Draft Report On

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

(AURANGABAD CITY)

for

Maharashtra pollution Control Board

By

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Indian Institute of Technology Bombay

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CSIR- National Environmental Engineering Research Institute

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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

A source Apportionment (SA) study has been carried out in recent past under MoEF&CC and CPCB. Under this study all the protocols and methodologies have been well established and explained by which these studies have been undertaken. The Central Government launched National Clean Air Programme (NCAP) as a long-term, time-bound, national level strategy to tackle the air pollution problem across the country in a comprehensive manner with targets to achieve 20% to 30% reduction in Particulate Matter concentrations by 2024 keeping 2017 as the base year for the comparison of concentration. Under NCAP, 122 non-attainment cities have been identified across the country based on the Air Quality data from 2014-2018.

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

1.3 General Description of City

Aurangabad is a city in the Indian state of Maharashtra. It is the administrative headquarters of Aurangabad district and is the largest city in the Marathwada region. The city is located on a hilly upland terrain in the Deccan Traps. Historically, there were 52 Gates in Aurangabad, some of them extant, because of which Aurangabad is nicknamed as the "City of Gates". The city, originally known as Khadki, was founded by Malik Ambar (Anbar) in 1610. After the fall of the Nizam Shahi dynasty in 1633, the city came under Mughal rule. It was later renamed Aurangabad after it became the headquarters of Aurangzeb during his vice royalty over the Deccan. With the dissolution of the princely state in 1948, Aurangabad was included in Hyderabad state in newly independent India. It later became part of Bombay State (1956-60) before that state was divided into Maharashtra and Gujarat. Aurangabad District is located mainly in the Godavari River Basin and partly in the Tapi River Basin. The district is from 19 to 20 degrees north latitude and 74 to 76 degrees east longitude. Aurangabad city is situated on the bank of river Kham a tributary of the Godavari River. It is located 512 meters above Sea Level. The city is surrounded by hills of the Vindhya Ranges and the river Kham passes through it. The city is a tourism hub which is surrounded by many historical monuments including Bibi Ka Maqbara and Panchakki. Ajanta Caves and Ellora Caves are also a world tourist spot which are UNESCO World Heritage Sites. The Aurangabad City Map is depicted in **Figure 1.1.**

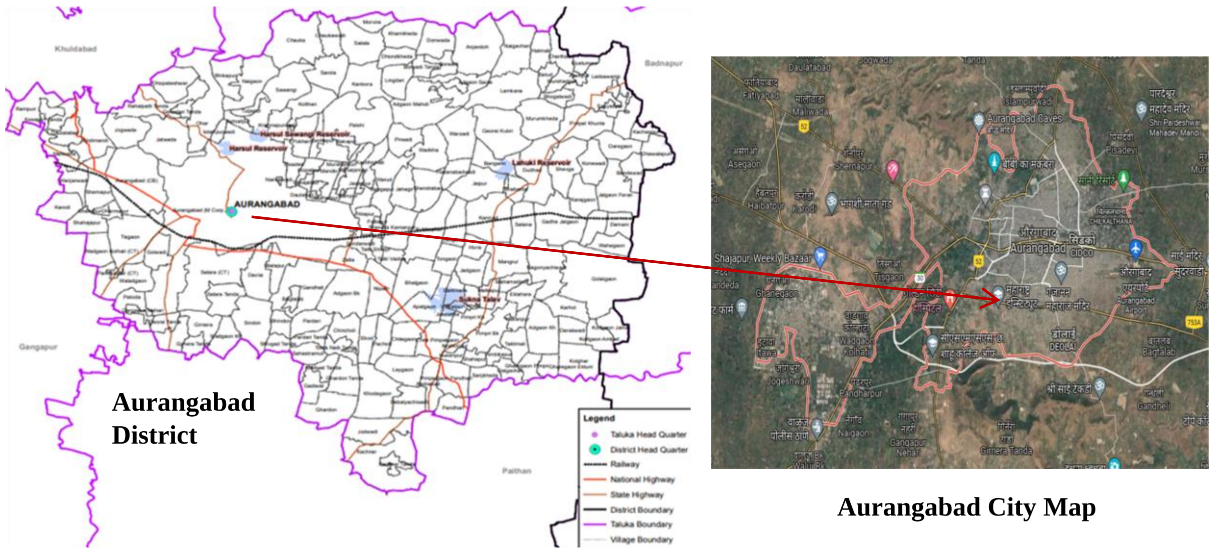
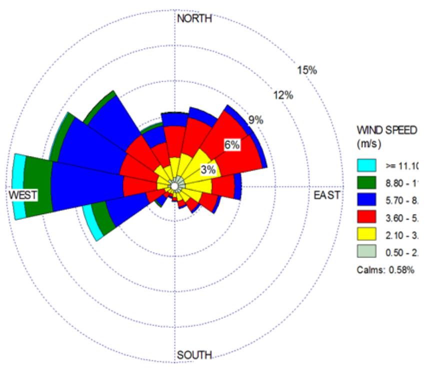


Figure 1.1 : Location of Study Area –Aurangabad City Map

1.4 Climate and Meteorology

The city is surrounded by hills on all directions. Aurangabad features a semiarid climate under the Koppen climate classification. The annual mean temperature ranges from 17 to 33°C, with the most comfortable time to visit in the winter i.e. from October to February. The highest temperature recorded was 46 °C (114 °F) on 25 May 1905. The lowest recorded temperature was 2°C (36 °F) on 2 February 1911. The climate of the district is characterised by a hot summer and general dryness throughout the year except during the south-west monsoon season. The year may be divided into four seasons. The cold season is from December to February and is followed by the summer season from March to May. The south west monsoon season is from June to September while October and November constitute the post-monsoon season.



In the cold season, the district is sometimes affected by cold waves in association with the eastward passage of western disturbances across north India, when the minimum temperature may drop down to about 2°C to 4°C. Most of the rainfall occurs in the monsoon season from June to September. Average annual rainfall is 710 mm. In general, the amount of rainfall increases as one proceeds from west to east. About 83 per cent of the total annual rainfall is received during the south-west monsoon season. July is the rainiest month of the year. Some rainfall occurs during May, October and November and is mainly in the form of thunder showers. The city is often cloudy during the monsoon season and the cloud cover may remain together for days. The daily maximum temperature in the city often drops to around 22°C due to the cloud cover and heavy rains.

1.5 Demographic Structure of the City

According to the 2011 Indian Census, Aurangabad has a population of 11,75,116 of which 6,09,206 are males and 5,65,910 are females. Population in the age range of 0 to 6 years is 1,58,779. The total number of literates in Aurangabad was 8,89,224 which constituted 75.67% of the population with male literacy of 79.34% and female literacy of 71.72%. The effective literacy rate of Aurangabad was 87.5%, of which male literacy rate was 92.2% and female literacy rate was 82.5%. There were 2,36,659 households in Aurangabad in 2011 **(Table 1.1)**. According to 2011 Census, the sex ratio in the district is recorded as 923. This is lower compared to the State average 929 *(Source: Primary Census of Aurangabad District, Maharashtra state, 2011)*. Aurangabad Municipal Corporation (AMC) is the local civic body. It is divided into six zones. The Municipal Council was established in 1936, the Municipal Council area was about 54.5 km^2. It was elevated to the status of Municipal Corporation including eighteen peripheral villages, making the total area under its jurisdiction to 138.5 km^2 extended its limits. The city is divided in 115 electoral wards called as Prabhag.

Table 1.1: Summary of Demographic Structure in Study Area

Demographic Parameters	Aurangabad Municipal Corporation
State/District	Maharashtra/Aurangabad
No. of Wards/Prabhags	115
Total No. of Households	2,36,659
Total Population	11,75,116
Sex Ratio (Females/1000 males)	923

1.6 Transportation

Aurangabad has central MSRTC bus stand for public transport centre. Buses are available to every major bus depots of Maharashtra. The city has one more additional bus stand name as CIDCO bus stand. This is constructed for serving load of old bus stand. Ola Cabs service is available in city. Aurangabad railway station is the major railway station under Nanded Railway division of the South Central Railway zone. It is located on the Secundarabad -Manmad section. The city has rail connectivity with major cities such as Hyderabad, Delhi, Nizamabad, Nagpur, Nasik, Pune, Nanded and Latur Road. This railway line runs on diesel locomotive engines. Aurangabad Airport (Chikhalthana Airport) is an airport serving the city and has connecting flights to all major cities of the country.

1.7 Industrial Growth

Maharashtra is one of the advanced States in the country and Aurangabad is one of the developing Districts of the State. Now a day's Aurangabad attracts many industrialists for business start-ups. Many large-scale industries have been started in the since past 10 years like two-wheelers, Videocon, Colgate, Garware Plastics, Crompton and Pharmaceutical companies are functioning in the district. Other small-scale industries such as oil mill, ginning, dairy products, leather goods, wool weaving etc. are also working. Aurangabad District is famous for Himroo mashroo weaving industries. Paithan has been associated with fine silk Paithani sarees. These materials have encouraged the establishment of number of ginning factories and sugar factories in the district.

1.8 Trade and Commerce

Agriculture is the main economic activity of the district. The chief manufactured articles are sugar cane, wheat, cotton, tobacco, food grain, and chief exported commodities are medicines, polyester films, tyre, milk, animal skin, sugar, cotton bales, Jowar, auto parts, industrial goods, maize, Paithani sarees etc., are exported to all over India and overseas also. The chief imported commodities are wheat, rice, cloth, cotton and sugar cane etc. Most of these goods are imported from surrounding places. Apart from the weekly markets and fairs Aurangabad, Paithan, Vaijapur and Sillod are important trade centres also.

1.9 Need of the Study

Particulate Matter in recent has been considered one of the most crucial pollutants with regard to its impact on human health. PM with aerodynamic diameter less than 10 µm (PM_{10}) and finer particle fraction $PM_{2.5}$ has shown increase in mortality *(Dockery and Pope, 1994; Schwartz et al., 1996),* asthma *(Anderson et al., 1992)* and visibility degradation *(Kim et al., 2006)*. On a global scale, Particulate matter (PM) emissions reach 3400 million tonnes/yr *(IPCC, 1996)*.

Anthropogenic sources account for only 10% of total PM emissions, whereas the natural primary PM emissions reach 85% (2900 tonnes/yr). A comprehensive understanding of the issues stated requires the ability to determine accurately the sources of natural and anthropogenic aerosols and their precursors. On the other hand, local sources when emitting in a limited region with low assimilative capacity, can cause severe air pollution problems.

The present study examines the contribution of these 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 entirety for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc.

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

1.10 Objectives

- To measure baseline Ground Level Concentration (GLC) of air pollutants and air toxic levels in different parts of the city including background, residential, commercial/mixed area and source specific "hot spots" viz. Kerbsides, industrial zones, etc.
- To prepare inventory for the various air pollutants, their emission rates and pollutant loads from various sources along with spatial and temporal distribution in the city of Aurangabad.
- To conduct source apportionment studies for PM_{10} and $PM_{2.5}$ and prioritize the source categories for evolving cost-effective air pollution mitigation strategies/ plans.
- To assess the impact of sources on ambient air quality under different management/ interventions/ control options.
- Draw a roadmap of short term and long-term measures as considered appropriate and cost effective to ensure "Cleaner air in urban areas".

1.11 Scope of the Project

The overall project scope includes air quality monitoring, complete characterization of deposited dust (PM_{10}) and limited $PM_{2.5}$, emission inventory, receptor and dispersion modeling and sources apportionment. The major areas of work encompassed and completed under the study are as follows:

- Ambient Air Quality Monitoring
  - The ambient air quality monitoring was undertaken at four locations in Aurangabad.
  - Air monitoring stations were installed at locations such as kerbside, residential, industrial and background (away from all the sources).
  - The air pollutants studied in this study include PM_{10} and $PM_{2.5}$, Ions and elements.
  - Ambient air quality monitoring was carried out at about 3-10 meters height from the ground level.
- Emission Inventory
  - All relevant information/data on emission inventory which were available through secondary sources were collected. Primary surveys were carried out for identification and spatial distribution of sources and preparation of detailed emission inventory for zone of influence (2 Km x 2 Km area) around each ambient air quality monitoring location.
  - The zone of influence (2 Km x 2 Km) around each monitoring location was first surveyed for identification of source types/categories.
  - In this zone of influence around each ambient air quality monitoring station, following methodology was used for estimating emissions:
    - For industries, after proper identification of all significant categories/sectors, emission factors of USEPA, WHO, etc. as well as information available with Pollution Control Boards, industries & other sources were looked into and based on scientific judgment and suitable rationale, emission factors were used for emission load calculation. A summary of common emission factor was also circulated by CPCB which were used. However, some city specific sources project team's literature was used. Representative statistical sample of the sources were used to work out emission estimates.
    - For vehicular sources, vehicle count surveys were carried out for all different types of roads (highways, major roads and minor roads) with focus on zone of influence around each monitoring locations. At selected locations, traffic surveys were carried out. The purpose of vehicle count data collection was to estimate total emission from line sources within the city as well as in the zone of influence. Vehicle emission inventory shall also need to estimate vintage technology and average use pattern. Parking lot

surveys as well as petrol pump survey were carried out. With a view to established fuel used and average driving pattern of citizens.

- Estimation of area sources was arrived at by taking total area under each emission source category/type and emission estimates were determined based on scientific judgment and considering available information on emission factors and their normalization for Indian conditions based on secondary data information.
- Emission inventory estimates were developed for all sites (zone of influence with 2 Km x 2 Km area) and later for the whole city.

▪ Dispersion and Receptor Modelling approach has been with a view to establish the sources and understand the dynamic of air pollutants movement. A detailed and relatively reliable emission inventory is required by adopting common methodology for all the major sources within 2 Km x 2 Km zone. Sampling locations are focused for receptor and dispersion modeling predictions. However, at city level only dispersion modeling has been used.

- ISCST 3 has been used for dispersion modeling of PM and NOx. The overall city level emission inventory based on secondary data and the detailed micro-level emission inventory compiled by primary survey at monitored locations were used as input to the model. The model run accounted for both the inventories simultaneously. Iso-concentration plots were generated for the whole city.
- EPA PMF v5 has been used for receptor modeling. In this case, the monitored receptor chemical concentration data and source profiles (based on information available through other studies) are key inputs to the model.

Chapter 2

Ambient Air Quality

2.1 Air Quality Monitoring Network of MPCB at Aurangabad City

Ambient air quality data of Aurangabad city is gathered from MPCB monitoring network for four sites, which was monitored at SBES College, Collector Office and C.A.D.A. Office (Residential Sites) and one CAAQMS station at Industrial site. The data is available from 2006 to 2020 at daily average level **(Figure 2.1).** It can be seen that at all the three sites, annual average concentration was reported as 9, 29 and 82 μg/m^3 for SOx, NOx and RSPM respectively. The RSPM concentrations exceeding the annual 24 average standard of 80 μg/m^3. At Aurangabad city, recorded annual SOx concentrations less than 25 μg/m^3 and were relatively clean. In the year 2019-20, Aurangabad, recorded annual average NOx concentrations which were higher than the prescribed annual average limit of 40 μg/m^3. The city reported AQI as Good, Satisfactory and Moderate. More than 95% AQI observations were in satisfactory category at SBES college, C.A.D.A. office. At CAAQMS station the AQI was Satisfactory for more than 80% observations' while Moderate AQI was recorded for ~65 and 16% observations.

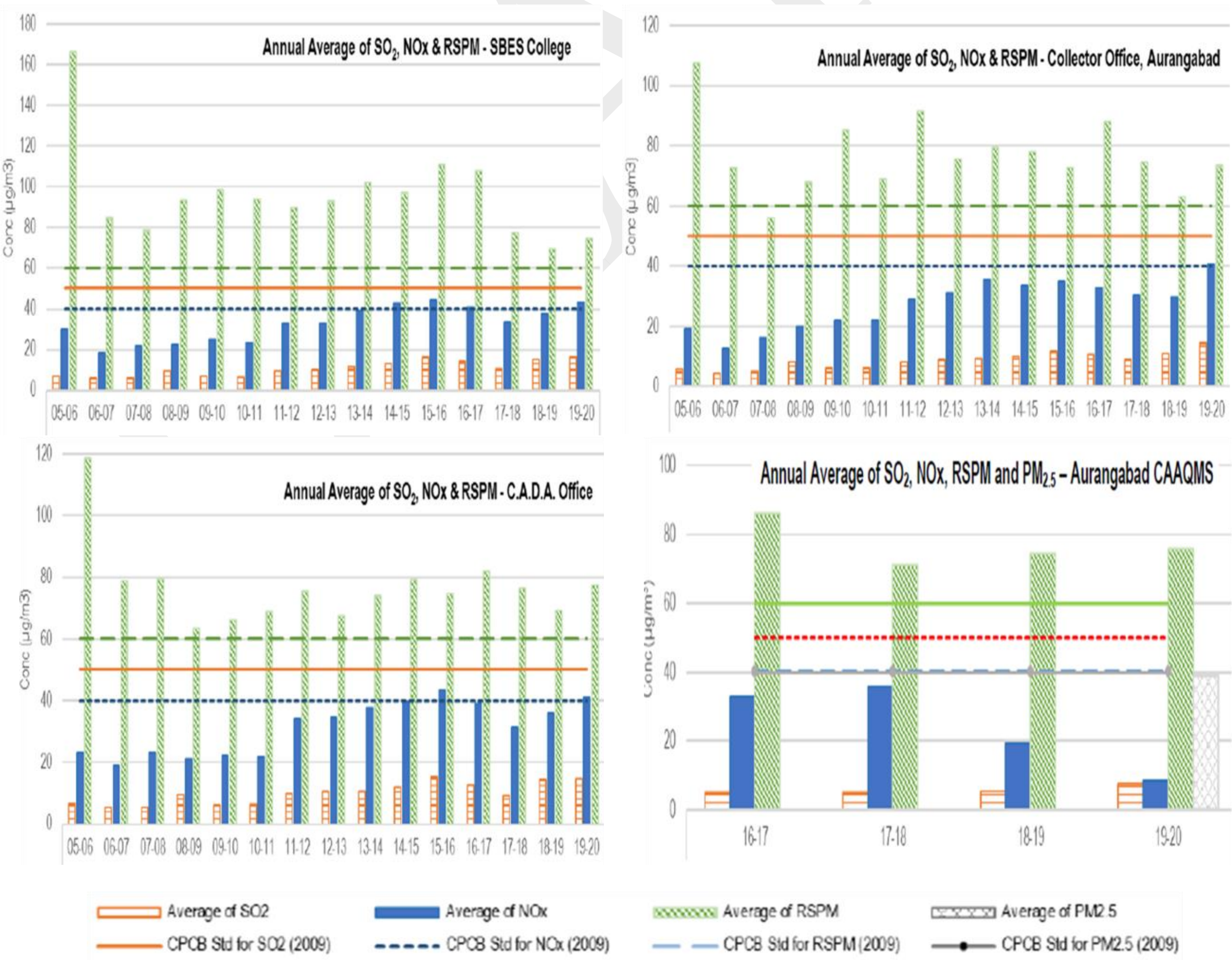
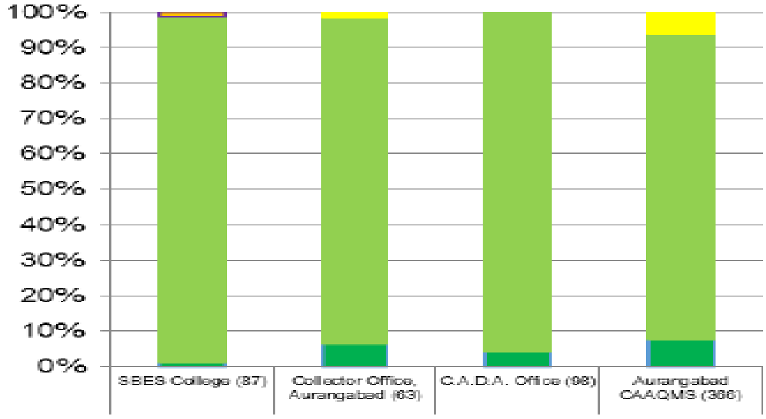


Figure 1.1 Average AAQ for Aurangabad City (MPCB Monitoring Network)



Percentage Occurrence for Classes of AQI - Aurangabad City 2019-20

2.2 Ambient Air Quality -Sampling During Summer 2019

The source apportionment of air pollutants warrants a comprehensive air quality monitoring. This was accomplished by carrying out air quality monitoring for 10 days continuously at all the four locations. In all the selected locations, levels of pollutants such as PM_{10} and $PM_{2.5}$ were recorded. Further, PM_{10} samples are analysed for EC/OC, ions and elements.

Design of air quality monitoring includes the factors such as population density, meteorology, topography, etc. During the study, proper guidelines were followed for the selection of the monitoring stations. Based on current wind pattern over the city, four sampling sites were selected as Control, Residential, Commercial & Kerb and Industrial. The locations of sampling sites are presented in **Table 2.1** and study area is depicted in **Figure 2.1**. An overall characteristic of the sites has been discussed below:

a) Dr. Babasaheb Ambedkar Marathwada University Campus (BAMU): It represents the "background site" for the study region and was located in the campus near to warden bungalow. It has hilly area to the south, slum and open barren land at the west side, to the north is army cantonment area and at the east side the main city area covered with commercial and residential areas. The site was located away from the internal university roads.

b) Garkheda: It represents the "residential site" and monitoring was carried out at Ulkanagari lane. Garkheda is the main residential area of the city and is well connected with the commercial and residential area. The main areas in this include Shivaji Nagar, Gajanan Nagar, Pundalik Nagar etc.

c) Padampura : It represents the "commercial site" and monitoring was carried out at the terrace of Kailash Veg Restaurant, Dr Bhapkar marg. This is the main commercial zone of the city. It is very near to Baba Petrol pump square of the city. To travel anywhere in the city one has to reach at Baba Petrol Pump Square. It is the connector point between industrial area, residential area and commercial area. All government offices are located in Padampura. There is continuous traffic flow in this area. The railway station is also located near to Padampura zone.

d) MPCB Office: It represents “industrial site” as is second largest MIDC area in Aurangabad city. The MIDC is named as Chikhalthana MIDC and is located to the west of the city. Maharashtra pollution Control Board office is located in this area. It is observed that there are total 117 air polluting industries in Aurangabad Industrial Clusters, out of which 24 air polluting industries in Chikhalthana MIDC. The roads in these areas are unpaved roads. The flow of heavy-duty vehicles is also high due to industrial sector located here.

Table 2.1: Details of Air Quality Monitoring Sites

Sampling Site	Type	Sampling Height (m)
BAMU	Control	3
Garkheda	Residential	3
Padampura	Commercial and Kerbsite	4
MPCB Office	Industrial	4

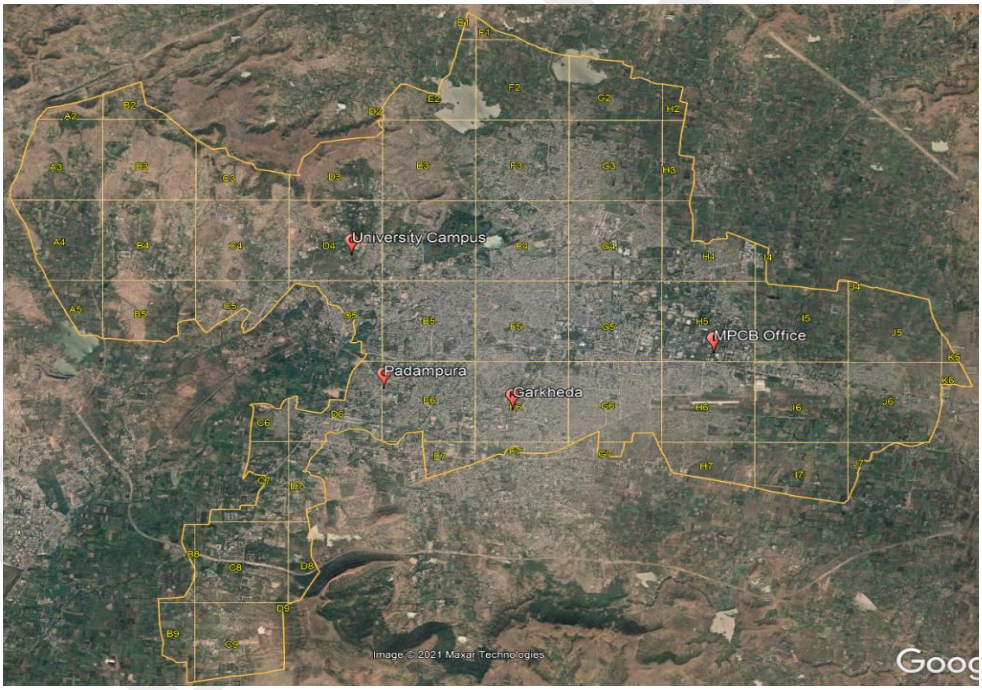


Figure 2.1: Study Domain and Sampling Sites at Aurangabad City

CPCB guidelines document for source apportionment through receptor modeling was followed. 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 on SA studies. The 24-hourly average concentrations of PM_{10} and $PM_{2.5}$ are presented **Figure 2.2** and ratio of $PM_{2.5}/PM_{10}$ is given in **Figure 2.3**.

