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

KOLHAPUR CITY

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 (Page 1.8)

Analyses have been carried by using the results from source apportionment, and also the results of inventory of air pollution sources (Table 7.1). The results and suggestions for Kolhapur 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, KMC and RTO.

- 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 four locations in Kolhapur 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 construction 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 near roadways, within, and around the city.

- $PM_{2.5}$ pollution was prominently influenced by industry and uncontrolled burning and vehicles.

- 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), which is not accounted for the inventory.

Suggested Action Plans

- 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 of 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.

- 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 cities in india, andtherefore 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.

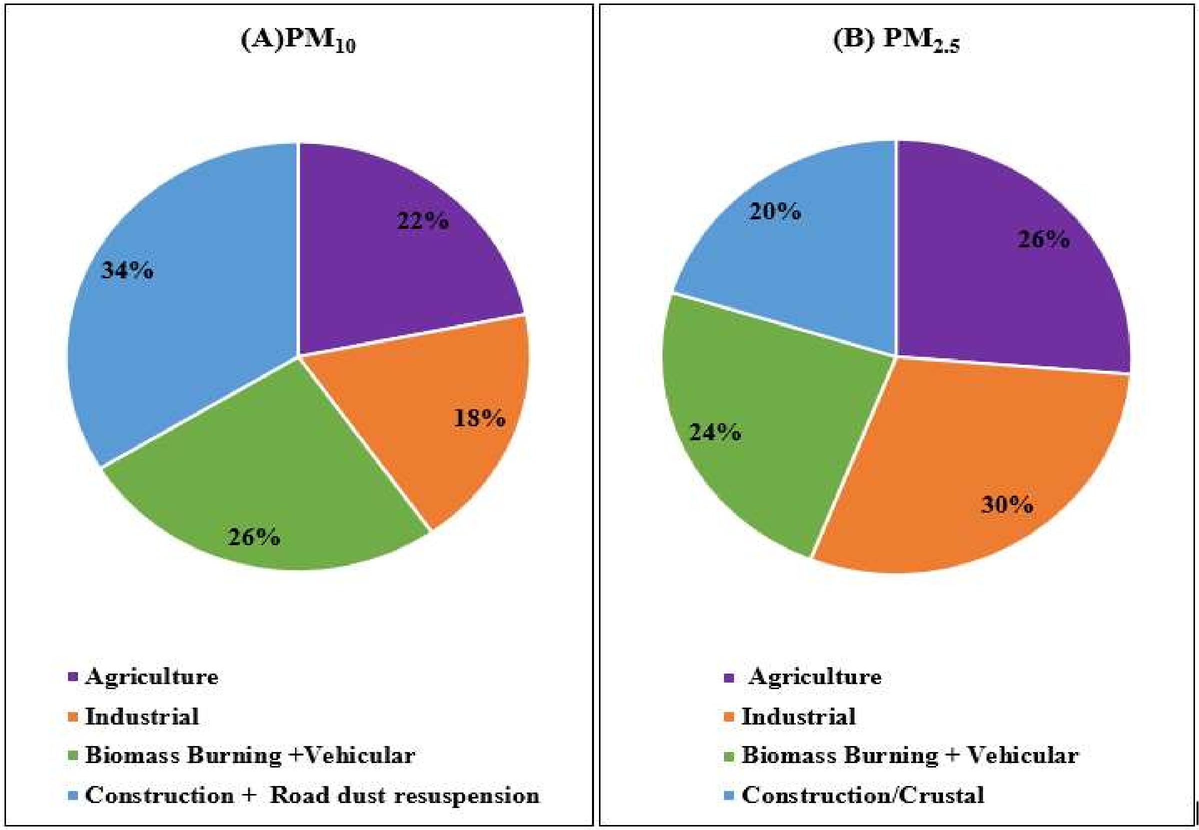

Figure ES-1: Percentage Contribution of Sources for (A) PM10 and (B) PM2.5 for Kolhapur

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Chapter 1

Introduction

1.1 Preamble

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

1.2 Background of the Study

The Central Government launched National Clean Air Programme (NCAP) as a long-term, time-bound, national level strategy to tackle the air pollution problem across the country in a comprehensive manner with targets to achieve 20% to 30% reduction in Particulate Matter concentrations by 2024 keeping 2017 as the base year for the comparison of concentration. Under NCAP, 122 non-attainment cities have been identified across the country based on the Air Quality data from 2014-2018.

Maharashtra Pollution Control Board (MPCB) and Government of Maharashtra (GoM) wish to have Source Apportionment and Emission Inventory studies for all non-attainment cities in Maharashtra state. The city specific air pollution reduction action plans need to be prepared which, inter-alia, include measures for strengthening the monitoring network, reducing vehicular/industrial emissions, increasing public awareness etc. Implementation of the city specific action plans will be regularly monitored by Committees at Central and State level namely Steering Committee, Monitoring Committee and Implementation Committee.

1.3 Objectives

- To measure baseline air pollutants (Particulate Matter) in different parts of the city which includes "hot spots" and kerbside as well.
- To inventorise the 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 MoEFCC or any relevant workable options.

1.4 Scope of the Project

- All sources of air pollution emission inventory estimation to be carried out
- Monitoring the air quality of the city for a period of 10 days, which includes locations such as residential, commercial, outskirts and sensitive areas.
- On each station 24 hrs average data will be considered as air quality monitoring data for continuous 10 days of sampling
- Actual meteorological data must be obtained from weather monitoring stations and must be analysed for dispersion modelling exercise
- The data will be analysed for preparation of emission inventory in the city
- Source apportionment analysis will be carried out for particulate matter using appropriate model. For this purpose, relevant detail pertaining to the city will be gathered.
- For dispersion model exercise, model such as AERMOD or ISCST3 will be used based on different scenario and conditions
- Receptor modelling exercise will be carried out for source apportionment. The particulate matter filter samples will be analysed for marker elements such as anions, cations, trace metals, organic carbon and elemental carbon
- On completion of data collection, validation and interpretation of the assimilated information, a road map will be drawn considering all possible measures for air quality improvement in the region. These measures will be classified into short term and long term with due priority to low cost measures that will give maximum benefits.

1.5 City Information

Kolhapur City stands on rising ground on the south bank of the river Panchganga, bounded on the north by the Panchganga river, on the east by the boundaries of Uchgaon village, on the south by the boundaries of Kalambe and Panchgaon villages and on the west by the boundaries of Nave palinge, Padali and Singnapur villages and by the Panchganga river.

Kolhapur derives its importance from its past political associations and its position as a great commercial, religious and educational centre. It was the capital of the former Kolhapur State, a premier state in the Deccan, and was also the seat of the Residency for Deccan States. Its importance as a commercial centre is well known. Kolhapur is a big market for Jaggery (Gul) of which the district is a very large producer. This Jaggery is supplied to various parts of India and is exported to different countries. As a religious centre, Kolhapur is known as the Dakshin Kashi or the Kashi of the South, the ancient temple of Mahalaksmi being the main attraction. The city has two Arts and Science Colleges, one Law College, one B. T. College and one Commerce College. It has also 20 High Schools. There are numerous cheap hostel facilities. Kolhapur has produced many well-known artists and sculptors and it has also been the birth place of Marathi film industry. It has been a sports centre and has produced many well-known wrestlers, cricketers and sportsmen who have represented India in international contests. Although mainly a residential and commercial town till lately, Kolhapur is now fast becoming an industrial town with emphasis on the engineering industry. The Kolhapur City Map is depicted in **Figure 1.1**.

The modern development of Kolhapur can be said to have started when the British obtained political suzerainty in 1844 and built the residency during 1845-48. In the city, fields and vacant sites came to be developed as population increased.

1.6 Geography

Kolhapur is an inland city located in south-west Maharashtra state, 228 Km south of Pune, 615 Km north-west of Bengaluru and 530 Km west of Hyderabad. Within Maharashtra, Kolhapur's nearest cities and towns are Ichalkaranji (27 Km), Kodoli (35 Km), Peth-Vadgaon (15 Km) Kagal (21 Km), Sangli (49 Km), Satara (115 Km), and Miraj (50 Km), Gadhinglaj (67 Km). Kolhapur has an elevation of 569 meters (1867 ft). It lies in the Sahyadri mountains in the Western Ghats. Chandgad is the coolest place in the Kolhapur district. Tambraparni river dam is the spectacular place near Umgaon village.

1.7 Climatic Conditions

Kolhapur's climate is a blend of coastal and inland elements common to Maharashtra. The temperature has a relatively narrow range between 10^0C to 35^0C. Summer in Kolhapur is comparatively cooler but much more humid, than neighboring inland cities. Maximum temperatures rarely exceed 38^0C and typically range between 33 and 35^0C. Lows during this season are around 24^0C to 26^0C. The city receives abundant rainfall from June to

September due to its proximity to the Western Ghats. The heavy rains often lead to severe flooding during these months. Kolhapur experiences winter from November to February. The winter temperatures are warmer than other cities in Maharashtra such as Pune and Kolhapur. Lows range from 9^0C to 16^0C while highs are in the range of 26^0C to 32^0C due to its high elevation and being adjacent to the Western Ghats. Humidity is low in this season making the weather much more pleasant.

1.8 Population

As per the reports of 2011, Census of India, population of Kolhapur city is 5,49,236. The religion wise population of Hindu is 4,60,774 (83.89%), Muslims- 59,760 (10.88%), Jain- 18,420 (3.35%), Christian- 5,251 (0.96%), Buddhist- 2,929 (0.53%), Not Stated- 1,289 (0.23%), Sikh- 581 (0.11%), Others- 232 (0.04%).

1.9 Industries

The city is the home of Kolhapuri chappal, a hand-crafted buffalo leather slipper that is locally tanned using vegetable dyes. Other handicrafts include: hand block printing of textiles; silver, bead and paste jewellery crafting; pottery; wood carving and lacquer ware; brass sheet work and oxidised silver artwork; and lace and embroidery making. Kolhapur is also an industrial city with approximately 300 foundries producing exports with a value of 15 billion rupees per year. A manufacturing plant of Kirloskar Oil Engines [KOEL] is set up in 5 star MIDC at Kagal near Kolhapur, and the Raymond clothes plant is also located in the same industrial area. Kolhapur has two more industrial areas, Gokul-Shirgaon MIDC, Shiroli MIDC and Udyamnagar is an industrial area in the city. Kolhapur is also famous for gold jewellery which includes a type of necklace called Kolhapuri saaj, patlya (two broad bangles), chinchpeti (choker), tanmani (short necklace), nath (nose ring), and bajuband (an amulet).

1.10 Business and Economy

Over the years Kolhapur district has emerged for having one the highest per capita income in India. Today, Kolhapur boasts for having the maximum number of Mercedes car owners, being the sugar bowl of India and with sugar spinning and textile mills spread throughout Kolhapur district it surely has raced ahead of many other cities in terms of economic growth in recent years and has established itself as a prominent destination in the state of Maharashtra. The major industries in Kolhapur district are spinning mills, sugar industries, and textile mills and supported by industries in sectors like engineering goods, poultry, foundry, and chemicals etc. which generate employment for lakhs of people in and around Kolhapur. The major small-scale industries are into manufacturing auto spare parts, casting work, engineering works, diesel engines, silver ornaments and Kolhapuri chappals. There are many other small scale and cottage industries in rural areas which run down through generations into trades like hand-loom-weaving, gold smithy, oil crushing, brick and tile making, leather works and tanning and black smithy etc.

Along with urban areas the village of Hupari near Kolhapur city has today become a busy and well known place for gold and silver industry. Jewellery made here is unique and is made keeping in traditional artistry. The specialty jewellery crafted here are Anklets or Payal of various length and designs, Gujrav and special kinds of necklaces. Silver jewellery from Hupari is in great demand in India and abroad. The Kolhapuri Saaj is a speciality of Kolhapur is exported to countries like America and Australia. This industry has annual turnover of Crores each year and employs thousands of artisans and traders in and around Kolhapur.

1.11 Agriculture in Kolhapur

Having fertile Agricultural Land in and around Kolhapur district agriculture is the backbone of the economy of Kolhapur. Rice and sugarcane are the chief crops grown in this region on a large scale. Maharashtra is the largest producer of the Jaggery in India. Kolhapur district has been producing sugarcane and Jaggery since a long time. Jaggery is sold by brokers on behalf of agriculturist to other parts of India. Jaggery of Kolhapur is also exported to countries in Asia, Africa and other continents across the world. Kolhapur district also has a presence of many sugar refineries and collectively they process more than 50,00,000 metric ton of sugarcane. Sugarcane farmers of Kolhapur itself bring in approximately 13 billion to the economy. Sugar from this region is exported all across India and abroad.

1.12 Textile Industry in Kolhapur

The Kolhapur industry is driven predominantly by the textile industry and is mainly dominated by local manufacturers and Marwari Rajasthani traders. Ichalkaranji, a city in Kolhapur district is home to one of the oldest textile industries in India. Also known as the "Manchester of Maharashtra" Ichalkaranji has nearly 5,000 textile factories and is known to be one of India's largest centres for small scale industry. A few decades ago Ichalkaranji was famous for textile goods like cotton poplin, dhoti, and cotton saris but with changing times and technological advancement Kolhapur is now home to domestic and international fashion brands such as Raymond's of India, Armani, Banana Republic, Hugo Boss, Paul smith and many more. Textile goods manufactured in city are sold all over India as well as exported to various parts of the world.

1.13 Arts and Handicraft Industry in Kolhapur

Kolhapur is well known for its local arts and Handicraft market. Kolhapuri chappals a specialty is manufactured by the local cobbler community and skilled people dedicated to this art and are famous throughout India and abroad. There are 15 co-operative societies of Kolhapuri chappals manufacturers in the district employing thousands of people directly or indirectly i.e., Artisans, dealers, raw material suppliers, helpers and others. The Kolhapuri chappals manufactured are of two major types 1) Export Variety 2) Fancy Variety. The total production of export variety and fancy Kolhapuri chappals is estimated to be Crores annually. Within the city centrally located Shivaji Market has a concentration of 150 shops of which most exclusively deal with Kolhapuri chappals. The rest of the production of fancy variety is sold locally and rest in Mumbai, New Delhi, Ahmedabad, Bangalore and other commercial centres in the country through dealers and other retail outlets. Kolhapuri Chappals are mainly exported to China, Japan, France and Australia.

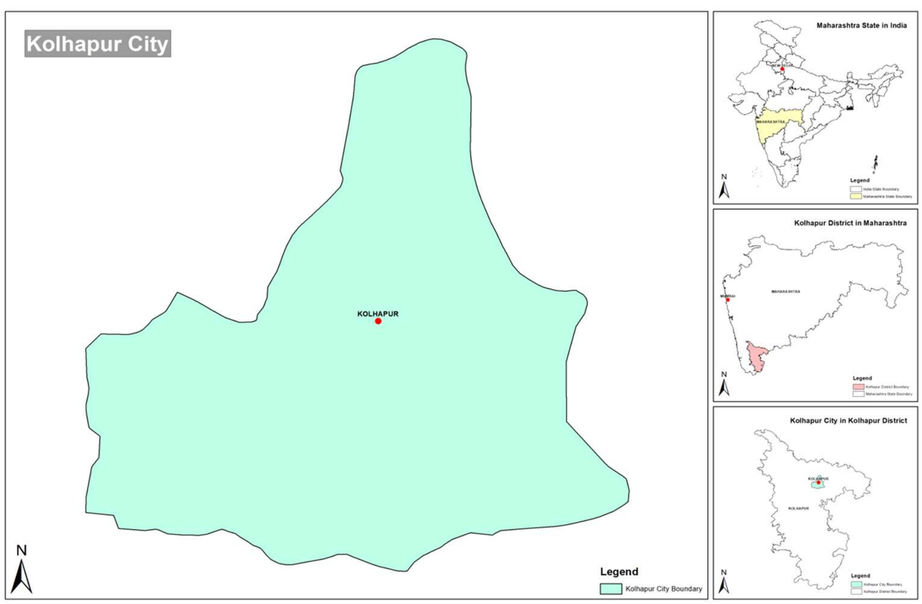


Figure 1.1: Location map of Kolhapur City

1.14 Need of the Study

The present study examines the contribution of the sources to aerosol mass, which is an important factor in the development of effective strategies for the control of aerosol-associated problems. Besides PM, other pollutants and their sources are needed to be inventoried with a view to ascertain the point of generation. Pollutants of all origin should be considered in entirely for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc.

Strategies for sector specific pollutants need to be drawn from scientific evidences which are concrete and clear. These facts can be derived from the use of multitude of techniques such as emission inventory, dispersion modeling, receptor modeling and finally cost effectiveness analysis of varied options. Therefore, MPCB has sponsored CSIR-NEERI and IIT (B) to jointly execute the source apportionment studies for 10 cities of Maharashtra.

1.15 Organisation of the report

The report organization is shown Figure 1.2 Chapter 7 highlights the outcomes and the recommendations from this study

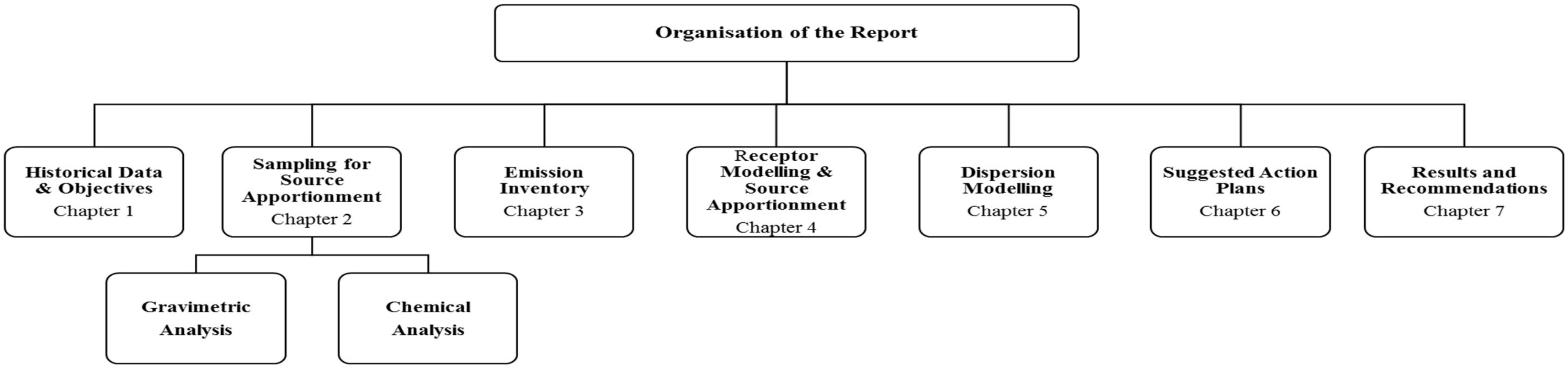


Figure 1.2: Flow chart for the organisation of the present study

Chapter 2

Ambient Air Quality

2.1 Air Quality Monitoring Network of MPCB at Kolhapur City

Ambient air quality data of Kolhapur city is gathered from MPCB monitoring network for three sites, which was monitored at Shivaji University Campus and Mahadwar Road for (Residential sites) and Ruikar Trust (Rural and other areas). The data is available from 2006 to 2020 for daily average level **(Figure 2.1a & b)**.

