Draft Report On

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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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 needs 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-spot and kerb-sites
- Inventory of all types of emissions from the city
- To conduct source apportionment study for particulate matter
- Air pollution reduction action plan

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 analyzed for dispersion modelling exercise
- The data will be analyzed 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.

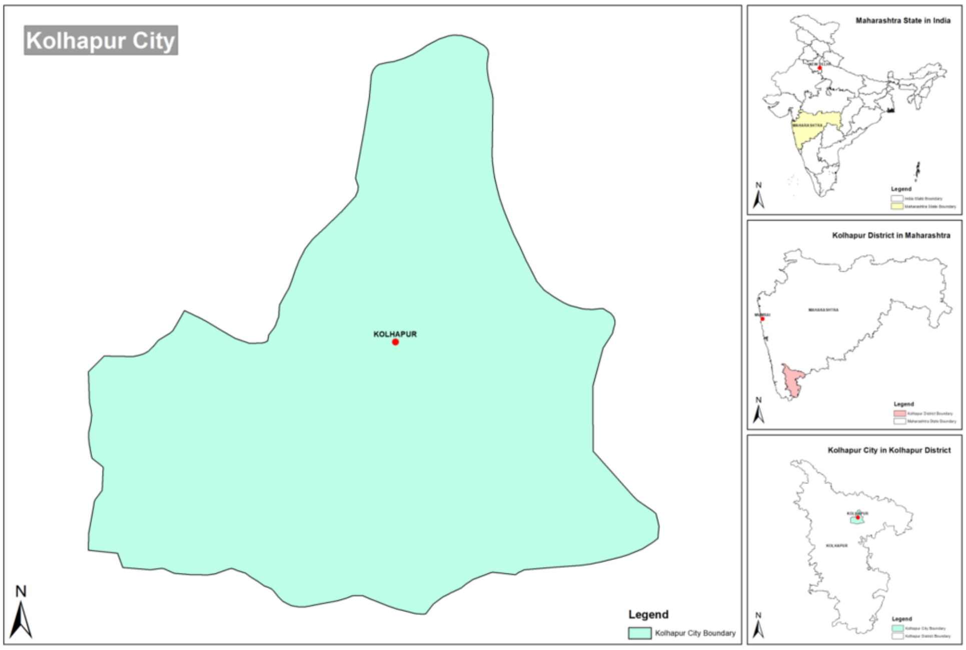


Figure 1.1 : Location map of Kolhapur City

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.

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.

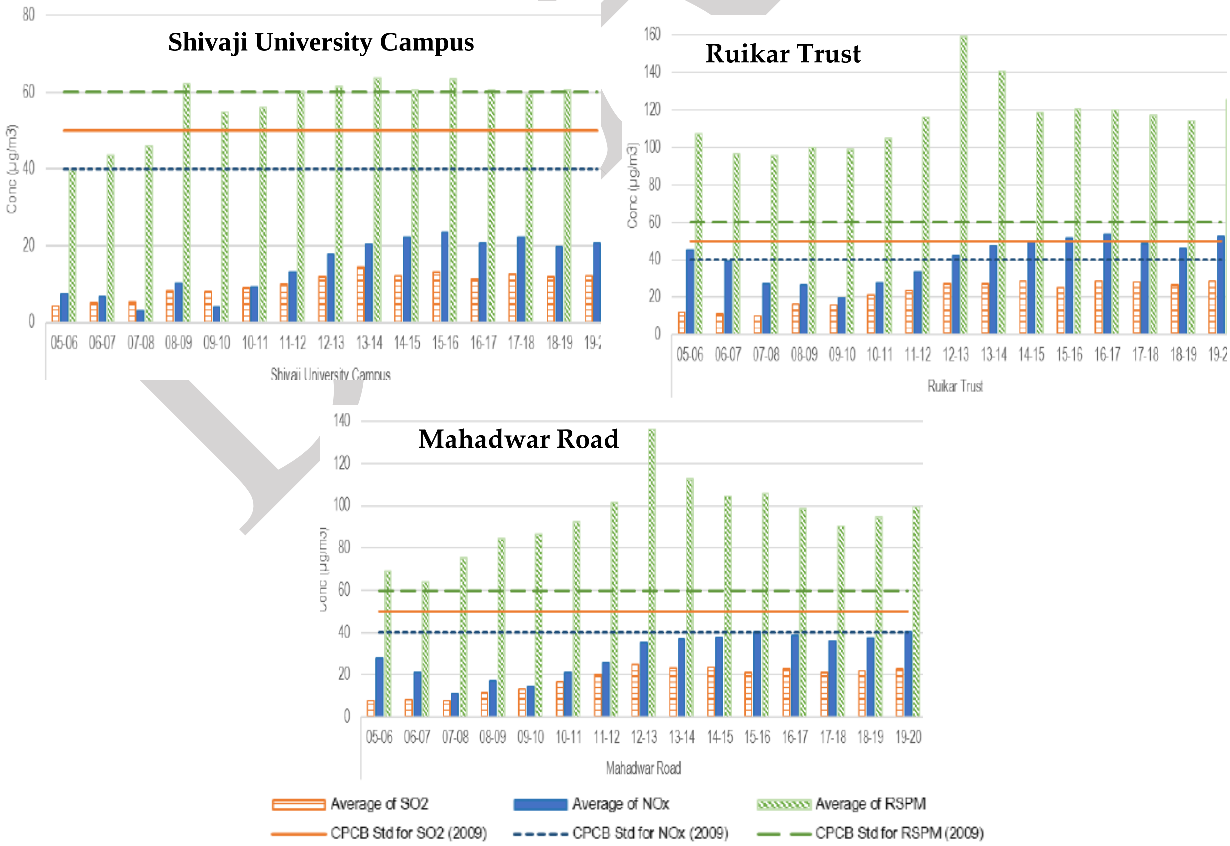


Figure 2.1a : Annual Average Trend of SO_2, NOx, and RSPM at Kolhapur (MPCB Network)

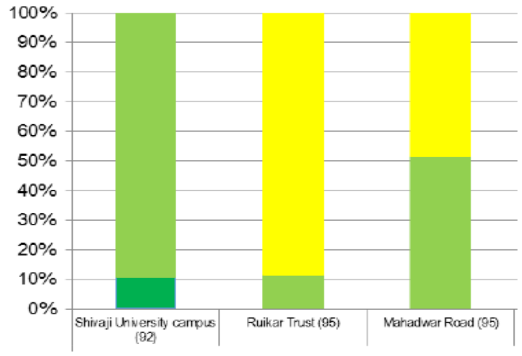


Figure 2.1b : Percentage Occurrence for Classes of AQI - Kolhapur City 2019-20

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.**

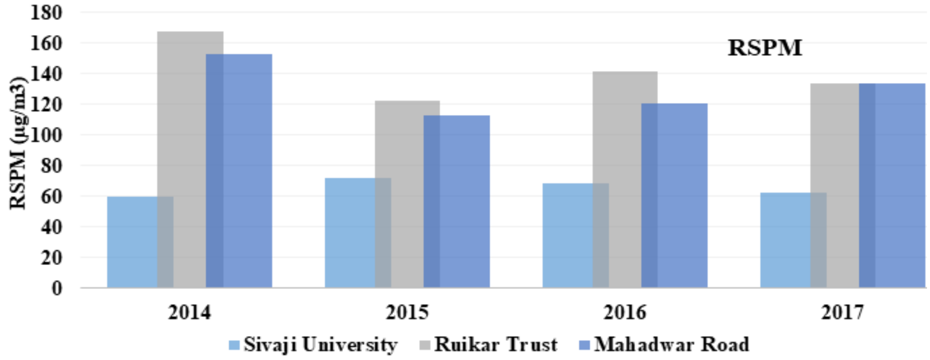


Figure 2.1c : Annual Average Concentration of RSPM over Kolhapur (2014-2017)

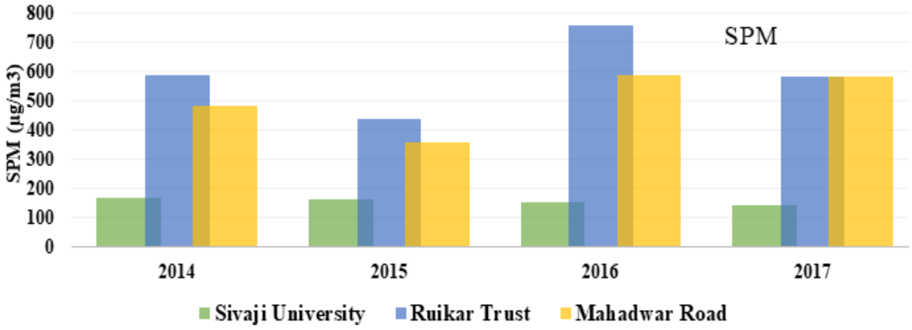


Figure 2.1d : Annual Average Concentration of SPM over Kolhapur (2014-2017)

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**
Davolkar 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 occasions 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.

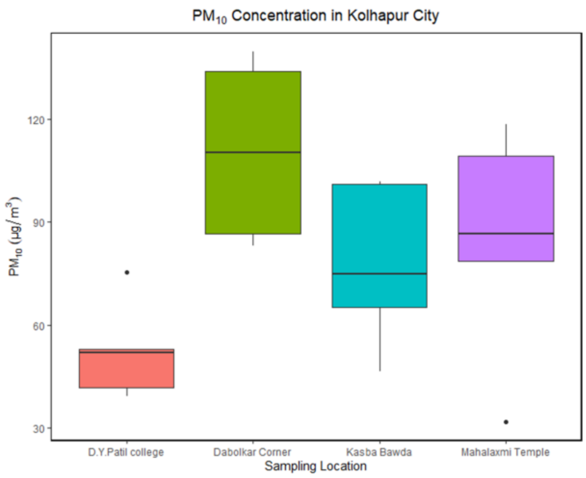


Figure 2.2a : PM_{10} Concentrations

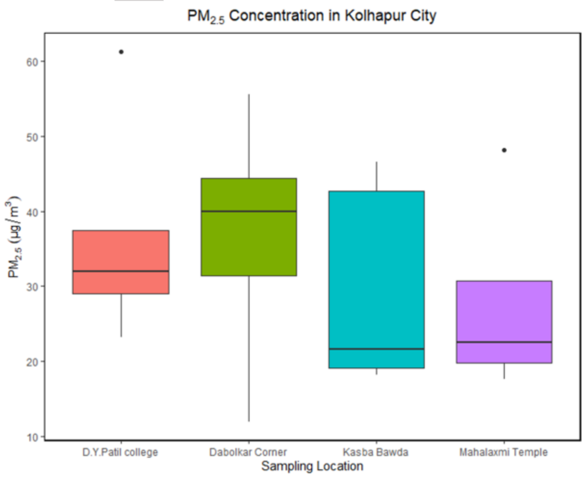


Figure 2.2b : $PM_{2.5}$ Concentrations

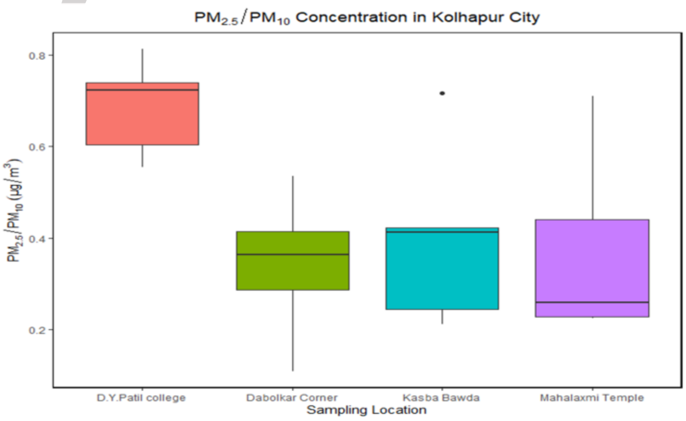


Figure 2.2c : $PM_{2.5}/PM_{10}$ Monitored Concentrations in Kolhapur City

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 city. 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.

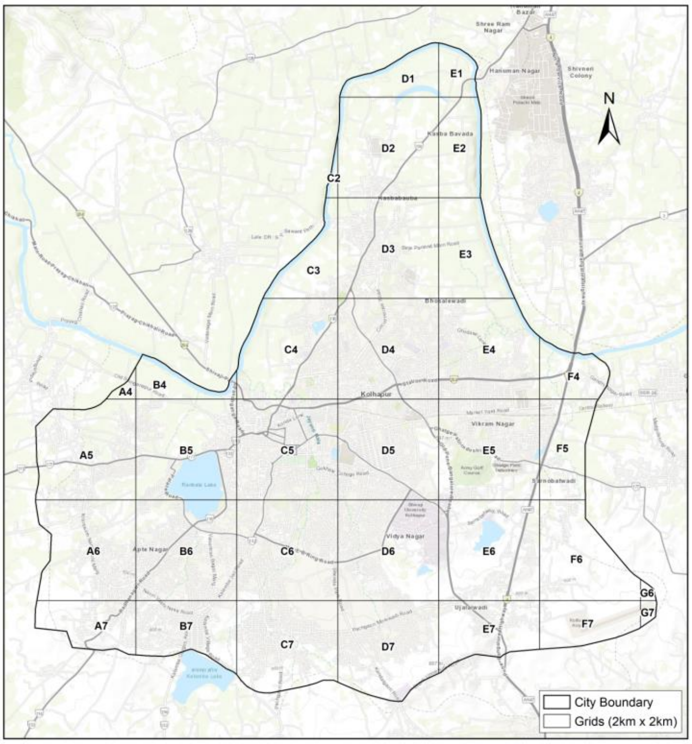


Figure 3.1 : 2 Km x 2 Km Grid Plotted Over Kolhapur City

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.

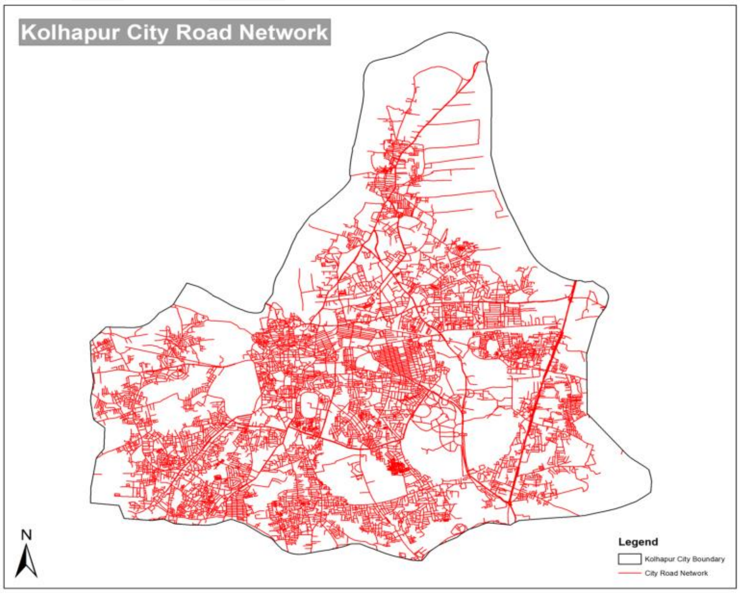


Figure 3.2 : Road Network in Kolhapur City

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.**

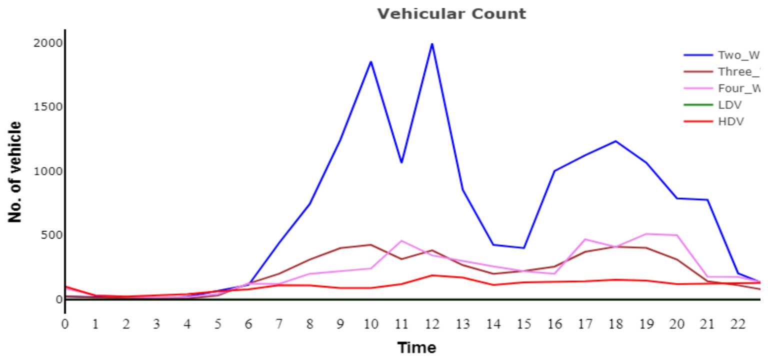


Figure 3.3 : Vehicular Count at One Traffic Intersection in Kolhapur City

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.

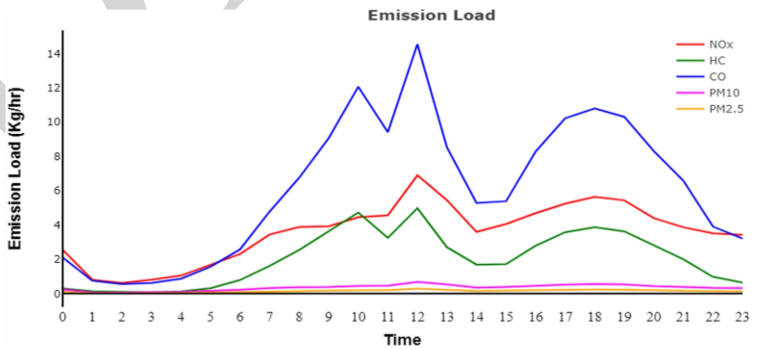


Figure 3.4 : Hourly Vehicular Emission Load

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%).

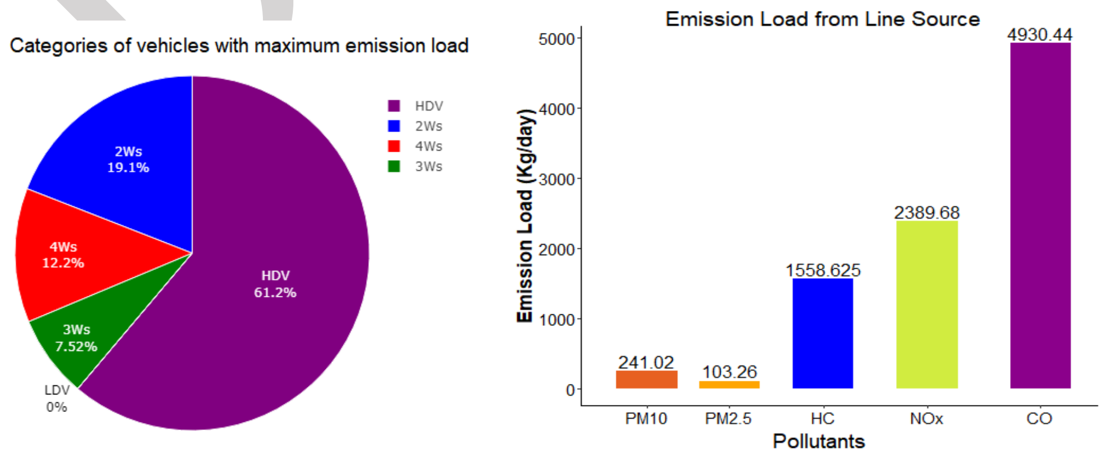


Figure 3.5 : Total Emission Load from Line Source

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.**

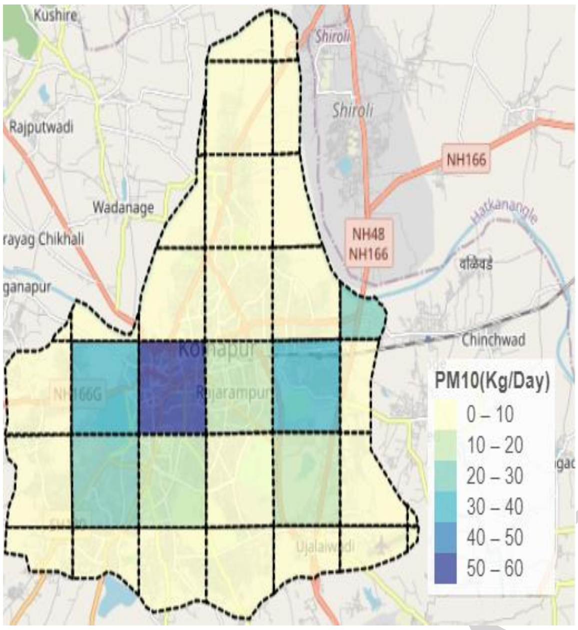


Figure 3.6 : Grid-wise PM_{10} Emission Load From Line Source

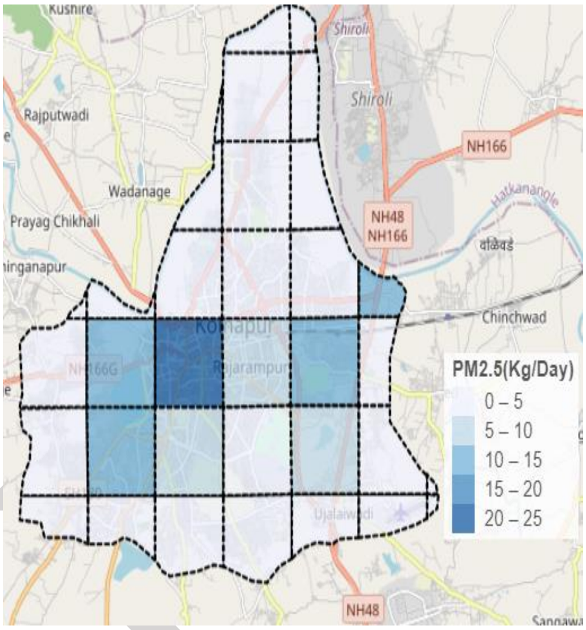


Figure 3.7 : Grid-wise $PM_{2.5}$ Emission Load From Line Source

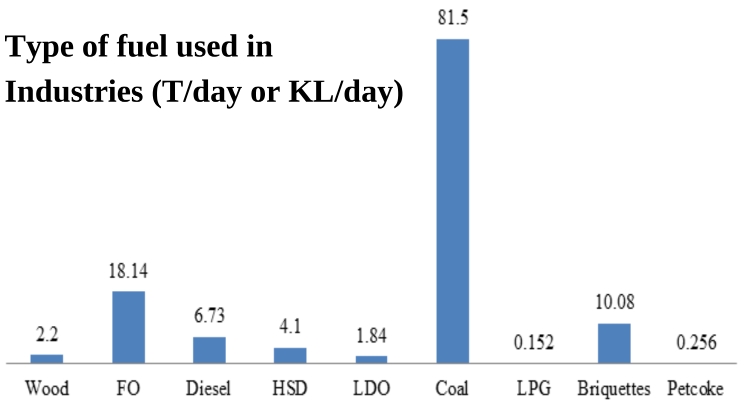
3.9 Point Source Emission Load

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



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**.

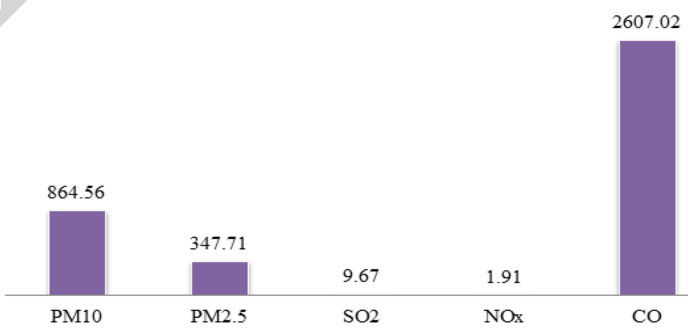


Figure 3.8 : Total Emission Load from Point Source

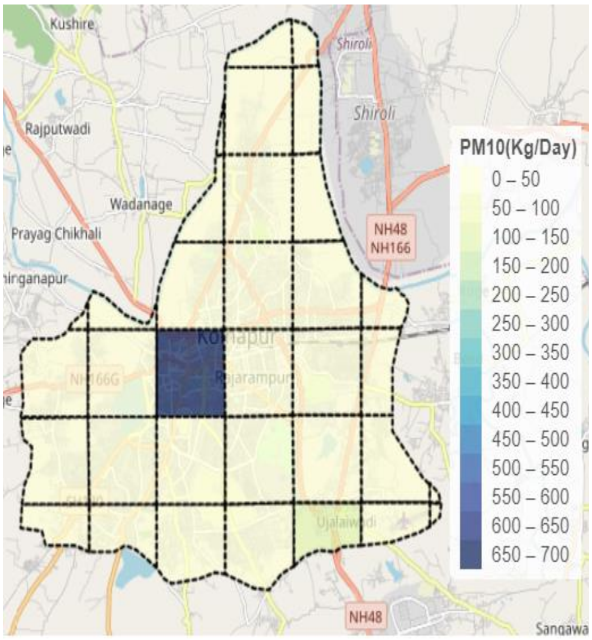


Figure 3.9 : Grid-wise PM_{10} Emission Load From Point Source

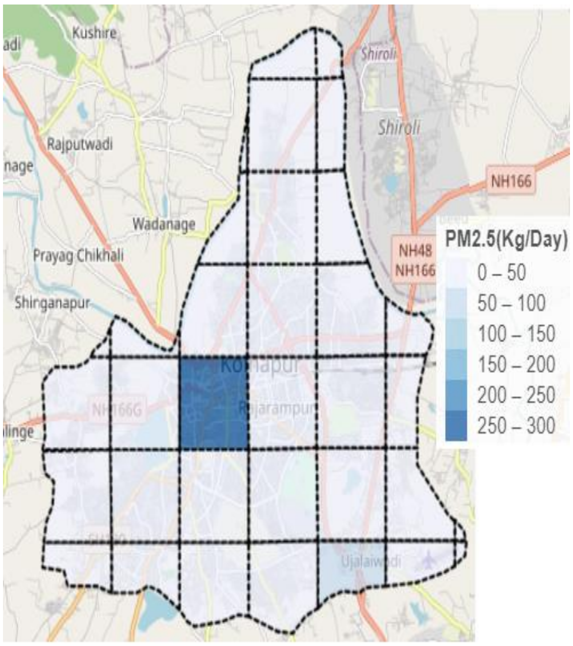


Figure 3.10 : Grid-wise $PM_{2.5}$ Emission Load From Point Source

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.

