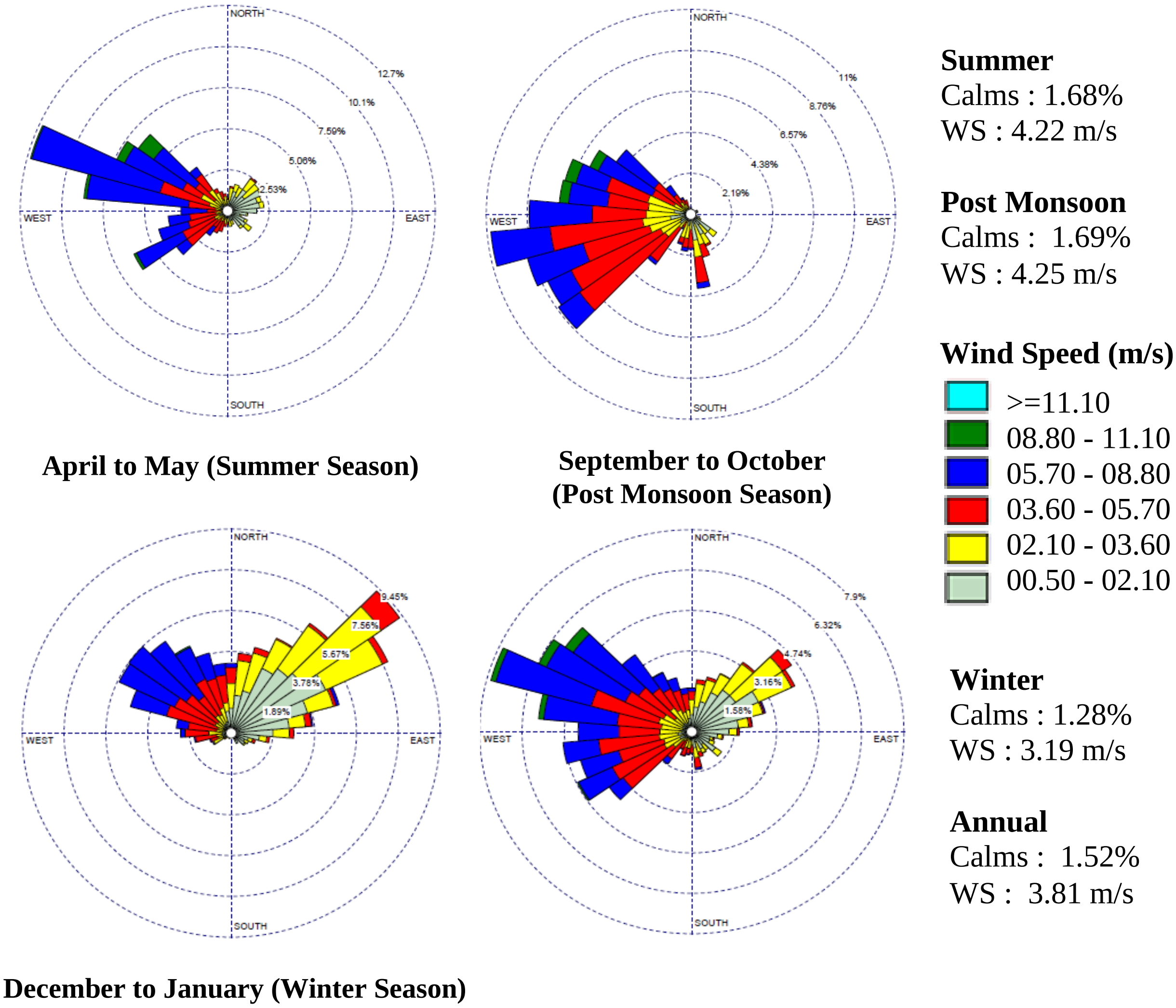


Figure 5.1: Wind Roses based on MM5 dataset for the Study Area (Mumbai)

Annual windrose shows, the predominant direction is from WNW (6.3 to 7.9%); and WSW (4.7 to 6.3%) in both direction wind speed mostly is in the range 5.7 to 8.8 m/s or less. Some percent its move around ENE direction, where predominant wind speed is in the ramge of 2.1 to 3.6 m/s. Calm condition is around 1.52%. Average wind speed is 3.81 m/s. During December to January (winter season) the predominant directions are blowing from NE (9.5%) or less and WNW (5.67%). The predominant wind speeds are 2.1 to 3.6 m/s in NE direction, whereas N is 3.6 to 5.7 m/s and in WNW direction shows, it is around 5.7 to 8.8 m/s or less. Calm condition is around 1.28%. Average wind speed is 3.19 m/s. During Post Monson the predominant wind directions are blowing mostly from WNW, W and WSW (4 to 8%) and the wind speed is moving from 3.6 to 5.7 m/s or more. Average wind speed is 4.25 m/s and calm condition is 1.69%. In Summer season the predominant wind directions are blowing from WSW towards W and some part inclined towards WNW (4 to 6%), the wind speed moves around 3.6- 8.8 m/s. Average wind speed is 3.81 m/s and calm condition is 1.52%.

5.4 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 and Table 5.1**. 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, both discrete receptors and receptor grids, are computed by the terrain pre-processor.

Table 5.1: Summary of Type and Number of Sources

Emission Source	Modelled Source Type	Number of Sources
Area sources	Area source includes Bakery, Crematoria, Building Construction, Hotels & Restaurants, Open Eatouts Domestic Sector, Open Burning etc.	24 Mumbai Municipal Wards
Vehicles	VehicleVolume (Major & Arterial Roads, connecting State & National Highways)	254 Roads
Major Industries with stack heights more than 10m	Point (LSI from Red Industries) (75 Industries)	131 Stacks
Industries which include Medium and small scale industries with less than 15m stacks	Area (MSI and SSI from Red, Orange & Green Industries) (122 MSI & SSI Industries)	19 Industries
Road dust	Line Volume on each road	254 Roads

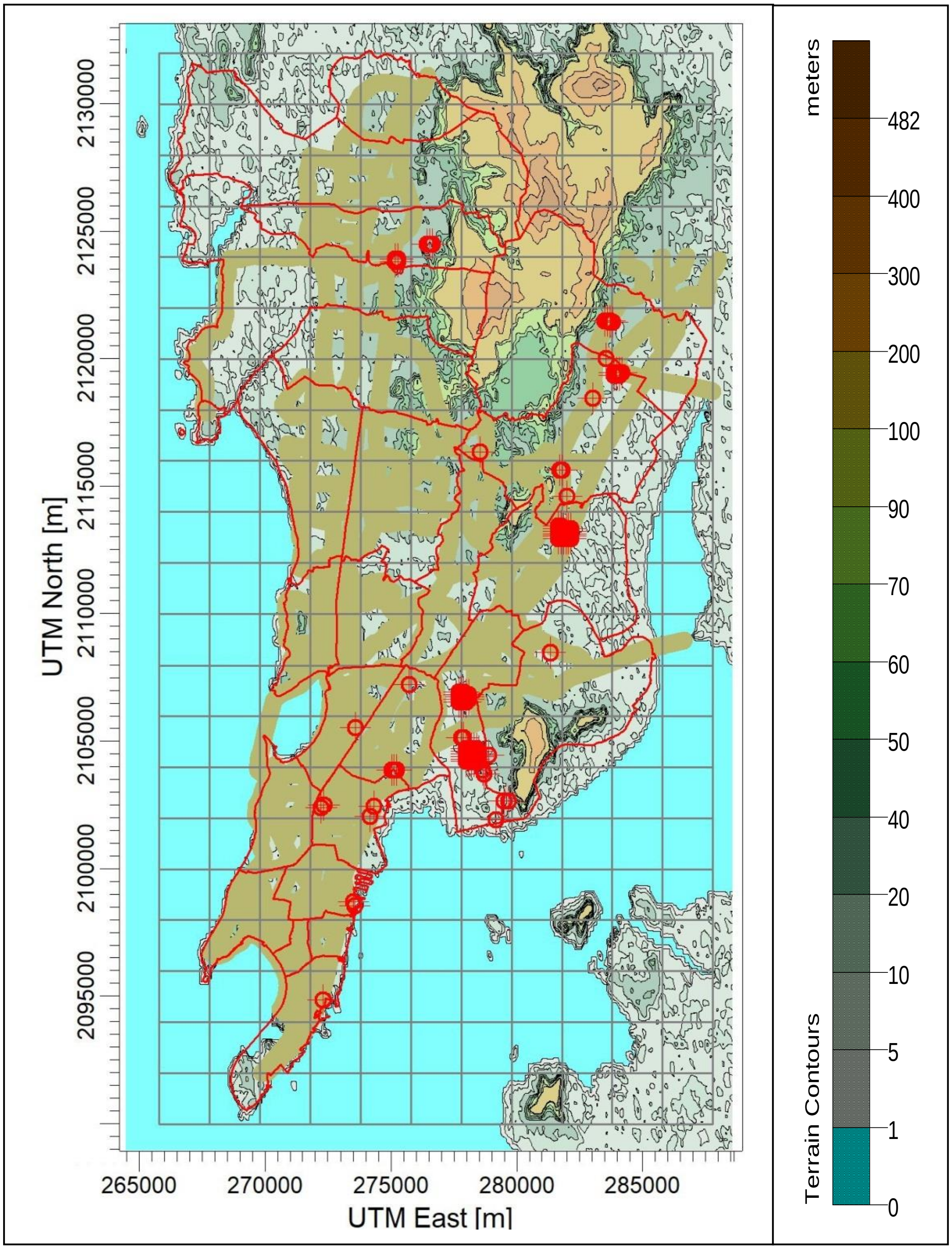


Figure 5.2: AERMAP Digital Elevation Model (DEM) Data and Emission Sour for Mumbai City

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 11 km^2 of the study areas 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.

5.5 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. Based on the emission load discussed in chapter 3, the estimations were made using the dispersion model.

5.4.1 Model Performance for PM

Table 5.2 represents average PM_{10} concentration observed at 5 monitoring locations, which ranged from 162 - 194 µg/m^3 during winter season, at an average of 176 µg/m^3. The predicted concentrations at these sites are in the range of 79 -131 µg/m^3. During summer season, the average concentrations observed at monitoring sites are in the range of 85 to 161 µg/m^3, with an average of 118 µg/m^3. The predicted average PM_{10} concentrations at these sites during summer were in the range of 55 to 110 µg/m^3. Post Monsoon concentrations were observed to be varying between 78 to 131 µg/m^3, at average of 100 µg/m^3. The predicted concentrations at these sites ranged from 47 to 109 µg/m^3. The annual concentration differs from 101 to 149 µg/m^3 for observed, whereas it is 56 to 126 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 0.4 to 1.1. All the predicted values were lying within FAC2. Variations in are presented in **Figure 5.3**.

It has been observed that prediction is less at Parel and Worli site for all seasons, whereas Sion and Kalbadevi predicted concentrations are closer to those observed. The predicted concentrations at Bandra sampling location are higher than observed concentration. The less prediction in all seasons shows the meteorological effect i.e. the wind speed is almost 3.2 to 4.2 m/s over the considered period.

Table 5.2: Comparison of Seasonal PM_{10} Average Concentrations (µg/m³) measurements with the 24-Hourly Model Simulation predictions

	Observed Concentration (µg/m³) #				Predicted Concentration (µg/m³)			
	Summer	**Post Monsoon**	**Winter**	**Annual**	**Summer**	**Post Monsoon**	**Winter**	**Annual**
Bandra	96.7	78.3	194.3	114.1	110.2	108.9	130.8	125.7
Sion	161.3	96.0	184.3	149.3	95.9	70.3	115.1	95.1
Parel	150.7	131.0	168.4	141.3	55.8	55.3	78.7	58.6
Kalbadevi	95.5	81.8	162.4	100.9	66.6	61.7	88.5	68.6
Worli	85.0	114.0	168.3	130.1	54.7	46.8	86.4	55.6
Ratio of Predicted to Observed Concentration								
Bandra	1.1	1.4	0.7	1.1				
Sion	0.6	0.7	0.6	0.6				
Parel	0.4	0.4	0.5	0.4				
Kalbadevi	0.7	0.8	0.5	0.7				
Worli	0.6	0.4	0.5	0.4				

Sum –Summer, PostMon- Post Monsoon, Win –Winter, Ann - Annual
 # Observed Concentration (Air Quality Status of Maharashtra 2016-17, MPCB

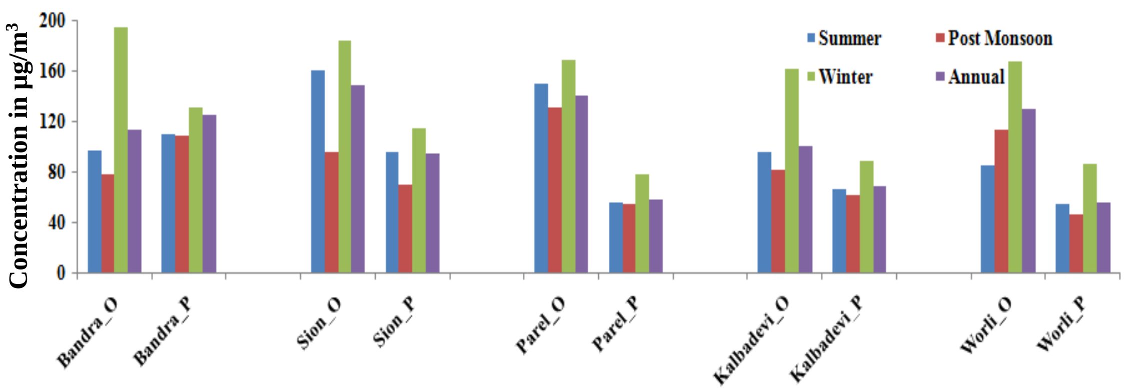


Figure 5.3: Observed and Predicted Concentration for All Seasons (PM - µg/m³)

5.5.1 Existing Scenario Concentration Contours for PM_{10}

The models were run for annual and all seasons for different source group combinations **(Table 5.2)**. The iteration for different source groups were estimated and presented in **Table 5.3** for PM concentrations. The annual and seasonal 24hourly 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 presented in **Annexure 2** and 10 highest concentrations in **Annexure 3**.

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

Sources Group	Summer	Post Monsoon	Winter	Annual
All Group	192.1	170.4	263.2	270.4
Area Source	35.2	32.2	43.8	36.9
Line Source	27.6	27.2	36.3	28.9
Point Source (LSI)	0.74	1.04	0.49	0.70
Point Source (MSI & SSI)	0.15	0.15	0.19	0.16
Resuspension Dust	184.2	163.7	253.5	261.1

Concentrations in $\mu g/m^3$

Observations

- The concentrations in winter season were almost double the CPCB standard of 100 $\mu g/m^3$ for PM. The Annual PM concentration is 270 $\mu g/m^3$, amongst which resuspension road dust accounts for 261 $\mu g/m^3$, while area and line sources ranges from 29 to 36 $\mu g/m^3$ and industrial sector disperses 0.16 to 0.70 $\mu g/m^3$ of the predicted PM emission load.
- The maximum 24 hourly predicted concentration from all sources in winter season was 263 $\mu g/m^3$. The predicted concentration due to re-suspended dust is around 253 $\mu g/m^3$ and that of the Tailpipe emission from Vehicles is 36.3 $\mu g/m^3$. The pockets of high concentration are observed close to major traffic junctions in central part city i.e near Sion Circle, Bandra, as well as Western Express Highway and Eastern Express Highway. The total emission of PM from vehicular sector is 4441.6 Kg/d (i.e. 4.78% of the total city emission load). Although, the number of heavy duty diesel vehicle accounts for 6% of the total vehicle number, the maximum PM emission load of 3092.1 kg/d (69.6%) is estimated from HDDV vehicles.
- Due to heavy vehicular traffic movements, contribution to total emission load from resuspension of dust road is also higher. The Annual dispersed resuspension of road dust of PM is around 261 $\mu g/m^3$, and in summer and post monsoon the concentration varies between 163 to 184 $\mu g/m^3$. The contribution of resuspension of road dust from unpaved road is around 45.1% and that from paved road is around 26.6% to the total estimated PM load in the city.

- The maximum 24 hourly predicted concentration from area sources was 43 µg/m^3 in winter season. The overall estimated emission load from areas source is 20783.7 Kg/d, i.e. 22.3% of the total emission load of the city. The major contributors to emission load are bakeries (3.5%), building construction (8%), road repairs and temporary metro rail work (3.2%).
- The impact of dispersed emission load from point source is mainly observed in Mahul -Chembur area of the study area, where major Red LSI categories of industries are mainly located. These industries have mandatory and regulatory obligation of retrofitting various pollution control options to their processes and technology. The annual maximum 24 hourly predicted concentration due to industries is 1.04 µg/m^3, and ranges around 0.4 to 0.7 µg/m^3 in summer and post monsoon.

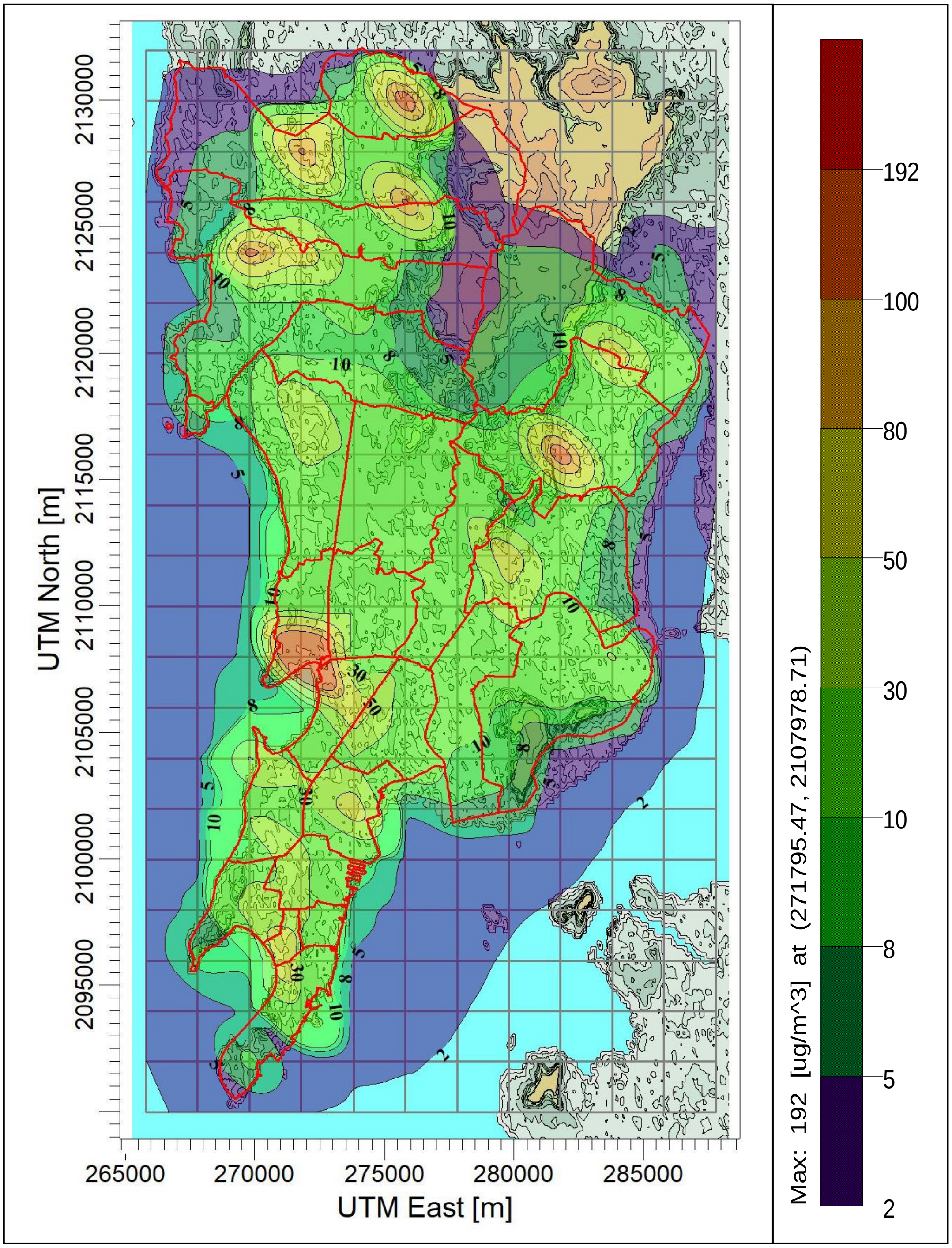


Figure 5.4: Isopleths of PM Due to All Source– Summer Season

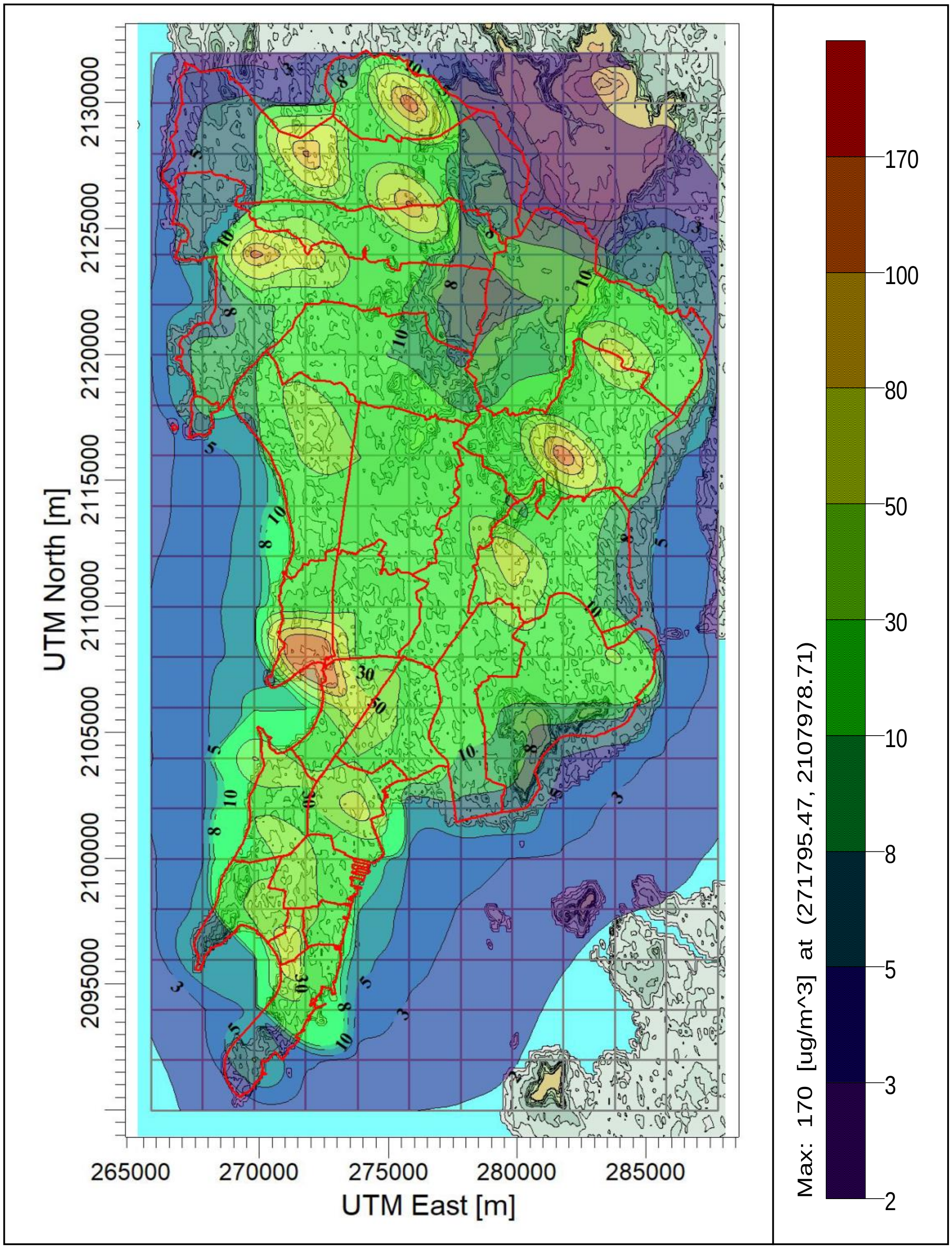


Figure 5.5 : Isopleths of PM Due to All Source– Post Monsoon Season

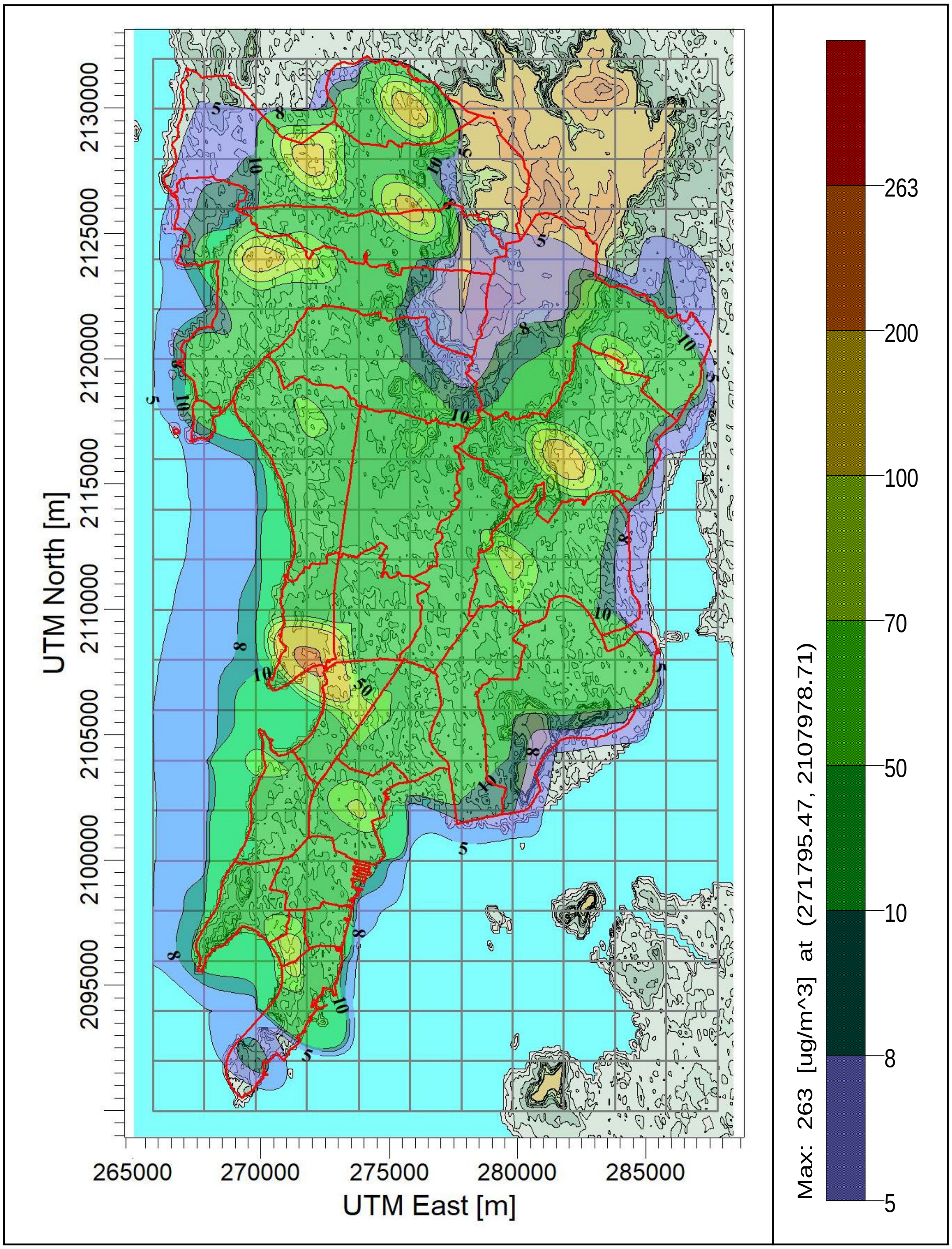


Figure 5.6: Isopleths of PM Due to All Source– Winter Season

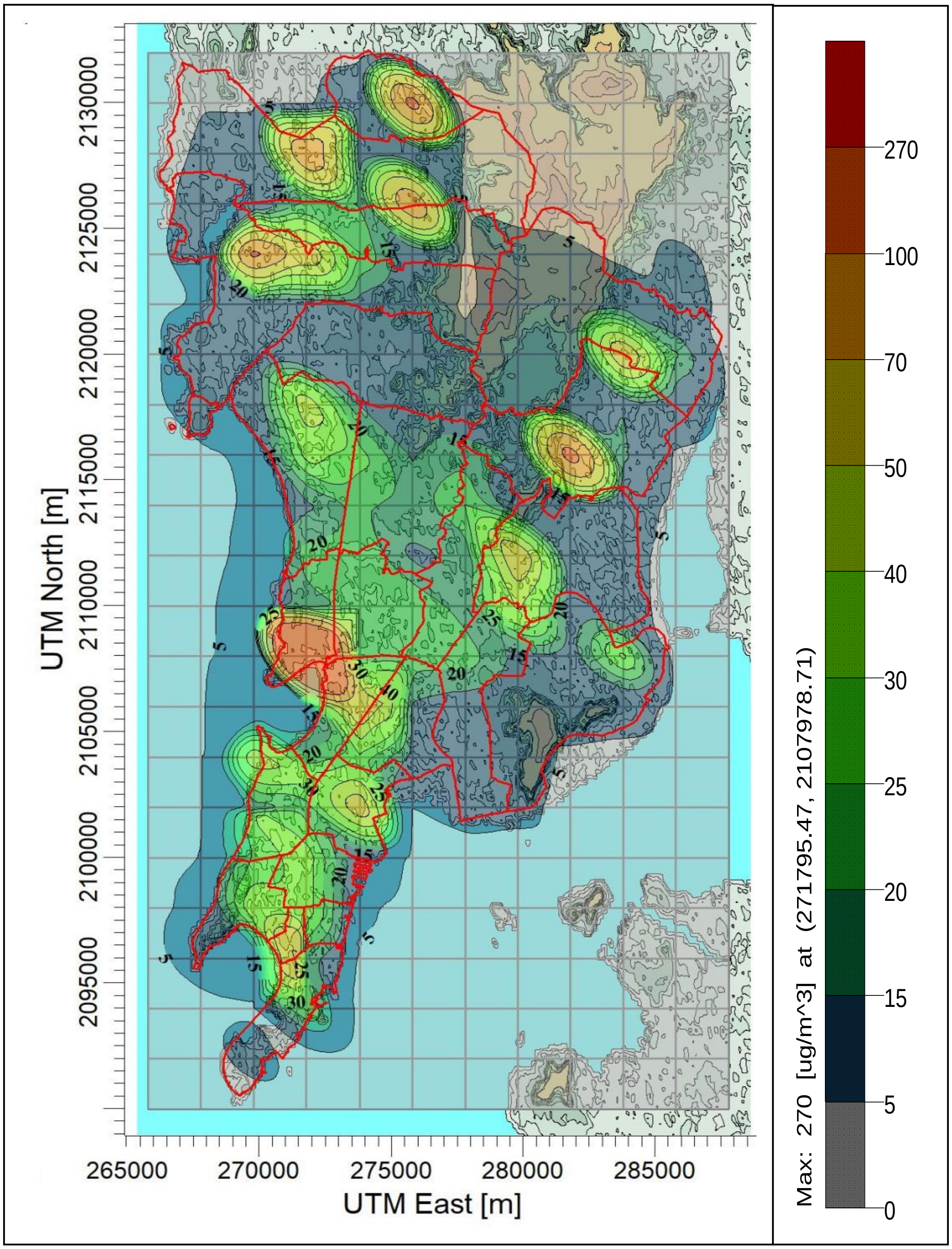


Figure 5.7: Isopleths of PM Due to All Source– Annual

5.4.3 Model Performance for NOx

The dispersion modelling was also carried out for NOx emissions for all seasons. **Table 5.4** has the average NOx concentration observed at 5 monitoring locations, which were in the range of 21 to 110 µg/m^3 during the winter season, at an average of about 49 µg/m^3. The predicted concentrations at these sites were in the range of 48 to 103 µg/m^3. Likewise during the summer season the average concentrations observed at monitoring sites varied from 20 to 90 µg/m^3, at an average of about 40 µg/m^3. The predicted average NOx concentrations at these sites during summer were in the range of 30 to 96 µg/m^3. In post monsoon season, concentrations varies between 17 to 57 µg/m^3, at an average of 35 µg/m^3. The predicted concentrations at these sites ranged from 31 to 88 µg/m^3. The annual concentration differs from 25 to 86 µg/m^3 (at an average of 42 µg/m^3) for observed, whereas, it is 41 to 96 µg/m^3 (at an average of 53 µg/m^3) for predicted concentrations. 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 0.7 to 2.7. Some predicted values were exceeding the FAC2. Variations in are presented in **Figure 5.8**.