It can be seen that at all the three sites, annual average concentration was reported as 17, 28 and 89 µg/m^3 for SOx, NOx and RSPM respectively. Most of the times RSPM concentrations exceeding the annual 24 average standard of 60 µg/m^3. Similarly, in Kolhapur RO, highest annual average SO_2 concentration was recorded at Ruikar Trust (29 µg/m^3), followed by Mahadwar Road AAQMS (23 µg/m^3). The annual NOx concentrations are exceeding from 2015 onwards at Ruikar Trust and Mahadwar Road, which were higher than the prescribed annual average limit of 40 µg/m^3. In Kolhapur, 42% of all observations were Satisfactory and 35% were Moderate AQI. At Shivaji University there were no polluted days as all observation were under Good and Satisfactory categories.

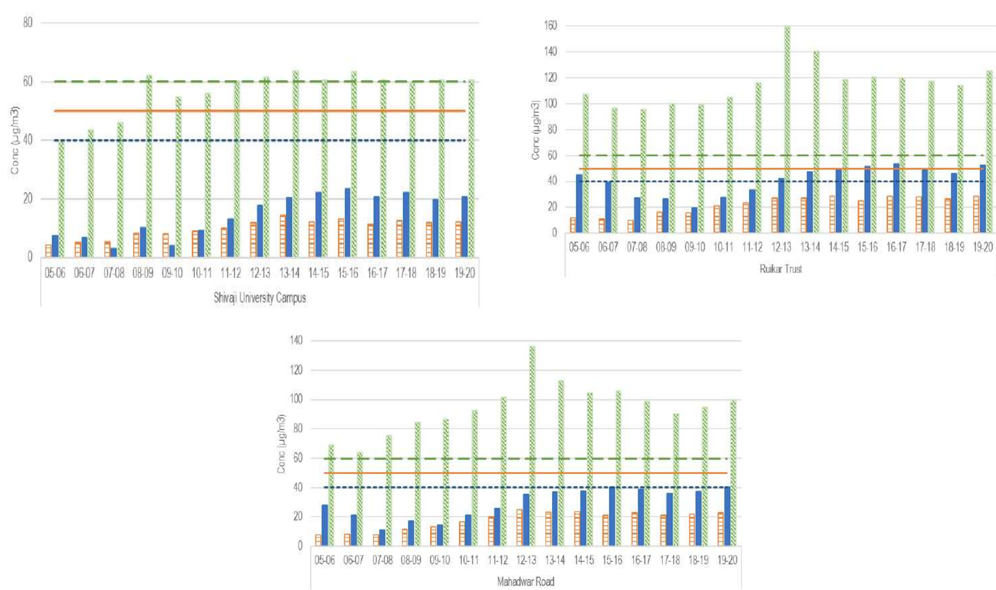


Figure 2.1(a): Annual Average Trend of SO2,NOX and RSPM at Kolhapur (MPCB Network)

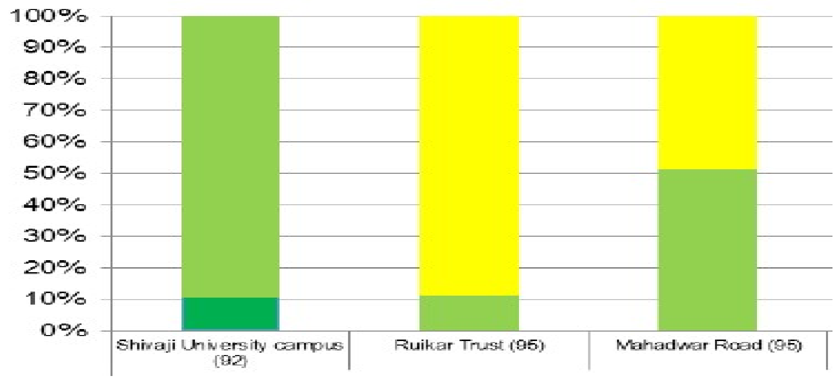


Figure 2.1 (b) : Percentage Occurrence for Classes of AQI-Kolhapur City 2019-20

The Kolhapur Municipal Corporation is the causative administration and has the managing authority for planned development in Kolhapur city. The annual average concentration of RSPM and SPM over Kolhapur for the last four years is analysed and it is observed that the levels of both the pollutants are increasing in last three years as shown in **Figure 2c & 2d.**

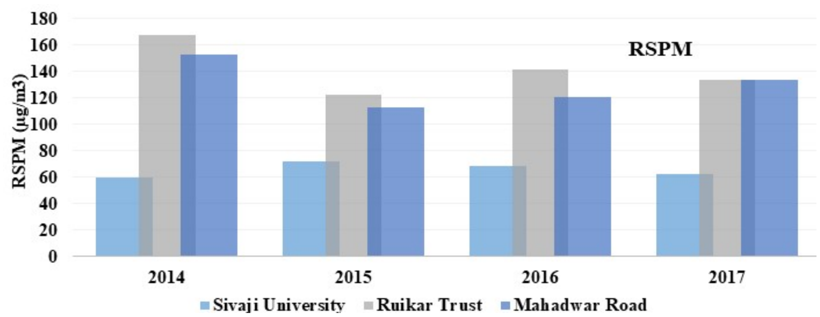


Figure 2.1 (c): Annual Average Concentration of RSPM over Kolhapur (2014-2017)

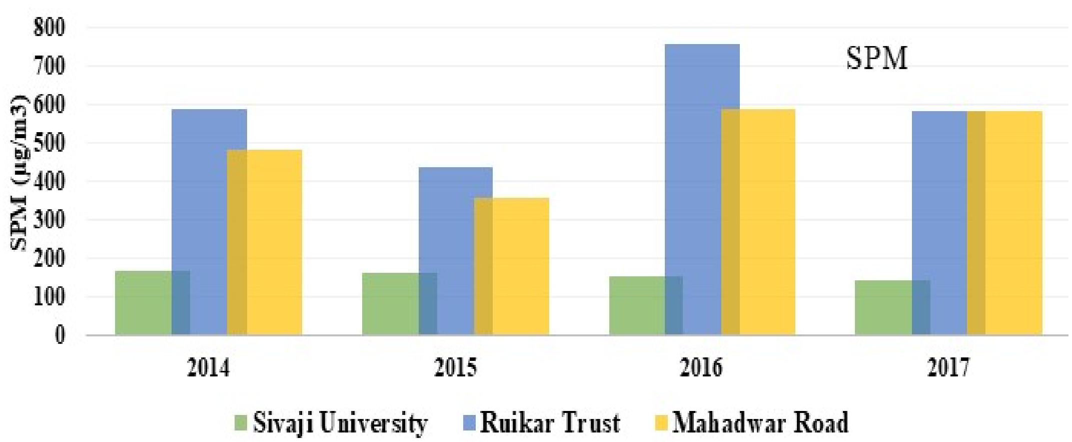


Figure 2.1 (d) : Annual Average Concentration of SPM over Kolhapur (2014-2017)

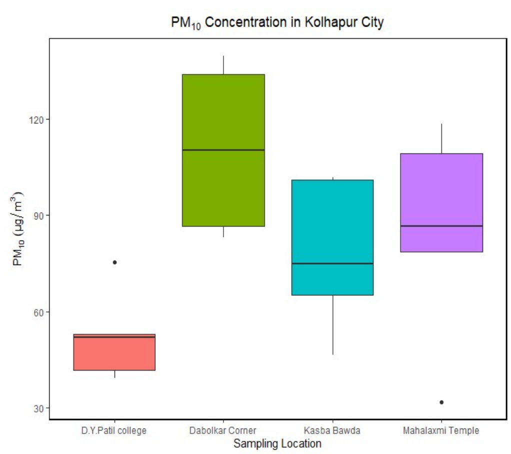
2.2 Ambient Air Quality- Sampling During Summer 2019

For ambient air quality monitoring, the protocol as per source apportionment study was followed as given by CPCB. Monitoring for particulate Matter of diameter 10 micron and 2.5 micron (PM_{10} and $PM_{2.5}$, respectively) was carried out following the standard operating procedures prescribed in CPCB guidelines document. The sampling was carried out at 4 sites as per the scope of project. The description of the sites is given in **Table 2.1**

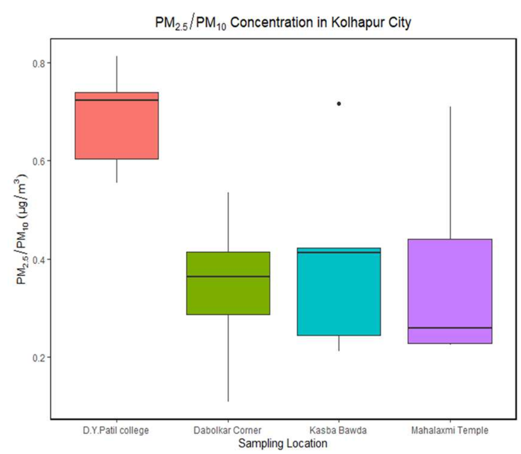
Table 2.1: Description of Sampling Sites (Kolhapur City)

Sampling Location	Type	Characteristics
Dabholkar Corner	Kerb Site	Main market
Mahalaxmi Temple	Residential & Commercial	Maximum residential and commercial zone. Tourist place
Kasba Bavada	Residential	Dense residential area
D.Y. Patil College	Reference Site	

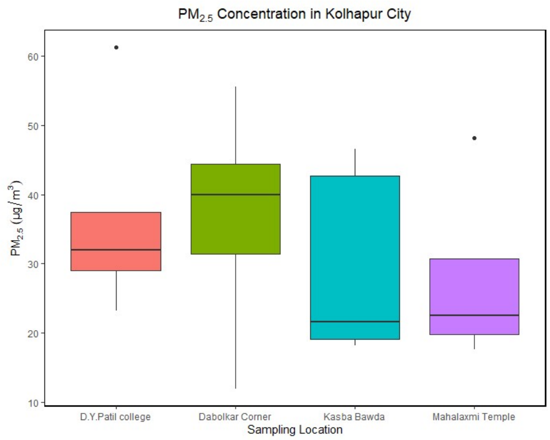
Air quality results at four sites in terms of PM_{10} and $PM_{2.5}$ concentration are given in **Figure 2.2a & b**. It can be seen that PM_{10} concentration violated the CPCB threshold (100 µg/m^3) during the entire study period at all the sites. $PM_{2.5}$ concentration exceeded the CPCB standard of 60 µg/m^3 only at one occasion in MIDC. $PM_{2.5}/PM_{10}$ ratio is also plotted in **Figure 2.2c** to assess the dominance of combustion activities at the sampling sites. High ratio generally suggests the presence of combustion activity at or near the site.



PM_{10} Concentrations



$PM_{2.5}$/ PM_{10} Concentrations



$PM_{2.5}$ concentrations

Figure 2.2 : PM_{10}, $PM_{2.5}$ and $PM_{2.5}$//PM_{10} concentrations in Kolhapur city

Table 2.2: 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 µg/m^3	5 µg/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

Chapter 3

Emission Inventory

3.1 Introduction

An air emission inventory is a compilation of air pollutant emissions from sources of anthropogenic (human-made) and biogenic (naturally occurring) sources. The sources are categorized into three sectors, each making up one component of the inventory. The emission inventories consist of actual and projected air emissions.

Due to violation of permissible limit of particulate matter standards, CPCB has listed Kolhapur city as one of the non-attainment cities. The number of non-attainment cities listed in India is 132. Out of which 18 cities are from Maharashtra. 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. It helps in assessing the impact of additional nearly sources in and around the region and also to evaluate the control strategies for certain emission sources.

Extensive fossil fuel use and speedy growth of energy intensive sectors like power, steel, cement, chemicals and fertilizers, transport etc. have contributed to high growth rate of emissions at above 5% per annum during 2000s in India. National level emission inventories have been prepared by several researchers for metro cities in India. Kolhapur city has no emission inventory estimate report earlier published. Keeping in view the lack of exclusive emission inventory estimates for Kolhapur, the emission inventory has been prepared for PM_{10}, $PM_{2.5}$, SO_2 and NOx emitted from various sources.

3.2 Emission Inventory: Concept & Need

To improve the air quality in the area/city, detailed information of air pollution sources along with the local meteorological condition and topographical factors are needed. For the purpose the effective science-based air quality management is a need of the hour. Emission inventories helps to identify the emission sources in the region and contribution of each source to the total emission which will eventually guide us to set priorities for the action plan for different sources, evaluating the various options available to reduce the emissions from identified potential sources and formulate and implement the appropriate action plan. Thus, an inventory provides basic information of sources and sink of different gases along with information like what gases to mitigate, how to mitigate, when to mitigate and where the mitigation action should be allocated. In addition to the above, it has been used as one of the important fundamental components in air quality modelling application.

For scientific purposes, emission inventories can be used as an input for dispersion modelling and taking immediate actions on the source to reduce air pollution. As mentioned earlier the emission inventory is an essential input required to forecast the air quality, moreover, the quality of forecast depends on the accuracy and reliability of emission inventories.

3.3 Present Objective

In the present study, an attempt has been made to develop a very high-resolution Emission Inventory. The grids have been plotted over Kolhapur city of 2 Km x 2 Km **(Figure 3.1).** The inventory has been developed for PM_{10}, $PM_{2.5}$, NOx and SO_2. The high-resolution emission inventory developed for Kolhapur city will help in appropriate and timely implementation of the action plans. Effective solutions to reduce air pollution require a process of continual improvement in understanding where pollution is coming from and how much each source is contributing. A robust Kolhapur emission inventory will provide information to policy makers to significantly aid in the design and implementation of emission reduction plans and regulations. There is a need for sharing existing sources and studies to frame solutions.

3.4 Generation of Activity Data & Emission Factor

Emission of particulate matter is related with different source emissions. Its intensity determines the control action required on the emission source to reduce emissions. So, it is the need of the day to identify the emission source to reduce air emission load of Particulate matter. For this purpose, the potential sources of emission are considered in the present work and source specific activity emission load estimates are done.

The activity data consist of two types, (1) Primary Data and (2) Secondary data. Primary data consists of the data collected by actual visualization the site details. This data is not available in any documents/ books. Secondary data is readily available with the offices and can be collected. The data sets available have very less information. For example, corporations have the data of hotels, restaurants and bakeries, but they do not have data on type of fuel used. This fuel data must be available with offices. It will be very much easy to target reduction in the use of fuel emitting more pollution load into atmosphere. Primary data for brick kilns, vehicular count, bakeries and hotels survey, slum areas survey, MSW burning and dump yard survey, road re-suspension, paved-unpaved roads and city activities survey has been carried out. CSIR-NEERI has conducted a detailed survey for Kolhapur city for source data collection. The same data is used for the estimation of emission inventory. To make the emission inventory more accurate a large number of site-specific primary data has been collected. The secondary data sets have been collected from all possible authentic sources for the selected departments in the city.

The purpose of generating primary data is to generate the information not available and to improve the data accuracy and authenticity of the secondary data available. To collect such data an extensive field survey work was carried out during several years. The primary data is collected by carrying out surveys at the brick kilns, MSW dumping yards, door to door survey for residential, commercial sectors, local transport offices, vehicular count at traffic intersections and fuel used data are collected. Data sheets were prepared to collect the required information for emission inventory.

Residential and commercial sectors contribute significant amount of emission to air. To estimate the emission load from this sector data for fuel used, quantity required per day, time required for cooking etc. has been collected.

3.5 Secondary Data Collection

Information or data available for number of slums, hotels, industries, thermal power plants, number of registered vehicles etc, are collected. Also, the data related to the fuel consumption in industries and thermal power plants has been obtained from the published official governmental resources. In addition to this, CSIR-NEERI has in house data repository for the information required. The information was collected for different projects on-going.

3.6 Role of GIS

GIS has made it possible to directly view the source emission. The grids plotted over Kolhapur city, makes it easier to identify the maximum emission load and the source responsible. The required information is feeded and the required maps are prepared. Maps for water bodies, railway network, and road network in Kolhapur city are prepared by the use of GIS. Also, geo-mapping of emission load is done using GIS technology for developing accurate emission inventories. GIS will substantially improve ability to develop effective plans to meet air quality standards and help understand the effects of air pollution at the local community level. The GIS based emission inventory is used to meet the goal about when and where the emissions occur, and how they can be reduced to benefit the most people. With the help of GIS we can improve air quality in those areas that are disproportionably affected by air pollution.