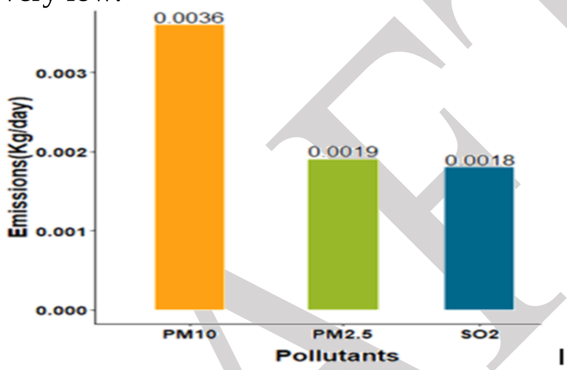


Figure 3.11 : Emission Load from Bakeries (Kg/Day)

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.

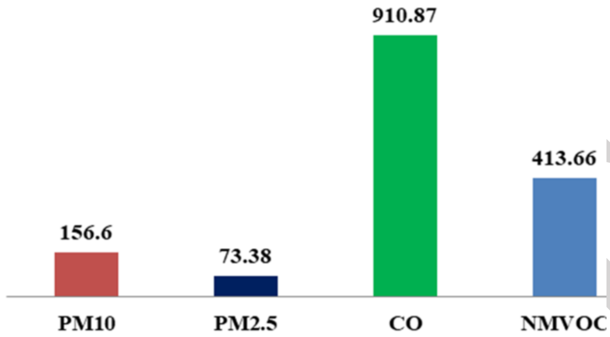


Figure 3.12 : Emission Load from Crematories (Kg/Day)

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**.

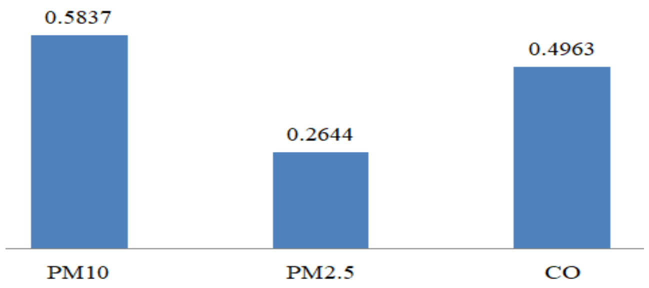


Figure 3.13 : Emission Load from Open Eatout (Kg/Day)

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

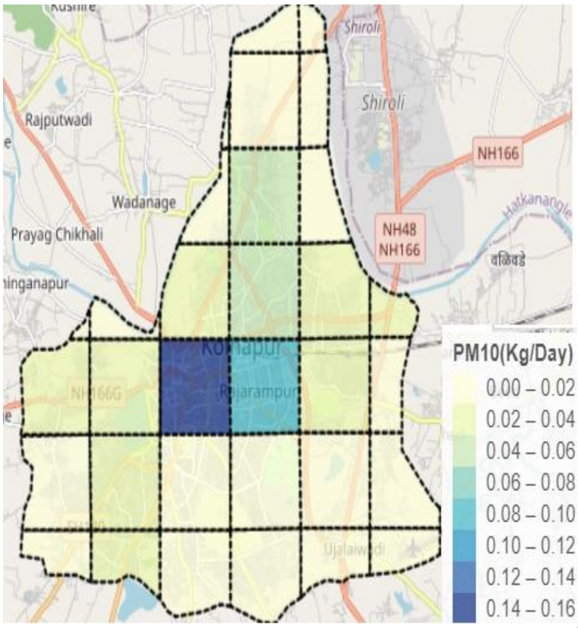


Figure 3.14 : Grid-wise PM_{10} Emission Load From Open Eat-outs

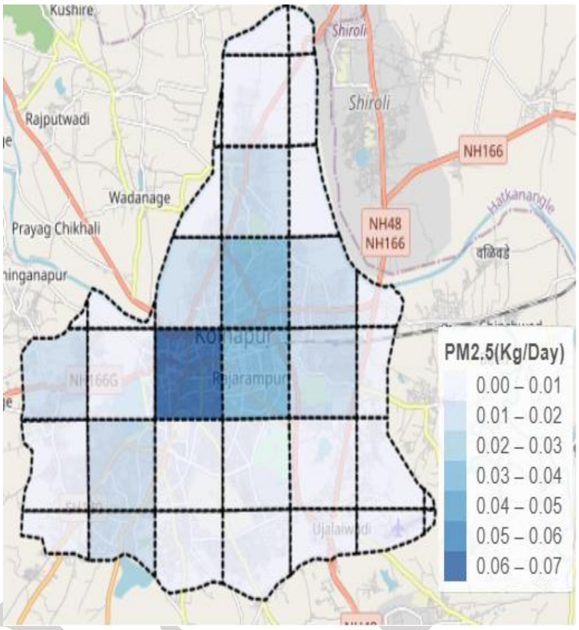


Figure 3.15 : Grid-wise $PM_{2.5}$ Emission Load From Open Eat-outs

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**.

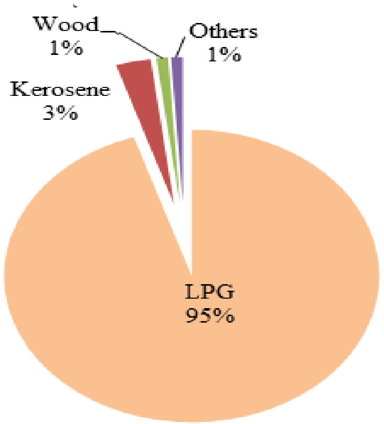


Figure 3.16 :
Fuel Pattern in Domestic Sector

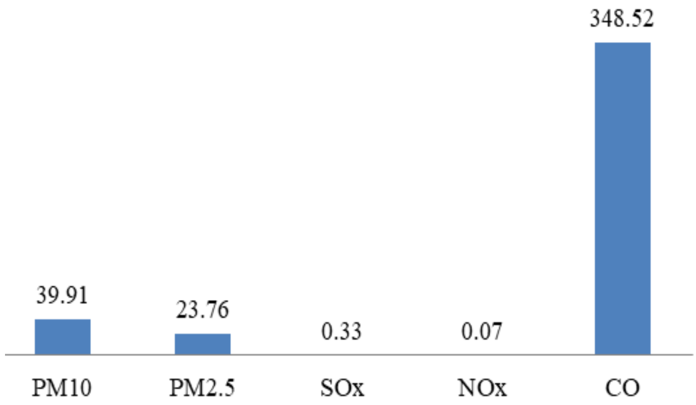


Figure 3.17 :
Emission Load from Domestic Sector (Kg/Day)

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).**

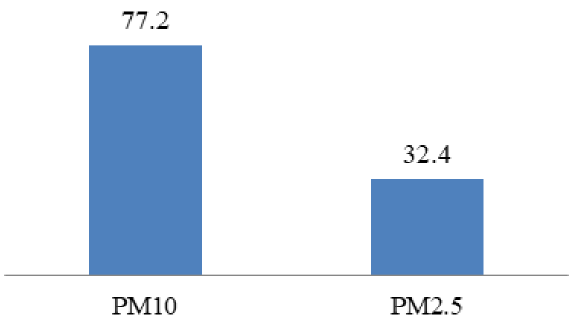


Figure 3.18 : Emission Load from Building Construction (Kg/Day)

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.

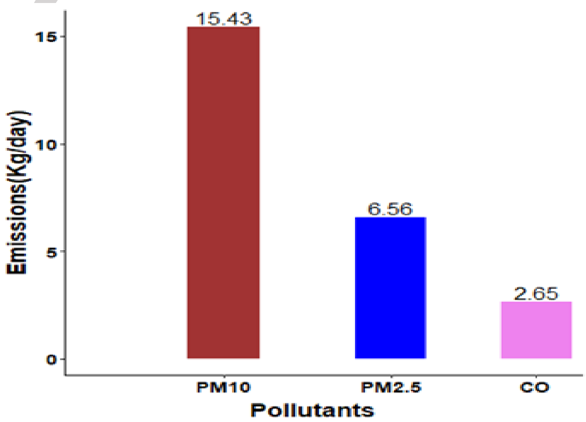


Figure 3.19 : Emission Load from Hotels and Restaurants (Kg/Day)

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).**

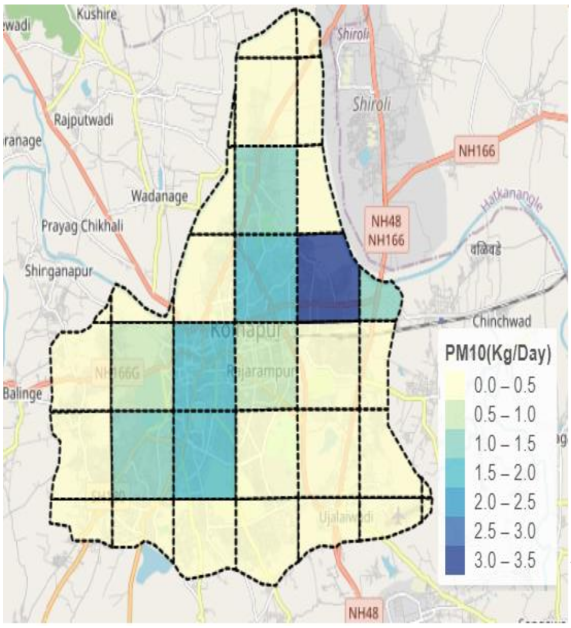


Figure 3.20 : Grid-wise PM_{10} Emission Load From Hotels and Restaurants

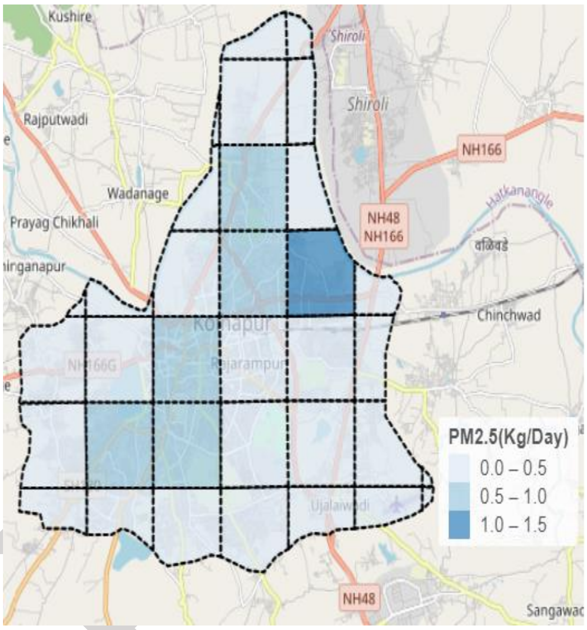


Figure 3.21 : Grid-wise $PM_{2.5}$ Emission Load From Hotels and Restaurants

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.

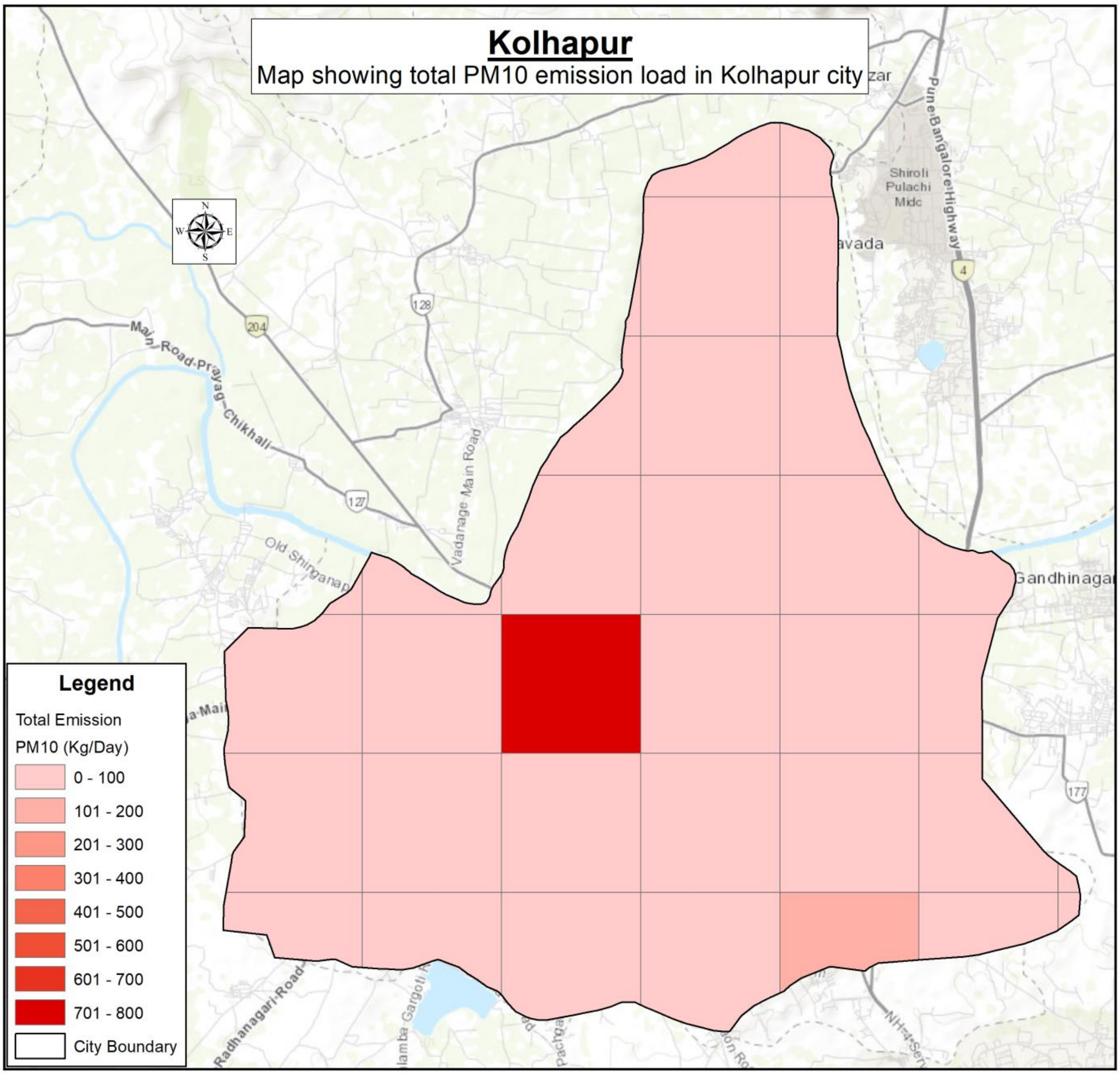


Figure 3.22 : Total Grid-wise PM_{10} Emission Load for Kolhapur City

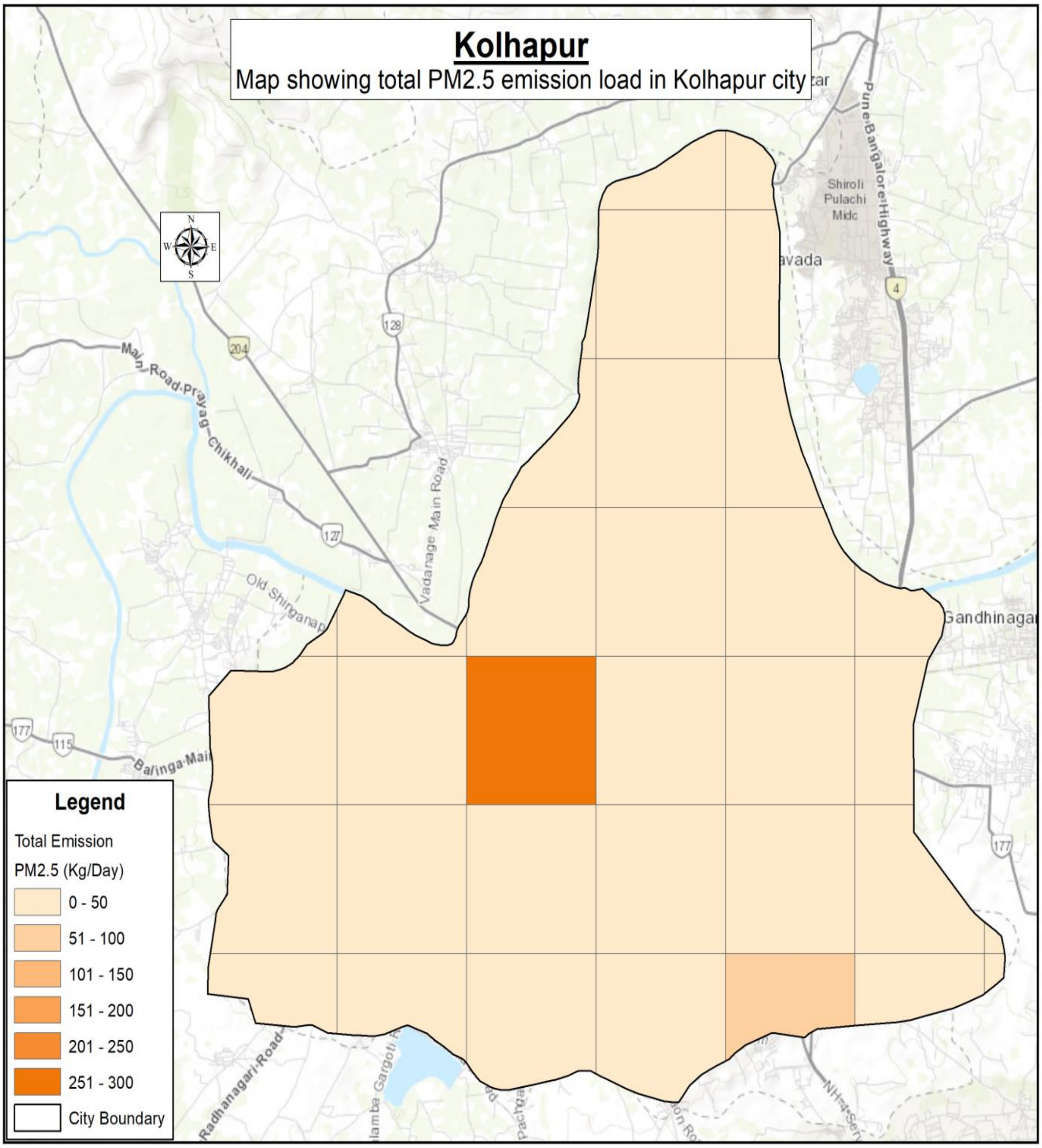


Figure 3.23 : Total Grid-wise $PM_{2.5}$ Emission Load for Kolhapur City

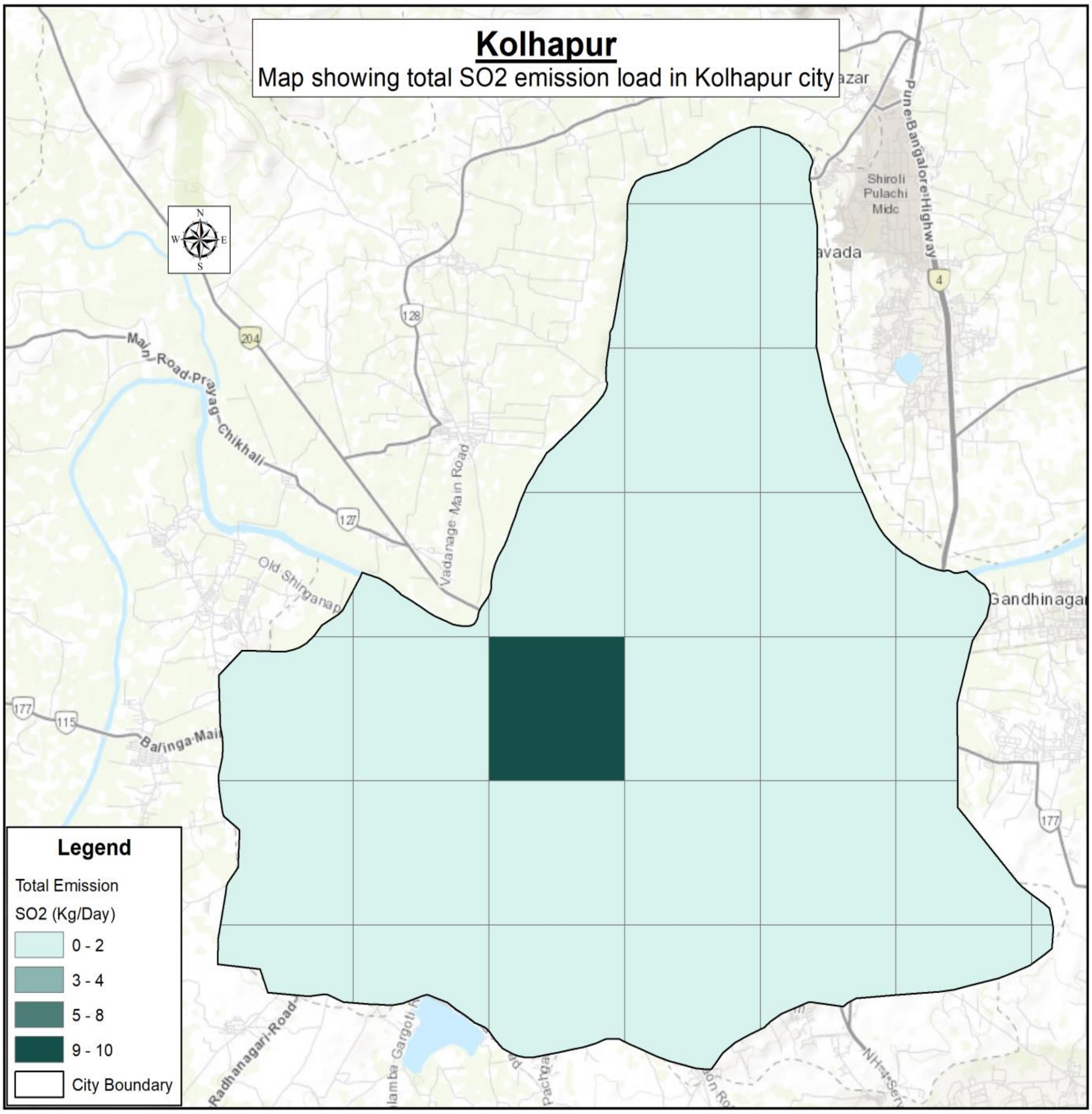


Figure 3.24 : Total Grid-wise SOx Emission Load for Kolhapur City

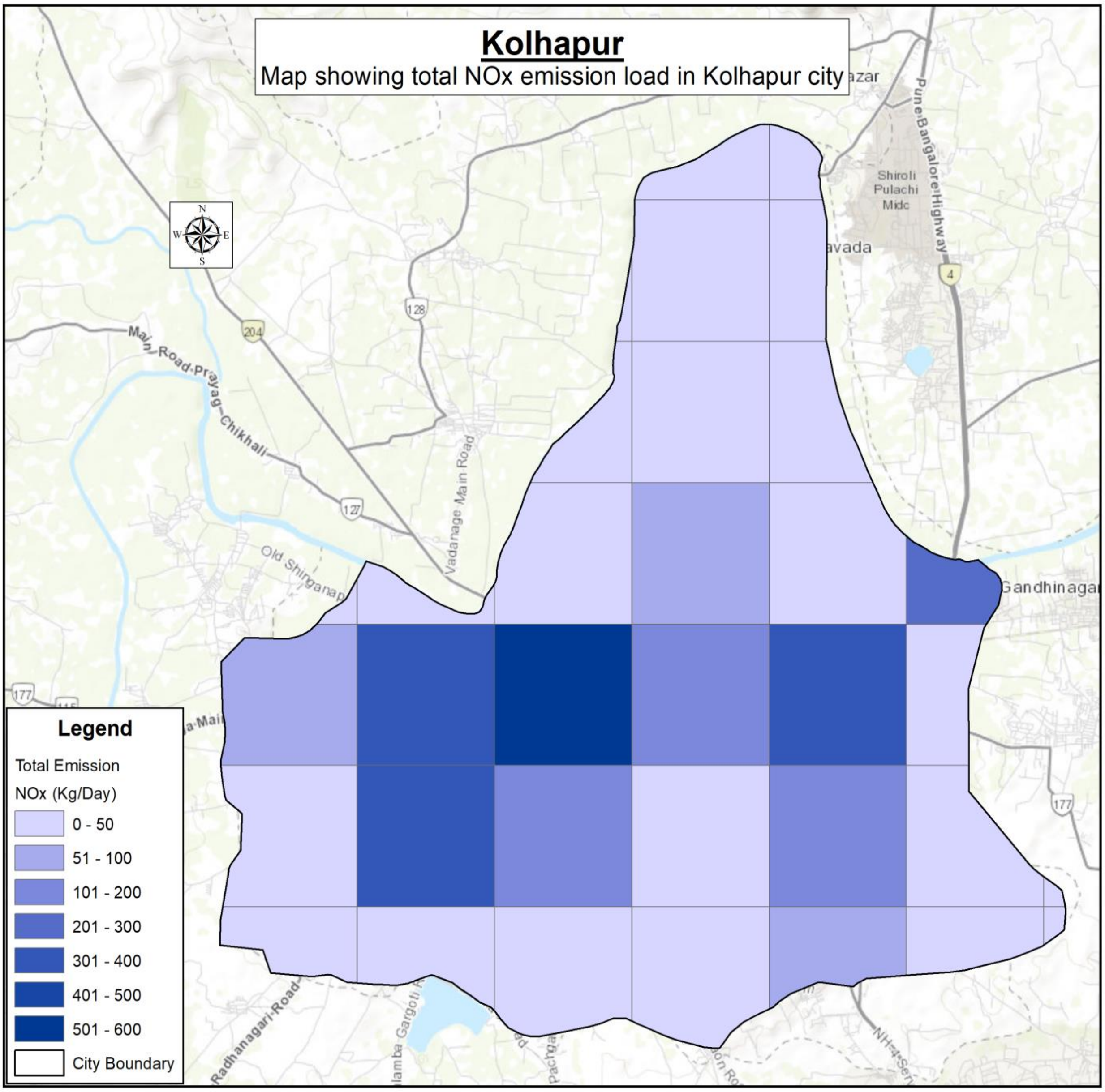


Figure 3.25 : Total Grid-wise NOx Emission Load for Kolhapur City

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study Using EPA PMF v5.0

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

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

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

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

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

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

4.2 Methodology

For the present study EPA, PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for the identification of sources and their positive contributions to ambient air pollution. The study was carries out for representative samples of $PM_{2.5}$ and PM_{10} collected during the 01 May, 2019 to 10 May, 2019 sampling campaign at 4 locations: Dabolkar Corner (Kerb Site); D.Y.Patil College (Control); Kasba Bawda (Residential) and Mahalaxmi Temple (Residential & Commercial). The concentration and uncertainty data were obtained from the gravimetric analysis ($PM_{2.5}$ and PM_{10}); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (46 elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb, Bi, Th and In); and Ionic Analysis (9 ions: Na^{+}, NH_4^{+}, Ca^{2+}, Mg^{2+}, F^{-}, Cl^{-}, Br^{-}, $NO_3^{2-}$and SO_4^{2-}) for both PM_{10} and $PM_{2.5}$ for all sources as listed above.