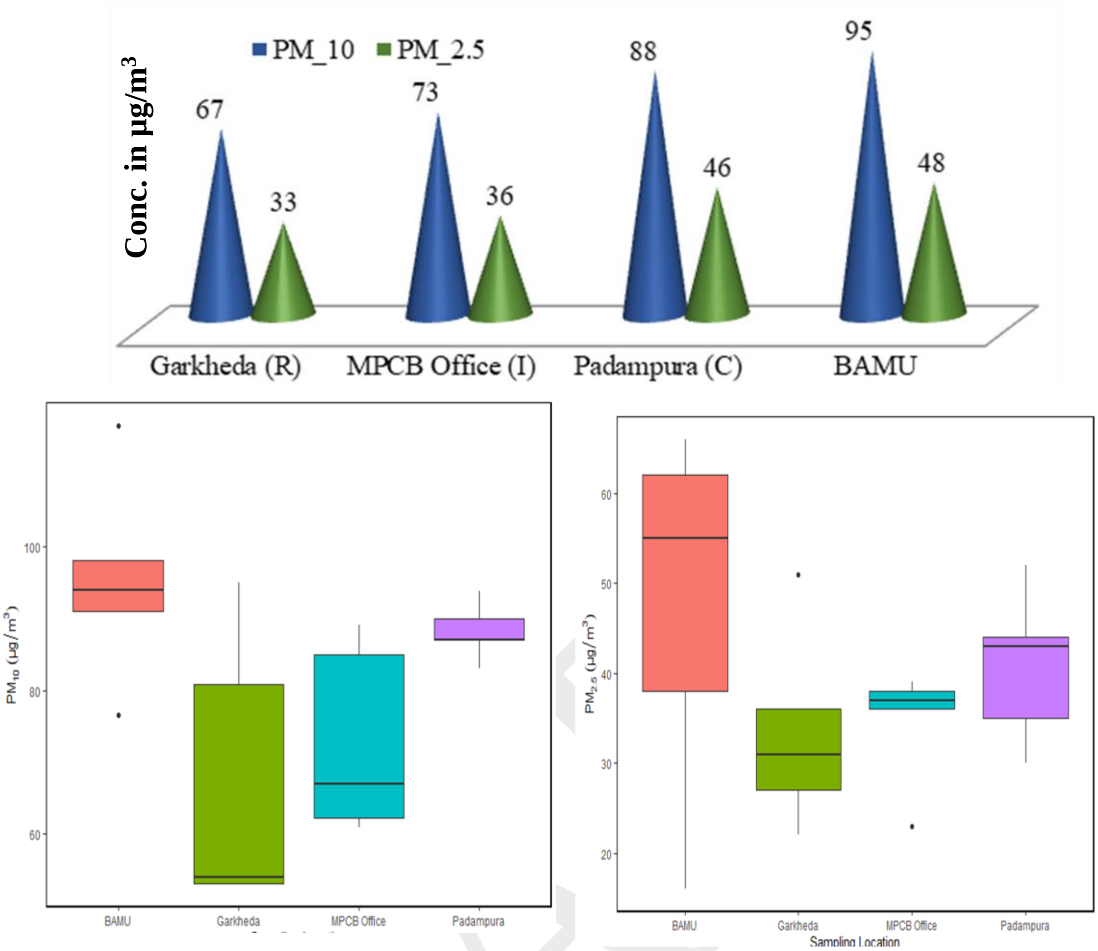


Figure 2.2 : Observed Concentrations of PM_{10} and $PM_{2.5}$ During Monitoring

The 24-hourly averages for particulate matter at all sites for PM_{10} are below the standard limit of 100 µg/m^3. The site named BAMU is background site were concentration for PM_{10} is found to be highest i.e. 98 µg/m^3. The second highest concentration is seen at the Padampura commercial zone. At the other two sites the concentration is seen to be 73 and 67 µg/m^3 respectively. The 24-hourly averages for particulate matter at all sites for $PM_{2.5}$ exceed the USEPA standard concentration of 35 µg/m^3. The concentration of $PM_{2.5}$ at BAMU, Padampura and MPCB office is seen to be 48, 46 and 36 µg/m^3 respectively.

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: point sources (stationary), area sources and line sources (on-road mobile sources). The emission inventories consist of actual and projected air emissions.

Due to violation of permissible limit of particulate matter standards, CPCB has listed Aurangabad city as one of the non-attainment cities. The number of non-attainment cities listed in India is 132. Out of which 18 cities are from Maharashtra. Emissions inventory is the first exercise, under that identification and quantification of various sources are necessary to link them with the existing air quality levels measured at certain locations as well as predict air quality for whole region. It helps in assessing the impact of additional nearly sources in and around the region and also to evaluate the control strategies for certain emission sources.

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. No emission inventory for Aurangabad district is available till today.

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 Aurangabad city of 2 Km x 2 Km **(Figure 3.1)**. To cover entire city under the grid, the domain of the city is marked as 22 x18 Kms. The inventory has been developed for PM_{10}, $PM_{2.5}$, NOx and SO_2. The high-resolution emission inventory developed for Aurangabad city will help in appropriate and timely implementation of the action plans.

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 resuspension, paved-unpaved roads and city activities survey has been carried out. CSIR-NEERI has conducted a detailed survey for Aurangabad 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.

Through secondary 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.

3.5 Role of GIS

GIS has made it possible to directly view the source emission. The grids plotted over Aurangabad city, makes it easier to identify the maximum emission load and the source responsible **(Figure 3.1).** The required information is feeded and the required maps are prepared. Maps for water bodies, railway network, and road network in Aurangabad 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.

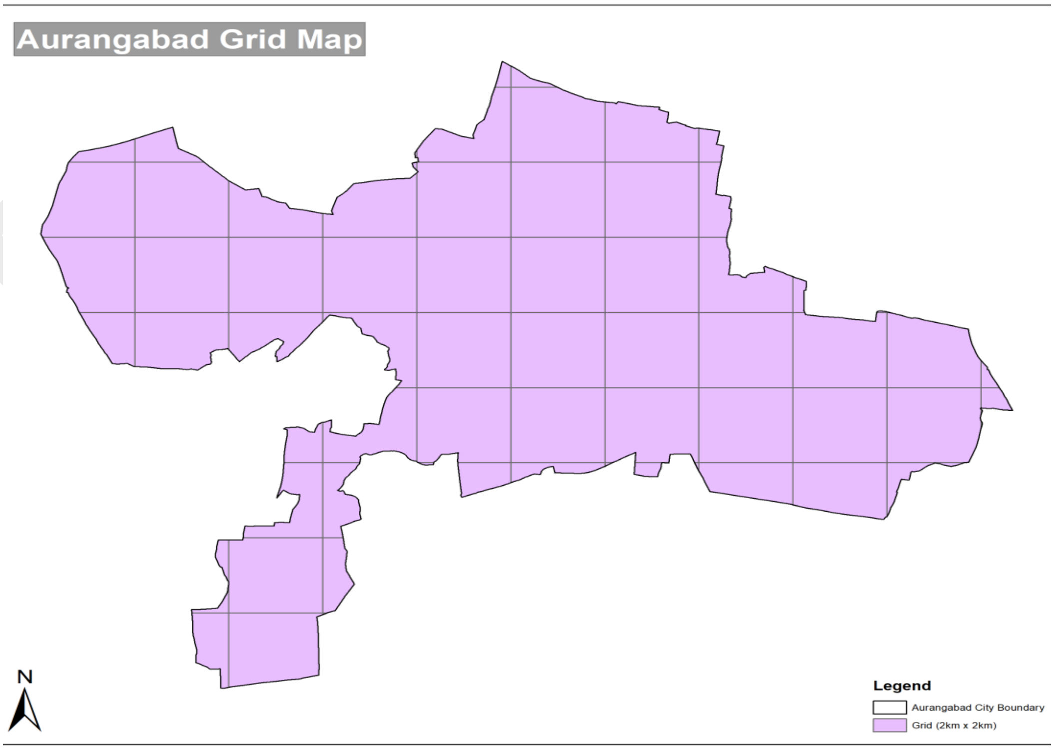


Figure 3.1 : Grid Map Aurangabad City

3.6 Emission Factor

An emission factor (EFs) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with the associated activity responsible for emission. Typically, EFs of a fuel depends on the chemical composition of fuel, combustion type, temperature and efficiency of any emission control device. There are very limited measured EFs available in literature for India. EF defines the source strength as emission per unit time and per unit activity of the process. Country specific technology based EFs for most of the sectors are not yet available for India. Hence, in the development of emission inventory, emission factors are selected from CPCB, ARAI, USEPA AP42 and old SA study reports prepared by CSIR-NEERI on SA study. EF used in the present work is collected with valid scientific judgments and acceptability by global community. The used EFs for the estimation of pollution load from different sources are discussed in respected sector. The emission estimation for pollution load is calculated by available emission factors. The required data is collected from surveys and secondary data in a unique format. A grid wise emission load in Kg/Day for the specific source is being generated.

3.7 Road Map Digitisation

Major Roadways : Aurangabad is well connected with roads connecting to major cities of Maharashtra and other states. National Highway 211 from Dhule to Solapur passes through the city. Aurangabad has road connectivity to Jalna, Pune, Ahmednagar, Nagpur, Beed, Mumbai and the route is currently being upgraded into four lane road of National Highway standard. A new Nagpur-Aurangabad- Mumbai Express highway is also being developed named as Samruddhi Mahamarg. The Maharashtra State Road Transport Corporation (MSRTC) and numerous other private bus operators provide bus service connecting the city to all parts of the state. The road network in the Aurangabad city is depicted in **Figure 3.2**.

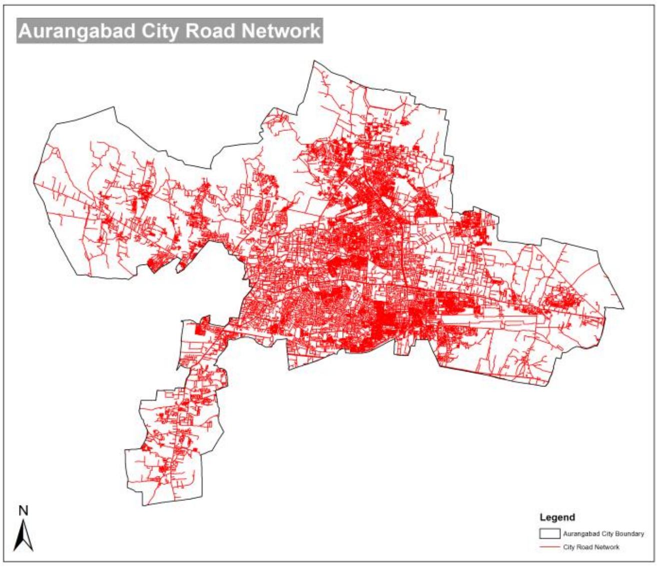


Figure 3.2 : Road Network in the Aurangabad City

3.7.1 On Road Vehicles (Emission Inventory)

The increase in the vehicular population resulted in rapid increase of vehicles in Aurangabad city. Aurangabad district has one Regional Transport Offices located at Aurangabad (MH20). Following vehicle categories are considered in the present study.

- Two wheelers
- Three Wheelers (includes petrol, diesel and CNG/LPG vehicles)
- Four Wheelers (includes all fuel types and vehicular categories)
- Light Commercial Vehicles (includes city buses, delivery vans, travellers, tempos etc)
- Heavy Commercial Vehicles (HCV), (includes trucks, heavy loaded buses, Trailors, multi axle carriers.

In order to arrive at the actual grid-wise vehicular emissions scenario, vehicular counts on major traffic corridors as well as within the city was planned. The road width and length were measured. The intensity of traffic on the routes was studied.

Major work elements included in the preparation of vehicular emission inventory were:

- Vehicle counts at representative major traffic junctions in different parts of Nashik.
- Estimation of VKT (Vehicle Kilometres Travelled) for different categories of vehicles **(Figure 3.3).**
- Selection of appropriate emission factors from the ARAI vehicle emission study.
- Preparation of emission inventory (grid-wise) and identification of major sources / hot spots in each grid.

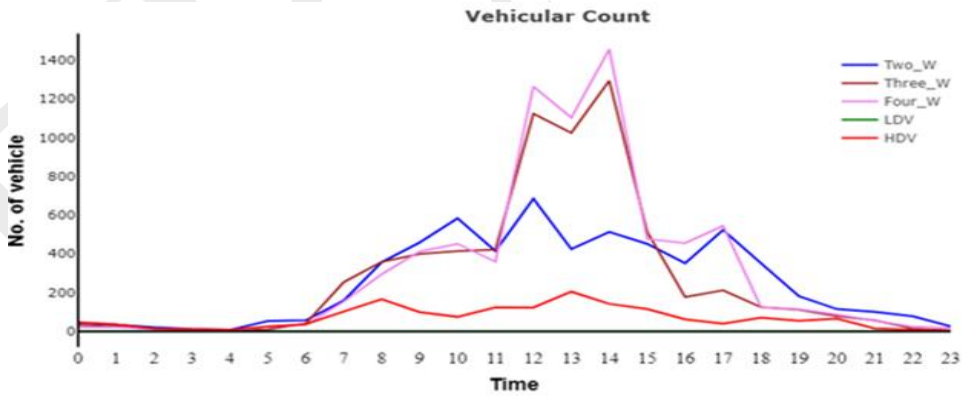


Figure 3.3 : Total Hourly Count of Vehicles in the City

Emissions from the on-road vehicles depend mainly on the type of vehicle and fuel used in the vehicle. Emission factors available from ARAI are used for vehicular emission load estimation **(Table 3.1)**. All Bharat Stage norms implemented in the state of Maharashtra are used for estimation. Emission load estimation by using information of the number of registered vehicles in district may lead to wrong conclusions. Therefore, on the basis of information collected in primary survey, the actual vehicle km travelled in particular grid has been analysed.

Table 3.1: Emission Factors Considered for Emissions Estimation

Emission Factor for BS-III Stage Engine					
Vehicular Type	PM	NOx	HC	CO	Unit
2 Wheeler	0.035	0.27	0.61	1.65	g/km
3W_Petrol	0.05	1.2	0.7	1.20	g/km
3W_Diesel	0.05	0.5	0.5	0.50	g/km
4W_Petrol	0.05	0.12	0.19	3.01	g/km
4W_Diesel	0.12	0.67	0.2	0.51	g/km
HDV	1.24	9.3	0.37	6.00	g/km

Emission Factor for BS-IV Stage Engine					
Vehicular Type	PM	NOx	HC	CO	Unit
2 Wheeler	0.1	0.1	0.13	1.81	g/km
3W_Petrol	0.035	0.5	0.3	0.75	g/km
3W_Diesel	0.035	0.5	0.3	0.75	g/km
4W_Petrol	0.08	0.1	0.1	1.00	g/km
4W_Diesel	0.08	0.1	0.1	1.00	g/km
HDV	0.06	0.39	0.42	0.74	g/km

Emission Factor for BS-VI Stage Engine					
Vehicular Type	PM	NOx	HC	CO	Unit
2 Wheeler	0.0045	0.09	0.068	0.5	g/km
3W_Petrol	0.025	0.1	0.10	0.22	g/km
3W_Diesel	0.0045	0.08	0.10	0.5	g/km
4W_Petrol	0.0045	0.06	0.10	1.00	g/km
4W_Diesel	0.0045	0.08	0.10	0.5	g/km
HDV	0.01	0.08	0.10	0.5	g/km

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. Hourly emission of different pollutants from different type of vehicle is given in **Figure 3.4**.

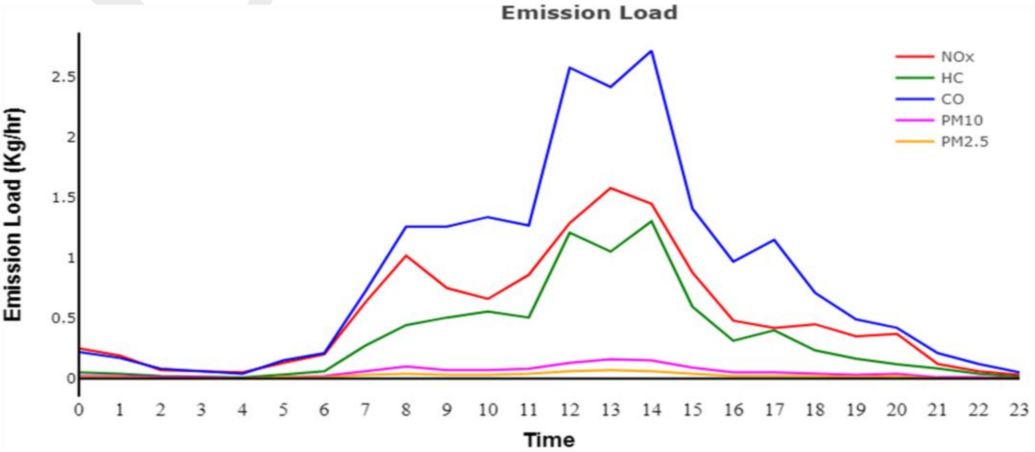
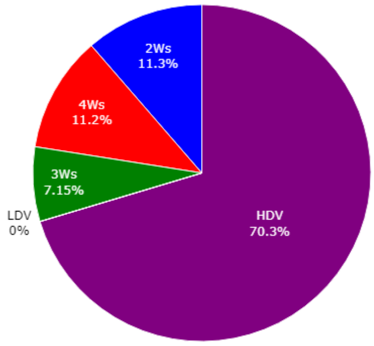


Figure 3.4: Hourly Emission Load (kg/hr) Due to Vehicular Traffic

The figure above represents the hourly emission load emitted from vehicular sector. The particulate matter emission load is at peak during morning 06:00 hrs to 09:00 hrs and during evening time of 18:00 hrs to 20:00 hrs. Values for NOx, HC and CO are also seen high during morning 06:00 hrs to 09:00 hrs, 12:00 hrs to 14:00 hrs and 17:00 hrs to 22:00 hrs. This is due to the heavy vehicular traffic running continuously in the night from highways in the district. The graph shows the total emission load from different vehicle category. 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 1.6, 0.7, 8.8, 6.2 and 11.3 tonnes per day respectively **(Figure 3.5**). The maximum emission load of particulates is from heavy duty vehicles (70.3%).



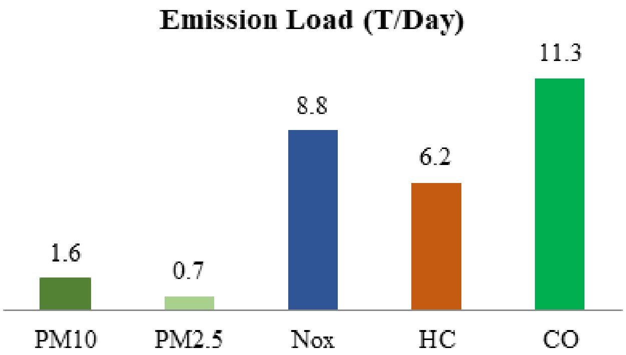


Figure 3.5 : Particulate Emission Load from Line Source

3.8 Industry (Emission Inventory)

The state is gearing up for the rapid infrastructural as well as industrial development; likewise, Aurangabad is changing it's identified of being an automobile hub for industrial sector. The decadal population growth is tremendous owing to this industrialization of the region. The Maharashtra Pollution Control Board Regional office is functioning at Aurangabad. There are three industrial areas in Aurangabad city, namely Waluj MIDC, Shendra MIDC and Chikhalthana MIDC. The Chikhalthana MIDC area is located in the city limit while Waluj and Shendra MIDC are 10 and 15 Kms away from the city.

There are about 3494 micro scale, 954 small scale, 214 medium scale and 04 large scale industrial units registered with DIC office. Majority of the Industries which came up in the city or Industrial areas are Automobiles and pharma industries. Out of these industries area, only Chikhalthana MIDC is taken into consideration for emission load estimation from industries i.e. point source emission load. There are total 117 air polluting industries in Aurangabad Industrial Cluster out of which 24 industries are located in Chikhalthana MIDC, 18 in Shendra MIDC, 68 in Waluj MIDC.

Emission from industries occurs as a result of various industrial activities happening in different categories of industries falling under the study area. The emissions are caused due to burning of different types of fossil fuels by industries. The different pollutants are released through chimneys/stacks to the surrounding area.

3.8.1 Type of Fuel and Quantity

The fuel consumption pattern of industries reveals that Aurangabad industrial cluster is highly depended on LPG for automobile and pharma industry sector. In this assessment, data on industrial emissions was obtained by means of consent approved by MPCB **(Table 3.2).**

Table 3.2: Fuel used in Industrial Sector

Fuel	Quantity	Unit
Bagasse	13	Ton/Day
Briquettes	182.418	Ton/Day
Coal	1248.65	Ton/Day
Diesel	4929	KL/Day
Furnace Oil	1019.04	KL/Day
HSD	94618	KL/Day
LDO	8.211	KL/Day
LPG	243974	KL/Day
Wood	9.455	Ton/Day
Petcoke	300	Ton/Day

It can be observed that the most common fuels used in the industries of this region are furnace oil, coal and LPG. As per the regulation, many industries have installed control equipment to control air pollution. Emission load for PM_{10}, $PM_{2.5}$, SOx, NOx, and CO are estimated. The sulphur content for coal is considered as 0.5%. The industries location is depicted in **Figure 3.6**. The emission load calculated from industries is shown in **Figure 3.7.**

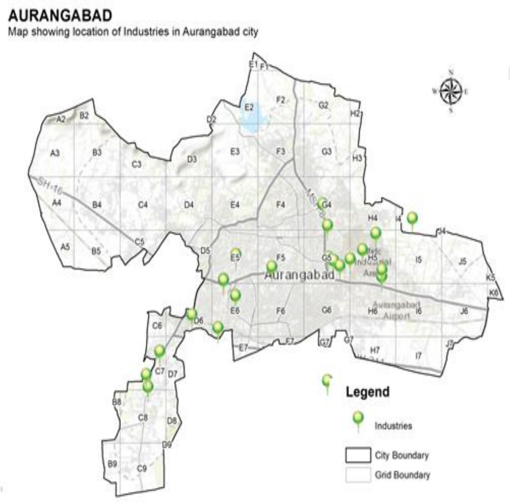


Figure 3.6: Location of Industries at Aurangabad City

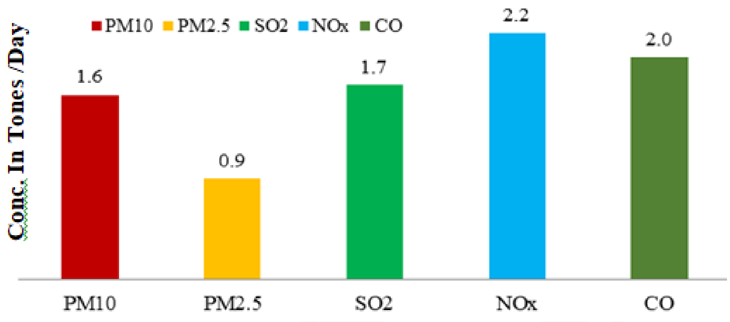
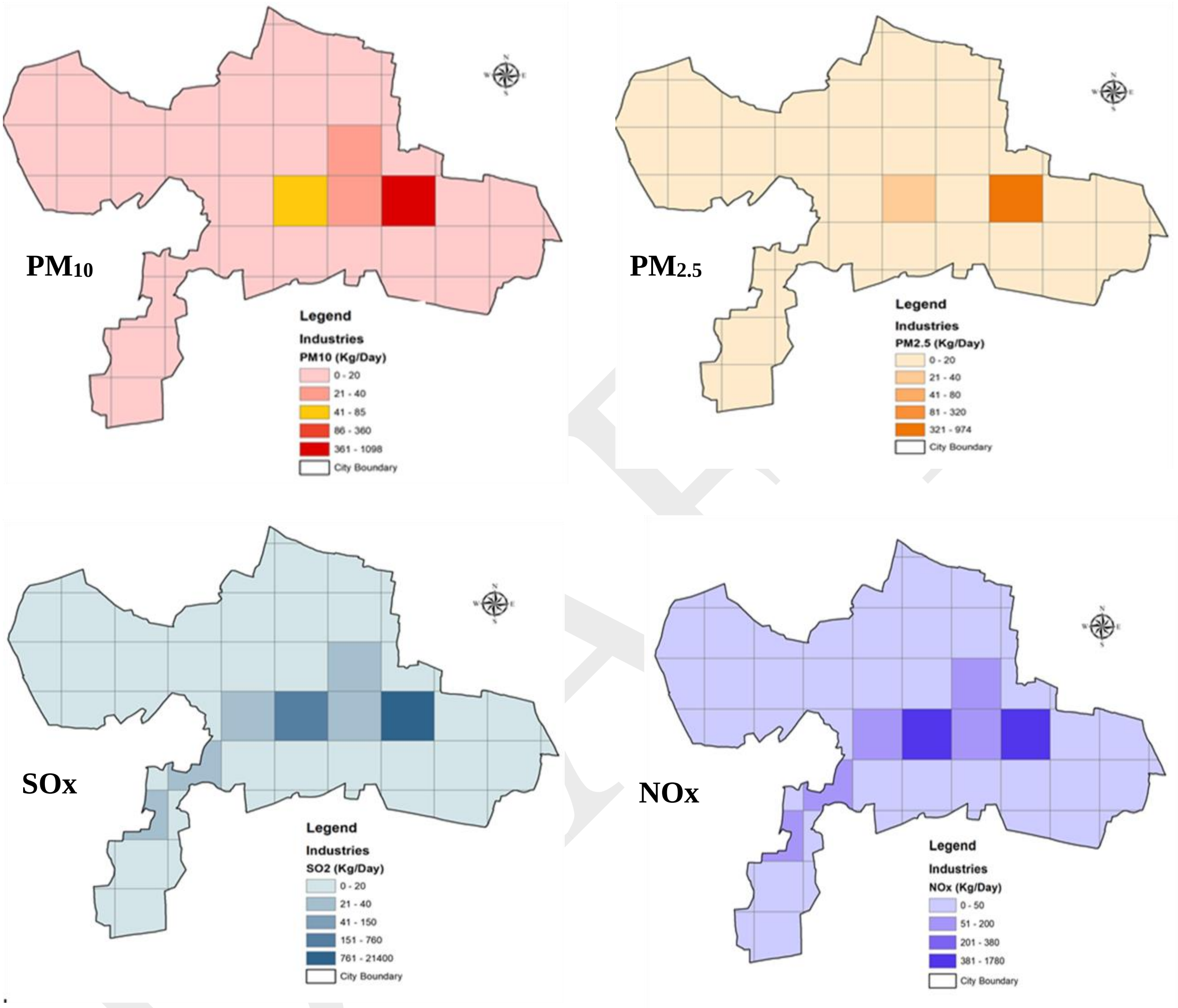


Figure 3.7 : Emission load in Tonnes /Day from Point Source

The emission load for PM_{10}, $PM_{2.5}$, SOx, NOx and CO for point source is estimated to 1.6, 0.9, 1.7, 2.2 and 2.0 tonnes per day. The grid wise kg/day emission load for PM_{10}, $PM_{2.5}$, SO_2, NOx and CO is presented in **Figure 3.8**. It was observed that Petcoke fuel is used in Aurangabad on larger scale.



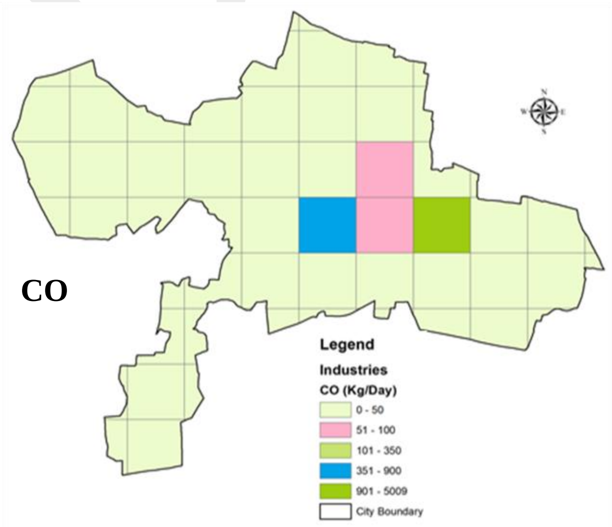


Figure 3.8 :
Grid-wise Emission Load of Different Pollutant (Kg/Day) (Industrial Source)

3.9 Area Source

An area source may be defined as a collection of similar units within a geographic area. Area sources collectively represent individual sources that are small and numerous and that cannot be inventoried as specific point, mobile or biogenic sources. Area sources includes bakeries, hotels/restaurants, crematories, construction activities domestic cooking, open eat outs, paved/unpaved road dust, solid waste dumping ground, refuse burning, stone crushers and brick kilns etc. These sources have been described along with the methodologies for load estimation.