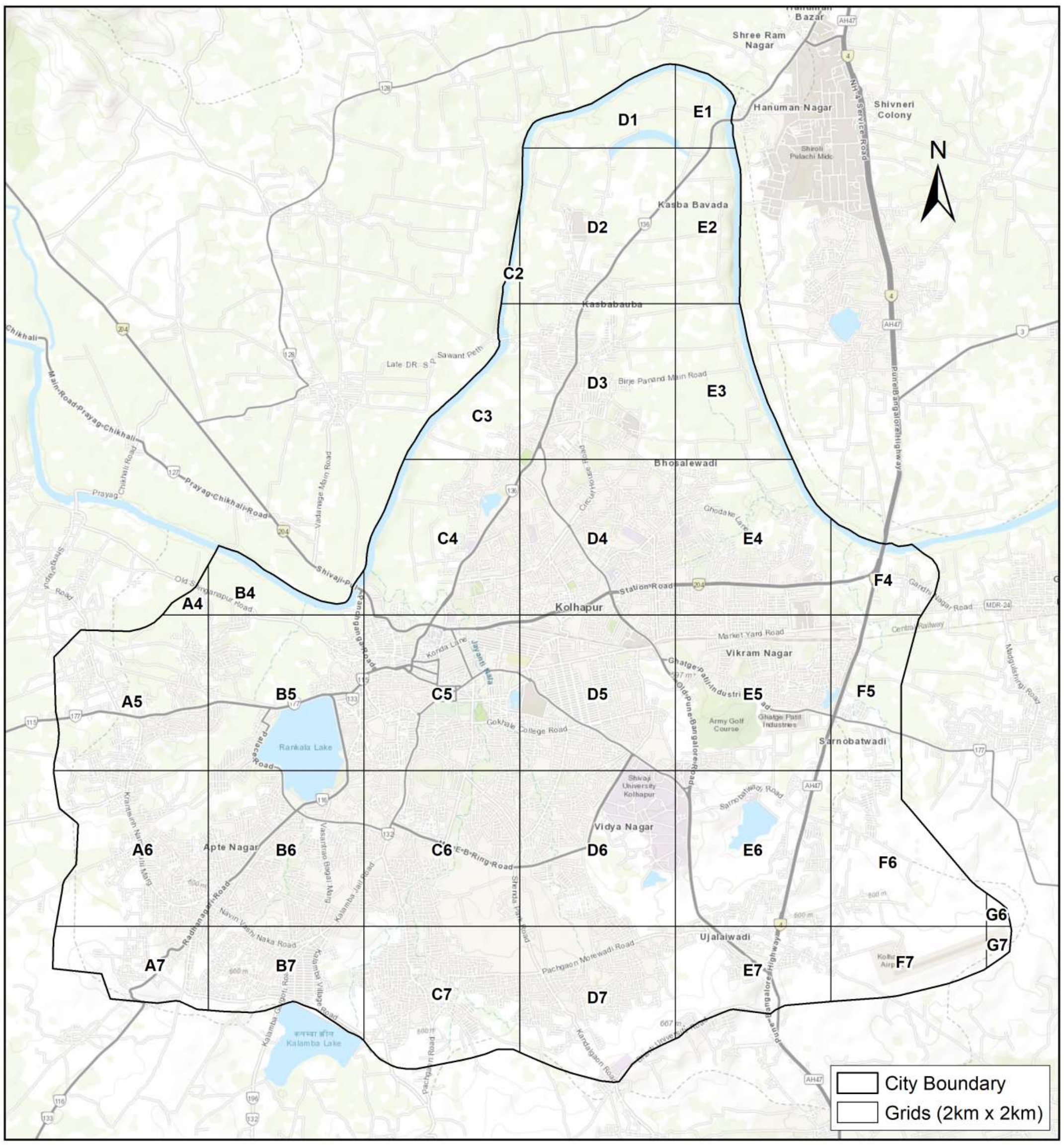


Figure 3.1: 2 Km x 2 Km Grid Plotted Over Kolhapur City (Source: CSIR-NEERI)

3.7 Road Condition in Kolhapur City

The data on road condition is provided by Kolhapur Municipal Council. In order to reduce the particulate matter air pollution, improvement in these road conditions will be helpful. The road is divided into two groups, one is based on the construction material of road and the other is road width. Construction material helps in identifying the road that can be improved to reduce the re-suspension of road dust. The road length that can be swept using truck mounted vacuum cleaner. **Figure 3.2** shows the road network in Kolhapur city.

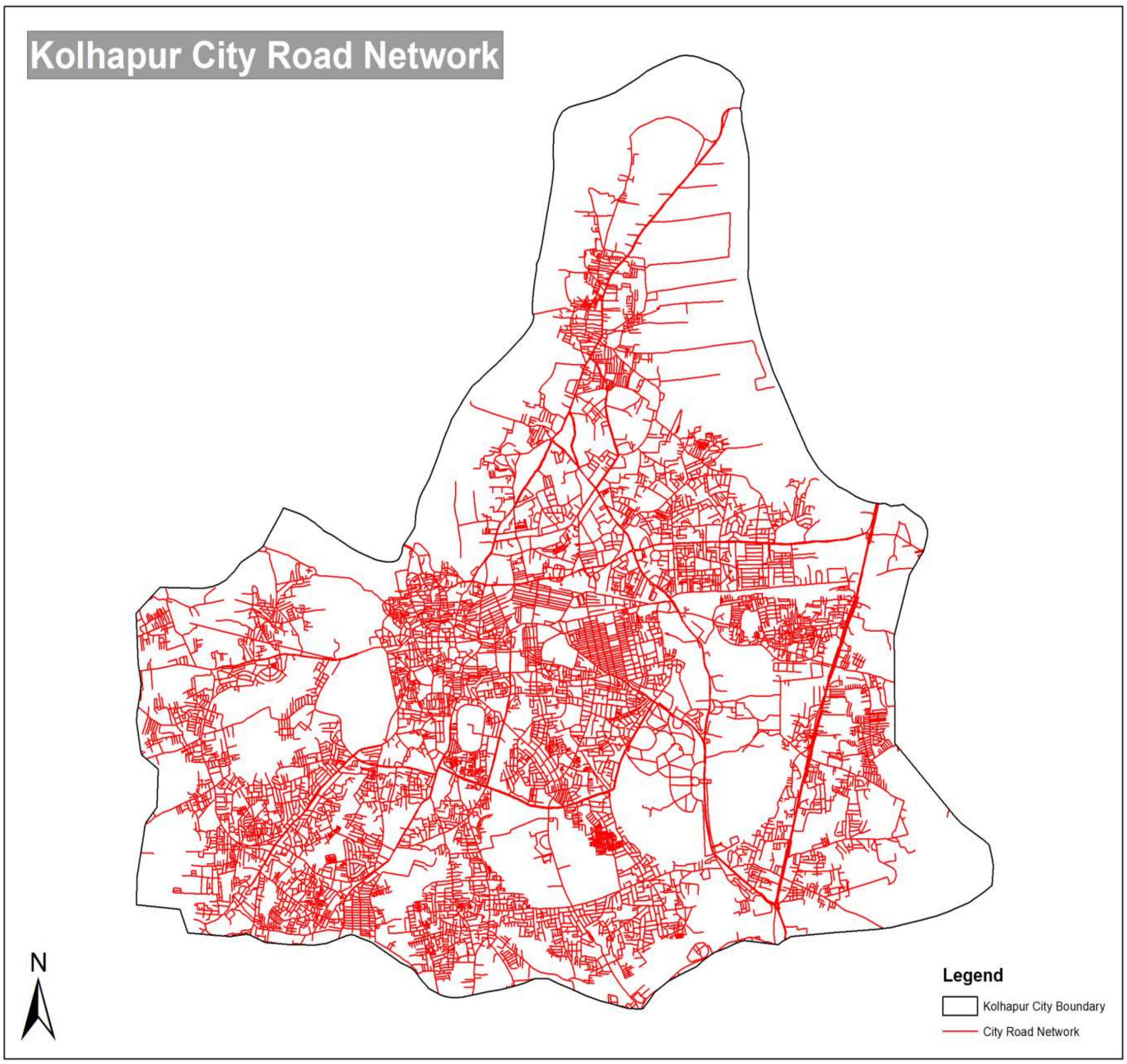


Figure 3.2: Road network in Kolhapur city (Source: CSIR-NEERI)

3.8 Vehicle Count

As per line sources, vehicle counting was carried out in 20 different locations across the city boundary. Traffic Counting was carried out as per the methodology. The collected data is used for vehicular emission estimation per hour and then identified for its grid position. The percentage of different type of vehicle viz. 2w, 3w, 4w, etc. operating with different fuel is estimated as per "A Report on Total Fuel Consumption by Transport Sector in India", Press Information Bureau, Government of India, Ministry of Petroleum & Natural Gas, dated January 28, 2014. The vehicular count at one such location is shown in **Figure 3.3**

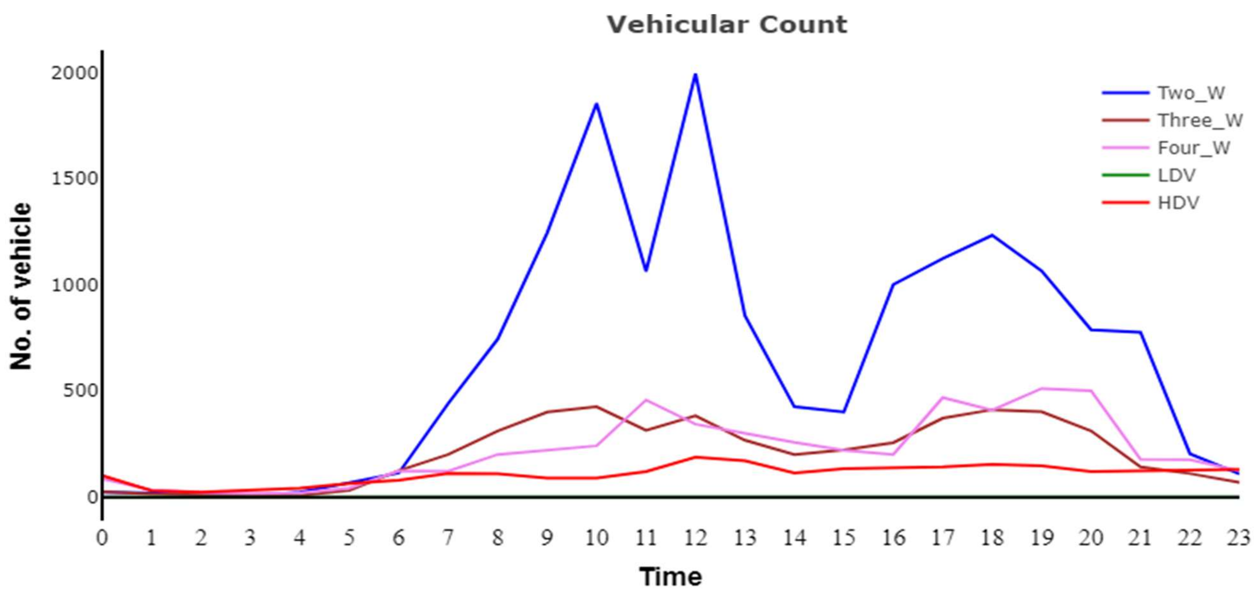


Figure 3.3: Vehicular Count at One Traffic Intersection in Kolhapur City

Since the vehicles of same category uses different fuels, it is considered that 55% of vehicle category use diesel as fuel and 45% of vehicular category use petrol as fuel. Ref: "A Report on Total Fuel Consumption by Transport Sector in India", Press Information Bureau, Government of India, Ministry of Petroleum & Natural Gas, dated January 28, 2014. The Figure 3.4 represents the hourly emission load emitted from vehicular sector. The particulate matter emission load starts increasing during day time at around 6:00 AM in morning and drops around 11:00 PM at night. The concentration is high during 12:00 hrs. Same peaks are also seen for NOx, HC and CO emission load.

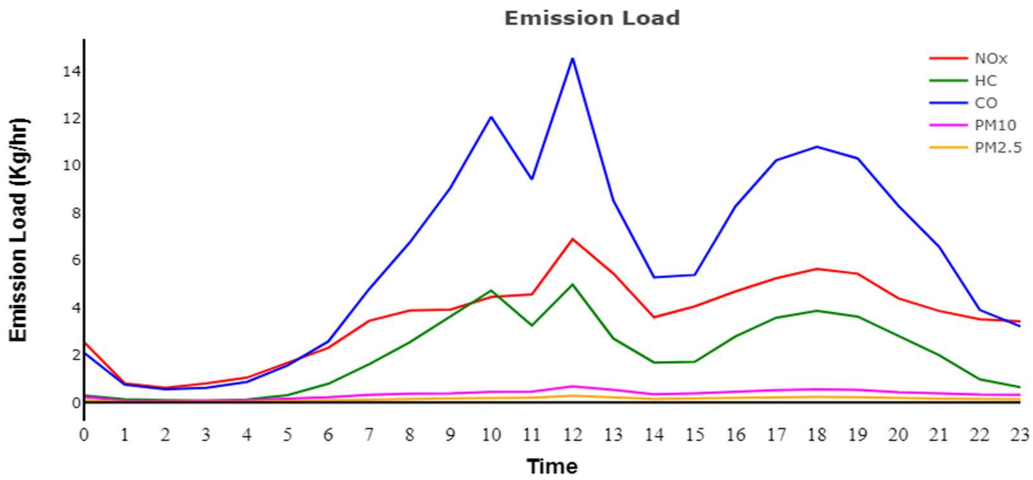


Figure 3.4: Hourly Vehicular Emission Load

Following emission factors are used to calculate emission load from line sources. The emission factors derived by ARAI, Pune are used for calculations **(Table 3.1)**.

Table 3.1 : Emission Factors Considered for Emissions Estimation

Emission Factor for BS-III Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2-Wheeler	0.035	0.27	0.61	1.65	g/km
2	3W_Petrol	0.05	1.2	0.7	1.20	g/km
3	3W_Diesel	0.05	0.5	0.5	0.50	g/km
4	4W_Petrol	0.05	0.12	0.19	3.01	g/km
5	4W_Diesel	0.12	0.67	0.2	0.51	g/km
6	HDV	1.24	9.3	0.37	6.00	g/km
Emission Factor for BS-IV Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2-Wheeler	0.1	0.1	0.13	1.81	g/km
2	3W_Petrol	0.035	0.5	0.3	0.75	g/km
3	3W_Diesel	0.035	0.5	0.3	0.75	g/km
4	4W_Petrol	0.08	0.1	0.1	1.00	g/km
5	4W_Diesel	0.08	0.1	0.1	1.00	g/km
6	HDV	0.06	0.39	0.42	0.74	g/km
Emission Factor for BS-VI Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2-Wheeler	0.0045	0.090	0.068	0.50	g/km
2	3W_Petrol	0.0250	0.100	0.100	0.22	g/km
3	3W_Diesel	0.0045	0.080	0.100	0.50	g/km
4	4W_Petrol	0.0045	0.060	0.100	1.00	g/km
5	4W_Diesel	0.0045	0.080	0.100	0.50	g/km

6	HDV	0.0100	0.080	0.100	0.50	g/km

The final emission load estimated is expressed in percentage and Kg/hr. The emission loads for PM_{10}, $PM_{2.5}$, NOx, HC and CO from vehicular category are found to be 241, 103, 1559, 2390 and 4930 kg/day respectively **(Figure 3.5**). The maximum emission load of particulates is from heavy duty vehicles (61.2%).

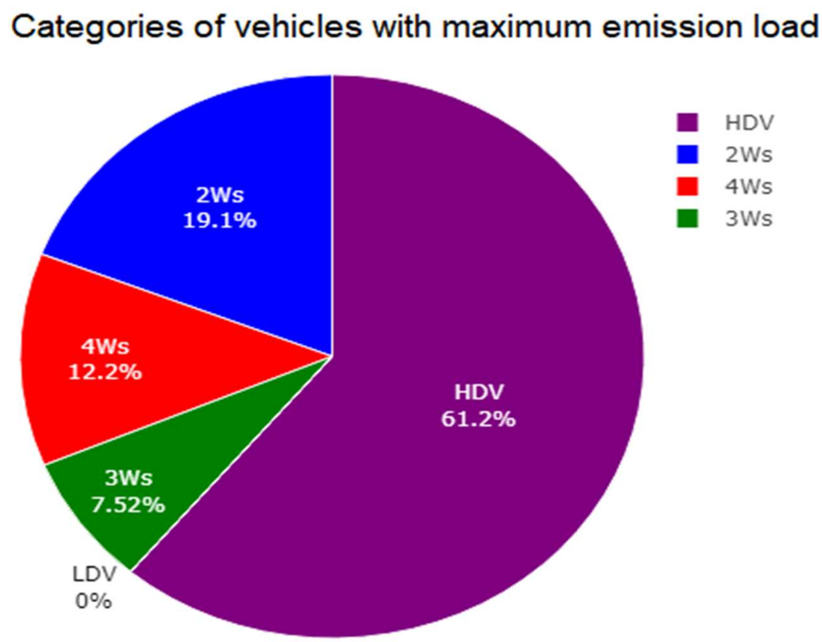


Figure 3.5: Total Emission Load (%) from Line Source

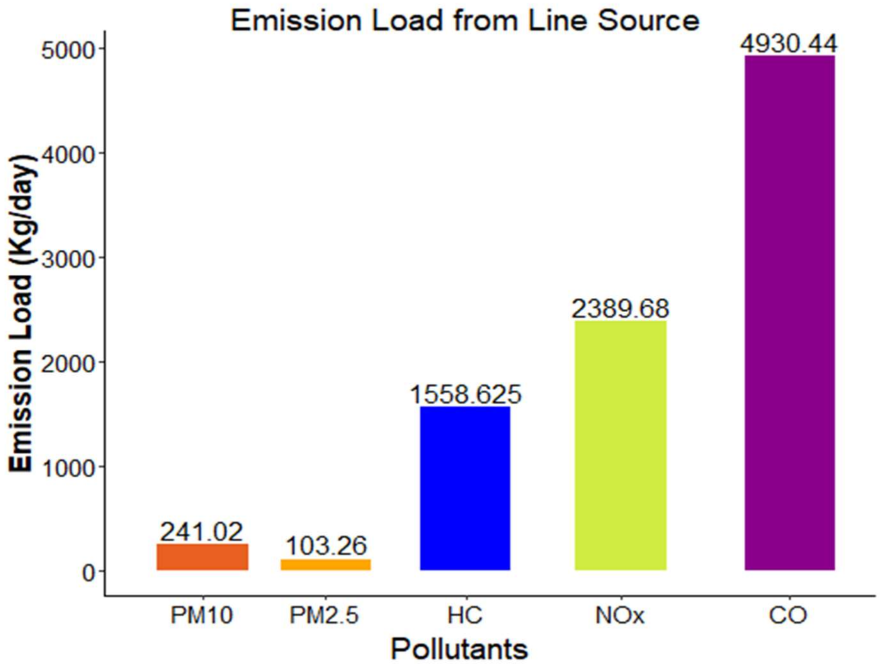
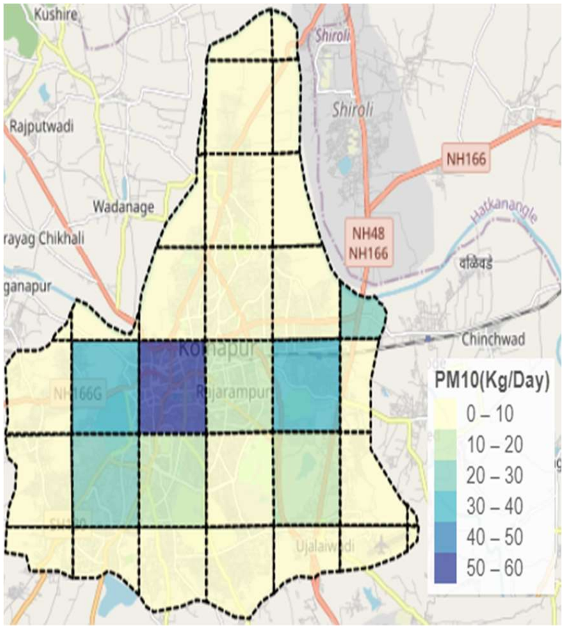


Figure 3.6: Total Emission Load from Line Source

3.8.1 Grid-wise Line Emission Load (Line Source)

The maximum emission load is seen in commercial areas of the city. This is due to high traffic flow in the region. The emission load for PM profile is shown in the **Figure 3.6 & 3.7.**



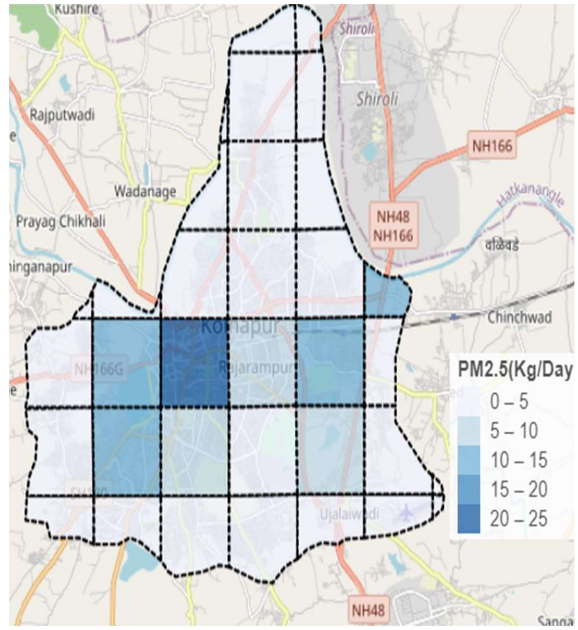


Figure 3.7: Grid-wise PM_{10} Emission Load From Line Source

Figure 3.8: Grid-wise PM_{10} Emission Load From Line Source

3.9 Point Source Emission Load

The Indian foundry industry is a leading engineering sector with annual production of over 7 million tonnes of castings, accounting for about 8- 9% of total castings production in the world. There are approximately 4,500 foundry units in the country out of which 90% can be classified as small-scale units, 8% as medium-scale units, and 2% as large-scale units. The foundry industry is dispersed across various geographical clusters, of which the Kolhapur cluster is one of the major ones. Kolhapur was traditionally an agro-based economy. Demand for oil engines and agricultural implements grew with industrialization in the region. This led to the emergence of the foundry industry which evolved around the 1960s. Today Kolhapur is a leading foundry cluster, renowned for manufacturing quality castings.

