Draft Report On

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

(AMRAVATI CITY)

for

Maharashtra pollution Control Board

By

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&

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Chapter 1
Introduction

1.1 Background of the City

Amravati named after Ambadevi temple was called 'Audumbaravati or Udumbaravati' in ancient times due to the presence of a large number of Audumber trees in the region. Earlier, it was also known as Indrapur-the capital of lord Indra. In 17th century, the city was mainly owned by Mughal Aurangzeb, whereas in 1722, it was given as a gift to Bhosle by Shahu Maharaj, who maintained it. British government however conquered the city in late 18th century. Amravati city (21.30' 21.50'N; 76.35' 78.27'E, 343 MSL) includes the municipal boundaries and has total area of about 121.65 Sq. Km. The city is located on the National Highway NH-6 leading to Mumbai in the west and Kolkata in the east. Amravati has good road and rail connectivity with almost all important cities in India. Amravati district constitutes 3.96% of the total area of the Maharashtra state and is located in the Vidarbha region on the north eastern side. It located 156 Kms west of Nagpur and is located near the hills with Purna basin to the West and the Wardha basin to the East. There are two lakes in the eastern part of the city, Chhatri Talao and Wadali Talao. Pohara and Chirodi hills are to the east of the city. The Maltekdi hill is inside the city, it is 60 meters high.75% of the district is covered by Deccan trap while 25% area is covered by Purna alluvium. Amravati City Boundary limit and Municipal Ward Map is depicted in **Figure 1.1.**

1.2 Demographic Structure of the City

The population of Amravati city in 2011 was 6,46,801 of which males and females are 330,544 and 316,257 respectively. The sex ratio of Amravati city is 957 per 1000 males. The population in the age range of 0-6 years was 62,497. The effective literacy rate (population over 7 years of age) was 93.03%. The summary of demographic structure of the city is given in **Table 1.1** and the Wardwise population of the city is represented in **Table 1.2**.

Table 1.1: Summary of Demographic Structure in Study Area

No.	Demographic Parameters	Amravati Municipal Corporation
1	State/District	Maharashtra/Amravati
2	No. of Prabhags	22
3	Total No. of Households	136796
4	Total Population	647057
5	Density of Population (Km^2)	5319
6	Sex Ratio (Females/100 males)	961
7	Scheduled Castes	111435 (17.22%)
8	Scheduled Tribes	15955 (2.47%)
9	Literate	535594 (82.77%)
10	Main Worker	189628 (29.31%)
11	Marginal Worker	18908 (2.92%)
12	Non Worker	438521 (67.77%)

Source : Primary Census Abstract, 2011 (Amravati District, Maharashtra state)

Table 1.2: Ward wise Population of Amravati City

Ward No.	Ward Name	Total Population
1	Shegaon - Rahatgaon	27457
2	Shri Sant Gadgebbaba P.D.M.C	26952
3	Navasari	30705
4	Navasari colony	31005
5	Mahendra Colony-New Cotton market	29268
6	Vilas Nagar -Morbag	29597
7	Jawahar Stadium	27135
8	Jog Stadium -Chaparashi pura	26829
9	S.R.P.F. -Wadali	20452
10	Benoda -Bhimtekadi -Dastur Naga	32235
11	Frejarpura	28585
12	Rukhmini Nagar -Swami Vivekanand	26930
13	Ambapeth -Gaurakshan	27848
14	Jawahar Gate -Budhwara	29870
15	Chhaya Nagar -Gavalipura	32705
16	Alim Ngar -Rahmat Nagar	32004
17	Gadgadeshwar	31860
18	Rajapeth -Shri Sant Kanwarram	32501
19	Sai Nagar	30452
20	Sutgirni	32518
21	Juni Wasti Badnera	32442
22	Navi Wasti Badnera	27707

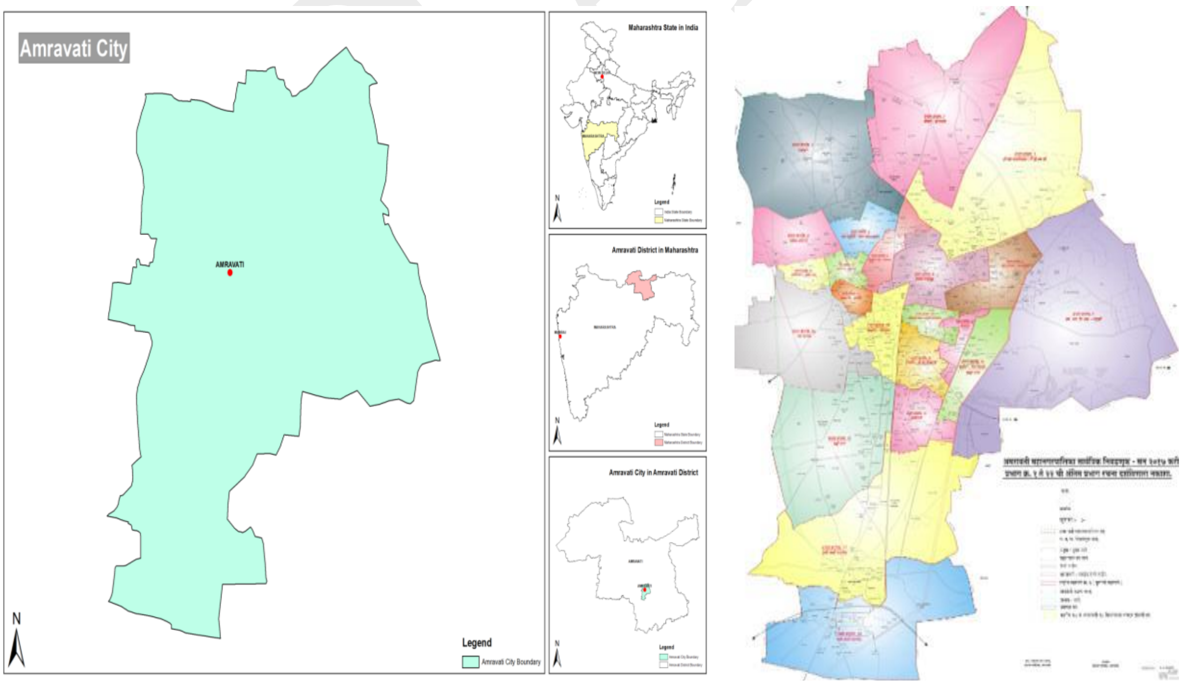


Figure 1.1 : Amravati City Boundary Limit and Municipal Ward Map

1.3 Economic Profile

The per capita income of Amravati is Rs. 63,467, which is quite lower to GDP of the state (Rs. 95,339) making it as one of the poorer in the state *(Survey of Maharashtra 2012-13)*. Around 64% of the people live in rural areas and 36% in urban areas. The economy of the region depends on agriculture. Food grains, sorghum, cotton, red gram, wheat, green chickpea, sugarcane, green chillies, oranges, sweet lime and betel leaves are the major crops in the region being cultivated. About 70% of the labor force is engaged in agriculture, of which 17% are farmers and 52% are laborers *(Census of India, 2011)*. In addition to the agriculture, Amravati is also known as the major hub/market for textiles. It is also growing as an industrial center with many cotton mills. Many textile industries such as Raymonds, Finlay mills etc. have been established in the outskirts of the city.

1.4 Climate and Meteorology

Amravati has a tropical wet and dry climate with hot and dry summers and mild to cool winters. Summer lasts from March to June, monsoon from July to October and winter from November to March. The maximum temperature in summer is recorded as 44°C and minimum as 29°C. In winter, maximum temperature is usually around 28°C and minimum is around 19°C. Wind speed is around 10mph (16.9 km/h) from North West (World weather online, 2018). The windrose diagram for summer, winter and whole year is shown in **Figure 1.2**. It can be seen that the predominant wind direction is from West, NE and NW direction.

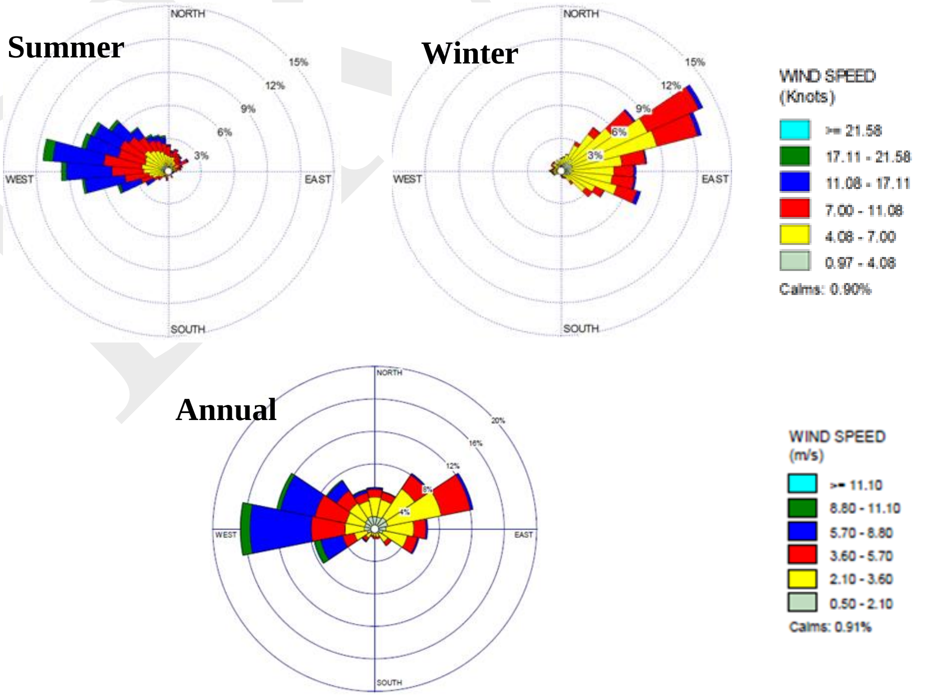


Figure 1.2 : Windrose Diagram for Amravati City

1.5 Transportation

Mode of transport in the city is mainly city bus service which is provided by Amravati Municipal Corporation (AMC) and Maharashtra State Road Transport Corporation (MSRTC), private auto rickshaws and cycle rickshaws. 2 wheelers are highest in the city. For intercity and interstate transport MSRTC along with the private operators provide bus services to other major cities like Nagpur, Bhopal, Mumbai, Pune, Aurangabad etc. In addition to the bus facility the district has mainly three railway stations, Amravati, New Amravati and Badnera junction. Badnera is a junction station on the Howrah–Nagpur–Mumbai, central line.

1.6 Industrial Profile

As per the Environment Status Report (2016-17), there are 1138 industries in Amravati region. Out of those, 316 are in orange category and 78 are in red category of industries. Oil mills, dal mills, cottage industries producing handloom cloth, rope making, ginning and pressing industries and spinning mills are the major small scale industries in the region. The city has significant industrial development potential (Smart Cities Challenge –Amravati Municipal Corporation, October 2015). A 2,700 MW Thermal Power Plant is set up by India Bulls named “Ratan India Thermal Power Plant”, at Nandgaon Peth/Sawardi MIDC. The Thermal power plant is 20 kms away from the city towards north east.

1.7 Objectives

- To undertake emission estimation of all the sources of particulate matter in the city and prepare an existing emission inventory of various sources.
- To undertake projection of existing emissions of particulate matter and provide source specific mitigation measures for reducing it.
- To prepare source specific action plan for mitigating air pollution in short and long term.

Chapter 2
Ambient Air Quality

2.1 Ambient Air Quality -Secondary Data

Based on last 5 years National Ambient Monitoring Plan (NAMP) data obtained from the MPCB website for PM_{10}, SO_2 and NOx concentration. Since MPCB provides the AAQ data on SPM, RSPM &/or PM_{10} only and $PM_{2.5}$ concentration is not provided by them or any other agency, it was not possible to give the historical picture of $PM_{2.5}$ concentration. **Figure 2.1** shows the data averaged over the three sites for the entire city. It can be seen that PM_{10} is much above the annual CPCB standard (60 µg/m^3), whereas SO_2 and NO_2 are much below the CPCB standard of 50 and 40 µg/m^3, respectively. The three monitoring sites, namely Govt. College of Engineering, Amravati, Building of Apurva Oil Industries (Industrial) and Vanita Samaj Building (Commercial) were depicted in **Figure 2.2a** and annual average of PM_{10} concentration is plotted in **Figure 2.2b**. Monthly variation plot of PM_{10} concentration shows that highest concentration is recorded in April and May, whereas lowest concentration is observed in July and August at the three sites **(Figure 2.2c)**.

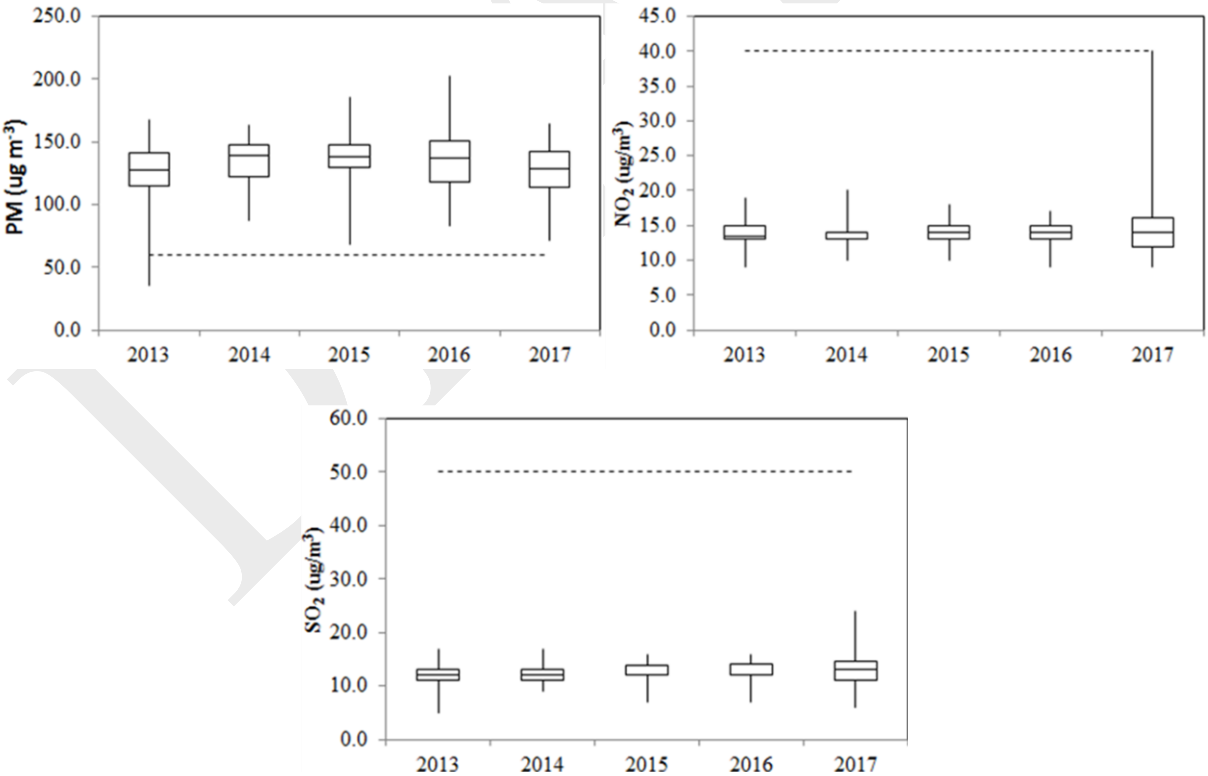


Figure 2.1 : PM_{10}, NO_2 and SO_2 Concentration During Last 5 years

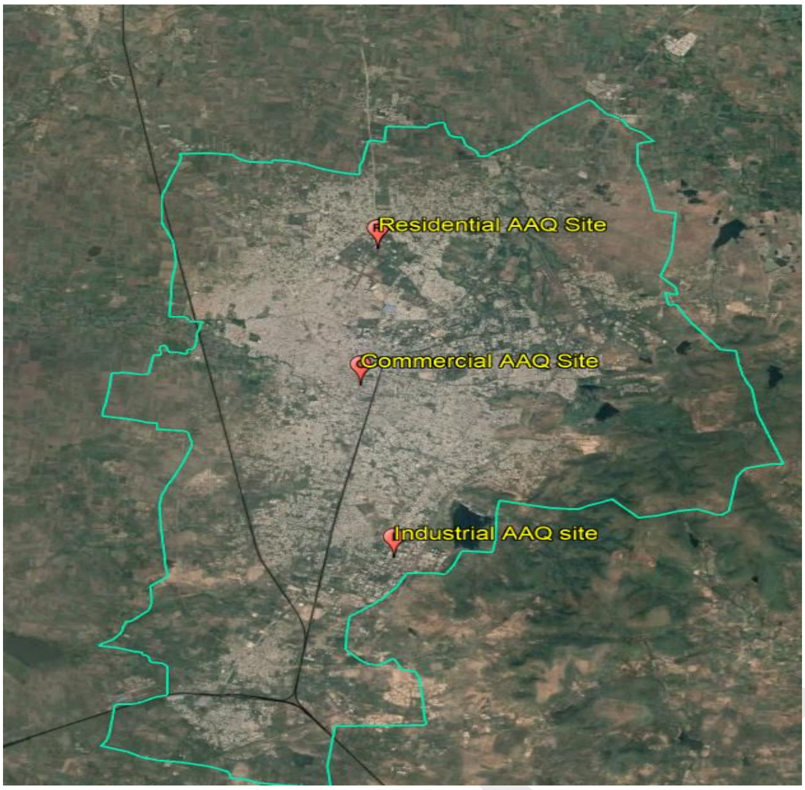


Figure 2.2a : MPCB AAQ Sites in Amravati City

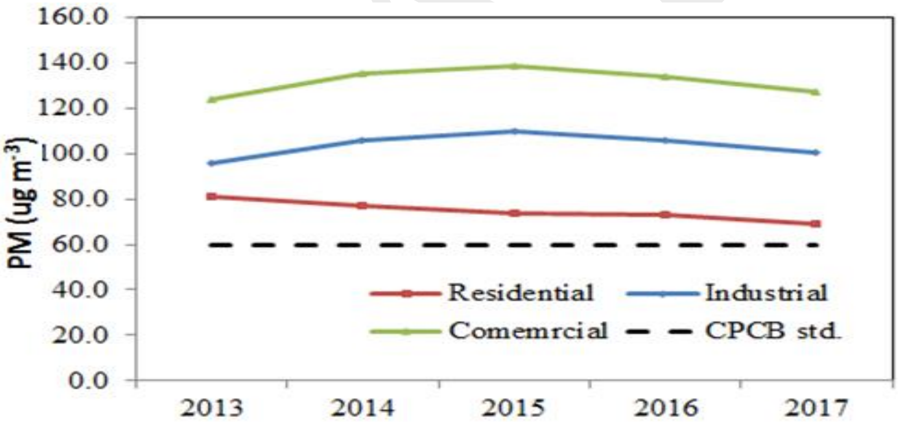


Figure 2.2b : PM$_{10}$ Concentration at Three Sites in Amravati During 2013-2017

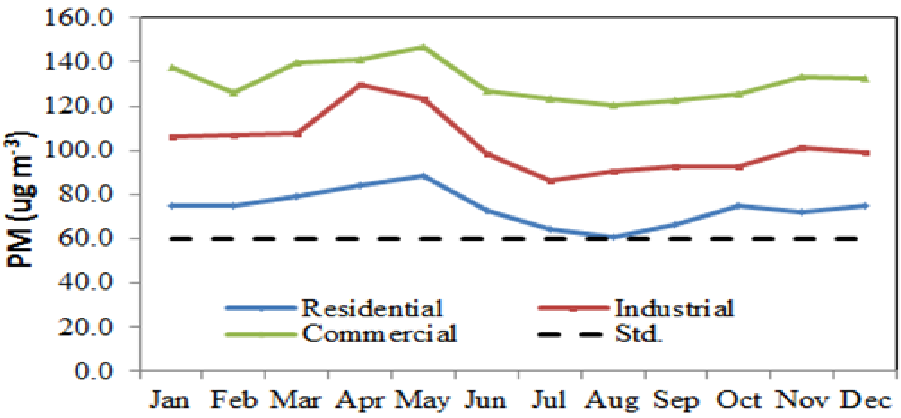


Fig. 2.2c: Monthly Variations in PM$_{10}$ Concentration

2.2 Ambient Air Quality - Sampling During Summer 2019

Ambient air quality monitoring exercise was carried out keeping in view the protocol for source apportionment (SA) study. 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 as per standard operating procedures prescribed in CPCB guidelines document on SA studies. The sampling was carried out at 4 sites selected based on the land-use activity and dispersion modeling results. The location of the sites is given in **Figure 2.3**. The description of the sampling sites is given in **Table 2.1.**

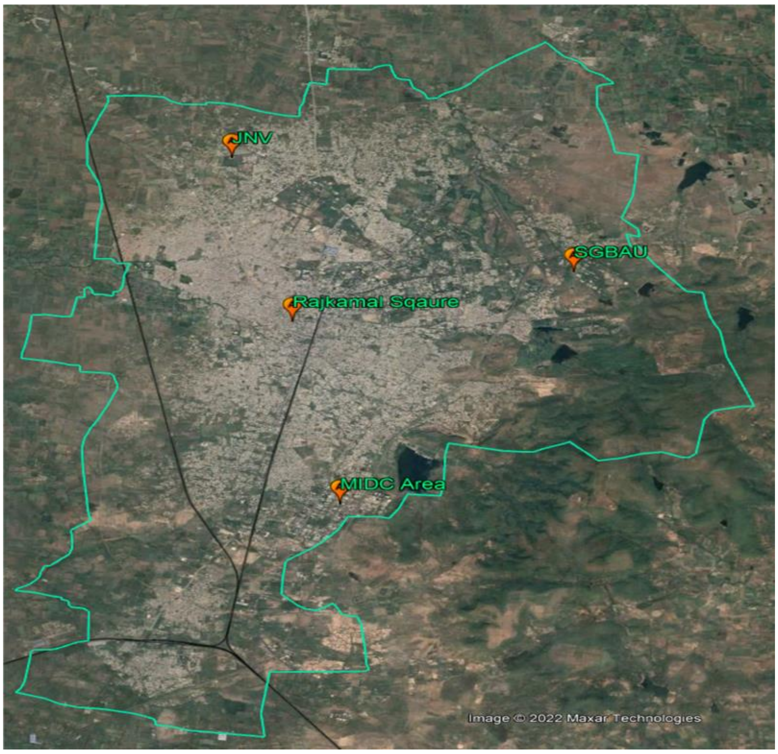


Figure 2.3 : Manual AAQ Sampling Sites

Table 2.1: Description of Sampling Sites

Sampling Location	Type	Geographic Location Lat./ Long.	Characteristics
Navoday Vidyalay	Residential	20.96447, 77.74209	1 Km away from highway, sporadic open burning observed, a crematorium at 600 m distance but not much in use
Rajkamal Square	Commercial/ Traffic	20.92867, 77.75265	Clothing shops, electrical, hardware, eateries, heavy flow of vehicles, congested with parked vehicles, roads and flyover construction undergoing
MIDC	Industrial	20.88098, 77.75844	Mumbai-Kolkata highway nearby
St. Gadge Baba University	Residential	20.94059, 77.79967	Road-1.5 km away, bus stand nearby, canteen and flow of staff vehicles

Air quality status at four sites in terms of PM_{10} and $PM_{2.5}$ is given in **Figure 2.4**. It can be seen that PM_{10} concentration violated the CPCB threshold (100 µg/m^3) during the entire study period at commercial/ traffic site (Rajkamal square). At residential site (St. Gadge Baba University), PM_{10} exceeded the standard at 40% of times. At another residential site named Jawahar Navodaya Vidyalaya (JNV), PM_{10} is observed to be at boundary line of CPCB standard. At industrial site (Sumit Agro), PM_{10} is observed to be 1.5 times the standard concentration. $PM_{2.5}$ on the other hand is observed to be below the CPCB threshold of 60 µg/m^3 at commercial/ traffic, industrial and residential site except at Jawahar Navodaya Vidyalaya, it exceeded the standard once (on 26th May 2019). Open burning activity was witnessed on this day leading to the exceedance of $PM_{2.5}$.

