Draft Report On

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

(CHANDRAPUR CITY)

for

Maharashtra pollution Control Board

By

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Chapter 1
Introduction

1.1 Preamble

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

1.2 Background of the City

Administrative headquarter is at Chandrapur. There are 15 tehsils namely, Chandrapur, Varora, Bhadravati, Chimur, Nagbhid, Bramhapuri, Sawli, Sindewahi, Mul, Pobhurna, Ballarpur, Korapana Rajura, Gondpimpri, and Jivati. There are 847 grampanchayats. Chandrapur is a city and a municipal corporation in Chandrapur district of Maharashtra state, India. It is the district headquarters of Chandrapur district. It was earlier known as Chanda, the official name until 1964. Chandrapur is a fort city founded by Khandkya Ballal Shah, a Gond King of the 13th century. The city sits at the confluence of the Erai River and Zarpat River. The area around the city is rich in coal seams. Hence, Chandrapur is also known as the "Black Gold City". Chandrapur district is located in the eastern edge of Maharashtra state in Vidarbha region. It is surrounded by Chandrapur, Bhandara, Wardha on north, Adilabad on south, Gadchiroli on east and Yavatmal on west side. The city is located on the confluence of rivers “Erai” and “Zarpat”. The northern portion of the city is at high elevation and southern at low as per topographical map i.e. 56 m. Chandrapur district has an area of 11,443 sq.km. Chandrapur is 761 feet above sea level (19.3°N to 20.45°N and 78.46°E). Chandrapur city is spread in an area of 70 sq. Kms **(Figure 1.1)**. A dam is constructed over river Erai with a total water holding capacity of 20 million cubic meters.

1.3 Background of the Study

The Central Government launched National Clean Air Programme (NCAP) as a long-term, time-bound, national level strategy to tackle the air pollution problem across the country in a comprehensive manner with targets to achieve 20% to 30% reduction in Particulate Matter

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concentrations by 2024 keeping 2017 as the base year for the comparison of concentration. Under NCAP, 122 non-attainment cities have been identified across the country based on the Air Quality data from 2014-2018.

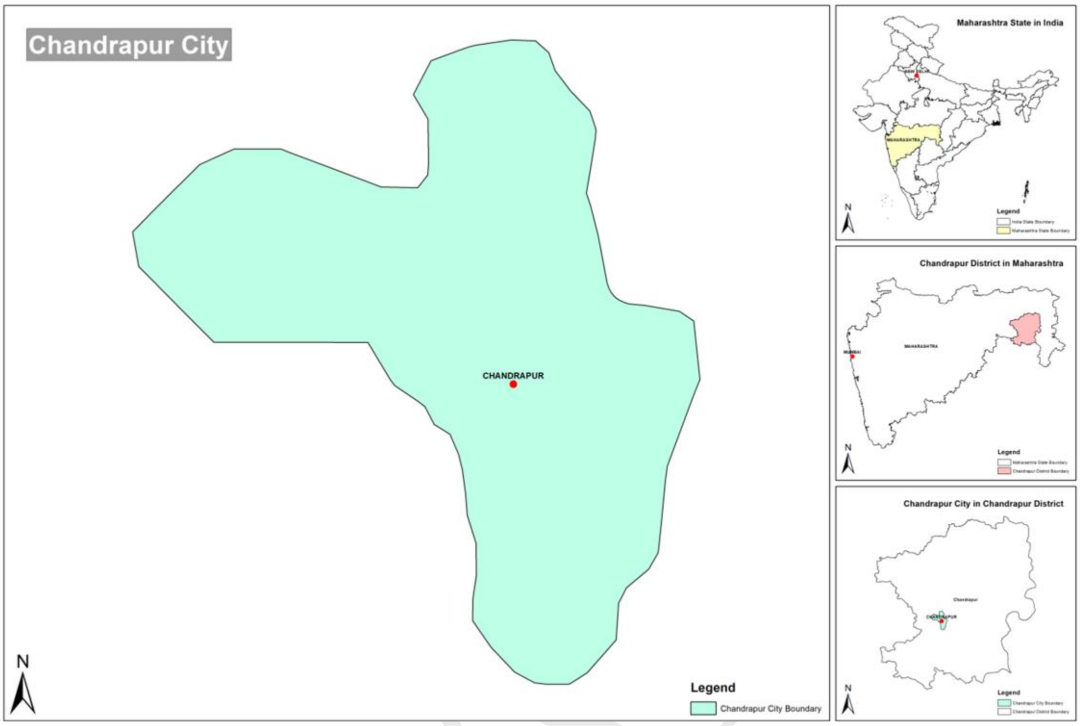

Figure 1.1: Chandrapur City Location Map

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

1.4 Population of the City

Chandrapur city has Municipal Corporation. As per provisional reports of Census 2011 India, population of Chandrapur in 2011 was 3,20,379 of which male population is 1,64,085 and female population 1,56,294 respectively. Population of Children with age of 0-6 is 31,345, Female Sex Ratio is of 953 against state average of 929. Moreover Child Sex Ratio in Chandrapur is around 914 compared to Maharashtra state average of 894. Literacy rate of Chandrapur city is 89.42 % higher than state average of 82.34%. In Chandrapur, Male literacy is around 93.45% while female literacy rate is 85.21%. Chandrapur Municipal Council has total administration over 74,276 houses to which it supplies basic amenities like water and sewerage.

The current metro area population of Chandrapur in 2022 is 3,61,000 with a 1.4% increase from 2021 **(Figure 1.2)**.

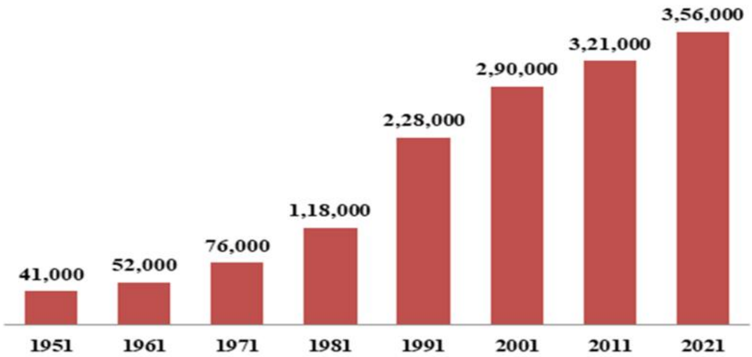

Figure 1.2: Population of Chandrapur City

The Chandrapur city is spread over an area of 76 km^2. There are three zonal offices of Municipal Corporation to look after the 61 wards **(Figure 1.3)**. The ward-wise population of the city is approximately 3000 nos. in each ward.

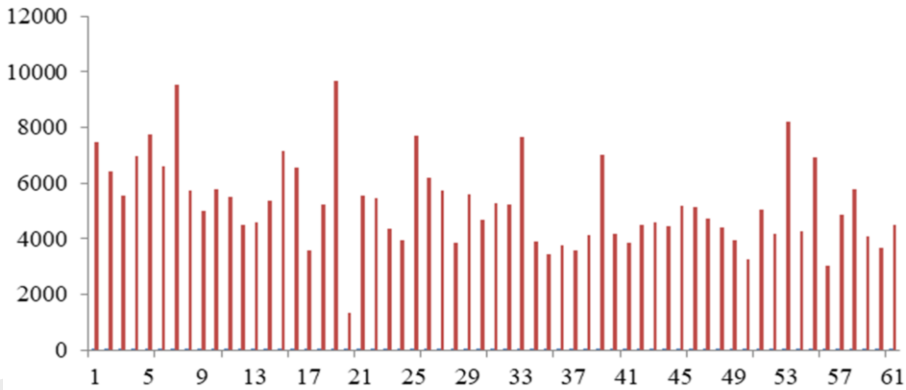

Figure 1.3 : Ward-wise Population of Chandrapur City

1.5 Industry

About 6000 small and big scale industries are located at Chandrapur. Chandrapur, also known as 'City of Black Gold', has one of the oldest coal mines in the country. The mammoth coal mines around the city also contribute to the heavy industrialization of the city. The second biggest coal producers in India, the Western Coalfields Limited (WCL) have their mines in the district. Most of the Cement manufacturing companies have their plants in Chandrapur District as it is rich in natural resources of Limestone. The city houses various cement factories in its vicinity. Prominent among these are the ones established by Manikgarh Cement, Ulltratech Cement (formerly L&T Cement), Associated Cement Companies (ACC) and Gujarat Ambuja (Maratha Cement Works). Chandrapur Super Thermal Power Station (often abbreviated as CSTPS) is a thermal power plant located in Chandrapur. The power plant is one of the coal based power plants of MAHAGENCO. The coal for the power plant is sourced from Durgapur and Padmapur

Collieries of Western Coalfields Limited. The plant was officially inaugurated by the then Prime Minister Indira Gandhi on 8th October 1984. With the total capacity of 3340 MW, the plant is the largest power plant in the Maharashtra. It accounts for more than 25% of Maharashtra's total needs. The plant gets water supply from Erai Dam when in normal conditions. In the summer of 2010 due to less water in Erai, the plant also got water supply from Chargaon Dam. Other major industries include a ferro-manganese and silico-manganese plant of Maharashtra Elektrosmelt Ltd. (MEL), a subsidiary of Steel Authority of India Limited (SAIL).

1.6 Economy

Rice is the primary crop of the district. Chandrapur ranks fourth in rice production within the State. Sorghum is also produced to a certain extent. Cotton is grown in the Wardha River basin. Sesame is also harvested on a large scale in this district. Chandrapur district is also famous for its cement industry and houses the largest number of cement factories in the State. Since coal is abundant in the district, thermal power from coal is a major industry in the district. Rice mills provide employment to many across the district.

Silk-yarn industry is coming up in Nagbhid and Savali talukas. The water pitchers here are famous. Visapur in Nagbhid taluka has a factory for making plywood from wood. With more than 21% of the total population in Chandrapur district being tribal, the district has been given the special status of a tribal district. The Kolamb tribal (also known as the Kolam) live mostly in the forest and mountainous regions. The Pardhan tribe also occupies this region. Madiya Gond, a tribe given the special status of a primitive tribe by the Central government, also occupies this region.

1.7 Availability of Minerals

Chandrapur District has been endowed with various valuable mineral resources. The important minerals found in the district are Coal, Iron and limestone. Chandrapur has an abundance of mineral resources. Coal is a major resource found in the Wardha River basin. Coal is mined in Ghuggus and Ballarpur in Chandrapur taluka, Rajura in Sashti and Manjri and Warora in Bhadravati talukas. Iron ore is found in Pimpalgaon, Bhisi and Asola (Gunjevahi) in Chimur taluka and Ratnapur and Lohar Dongri in Brahmapuri taluka. Limestone is found mainly in Warora taluka. Limestone stretches are also found in many places in Rajura taluka. There are approximately 1026 million tons of limestone deposits found in the district. Majority of the copper deposits in the State are in this district. Some mineral deposits like granite, sandstone, jambha (red, porous stone) are also found in few parts of Chandrapur district.

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1.8 Forest

During the year 2010-11, an estimated 5004 Km^2 of area was under forest which constituted 43.73% of the total area. Forest resources contribute significantly to the economy of the district. Bamboo, Mahuva, tendu leaves and teak wood are the main resources of the district. More than 35% of the total geographical area of Chandrapur district consists of dense forest and ranks third in the State after Gadchiroli and Nandurbar districts as for area under forest cover. The district abounds in a variety of forest-based produce, mainly teak wood, tendu leaves and bamboo and Mahua flowers. The region forming Chirol and Navegaon hills is known as Alapalli Forest. The famous Tadoba National Park is in this district.

1.9 Climate and Meteorology

The climate of the district can be classified as tropical hot climate with range of temperature through out of year. Primarily there are two prominent seasons in the district- the very hot summer and moderate winter. The summer months are very hot and prolonged while winter is short and mild. The monsoon season starts immediately after summer till late September. The southwest monsoon brings lots of rainfall during rainy season and there is no draught prone area in the district.

The temperature starts decreasing from the month of October. December is the coldest month Mean maximum temperatures during December is 28.2^{0}C and mean minimum is 11.6^0 C. The southern part is comparatively warmer than the north. This ranges between 29.6^0 to 14.6^0 C. The lowest recorded temperature is in the north is 3^{0}C and 8^{0}C in the south. The daily mean temperature starts rising from the month of February and may is the peak summer month when maximum temperature goes upto 43^0 C and minimum temperature is 28^0 to 29^0 C. In severe hot condition temperature raises up to 47^0 C. However temperature starts blackening after May due to onset of monsoon, which last from June to September when it is hot and humid.

The prominent wind direction is from south to north. In summer the wind direction is from east to south and monsoon from south to east. During winter, the wind direction changes from north to east frequently is characterized by blowing of wild and violent winds heralding the approach of hot season which last till middle of June. The district receives rainfall from the south west monsoon from June to September. The average rainfall is about 1200 mm. The rainfall generally increases as one goes from the west to the east.

1.10 Objectives

- To measure baseline air pollutants (particulate matter) in different parts of the city which includes hot-spot and kerb-sites.

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- Inventory of all types of emissions from the city.
- To conduct Source apportionment study for particulate matter.
- Air Pollution reduction action plan.

1.11 Scope of the Project

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

1.12 Need of the Study

The present study examines the contribution of the sources to aerosol mass, which is an important factor in the development of effective strategies for the control of aerosol-associated problems. Besides PM, other pollutants and their sources are needed to be inventoried with a view to ascertain the point of generation. Pollutants of all origin should be considered in entirely for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc. Strategies for sector specific pollutants need to be drawn from scientific evidences which are concrete and clear. These facts can be derived from the use of multitude of techniques such as emission inventory, dispersion modeling, receptor modeling and finally cost effectiveness analysis of varied options. Therefore, MPCB has sponsored CSIR-NEERI and IIT (B) to jointly execute the source apportionment studies for 10 cities of Maharashtra.

Chapter 2
Ambient Air Quality

2.1 Ambient Air Quality

Monitoring of air quality in the region has been going on for a considerable period. Many of the stations have been collecting data through manual system and some industries also monitor the ambient air through their manual/automatic stations.

2.2 Past Air Quality Monitoring Data

The trend analysis of ambient air quality of Chandrapur at NAMP and SAMP stations were done. There are 18 manual and 6 NAMP stations in Chandrapur. RSPM (Respirable Suspended Particulate Matter) and SPM (Suspended Particulate Matter) have been identified for regular monitoring at all the locations. The monitoring of pollutants is carried out for 24 hours (4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter) with a frequency of twice a week, to have 104 observations in a year. Air quality monitoring NAMP database of Chandrapur over the 4-year period i.e., from 2016 to 2020, is available from CPCB air quality data portal. Analysis on NAMP database was carried for assessing air quality trends by annual means for past 4 years **(Table 2.1)**. NAMP (National Air Quality Monitoring Programme) Data for annual average trend of PM_{10} and $PM_{2.5}$ for period 2016-21 is plotted and is shown in **Figure 2.1** for different sites. At some locations, the PM_{10} values exceed the regulatory limit values of annual average (60 µg/m^3).

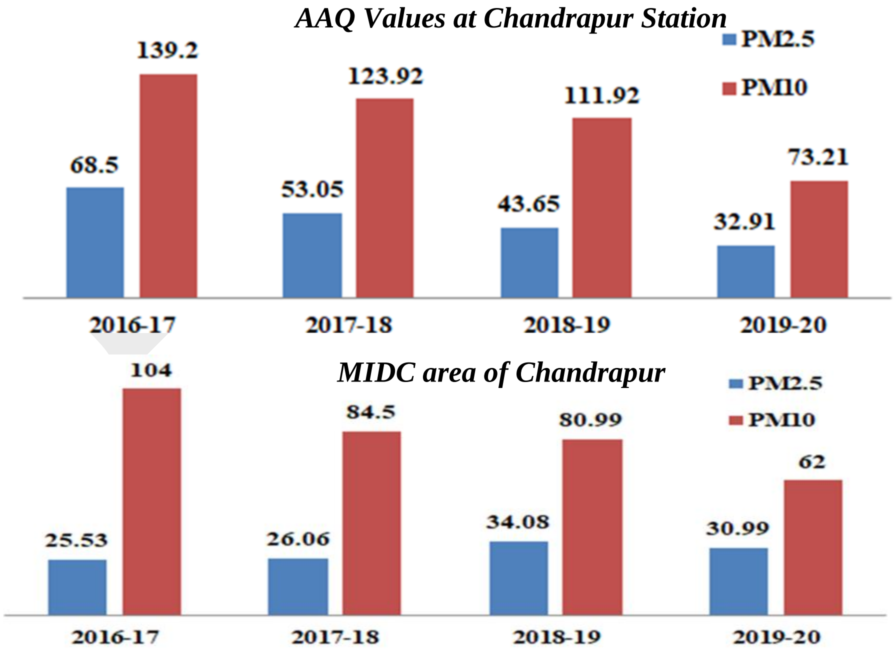

Figure 2.1: Ambient Air Quality Values at Chandrapur Station and MIDC Area of Chandrapur

Table 2.1: AAQMS Data Analysis from 2016-2020

Monitoring Station	Annual Avg. of RSPM (µg/m^3)			
	Industrial		Residential & Commercial	
Year	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**	**PM_{10}**
2016-17	68.5	139.2	25.53	104
2017-18	53.05	123.92	26.06	84.5
2018-19	43.65	111.92	34.08	80.99
2019-20	32.91	73.21	30.99	62

*Source: MPCB, Maharashtra

2.3 Manual AAQ monitoring by NEERI

The ambient air quality monitoring network involves measurement of a number of air pollutants at number of locations in the city so as to meet objectives of the monitoring. Any air quality monitoring station involves selection of pollutants, selection of locations, frequency, duration of sampling, sampling techniques, infrastructural facilities, man power and operation and maintenance costs. The network design also depends upon the type of pollutants in the atmosphere through various common sources, called common urban air pollutants, such as Particulate matter (both PM_{10} & $PM_{2.5}$), Sulphur dioxide (SO_2), Oxides of Nitrogen (NO_x), and Carbon Monoxide (CO) etc. For Chandrapur city particulate monitoring was carried out at all the selected locations. The areas to be chosen primarily are such areas which represent high traffic density, industrial growth, human population and its distribution, emission source, public complaints if any etc.

The objective of monitoring is to determine air pollution status and trend information. The information is used to determine, whether pollution control strategies as advised by implementing authority are giving acceptable values that is lowering of pollution levels or new or additional control are required to achieve acceptable levels.

As per the work order issued by MPCB Maharashtra, the AAQ monitoring was carried out to measure baseline air pollutants (particulate matter) in different parts of the city which includes hotspots and kerbside as well. The selection of location and details of sampling sites are given in **Table 2.2** and are graphically represented in **Figure 2.2.**

Table 2.2: Details of AAQ Monitoring Stations

Code	Site Name	Type	Latitude	Longitude
Site A	Gajanan Maharaj Temple	Residential	79°16’34.30”	19°58’30.83”
Site B	Krishna nagar	Reference	79°19’35.81”	19°58’12.92”
Site C	Tirtharup Nagar	Industrial	79°18’24.00”	19°58’43.00”
Site D	Balaji Ward	Commercial	79°07’40.00”	19°56’33.00”

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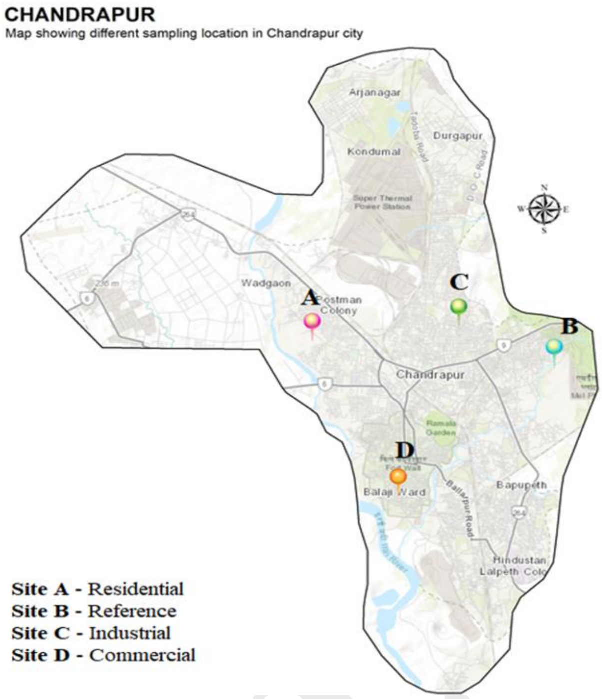

Figure 2.2 : AAQ Monitoring Locations in Chandrapur City

Air quality status at four sites in terms of PM_{10} and $PM_{2.5}$ concentration is given in **Figure 2.3.** It can be seen that PM_{10} & $PM_{2.5}$ concentrations violated the CPCB threshold (100 & 60 μg/m^3) during the entire study period at all the sites.

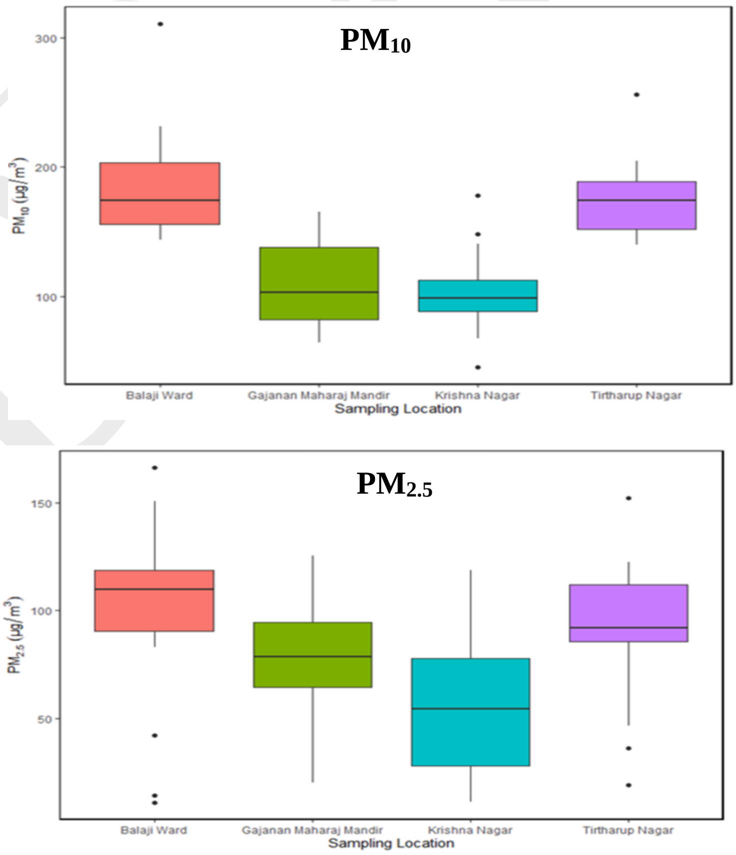

Figure 2.3 : PM_{10} and $PM_{2.5}$ Concentrations for Chandrapur City

Chapter 3

Emission Inventory

3.1 Introduction

An air emission inventory is a compilation of air pollutant emissions from sources of anthropogenic (human-made) and biogenic (naturally occurring) sources. The sources are categorized into three sectors, each making up one component of the inventory. The emission inventories consist of actual and projected air emissions. Due to violation of permissible limit of particulate matter standards, CPCB has listed Chandrapur 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 in industrial sector have deteriorated the air quality of the city and have contributed to high growth rate of emissions. National level emission inventories have been prepared by several researchers for metro cities in India. Chandrapur city has no emission inventory estimate reports earlier published. Keeping in view the lack of exclusive emission inventory estimates for Chandrapur, 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 Chandrapur 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 Chandrapur 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 Chandrapur 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 Chandrapur 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.

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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.

3.6 Role of GIS

GIS has made it possible to directly view the source emission. The grids plotted over Chandrapur 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. Geo-mapping of emission load is done using GIS technology for developing accurate emission inventories **(Figure 3.1)**. 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.

3.7 Emission Factor

An emission factor (EFs) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with the associated activity responsible for emission. Typically, EFs of a fuel depends on the chemical composition of fuel, combustion type, temperature and efficiency of any emission control device. There are very limited measured EFs available in literature for India. EF defines the source strength as emission per unit time and per unit activity of the process.