There are approximately 300 foundry units located in the Kolhapur and Sangli districts of the region. While units in Sangli are located mainly in the Miraj and Palus industrial areas, foundries in the Kolhapur district are spread across eight major industrial estates. The cluster primarily manufactures ferrous (iron) castings covering both SG iron and grey-iron castings. The total production of the Kolhapur foundry cluster is estimated to be 6,00,000 tonnes per annum. A majority of the foundry units in the cluster cater to the automotive sector along with other sectors such pumps/valves, sugar, textiles, etc. The cluster has experienced growth in turnover, employment and exports over the past few years. Almost 30% of production is being exported to several countries and catering to numerous industries. The Kolhapur industry is driven predominantly by the textile industry and is mainly dominated by local manufacturers and Marwari Rajasthani traders. Kolhapur is well known for its local arts and Handicraft market. Kolhapuri chappals a specialty is manufactured by the local cobbler community and skilled people dedicated to this art and are famous throughout India and abroad. The Industrial emissions are estimated based on the activity data received from MPCB on industry wise fuel use, type, etc as per the questionnaire and from MPCB's CTE and CTO files. The emission load is estimated based on these factors as per CPCB methodology. The control option like fuel change, implementation of APC Systems with greater efficiency, strict compliance and maximizing use of renewable energy source are suggested and the reduction in emissions are estimated as improved Emission Scenarios for point sources. The types of fuel used in industries found in Kolhapur MIDC's are wood, coal, furnace oil, diesel, Petcoke, bagasse and briquettes etc. **(Table 3.2).**

Table 3.2: Quantity of Fuel Consumed by Industries in Kolhapur Area

Fuel	Quantity	Unit
Wood	2.2	Ton/Day
FO	18.14	KL/Day
Diesel	6.73	KL/Day
HSD	4.1	KL/Day
LDO	1.84	KL/Day
Coal	81.5	Ton/Day
LPG	0.152	Ton/Day
Briquettes	10.08	Ton/Day
Petcoke	0.256	Ton/Day

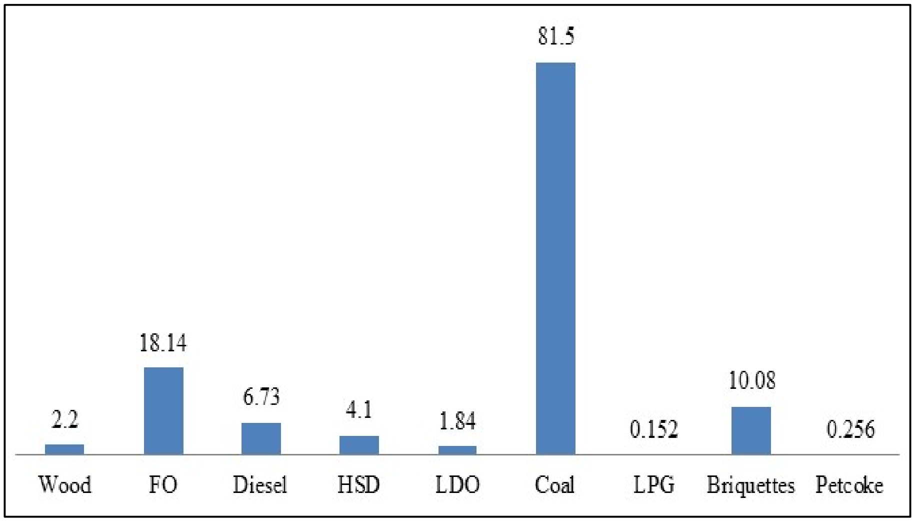


Figure 3.9 Type of fuel used in Industries (T/day or KL/day)
(Source: CSIR-NEERI)

The emission load for PM_{10} and $PM_{2.5}$ for point source is estimated 864.56 Kg/d and 347.71 kg/d respectively. Total PM emission load from point source is presented in **Figure 3.8** and grid wise kg/day emission load for PM_{10} and $PM_{2.5}$ is presented in **Figure 3.9 & 3.10**.

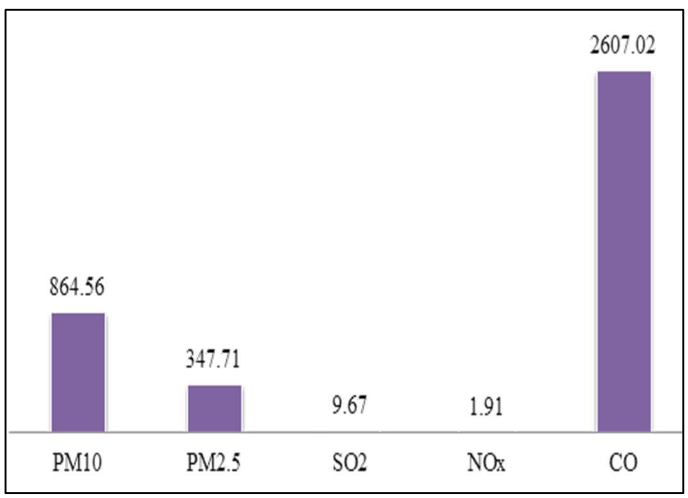


Figure 3.10: Total Emission Load from Point Source (Source: CSIR-NEERI)

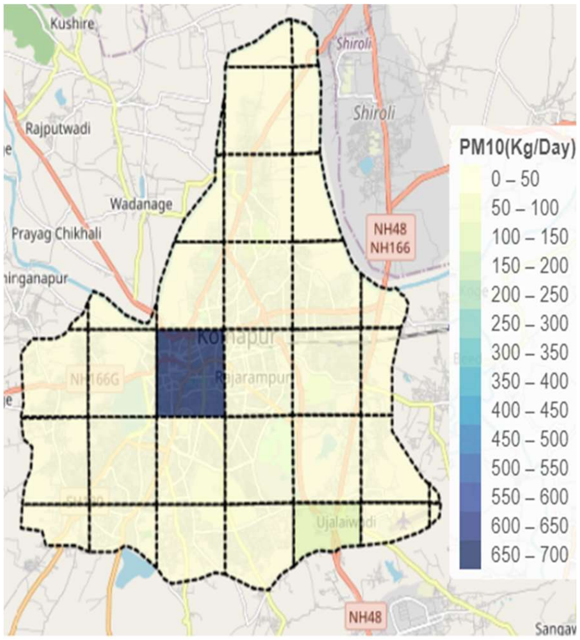


Figure 3.11: Grid-wise PM_{10} Emission Load From Point Source

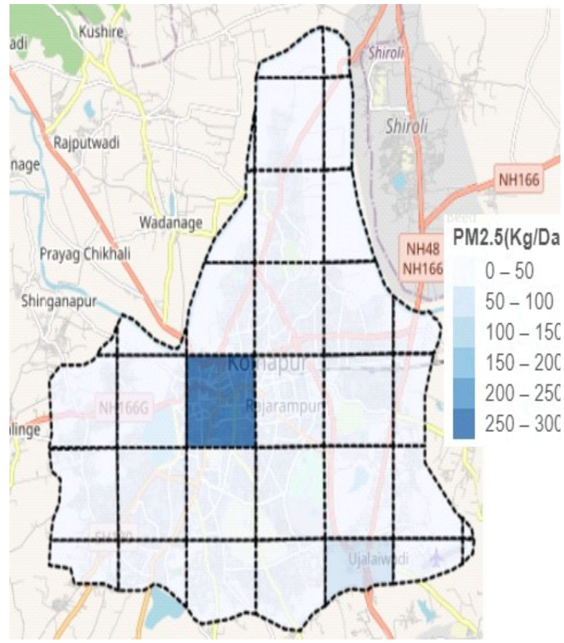


Figure 3.12: Grid-wise $PM_{2.5}$ Emission Load From Point Source

3.10 Area Sources

Emissions from sources that are too small and difficult to be survey individually, are considered collectively as area sources. Domestic sources, therefore, constitute area sources. To calculate domestic emissions the entire region was divided into square grids of 2 Km x2 Km. The population density and fuel usage pattern were considered while estimating the domestic emissions in each of the grids. The data on consumption of fuels (coal, kerosene, wood and LPG) for crematories, hotels, restaurants, open eat-outs, slums, bakeries were collected from respective sub divisions of Municipal Corporation. This consumption data and corresponding emission factors given by CPCB were used for calculating emission load from respective sources.

3.10.1 Bakery

Even though Bakeries emit less pollution but for the ovens, boilers, hot water generators, DG sets emit flue gases through small stacks. Bigger plants with more than two or three production line of Bread or Biscuit ovens emits considerable amount of flue gases which consists of particulate matters, Sulphur dioxides, Nitrogen oxides. There are 12 bakeries spread all across the city. Considering the operation of bakeries, it was observed the fuel consumption pattern is of mixed nature. There have been reported cases of unorganized bakeries comprising small bakery units characterized by low levels of packing and distribution mainly in neighbouring areas. These small time bakeries operate mainly on out dated combustion technologies and traditional methods of manufacturing baked goods that utilize solid fuels in large quantity without any control measures for emission. Consumption of wood and LPG as fuel in bakery processes is one of the major source for PM emission loads from bakeries. Through survey it was observed, mostly bakeries operate for 12-16 hours per day and the peak season of business is during festivals. The information on fuel used in combustion process was collected from survey of bakery units. For the calculation of emission load, the fuel information provided during survey was only considered.

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

In similar way emission for others pollutants have been estimated. The emission load for particulate matter (PM_{10}) is estimated to be 0.0036 Kg/day while that of $PM_{2.5}$ is estimated to be 0.0019 Kg/day **(Figure 3.11)**. As there are only 12 registered bakeries and operating on LPG, the emission from bakeries is very low.

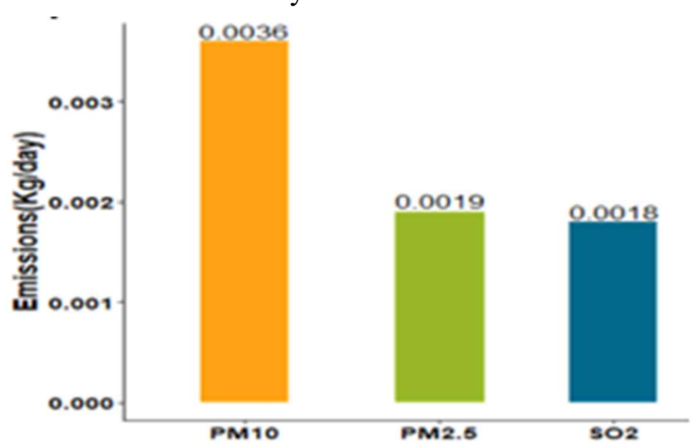


Figure 3.13: Emission Load from Bakeries (Kg/Day)

3.10.2 Crematories

A traditional Hindu funeral pyre takes six hours and burns 250-300 Kgs of wood to burn a body completely. Every year, 50-60 million trees are burned during cremations in India. Cremation is a process where a cadaver, human rests or arid human rests are subjected to high controlled temperatures with the main objective to reduce them to ashes. The cremation process generates particulate matter and gaseous pollutants such as PM_{10}, $PM_{2.5}$, carbon monoxide (CO), nitrogen oxides (NOx). Particulate matter and gaseous pollutant emissions depend on the type of fuel used for cremation and eventually the emission control equipment. There are 4 crematories in Kolhapur city. The average dead bodies burnt per day are 5 nos. The daily wood consumption required to burn a single dead body is assumed as 300 Kg, 5 Litres of Kerosene and 2 Kgs of cowdung cakes (NEERI SA report for Mumbai).

Emission Estimations:

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

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)

Number of dead bodies cremated per day was obtained from Birth and Death cell of Kolhapur Municipal Corporation. The total emission load for PM_{10}, $PM_{2.5}$, CO and NMVOCs is estimated to be 156.6, 73.38, 910.87, and 413.66 Kg/Day. The graphical representation of the same is given in **Figure 3.12**. The emission load from crematories is also calculated grid-wise. This will help for policy makers to arrive at a decision to control emission from crematories, if required.

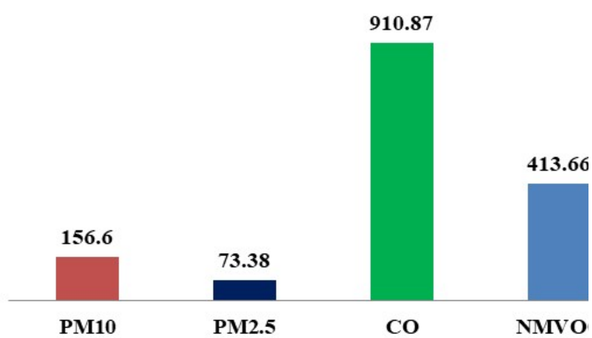


Figure 3.14: Emission Load from Crematories (Kg/Day)

3.10.3 Open Eat outs

Many of us have a favourite cooking smell. Maybe yours is baking bread or frying bacon but new types of equipment are revealing how restaurants contribute to our air pollution. Eat-outs cook with large amounts of oils and other organic matter, which is aerosolized and ventilated. This carries the organic aerosol produced in the cooking process into the urban environment. On the basis of primary survey, the fuel preference for open eats out in Kolhapur city is LPG, followed by coal. Average operating hours of street vendors is 8 hours. A questionnaire survey was carried out to collect necessary data for the estimation of emission load from this source. There are total 185 registered open eat outs in the city.

Emission Factor

Emission from LPG burning (PM) per day

= Number of street vendors operating on LPG x fuel consumption per day x EF

Emission from Coal burning (PM) per day

= Number of street vendors operating on Coal x fuel consumption per day x EF

Based on the above information, the total emission load emitted from open eats outs for PM_{10}, $PM_{2.5}$ and CO is found to be 0.58, 0.26 and 0.5 Kg/day. The bar plot is shown in **Figure 3.13**.

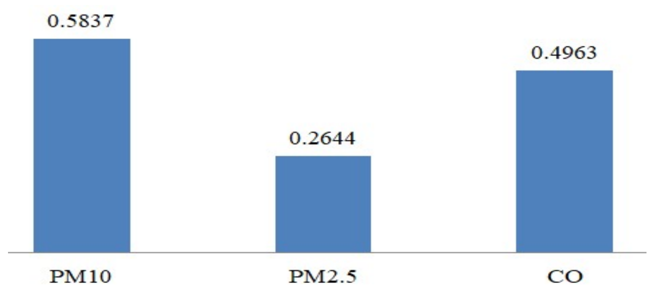


Figure 3.15: Emission Load from Open Eatout (Kg/Day)

The grid wise emission load from open eat-outs is shown in **Figure 3.14 & 3.15** of the report.

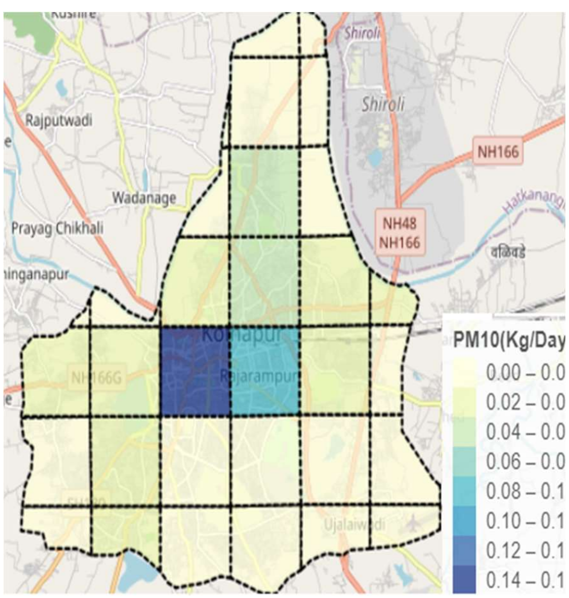


Figure 3.16 Grid-wise PM_{10} Emission Load From Open Eat-outs

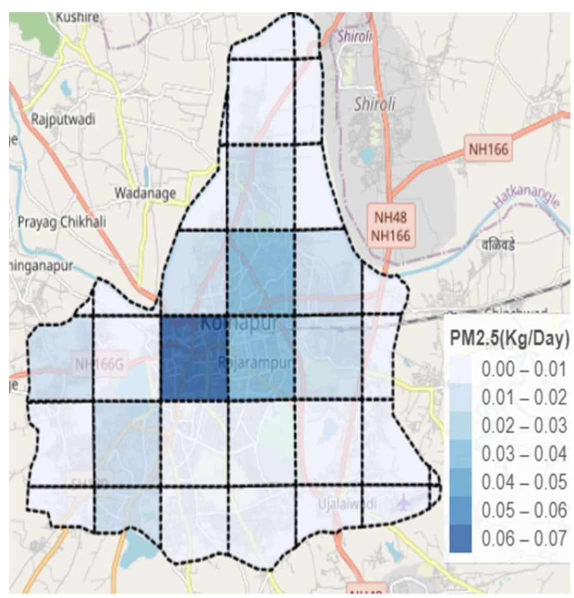


Figure 3.17: Grid-wise $PM_{2.5}$ Emission Load From Open Eat-outs

3.10.4 Domestic Sector

Burning solid fuels like firewood in homes for cooking, heating, and other energy services is the single largest source of air pollution exposure in India. When families burn solid fuels (like wood, dung, and agricultural waste) in their homes, various kinds of air pollutants are generated. One of the many pollutants emitted by this combustion of solid fuels is fine particulate matter ($PM_{2.5}$, particulate matter with aerodynamic diameter 2.5 µm). As per the survey conducted in Kolhapur city, 95% of the households are fully dependent on domestic LPG connections to meet the cooking demands. This LPG consumed is a clean source of fuel. During survey it was seen that in slum areas, kerosene and pieces of wood were used to cook food and heat water.