$PM_{2.5}/PM_{10}$ ratio is also plotted in **Figure 2.5** to assess the dominance of combustion activities at the sampling sites. High ratio generally suggests the presence of combustion activity at or near the site. PM_{10} concentration is observed to be high at MIDC sites followed by Rajkamal Square; whereas $PM_{2.5}$ concentration is observed to be high at Jawahar Navodaya Vidyalaya followed by MIDC. $PM_{2.5}/PM_{10}$ ratio is observed to be highest at Jawahar Navodaya Vidyalaya followed by St. Gadge Baba University, MIDC and Rajkamal Square. It can be seen that $PM_{2.5}/PM_{10}$ ratio is less than 0.5 at all the sites during the sampling period except on two days at Jawahar Vidyalay when open burning cases were observed.

This suggests that at the residential sites, combustion activity is prevalent. The chances of traffic and other combustion activities related emissions from nearby areas contributing to high $PM_{2.5}/PM_{10}$ ratio at these sites cannot be ruled out. Further the medium of the ratio is less than 0.5 suggesting the anthropogenic emissions are quite less in the city.

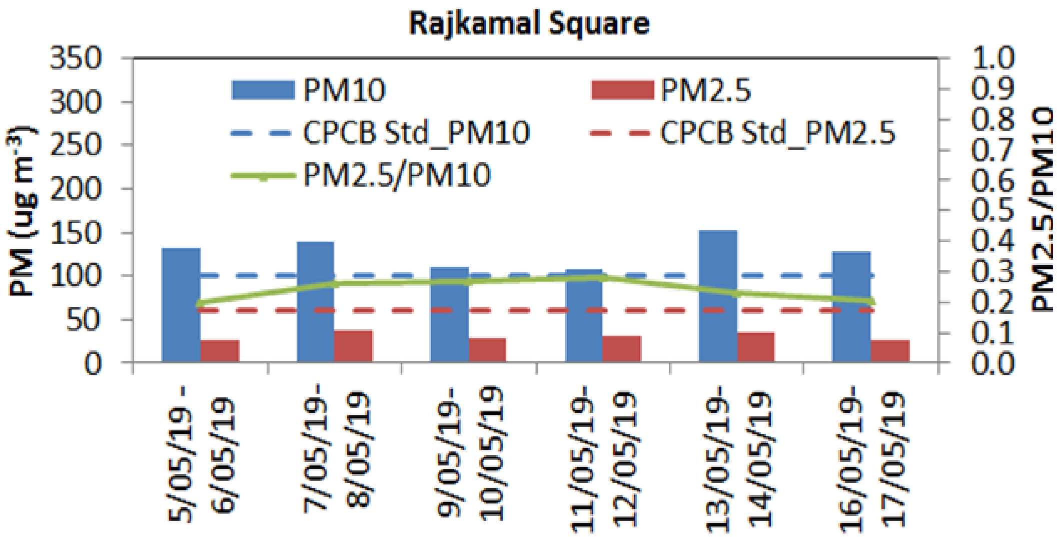


Figure 2.4 : PM_{10} and $PM_{2.5}$ Concentration at Sampling Sites

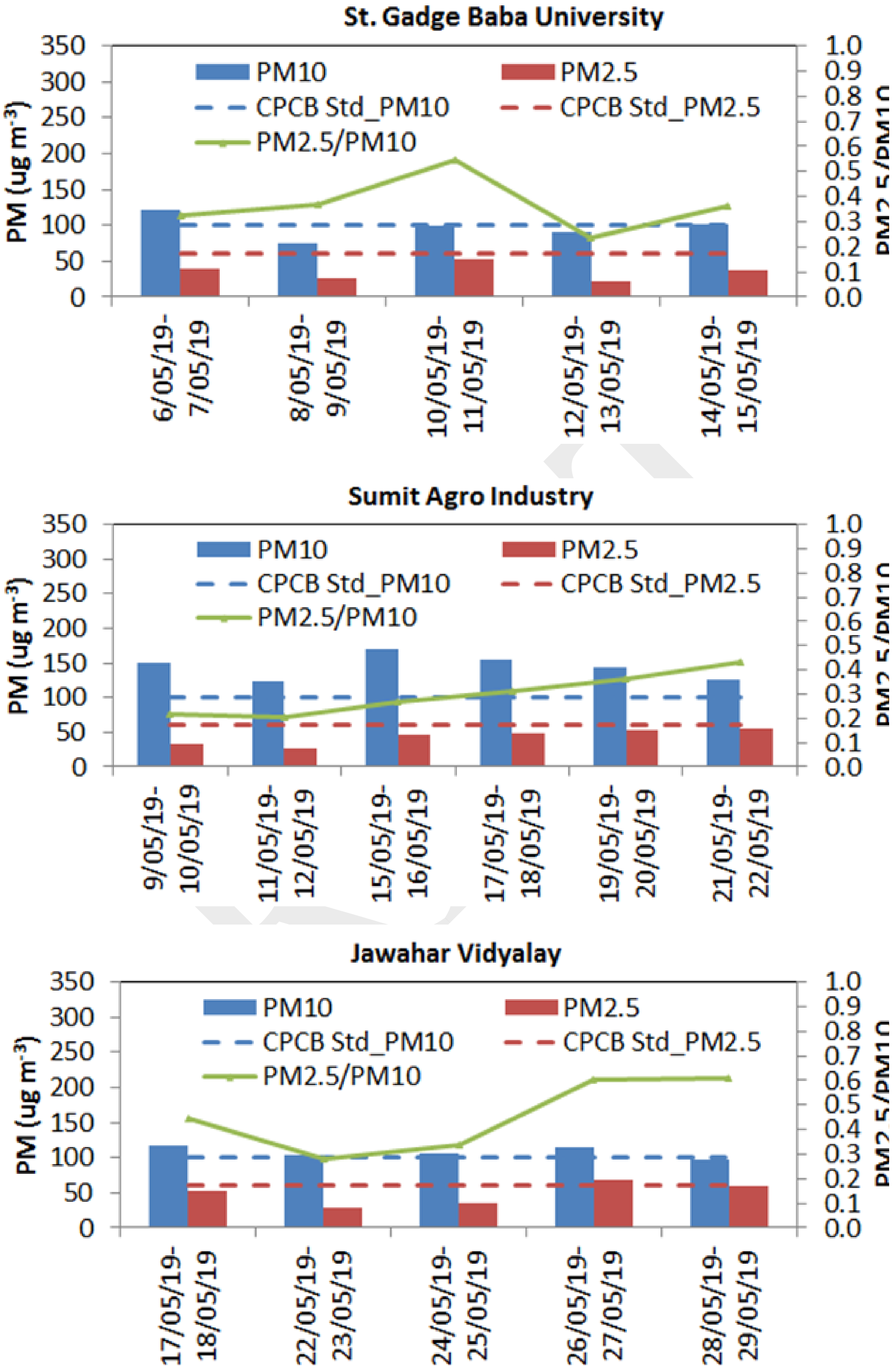


Figure 2.4 (Contd..) : PM_{10} and $PM_{2.5}$ Concentration at Sampling Sites

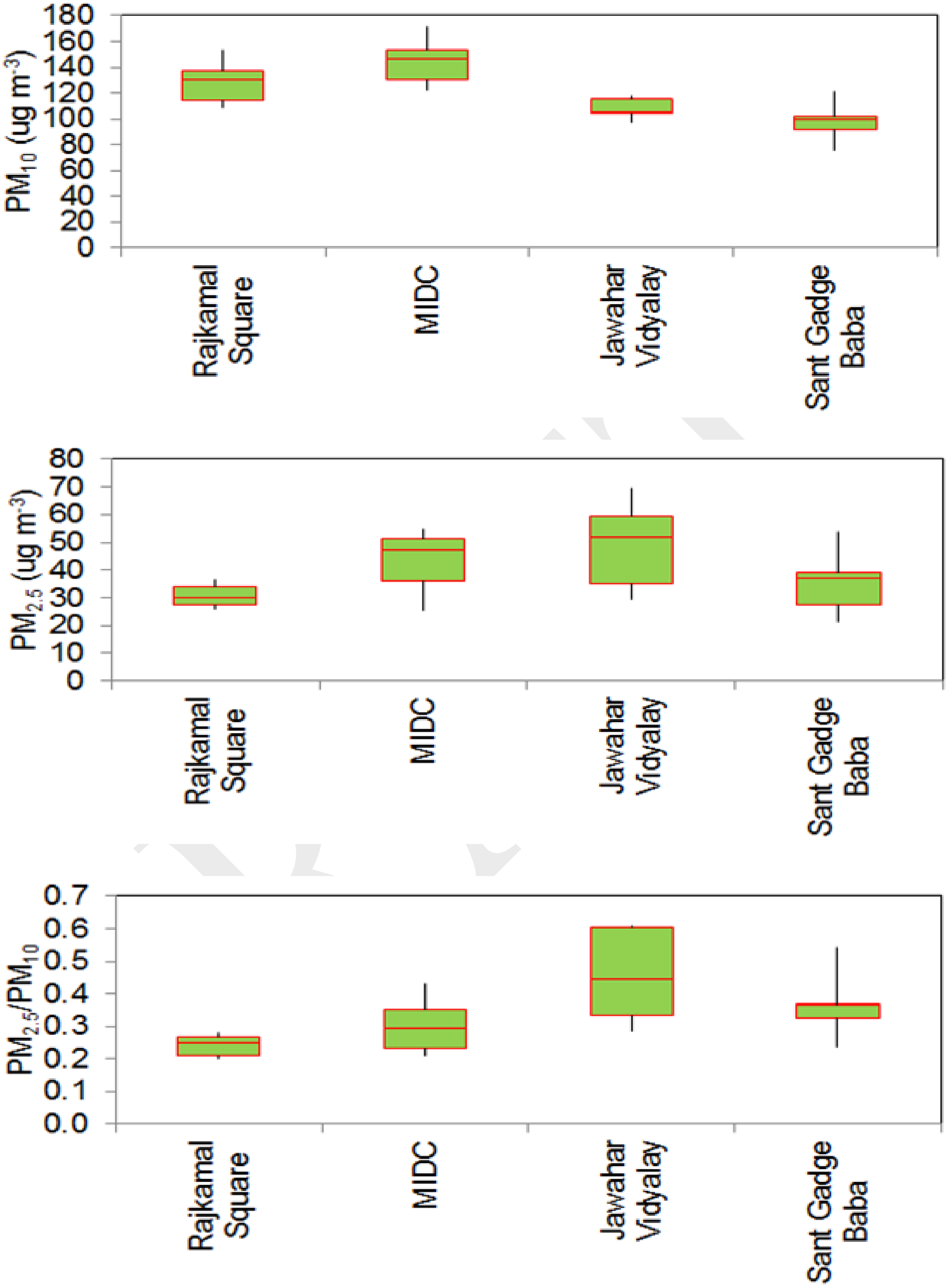


Figure 2.5 : PM_{10} and $PM_{2.5}$ and $PM_{2.5}/PM_{10}$ Ratio

Chapter 3

Emission Inventory

3.1 Introduction

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

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

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

3.2 Emission Inventory: Concept & Need

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

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

3.3 Present Objective

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

3.4 Generation of Activity Data & Emission Factor

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

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

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

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

3.5 Secondary Data Collection

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

3.6 Role of GIS

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

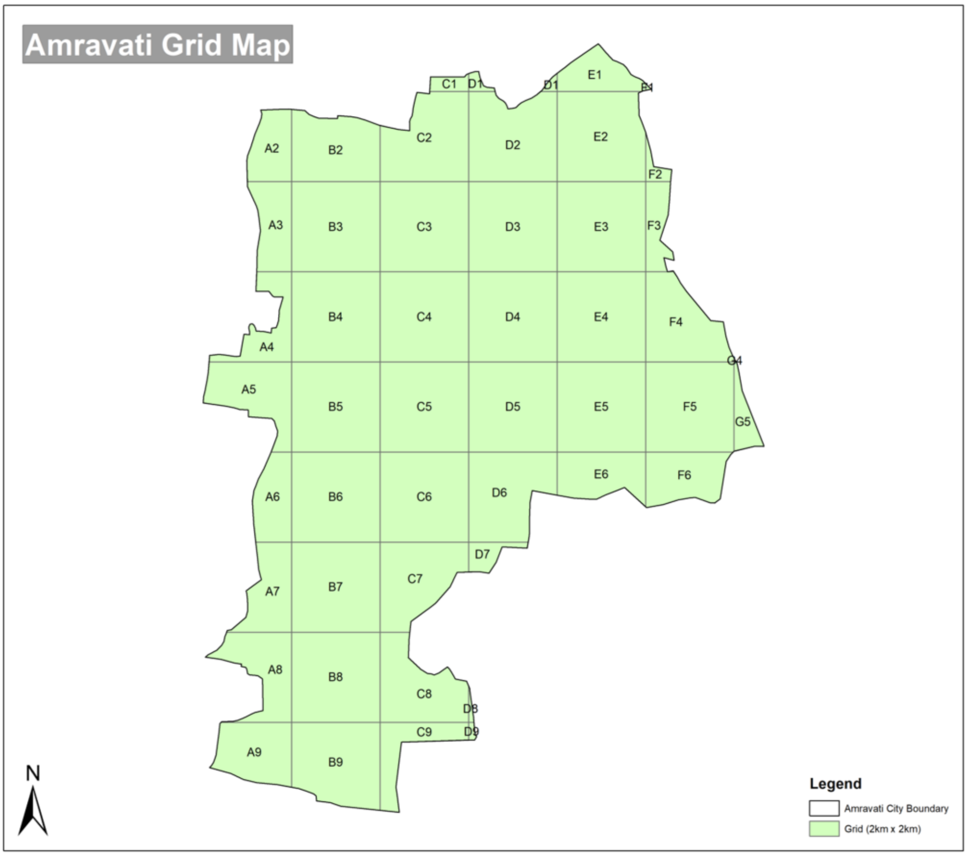


Figure 3.1 : A 2 x 2 Kms Grid Over the Amravati City

3.7 Road Network in Amravati City

The data on road condition is provided by Amravati Municipal Council. The total road network in the city is represented in **Figure 3.2.**

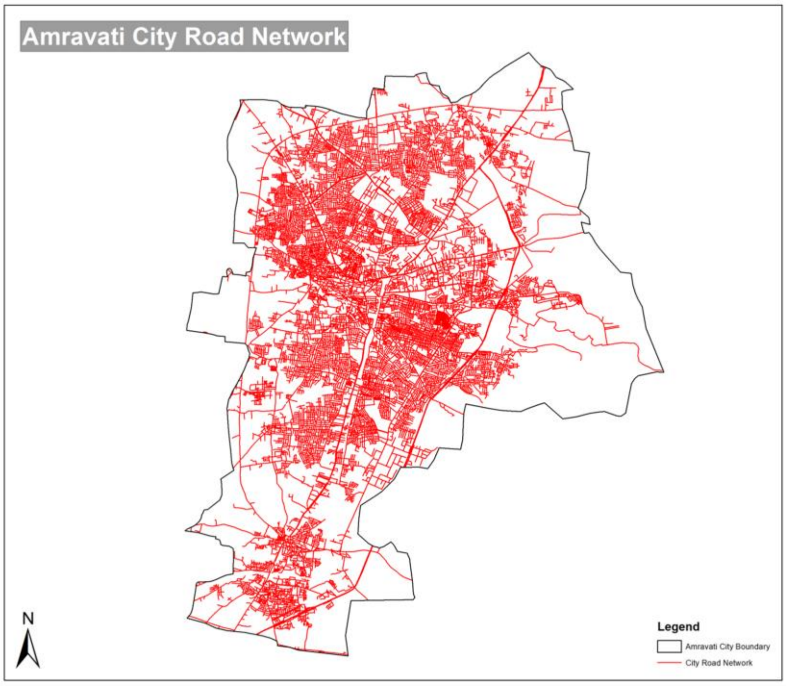


Figure 3.2 : Road Network in the City

3.8 Line Source

There are about 2,58,925 Lakhs registered vehicles in Amravati District. The data collected from regional transport office of Amravati is represented in **Table 3.1**.

Table 3.1: Number of Vehicles in the District

No.	Type of Vehicles	No of Vehicles
1	2 wheelers	213538
2	4 wheelers	19702
3	Auto Rickshaws	6402
4	Mini Bus	163
5	School Bus	200
6	Trucks/Tankers	3496
7	Tractors	5974
8	Trailers	3490
9	Others	243
10	**Total**	**253208**

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

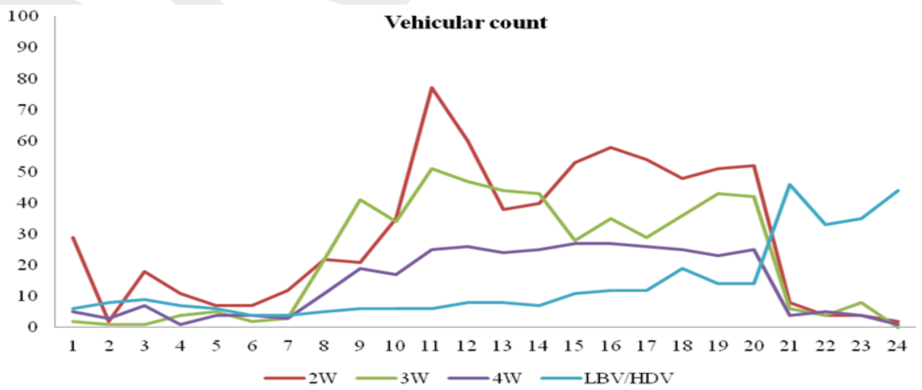


Figure 3.3 : Hourly Traffic Count in Amravati City at a Count Location

Following emission factors **Table 3.2** are used to calculate emission load from line sources. The emission factors derived by ARAI, Pune are used for calculations. During survey, it was informed that the city has 5 parking sites located at Badnera cycle stand, central railway (pay and park), city hospital, railway station parking and Main MSRTC Bus depot. Public transport in Amravati city is a road based bus, operated by AMC.

Table 3.2: Emission Factors Considered for Emissions Estimation

Emission Factor for BS-III Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.035	0.27	0.61	1.65	g/km
2	3W_Petrol	0.05	1.2	0.7	1.20	g/km
3	3W_Diesel	0.05	0.5	0.5	0.50	g/km
4	4W_Petrol	0.05	0.12	0.19	3.01	g/km
5	4W_Diesel	0.12	0.67	0.2	0.51	g/km
6	HDV	1.24	9.3	0.37	6.00	g/km
Emission Factor for BS-IV Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.1	0.1	0.13	1.81	g/km
2	3W_Petrol	0.035	0.5	0.3	0.75	g/km
3	3W_Diesel	0.035	0.5	0.3	0.75	g/km
4	4W_Petrol	0.08	0.1	0.1	1.00	g/km
5	4W_Diesel	0.08	0.1	0.1	1.00	g/km
6	HDV	0.06	0.39	0.42	0.74	g/km
Emission Factor for BS-VI Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.0045	0.090	0.068	0.50	g/km
2	3W_Petrol	0.0250	0.100	0.100	0.22	g/km
3	3W_Diesel	0.0045	0.080	0.100	0.50	g/km
4	4W_Petrol	0.0045	0.060	0.100	1.00	g/km
5	4W_Diesel	0.0045	0.080	0.100	0.50	g/km
6	HDV	0.0100	0.080	0.100	0.50	g/km

Currently the city buses operated by AMC are privatized with the operation & maintenance done by the contractors. A total of 27 buses run throughout the city covering a daily run of 3963 Kms. 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. The total emission load from line source is found to be 0.43 tons per day in Amravati city. The emission load from different category of vehicle is shown in **Table 3.3** and **Figure 3.4**.