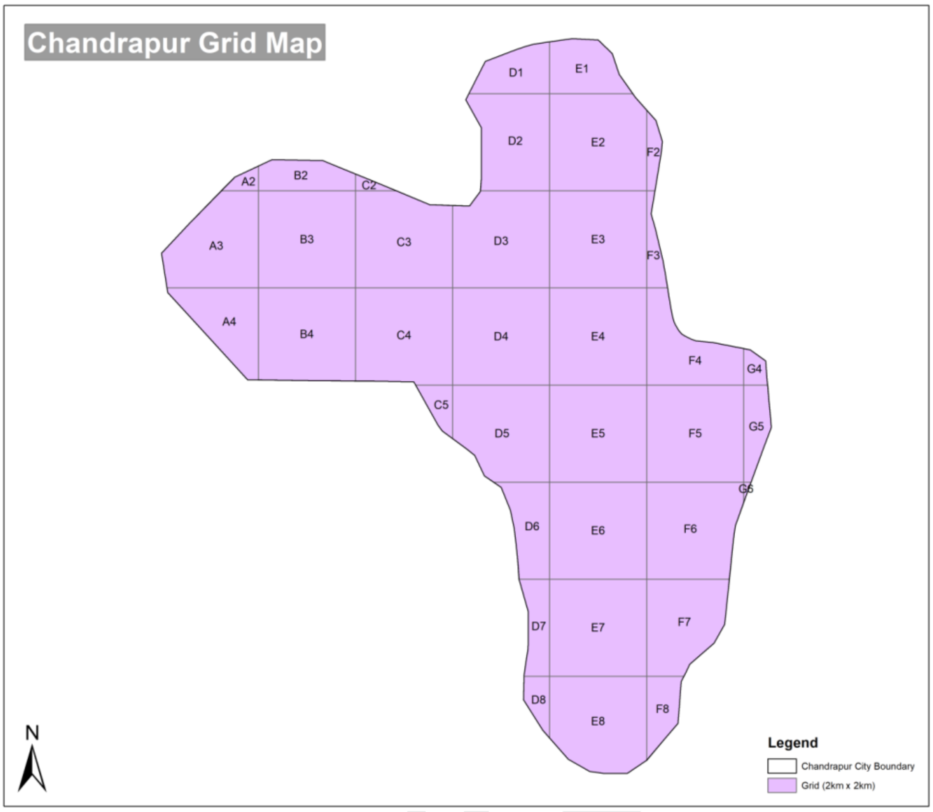

Figure 3.1 : A 2 x 2 Km Grid Plotted Over Chandrapur City Boundary

Country specific technology based EFs for most of the sectors are not yet available for India. Hence, in the development of emission inventory, emission factors are selected from CPCB, ARAI, USEPA AP42 and old SA study reports prepared by CSIR-NEERI on SA study. EF used in the present work is collected with valid scientific judgments and acceptability by global community. The used EFs for the estimation of pollution load from different sources are discussed in respected sector. The emission estimation for pollution load is calculated by available emission factors. The required data is collected from surveys and secondary data in a unique format. A grid wise emission load in Kg/day for the specific source is being generated.

3.8 Line Source Emissions

Moving vehicles are known to be a major source of air pollution in an urban area. It is widely accepted that effectiveness of measures put into force to improve air quality was in the past limited by a partial knowledge of road transport emissions. In this study we have performed a comparison between the road traffic, road length and available road width for the roads of the city. The traffic surveys can change the contribution of the vehicular categories while statistically–based annual mileages are crucial for determining the apportionment.

3.8.1 Road Network

A GIS is an organized collection of computer hardware, software, geographic data, and personnel to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. Arc-GIS Network Analyst enables users to dynamically model realistic network conditions, including turn restrictions, speed limits, height restrictions, and traffic conditions, at different times of the day. Arc-GIS proved to be one of the most user friendly, effective and time-saving tools in the field of both traffic engineering and transportation planning. The road network of the city is digitized using the data available. The total road network of the Chandrapur city is 876 Kms. The road network depicted in **Figure 3.2** shows the available road length density is respective grids.

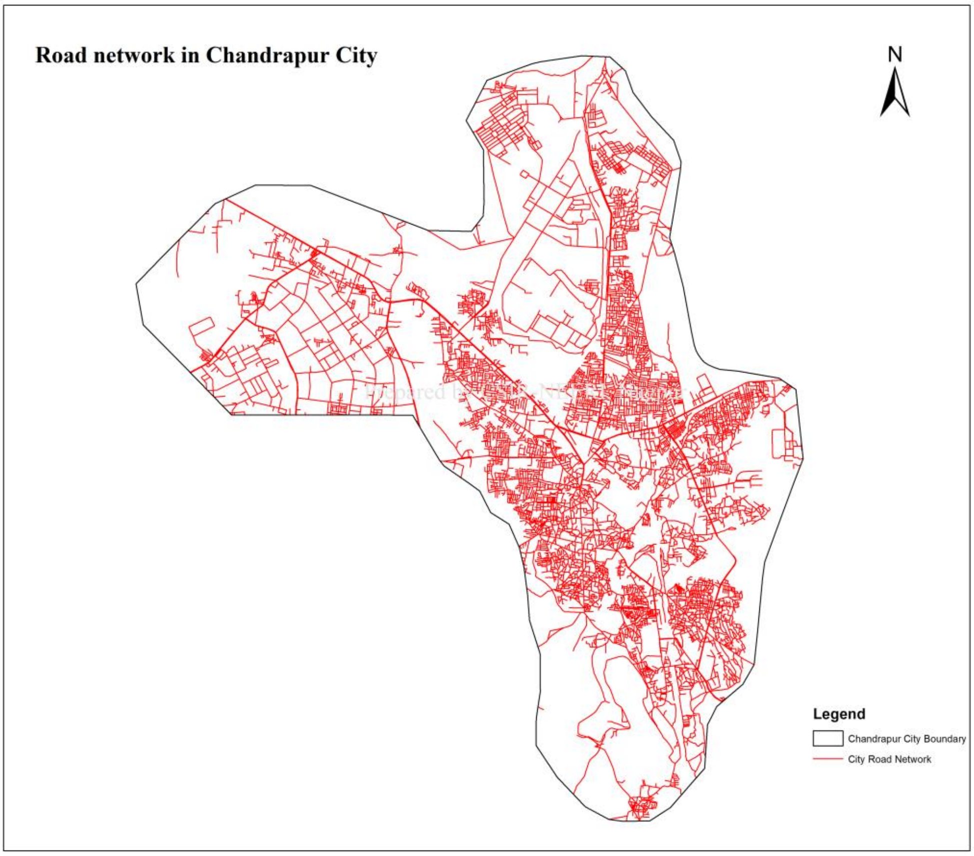

Figure 3.2 : Road Network of Chandrapur City

3.8.2 Vehicle Count

Emissions from road traffic are determined from the number of vehicles and how much do they move or, alternatively, from how much fuel is consumed in the area. While some pollutants are more dependent on how many kilometres are driven and on which driving conditions (PM_{10}, $PM_{2.5}$, NOx & CO). The densities of vehicles in circulation were obtained by counting vehicles using available video photography. The traffic count locations were set as per the traffic patterns of the city. For a set of 40 links average annual traffic volumes were available from video photography and manual traffic count surveys. The estimated traffic volumes from all monitoring points were used for further emission load estimations.

After identifying the vehicle categories, the fuel pattern is assumed based on a report released by MoPNG, "Total Fuel Consumption by Transport Sector in India". The available sets of emission factors derived by ARAI, Pune were used. The total road length available in respective grid is considered as the vehicle kilometre travelled for the categories of vehicle per day. Following emission factors are used to calculate emission load from line sources **(Table 3.1)**. The emission factors derived by ARAI, Pune are used for calculations.

Table 3.1: Emission Factors Considered for Emissions Estimation

No.	Vehicular Type	PM	NOx	HC	CO	Unit
Emission Factor for BS-III Stage Engine						
1	2 Wheeler	0.035	0.27	0.61	1.65	g/km
2	3W_Petrol	0.05	1.2	0.7	1.2	g/km
3	3W_Diesel	0.05	0.5	0.5	0.5	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	LDV/HDV	1.24	9.3	0.37	6	g/km
Emission Factor for BS-IV Stage Engine						
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	g/km
5	4W_Diesel	0.08	0.1	0.1	1	g/km
6	LDV/HDV	0.06	0.39	0.42	0.74	g/km
Emission Factor for BS-VI Stage Engine						
1	2 Wheeler	0.0045	0.09	0.068	0.5	g/km
2	3W_Petrol	0.025	0.1	0.1	0.22	g/km
3	3W_Diesel	0.0045	0.08	0.1	0.5	g/km
4	4W_Petrol	0.0045	0.06	0.1	1	g/km
5	4W_Diesel	0.0045	0.08	0.1	0.5	g/km
6	LDV/HDV	0.01	0.08	0.1	0.5	g/km

Since the vehicles of same category in four wheelers uses different fuel, it is considered that 55% of four vehicle category use diesel as fuel and 45% of vehicular category use petrol as fuel.

From the below figure, it can be concluded that the major count of traffic is from 2 wheelers. Two major peaks are seen for 2 wheelers, one during the early morning from 06:00 Hrs to 11:00 Hrs and the other from 14:00 Hrs to 18:00 Hrs. The major groups of working people travel to their offices using 2 wheelers. The same peak but at a smaller number is seen for private 4 wheelers **(Figure 3.3)**.

It is also clear that the city traffic starts at 06:00 Hrs in the morning and lasts till 21:00 Hrs. After that the city traffic is nearly zero which gradually increases from morning 05:00 Hrs again. Same pattern of traffic flow is seen for four wheelers & Heavy Duty Commercial vehicles (HDV). The number of 3 wheelers in the city is at a constant count throughout the day. Only during 20:00 Hrs a peak is seen.

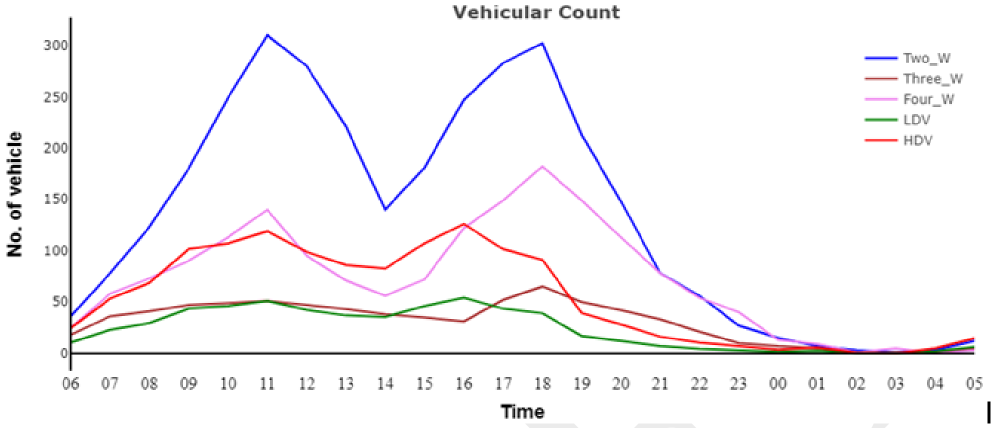

Figure 3.3: Hourly Vehicular Flow Pattern at One Location in Chandrapur City

From the vehicular count, the variation is seen in hourly emissions of all pollutants. Maximum emission load is for NOx & CO. Particulate emission load is varying from 0 to 1 Kg/Hr from 06:00 Hrs to 23:00 hrs **(Figure 3.4)**. The emission load during night is seen to be zero due to very low numbers of vehicles moving on road.

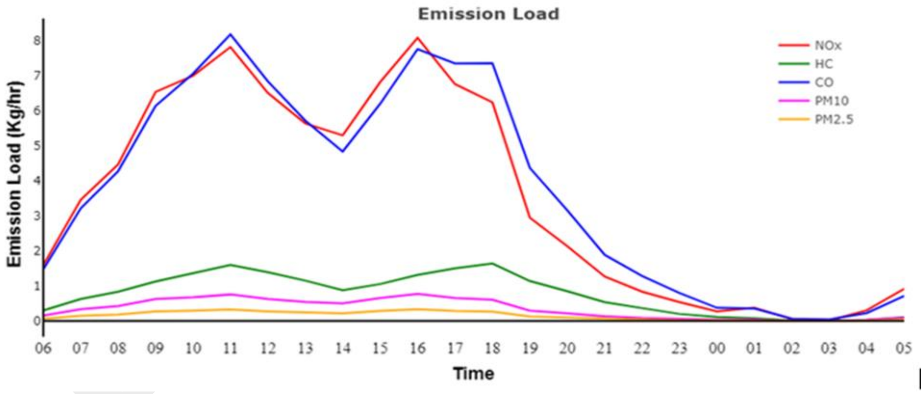

Figure 3.4: Hourly Vehicular Emission Load at One Location in Chandrapur City

The total emission load from vehicular count estimates for PM_{10}, $PM_{2.5}$, NOx, HC and CO is estimated to be 154, 66, 625, 1601 and 2213 Kg/day **(Figure 3.5)**. Out of the total emission load estimated, 56.6% emission load is from HDVs followed by LDVs (22.4%), 2 wheelers (11.3%), 3 wheelers (5.27%) and 4 wheelers (4.36%) respectively **(Figure 3.6).**

The grid-wise emission load for PM_{10} and $PM_{2.5}$ due to vehicular traffic flow is shown in following figures **(Figure 3.7 and 3.8)**. The Grid number E5 shows the maximum emission load.

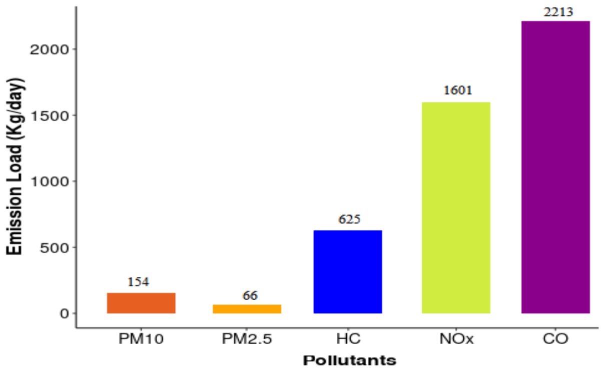

Figure 3.5: Total Vehicular Emission Load

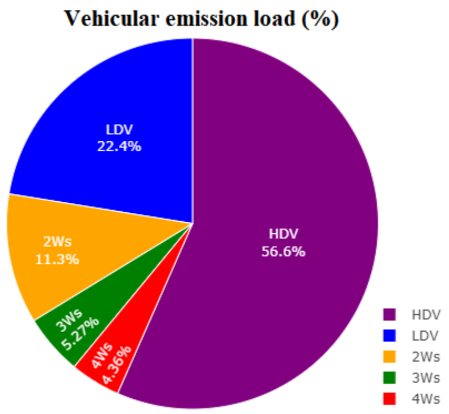

Figure 3.6: Vehicular Emission Load (%)

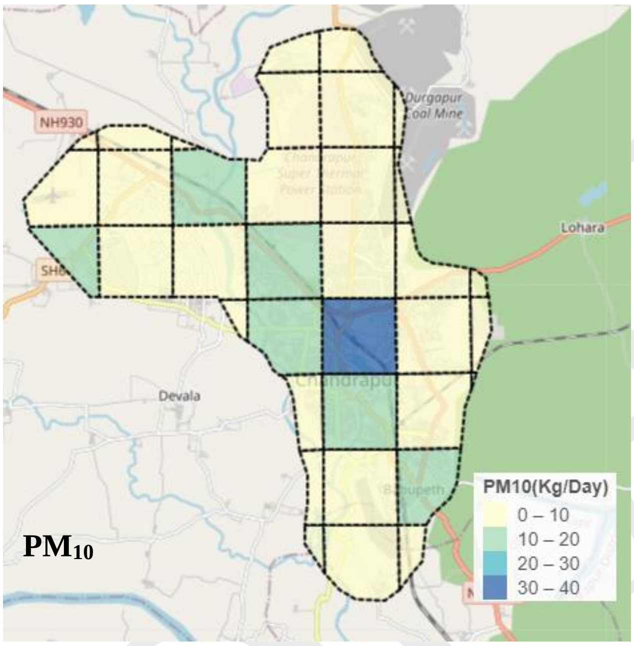

Figure 3.7: Grid-wise Emission Load for PM_{10} From Line Source

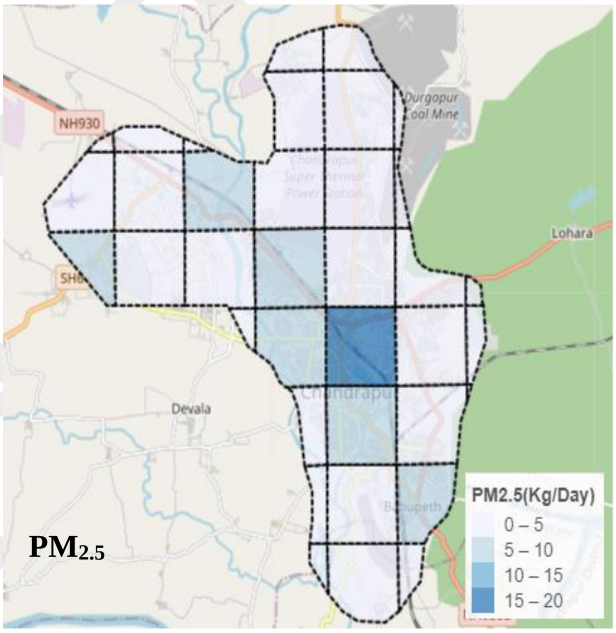

Figure 3.8: Grid-wise Emission Load for $PM_{2.5}$ From Line Source

3.9 Point Source

Chandrapur Super Thermal Power Station (often abbreviated as CSTPS) is a thermal power plant located in Chandrapur district in the Indian state of Maharashtra. The power plant is one of the coal based power plants of MAHAGENCO. The coal for the power plant is sourced from Durgapur and Padmapur Collieries of Western Coalfields Limited. With the total capacity of 3340 MW, the plant is the largest power plant in the Maharashtra. It accounts for more than 25% of Maharashtra's total needs. There are in all 9 units at Chandrapur thermal power plant with a coal consumption of 36000 tonnes per day. Large scale industries such as wooden furniture, Dal Mills, Cold storages, Jam & Jellies, fabrication workshops etc are located in Chandrapur. It also has industries like manufacturing of turmeric powder, rice flake mills, leather garments and shoe industries, tiles and pavers making, brick kilns etc. The fuel required in industries for product production is given in **Table 3.2.**

Table 3.2 : Type and Quantity of Fuel

Fuel	Quantity	Unit
Coal TPP	41935	Ton/day
Furnace Oil	8	KL/day
LDO	5.77	KL/day
Wood	5.5	Ton/day
Coal	4.8	Ton/day
Diesel	1.15	KL/day
HSD	0.84	KL/day
Briquettes	0.2	Ton/day
LPG	0.004	Ton/day

After considering all the installed air pollution control systems in the industries, the total emission load is estimated **(Table 3.3 and Figure 3.9)**.

Table 3.3: Emission Load from Point Source (9 Unit TPP)

ID	PM_{10} [Kg/D]	$PM_{2.5}$ [Kg/D]	SO_2 [Kg/D]	NOx [Kg/D]
UNIT_3	1685	653	85	17
UNIT_4	1685	653	85	17
UNIT_5	2376	921	120	24
UNIT_6	2376	921	120	24
UNIT_7	2592	1005	130	26
UNIT_8	2592	1005	130	26
UNIT_9	2592	1005	130	26
Total	**15898**	**6162**	**800**	**160**

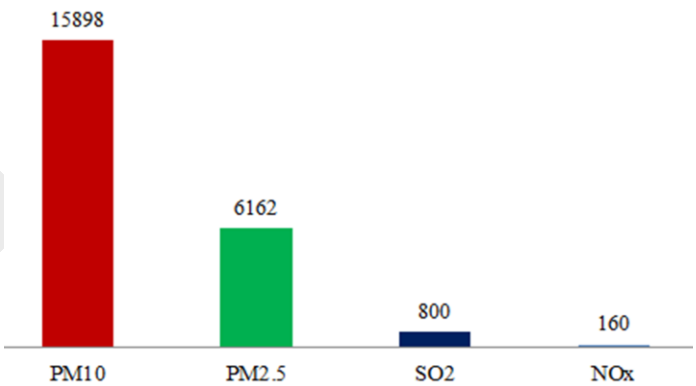

Figure 3.9 : Emission Load from Point Source (Kg/d)

The grid-wise emission load for PM_{10} and $PM_{2.5}$ from point sector is represented in **Figure 3.10 and Figure 3.11** for particulate matter.

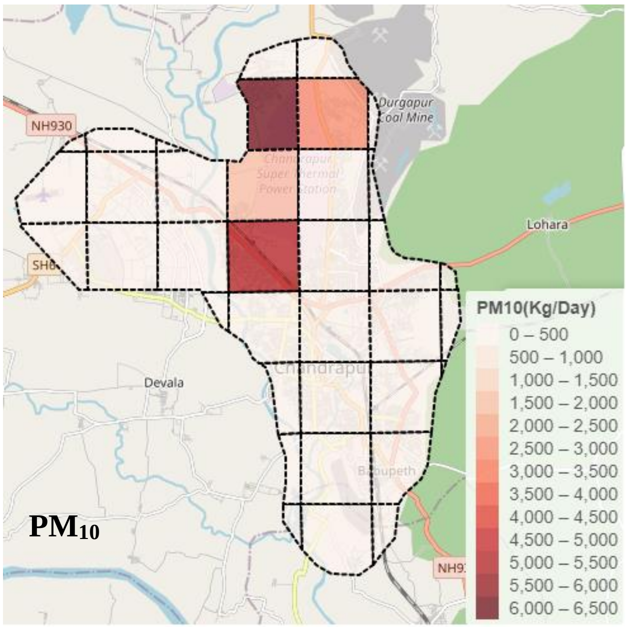

Figure 3.10 : Grid-wise Emission Load for PM_{10} From Industries

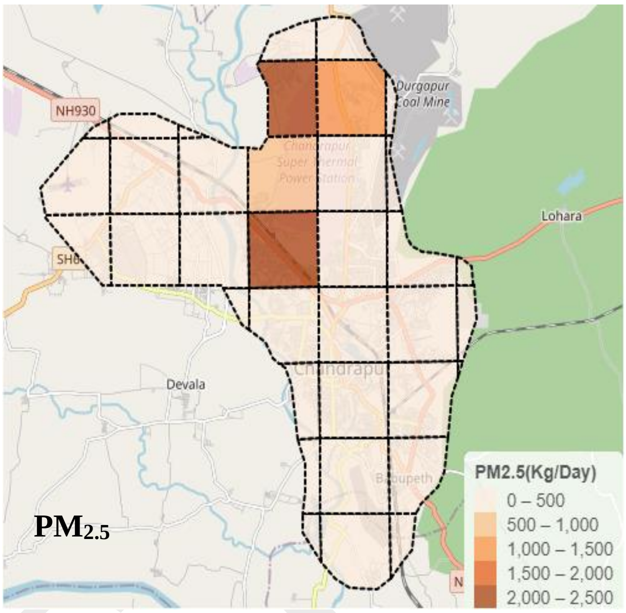

Figure 3.11: Grid-wise Emission Load for $PM_{2.5}$ From Industries

3.10 Area Sources

An area source is defined as a collection of similar emission units within a geographic area. Area sources collectively represent individual sources that are small and numerous and that have not been inventoried as specific point, mobile, or biogenic sources. Individual sources are typically grouped with other like sources into area source categories. These source categories are grouped in such a way that they can be estimated collectively using one methodology. The main reason not to treat them as point sources is that the effort required gathering data and estimating their emissions. The main distinction between point and area sources is the methodology used to estimate emissions. Point sources are inventoried individually, and area sources are inventoried collectively. Any specified area (e.g., city, town, or census division) could be used to define an area source. User-defined areas such as grid cells or polygons could also be used. Area sources include a wide range of sources, such as residential cooking facilities, rice straw/biomass burning, gas stations, construction activities, printing facilities, auto repair facilities, paint spraying facilities, and so on.

The aggregation of all these sources contributes a considerable emission to air quality. For distributing on the map, emissions from these sources are estimated by each grid cell. In the beginning, a list of all sources and their information are collected from related local city office or other related Departments, as well as the data of inhabitants, the number of households, and the density rate in each ward. These data are used for calculating emission from common sources distributed evenly, such as household cooking; using a top-down approach by which the total emissions for the whole region are calculated, and then they are distributed by each grid cell according to the number of households and the density rate.

Sources with the same characteristic are classified under a category, and an appropriate emission estimation method is chosen depending on the source characteristic and the data available. The total emissions of one grid include the emission from household activities and from other sources. Source categories are different depending on the feature of the study area, and some common categories for cities in developing countries are: biomass (straw) burning, solid waste open burning, household cooking, smoke for meat and fish curing, gas stations, construction, concrete mixing, garages, commercial/consumer solvent used, and graphic arts.

A team of scientist and project assistants from CSIR-NEERI visited the city offices and Chandrapur Municipal Corporation during year 2018-19 for reconnaissance survey and baseline data collection. The team discussed with the concerned officials and obtained information through questionnaire. The information obtained is per the scope of work.

3.10.1 Bakeries

Bakeries report air pollution emissions from the burning of fuels in ovens and boilers, as well as from the production of baked yeast products. Burning fuel emits carbon monoxide, nitrogen oxides, particulate matter (dust and smoke), sulfur oxides, and VOCs. A survey of retail and commercial bakeries located in Chandrapur city was conducted to determine the annual consumption of the fuel required for production. Retail and commercial bakeries located within the city were identified through searches utilizing the data available with Chandrapur Municipal Corporation, Google portal etc.