3.9.1 Bakery

Bakery industry is mainly concentrated in the state of Andhra Pradesh, Maharashtra, West Bengal, Karnataka and Uttar Pradesh, out of which more than 60% of bakery is accounted to be unorganized. Being an essential item in urban areas, bakeries mainly operate from the midst of the city. An initial survey was arranged city wide to assess bakery related activities taking place in the jurisdictions of the city. There are 146 large and medium scale 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 coal 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 Ramzan festival. Being a semi-urban region, the fuel consumption in the bakeries was low as compared to other metro and urban cities. About 2200 kg of wood, 1400 kg of coal and 100 kg of LPG is being used on the daily basis in the bakeries of Aurangabad City. Data regarding bakeries was obtained from AMC, and ground level survey. The study area was divided into array of 2 km x 2 km grid to quantify the average fuel consumption and their subsequent emission across region. In our study, fuel that came into survey was taken into account for emission load. The location of bakeries is geo-mapped in the city **(Figure 3.9).**

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 37 Kg/day while that of $PM_{2.5}$ is estimated to be 23 Kg/day **(Figure 3.10)**. The emission load for SOx, NOx and CO is estimated to be 18, 13, 156 Kg/day respectively. The grid-wise emission graphs are shown in **(Figure 3.11).**

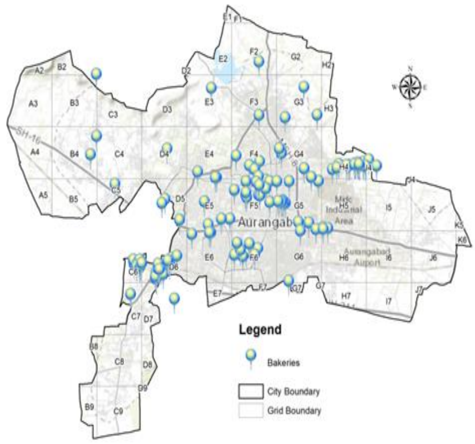


Figure 3.9: Location of Bakeries at Aurangabad City

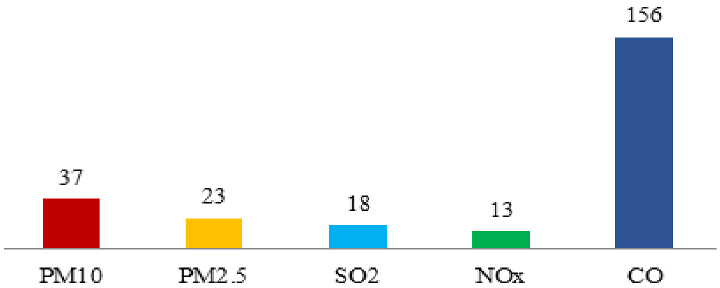


Figure 3.10 : Emission Load from Bakeries (Kg/d)

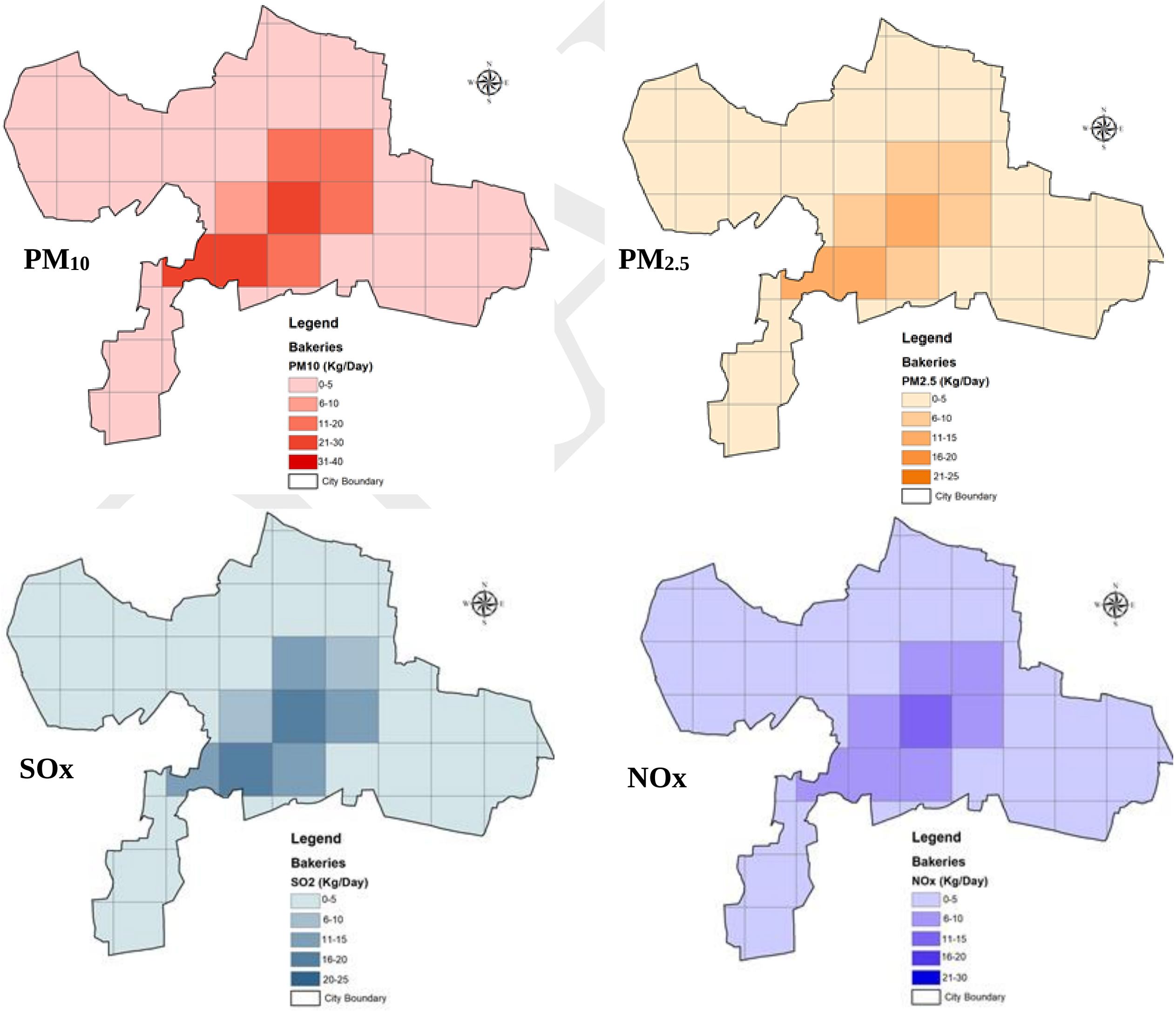


Figure 3.11 : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Bakeries)

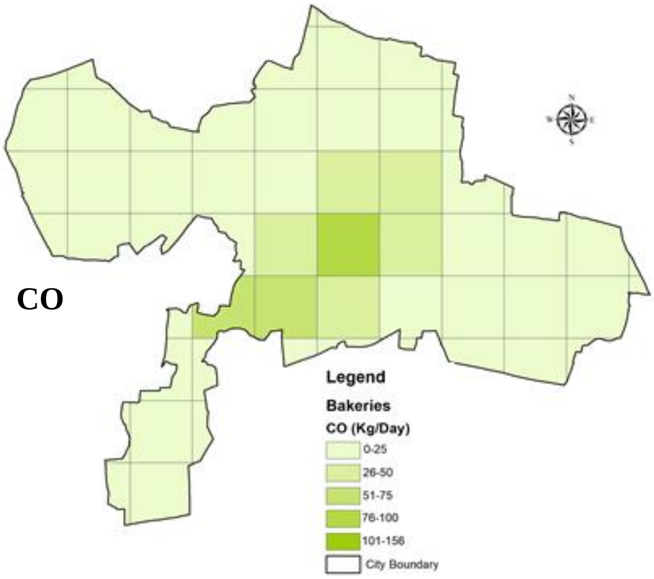


Figure 3.11 (Contd..) : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Bakeries)

3.9.2 Crematoria

The fiery dissolution of the body is considered as death rite in Hindu religion. Existing cremation grounds of city are located along the bank of rivers or nallahs. There are total 22 wood based cremation centres located in the city. As per the assumption from previous studies and in consultation with AMC the average wood requirement for burning a dead body is about 300 Kg and additives like kerosene is used to burn the dead bodies. In this study, emission from wood and kerosene is considered. Emission from this category of Area source release major pollutants like PM_{10}, $PM_{2.5}$, SOx, NOx and CO. Data regarding number of death cremated was obtained from Birth and Death cell of Aurangabad Municipal Corporation. The location of bakeries is geo-mapped in the city **(Figure 3.12)**. Emission estimation procedure is given below. The emission load from different pollutants is presented in **(Figure 3.13)**. The grid-wise emissions load from crematoria is shown in figures **(Figure 3.14).**

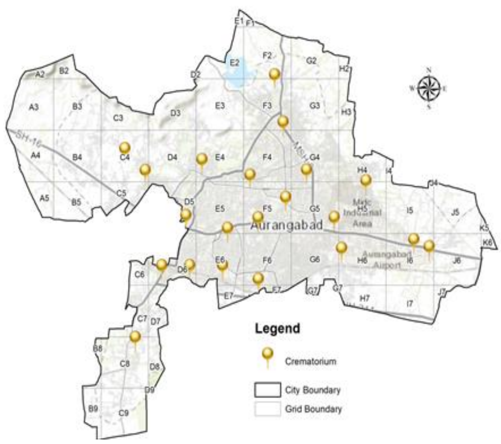


Figure 3.12: Location of Crematoria at Aurangabad City

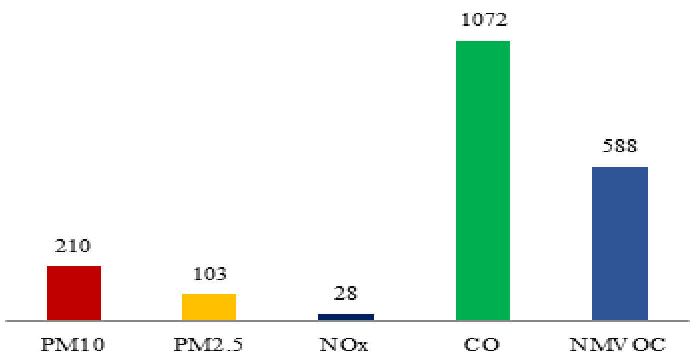
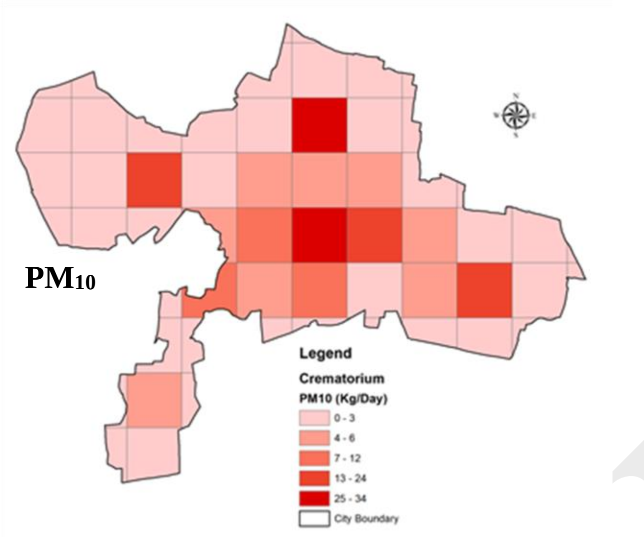
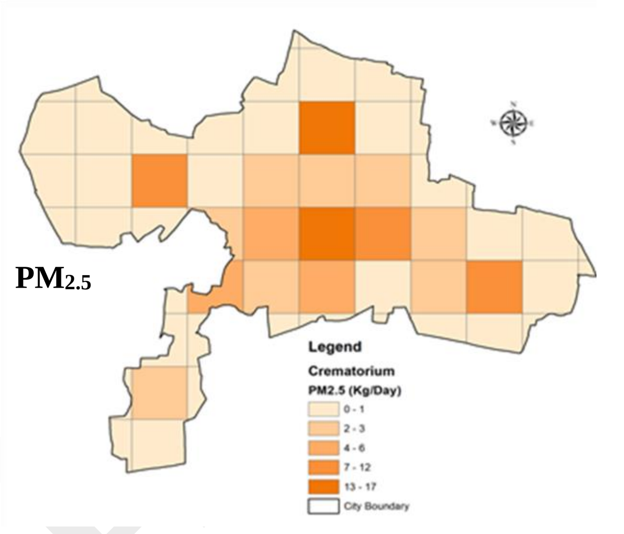
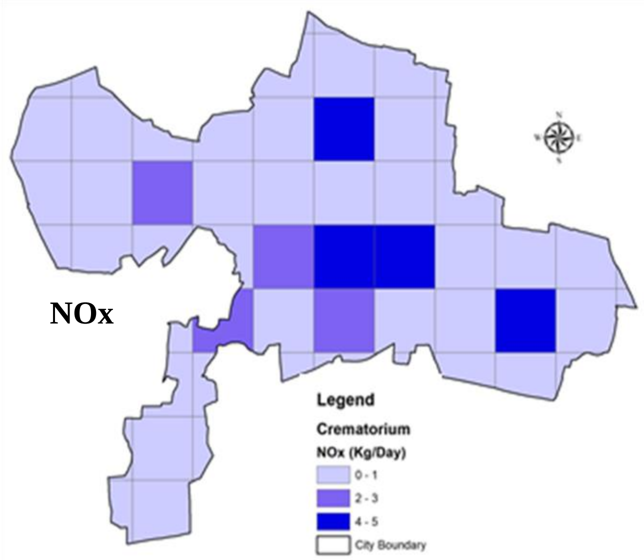


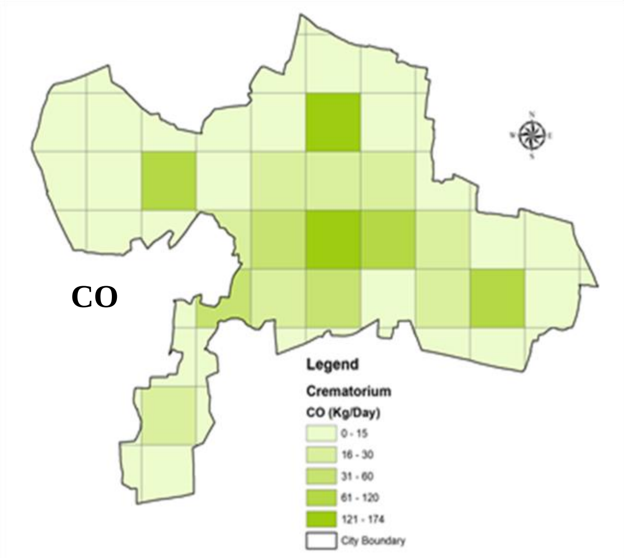
Figure 3.13 : Emission Load from Crematoria (Kg/d)

Emission Estimations:
Emission (TSP) =No. of Hindu Death /yr * wood required per body (kg) * emission factor
Emission Factor (PM10) Wood Consumption = 17.3 (kg/t)
Emission Factor (SPM) Kerosene = 1.95 (kg/t)
Emission Factor (PM10) Kerosene = 0.61 (kg/t)









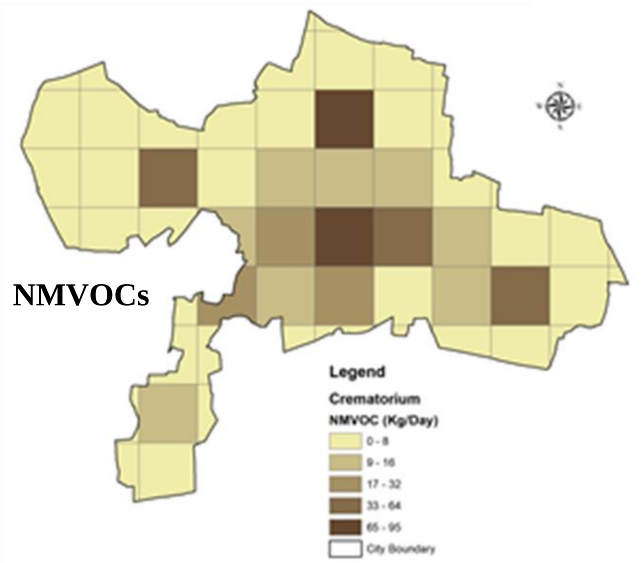


Figure 3.14 :
Grid-wise Emission Load of Different Pollutant (Kg/Day) (Crematoria)

3.9.3 Open Eat outs

This informal sector even though being small in size, contribute emission load on large area because of the variable fuel consumption pattern for their operations and absence of any control measures for these emissions. On the basis of primary survey, the fuel preference for open eats out in Aurangabad city is LPG, followed by coal. Average operating hours of street vendors is 12 hours. Data regarding number of street vendors is not available since it is considered as illegal operation. Therefore, a questionnaire survey was carried out to collect necessary data for the estimation of emission load from this source. These numbers have been verified by visiting representative areas where these eat outs are prevalent. Distribution of open eats outs are shown in the **Figure 3.15**.

Emission Estimates

Total emissions = Emissions from kerosene burning + LPG burning + Coal burning

Emission from kerosene burning (PM) per day
= Number of street vendors operating on kerosene x fuel consumption per day x EF

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

The number of illegal and unorganized open eat outs is concentrated in region adjoining to industrial and commercial clusters. Accounting the commercial and mixed activities in and around Chikhalthana and Waluj MIDCs of Aurangabad, the likelihood of floating population is high. Thus, the emission load from these wards is maximum and lowest is seen from University area (BAMU). The emission load from different pollutants is presented in **(Figure 3.16**). The grid-wise emissions load from crematoria is shown in figures **(Figure 3.17).**

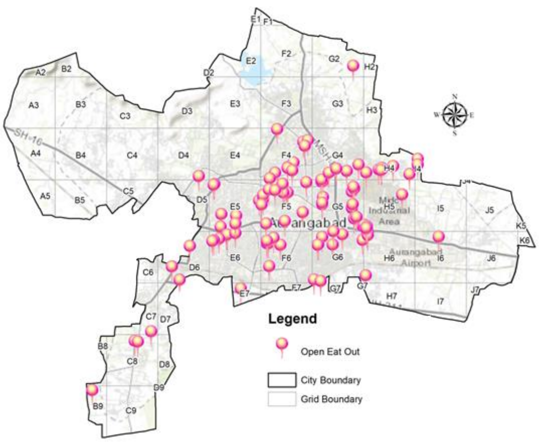


Figure 3.15: Location of Open Eat outs at Aurangabad City

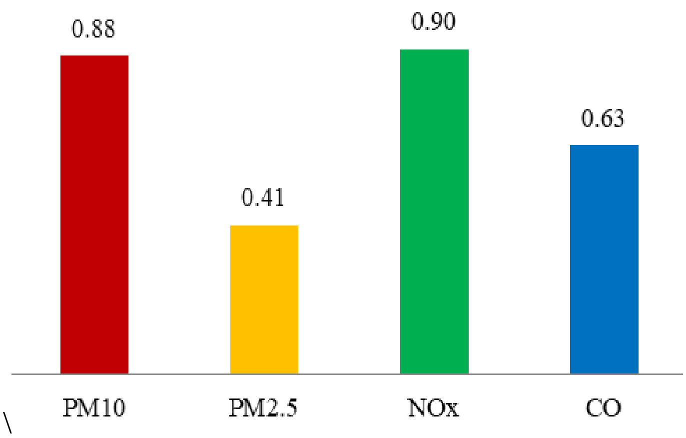


Figure 3.16 : Emission Load from Open Eat outs (Tonnes /day)

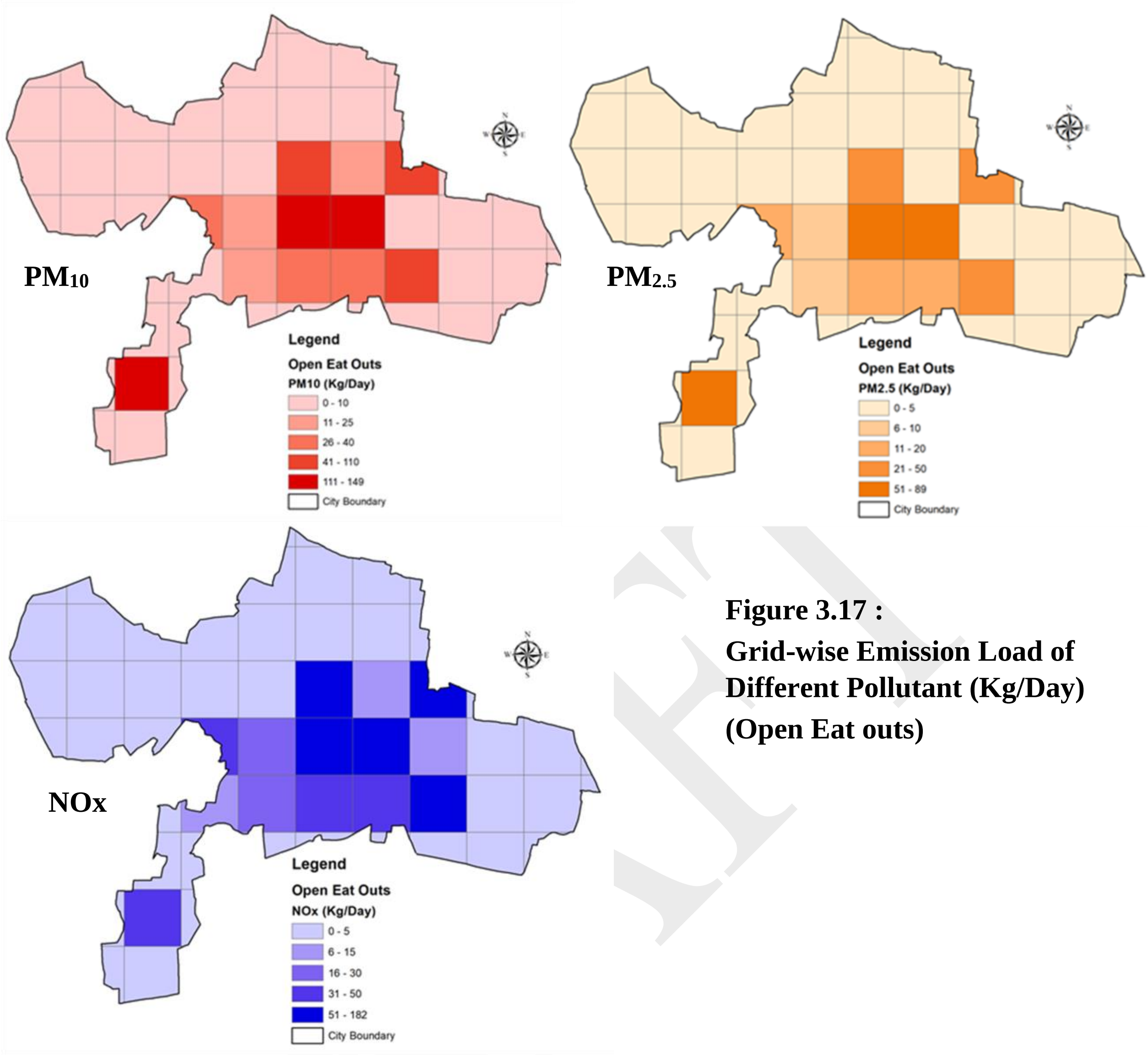


Figure 3.17 : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Open Eat outs)

3.9.4 Domestic Sector

Attributing to the demography of the region and standard of living of the population, the fuel consumption pattern is varied at individual level. As non-slum population is more organized considering their source of income, their primary domestic fuel is LPG. Due to the recent policy change from the government under PMUY, the consumption of LPG has grown in slum areas. Along with LPG, slum population use locally available resources such as wood, coal, kerosene etc. There are total 21 nos. of domestic gas distributors in the city. The total consumers registered are around 2.35 Lakhs. The monthly consumption of the domestic gas is around 35 tonnes/month. This is nearly equal to 2200 cylinders (14.6 kg each) per month. Percentage of slums was obtained from Census 2011 report. The total fuel consumption other than domestic gas is 1578, 631, 63, 1262 and 6571 Kg/month for Wood, Dung cakes, Crop residue, Coal and Kerosene respectively.