Table 5.4: Comparison of Seasonal NOx Average Concentrations (µg/m^3) measurements with the 24 Hourly Model Simulation predictions

	Observed Concentration (µg/m^3) #				**Predicted Concentration (µg/m^3)**			
	Summer	**Post Monsoon**	**Winter**	**Annual**	**Summer**	**Post Monsoon**	**Winter**	**Annual**
Bandra	33.0	54.7	39.7	42.5	38.5	36.8	48.2	41.2
Sion	90.3	57.0	110.3	85.9	96.4	88.1	103.2	95.9
Parel	28.7	20.7	34.3	25.9	32.9	49.6	49.5	44.0
Kalbadevi	19.8	17.0	20.7	24.8	42.3	31.4	55.3	43.0
Worli	29.1	27.3	41.7	29.3	29.5	40.7	52.6	40.9
Ratio of Predicted to Observed Concentration								
Bandra	1.2	0.7	1.2	1.0				
Sion	1.1	1.5	0.9	1.1				
Parel	1.1	2.4	1.4	1.7				
Kalbadevi	2.1	1.8	2.7	1.7				
Worli	1.0	1.5	1.3	1.4				

Sum –Summer, PostMon- Post Monsooon, Win –Winter, Ann - Annual
 # Observed Concentration (Air Quality Status of Maharashtra 2016-17, MPCB

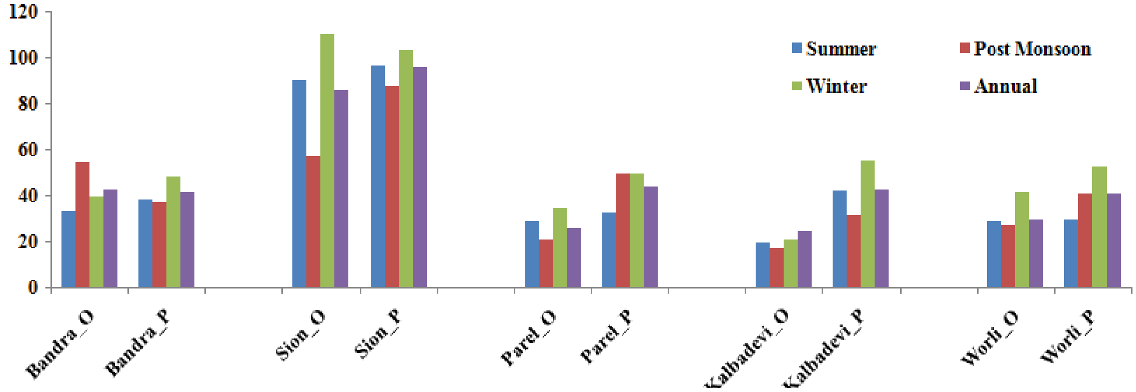


Figure 5.8: Observed and Predicted Concentration for All Seasons (NOx - µg/m^3)

5.5.2 Existing Scenario Concentration Contours for NOx

The models were run for annually and all seasons for different source group combinations **(Table 5.2)**. 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 10 highest concentrations in **Annexure 5**.

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

Sources Group	Summer	Post Monsoon	Winter	Annual
All Group	210.1	219.3	271.2	227.1
Area Source	51.5	49.43	64.8	54.0
Line Source	198.5	208.4	256.2	215.3
Point Source (LSI)	45.3	106.2	33.8	62.6
Point Source (SSI & MSI)	9.62	9.02	12.9	10.01

Concentrations in µg/m^3

Observations

- The annual average NOx concentrations exceeds the CPCB 24 hourly standard of 80 µg/m^3, which is also reflected in summer and worse in winter. The observed and predicted ratio is highest in winter and worst at Parel and Kalbadevi areas.
- The Annual NOx concentration dispersed from all sources is 227 µg/m^3, out of which the concentration of line source is 215 µg/m^3, and that from area source and LSI industries varies from 54 to 62 µg/m^3.
- The maximum 24 hourly predicted concentration due to all sources in winter was 271 µg/m^3, out of which 256 µg/m^3 is from Tailpipe emission from Vehicles. The pockets of high concentration are observed close to major traffic junctions in central part city i.e near Sion Circle, Bandra, as well as Western Express Highway and Eastern Express Highway. The line source contributes 40526.1 kg/d, which is 28.2% of the total estimated city emission load in emission inventory. The HDDV and CNG Buses contribute around 16.1% (23190.7 kg/d) and 4.6% (6636.6 kg/d), respectively of the total load.
- The predicted concentration from Red LSI in winter is 33.8 µg/m^3, whereas from MSI and SSI category of industry is around 12.9 µg/m^3. The predicted concentration from Red LSI NOx is in the range of 33.8 to 106 µg/m^3 and that from MSI & SSI is between 9 to 12 µg/m^3. Industries are located mainly at eastern part of the city, where major impact from the point source is predicted.
- The maximum 24 hourly predicted concentration due to area sources was 64 µg/m^3 in winter. The overall impact of areas source is due to domestic sector (around 491514 kg/d of LPG consumption). The emission load of NOx from domestic sector is 26620.2 kg/d (i.e 18.5% of the total estimated emission load).

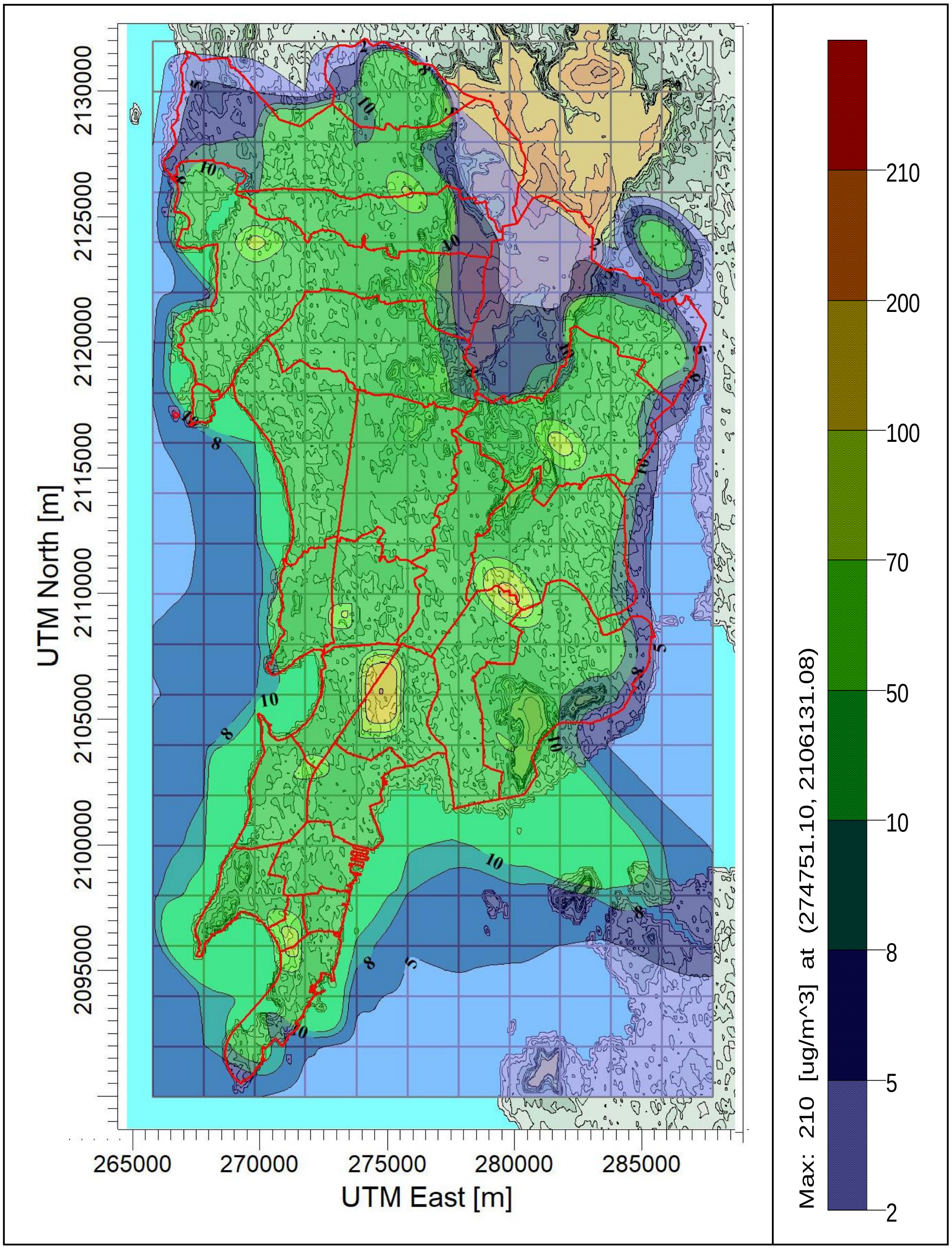


Figure 5.9: Isopleths of NOx Due to All Source– Summer Season

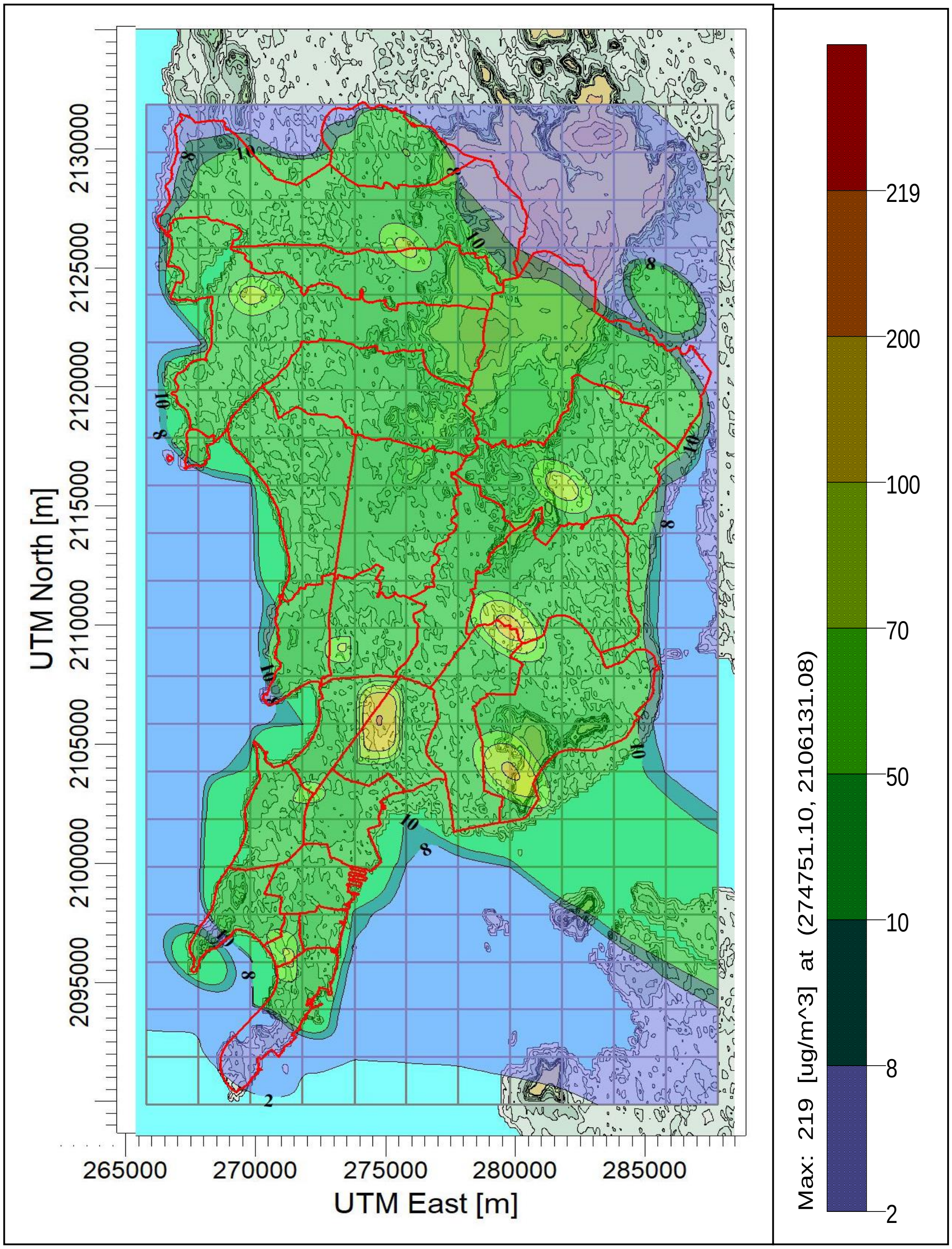


Figure 5.10: Isopleths of NOx Due to All Source– Post Monsoon Season

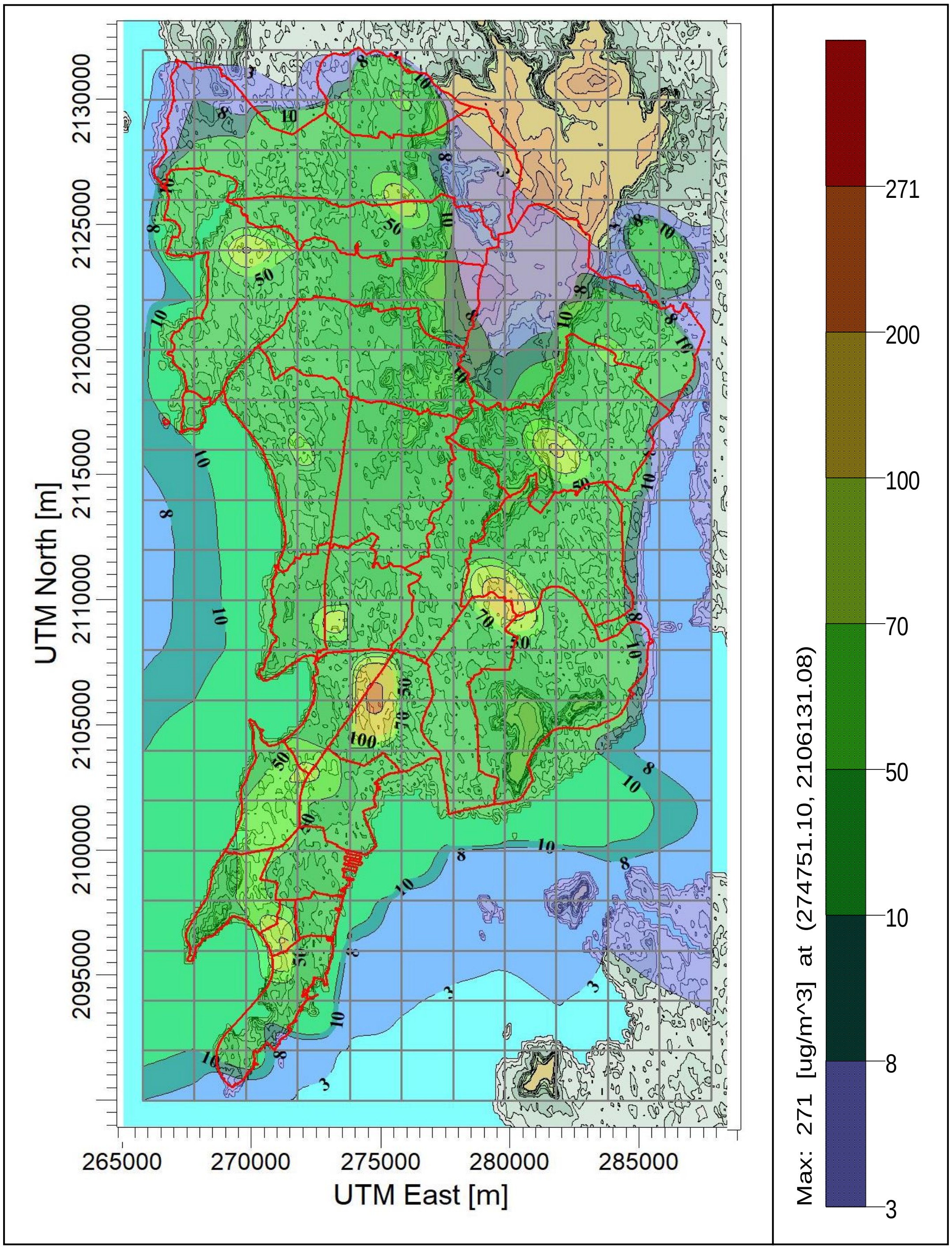


Figure 5.11: Isopleths of NOx Due to All Source– Winter Season

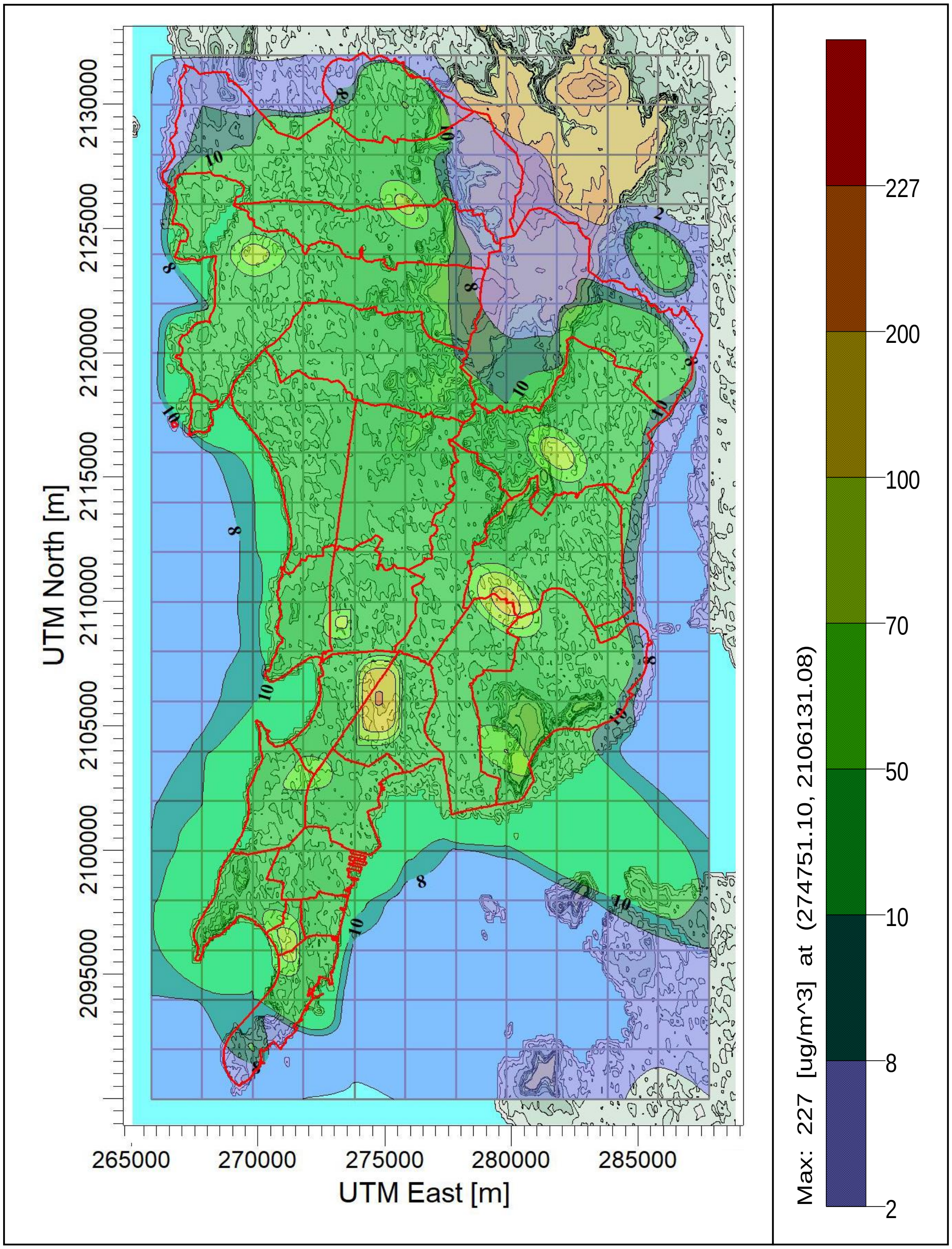


Figure 5.12: Isopleths of NOx Due to All Source– Annual

Each set of sources of air pollution require different strategies for control. Individual contribution of sources for ground level concentrations was therefore simulated in the dispersion model with individual set of sources take as input. Table 5.6 lists the cases for which the model was run for summer, post-monsoon, winter seasons and the annual average. Similar run was made for NOx.

Table 5.6: List of AERMOD simulations for PM Isopleths for delineated Sources only

A) AREA SOURCE – ALL (PM)

Sr. No.	Scenario	Figure No.
1	Isopleths of PM Due to Area Sources only Summer Season	5.13
2	Isopleths of PM Due to Area Sources only Post Monsoon Season	5.14
3	Isopleths of PM Due to Area Sources only Winter Season	5.15
4	Isopleths of PM Due to Area Sources only Annual	5.16
5	Isopleths of PM Due to Line Sources only Summer Season	5.17
6	Isopleths of PM Due to Line Sources only Post Monsoon Season	5.18
7	Isopleths of PM Due to Line Sources only Winter Season (Mumbai City)	5.19
8	Isopleths of PM Due to Line Sources only Annual (Mumbai City)	5.20
9	Isopleths of PM Due to Resuspension Dust only Summer Season (Mumbai City)	5.21
10	Isopleths of PM Due to Resuspension Dust only Post Monsoon Season (Mumbai City)	5.22
11	Isopleths of PM Due to Resuspension Dust only Winter Season (Mumbai City)	5.23
12	Isopleths of PM Due to Resuspension Dust only Annual (Mumbai City)	5.24
13	Isopleths of PM Due to Point Sources (LSI) only Summer Season (Mumbai City)	5.25
14	Isopleths of PM Due to Point Sources (LSI) only Post Monsoon Season(Mumbai City)	5.26
15	Isopleths of PM Due to Point Sources (LSI) only Winter Season(Mumbai City)	5.27
16	Isopleths of PM Due to Point Sources (LSI) only Annual (Mumbai City)	5.28
17	Isopleths of PM Due to Point Sources (MSI & SSI) only Summer Season (Mumbai City)	5.29
18	Isopleths of PM Due to Point Sources (MSI & SSI) only Post Monsoon Season (Mumbai City)	5.30
19	Isopleths of PM Due to Point Sources (MSI & SSI) only Winter Season (Mumbai City)	5.31
20	Isopleths of PM Due to Point Sources (MSI & SSI) only Annual (Mumbai City)	5.32

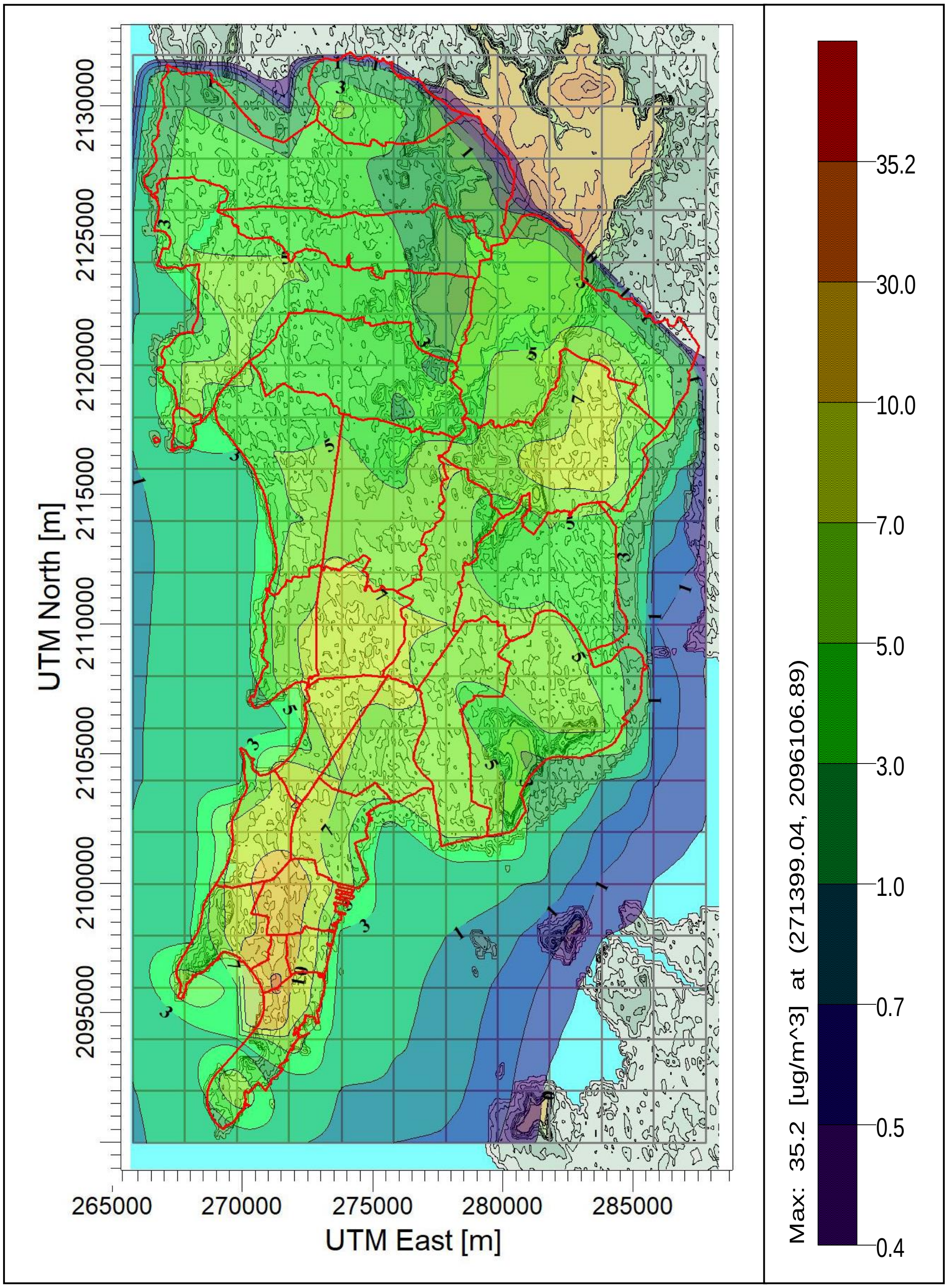


Figure 5.13: Isopleths of PM Due to Area Sources only Summer Season

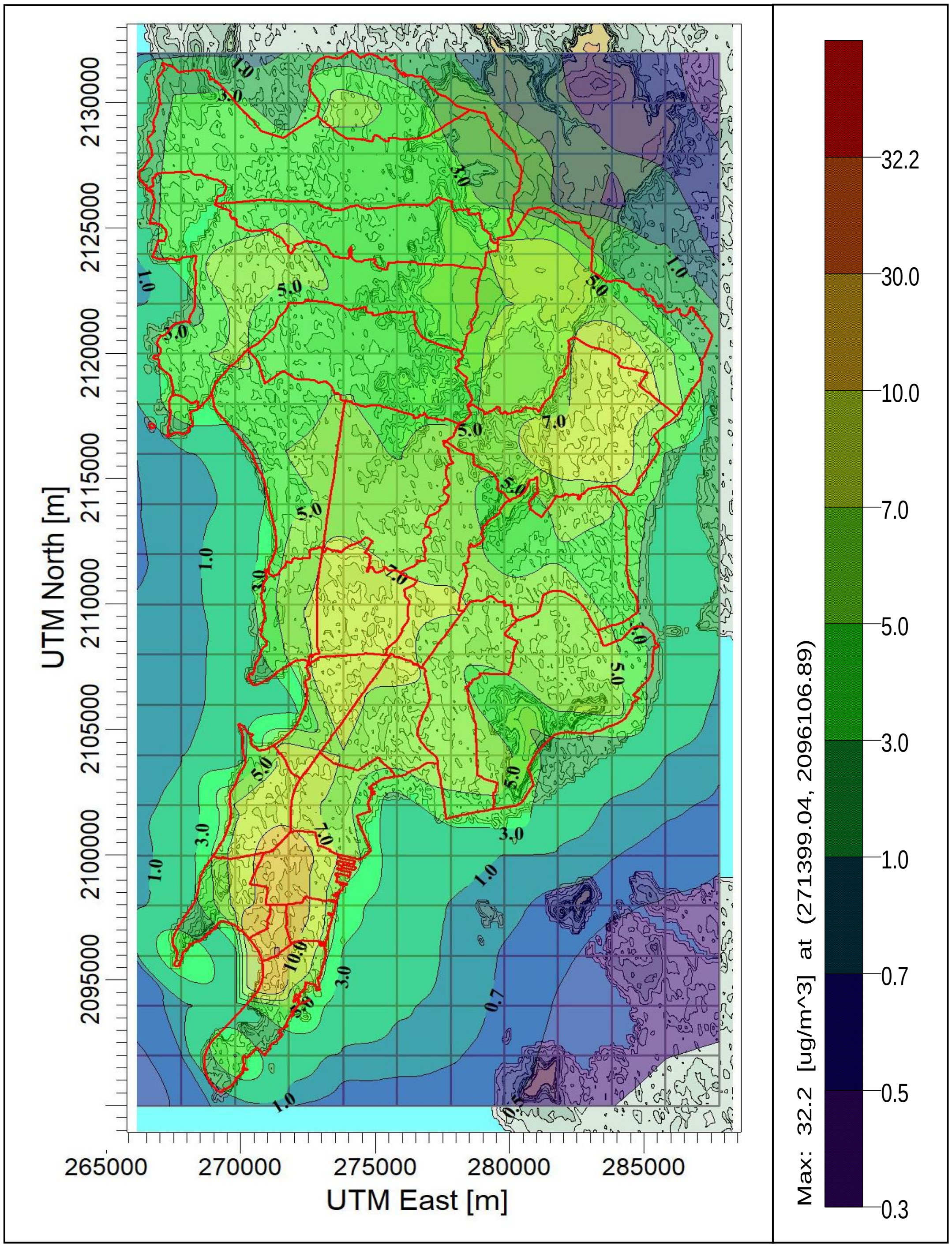


Figure 5.14: Isopleths of PM Due to Area Sources only Post Monsoon Season

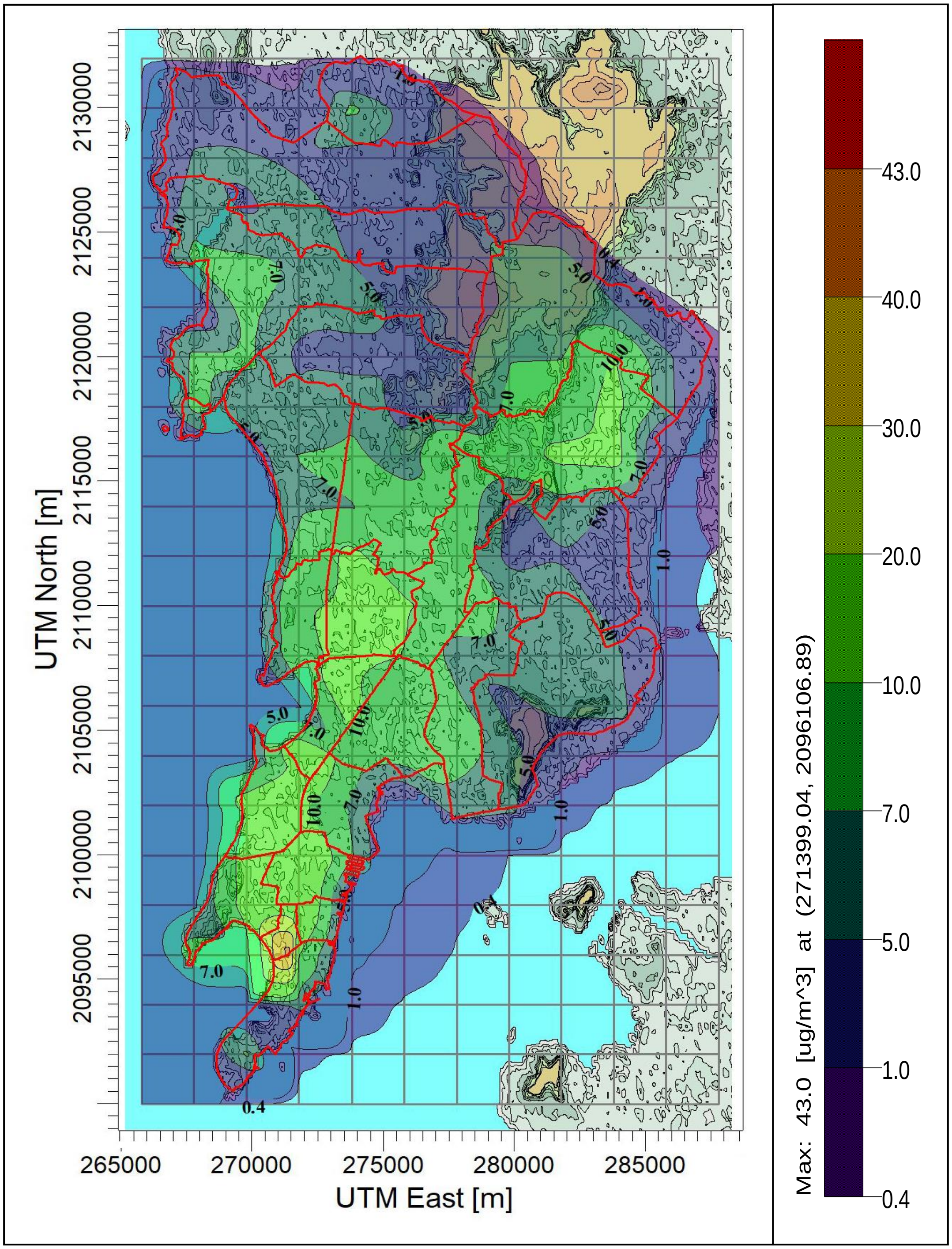


Figure 5.15: **Isopleths of PM Due to Area Sources only Winter Season**

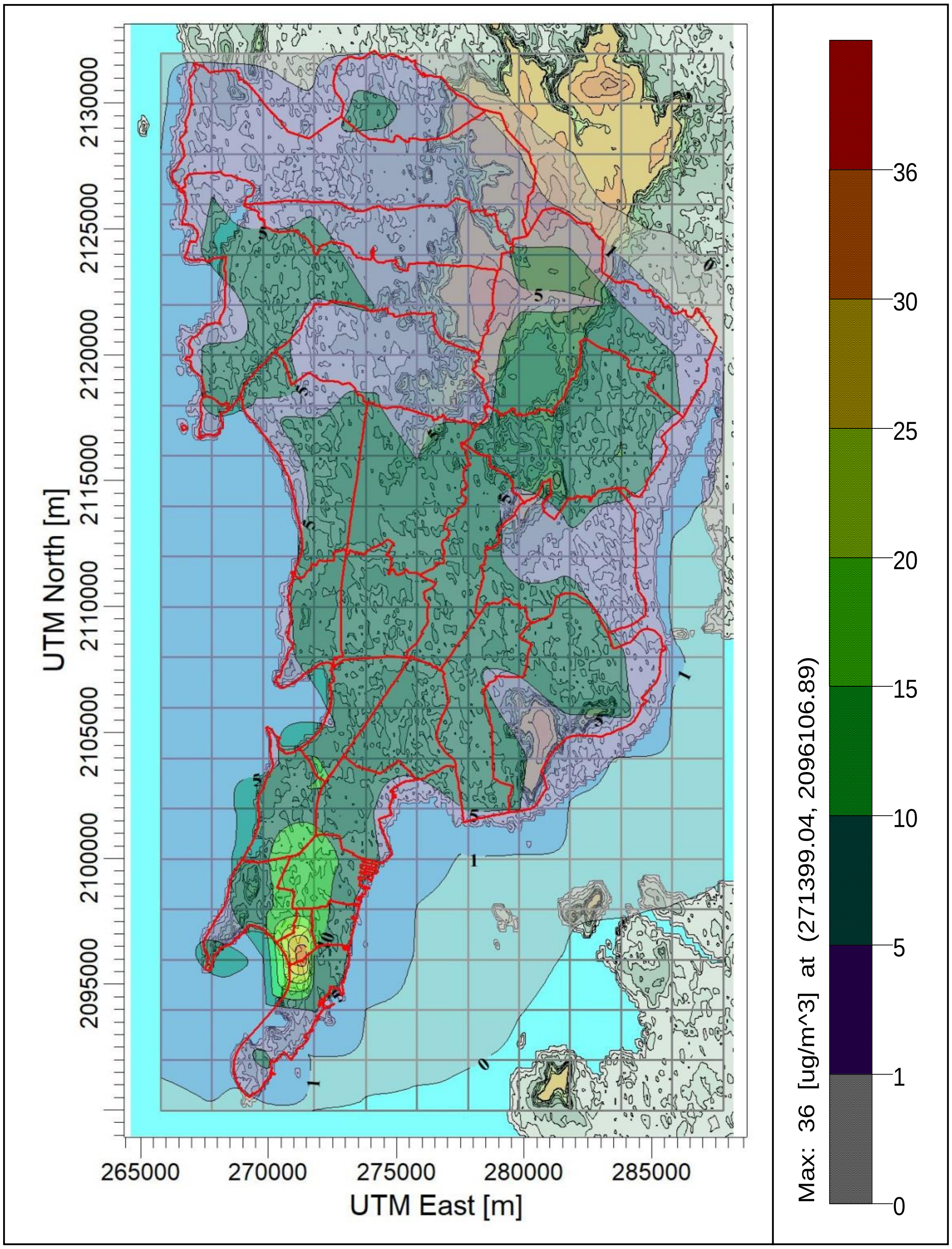


Figure 5.16: Isopleths of PM Due to Area Sources only Annual

B) LINE SOURCE – ALL (PM)