There are 10 registered bakeries in the city with fuel as LPG and wood. The location of the registered bakeries is shown in **Figure 3.12**. The emission load is estimated to be 324.55, 227, 2369 Kg/Day for PM_{10}, $PM_{2.5}$ and CO emissions (**Figure 3.13**).

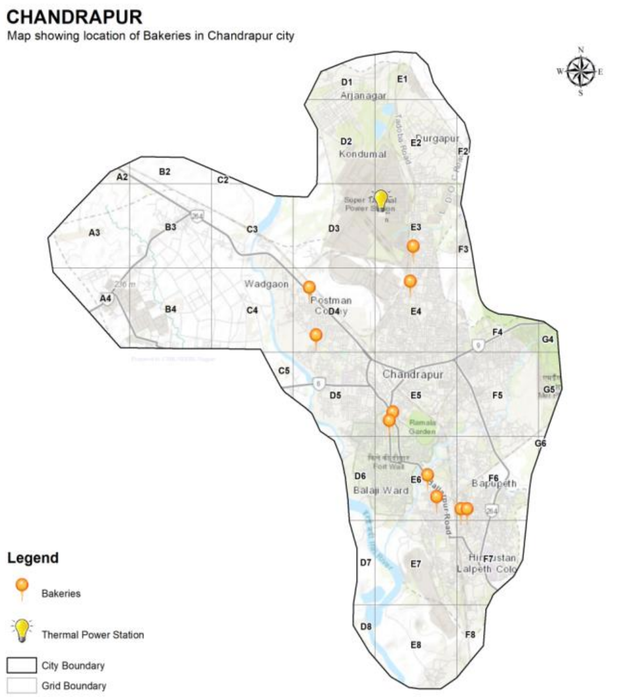

Figure 3.12 : Location of Bakeries in Chandrapur City

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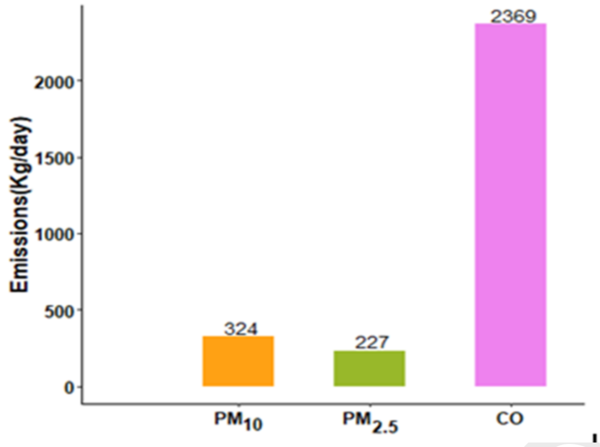


Figure 3.13 : Total Emission Load from Bakeries (Kg/d)

Grid-wise emission load from bakeries for different pollutants is shown from **Figure 3.14 and 3.15** below :

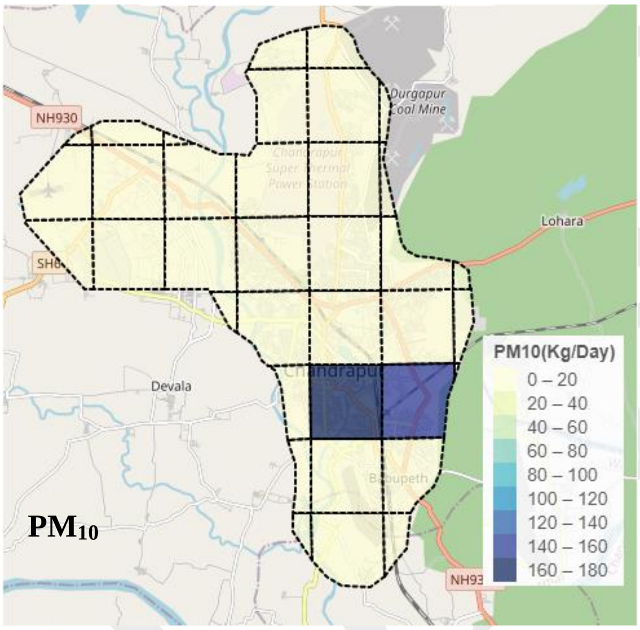


Figure 3.14 : Grid-wise Emission Load for PM_{10} From Bakeries

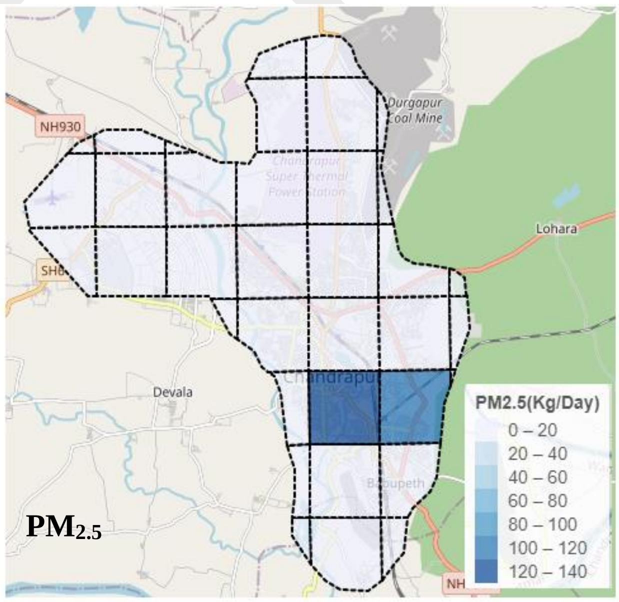


Figure 3.15: Grid-wise Emission Load for $PM_{2.5}$ From Bakeries

3.10.2 Crematories

Cremation is the disposal of a dead body by the process of burning. This can be undertaken either in an uncontrolled, open burning fashion on funeral pyres, or in a controlled fashion within a cremator, installed within a crematorium or crematory. There are various types of emissions during cremation of a dead body in a crematorium because of burning of wood, use of diesel, kerosene, cowdung cakes etc. Emissions like PM, CO, NOx, SO_2, and heavy metals etc. are released into the air which is harmful to health and environment. There are six crematories in Chandrapur city. The locations in the grids are plotted with the help of GIS as shown in **Figure 3.16.**

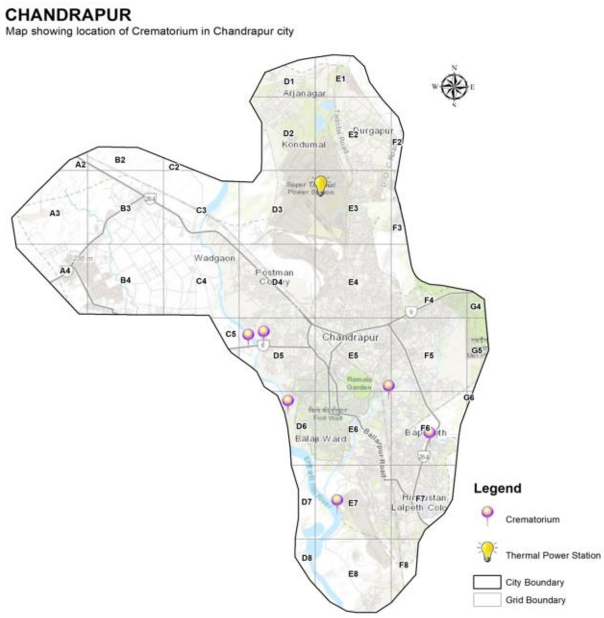


Figure 3.16 : Location of Crematories in Chandrapur City

No authentic information was available regarding the number of dead bodies cremated in each crematory. All the crematories in Chandrapur city are of open pyre type. As per old literature available it was concluded that for cremation of a single dead-body requires 300 Kg of wood, 5 Kg of Kerosene and 4 to 5 Kgs of Dung cakes for cremation. Based on the population statistics report on religion data of Census of India 2011 and data issued from death cell of Municipal Corporation, the total dead bodies' cremated using firewood was estimated. The emission load from crematories is given in **Figure 3.17**.

Emission Estimations:

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

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

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

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

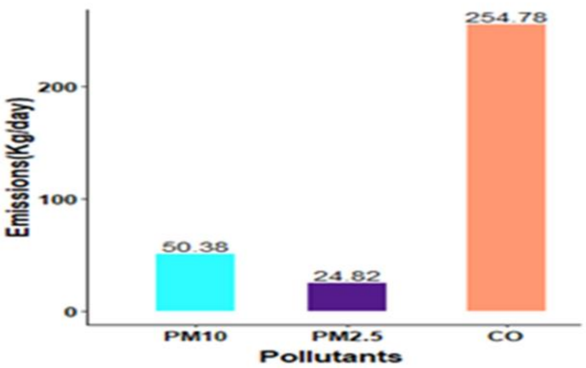
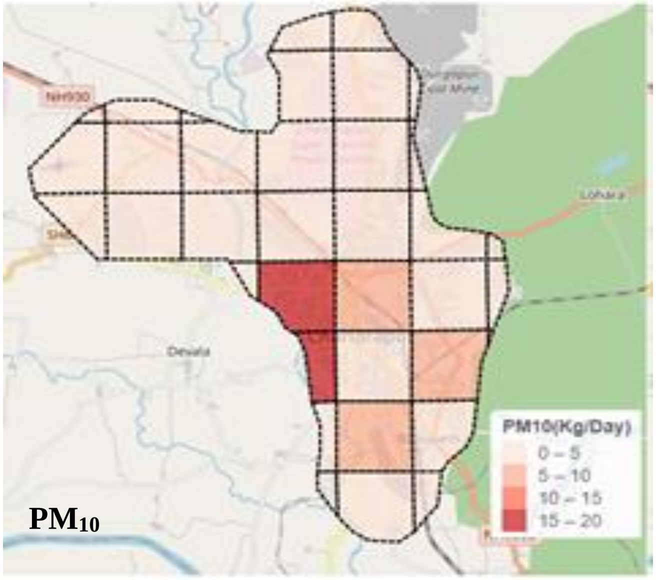


Figure 3.17 : Emission Load from Crematories (Kg/da)

The grid-wise emission load for PM_{10} and $PM_{2.5}$ from crematories is shown in **Figure 3.18 and Figure 3.19.**



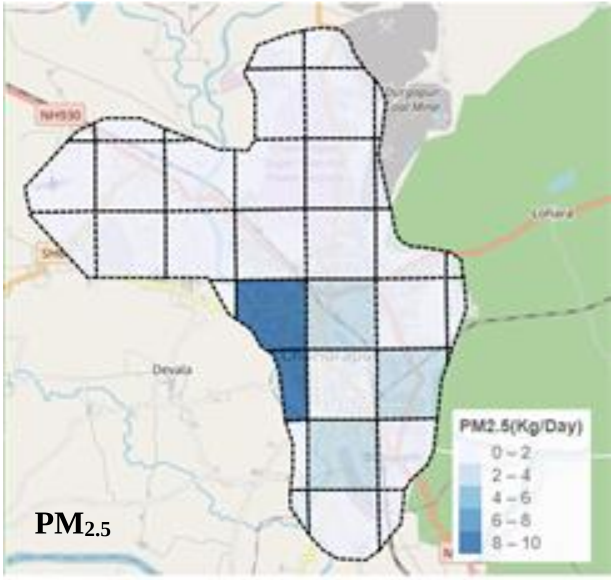


Figure 3.18 : Grid-wise Emission Load for PM_{10} From Crematories

Figure 3.19: Grid-wise Emission Load for $PM_{2.5}$ From Crematories

3.9.3 Open Eat outs

In India, the national policy for urban street vendors /hawkers notes that street vendors constitute approximate 2% of the population of a metropolis. In Chandrapur, around commercial centres mainly street hawkers / open eat outs operate providing meals /snacks and tea. Municipal Corporation /government consider street vendors as encroachers, but this forms an important unorganized sector of business. The average consumption of kerosene per day is approximately 8 litres, 4 Kg/day LPG and 10 Kg/day of coal for cooking purpose. Average operating hours of street vendors is 12 hours. Data regarding number of street vendors was made available by Chandrapur Municipal Corporation. Many open eatouts are illegal and are operating. Therefore, CMC regularly takes action on street vendors. Based on the data of areas of such action taken on number of street vendors by MCGM (License Department), surveys were carried out. There are total 105 registered open eatouts in Chandrapur city. These number have been checked by visiting representative areas where these eat outs are prevalent. Fuel use pattern was estimated on the basis of primary survey which involved consultations with operators. On the basis of

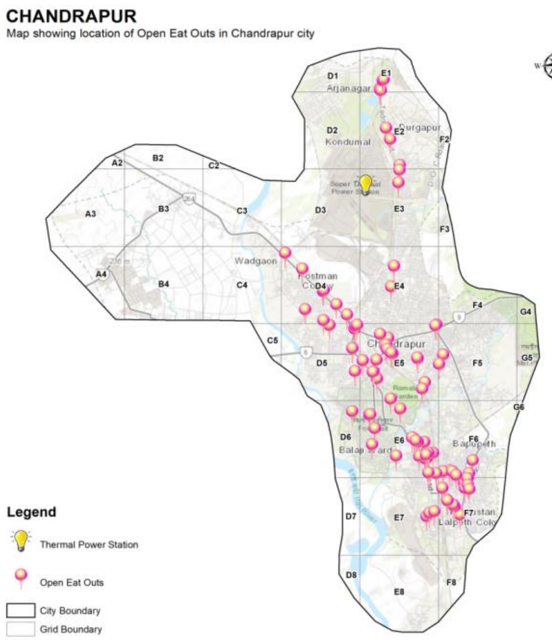


Figure 3.20 : Location of Open-eatouts in Chandrapur City

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primary survey, 66% of the vendors use LPG as fuel, 20% rely on coal, 11 % on wood and 3% open eatouts rely on kerosene. The locations in the grids are plotted with the help of GIS as shown in **Figure 3.20.** The emission load from open eatouts is given in **Figure 3.21.** The grid-wise emission load for PM_{10} and $PM_{2.5}$ from open-eatouts is shown in **Figure 3.22 and 3.23.**

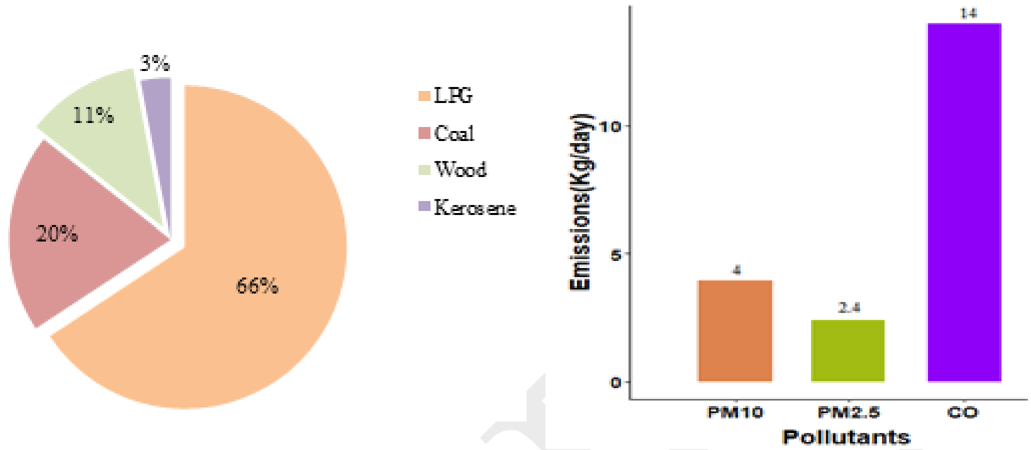

Figure 3.21 : Fuel Consumption and Emission Load from Open Eat-outs

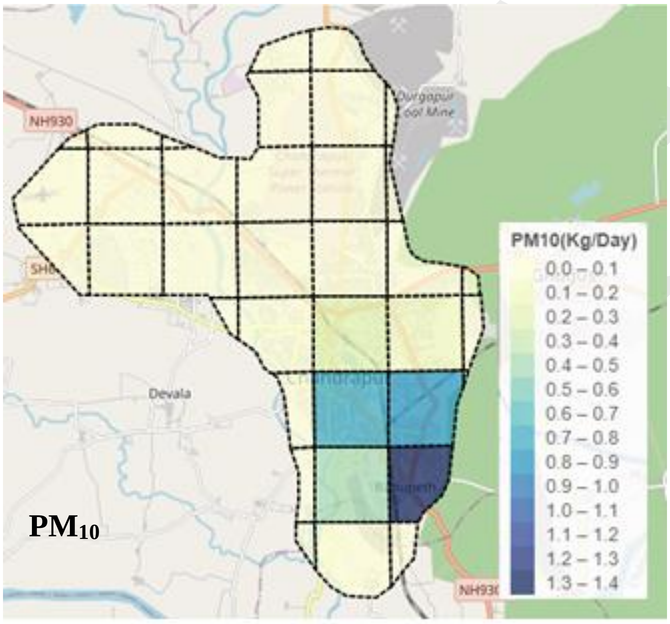

Figure 3.22 : Grid-wise Emission Load for PM_{10} From Open Eat-outs

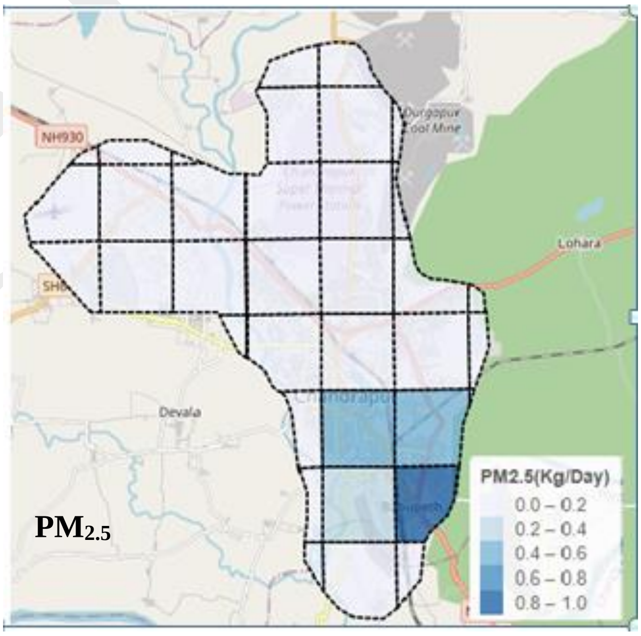

Figure 3.23: Grid-wise Emission Load for $PM_{2.5}$ From Open Eat-outs

3.9.4 Domestic Sector

There are 61 wards under Chandrapur Municipal Corporation. The total number of domestic LPG consumption during the year 2017-18 is reported to be 102.47 thousand million tonnes. There are total 8 domestic agencies/distributors which have 1.22 Lakhs registered consumers. The total sell of Kerosene for the year 2018 was about 24000 litres. The major distributors are HP & Indane gas. In slum areas, the LPG connections are issued but people use to prefer chulha and kerosene for cooking. As coal is easily available, chulha is seen in most of the houses of slum areas. Based on primary survey it is estimated that the slum population (88%) consumes kerosene as major cooking fuel. Average kerosene consumption by a slum household is about 15 Litres/month. The number of members in a slum household and non-slum household is assumed to be 4. The emission load from domestic sector is given in **Figure 3.24.**

Emission Estimation

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

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

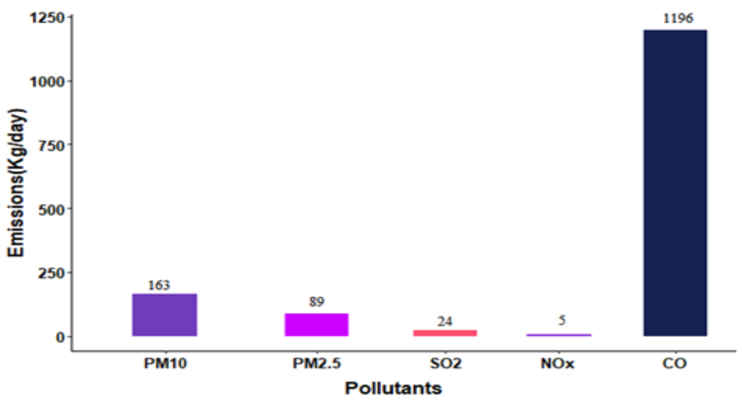

Figure 3.24 : Emission Load from Domestic Sector

The grid-wise emission load for PM_{10} and $PM_{2.5}$ from domestic sector is shown in **Figure 3.25 and 3.26.**

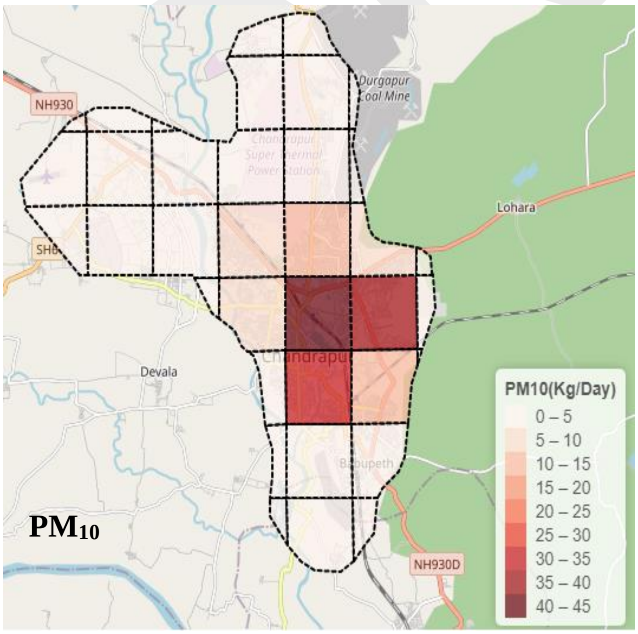

Figure 3.25 : Grid-wise Emission Load for PM_{10} From Domestic Sector

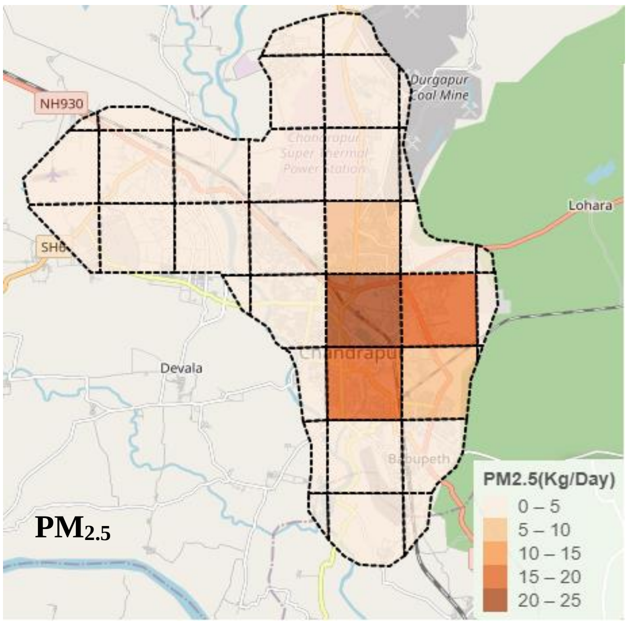

Figure 3.26 : Grid-wise Emission Load for $PM_{2.5}$ From Domestic Sector

3.10.5 Building Construction

With a scope of being developed as smart city, there are drastic infrastructural developments taking place in Chandrapur city. The handling and construction activities contribute towards fugitive dust particulate matter in large proportions. Particulate emissions are predominantly due to site preparation work, which includes heavy construction activities. Data related to construction activity was obtained from Building construction department of Chandrapur Municipal Corporation and from RERA website. During survey, 24 construction sites were found in operation.

Assumptions

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

Emissions Estimation

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

- **Step 1:** Total No. of construction activities. This was obtained from RERA database.
- **Step 2:** Acres disturbed
- **Step 3:** Months of activity (Buildings construction activity = 8-12 months)
- **Step 4:** Acre x months of activity Buildings construction activity = 8 x total number of acres disturbed
- **Step 5:** PM_{10} Tons/years = 1.2 x total number of acre-months (AP42, Section 13.2.3.3– PM_{10} - 1.2 tones/ acres months)

The emission load from building construction is given in **Figure 3.27.**

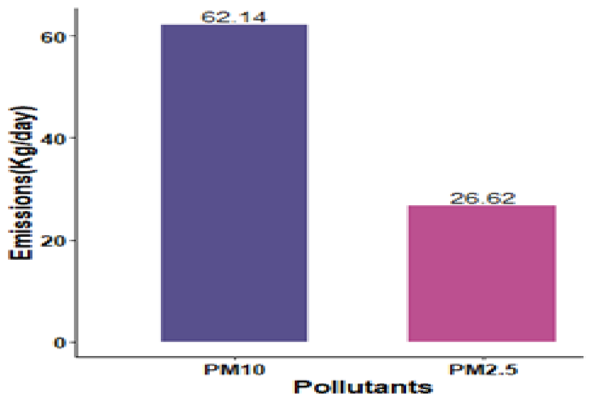

Figure 3.27 : Emission Load from Building Construction

3.10.6 Hotels and Restaurants

Information on hotels and restaurants was obtained directly by consulting the members of Hotel and Restaurant Owners Association of Chandrapur. There are around 106 hotels and restaurants within Chandrapur city. The locations of these hotels are marked on the Chandrapur city map with the help of GIS. During survey, it was revealed that there are too many hotels and restaurants operated but are unregistered and unorganized. In addition, there are a number of staff canteens for government and private offices. Hotels and Restaurants use LPG cylinders and coal for their operation. An LPG commercial cylinder of minimum capacity of 19 Kg is widely used for cooking in these hotels and restaurants. The coal is used for cooking tandoors bhattis. The primary survey of Hotels and Restaurants gave a daily average LPG consumption of 57% cylinder of 19 Kg capacity and coal consumption of 0.82 Kg per hotel/restaurant per day. The quantity of fuel required is totally dependent on the number of customers and varies per day. Hence the average of 30 days is considered for real time emission load.