Table 3.3: Contribution of Vehicles to PM Load

Vehicles	PM (Ton/Day)
2W	0.046
3W	0.051
4W	0.048
HDV	0.285

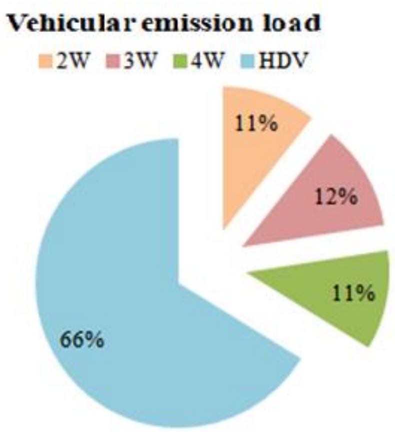


Figure 3.4 : Percent Emission Load from Line Source

3.9 Point Source

Amravati region is developing at a rapid pace today paving way for the establishment of various other industries in the area. Industries like auto repairing and engineering, textile industries, ginning and pressing, metal ware industries, etc. are established on large scale. The expansion in the roadways, construction of flyovers, nearness to highway and a boom in the motor vehicles have given an upper hand to this small scale industry. The people in this industry are mainly engaged in engineering works like welding, manufacturing of agricultural equipment, vehicle repairing and production of spare parts for the machines.

As Cotton is being the major crop of this region, Amravati is home to a number of cotton mills. The first textile mill to be opened in this region was in the year 1885 and it was known as the Berar Manufacturing Company Ltd. This is another industry that relies heavily on the production of cotton in this region. Just like the textile industry, it is yet another old industry to be established here. A part of the cottage industry, metalworking is an old industry in Amravati. The city was well known for its production of pharmaceutical, musical bells tied around cattle and gongs. As on year 2016-17, the total numbers of registered units in Amravati district are 4077 approximately. All the consents from pollution control board are verified and it is seen that out of the registered 4077 units, 48 industries in Amravati MIDC and nearby are using solid fuel for manufacturing processes. Hence the fuel used in these industries is considered for emission load estimation **(Figure 3.5)**.

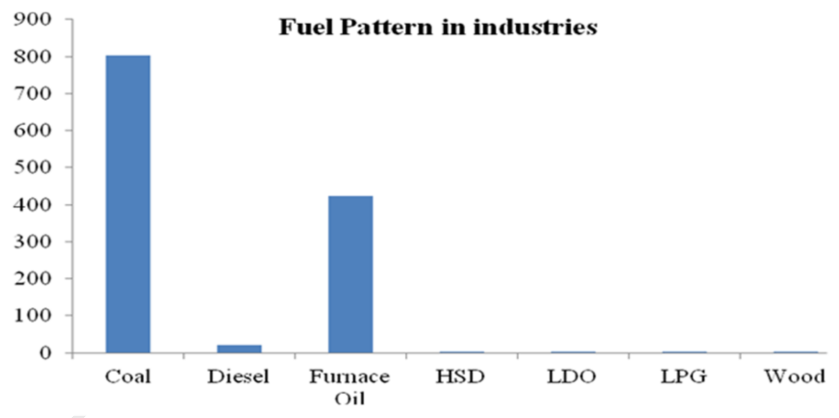


Figure 3.5 : Fuel Pattern in Industries (TPD)

From the above figure it is clear that coal and furnace oil are used in large quantity in the industries located in Amravati MIDC. The emission factors used from estimation of emission load is referred from AP42 and CPCB documents. The emission load from industries is calculated in the **Table 3.4** and **Figure 3.6**.

Table 3.4 : Point Source Emission Load

Fuel	PM_{10} Load (TPD)	$PM_{2.5}$ Load (TPD)
Coal	0.0439	0.03
Furnace oil	0.016	0.011
Wood	0.452	0.302
Diesel	0.213	0.142
HSD	0.054	0.036
Briquettes	0.021	0.014
Bagasse	0.009	0.006
LDO	0.005	0.003
Total	**0.8139**	**0.544**

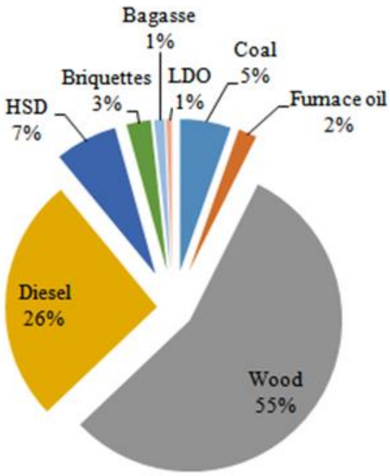


Figure 3.6: Percent Emission Load from Point Source

3.10 Area Source

The individual sources that cannot be considered as point and mobile / line sources are categorized as area sources, which includes; bakeries, open eat outs, hotels/restaurants, crematories, construction, domestic cooking, paved/unpaved road dust, solid waste burning. The details of the major area sources in short are given below. The details on the solid waste generation and construction activities are given in the respective sections.

3.10.1 Bakery

Based on the survey, it was observed that there are 12 major bakeries in the representative area. Wood and coal burning are the two major fuels used in these bakeries. The fuel consumption in each bakery ranges from 20-300 kg/d. It was found that most of the bakeries are operating as coal based (63.64%) with average coal usage of 590 kg/d. The wood based bakeries are 36.36% with average daily consumption of 845 kg/d.

Emission Estimates:

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

The PM emission load from bakeries is given in **Table 3.5.**

Table 3.5: Emission Load from Bakery

Source	Fuel/Type	PM_{10} (TPD)	$PM_{2.5}$ (TPD)
Bakery	Wood	0.014	0.0061
	Coal	0.0092	0.0095

3.10.2 Open Eat-outs

Based on the survey, it was observed that 234 open eat out units are operating in the city. Most of the open eat-outs are operating as LPG based (82.4%) with kerosene (12.8%), coal (12%), diesel (1.2%) and wood (2.4%) based units. The average consumption of kerosene per day is approximately 1-3 litters, ½ cylinder (21kg capacity) /day of LPG, 4 kg/day of diesel, 10-30 kg/day of wood, and 1 kg/day of coal for cooking. Average operating hours of street vendors is 12 hours. The actual number of tea stalls/snack bars/fast food centres could be more than the observed number, however the observed data through survey is considered for the emission estimates. The PM emission load from open eat-outs is given in **Table 3.6.**

Emission Estimates:

Emission from fuel burning (PM) per day

= Number of street vendors operating on particular fuel x fuel consumption per day x emission factor

Table 3.6 : Emission Load from Open Eat-outs

Source	Fuel/Type	PM_{10} (TPD)	$PM_{2.5}$ (TPD)
Open Eat-outs	Kerosene	0.000156	0.000104
	Coal	0.000448	0.000299
	Wood	0.0022	0.001496
	Diesel	0.0	0.0
	LPG	-	0.0018

3.10.3 Hotels and Restaurants

There 236 hotels in the city. Hotels and restaurants are mostly LPG based (91.1%) with presence of kerosene (3.81%), coal (1.6%) and wood (3.38%) units. The PM emission load from hotels is given in **Table 3.7.**

Emission Estimates:

Emission Load from LPG

Only $PM_{2.5}$ emissions are present in the LPG

Total emissions (PM2.5) due to LPG burning in Hotels

= Number of Hotels x LPG consumption (TPD) x Emission Factor (Kg/MT)

Emission Load from Coal

= No. of Hotels x Coal consumption (TPD) x Emission Factor (Kg/MT)

Table 3.7 : Emission Load from Hotels & Restaurants

Source	Fuel/Type	PM_{10} (TPD)	$PM_{2.5}$ (TPD)
	Wood	0.00229	0.0014
	Coal	0.00282	0.00188
	LPG	--	0.0038

3.10.4 Crematoria

There are 12 crematories in the city. About 3338 number of bodies/year are burnt. Crematoria are operating as wood and kerosene based units. Based on the survey, it was observed that the wood consumed per body is 300 Kgs, Kerosene consumed per body is 5 litres and dung cakes consumed is 5 Kgs per body. The PM emission load from crematories is given in **Table 3.8.**

Emission Estimations:

Emission (TSP) =No. of Hindu Death /yr * wood required per body (Kg) * emission factor + Number of Hindu Death /yr * kerosene required (litres) * emission factor

Table 3.8 : Emission Load from Crematories

Source	Fuel/Type	PM_{10} (TPD)	$PM_{2.5}$ (TPD)
Crematoria	Wood	0.0398	0.0265
	Dung Cakes	0.00011	0.0

3.10.5 Household Fuel Consumption

There are 22 wards in the city and 10 LPG distributors in the area. The fuel consumption pattern is executed based on the Census 2011 report. The number of LPG holders is projected based on the assumption of population growth rate of 1.77% as per the **Table 3.9**. As per the Prime Minister Ujjawala Yojana (PMUY) 2017, the numbers of consumers shifted from other fuel to LPG are 63%. The distribution of the fuel consumption pattern of the households is given below **Table 3.10.**

Table 3.9: Distribution of Domestic Fuel Consumption Pattern

No. of households	Firewood	Crop residue	Cow dung	Coal	Kerosene	LPG	Electricity	Other
165617	49558	6369	535	244	7950	98836	41	2194

Table 3.10: Assumptions of Per Capita Fuel Consumption Pattern

Fuel	Per Capita Consumption	Unit
LPG	12	Cylinder/year
Kerosene	0.833	Ltr/d
Wood	4	kg/d
Coal	5	Kg/d
Cow dung	3	Kg/d
Crop residue	3	Kg/d

For emission calculations, the assumption on the usage of each fuel unit based on the survey and literature (NEERI Report-Mumbai, 2011).

3.10.6 Fuel Consumption in Slum Population

A survey of 36 households was conducted, spread over 7 areas within the city which were known to have significant slum population. It was seen that majority of the slum houses used a combination of fuels such as LPG (6.06%), wood (77.79%) and kerosene (16.13%). The kerosene consumption based on ration shops survey was found to be 7179 litres/month. The PM emission load from domestic combustion is given in **Table 3.11.**

Table 3.11 : Emission Load from Domestic Combustion

Source	Fuel/Type	PM_{10} (TPD)	$PM_{2.5}$ (TPD)
Domestic	Kerosene	0.0034	0.0023
	Wood	0.398	0.265
	Coal	0.012	0.0084
	Crop residue	0.18	0.120
	Cow-dung	0.0069	0.0046
	LPG	-	0.031

3.10.7 Building & Road Construction

There were 109 numbers of building constructions going on in the city. The data is issued from construction department of AMC and 7 road constructions were ongoing during the survey of the city. The data upto year 2018 is considered for the study. The PM emission load from construction activity is given in **Table 3.12.**

Emission Estimation:

PM_{10} Tons /years = 1.2 x total number of acre – months (AP42, Section 13.2.3.3)

Acre-months: construction area (acres) x months of activity (18 for new and 6 for old/on-going construction)

Table 3.12: Emission Load from Construction

Source	Type	PM_{10} (TPD)	$PM_{2.5}$(TPD)
Construction	Building	0.047	0.0315
	Road	0.94	0.063

3.10.8 Road Dust

Due to the plying vehicles, resuspension of road dust, which may either be paved or unpaved, is a major cause of concern with respect to particulate matter. Road length data is given in **Table 3.13**, which shows that unpaved road length is higher than paved road length. Silt loading of the paved surface, mean weight of the vehicles traveling over the surface and vehicle kilometre travelled (VKT) are the three important parameters required for computing the emission load from road dust. The average weight of vehicle is considered as given in **Table 3.14.** The PM_{10} emission load for road dust is given in **Table 3.15**.

Table 3.13: Road Length in the City

Road Type	Length (Km)
Bitumen	366.78
Concrete Road/Paver block	226.49
WBM	522.4
Un surface Road	420.14
Total	**1535.81**

Table 3.14: Categorised Vehicular Weight

Vehicle	2w	3w	4w	Bus/Truck
Weight (Kg)	175	450	1425	7500

Source: NEERI Report-Mumbai, 2010 *(cross-referred*: *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)*

Emission Estimates:

Paved Road dust

Emission factor, E_Pvd = $\{k \times (sL/2)^{0.65} (W/3)^{1.5} - C\} (1-P/4N)$

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

k = particle size multiplier for particle size range and units of interest (k (g/vkt) = $PM_{2.5}$ -1.1, PM_{10}-4.6)

sL =Road surface silt loading (grams per square meter) (g/m^2) – 0.531

(Source: NEERI Report-Mumbai, 2010)

W = average weight (tons) of the vehicles traveling on the road (as per above table)

P = No. of wet days with at least 0.254 mm of precipitation during avg. period (assumed 120 days)

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);

Emission from Paved Road (g/d)= E_Pvd (g/VKT) x VKT (km/d)

Emission Estimation for Unpaved Dust

Emission factor, E_unpvd= $\{([k (s/12)^a (S/30)^d] /(m/0.5)^c - C)\} * (365-P)/ 365$

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

s = surface material silt content (%), m= surface material moisture content (%),

S= mean vehicle speed (mph);

k =particle size multiplier (lb/vmt) ($PM_{2.5}$= 0.21, PM_{10}=1.386)

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

C= Break and tire wear correction ($PM_{2.5}$=0.00036, PM_{10}=0.00047) - lb/VMT

Table 3.15: Emission Load from Area Sources – Road Dust

Source	Type	PM_{10} (TPD)	$PM_{2.5}$(TPD)
Road dust	Paved	0.032	0.021
	Unpaved	0.027	0.018

3.11 Total Emission Load (for Amravati City)

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Amravati city vide emission inventory is developed as shown in **Table 3.16 and Figure 3.7**.

Table 3.16 : Total Emission Load from All Sources

No.	Type of Sources	PM_{10}	$PM_{2.5}$
A.	**Area Sources**		
1	Bakeries	0.0232	0.0156
2	Open Eat-outs	0.0028	0.0037
3	Crematories	0.04	0.027
4	Construction	0.987	0.095
5	Road Dust Re-suspension	0.059	0.039
6	Domestic	0.6	0.43
7	Hotels & restaurants	0.009	0.003
B	**Line Source**	0.344	0.086
C	**Point Source**	0.814	0.544
	Total Emission Load	**2.879**	**1.2433**
*All values are in Tonnes/day			

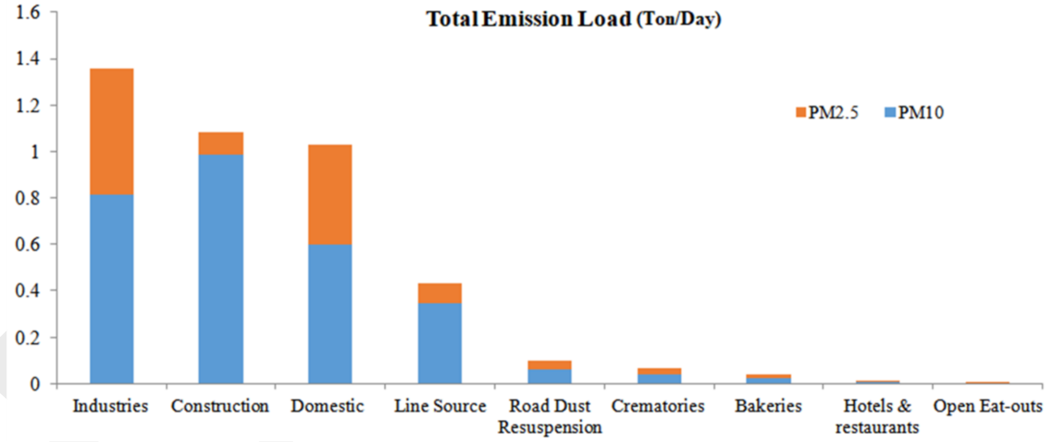


Figure 3.7 : Total Emission Load from All Sources (Ton/day)

3.12 Grid-wise Emission Inventory

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. The grid-wise emission load from respective source is given in **Table 3.17**. The pictorial view of grid-wise emission load is shown in **Figure 3.8**.

Table 3.17 : Grid-wise Emission Rate of PM_{10}

No.	ID	Emission rate [kg/d]	No.	ID	Emission rate [kg/d]
1	A3	266.68	12	C5	4.13
2	B3	64.02	13	D5	170.10
3	C3	15.73	14	E5	124.30
4	D3	0.03	15	B6	226.93
5	E3	7.42	16	C6	2.81
6	A4	75.33	17	D6	1.70
7	B4	40.60	18	B7	234.89
8	C4	0.58	19	C7	288.28
9	D4	73.46	20	D7	192.30
10	E4	84.53	21	B8	35.95
11	B5	28.36	22	C8	4.79

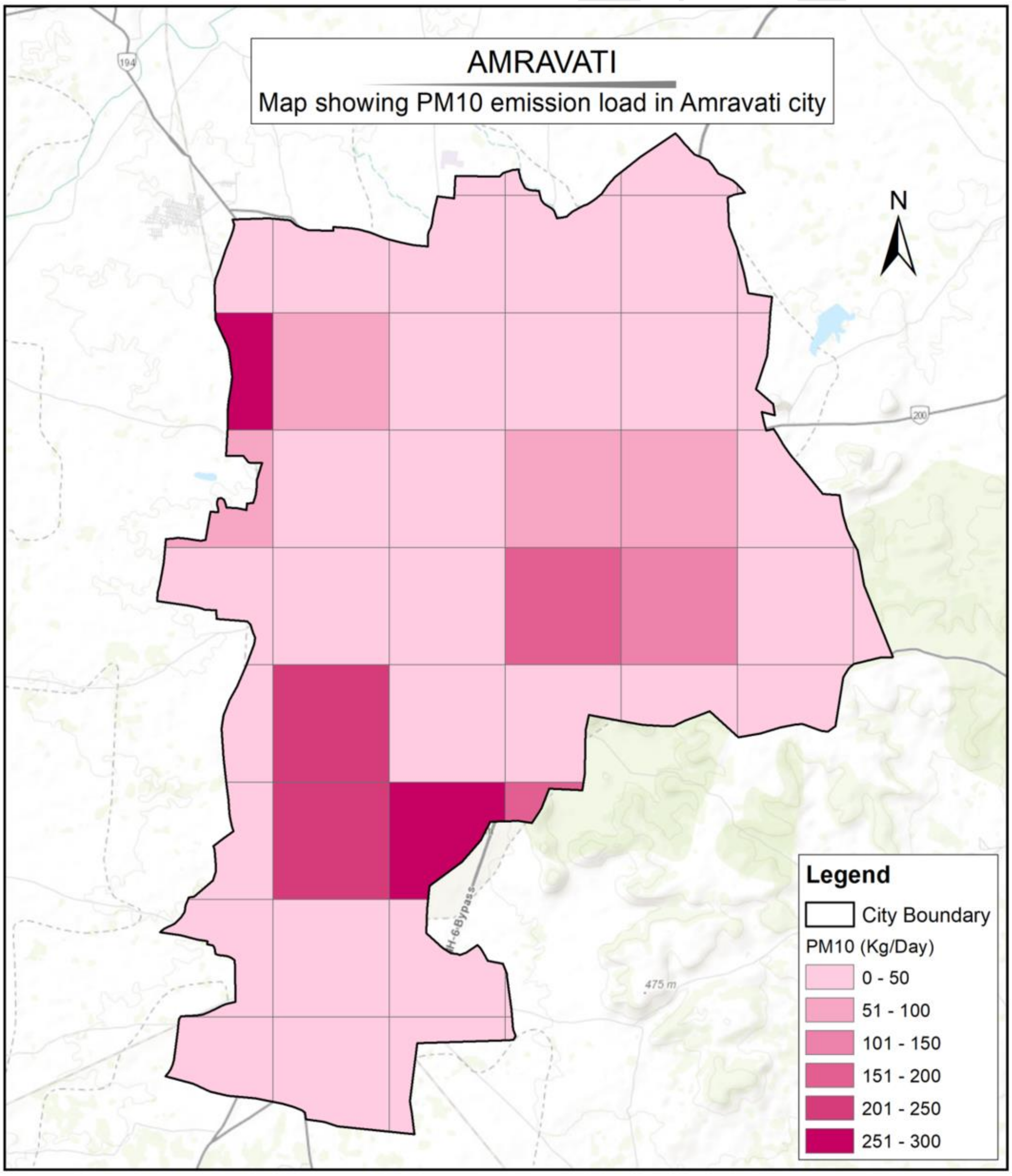


Figure 3.8: Grid-wise Emission Load for Amravati City

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study Using EPA PMF v5.0

Positive matrix factorization (PMF) is a receptor modeling tool used for 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; Zhong et al., 2016; Gadi et al., 2019)*. It requires concentration dataset of samples and associated uncertainty as inputs and gives several variables such as factor profiles, their contribution and error in modeling as output *(Polissar, 1998; Paatero and Hopke, 2003; Pakbin et al., 2011)*. The chemically speciated air samples can be assembled as a data matrix 'X' of i x j dimensions, in which i is the number of samples and j is the number of chemical species measured during analysis. It is based on chemical characterization of collected particles, are aimed to solve Eq 1.1.

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

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, difference between the measured and calculated amount.

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

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

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

4.2 Methodology

For the present study EPA PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for identification of sources and their positive contributions to ambient air pollution. The study was carried out for representative samples of $PM_{2.5}$ and PM_{10} collected during the 28 April, 2019 to 03 June, 2019 sampling campaign at 4 locations: Rajkamal Square (Commercial /Traffic), St. Gadge Baba University and Navoday Vidyalay (Residential) and MIDC (Industrial). The concentration and uncertainty data were obtained from the gravimetric analysis ($PM_{2.5}$ and PM_{10}); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (19 elements: Ag, Al, As, Cd, Co, Cr, Cu, K, Mg, Mn, Ni, Pb, Se, Si, Sr, Ti, Zn, Na, Mg ; and Ionic Analysis (08 ions: Na^+, NH_4^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, 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: 'Concentration' file and 'Uncertainty' file. The input file is prepared using concentration data set of samples and associated uncertainty and both these data sets should be in same format (csv or xls) with all the elements analysed for the study in same units (μg/m^3). The concentration file is prepared by multiplying the concentration data as well as the uncertainty (i.e., standard deviation of analysis) obtained in μg/cm^2 with area of Filter paper (i.e., 11.9 cm^2 @ 39mm ϕ deposit area) from the ED -XRF and ionic analysis and then dividing the mass by the flow rate of Mini volume samplers (7.2 m^3, taking the sampling time as 24 hours @ 5 lpm. Here note that PMF works on non-negative aspect so if the concentration of any species is below detection limit or zero then that value needs to be replaced by 0.5 x Minimum Detection Limit (MDL) of that species. The MDL of all the elements is given in **Table 4.1**.