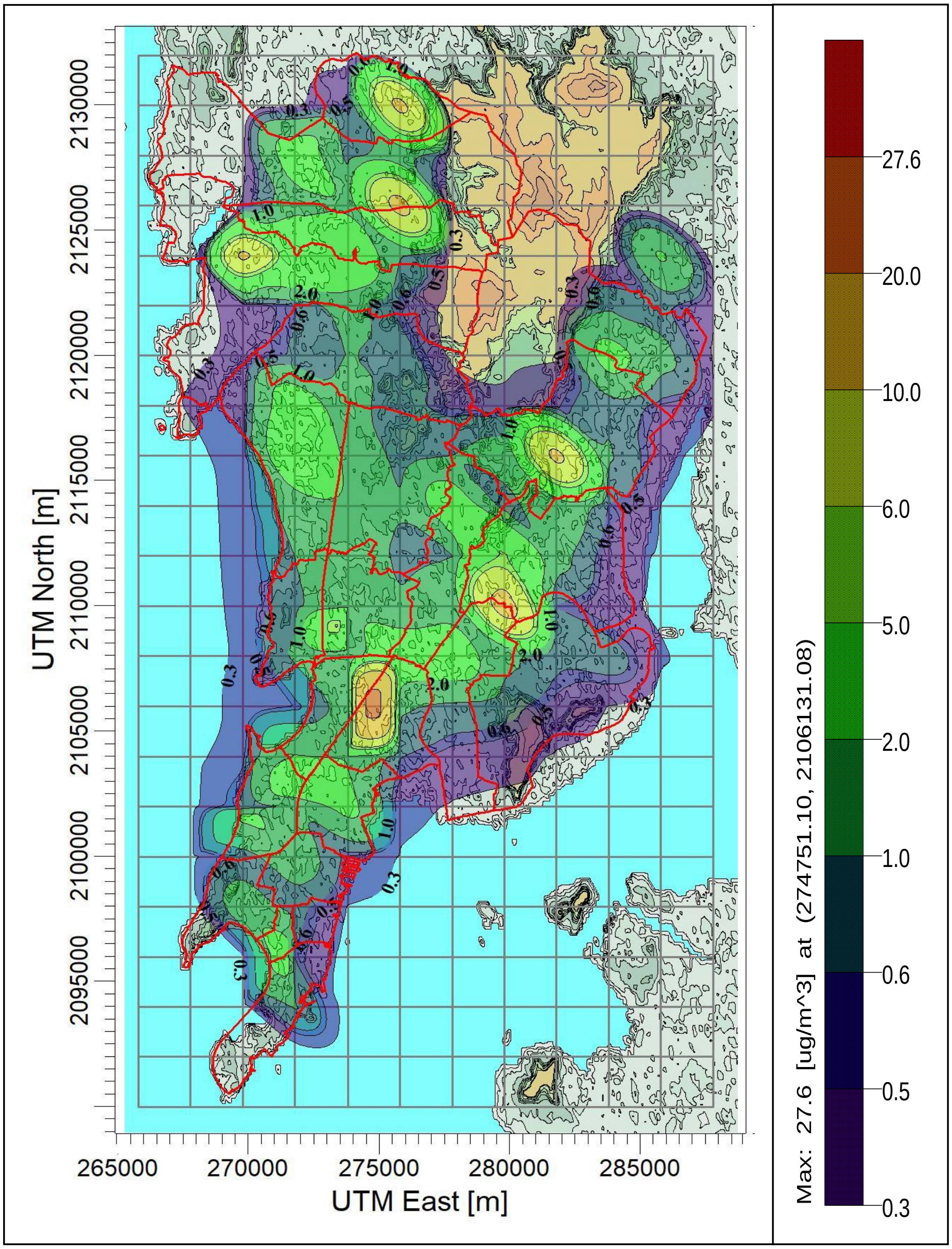


Figure 5.17: Isopleths of PM Due to Line Sources only Summer Season

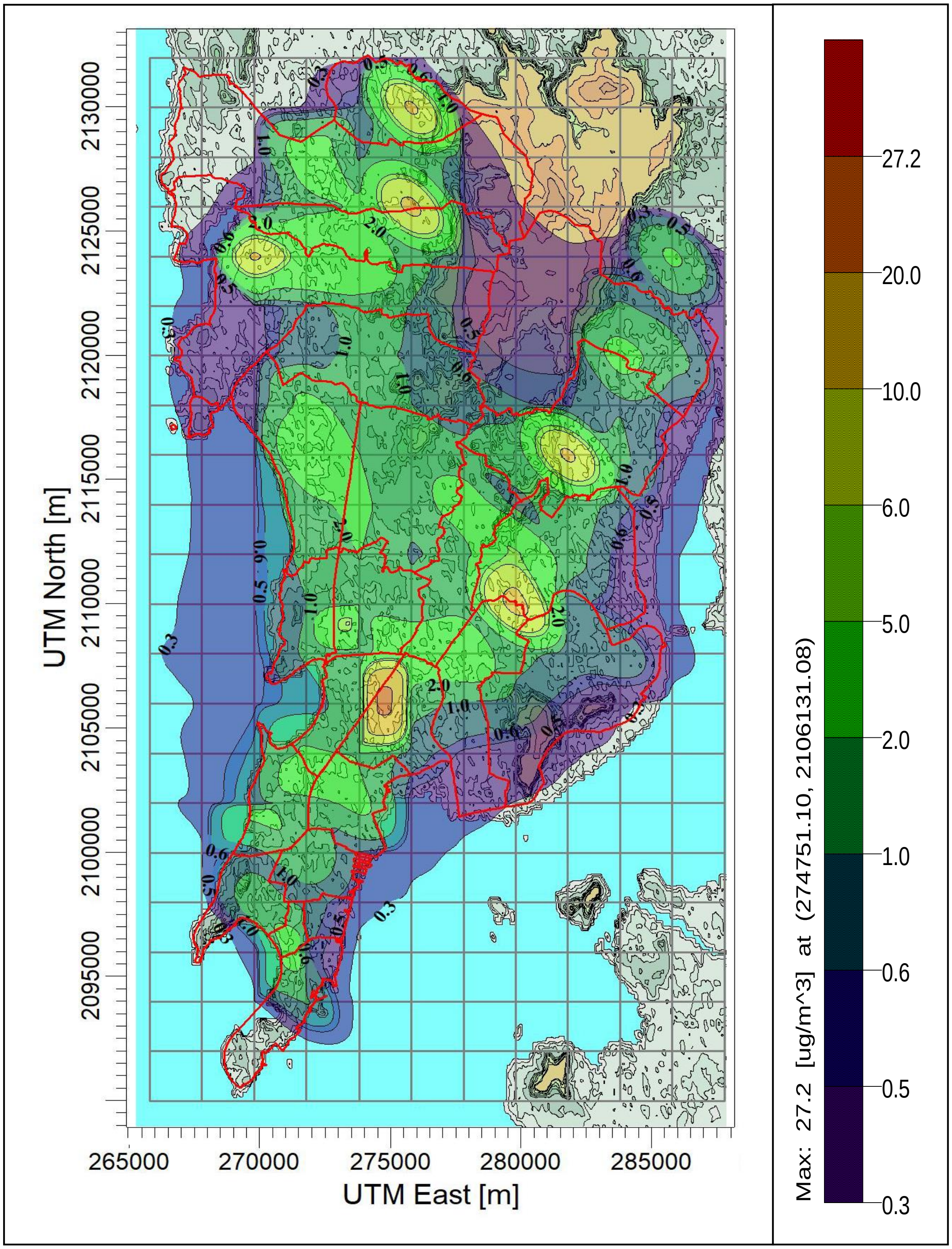


Figure 5.18: Isopleths of PM Due to Line Sources only Post Monsoon Season

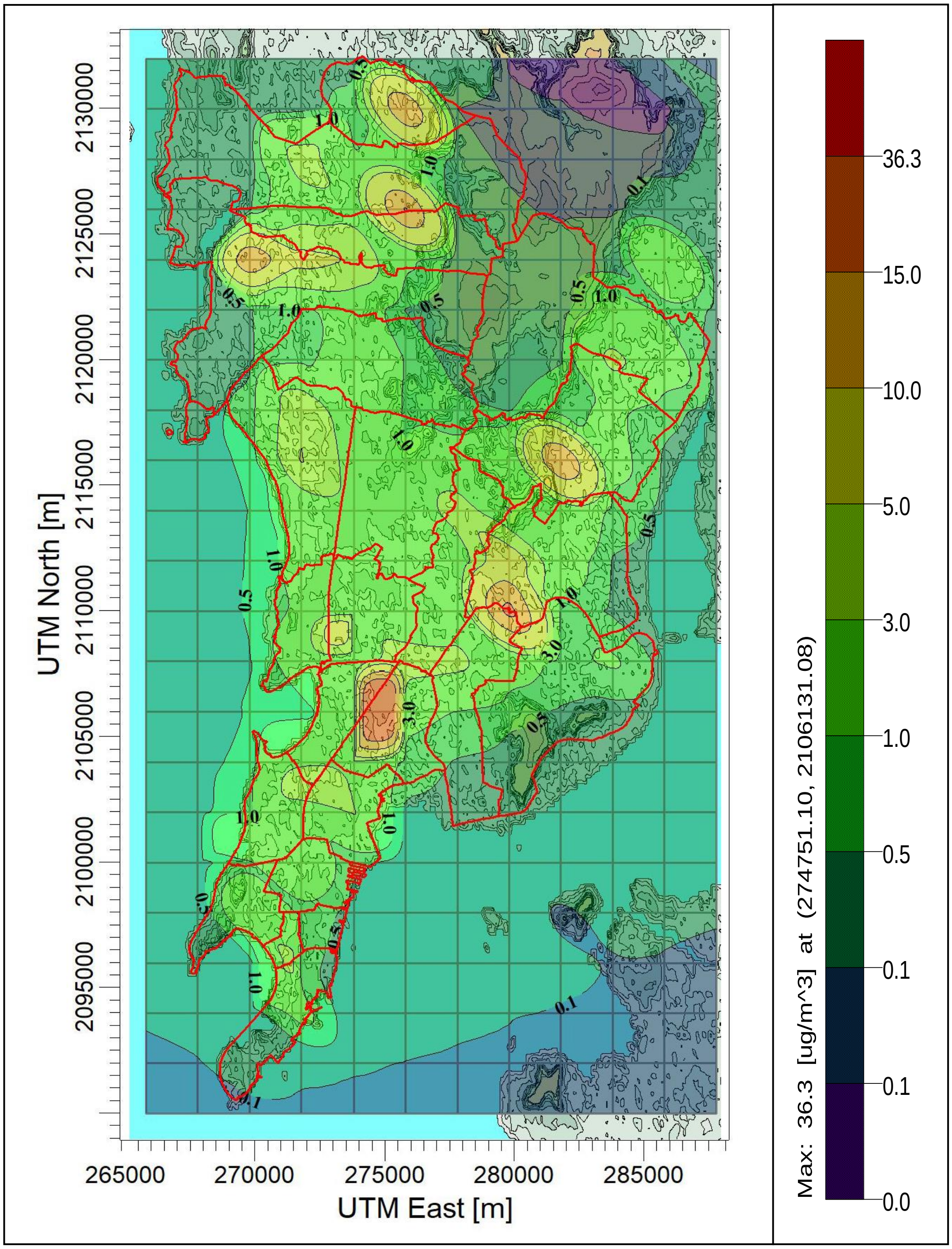


Figure 5.19: Isopleths of PM Due to Line Sources only Winter Season

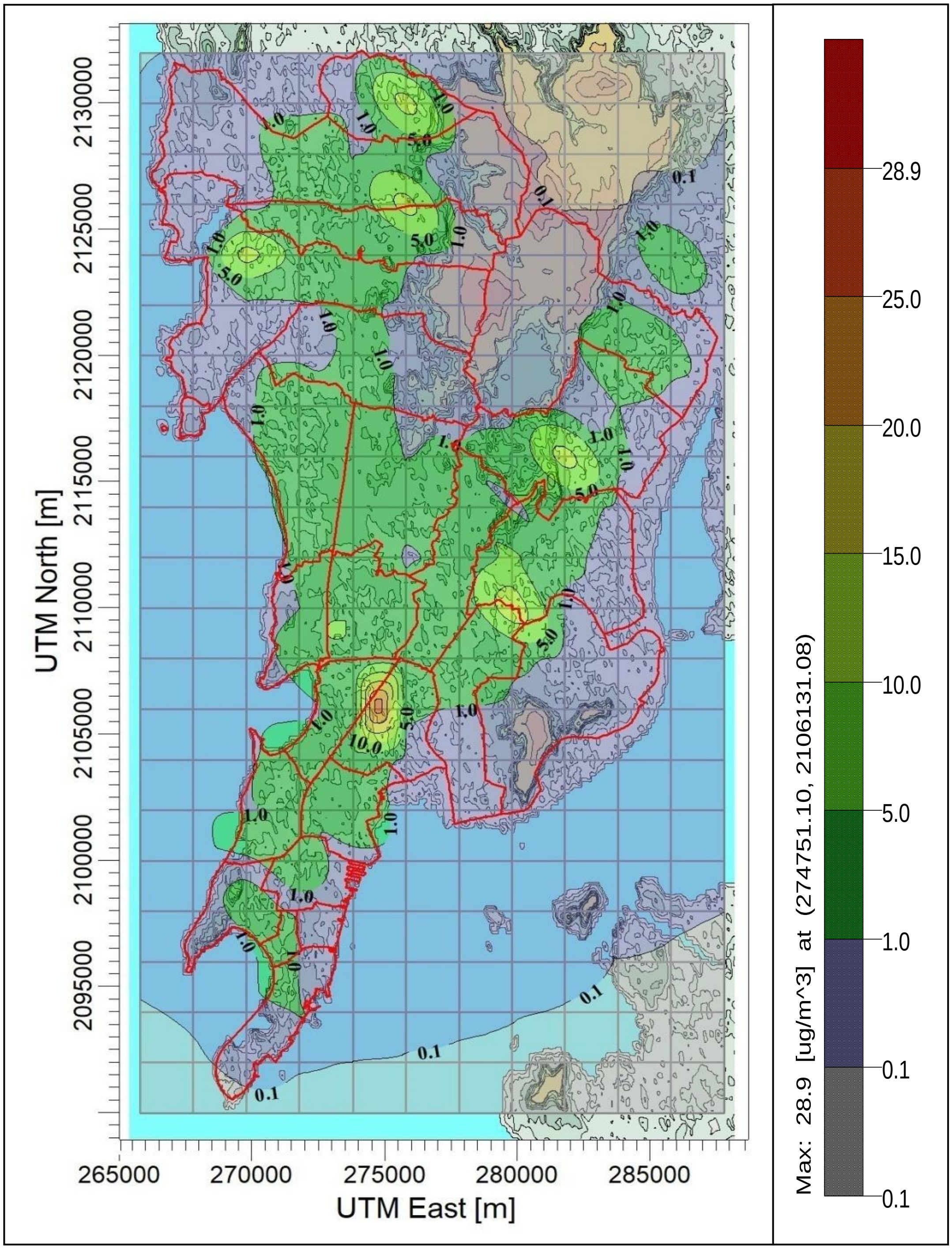


Figure 5.20: Isopleths of PM Due to Line Sources only Annual

C) RESUSPENSION DUST– ALL (PM)

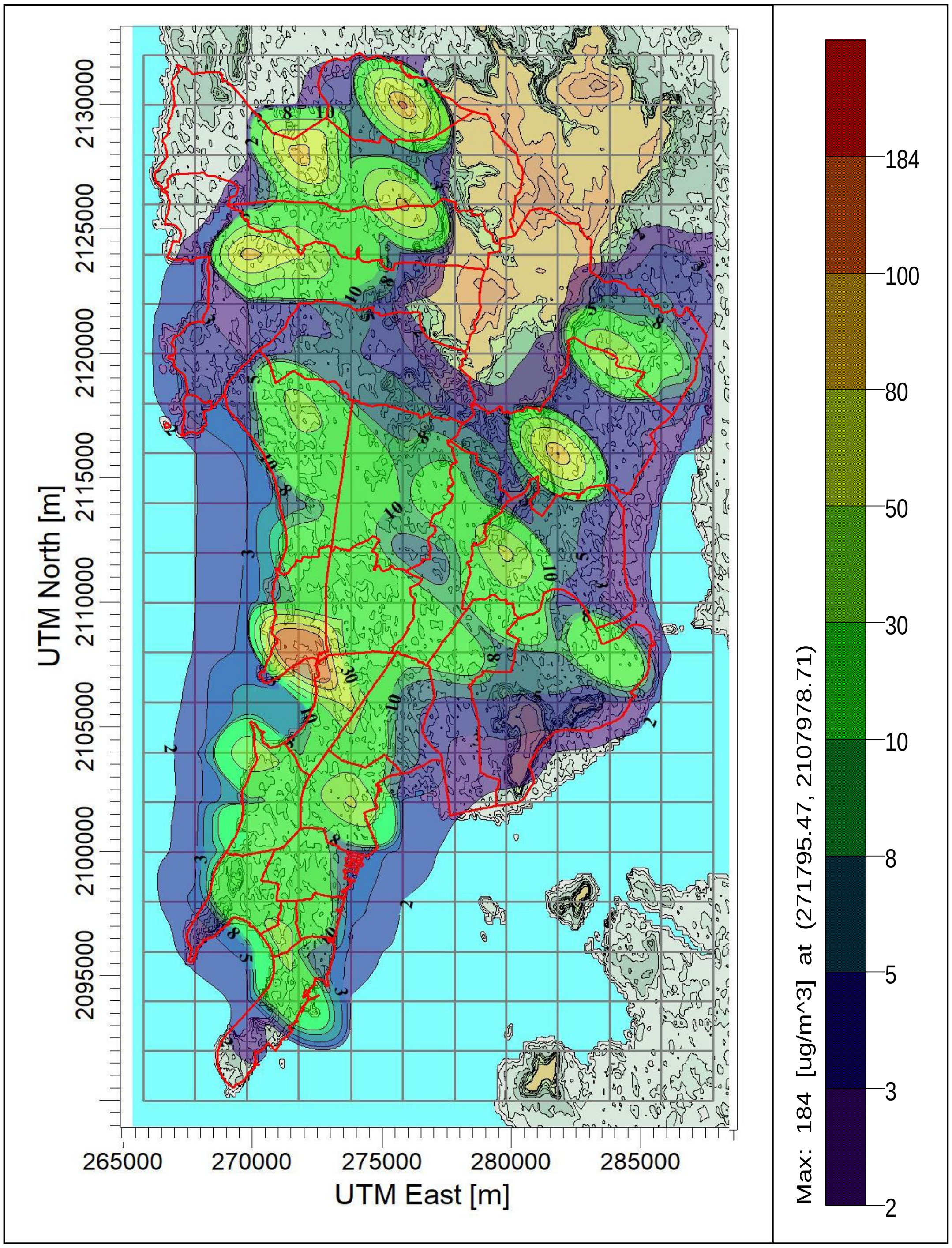


Figure 5.21: Isopleths of PM Due to Resuspension Dust only Summer Season

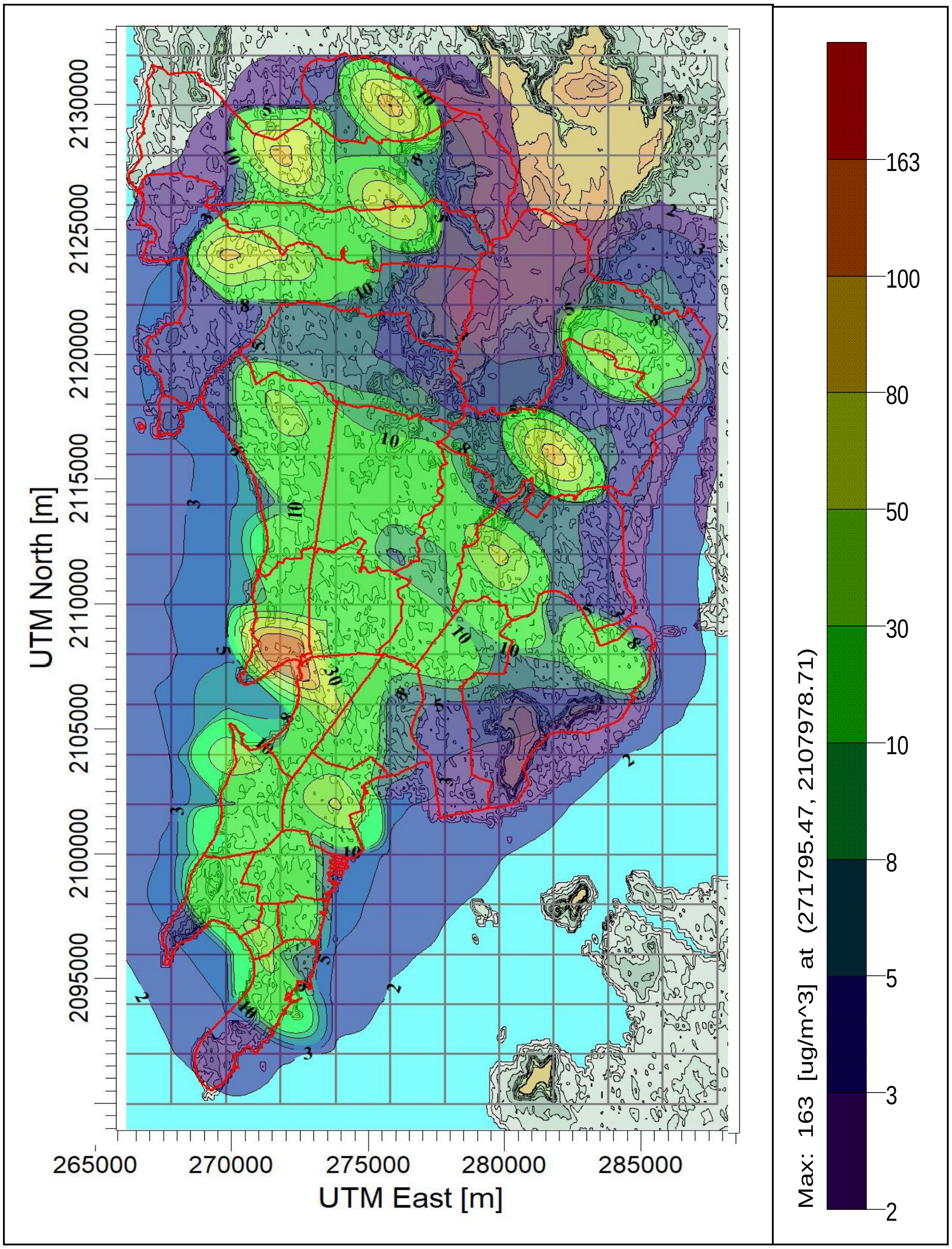


Figure 5.22: Isopleths of PM Due to Resuspension Dust only Post Monsoon Season

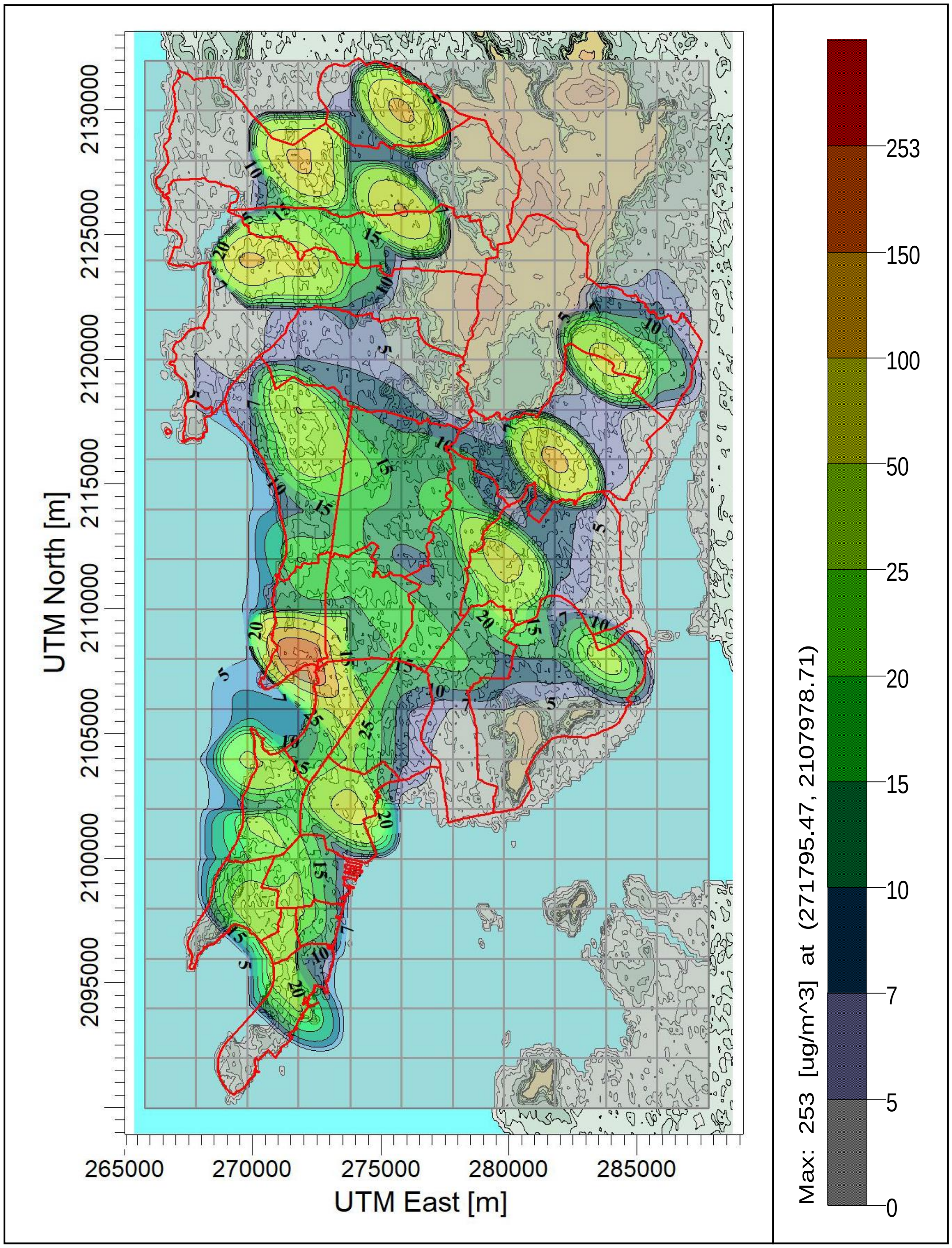


Figure 5.23: Isopleths of PM Due to Resuspension Dust only Winter Season

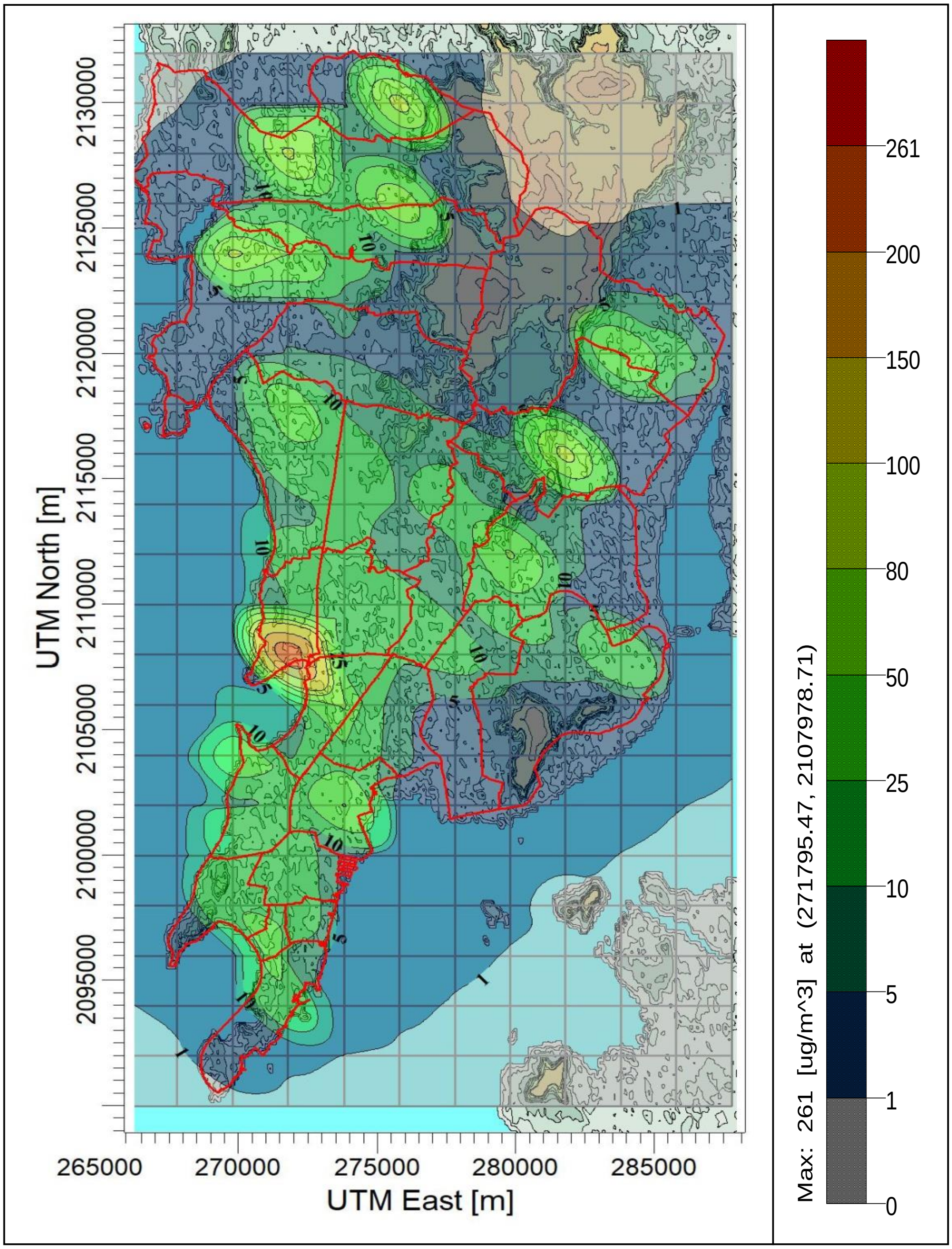


Figure 5.24: Isopleths of PM Due to Resuspension Dust only Annual

D) POINT SOURCE – LSI (PM)