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

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

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

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

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

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

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

Elements (a)	µg/cm^2	µg/m^3#	Elements (a)	µg/cm^2	µg/m^3#
Na	0.0876	0.211	Ag	0.0192	0.046
Mg	0.0414	0.1	Cd	0.0260	0.063
Al	0.0128	0.031	Sn	0.0488	0.118
Si	0.0050	0.012	Sb	0.0700	0.169
P	0.0134	0.032	Te	0.0866	0.209
S	0.0090	0.022	I	0.1176	0.283
Cl	0.0100	0.024	Cs	0.0040	0.01
K	0.0162	0.039	Ba	0.0092	0.022
Ca	0.0048	0.012	La	0.0054	0.013
Sc	0.0074	0.018	W	0.0060	0.014
Ti	0.0020	0.005	Au	0.0022	0.005
V	0.0042	0.01	Hg	0.0020	0.005
Cr	0.0020	0.005	Pb	0.0056	0.013
Mn	0.0110	0.026	In	0.0274	0.066
Fe	0.0102	0.025	Pd	0.0126	0.03
Co	0.0044	0.011			

#Based on nominal air sampled @ 5LPM per sampling day
ED- XRF; (b) IC; (c)Based on DRI SOP for EC/OC (URL 2)

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

Elements (a)	**µg/cm²**	**µg/m³#**	**Ions (b)**	**PPM**	**µg/m³#**
Ni	0.0030	0.007	Na^{+}	0.008	0.001
Cu	0.0050	0.012	NH_4^{+}	0.009	0.001
Zn	0.0020	0.005	K^{+}	0.02	0.003
Ga	0.0020	0.005	Mg^{2+}	0.02	0.003
Ge	0.0010	0.002	Ca^{2+}	0.03	0.004
As	0.0092	0.022	F^{-}	0.002	0.0002
Se	0.0010	0.002	Cl^{-},	0.005	0.001
Br	0.0010	0.002	NO_2^{-}	0.01	0.001
Rb	0.0102	0.025	Br^{-}	0.02	0.003
Sr	0.0086	0.021	NO_3^{2-}	0.06	0.008
Y	0.0090	0.022	SO_4^{2-}	0.02	0.008
Zr	0.0100	0.024	**EC-OC (c)**	**PPM**	**µg/m³#**
Mo	0.0104	0.025	EC	0.06	0.063
Rh	0.0108	0.026	OC	0.45	0.013

#Based on nominal air sampled @ 5LPM per sampling day
ED- XRF; (b) IC; (c)Based on DRI SOP for EC/OC (URL 2)

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

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

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

4.3 Results

The results of both cases for PM_{10} & $PM_{2.5}$ & mentioned in Section 1.2 are presented in this section.

4.3.1 PM_{10}

After the EPA PMF run analysis, 5 factors were identified in the study location for PM_{10} Samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and b)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for PM_{10} is presented in **Figure 4.2 (a and b).**

Factor 1: Industrial Emissions/ Fossil Fuel Combustion

Factor 1 was identified as mix of Industrial Emissions and Fossil Fuel combustion, due to collinearity of the species, which reflect the mix contribution. The Major Factor Profiles (% of species sum) tracers outlined as OC, Br^-, PO_4^-, Cd and Ca^{2+} (14%, 8%, 41%, 8% and 10%) with minor indicators such as EC, Ca and Fe. This factor contributed to about 15.51% of total PM_{10} emissions. OC, EC and Br^- are used as a marker of fossil fuel combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. PO_4^-, Fe and Cd are the indicator of industrial sources *(Shukla and Sharma, 2008, Rai et al., 2016)*.

Factor 2: Fossil Fuel Combustion

Factor 2 was identified as Coal Combustion by Major Factor Profiles (% of species sum) such as EC, OC, Br^- and SO_4^{2-} (10%, 34%, 20% and 10%) with minor markers such as NH_4^{2+}, Cd and Na^+. This source contributed to about 19.01% of total PM_{10} Pollution. As per the previous studies EC, OC, Br^-, Fe, Cl^-, SO_4^{2-} and NH_4^{2+} are used as a marker of fossil fuel combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*.

Factor 3 : Vehicular Emission

Factor 3 Vehicular Emission accounted for 24.21% of the total PM_{10} Pollution. The Major Factor Profiles (% of species sum) identified as EC, OC, Ca^{2+} and Cd (15%, 34%, 12% and 10%) and minor indicators such as Zn, Fe, Pb, Co and Ca. 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 tyre and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Patil et al., 2013; Jain et al, 2017; Mukherjee et at., 2018, Pawar et al., 2020)* Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles. The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012 ; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018; Jain et al., 2017; Pawar et al., 2020)*.

Factor 4: Biomass Burning / Construction Dust

Factor 4 is identified as Biomass burning which accounted for relatively larger contributions of 20.28% to the total PM_{10} mass. PMF rotation gives collinearity of the species, which reflect the mix contribution. The Major Factor Profiles (% of species sum) identified as K^+, Br^-, Ca, Cd, Fe and EC (~5%, 19%, 21%, 19%, 10% and 11%) and minor indicators such as Ca^{2+}, Na^+ and Cl^- contributed to this factor. There have been many studies in the past suggesting that K^+ and OC are clear indicator of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020)*. Ca, Ca^{2+}, Na^+ and Cl^- are indicators of construction dust *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020)*.

Factor 5: Re-suspension Dust/ Construction Dust

Factor 5 is identified Re-suspension Dust and Construction Dust with 21% of total PM_{10} emissions indicated by Major Factor Profiles (% of species sum) as key markers OC, EC, SO_4^{2-} and Ca^{2+} (~33%, 10%, 31% and 7%) and minor markers such as Br^-, Cl^- and Ca. As per past studies Fe, Ca, Na and Al are indicators of road dust re-suspension, whereas substantial amount of paved road dust is being re-suspended by vehicular movements which is indicated by minor markers such as Pb, Zn and Al are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*. Since the study was done in dry conditions wind-blown dust has large influence on this source. Ca, Si, Ca^{2+}, Mg, Cl^- are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et.al., 2020)*. Construction dust is mainly contributed from all infrastructure development going in and around the city.

4.3.2 $PM_{2.5}$

After the EPA PMF run analysis, 5 factors were identified in the study location for $PM_{2.5}$ samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and c)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for $PM_{2.5}$ is presented in **Figure 4.2 (c and d)**.

Factor 1: Fossil Fuel Combustion

Factor 1 was identified as coal combustion by Major Factor Profiles (% of species sum) such as EC, Br^- and NH_4^{2-} (10%, 32% and 43%) with minor indicators such as Ca^{2+} and Cu. This source contributed to about 13.72% of total $PM_{2.5}$ Pollution. EC, Br- and NH_4^{2-} are used as a marker of fossil fuel combustion *(Kumar et al., 2001; ; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*.

Factor 2: Vehicular Emission

Factor 2 accounted for 25.62% of the total $PM_{2.5}$ Pollution. The Major Factor Profiles (% of species sum) traced as EC, OC and Cd (57%, 18% and 8%) and minor indicators such as NO_3^-, Zn, Pb and Cu. 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 tyre and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Patil et al., 2013; Jain et al, 2017; Mukherjee et at., 2018, Pawar et al., 2020)*. Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles. The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012 ; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018; Jain et al., 2017; Pawar et al., 2020)*.

Factor 3: Industrial Emissions/ Fossil Fuel Combustion

Factor 3 was identified as Industrial emissions and fossil fuel combustion due to collinearity of the species, which reflect the mix contribution. The Major Factor Profiles (% of species sum) tracers outlined as OC, EC and NO_3^{2-} (14%, 50% and 31%) with minor indicators such as NH_4^{2+} and Cd. This factor contributed to about 21.31% of total $PM_{2.5}$ emissions. OC, EC and NH_4^{2+} are used as a marker of fossil fuel combustion *(Kumar et al., 2001; ; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. NO_3^{2-} and Cd is indicator of industrial sources *(Shukla and Sharma, 2008, Rai et al., 2016)*.

Factor 4: Biomass Burning/ Construction Dust

Factor 4 is identified as Biomass burning and Construction Dust which accounted for relatively larger contributions of 24.42% of total $PM_{2.5}$ emissions. PMF rotation gives collinearity of the species, which reflect the mix contribution. The Major Factor Profiles (% of species sum) identified as K^+, OC, and EC (~11%, 15%, and 63%) and minor indicators such as NO_3^{2-}, Ca^{2+} and Cd contributed to this factor. There have been many studies in the past suggesting that K^+ and OC are clear indicator of biomass burning, Ca, Ca^{2+}, Na^+ and Cl^- are indicators of construction dust *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al.,* *2017; Mukherjee et at., 2018; Garaga et al., 2020)*. It is a known fact that biomass is a widely used energy source as well as there is issue of illegal litter burning in India which has resulted in the nominal contributions of biomass burning in this location.

Factor 5: Re-suspension of Road Dust /Construction Dust

Factor 5 is identified as Re-suspension of Road Dust and Construction dust with 14.93% of total $PM_{2.5}$ emissions indicated by Major Factor Profiles (% of species sum) as key markers OC, NO_3^{2-} and Ca^{2+} (~8%, 70% and 12%) and minor markers such as Na^+, Cl^-, Cd and K^+. As per past studies Fe, Ca, Na and Al are indicators of road dust re-suspension, whereas substantial amount of paved road dust is being re-suspended by vehicular movements which is indicated by minor markers such as Pb, Zn and Al are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*. Since the study was done in dry conditions wind-blown dust has large influence on this source. Ca, Si, Ca^{2+}, Mg, Cl^- are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al., 2020)*. Construction dust is mainly contributed from all infrastructure development going in and around the city.

Table 4.2 : Percentage Source Contribution for Kolhapur

Most likely source(s)	PM_{10}	Most likely source(s)	$PM_{2.5}$
Industrial Emissions/ Fossil Fuel Combustion	15.51	Fossil Fuel Combustion	13.72
Fossil Fuel Combustion	19.01	Vehicular Emission	25.62
Vehicular Emission	24.21	Industrial Emissions/ Fossil Fuel Combustion	21.31
Biomass Burning / Construction Dust	20.28	Biomass Burning/ Construction Dust	24.42
Re-suspension of Road Dust/ Construction Dust	20.99	Re-suspension of Road Dust /Construction Dust	14.93

4.4 Positive Matrix Factor Analysis Conclusion

After PMF analysis, five factors were identified contributing to both fraction of the PM. Some of the identified factors are co-existing; modal could not differentiate the sources due to many overlapping species. Both source categories were found to be contributing almost the same for both $PM_{2.5}$ and PM_{10}. The contribution of vehicular pollution is more in $PM_{2.5}$ (25.62%) is found to be higher than PM_{10} (24.21%); whereas Re-suspension and construction dust contributions were dominated by PM_{10} (21%) as compared to $PM_{2.5}$ (14.93%). The biomass burning/construction dust and Industry/fossil fuel combustion is contributing in range of 20-24% and 15-13% respectively. PMF modelling could not segregate between these two sources are some of the markers are common in both sources.

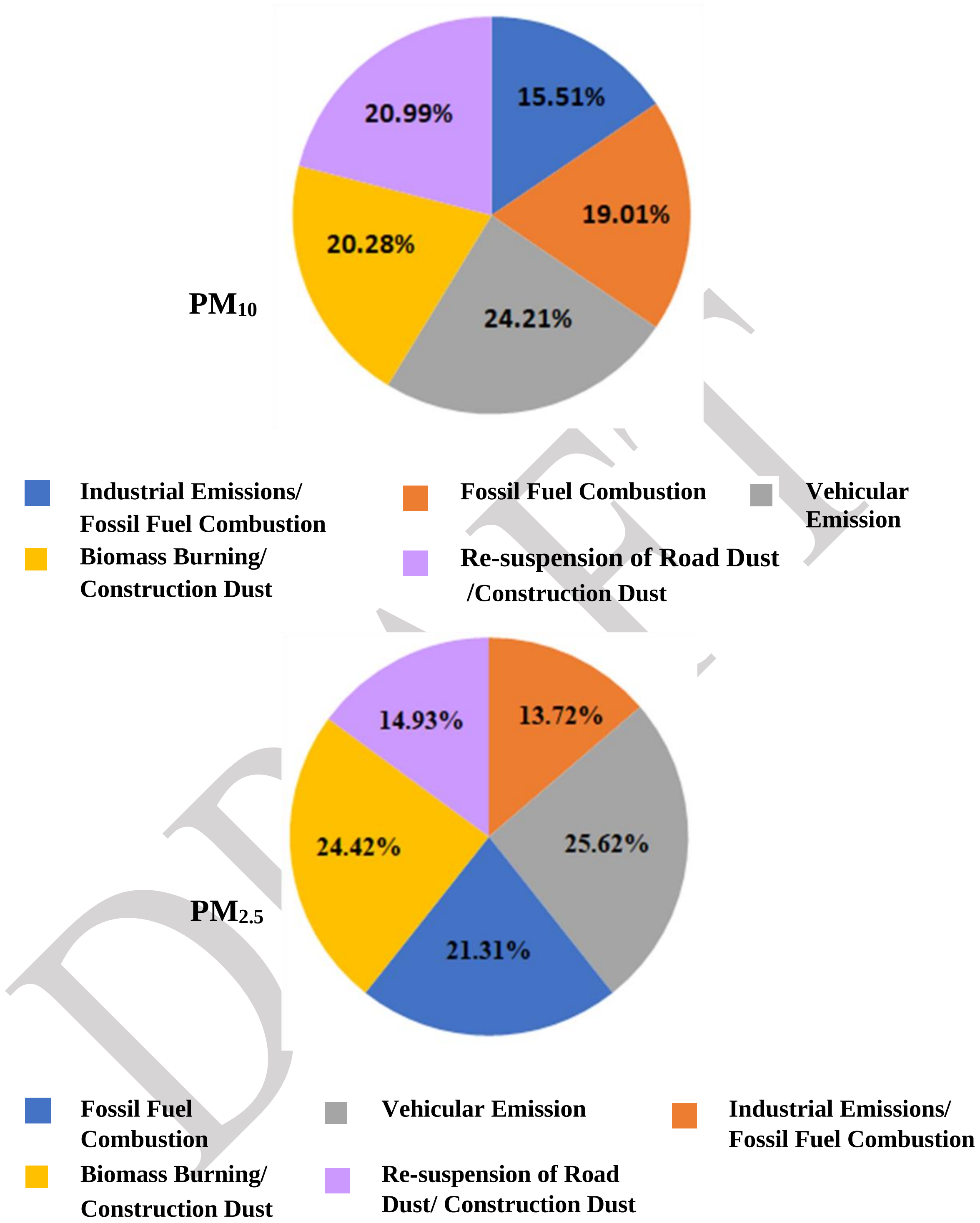


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Kolhapur City

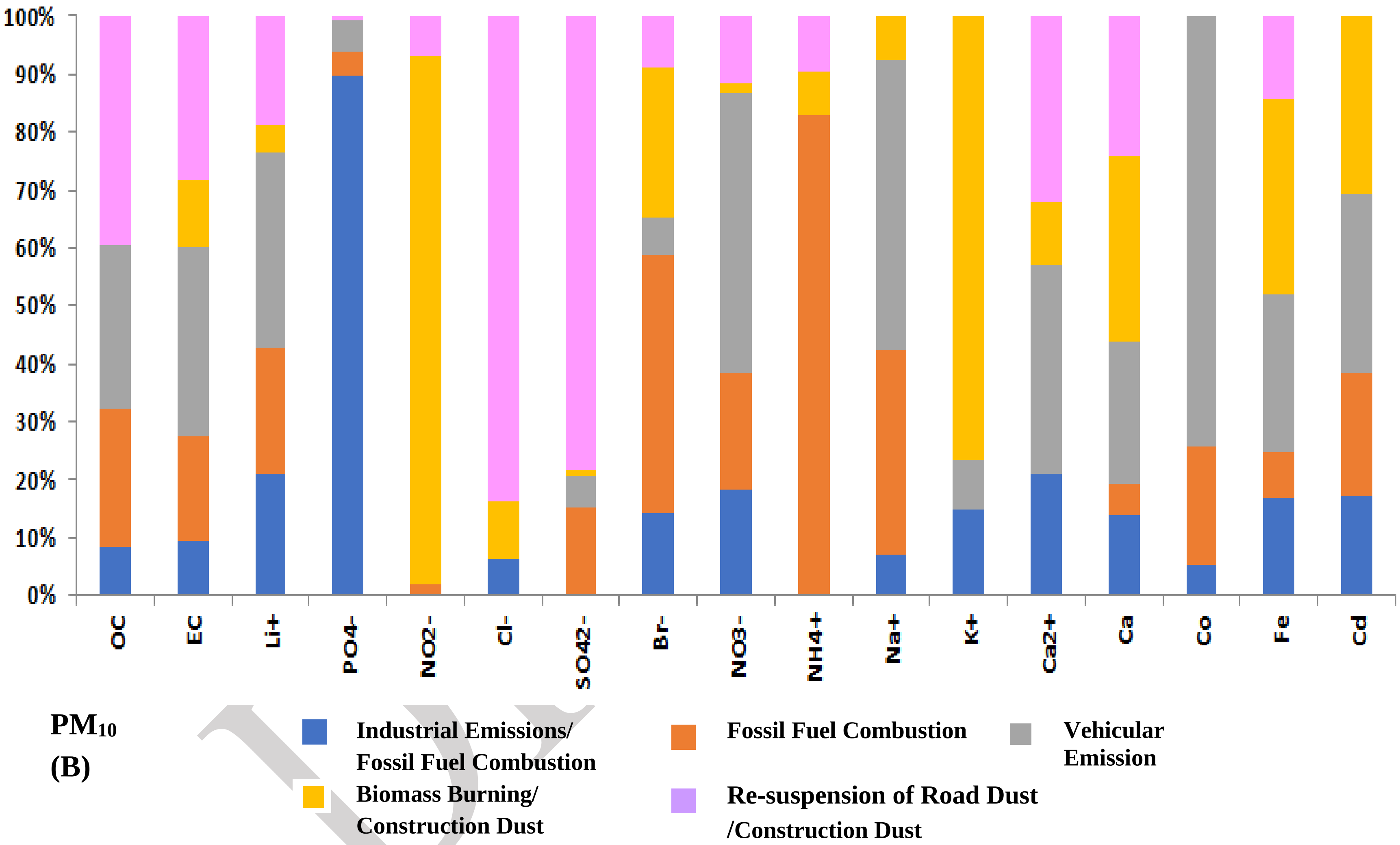
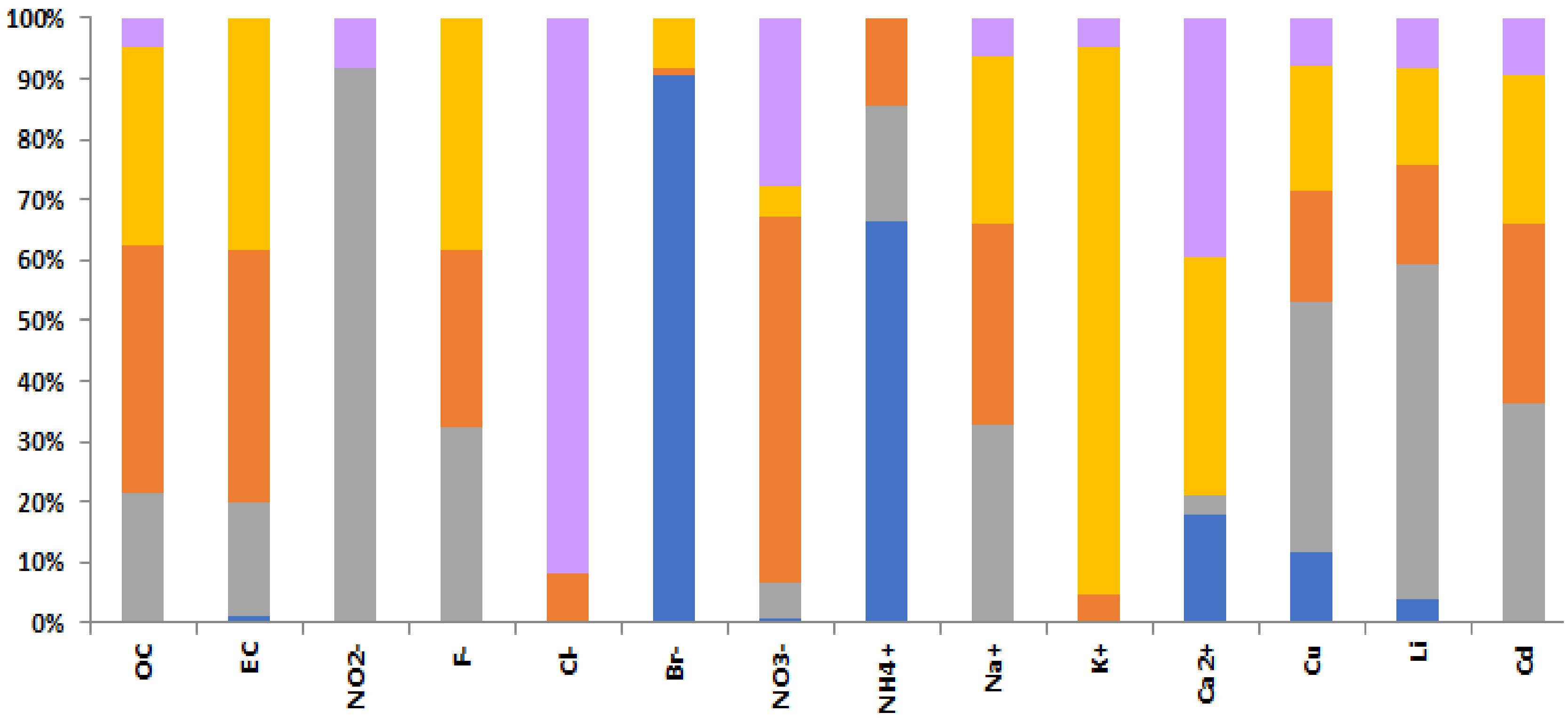


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Kolhapur City



$PM_{2.5}$ (C)

Fossil Fuel Combustion | **Vehicular Emission** | **Industrial Emissions/ Fossil Fuel Combustion** | **Biomass Burning/ Construction Dust** | **Re-suspension of Road Dust/ Construction Dust**