Emission Estimation

PM emission load from LPG = Nos. of LPG cylinders consumed x Capacity of the cylinder (14.6 Kg) x EF (Kg/T)

Total emissions (PM) from Kerosene = Nos. of households x kerosene consumption (tons/day) x emission factor (Kg/T)

The overall emission load from domestic sector is found to be 39.91, 23.76, 0.33, 0.07 and 348.52 Kg/day for PM_{10}, $PM_{2.5}$, SOx, NOx and CO respectively. The fuel pattern and emission load is shown in **Figure 3.16 & 3.17**.

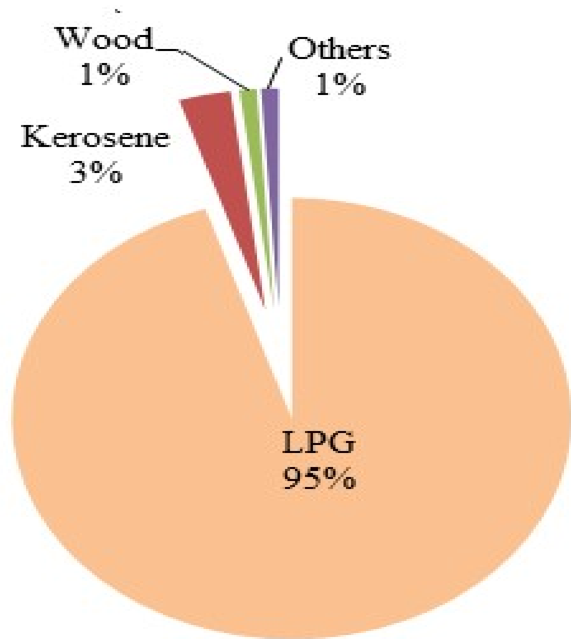


Figure 3.18:Fuel Pattern in Domestic Sector

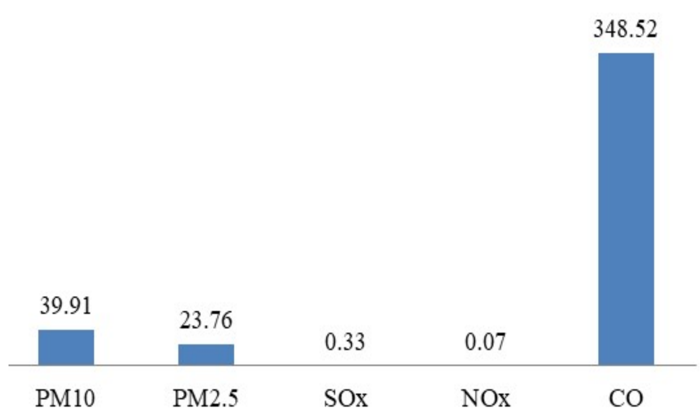


Figure 3.19: Emission Load from Domestic Sector (Kg/Day)

3.10.5 Building Construction

With a scope of being developed as smart city, there are drastic infrastructural developments taking place in Kolhapur city. Real estate sector is booming in the city. The handling and construction activities contribute towards fugitive dust particulate matter in large proportions. Particulate emissions are predominantly due to site preparation work, which includes heavy construction activities. Data related to construction activity was obtained from Building construction department of KMC and from RERA website. During survey, 38 construction sites were found in operation.

Assumptions

- The project duration was estimated at 8-12 months for building construction related activities.
- The area of influence of each construction activity was taken as per authorized by RERA registrations.

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. This was obtained from RERA database.
- **Step 2:** Acres disturbed
- **Step 3:** Months of activity (Buildings construction activity = 8-12 months)
- **Step 4:** Acre x months of activity Buildings construction activity = 8 x total number of acres disturbed
- **Step 5:** PM_{10} Tons/years = 1.2 x total number of acre-months
  (AP42, Section 13.2.3.3– PM_{10} - 1.2 tones/ acres months).

The emission load from different pollutants is presented in **(Figure 3.18).**

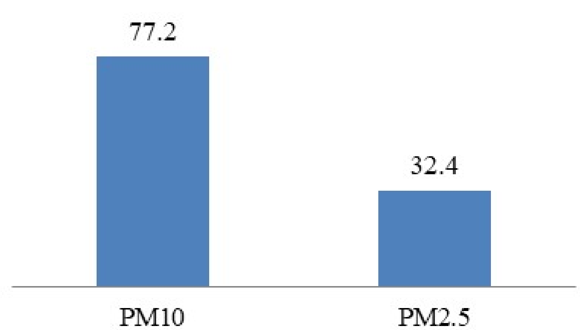


Figure 3.20: Emission Load from Building Construction (Kg/Day)

3.10.6 Hotels and Restaurants

The hospitality industry encompasses a wide range of services and activities such as lodging, restaurants, food services, and convention centres. The lodging sector consists of hotels, motels, resorts, and bed and breakfasts. These operational activities release pollutants into the air. There are around 81 hotels registered with the KMC License department. Most of the hotels and restaurants use commercial LPG cylinders and coal for tandoors for their operation.

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/T)

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/T).

The emission load from different pollutants is presented in **(Figure 3.19).** The estimated emission load from PM_{10} and $PM_{2.5}$ is 15.43 and 6.56 kg/d respectively.

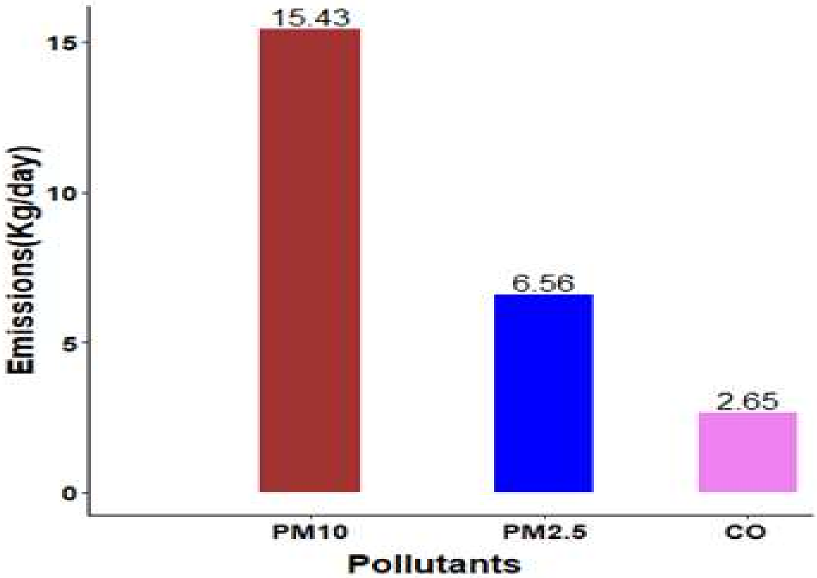


Figure 3.21: Emission Load from Hotels and Restaurants (Kg/Day)

The grid-wise emissions load from Hotels and Restaurants for PM_{10} and $PM_{2.5}$ is shown in figures **(Figure 3.20 and 3.21).**

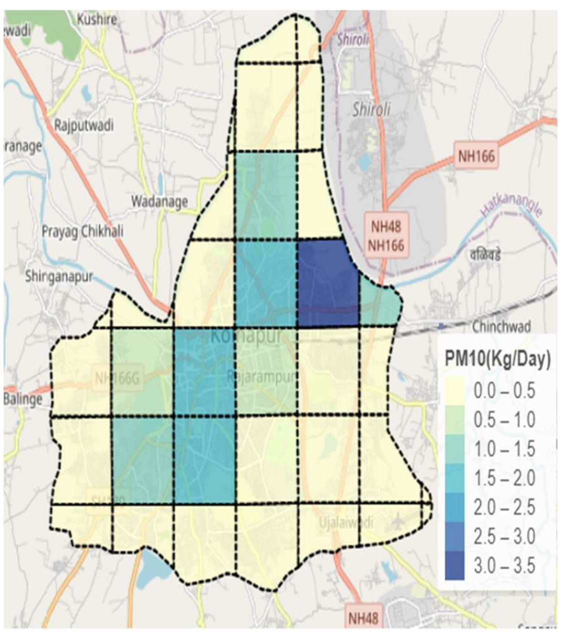


Figure 3.22: Grid-wise PM10 Emission Load From Hotels and Restaurants

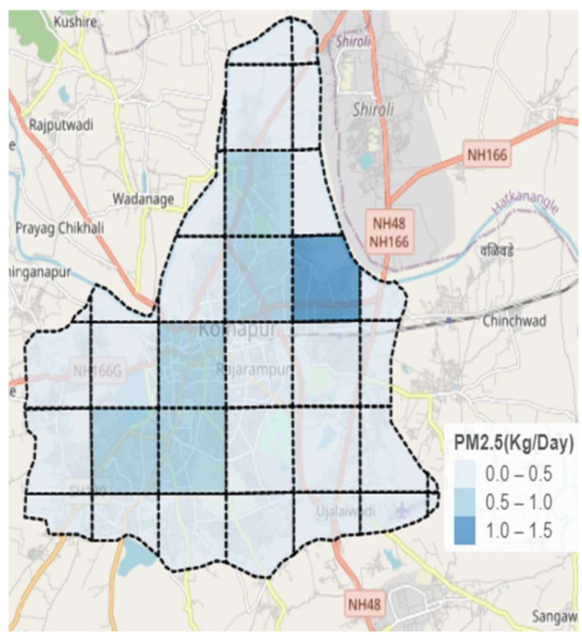


Figure 3.23: Grid-wise $PM_{2.5}$ Emission Load From Hotels and Restaurants

3.10.7 Total Emission Inventory

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Kolhapur city vide emission inventory is developed as shown in **Table 3.3**.

Table 3.3: Total Emission Load from All Sources

No.	Sector	PM_{10}	% PM_{10} Contr.	$PM_{2.5}$	% $PM_{2.5}$ Contr.	Unit
A.	**Area Source**					
1	Bakeries	0.0036	0.0003	0.0019	0.0003	Kg/Day
2	Open Eat-outs	0.5837	0.04	0.2644	0.04	Kg/Day
3	Hotels & Restaurants	15.43	1.11	6.56	1.12	Kg/Day
4	Crematoria	156.6	11.22	73.87	12.57	Kg/Day
5	Domestic	39.91	2.86	23.76	4.04	Kg/Day
6	Building Construction	77.2	5.53	32.4	5.51	Kg/Day
B.	**Line Source**					
1	Vehicular flow	241.02	17.27	103.26	17.57	Kg/Day
C.	**Point Source**					
1	Industries	864.56	61.96	347.71	59.15	Kg/Day
D.	**Total Emission Load**	**1395.307**		**587.826**		Kg/Day
Total Emission Load (TPD)		**1.40**		**0.59**		**Ton/Day**

3.11 Grid-wise Emission Inventory

The grid wise emission inventory considering load from point, area and line were estimated and presented in **Figure 3.22 through Figure 3.25**. These grid wise emission loads will be effective in consideration of policy making decisions for reducing air pollution to a great extent.

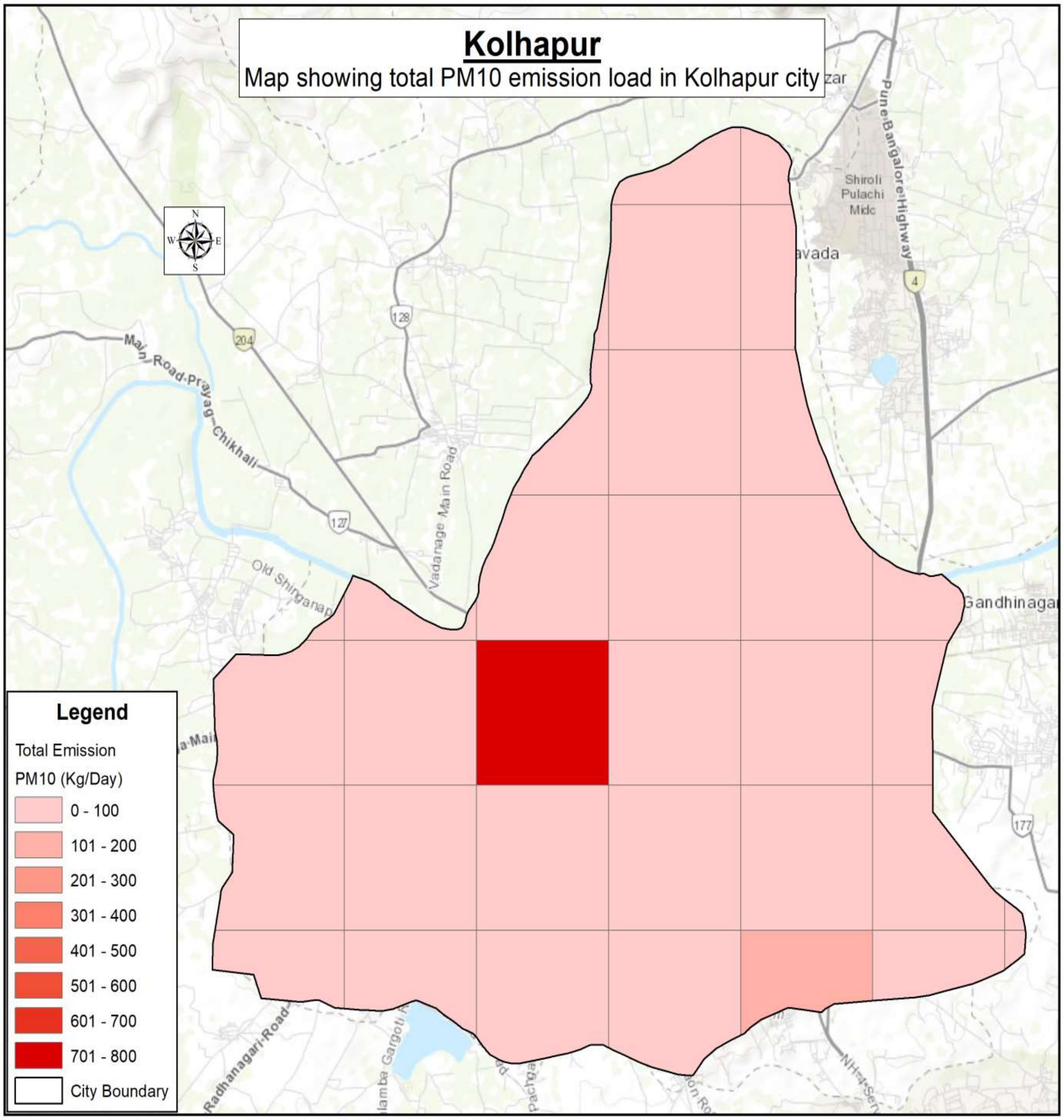


Figure 3.24: Total Grid-wise PM_{10} Emission Load for Kolhapur City (Source: CSIR-NEERI)

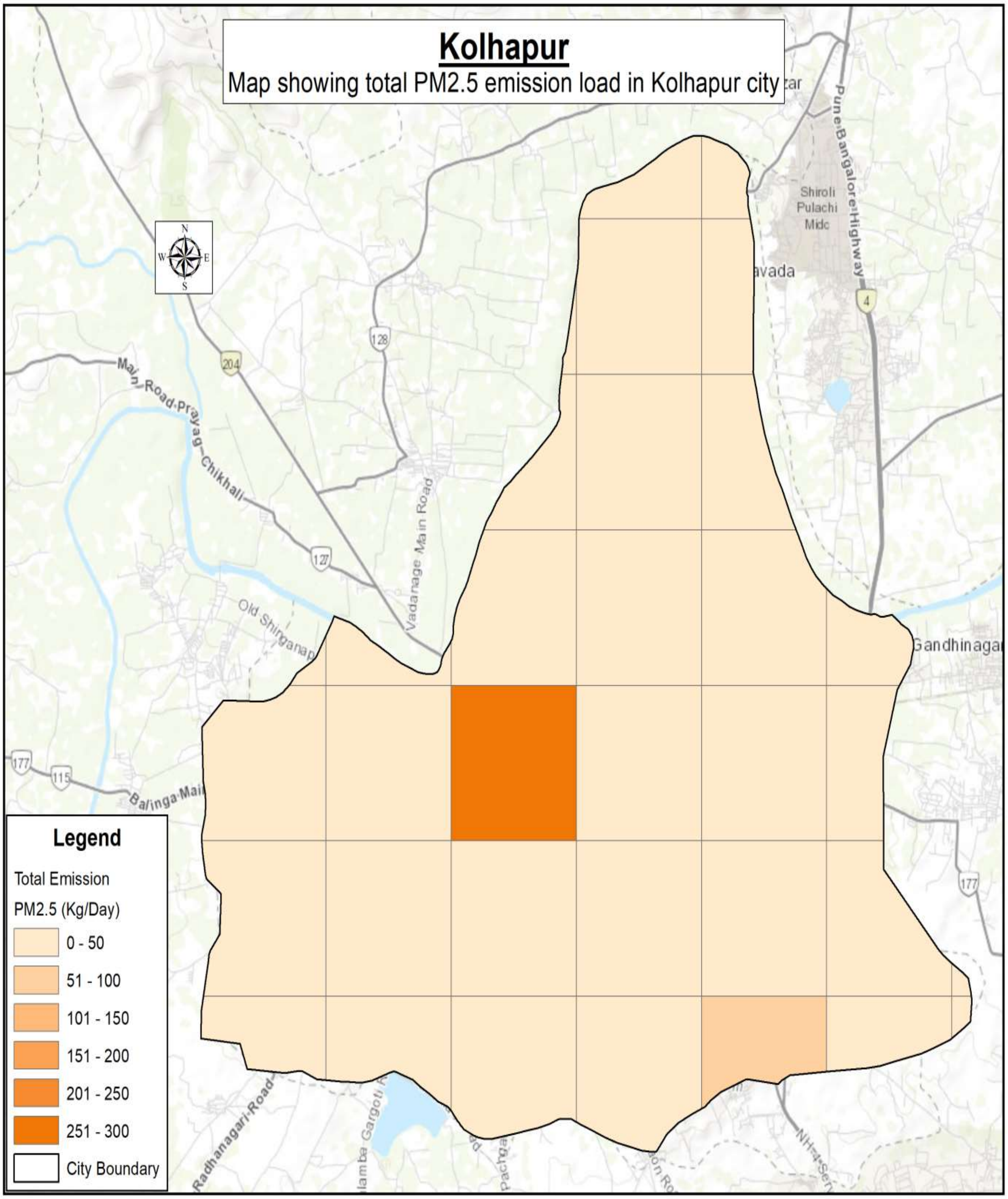


Figure 3.25: Total Grid-wise $PM_{2.5}$ Emission Load for Kolhapur City(Source: CSIR-NEERI)