Based on survey it was found that the consumption of kerosene, coal and wood is prevalent in slum areas. They are having a registered gas connection, but they rent the cylinders for extra income and cook food on chulha by using coal, wood or kerosene. The emission load from different pollutants is presented in **(Figure 3.18)**. The grid-wise emissions load from crematoria is shown in figures **(Figure 3.19).**

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)

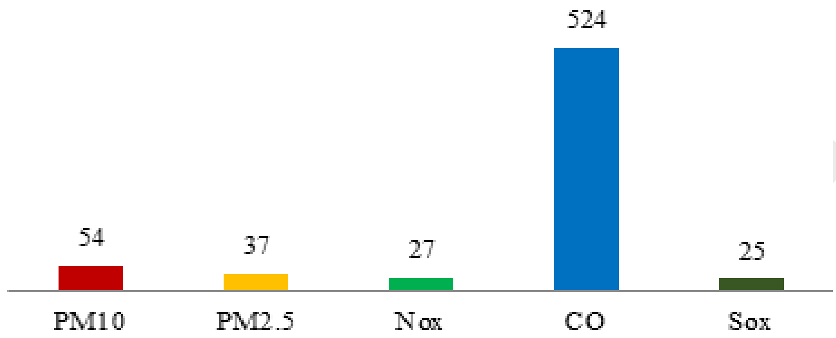


Figure 3.18 : Emission Load from Domestic Sector (Kg/d)

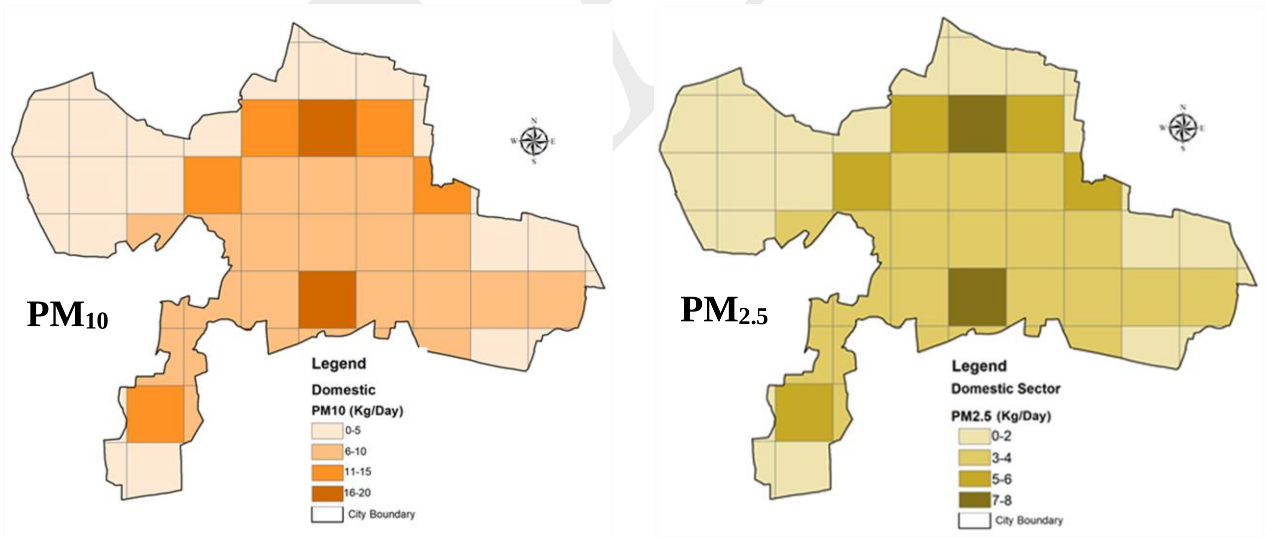


Figure 3.19 : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Domestic Sector)

3.9.5 Building Construction

With a scope of being developed as smart city, there are drastic infrastructural developments taking place in Aurangabad 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 AMC and from RERA website. At total 91 places the construction activities were in progress at the time of survey. The data is collected during May 2019.

Assumptions

- The project duration was estimated at 8 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 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 3.20).** The grid-wise emissions load from crematoria is shown in figures **(Figure 3.21).**

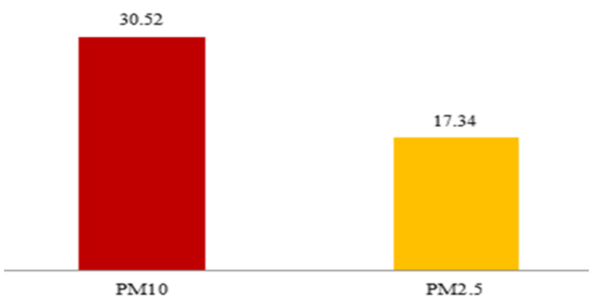


Figure 3.20 : Emission Load from Building Construction (Kg/d)

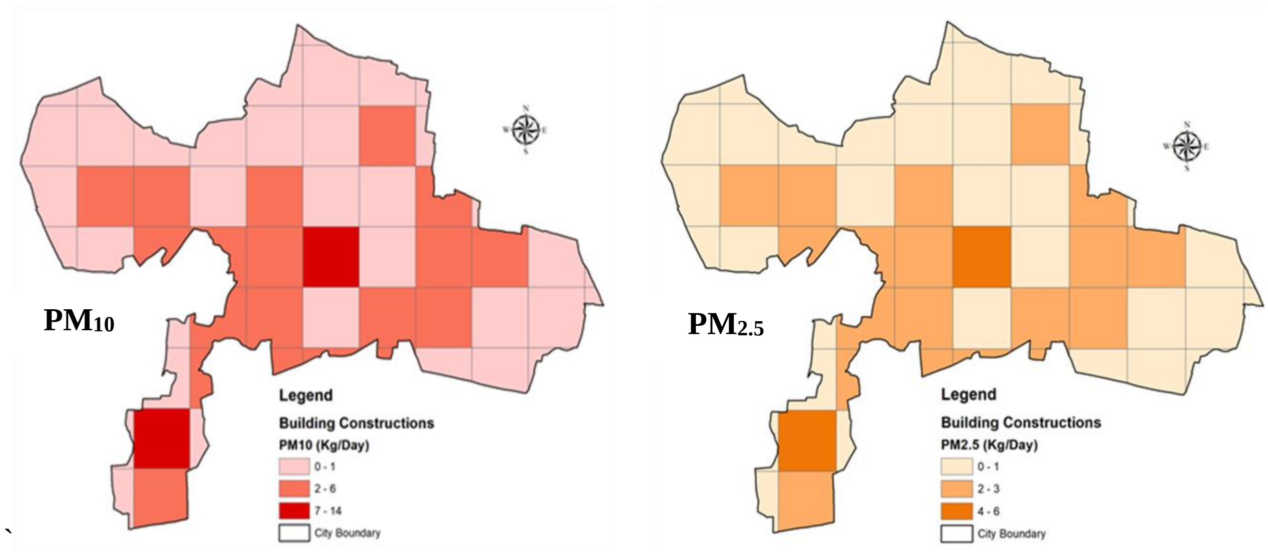


Figure 3.21 : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Building Construction)

3.9.6 Hotels and Restaurants

There are around 342 hotels registered with the AMC License department. It was observed that the large number of tea stalls/snack corners/fast food centres, which have fuel consumption almost same as a hotel, could be more than twice the registered number and remains unaccountable. In addition, institutions and organizations have their own canteen/hotels within their premises and their fuel consumption patterns are unknown. Hotels and Restaurants use LPG cylinders and coal for their operation. LPG commercial cylinders of 19 kg are used for cooking and coal is used in the tandoor bhattis. The tandoors are operated mostly in unsafe confined or open areas without any proper ventilation or control measures. The primary survey of Hotels and Restaurants gave an annual LPG consumption of 2500 cylinder per year, coal consumption of 6 tonnes per year, wood consumption 26 tonnes per year and Kerosene consumption of 8 KL per year. Domestic cylinders are also consumed in the commercial sector illegally for which data was not easily available.

The total LPG consumption of hotels in the city is around 1000 Kg/day and that for coal, wood and kerosene are 17 Kg/day, 72 Kg/day and 22 litres/day.

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)

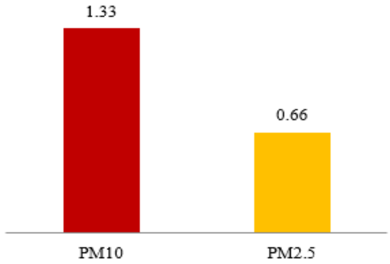


Figure 3.22 : Emission Load from Hotels and Restaurants (Kg/d)

The emission load from different pollutants is presented in **(Figure 3.22).** The grid-wise emissions load from crematoria is shown in figures **(Figure 3.23).**

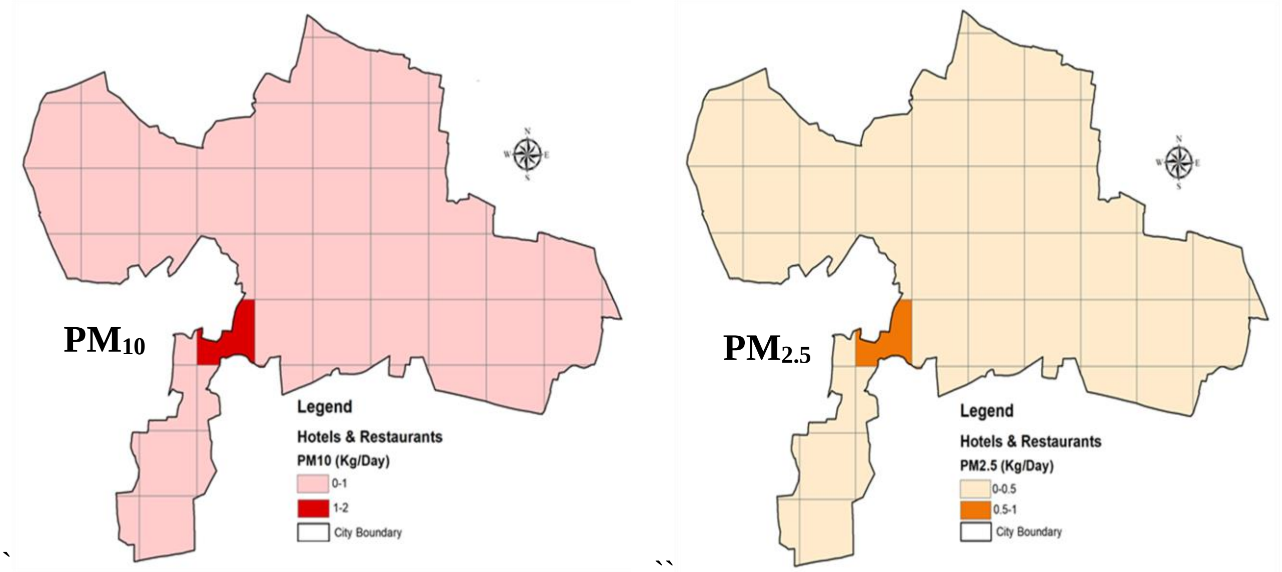


Figure 3.23 : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Hotels and Restaurants)

More emission load is seen in grid number D6. Total 86 hotels and restaurants are located in this grid. This is due to large quantity of fuel consumed by hotels and restaurants in this area. of hotels and restaurants located in this grid. Aurangabad Railway station and commercial zone Padampura falls in this grid. Hence the pollution load is seen to be high. Many snacks centre uses coal and wood to make tea and coffee.

3.9.7 Open Burning

It is estimated that solid waste generated in small, medium and large cities and towns in India is about 0.1 kg, 0.3-0.4 kg and 0.5 kg per capita per day respectively. Rapid urbanization combined with development will double the solid waste generation. Semi urban centres generate disproportionately high mixed waste, sometimes creating unrest around the way they are disposed. Most of the waste is sent to landfills, or worse, to open dumps, raising concerns about air pollution, social unrest, and impact on poverty and so on.

Open burning is one of the major contributors in Area Sources. Open burning is an illegal method of burning solid waste; materials commonly disposed of in this manner include municipal waste, auto body components, wood refuse, small scale industrial refuse and leaves. With the increase in population of the city waste generation also increases.

The waste generation in Aurangabad city is around 450 TPD. Aurangabad Municipal Corporation has installed two solid waste processing plants in the city. The capacity of each plant is 100 tonnes per day. The plants are located at Padegaon and Chikhalthana respectively. The third processing plant of 100 ton capacity is in pipeline at Harsul area. As the open burning cases often get unreported and data for the same is missing, it was assumed that about 4% (18 tonnes) of the total solid waste is burnt in the wards containing solid waste landfill sites.

Emission Factor (kg/T) PM_{10} = 8, $PM_{2.5}$ = 5.44, CO = 42, SO_2 = 0.5000 and NOx = 3

The emission load from different pollutants is presented in **(Figure 3.24).** The grid-wise emissions load from crematoria is shown in figures **(Figure 3.25).**

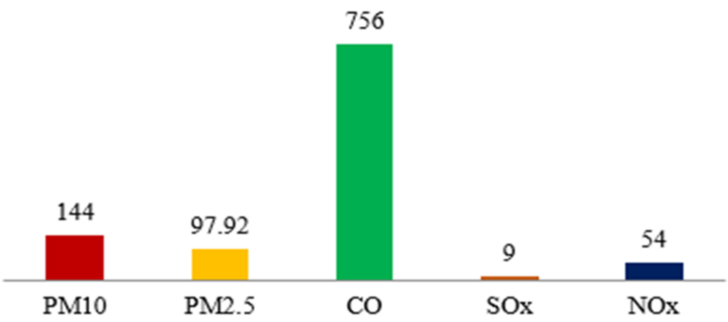


Figure 3.24 : Emission Load from Hotels and Restaurants (Kg/d)

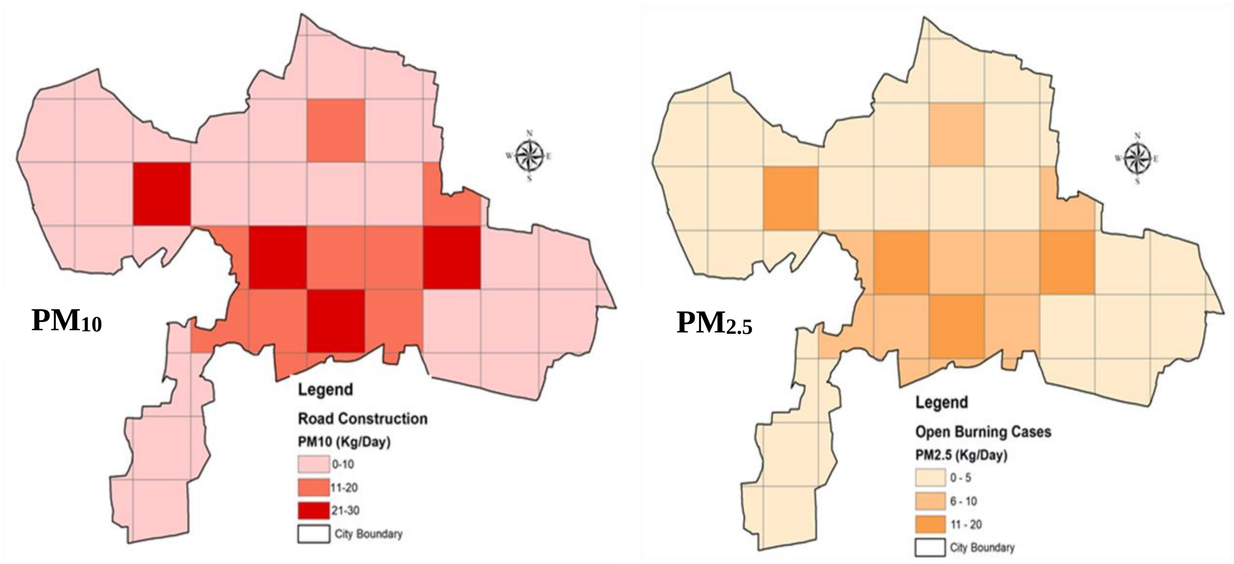


Figure 3.25 : Grid-wise Emission Load of Different Pollutant (Kg/Day) (Open Burning)

3.9.8 Road Resuspension

Total constructed road length within corporation area is 1927 Kms. 96% (1850 kms) of the total road was considered as paved, while remaining was accounted as unpaved (77 kms). As motor vehicle moves over road surface, it leads to resuspension of dust from unpaved roads or settled dust from the paved surface by the turbulent wake of the vehicle and emitted as particulate matter. Emissions are estimated as a function of the silt loading of the paved surface and mean weight of the vehicles travelling over the surface. Data source such as road length was obtained by using GIS model, information received from Aurangabad Municipal Corporation and Public Works Department of the region. Major portion of this constitute the vehicle population in city. It is observed that increase in the vehicle population in every year is remarkable.

- Emission Estimates for Paved Road Dust

Vehicle Weight

Vehicle registered (2017)		% Vehicle count (A)	Average Weight (B) (kg)	Vehicle Weight by % (A*B) (kg)
2 W	119897	0.36	175	63
3 W	57975	0.17	450	76.5
Cars	94253	0.28	1425	399
HDDV	61080	0.18	20000	3600
Total	333205			4138
Total				4.1 tonnes

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

It was observed from the vehicular survey, that the percentage of two wheelers in terms of number as well as movement within the city is highest (over 46%) among the other categories, followed by 4 wheelers (30%). Aurangabad has considerable amount of heavy delivery vehicular movement due to presence of flyover (state highway). The highest heavy delivery vehicular movement was observed during night. There is huge dependency on 2-wheelers and private vehicles are evident for mobility across city. An average VKT of 450316 km/day was estimated for all categories of vehicles travelling within city limits.

Annual / Long Term Avg. E factor

EF = (k (sL/2)^0.65*(W/3)*1.5-C)*(1-P/4N)

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

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

Values of k (g/vkt) $PM_{2.5}$ = 1.1, PM_{10} = 4.6

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

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

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

C= Break and tire wear correction ($PM_{2.5}$ = 0.1005, PM_{10} = 0.1317)

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

EF (PM_{10}) = (k (sL/2)^0.65*(W/3)*1.5-C)*(1-P/4N) = 0.996 g/vkt

EF ($PM_{2.5}$) = (k (sL/2)^0.65*(W/3)*1.5-C)*(1-P/4N) = 0.244 g/vkt

Emission load from paved dust (Kg/Day)

= VKT*EF (PM_{10})

= 450316 * 0.996 * 0.001 * 0.96

PM_{10} = 430.57 Kg/Day

Emission load from paved dust (Kg/Day)

= VKT*EF ($PM_{2.5}$)

= 450316 * 0.224 * 0.001 * 0.96

$PM_{2.5}$ = 96.83 Kg/Day

Emission Estimates for Unpaved road dust

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

EF = size specific emission factor, (lb/vmt),

s = surface material silt content (%),

m= surface material moisture content (%),

S= mean vehicle speed (mph);

k = particle size multiplier (lb/vmt), $PM_{2.5}$= 0.27, PM_{10}=1.8 (lb/vmt)

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

C= Break and tire wear correction ($PM_{2.5}$=0.00036, PM10=0.00047) - lb/VMT

a. $PM_{2.5}$=1, PM_{10}=1, b. $PM_{2.5}$=0.2, PM_{10}=0.2; c. $PM_{2.5}$=0.5, PM_{10}=0.5

EF (PM_{10}) = {([k (s/12)^a (S/30)^d] /(m/0.5)^c-C)} *((365-P)/ 365)

= (((1.8 (18.4/12)^1 (12.5/30)^0.5) / (6.65/0.5)^0.2-0.00047)) *((365-120)/365)

= 0.712 lb/vmt

= 200.821 g/vkt

EF ($PM_{2.5}$) = 60.06 g/vkt

Emission load from unpaved dust (Kg/Day)

= VKT*EF (PM_{10})

= 450316 * 200.821 * 0.001 * 0.04

PM_{10} = 3617.32 Kg/Day

Emission load from unpaved dust (Kg/Day)

= VKT*EF ($PM_{2.5}$)

= 450316 * 60.06* 0.001 * 0.04

$PM_{2.5}$ = 1081.84 Kg/Day

The emission load from different pollutants is presented in **(Figure 3.26).**

Emission Load from Paved and Unpaved Road Dust

Paved Roads (Kg/Day)		Unpaved Roads (Kg/Day)	
PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$
430.57	96.83	3617.32	1081.84

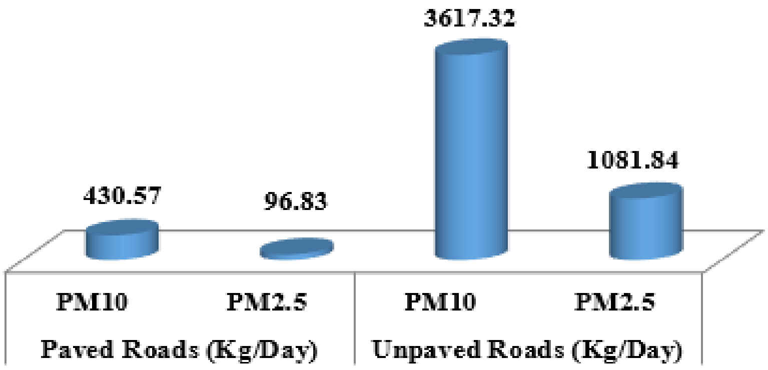


Figure 3.26 : Emission Load from Paved & Unpaved Road Dust (Kg/d)

3.10 Total Emission Inventory (Aurangabad City)

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Aurangabad city vide emission inventory is developed as shown in **Table 3.3**. Total tons /day emission load for pollutants in Aurangabad city is depicted in **Figure 3.27**.

Table 3.3 : Total Emission Load from All Sources (All Units in TPD/Day)

	Sector	PM_{10}	$PM_{2.5}$	NOx	SOx	CO
A.	**Area Source**					
	Bakeries	0.04	0.02	0.01	0.02	0.16
	Open Eat-outs	0.0009	0.0004	0.0009	0.0000	0.0006
	Hotels & Restaurants	0.0013	0.0007			
	Crematoria	0.21	0.10	0.03	0.00	1.07
	Domestic	0.05	0.04	0.03	0.03	0.52
	Building Construction	0.03	0.02			
	Open Burning	0.14	0.10	0.05	0.01	0.76
B.	**Line Source**					
	Vehicular flow	1.6	0.7	8.8		11.3
C.	**Point Source**					
	Industries	1.6	0.9	2.2	1.7	2
D.	**Resuspension of Road Dust**					
	Paved Roads	0.43	0.10			
	Unpaved Roads	3.62	1.08			
	Total Emission Load (TPD)	**7.7**	**3.1**	**11.1**	**1.8**	**15.8**

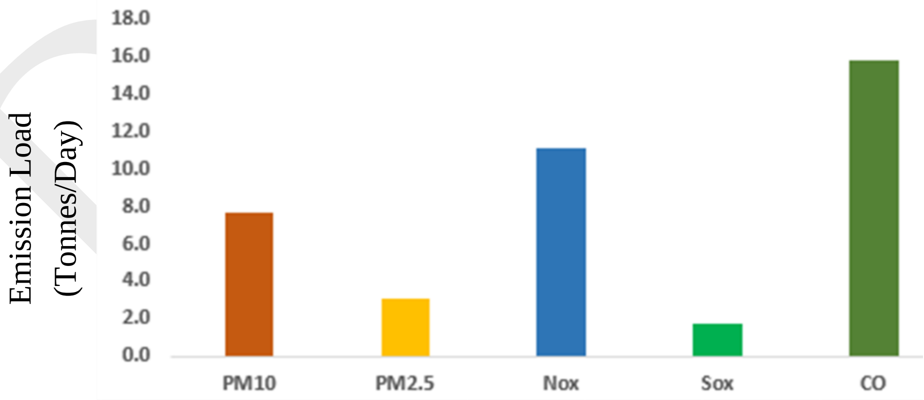


Figure 3.27 : Total Emission Load (Tons/Day) for Pollutants in Aurangabad City

Percent PM emission load from different sources is presented in **Figure 3.28**. The highest contributors to PM emissions are Resuspension of Road Dust (52.4%), emission load from industries and vehicular source is (20.7). Among area sources Crematoria and Open Burning are contributing higher i.e 44 and 30% respectively.

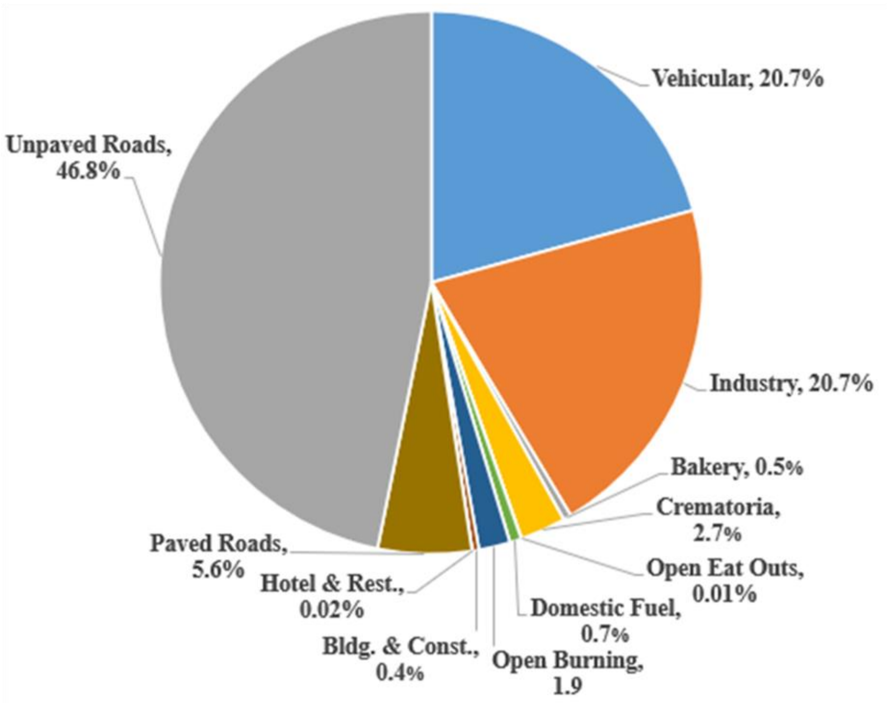


Figure 3.28 : Percent Emission Load of PM from Different Sources in Aurangabad City

3.11 Grid-wise Emission Inventory

Pollution in the atmospheres of megacities has become a major source of concern for public authorities. To understand this precisely, the details of the sources responsible for emission inventory are presented for respective pollutants **(Figure 3.29 to Figure 3.32)**. The sources considered for estimation of emission load were point, area and line sources. These grid wise emission loads will be effective in consideration of policy making decisions for reducing air pollution to a great extent.