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

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

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; Sharma et al., 2016; Zhong et al., 2016; Taghvaee et al., 2018) to identify the sources. Also, all the results from various run and error estimation were obtained in the form of datasheets which were used for further analysis to obtain percentage contributions of each source at receptor locations and percentage of elemental contribution from that source.

4.3 Results

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

4.3.1 PM_{10}

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

Factor 1: Construction Dust

First factor is identified as Construction dust with 16.34% of total PM_{10} emissions indicated by key markers OC, EC, NO_3^{2-}, Mn, Na^+, Ca^{2+} and K (~29.43%, 17.24%, 9.94%, 3.3%, 3.15%, 6.57% and 5.52%). Ca^{2+}, Mg, Mn OC, Na^+ are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al.,2020)*. Construction dust is mainly contributed from all infrastructure development projects going in and around the city.

Factor 2: Fossil Fuel Combustion

Second factor was identified as coal combustion the presence of tracers, such as OC, Ca^{2+}, NH_4^2, Se, Sr and Ti (~14.3%, 7.18%, 17.27%, 7.95%, 8%, 7.26%) with minor indicators such as Zn, Cd, Mn, Mg, Na, Cl^-, Pb suggest the source of fossil fuel combustion contributed to about 13.2%. of total PM_{10} Pollution. Se, Cd, 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).*

Factor 3: Industrial Emissions

Industrial Factor is represented by the significant levels of OC(18.17%), SO_4^{2-}(8.13%), Cr (16.33%), Cu (12.53%), Pb (10.93%), Sr (11.17%) and Ti (8.02%) contributed to 20.36% of total PM_{10} emissions. Cr, Co, Cu and Sr are indicators of Industrial emissions from various previous studies *(Basha et al., 2010; Patil et al., 2013; Jain et al., 2017; Garaga et al., 2020; Pawar et al., 2020)*. Cr and Cu are also indicators of tannery industry and incinerators *(Shukla and Sharma, 2008, Rai et al., 2016)*. Sr and Ti is the indicator of dust emitted during industrial operations.

Factor 4: Vehicular Emission

Forth factor accounted for 9.74%, with indicators OC (35.46%), EC (29.24%), NO_3^{2-}(10.81%), K (4%) and Zn (8.09%) and minor indicators such as Pb, Mg, Al, SO_4^{2-} contributed to this factor. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017 Mukherjee et at., 2018, Pawar et al., 2020)*. Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018;; Jain et al., 2017; Pawar et al., 2020).*

Factor 5: Resuspended Road Dust/ Wind-blown Dust

Fifth Factor is represented by the significant levels of OC (34.25%), EC (21.50%), SO_4^{2-}(10.69%), Ca^{2+} (4.95%), K (5.23%) and Al (3.56%) and minor indicators such as Mg, Mn, Ti and NH_4^{2-} contributing to 20.48% of total PM_{10} Pollution. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor. K, Mg, Si and Ti are good tracer of crustal dust *(Kothai et al., 2008; Patil et al., 2013; Jain et al., 2017; Keerthi et al., 2018; Garaga et al., 2020)* whereas substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as EC, OC, Al, Mn are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*. Road dust gets re-suspended due to natural gust of winds or moving objects like vehicles *(Zhang, 2008; Kothai, 2011; Banerjee et al., 2015; Ashrafi et al., 2018)*. Since the study was done in dry conditions windblown dust has large influence on this source.

Factor 6: Biomass Burning/ Wood Combustion

Sixth factor is identified as Biomass burning which accounted for relatively larger contributions of 19.88%. Major proportions of K^+, OC, NO_3^{2-}, SO_4^{2-} and EC (~7.47%, 47.56%, 6.19%, 4.9%, 22.34%) and minor contributors such as Al, K, Na^+, NH_4^{2-}. There have been many studies in the past suggesting that K^+, OC, NO_3^2 and SO_4^{2-} are clear indicator of biomass burning *(Shukla and Sharma, 2008; Police et al.,2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020)*. OC and NH_4^{2-} are indicators of wood combustion *(Jain et al., 2017)*.

4.3.2 $PM_{2.5}$

After the EPA PMF run analysis, 6 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: Industrial emissions

First factor is identified as Industrial Emissions with 17.53% of total $PM_{2.5}$ emissions which was indicated by high levels of OC (26.89%), EC (9.57%), Pb (10.31%), Cr (15.5%), Sr (9.33%) and SO_4^{2-}(13.38%). Earlier studies reported that Cr, SO_4^{2-} and Sr are indicators of oil combustion in industrial process *(Rai et al, 2016)*; whereas Pb, EC-OC are major indicators of process and fuel combustion in industries as per previous studies *(Kumar et al., 2001, Gupta et al.,2012, Jain et al., 2017, Pawar et al., 2020)*.

Factor 2: Secondary Aerosols

Second Factor is represented by the significant levels of OC (15.97%), EC (12.35%), NO_3^{2-} (4.33%), NH_4^{2-} (9.27%), SO_4^{2-} (11.22%), K (13.88%) and Mg (17.07%) contributing to about 15.87% of total $PM_{2.5}$ Pollution. The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols *(Patil et al., 2013; Police et al.,2016; Sharma et al., 2016; Jain et al., 2017, Mukherjee et at., 2018; Garaga et al., 2020)*.

Factor 3: Vehicular Emission

Third factor accounted for 24.64%, with indicators OC (46.8%), EC (26.81%), NO_3^{2-} (7%), K^+ (2.42%) and Ca^{2+} (1.38%), Al (2.78%) and minor indicators such as Pb, Zn, Mn contributed to this factor. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of tyre and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Patil et al., 2013; Jain et al, 2017; Mukherjee et at., 2018, Pawar et al., 2020)*. Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles. The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012 ; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018; Jain et al., 2017; Pawar et al., 2020)*.

Factor 4: Biomass Burning/Wood Combustion

Fourth factor is identified as Biomass burning which accounted for relatively larger contributions of 18.53%. Major proportions of K^+, OC, NH_4^{2-} , SO_4^{2-} and EC (~8.3%, 35.15%, 9.07%, 7% and 10.67%) were contributed to this factor. There have been many studies in the past suggesting that K^+ and SO_4^{2-} are clear indicator of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020)*. OC and NH_4^{2-} are indicators of wood combustion *(Jain et al., 2017)*. It is a known fact that biomass is a widely used energy source as well as there is issue of illegal litter burning in India which has resulted in the nominal contributions of biomass burning in this location.

Factor 5: Resuspended Road Dust/ Wind-blown Dust

Fifth Factor is represented by the significant levels of OC (30.98%), EC (17.73%), Cu (4.71%), Ni (7.09%), K (12.52%) and Mg (11.12%) and minor indicators such as Pb, Si, Ti, Sr and Ca^{2+} contributing to 9.46% of total $PM_{2.5}$ Pollution. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor. K, Mg, Si and Ti are good tracer of crustal dust *(Kothai et al., 2008; Patil et al., 2013; Jain et al., 2017; Keerthi et al., 2018; Garaga et al., 2020);* whereas substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as EC, OC, Ni, Pb which are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*. Road dust gets re-suspended due to natural gust of winds or moving objects like vehicles *(Zhang, 2008; Kothai, 2011; Banerjee et al., 2015; Ashrafi et al., 2018)*. Agricultural activities can also lead re-suspension of soil but absence of any major hotspots in the agricultural land use rules out any such re-suspension.

Factor 6: Fossil fuel Combustion

Factor 6 was identified as coal combustion due to the presence of tracers, such as EC, OC, Cl-, NO_3^2, Al, Se, Si and Ti (~26.67%, 33.18%, 4.25%, 12.15%, 2.88%, 2.14%, 2.89% and 6.13%) with minor indicators such as Zn, Cd, Mn, Sr, Co, Cr, EC and OC suggesting the source of fossil fuel combustion contributed to about 13.97% of total $PM_{2.5}$ Pollution. Se, Cd, 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)*.

Table 4.2 : Percentage Source Contribution for Aurangabad

Most likely source(s)	PM_{10}	Most likely source(s)	$PM_{2.5}$
Construction Dust	16.34	Industrial Emission	17.53
Fossil Fuel Combustion	13.20	Secondary Aerosols	15.87
Industrial Emissions	20.36	Vehicular Emission	24.64
Vehicular Emission	9.74	Biomass Burning/ Wood Combustion	18.53
Resuspended Road Dust/ Wind-blown Dust	20.48	Resuspended Road Dust/ Wind-blown Dust	9.46
Biomass Burning/ Wood Combustion	19.88	Fossil fuel Combustion	13.97

4.4 Positive Matrix Factor Analysis Conclusion

After PMF analysis, six factors were identified contributing to both fraction of the PM. The contribution of vehicular pollution is more in $PM_{2.5}$ (24.64%) is found to be higher than PM_{10} (9.74%) whereas Road dust resuspension/windblown dust contributions were dominated by PM_{10} (20.48%) as compared to $PM_{2.5}$ (9.46%). The biomass burning and fossil fuel combustion is contributing almost same in both the cases in range of 18-20% and 13-14% respectively. Secondary aerosols and Oil combustion from Industrial source was found only in $PM_{2.5}$ whereas Construction dust and Industrial emissions were found to be contributing highly to PM_{10}.

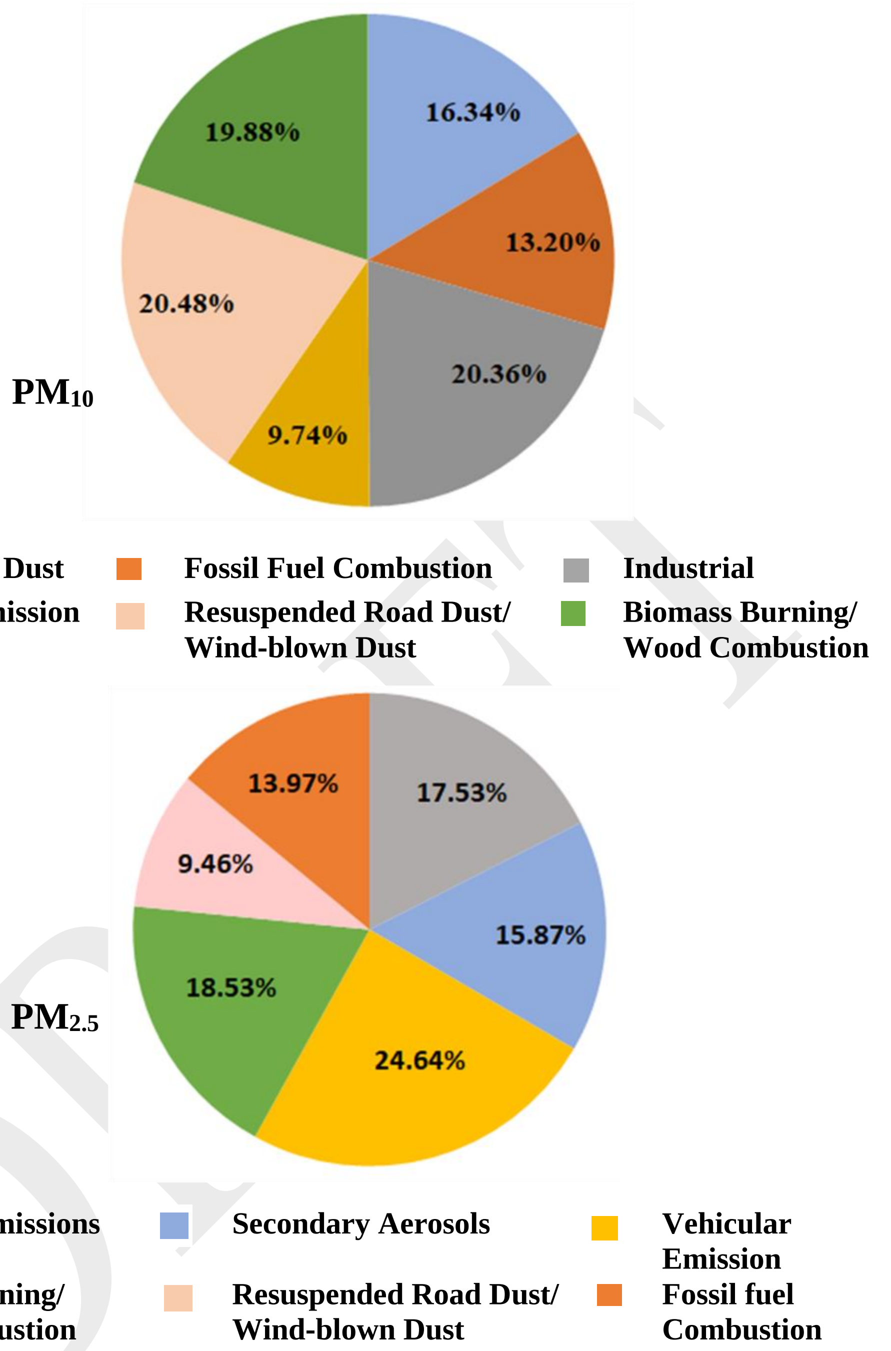
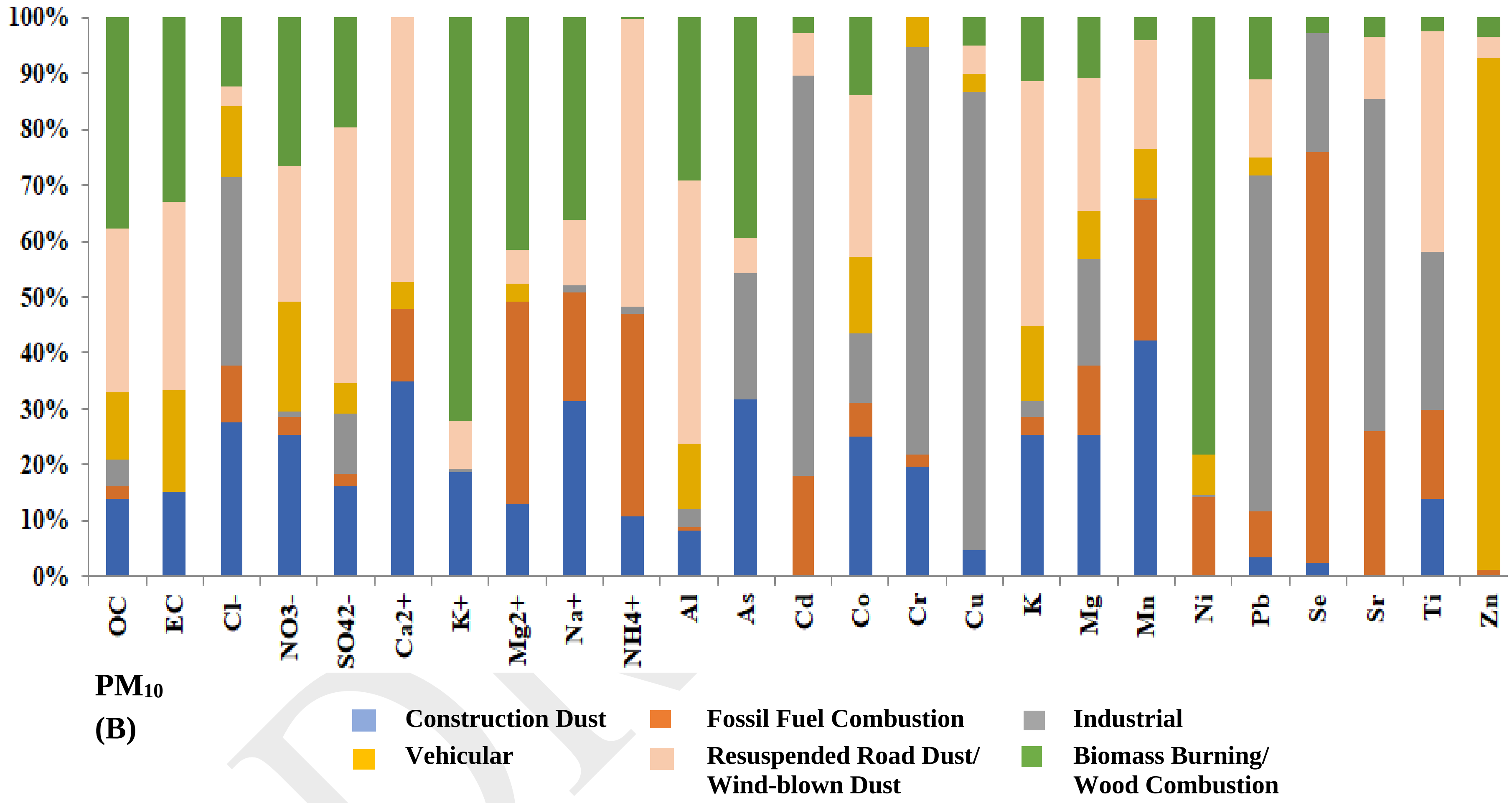


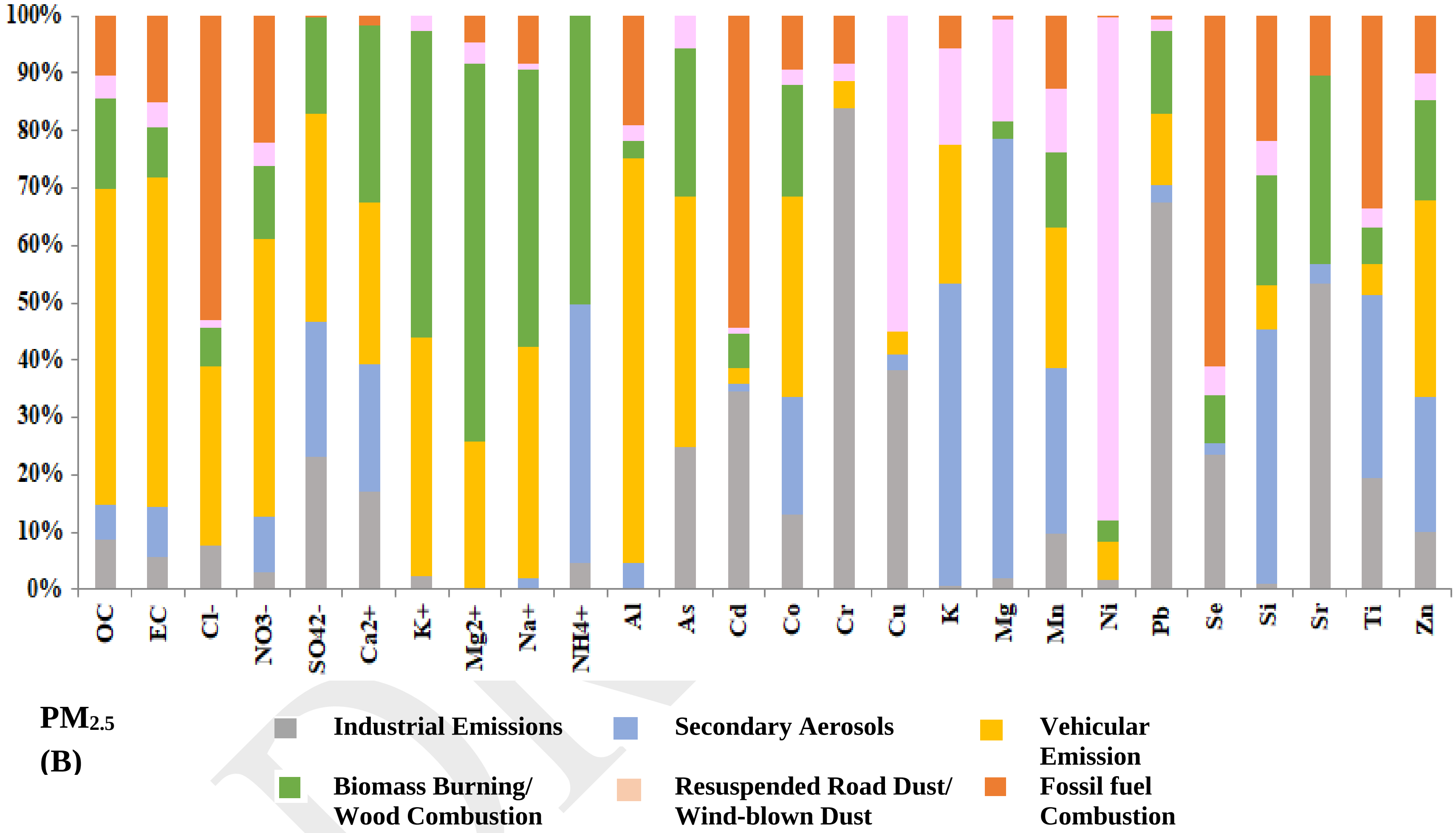
Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Amravati City



PM_{10}

(B)

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



$PM_{2.5}$ (B)