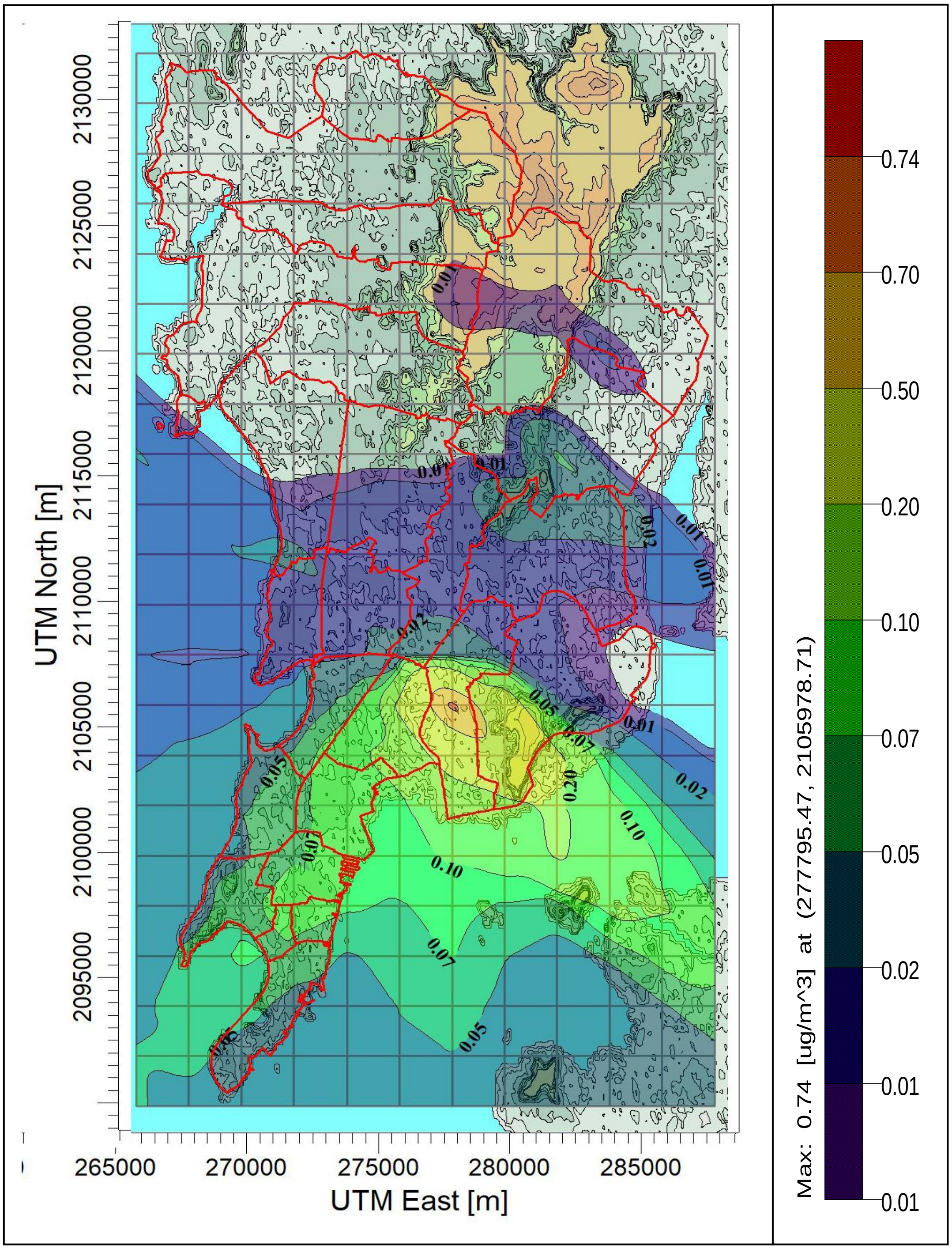


Figure 5.25: Isopleths of PM Due to Point Sources (LSI) only Summer Season

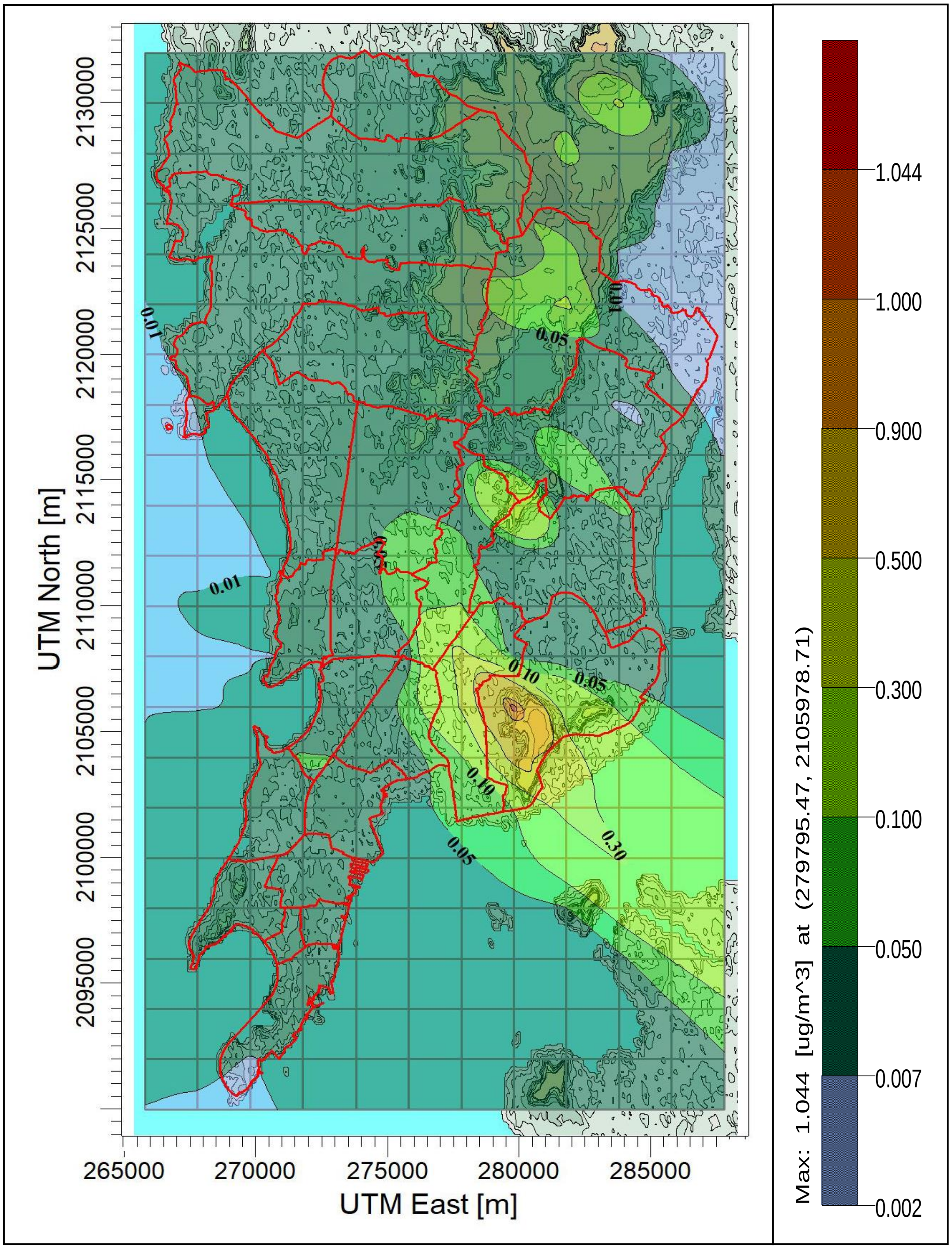


Figure 5.26: Isopleths of PM Due to Point Sources (LSI) only Post Monsoon Season

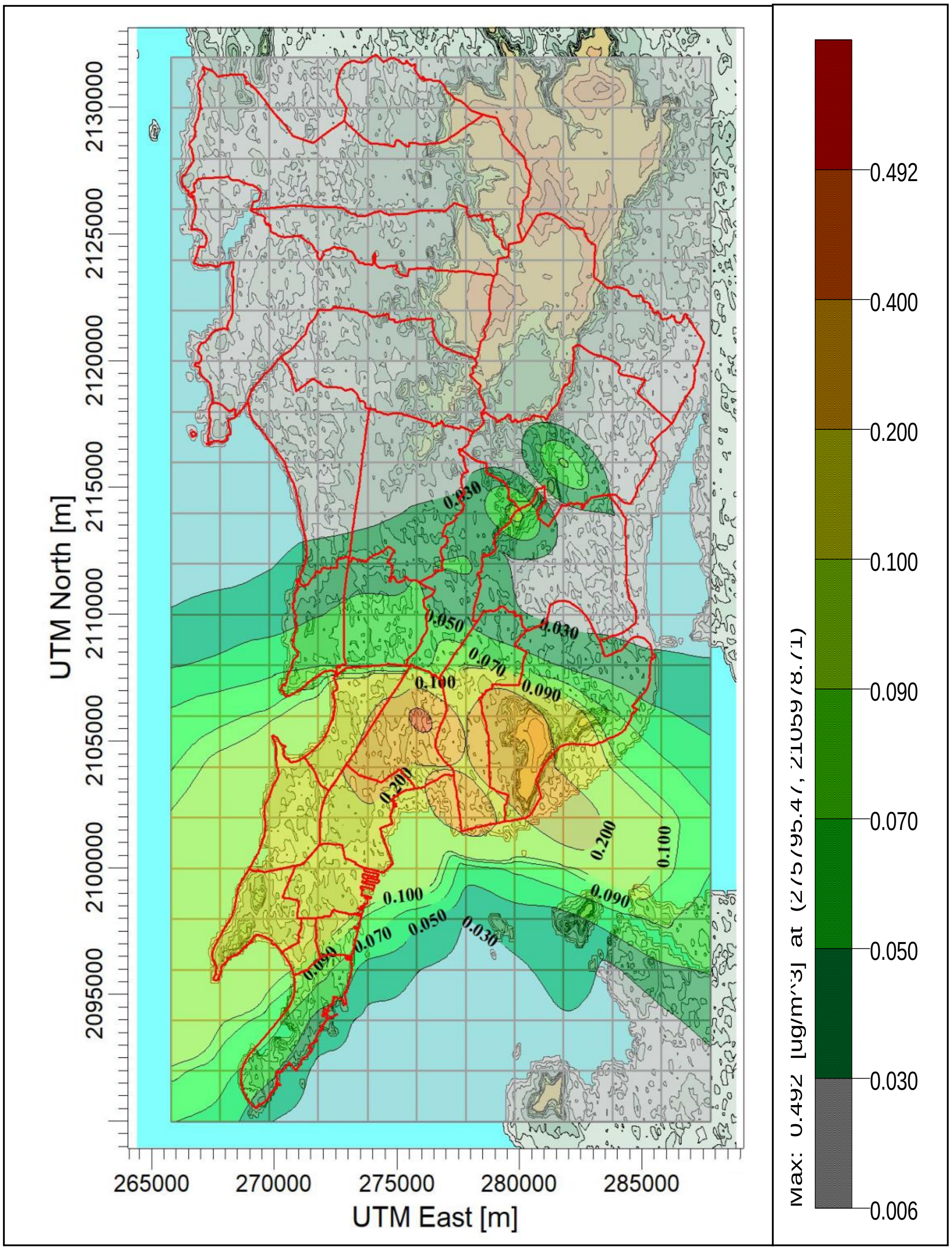


Figure 5.27: Isopleths of PM Due to Point Sources (LSI) only Winter Season

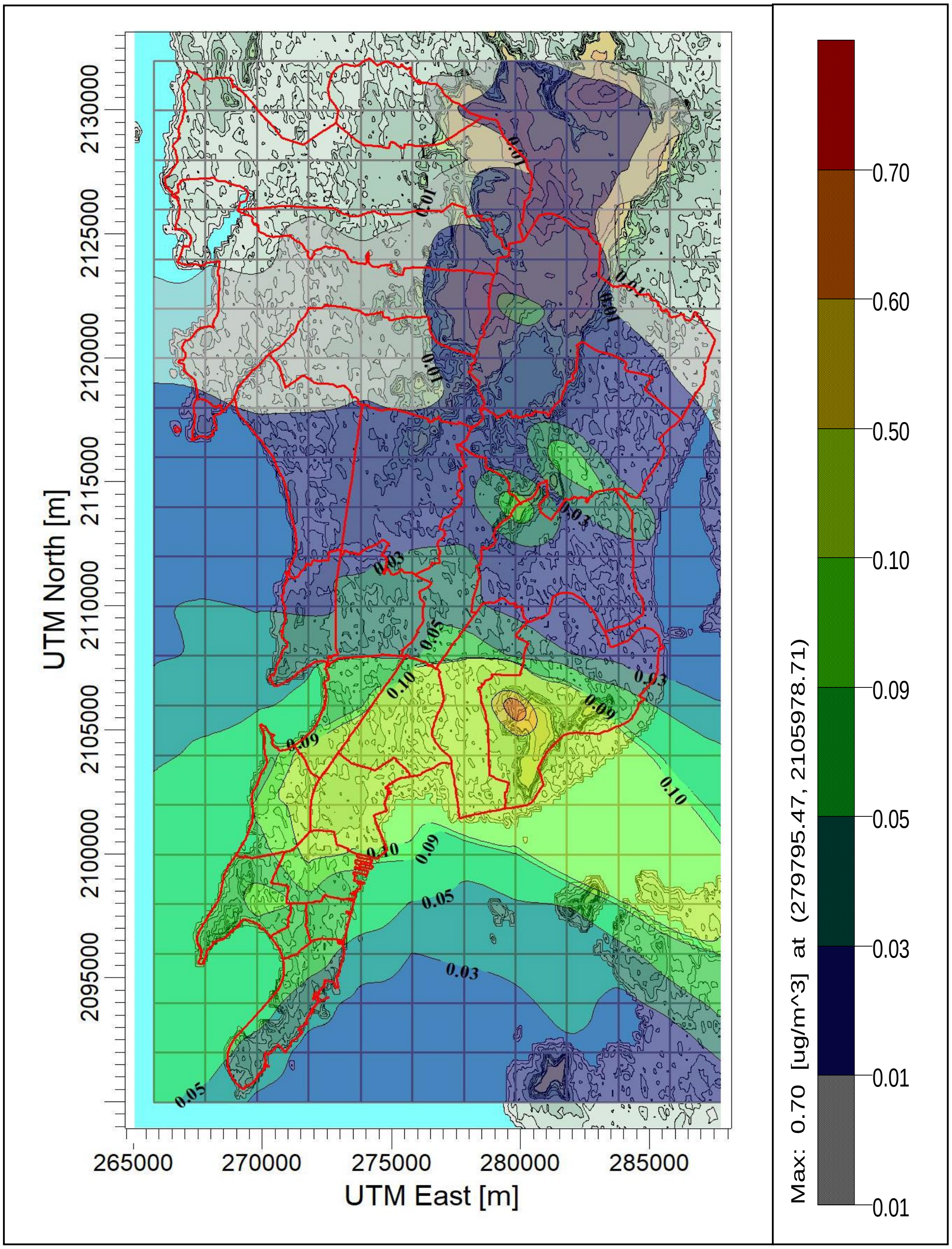


Figure 5.28: Isopleths of PM Due to Point Sources (LSI) only Annual

E) POINT SOURCE – MSI & SSI (PM)

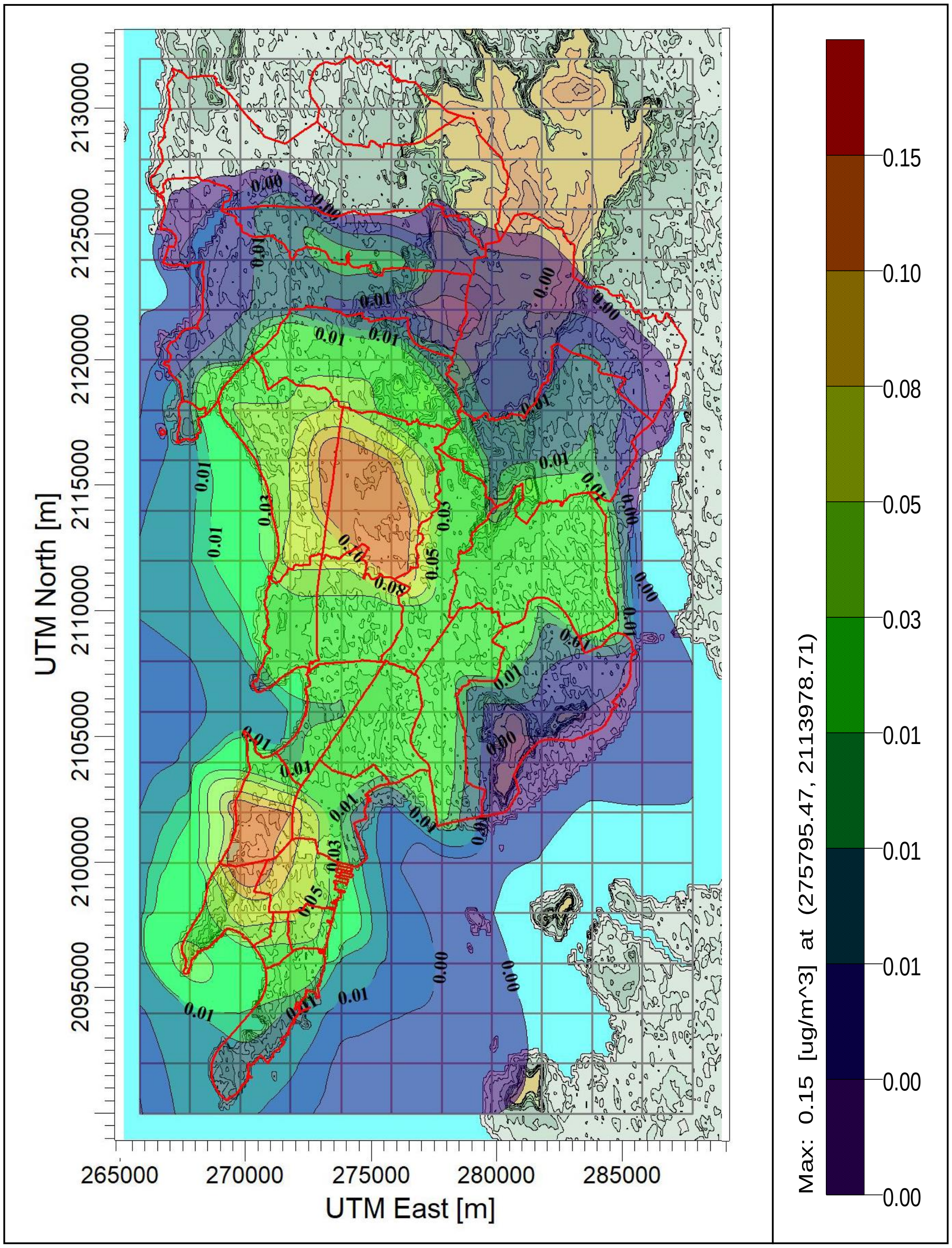


Figure 5.29: Isopleths of PM Due to Point Sources (MSI & SSI) only Summer Season

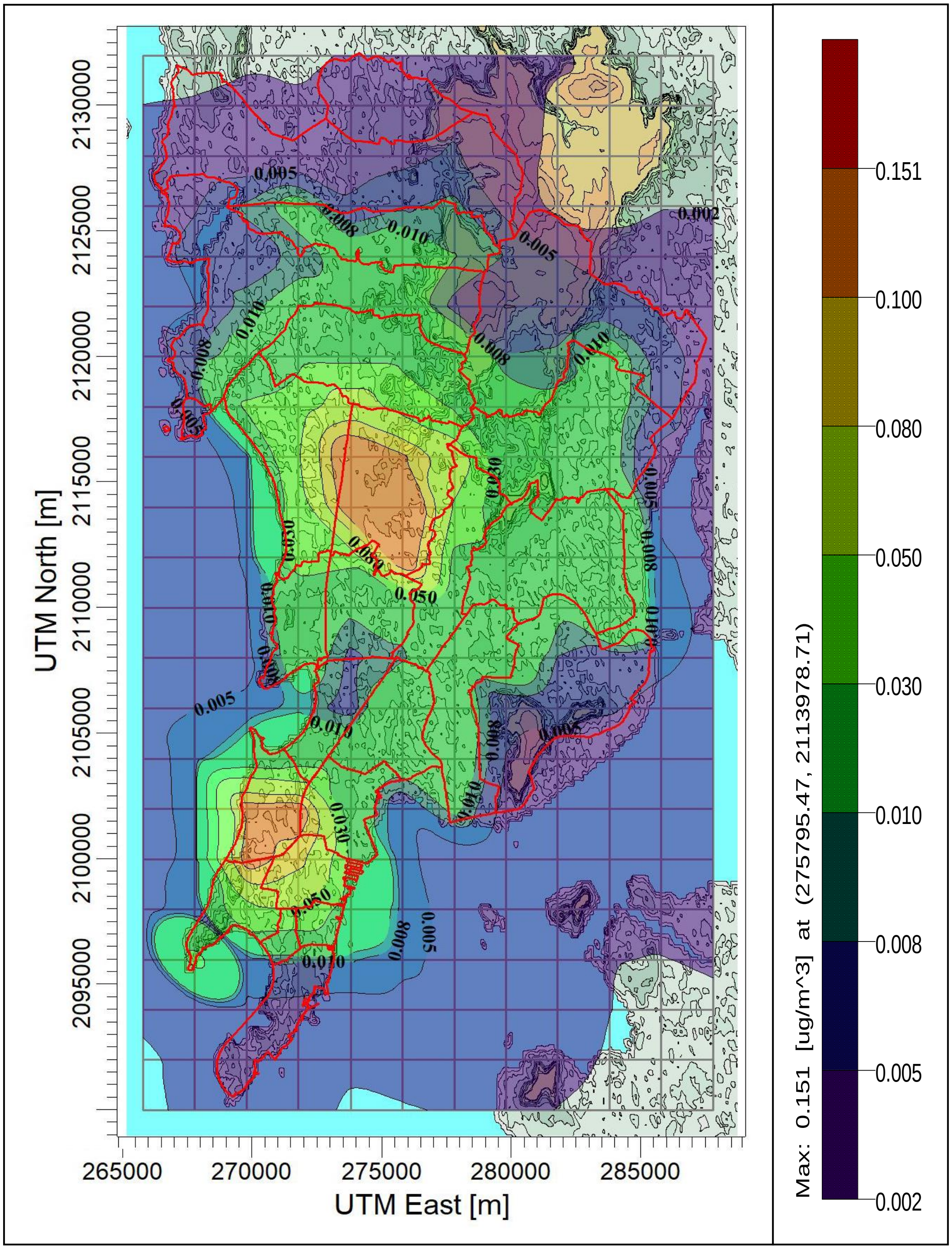


Figure 5.30: Isopleths of PM Due to Point Sources (MSI & SSI) only Post Monsoon Season

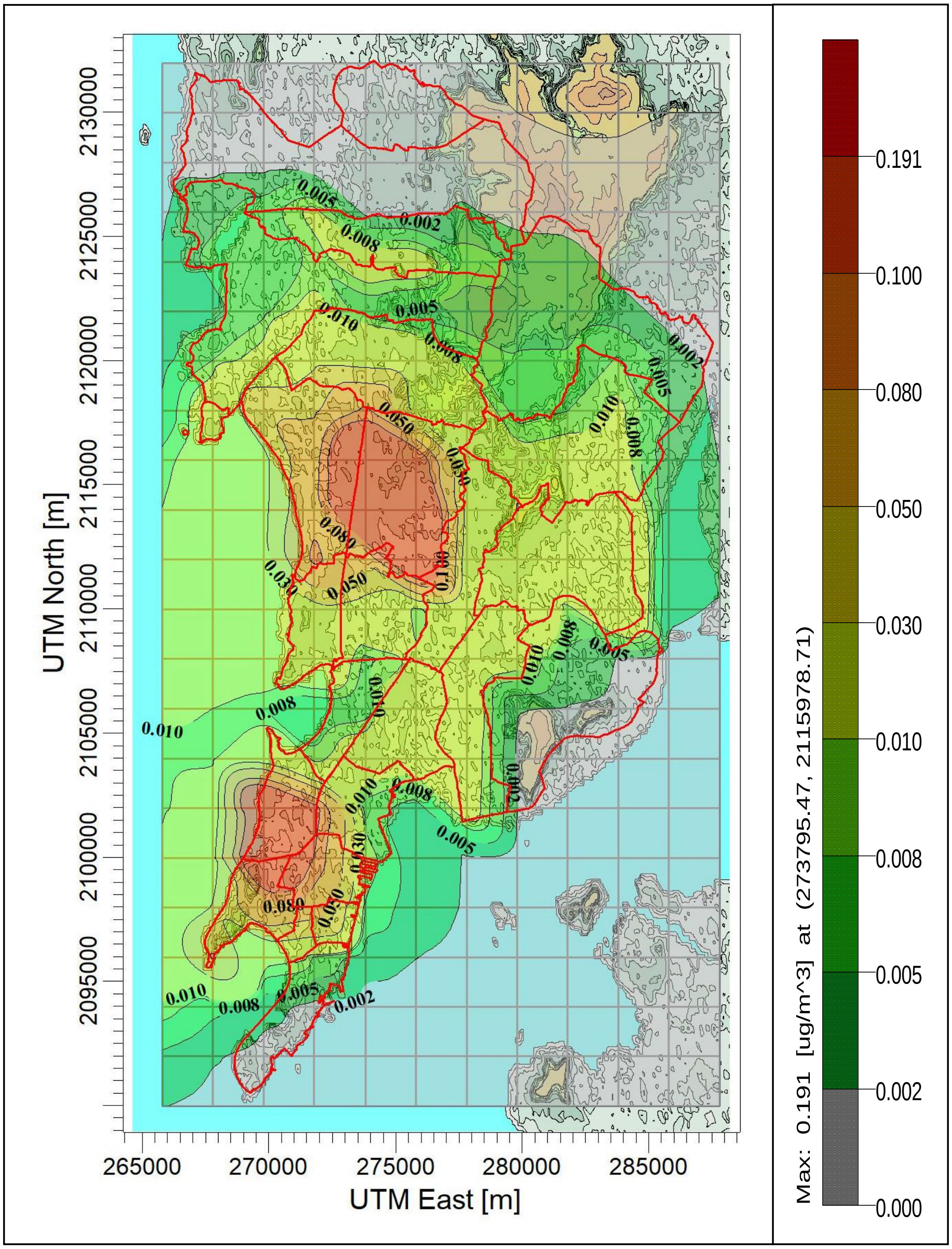


Figure 5.31: Isopleths of PM Due to Point Sources (MSI & SSI) only Winter Season

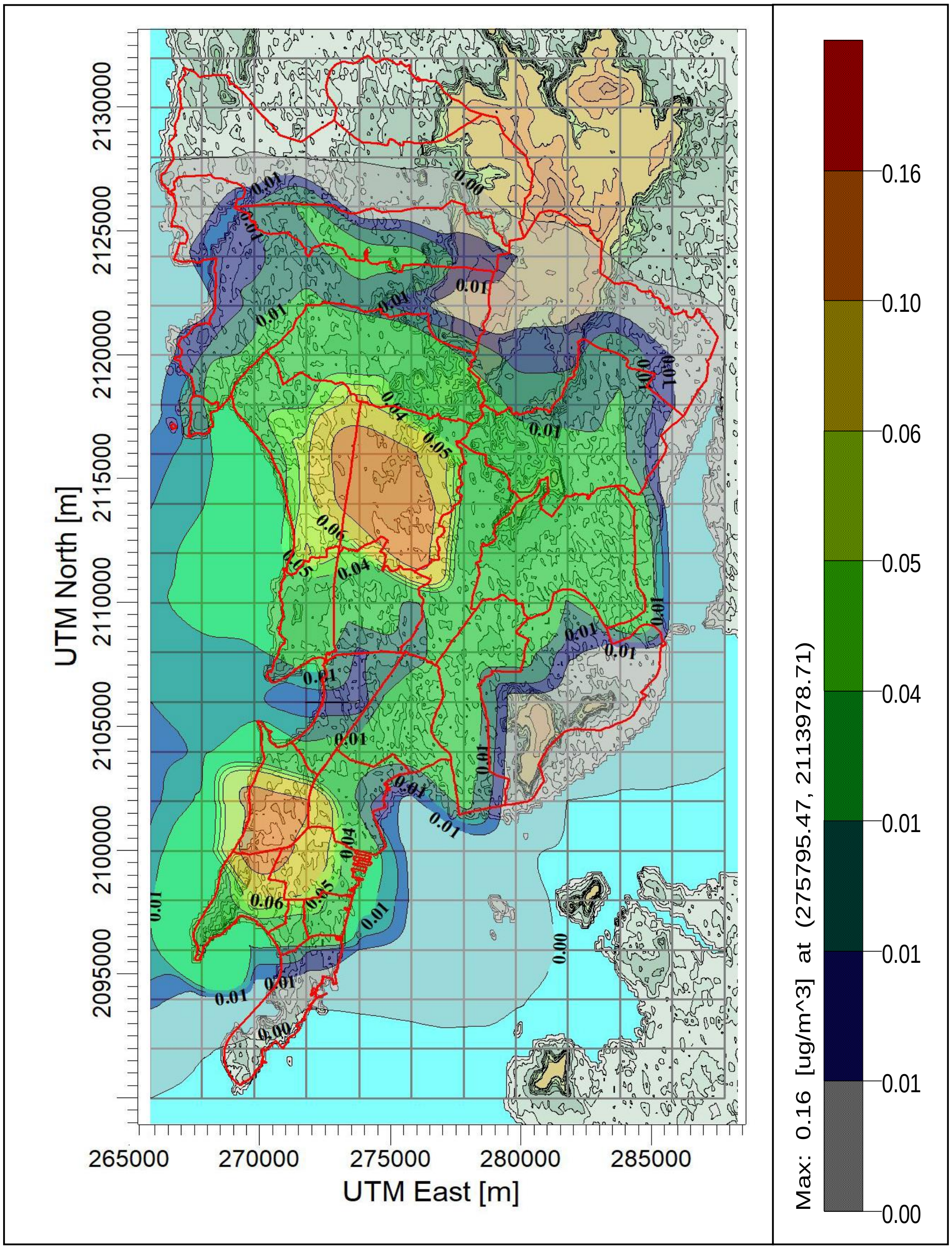


Figure 5.32:Isopleths of PM Due to Point Sources (MSI & SSI) Only Annual

Table 5.7: List of AERMOD simulations for NOx Isopleths for delineated Sources only

Sr. No.	Scenario	Figure No.
1	Isopleths of NOx Due to Area Sources only Summer Season (Mumbai City)	5.33
2	Isopleths of NOx Due to Area Sources only Post Monsoon Season (Mumbai City)	5.34
3	Isopleths of NOx Due to Area Sources only Winter Season (Mumbai City)	5.35
4	Isopleths of NOx Due to Area Sources only Annual (Mumbai City)	5.36
5	Isopleths of NOx Due to Line Sources only Summer Season (Mumbai City)	5.37
6	Isopleths of NOx Due to Line Sources only Post Monsoon Season (Mumbai City)	5.38
7	Isopleths of NOx Due to Line Sources only Winter Season (Mumbai City)	5.39
8	Isopleths of NOx Due to Line Sources only Annual (Mumbai City)	5.40
9	Isopleths of NOx Due to Point Sources (LSI) only Summer Season (Mumbai City)	5.41
10	Isopleths of NOx Due to Point Sources (LSI) only Post Monsoon (Mumbai City)	5.42
11	Isopleths of NOx Due to Point Sources (LSI) only Winter Monsoon (Mumbai City)	5.43
12	Isopleths of NOx Due to Point Sources (LSI) only Annual (Mumbai City)	5.44
13	Isopleths of NOx Due to Point Sources (MSI & SSI) only Summer Season (Mumbai City)	5.45
14	Isopleths of NOx Due to Point Sources (MSI & SSI) only Post Monsoon Season (Mumbai City)	5.46
15	Isopleths of NOx Due to Point Sources (MSI & SSI) only Winter Season (Mumbai City)	5.47
16	Isopleths of NOx Due to Point Sources (MSI & SSI) only Annual (Mumbai City)	5.48

A) AREA SOURCE – ALL (NOx)