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

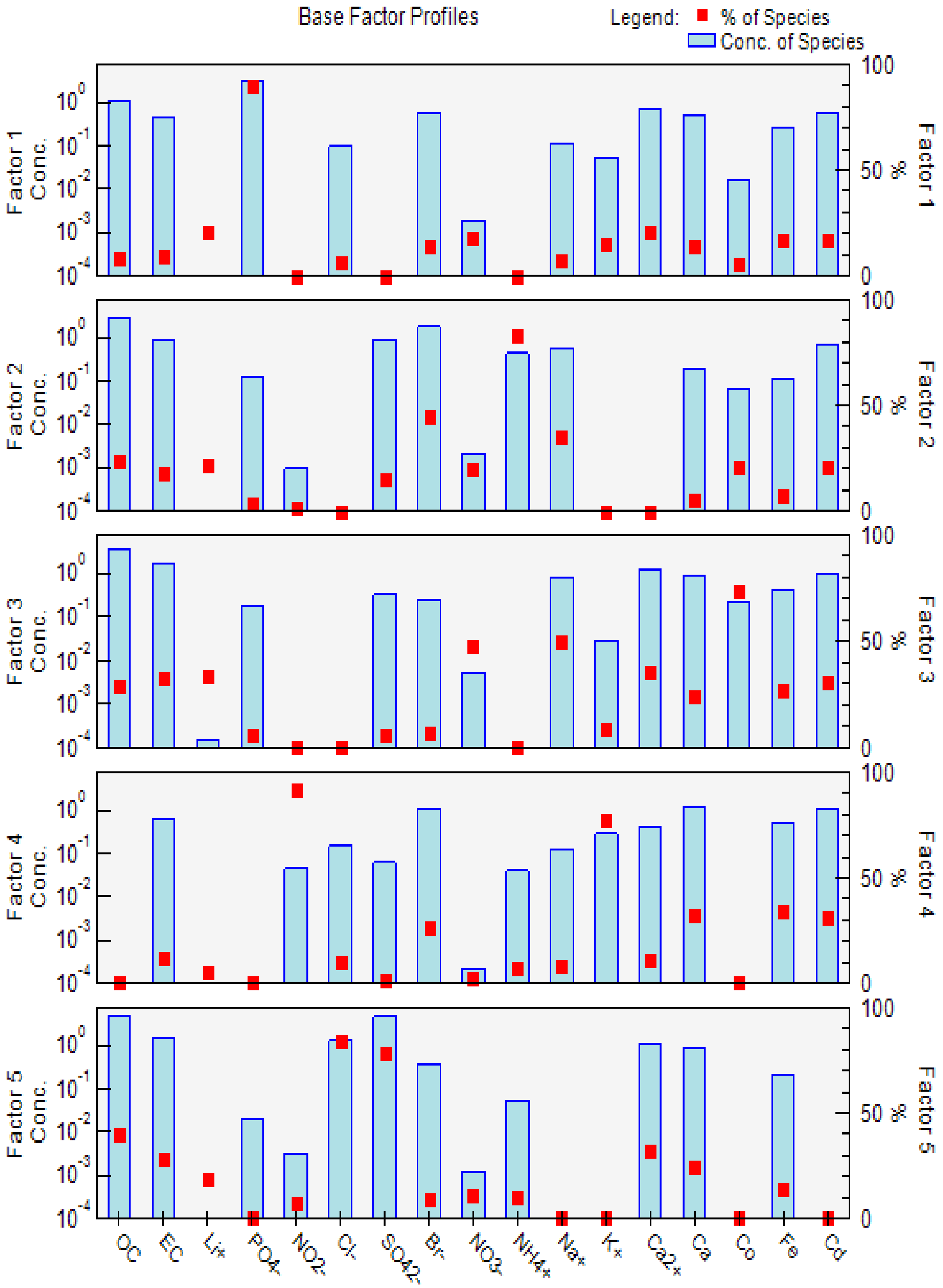


Figure 4.2 a : PM_{10} Base Factor Profiles

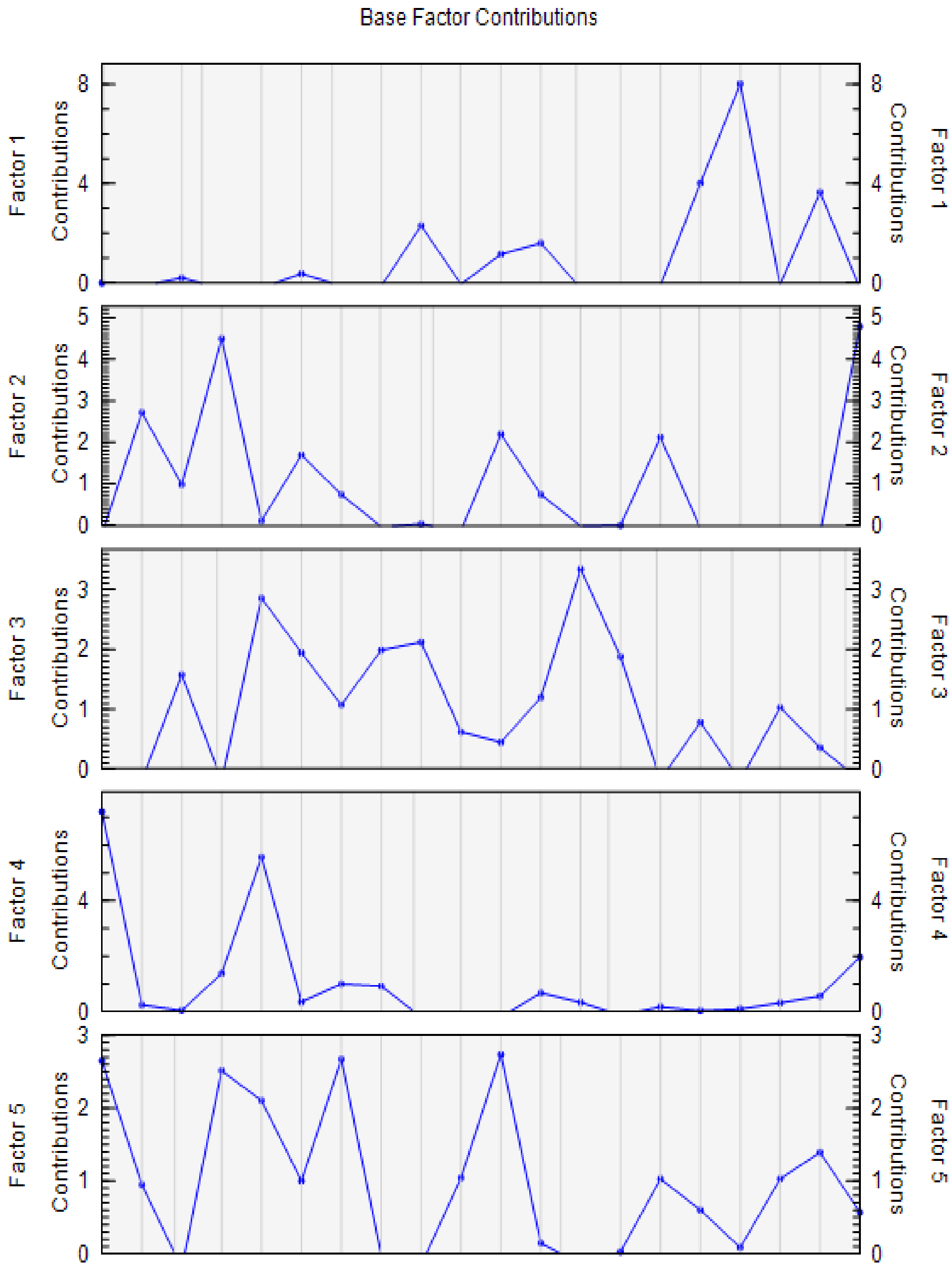


Figure 4.2 b : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, Br^-, PO_4^-, Cd, Ca^{2+} *EC, Ca, Fe*	15.51	Industrial Emissions/ Fossil Fuel Combustion
Factor 2	EC, OC, $Br^{-,}$ SO_4^{2-} *NH_4^{2+}, Cd*	19.01	Fossil Fuel Combustion
Factor 3	EC, OC, $Ca^{2+,}$ Cd *Zn, Fe, Pb, Co, Ca*	24.21	Vehicular Emission
Factor 4	K^+, Br^-, Ca, Cd, Fe, EC *Ca^{2+}, Na^+, Cl^-*	20.28	Biomass Burning / Construction Dust
Factor 5	OC, EC, SO_4^{2-}, Ca^{2+} *Br^-, Cl^-, Ca*	20.99	Re-suspension Dust/ Construction Dust

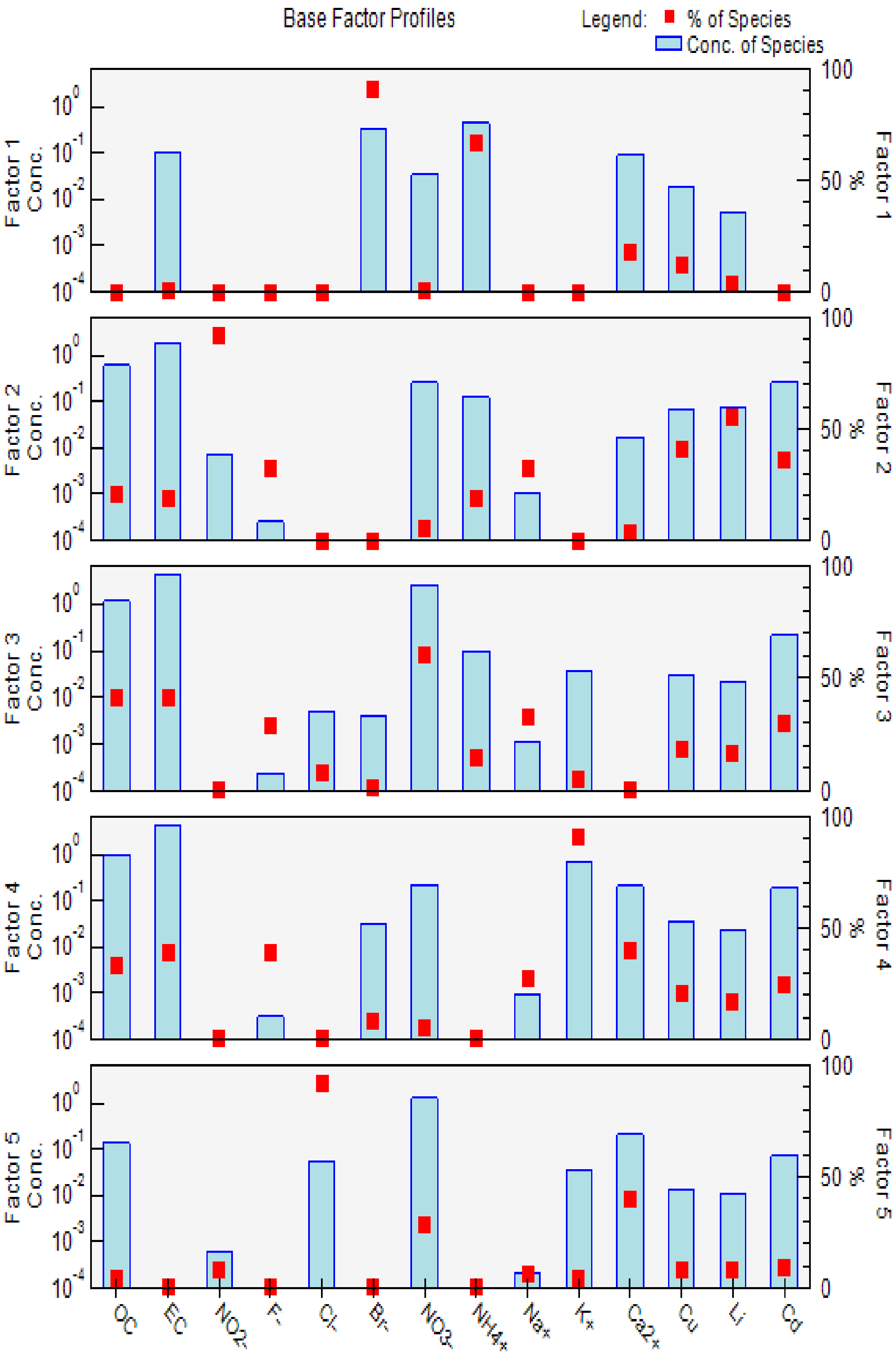


Figure 4.2 c : $PM_{2.5}$ Base Factor Profiles

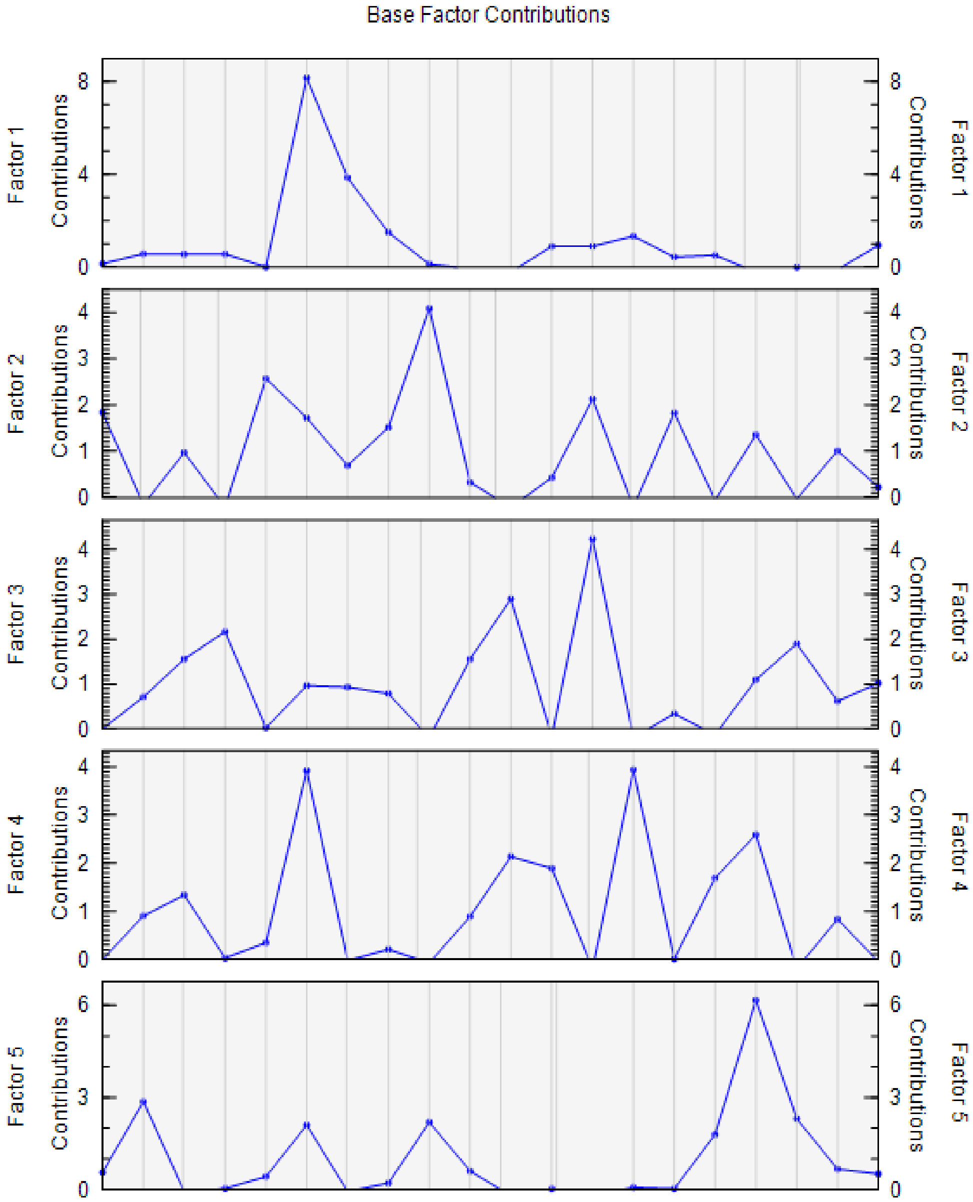


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	EC, Br^-, NH_4^{2-} *Ca^{2+}, Cu*	13.72	**Fossil Fuel Combustion**
Factor 2	EC, OC, Cd *NO_3^-, Zn, Pb, Cu*	25.62	**Vehicular Emission**
Factor 3	OC, EC, NO_3^{2-}, *NH_4^{2+}, Cd*	21.31	**Industrial Emissions/ Fossil Fuel Combustion**
Factor 4	K^+, OC, EC *NO_3^{2-}, Ca^{2+}, Cd*	24.42	**Biomass Burning/ Construction Dust**
Factor 5	OC, NO_3^{2-}, Ca^{2+} *Na^+, Cl^-, Cd, K^+*	14.93	**Re-suspension of Road Dust /Construction Dust**

4.5 Emission Inventory and Source Apportionment

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

The PM_{10} and $PM_{2.5}$ emission load estimated in emission inventory from vehicle tail pipe sources is around 0.2 TPD and 0.1 TPD, respectively. Among line sources, emissions from Heavy Duty (61.2%) vehicles are the maximum followed by 2-wheeler (19.1%) and 4-wheelers (12.2%). 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, chemicals etc. and many other small scale industries which generate employment for lakhs of people in and around Kolhapur. The types of fuel used in industries found in Kolhapur MIDC's are wood (2.2 TPD), coal (81.5 TPD), furnace oil (18.1 KL/day), diesel (6.73 KL/day), Petcoke (0.3 TPD), briquettes (10.1 TPD) etc. The maximum particulate matter (PM_{10}) is 864.56 Kg/Day and for $PM_{2.5}$ is 347.71 Kg/Day respectively.

As there are only 12 registered bakeries and operating on LPG, the PM_{10} (0.0036 kg/day) and $PM_{2.5}$ (0.0019 kg/day) emission from bakeries is very low. The total emission load for PM_{10}, $PM_{2.5}$, CO and NMVOCs from crematorium is estimated to be 156.6, 73.38, 910.87, and 413.66 Kg/Day. The highest PM_{10}, emission load contributed by Area Source is from crematorium. 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 and emission load that from Hotel & restaurants of the study area was found to be around 15.43 kg/day, 6.7 kg /day and 2.6g kg/day, respectively. 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 PM_{10} and $PM_{2.5}$ emission load estimated from building construction is 77.2 kg/day and 32.4 kg/day, respectively. The PM_{10}, emission load from all the sources of the city was calculated to be around 1.4 TPD, out of which ~62% of load is calculated from Industrial Source, ~21% from Area Source and ~18 from Line Source.

Ambient Air quality was monitored at four sites in study area for PM_{10} and $PM_{2.5}$ concentration and it can be seen that PM_{10} concentration violated the CPCB threshold (100 $\mu g\ m^{-3}$) during the entire study period at all the sites. $PM_{2.5}$ concentration exceeded the CPCB standard of 60 $\mu g\ m^{-3}$ only at one occasions in MIDC. In EPA during the PMF run analysis, some of the factors identified in the source apportionment research were found to be in a mix contribution form, indicating that the factor species from distinct sources were collinear. Hence, couldn't be further resolved to particular source of emission load in the vicinity. Various Sources were identified from the vicinity of the monitoring locations for in Source Apportionment Study from the analysis of their Elements, Ions and Carbon (Elemental and Organics) factor species contributions to the corresponding sources.

With which, 5 factors were identified in the study location for PM_{10} and $PM_{2.5}$ samples. The highest factor contribution in both PM_{10} and $PM_{2.5}$ emission load is found from tailpipe emission of Vehicular Sources (~26%). The other factor identified for $PM_{2.5}$ load is Biomass Burning/ Industrial Emission (~25%), Industrial Emission/ Fossil Fuel Combustion (~21%), Re-suspension of Road Dust and Construction Dust (~15%) and Fossil Fuel Combustion (~14%). For PM_{10}, factor identified were Re-suspesnion of Road dust/Construction Dust (21%), Biomass Burning (~21%), Fossil Fuel Combustion (~19%) and Industrial Emission (~16%). Both source categories were found to be contributing almost the same for both $PM_{2.5}$ and PM_{10}. These results are well corroborated with apportionment of particulate matter; considering nature and quantum of the activities that is carried out in and around the study area.

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Chapter 5

Source Dispersion Modeling

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

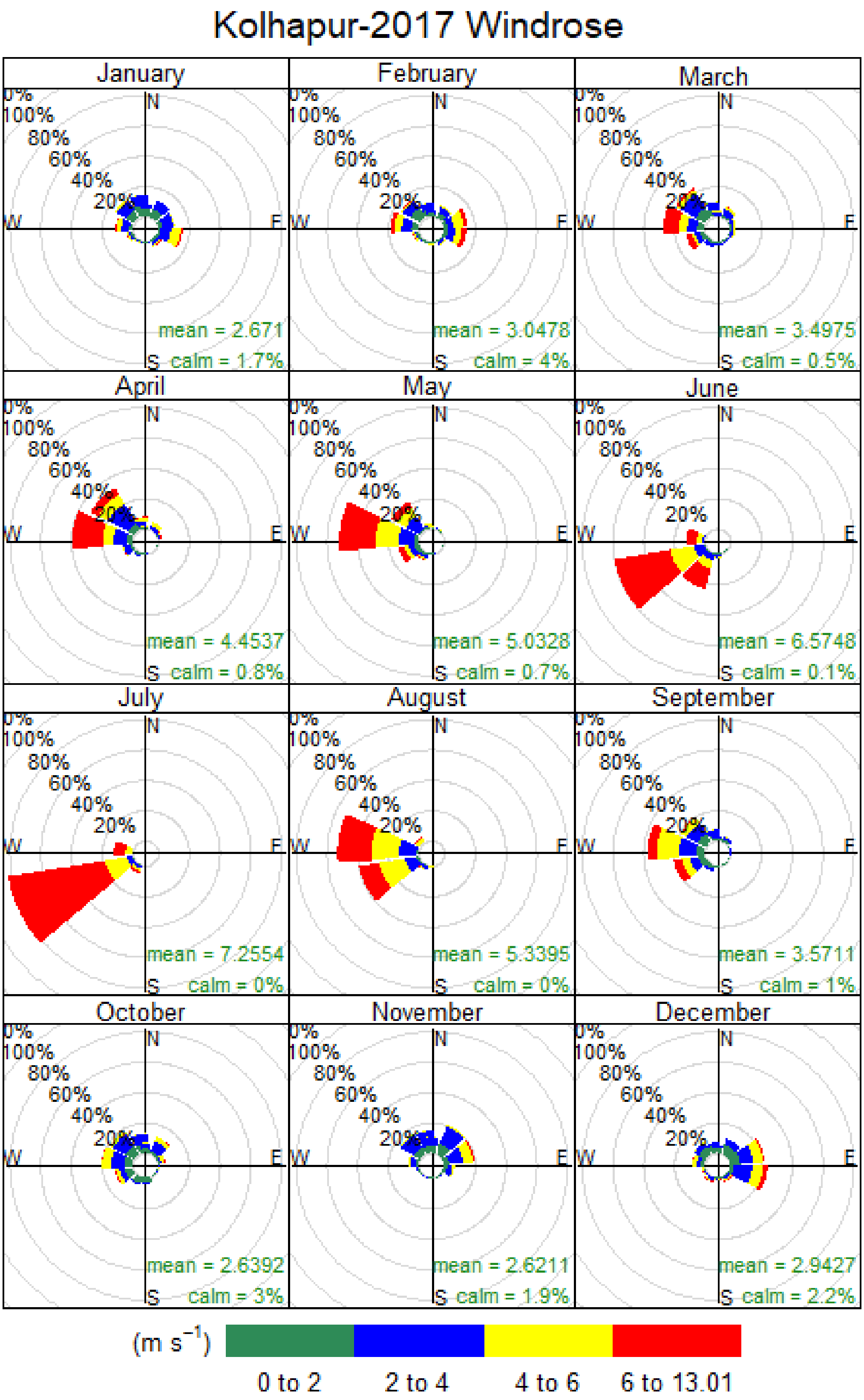


Figure 5.1 : Monthly Wind Rose Diagram of Kolhapur

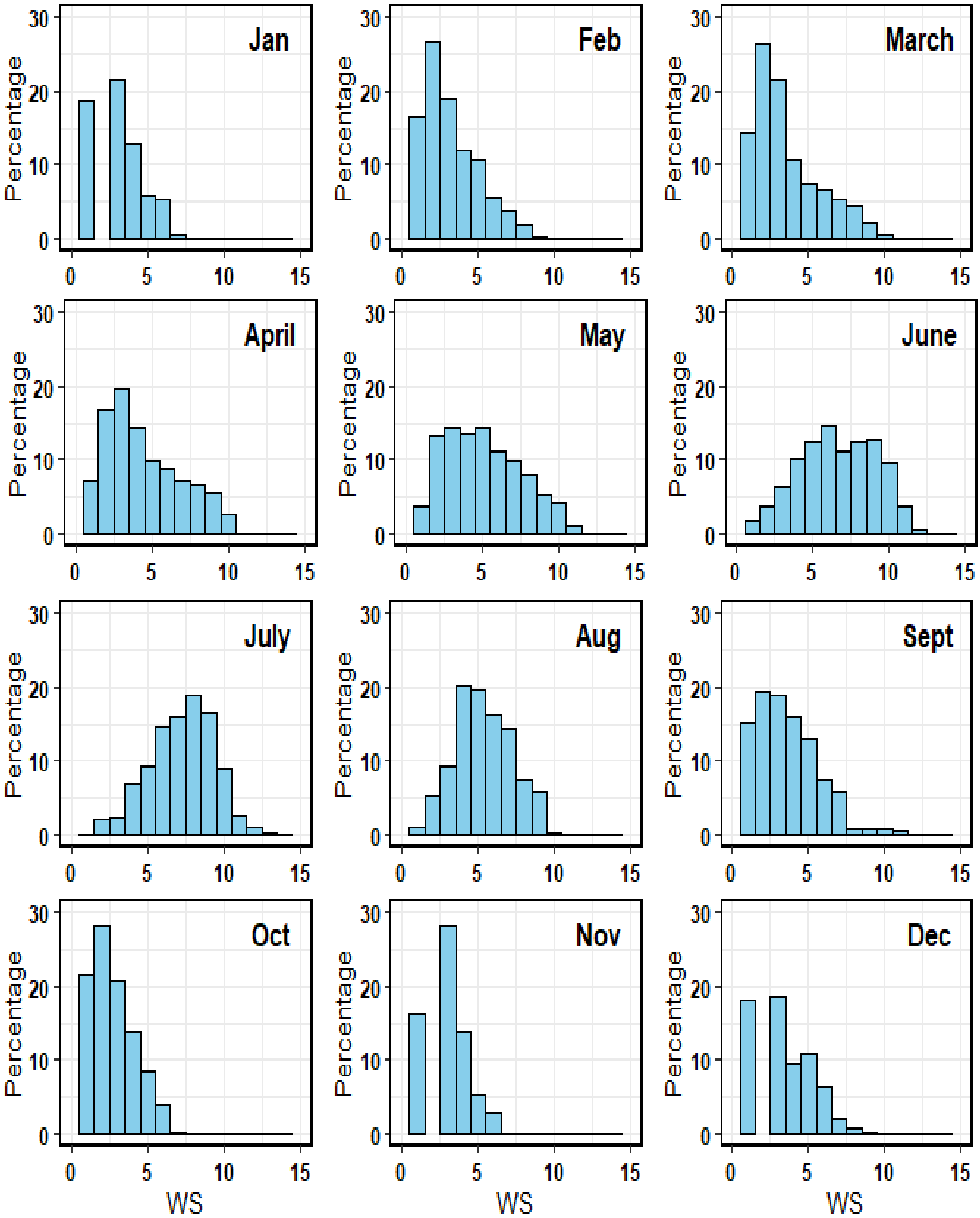


Figure 5.2 : Monthly Wind Speed Frequency in Kolhapur

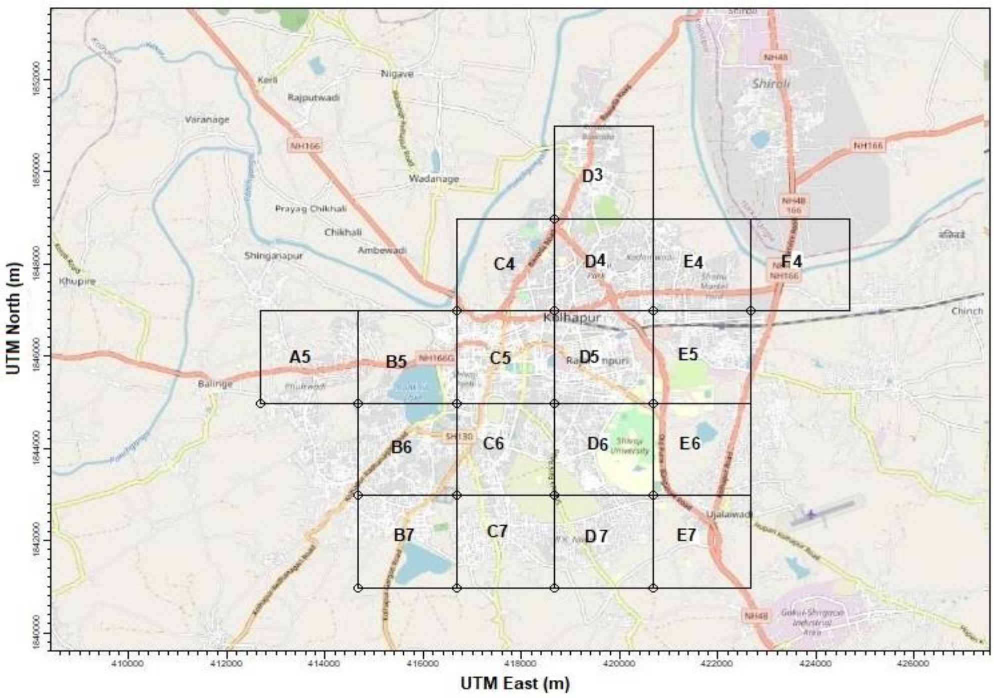


Figure 5.3 : Grid Over Kolhapur City for Dispersion Modelling

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. 2000 m x 2000 m. 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}.