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

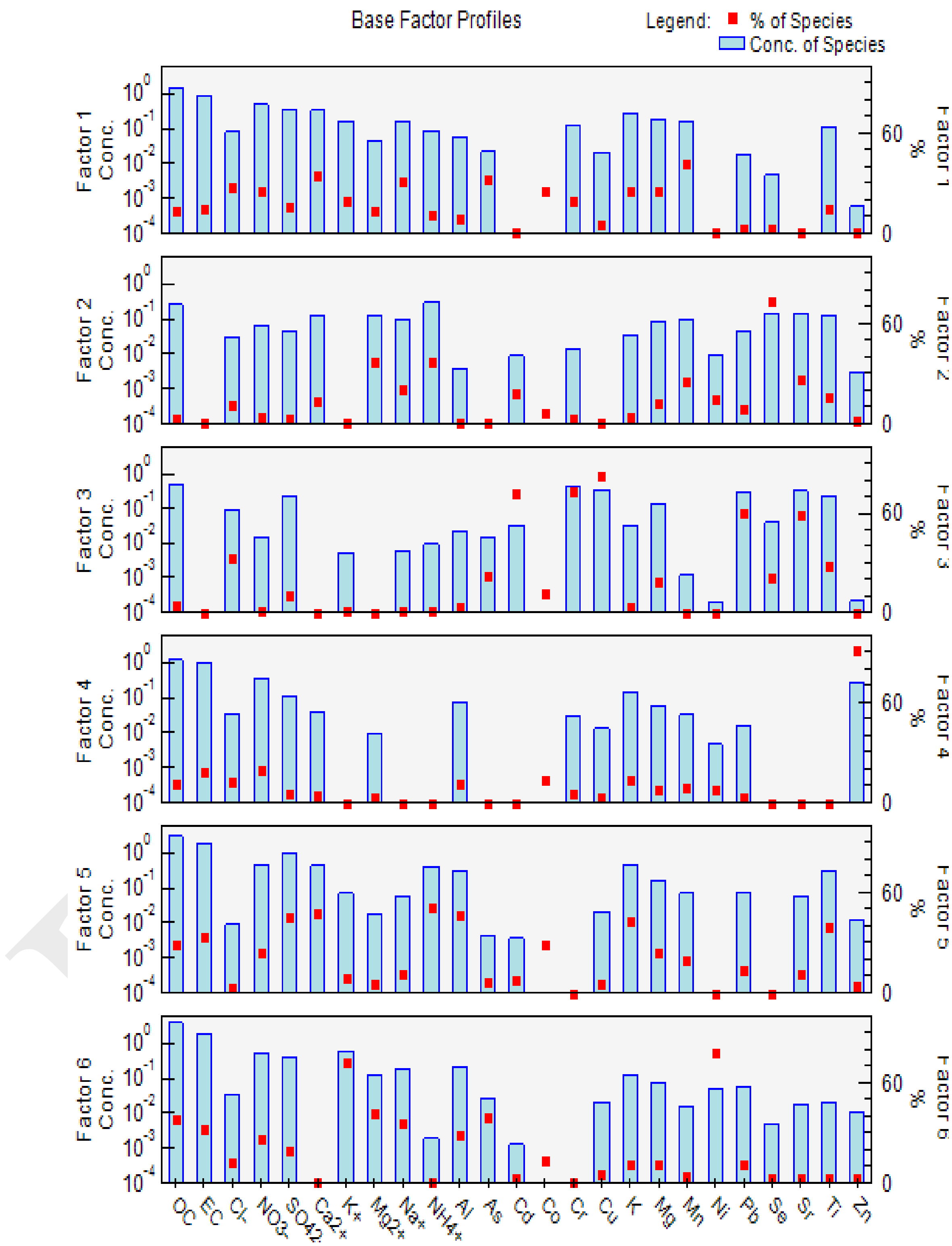


Figure 4.2 a : PM_{10} Base Factor Profiles

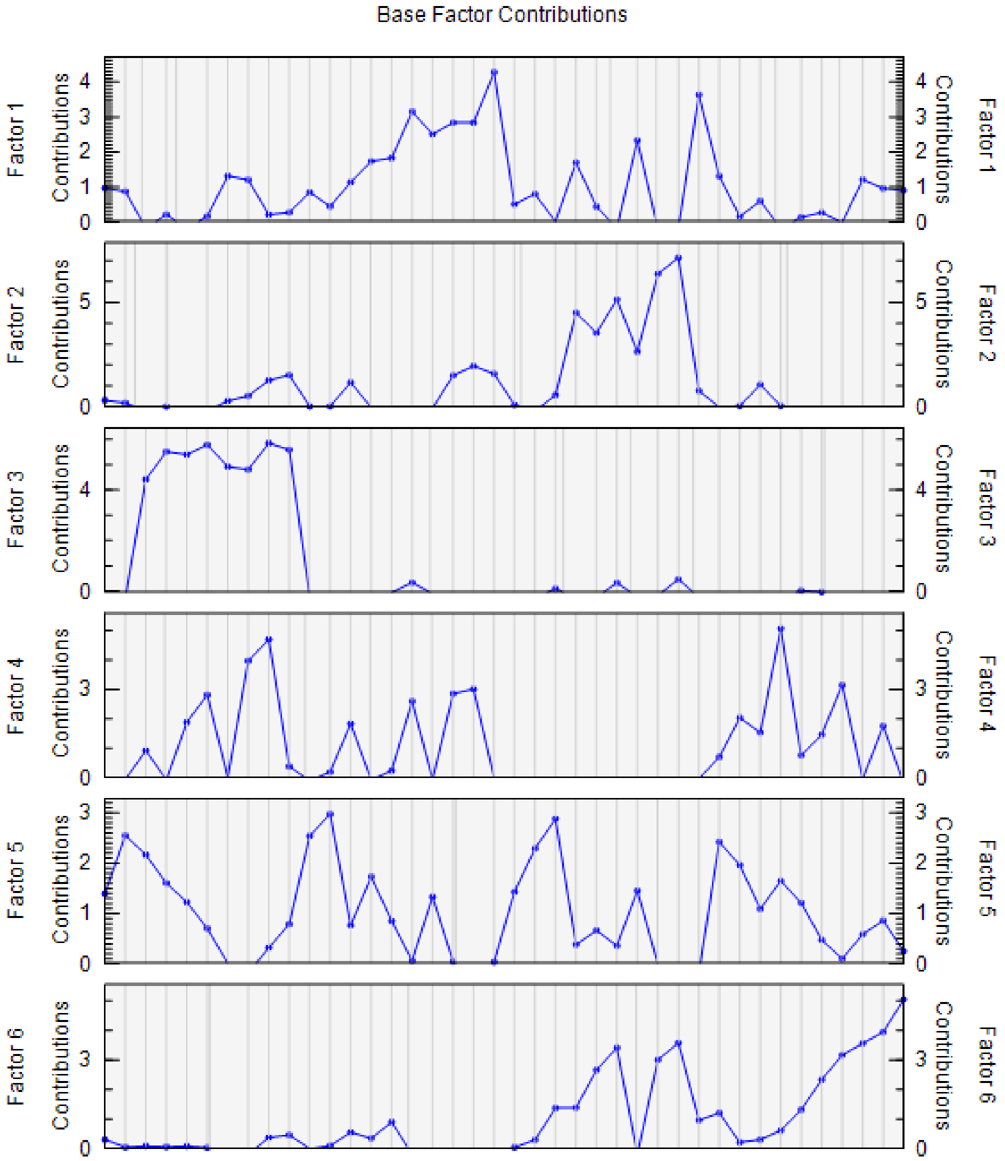


Figure 4.2 b : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, EC, NO_3^{2-}, Mn, Na^+, Ca^{2+}, K	16.34	Construction Dust
Factor 2	OC, Ca^{2+}, NH_4^2, Se, Sr and Ti	13.2	Fossil Fuel Combustion
Factor 3	OC, SO_4^{2-}, Cr, Cu, Pb, Sr, Ti	20.36	Industrial Emissions
Factor 4	OC, EC, NO_3^{2-}, K, Zn	9.74	Vehicular Emission
Factor 5	OC, EC, SO_4^{2-}, Ca^{2+}, K, Al	20.48	Resuspended Road Dust/ Wind-blown Dust
Factor 6	K^+, OC, NO_3^{2-}, SO_4^{2-}, EC	19.88	Biomass Burning/ Wood Combustion

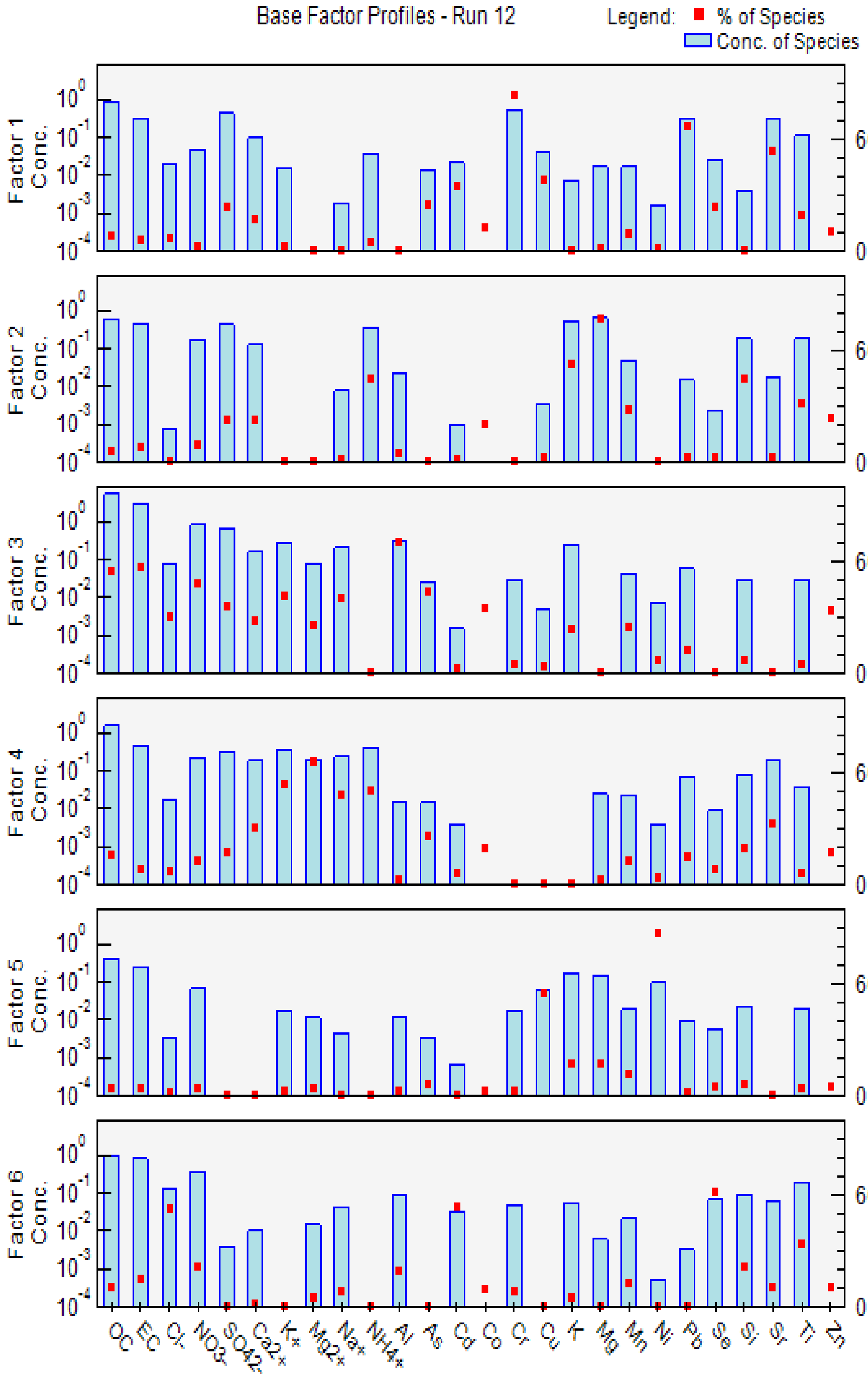


Figure 4.2 c : PM2.5 Base Factor Profiles

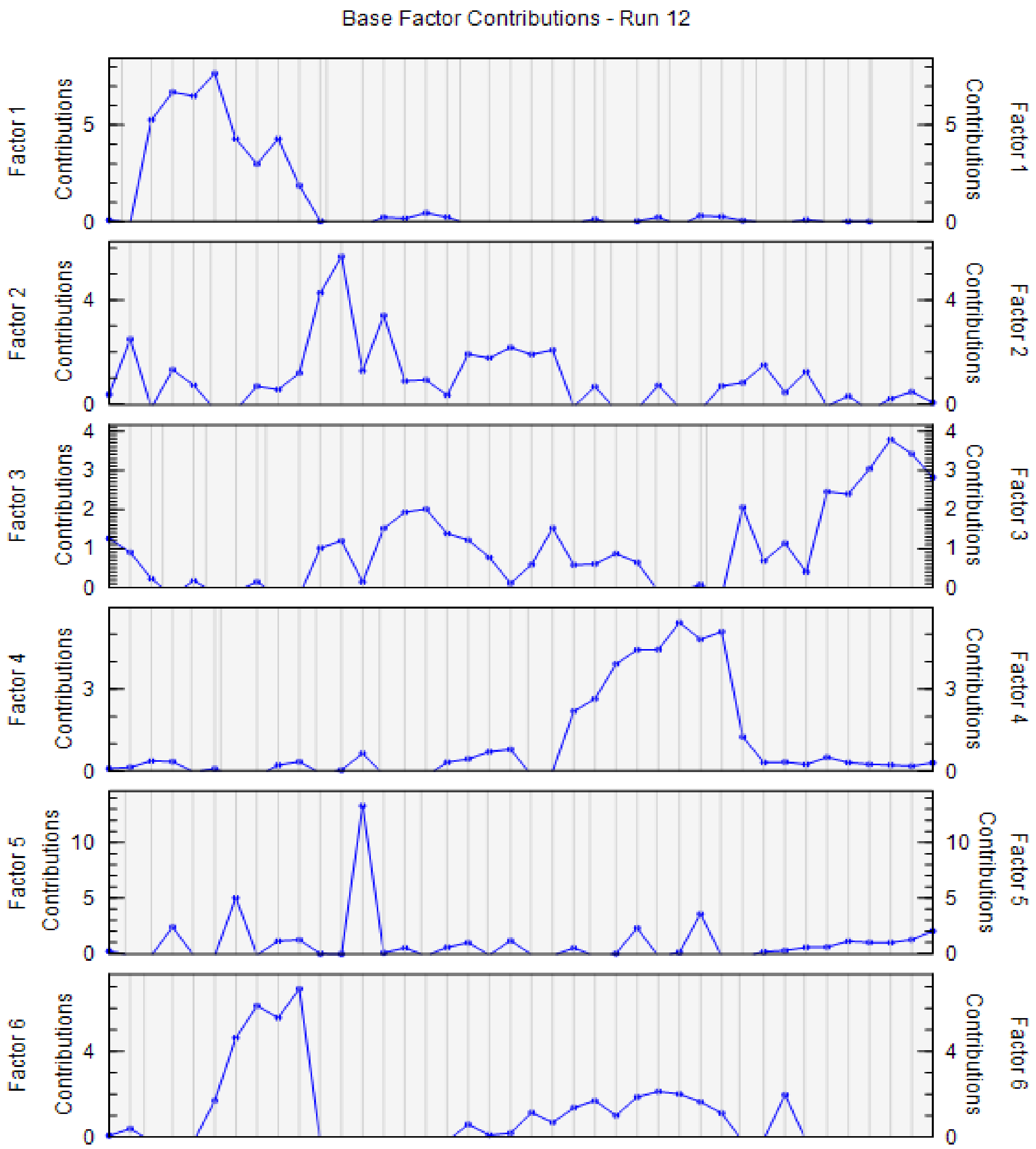


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, EC, Pb, Cr, Sr, SO_4^{2-}	17.53	Industrial Emissions
Factor 2	OC, EC, NO_3^{2-}, NH_4^{2-}, SO_4^{2-}, K, Mg	15.87	Secondary Aerosols
Factor 3	OC, EC, NO_3^{2-}, K^+, Ca^{2+}, Al	24.64	Vehicular Emission
Factor 4	K^+, OC, NH_4^{2-}, SO_4^{2-}, EC	18.53	Biomass Burning/ Wood Combustion
Factor 5	OC, EC, Cu, Ni, K, Mg	9.46	Resuspended Road Dust/ Wind-blown Dust
Factor 6	EC, OC, Cl-, NO_3^{2}, Al, Se, Si, Ti	13.97	Fossil fuel Combustion

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 highest PM emissions are estimated from industries (45.6%), vehicular source (9.6%) and re-suspension of road dust (4%). The emission loads of PM_{10}, $PM_{2.5}$, from vehicular sources are calculated to be around 0.259 and 0.172 tonnes /day, respectively. The maximum emission load of particulates is from 2 wheelers vehicles (66%). The emission load of PM_{10} and $PM_{2.5}$ from re-suspension of road dust by the movement of vehicles is estimated to 0.106 and 0.071 TPD, respectively.

Majority of the industrial units are textile, automobiles, bulk drug units and brick klins. There are approximately 57 industrial units in and around the 5 km radius of the city. As per the MSME, 2015-16 approximately 500 hectare is allotted to upcoming textile park. There are in all 9 brick kilns in the area. The fuel consumption pattern in brick kilns is wood (23.82%), coal (60.25%) and ash (15.91%). From brick kilns, the PM_{10} emission load is 0.88 TPD. Around 48%, PM_{10} industrial emission load is from (coal, brick kiln and wood). The emission load for PM_{10} and $PM_{2.5}$ is around 5.209 and 3.473 tones/day, if industries outskirt of Amravati city are excluded and with them PM_{10} load is estimated to be 7.59 TPD. The maximum contribution is from combustion of coal (85%), followed by wood (8.7%) and diesel (4%).

It was observed that Petcoke fuel is used in Amravati on larger scale, followed by 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 emission load for PM_{10} and $PM_{2.5}$ from different area sectors were Bakeries (0.023, 0.016 T/d); Open Eatout (0.003, 0.004 T/d); Hotels & Restaurants (0.005, 0.007 T/d); Crematoria (0.040, 0.027 T/d); Domestic (0.60, 0.43 T/d) and Open Burning (0.42, 0.28 T/d) respectively. Overall contribution of area domestic and commercial burning is around 24.6% from area source.

The locations of monitoring selected for ambient air quality monitoring viz. commercial/ traffic site (Rajkamal square), residential sites (St. Gadge Baba University & Jawahar Vidyalay) and industrial site (Sumit Agro MIDC). PM_{10} concentration violated the CPCB threshold (100 $\mu g\ m^3$) at commercial /traffic areas, whereas at residential and industrial sites exceedence was around 40%. High $PM_{2.5}/PM_{10}$ ratio generally suggests the presence of combustion activity at or near the sites. Most of the factors identified in source apportionment study of Amravati City were observed to be in as mix contribution form, which reflected collinearity of the factor species from different sources. 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. $PM_{2.5}$ (24.64%) has a higher contribution of vehicular pollution than PM_{10} (9.74%), but PM_{10} (20.48%) has a higher proportion of road dust resuspension/windblown dust than $PM_{2.5}$ (9.46%). In both scenarios, biomass burning and fossil fuel combustion provide nearly the same amount of 18-20% and 13-14%, respectively. Only secondary aerosols and sources of oil combustion from Industrial Emissions were detected in $PM_{2.5}$, whereas construction dust and industrial emissions were shown to have a significant role in PM_{10}. These results are well corroborated with apportionment of particulate matter; considering nature and quantum of the activities that is carried out in and around the study area.

References :

- Ashrafi, K., Fallah, R., Hadei, M., Yarahmadi, M., Shahsavani, A. (2018). Source Apportionment of Total Suspended Particles (TSP) by Positive Matrix Factorization (PMF) and Chemical Mass Balance (CMB) Modeling in Ahvaz, Iran. Arch. Environ. Contam. Toxicol. 75, 278–294. https://doi.org/10.1007/s00244-017-0500-z
- Banerjee, T., Murari, V., Kumar, M., Raju, M.P. (2015). Source apportionment of airborne particulates through receptor modeling: Indian scenario. Atmospheric Res. 164–165, 167-187. https://doi.org/10.1016/j.atmosres.2015.04.017
- Basha, Shaik, Jayaraj Jhala, R. Thorat, Sangita Goel, Rohit Trivedi, Kunal Shah, Gopalakrishnan Menon, Premsingh Gaur, Kalpana Mody, and Bhavanath Jha. "Assessment of Heavy Metal Content in Suspended Particulate Matter of Coastal Industrial Town, Mithapur, Gujarat, India." Atmospheric Research 97 (July 2010): 257–65. https://doi.org/10.1016/j.atmosres.2010.04.012.
- Bhuyan, Pranamika, Pratibha Deka, Amit Prakash, Srinivasan Balachandran, and Raza Hoque. "Chemical Characterization and Source Apportionment of Aerosol over Mid Brahmaputra Valley, India." Environmental Pollution 234 (March 2018): 997–1010. https://doi.org/10.1016/j.envpol.2017.12.009.
- Cesari, D., Donateo, A., Conte, M., Contini, D. (2016). Inter-comparison of source apportionment of PM_{10} using PMF and CMB in three sites nearby an industrial area in central Italy. Atmospheric Res. 182. https://doi.org/10.1016/j.atmosres.2016.08.003
- Das, R., Khezri, B., Srivastava, B., Datta, S., Sikdar, P.K., Webster, R.D., Wang, X. (2015). Trace element composition of $PM_{2.5}$ and PM_{10} from Kolkata – a heavily polluted Indian metropolis. Atmospheric Pollut. Res. 6, 742–750. https://doi.org/10.5094/APR.2015.083
- Gadi, R., Shivani, S., Sharma, S.K., Mandal, T. (2019). Source apportionment and health risk assessment of organic constituents in fine ambient aerosols ($PM_{2.5}$): A complete year study over National Capital Region of India. Chemosphere 221, 583–596. https://doi.org/ 10.1016/ j. chemosphere.2019.01.067
- Garaga, Rajyalakshmi, Sharad Gokhale, and Sri Kota."Source Apportionment of Size-Segregated Atmospheric Particles and the Influence of Particles Deposition in the Human Respiratory Tract in Rural and Urban Locations of North-East India." Chemosphere 255 (May 2020): 126980. https://doi.org/10.1016 /j.chemosphere.2020.126980.