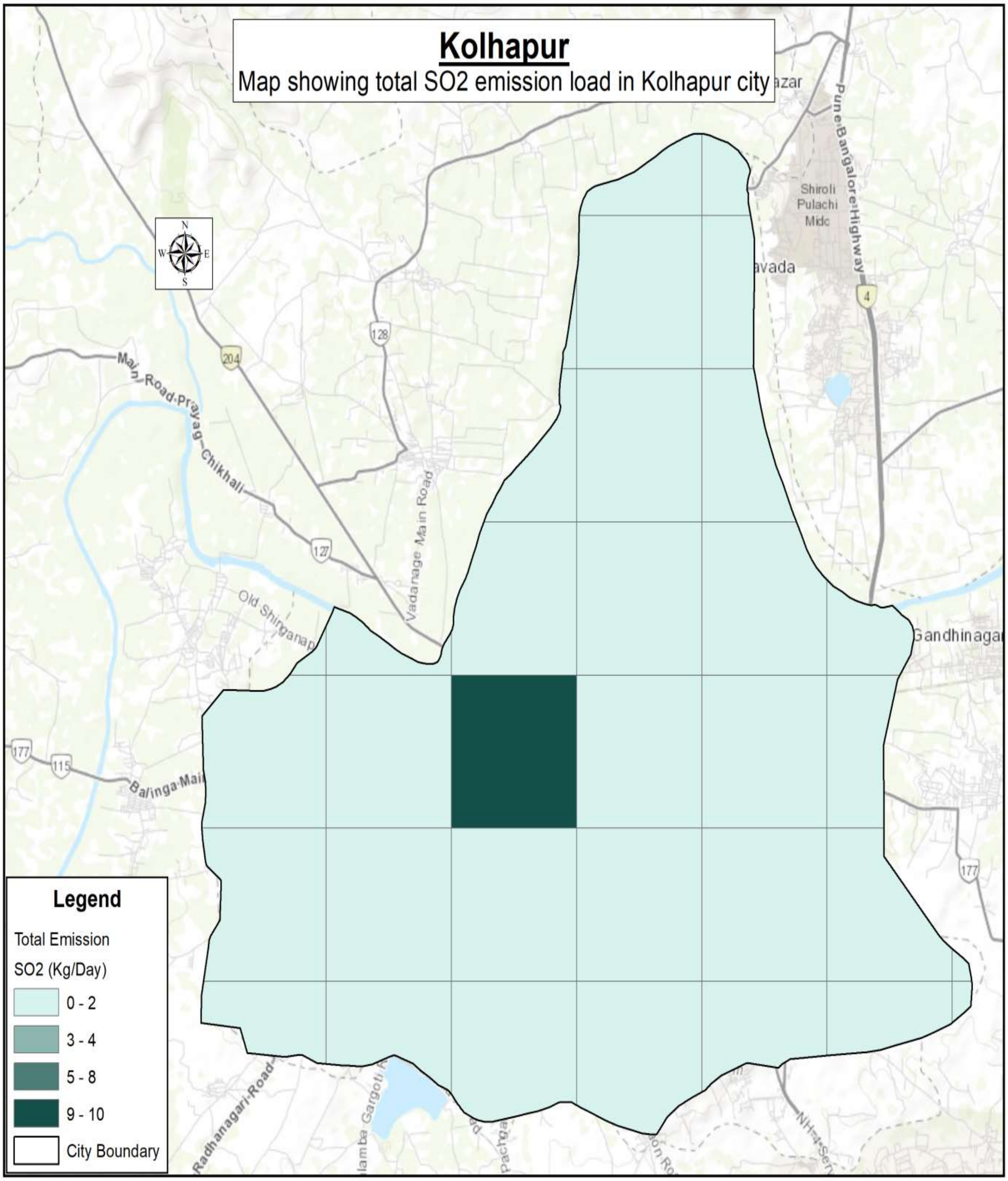


Figure 3.26: Total Grid-wise SOx Emission Load for Kolhapur City (Source: CSIR-NEERI)

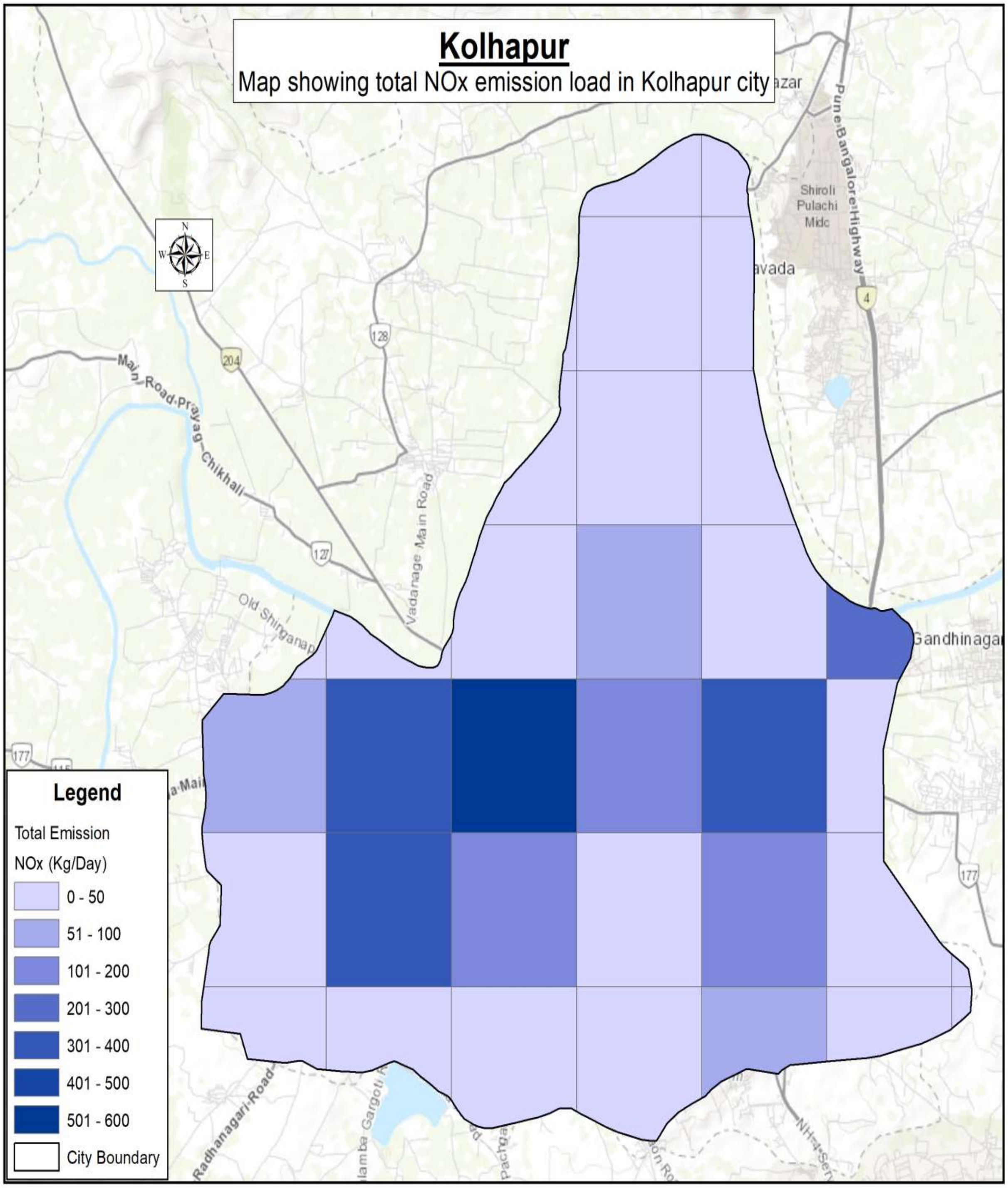


Figure 3.27: Total Grid-wise NOx Emission Load for Kolhapur City(Source: CSIR-NEERI)

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 analysed during the assessment.

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

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

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)

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

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 4 locations: Dabolkar Corner (S1); D.Y.Patil college (S2); Kasba Bawda (S3) and Mahalaxmi Temple (S4). 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 (Paatero & Hopke, 2003). 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 (Paatero et al., 2002). 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.**

Table 4.1: Percentage source contribution for PM_{10} and $PM_{2.5}$

Most likely source(s)	% Contribution	
	PM_{10}	**$PM_{2.5}$**
Agriculture	22	26
Industrial	18	30
Biomass Burning +Vehicular	26	24
Construction/ Road dust	34	20

4.3.1 Factors of PM_{10} and $PM_{2.5}$

EPA PMF run analysis identified 4 factors in the study location for PM_{10} and $PM_{2.5}$ samples with factor finger prints as shown in Figure 4.2 and Figure 4.3

Factor 1: Agriculture

Factor 1, representing approximately 22% and 26% of total PM_{10} and $PM_{2.5}$ emissions respectively. This factor is characterized by a combination of elements associated with agriculture such as Br-, NH_4^{3-}, Na^+, OC, Li+, PO_4-. The presence of organic carbon (OC) in this factor further can originate from the decomposition of organic matter commonly found in agricultural soils. Furthermore, the inclusion of phosphate ions (PO4-) in Factor 1 emphasizes the contribution of fertilizers containing phosphorus compounds, commonly used in agriculture to enhance plant (Srivastava & Ramanathan, 2018).

Factor 2: Industrial source

Factor 2 is identified as an industrial source, contributes significantly to both PM_{10} and $PM_{2.5}$ emissions, accounted for 18% and 30%, respectively. The key indicators for this source encompassed SO_4^{2-}, NO_3^{2-}, Na^+, Co, Ca^{2+}, NO_2^-, Ba, Cu, Li, Ti. The presence of SO_4^{2-} and NO_3^{2-} suggests emissions from industrial processes involving sulfur and nitrogen compounds, such as combustion and chemical production. Additionally, the inclusion of Na^+, Co, Ca^{2+}, NO_2^-, Ba, Cu, Li, and Ti further underscores the industrial processes, including metal manufacturing, combustion of fossil fuels, and chemical production (Gupta et al., 2012; Sharma et al., 2016; Taghvaee et al., 2018; Zong et al., 2016). Locations of industries surrounding the study region justify the influence of industrial activities on this observed factor.

Factor 3: Biomass Burning and Vehicular Emissions

Factor 3 is identified as construction dust with 21% and 22% of total PM_{10} and $PM_{2.5}$ emissions respectively indicated by key markers EC, OC, NH_4^{3-}, F^-, K+, Na^+, Ca^{2+}, Cu, Cl^-, Cr, Cu, Fe, Se, Zn are major indicators of Biomass burning and vehicular emissions. There have been many studies in the past suggesting that K^+ and OC are clear indicator of biomass burning Garaga et al., 2020; Police et al., 2016) whereas NH_4^{3-} is a major indictor of wood combustion (Jain et al., 2019; Mukherjee et al., 2018; Police et al., 2016). 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., 2019; Mukherjee et al., 2018; Panwar et al., 2020; Shukla & Sharma, 2008). Also, EC, SO_4^{2-}, S & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles .(Keerthi et al., 2018).

Factor 4: Construction + Road dust resuspension

Factor 4 is represented by the significant levels OC, EC, Li+, PO_4-, Br-, NO_3^{2-}, Cl^-, Ca^{2+}, Ca, Cr, Fe, Se contributing to 34% and 20% of both PM_{10} and $PM_{2.5}$ pollution respectively. Substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by Fe, OC and EC 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 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. Ca and Ca^+ are major indicators of construction dust from cement and aggregate mixing (Bhuyan et al., 2018; Garaga et al., 2020; Keerthi et al., 2018; Patil et al., 2013). This is mainly contributed from all infrastructure development going in and around the city.

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 Kolhapur. The study identified 4 distinct factors, shedding light on the sources influencing particulate matter in the city. Notably, Construction and Road dust resuspension are dominant in PM_{10} pollution while, Industrial emissions are dominant in $PM_{2.5}$ pollution. To address these findings, stricter regulations and monitoring for construction activities, effective road dust management measures, stricter regulations and emission control measures for industrial facilities should be considered. Implementation of cleaner technologies, regular maintenance, and adherence to environmental standards can help mitigate the impact of industrial activities on air quality.

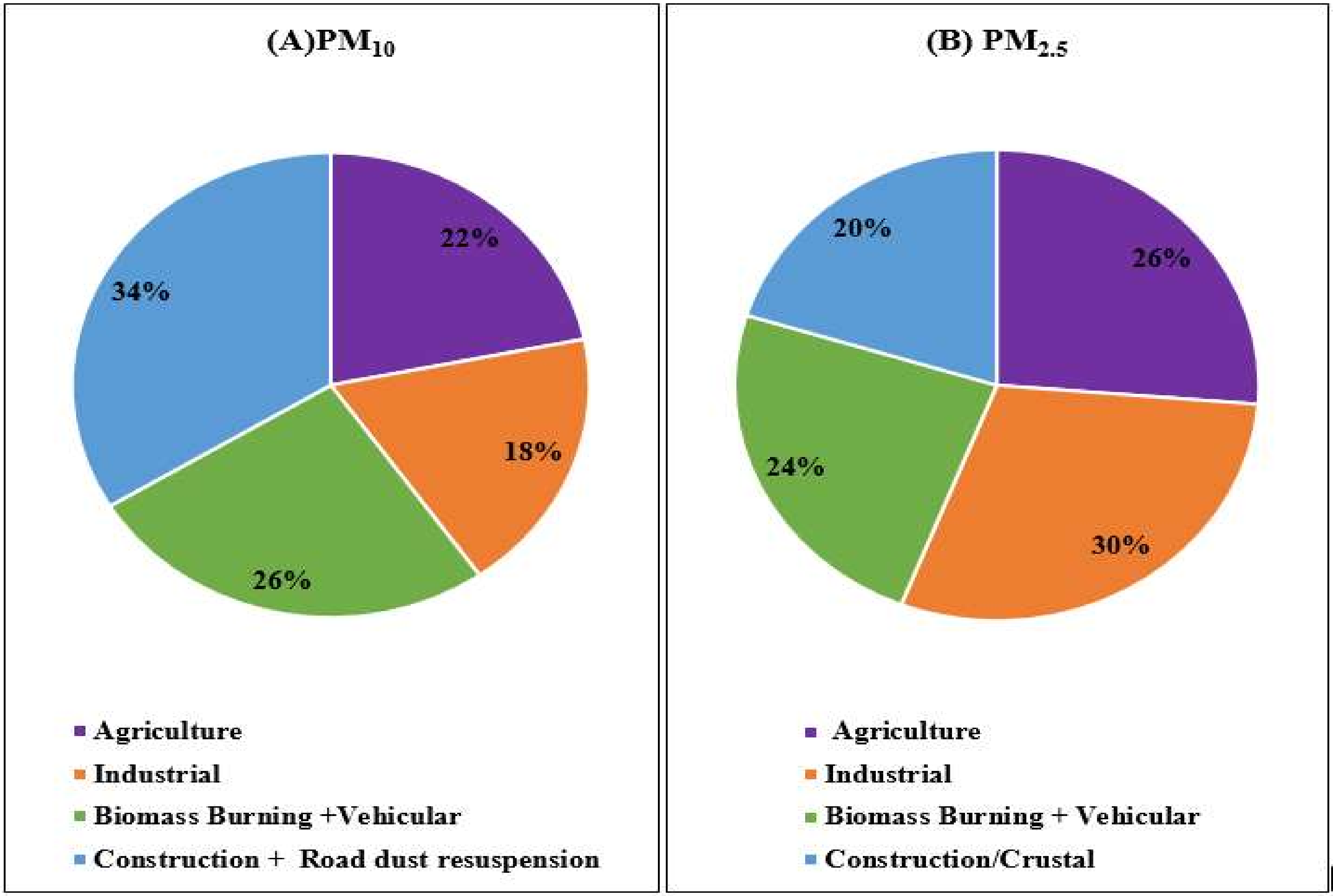


Figure 4.1: Percentage Contribution of Sources for (A) PM_{10} and (B) $PM_{2.5}$ for Kolhapur