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

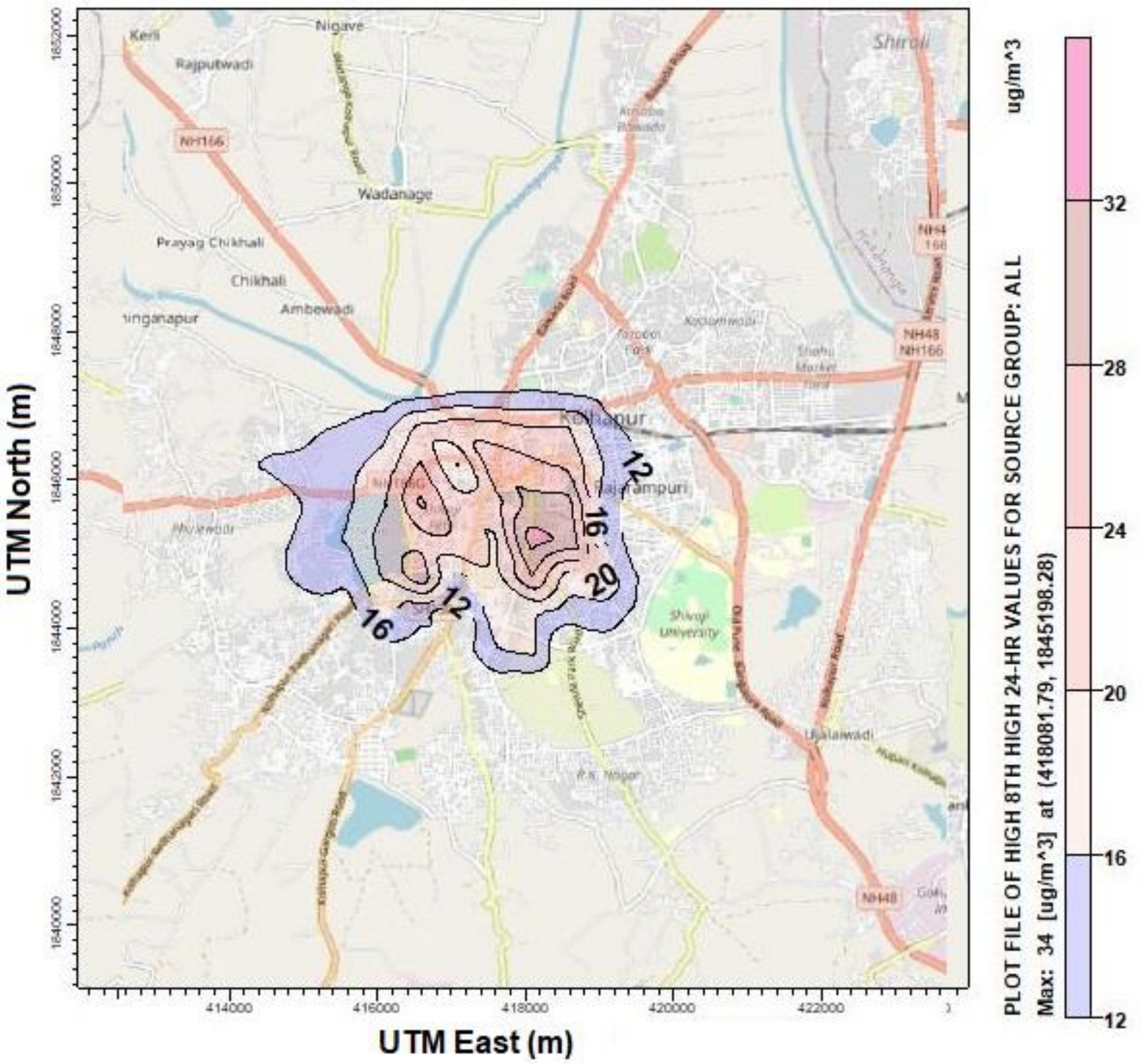


Figure 5.4 : GLC of PM_{10} in Kolhapur Determined by Simulation using AERMOD (Area Source Emission)

Figure 5.4 shows the GLC of PM_{10} in Kolhapur city. It can be seen that the maximum GLC of PM_{10} is very low and is around 7 µg/m^3. Since this value is lower than the regulatory limit, all other pollutant's GLC will be below the regulatory limit value.

Chapter 6

Action Plan for Control of Air Pollution

6.1 Emission Reduction Action Plan for Kolhapur City

The action 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 and states to prevent overloading of vehicles.	Reduction of Air Pollution Load from existing vehicles- /Medium	Implementation/ Policy	KMC/RTO
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

Table 6.1 (Contd..) : 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)			
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 and BS-III)	Reduction of Air Pollution Load from existing vehicles-/Medium	Implementation/ Policy Decision/ Feasibility study	RTO, KMC
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			

Table 6.1 (Contd..) : Action Plan to Mitigate Air Pollution from Various Sources

Control Option	Expected Reduction and /Impacts	Technical Feasibility	Responsible/ Implementing Agency
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 emissions for QA/QC	Reduction of Air Pollution Load from industries /High	Implementation/ Feasibility Studies	MPCB/MIDC
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.
Introduce water fountains at Major Traffic intersection, wherever feasible.	Reduction of Air Pollution Load from resuspended dust-/Low	Implementation or feasibility/Probing study for use of dry scrubbing system at traffic corridiors	Municipal Corporation

Table 6.1 (Contd..) : Action Plan to Mitigate Air Pollution from Various Sources

Control Option	Expected Reduction and /Impacts	Technical Feasibility	Responsible/ Implementing Agency
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 cooking- Medium	Implementation/ Feasibility	Maharashtra Govt./ KMC
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			

Table 6.1 (Contd..) : Action Plan to Mitigate Air Pollution from Various Sources

Control Option	Expected Reduction and /Impacts	Technical Feasibility	Responsible/ Implementing Agency
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			

6.2 The Overall PM Emission Management

- The dominant parameter is Particulate Matter, ascribed to growing industrial activity in the foundry, vehicular traffic, stone crushing units and construction projects as well as commercial and infrastructure development including road construction etc.
- There is a deficiency of collective policy enterprise among the administrations and organisation with regard to air quality improvement. These contract enterprises can be affirmed and kept up-to-date only if there is an apex body, which will monitor and mentor the involving departments from time to time from various sources. These sources could be State Pollution Control Board, Regional transport office, Municipal Corporation, MIDC, Oil Companies, Anti-Adulteration cell, and a representative from ULB and NGOs, school and colleges. The regulatory framework, if needs can be communicated to the apex body for starting the initiative for policy formation.
- Provision of cycle lanes in city roads and promotion from Government to use cycles by the citizen will help decongestion of traffic and resuspension issues.

- As per the provisions of 73 (3), Central Govt. can restrict and limit the number of contract carriers in the cities/towns were the heavy population is not less than 5 lakhs. Accordingly, Maharashtra Govt. has issued notification restricting number of contract carriers in the city of Mumbai, Thane, Pune, Nagpur, Solapur, Nashik, Aurangabad etc., the provision of Act & Rules need to be reviewed and amended suitably in the light of increasing population & urbanization of these cities. The traffic of heavy goods vehicles may be routed outside the city area by creating by-passes & ring roads before entry and exit of the city.
- Industries should adopt stack emission norms beyond those prescribed by CPCB Industries/power plants, which should be followed by regular QA/QC & performance audit.
- Fuel consumption in DG set operation in industrial should be regulated with stringent surveillance and made to follow stack emission standards with the installation of efficient air control equipment. The dependency on DG set on power cut should be replaced by a conventional source of energy.
- It is not just adequate to assess air pollutant concentrations and evaluate their origins. It is every bit important to propagate that message to the public through various mediums such as web / mobile application, information boards in public spaces as well apportioning crucial studies carried on air pollution with the public. This ascertains public consciousness of the issues and can assist in developing pressure on the concerned authorities to address the question.

Some of the technologies developed by NEERI to curb air pollution load from line sources can be implemented phase wise. (Annexure IV and V).

6.3 Monitoring Mechanism for Implementation

The aforesaid action plan shall be implemented by Maharashtra State Pollution Control Board with co-ordination of Department of Environment and Forest, Govt. of Maharashtra, Urban Development and Housing Department, Govt. of Maharashtra, Transport Department, Kolhapur Municipal Corporation, Traffic police and District administration. Maharashtra State Pollution Control Board shall regularly review the implementation of aforesaid action plan.

Annexure – I

Design of a Clean Tandoor Community Kitchen System (CTCKS)

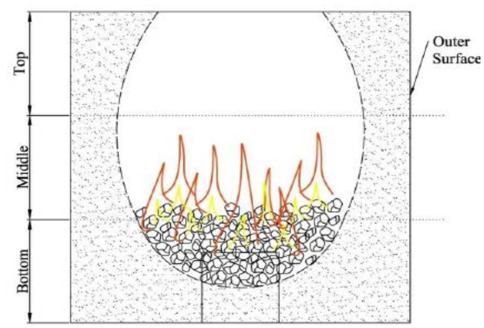
Design of a Clean Tandoor Community Kitchen System (CTCKS)

The objective of the experiment is to design a clean tandoor community kitchen system to reduce air pollution. There are no standards or guidelines to evaluate the performance of the tandoors w.r.t. its thermal efficiency, emissions and safety. While such standards are developed for the cook stoves however, tandoors are not considered probably due to their limited use. Also there is no BIS/ISI product Quality Mark for Tandoor in India to ensure quality of the tandoor even w.r.t. to material of construction. In most of the cases, it was found that there was no control devices installed at any tandoor facilities surveyed.

Air quality policies have so far focused on formulating and implementing abatement strategies for ambient (outdoor) air pollution, while indoor air quality sources (or human exposure) have not been adequately taken into account. To date, it is not clear whether measures implemented on outdoor air pollution will prove effective (and sufficient), once the total picture, that is the relative contribution of indoor and outdoor sources to total human exposure, is clear. Indeed, compliance with existing National Ambient Air Quality Standards (NAAQS), intended to protect public health, depends exclusively on outdoor measurements of pollutants. However, such measurements are subject to biases because most people spend much of their time indoors in different microenvironment than outdoor, and air pollutant concentrations are often much higher in these micro-environment than ambient with higher exposure conditions too, e.g. during cooking, etc. Therefore, estimates of human exposure to inhaled air pollutants are necessary for a realistic appraisal of the health risks these pollutants pose and for the design and implementation of strategies to control and limit those risks.

Based on the Material of Construction (MoC) the tandoor can be classified as Stainless Steel (SS), Sheet (Aluminium/Mild Steel) and Iron/Steel Drum (made from cutting the liquid fuel/oil drums etc.). The cost of the tandoor varies based on the MoC i.e. SS (Round/Square) Tandoor would cost between Rs. 16,000 – 22,000 or even higher, whereas the Sheet (Aluminium/Mild Steel) based are priced at Rs. 8,000 – 12,000 and Drum Based at Rs. 3,000 – 5,000. As per secondary data and surveyed tandoors it was found to be natural draft. The insulation material used at tandoor covers use of clay, glass-wool, ceramic, vermiculite, fire brick, mud etc. in order to retain heat for longer duration. It was observed that the cooking area is mostly outdoor (>92%). The tandoor was used "outdoor" primarily means that the tandoor oven for cooking purpose is placed beside but outside the compound walls of the restaurant premises under a shaded, however this is just adjacent to the seating area for customers and therefore emissions form tandoor can easily disperse inside the eating/seating area, unless a proper ventilation is provided. No control device to reduce the emission or ventilation to reduce the exposure was present in over 90% of the surveyed restaurants thus showing least concerns on emission exposure. It was also observed that, the quantity of fuel used varies from 5kg to 40kg per day. Cost of the fuel lies in the range of Rs.20-40 per kg of coal (>70%). Over 41% of the tandoors were ignited in the morning for full day operation. About 0.11 to 0.35 kg of ash is generated by burning per kg of charcoal/coal for over 71% of the restaurants. The ash and un-burnt fuel was disposed in dustbin using polythene bags.

The thermal profile across the tandoor over was also recorded using Amprobe IR-750 Temperature Gun (n=139) to understand the temperature requirements of the tandoor surveyed, for effective cooking. The tandoor oven can be divided into 3 major sections: Top, Middle and Bottom as depicted below. The combustion of coal/charcoal takes places in the bottom section. The middle section transfers the heat to the top section where the food is cooked. The median temperatures at the top, middle and bottom sections were observed as 184°C, 383°C and 580°C respectively, where the median outer body temperature of the tandoor was 56°C owing the insulation layer between the tandoor oven and the outer body of the tandoor.



Classification of Temperature Zones in Tandoor Bhatti

A cleaner, efficient tandoor is proposed based on Pellet based fuel with forced Draft arrangement with an aim to design a clean combustion device in order to reduce the emissions, keeping in mind that functionality and feel of the tandoor doesn't change significantly in order to bypass any hurdle in the adoption of the proposed design. A tandoor system can be primary divided into two parts: firstly, combustion chamber section and oven section. Considering the combustion chamber section in the existing designs in it was observed that most of the tandoors were natural draft with insufficient air to fuel ratio. Therefore, in order to supply sufficient oxygen, a forced Draft fan is considered to increase the air to fuel ratio in order to improve the fuel combustion. Also the quality of coal used in tandoor is a major concern which is also responsible for higher emissions, keeping this in mind, low cost biomass pellets is suggested as an alternate fuel for heating the tandoor oven to reach the desired temperature. The advantage with using a pellet based forced draft combustion tandoor will be reduced emissions with increased thermal efficiency, which can be supported by retrofitting the commercial size forced draft improved Cookstove readily available in market and are tested by BIS 2013 to meet the efficiency and emission standards.

However, since these cookstove are designed for semi-commercial and community cooking, some modifications will be required, which can be done by the respective developer/manufacturer. These stoves are listed in ***Annexure*** and can be readily retrofitted to a tandoor oven to improve the combustion process. The design of the tandoor oven is kept similar to the available designs of tandoor, so that it doesn't affect the functionality issues or create any adoption hurdle. The selection of material of construction of tandoor should consider the following: clay for oven with high heat capacity material to retain heat for longer duration and body parts material for its long life and selection of low cost and effective insulation for tandoor oven.

Figure 1 to 4 below shows the concept design of the tandoor drawn not to scale as the size of the tandoor may vary based on required power output. The proposed tandoor system also incorporates a continuous pellet/fuel fed mechanisms so as to enable the uninterrupted and automatic supply of fuel to the combustion chamber for continued functioning of tandoor system. The proposed design of the tandoor can be fitted with chimney (natural or induced forced draft). However, the design of chimney will depend on the available space and vary from restaurant to restaurant. The design of chimney is not dealt in this study but it is recommended to use and install commercial available chimneys along with the proposed tandoor in order to reduce the human exposure. Although this would significantly reduce the pollutant exposure, however would anyway contribute to ambient air.

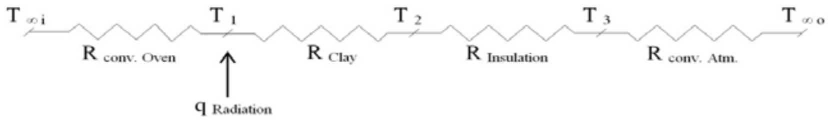
Advantages of pellet based tandoor also leads to reduced ash generation. Pellets based tandoor will also generate market for pellet industry and enable the use of agro-waste residues for development of an alternative fuel, promote employment generation in rural areas and would partly contribute to emission control and avoid disasters like smoke haze from stubble burning.

Design Methodology

The community tandoor involves different modes of heat transfer phenomena occurring simultaneously inside a tandoor, which can be described under three primary categories: Conduction, Convection and Radiation. The process of heat transfer involves heat transfer from the burning of fuel, convection within the hot gases, heating of the tandoor clay by convection and radiation; conjugate heat transfer between the heated gases inside the tandoor chamber and the tandoor clay; conduction of heat across the tandoor surface (clay and insulation); convection between the outer tandoor surface and the surrounding atmosphere. The process of heat transfer is dominated by radiation as compared to other modes of heat transfer. In a tandoor, three modes of heat transfer i.e. Conduction, Convection & Radiation are accounted together for minimizing the heat transfer through the walls and heat balance

Eq. (1) and Eq. (2).can be given as:

$$\dot{Q}_{cond.} + \dot{Q}_{conv.} + \dot{Q}_{rad.} = \dot{Q}_{total} \qquad (1)$$



$$\frac{T_{\infty i} - T_1}{R_{conv\cdot oven}} + q_{rad} + \frac{T_2 - T_1}{R_{clay}} + \frac{T_3 - T_2}{R_{insulation}} + \frac{T_{\infty o} - T_3}{R_{conv\cdot Atm}} = \dot{Q}_{total} \qquad (2)$$

The conjugate heat transfer between the hot gases (fluid) and the tandoor clay (solid) can be given by Eq. (3) and Eq. (4):

$$T_{w,s} = T_{w,f} \qquad (3)$$

$$k_s \left(\frac{\partial T}{\partial n}\right)_{w,s} = k_f \left(\frac{\partial T}{\partial n}\right)_{w,f} \qquad (4)$$

The heat transfer coefficient can be calculated using the existing relation in Eq. (5):

$$h = \frac{Nu_L * k}{L} \qquad (5)$$

In order to minimize the heat losses and to prevent the heat transfer from the oven to the atmosphere, effective heat insulation material is needed in between the oven and the outer tandoor casing. Critical thickness of Insulation is determined, where thickness of insulation corresponding to the critical radius of insulation is calculated to decrease the heat transfer. If insulation thickness is beyond its critical radius, heat transfer rate increases. This radius at critical heat loss is given as Eq. (6).

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$$r_{cr} = \frac{k}{h} \qquad (6)$$

Design of Forced Draft Stove

The following relations were used to design the pellet based forced draft cookstove.

Power Output: Power output rating is determined by the formula in Eq. (7):

$$P_o = F \times H_{fuel} \times \eta / 360000 \text{ kW} \quad (7)$$

Energy input: The amount of energy supplied by the fuel fed into the stove can be computed using the formula in Eq. (8):

$$FCR = \frac{Q_n}{CV \times \eta} \quad (8)$$

Combustion chamber diameter: The diameter of the combustion chamber is calculated by using the following formula in Eq. (9):

$$D = \sqrt{\frac{1.27 \times FCR}{SGR}} \quad (9)$$

Height of the combustion chamber: The height of the chamber is calculated by using the following formula in Eq. (10):

$$H_b = \frac{SGR \times T}{\rho} \quad (10)$$

Amount of Primary Air needed for gasification (Pa): According to Mukunda et al. (2010) primary air, which is mainly responsible for gasification is usually 1.5 times FCR as depicted in Eq. (11):.

$$P_a = 1.5 \times FCR \quad (11)$$

Area for Primary Air Requirement (Ap): The total primary area required for forced air flow is divided into two parts for design suitability. A primary window is provided at bottom to feed wood logs and other lower bulk density materials. Holes are provided at the top section of the combustion chamber for gasification of fuel. Therefore 13 holes were drilled throughout the circumference of the stove (Eq. (12)):

$$A_p = \frac{P_a}{\rho_{air} \times v} \quad (12)$$

According to Mukunda et al. (2010) secondary air, which is mainly responsible for combustion is usually 4.5 times FCR as given in Eq. (13):. Velocity was assumed as 1 ms-1 for penetration of air into the reactor (Witt, 2005).

$$S_a = 4.5 \times FCR \quad (13)$$

Tandoor Design Details

The material of construction for proposed tandoor may vary across different manufactures but it is recommended to use mild steel, stainless steel and Iron based alloys for all primary purposes of constructions. The use of these materials for tandoor fabrication will enable the tandoor to be economically viable and it is within the budget of potential users. The design has been optimized keeping the user requirements in mind. As such, no further training or skilled trainer is required for use of proposed product design. The material details for different child parts of pellet based tandoor are tabulated in Table below. The conceptual designs of Clean Tandoor Community Kitchen System (CTCKS) are depicted in Figures 1-4 (Not drawn to scale). Based on design value, from expression for diameter, height, combustion chamber and air requirement, design specifications of improved pellet stove is tabulated in Figure. The detailed design of the different child parts along with their dimensional details required to fabricate the CTCKS is delineated below.