- Gupta, I., Salunkhe, A., & Kumar, R. (2012). Source Apportionment of PM_{10} by Positive Matrix Factorization in Urban Area of Mumbai, India. The Scientific World Journal, 2012, 1–13. doi:10.1100/2012/585791
- Gupta, Indrani, Abhaysinh Salunkhe, and Rakesh Kumar. “Source Apportionment of PM_{10} by Positive Matrix Factorization in Urban Area of Mumbai, India.” The Scientific World Journal 2012 (May 2012): 585791. https://doi.org/10.1100/2012/585791.
- Habil, M., Massey, D.D., Taneja, A. (2016). Personal and ambient $PM_{2.5}$ exposure assessment in the city of Agra. Data Brief 6, 495–502. https://doi.org /10.1016/j.dib. 2015.12.040
- Jain, Srishti, Sudhir Kumar Sharma, Nikki Choudhary, R. Masiwal, Mohit Saxena, Ashima Sharma, Tuhin Mandal, Anshu Gupta, NC Gupta, and Chhemendra Sharma. “Chemical Characteristics and Source Apportionment of $PM_{2.5}$ Using PCA/APCS, UNMIX, and PMF at an Urban Site of Delhi, India.” Environmental Science and Pollution Research 24 (June 2017): 14637–56. https://doi.org/10.1007/s11356-017-8925-5.
- Jain, Srishti, Sudhir Kumar Sharma, Manoj Srivastava, Abhijit Chatterjee, Rajeev Kumar Singh, Mohit Saxena, and Tuhin Mandal. “Source Apportionment of PM_{10} Over Three Tropical Urban Atmospheres at Indo-Gangetic Plain of India: An Approach Using Different Receptor Models.” Archives of Environmental Contamination and Toxicology, January 19. https://doi.org/10.1007/s00244-018-0572-4.
- Jiang, S.Y., Kaul, D.S., Yang, F., Sun, L., Ning, Z. (2015). Source apportionment and water solubility of metals in size segregated particles in urban environments. Sci. Total Environ. 533, 347–355. https://doi.org/10.1016/j.scitotenv.2015.06.146
- Keerthi, R., N. Selvaraju, Lity Alen Varghese, and N. Anu. “Source Apportionment Studies for Particulates (PM10) in Kozhikode, South Western India Using a Combined Receptor Model.” Chemistry and Ecology 34, No. 9 (2018): 797–817. https://doi.org/10.1080/ 02757540.2018.1508460.
- Kothai, P. (2011). Chemical Characterization and Source Identification of Particulate Matter at an Urban Site of Navi Mumbai, India. Aerosol Air Qual. Res. https://doi.org/ 10.4209/aaqr.2011.02.001
- Kothai.; I.V. Saradhi, P. Prathibha, Philip Hopke, Gauri Pandit, and Vijay Puranik. “Source Apportionment of Coarse and Fine Particulate Matter at Navi Mumbai, India.” Aerosol And Air Quality Research 8 (December 2008): 423–36. https://doi.org/10.4209/aaqr. 2008.07.0027.
- Kumar, A.Vinod, Rashmi Patil, and K.S.V Nambi. “Source Apportionment of Suspended Particulate Matter at Two Traffic Junctions in Mumbai, India.” Atmospheric Environment 35 (September 2001): 4245–51. https://doi.org/10.1016/S1352-2310(01)00258-8.
- Maykut, N. N., Lewtas, J., Kim, E., & Larson, T. V. (2003). Source Apportionment of $PM_{2.5}$ at an Urban IMPROVE Site in Seattle, Washington. Environmental Science & Technology, 37(22), 5135–5142. doi:10.1021/es030370y
- Mukherjee, Subrata, Vyoma Singla, Govindan Pandithurai, Pramod Safai, G. Meena, K. Dani, and Anil Kumar. “Seasonal Variability in Chemical Composition and Source Apportionment of Sub-Micron Aerosol over a High-Altitude Site in Western Ghats, India.” Atmospheric Environment 180 (February 2018). https://doi.org/10.1016/j.atmosenv. 2018.02.048.
- Norris, G., R. Duvall, S. Brown, AND S. Bai (2014). EPA Positive Matrix Factorization (PMF) 5.0 Fundamentals and User Guide. https://www.epa.gov/sites/production/files/2015-02/documents/pmf_5.0_user_guide.pdf
- Paatero, P., Hopke, P. (2003). Discarding or Downweighting High-Noise Variables in Factor Analytic Models. Anal. Chim. Acta 490, 277–289. https://doi.org/10.1016/S0003-2670(02)01643-4
- Paatero, P., Hopke, PK., Song, XH., Ramadan, Z. (2002).Understanding and controlling rotations in factor analytic models, Chem. and Intell. Lab. Sys., 60, 253-264 https://linkinghub.elsevier.com/retrieve/pii/S0169743901002003

- Pakbin, P., Ning, Z., Schauer, J., Sioutas, C. (2011). Seasonal and Spatial Coarse Particle Elemental Concentrations in the Los Angeles Area. Aerosol Sci. Technol. 45, 949–963. https://doi.org/10.1080/ 02786826.2011.571309
- Panwar, Pooja, Vignesh Prabhu, Ashish Soni, Disha Punetha, and Vijay Shridhar. "Sources and Health Risks of Atmospheric Particulate Matter at Bhagwanpur, an Industrial Site along the Himalayan Foothills." SN Applied Sciences 2 (April 2020). https://doi.org/10.1007/ s42452-020-2420-1.
- Patil, R.; Kumar, R.; Menon, R.; Shah, M.; and Sethi, V. (2013) Development of Particulate Matter Speciation Profiles for Major Sources in Six Cities in India. Atmospheric Research 132–133 : 1–11. https://doi.org/10.1016/j.atmosres.2013.04.012.
- Police, Sandeep, Sanjay Sahu, and Gauri Pandit."Chemical Characterization of Atmospheric Particulate Matter and Their Source Apportionment at an Emerging Industrial Coastal City, Visakhapatnam, India." Atmospheric Pollution Research 7 (April 2016). https://doi.org/ 10.1016/j.apr.2016.03.007.
- Polissar, A., Hopke, P., Malm W., Sisler J., (1998). Atmospheric aerosol over Alaska: 1. Spatial and seasonal variability. https://doi.org/10.1029/98JD01365
- Rai, Pragati, Abhishek Chakraborty, Anil Mandariya, and Tarun Gupta. "Composition and Source Apportionment of PM_1 at Urban Site Kanpur in India Using PMF Coupled with CBPF." Atmospheric Research 178–179 (April 2016): 506–20. https://doi.org/10.1016/ j.atmosres.2016.04.015.
- Reff, A., Eberly, S.I., Bhave, P.V. (2007). Receptor Modeling of Ambient Particulate Matter Data Using Positive Matrix Factorization: Review of Existing Methods. J. Air Waste Manag. Assoc. 57, 146–154. https://doi.org/10.1080/10473289.2007.10465319
- Sharma, S. K., Mandal, T. K., Jain, S., Sharma, A., & Saxena, M. (2016). Source Apportionment of $PM_{2.5}$ in Delhi, India Using PMF Model. Bulletin of Environmental Contamination and Toxicology, 97(2), 286–293. doi:10.1007/s00128-016-1836-1
- Sharma, Sudhir Kumar, Tuhin Mandal, Srishti Jain, Saraswati Yadav, Ashima Sharma, and Mohit Saxena. "Source Apportionment of $PM_{2.5}$ in Delhi, India Using PMF Model." Bulletin of Environmental Contamination and Toxicology 97 (August 2016): 286–93. https://doi.org/10.1007/s00128-016-1836-1.
- Shukla, SP, and Mukesh Sharma. "Source Apportionment of Atmospheric PM_{10} in Kanpur, India." Environmental Engineering Science 25 (July 2008): 849. https://doi.org/ 10.1089/ees.2006.0275.
- Taghvaee, S., Sowlat, M. H., Mousavi, A., Hassanvand, M. S., Yunesian, M., Naddafi, K., & Sioutas, C. (2018). Source apportionment of ambient PM 2.5 in two locations in central Tehran using the Positive Matrix Factorization (PMF) model. Science of The Total Environment, 628-629, 672–686. doi:10.1016/j.scitotenv.2018.02.096
- Waked, A. ;Favez, O.; Alleman, L. Y.; Piot, C.; Petit, J.E.; Delaunay, T.; Verlinden, E.; Golly, B.; Besombes, J.L.; Jaffrezo, J.L.; Leoz-Garziandia, E. (2014). Source apportionment of PM10 in a north-western Europe regional urban background site (Lens, France) using positive matrix factorization and including primary biogenic emissions. Atmos. Chem. Phys. 14, 3325–3346. https://doi.org/10.5194/acp-14-3325-2014
- Zhang, H. (2008). An assessment of heavy metals contributed by industry in urban atmosphere from Nanjing, China. Environ. Monit. Assess. 154, 451–8. https://doi.org/ 10.1007/s10661-008-0411-6
- Zong, Z.,Wang, X., Tian, C., & Chen, Y., & Qu, L., Ji, L., Zhi, G., Li, J., Zhang, G. (2016). Source apportionment of $PM_{2.5}$ at a regional background site in North China using PMF linked with radiocarbon analysis: insight into the contribution of biomass burning. Atmospheric Chemistry and Physics. 16. 11249-11265. doi:10.5194/acp-16-11249-2016.
- URL 1: EPA PMF v5.0 Software link: https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses
- URL 2: DRI EC-OC Manual : https://www.epa.gov/sites/production/files/2018-10/ documents/csn_improvea_ model2015_2-231r0_053118_508comp-dri.pdf
- URL 3 : US EPA Speciates : https://www.epa.gov/air-emissions-modeling/speciate-0

Chapter 5

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 Amravati 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 Amrawati 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 Kms radius is considered which covers the entire Amrawati 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 brings 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 Kms radius 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. Since the standard weighted emission load of PM_{10} is the highest, the source dispersion modelling is carried out only for PM_{10} **(Table 5.1)**. The GLC of all other pollutant (SOx and NOx) 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.

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

Parameter	Regulatory Stand.[µg/m^3]	Area Emission	Industry Emission	Vehicle Emission	City Emission
PM_{10}	**100**	1.7	0.8	0.3	2.9
$PM_{2.5}$	60	0.6	0.5	0.1	1.2

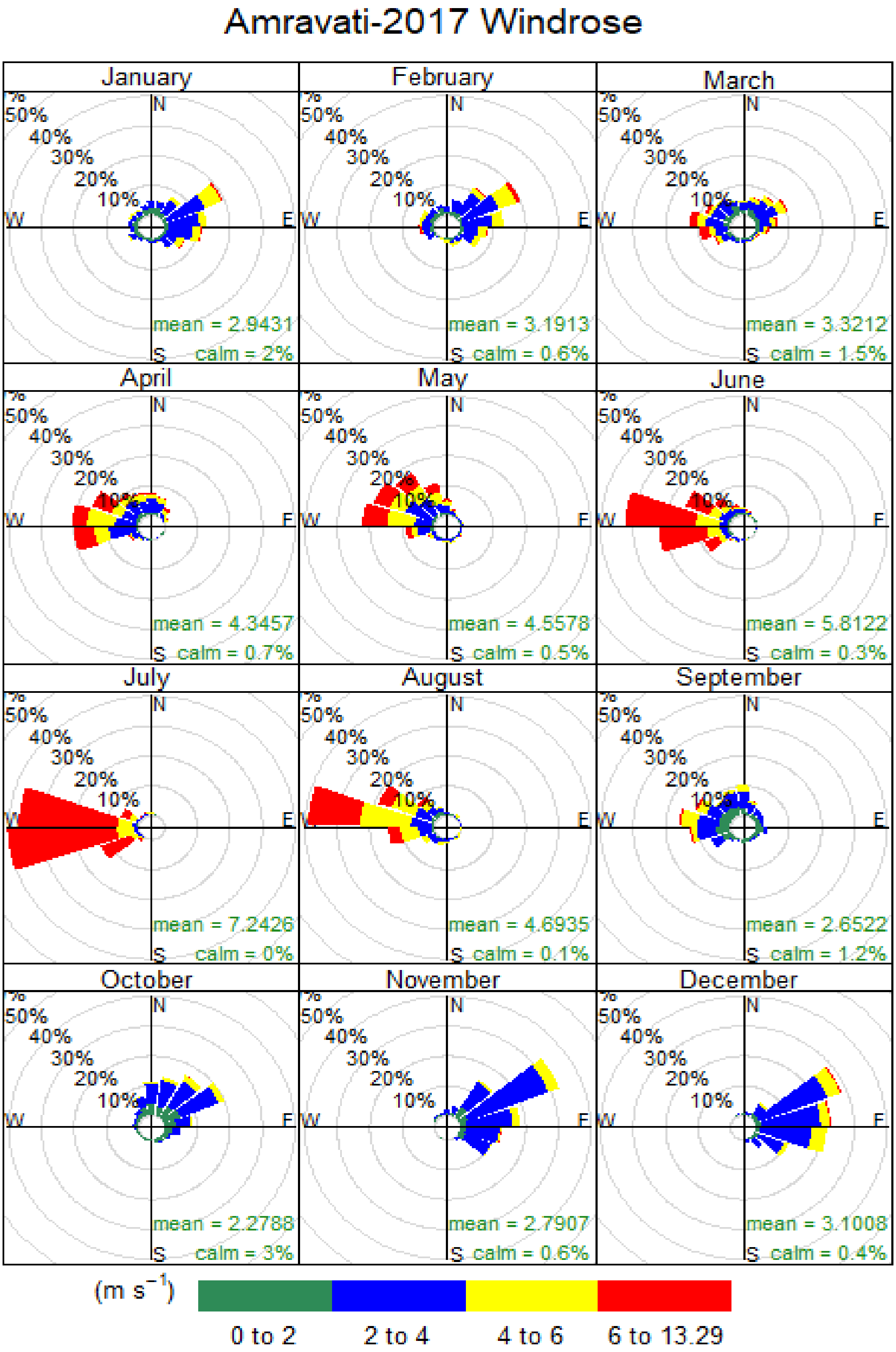


Figure 5.1 : Monthly Wind rose Diagram of Amravati

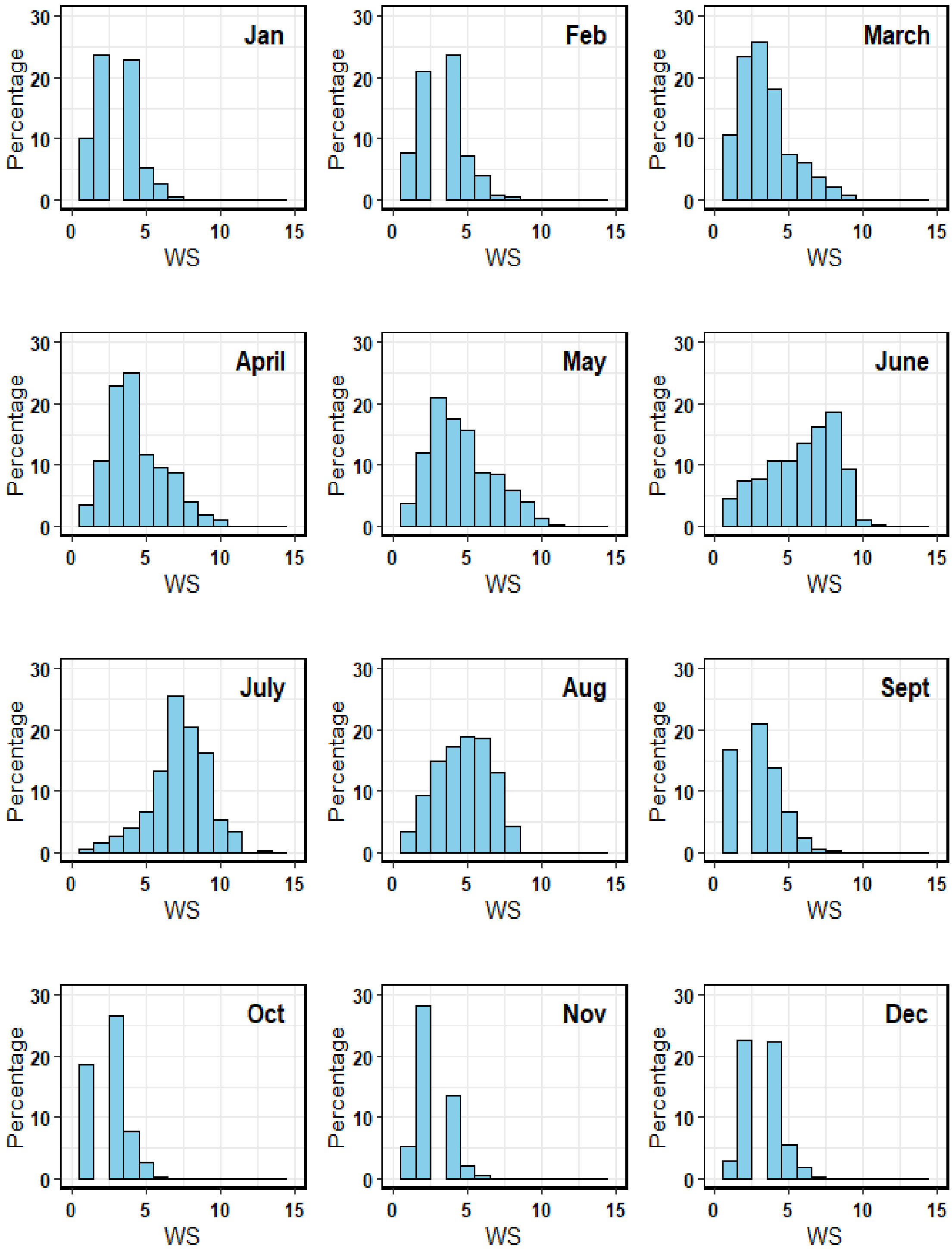


Figure 5.2 : Monthly Wind Speed Frequency in Amravati

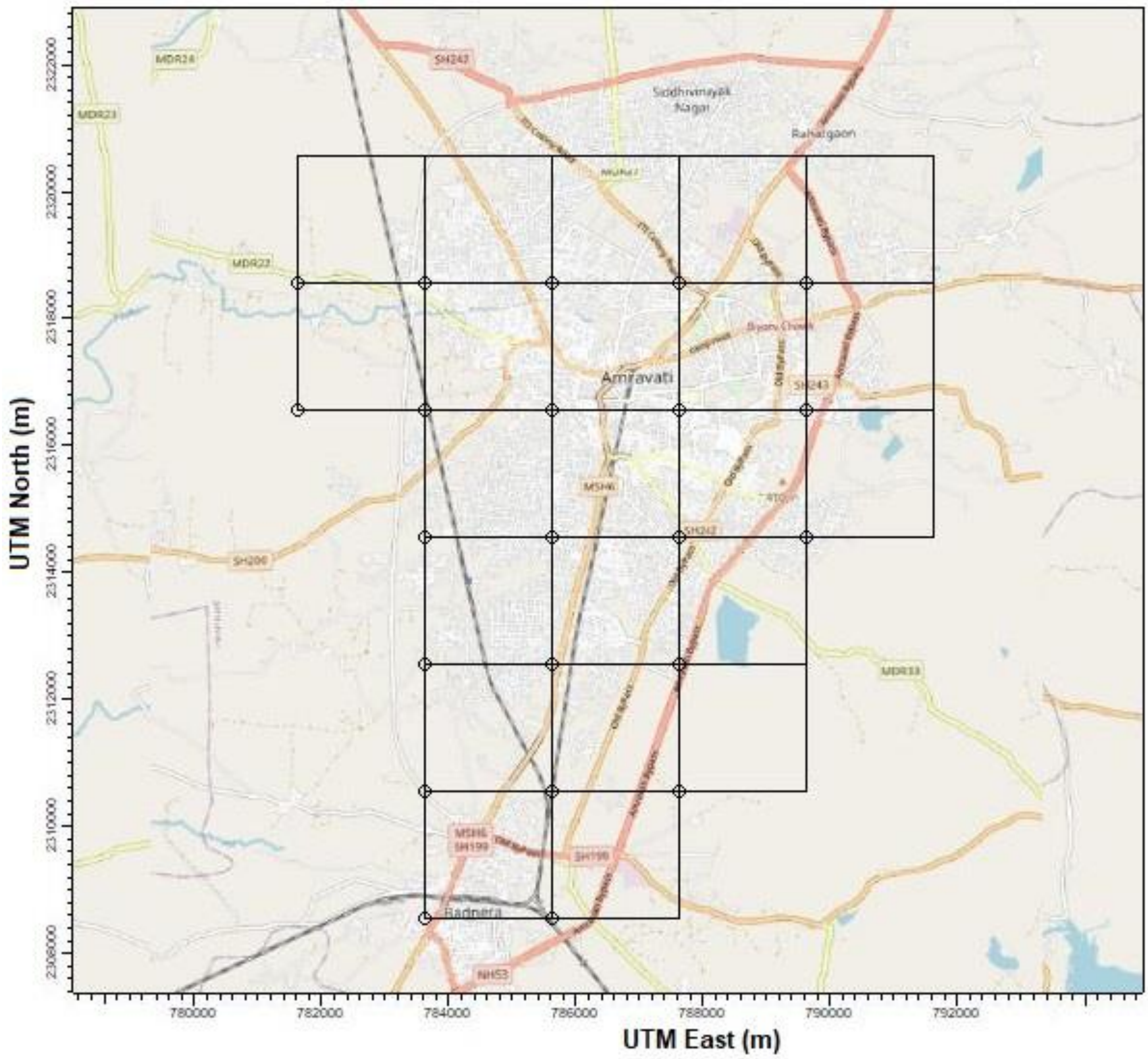


Figure 5.3: Grid Over Amrawati City for Area Source Emission

Figure 5.3 shows the grid setup on the Amrawati city for the purpose of finding the emission load for each grid area. **Table 5.2** shows the emission load from each grid that is used for dispersion modelling. With this emission load, the source dispersion modelling is executed and the ground level concentration (GLC) of pollutant is determined. **Figure 5.4** shows the GLC of PM_{10} in Amravati city.

Simulation using AERMOD yields maximum GLC of PM_{10} is very low and is around 55 µg/m^3 **(Figure 5.4)**. Since this value is lower than the regulatory limit, all other pollutants GLC will be below the regulatory limit value.