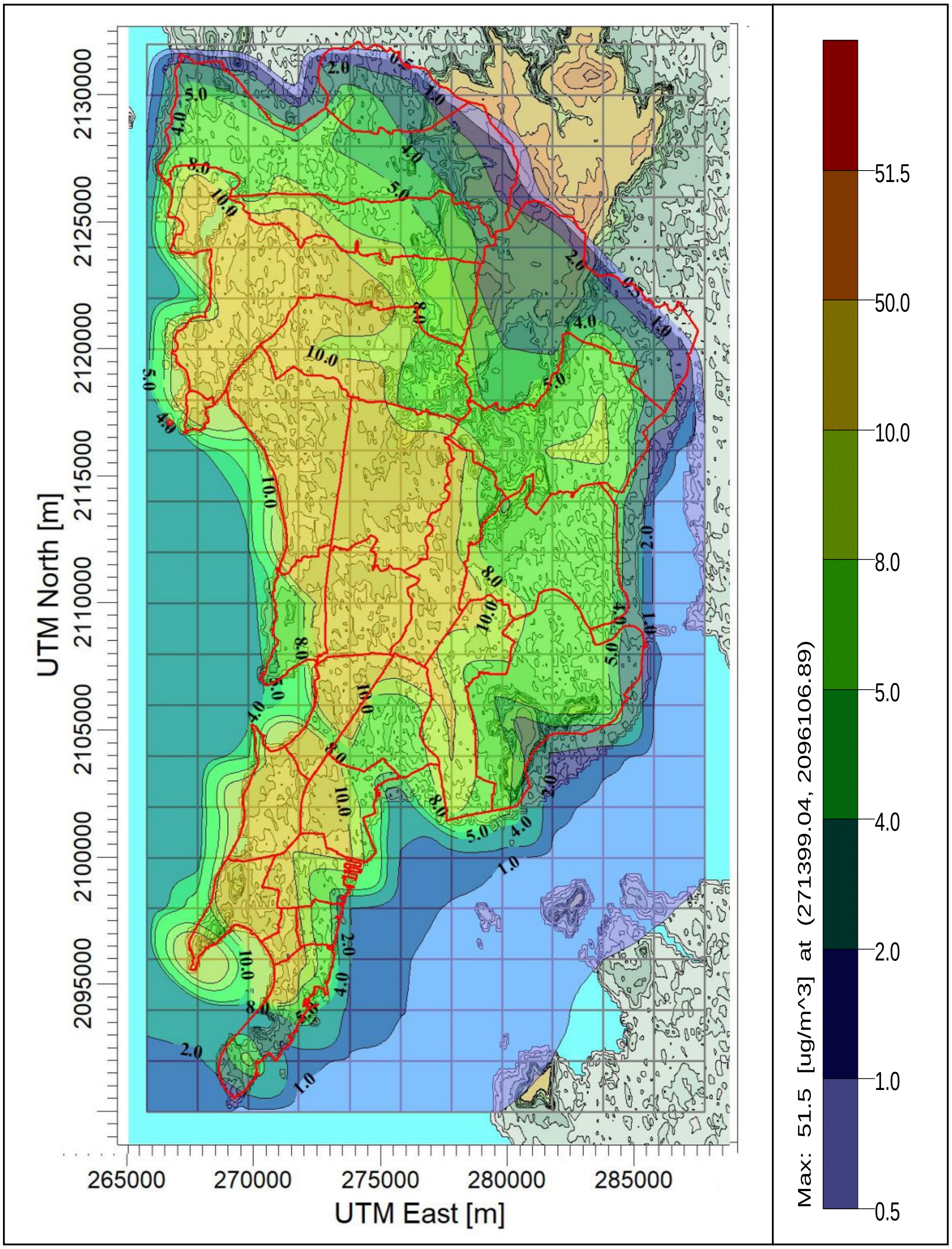


Figure 5.33: Isopleths of NOx Due to Area Sources only Summer Season

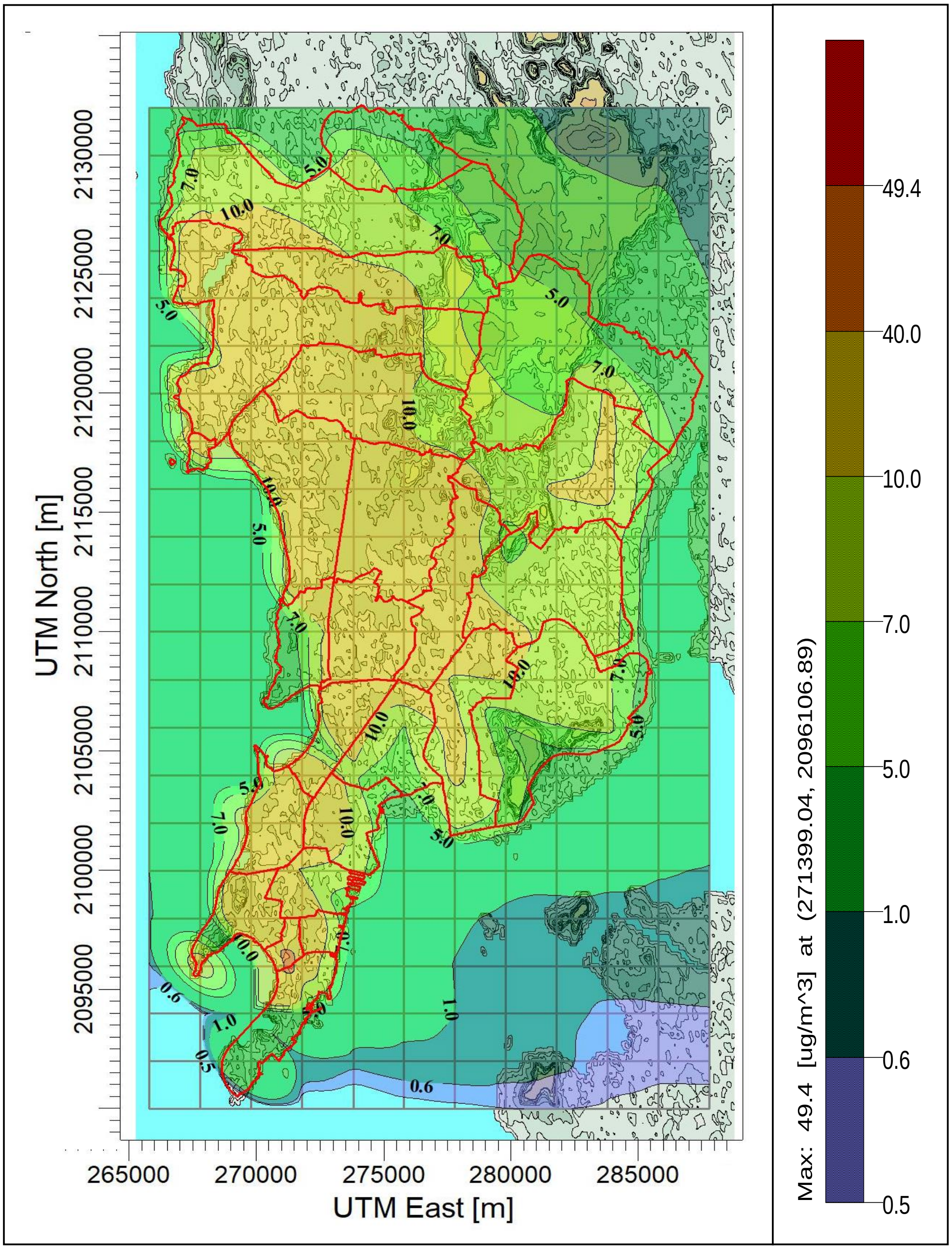


Figure 5.34: Isopleths of NOx Due to Area Sources only Post Monsoon Season

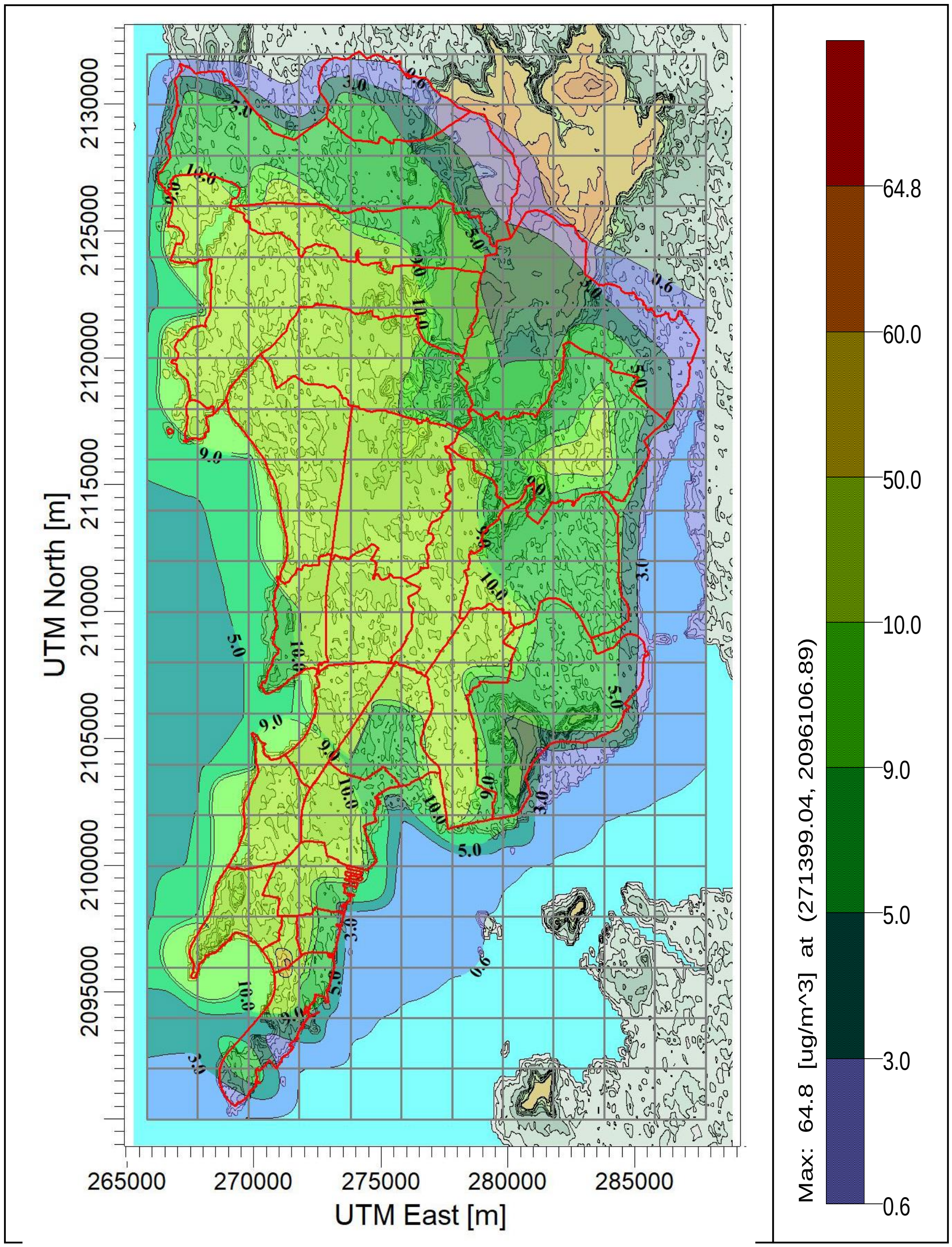


Figure 5.35: Isopleths of NOx Due to Area Sources only Winter Season

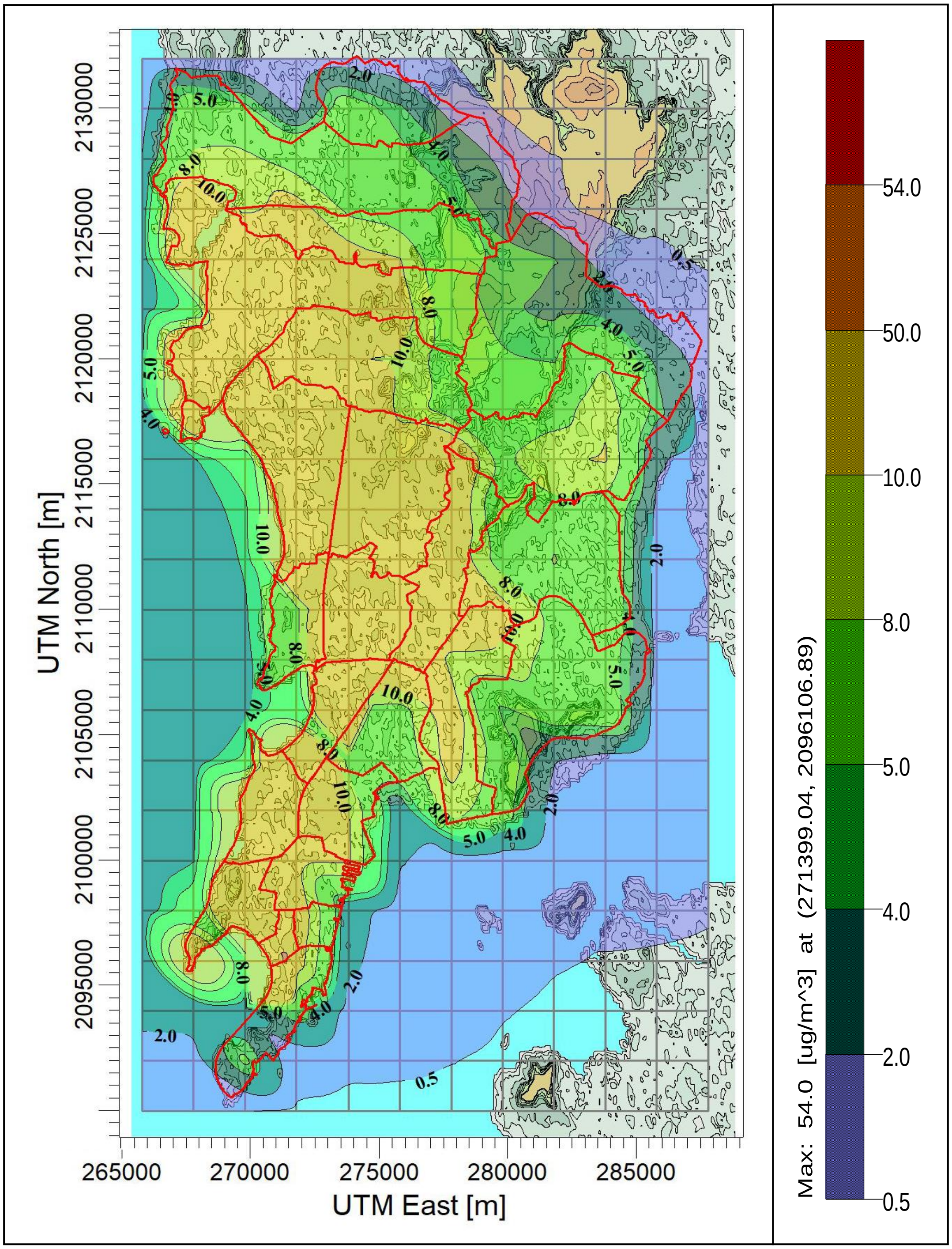


Figure 5.36: Isopleths of NOx Due to Area Sources only Annual

B) LINE SOURCE – ALL (NOx)

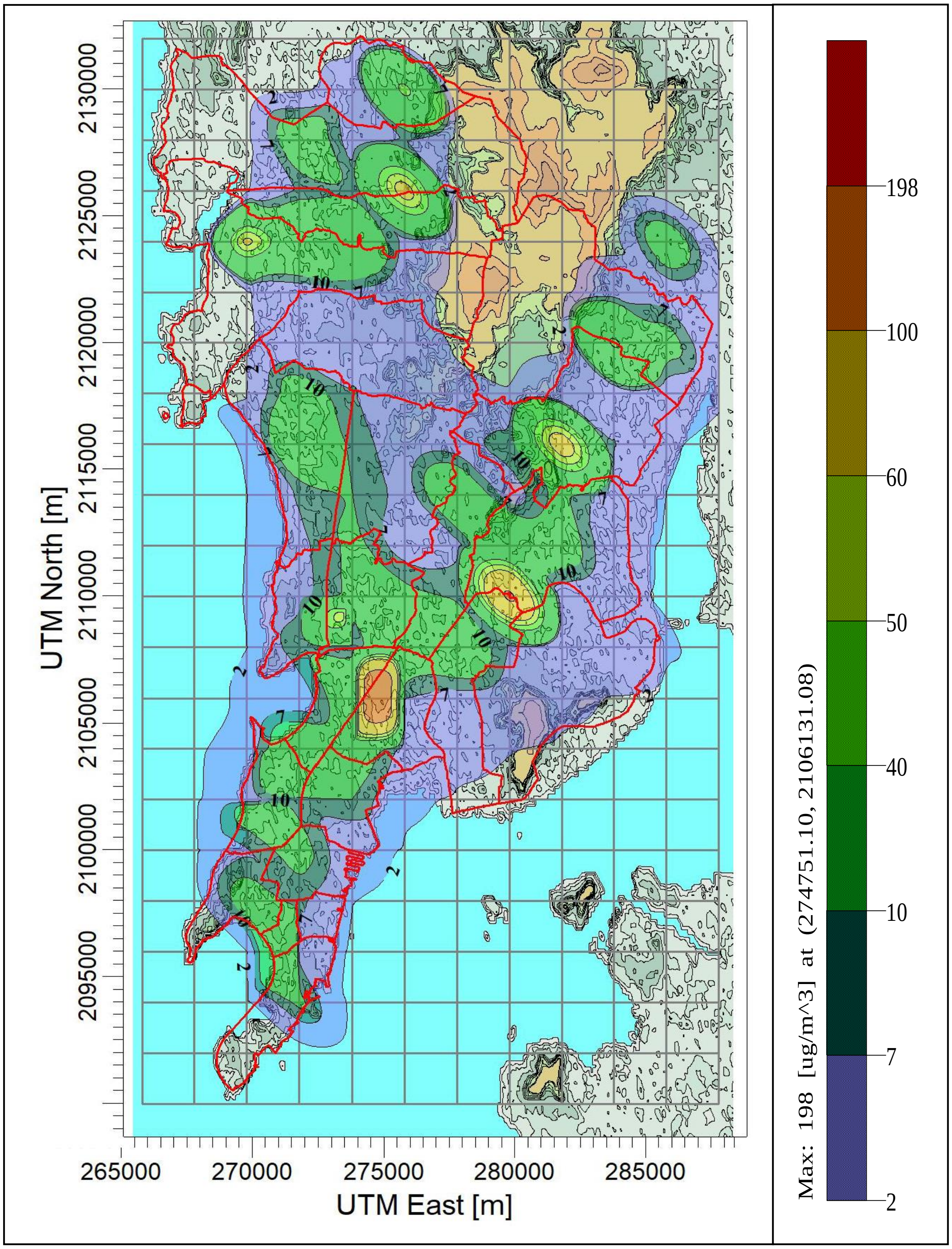


Figure 5.37: Isopleths of NOx Due to Line Sources only Summer Season

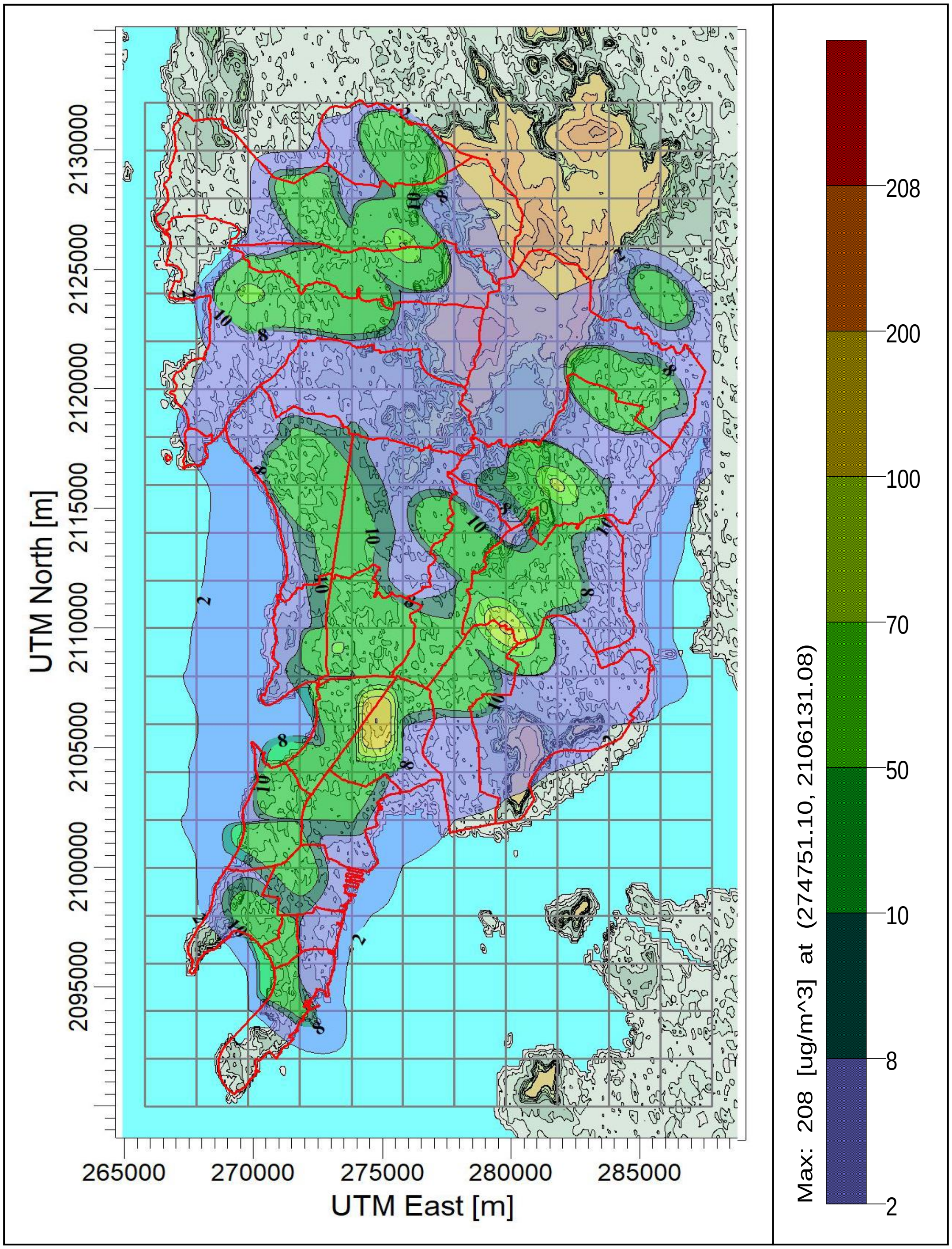


Figure 5.38: Isopleths of NOx Due to Line Sources only Post Monsoon Season

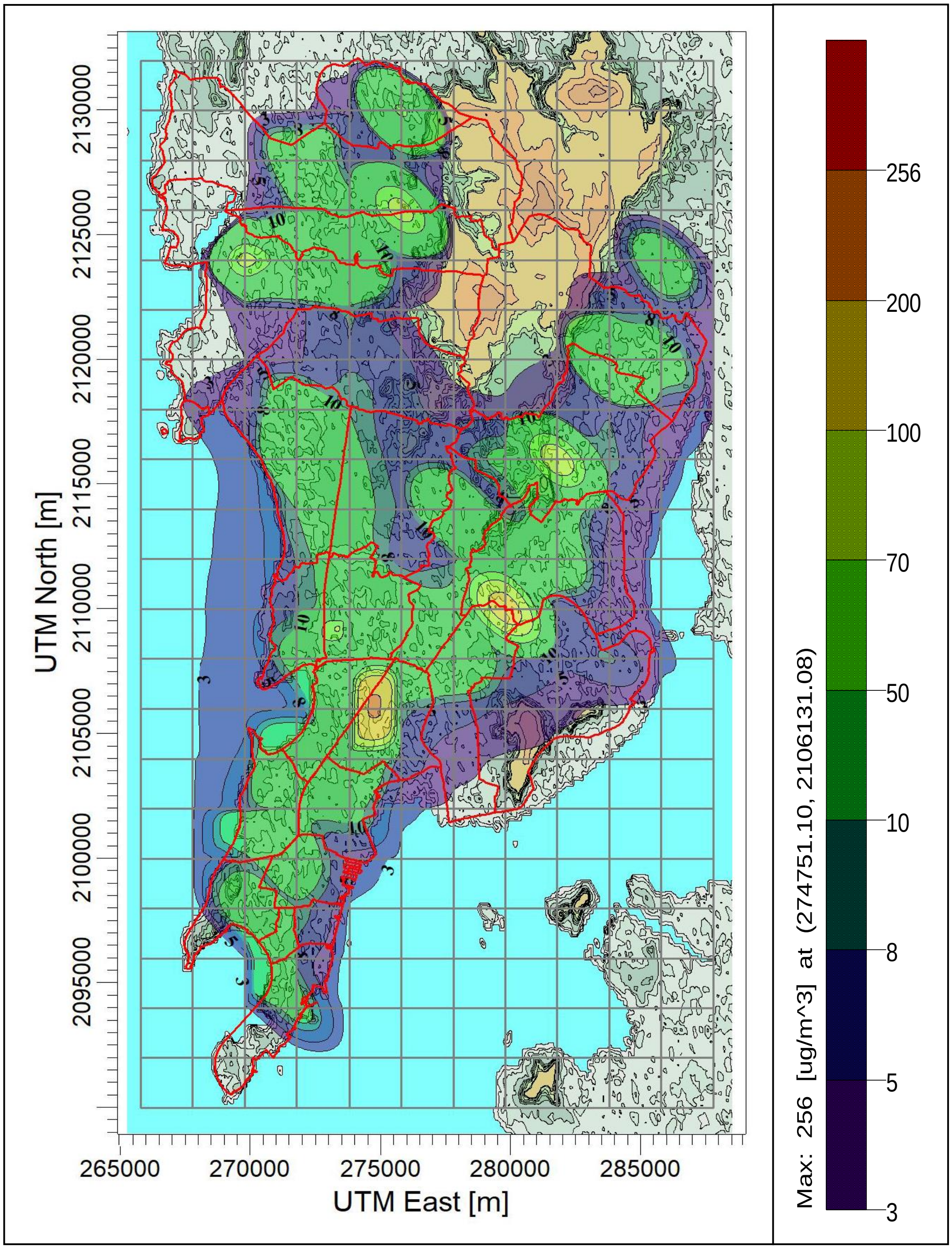


Figure 5.39: Isopleths of NOx Due to Line Sources only Winter Season

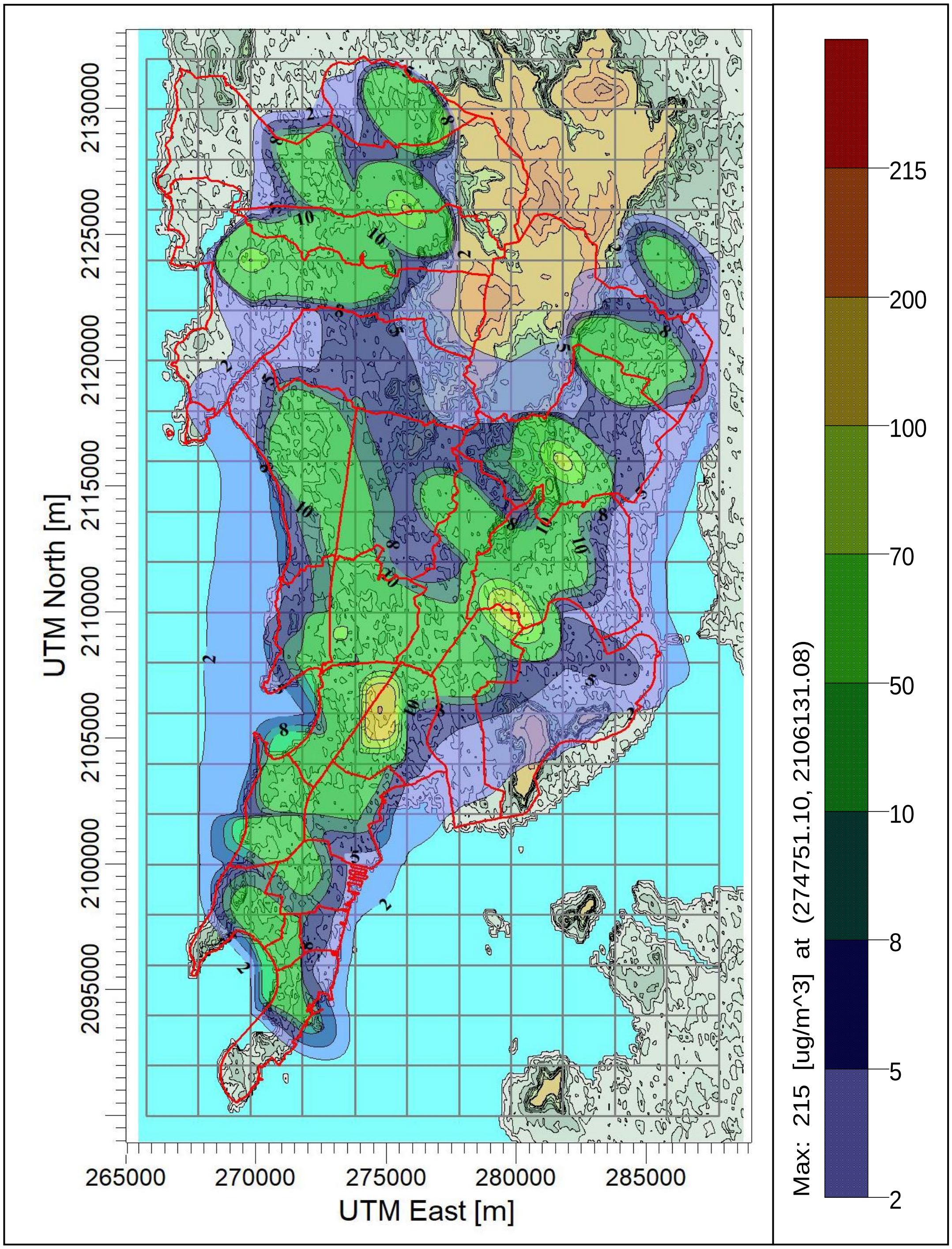


Figure 5.40: Isopleths of NOx Due to Line Sources only Annual

C) POINT SOURCE – LSI (NOx)

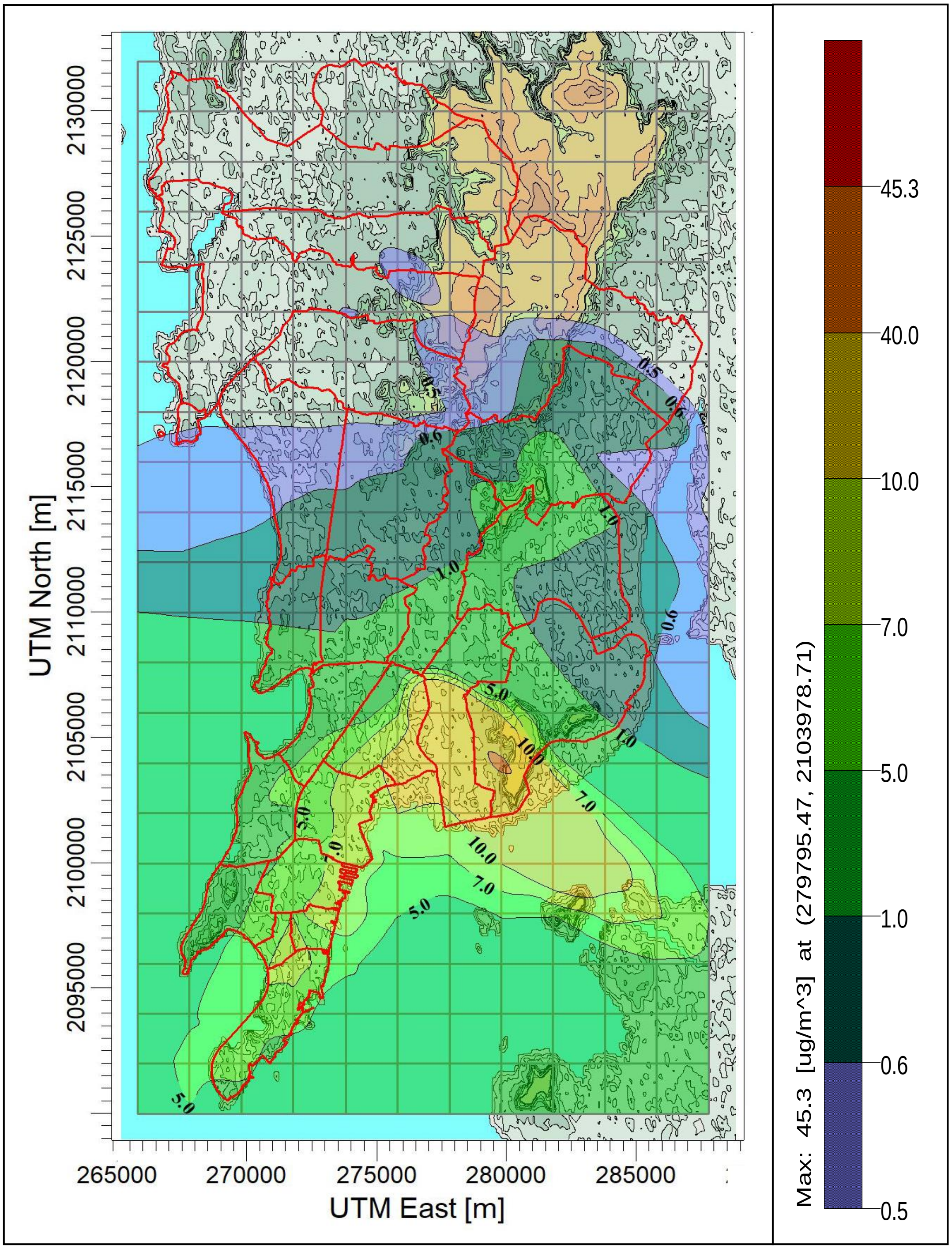


Figure 5.41: Isopleths of NOx Due to Point Sources (LSI) only Summer Season

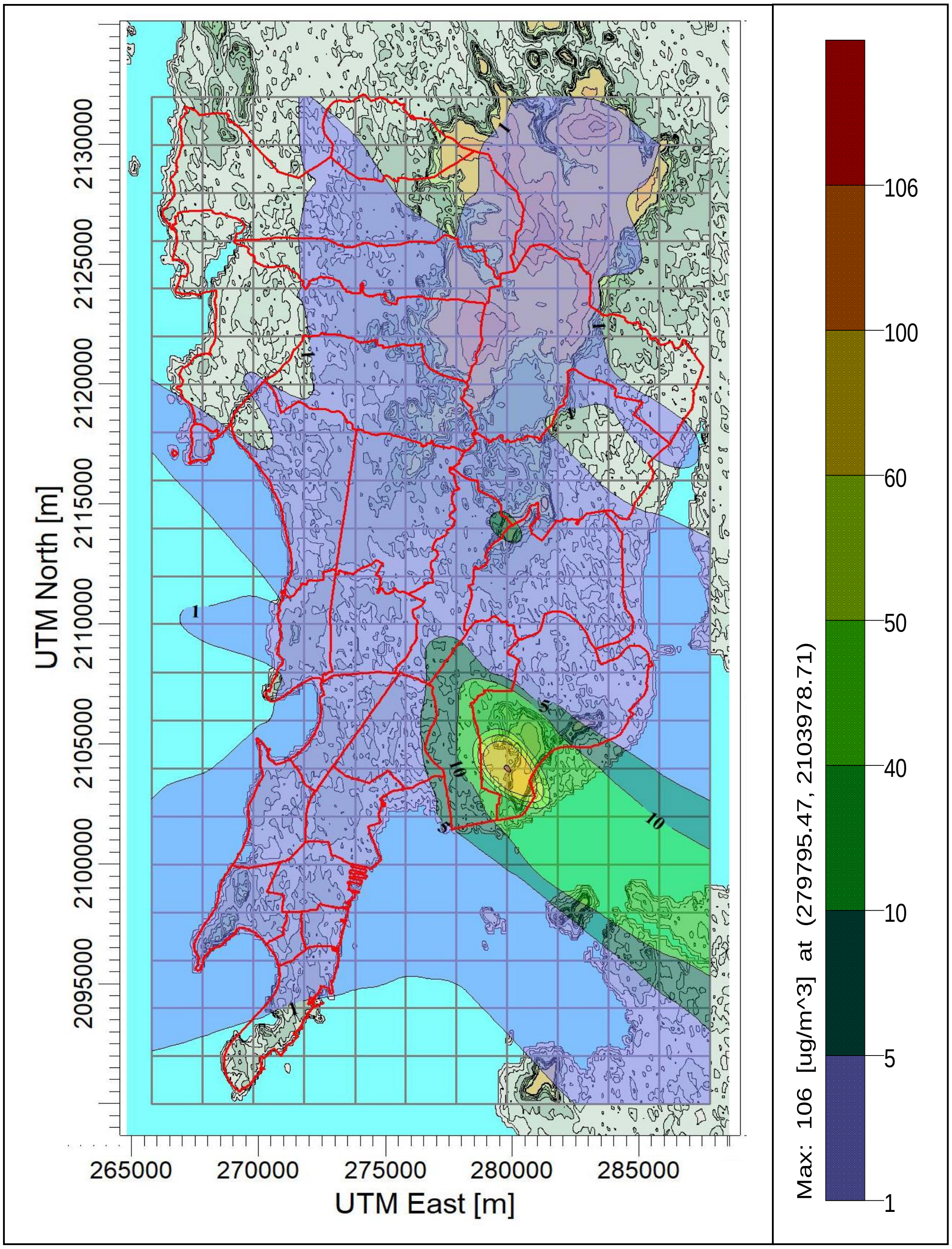


Figure 5.42: Isopleths of NOx Due to Point Sources (LSI) only Post Monsoon Season