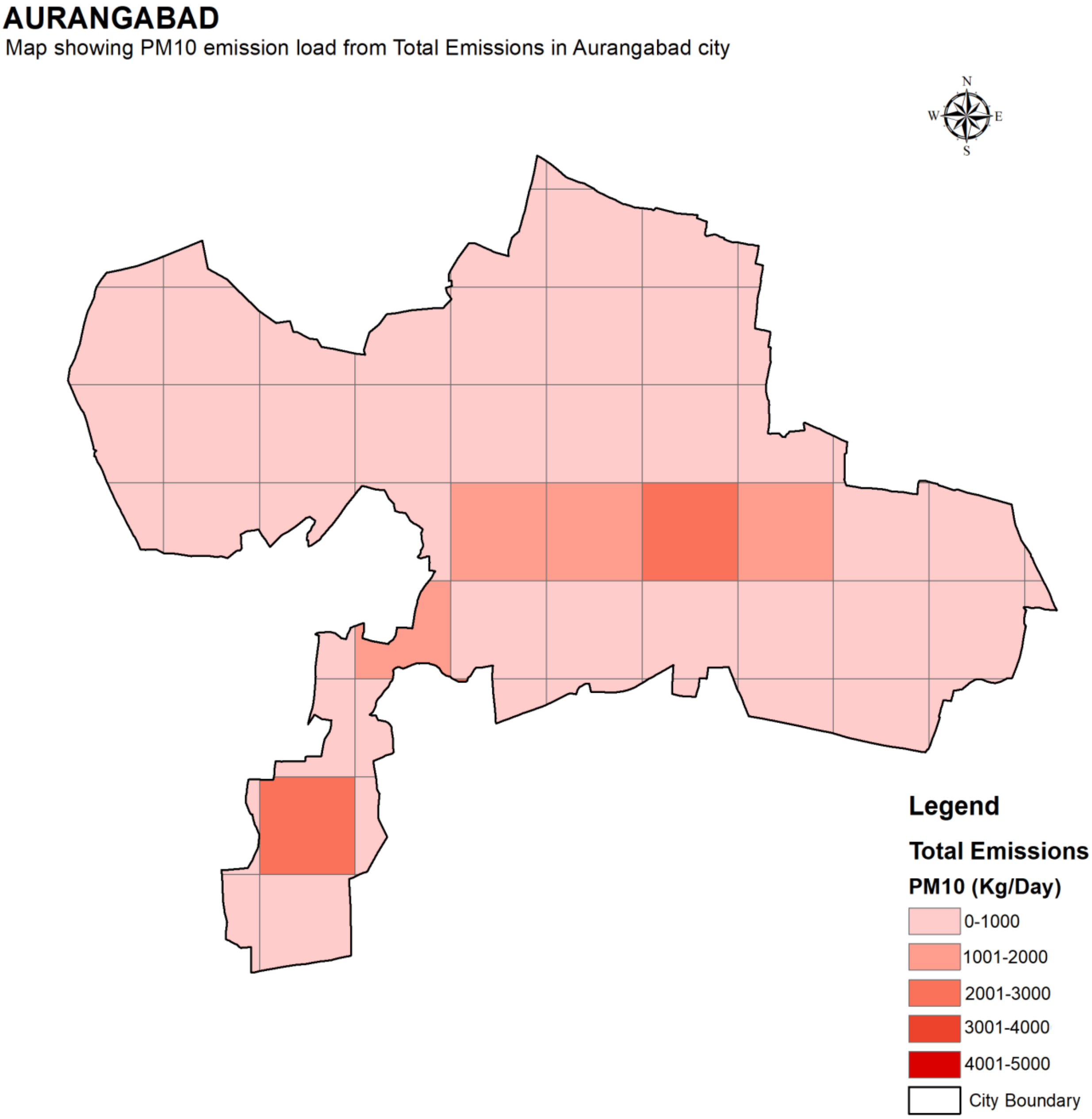


Figure 3.29 : Total Grid-wise Emission Load for PM_{10} (Kg/day)

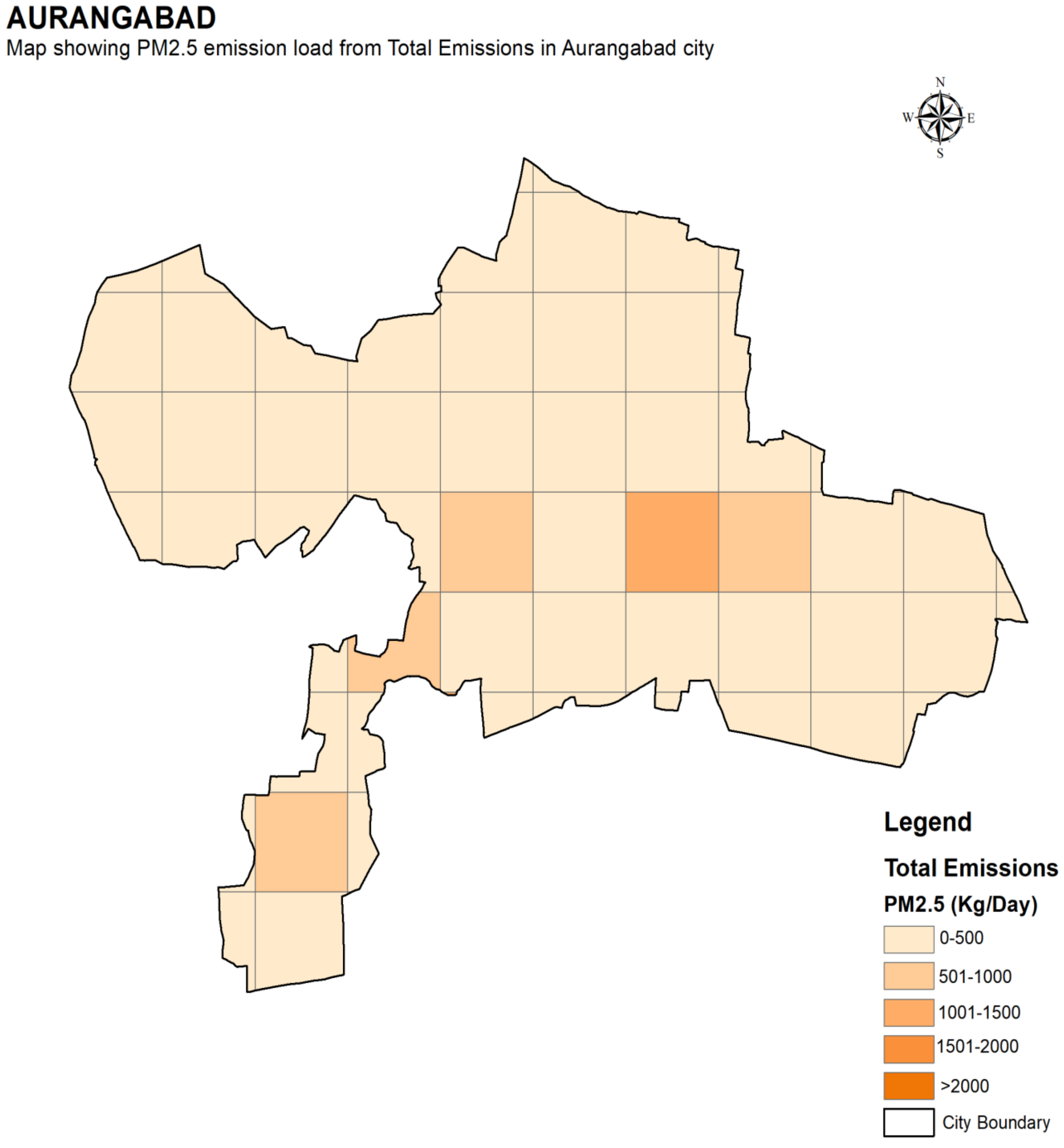


Figure 3.30 : Total Grid-wise Emission Load for $PM_{2.5}$ (Kg/day)

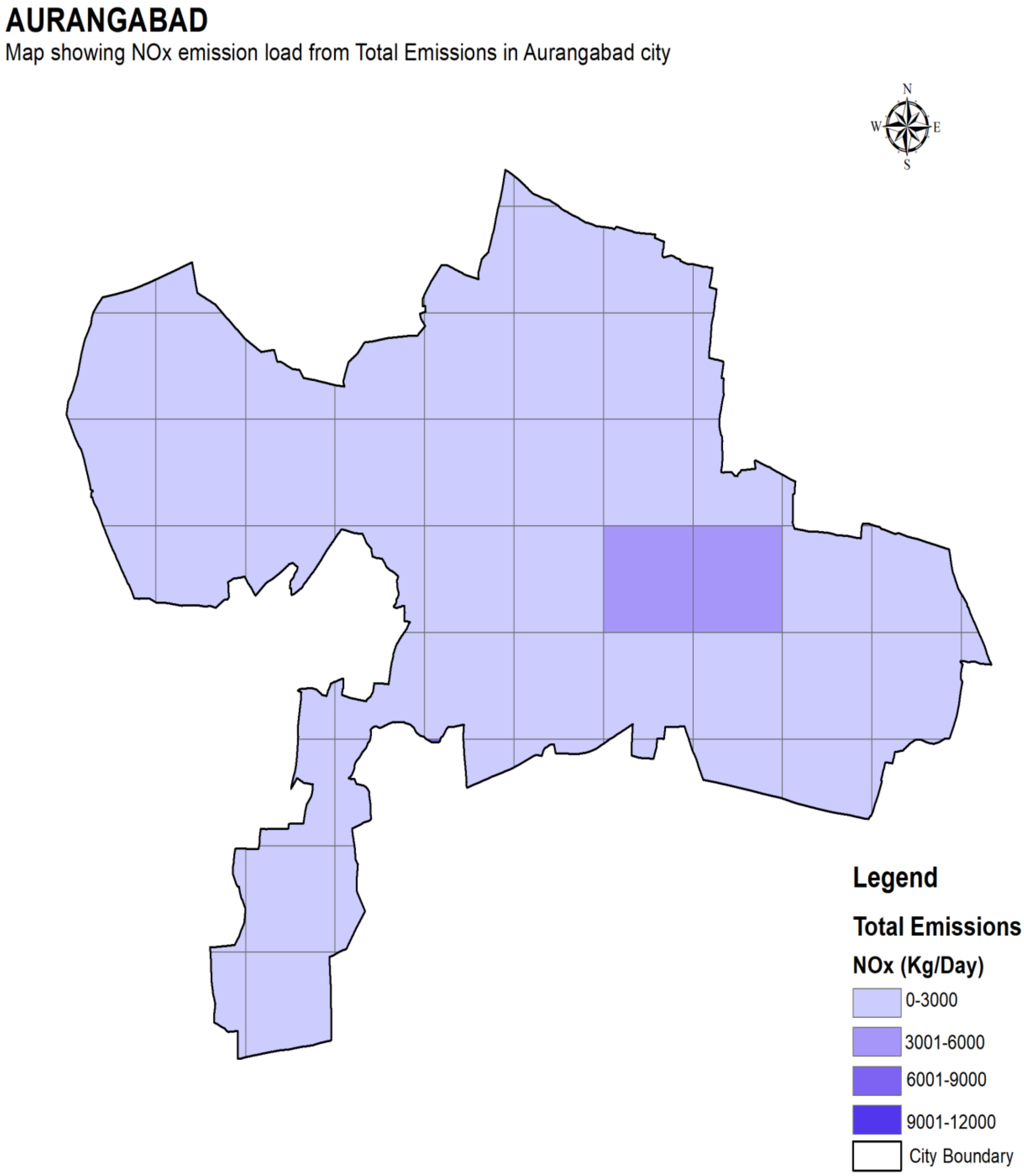


Figure 3.31 : Total Grid-wise Emission Load for NOx (Kg/day)

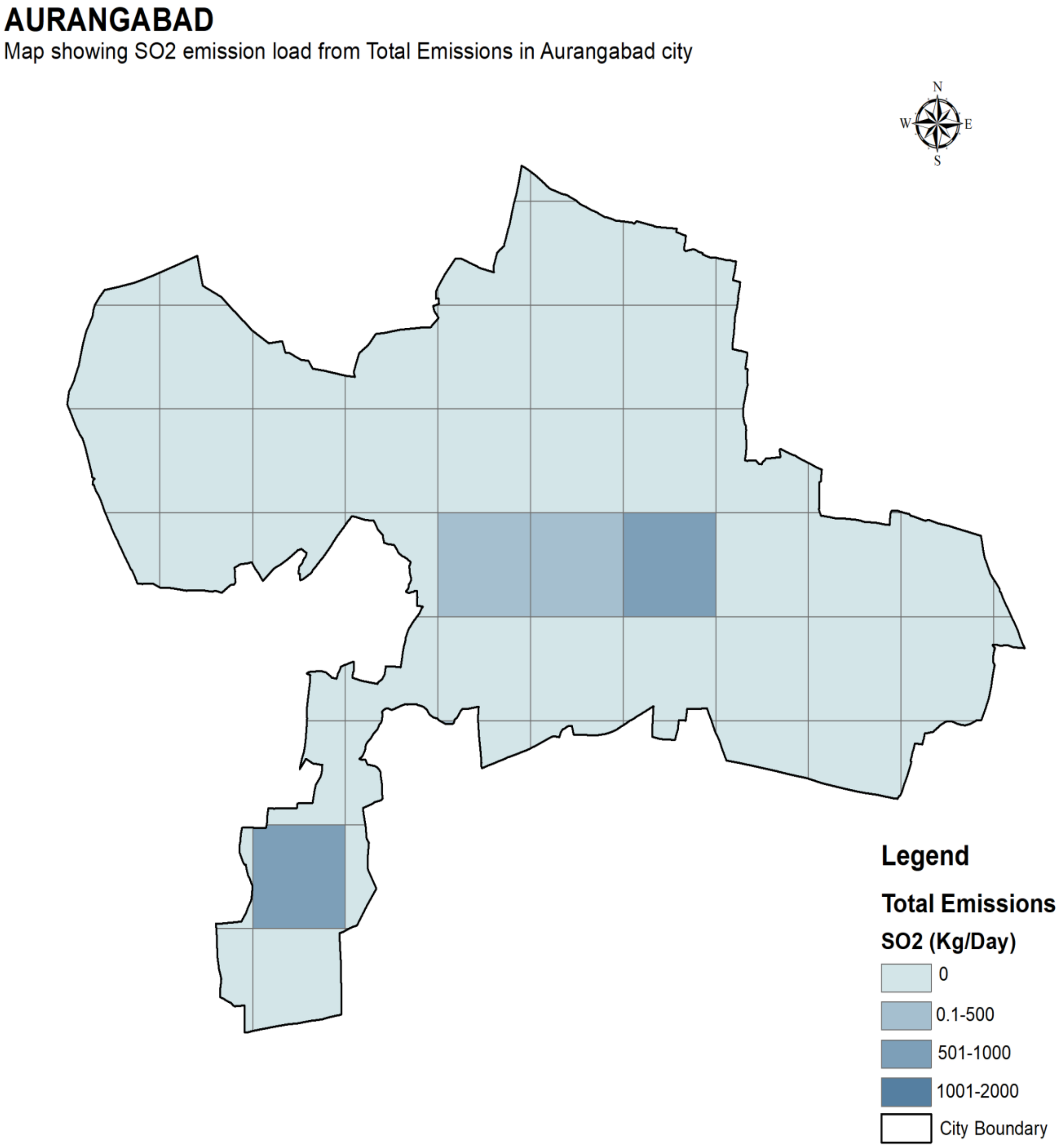


Figure 3.32 : Total Grid-wise Emission Load for SOx (Kg/day)

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 carried out for representative samples of $PM_{2.5}$ and PM_{10} collected during the 7 May 2019 to 16 May 2019 sampling campaign at 4 locations: University Campus; MPCB Office, Padampura, and Gharkheda. 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/cm^2	µg/m^3#	Ions (b)	PPM	µg/m^3#
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/m^3#**
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 $PM_{2.5}$ & PM_{10} 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 $PM_{2.5}$ and PM_{10} is presented in **Figure 4.2 (a to d).**

Factor 1: Resuspended Road Dust/ Wind Blown Dust

Factor 1 was identified by Resuspended Road Dust/ Wind Blown Dust, the significant levels of OC, SO_4^{2-}, Al, Cl and NO_3^-(~38%, 8.46%, 14.55%, 5.56%, and 4.53%) and minor indicators such as K^+, Ca^{2+}, Cl^-, Zn, Fe, Mg and Na contributed to 21.02% of total PM_{10} emissions. Earlier studies reported that, Al and SO_4^{2-} are major indicators of resuspended Road dust, whereas Zn and Fe are deposited by vehicular emissions which are resuspended due to wind-driven airborne dust from surface soils and paved roads *(Gupta et al., 2011; Rai et al., 2016; Zong et al., 2016; Buyan, 2018)*. Fe, Ca, Na 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.

Factor 2: Crustal Dust

Factor 2 is identified as Crustal dust which accounted for 16.63% of total PM_{10} contribution with major indicators such as OC, SO_4^{2-}, Al, K, and Fe (~54.15%, 6.68%, 7.79%, 4.50%, and 8.90%) and Mg, Ca^{2+}, Br^- and Na as minor indicators contributed to this source. As per past studies, Ca^{2+}, SO_4^{2-} and Al are along with major indicators of crustal dust, as also K, Mg, Si and Ca are the good tracer of Crustal Dust *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al., 2020)*.

Factor 3: Construction Dust/Fossil Fuel Combustion

Factor 3 represented by collinearity of the species, which reflect the mix contribution from Construction Dust/Fossil Fuel Combustion, which accounted for 20.63% of total $PM_{10.}$ Contribution with major indicators such as OC, Br^-, SO_4^{2-}, Fe, and Zn (~ 37.50%, 6.67%, 8.94%, 11.51%, and 7.33%) with minor contributions like Na^{+}, Cl, Ca^{2+}, Mg, and Al. Earlier studies reported that, elements such as Br^{-}, Cl, along SO_4^{2-} have been widely used as a marker of Fossil fuel combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al., 2016; Sharma et al., 2016; Jain et al., 2018)*. Ca^{2+}, Mg, K, Na^{+}, and Cl^{-} are 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)*.

Factor 4: Industrial/Biomass Burning

Factor 4 was identified as Industrial emissions by the presence of tracers, such as OC, Mg, and Cu, (~51%, 8.94%, and 3.90%) with minor indicators such as K^{+}, Cl, Fe, Mn Ni, and Ag contributed to about 21.32%. of total PM_{10} Pollution. The modal could not differentiate all the sources as the major indicator species of these sources were overlapping with each other. Earlier studies reported that Fe, Cr are the indicators of industrial emissions as these elements are greatly used in various industries like machinery, battery, and electroplating purposes *(Taghvaee et al., 2018)*. K, EC, OC, Al, Cu are the indicators of wood based and biomass-based boilers for industrial process *(urbanemissions.info)*. There have been many studies in the past suggesting that OC, K, K^{+}, and SO_4^{2-} are clear indicators of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et al., 2018; Garaga et al., 2020).*

Factor 5: Vehicular Emissions

Factor 5 accounted for 20.40% of total PM_{10} Pollution with major indicators such as OC, Al, K, Mn, and Fe (~36.09%, 9.82%, 6.79%, 12.26%, and 6.53%) and minor indicators such as Zn, Cl, Br^{-}, Ni and NO_3^{-}. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions and wear and tear of tires. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017; Mukherjee et al., 2018, Pawar et al., 2020).* Also, OC, Cl, and Br^{-} were present in this factor indicating emissions from the burning of fossil fuel from vehicles *(Jain et al., 2018; Keerthi et al., 2018).*

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 $PM_{2.5}$ and PM_{10} is presented in **Figure 4.2 (a to d)**.

Factor 1: Fossil Fuel Combustion & Vehicular Source

Factor 1 is identified as vehicular emissions and fossil fuel combustion accounted for 15.16% of total $PM_{2.5}$ emissions; as collinearity of the species were found, which reflect the mix contribution. Major indicators such as OC, Si, Cl, Ti, Zn, and Fe (~45.08%, 7.20%, 6.50%, 5.13%, 3.73%, and 4.40%) and minor indicators such as Pb, Cr, Mn, As and Sn. Earlier studies reported that, emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Gupta et al., 2012; Sharma et al., 2016; Jain et al., 2017; Keerthi et al., 2018; Mukherjee et al., 2018, Pawar et al., 2020)*. Also, As, Fe, Cl^-, Br & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles *(Kumar et al., 2001; Patil et al., 2013; Rai et al., 2016; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018)*.

Factor 2: Vehicular Emissions

Factor 2 accounted for 16.17% of total $PM_{2.5}$ Pollution with major indicators such as OC, K, Fe, Zn, and Ni (~42.62%, 12%, 11%, 5.90%, and 4.03%) and minor indicators such as Al, Cd, Al, Pb, and Mn. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017; Mukherjee et al., 2018, Pawar et al., 2020)*.

Factor 3: Industrial Emissions

Factor 3 was identified as Industrial emissions by the presence of tracers, such as OC, Cl^-, SO_4^{2-}, K, Zn, and Mg (~35.2%, 5.33%, 5.63%, 5.81%, 5.31%, and 5.71%) with minor indicators such as Ag, Cd, Zn, Ti, Fe, and Si suggest the source of Industrial emissions/fossil fuel combustion contributed to about 25.65%. of total PM_{10} Pollution. As per past studies, As Cl^- along with SO_4^{2-} have been widely used as a marker of coal combustion in power plants *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. K, EC, OC, Al, Cu are the indicators of wood based and biomass-based boilers for industrial process *(urbanemissions.info)*. Fe, Cr are the indicators of industrial emissions as these elements are greatly used in various industries like machinery, battery, and electroplating purposes (Taghvaee et al., 2018).

Factor 4: Resuspended Road Dust/Wind Blown Dust

Factor 2 was identified as Resuspended Road dust/ Wind Blown Dust by significant levels of Al, Si, K, Ti, Zn, Fe, and OC (~11.84%, 3.99%, 5.53%, 4.89%, 7.28%, 8.41% and 39.59%) and minor indicators such as Ca^{2+}, Mg and Mn contributed to 20.44% of total $PM_{2.5}$ emissions. Al, Si, and Ti are major indicators of resuspended due to vehicular movements and wind-driven airborne dust from surface soils and paved roads *(Gupta et al., 2011; Rai et al., 2016; Zong et al., 2016; Buyan, 2018)*. Fe, Ca, Na 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

Factor 5: Crustal Dust/ Biomass Burning

Factor 5 is identified as Biomass burning and Crustal dust which accounted for 22.57% of total $PM_{2.5}$ Contribution, with major indicators such as OC, Ca^{2+}, SO_4^{2-}, Ti, Mg, and Na (~8.91%, 7.93%, 19.16%, 12.70%, 10.84%, and 10%) with minor indicators like Fe, Zn, K^+, and Cl^-. There have been many studies in the past suggesting that Ca^{2+} and Ti are major indicators for Crustal Dust *(Patil et al., 2013; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017, Mukherjee et al., 2018; Garaga et al., 2020).* Also, OC, K, K^+, and SO_4^{2-} are clear indicators of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et al., 2018; Garaga et al., 2020)*. The modal could not differentiate all the sources as the major indicator species of these sources were overlapping with each other.

Table 4.2 : Percentage Source Contribution for Aurangabad

Most likely source(s)	PM_{10}	Most likely source(s)	$PM_{2.5}$
Resuspended Road Dust/ Wind Blown Dust	21.02	Fossil Fuel Combustion/ Vehicular	15.16
Crustal Dust	16.63	Vehicular Emissions	16.17
Construction Dust/ Fossil Fuel Combustion	20.63	Industrial Emissions	22.65
Industrial/Biomass Burning	21.32	Resuspended Road Dust/ Wind Blown Dust	20.44
Vehicular Emissions	20.40	Crustal Dust/ Biomass Burning	22.57

4.4 Positive Matrix Factor Analysis Conclusion

After PMF analysis, five factors were identified contributing to both fraction of the PM. 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 imprecise contribution of Resuspended Road Dust is around (~20%), Crustal Dust (~16-22%), Vehicular Emission (~16-20%), Biomass Burning (~22%) and Fossil Fuel Combustion (~15-20%). The contribution of Biomass burning, Crustal dust, and Industrial emissions dominated in the $PM_{2.5}$ size range, whereas Road dust resuspension/ windblown dust, construction dust, and Fossil Fuel Combustion contributions dominated in the PM_{10} size range.