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

No.	ID	Emission Rate [kg/d]	No.	ID	Emission Rate [kg/d]
1	A3	266.68	12	C5	4.13
2	B3	64.02	13	D5	170.10
3	C3	15.73	14	E5	124.30
4	D3	0.03	15	B6	226.93
5	E3	7.42	16	C6	2.81
6	A4	75.33	17	D6	1.70
7	B4	40.60	18	B7	234.89
8	C4	0.58	19	C7	288.28
9	D4	73.46	20	D7	192.30
10	E4	84.53	21	B8	35.95
11	B5	28.36	22	C8	4.79

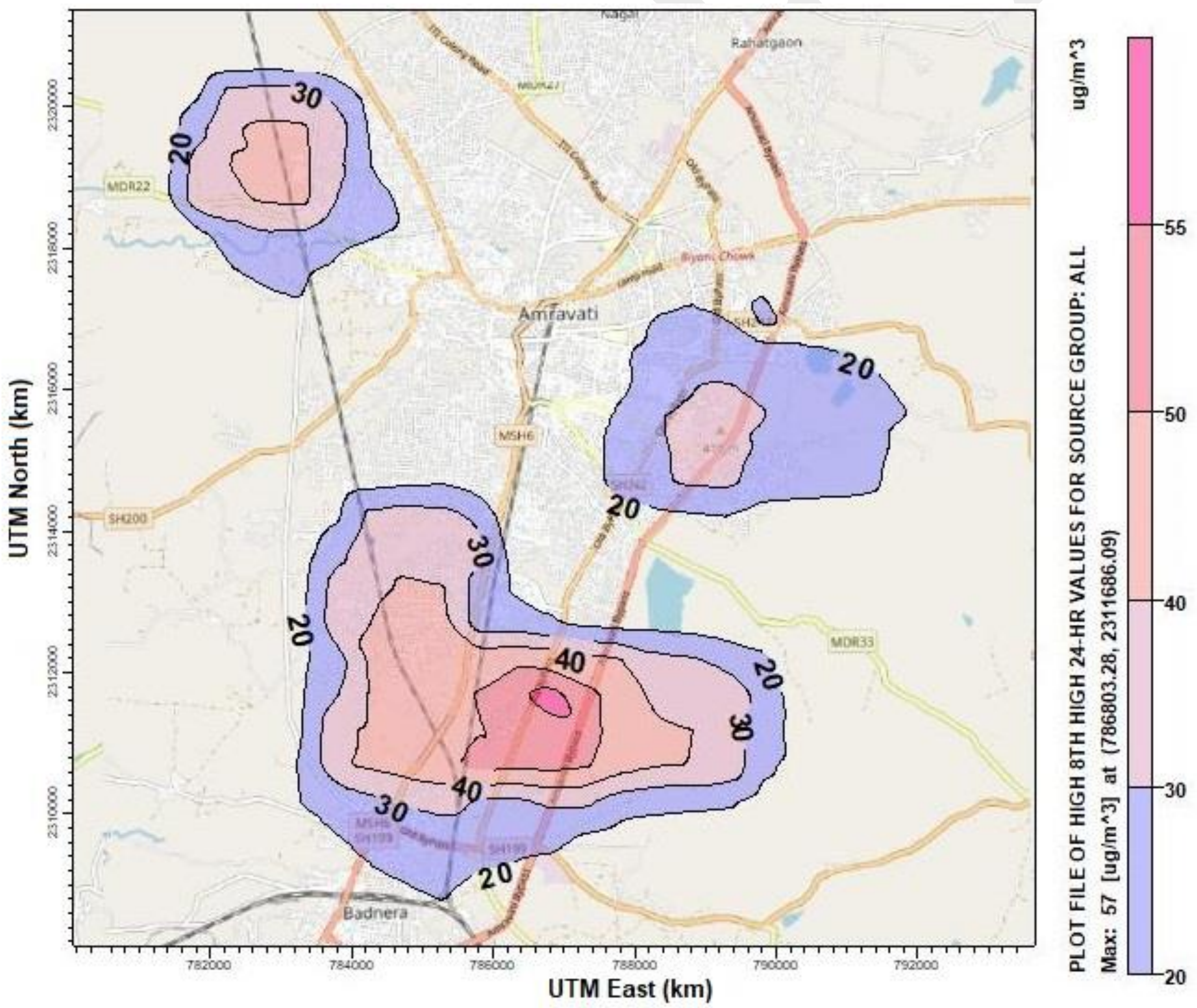


Figure 5.4: Isopleth of GLC of PM10 Over Amravati City Due to Area Source Emission.

Chapter 6

Action Plan for Control of Air Pollution

6.1 Emission Reduction Action Plan for Amravati 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	25% reduction in emissions	• Heavy duty vehicles are the significant contributors to PM load. Although the number is less, high emissions are observed due to high emission factor and VKT. High number of heavy duty, 4Ws are observed at Shegaon Sq., Dastur Nagar Sq., Old bypass, Welcome gate. Bypass exists for non-destined vehicles. • Retro fitment of Diesel Oxidation Catalyst (DOC) in 4-wheeler public transport. • Retro-fitment of Diesel Particulate Filter in 4-wheeler public transport. • Inspection/maintenance of all commercial vehicles. Restrict commercial vehicle entering city by having ring roads. • 2W are significant contributor to PM load. With proper maintenance, the emissions are assumed to be same in spite of increase in number of vehicles. • High number of 2Ws are observed at Railway stn bridge, Pachwati Sq. Shegaon naka, Kathora naka sq. and Tapovan sq. • For reducing the traffic congestion, no parking zones at the traffic areas need to be delineated. Roads hindering the smooth traffic movement need to be identified and either may be closed and traffic may be diverted or some other suitable option may be exercised. Roads need to be identified for widening. • Maintain potholes free roads for free flow of traffic. Introduce bi-cycle tracks/paths and encourage the use of bi-cycles. • Immediate launch of extensive fuel adulteration drive and random monitoring of fuel quality data.

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

Sources	Short Term- 2019	Long Term- 2022	Action Required
Vehicles (Contd..)	10% reduction in emissions	25% reduction in emissions	• Launch public awareness campaigns for air pollution control, vehicle maintenance, minimizing use of personal vehicles, lane discipline etc. NGOs need to be involved for this purpose.
The above mitigation measures reduce the line source emissions by 10% in short term and 25% in long term			
Point Source			
Industry	To get the 10% reduction in emissions till 2019	To get the 25% reduction in emissions till 2022	• The coal-based power plant is up to date with the control technologies required for particulate emission control. • The existing capacity of TPP is 1350 MW which is proposed for expansion up to 2700 MW in next few years. Considering the increase in capacity, PM_{10} emission load from TPP will increase twice. Considering this fact in mind, the following suggestions are made: ▪ Change in coal quality with less ash content. The need is to focus on the less ash content and high calorific value of the coal to increase the plant efficiency. ▪ Technological improvement option as given in *Ma et al. (2017)* can be studied. ▪ Efficacy of use of solar power needs to be studied. • For the other coal-based industries, the aged boilers need to be replaced. The latest control technologies are needed for these industries as the PM emission load is quite high. • Efficacy of use of solar power in industries and other control measures needs to be studied. • Visit observations: water sprinkling after the arrival of the officials, needs to be a regular practice in fugitive dust areas. Regular audit of stack emissions for QA/QC. Strict emission control norms. • Brick kilns: Brick kiln contribution is higher. Shifting of natural draft brick kilns to induced draft, banning of operation of Brick kilns in city area is envisaged for the emission reduction.
The above mitigation measures reduce the point source emissions by 10% in short term and 25% in long term			

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

Sources	Short Term-2019	Long Term-2022	Action Required
Area Source			
Fuel burnt Res and Commercial Cooking Domestic combustion	5% reduction in emissions	20% reduction in emissions	As given below for individual sources ▪ Household wood and cow-dung burning is to be reduced. Increase in LPG usage through Ujjwala scheme. ▪ Alternate fuel options e.g. solar needs to be assessed and exercised. ▪ Crop residue burning needs to be banned gradually but at least 60% reduction in the practice is required.
Hotels, dhaba and open eat-outs			Use of LPG in hotels and eateries.
Bakery			In bakeries, reduction in wood usage is to be emphasized through replacement with other options such as electric-ovens.
Crematoria			Total 10 crematories. Renewable fuel/biomass briquette etc. to be encouraged.
Assumptions or required actions to reduce the emissions: To get the 5% reduction in emissions, LPG consumers (domestic) need to be increased to 10% in 2019 in order to reduce the emissions from wood. The PM_{10} load will be reduced from wood combustion but from LPG, $PM_{2.5}$ emissions will increase. To get the 20% reduction in emissions till 2022, crop residue burning needs to be banned or at least practice needs to be reduced to 60%. The emissions from hotels, open eat outs and crematories are not much. Few general regulations in all these source activities will help maintain the reduced levels. However, the increase in population and people's consumption pattern need to be taken care off.			
Solid waste/open burning	5% reduction in emissions	15% reduction in emissions	• Increase in segregation, collection and proper disposal with increased Green Belt. • Launch extensive drives against open burning. Decrease in waste burning. Public awareness drives. • Proper collection of Horticulture waste and its disposal following composting-cum-gardening approach. • Bio-methanation and biogas plant need to be installed
Assumptions or required actions to reduce the emissions: To get the 5% reduction in emissions, solid waste burning needs to be reduced to 5% in 2019. Bio-methanation and biogas plant installation till 2022 will surely reduce the emissions to 15%. Increase in green belt resulted in the air quality improvement in terms of PM_{10} to 0.13% *(Nowak et al., 2014)*.			

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

Sources	Short Term-2019	Long Term-2022	Action Required
Area Source (Contd..)			
Road Dust and C&D	20% reduction in emissions	40% reduction in emissions	• Enforcement of construction & demolition rules. • Reduction in unpaved roads by paving. • AMC has proposed plan for creation of green buffers along the traffic corridors (AMC has passed the order Vide letter no AMC/ENV/MC/817/2017 dated 07/02/2016 forwarded to GM BSNL, PWD, for proper action). Plantation drive along the road side, Greening of open areas, garden, community places, schools and housing societies. • Wall to Wall paving (brick). • Ensure carriage of construction material in closed/covered Vessels. Control measures for fugitive emissions from material handling, conveying and screening operations through water sprinkling, curtains, barriers and suppression units.
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, Amravati Municipal Corporation, Traffic police and District administration. Maharashtra State Pollution Control Board shall regularly review the implementation of aforesaid action plan.

References

- Air Quality –Indian Clean Air Programme (ICAP) (2007). Automotive Research Association of India (ARAI) Available via http://cpcb.nic.in/.
- Brief Industrial Profile of Amravati District (2015-16). MSME Development Institute, Govt. of India, Ministry of MSME.
- Census of India (2011). Available via censusindia.gov.in/2011-common/census_2011.html.
- CPCB Six City Study Report (2010). Air Quality Assessment, Emission Inventory and Source Apportionment Studies, Central Pollution Control Board, New Delhi.
- Environment Status Report (2016-17). Prepared by Core Project Engineers and Consultant Pvt. Ltd. for Amravati Municipal Corporation.
- Khandve, P. V, Rai, R. K. (2011). Municipal Solid Waste Management at Amravati City - Present practice and future challenges, I. J. Environmental Sciences 2(2). 625-635.
- Ma et al., Aerosol and Air Quality Research, 17: 636–643, 2017.
- NEERI Report-Delhi (2010). Air Quality Assessment, Emission Inventory and Source Apportionment Studies-Delhi, National Environmental Engineering Research Institute.
- NEERI Report-Mumbai (2010). Air Quality Assessment, Emission Inventory and Source Apportionment Studies-Mumbai, National Environmental Engineering Research Institute.
- Nowak et al. (2014). Trees and Forests Effect on Air Quality and Human Health in the United States. Environmental Pollution 193, 119-129.
- Primary Census Abstract (2011). For Amravati District, Maharashtra State.
- Smart City Challenge- Amravati Municipal Corporation (2015). Available via http://amtcorp.org/eipprod/49/ downloads/smart city/amravati-smartcity-plan.pdf.
- Survey of Maharashtra, (2012-13). Available via https://www.maharashtra.gov.in/PDF/EcoSurvey_2013_Eng.pdf.

Annexure – I

Design of a Clean Tandoor Community Kitchen System (CTCKS)

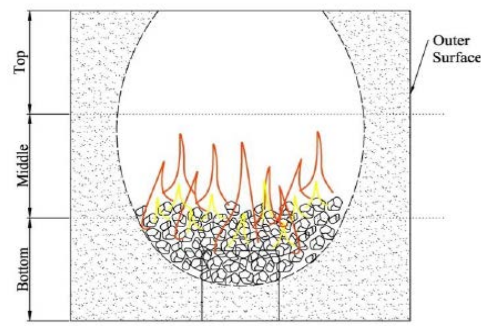
Design of a Clean Tandoor Community Kitchen System (CTCKS)

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

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

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

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



Classification of Temperature Zones in Tandoor Bhatti

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

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

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

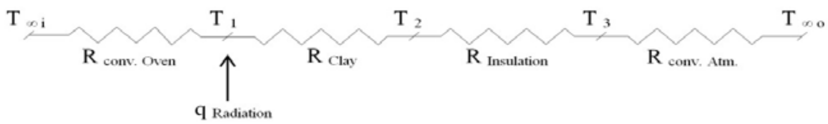
Advantages of pellet based tandoor also leads to reduced ash generation. Pellets based tandoor will also generate market for pellet industry and enable the use of agro-waste residues for development of an alternative fuel, promote employment generation in rural areas and would partly contribute to emission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

Design Methodology

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

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

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



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

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

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

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

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

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

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

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):

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

Design of Forced Draft Stove

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Tandoor Design Details

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

Illustrative materials for different parts of CTCKS

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

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

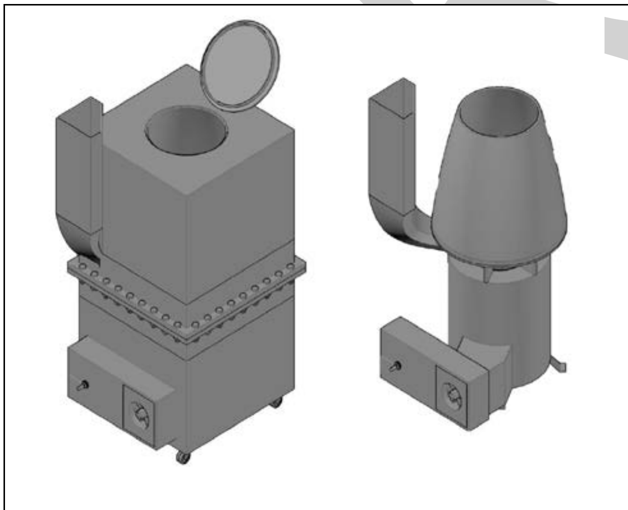


Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing

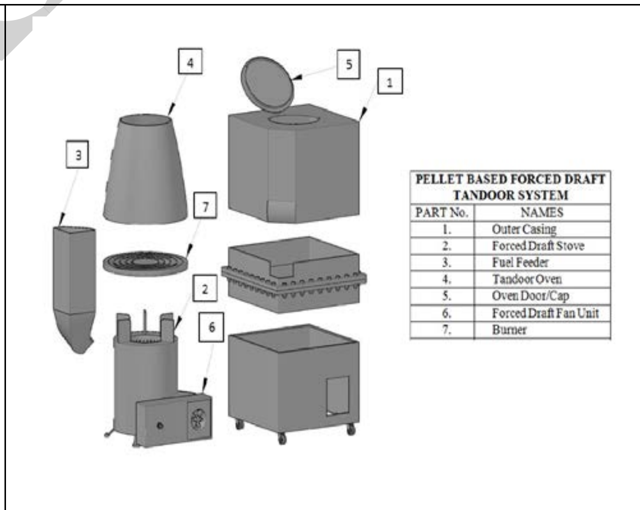


Fig. 2 Exploded view CTCKS: Inner Assembly & Outer Casing

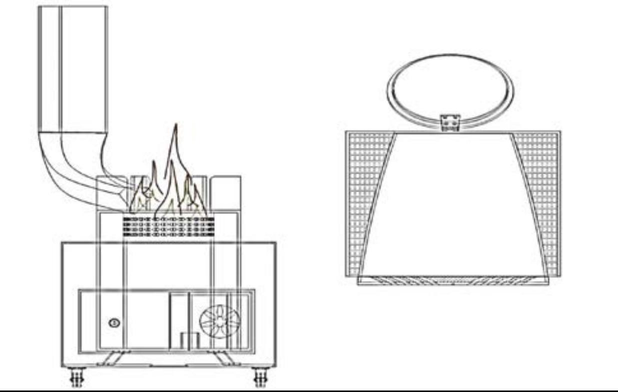


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)

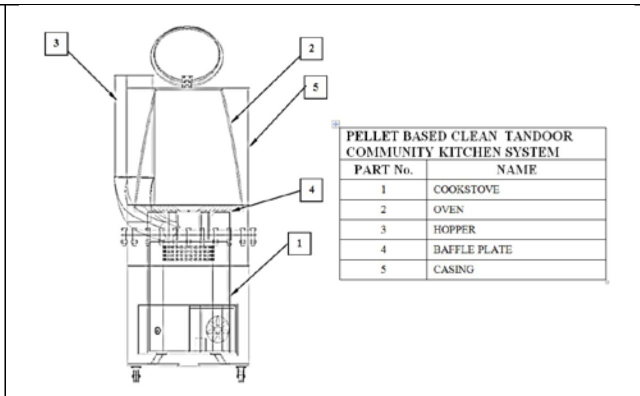


Fig. 4 Line diagram of CTCKS

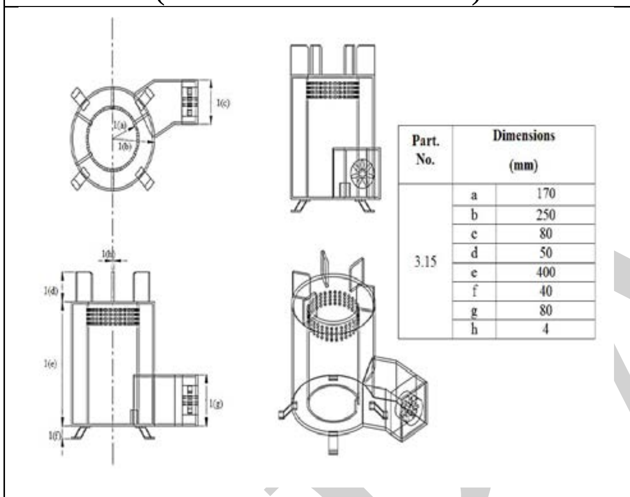


Fig. 5 Child Parts of CTCKS: Cookstove

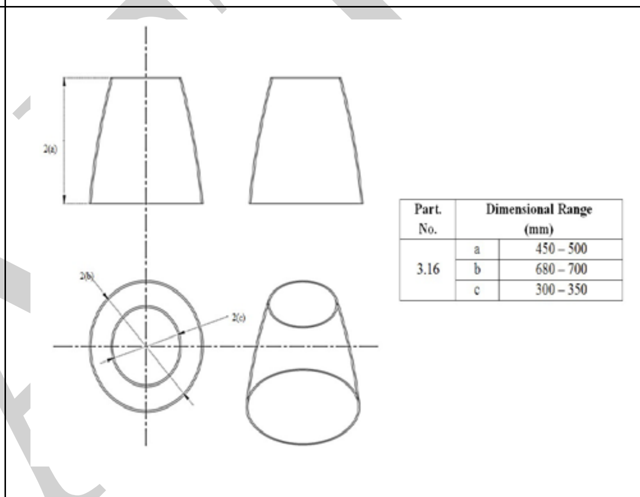
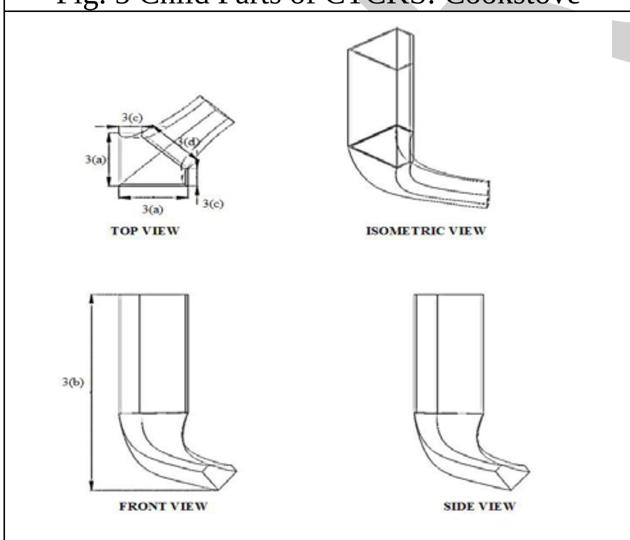
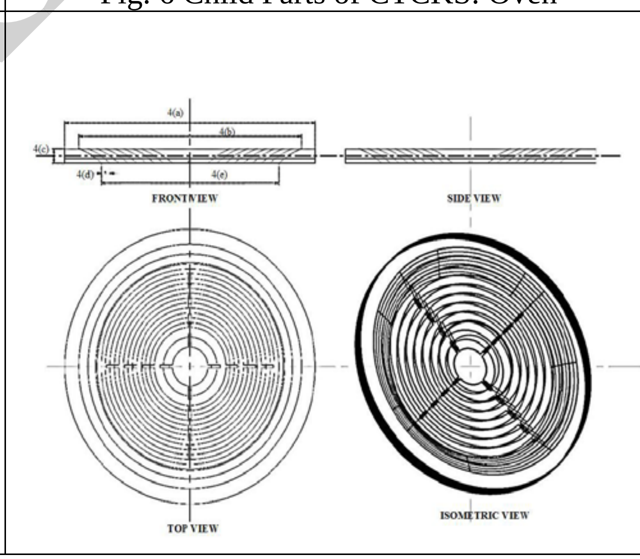


Fig. 6 Child Parts of CTCKS: Oven



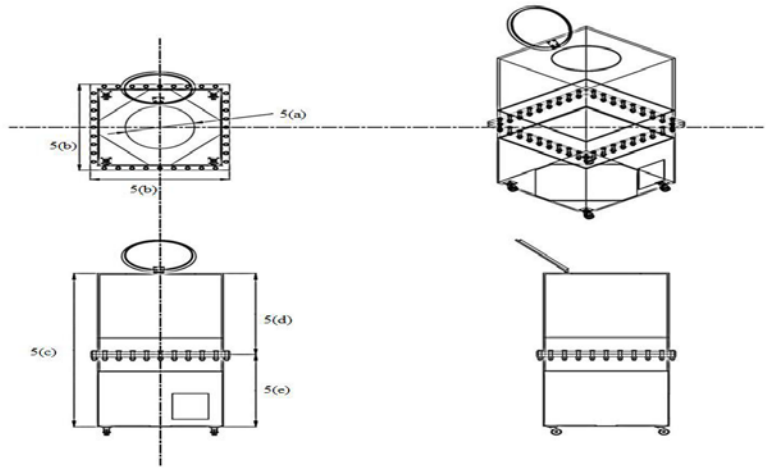


Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

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.