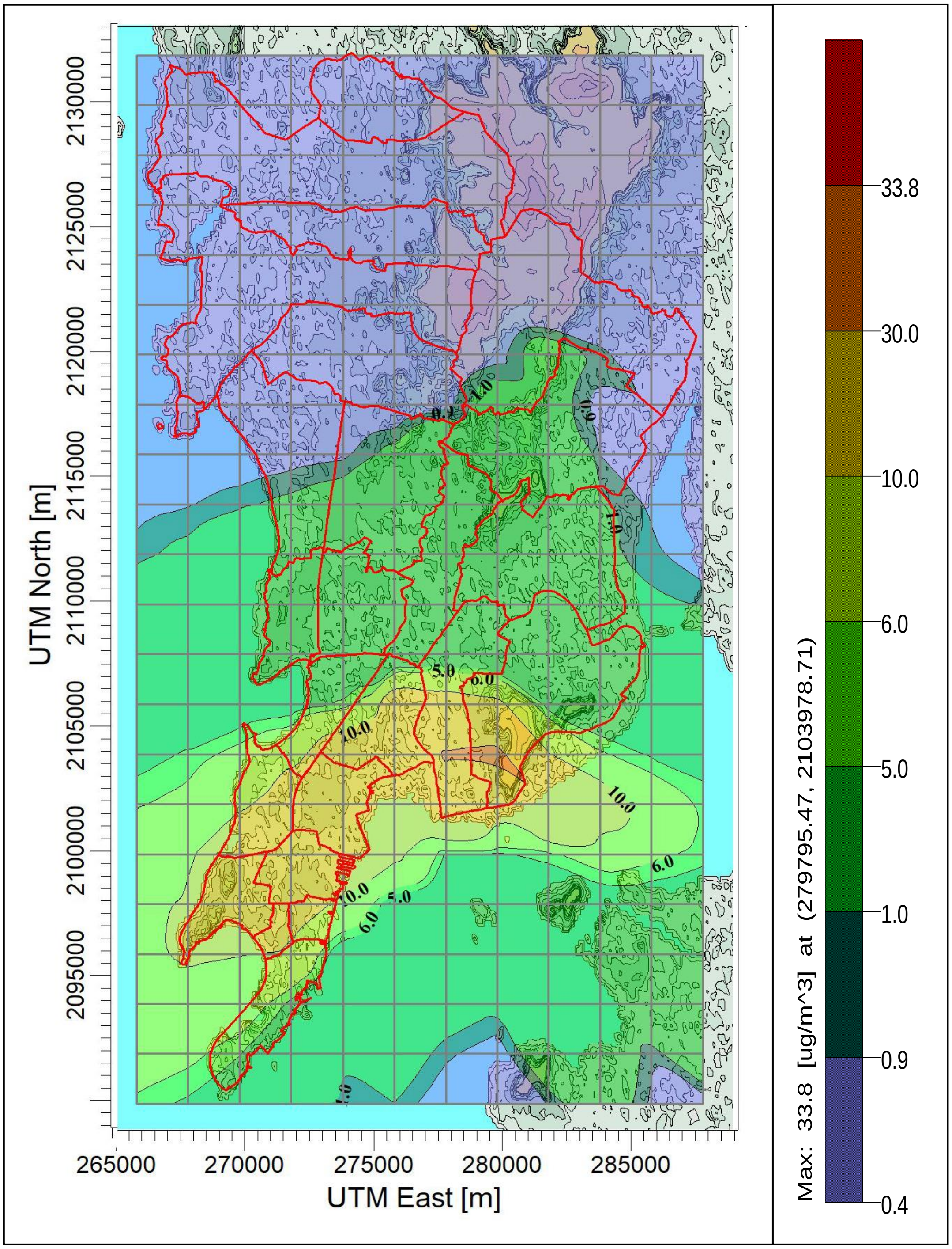


Figure 5.43: Isopleths of NOx Due to Point Sources (LSI) only Winter Season

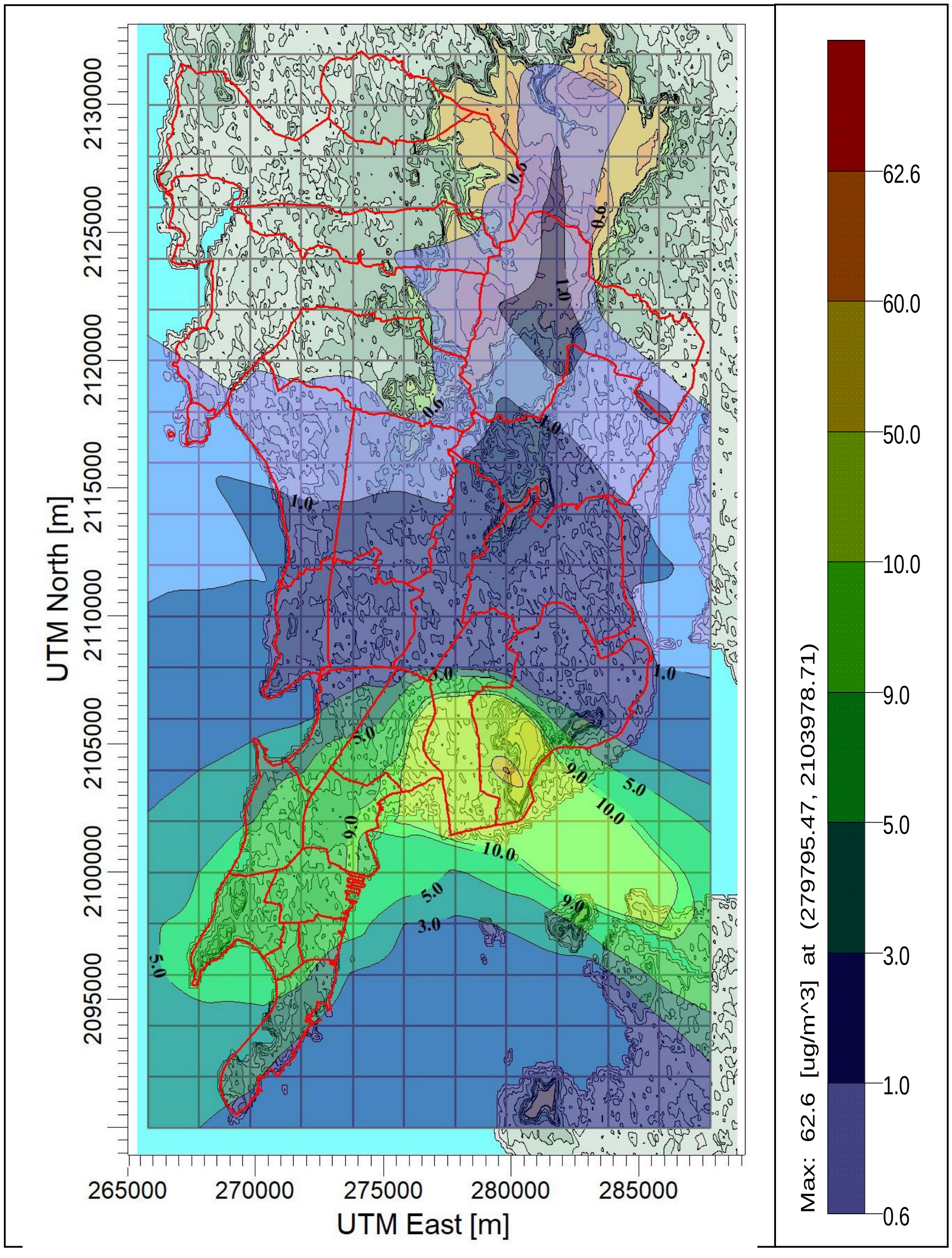


Figure 5.44: Isopleths of NOx Due to Point Sources (LSI) only Annual

E) POINT SOURCE – MSI & SSI (NOx)

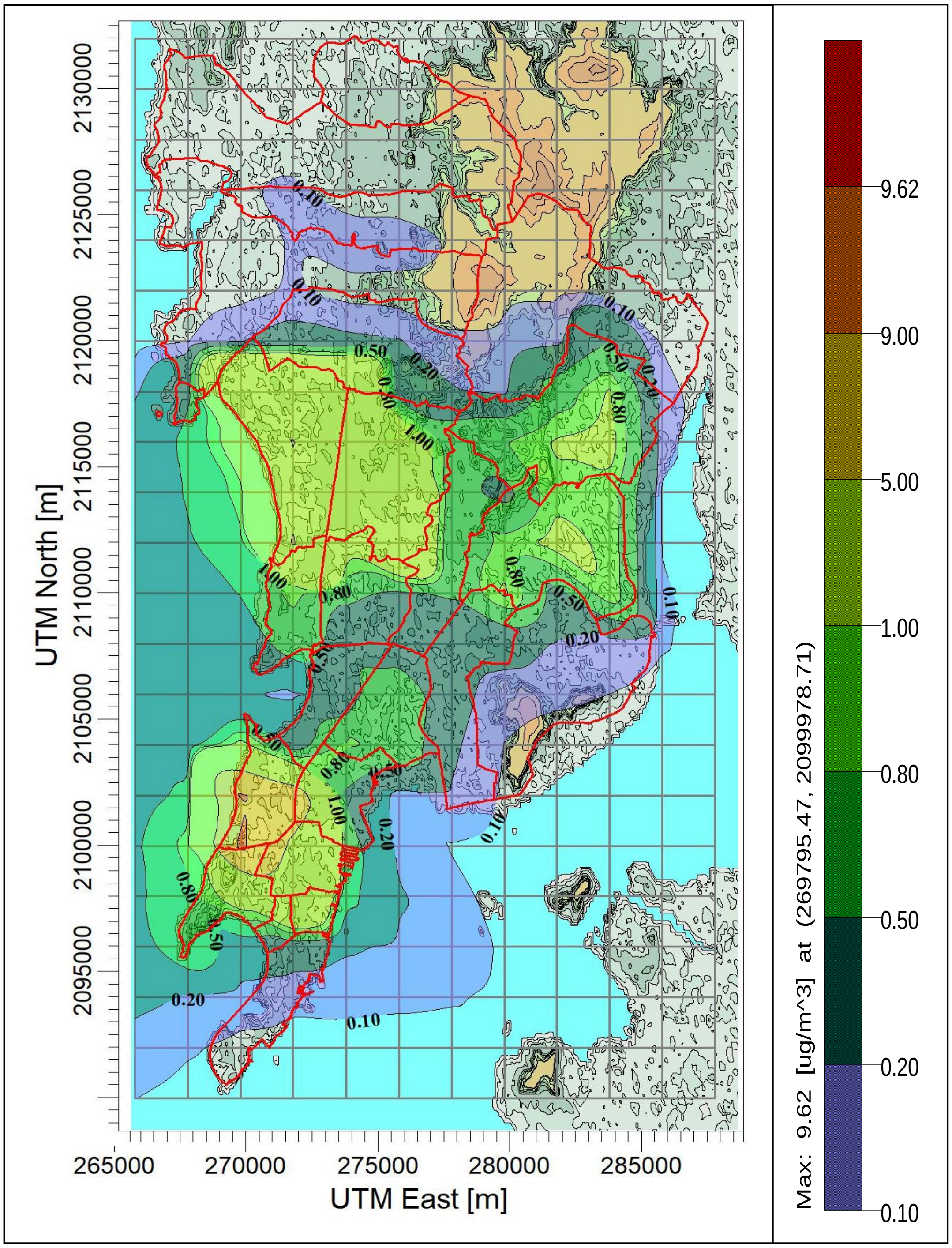


Figure 5.45: Isopleths of NOx Due to Point Sources (MSI & SSI) only Summer Season

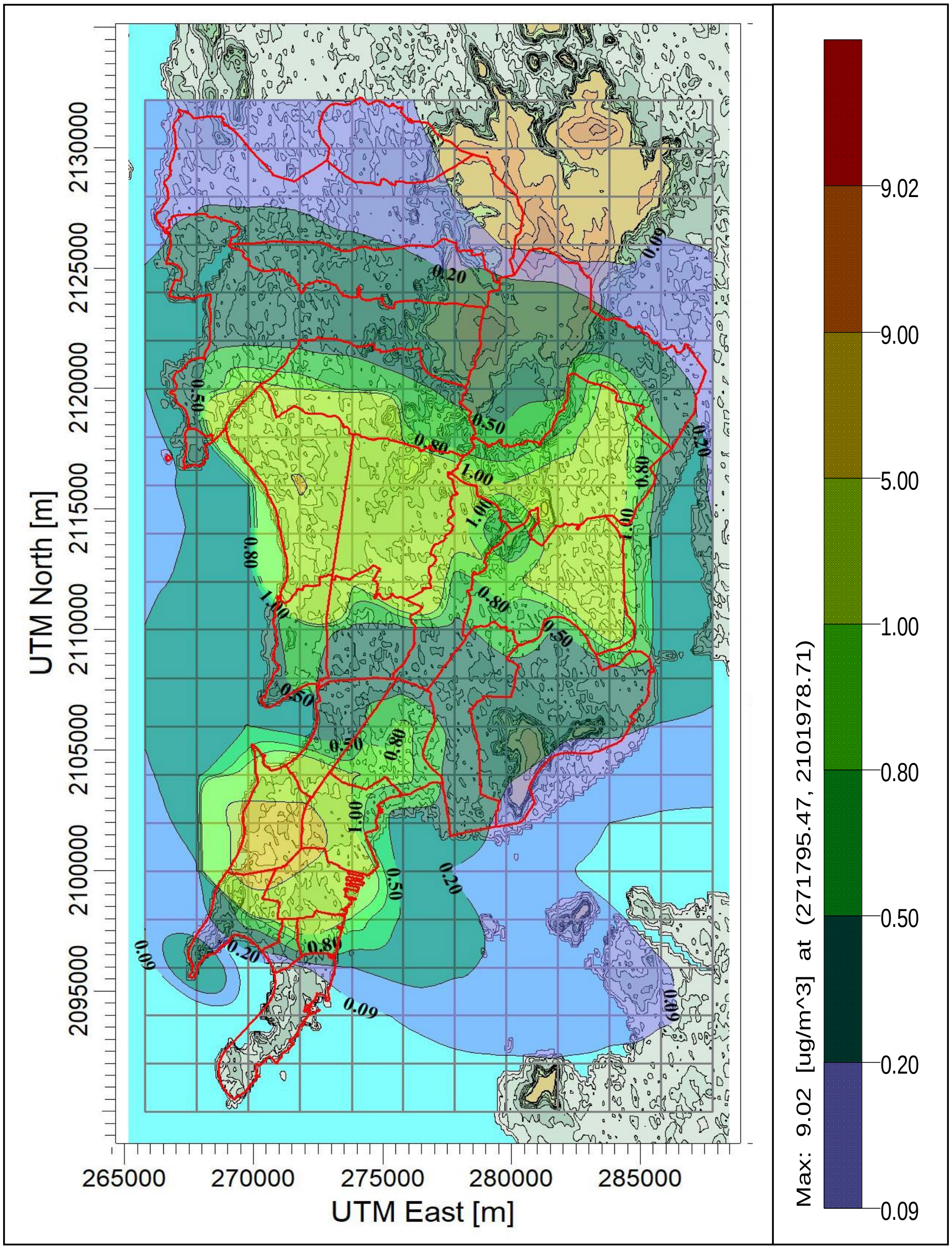


Figure 5.46: Isopleths of NOx Due to Point Sources (MSI & SSI) only Post Monsoon Season

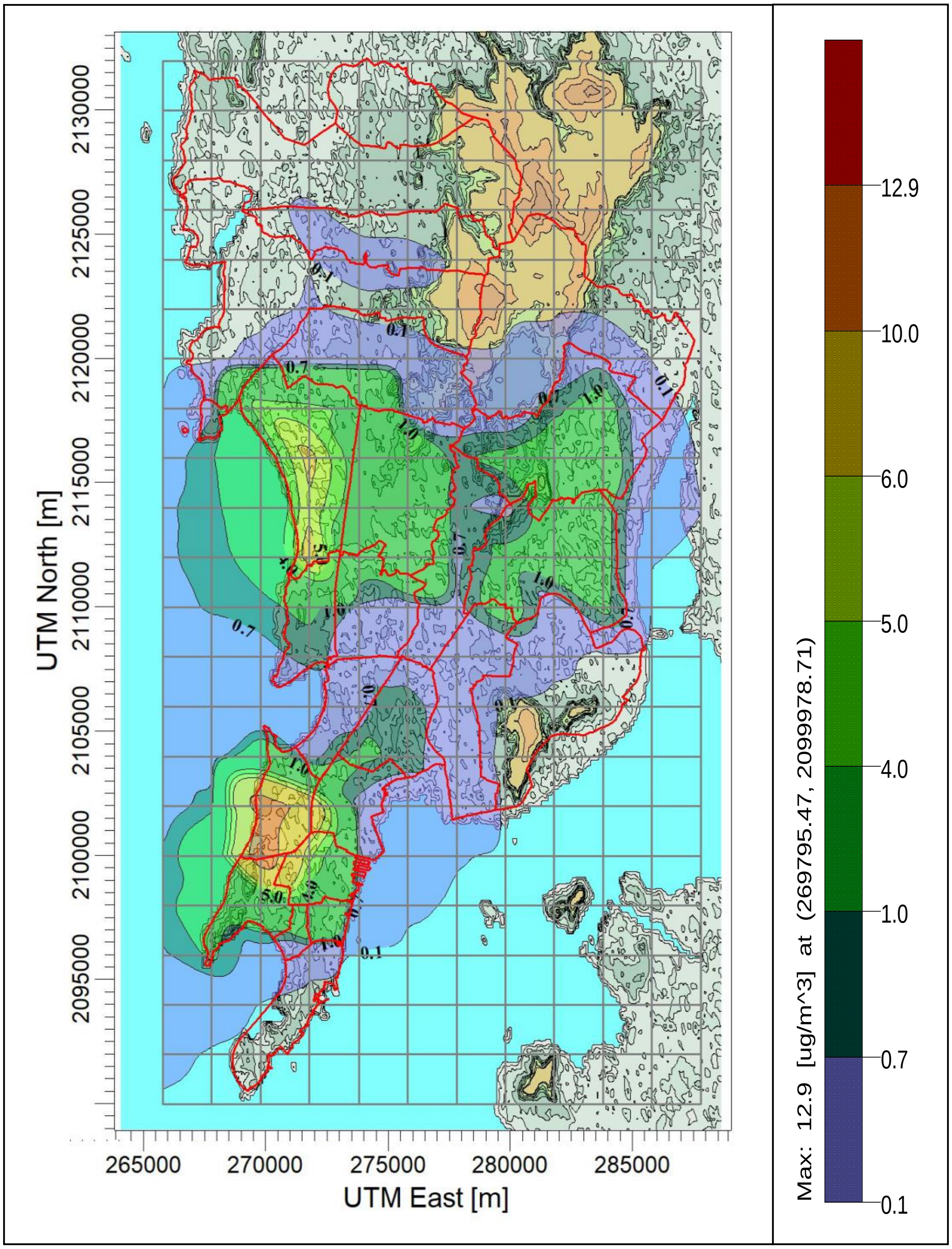


Figure 5.47: Isopleths of NOx Due to Point Sources (MSI & SSI) only Winter Season

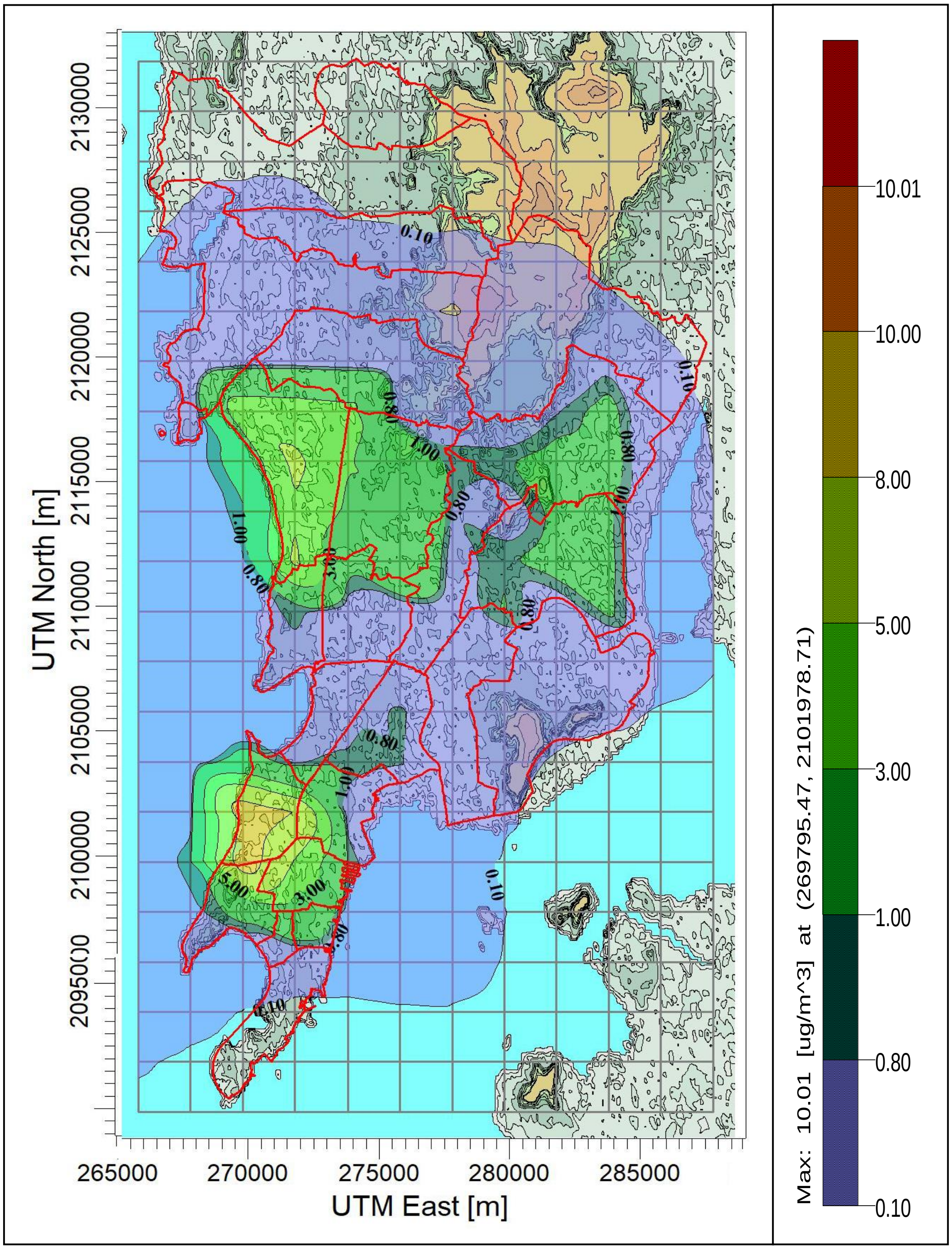


Figure 5.48: Isopleths of NOx Due to Point Sources (MSI & SSI) only Annual

Chapter 6

Simulations Based on 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 improvement alone but also by the nature of the recommendations, fiscal and administrative requirements implementing agencies and acceptance from a large group of stakeholders. Prioritization issues are also driven by the comparative account of short-term and long-term implementation dilemma. Some of these considerations have been used here to prioritize the options in each case of vehicular, industrial and area sources, and are presented in the following sections.

6.1 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 as given in **Table 6.1.** Dispersion runs were carried out for many scenarios and based on options, wherever the effectiveness of PM and NOx reductions were significant, those were selected and included for the model runs. In order to achieve maximum reduction in emission loads, it is essential to prioritize selected control option, taking into account their respective sources. 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. Priority I was considered for 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 are further aggressively implemented during the long term stage **(Priority II= Priority I + 5 years)**, so as to cover the aspects which would not be 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 (BaU) Scenario considering the growth of vehicles and activities within the area sources, no changes were assumed for industrial growth in Mumbai city. The annual predicted concentrations for different sources in BaU and control option scenario are presented in **Table 6.2** and **Table 6.3** for PM and NOx.

Table 6.1: Summary of Options used for City Based Model Run

Category		**Control Options**	**Priority I**	**(Priority II= Priority I + 5 years)**
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]
			Power Plant : Coal to NG -50%	100% to NG
Area Sources		Domestic	25% of slums to use LPG/ PNG 50% of non slum to use LPG/PNG	50% of slum to use LPG 100% same
		Hotel & 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%

	Ports	Awareness and Management	
	Airports	Awareness and Better Inventory	
	Railways	100% on electric	100% on electric

Table 6.2: Comparison of PM_{10} Concentrations BaU With Preferred Priority I (now) **& Preferred Priority II (+5 years)**

Sources Group	Base Year	BaU Now	BaU Now + 5 years	Preferred –(Priority I)	Preferred –(Priority II)
All Group	270.4	293.2	308.3	202.1	135.4
Area Source	36.9	38.1	40.7	27.6	17.4
Line Source	28.9	31.4	35.4	21.7	14.5
Point Source (LSI)	0.70	0.70	0.70	0.52	0.30
Point Source (MSI & SSI)	0.16	0.16	0.16	0.12	6.9E-02
Resuspension Dust	261.1	284.1	299.3	196.1	131.5

Concentrations in $\mu g/m^3$

Table 6.3: Comparison of NOx Concentrations BaU With Preferred Priority I (now) **& Preferred Priority II (+5 years)**

Sources Group	Base Year	BaU Now	BaU Now + 5 years	Preferred –(Priority I)	Preferred –(Priority II)
All Group	227.1	245.3	276.2	164.3	154.2
Area Source	54.0	57.0	61.5	38.1	37.8
Line Source	215.3	233.2	263.3	156.4	146.2
Point Source (LSI)	62.6	43.8	43.8	29.3	27.2
Point Source (MSI & SSI)	10.01	10.1	10.1	6.68	6.20

Concentrations in $\mu g/m^3$

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. 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 2025 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 the short term and Preferred Option II (i.e. options 1 to 11 for vehicles and all options for industries and area) in 5 yearsfrom now are given in **Figures 6.1 through 6.8.**

The annual predicted 24 hourly average concentrations were compared with the BaU scenarios considering the future growth and after implementation of preferred option for Priority I and Priority II for both PM and NOx are presented in **Figures 6.9 and 6.10** respectively.