Emission Estimations

- Emission Load from LPG

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

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

  = Number of Hotels x LPG consumption (Tons/day) x Emission Factor (Kg/T)

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

- Emission Load from Coal

  Total emissions (PM) due to coal burning in Hotels

  = No. of Hotels x Coal consumption (Tons/day) x Emission Factor (Kg/T).

The emission load from hotels and restaurants is given in **Figure 3.28.** The grid-wise emission load for PM_{10} and $PM_{2.5}$ from hotels and restaurants is shown in **Figure 3.29 and 3.30.**

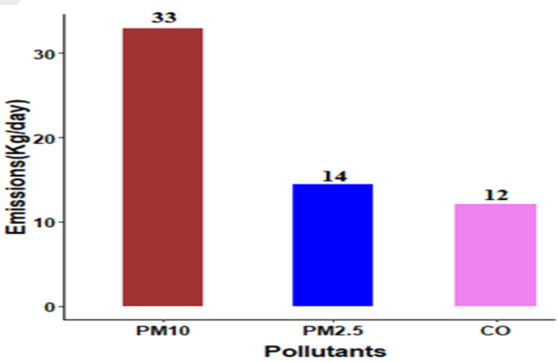

Figure 3.28 : Emission Load from Hotels and Restaurants

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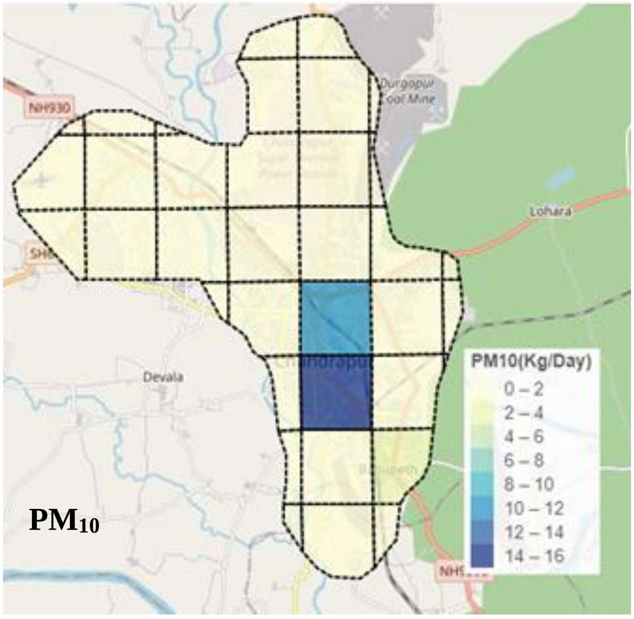

Figure 3.29 : Grid-wise Emission Load for PM_{10} From Hotels and Restaurants

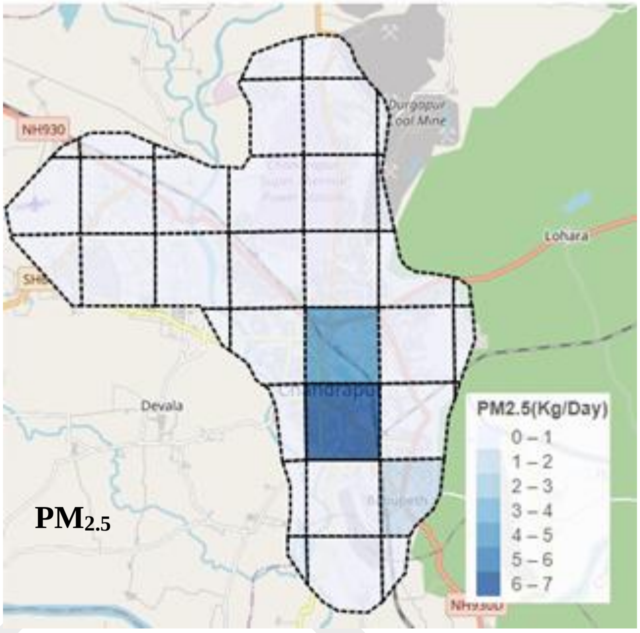

Figure 3.30 : Grid-wise Emission Load for $PM_{2.5}$ From Hotels and Restaurants

3.10.7 Brick Kilns and Stone Crushers

The brick kilns emit toxic fumes containing suspended particulate matters rich in carbon particles and high concentration of carbon monoxides and oxides of sulphur (SOx). Stone crusher creates lot of noise and it emits dust particles in environment. Because of more concentration of dust particles in environment (air), it creates pollution. There are no brick kilns and stone crusher located in the city limits. Hence they are not considered while estimating emission inventory load for the city boundary.

3.11 Total Emission Inventory

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Chandrapur city vide emission inventory is developed as shown in **Table 3.4**. Total tons /day emission load for pollutants in Chandrapur city is depicted in **Figure 3.31**.

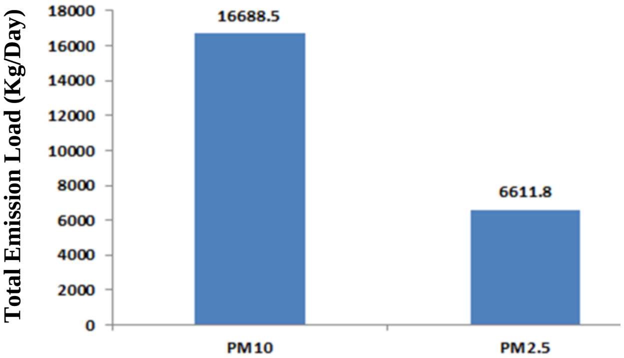

Figure 3.31: Total Emission Load from All Sources

Table 3.4 : Total Emission Load for all Pollutants (Kg/d)

No.	Sector	PM_{10}	$PM_{2.5}$
1	**Line Source**	**154.0**	**66.0**
2	**Point Source**	**15898.0**	**6162.0**
3	**Area Source**		
i	Bakeries	324.0	227.0
ii	Crematoria	50.4	24.8
iii	Open Eat-outs	4.0	2.4
iv	Domestic	163.0	89.0
v	Building Construction	62.1	26.6
vi	Hotels & Restaurants	33.0	14.0
Total Emission Load (Kg/day)		**16688.5**	**6611.8**
	Total Emission Load (Ton/day)	**16.69**	**6.61**

3.12 Grid-wise Emission Inventory

In each of the grids, activities contributing to air pollution are mapped. Grid-wise Emission inventory is a scientific way to identify aggregated local source contribution and their region-specific spatial distribution within a confined boundary. It is a more effective tool to identify hot spots and plan control measures. The grid-wise emission inventory includes pollutants including particulate matter (10 microns and 2.5 microns), sulfur dioxide, oxides of nitrogen and carbon monoxide **(Figures 3.32 through 3.35)**.

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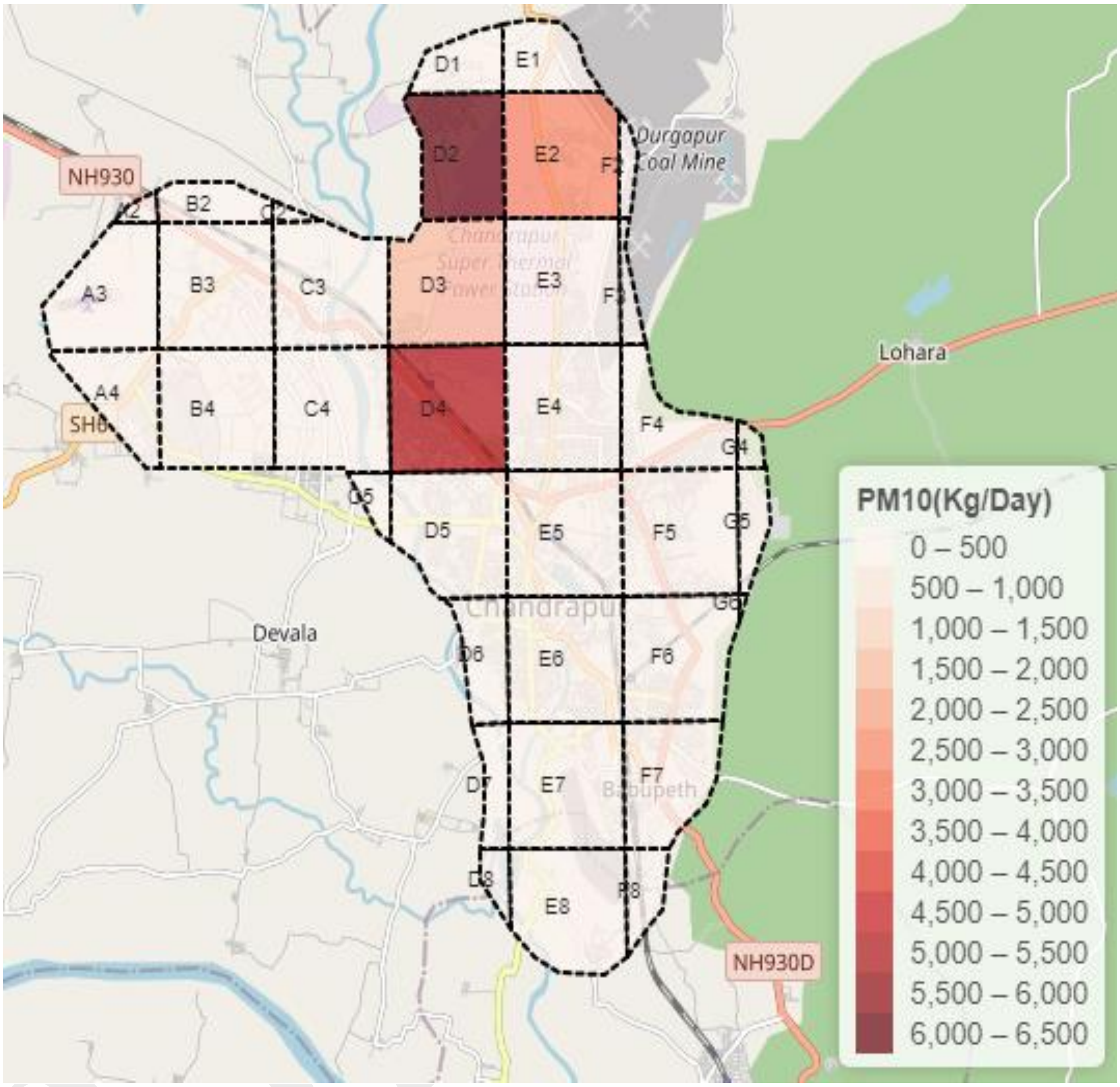

Figure 3.32 : Total PM_{10} Emission Load from All Sources

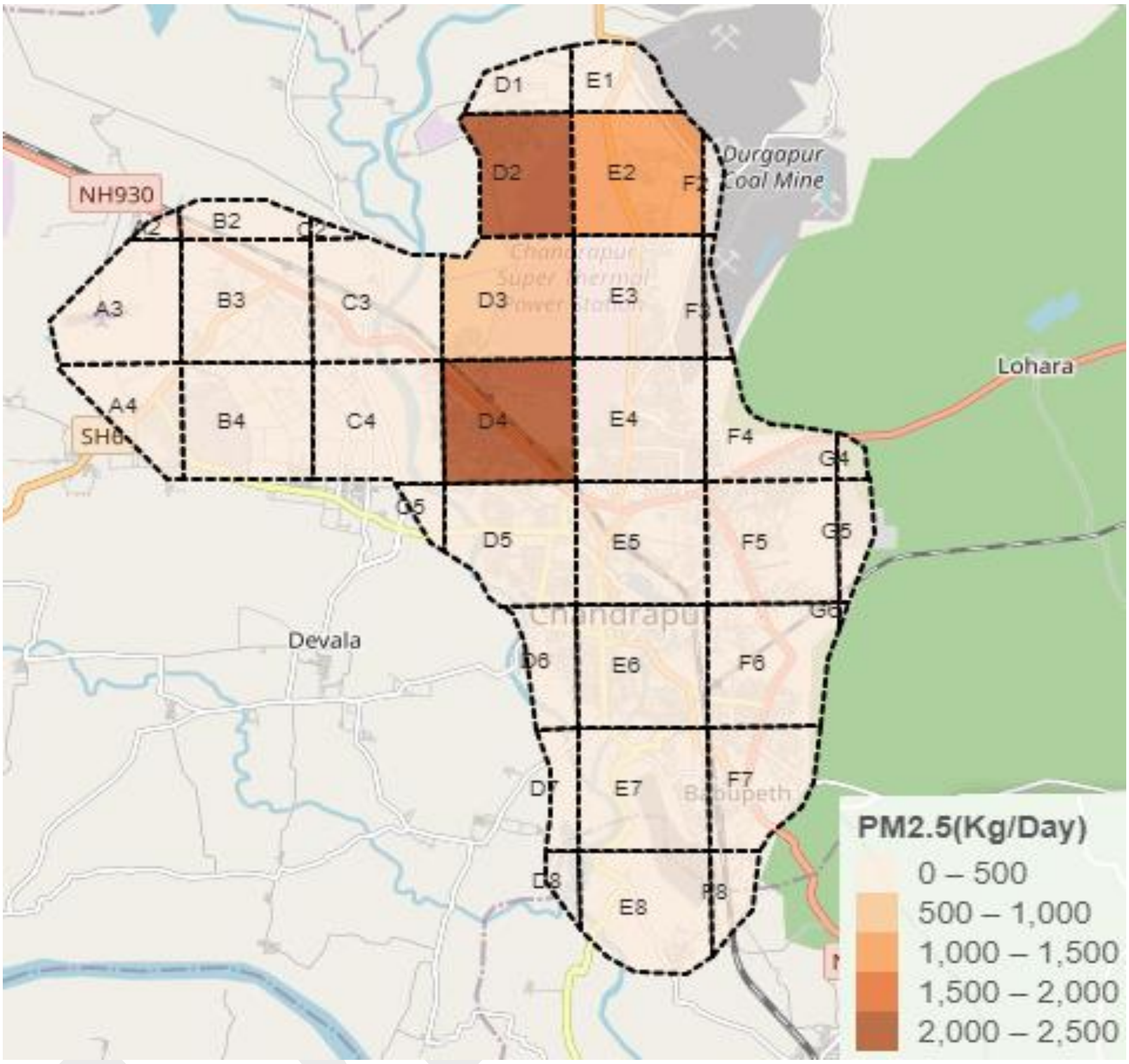

Figure 3.33 : Total $PM_{2.5}$ Emission Load from All Sources

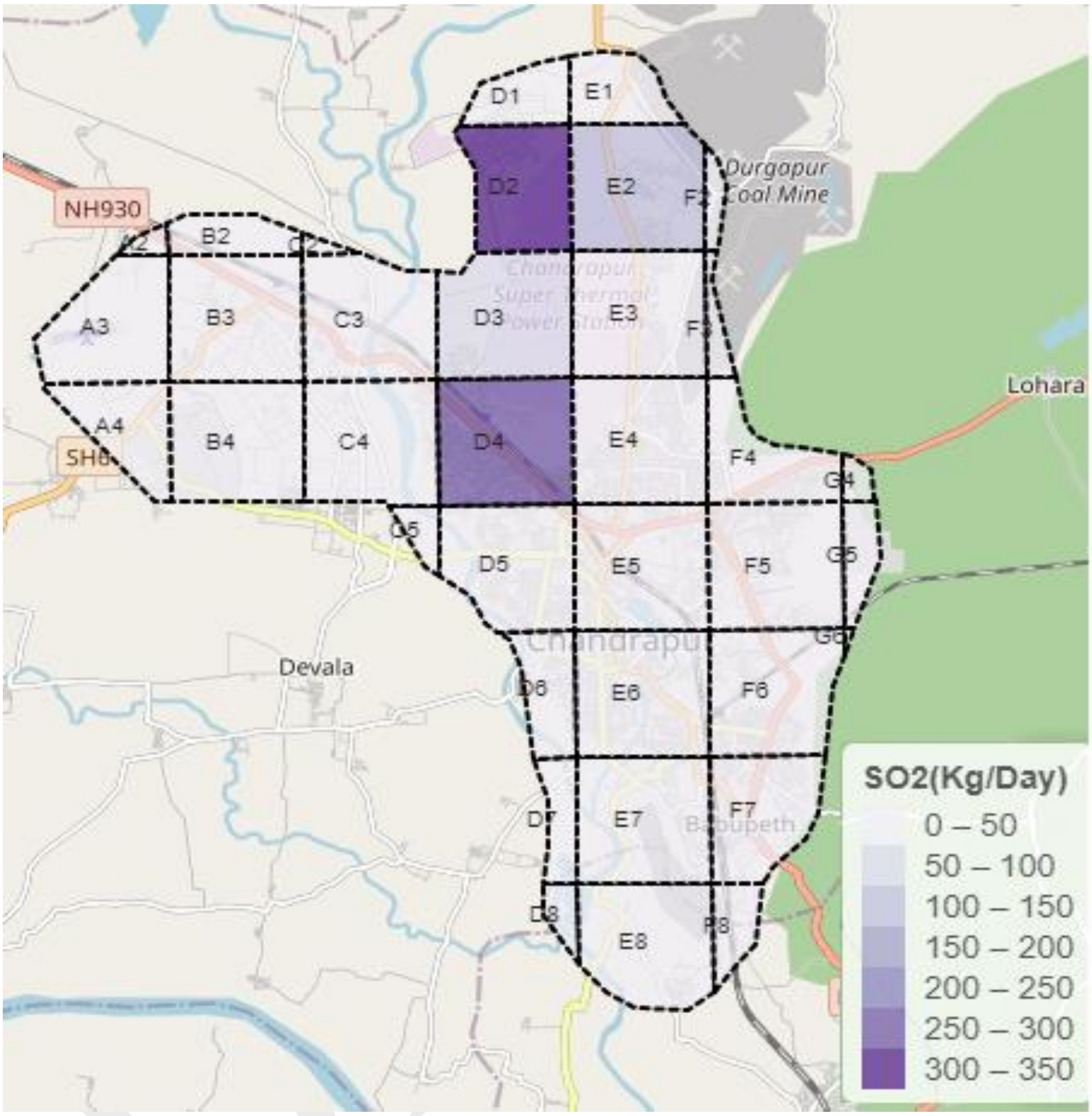

Figure 3.34 : Total SOx Emission Load from All Sources

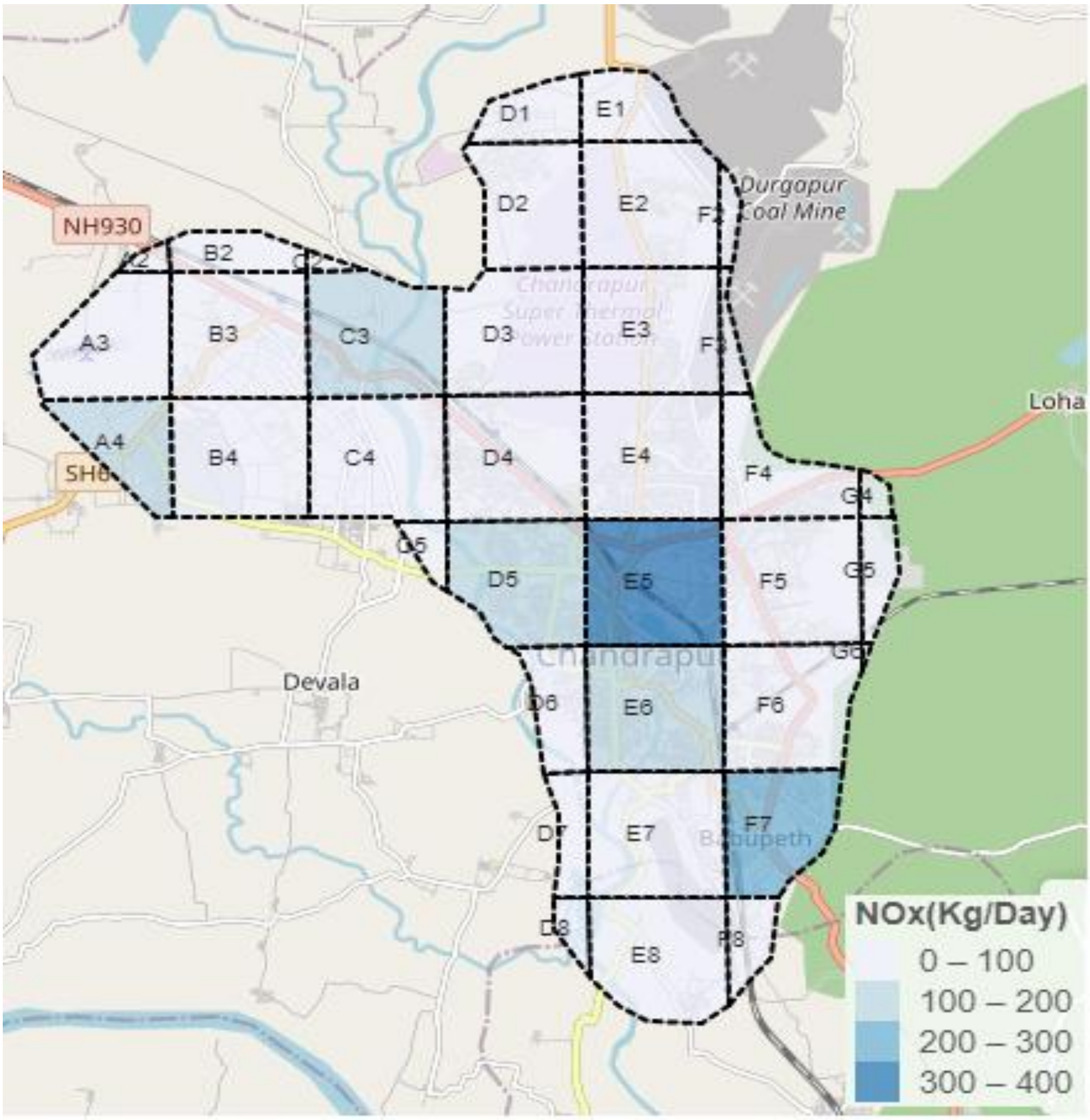

Figure 3.35 : Total NOx Emission Load from All Sources

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study Using EPA PMF v5.0

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

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

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

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

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

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

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4.2 Methodology

For the present study EPA, PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for the identification of sources and their positive contributions to ambient air pollution. The study was carries out for representative samples of $PM_{2.5}$ and PM_{10} collected during the November 19, 2020 to December 15, 2020 sampling campaign at 4 locations: Tirtharup Nagar (Industrial); Balaji Ward (Commercial); Gajanan Maharaj Mandir (Residential) and Krishna Nagar (Reference). The concentration and uncertainty data were obtained from the gravimetric analysis ($PM_{2.5}$ and PM_{10}); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (46 elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb, Bi, Th and In); and Ionic Analysis (12 ions: Na^+, NH_4^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, NO_2^-, Br^-, NO_3^{2-}, PO_4^{3-} and SO_4^{2-}) for both PM_{10} and $PM_{2.5}$ for all sources as listed above.

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

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

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

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

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/cm²**	**µg/m³#**	**Elements (a)**	**µg/cm²**	**µg/m³#**
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)

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

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

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

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

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

After matching all the criteria as described above, the model runs were considered for further analysis. The factor fingerprints, factor profiles and contribution obtained from these optimized runs were matched with the standard factor fingerprints and previous studies *(Maykut et al.,*

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2003; Gupta et al., 2012; Patil et al., 2013; Sharma et al., 2016; Zong et al., 2016; Police et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Taghvaee et al., 2018; Garaga et al., 2020) to identify the sources. Also, all the results from various run and error estimation were obtained in the form of datasheets which were used for further analysis to obtain percentage contributions of each source at receptor locations and percentage of elemental contribution from that source.