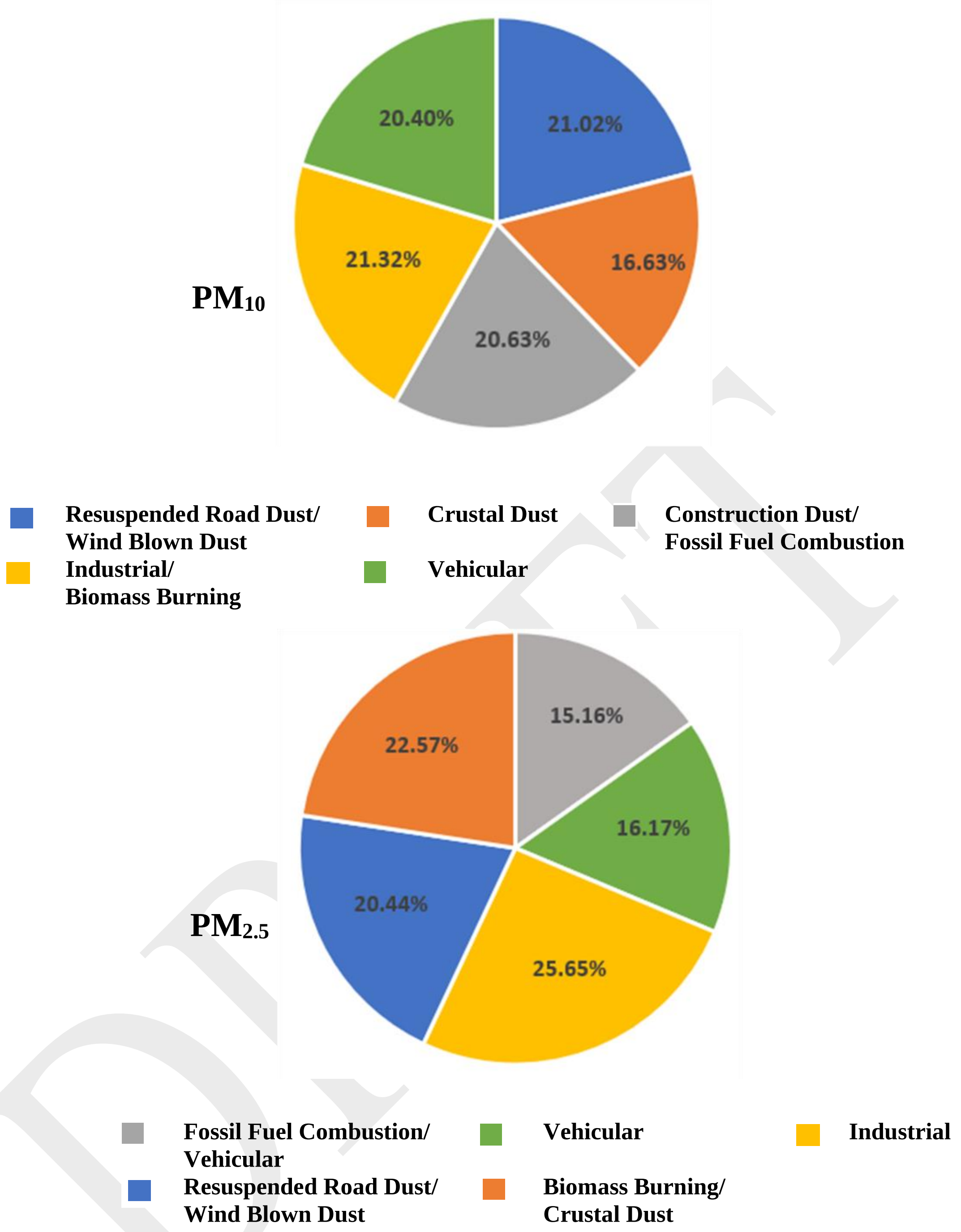


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Aurangabad City

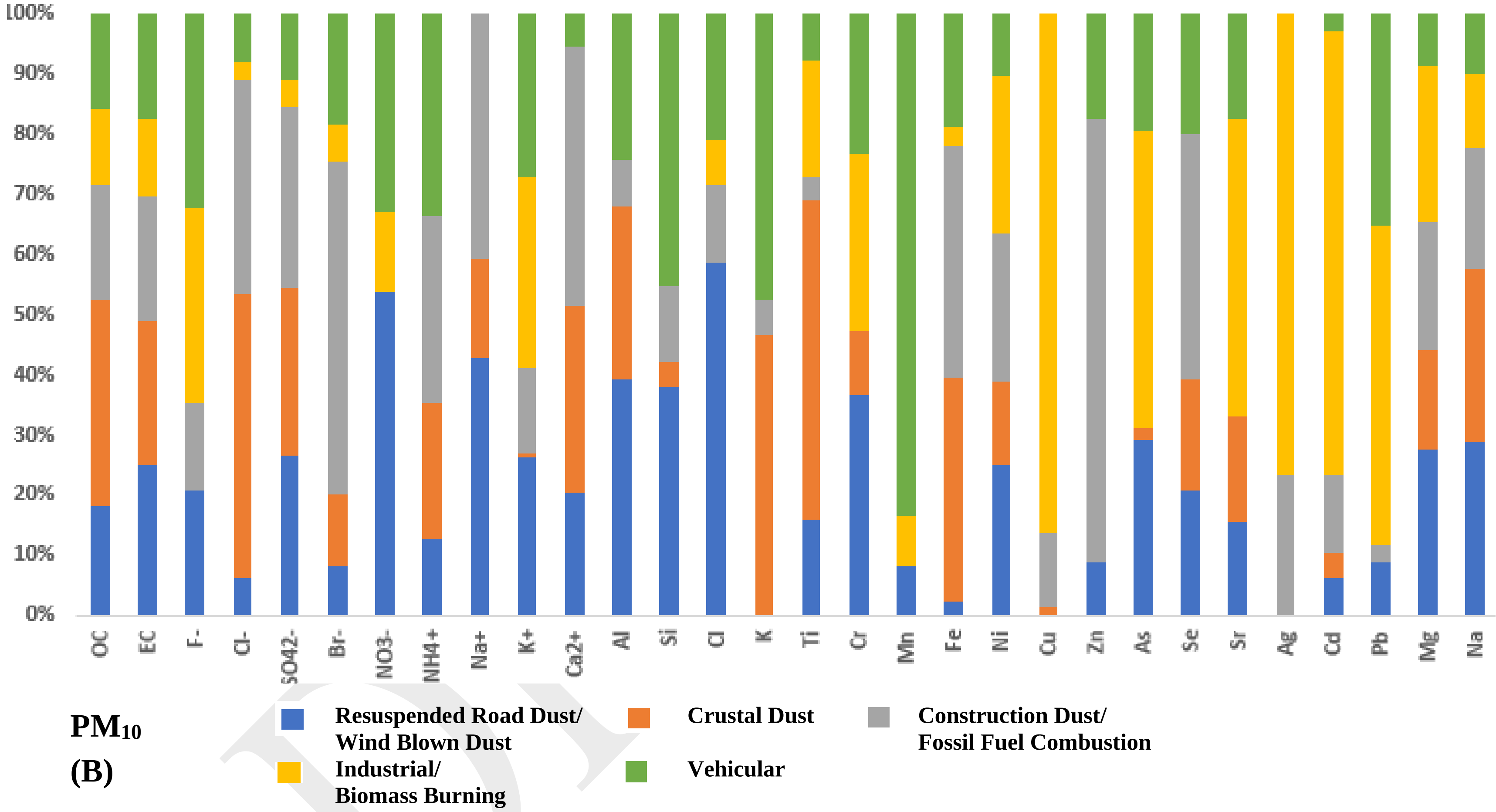
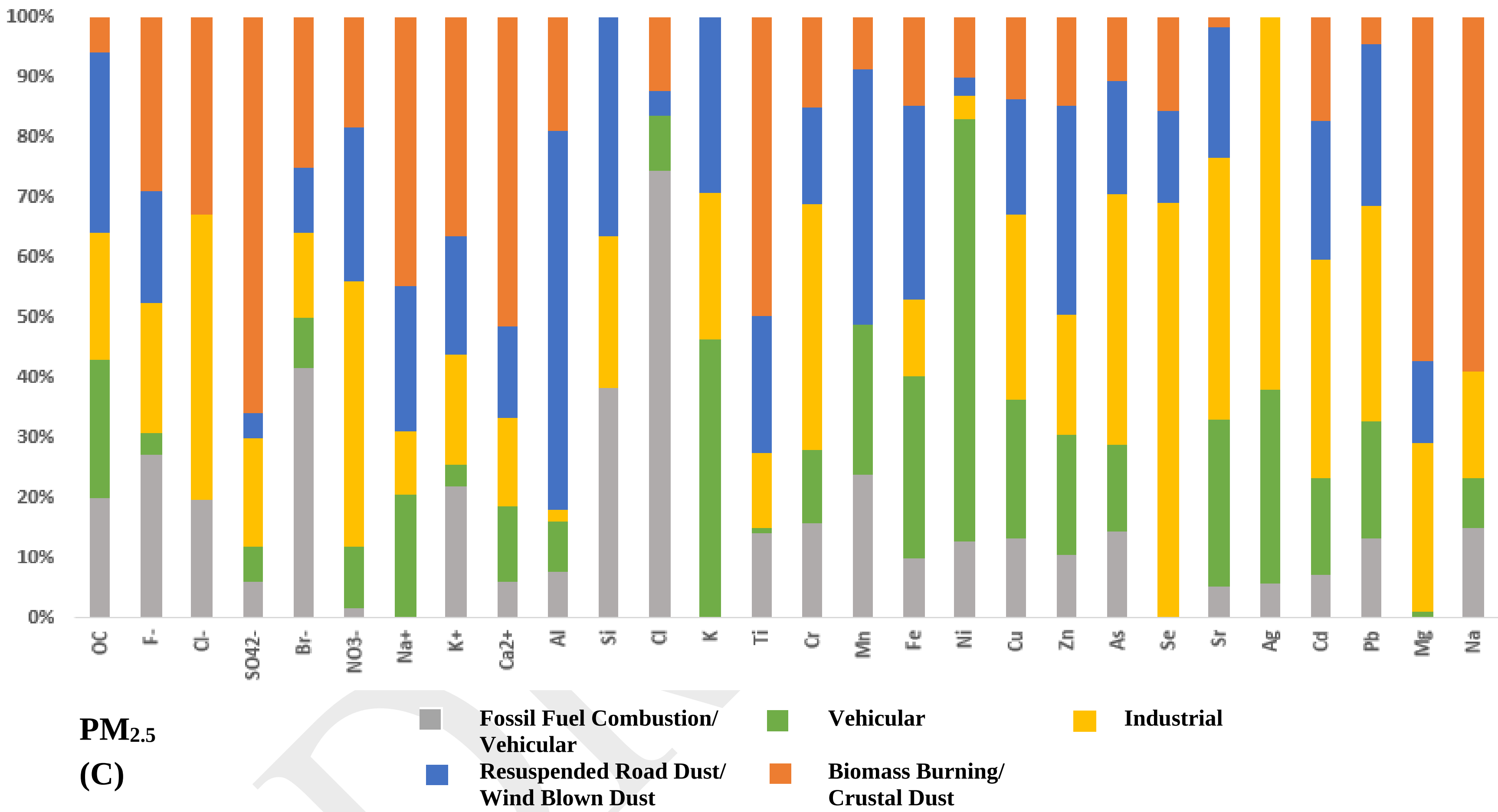


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Aurangabad City



$PM_{2.5}$ (C)

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

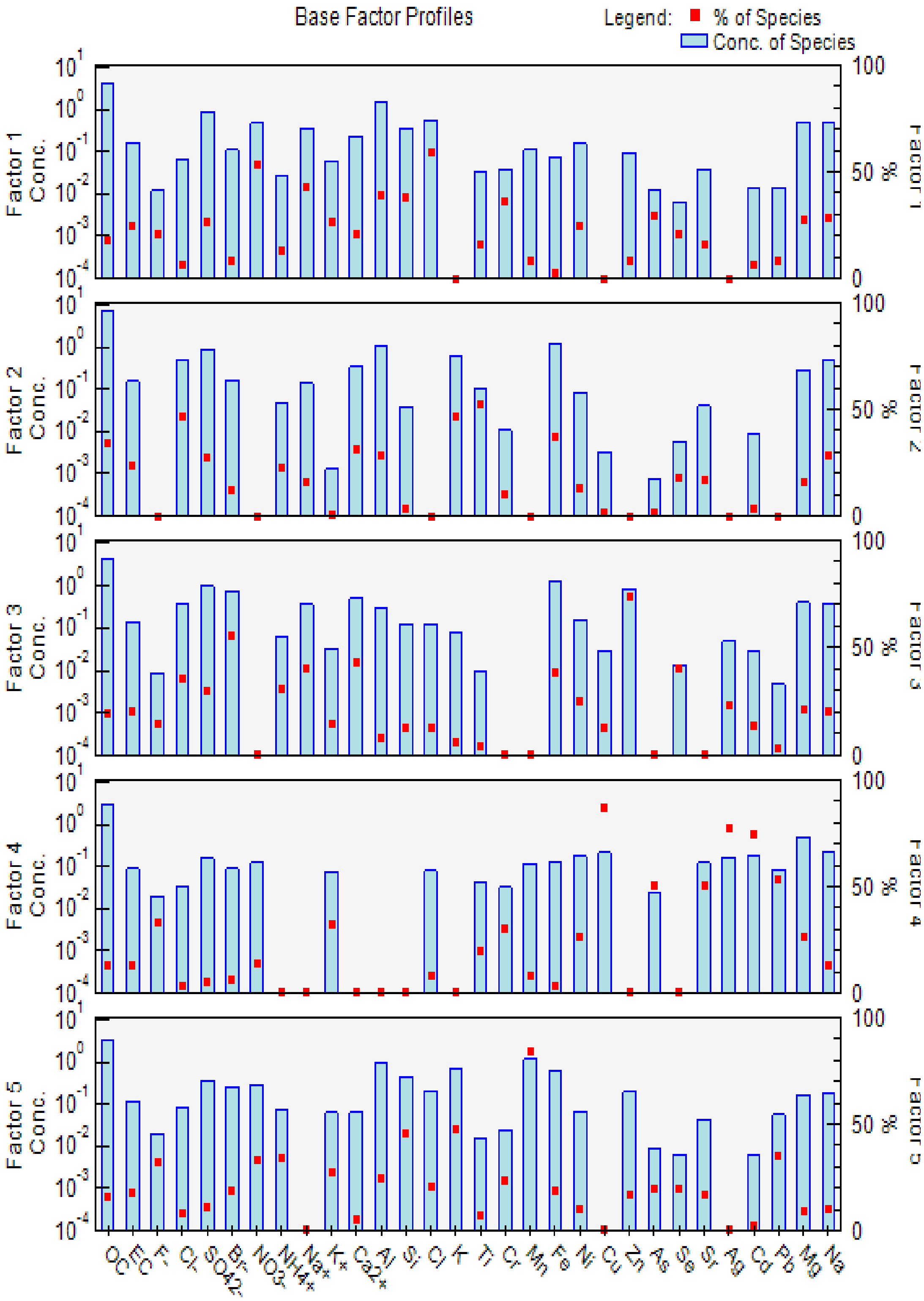


Figure 4.2 a : PM_{10} Base Factor Profiles

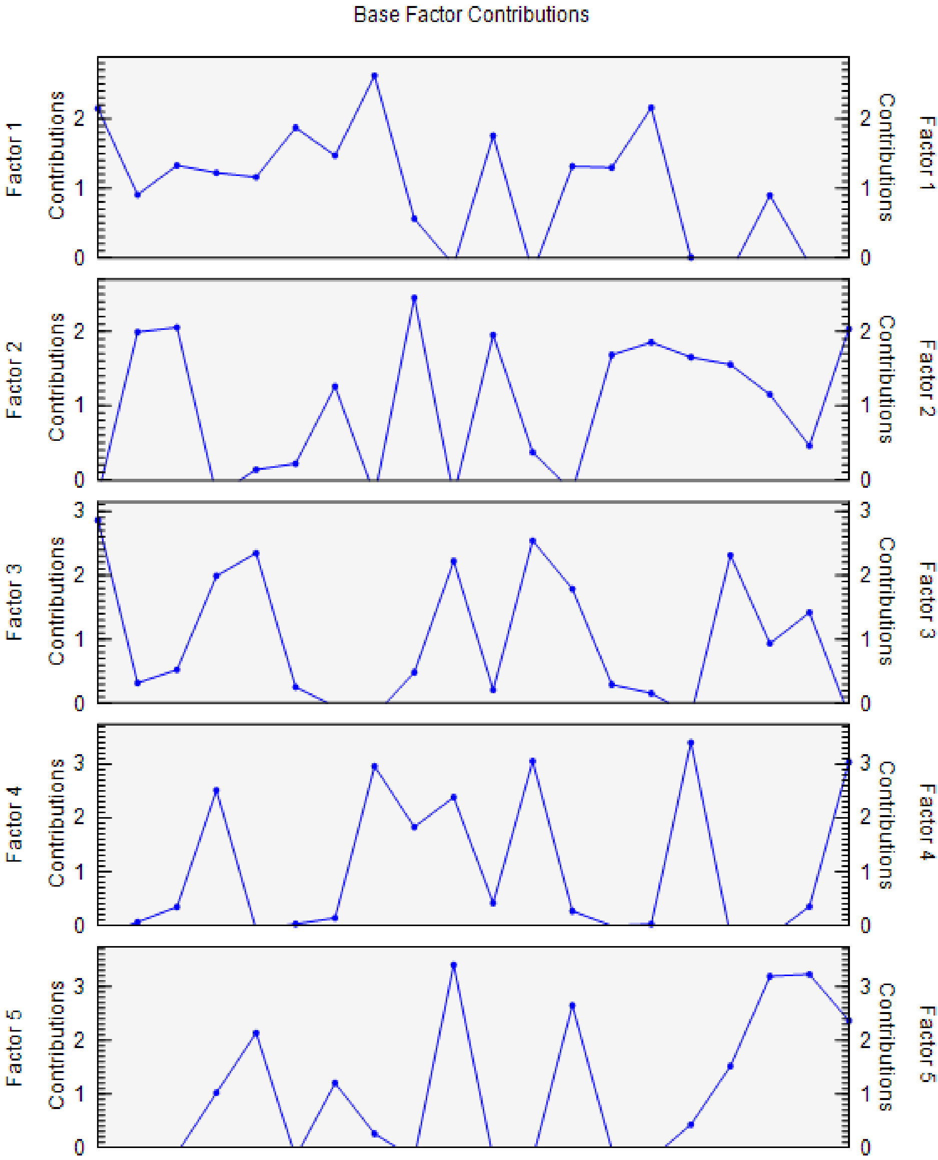


Figure 4.2 b : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, SO_4^{2-}, Al, Cl, NO_3^- *K^+, Ca^{2+}, Cl^-, Zn, Fe, Mg, Na*	21.02	Resuspended Road Dust/ Wind Blown Dust
Factor 2	OC, SO_4^{2-}, Al, K, Fe *Mg, Ca^{2+}, Br^-, Na*	16.63	Crustal Dust
Factor 3	OC, Br^-, SO_4^{2-}, Fe, Zn *Na^+, Cl, Ca^{2+}, Mg, Al*	20.63	Construction Dust/ Fossil Fuel Combustion
Factor 4	OC, Mg, Cu *K^+, Cl, Fe, Mn Ni, Ag*	21.32	Industrial/Biomass Burning
Factor 5	OC, Al, K, Mn, Fe *Zn, Cl, Br^-, Ni and NO_3^-*	20.40	Vehicular Emissions

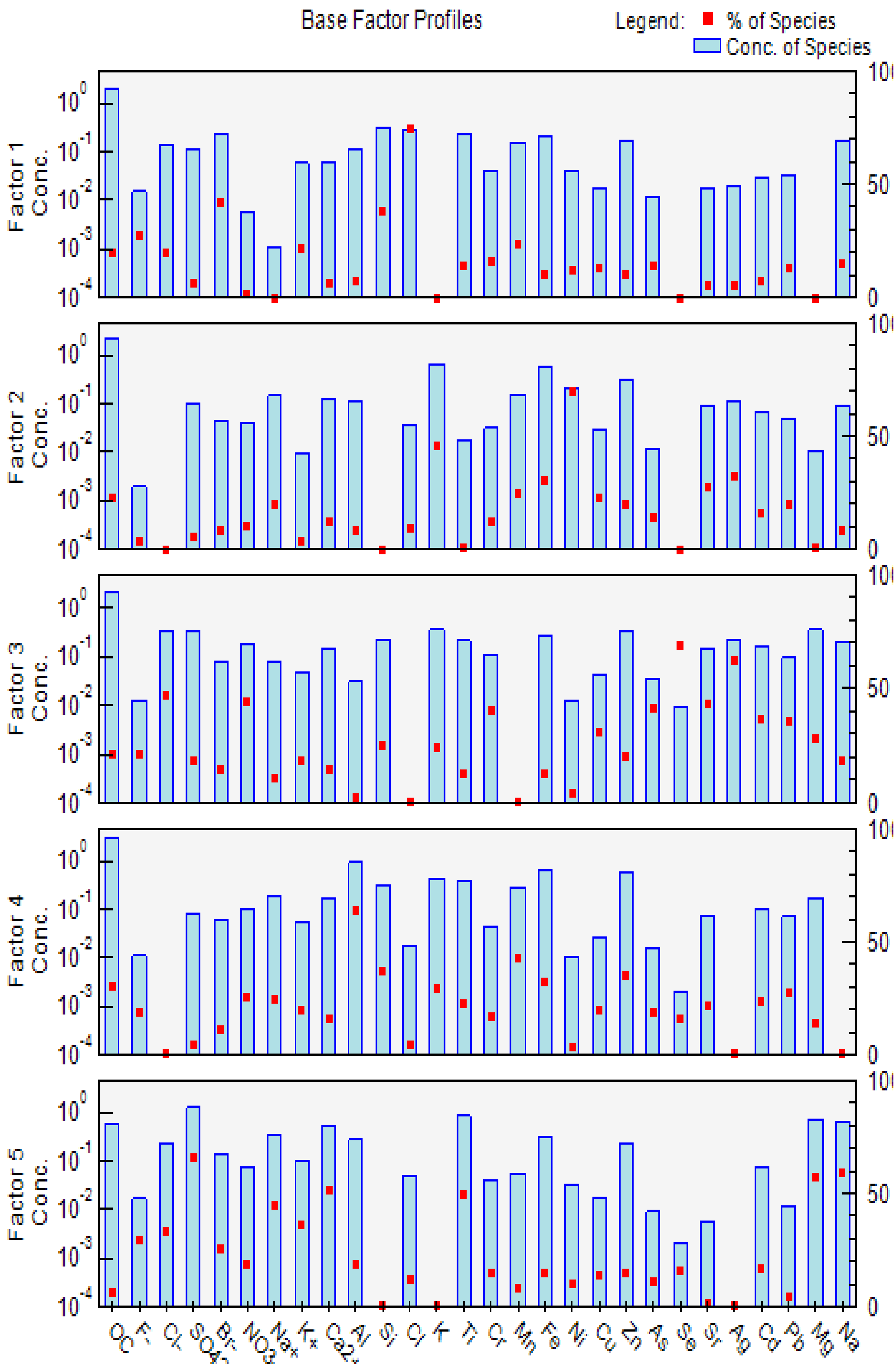


Figure 4.2 c : $PM_{2.5}$ Base Factor Profiles

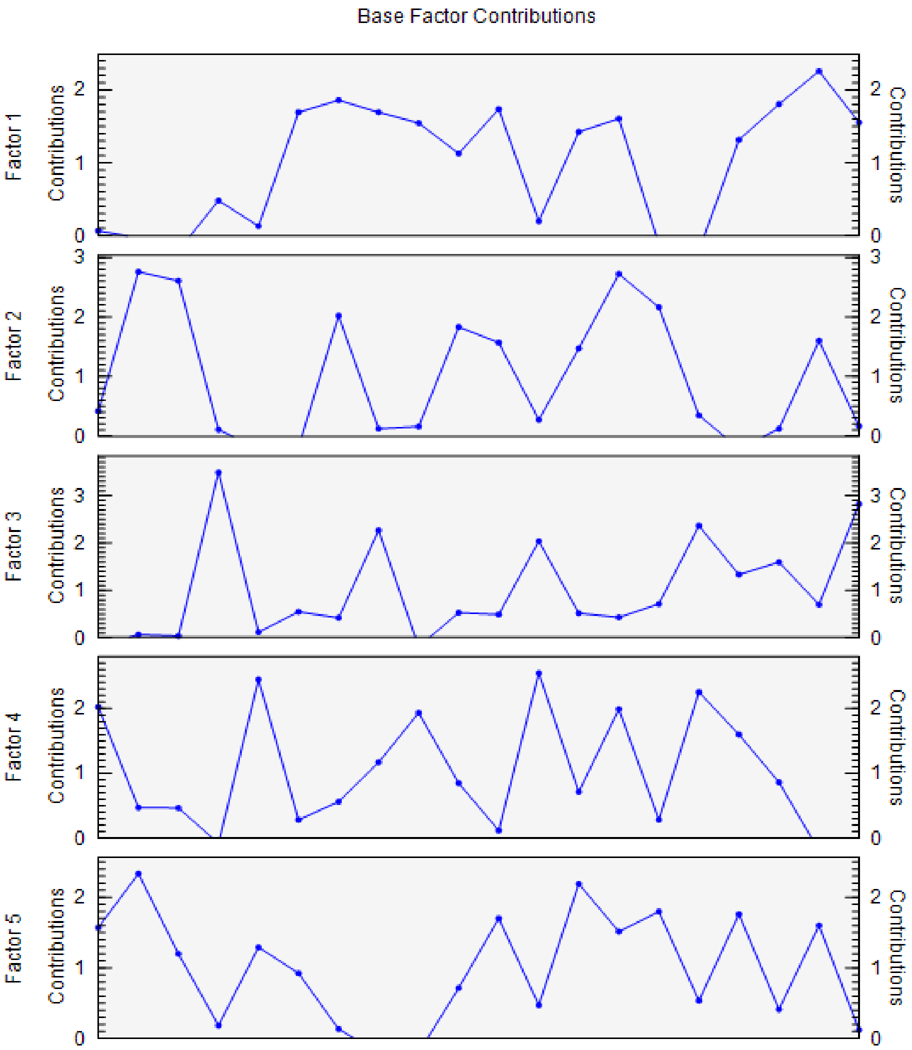


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, Si, Cl, Ti, Zn, Fe *Pb, Cr, Mn, As, Sn*	15.16	Fossil Fuel Combustion/ Vehicular
Factor 2	OC, K, Fe, Zn, Ni *Al, Cd, Al, Pb, Mn*	16.17	Vehicular Emissions
Factor 3	OC, Cl^-, SO_4^{2-}, K, Zn, Mg *Ag, Cd, Zn, Ti, Fe, Si*	22.65	Industrial Emissions
Factor 4	Al, Si, K, Ti, Zn, Fe, OC *Ca^{2+}, Mg, Mn*	20.44	Resuspended Road Dust/ Wind Blown Dust
Factor 5	OC, Ca^{2+}, SO_4^{2-}, Ti, Mg, Na *Fe, Zn, K^+, Cl^-*	22.57	Crustal Dust/ Biomass Burning

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.

In Emission Inventory, the top contributors to PM emissions estimated are re-suspension of road dust (52%), pollution from industries (21%) and vehicular source (21%). Line sources: The emission loads for PM_{10}, $PM_{2.5}$, NOx, HC and CO from vehicular category are found to be 1.6, 0.7, 8.8, 6.2 and 11.3 tonnes per day respectively. The maximum emission load of particulates is from heavy duty vehicles (70.3%). The emission load for PM_{10} and $PM_{2.5}$ from re-suspension of road dust by the movement of vehicles is estimated to 4.1 and 1.2 TPD. Majority of the Industries which came up in the city or Industrial areas are Automobiles, bulk drug units, distilleries, breweries, electroplating industries, and pharma industries. Emission from industries occurs as a result of various industrial activities happening in different categories of industries falling under the study area. The emissions are caused due to burning of different types of fossil fuels by industries. The different pollutants are released through chimneys/stacks to the surrounding area. It can be observed that the most common fuels used in the industries of this region are furnace oil, coal and LPG. The emission load for PM_{10}, $PM_{2.5}$, SOx, NOx and CO for point source is estimated to 1.6, 0.9, 1.7, 2.2 and 2.0 tonnes per day. It was observed that Petcoke fuel is used in Aurangabad on larger scale. In Area Sources, the total fuel consumption other than domestic gas is 1578, 631, 63, 1262 and 6571 Kg/month for Wood, Dung cakes, Crop residue, Coal and Kerosene respectively. Due to the recent policy change from the government under PMUY, the consumption of LPG has grown in slum areas. Along with LPG, slum population use locally available resources such as wood, coal, kerosene etc. The total LPG consumption of hotels in the city is around 1000 Kg/day and that for coal, wood and kerosene are 17 Kg/day, 72 Kg/day and 22 litres/day. The emission load for PM_{10}, $PM_{2.5}$, SOx, NOx and CO for area source is estimated to 0.5, 0.3, 0.05, 0.12 and 2.5 tonnes per day.

The locations of monitoring selected for Ambient Air Quality Monitoring were Dr. Babasaheb Ambedkar Marathwada University (background Site), Garkheda (Residential Site), Padampura (Commercial Site) and MPCB Office (Industrial Site). Most of the factors identified in source apportionment study of Aurangabad City were observed to be in as mix contribution form, which reflected collinearity of the factor species from different sources. 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. The major sources identified for emissions of PM_{10} and $PM_{2.5}$ load were Biomass Burning, Fossil Fuel Combustion, Vehicular Tail-Pipe Emissions, Industrial Emissions, Re-suspension of Road Dust, Wind Blown Dust, Crustal Dust and Construction Dust. The highest contributing source identified for PM_{10} load is a mix of emissions from Industrial activities and Biomass Burning sources (21.3%), followed by mix of emissions from Re-suspension of Road Dust and wind-blown dust (21%). Whereas, the highest contributing source identified for $PM_{2.5}$ emission load is from Industrial sources (22.65%), followed by mix of emission from Crustal Dust and Biomass Burning sources (22.57%). 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 Overview

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 Aurangabad 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 Aurangabad 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 Aurangabad city. Monthly windrose diagram is plotted and the same is shown in **Figure 5.1**. It can be seen that January to March is a period of very low wind with predominant wind from North. Strong winds starts in April from North-West. Gradually the summer sets with predominant wind of more than 6 m/s from the West. July bring monsoon wind, which is very strong and is from the west. In order to understand the monthly variation of wind speed, its frequency distribution is plotted and 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.[$\mu g/m^3$]	Area Emission	Industry Emission	Vehicle Emission	Res. Road Dust Emission	City Emission
PM_{10}	100	0.48	1.6	1.6	4.05	7.73
$PM_{2.5}$	60	0.28	0.9	0.7	1.18	3.06
NOx	80	0.12	2.20	8.80		11.12
SOx	80	0.05	1.70			1.75

Since the standard weighted emission load of PM_{10} is the highest, the source dispersion modelling is carried out only for PM_{10}. The GLC of all other pollutant will be below the values obtained for PM_{10} as the model option is conservative pollutant. With this consideration dispersion simulation is carried out for PM_{10} only.