Illustrative materials for different parts of CTCKS

Part Name	Material	Thickness
COOKSTOVE	Stainless Steel Mild Steel Cast iron	Min. 1 mm Min. 1.6 mm Min. 6 mm
OVEN	Mud Clay	As per existing tandoor
HOPPER	Sheet Metal Aluminum Alloy	Min. 1.6 mm sheet Min. 1 mm sheet
BAFFLE PLATE	Stainless Steel Mild Steel Cast iron	Min. 1 mm Min. 1.6 mm Min. 6 mm
CASING	Sheet Metal (Aluminum) (1.5 mm) Stainless Steel (1.6mm)	Min. 1.5 mm sheet Min. 1.6 mm sheet
INSULATION	Sand Ceramic wool Liquid Foam	Min. 50 mm Min. 16 mm Min. 10 mm

NOTE: Dimensional tolerances shall be ± 3 percent. Various components of the tandoor shall be manufactured as per standard engineering practices. The construction of the tandoor shall be sturdy as per the given design details, so that while in actual use on level floor they should not get shaky or fall with little impacts

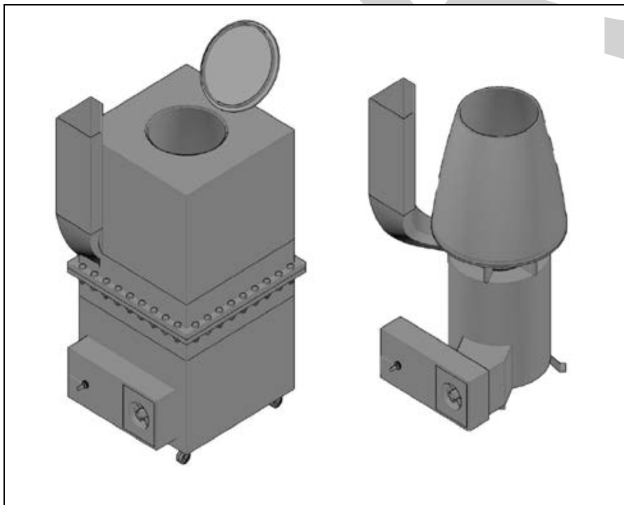


Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing

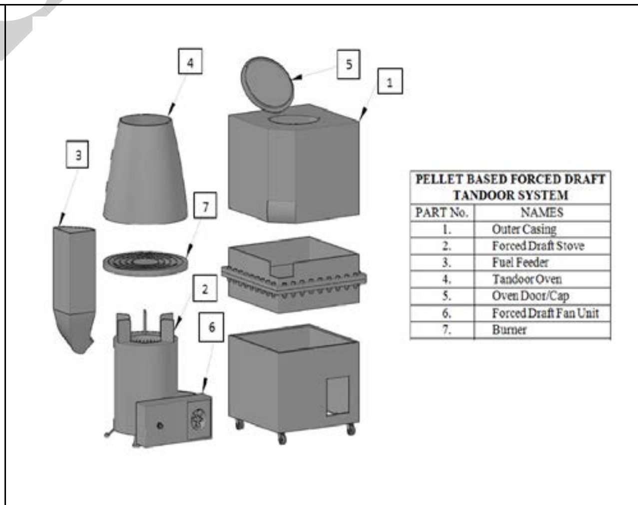


Fig. 2 Exploded view CTCKS: Inner Assembly & Outer Casing

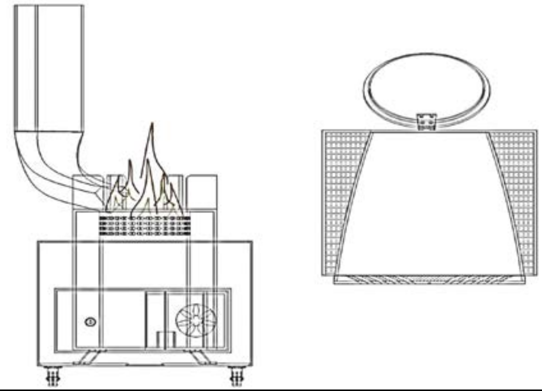
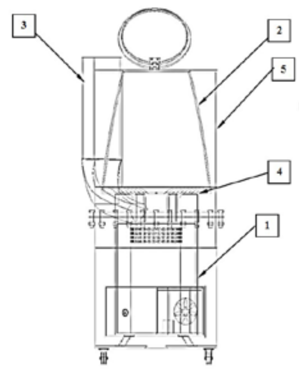
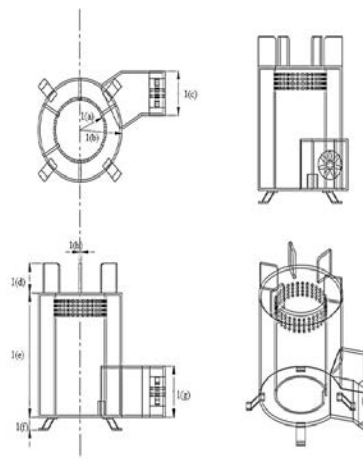


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)



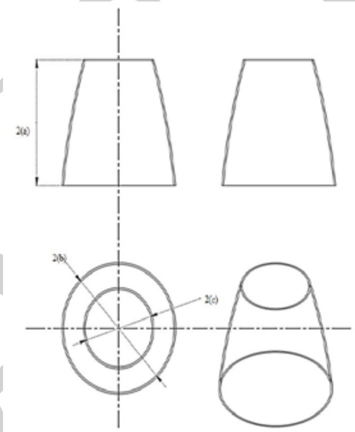
PELLET BASED CLEAN TANDOOR COMMUNITY KITCHEN SYSTEM	
PART No.	NAME
1	COOKSTOVE
2	OVEN
3	HOPPER
4	BAFFLE PLATE
5	CASING

Fig. 4 Line diagram of CTCKS



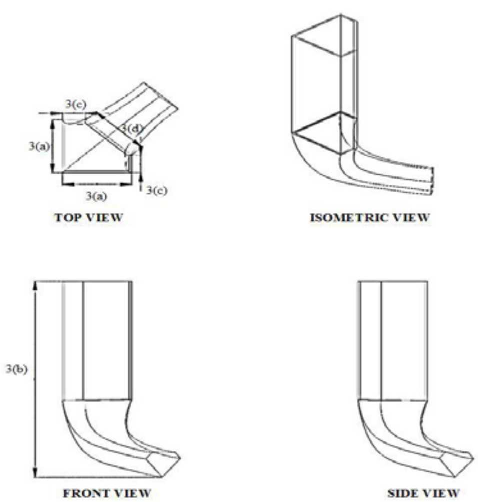
Part. No.	Dimensions (mm)	
3.15	a	170
	b	250
	c	80
	d	50
	e	400
	f	40
	g	80
	h	4

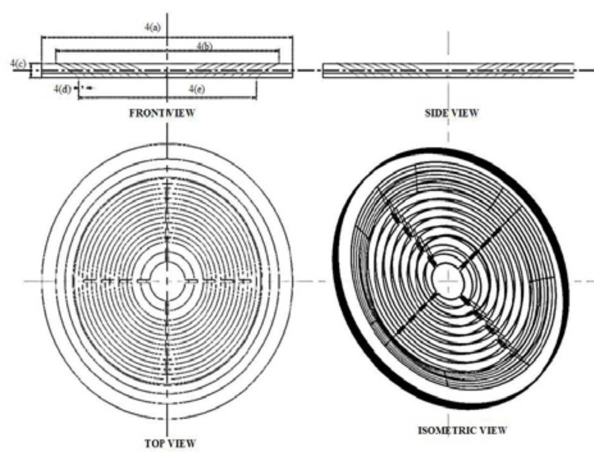
Fig. 5 Child Parts of CTCKS: Cookstove



Part. No.	Dimensional Range (mm)	
3.16	a	450 – 500
	b	680 – 700
	c	300 – 350

Fig. 6 Child Parts of CTCKS: Oven



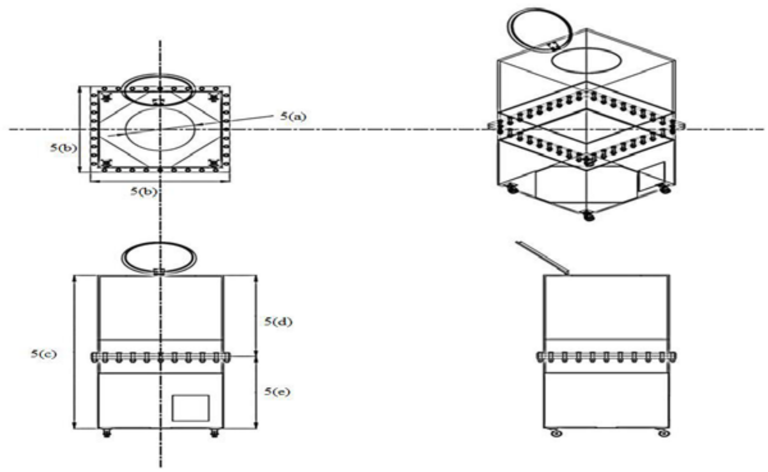


Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

Fig. 7 Child Parts of CTCKS: Hopper

Part. No.	Dimensional Range (mm)	
3.18	a	680 – 700
	b	580 – 600
	c	35 – 40
	d	20 – 30
	e	540 – 560

Fig. 8 Child Parts of CTCKS: Baffle Plate



Part. No.	Dimensional Range (mm)	
3.19	a	300 – 350
	b	750 – 820
	c	850 – 900
	d	450 – 500
	e	550 – 600

Fig. 9 Child Parts of CTCKS: Casing

In order to assemble the child parts of Clean Tandoor Community Kitchen System as per there construction, the following sequence shall be followed:

The forced draft cookstove (Fig. 5) shall be mounted by a baffle plate (Fig. 8), which will act as guided vanes to divert the flames of the stove (generated from the burning of pellets) to heat the inner wall of the tandoor called as oven (Fig. 6). A hopper (Fig. 7) can be attached in the space between the baffle plate (Fig. 8) and forced draft cookstove (Fig.4) in order to maintain continuous fuel feeding to the combustion chamber for its continued operation. This assembled unit thus formed is depicted in Fig. 4. The assembled unit will be inscribed in an outer casing (Fig. 9). The insulation material is provided between the tandoor oven (Fig. 6) and outer casing (Fig. 9) in order to prevent the heat loses from the tandoor oven (Fig. 3.16). An oven door/cap (Fig. 9) is provided to cover the tandoor oven (Fig. 3.16) when the tandoor system is not in use. This will prevent heat/energy losses and will save fuel, as already practiced in conventional tandoors.

Although it appears that the contribution of tandoors to ambient air quality is not very significant, however considering the exposure risks as well as number of unregistered restaurants, it will be worth introducing an improved tandoor for such application. It is therefore expected that the improved design of Clean Tandoor Community Kitchen System will bring air quality improvement as well as health benefits in the entire region, if implemented in large scale. Following actions are recommended for implementation in hotel/restaurant enterprises:

- All the restaurants/hotel enterprises of sitting capacity more than 10 should not use coal/charcoal and shift to pellets as a primary fuel to fire the tandoors. The use of pellets in tandoors will reduced the air emissions significantly while also reducing the fly ash generation.
- The tandoor manufacturing is quite an unorganized sector while there are no emission norms for this commonly used combustion cocking device. It is therefore recommended that similar to improved cookstove, emission norms and test protocols should be developed by responsible agencies for tandoor.
- Pellet based tandoor will also generate market for pellet industry and enable the use of agro-waste for development of an alternative fuel, promote employment generation rural areas and pollution from stubble burning can be significantly avoided, as it has already become a matter of great concern. In this way, introduction of pellet based tandoor become an effective option also to reduce indirect pollution load.
- The crop residue burning from nearby areas can be partly minimized by turning local biomass to pellets and with introduction of improved tandoor even in these localities for local consumption of pellets.
- The use of electric or gas-based tandoors may also be promoted in small capacity restaurants/hotel enterprises (less than 10 customers) as well as those can afford the same. Pellets are also economically viable option with cost to CV ratio of approx. Rs 2/- per 1000 calorie energy output (CV) as against Rs 4/- per 1000 calorie energy output for charcoal (considering cost as Rs 8/kg for pellets and Rs 30/kg for charcoal). The advantage of charcoal is slow burning rate (smoldering combustion) without forced draft. This can be partly compensated with an automatic pellet feeder and controlling air to fuel ratio through forced draft flow rate.

Its widespread adoption in crop burning states will create local demand for stubble based pellets and other fuels, thus reducing air pollution from open crop/stubble burning.

Annexure :

MNRE's Approved Models of Community Size Cookstoves - Natural Draft/ Forced Draft

III. Community SizeCookstoves - Natural Draft				
1.	Shri Vikram S. Kale, Proprietor, Vikram Stoves & Fabricators. A-37, MIDC, P O Box No.25 Osmanabad-413501, Maharashtra Telefax : 02472 228401. (M) 09422465477,9922157777,9422465457 vikramskale@rediffmail.com www.vikramstoves.com	Vikram Jumbo Bio Super, top feeding	Thermal Efficiency : 28.10% CO : 1.15g/MJd TPM :123.67mg/MJd Power Output : 3.64 kW	
2.	Digvijay Sales & Engineering Works, IshkrupaVidyanagar, Parali Vaijinath-431515, Beed-431515(MS) Manufacuturing Unit: VimalUdyog B-110, Additional MIDC, Harangul, Latur-413512, Maharashtra (M) 9869254891 digvijaysalesengworks@rediffmail.com	Digvijay Community Chulha Top feeding	Thermal Efficiency : 30.28% CO : 1.73g/MJd TPM :168.85mg/MJd Power Output : 4.209 kW	
IV. Community Size Cookstoves - Forced Draft				
1.	Shri Ashwin Patel, DirectorAlpha Renewable Energy Pvt. Ltd.At. & Po. Vasna (Borsad), Ta. Borsad, Dist. Anand, Gujarat, India-388 540 Tele:02696-290380; (M):09904184849 info@alphaindia.co.in, ap@wallguard.net	XXXL Plus Stove	Thermal Efficiency : 35.52% CO : 1.97g/MJd TPM : 78.93mg/MJd Power Output : 3.78 kW	
2.	Shri Sashidhara B T, Proprietor Sacks Right Energy InnovationsNo.83/84, Kempegowda Circle 14th A Cross, Thigalarapalya Main Road, Peenya 2nd Stage, Bangalore - 560 058 (M): 9900241276,9886425879 Email: wedesignforyou2000@gmail.com Sin_e@yahoo.co.in	Ojas - M06 (Fuel-Pellets)	Thermal Efficiency : 35.11% CO : 1.05 g/MJd TPM : 69.01 mg/MJd Power output : 5.43 kW	

3.	Mr. Sandeep Kashyap, M/s. Navitas Green Power(Fuel Management) Pvt. Ltd. Udyog Vihar, Gurgaon Ph- 0124-4987400 124-4987499(Fax) Mb: 9910402185 Email- sandeep.kashyap@sar-group.com	Navshakti Cookstoves, Model: NSTF10 (Fuel -Pellet)	Thermal Efficiency : 42.80% CO : 1.03g/MJd TPM : 68.45mg/MJd Power Output : 12.2 kW	
		Navshakti Continous Cookstove, Model No. NSCF10	Thermal efficiency : 35.42% CO : 1.34 g/MJd TPM : 123.28mg/MJd Power output : 11.46 kW	
4.	Teri, PMU Lab Jagdishpur, Amethi, U.P	IMPMETAL TERI SPFB_0514b	Thermal efficiency : 37.12% CO : 1.59 g/MJd TPM : 105.62mg/MJd Power output : 9.11 kW	
5.	M/s. Supernova Technologies Pvt. Ltd. Gujarat Tel: +91 2692 237037 sntgstove@yahoo.com , sntgujarat@gmail.com www.supernovawindsolar.com	Supernova-SGDCM	Thermal efficiency : 36.10% CO : 4.63 g/MJd TPM : 112.17mg/MJd Power output : 4.62 kW	
6.	M/s TERI , Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi-110003	IMPMETAL-TERI-SPFC-1114	Thermal efficiency :36.49 % CO : 1.71 g/MJd TPM : 133.65mg/MJd Power output : 3.36 kW	
		IMPMETAL-TERI-SPFM-0414N	Thermal efficiency :35.41 % CO : 1.889 g/MJd TPM : 116.63mg/MJd Power output : 4.256 kW	
7.	M/s Phoenix Udyog (P) Ltd., Nahan Road, Moginand, Kala-Amb-173030, Dist. Sirmour (Himachal Pradesh) Tel: 09816103575 Email: phoenix.hp@rbsgroup.in	TERI SPFB-0514C	Thermal efficiency :37.32 % CO : 0.830 g/MJd TPM : 92.38 mg/MJd Power output : 9.05 kW	
		TERI SPFM-0414E	Thermal efficiency :35.75 % CO : 2.22 g/MJd TPM : 138.73mg/MJd Power output : 4.26 kW	

Annexure – II

Design of Air Pollution Control System for Open Pyre Type Green Crematorium

Design of Air Pollution Control System for Open Pyre Type Green Crematorium

A short term and localized air pollution control system is proposed in terms of design of air pollution control system for green crematoria. Cremation is the combustion, vaporization and oxidation of dead body with wood/fuel to basic chemical compounds, such as gases, ashes and mineral fragments retaining the appearance of dry bone. Normally wood, kerosene and dung cake is used for subjecting the dead bodies to flame in these crematoria. The emissions from it contain various pollutants due to incomplete / intermittent and complete combustion of fuel as well as flesh during the process. These ranges from PM, VOCs, CO, NOx, SOx, heavy metals (cadmium, mercury, and lead), dioxins and furans. Their presence in large numbers in an urban area creates lots of air pollution in the surrounding areas. These emissions can represent significant acute (short term) and chronic (long-term) health hazards to nearby residents. These health effects include irritation of the skin, eyes, and mucous membranes, central nervous system depression, respiratory effects and cancer. In view of this, there is a need to reduce the emissions from these units through design of air pollution control system for green crematoria.

The burning takes about 8-10 hours in which the flesh and wood is burnt. About 250-300 kgs of wood is required per body. Particles and gases from the cremation sites can be carried over long distances by wind and then settle on ground or water and other receptors. The effects of this settling include: making lakes and streams acidic; changing the nutrient balance; depleting the nutrients in soil; damaging sensitive forests and farm crops; and affecting the diversity of ecosystems.

There are two main types of crematoria found in urban environment depending on the type of fuel:

- Open pyre crematoria using wood as fuel (found in abundant) and
- Crematoria using electricity /Natural gas as fuel.

Most of these types are not having any air pollution control systems attached to it. In developed countries these crematoria’s are fired by fuel and have primary/secondary combustion chambers for increasing the performance of combustion process. The air pollution control system is usually attached to these units. The emission control options for crematoria’s are can hence be categorized as by use of clean fuel, change in technology and application of air pollution control systems.

Electric Cremation vs The Traditional Funeral Pyre

Electric cremation commissioned as a part of the Ganga Action Plan. The basic idea was to serve the purpose of river friendly cremation. Electric cremation is comparatively less expensive. Relatives can take the mortal remains within a few hours of cremation. In electric cremation, wood is not burned and there are no gas emissions. It is no doubt an unconventional way of cremation but it helps in saving resources like wood (500-600 kg of firewood), kerosene (three litres of kerosene), some prefer desi ghee, and 300-400 cowdung cakes per dead body. It is the most economical option for funeral.

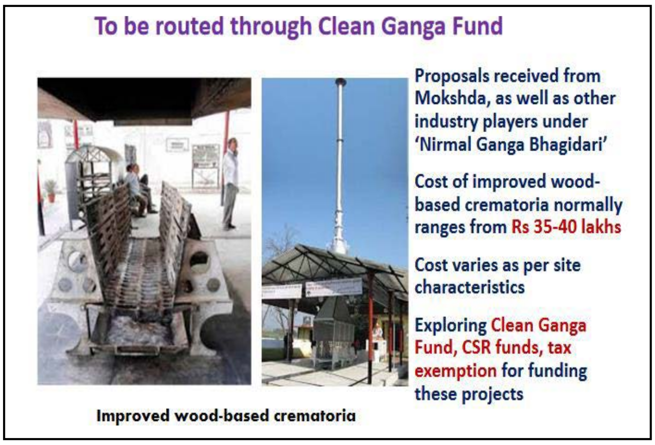
There has always been a controversy on the use of the electric crematoriums due to rituals as most persons follow the traditional burning of the bodies. In metropolitan cities it is promoted by the Government, private NGOs and environmentalists, but not to a great extent and most of these have failed due to finance and religious reasons.

According to a report, all the year round, around 50 to 60 million trees are burned during cremations in India. While burning the wood, there is also emission of million tonnes of carbon dioxide gas which is not good for the environment. Also, cremation in open grounds generates large amounts of ashes, which are later thrown into rivers and water bodies, especially the Ganga river, thereby polluting the water. These are all environmental threats caused by cremation.

However, electric cremation has not been popularised much in India, as Hindus still do not want to shed away their traditional belief. Orthodox families believe that a electric crematorium, which also is a covered crematorium, won't allow the soul to be released from the body and thereby it mingles with other souls and the concerned person will not be reincarnated again.

Green Cremation system

It is an alternate method of cremation in which the Hindus can also follow all their traditional rituals. It is affordable, energy efficient, and generates less water and air pollution, while all the religious needs of Hindus are taken into consideration. Cremation is done by cow dung are significance to the scarcity of wood. Although, other gases evolving due to cow dung need further study, particulate matter may drastically reduce.



In the Green Cremation system, a man sized metal grate is constructed beneath a roof and a chimney, and woods are placed on the metal base. The use of chimney enables better air circulation and reduces heat loss. It uses much lesser amount of wood (around 150-200 kg) to burn a body as compared to the wood (500-600 kg) used in the traditional funeral pyre. Also, it takes less time for the entire cremation, somewhere around 2 hours, as compared to 6-8 hours in the traditional cremation. While the emissions are reduced by 60%, the cost is also reduced significantly. Further the emission control system attached to the hood of the open pyre shed and dome constructed may help in reducing the emissions vis a vis ambient air quality around the cremation unit. Detailed diagram of emission control system for open type with side enclosed crematoria **(Figure 1)**.

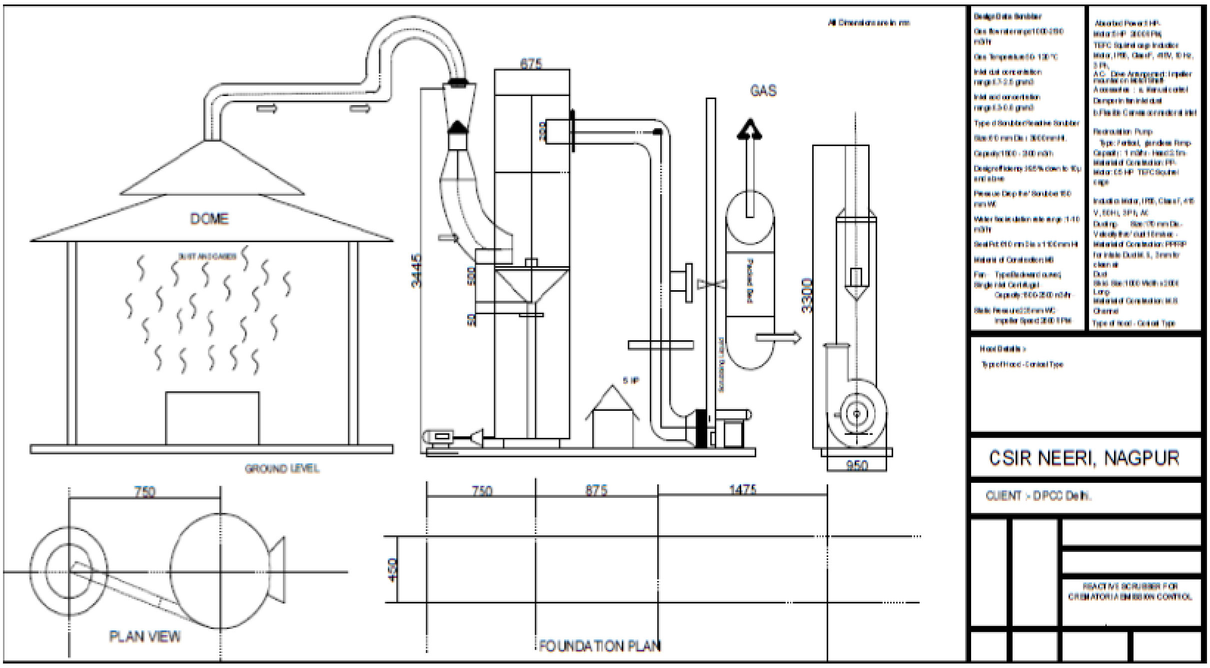


Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

Past Studies for Single Open Pyre Crematoria Emission Control at Nagpur, undertaken by CSIR-NEERI, Nagpur

Many technology including clean fuel, electricity etc were installed in various parts of country. However due to religious faith etc, these are not preferred. Hence the National Air Quality Standards for PM_{10} (100 ug/Nm^3) and other gases is not possible to comply without installation of adequate pollution control device. Regarding control option for such high emissions throughout the period, installation of bag filter is not advisable because of the high temperature of the flue gas, presence of smoke and volatile and larger space requirement for bag filter. The concept of wet scrubbing may be preferred for both dust and gases emission control. CSIR NEERI, Nagpur under in its 12th plan project on National Clean Air Mission has undertaken a demonstration study of emission control system at single chamber open pyre crematoria at Mokshadham, Nagpur Aug 2014. Under this study, various field evaluation were made for sizing and selection of emission control options like velocity and temperature profiling, emission and AAQ monitoring, feasibility and sizing/selection of hood, ducting and emission control system.

The performance of the reactive scrubbing emission control system of NEERI was tested to handle gases over a wide temperature range and inlet particulate concentrations (1500 to 2,000 mg/m^3) typical for crematoria offgas. Tests showed that the scrubbing process is very efficient and easily reduces these emissions to less than 350-400 mg/m^3. The ability to control solids loading in the scrubber liquid was also accomplished in this scrubber. The advantages of using this type of separation device are its compact size, low equipment cost, as it is constructed entirely of MS that can tolerate the corrosive nature of the scrubber solution. Tests done with a various oxidizing agents like with lime showed that the scrubber was able to remove nearly 70 percent of the particle matter along with acidic gases. The Velocity and temperature profile studies were undertaken around the cremation site during burning process as per **Figure 2**.

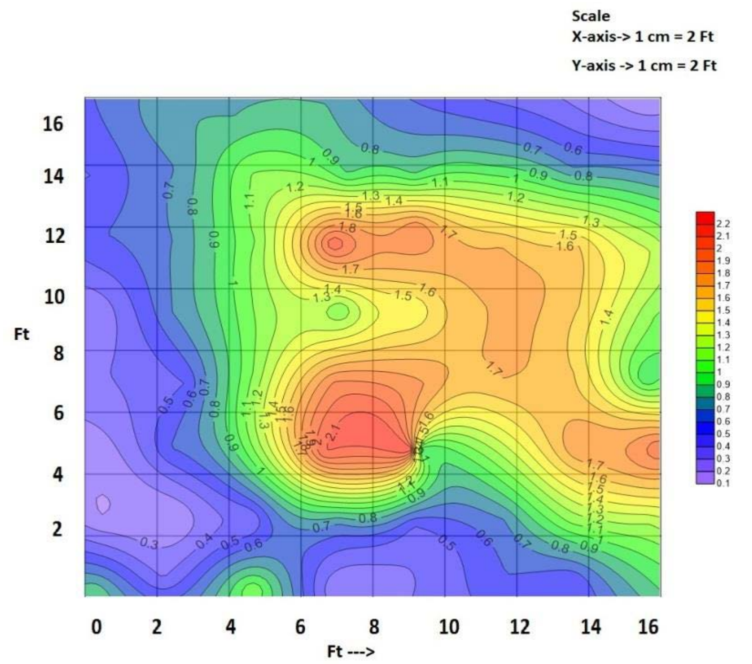


Figure 2 : Velocity profile of fumes during cremation

According to the velocity profile and temperature profile studies a hood and ducting was sized and installed at the shed of the single chamber open pyre crematoria and emission monitoring was undertaken to monitor various types of emissions during cremation of a dead body in a crematorium because of burning of wood, use of diesel, kerosene, cow-dung cakes and flesh burning. The hood is provided over the cremation in order to cover maximum area of dissipation of gases. Emissions like PM, CO, NOx, SO_2, NH_3, HC, etc. were monitored apart from flue gas hydraulic data. The emission load is estimated based on the input received from some crematoria and along with off gas flow, velocity and temperature profile, a hood and ducting followed by a reactive venturi scrubber is sized and installed as given in **Figure 3 and 4**.