A) Predicted Scenario for PM

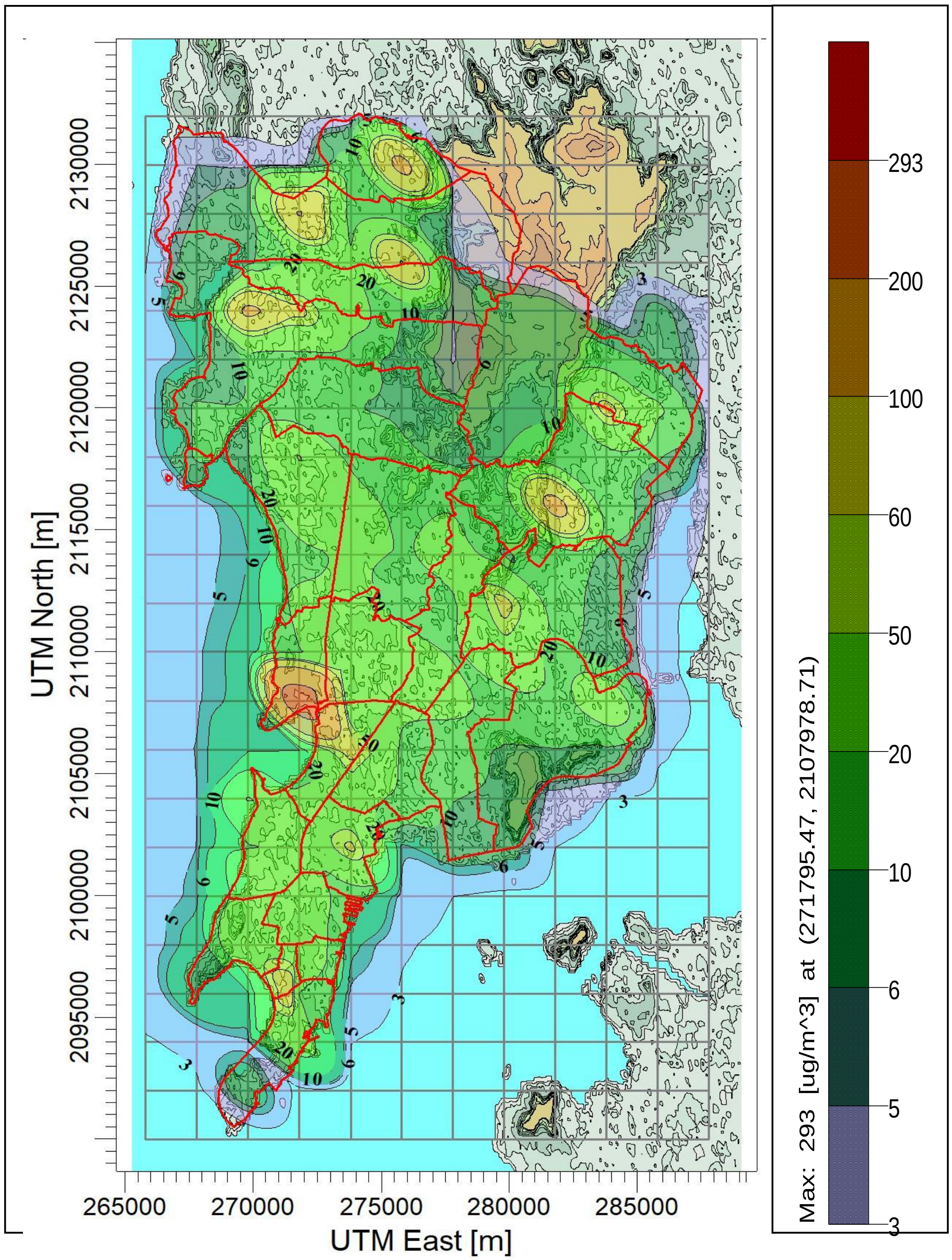


Figure 6.1: Isopleths of PM Due to All Source– BaU (Now)

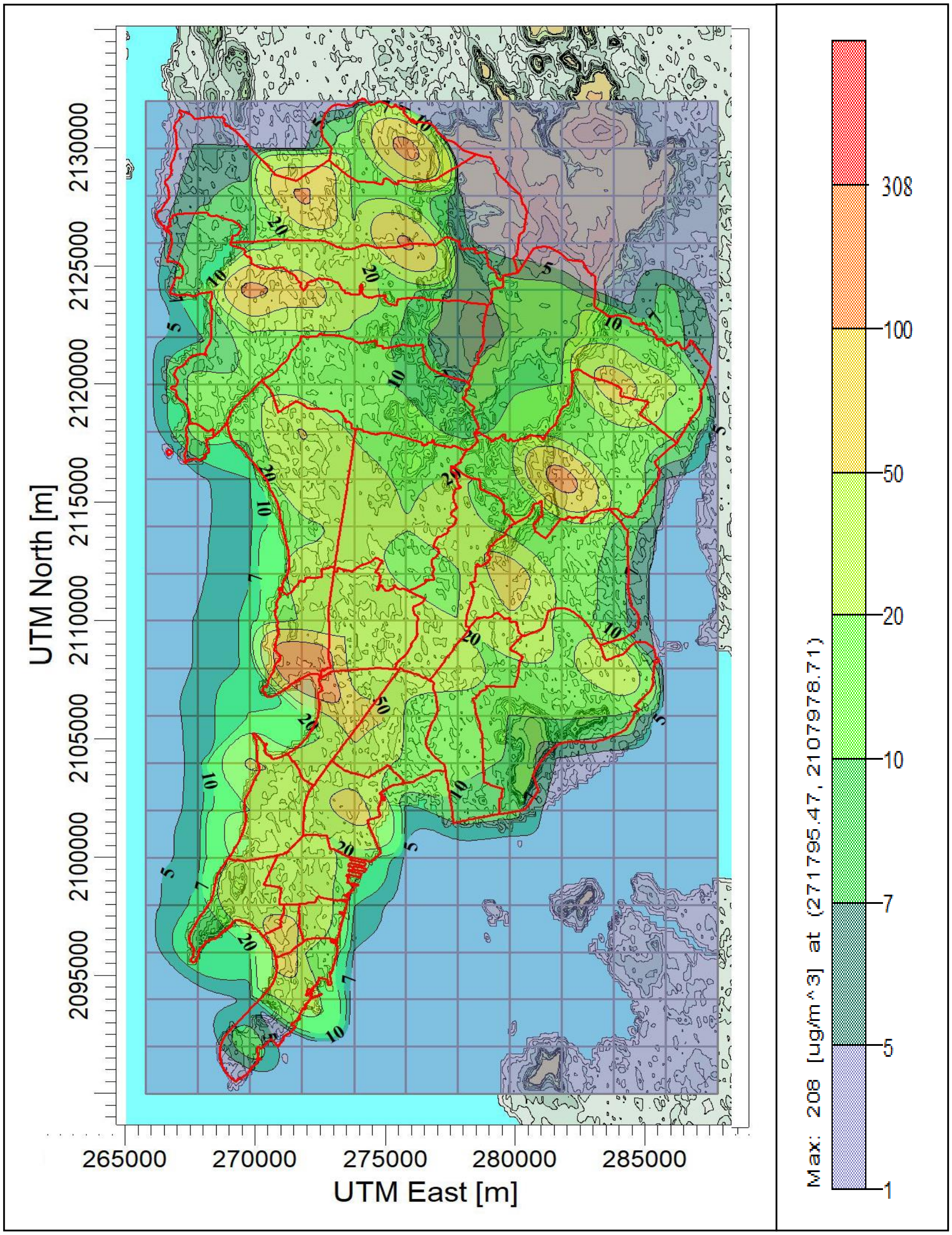


Figure 6.2: Isopleths of PM Due to All Source– BaU (5 years from now)

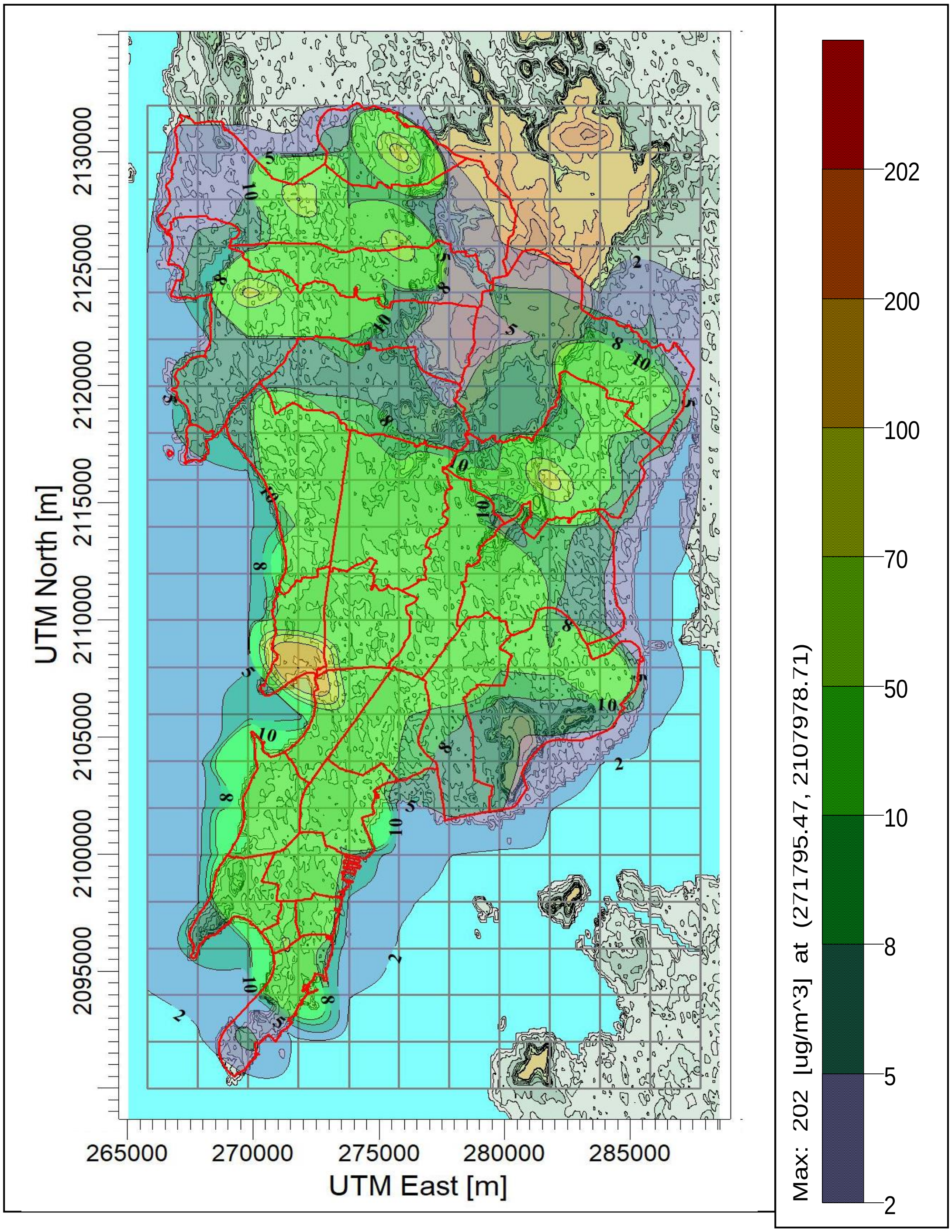


Figure 6.3: Isopleths of PM Due to All Source– Preferred Priority I (Now)

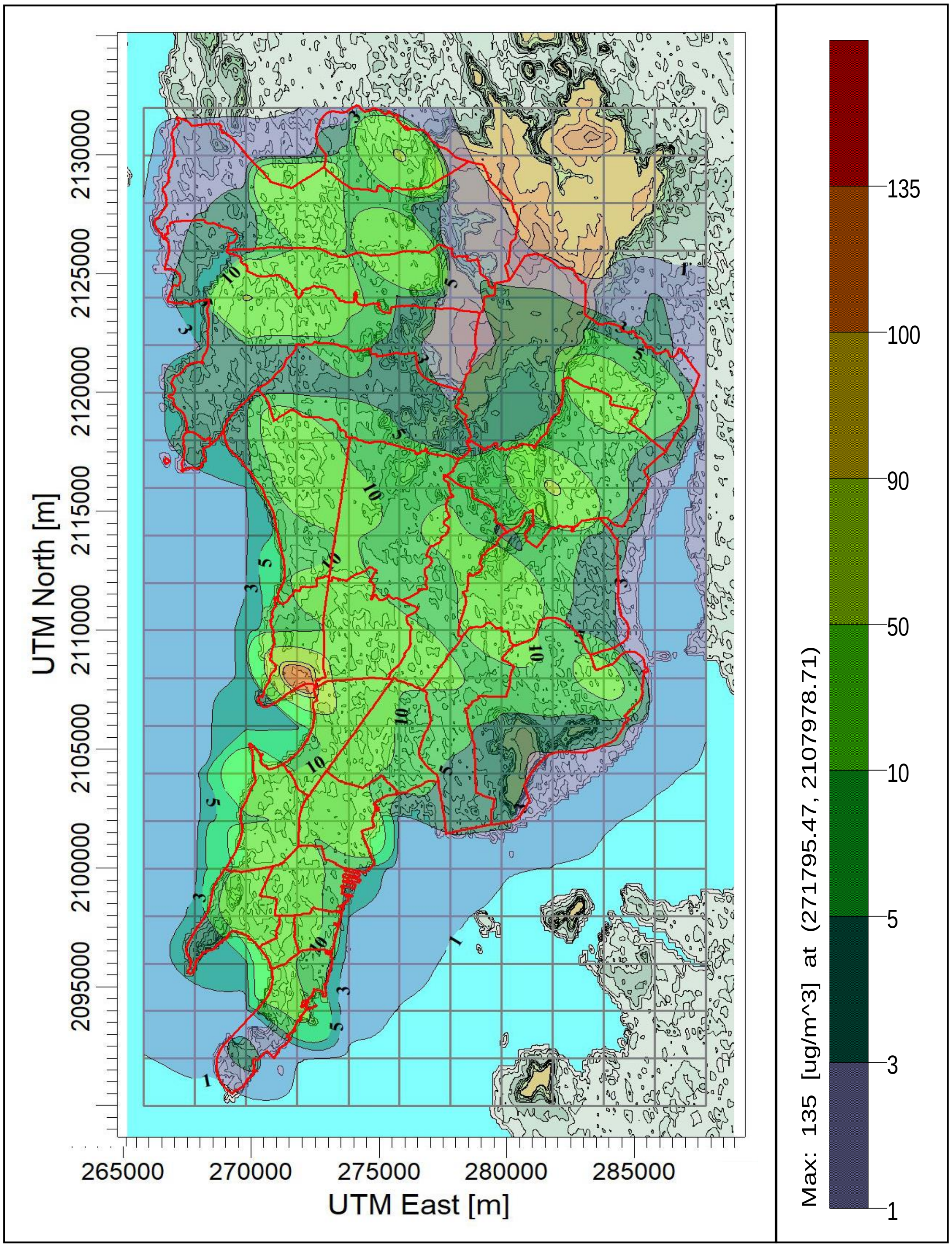


Figure 6.4:Isopleths of PM Due to All Source– Preferred Priority II (5 years from now)

A) Predicted Scenario for NOx

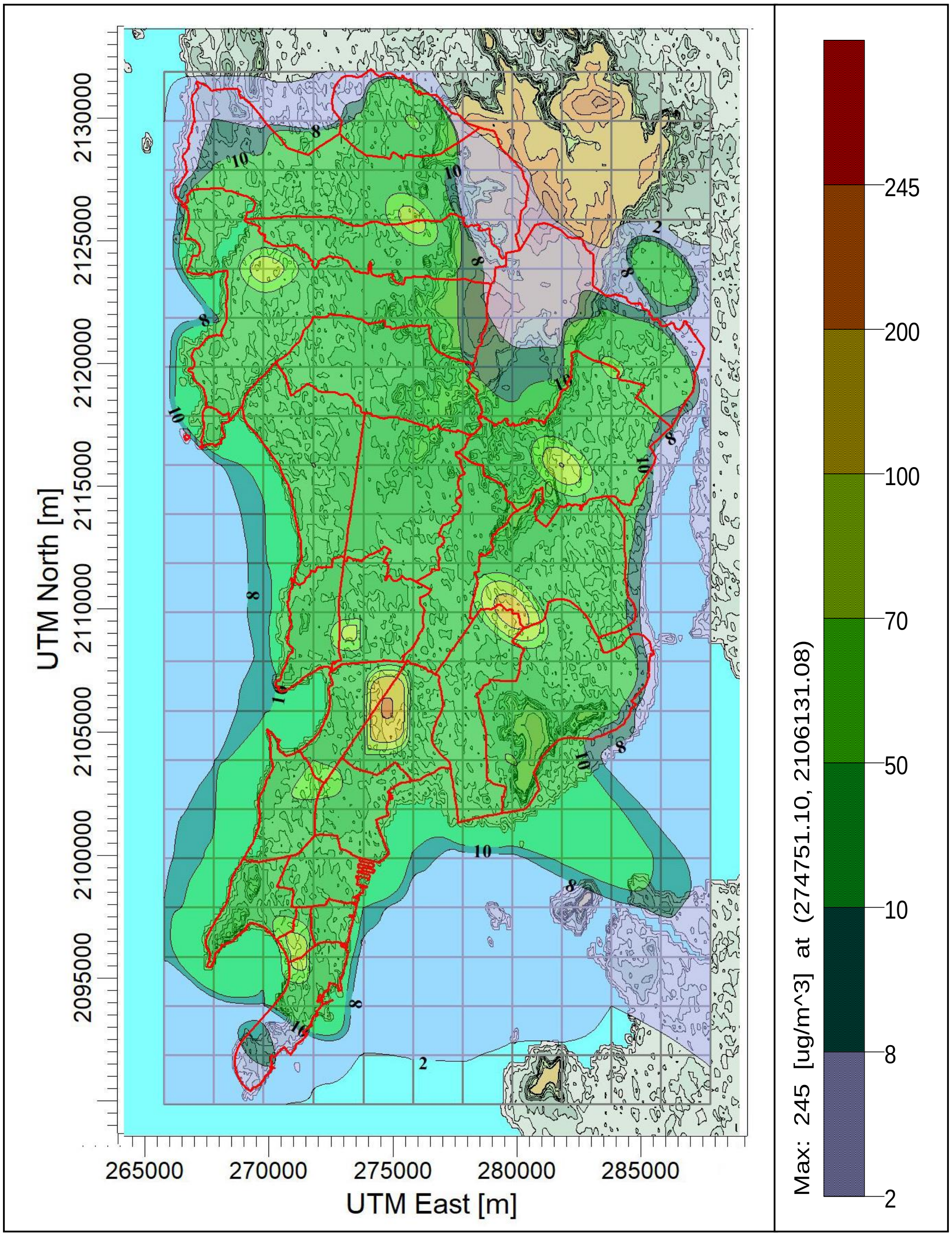


Figure 6.5: Isopleths of NOx Due to All Source– BaU (Now)

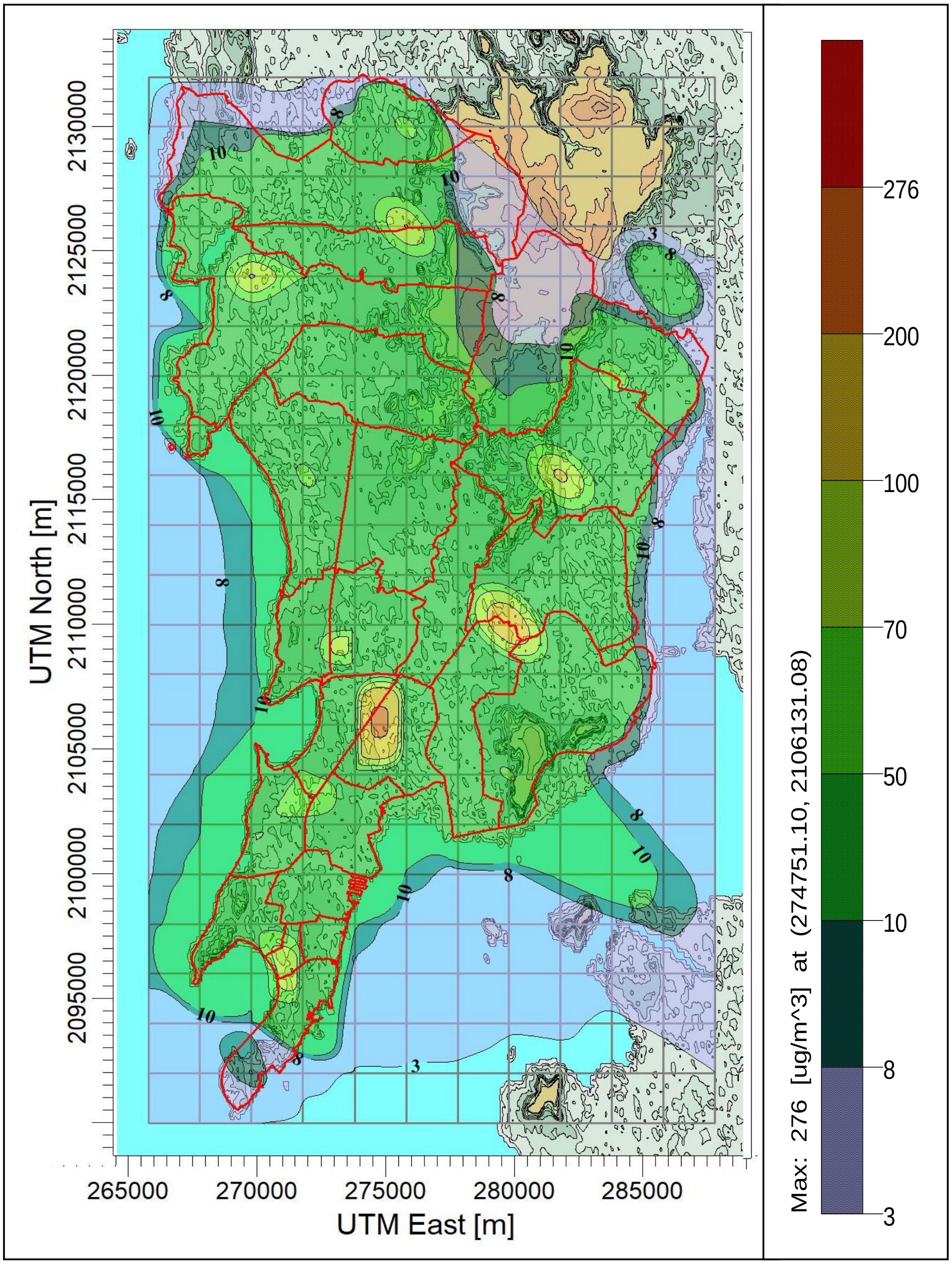


Figure 6.6: Isopleths of NOx Due to All Source– BaU (5 years from now)

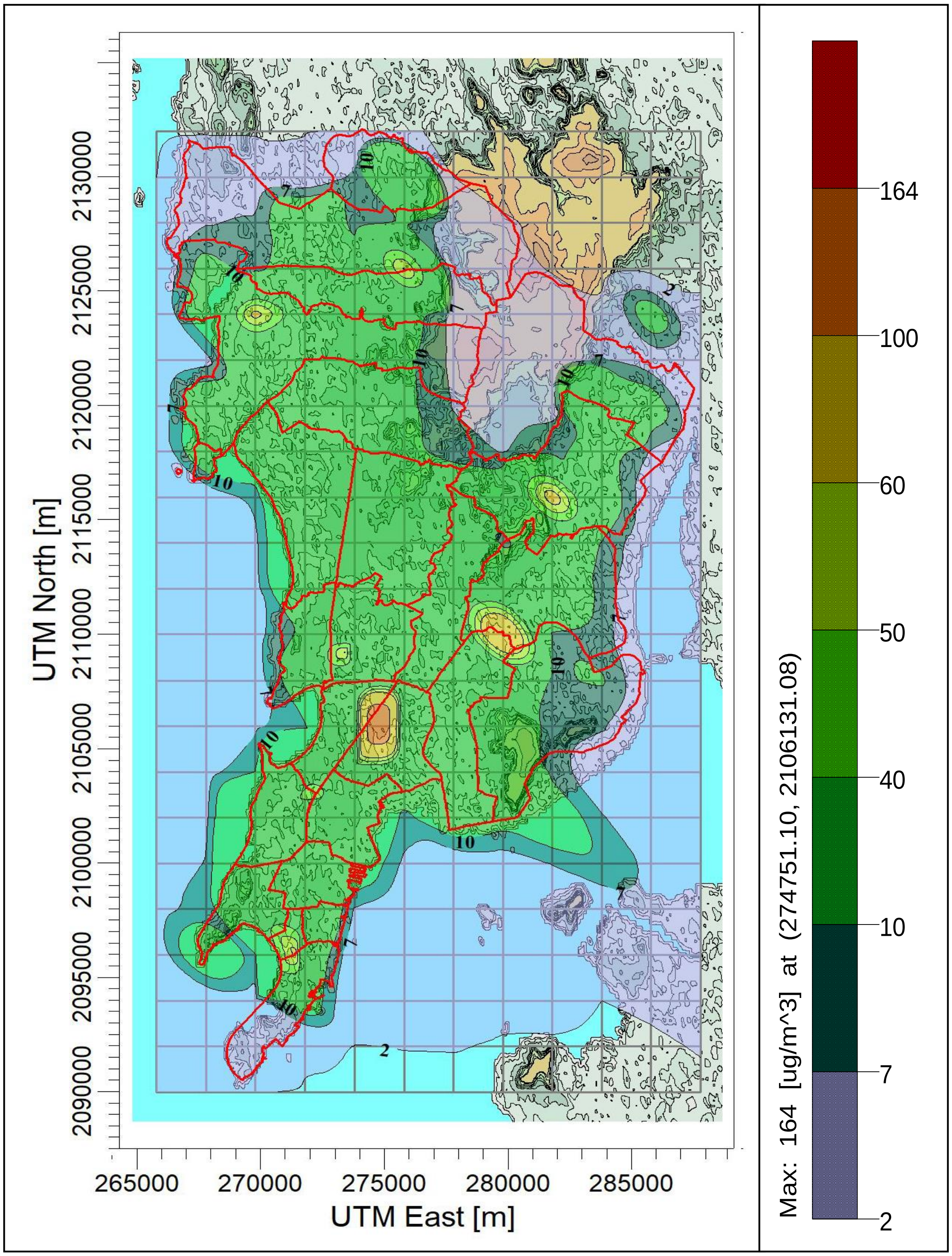


Figure 6.7: Isopleths of NOx Due to All Source– Preferred Priority I (Now)

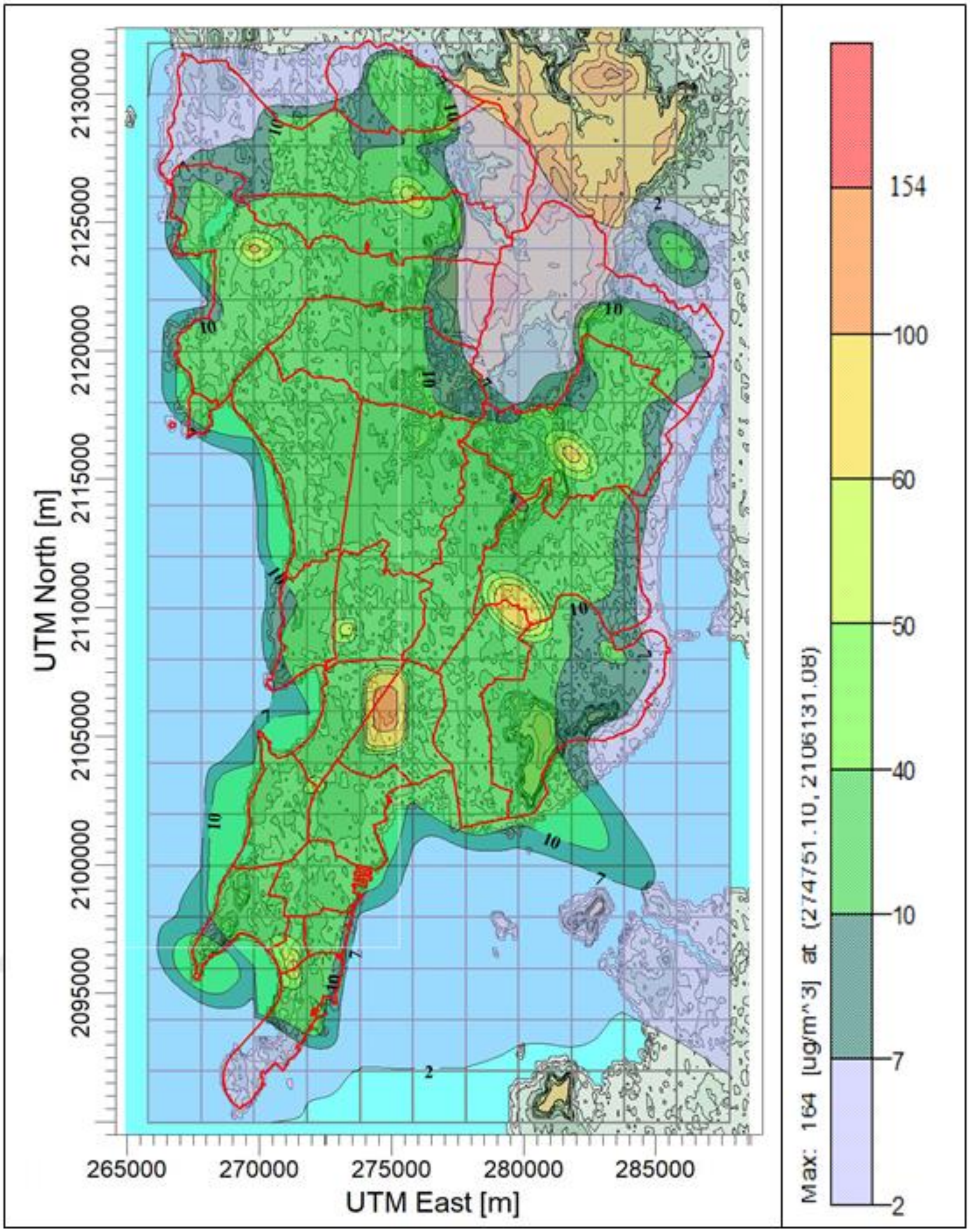


Figure 6.8: Isopleths of NOx Due to All Source– Preferred Priority II (5 years from now)

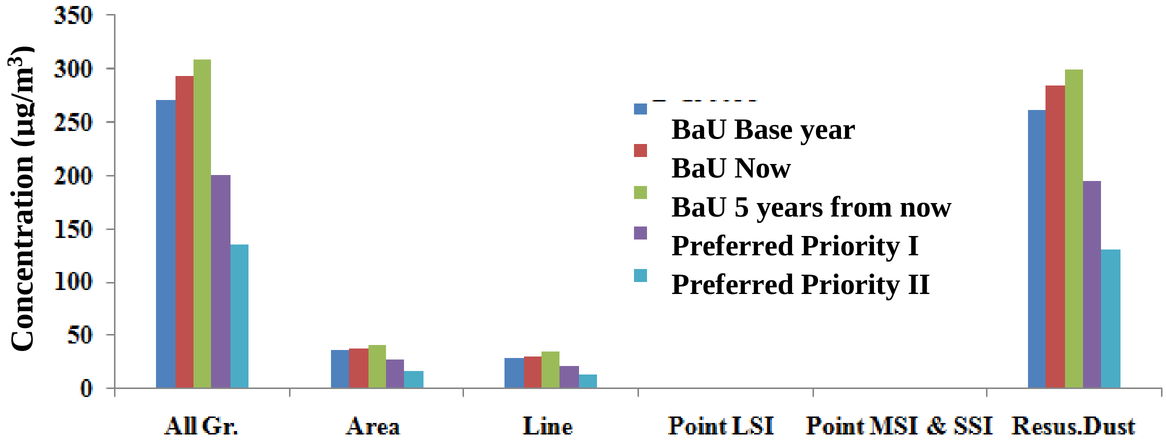


Figure 6.9: PM Scenario Compared with BaU of Base for Preferred Priority I (now) and Preferred Priority II (5 years from now)

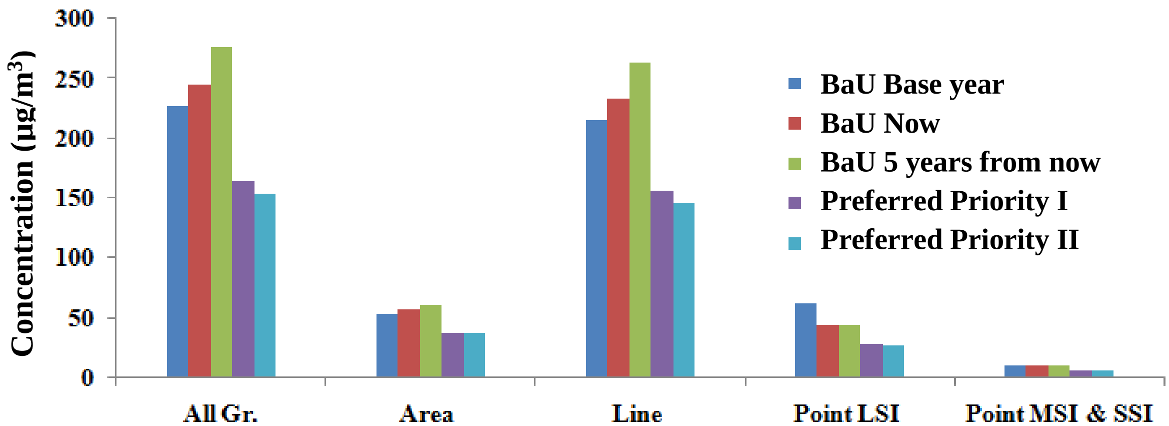


Figure 6.10: NOx Scenario Compared with BaU of Base for Preferred Priority I (now) **and Preferred Priority II (5 years from now)**

In the 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 resuspension of dust will be reduce.

6.2 Prioritizing Technical Measures

Table 6.4 presents the considerations in prioritizing various measures for vehicular, industrial and area sources, respectively. The options discussed are also detailed with regard to action that may be taken up at city, state or central levels. **Table 6.5** delineates the prioritized action plan components with ranking for vehicles, industries and area sources.

Table 6.4: 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						
Sulphur reduction in diesel	Technically feasible and being implemented	Moderate. Reported elsewhere 200 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	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	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

			marker system shall be highly dependent upon the joint working relation of Oil companies and AAC.	proactive in proposing these values, which can be checked easily in any laboratory. They also need to be more accountable.		

Source (Air pollution from motor vehicles, Faiz Asif, Weaver C.S. and Walsh M.P., The World Bank, Washington, D.C., 1996)

Table 6.4 (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 Mumbai for dispensing CNG/LPG is fairly good and is improving	High, more than 90 % reduction in PM can be achieved compared to diesel #	Can be applicable mainly for vehicles, which are supposed to ply within the city. Applicable to only local public transport, taxies, 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 6.4 (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	High emission due to fuel burning at idle or slow moving traffic	Road quality improvement is a matter of technology and quality of work carried out. Concretization of road may be the solution. New road planning and Traffic management are being taken as integral part of the MUTP.	Better planning and training in traffic management Road construction norms to be evolved and implemented	It will reduce traffic junction hotspot of all the pollutants It will also reduce continuous source of dust	State Government, BMC, MMRDA, Transport police, other utilities.
Standards for new and In-use vehicles	No technical issue with new vehicles. For in-use old vehicles, technical feasibility needs to be established	Marginal improvement from newer vehicles except when implementation is for BS -II and Euro Norms. In-use vehicles emission reduction can be substantial	The process of in-use vehicles standards may take time as they need to be revised at central level. Inadequate infrastructure and manpower at local levels could be other major barriers.	After the legislation is in place, provision of strict penalty leading to cancellation of vehicle registration.	As the old vehicle population is substantial, the standards will bring in the much needed control on emissions of all types	MoRTH, Transport Office Govt. Maharashtra

Introduction of new technology vehicles	New technology based vehicles emit less per unit distance travelled Electric vehicles	High compared to grossly polluting, moderate with respect to in-use vehicles	Emphasis to allow only a type of technology to be permitted may meet with resistance from manufacturer as well as buyer. (e.g. rule to allow only 4 stroke vehicle to be registered)	This needs to be backed with proper legislation. Else charge higher registration fee or subject them to carry out more frequent I&C test. Electric vehicles for grossly polluting high VKT vehicles are a good option. It needs regulatory push	It will lead to better compliance from on-road emission test and overall improvement in emission of all the pollutants. Electric vehicles provide localized benefits of no air pollution	MoRTH, Transport Office Govt. Maharashtra, MNRE

Table 6.4 (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. Cost sharing for its implementation.	Presently no legislation. Need to frame one including a mechanism by which the system can be evaluated by an appropriate agency.	Short time frame, high levels of compliance expected for all the in-use older vehicles.	MoRTH, Transport Office Govt. Maharashtra, vehicle manufacturer, vehicle fleet owners
Higher usage of Public Transport	Dedicated bus lane, better buses, low cost of travel, faster travel etc.	Effectiveness is high as less and less road space will be occupied by private vehicles, faster movement of	Feasibility to be established for bus lane. Finances for better buses Measures to reduce the cost of travel by way of	Local level planning in coordination with all the authorities involved in MUTP.	Future growth of the city will entirely depend upon the levels of public	BMC, MMRDA, MSRDC,BEST,

		public transport in comfort shall lead to low emissions	cross financing.		transport availability. Cheaper and faster mode of public transport will lead to higher per capita efficiency.	