4.3 Results

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

4.3.1 PM_{10}

After the EPA PMF run analysis, 3 factors were identified in the study location for PM_{10} Samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and b)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for PM_{10} is presented in **Figure 4.2 (a and b).**

Factor 1: Industrial/Fossil Fuel Burning/ Vehicular emissions

First factor was identified as Industrial emissions/ fossil fuel combustion/ vehicular emissions the presence of tracers, such as OC, EC, Ca^{2+}, NO_3^{2-}, Al, Fe and SO_4^{2-} (~29.32%, 2.5%, 3.64%, 3.09%, 6.48%, 6.79%, 13.64%) with minor indicators such as Na, Mg, Mn, S and NH_4^{3-}. This factor contributed to about 51% of total PM_{10} pollution. OC, S, NH_4^{3-} and SO_4^{2-} have been widely used as a marker of fossil fuel combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. Fe, Zn and Pb are indicators vehicular emissions *(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 *(Keerthi et al., 2018; Jain et al., 2017).*

Factor 2: Biomass/ Waste burning

Second factor identified as biomass/waste burning accounted for 25.44% of total PM_{10} concentration by major indicators such as of OC, SO_4^{3-}, Si, S, K and Mg (~39.72%, 14.49%, 8.06%, 5.67%, 4.35% and 4.74%) and minor indicators such as Na, Al, NH_4^{3-}, NO_3^{2-}, Al and Fe. There have been many studies in the past suggesting that OC, 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)*. 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.

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Factor 3: Road Dust/Construction Dust

First factor is identified as Road and construction dust which accounted for contributions of 23.74%. Major proportions of Al, Si, S, Ca, Fe, Mg and Na (~ 9.82%, 21.55%, 9.12%, 13.59%, 12.09%, 14.10% and 6.18 %) and minor species such as OC, EC, Cl and Mn contributed to this factor. Ca, Si, Ca^{2+}, Mg, 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. Paved road dust being resuspended by vehicular movements is indicated markers such as Al, Si and S *(Jain et al., 2017, Pawar et al., 2020).*

4.3.2 $PM_{2.5}$

After the EPA PMF run analysis, 3 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 $PM_{2.5}$ are presented in **Figure 4.2 (c and d)**.

Factor 1: Secondary Aerosols/Construction Dust

First factor is identified as Secondary aerosols which accounted for contributions of 21.16%. Major proportions of OC, SO_4^{2-}, NO_3^{2-} and NH_4^{3-} (~ 46.38, 26.51%, 4.74% and 3.75%) and minor species such as Ca, Ca^{2+}, EC, Cl^- and NO_2^- contributed to this factor. 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)*. The formation of secondary aerosols is due to the chemical transformation. These secondary ions are derived from gas to particle conversion processes involving photo-chemical reaction of gaseous precursors such as SO_2 and NO_x which are largely emitted from local and regional sources *(Garaga et al., 2020)*. Since these are background pollutant sources, they are found in all samples for entire study duration. Ca, Ca^{2+}, Mg, Cl^- are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al., 2020).* Construction dust is mainly contributed from all infrastructure development projects going in and around the city.

Factor 2: Industrial/Fossil Fuel Burning/ Vehicular emissions

Second factor was identified as Industrial emissions/ fossil fuel combustion/ vehicular emissions the presence of tracers, such as OC, NH_4^{2-} and SO_4^{2-} (~41.6%, 8.69%, 27.26%, 18.50%, 34.4%) with minor indicators such as EC, Pb, Zn, Fe, S and Cr. This factor contributed to about 50.43% of total $PM_{2.5}$ pollution. S, NH_4^{2-} and 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*

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al., 2016; Jain et al., 2018). Location of industrial regions in some of this study area could be the possible reason of this source. 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 *(Keerthi et al., 2018; Jain et al., 2017)*.

Factor 3: Road or Crustal Dust/ Biomass Burning

Third factor is identified as Biomass burning which accounted for contributions of 28.42% with major proportions of OC, Si, S, K, Mg and Na (~11.33%, 7.0%, 29.82%, 10.63%, 19.8%, 8.70%) and minor indicators such as NH_4^{3-}, SO_4^{3-}, Al and Fe. There have been many studies in the past suggesting that OC, 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)*. 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. Paved road dust being resuspended by vehicular movements is indicated markers such as Al, Si and S *(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)*. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor.

Table 4.2 : Percentage Source Contribution for Chandrapur

Most likely source(s)	**%Contribution**	
	PM_{10}	**$PM_{2.5}$**
Construction Dust/ Secondary Aerosols	--	21.16
Industrial/ Fossil Fuel Burning/ Vehicular emissions	51	50.43
Road or Crustal Dust/ Biomass Burning	--	28.42
Crustal/Construction Dust	23.74	--
Biomass/ Waste Burning	25.44	

4.4 Positive Matrix Factor Analysis Conclusion

The contribution of Biomass burning is more in $PM_{2.5}$ (28.42%) is found to be higher than PM_{10} (25.43%) whereas Industrial/ Fossil Fuel Burning/ Vehicular emissions in contributions were almost same in both $PM_{2.5}$ and PM_{10}. Construction dust also contributed in range of 21-24% in both $PM_{2.5}$ and PM_{10}. As these sources are collinear and indicative markers are similar so it is difficult to separate them using PMF.

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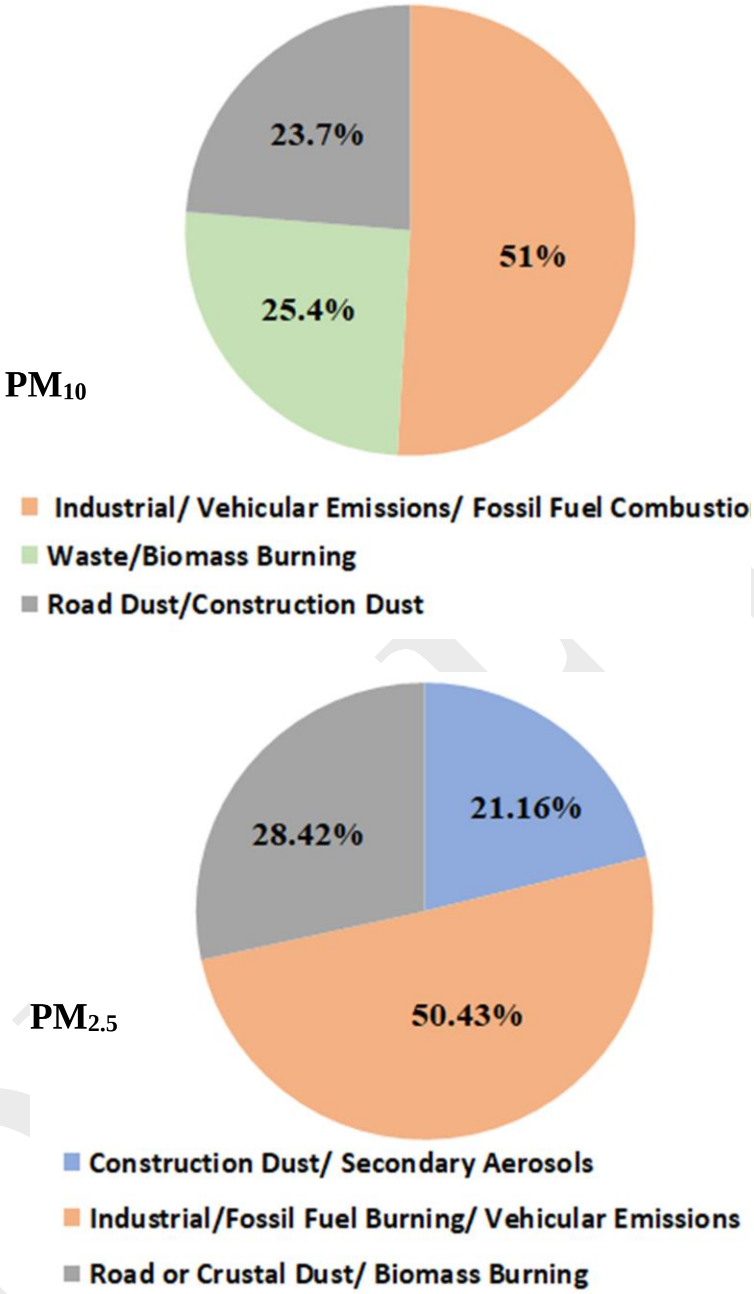


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Chandrapur City

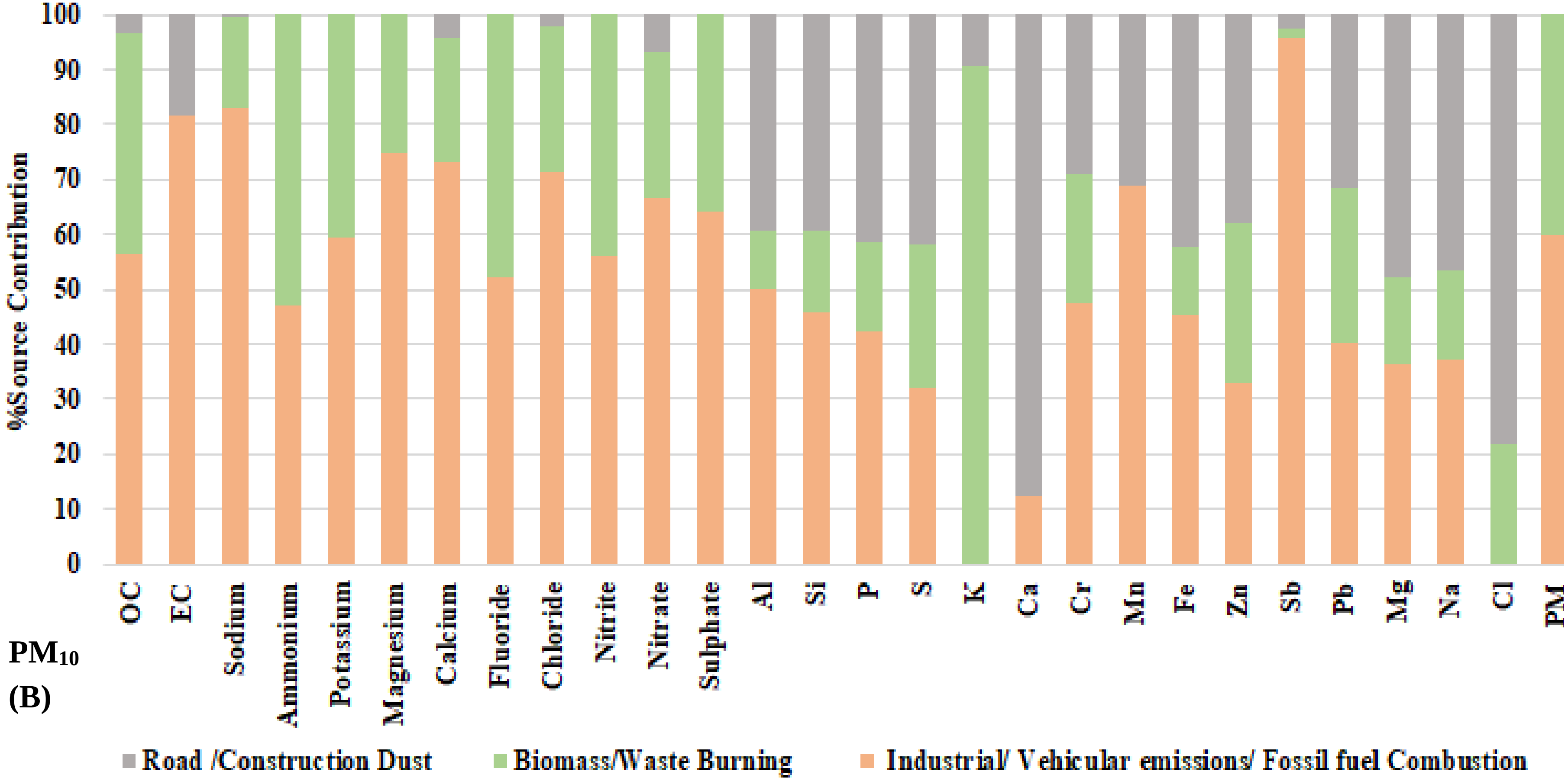
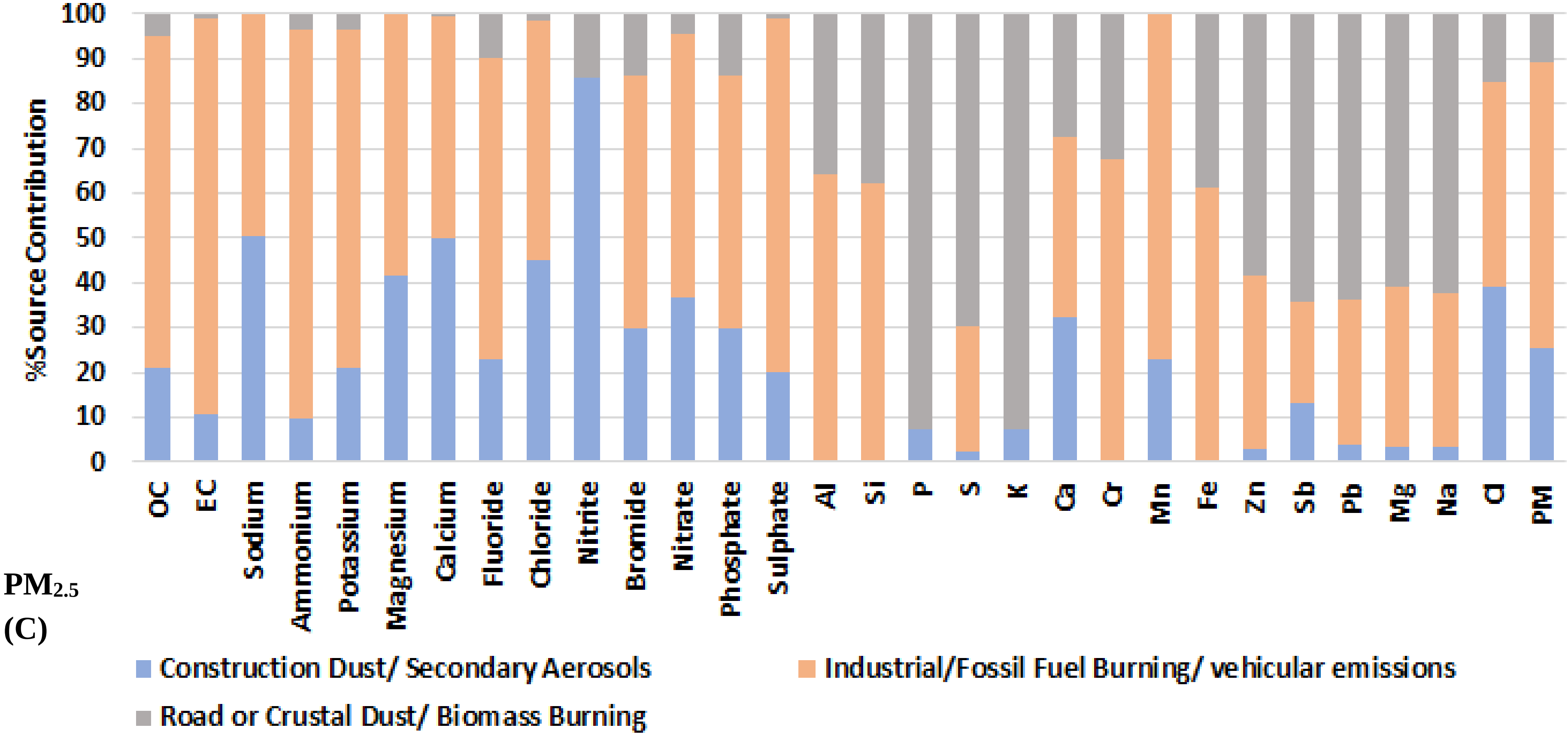


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Chandrapur City



$PM_{2.5}$
(C)

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

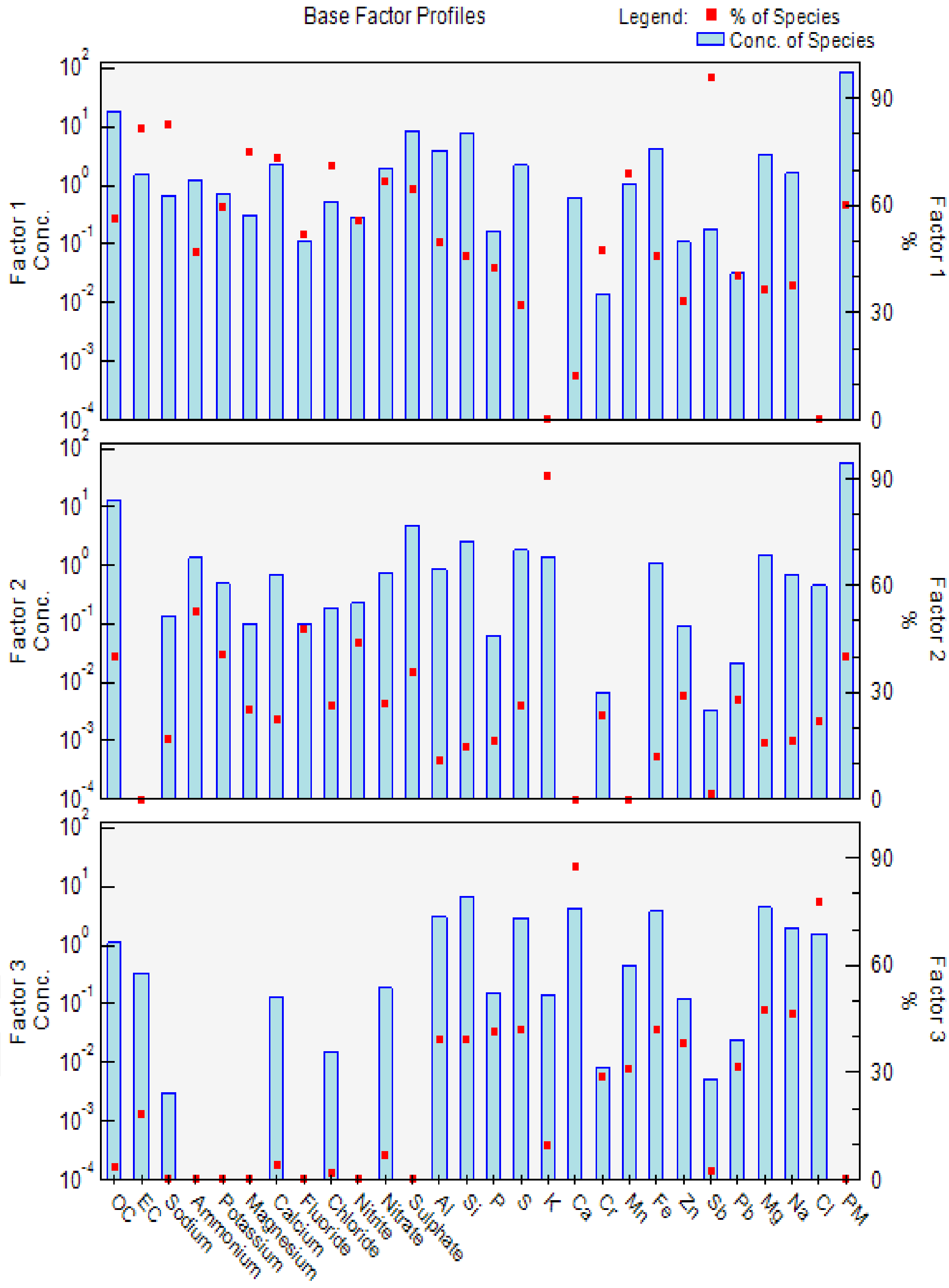


Figure 4.2 a : PM_{10} Base Factor Profiles

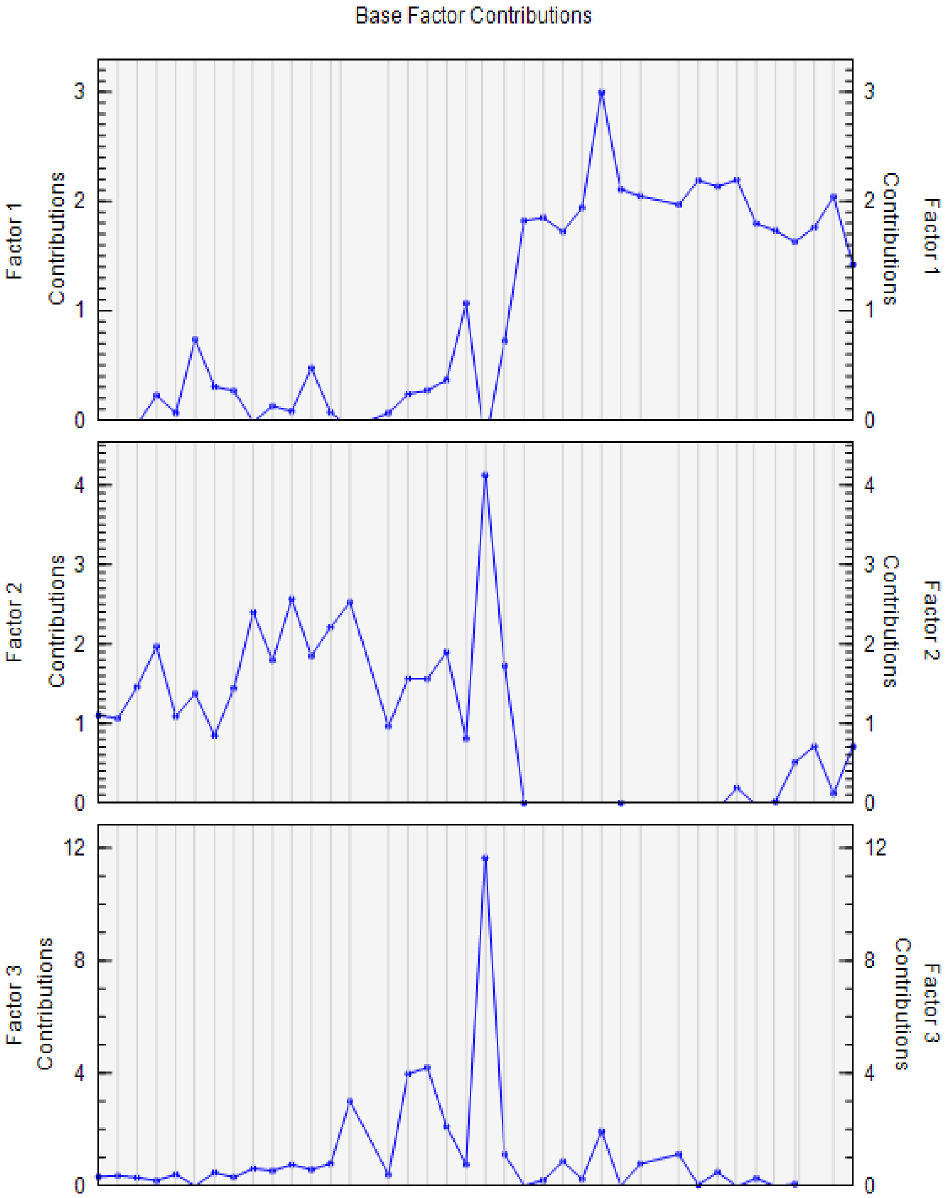


Figure 4.2 b : PM_{10} Base Factor Contributions

Factors	Predominant Factors	% Contribution	Factor Name
Factor 1	OC, SO_4^{2-},Si, Mg, Fe, Al	51	Industrial/ Vehicular Emissions/ Fossil Fuel Combustion
Factor 2	OC, SO_4^{2-}, K^+, Si, K, NH_4^{3-}, F^-	25.44	Waste/ Biomass Burning
Factor 3	Fe, Mg, Ca, Si, S, Al, Na, Cl	23.74	Road Dust/ Construction Dust