These off gases are sucked at varying rates from and are further contacted with the liquid in the venturi scrubber to get maximum reduction by efficient gas /liquid contact **(Figure 5)**. Plain water and lime are used to study the performance. The suction capacity is adjusted depend on the emission rate from the burning, wind flow. The liquid to gases ratio are basis of maximum liquid droplet contact with the incoming gaseous pollutant. The dust and gas pollutant get absorbed into the liquid and collect into the receiver. Recycle of liquid are also provided with the help of pump to maximize use of slurry/water. The distribution of particle size tends to be heterogeneous, ranging from some very large ash particles greater than 200 microns to fine dusts less than 75 microns. There may also be emissions of sub-micron metal salts (metal fume) and sub-micron particulate material formed from the condensing products of incomplete combustion. Visible smoke emissions are closely related to total particulate matter. Dark smoke is associated with sub-micron particles, formed from condensing products of incomplete combustion. Modern, secondary, combustion control cremator units should be able to absorb these species effectively into the solvent. In this study total particulates are monitored and their scrubbing efficiency was observed.

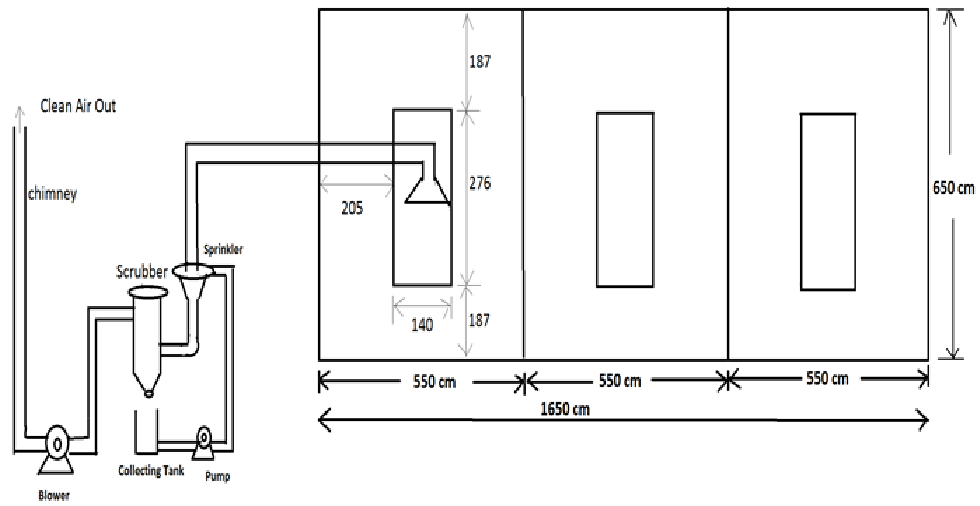


Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

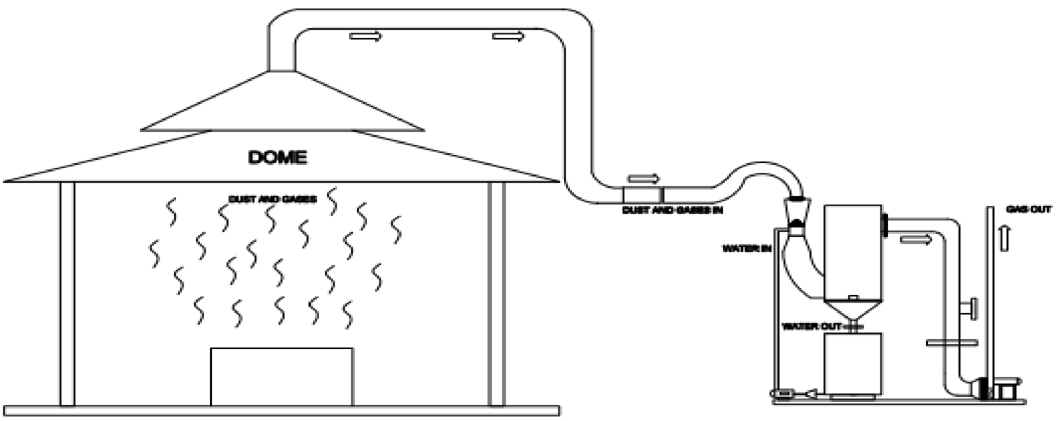


Figure 4 : Schematic view of Air Pollution Control System

The salient feature of Emission Control System installed in single chamber open pyre crematoria for demonstration as given in **Figure 1** is as follows:

- Hood size = 2500*2500*1000m height
- Ducting = 250 mm diameter 10m
- Scrubber Flow Rate = 8000m3/hr.
- Diameter of scrubber tank = 1200mm,
- Blower capacity = 7.5hp @1440rpm, variable speed
- Rotary air lock valve arrangement
- Water Pump capacity : 1 HP variable speed
- Material of Construction: mild steel of 4mm thickness
- The hood is supported by structural channel.
- Electrical 3 phase connection is required for 10 HP load
- Civil work for foundation of blower & Scrubber is required.
- Stack of 10 m height
- Capital Cost Approx. Rs. 8-10 Lakhs

Application of such emission control system in the single chamber Mokshada type crematoria at Mumbai may be done after the field evaluation studies of off gases emanating from such units.

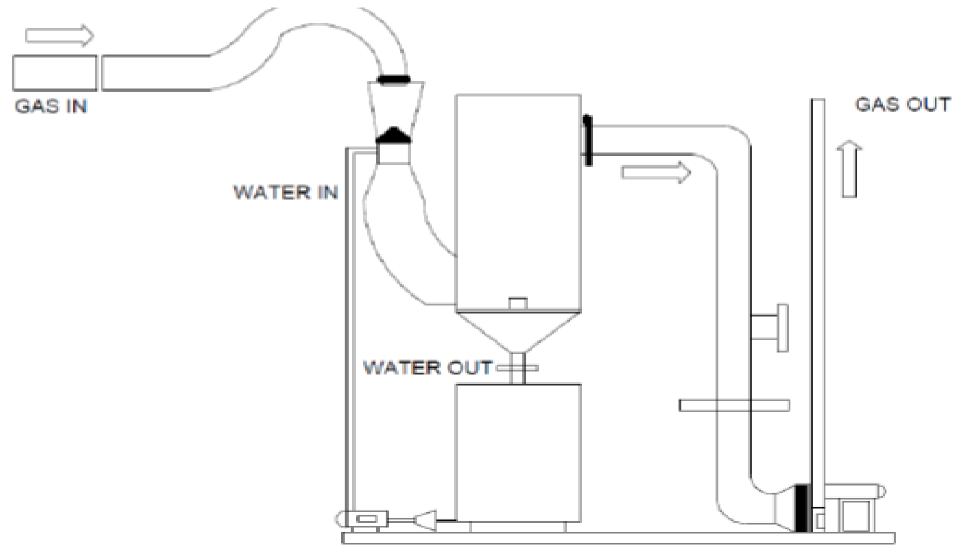


Figure 5 : Schematic of Reactive Scrubber

Gaseous Emission Control System

As crematoria flue gases contains higher percentage of organic, inorganic matter and particulate dust material which can be removed efficiently by Venturi Scrubber. Gases from the Venturi Scrubber outlet are further fed into a packet bed demister-cum-aerosol trap which serves dual purpose of removing water droplets as well as condensed fumes. This bed can be recycled at regular intervals of time. It can work on longer period though, if the flue gas contains less moisture. Cleaned gas escapes into the atmosphere from the last unit through an I.D. fan

Design of APC System Emission capture system

In order to capture the existing fugitive emissions from the open pyre systems. The rectangular and canopy hood needs to be used. The gases emitted from the platform, needs to be sucked at a sufficient height in order to accommodate the plume width at the height of the hood. Since the open pyre combustion is an intermittent emission source, it is necessary to establish the maximum or peak plume flow rate conditions that can be expected during the course of process operations.

The canopy hood volume is expressed by the following equation:

Hood Volume = T_d (Qp-Qs) Where,

T_d = duration of plume surge (s)

Qp= peak plume flow rate (m^3/s)

Qs= hood exhaust flow rate (m^3/s)

Equation used to find Dimensions. $Dc = 0.5 * X_c^{0.88}$

Where:

DC = column diameter at hood face.

XC = y +z = the distance from the hypothetical point source to the hood face, ft

Y = distance from the process surface to the hood face, ft

Z = distance from the process surface to the hypothetical point source, ft

$Z = (2 * D_S)^{1.138}$

Where:

DS = diameter of hot source, ft

Emission control system

The emission control system is proposed to be attached to the emission capture system. This reactive wet scrubbing system is used for emission control. The necessary liquid to gas ratio,

$Q_L/Q_G = [1.09(dd-0.0050/\mu g)]^{2/3}$

Q_L= liquid volumetric flow rate (m^3sec^{-1})

Q_G = gas volumetric flow rate (m^3sec^{-1})

d_d = droplet diameter, m

μg= gas viscosity, ($msec^{-1}$)

After scrubbing, the outlet gas contains few percentage of moisture which can be further eliminated by demister. Generally, Souder's equation as used for phase separator or for knocks out drums. That is,

Vd = k x [(L-G)/G]^0.5

L & G are liquid & gas densities.

Where k is the important part & is called the capacity design factor. It depends on type of de-mister pad. Selection of a too low or too high k is always having a negative impact in case of demisters as the efficiency greatly depends on velocities.

In case of lower velocities, droplets have low momentum to get path impingement & coalescence & therefore avoid capture into bigger drops & thus escape from the pad. At higher velocities the vapors have sufficient kinetic energy to re-entrain them. Therefore, correct range of k selection is necessary.

Based on past experiences & designs a value of k = 0.42 is most suitable for many applications. So after choosing k get the design velocity & then find out the diameter of separator.

Many of the Municipal Corporation is taking initiatives for shifting from traditional way of cremation to Green Crematoria. Ingenuity will be coming through public awareness and extensive efforts will require from all stake holders and NGOs for change in mindset.

Annexure – III

Design of Passive Gas Venting System for Landfill Sites

Design of Passive Gas Venting System for Landfill Sites

In developing countries, such as India, inventory estimation of methane (CH_4) emission from landfills has large uncertainties due to inadequate data availability on MSW management and emissions. During the cradle to grave process, MSW management process passes through various stages, such as sorting of recyclable and compostable materials before final disposal to landfills. These stages may change the quantity and properties of waste ultimately reaching the landfill sites, thereby influencing GHG emissions. Therefore, in-situ measurements of GHG emission fluxes from the landfill are important to reduce uncertainties in inventory estimates from this important GHG source. Many researchers have earlier reported about CH_4 emission estimates from MSW handling at national and city levels.

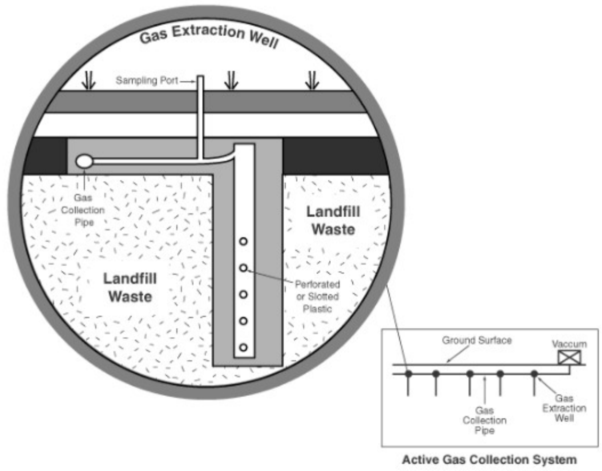
Most of the MSW generated is disposed of non-scientifically in open dumps, which causes a serious threat of landfill gas (LFG) emissions. The present note will focus on the landfill sites for the LFG emissions and designing the appropriate gas venting for the landfill sites.

Landfill Gas Collection System

Landfill gas can be collected by either a passive or an active collection system. A typical collection system, either passive or active, is composed of a series of gas collection wells placed throughout the landfill. The number and spacing of the wells depends on landfill specific characteristics, such as waste volume, density, depth, and area. As gas is generated in the landfill, the collection wells offer preferred pathways for gas migration. Most collection systems are designed with a degree of redundancy to ensure continued operation and protect against environmental hazards.

Active Gas Collection System

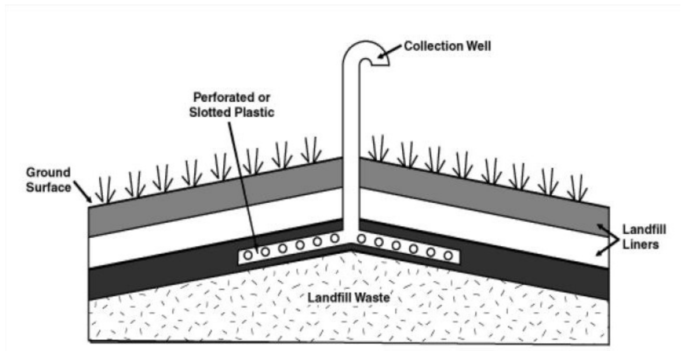
Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however, wells in the active system should have valves to regulate gas flow and to serve as a sampling port. Sampling allows the system operator to measure gas generation, composition, and pressure. Active gas collection systems include vacuums or pumps to move gas out of the landfill and piping that connects the collection wells to the vacuum. Vacuums or pumps pull gas from the landfill by creating low pressure within the gas collection wells. The low pressure in the wells creates a preferred migration pathway for the landfill gas. The size, type, and number of vacuums required in an active system to pull the gas from the landfill depend on the amount of gas being produced. With information about landfill gas generation, composition, and pressure, a landfill operator can assess gas production and distribution changes and modify the pumping system and collection well valves to most efficiently run an active gas collection system. The system design should account for future gas management needs, such as those associated with landfill expansion.



Active venting systems

Passive Gas Collection System

Passive gas collection systems use existing variations in landfill pressure and gas concentrations to vent landfill gas into the atmosphere or a control system. Passive collection systems can be installed during active operation of a landfill or after closure. Passive systems use collection wells, also referred to as extraction wells, to collect landfill gas. The collection wells are typically constructed of perforated or slotted plastic and are installed vertically throughout the landfill to depths ranging from 50% to 90% of the waste thickness. If groundwater is encountered within the waste, wells end at the



Passive Venting Systems

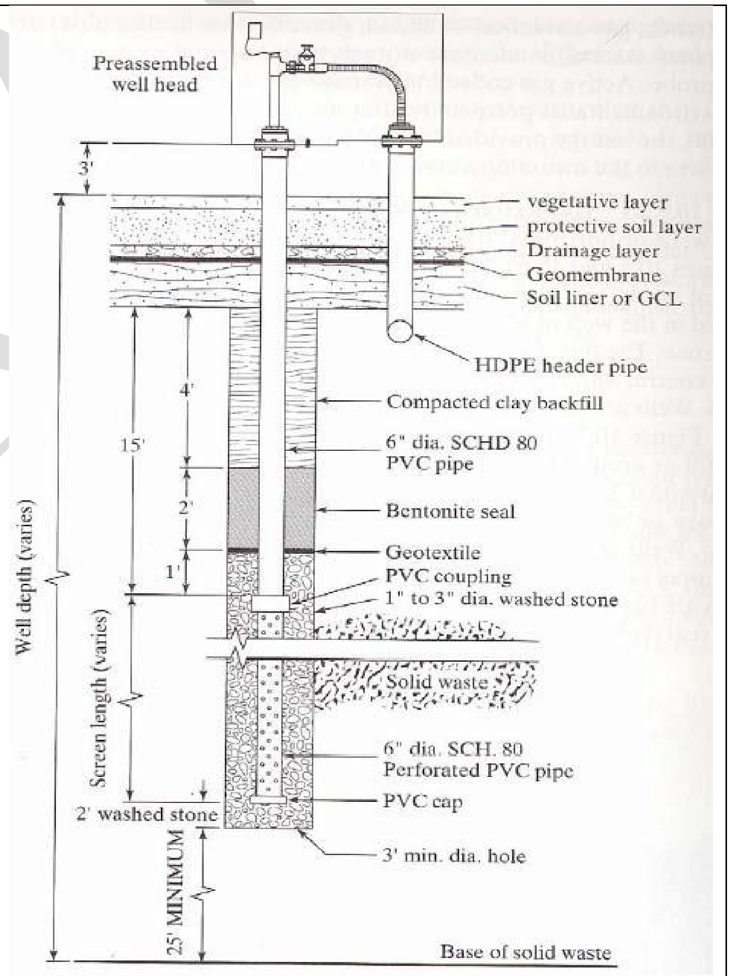
groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill as shown below. Horizontal wells may be appropriate for landfills that need to recover gas promptly (e. g., landfills with subsurface gas migration problems), for deep landfills, or for active landfills. Sometimes, the collection wells vent directly to the atmosphere. Often, the collection wells convey the gas to treatment or control systems (e.g., flares).

Criteria and Process Diagram of Passive Vents

Passive venting of low quality landfill gas or other CH_4 gas sources can be effectively controlled by the installation of passive venting systems. They consist of a horizontal network of slotted HDPE pipes connected together and fed to vertical venting columns. The columns are normally fitted with a rotating aspiromatic cowl to provide a small vacuum and increase the efficiency of the extraction. Other static type cowls are also available. The typical design of passive gas venting system is shown below :

The typical components of passive gas collection system are as follows:

- Vertical HDPE vent pipe
- Protective steel vent stack
- Rotating Aspiromatic cowl
- Static vent cowl
- ‘Chinaman’s Hat’ cowl
- Bird protection cage
- High strength embedment lugs
- Anti flash-back gauze
- Bentonite seal
- Horizontal HDPE slotted pipe
- Vertical HDPE slotted pipe
- HDPE tee
- HDPE couplers
- Stone filled trench
- HDPE capping membrane



Typical Design of Passive Vent System

Data Requirement and Design of Passive Vent System for Landfill Sites

✓ ***Data Requirement***

The data required to estimate LFG generation in a landfill includes the following:

- Design capacity of the landfill
- Quantity of waste in landfill or the annual waste acceptance rate the landfill
- Rate of decay of organic matter
- Efficiency of gas collection systems (if any)
- Duration of operation

LandGem model can be used as an estimation tool for quantifying LFG generation and recovery from landfill sites. The model requires historical data for landfill opening and closing years, waste disposal rate, average annual precipitation and collection efficiency.

✓ ***Proposed Design of Passive Gas Venting System***

Depending on the potential impacts of LFG and local regulatory criteria, gases are either dispersed into atmosphere or collected and treated. Before designing the gas venting system, following should be taken into consideration:

- Size and depth of landfill
- Nature of waste and potential of producing CH_4 and other gases
- Age of dumped waste
- Existing gas collection and monitoring system
- Hydro-geologic conditions surrounding the landfill

After evaluating the above points by collecting information from concerned authority and also through experimental studies, the appropriate design of passive venting will be proposed for the landfill sites of Mumbai.

Methods to Treat Landfill Gas

Some passive gas collection systems simply vent landfill gas to the atmosphere without any treatment before release. This may be appropriate if only a small quantity of gas is produced and no people live or work nearby. More commonly, however, the collected landfill gas is controlled and treated to reduce potential safety and health hazards. Common methods to treat landfill gas include combustion and non-combustion technologies, as well as odor control technologies.

Combustion Methods

Combustion is the most common technique for controlling and treating landfill gas. Combustion technologies such as flares, incinerators, boilers, gas turbines, and internal combustion engines thermally destroy the compounds in landfill gas. Over 98% destruction of organic compounds is typically achieved. Methane is converted to carbon dioxide, resulting in a large greenhouse gas impact reduction. Combustion or flaring is most efficient when the landfill gas contains at least 20% methane by volume. At this methane concentration, the landfill gas will readily form a combustible mixture with ambient air, so that only an ignition source is needed for operation. At landfills with less than 20% methane by volume, supplemental fuel (e. g., natural gas) is required to operate flares, greatly increasing operating costs. When combustion is used, two different types of flares can be chosen: open or enclosed flares. Some public concerns have been raised about whether the combustion of landfill gas may create toxic chemicals. Combustion can create acid gases such as SO_2 and NO_X. The generation of dioxins has also been questioned. Because of the potential imminent health threat from other components of landfill gas, landfill gas destruction in a properly designed and operated control device, such as a flare or energy recovery unit, is preferable to uncontrolled release of landfill gas.

Non-combustion Methods

Non-combustion technologies were developed in the year 1990 as an alternative to combustion, which produces compounds that contribute to smog, including nitrogen oxides, sulphur oxides, carbon monoxide, and particulate matter. Non-combustion technologies fall into two groups: energy recovery technologies and gas-to-product conversion technologies. Regardless of which non-combustion technology is used, the landfill gas must first undergo pre-treatment to remove impurities such as water, NMOCs, and carbon dioxide. Numerous pre-treatment methods are available to address the impurities of concern for a specific landfill. After pre-treatment, the purified landfill gas is treated by non-combustion technology options.

It is feasible to go for comprehensive primary data collection at all the landfill sites in Mumbai to develop a more realistic venting systems required to be installed at landfill sites.

Annexure – IV

Dust Control Measures

Dust Control Measures

The environmental impacts of dust emissions can cause widespread public concern about environmental degradation and/or a decline in amenity. The nature and extent of the problem and significance of the effects usually depend on the nature of the source, sensitivity of the receiving environment and on individual perceptions. For example, the level of tolerance to dust deposition can vary enormously between individuals. However, individual responses can also be affected by the perceived value of the activity producing the dust. For example, people living in rural areas may have a high level of tolerance for the dust produced by activities such as ploughing or top-dressing, but a much lower tolerance level for dust from unsealed roads.

Many forms of dust are considered to be biologically inert, and hence the primary effects on people relate to our sense of aesthetics. Dust directly causes eye irritation, lung disorders, health issues etc. Dust may also contain toxic metals like mercury and lead which can be carcinogenic in nature. Dust could settle on the window glass, ledges, flowers, fruits and vegetables, leaves etc. thereby reducing the aesthetic value. In New South Wales maintenance of dust deposited houses were estimated about ranging from $500–$1000 with an average value of $90 per annum. This really affects the property value. Dust also affects the visibility, thereby affecting the air quality level. Dust can also affect the growth of plants through:

- Reducing photosynthesis due to reduced light penetration through the leaves. This can cause reduced growth rates and plant vigour. It can be especially important for horticultural crops, through reductions in fruit setting, fruit size and sugar levels.
- Increased incidence of plant pests and diseases. Dust deposits can act as a medium for the growth of fungal diseases. In addition, it appears that sucking and chewing insects are not affected by dust deposits to any great extent, whereas their natural predators are affected.
- Reduced effectiveness of pesticide sprays due to reduced penetration.
- Rejection and downgrading of produce

Dust Control Agents

Water is one of the most primitive agents which are used as dist control measure. But it is less effective as compare with other chemical agents. Foam based system are also used to reduce dust. Lastly, one can reduce dust emission by reducing the production. Variety of chemical dust suppressant is available to suppress fugitive dust emissions. But they are being more expensive that of water. Comparing to water, they are more effective in suppressing dust and are applied much less frequently. Examples of dust suppressants include the following:

- liquid polymer emulsions
- agglomerating chemicals (e.g., lignosulfonates, polyacrylamides);
- cementitious products (e.g., lime-based products, calcium sulphate);
- petroleum based products (e.g., petroleum emulsions); and
- chloride salts (e.g., calcium chloride and magnesium chloride).

While the application of water and chemical dust suppressants are proven and effective options for mitigating dust, they have to be applied judiciously. Their usage, while mitigating dust, can trigger hazardous environmental consequences. It is important to keep these environmental consequences in mind when deciding on the extent to which water and chemical dust suppressants are to be utilized.

Selecting dust control agents

When selecting materials for dust control consider these basic requirements:

- environmentally compatible
- easily applied with common road
- maintenance equipment
- workable and responsive to maintenance
- reasonably effective at controlling dust
- not degrading to ride quality
- relatively harmless to vehicles using road
- posing little hazard or inconvenience to adjacent residents
- cost competitive

The most common dust control agents are chlorides, asphalt products, and lignin. Calcium- Magnesium Acetate (CMA) and $MgCl_2$ has been proposed as dust binder and its application on paved roads in Sweden, Austria, Germany and UK in order to mitigate road dust emissions *(Norman and Johansson, 2006; Barratt et al., 2012)*. These previous studies showed that in most cases a reduction of kerbside PM_{10} concentrations was reached. The effectiveness of CMA in binding deposited particles seems to be closely related to the degree of road moisture *(Gustafsson et al., 2010)*. This is a crucial aspect, mostly when evaluating the potential effectiveness in South European environments, where the higher solar radiation might further reduce the life-time of the air quality benefit. $MgCl_2$ has been also proposed and tested in Norway as a possible dust suppressant due its high hygroscopic and deliquescent properties. CMA and $MgCl_2$ were used in combination in a South European city, characterized by a relatively dry climate. In this scenario, emissions of road dust were estimated to reduce PM_{10} and $PM_{2.5}$ background levels by 16-17% and 6-8% respectively, as annual average between 2003-2009. Road cleaning activities (using $MgCl_2$) have been recently tested in one of the commercial district of Barcelona, resulting in a daily reduction of PM_{10} measured at traffic site by 7-10% and larger decrease for specific tracers of mineral and brake dust. Application rate for CMA and $MgCl_2$ has been given in **Table 1**.