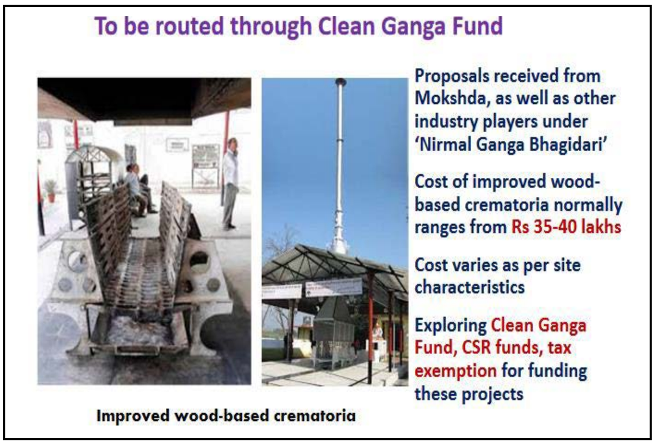
There has always been a controversy on the use of the electric crematoriums due to rituals as most persons follow the traditional burning of the bodies. In metropolitan cities it is promoted by the Government, private NGOs and environmentalists, but not to a great extent and most of these have failed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

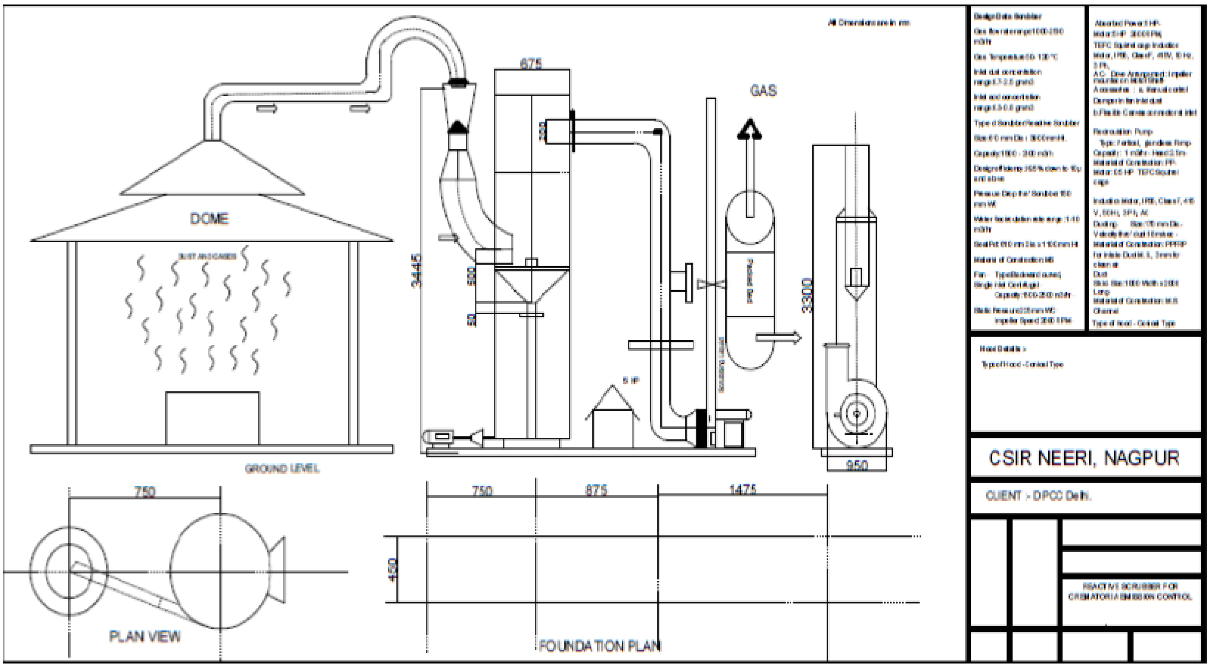


Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

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**.

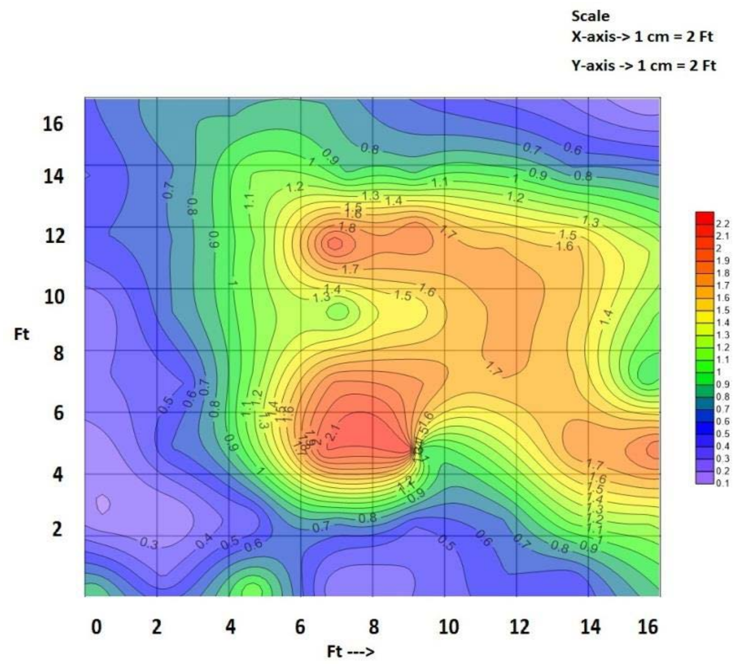


Figure 2 : Velocity profile of fumes during cremation

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.

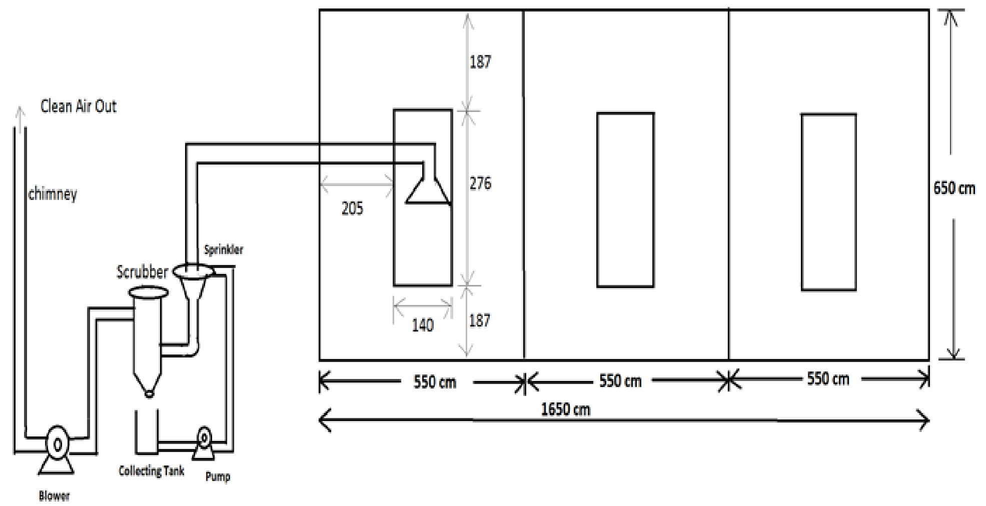


Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

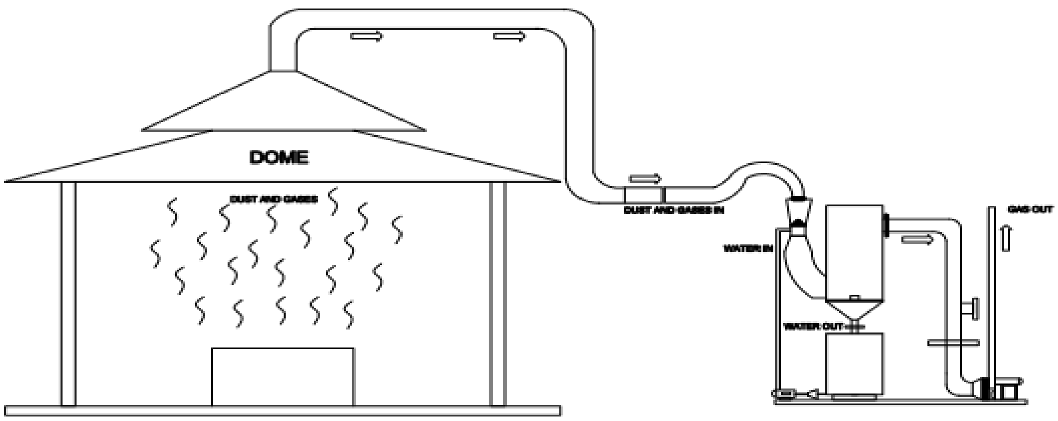


Figure 4 : Schematic view of Air Pollution Control System

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.

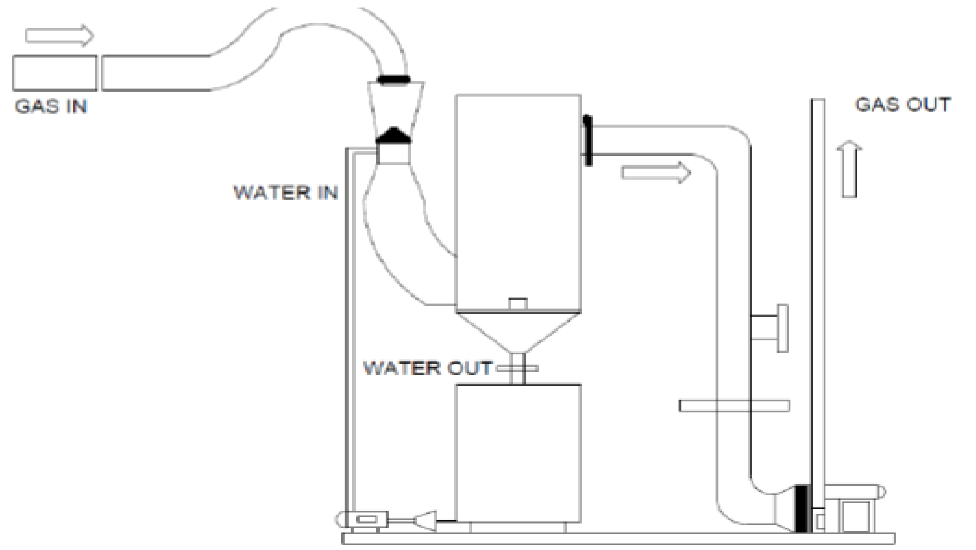


Figure 5 : Schematic of Reactive Scrubber

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,

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

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.

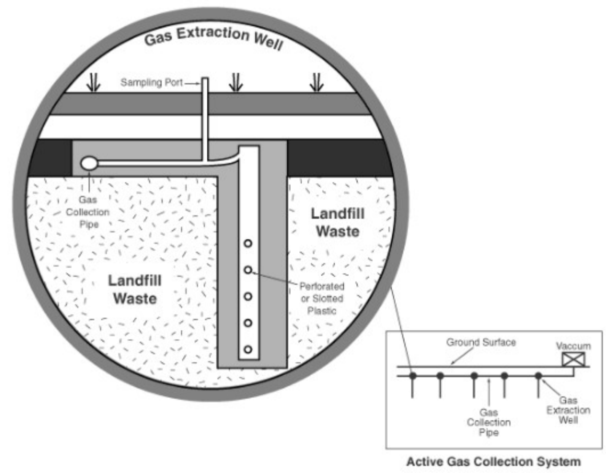
Most of the MSW generated is disposed of non-scientifically in open dumps, which causes a serious threat of landfill gas (LFG) emissions. The present note will focus on the landfill sites for the LFG emissions and designing the appropriate gas venting for the landfill sites.

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

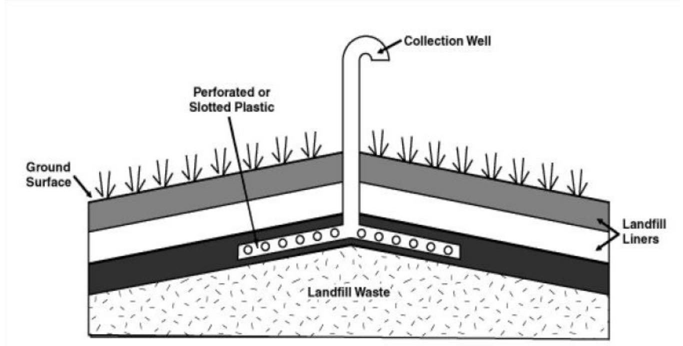
Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however,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

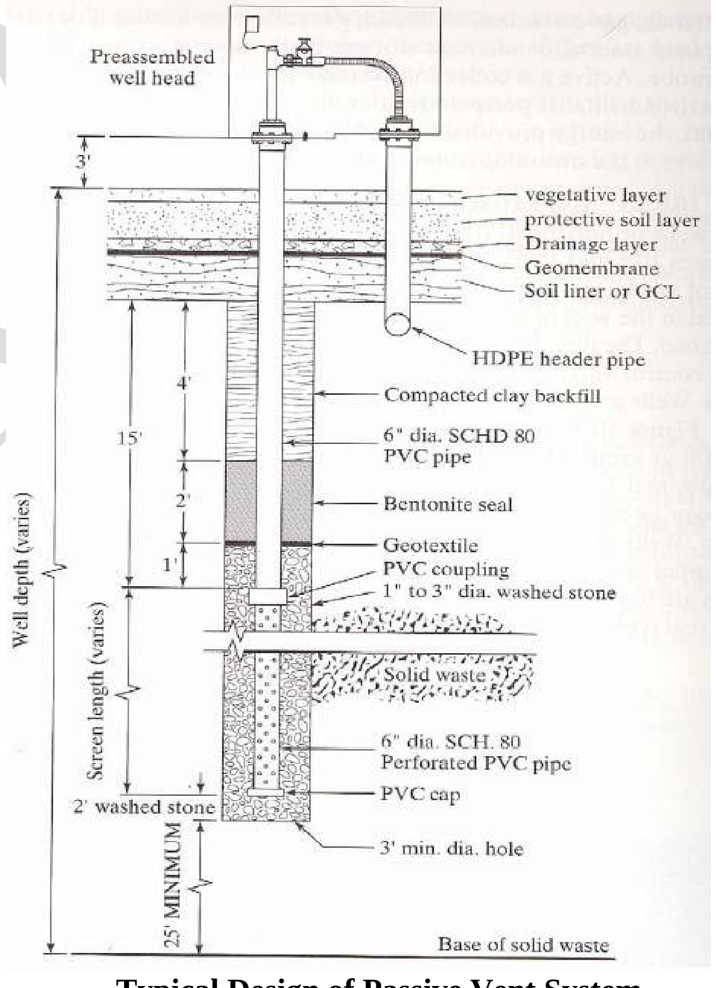
groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill as shown below. Horizontal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

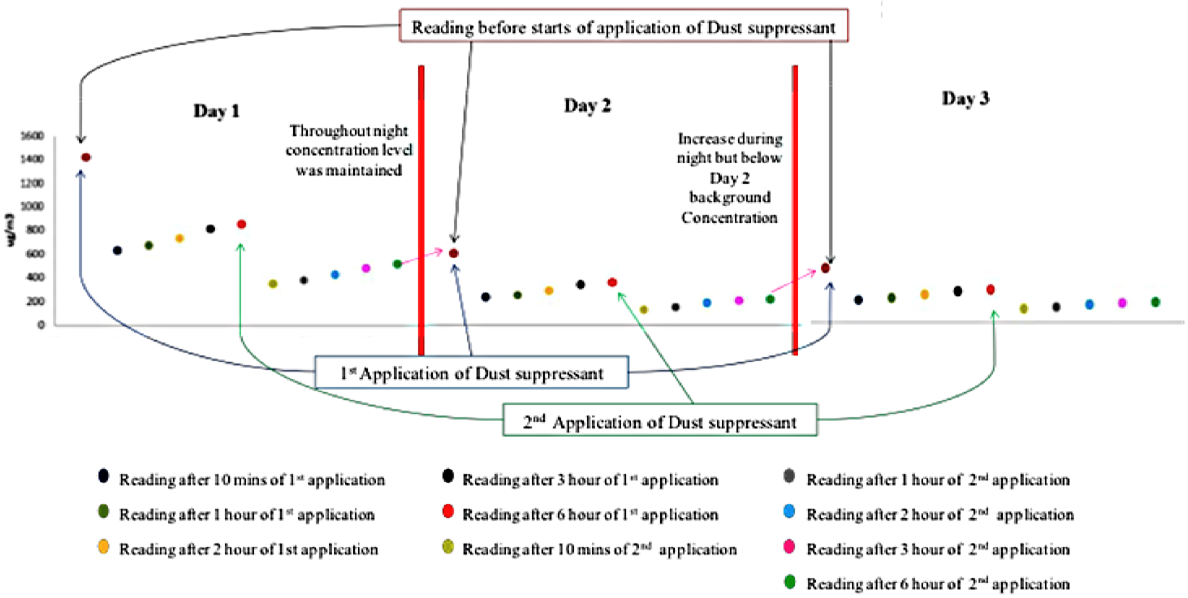
Advantages

- 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.



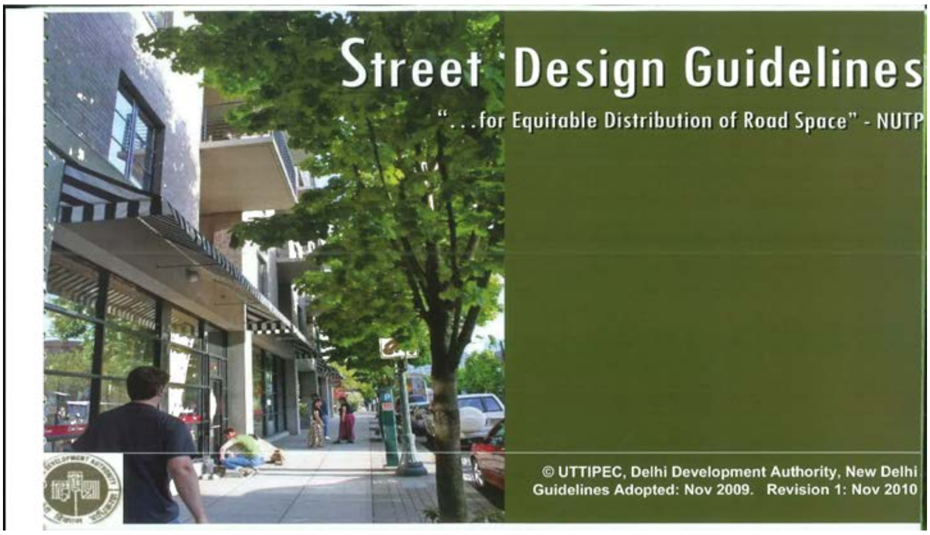
Bioswale : System for Storm Water and Dust Suppression Road Side

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.

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

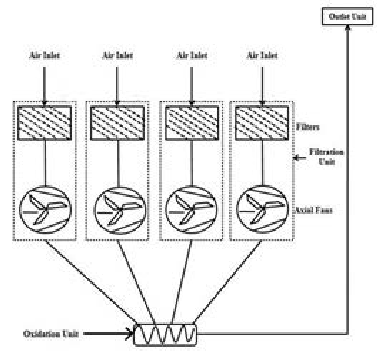
Air pollution is a local problem and its solution can be derived from technologies coupled with local conditions and requirements. Creating change in meteorological parameters like wind with the help of devices such as fans and also removal of the pollutant near to the source may help in reducing ambient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



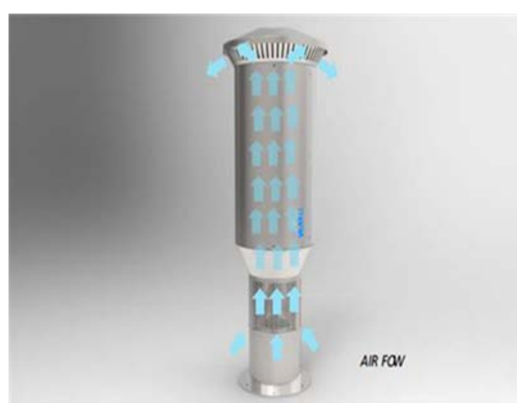
UV- TiO2 adsorption-photocatalytic oxidation has a lot of advantages. They are very efficient in removal of VOCs. Pichat et al. (2000) have shown that ozone can be directly eliminated by TiO_2 nanoparticles in a process that is promoted by both heat (in the ambient temperature range of 0° to 50°C) and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

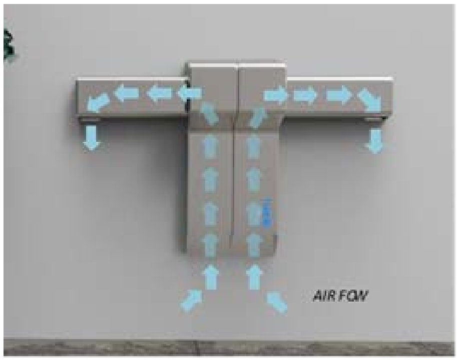
WAYU is a device jointly developed by IIT-CSIR-NEERI focused on controlling pollution in ambient air. WAYU has been successfully tested in a pilot project of 25 devices in Mumbai in collaboration with Maharashtra Pollution Control Board (MPCB). With an aim to solve the ever rising menace of air pollution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

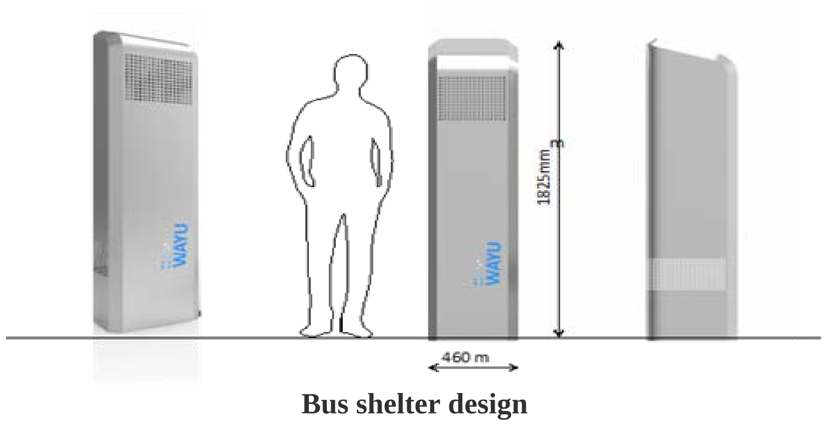


WAYU device improved design



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.