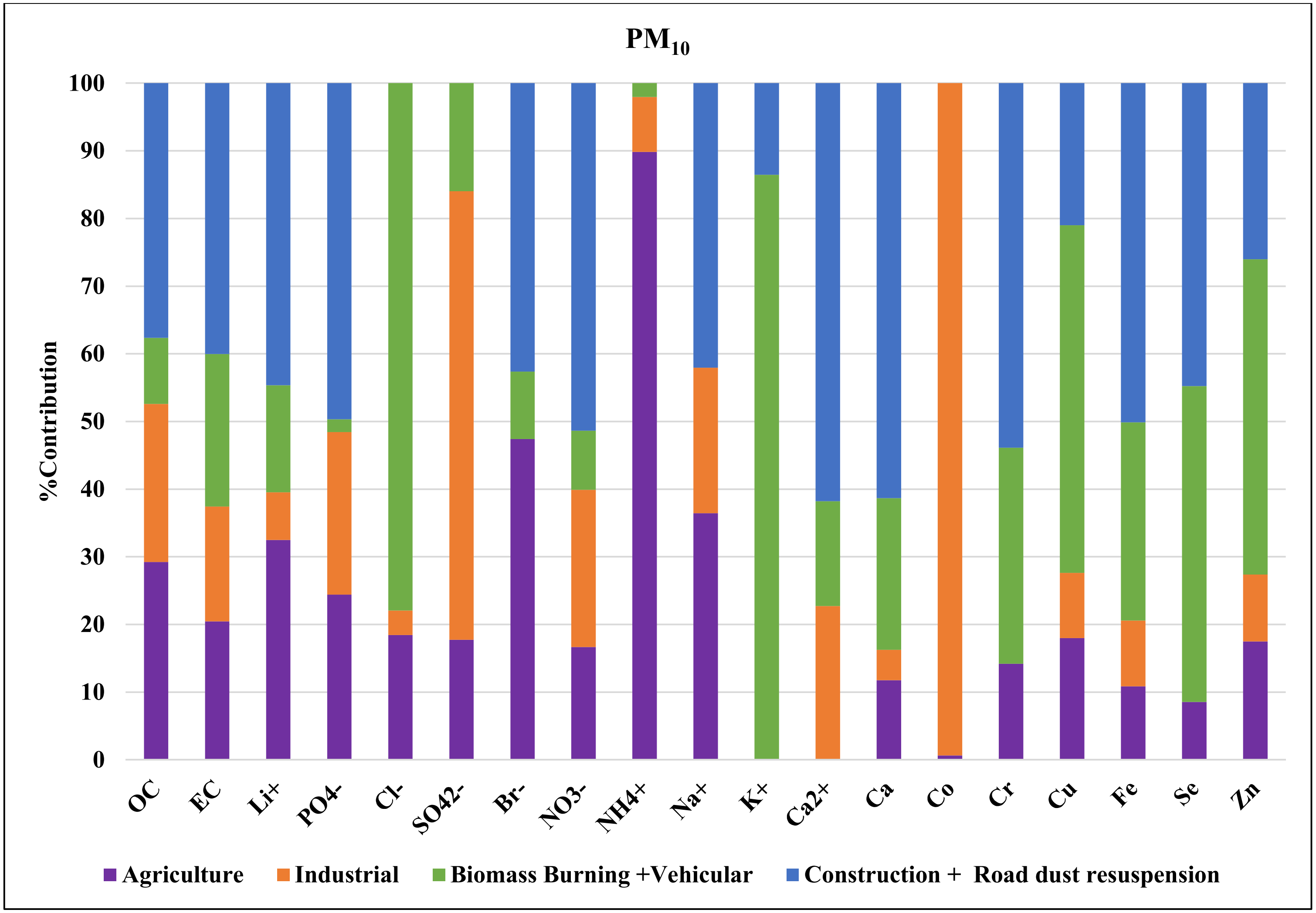


Figure 4.2: Factor Fingerprints of PM_{10} for Kolhapur

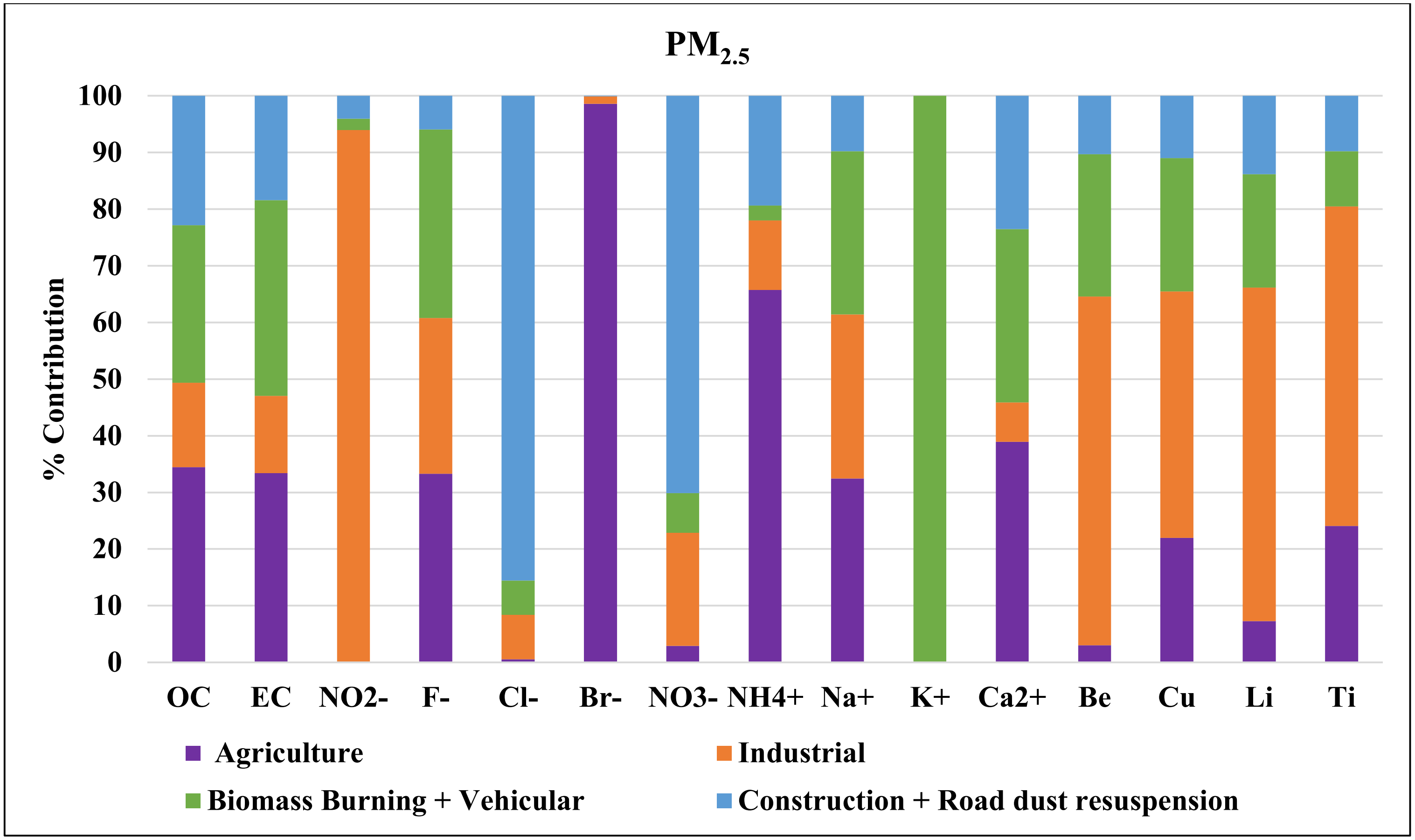


Figure 4.3: Factor Fingerprints of $PM_{2.5}$ for Kolhapur

Chapter 5

Air Pollutions Dispersion Modelling

5.1 Introduction

Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by single or multiple sources. Air quality dispersion modeling has been undertaken with a view to identify the impact and the important sources on ambient air quality in Kolhapur region. Emission inventory for different pollutant is generated and its dispersion simulated to determine the ground level concentration (GLC) of pollutants. AERMOD Source dispersion modeling tool has been also used for the whole city air quality scenario generation for emission loads from all grids in the city. The existing scenario model runs are to establish the dispersion pattern of pollutants due to local meteorology and emission from all possible sources. Model runs also provide an idea about missing sources or additional sources which may have been accounted for earlier. The scenarios for different seasons, locations and sources have been generated to bring out the contributions and their variability. The output of modeling exercise is shown through isopleths and tables.

5.2 Model Input

Air quality modeling is carried out for complete one year. The Gaussian Dispersion Model (GDM) is used to predict spatial distribution of different pollutant's concentration in ambient air. The model has various options including the capability to handle Polar or Cartesian coordinates, simulating point, area, and volume sources, consideration of wet and dry deposition, accounting for terrain adjustment, building downwash algorithm, etc. The data pertaining to source characteristics, meteorological parameters and receptor network required as input to the model include

(i) Source data: physical dimensions (stack location, stack height, stack top inner diameter), exit velocity, temperature of gas and pollutant emission rate and location. For Kolhapur city, the emission from different sources like vehicular emission, crematoria, bakery, road side eatery, etc. are combined in their respective grid and area source emission in terms of $g/s/m^2$ is determined as input to the model.

(ii) Hourly meteorological data for the simulation period: wind speed, wind direction, ambient temperature, mixing height and upper air data generated from weather research forecast (WRF) model at hourly interval.

(iii) Co-ordinates of receptors, where the model would estimate the ground level concentration of pollutants.

5.3 Meteorological Data

Meteorological conditions play a vital role in transport and dispersion of pollutants in the atmosphere. WRF processed hourly meteorological data is generated and used AERMET, which estimates the surface and vertical profile of meteorology. The meteorological data is used in estimating the horizontal and vertical dispersion coefficient (σx, σy) from the estimated atmospheric turbulence. For this study, a meteorological domain of 25 km radius is considered which covers the entire Kolhapur city. Monthly windrose diagram is plotted and the same is shown in **Figure 5.1**. It can be seen that January to February is a period of very low wind without predominance to wind direction. March has a predominant wind direction of west, which subsequently pick up in next two month. In June the high wind from west-south predominates and continues till August. July to September being rainy months brings high wind, which gradually reduces and by October calm wind dominates. The distribution of wind speed frequency is shown in **Figure 5.2**. It can be seen that April to August shows very high wind speed where as for other months, the wind speed is relatively lower.

5.4 Modelling Domain & Result

A domain of 25 Km radium around the centre of the study area is considered for dispersion modelling. A receptor location in the study area were configured in a square grid pattern to facilitate coverage of all the important sites located in and around major urban growth centres with a spacing of 500 m. The area sources were distributed in a square grid pattern and an available emission rate within each grid was used. Hourly frequency distributions of wind speed, wind direction, ambient temperature, stability class and mixing height processed from AERMET is used in the model. There are five pollutant parameters, the dispersion of which is to be simulated. The regulatory limit value of all these parameters, and their emission rate are different **(Table 5.1)**. Therefore, it is felt appropriate to simulate only one pollutant parameter, which is highest in emission rate along with corresponding regulatory limit value. If this particular pollutant parameter meets the regulatory requirement, all other.

Table 5.1: Emission Load for All Pollutants (Tonnes/day)

Parameter	Regulatory Stand. 24 Hr. [µg/m^3]	Area Emission	Industry Emission	Vehicle Emission	City Emission
PM_{10}	100	289.73	241.02	864.56	1395.31
$PM_{2.5}$	60	136.86	347.71	103.26	587.83

Table 5.2: Grid-wise Emission Rate of PM_{10} [g/m^2/s]

No.	Grid No.	Emission Rate [kg/d]	No.	Grid No.	Emission Rate [kg/d]
1	A5	36.69	10	D4	11.17
2	B5	31.01	11	D5	58.63
3	B6	36.64	12	D6	10.25
4	B7	12.38	13	D7	10.01
5	C4	19.97	14	E4	82.6
6	C5	737.79	15	E5	38.27
7	C6	14.83	16	E6	13.89
8	C7	38.5	17	E7	125.07
9	D3	88.99	18	F4	28.61

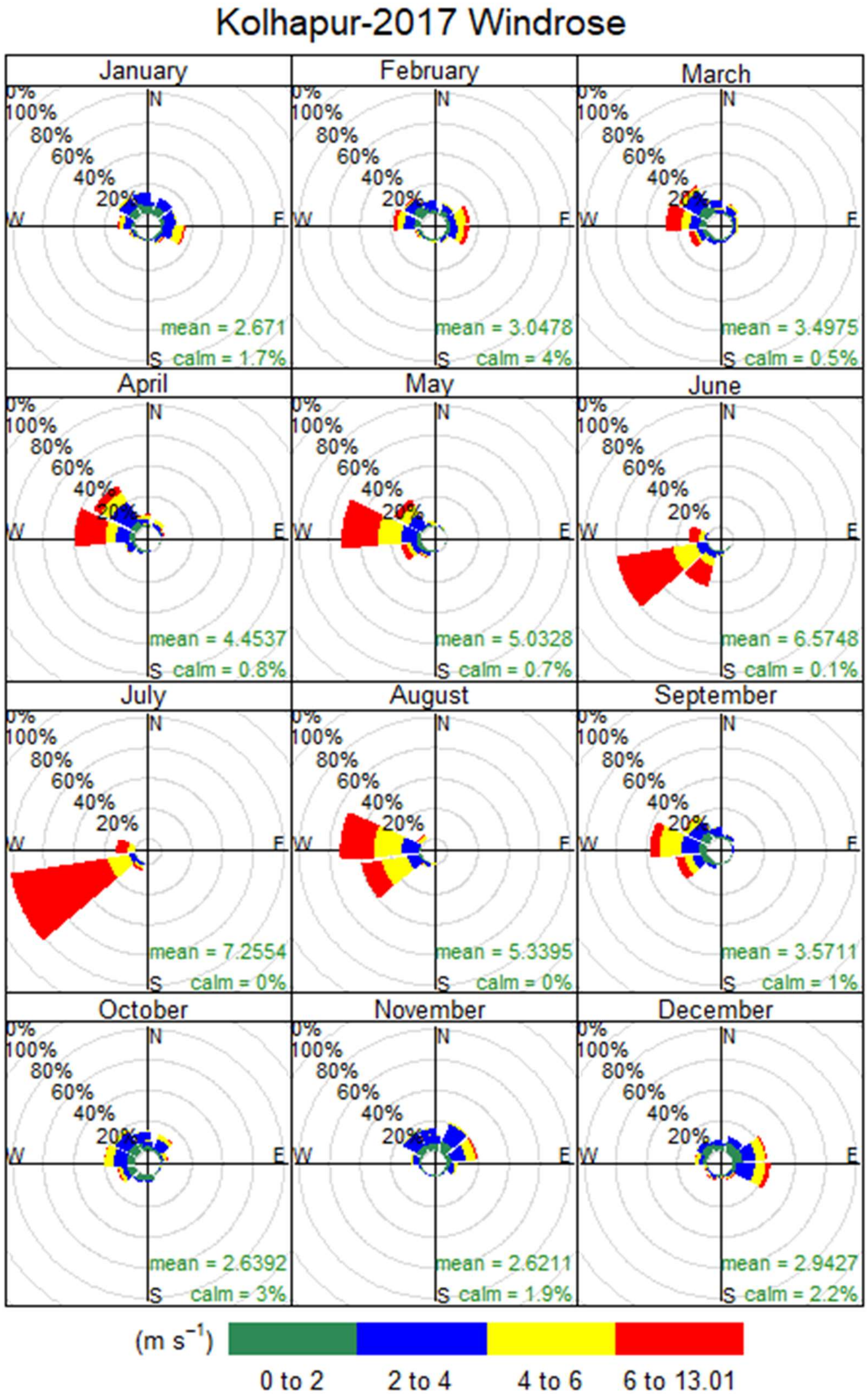


Figure 5.1: Monthly Wind Rose Diagram of Kolhapur (Source: CSIR-NEERI Aermod/Calpuff)

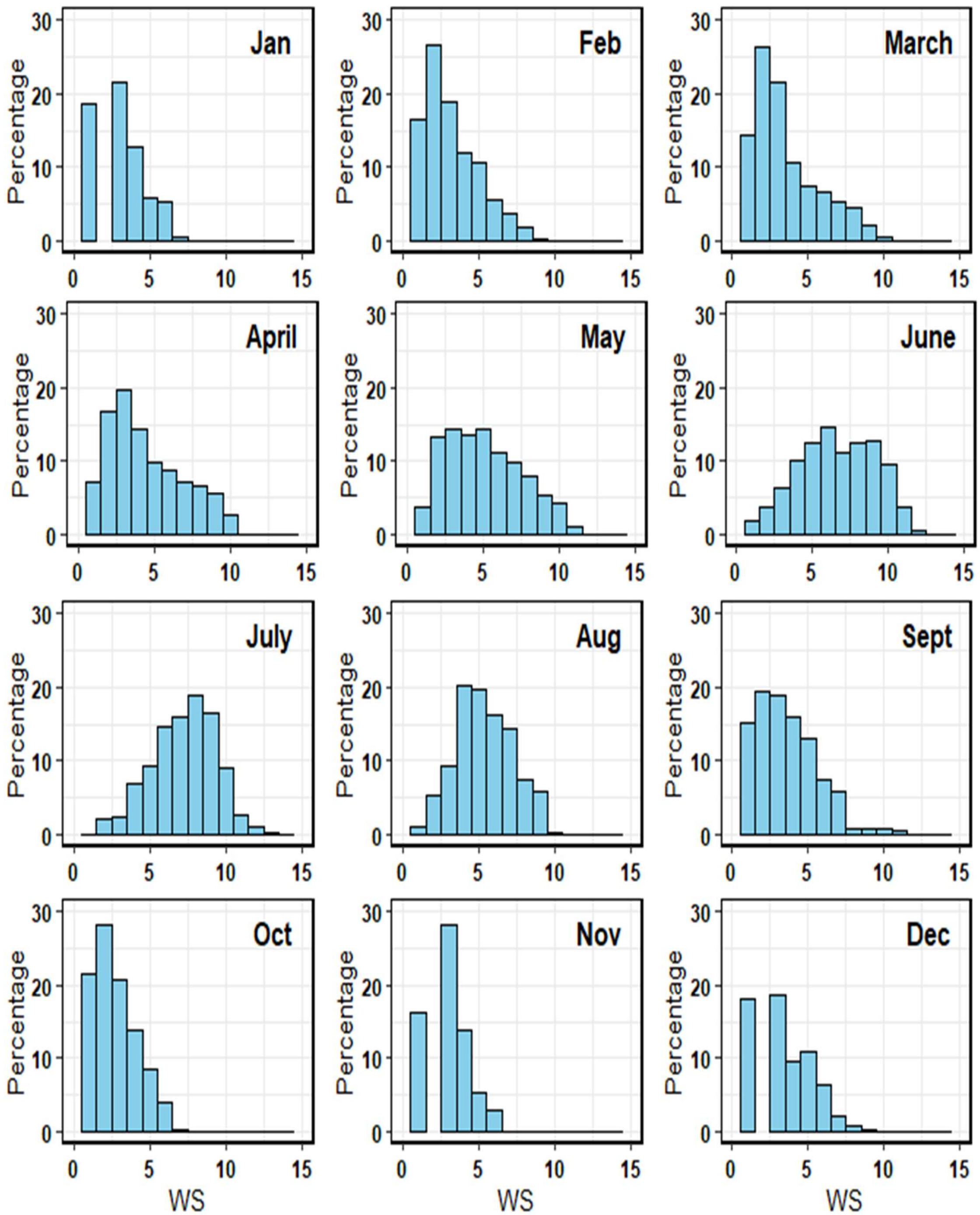


Figure 5.2: Monthly Wind Speed Frequency in Kolhapur(Source: CSIR-NEERI)

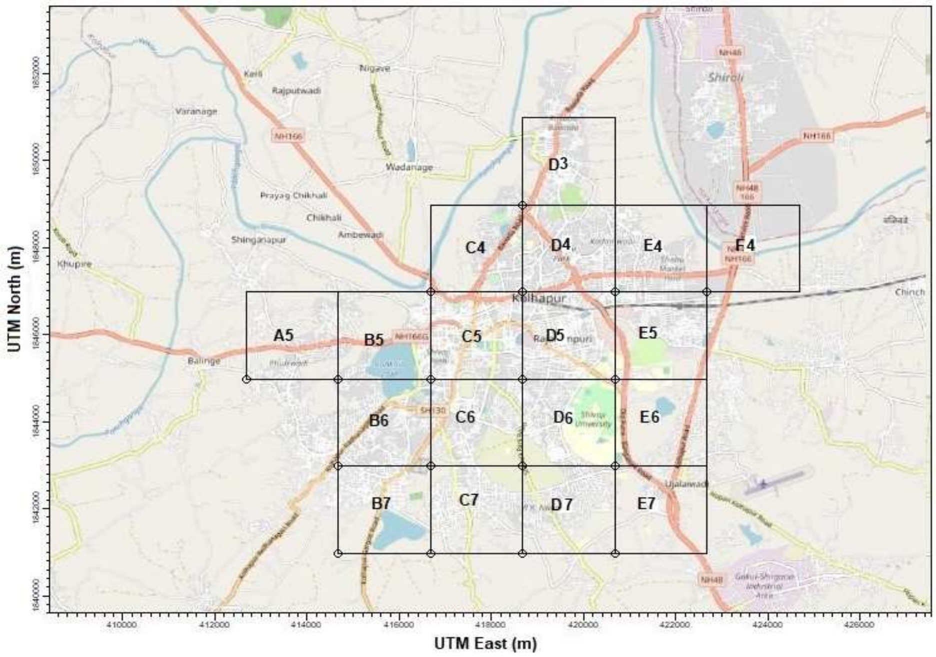


Figure 5.3: Grid Over Kolhapur City for Dispersion Modelling (Source: CSIR-NEERI)

A grid of 2 Km x 2 Km is placed over Kolhapur city for ease in emission inventory and is shown in **Figure 5.3**. Area source emission rate is estimated by first adding all emissions within a grid in terms of gram per second, followed by its division with the area of grid i.e. 2 km x 2 km. This yields emission of pollutants in terms of g/s/m. **Table 5.2** shows the emission load from each grid that is used for dispersion modelling to simulate the ground level concentration of PM_{10}.