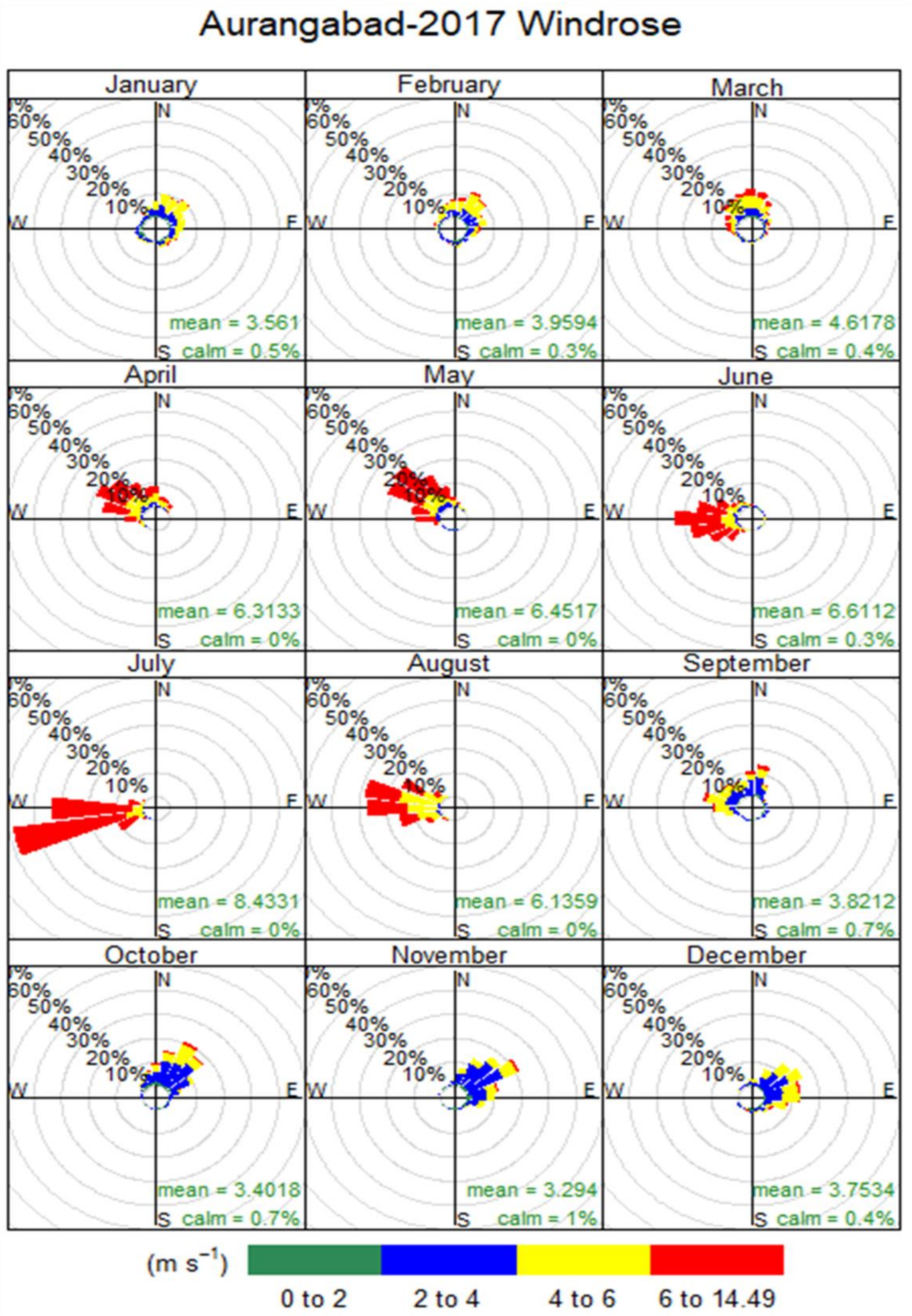


Figure 5.1: Monthly Windrose Diagram of Aurangabad

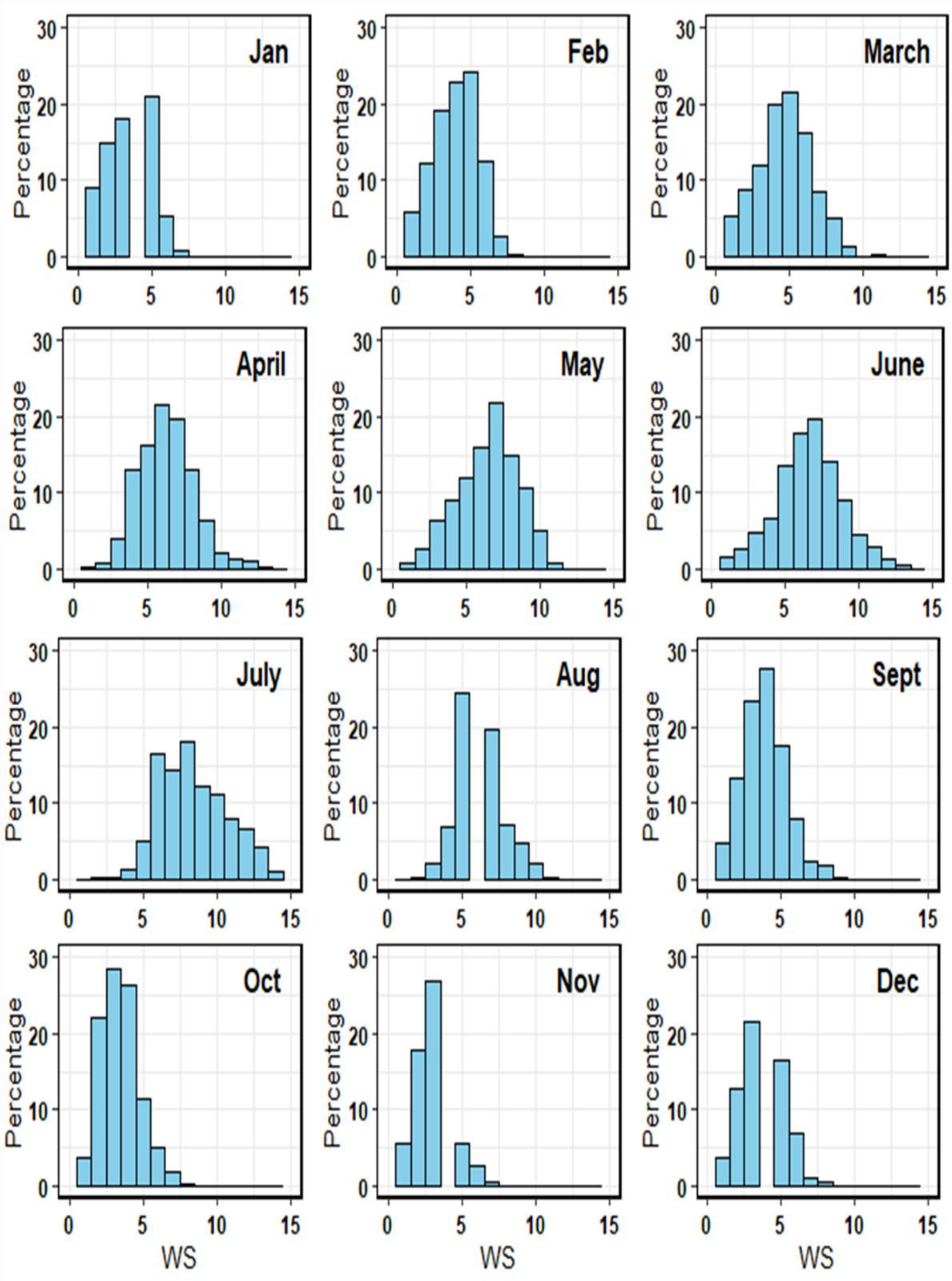


Figure 5.2 : Monthly Wind Speed Frequency in Aurangabad

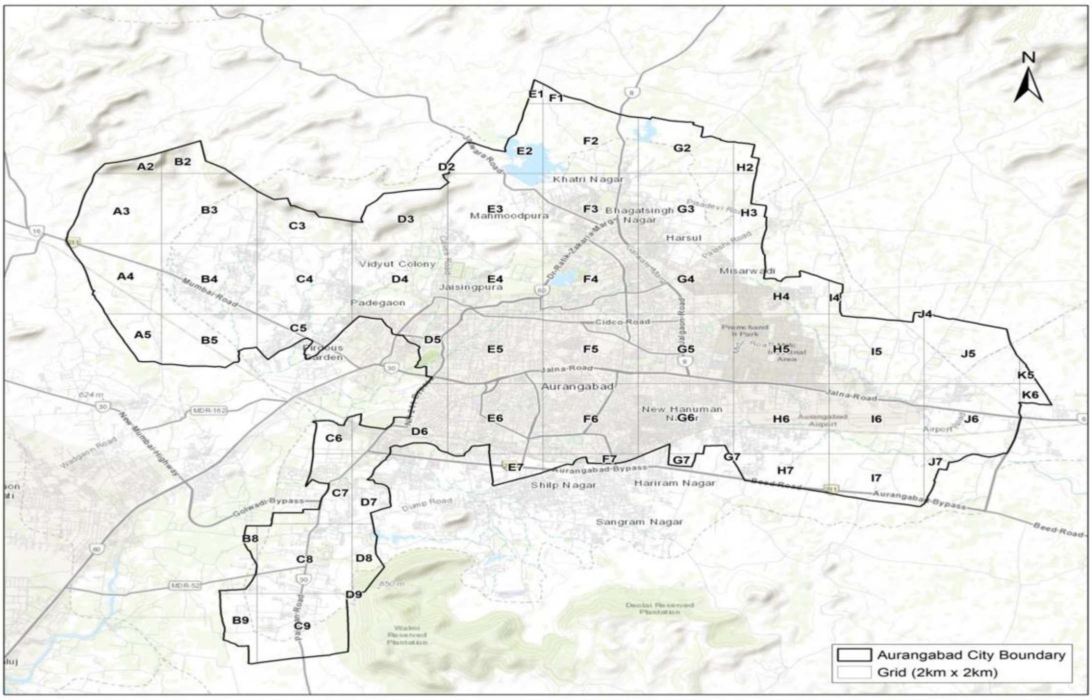


Figure 5.3 : Grid Over Aurangabad City for Area Source Emission

Figure 5.3 shows the grid setup on the Aurangabad city for the purpose of finding the emission load for each grid area. 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 $g/s/m^2$. **Table 5.2** shows the emission load from each grid that is used for dispersion modelling.

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

No.	ID	PM10 Emission Rate [kg/d]	No.	ID	PM10 Emission Rate [kg/d]
1	B4	71.00	18	F2	14.50
2	B5	0.50	19	F3	108.88
3	B9	7.30	20	F4	97.00
4	C4	8.50	21	F5	95.50
5	C5	126.50	22	F6	57.00
6	C6	168.50	23	F7	1.00
7	C7	199.50	24	G2	21.46
8	C8	235.00	25	G3	63.50
9	D4	1.00	26	G4	82.50
10	D5	57.50	27	G5	852.00
11	D6	60.00	28	G6	79.00
12	D7	74.00	29	G7	71.50
13	E3	14.50	30	H4	472.50
14	E4	17.66	31	H5	854.00
15	E5	161.50	32	H6	267.00
16	E6	119.50	33	I6	76.50
17	E7	16.61	34	J6	3.82

With this emission load, the source dispersion modelling is executed and the ground level concentration (GLC) of pollutant is determined

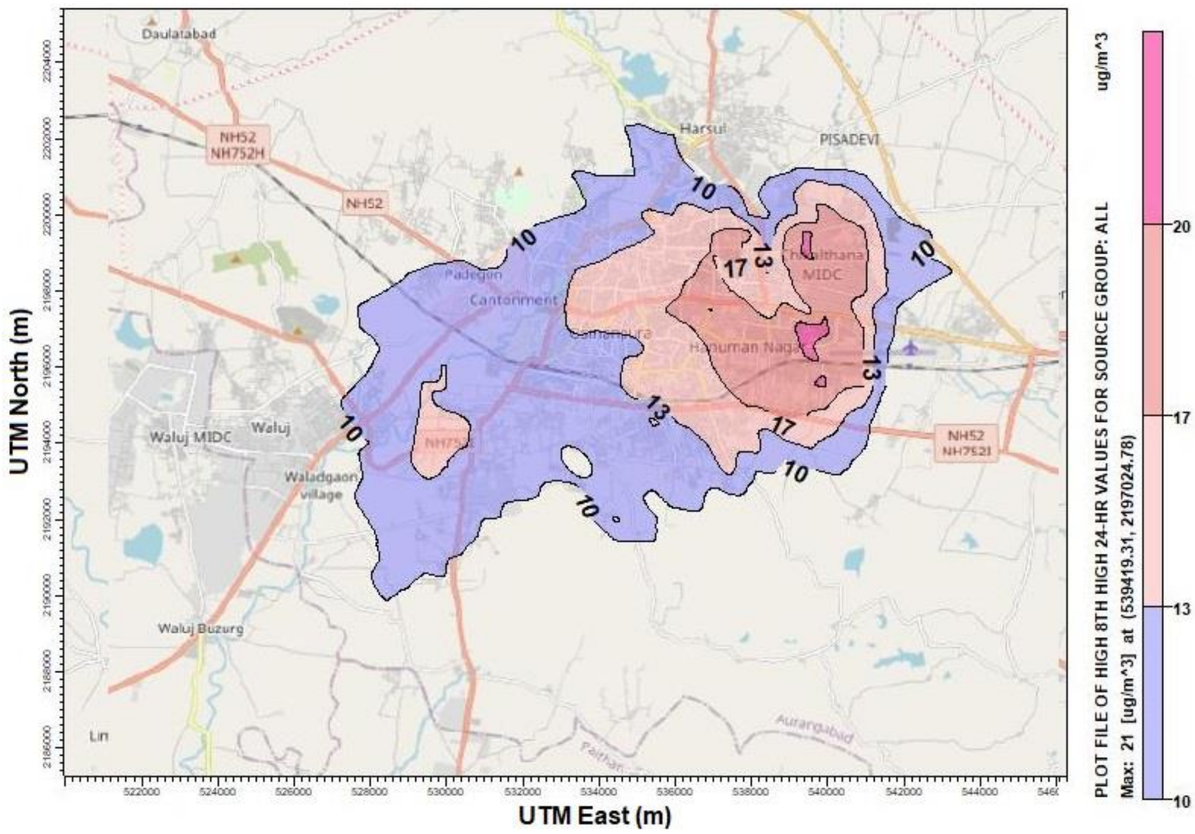


Figure 5.4: GLC of PM_{10} in Aurangabad Determined by Simulation using AERMOD

Figure 5.4 shows the GLC of PM_{10} in Aurangabad city. It can be seen that the maximum GLC of PM_{10} is very low and is around 20 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 Aurangabad City

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

Table 6.1: Action Plan for Control of Air Pollution

Sources	Short Term-2019	Long Term-2022	Action Required
Line Source			
Vehicles	10% reduction in emissions	30% reduction in emissions	• Launch extensive drives against polluting vehicles for ensuring strict compliance. • Increase in public transportation (No public transport buses yet in Aurangabad city. If Biodiesel used as a fuel, reduction will be more). • Prevent parking of Vehicles at non- designated areas. • Widening of roads and wall to wall pavement. • Steps for Promoting Battery operated vehicles. • Synchronize Traffic movements/Introduce Intelligent Traffic systems for Lane Driving. • Provide good public transport system. • Electric / Hybrid Vehicles. • OE-CNG for new public transport buses. • Bio-diesel (B5/B10: 5 - 10% blended). • Restrict commercial vehicles entering city by having ring roads.
The above mitigation measures reduce the line source emissions by 10% in short term and 30% in long term.			
Point Source			
Industry	To get the 10% reduction in emissions till 2019	To get the 30% reduction in emissions till 2022	• Action against industries doing high air pollution. • Alternate fuel (replacement of wood to Biomass briquettes, Indian coal to Indonesia or SA coal, ash content of briquettes after burning – 0.22%, One cubic meter (or approximately one ton) of briquettes produces as much heat as five cubic meters of air-dried and split firewood while burning, Briquettes produce 10 times less carbon dioxide than natural gas and 50 less carbon dioxide than coal).

Table 6.1 (Contd..) : Action Plan for Control of Air Pollution

Sources	Short Term-2019	Long Term-2022	Action Required
Industry (Contd..)			• Installation of CAAQMS. Installation/ up • gradation of air pollution control systems. • Regular audit of stack emissions for QA/QC. • Use of alternate fuel instead of pet coke at tyre manufacturing units
The above mitigation measures reduce the point source emissions by 10% in short term and 30% in long term.			
Area Source			
Fuel burnt Resi. and Commercial Cooking	10% reduction in emissions	50% reduction in emissions	• Household wood and cow-dung burning is to be reduced. Increase in LPG usage through Ujjawala Yojana scheme. • Alternate fuel options e.g. solar needs to be assessed and exercised. • Crop residue burning needs to be completely banned.
Domestic combustion			
Hotels, dhabas and open eat-outs			• Use of LPG in hotels and eateries.
Bakery			• Bakeries, electric ovens & LPG must be used.
Crematoria			• If wood replaced by electricity burners in Crematoria there will be less emissions of particulate matter. • Control equipments must be installed for air pollution control. • 50% Wood in each crematorium if replaced by biomass briquettes. This type of fuel used in crematoria gives 36% less emissions for $PM_{2.5}$ and 86% less SO_2 generation.
Solid waste/open burning	10% reduction in emissions	50% reduction in emissions	• On an urgent basis Aurangabad needs MSW dumping and treatment yard. • Penalty against people burning the MSW. • Policies against burning of MSW. • Implementation and penalty for societies not segregating waste which are generating MSW of 100 Kgs and more. • Awareness among people for segregating waste at source. • Bio-methanization and biogas plant need to be installed.

Table 6.1 (Contd..) : Action Plan for Control of Air Pollution

Sources	Short Term-2019	Long Term-2022	Action Required
Road dust and C&D	20% reduction in emissions	40% reduction in emissions	• New bypass for the city • Hand Sweeping / Mechanical sweepers • Cement Concrete roads • Wall to wall road pavement • No entry to heavy vehicles during day time. • Regular water spraying and maintenance of Bus depots, increase in green cover at the periphery of bus depot • Major traffic intersections to have water fountains • Enforcement of construction & demolition rules, implementation of measures for control of emissions during activity. • Control measures for fugitive emissions from material handling, conveying and screening operations through water sprinkling, curtains, barriers and suppression units. • Ensure carriage of construction material in closed/covered Vessels.
Assumptions or required actions to reduce the emissions: The above action plan shall reduce the PM_{10} emissions from construction activity and road dust.			

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

6.2 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, Aurangabad Municipal Corporation, Traffic police and District administration. Maharashtra State Pollution Control Board shall regularly review the implementation of aforesaid action plan.

6.3 Implementation Status

The Chief Secretary, Govt. of Maharashtra to convene the meetings with different concerned departments and direct for compliance of directions for implementation of air quality of Aurangabad. The Principal Secretary, Environment and Forest, Govt. of Maharashtra to also convene the meeting for follow up of the aforesaid directions. The Hon'ble Deputy Chief Minister to also review the issues subsequently for improvement of ambient air quality of Aurangabad.

Annexure – I

Design of a Clean Tandoor Community Kitchen System (CTCKS)

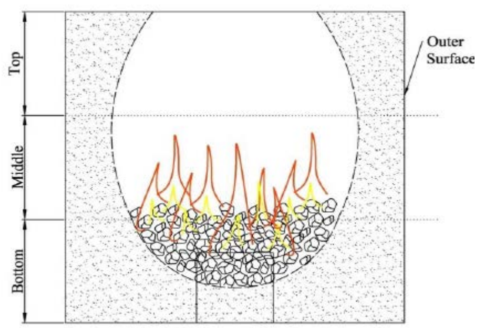
Design of a Clean Tandoor Community Kitchen System (CTCKS)

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.

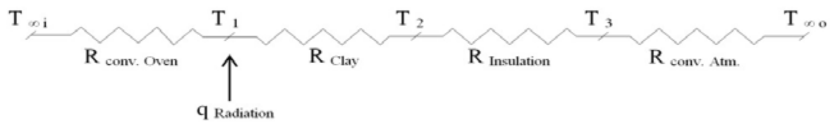
Advantages of pellet based tandoor also leads to reduced ash generation. Pellets based tandoor will also generate market for pellet industry and enable the use of agro-waste residues for development of an alternative fuel, promote employment generation in rural areas and would partly contribute to emission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

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



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

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

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

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

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

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

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).

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):

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

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

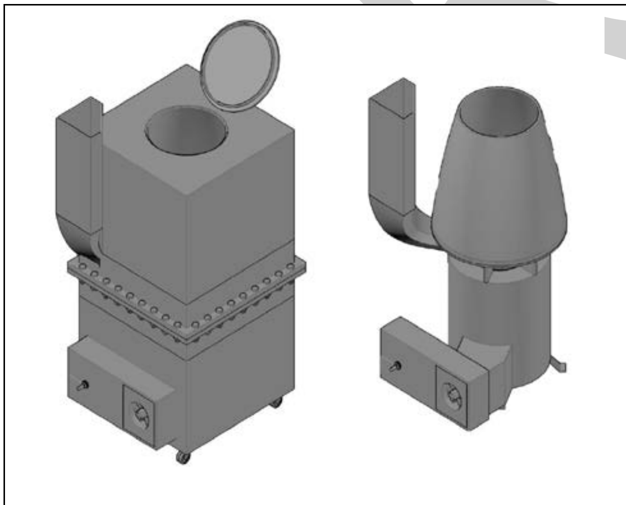


Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing

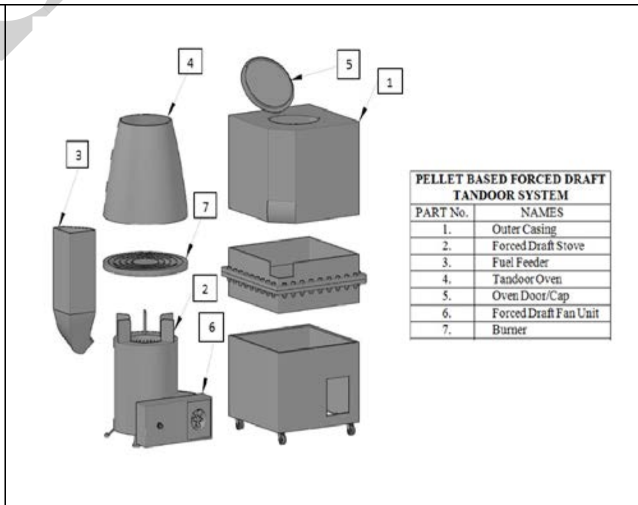


Fig. 2 Exploded view CTCKS: Inner Assembly & Outer Casing

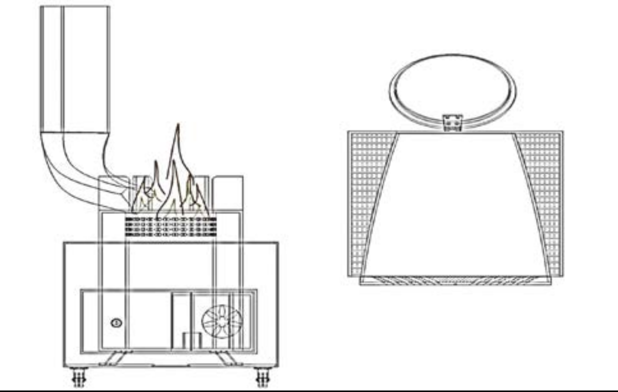
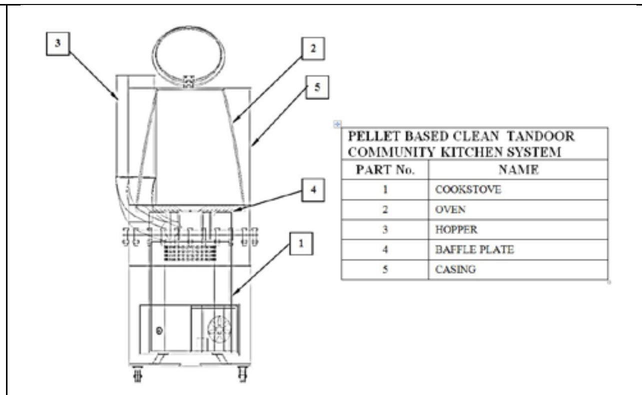
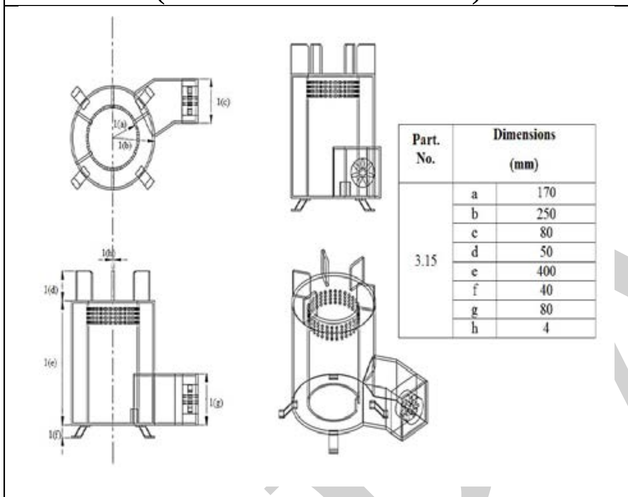


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)



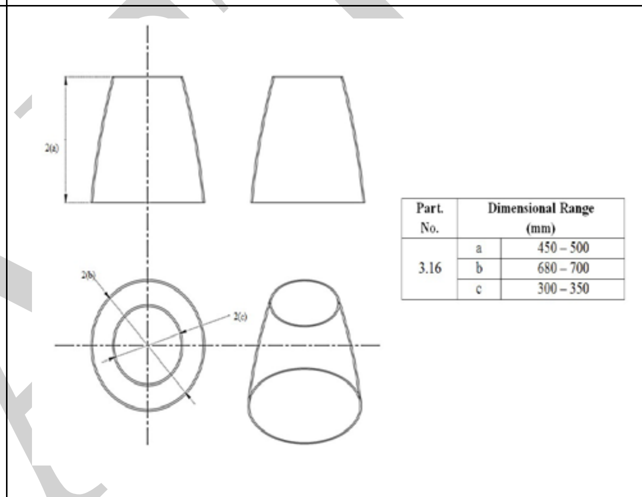
PELLET BASED CLEAN TANDOOR COMMUNITY KITCHEN SYSTEM	
PART No.	NAME
1	COOKSTOVE
2	OVEN
3	HOPPER
4	BAFFLE PLATE
5	CASING