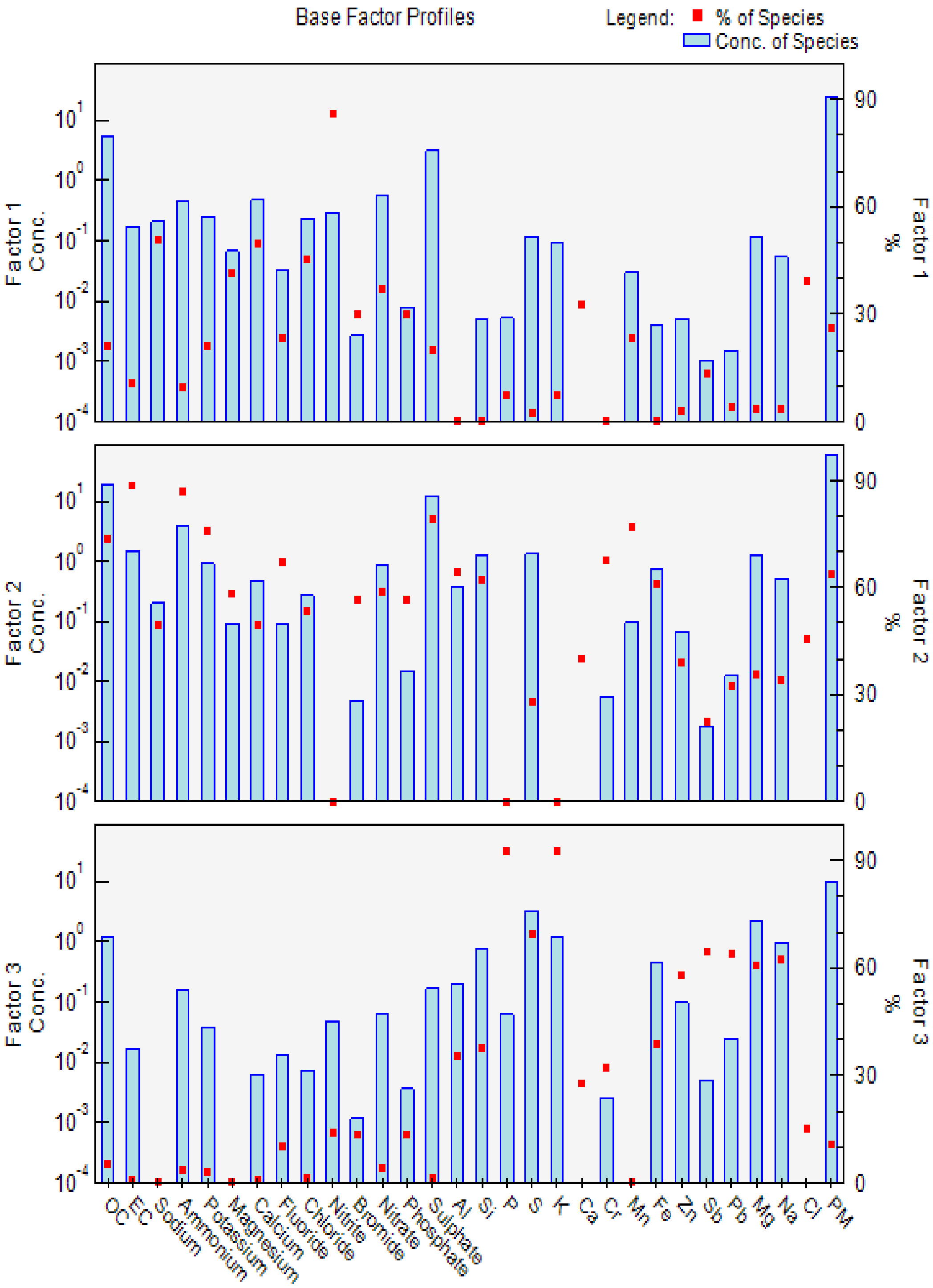


Figure 4.2 c : $PM_{2.5}$ Base Factor Profiles

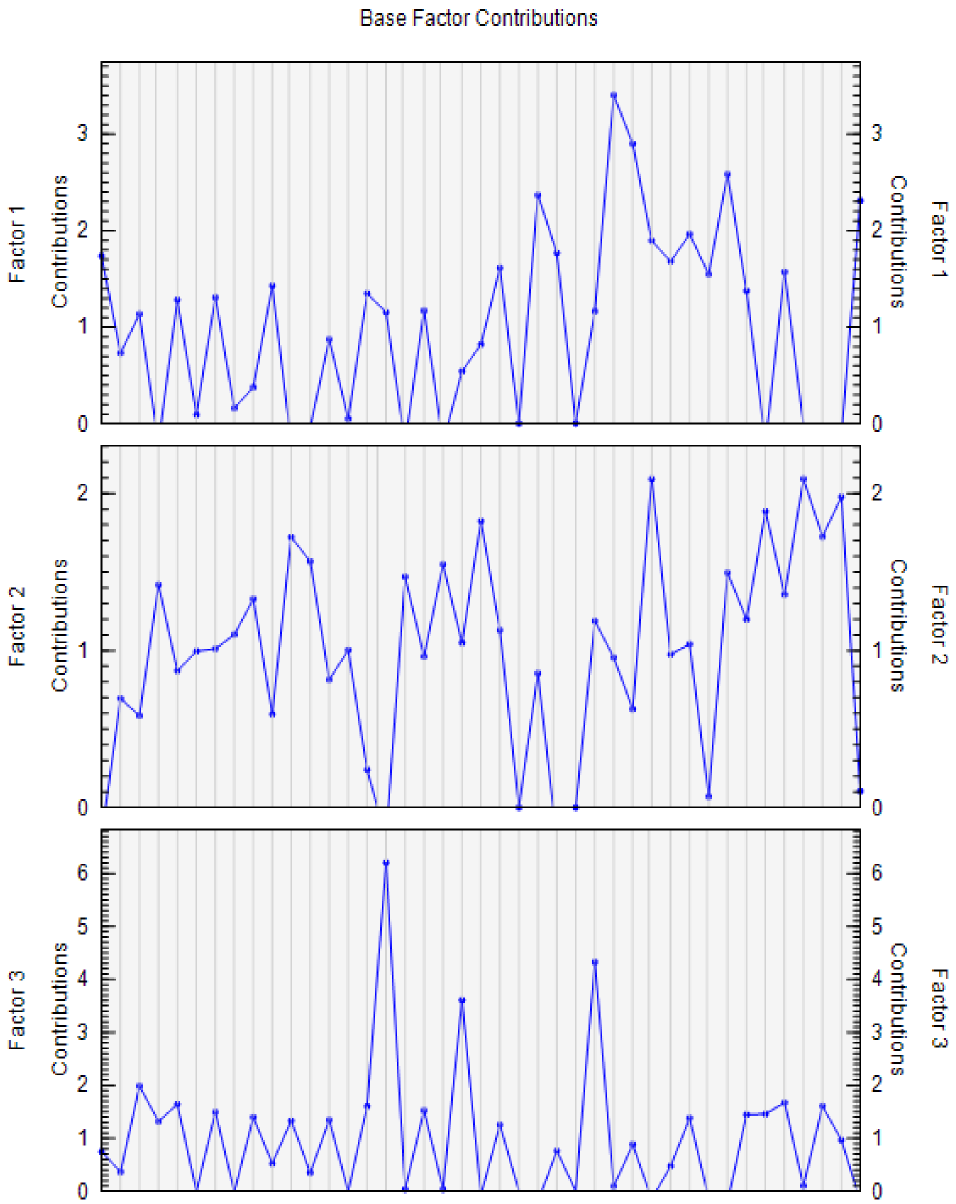


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

Factors	Predominant Factors	% Contribution	Factor Name
Factor 1	OC, SO_4^{2-}, NO_3^{2-}, Ca^{2+}, Na^+, Cl^-	21.16	Construction Dust/ Secondary Aerosols
Factor 2	OC, NH_4^{3-}, SO_4^{2-}, Mg, S	50.43	Industrial/Fossil Fuel Burning/ vehicular emissions
Factor 3	OC, Si, S, K, Mg, Na, P	28.42	Road or Crustal Dust/ Biomass Burning

4.5 Emission Inventory and Source Apportionment

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

The PM_{10} and $PM_{2.5}$ emission load estimated in emission inventory from vehicle tail pipe sources is around 154 and 66 kg/d, respectively. Among line sources, 56.6% emission load is from HDVs followed by LDVs (22.4%), 2 wheelers (11.3%), 3 wheelers (5.27%) and 4 wheelers (4.36%) respectively. There are in all 9 units at Chandrapur thermal power plant with a coal consumption of 36000 tonnes per day. Other than that large scale industry of wooden furniture, Dal Mills, Cold storages, Jam & Jellies, fabrication workshops etc are also located in Chandrapur. Coal TPP consumption is around 41935 TPD followed by FO, LDO (5 to 8 KL/day) and wood 5.5 TPD. Emission load 9 Units of TPP is around 15898 kg/d for PM_{10} and 6162 kg/d for $PM_{2.5}$, whereas SOx and NOx emission load is estimated as 800 and 160 kg/d.

As there are only 10 registered bakeries, operating on LPG and wood, the emission load of PM_{10} is (325 kg/day) and $PM_{2.5}$ (227 kg/day). The estimated emission load from crematorium is about 50 and 25 kg/d for both the fraction of PM, whereas CO is around 255 kg/d. There are about 1.22 lakhs registered LPG consumers as also kerosene consumption is also high 24000 litres for the year 2018. As coal is easily available people prefer to use chullha, where coal and kerosene as fuel in most of the houses of slum areas (88%). The emission load of 163 and 89 kg/d of PM_{10} and $PM_{2.5}$ respectively was estimated from domestic sector. As new construction and infrastructure development took place in Chandrapur city, 62 kg/d and 27 kg/d for PM_{10} and $PM_{2.5}$ was estimated from building sector. There are 106 hotels and restaurants, which gives emission of 33 and 14 kg/d from both the fractions of PM. Open eatouts emission are very low. The PM_{10}, emission load from all the sources of the city was calculated as 16689 and 6612 kg/d, out of which ~93 to 95% of load is calculated from Industrial Source, ~3 to 5% from Area Source and ~0.9 to 1 from Line Source.

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

With which, 3 factors were identified in the study location for PM_{10} and $PM_{2.5}$ samples. The highest factor contribution in both PM fractions is from mix sources as Industrial/ Fossil fuel burning /Vehicular emissions ie. is around 50 to 51%. The other factor in PM_{10} indicated as Crustal /Construction dust (23.74%) and Biomass/ Waste burning (25.44%), whereas in $PM_{2.5}$ tracers are Construction dust/ Secondary Aerosols (21.16%) and Road or Crustal dust/ Biomass burning (28.42%). Both source categories were found to be contributing almost the same for both PM_{10} and $PM_{2.5}$. These results are well corroborated with apportionment of particulate matter; considering nature and quantum of the activities that is carried out in and around the study area.

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Chapter 5
Source Dispersion Modeling

5.1 Introduction

Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by single or multiple sources. Air quality dispersion modeling has been undertaken with a view to identify the impact and the important sources on ambient air quality in Chandrapur 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 Chandrapur city, the emission from different sources like vehicular emission, crematoria, bakery, road side eatery, etc. are combined in their respective grid and area source emission in terms of $g/s/m^2$ is determined as input to the model.

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

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

5.3 Meteorological Data

Meteorological conditions play a vital role in transport and dispersion of pollutants in the atmosphere. WRF processed hourly meteorological data is generated and used AERMET, which estimates the surface and vertical profile of meteorology. The meteorological data is used in estimating the horizontal and vertical dispersion coefficient (σx, σy) from the estimated atmospheric turbulence. For this study, a meteorological domain of 25 km radius is considered which covers the entire Chandrapur city on its east side grids. Monthly windrose diagram is plotted and the same is shown in **Figure 5.1**. It can be seen that January to February is a period of very low wind with no predominant in wind direction. Persistent wind starts in March from west and becomes stronger in April, May, June with wind direction from west-north-west (WNW). The maximum wind speed during summer remains around 6 m/s. July bring monsoon wind, with wind speed up to 6 m/s. October to December are calm months with wind dispersed in all directions. 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 relatively higher wind speed where as for other months, the wind speed is relatively lower.

5.4 Modelling Domain & Results

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. There are five pollutant parameters, the dispersion of which is to be simulated. The regulatory limit value of all these parameters and their emission rate are different **(Table 5.1)**. Therefore, it is felt appropriate to simulate only one pollutant parameter, which is highest in emission rate along with corresponding regulatory limit value. If this particular pollutant parameter meets the regulatory requirement, all other.

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

Parameter	Regulatory Stand.[µg/m^3]	Area Emission	Industry Emission	Vehicle Emission	City Emission
PM_{10}	**100**	637	15898	154	16689
$PM_{2.5}$	**60**	384	6162	66	6612

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

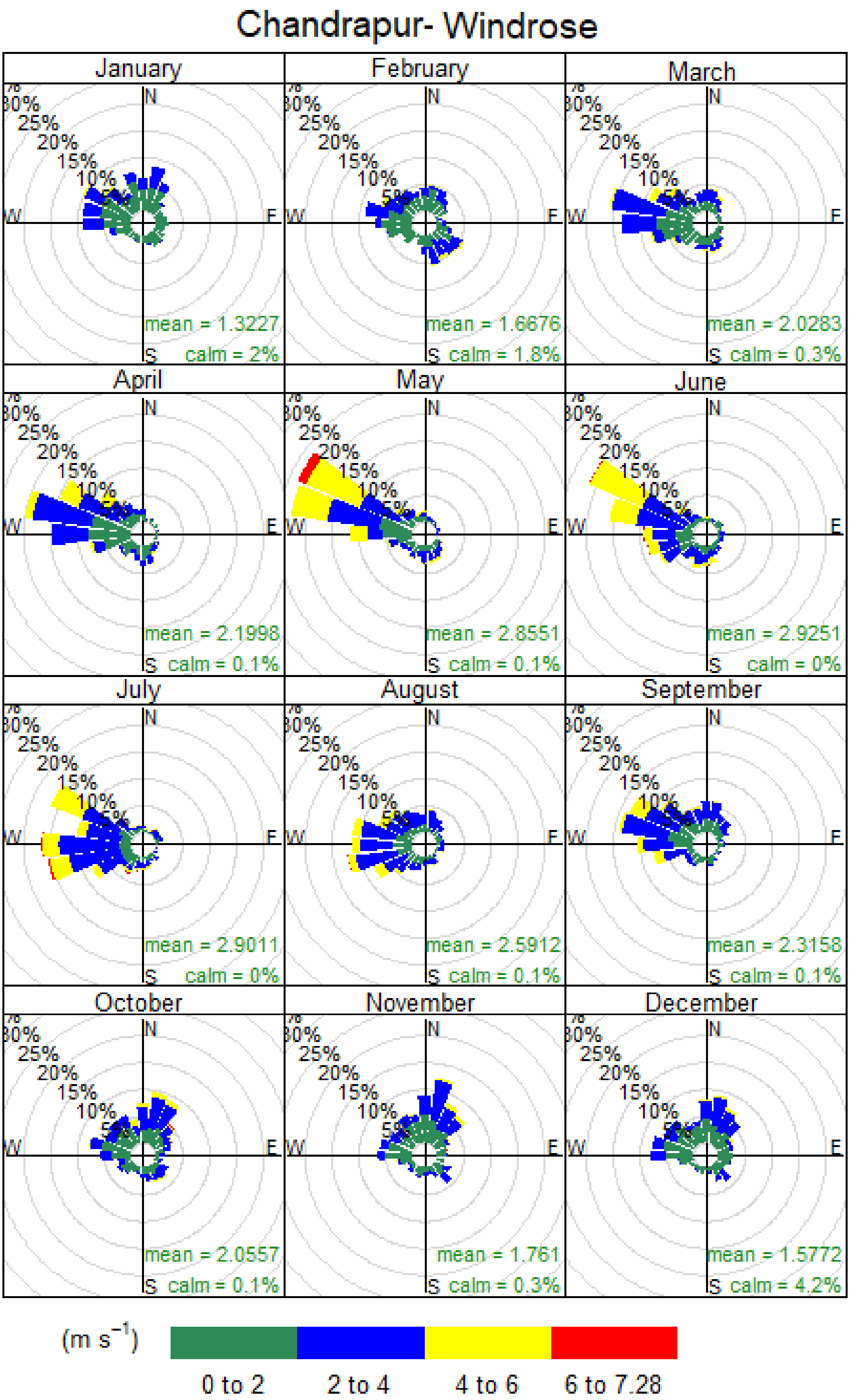

Figure 5.1: Monthly Wind rose Diagram of Chandrapur City

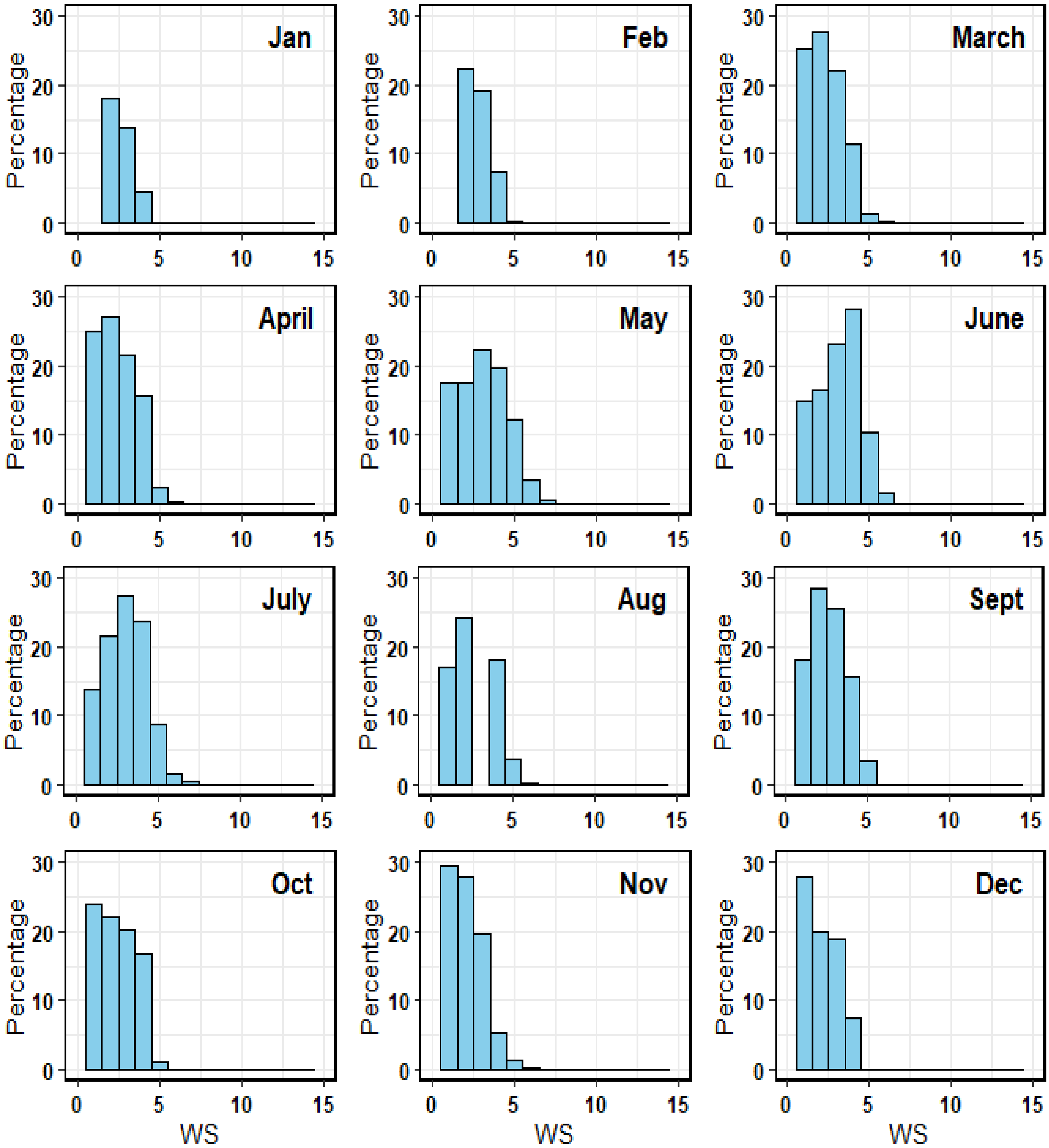

Figure 5.2: Monthly Wind Speed Frequency in Chandrapur City

5.5 Air Pollution Emission

Emission rate of air pollutant is determined and is used in dispersion modelling. Sources of emission is divided into two groups namely area source and elevated point source. Area source includes all sources that emit pollutants at ground level and elevated sources are of thermal power plant. Ground level concentration (GLC) of PM_{10} for both area source and point source is estimated together and is presented in **Table 5.2** and **5.3.** Grid over Chandrapur city, Area sources were identified and estimated for each grid as shown on map in **Figure 5.3.** Grid wise daily emission of PM_{10} from Chandrapur for area source is 790 kg/d and point source is around 28 kg/d.

Table 5.2: Area Source Emission in Chandrapur City

Type	ID	PM10	X1	Y1
		[Kg/D]	[m]	[m]
AREA	A4	21.38	313281.07	2209071.14
AREA	B3	0.01	315281.07	2211071.14
AREA	B4	58.73	315281.07	2209071.14
AREA	C3	19.51	317281.07	2211071.14
AREA	C4	40.00	317281.07	2209071.14
AREA	D4	23	319281.07	2209071.14
AREA	D5	51.31	319281.07	2207071.14
AREA	D6	26.79	319281.07	2205071.14
AREA	E1	26.00	321281.07	2215071.14
AREA	E2	0.31	321281.07	2213071.14
AREA	E3	14.00	321281.07	2211071.14
AREA	E4	27.00	321281.07	2209071.14
AREA	E5	22.00	321281.07	2207071.14
AREA	E6	43.00	321281.07	2205071.14
AREA	E7	6.08	321281.07	2203071.14
AREA	F4	6.23	323281.07	2209071.14
AREA	F5	36.64	323281.07	2207071.14
AREA	F6	167.29	323281.07	2205071.14
AREA	F7	138.00	323281.07	2203071.14
AREA	G5	63.50	325281.07	2207071.14
Total		**790.78**		

Table 5.3: Point Source Emission from Power Plant Stacks of Chandrapur City

Type	ID	PM10	X1	Y1
		[T/d]	[m]	[m]
POINT	UNIT_3	1.6848	320981.57	2213020
POINT	UNIT_4	1.6848	321026.19	2213086.91
POINT	UNIT_5	2.376	321186.57	2213183.51
POINT	UNIT_6	2.376	321247.9	2213266.88
POINT	UNIT_7	2.592	321335.12	2213365.57
POINT	UNIT_8	2.592	321112.08	2210771.25
POINT	UNIT_9	2.592	321112.08	2210771.25
POINT	DHARIWAL8	4.9248	312023	2213525
POINT	DHARIWAL9	4.9248	312027	2213529
POINT	GUPTA_ENERGY	2.592	304613	2204689
Total Point Emission		**28.3392**		

A scenario of area source emission and point source emission is considered and simulation carried out. Ground level concentration (GLC) of PM due to area and point source is shown in **Figure 5.4**. It can be seen that the maximum GLC of PM reaches 60 $\mu g/m^3$. In order to understand the impact of area and point source separately, two different scenarios of area and point source considered.

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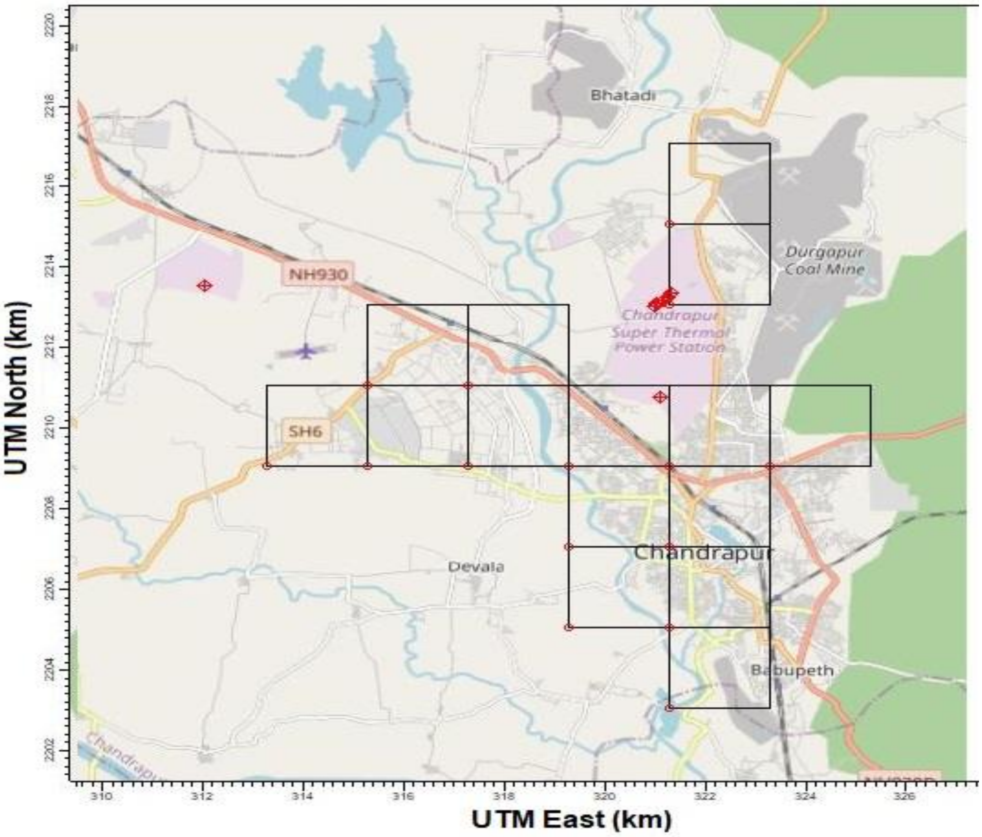

Figure 5.3 : Grid over Chandrapur City for Area Source Emission

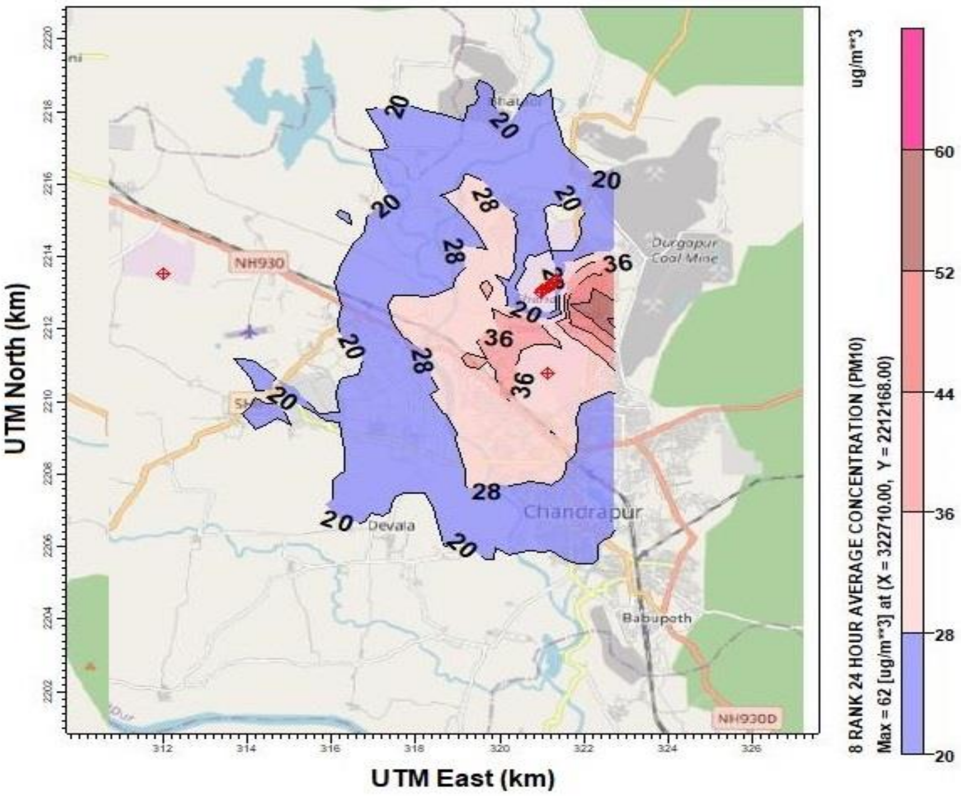

Figure 5.4 : GLC of PM_{10} in Chandrapur Determined by Simulation using AERMOD (Emission Source: Area + Point)

Figure 5.5 shows the GLC of PM due to area source alone in Chandrapur and it is found that due to small size anthropogenic sources, the GLC is above 16 µg/m^3. This indicates that the anthropogenic area source contribute very less in the ambient air PM levels. In this simulation, the re-suspension of road dust is not considered as its physical parameters are not measurable and certain. Management technique for road dust is known and if all road dust is removed ideally, the GLC of PM will be as predicted by the model.