Table 1: Application rates of dust control chemicals

Chemicals	Applications	Where to used	Reference
$MgCl_2$	20 g/m^2	Barcelona, Spain	Querol (2013)
	30% solution at 0 .5 gal./sq. yd.	Madison, Wisconsin, US	Wisconsin Transportation (1997)
CMA	20 g/m^2	Barcelona, Spain	Querol (2013)
	10 g/m^2	Klagenfurt, Austria	Gustafsson (2012)

Methods of Application

Dust control agent can be applied through vehicles and sprinkling on the road side (**Figure 1**). Also while transferring the materials (either via trains or trucks), they should be covered with tarapaulin. At the same time, dust control agent must be sprayed to reduce the emission of dust. This should be the responsibility of the owner rather than transportation agencies.

Figure 1 : Road side sprinkling of dust control agents

Covered vehicles must be used for transportation of coal and materials. One could use covered vehicles like dumpers for transportation of materials **(Figure 2)**. This would aid in reduction of fugitive dusts

Figure 2 : Covered transportation vehicles

Other references

- Gustafsson, M. (2012). PM10 reduction by the application of liquid Calcium-Magnesium Acetate (CMA) in the Austrian and Italian cities Klagenfurt, Bruneck and Lienz, presented at *Redust seminar*, *Helsinki*.
- Normana, M., Johanssona, C. 2006. Studies of some measures to reduce road dust emissions from paved roads in Scandinavia, Atmospheric Environment 40, 6154–6164.
- Querol, X. (2013). Methods used in Barcelona to evaluate the effectiveness of CMA and $MgCl_2$ in reducing road dust emissions, AIRUSE, LIFE11 ENV/ES/584.
- Wisconsin Transportation Bulletin. (1997). Dust Control on Unpaved Roads. Annexure

In order to achieve the maximum effect in terms of dust control and to reduce the environmental and other impacts; CSIR -NEERI has developed dust suppressant. It has been validated through laboratory studies and field trials under Indian conditions and scenarios.

Specifications/ Application

- CSIR - NEERI's dust suppressant need to be mixed with water with proportionate amount (10 - 15% depending on source of pollution; i.e., for road side dust 10% is enough while for coal mines, 15% is preferred).
- Application rate is 2 litre per unit area
- It is white (solid) and can be used as mist as well
- This chemical is based on hygroscopic salts like Magnesium Chloride and Calcium carbonate along with bio additive (name undisclosed, under stage of patenting).

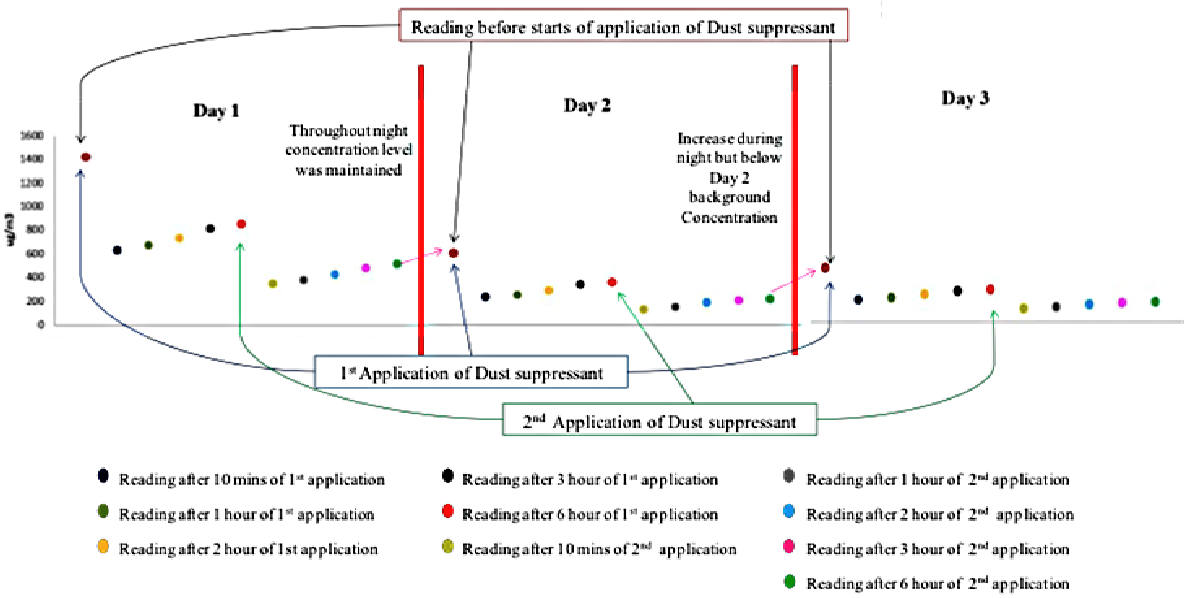
Advantages

- It is prepared, tested and applied as per Indian climatic conditions
- Treated water can be used for this purpose
- It is 40 to 60 times more effective than water
- While comparing with other dust suppressant, NEERI's suppressant showed better results
- No harmful byproduct is produced (tested and field trials conducted)

It has been tested by Enviro Policy Research India Pvt Ltd (EPRI) at three different construction site of Delhi.

Application of Dust Suppressant using Tanker at Delhi

The Effectiveness of Dust Suppressant: It showed 60 – 65% reduction from base concentration.



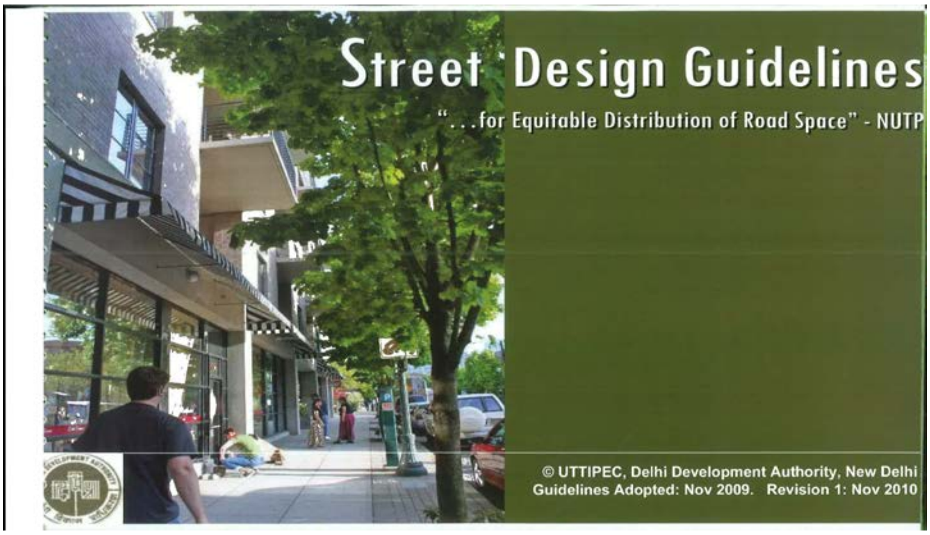
Bioswale : System for Storm Water and Dust Suppression Road Side

A biological filtration canal is a shallow depression created in the earth to accept and convey storm water runoff. A biological filtration canal uses natural means, including herbaceous vegetation and soil, to treat storm water by filtering out contaminants being conveyed in the water. Canals require shallow slopes that drain well, and function best under light to moderate runoff conditions.

Purpose: Storm water treatment and management, road side pollutant removal (SPM, suspended solids, nitrogen, phosphorus) by vegetation uptake, vegetation slows flow down and encourages sedimentation, cleans water and air by biota consumption, encourages infiltration into the subsurface zone, which reduces flow volume. Optimum design of channel dimensions, longitudinal slope, type of vegetation, and use of check dams will improve pollutant removal rates.

Building construction/demolition codes need to be used with specific reference to PM control. **UTTIPEC design manual has been recently created by Delhi Development authority for uniform roadside, drains, footpath and related design.** The same should be adopted for all future design for roads and pathways. Road construction/repair uses wood for melting tar, this technology needs to be abolished as over a large period of time, emissions are high.

Water spraying on the tires of trucks at the entry/exit point through construction of water pit. Appropriate barricading of the under construction site to avoid dispersion of the dust and particulate matter in the ambient air.



The Construction and Demolition (C&D) Waste Management Rules, 2016 was notified vide G.S.R. 317(E) 29th March, 2016 by the Ministry of Environment, Forest and Climate Change (MoEF&CC). building materials, debris and rubble resulting from construction, re-modeling, repair and demolition of any civil structure which delineated specific guidelines for waste generator, Service Provider and their Contractors, Local Authority, State Pollution Control Board or Pollution Control Committee, State Government or Union Territory Administration, Central Pollution Control Board and Criteria for Site Selection for Storage and Processing or Recycling Facilities for Construction and demolition Waste.

A) National Clean Air Programme (NCAP)

A time-bound national level strategy, National Clean Air Programme, was launched by Government to tackle increasing air pollution. The NCAP is envisaged to be dynamic and will continue to evolve based on the additional scientific and technical information as they emerge. Some of the measure and technologies developed for control of air pollution under NCAP are as follows.

Dust management

- Road dust and dust arising from construction and demolition are the major contributors to the pollution in Indian cities. City specific Plans need to evaluate the options of mechanical sweeping, greening and landscaping of the major arterial roads, identification of major impact roads including national high ways etc. Spraying of water twice per day (before peak hours of traffic) is very effective in reducing air borne dust load. Grassing of open spaces with native grasses also prevent dust pollution and clean air.

The mechanical sweepers were introduced in Delhi as manual sweeping by brooms blow more dust particles in air than it cleans off the ground. There is no proper mechanism or standard operating procedure (SOP) on how to dump the dust collected so that they don't return to the city after disposal.

- The Government has notified Construction & Demolition Waste Management Rules, 2016 which had been an initiative towards effectively tackling the issues of pollution and waste management. Basis of these Rules is to recover, recycle and reuse the waste generated through construction and demolition. Segregating construction and demolition waste and depositing it to the collection centres for processing is now be the responsibility of every waste generator. Local bodies are to utilize 10-20% material from construction and demolition waste in municipal and government contracts.
- It was noted that there was no regulation prescribing preventive measures to be taken for management of dust including road dust and C&D dust that arises during construction. Taking note of increasing air pollution and to keep dust material under control in towns and cities, the Ministry of Environment, Forest and Climate Change has issued a Dust Mitigation notification in January 2018 under EPA, 1986; making mandatory dust mitigation measures in infrastructural projects and demolition activities in the country. This would help to keep dust under control to reduce air pollution in metros and cities. The notified rules inserted 11-point

measures in the existing Act, empowering the ministry to issue notices against local authorities and state agencies for non-implementation of those actions.

Way Forward

- Introducing mechanical sweepers on the basis of feasibility study in cities;
- Evolve SOP for addressing the specific issue of disposal of collected dust from mechanical sweeping, taking into consideration all the above cited factors;
- Stringent implementation of C&D Rules, 2016 and Dust Mitigation notification, 2018 of Government of India;
- Wall to wall paving of roads to be mandated.
- Control of dust from construction activities using enclosures, fogging machines, and barriers- stringent implementation.
- Greening and landscaping of all the major arterial roads and national highways after identification of major polluting stretches.
- Maintenance and repair of roads on priority.
- Sewage Treatment Plant (STP) treated water sprinkling system having PVC (Polyvinyl Chloride) pipe line along the roads and at intersecting road junctions and spraying of water twice a day before peak traffic hours.

B) Dust Mitigation Notification by MoEFCC

Ministry of Environment, Forest and Climate Change vide notification dated January 25, 2018 has amended the Environment (Protection) Rules, 1986. Vide this amendment in Schedule-I –New serial number '106' has been inserted which relates to Mandatory Implementation of Dust Mitigation Measures for Construction and Demolition Activities for projects requiring Environmental Clearance:

- No building or infrastructure project requiring Environmental Clearance shall be implemented without approved Environmental Management Plan inclusive of dust mitigation measures.
- Roads leading to or at construction sites must be paved and blacktopped (i.e. metallic roads).
- No excavation of soil shall be carried out without adequate dust mitigation measures in place.
- No loose soil or sand or Construction & Demolition Waste or any other construction material that causes dust shall be left uncovered.
- Wind-breaker of appropriate height i.e. 1/3rd of the building height and maximum up to 10 meters shall be provided.
- Water sprinkling system shall be put in place.
- Dust mitigation measures shall be displayed prominently at the construction site for easy public viewing.

New serial number '107' has been inserted which relates to Mandatory Implementation of Dust Mitigation Measures for all Construction and Demolition Activities:

- Grinding and cutting of building materials in open area shall be prohibited.
- Construction material and waste should be stored only within earmarked area and road side storage of construction material and waste shall be prohibited.

- No uncovered vehicles carrying construction material and waste shall be permitted.
- Construction and Demolition Waste processing and disposal site shall be identified and required dust mitigation measures be notified at the site.

The serial numbers 106 and 107 above shall apply to cities and towns where value of particulate matter 10/ particulate matter 2.5 exceeds the prescribed limits in National Ambient Air Quality Standards

Use of Ready Mix Concrete

The Ready Mix Concrete (RMC) industry in India is still in its early stages with cement consumption of just 8-9 per cent of total production. This is evident from the fact that in the West, the RMC consumes 60 per cent of total cement production. However, over a period of time the demand for RMC is expected to grow exponentially. Godrej is a part of the Ready Mix Concrete Manufacturers Association (RMCMA) and actively participates in preparing guidelines for helping penetrate the use of RMC through forums and discussions. Use of RMC leads to time and cost efficiency since the construction does not need additional space to store the concrete. Since only the right amount of concrete mix is delivered hence it results in no wastage and reduces dust, dirt emissions. Godrej supplies range of ready mix concrete and sold under the brand name of TUFF. This mainly includes products like Enviro TUFF eco-friendly concrete, Recycled concrete blocks, Solid recycled concrete, Poro TUFF pervious concrete. These blocks are mainly made from industrial byproducts.

Autoclaved Aerated Blocks have also been introduced in Indian Market. These are manufactured by using fly ash mixed with cement, lime, water and an aeration agent placed in an autoclaved chamber. Godrej has introduced Autoclaved Aerated Blocks under the brand name of TUFF blocks AAC. As per the company’s claim, TUFFBLOCKS AAC decreases over 50% greenhouse radiation & integrated energy and utilizes at least 70% environmental waste.

Annexure – V

Wind Augmentation and purifYing Unit (WAYU)

‘Wind Augmentation and purifYing Unit (WAYU)’

The air quality at traffic intersections is one of the worst as vehicles typically undergo long idling, acceleration and deceleration there. This increases the quantity of air pollutants emitted by the vehicles at intersection. A numerical emission model run by Margarida et al. (2005) estimate an increase of 34%, 105% and 131% in NO, HC and CO emissions, respectively due to traffic signals at vehicular intersections.

India has experienced substantial increases in vehicle miles traveled (VMT) in recent years. The increased traffic has resulted in increased pollutant emissions and the deterioration of environmental quality and human health in several major cities in India. Pollutant concentrations near major intersections and roadways in the city are exceeding the Indian national ambient air quality standards (NAAQS). Thus, users (motorists, pedestrians, residents, etc.) in these corridors are exposed to unhealthy pollution levels. Exposure to vehicular air pollution directly affects respiratory, nervous and cardiovascular systems of humans, resulting in impaired pulmonary functions, sickness, and even death.

People standing stagnantly at a position, or moving slowly than usual average walking speed is more exposed than people passing by, because the time spent in a polluted microclimatic environment is much more, which increases the cumulative exposure to pollutants. As pedestrians pass by several types of human activities present on or beside sidewalks, they are affected by the pollution emitted by those activities. The breathing rate becomes factual in calculation the dose from exposure, and adds to the cumulative intake of air pollutants.

IIT Bombay, National Environmental Engineering Research Institute (NEERI) and Maharashtra Pollution Control Board (MPCB) have come together to address the issue of air pollution at traffic junctions. A device known as ‘Wind Augmentation and purifYing Unit (WAYU)’ to improve the air quality at urban intersections has been developed and integrated in a way that it can work with solar power. This device works basically on two principles:

- Wind generation for dilution of air pollutants
- Active Pollutants removal

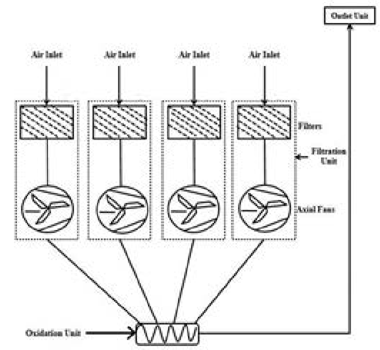
Air pollution is a local problem and its solution can be derived from technologies coupled with local conditions and requirements. Creating change in meteorological parameters like wind with the help of devices such as fans and also removal of the pollutant near to the source may help in reducing ambient air pollutant concentrations. Creating turbulence in the air with the help of turbo machines will disperse and dilute the pollutants. Trapping the pollutants with the help of suction units installed near to the source and purifying it will also have a sizable amount of impact. This can be done where the population density is high which is typically found in India near the traffic junctions.

The device uses low speed wind generators, appropriate size filters for long operation cycle with reasonable efficiency. It also has an oxidizer unit for removal of Carbon-monoxide and Hydrocarbons including VOCs. The air is passed through the filters where the particulates are removed. The air generators without filter can help in augmenting wind turbulence in near zone so that dilution takes place (like in nature).

In the next level where active pollutants are removed, filters and thermal system are used. The air is heated inside the specially designed with appropriate surface and retention time, within the thermal oxidisers where the carbon monoxide, hydrocarbons, VOCs get converted to carbon dioxide. At the outlet of the device, the discharged air has some exit velocity. This velocity of air creates air mixing and turbulence in the atmosphere which thereby helps bringing down the pollutant concentrations by the method of dispersion.

The WAYU device has a potential to lower the ambient concentrations of PM and VOCs by 50-70%.The effectiveness and influence zone of the WAYU device can be affected by the prevailing wind conditions. During the various experiments conducted was conducted inside closed boxes of various sizes, it was observed that the pollutant concentrations decreased rapidly by 90-95% within 15 minutes. The device can be powered with the help of solar power very efficiently. In this way the device becomes self-sustainable in its operation.

The primary treatment consists of filters of 10 microns and which is followed by oxidation systems. The oxidation systems consist of specially designed UV- TiO_2 adsorption, photo catalytic oxidation technology. In brief this technology can be explained as follows. Small particles of titanium dioxide (TiO_2) act to catalyze oxidation of adsorbed molecules in the presence of above-bandgap ultraviolet light (UV, wavelengths smaller than 390 nanometers). The particle size is usually in the range of 5 to 50 nm. The absorption of UV light produces electron-hole pairs in the titanium dioxide particles. The hole reaches the particle′s surface to react with hydroxyl (OH-) ions from adsorbed surface water and form highly reactive hydroxyl radicals. These radicals form when an OH- group loses its electron during an encounter with a hole. They are electrically neutral but highly reactive chemically. Airborne pollutant molecules can be adsorbed on the TiO_2 particle surface, at which time they react with adsorbed hydroxyl radicals. Ideally, reaction products remain on the surface until they are fully oxidized. The process just described represents the essence of catalytic photo-oxidation, but it should be understood that variations on this theme are encountered.



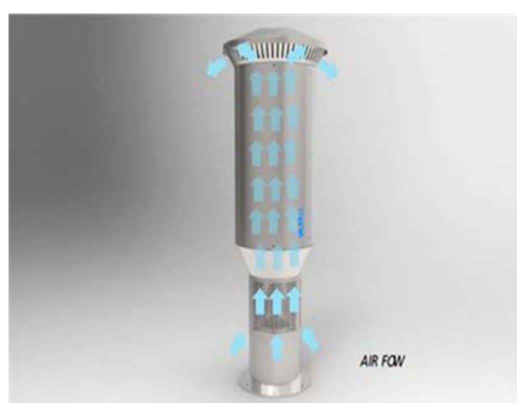
UV- TiO2 adsorption-photocatalytic oxidation has a lot of advantages. They are very efficient in removal of VOCs. Pichat et al. (2000) have shown that ozone can be directly eliminated by TiO_2 nanoparticles in a process that is promoted by both heat (in the ambient temperature range of 0° to 50°C) and by UV light. The catalytic activity of present-day TiO_2 anatase nanoparticle materials is sufficient to remove some VOCs from the air. Both the components of smog (ozone and particulate matter) are the result of emission of VOCs that can potentially be reduced by the active photocatalytic oxidation technology under consideration.

The unique design of the arrangement of the various components of the UV-TiO_2 activated carbon gives WAYU the edge for performing complete oxidation and satisfactory reduction in VOC concentrations.

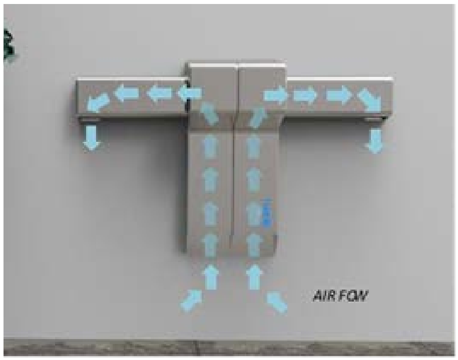
WAYU is a device jointly developed by IIT-CSIR-NEERI focused on controlling pollution in ambient air. WAYU has been successfully tested in a pilot project of 25 devices in Mumbai in collaboration with Maharashtra Pollution Control Board (MPCB). With an aim to solve the ever rising menace of air pollution in the national capital and other parts of India, CSIR-NEERI believes WAYU would be a vital cog in the armory to combat this menace.

Different Models

WAYU comes in various shapes and sizes. Various designs have been incorporated to suit according to different scenarios. These include improved design for traffic junctions, Bus shelters, traffic roundabouts, wall mounted models for flyover pillars, pedestrian pathways. In the scenario of Flyover pillars play a vital role. So a

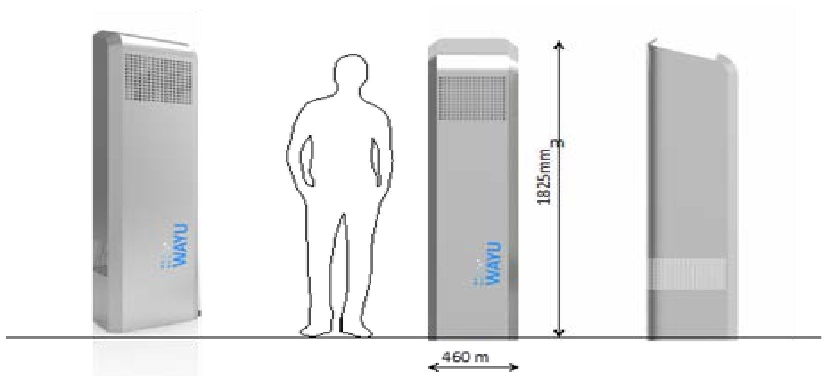


WAYU device improved design



Wall mounted/ Flyover Design

design which could be wall mounted was ideated. The design basically consists of a blower fan at the main extrution where the air is sucked at the bottom of the extrution and thrown to the right or left of the outlet which consists of linear activated carbon trays. These trays could be easily accessed from the front and could be changed once in a month. Here there are two UV tube lights which are basically of one feet and has been placed vertically in particular intervals to attain maximum level of treatment. The air is sucked from the bottom at 625mm height and the purified air is pushed out at 1825mm.The modularity of this concept leads to a futuristic look with stainless steel as its material used. Here the form could be easily manufactured because of its minimal bending profiles.



Bus shelter design

The design initiation started with the scenario of pedestrian was there is a constant flux of people moving around the environment. The design was finalized at a space that is closer to the road & the pedestrian paths were the Unit would be placed. The standalone device is of approximate 1825mm. The overall design is made in a very similar minimal approach with small continues chamfers which could be manufactured easily with stainless steel and laser cut technologies. There are three two- feet UV tube lights, which is been attached to the phases of the unit.

Traffic Roundabouts design

At Bus shelters stand-alone modules should be vital phase. Since each bus shelter has different design of the shelter we arrived at a very minimal half T -Section stand-alone module which could be fixed and two or one end of the bus stop. The air is sucked form a particular height and released from the top as shown in Figure 18.The overall dimensions were optimized for the easy accessibility of activated carbon filters and UV Tube light. This is a purifier, which could a public installation. The roundabouts are spaces where the vehicle – people ratio is very high. The design added in new features like an additional solar panel, which could make the standalone device run itself.

A polygon was taken in consideration, the octagon was chosen initially for the design as the bottom inlet could capture all the polluted particles and left out as clean air through the top. An extruded octagon was considered which could gradually reduce at the bottom too look like a tree. The inner details of this purifier are mainly three phases as the air purifier which is prototyped with cassettes at each sides. These trays would be filled with activated carbon and there is four feet tube lights at the center. The polluted air is sucked from the bottom and released at the top. This is a self-sustainable standalone device which requires no Power.

Why WAYU?

WAYU has the following advantages:

- Relatively cheaper than most devices in market for similar purpose
- Low power consumption facilitating the use of solar power
- Easy operation and maintenance
- Removes gaseous pollutants along with particulate matter unlike most of the devices which focus only on particulate matter
- Can be easily modified to suit any scenario and volume of air
- A range of designs in its portfolio makes it an attractive option for solving air pollution in spaces of all kinds
- An indigenously developed technology that propels MAKE IN INDIA initiative

Though commercial data for similar devices are not available, it is quite confidently estimated that the cost of per unit of WAYU is one of the cheapest devices for ambient air pollution control. The basic advantages besides the ones listed above include simplicity in construction and operation. The ability to couple with different energy sources such as solar make WAYU commercially a very viable option. With thoroughly tested technology WAYU is one of the most robust air purifiers that can be installed in both indoor and outdoor spaces. Aesthetically designed WAYU blends into the ambient environment and thus is not an eye-sore unlike other devices.