Table 6.4 (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	BMC, MMRDA, RTO,
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	MMRDA, Transport Department, Other institutions involved in awareness campaign

Table 6.4 (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 vehicular sector	High as many industries in Mumbai region use coal, HSD, LSHS, and FO	As the industrial growth is negative in Mumbai, the need of S reduction in conventional fuel is not being pressed upon	MPCB can specify the S levels for the fuel being used	S levels in fuel have been very strictly controlled for Tata Power. An example of this can be extended to other industries	MPCB, Industries
Combustion Processes	Change in combustion technology will be needed for shifting from coal/oil to natural gas	Moderate	Finances to change the process technology	No regulatory issue	It will lead to lower emission of CO and HC	MPCB
Alternate Fuel	Large no of industries are using NG and LPG	The higher percentage of use of cleaner fuel has already resulted in better air quality in the city		More allocation of NG/LPG to the industrial sector through MGL/GAIL/ Govt. of India	Better air quality in terms of SO_2, CO and HC will be achieved.	Mahanagar Gas, MPCB

Table 6.4 (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	MoEF can provide incentives to carry out the necessary change	It will lead to sustainable existence of industries within the city. Also lead to other pollutants reduction	MoEF, MPCB, BCCI, CII, CPCB
Location Specific emission Reduction	Specification of site specific emission standards	Medium as the power plant has already been subjected to strict S levels as well as PM emission by MPCB	Higher allocation of NG/LNG at lower cost is needed	State as well as central government can provide the necessary incentive on use of cleaner fuel by the power plant and other industries	High level emission shall have lower PM and other gaseous pollutants	GoM, MPCB, GoI, CPCB
Fugitive Emission control	Industrial process improvement better operation and maintenance	For localized region, very effective, particularly for industries with fine particles raw material or products. High efficiencies can be achieved for quarries.	Monitored data is scarce and therefore how and where to undertake the action will be limited	MPCB can work on the standards for fugitive emission and develop compliance system	Local area air quality improvement could be highly effective.	MPCB, Industries, CPCB

Table 6.4 (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
Bakeries /crematoria	Electric/LPG source based bakeries needing changes in design. Many crematoria have electric system, but need to convert all the other into electric system	Local grid based PM can be reduced.	Awareness to bakeries that the quality can still be maintained with electric or LPG ovens. Similarly, despite electric crematoria being available, people prefer using wood based pyres	Strict monitoring of emissions from bakeries and crematoria	Reduction in PM as well as odour will take place and is likely to improve the local air quality	MMRDA, BMC and MPCB
Biomass/trash burning, landfill waste	Better control on collection and disposal at the	Local area can have substantial	Awareness and local control. Apathy to take	ULB needs to address this issues	High level improvement in local area	BMC, MMRDA, MPCB

burning	respective sites. Landfill waste burning needs proper technology driven site management	reduction in PM. Very high effectiveness to adjoining grids	urgent action. No burning day vow to be taken by BMC		ambient air quality not only for PM but other pollutants	

Table 6.4 (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	BMC, MMRDA
Unauthorized SSI	Level of problem not well known. Need to understand what are the levels of operation and their contribution in each of the grids in the city	Local area improvement can be moderately good	Knowledge of the problem	Need for strict rules of such units and identification by MPCB/DIC and BMC	It will lead to large scale reduction of fire accidents as well as minimization of wastewater problem	MPCB, DIC, BMC
Construction	Construction activities which involve demolition, digging, construction, vehicle movement etc. need information on how to minimize the dust	Large scale improvement in local area is expected.	Emphasis on better construction practices and management plan for air emission and its	Penalty system to be employed by the local authorities for violating the best construction	Spillage on road and further re-suspension of dust can be minimized	BMC, MMRDA, Builders Association

			control by the implementing agencies	practices for air pollution control.		
Airport	High emissions from Airport vehicles. Aircraft emissions assessment of problem needed	Airport vehicles management will yield emission reduction. Options of aerobridge, pooling of passenger, dedicated transport system.	Planning and assessment to delineate the solution	DGCA, AAI need to integrate this issue in their plan.	Airport emission for other pollutants will reduce. Exposure to workers and passengers will reduce.	DGCA, AAI, MPCB
Railways Emissions	All trains are being change to electric. Limited use of diesel locomotive. Resuspension due to train can be minimize by platform cleaning.	Low, as the extent of problem is not in large areas.	Awareness to railways	Practices and norms to be framed	Exposure to population will reduce	CR, WR, MRVC

Table 6.5: Prioritization of Action Components for Ranking

Types	Components
Vehicular Sector	
Fuel Related	Sulphur reduction Alternative Fuel CNG/LPG Prevent fuel adulteration
Vehicle Technology related	Stringent Emission standards for new vehicles (Bharat IV and VI) Electric vehicles for high VKT vehicles Fuel Efficiency standards Conversion of private diesel cars to CNG/LPG Replacement of commercial diesel vehicles to CNG/LPG Retrofitment of catalytic converter & diesel oxidation catalyst -older vehicles Phase out of older vehicles Retrofitment of older vehicles with Bharat Stage III engines with DOC
In-Use vehicle	**Improvement and compliance system in existing PUC** Inspection and identification of highly polluting vehicles Augmentation of manpower and related infrastructure for Inspection and Certification
Policy and Public Processes	**Prioritization of public transport on roads (bus lanes, better buses, low cost of travel, faster travel, accessibility of transport).** 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 Incentive/subsidy for voluntary inspection and maintenance of vehicles Incentive/subsidy to phase out grossly polluting vehicles Drivers and Mechanics Training programmes Public awareness on use of alternate fuel (CNG/LPG), adulteration of fuels, benefits of various maintenance measures.
Road and Traffic Control	**Improvement of roads** Transportation planning and better road maintenance Pavement improvement and better sweeping for less resuspension Road Congestion –encroachment etc. Traffic Management: signal synchronization, one way, pedestrian plaza

Table 6.5 (Contd..) : Prioritization of Action Components for Ranking

Types	Components
Industrial Sector	
Fuel Related	Change of coal to NG Change of LSHS to LDO
Technology related	Clean combustion technology High efficiency control technology Clean process technology

Fugitive and other emissions	Industry specific plans Compliance monitoring design for fugitive emissions
Area Sector	
Fuel Related	Low sulfur fuel for bakeries, crematoria, diesel locomotive, ships PNG/ LPG for domestic fuel in place of kerosene LPG/ CNG for bakeries, crematoria NG/ electric for airport operations Electric operations of diesel locomotives
Biomass /landfill burning	Open burning to be stopped Landfill burning management Open eatout burning of coal /kerosene to be regulated
Construction / demolition of buildings	Norms for building construction / demolitions Regulation and compliance monitoring Material movement control Construction machineries use and its management
Road Construction/ Repairs	Road quality norms to be revisited Use and life of road warranties Stoppage of wood burning for tar melting or re-surfacing of the road Road repair technologies
Public Awareness	Public awareness programme to empower citizens to report small sources but highly prevalent Inclusion of road construction related burning in rules

All the above actions have been rated on the basis four criteria viz.
- Effectiveness - Ease of implementation - Cost implications - Time frame

These criteria may not be considered as firm, numbers as many of these cannot be easily quantified. The ranking carried out here therefore is of subjective 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 Mumbai could exist when a local road is dug up and/or being repaired, construction and demolition of buildings, biomass and refuse burning, industries short term emissions etc. All of such activities can be controlled and regulated through local ward-scale efforts and constant vigil on the part of citizen, pollution control agency and respective responsible implementing agency. Public participation may therefore be invited.

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. Changes in floor space index (allowing more built up per unit area) could lead to large scale increase in vehicle ownership and their presence on roads. Better air quality planning for the city also requires appropriate transport planning which is linked with land use.

All the proposed reduction plan could only reduce emissions caused by anthropogenic sources; however, natural background and secondary aerosols would continue to remain in the atmosphere, and need further attentions.

The benefits computed in the process described above will not only yield PM and NOx related pollution reduction but also co benefit of other pollutants (SO_2, VOCs, HC, CO etc) reductions as well. One of the other major co-benefits of these options (adoption of mass transport, use of cleaner fuel, efficient combustion etc) will provide large scale green house gas reduction. Mumbai as a big metro city will provide the impetus of overall mitigation of GHG, as well as reduction in secondary aerosols.

The benefits of air quality improvement plan suggested and delineated above again will yield desired results only if the adjoining urban centers and states also adopt measures suggested for Mumbai, as the objectives of clean air cannot be kept limited to the administrative boundary of Mumbai when it is in close proximity of major urban centers. A regional effort for air quality management is therefore of the essence.

Chapter 7

Results and Recommendations

This study has addressed several aspects of the air pollution status in Mumbai with an intent to identify the key sources of pollutants, where criteria pollutants have been used to represent the quality of air. An overview of the organisation of the work presented in this report is shown in Figure 1.2.

An attempt for the analysis has been made by using the results from source apportionment analysis, and also the results based on the source inventory-based dispersion model (Table 7.1). The same are discussed in the following sections.

7.1 Inventory

7.1.1 Results

The inventory for the point, line and area sources were compiled from secondary data made available by the offices of MPCB, MCGM and RTO. The inventory has been built ground up and is to be regarded as a best estimate, and is considered to be adequate for the present work to infer an order of magnitude estimate to identify the key sources (Chapter 3).

It is to be emphasised that the size of a particular source in the inventory is not a direct reflection of its contributions to ambient air pollution. The emissions are dispersed and diluted based on the wind conditions and the height of release of the emissions. The dispersion model helps in estimation of the ground level concentrations resulting from emissions from sources after the mixing, dilution and dispersion of the pollutants.

The results of the inventory based dispersion model are included in Section 7.2 below. About 60% of the PM_{10} results from road dust while 10% of the $PM_{2.5}$ is sourced from uncontrolled biomass/ garbage burning.

7.1.2 Recommendations

7.1.2.1 It is recommended that the inventory developed in this study may be digitised and maintained as a dynamic dataset for impact assessment of new sources which result from activities related with population growth, industrial installations and/or mobility-transport related projects for Mumbai (and the MMR). Further, it is important that each stakeholder may validate the inventory at a ward level.

7.1.2.2 Area and line sources are more likely to impact the ground level ambient air pollution than point sources, especially if the latter have been designed for emission through tall chimneys. Thus, the inclusion of all possible “near- ground level” emissions is crucial. The present work does not cover sources that are associated with small scale industries that are fall in the unorganised/unauthorised sector. This is visible in the results in Table 7.1, where the source apportionment results indicate that the contribution from industries is of the order of 12 to 20 %, while that from the dispersion model indicates less than1% of contribution from the point source (industries).

7.1.2.3 Maintenance of a ward-based inventory is therefore recommended as a part of the digitised database of inventory, specifically to include sources of unorganized sector activities.

7.1.2.4 There is a large uncertainty in the quantities and types of garbage and biomass (shed leaves from trees etc.) that are burnt in the open. Further, since they are burnt in an uncontrolled manner, the emission factors and the associated source chemical profiles also add to the uncertainty. Strict enforcement to ensure that open burning is prevented would be the most pragmatic approach to control emissions from this activity, and the associated perception and nuisance value. Timely collection of garbage would minimise the need for such enforcement efforts.

7.1.2.5 Services of the Fire Brigade department may be sought through ward-specific telephone/web based hotlines for quenching any uncontrolled garbage and/or biomass burning.

7.1.2.6 Transport-based models have been used successfully in the past for planning for mobility in MMR (Flyovers, Metros etc.). These same models (which includes all types of vehicles, speeds, congestion scenarios) may be readily adapted and utilised with a data layer of vehicular emissions to better quantify emissions at a level of an hourly temporal resolution.

7.1.2.7 Burning of plastics and anthropogenic dry wastes in an uncontrolled manner is a matter of health concern, and requires immediate attention. Measurements of the toxic emissions from these is rather tedious and, in a pragmatic sense does not require quantification for validating the need for prevention.

Table 7.1: Summary of source contributions

	Sources	A Source Apportionment estimate (PMF) (%)		B Source-specific estimates of contributions based on dispersion isopleths (µg/m³)				C % Source-specific estimates of contribution based on (B) and including (1) and (2)			
				Annual PM		Summer PM#		Annual PM		Summer PM	
		PM10	PM2.5	Max^	Avg	Max^	Avg	Max^	Avg	Max^	Avg
1	Marine aerosols@	18	26	UA	UA	UA	UA	18**	18**	18**	18**
2	Secondary aerosols@	9	22	UA	UA	UA	UA	9**	9**	9**	9**
3	Point: Industrial/ Fossil fuel combustion	20~	12	0.6	0.2	0.7	0.3	0.2	0.1	0.2	0.3
4	Line: Vehicular Emissions	14	16	22	6	20	6	6	6	7	6
	Line: Resuspended Road/ windblown dust	30	13	220	60	170	50	59	58	58	51
5	Area: Construction	9		30	10	25	15	8	10	8	15
	Area: Biomass burning	11$	11								
		100%	100%	373	104	295	98	100%	100%	100%	100%
	Reference	Chapter 4		Figure 1.1 b							

@These two sources emerge as distinct factors in PMF analysis but are not accounted for in the inventory [total (18%) + (9%)] = 27%]

UA= cannot be accounted for in the inventory

^At hot spots

~May include biomass burning

$ In $PM_{2.5}$, therefore all of PM_{10}

#Sampling for SA was carried out in the summer season

7.2 Source Apportionment (PMF and Dispersion Models)

7.2.1 Results

7.2.1.1 Sampling for the source apportionment component of the work were carried out at six locations to cover representative air pollution (Chapter 2). Airmetrics (Federal Reference Method) samplers were special ordered for the study for a customised flowrate of 5 lpm to prevent filter overloading in 24-hour averaged samples. The sampling period was during May-June 2019.

7.2.1.2 The chemical analyses were carried out as per CPCB guidelines (Table2.1). The source apportionment analysis was conducted employing the EPA Positive Matrix Factorization (PMF) method and the results are summarised as Figures 4.1, 4.2 and 4.3 and Tables 4.1.

7.2.1.3 The findings revealed that resuspended road dust emerged as the predominant contributor for PM10 pollution. This occurrence is attributed to the high dust loadings on the roads, and the ongoing construction activities (Metro as well as real-estate developments) near roadways, within, and around the city.

7.2.1.4 Additionally, PM2.5 pollutions was prominently influenced by secondary aerosols (22%) and marine sources (26%) adding to 48% of the total contribution. The presence of marine aerosols is linked to the coastal location of Mumbai, while secondary aerosols are known to be formed from gaseous pre-cursors. Research efforts to study secondary aerosols in India has been limited thus far, and need to be strengthened to improve the understanding and therefore control of this significant component of ambient PM2.5.

7.2.1.5 Dispersion modelling was carried out using AERMOD dispersion model (Chapter 5). The inputs for sources were taken from the inventory developed in Chapter 3, and the datasets made available by MPCB. MM5 data were used for the meteorological inputs. Simulations were made for several scenarios as listed in Table 5.6 and 5.7 for PM and NOX (annual and three seasonal averages: Summer, post-Monsoon and Winter), as well as for delineated sources to understand the relative contributions from point (industrial), line (vehicular) and area sources.

7.2.1.6 Results of the delineated sources indicate that the dominant source for PM is road-dust resuspension. Similarly, the NOx emissions are from vehicular sources.

7.2.1.7 Such delineation also helps in ward-wise identification of “hot-spots’ that are specific to a particular kind of pollutants and sources, and would help in decision making for the kind of efforts required in the respective wards.

7.2.1.8 The influence of open burning could not be quantified adequately in the inventory as stated earlier, but survey observations point to this as a local (and an extremely toxic) source. However, the results of the source apportionment part of the work confirms the contribution from “smoke” that results from biomass combustion, including that of other uncontrolled open burning.

7.2.1.9 Table 7.1 highlights the contribution from the various sources to the concentrations of PM in the air. These data are extracted from previous chapters to bring focus to the immediate action items.

An assessment was made using the Positive Matrix Factorization (PMF) results and dispersion isopleths, as presented in Table 7. 1. The data were used for better understanding of the contributions of various pollution sources as cross validated by the approaches of receptor model and source inventory based dispersion isopleths.

PMF results highlight that the marine aerosols (18%) and secondary aerosols (9%) collectively account for 27% of the overall pollution. This contribution is substantial and could not have been accounted for in the emission inventories in dispersion models. Mitigating marine aerosols is not feasible due to Mumbai's geographical location. The study focused on PM. The role of precursors that contribute to the formation of secondary aerosols needs to be recognised and studied further.

Source apportionment results also indicate a 20% contribution from industrial and combustion sources. The source inventory-based dispersion model however, indicates only 0.2% contribution. This discrepancy is attributed to the dispersion of known industrial sources, which, despite their significant presence as a source in the inventory, gets dispersed and diluted, and therefore do not contribute to the collected samples. On the other hand, the SA exercise points to the substantial impact of local ground-level sources from unorganized and informal Small-Scale Industries (SSI), such as "bhatties" and smelters which could not be included in the emission inventory. Additionally, this source also includes the issue of garbage/waste burning, which adds to the contribution from ground-level sources. Therefore, inclusion of a ward-wise inventory of such local ground level source is necessary.

Further, in both cases resuspended road dust stands out as a significant contributor, constituting 30% of PM10 by PMF approach and ~58% of PM by inventory-based dispersion isopleths. This deviation may be attributed both to the limitations of PMF as well as the dispersion model (source inventory and meteorology). The results also reveal a strong agreement between the PMF-derived estimates and the dispersion isopleths for the area sources (Biomass burning + Construction dust).

7.3 Action Plans

An assessment of impact of various control measures has been carried out in Chapter 6.

The action plans include interventions required for point, line and area sources. The scenarios are set up as Priority I which is immediately implementable and Priority II which are expected to take a little longer to implement (5-year time frame).

The analysis indicates that sustained and concerted efforts in all sectors is the key to reaching a point of acceptable air quality. Further, while the focus has been on primary sources of PM, the control of sources in all sectors would lead to the outfall of control on the pre-cursors for secondary aerosols.

7.4 Suggestions for Success of Sustained Efforts

The following recommendations have emerged from several discussions at meetings, conferences, stakeholder workshops throughout India with experts from multiple organisations (Numerous to list and gratefully acknowledged).

Each city carries its own pulse and character, and therefore a "one size fits all" approach is not likely to be feasible or effective. However, some basic infrastructural and systemic additions in the concerned agencies may help streamline the efforts and start producing results in time, to be then sustained. While the experience of the present study and these recommendations are based on the work carried out in 19 cities on Maharashtra (supported through MPCB), the same would be applicable to all cities in India (including the smaller cities that are presently not listed as non-compliant due to the size of the population criterion used).

7.4.1 The monitoring network needs to be strengthened on the basis of results of the seasonal variations and sources; the approach suggested is that of ward-based monitoring for efficient administrative execution or relevant control measures.

7.4.2 Background air quality stations are essential to monitor the contribution of long range sources, varying in direction with seasons. The background for one season could become the downwind for another.

7.4.3 The CAAQMS, while requiring a relatively larger capital and operational costs, offer a robust coverage of a large number of pollutants as well as temporal resolution. Therefore, quality assurance and quality control are essential (through independent third party audits).

7.4.4 Reliance on CAAQMS alone is not recommended. Integration of NAMP data needs to continue to validate the CAAQMS measurements as well as maintain historical continuity. Additional NAMP stations (PM_{10} and $PM_{2.5}$) may also be decided based on the results of the dispersion modelling to capture the hotspots and background concentrations (upwind and downwind of key sources).

7.4.5 Use of low-cost sensors (LCS) is being considered, and the results from other parts of the country where LCS networks have been tested need to be assessed before including these for regulatory requirements. The adequacy of the CAAQMS density may also be studied by comparison in this effort, where the cost of lesser number of CAAQMS may be found to be less than deployment of a large number of sensors, but provide the advantage of data of better quality. A hybrid mode in a smaller city may also be tested.

7.4.6 The monitoring network may also be designated for different kind/quality of data, possibly as:

- Residential areas (ward-specific)
- Kerb side
- Hot spot (say industrial region or high density populated areas)
- Urban background and
- Research grade data

7.4.7 Data from CAAQMS's are now available for 24 locations within Mumbai, and 32 in all of MMR. The location of these CAAQMS and the local ward-specific activities may be co-related for prevention of air pollution at a local scale. This assessment is required as a routine exercise with a monthly frequency once–a–month frequency.

7.4.8 The parameters measured in CAAQMS are a rich data resource, and need to be assessed based on sources of each pollutant. AQI was designed for an “easy to communicate to the public” based commitment. However, understanding of the primary and secondary pollutants require parameter specific understanding, and is highly recommended preferably by more than one institute for comparison and mutual discussion.

7.4.9 The focus for the present study has been on primary sources of PM, and the CAAQMS address the NAAQS partially. Industrial hazardous pollutant emissions are important and need to be scoped for further studies based on location specific requirements. The cumulative effect of contributions from the already operating sources is essential before any new sources are permitted as the carrying capacity airshed maybe exceeded.

7.4.10 Air pollution data from CAAQMS’s for monsoon season needs to be included in the analysis for contribution from resuspended dust. Since monsoon rains makes all roads wet, the “free” dust gets sticky and remains as a “slurry” on the ground, and thus the contribution from resuspended road dust disappears (as also reported in a similar study for Chandrapur [Sreekanth, 2016]. This annual “episodic” event would help ascertain the overall contribution from uncontrolled dust, which is otherwise very difficult to quantify.

7.4.11 Mumbai needs to be viewed as a part of the larger MMR airshed. The influence on meteorology (wind directions, wind speeds, mixing heights etc.) need to be included for the entire region with all sources included. Diurnal land-sea breezes are also likely to have a significant impact on hourly air pollution levels and need to be assessed as a finer temporal scale for the entire region.

7.4.12 Long range transport of dust is also known to affect the MMR, however only as episodic “dust storm” events. The day-to-day contribution of dust from agricultural activities outside the MMR may need to be included to understand the background levels of pollution in the region.

7.4.13 Since air pollution is a public health matter, a database of health data for upper respiratory and pneumonia related cases (especially for children and the elderly) may be made available for correlating with ward-specific air quality.

7.5 Further Work

7.5.1 In this study, as in many others listed in Table 6.5, the "What" needs to be controlled for air pollution in Mumbai has been addressed. The "How" is also known technically in most cases. The linkage between what is known, and its implementation needs to be strengthened. As an example, the relationship of road design with shoulders that are included for prevention of dust moving onto the roads, requires some additional thought and discussion. The roads need to be amenable for mechanical sweeping, where dust from the unpaved shoulders is prevented from "drifting" onto the road, and biomass from trees can be removed by vacuum trucks. The road dividers have also been found to be source of dust seeping onto the roads due to watering of the plants.

7.5.2 The effort would also require a sector-wise cost analysis for a time-bound implementation by the industry, transport department and the urban local bodies. The cost of public health due to air pollution is well established in previous studies and outweighs the cost of control of air pollution at source itself.

7.5.3 Long term sustained success will require public participation and a reward based approach (rather than enforcement based) maybe attempted – even as a test case in a few wards where the pro-active citizen participation could set an example for success.

7.5.4 Management of air quality is a new emerging problem for the MMR, and therefore asks for a new team and a new administrative structure. The work is of a nature that would require day-to-day data collection, analysis and ground level control of sources through multiple agencies. This team could also monitor the progress laid out for the immediate as well as for the next 5 to 10 years, and pool in the resources for the entire state as through multiple agencies (MPCB, MCGM, RTO, Fire Brigade, IoR's, Research Institutes and Industries and other stakeholders).

7.5.5 Use of satellite data is highly recommended as a mainstream analytical tool for the entire state of Maharashtra. Collaborations with ISRO, IMD and National Remote Sensing Agency are essential for this effort.

ANNEXURE - 1

Emission Factors

(Area, Line and Point Sources)

Annexure 1

Emission Factors

A) Area Source

<u>Bakery</u>

<u>Emission Factor for Wood Burning</u> (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*
<u>Emission Factor for Diesel Burning</u> (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

<u>Emission factors for wood burning</u> (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)
<u>Emission Factor Kerosene</u> (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)
<u>Emission Factor Electric</u> (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

<u>Emission factor for LPG</u>
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 $PM_{2.5}$
<u>Emission factor for Kerosene :</u> 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
<u>Emission factor for Coal</u> : 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 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 II

Base Factor Profiles for PM_{10} and $PM_{2.5}$

In Section 4.2, Positive Matrix Factorization (PMF) was carried out to identify sources contributing to air pollution for PM_{10} and $PM_{2.5}$. The results are visually represented as base factor profiles for PM_{10}(Figure AII-1) and $PM_{2.5}$ (FigureAII-2) respectively. The concentration of individual species assigned to each factor is illustrated through pale blue bars, while the percentage distribution is indicated by red boxes. The identification of these factor profiles and their corresponding contributions to the overall pollution levels of PM10 and PM2.5 is meticulously outlined in Table AII-1 and Table AII-2 respectively.

Figure AII-1: PM_{10} Base Factor Profiles

Table AII-1: PM_{10} Base Factor Contributions

	Predominant Factors	% Contribution	Factor Name
Factor 1	Na^+, Cl^-, SO_4^{2-}, OC, Mg, Na, Ca^{2+}	18.12	Marine Aerosols
Factor 2	OC, Na^+, Cl^-, NO_3^{2-}, Na, SO_4^{2-}, Fe, Mg, NH_4^{2-}	9.10	Secondary Aerosols
Factor 3	OC, EC, Ca^{2+}, Si, Fe	13.58	Vehicular Emissions
Factor 4	OC, Ca^{2+}, Cl^-, SO_4^{2-}, NO_3^{2-}, Si Mg	20.12	Industrial Emissions/ Fossil Fuel Combustion
Factor 5	Ca^{2+}, F^-, Ca, Mg, SO_4^{2-} and Si	9.43	Construction Dust
Factor 6	Si, Ca^{2+}, Fe, Mg, Ca, Al	29.62	Resuspended Road / Wind-blown dust

Figure AII-2: $PM_{2.5}$ Base Factor Profiles

Table AII-2: $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Contribution	Factor Name
Factor 1	Na^{+}, Cl^{-}, SO_4^{2-}, OC, Ca^{2+}	26.40	Marine Aerosols
Factor 2	OC, EC, NO_3^{2-}, NH_4^{2-}, SO_4^{2-}, Ca^{2+}, Mg	22.18	Secondary Aerosols
Factor 3	OC, EC, Ca^{2+}, Mg	15.88	Vehicular Emission
Factor 4	K^{+}, OC, SO_4^{2-} and Mg^{2+}	11.04	Biomass Burning/ Wood Combustion
Factor 5	OC, Na^{+}, Ca, Cl^{-}, SO_4^{2-}, Mg	12.94	Resuspended Road Dust/ Wind-Blown Dust
Factor 6	OC, Ca^{2+}, F^{-}, SO_4^{2-}, Mg, Fe	11.55	Fossil Fuel Combustion/ Industrial Emissions

Annexure III

Insights from Past Source Apportionment Studies of Mumbai

Over the past decades, Mumbai has been the subject of several source apportionment studies utilizing diverse receptor models. These investigations aim to identify and understand the sources of PM pollution across various locales within the city. A comparison of the present work with findings from other source apportionment studies in Mumbai, including Kumar et al. (2001), Chelani et al. (2010), Gupta et al. (2012), and Police et al. (2018) was considered to be important.

As listed in Table AIII-1 and illustrated in Figure AIII-1, from previous studies it is estimated that the industrial emissions contribute an average of approximately 32%, while vehicular emissions account for approximately 15% of the pollution. The collective impact of construction and biomass burning was found to range from 9% to 11% (Table AIII-1 A: average contribution (%)). The present investigation highlights the dominance of road dust (30%) and marine aerosols (18%), indicative of the influence of local urbanization and coastal factors. Present results are in same range as previous studies s shown in Table AIII-1 B: Present work (%).

Several other studies, including Gajghate et al., 2012, CPCB, 2010 (URl 2) and Goyal, 2008, were not included in this analysis due to difficulty in making direct comparisons between sources which have been classified differently in these studies. Additionally, studies such as Joseph et al., 2012, focusing on the mass closure method, and, studies by Herlekar et al., 2012; Srivastava, 2004 concentrating on source apportionment for vehicular sources using organic markers, were also not included for comparison as their scopes were quite different.

Table AIII-1: Comparison of factor contributions for PM_{10} reported in previous work for Mumbai

Reference	Receptor Model	Site	Road Dust	Vehicular Emissions	Marine Aerosols	Industrial+ Smelting+ Powerplant+ combustion	Secondary Aerosols	Construction	Biomass / Waste burning	Other sources
Kumar et al., 2001	Varimax	Sakinaka	41	15	15	12	-			17
		Gandhinagar	33	18	15	19	-			15
Chelani et al., 2008	CMB	Mazogaon	14.4	0.8	2.3	57.5	-			25
		Khar	-	3.6	-	86.7	-			10
		Goregaon	13.9	2.3	8.5	52.5	-			23
		Vikhroli	56.9	-	6.3	15	-			22
		Haji Ali	11.3	13.5	33.8	16.5	-			25
		Marol	15	17.3	6.8	36	-			25
		Sion	38.9	0.8	4	34.9	-			21
		Chembur	9	15.2	31.1	31.9	-			13
		Vileparle	10	20.6	3.6	38.4	-			27
		Colaba	8.3	-	13.2	61.3	-			17
		Borivali	17.7	13.3	15	41.6	-			12
Gupta et al., 2012	PMF	Mahul	27	20	3	27	15	2		6
		Khar	18	23	-	2	19	25	13	13
		Dharavi	15	25	-	9	23	28	7	0
		Colaba	19	22	-	24	23	6	3	6
Police et al., 2018	PMF	Trombay	25.3	12.6	15	18.2	-		13.8	29
A) Average contribution (%)			**22**	**14**	**12**	**32**	**20**	**15**	**9**	**17**
B) Present work (6 locations)			**30**	**14**	**18**	**20**	**9**	**9**	**11**	**0**

Other studies which have not been considered for comparison

Reference	Receptor Model	Site	Road Dust	Vehicular Emissions	Marine Aerosols	Industrial+ Smelting+ Powerplant+ combustion	Secondary Aerosols	Construction	Biomass / Waste burning	Other sources
Gajghate et al, 2012	Varimax	Santacruz	20	30	14	-	-	-		36
Goyal N. Thesis	PMF	Worli	28.7	-	35.3	-	4.2	23.6		8.2
		Parel	16.9	-	-	-	6.3	29.4		47.4

Note: CMB = Chemical Mass Balance and PMF = Positive Matrix Factorization

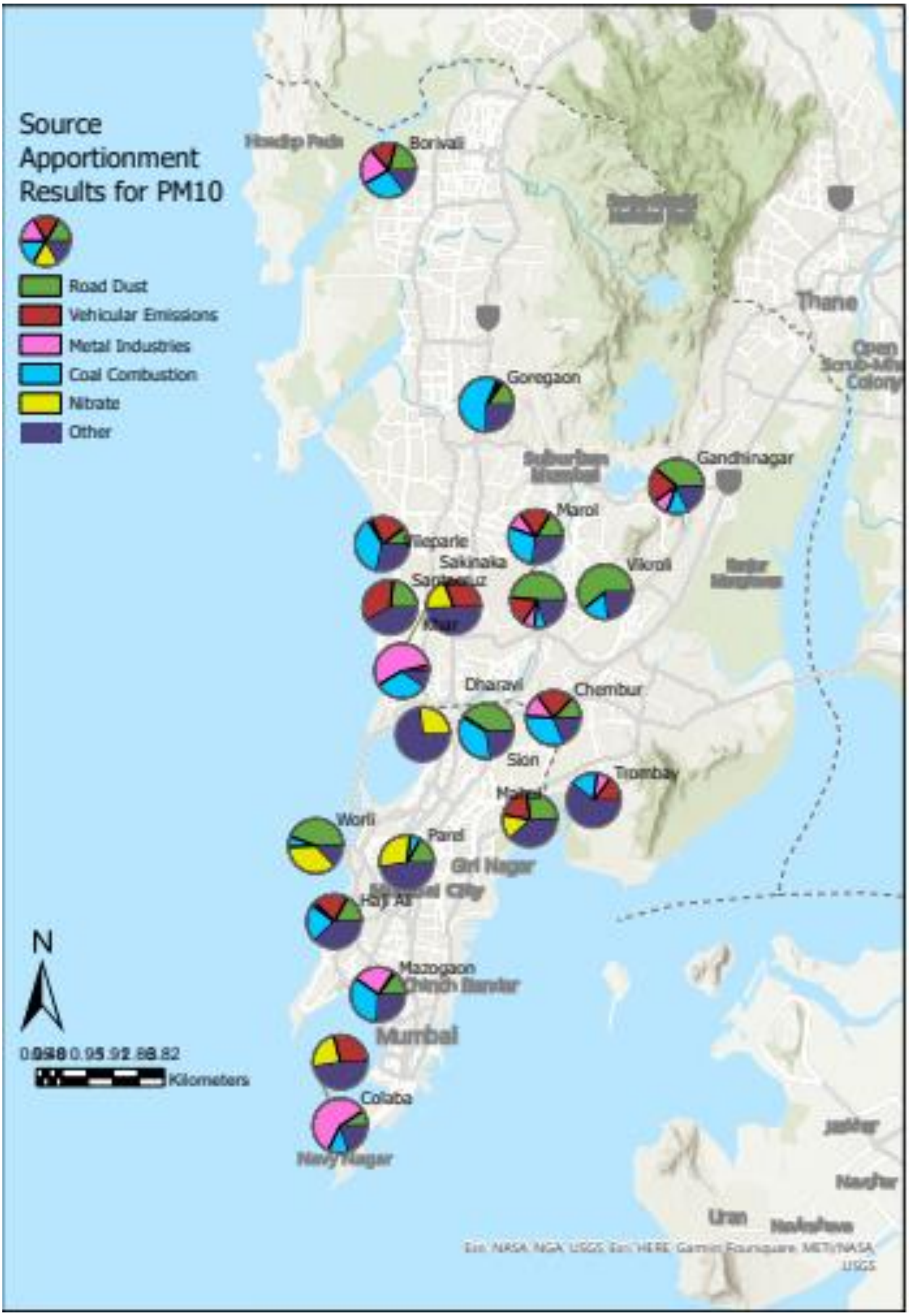


Figure AIII-1: Summary of results from previous source apportionment studies carried out in Mumbai

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