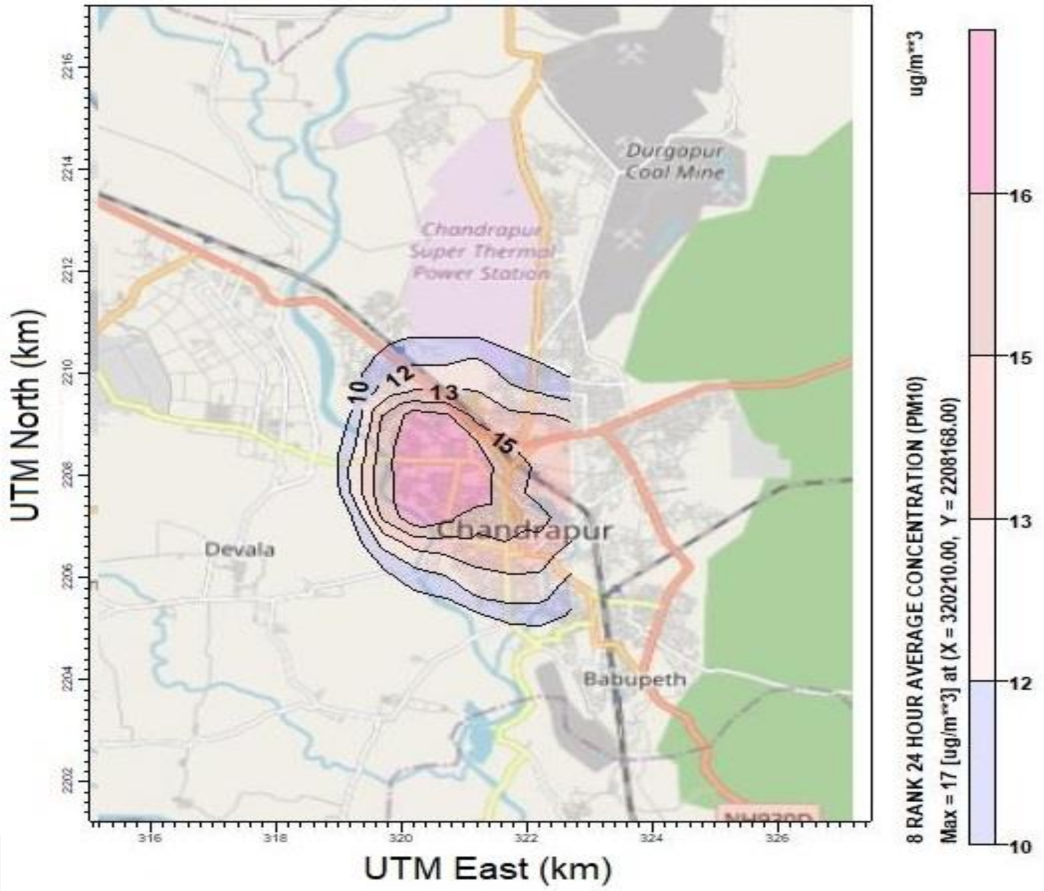

Figure 5.5 : GLC of PM_{10} in Chandrapur Determined by Simulation using AERMOD (Emission Source: Gridded Area)

Another scenario, wherein only the point source is considered, the GLC of PM is determined and is shown in **Figure 5.6**. It can be seen that area near TPP has higher levels of PM up to 60 µg/m^3, which is also found when both the area and point sources were considered.

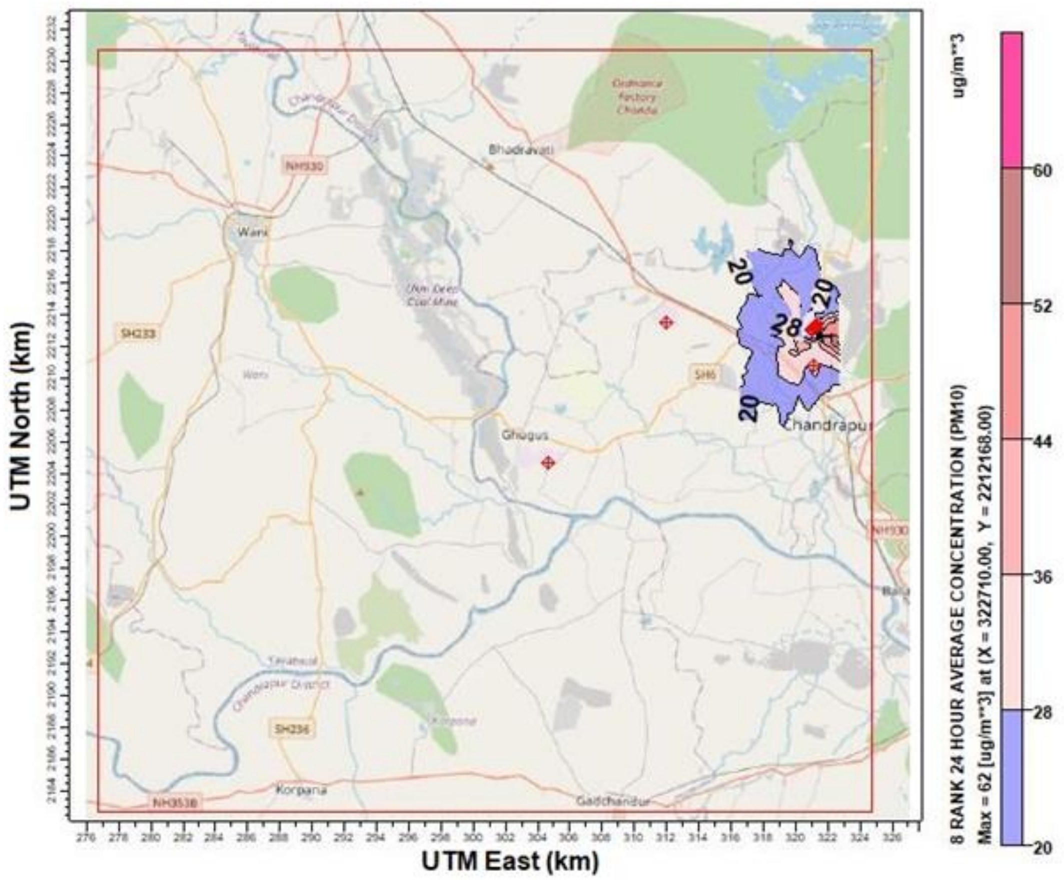

Figure 5.6: GLC of PM_{10} in Chandrapur determined by simulation using AERMOD (Emission Source: Elevated Point Source - TPP).

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Chapter 6

Action Plan for Control of Air Pollution

6.1 Emission Reduction Action Plan for Chandrapur City

Major source of air pollution in Nagpur city is:

- Industrial Emission
- Vehicular emission

Minor emission is from

- Road dust re-suspension
- Area Source
- Unmanaged Solid Waste

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

Table 6.1 : Action Plan to Control Emissions from Various Sources

Control Option	Action	Responsible Agencies
Vehicular Emission		
Launch extensive drives against polluting vehicles for ensuring strict compliance	Monthly special drive at toll plaza for random checking of PUC for vehicles.	RTO
No heavy duty vehicle traffic through city	Prompting use of by-pass road to avoid entry of heavy vehicles in the city. Major haul trucks with heavy loads should not pass through the main city. The plan being made should be implemented in next 1 - 1.5 years.	RTO, PWD
Overloading of vehicles to be stopped	Online checking when vehicles leave industries with their guarantee that the vehicle is not carrying more material than its designated loads. All commercial vehicle carrying coal, cement etc. must get tagged with user industries.	RTO, WCL, Concerned Industry
Regular Inspection & Maintenance Programme	Set up a mechanism of Inspection and Maintenance programme for all vehicles in the district through automated system assessment. The I&M center shall also test all vehicles for their inbuilt emission tests.	RTO
Phasing out polluting engines and vehicles beyond a fixed period of use	All commercial vehicles should be phased out after 8yrs of age or subjected to two years extension after rigorous I&M tests. All private vehicles should be subjected to proper assessment and fitness tests through I&M centers. All autos and buses shall also be subjected to I&M tests.	RTO
Designed place for truck parking and maintenance related activities.	A separate designated place should be allocated to prevent illegal parking and repair shops on the roads and kerb side.	CCMC, RTO
Public transport Improvement	Public transport improvement needs to be undertaken on urgent basis. There is a need of at least 75 additional buses in additional to industrial transport systems being made available by industries for its workers.	CCMC

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Table 6.1 (Contd..) : Action Plan to Control Emissions from Various Sources

Control Option	Action	Responsible Agencies
Vehicular Emission (Contd..)		
Pilots on Bioswale for dust reduction	Bioswale design and implementation for roadside improvement of dust control	CCMC
Road Design for improved traffic management	Current Road Design makes the kerb side open and that leads to illegal movement of vehicles. The future road and kerb side design must take into account the method wherein the kerbside is completely made inaccessible for vehicle plying. This would help prevent dust entering on to the road.	CCMC
Industry Emission		
Use of high quality coal	Power plants in Chandrapur region should be allowed to use high quality Coal (low ash). The units connected with the low stack height should not be allowed to operate on high ash containing coal. The other units of CSTPL can use high ash coal, however, their ESP system need to meet the load of PM.	MPCB, CTPS, Other Power Plants
Proper use of PM reduction actions such as ammonia dosing	Use of ammonia emission has been of limited use and the data indicates it is not based on PM load and corresponding loads. The ammonia dosing is primarily done on preliminary estimates but the same cannot be checked and verified.	MPCB, CTPS, Other Power Plants
Ash bund management	Ash bund management of the CSTPL is very poor resulting in spillage of the ash pond and pollution of water courses and natural drains. The same should be completely revamped as minor repair and maintenance carried out after every incident has not been very effective.	MPCB, CTPS, Other Power Plants
Data triangulation	The air pollution control units, data triangulation method through audit process wherein all data sources and measurements are seen together to assess the efficiencies.	MPCB, RTO, WCL
Use of Dust suppression chemicals for Loading of vehicles/wagons	Trucks carrying coal must be loaded within the carriage area and after it, a chemical dust suppression spray should be carried out to prevent dust particle getting blown away due to wind effect during transportation. This technique can also be used on railway wagons after the loading has been done. There is a need to undertake a pilot for a particular mine area completely and compare the same with other mine, so that it can be replicated.	MPCB, RTO, WCL
Converted trucks for coal transportation	The average trucks carrying the coal must be converted gradually to closed system so that on road spillage can be avoided. These designs need to be implemented at the earliest as the open truck with tarpaulin cover has limited efficiency.	MPCB, RTO, WCL
Overburden Management	Implementation of DGMS rules for new dumps	MPCB, WCL
Stabilization of Old OB dumps	For old dumps, slope stabilization and Plantation	MPCB, WCL

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Table 6.1 (Contd..) : Action Plan to Control Emissions from Various Sources

Control Option	Action	Responsible Agencies
Industry Emission (Contd..)		
Air Pollution Control Equipment Assessment	The air pollution control units assessment should be carried out with proper data triangulation method through audit process wherein all data sources and measurements are seen together to assess the efficiencies. This assessment should be carried out through third party and appointed independently by MPCB to avoid any conflict of interest.	MPCB, Cement Industries
Air Quality Prediction	A fine grid air quality management model for cement should be set up to predict PM and NOx, based on real term emission which shall come from its data feed of stacks emissions. This model should be aligned with MPCB and a public domain to share the information to all.	MPCB, Cement Industries
Material Handling for Dust reduction	Fugitive dust emission control could be achieved through site specific analysis and assessment of each plant. Proper Loading unloading and specific parking areas for trucks.	MPCB, Cement Industries
Road Cleaning	Once every week, all the internal haul roads as also 2 kms radius roads should be cleaned either mechanically or through water sprinkler. Since the region is water scarce, they can use treated domestic water.	Cement Industries
Re-suspension Dust		
Road Dust reduction	Blacktopping of metaled roads including pavement of Road shoulders	CCMC, PWD
Concrete Roads	More concrete Roads to be made in the city with planning of over 50% main roads to be concretized	City Engineer CCMC, PWD
Reduction in Fugitive dust at Construction Site	Proper onsite provisions for avoiding dust created such as sprinkling of water. Use of RMC instead of instant concret.	CCMC
Area Source		
Promotion of LPG to stop use of coal	Increased use of LPG through promotional scheme.	CCMC, Industries through CSR
Improved Chulahs	Actions for prohibiting use of low calorific fuels in the house holds for unavoidable low calorific value fuel usage providing smokeless chulhas (certified by MNRE) for a limited period till use of such fuels is completely stopped.	CCMC, Industries through CSR, MPCB
Improved fuels for Crematoria	Currently either wood or kerosene is used, use of electric fired crematoria to be promoted	CCMC
Cleaner fuel for hotels and Dhabas	Hotels and dhabas need to be educated and compulsorily asked to use LPG for its cooking purposes. Registration of all eatouts.	CCMC, MPCB
Improved combustion devices	Use of the efficient tandoors can be made compulsory for restaurants and hotels. Improved ovens for bakeries.	CCMC, MPCB

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Table 6.1 (Contd..) : Action Plan to Control Emissions from Various Sources

Control Option	Action	Responsible Agencies
Biomass Burning		
Segregation and Collection of MSW	About 143 T/day of MSQ. Segregation is initiated. Segregation of waste need to followed strictly	City Engineer CCMC
Composting	Composting plant capacity 50 MT/day	City Engineer CCMC
Household composting to community level	In each wards some household composting pits are created in un-scientific manner, a guideline to be issued by Municipal Corporation for household composting plants.	Public, Ward Members, CCMC
Bio-gas Plant at MC	For segregated waste installation of Bio gas plant of capacity of 30-50 MT/day may be considered	CCMC
Community level Biogas plants	Biogas plants for vegetable markets, function halls etc.	Community CCMC
Reduction of the trash and MSW burning	Prohibitory actions for stopping open air trash burning and awareness programmes.	MPCB

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 Chandrapur Municipal Corporation, 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, Traffic police and District Administration and other with different stakeholders. Maharashtra State Pollution Control Board shall regularly review the implementation of aforesaid action plan.

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Annexure – I

Design of a Clean Tandoor Community Kitchen System (CTCKS)

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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

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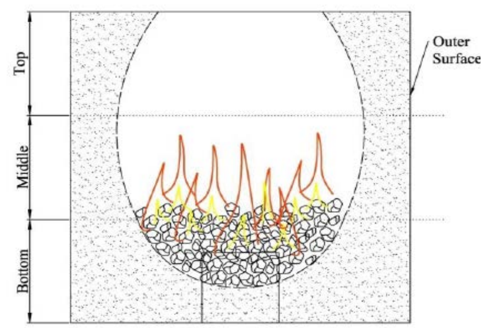
was present in over 90% of the surveyed restaurants thus showing least concerns on emission exposure. It was also observed that, the quantity of fuel used varies from 5kg to 40kg per day. Cost of the fuel lies in the range of Rs.20-40 per kg of coal (>70%). Over 41% of the tandoors were ignited in the 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

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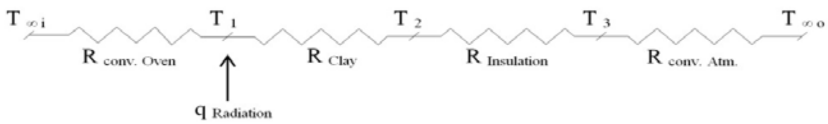
Eq. (1) and Eq. (2).can be given as:

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



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

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

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

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

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

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

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

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

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

Design of Forced Draft Stove

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

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

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

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

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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

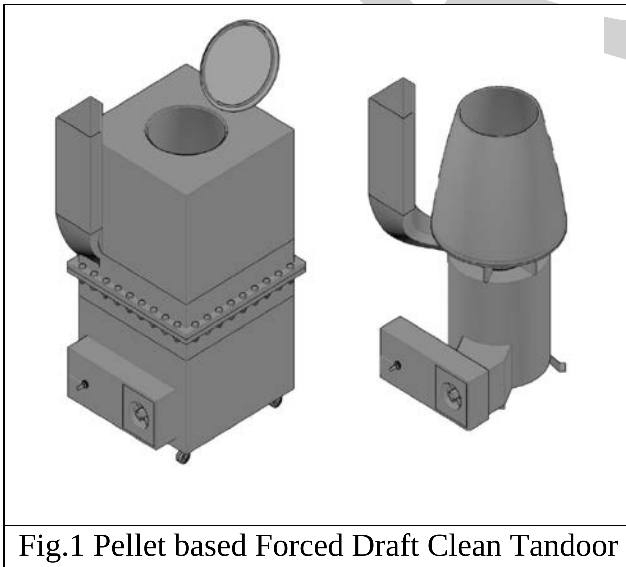

Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing

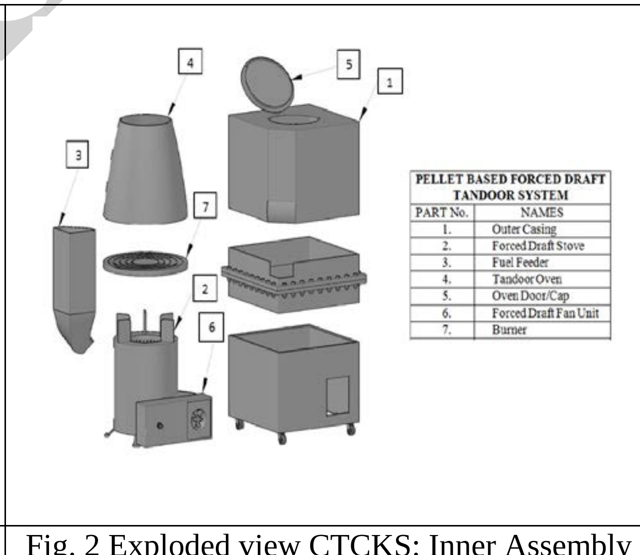

Fig. 2 Exploded view CTCKS: Inner Assembly & Outer Casing

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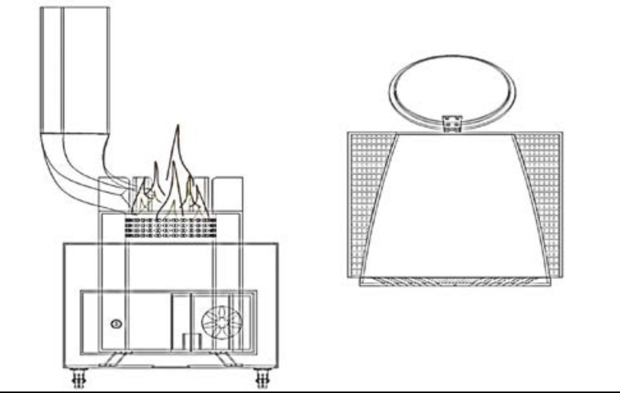
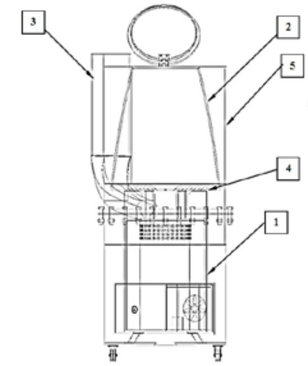
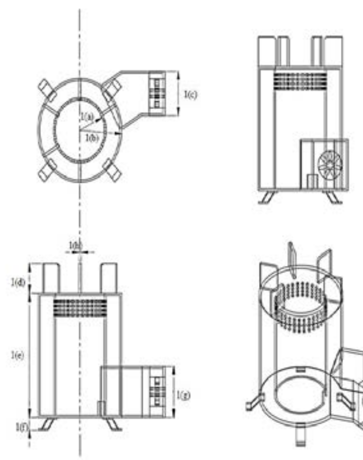


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)



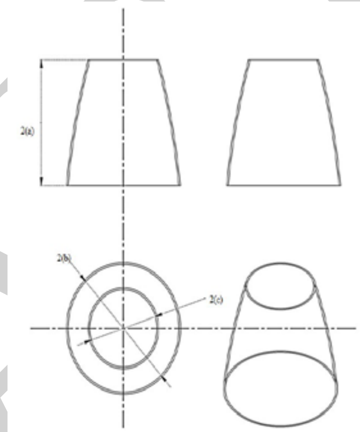
PELLET BASED CLEAN TANDOOR COMMUNITY KITCHEN SYSTEM	
PART No.	NAME
1	COOKSTOVE
2	OVEN
3	HOPPER
4	BAFFLE PLATE
5	CASING

Fig. 4 Line diagram of CTCKS



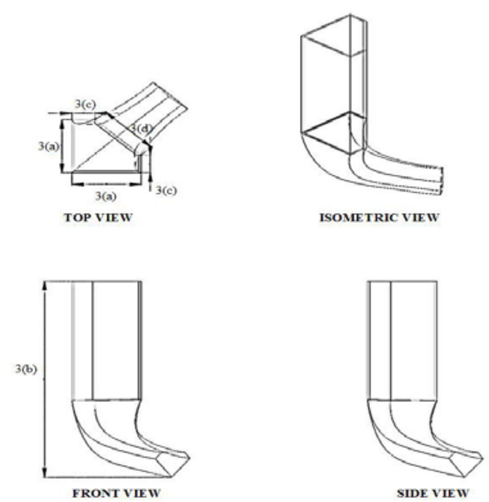
Part. No.	Dimensions (mm)	
3.15	a	170
	b	250
	c	80
	d	50
	e	400
	f	40
	g	80
	h	4

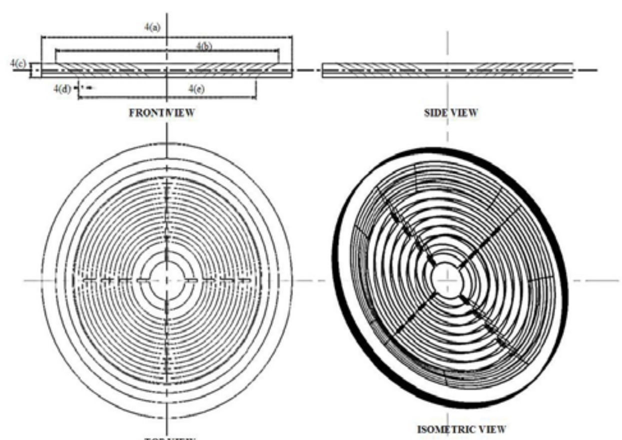
Fig. 5 Child Parts of CTCKS: Cookstove



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

Fig. 6 Child Parts of CTCKS: Oven



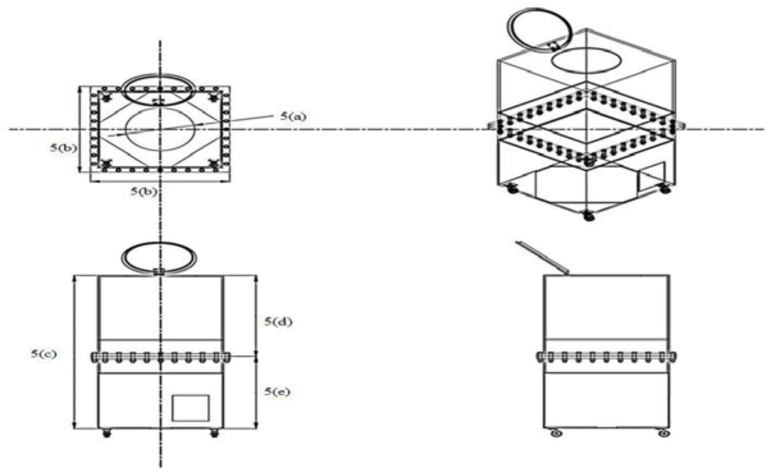


Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

Fig. 7 Child Parts of CTCKS: Hopper

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

Fig. 8 Child Parts of CTCKS: Baffle Plate



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

Fig. 9 Child Parts of CTCKS: Casing

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

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

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

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

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

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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

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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

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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.