Fig. 4 Line diagram of CTCKS



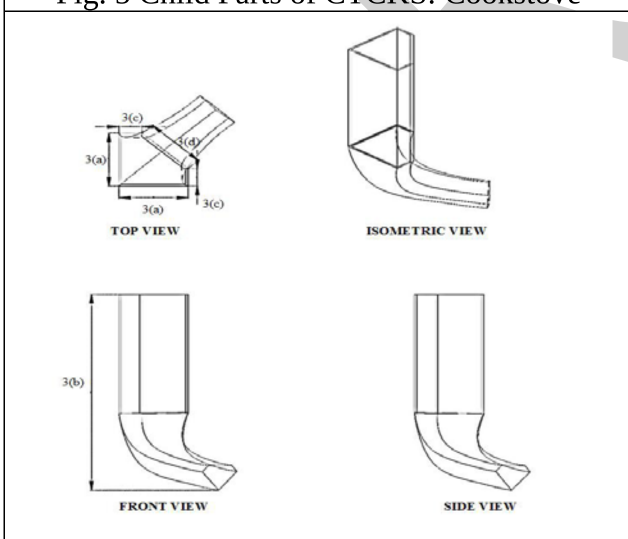
Part. No.	Dimensions (mm)	
3.15	a	170
	b	250
	c	80
	d	50
	e	400
	f	40
	g	80
	h	4

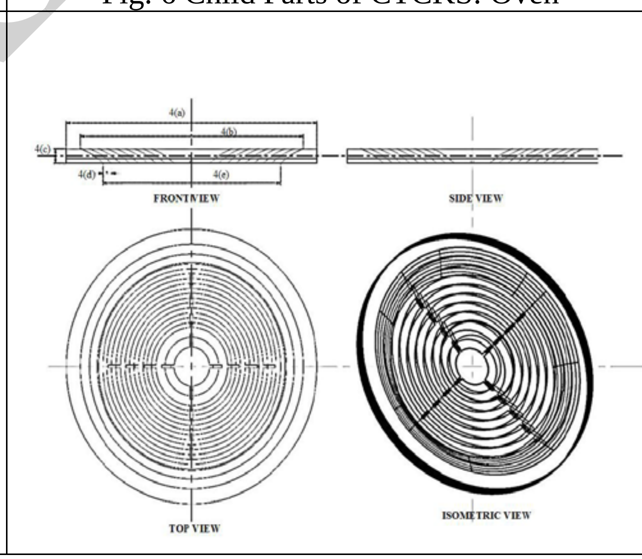
Fig. 5 Child Parts of CTCKS: Cookstove



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

Fig. 6 Child Parts of CTCKS: Oven



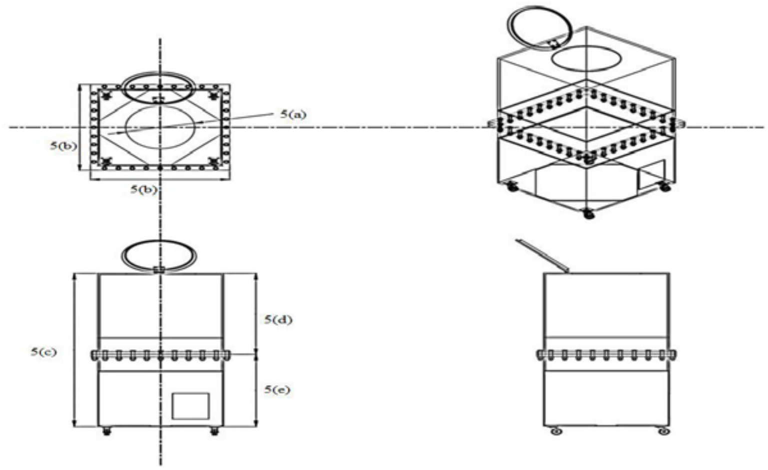


Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

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.

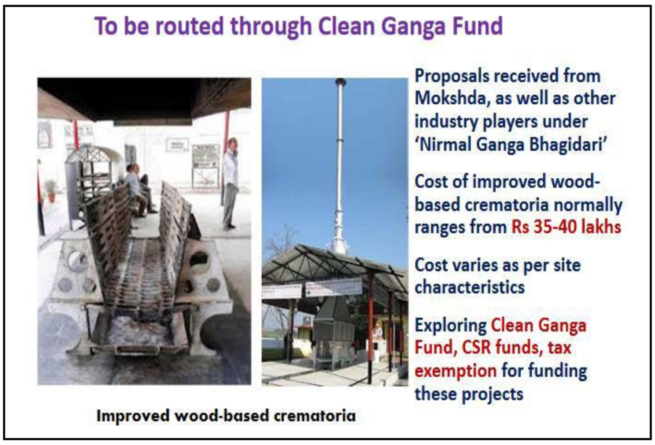
There has always been a controversy on the use of the electric crematoriums due to rituals as most persons follow the traditional burning of the bodies. In metropolitan cities it is promoted by the Government, private NGOs and environmentalists, but not to a great extent and most of these have failed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

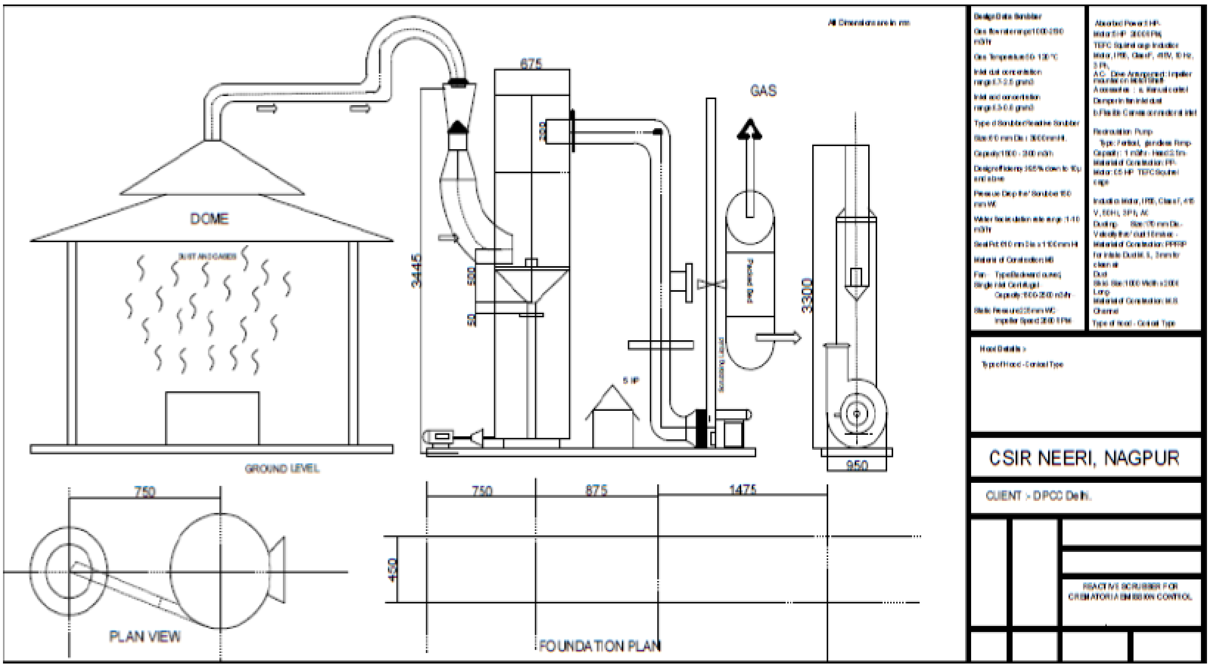


Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

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 12^{th} 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**.

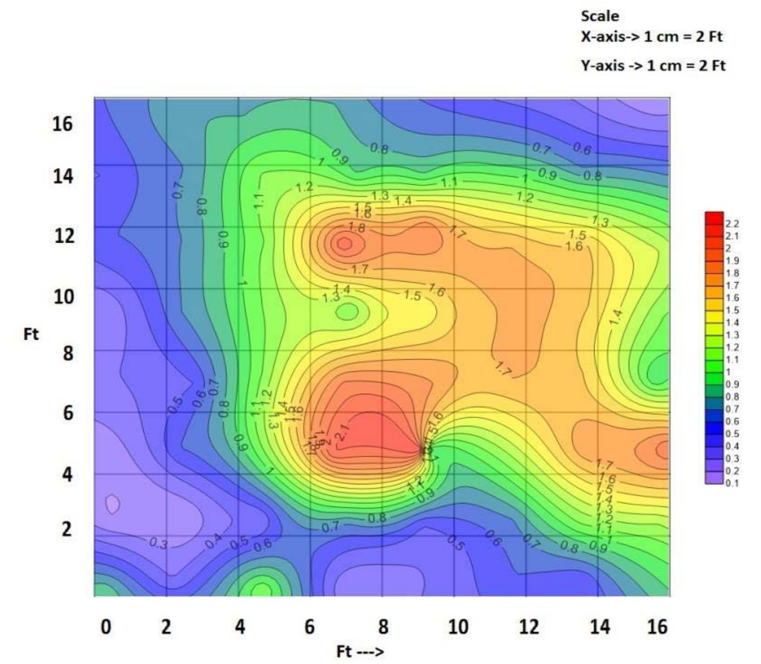


Figure 2 : Velocity profile of fumes during cremation

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.

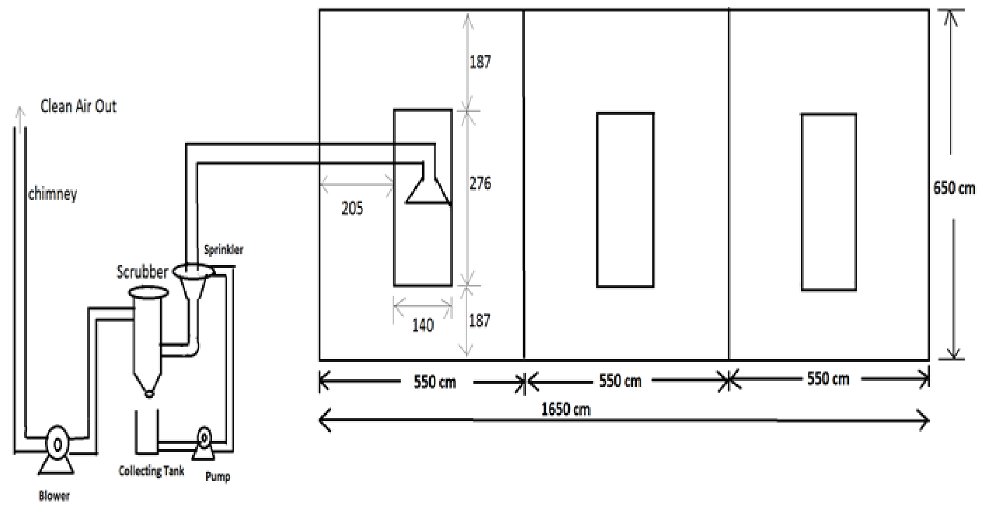


Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

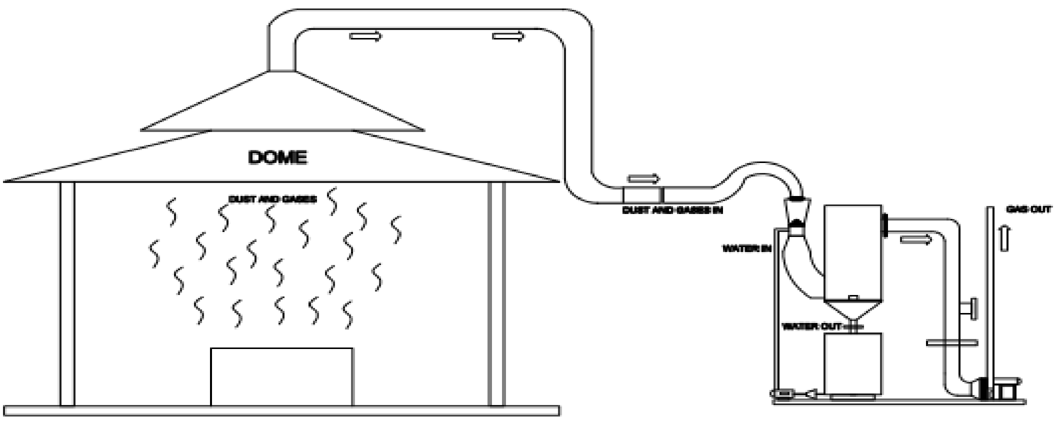


Figure 4 : Schematic view of Air Pollution Control System

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.

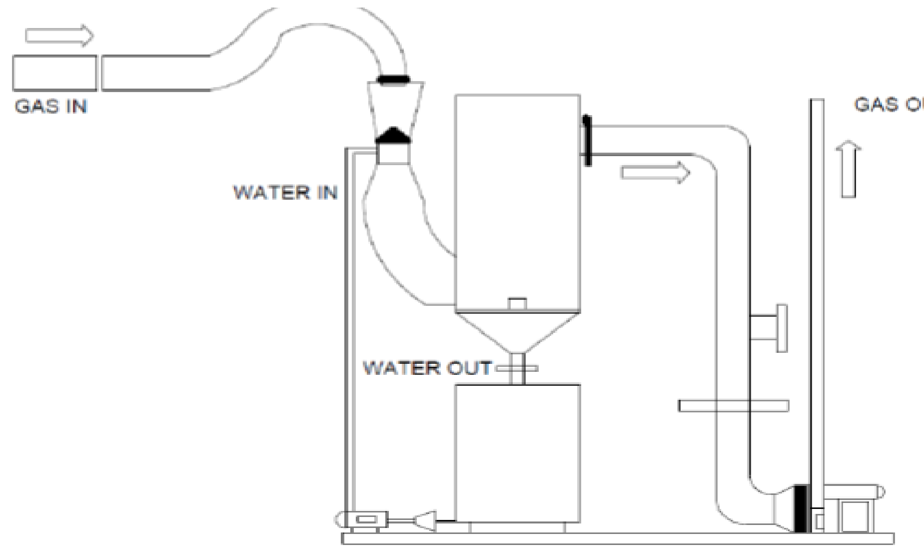


Figure 5 : Schematic of Reactive Scrubber

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.

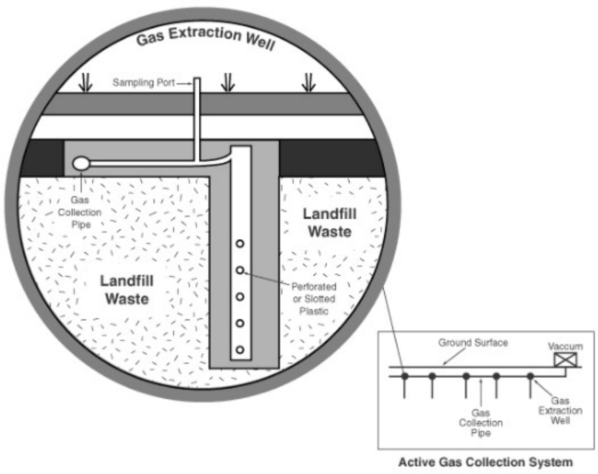
Most of the MSW generated is disposed of non-scientifically in open dumps, which causes a serious threat of landfill gas (LFG) emissions. The present note will focus on the landfill sites for the LFG emissions and designing the appropriate gas venting for the landfill sites.

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

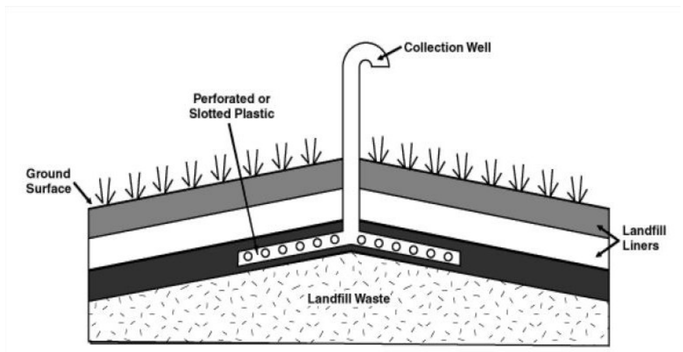
Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however, 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

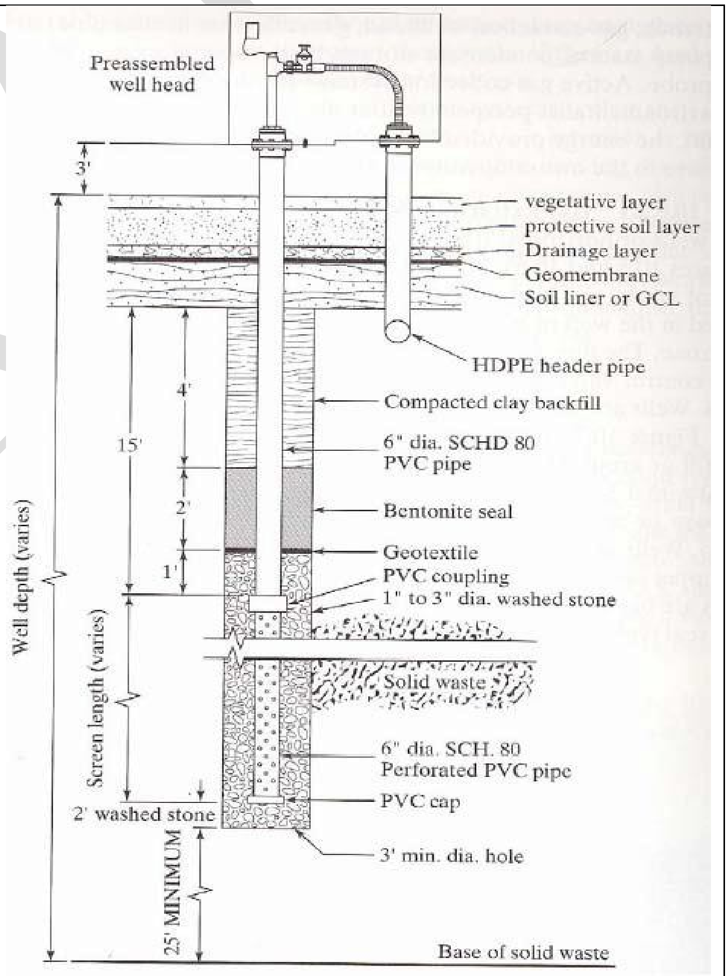
groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill as shown below. Horizontal 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 SO2 and NOX. 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).

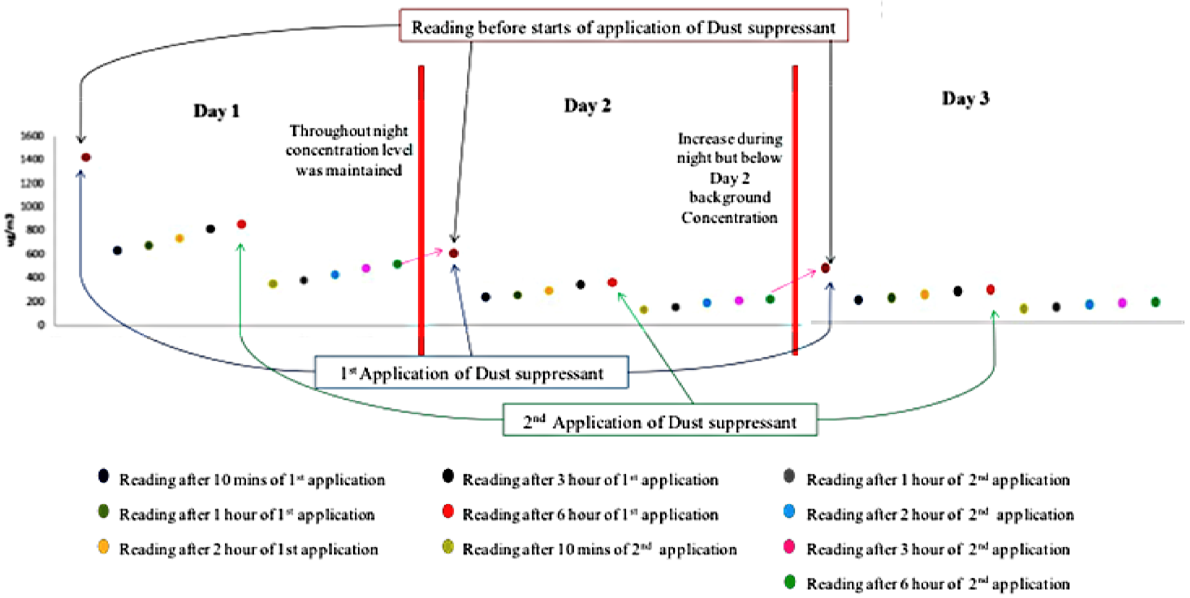
Advantages

- 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.

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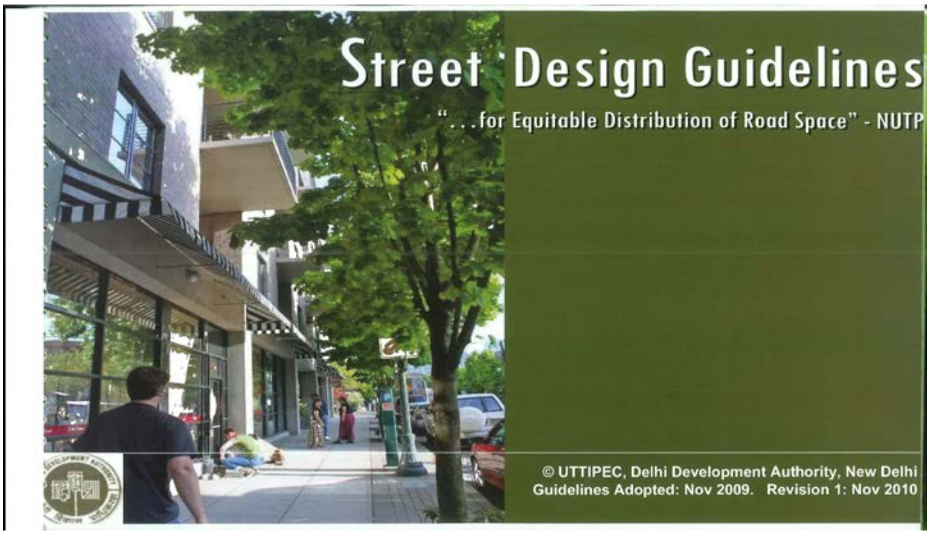
Building construction/demolition codes need to be used with specific reference to PM control. **UTTIPEC design manual has been recently created by Delhi Development authority for uniform roadside, drains, footpath and related design.** The same should be adopted for all future design for roads and pathways. 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

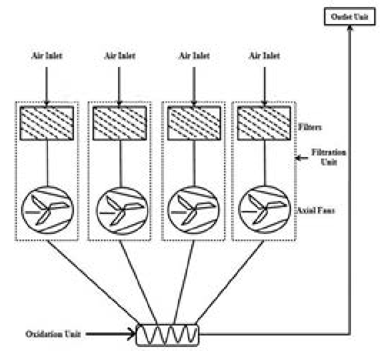
Air pollution is a local problem and its solution can be derived from technologies coupled with local conditions and requirements. Creating change in meteorological parameters like wind with the help of devices such as fans and also removal of the pollutant near to the source may help in reducing ambient 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.



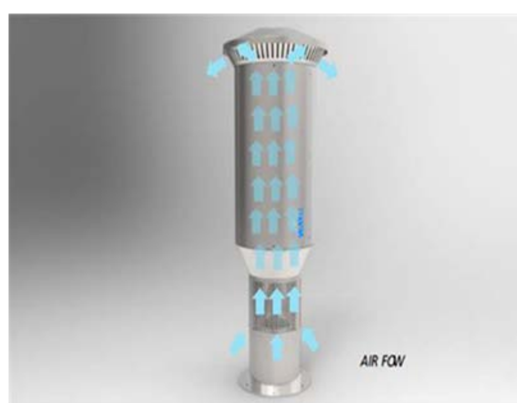
UV- TiO2 adsorption-photocatalytic oxidation has a lot of advantages. They are very efficient in removal of VOCs. Pichat et al. (2000) have shown that ozone can be directly eliminated by TiO_2 nanoparticles in a process that is promoted by both heat (in the ambient temperature range of 0° to 50°C) and 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.

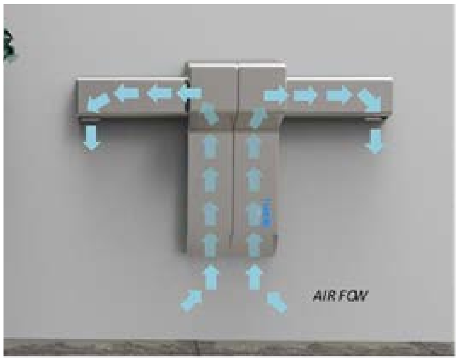
WAYU is a device jointly developed by IIT-CSIR-NEERI focused on controlling pollution in ambient air. WAYU has been successfully tested in a pilot project of 25 devices in Mumbai in collaboration with Maharashtra Pollution Control Board (MPCB). With an aim to solve the ever rising menace of air pollution 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

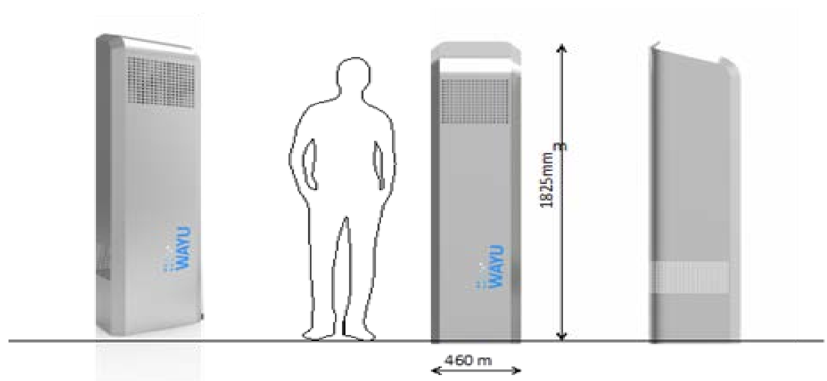


WAYU device improved design



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.