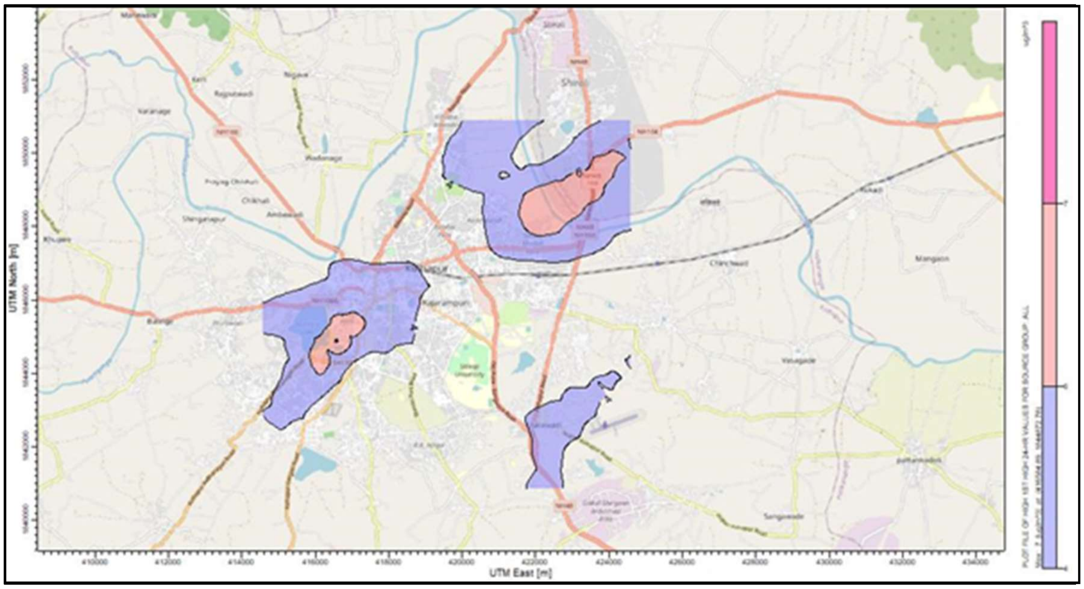


Figure 5.4: GLC of PM_{10} in Kolhapur Determined by Simulation using AERMOD (Area Source Emission) (Source: CSIR-NEERI)

Figure 5.4 shows the GLC of PM_{10} in Kolhapur city. It can be seen that the maximum GLC of PM_{10} is in the 28-36 µg/m^3 range. The sampling data in the present work matches the isopleths. [Background Site: DY Patil and Kerbsite Site: Dabholkar Corner and Commertial Site: Mahalaxmi Temple]. However the concentration predicted by the model are much lower than the measured concentrations. This may point to a need for strengthening the source inventory.

Chapter 6

Suggestions for Actions for Control of Air Pollution

6.1 Emission Reduction Action Plan for Kolhapur City

The suggested actions plan based on the emission load and its reduction is presented in **Table 6.1.**

Table 6.1: Action Plan to Mitigate Air Pollution from Various Sources

Control Option	Expected Reduction and /Impacts	Technical Feasibility	Responsible/ Implementing Agency
Vehicle Emissions (Overall Reduction Proposed from Various Mitigation Strategies)			
Launch extensive drives against polluting vehicles for ensuring strict compliance	Pollution from existing vehicle to get reduced - /Low	Surveys/Identification and maintenance/better combustion/ Emission reduction steps Introduction of Bharat Stage VI Vehicles	RTO
Launch public awareness campaigns for air pollution control, vehicle maintenance, minimizing use of personal vehicles, lane discipline etc.	Pollution from existing vehicle to get reduced - /Low	Maintenance /Strict compliance	Traffic Dept./ RTO
Prevent parking of vehicles at Non-designated areas.	Designated parking will reduce the Traffic congestion and thereby reduction in pollution - /Low	Parking Plan of city to reduce congestion and easy driving of vehicles	KMC/RTO
Prepare action plan for widening of road and improvement of Infrastructure for decongestion of Roads.	Reduction of Air Pollution Load from existing vehicles /Low	Implementation	KMC
Prepare Plan for the construction of expressways/ bypass to avoid congestion	Reduction of Air Pollution Load from existing vehicles- /Low	Implementation/ Policy	KMC
Steps for Promoting Battery operated vehicles.	Reduction of Air Pollution Load from existing vehicles- Medium	Implementation/ Policy	RTO
Install weigh in Motion bridges at the borders of the cities/ Towns	Reduction of Air Pollution Load from existing vehicles-	Implementation/ Policy	KMC/RTO

and states to prevent overloading of vehicles.	/Medium		
Synchronize Traffic movements/Introduce Intelligent Traffic systems for Lane Driving	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation	RTO/ Traffic Dept.
Installation of Remote Sensor based PUC systems	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation	RTO
Vehicle Emissions (Overall Reduction Proposed from Various Mitigation Strategies)			
Sulphur reduction in diesel	Reduction of Air Pollution Load from existing vehicles-/High	Implementation Policy Decision	
Introduction of new technology vehicles	Reduction of Air Pollution Load from new vehicles- /Medium	Implementation Policy Decision	
Provide good public transport system	Improved Bus/Metro/etc- /Medium	Implementation of Policy Decision	MSRTC, KMC, RTO
Standards for new and in-use vehicles	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation/ Policy Decision	RTO
Alternative fuels	Reduction of Air Pollution Load from existing/new vehicles /Medium	Implementation/ Policy Decision	RTO
Implementation of BS-VI norms	reduction of Air Pollution Load from existing/new vehicles/ Medium	Implementation/ Policy Decision	RTO
Electric/Hybrid Vehicles	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation/ Policy Decision/ Feasibility study	RTO
OE-CNG for new public transport buses	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation/ Policy Decision/ Feasibility study	RTO, KMC
Ethanol blending (E10-10% blend)	Reduction of Air Pollution Load from existing vehicles- Medium	Implementation/ Policy Decision/ Feasibility study	RTO
Bio-diesel (B5/B10:5-10% blend)	Reduction of Air Pollution Load from existing vehicles- Medium	Implementation/ Policy Decision/ Feasibility study	
Retro-fitment of Diesel Oxidation Catalyst (DOC) in 4-Wheeler public transport (BS-II	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation/ Policy Decision/ Feasibility study	RTO, KMC

and BS-III)			
Banning of 10 year old commercial vehicles	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation/ Policy Decision/Alternative option	RTO
Inspection/maintenance to all BSII & BSIII commercial vehicles	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation	RTO, KMC
Restrict commercial vehicle entering city by having ring roads.	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation	RTO, KMC
The effectiveness of proposed control option in short and long term is 30% and 50% respectively			
Point Source (Overall Reduction Proposed from Various Mitigation Strategies)			
Action against non-complying industrial units	Reduction of Air Pollution Load from casting, foundries, stone crusher SSIs /Medium	Implementation/ Feasibility Studies	MPCB/MIDC
Sulphur reduction in fuel	Reduction of Air Pollution Load from industries- /Medium	Implementation/ Feasibility Studies	MPCB/MIDC
Improved Combustion technology	Reduction of Air Pollution Load from industries- /Medium	Implementation/ Feasibility Studies	MPCB/MIDC
Alternate fuel	Reduction of Air Pollution Load from industries- /Medium	Implementation/ Feasibility Studies	MPCB/MIDC
Promoting cleaner industries	Reduction of Air Pollution Load from industries /High	Implementation/ Feasibility/ Policy Studies	MPCB/MIDC
Location specific Emission reduction	Inputs/suggestions from Source Apportionment studies	Implementation/ Feasibility/ Policy Studies	MPCB/MIDC
Fugitive emission control	Reduction of Air Pollution Load from industries /High	Implementation/ Feasibility/ Policy Studies	MPCB/MIDC
Banning of new industries in existing city limit	Reduction of Air Pollution Load from industries /High	Implementation/ Feasibility/ Policy Studies	MPCB/MIDC
Installation /upgradation of air pollution control systems	Reduction of Air Pollution Load from industries /High	Implementation/ Feasibility/ Policy Studies	MPCB/MIDC
Use of high grade coal	Reduction of Air Pollution Load from industries /High	Implementation/ Feasibility/ Policy Studies	MPCB/MIDC
Regular audit of stack	Reduction of Air	Implementation/	MPCB/MIDC

emissions for QA/QC	Pollution Load from industries /High	Feasibility Studies	
The effectiveness of proposed control option in short and long term is about 30% and 50% respectively			
Re-suspension of Road Dust (Overall Reduction Proposed from Various Mitigation Strategies)			
Prepare plan for creation of green buffers along the Traffic corridors	Reduction of Air Pollution Load from resuspended dust- /Low	Implementation	Municipal Corporation
Maintain Pothole Free Roads for Free flow Traffic	Reduction of Air Pollution Load from resuspended dust- /Low	Implementation	Municipal Corporation, Traffic Dept.
Re-suspension of Road Dust (Contd..)			
Greening of open areas, garden, community places, schools and housing societies.	Reduction of Air Pollution Load from resuspended dust- /Low	Implementation	Municipal Corporation
Blacktopping of metaled Roads including pavement of Road shoulders	Reduction of Air Pollution Load from resuspended dust- /Low	Implementation	Municipal Corporation
Wall to Wall paving (brick)	Reduction of Air Pollution Load from resuspended dust- /Low	Implementation	Municipal Corporation
Road design improvement	Reduction of Air Pollution Load from resuspended dust- /Low	Implementation	Municipal Corporation
Construction & Demolition Waste			
Enforcement of construction & demolition rules.	Reduction of Air Pollution Load from C&D projects- High	Implementation	Town Planning Authority, KMC
Control measures for fugitive emissions from material handling, conveying and screening operations through water sprinkling, curtains, barriers and suppression units.	Reduction of Air Pollution Load from C&D projects- High	Implementation/ Feasibility of wet/ Dry scrubbing to be tested	Town Planning Authority, KMC
Better construction practices with PM reduction of 50%	Reduction of Air Pollution Load from C&D projects- High	Implementation/ Feasibility	Town Planning Authority, KMC
Ensure carriage of construction material in closed/covered Vessels	Reduction of Air Pollution Load from C&D projects- Medium	Implementation/ Feasibility	Town Planning Authority, KMC
The effectiveness of the proposed control option in short and long term is about 20% and 50% respectively			
Cooking Fuels			
Shift to LPG from solid fuel & kerosene for domestic applications	reduction of Air Pollution Load from commercial/Residential	Implementation/ Feasibility	Maharashtra Govt./ KMC

	cooking- Medium		
Better cook-stove designs	reduction of Air Pollution Load from commercial/Residential cooking- Medium	Implementation/ Feasibility	MNRE/ KMC
Use of LPG in Hotels and "Dhabas" and renewable fuel/oil/Electricity/gas etc in Crematoria	reduction of Air Pollution Load from C&D projects- Medium	Implementation/ Feasibility of use of solar power to be probed	Maharashtra Govt./ KMC
The effectiveness of proposed control option in short and long term is about 20% and 40% respectively			
Crematoria's and Open Burning			
The crematoria present in the city limits	These should have green belt alongside or control systems attached to it else they could be shifted away from the residential areas. Shifting to use of briquettes rather than wood and use of electric crematoria should be promoted. The crematoria's open pyre type to use cow dung/ briquettes/and pollution control system for reducing the emissions. Use of Gas fired/electric fired crematoria may be promulgated	Implementation/ Feasibility	MNRE/ KMC
Open burning in solid waste dumping sites, etc to be banned	Banning of open burning	Implementation/ Feasibility	KMC
MSW Management through proper segregation and Management	Banning of open burning. Solid waste management to be undertaken to reduce emissions (Bio gas generation, Waste to energy plant) etc may be practiced	Implementation/ Feasibility	KMC
The effectiveness of proposed control option in short and long term is about 40% and 60% respectively			

Chapter 7

Results and Recommendations

This study has addressed several aspects of the air pollution status in Kolhapur 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 (Page 1.8).

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, Local equivalent (KMC) 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.

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 Kolhapur city and the region. Further, it is important that each stakeholder may validate the inventory at a ward level, especially for all non-industrial municipal domain activites.

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. In Table 7.1 source apportionment results indicate that the contribution from industries is of the order of 18 to 30 %, while that from the dispersion model indicates about 60% of contribution from the point source (industries).

7.1.2.3 This is difference points to a weakness in the inventory that is related with non-point sources and requires further work in inventory development. Source apportionment includes a ~30% contribution from dust and ~25% from biomass burning, which all unrepresented inventory.

7.1.2.4 Maintenance of a ward-based inventory is therefore recommended as a part of the digitised database of inventory, specifically to fully include area and line sources.

7.1.2.5 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.

7.1.2.6 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.

7.1.2.7 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 (a): Summary of Source Apportionment Results for Kolhapur (Figure 4.1)

No.	Most likely source(s)	% Contribution	
		PM_{10}	$PM_{2.5}$
1	Agriculture	22	26
2	Industrial	18	30
3	Biomass Burning +Vehicular	26	24
4	Construction/ Road dust	34	20
	Total	100	100

Table 7.1 (b): Key Sources from Inventory (Table 3.3)

No.	Sector	% PM_{10}	% $PM_{2.5}$
A.	**A. Area Source**		
1	Bakeries	0.0003	0.0003
2	Open Eat-outs	0.04	0.04
3	Hotels & Restaurants	1.11	1.12
4	Crematoria	11.22	12.57
5	Domestic	2.86	4.04
6	Building Construction	5.53	5.51
	B. LineSource		
1	Vehicular flow	17.27	17.57
C.	**C. Point Source**		
1	Industries	61.96	59.15
	Total	100	100

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 four 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 (Table2.2). 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 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 around the city.

7.2.1.4 Additionally, PM2.5 pollution was prominently influenced by Industry (30%) Agriculture (26%) and Biomass burning/Vehicles (23%)

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.

7.3 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 10 cities in 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 use of size of the population criterion used).

7.3.1 Realizing the impact of air quality on health, there is an ardent need of air quality surveillance system in place in the city. This should be led by urban

local body, equipped with qualified and trained manpower. This calls for establishing an air quality monitoring cell (AQM Cell) in each ULB with dedicated responsibility.

AQM Cell should co-ordinate between regulatory authority (MPCB) and other department of ULB and traffic department for regular data gathering. A dash board of gridded emission inventory should be ready with the ULB for regular updating. Each department related with emission activity should have access to the dash board and direct data entry will give online updated emission inventory. For example, crematoria data should be entered in the dash board, which will update the emissions from crematoria.

7.3.2 Each AQM Cell should have air quality monitoring system for the city. This should include manual monitoring and CAAQMS.
The manual AQM need not necessarily be National Network, instead based on the city needs, up-wind background monitoring, city down-wind monitoring, rotation of monitoring station depending on predominant wind direction, source dispersion modelling based monitoring station needs to be set up. Monitoring of only PM, SO_2 and NOx, which are criteria pollutants, needs to be carried out. Capacity building of AQM Cell for manual monitoring should be a part along with setting the laboratory infrastructure. The cell should have appropriate laboratory, computational facility, etc. or should have tie up with local Government academic Institution for the same.
The CAAQMS data should be directly accessible to the AQM Cell. Dash board of CAAQMS data should provide daily updated status of air quality, so that any corrective action, calibration if needed can be taken. Meteorological station along with ozone monitoring must be a part of CAAQMS.

7.3.3 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

This may be integrated with National Network also.

7.3.4 Meteorological data of ULB for previous years should be analysed to present the boundary layer height and ventilation. The data for each year should be updated based on the meteorological data gathered through CAAQMS station.

7.3.5 A significant part of the air pollution in urban centres is from vehicular emissions. The correct estimate of vehicular emissions is possible only if the vehicle type identification and its counting on each road can be carried out. Artificial Intelligence / Machine Learning (AI/ML) tool can be used for online identification and counting of vehicles. Such tools are already developed and ready. CCTV operators are required to give access to the IP address so that online counting of vehicles can be carried out and used in the emission inventory and source dispersion modelling.

7.3.6 Dispersion modelling of the gridded emission should be carried out and be ready online with the AQM Cell. All additional emission load should be included regularly so as to improve the prediction of ground level concentration of pollutant.

7.3.7 Health data from primary health centre should be digitised and online for drawing any correlation with air pollution and health condition. The hospitals, should be taken on-board the AQM cell.

7.4 Further Work

7.4.1 The strength of using the results of this study depends on the validation of the source inventory at the ground level. Control measures would need to be strategized accordingly.

7.4.2 The effort would 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.

7.4.3 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.

7.4.4 Management of air quality is a new emerging problem for cities in india, 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, RTO, Fire Brigade, IoR's, Research Institutes and Industries and other stakeholders).

7.4.5 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. Efforts for the same for Chandrapur and all of Maharashtra as a region have been reported by Chaudhari (2024)

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