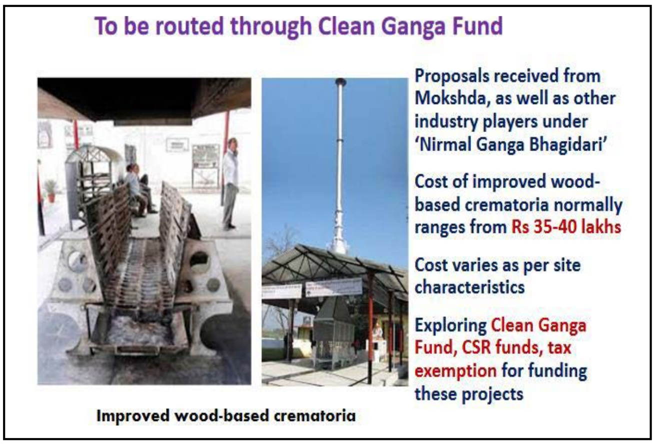
There has always been a controversy on the use of the electric crematoriums due to rituals as most persons follow the traditional burning of the bodies. In metropolitan cities it is promoted by the Government, private NGOs and environmentalists, but not to a great extent and most of these have failed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

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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)**.

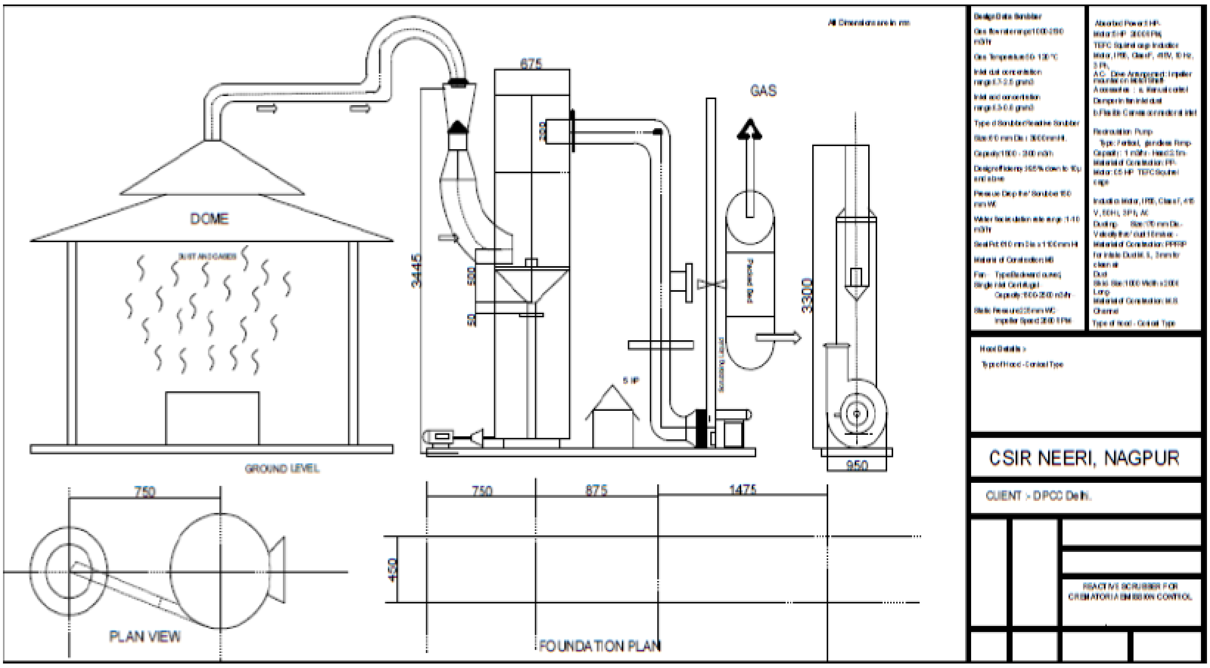

Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

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

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reduces these emissions to less than 350-400 mg/m^3. The ability to control solids loading in the scrubber liquid was also accomplished in this scrubber. The advantages of using this type of separation device are its compact size, low equipment cost, as it is constructed entirely of MS that can tolerate the corrosive nature of the scrubber solution. Tests done with a various oxidizing agents like with lime showed that the scrubber was able to remove nearly 70 percent of the particle matter along with acidic gases. The Velocity and temperature profile studies were undertaken around the cremation site during burning process as per **Figure 2**.

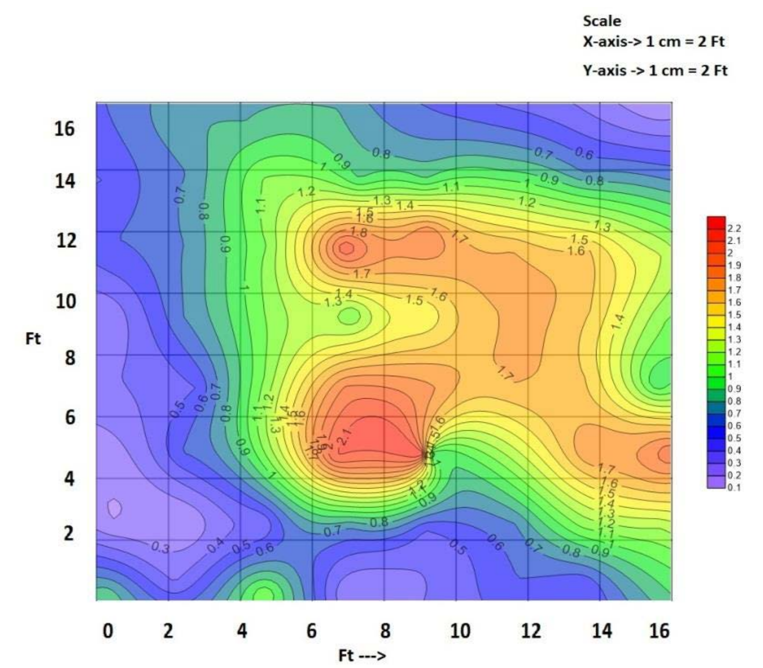

Figure 2 : Velocity profile of fumes during cremation

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

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

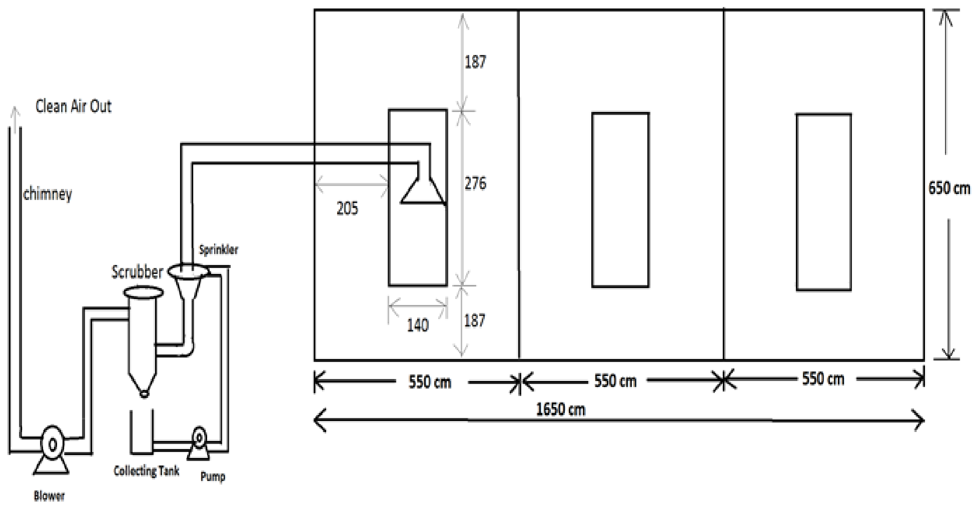

Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

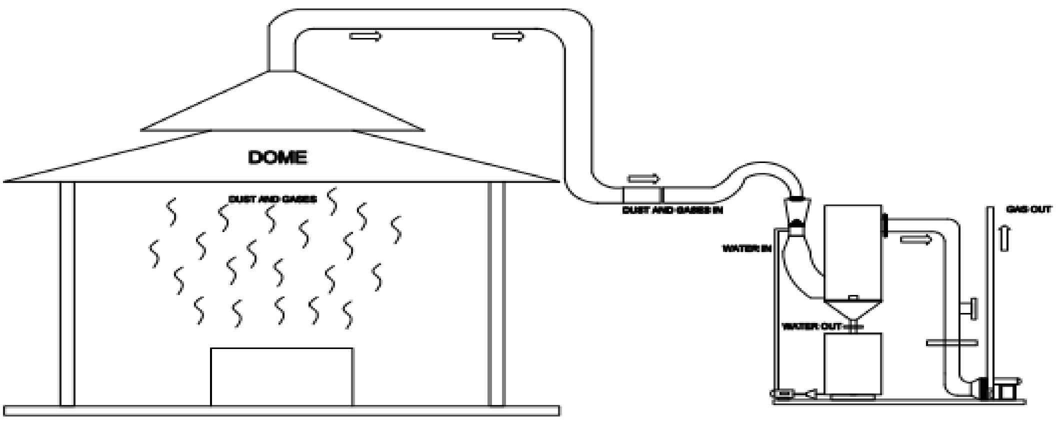

Figure 4 : Schematic view of Air Pollution Control System

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

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

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

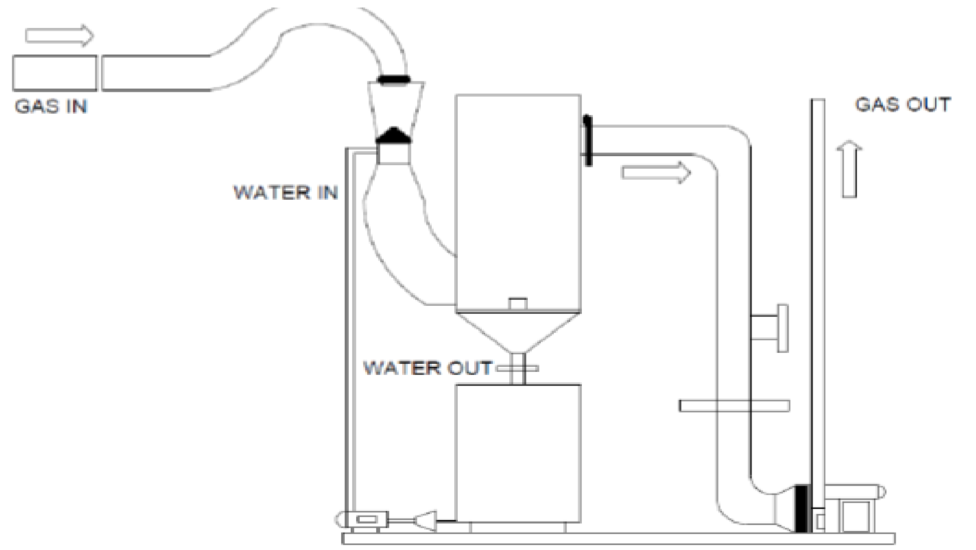

Figure 5 : Schematic of Reactive Scrubber

Gaseous Emission Control System

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

Design of APC System Emission capture system

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

The canopy hood volume is expressed by the following equation:

Hood Volume = T_d (Qp-Qs) Where,

T_d = duration of plume surge (s)

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

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

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

Where:

DC = column diameter at hood face.

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

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

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

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

Where:

DS = diameter of hot source, ft

Emission control system

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

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

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

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

d_d = droplet diameter, m

μg= gas viscosity, ($msec^{-1}$)

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

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

L & G are liquid & gas densities.

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

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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.

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Annexure – III

Design of Passive Gas Venting System for Landfill Sites

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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.

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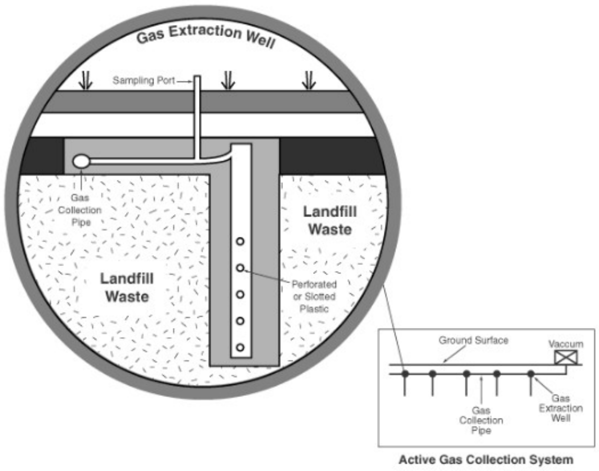
Active Gas Collection System

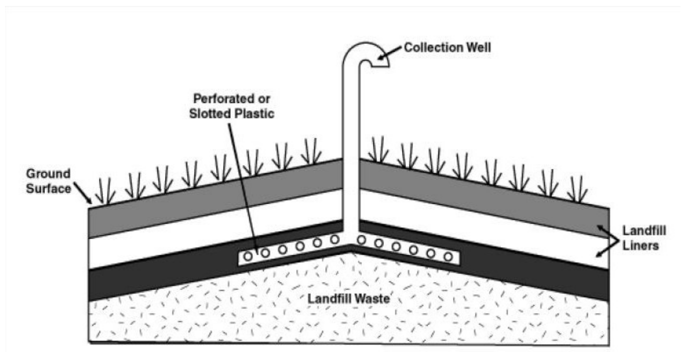
Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however,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

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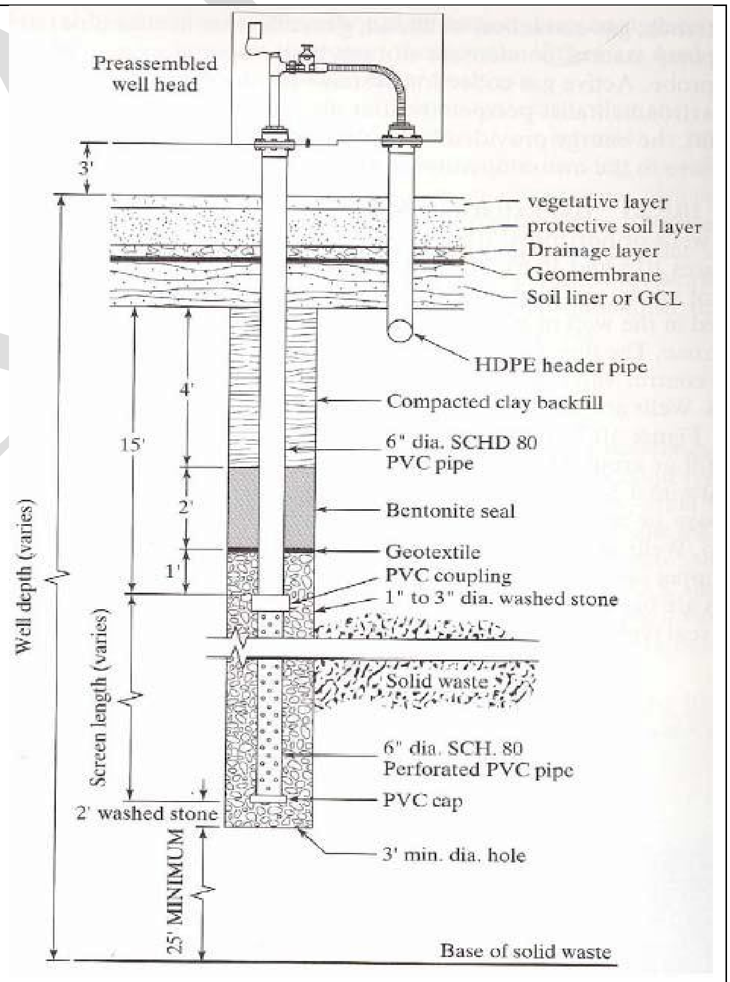
groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill as shown below. Horizontal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

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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.

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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.

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Annexure – IV

Dust Control Measures

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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).

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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)

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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

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- Normana, M., Johanssona, C. 2006. Studies of some measures to reduce road dust emissions from paved roads in Scandinavia, Atmospheric Environment 40, 6154–6164.
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- 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).

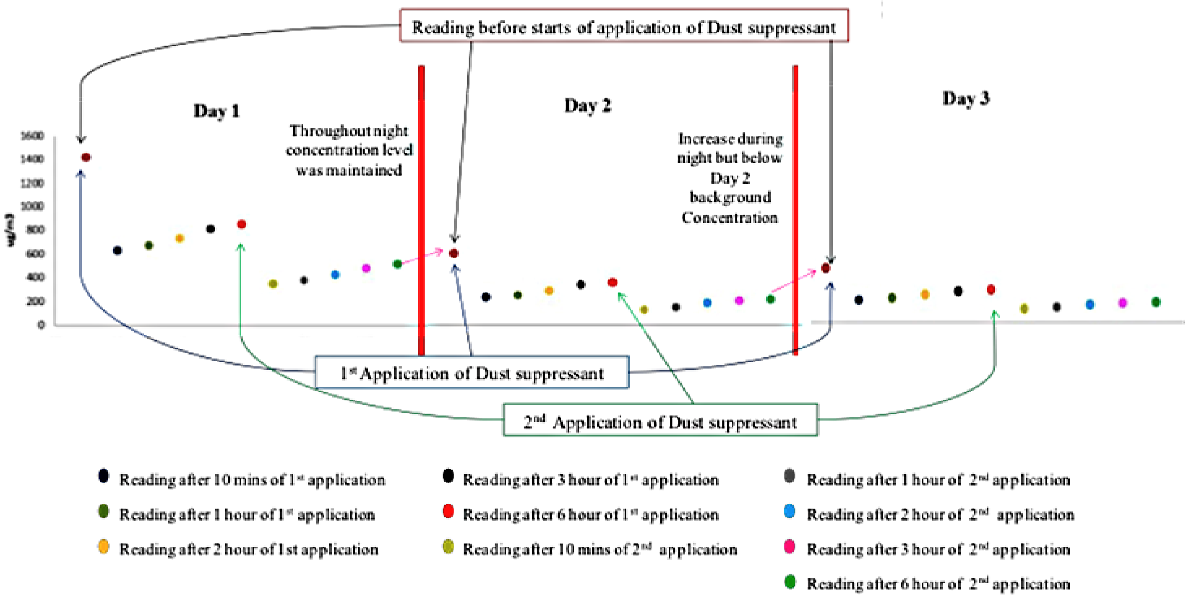
Advantages

- 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.



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Bioswale : System for Storm Water and Dust Suppression Road Side

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

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

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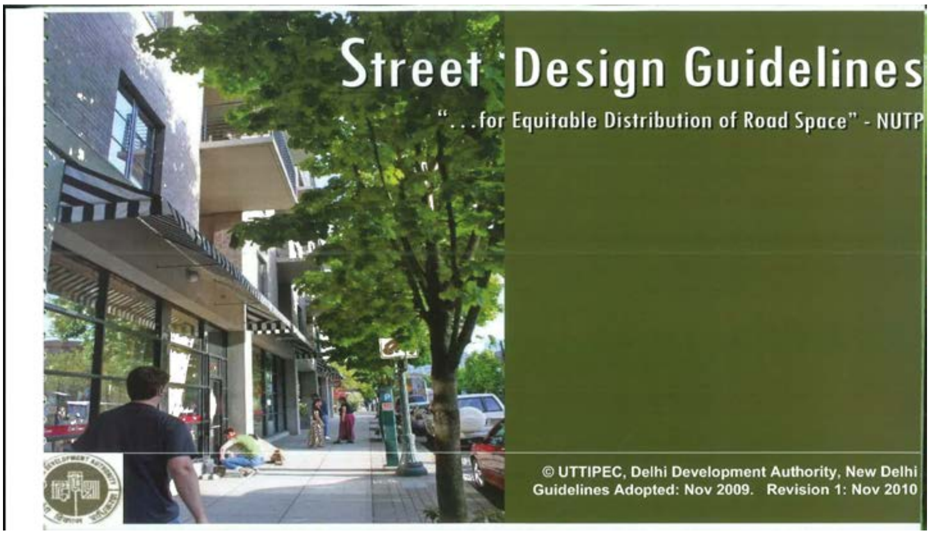
Building construction/demolition codes need to be used with specific reference to PM control. **UTTIPEC design manual has been recently created by Delhi Development authority for uniform roadside, drains, footpath and related design.** The same should be adopted for all future design for roads and pathways.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

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



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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

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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.

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- 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.

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Annexure – V

Wind Augmentation and purifYing Unit (WAYU)

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‘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

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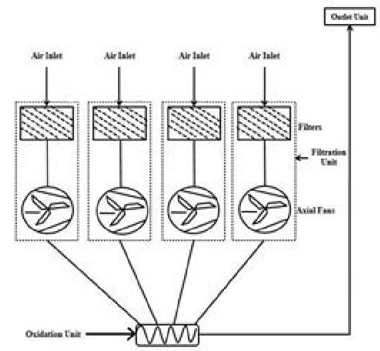
Air pollution is a local problem and its solution can be derived from technologies coupled with local conditions and requirements. Creating change in meteorological parameters like wind with the help of devices such as fans and also removal of the pollutant near to the source may help in reducing ambient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



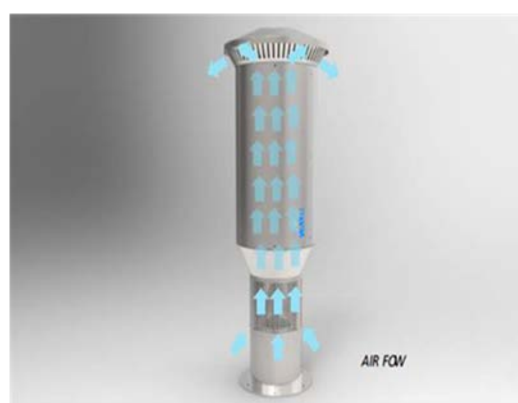
UV- TiO2 adsorption-photocatalytic oxidation has a lot of advantages. They are very efficient in removal of VOCs. Pichat et al. (2000) have shown that ozone can be directly eliminated by TiO_2 nanoparticles in a process that is promoted by both heat (in the ambient temperature range of 0° to 50°C) and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

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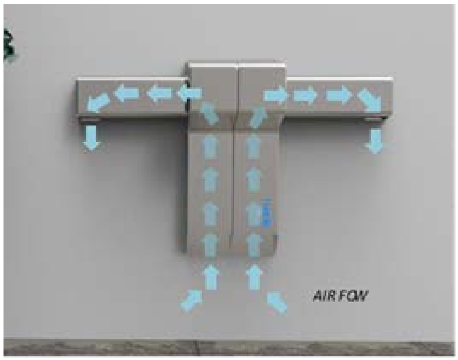
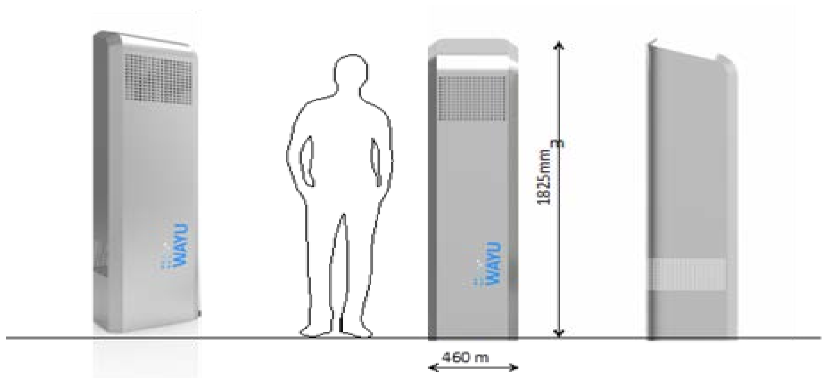


Wall mounted/ Flyover Design

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.

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.



Bus shelter design

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.

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