Draft Report On

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

(SOLAPUR CITY)

for

Maharashtra pollution Control Board

By

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CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ANNEXURES

Chapter 1
Introduction

1.1 Preamble

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

1.2 Background of the Study

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

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

1.3 Objectives

- To measure baseline air pollutants (particulate matter) in different parts of the city which includes hot-spot and kerb-sites.
- Inventory of all types of emissions from the city.
- To conduct Source apportionment study for particulate matter.
- Air Pollution reduction action plan.

1.4 Scope of the Project

- All sources of air pollution emission inventory estimation to be carried out.
- Monitoring the air quality of the city for a period of 10 days, which includes locations such as residential, commercial, outskirts and sensitive areas.
- On each station 24 hrs average data will be considered as air quality monitoring data for continuous 10 days of sampling.
- Actual meteorological data must be obtained from weather monitoring stations and must be analyzed for dispersion modelling exercise.
- The data will be analyzed for preparation of emission inventory in the city.
- Source apportionment analysis will be carried out for Particulate matter using appropriate model. For this purpose relevant detail pertaining to the city will be gathered.
- For dispersion model exercise, model such as AERMOD or ISCST3 will be used based on different scenario and conditions.
- Receptor modelling exercise will be carried out for source apportionment. The particulate matter filter samples will be 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.

1.5 Background of City

Solapur located in the south-western region of Maharashtra at (17.68°N 75.92°E) on major road and rail routes between Mumbai and Hyderabad, with a branch line to the cities of Bijapur and Gadag in the neighbouring state of Karnataka. Please refer **Figure 1.1** for relative location. It is situated on the Deccan plateau and has an average elevation of 458 metres (1502 feet).

Gulbarga district is to the southeast of Solapur while Bijapur District to the south, Sangli district to the southwest; Satara district on the west, and Pune district on the northwest. It is bordered by Ahmednagar district on the north; Osmanabad district on the north and northeast. It is situated at a distance of 410 km (250 mi) from the Maharashtra State Capital: Mumbai. Solapur is at a distance of 245 km (152 mi) from Pune and 305 km (190 mi) from Hyderabad. 'Solapur' is believed to be derived from the combination of two words: 'Sola meaning "sixteen" and pur meaning "village". The present city of Solapur was considered to be spread over sixteen villages viz. Aadilpur, Ahmedpur, Chapaldev, Fatehpur, Jamdarwadi, Kalajapur, Khadarpur, Khandervkiwadi, Muhammadpur, Ranapur, Sandalpur, Shaikpur, Solapur, Sonallagi, Sonapur and Vaidakwadi and all these villages are now merged with Solapur Municipal Corporation.

The present Solapur district was previously part of Ahmednagar, Pune and Satara districts. In 1838 it became the Sub-district of Ahmednagar. It included Barshi, Mohol, Madha, Karmala, Indi, Hippargi and Muddebihal Sub-divisions. In 1864 this Sub-district was abolished. In 1871 this district was reformed joining the Sub-divisions viz. Solapur, Barshi, Mohol, Madha and Karmala and two Subdivisions of Satara district viz. Pandharpur, Sangola and in 1875 Malshiras Sub-division was also attached. After the State reorganisation in 1956 Solapur was included in Bombay State and it became a full-fledged district of Maharashtra State in 1960. It is classified as a 2 Tier and B-2 class city by House Rent Allowance (HRA) classification by the Government of India. It is the 49th most populous city in India and the 43rd largest urban agglomeration. **Figure 1.2** shows the city with 2 Km x 2 Km grid.

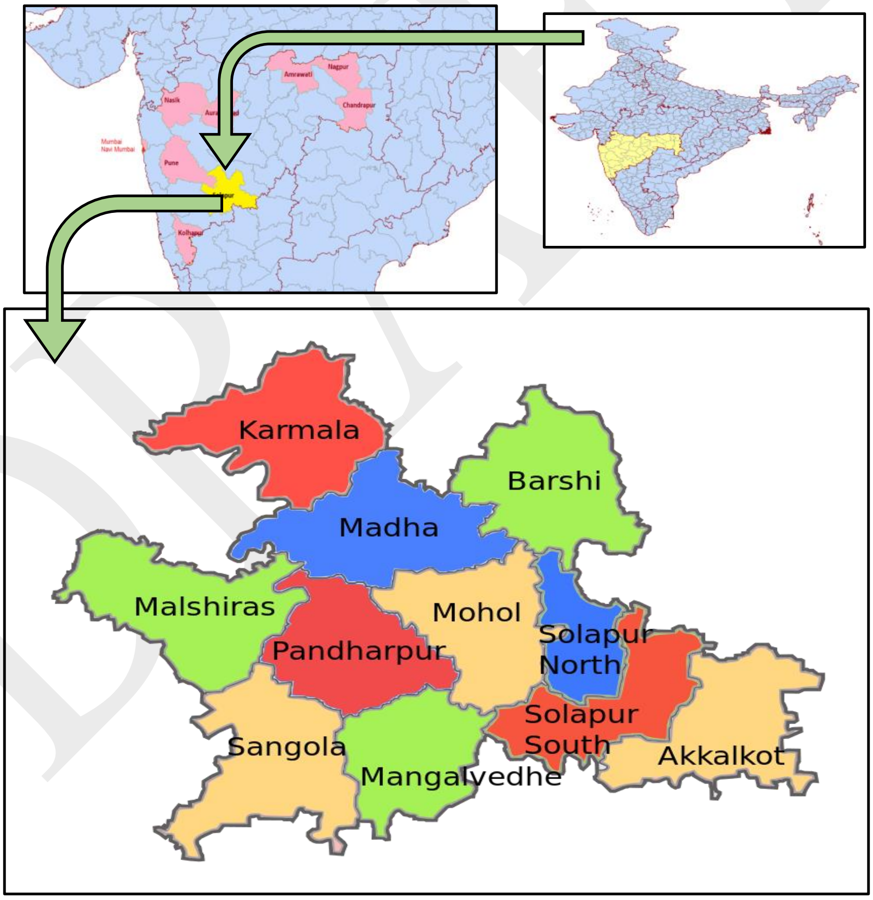


Figure 1.1 : Location of Study Area – Solapur City

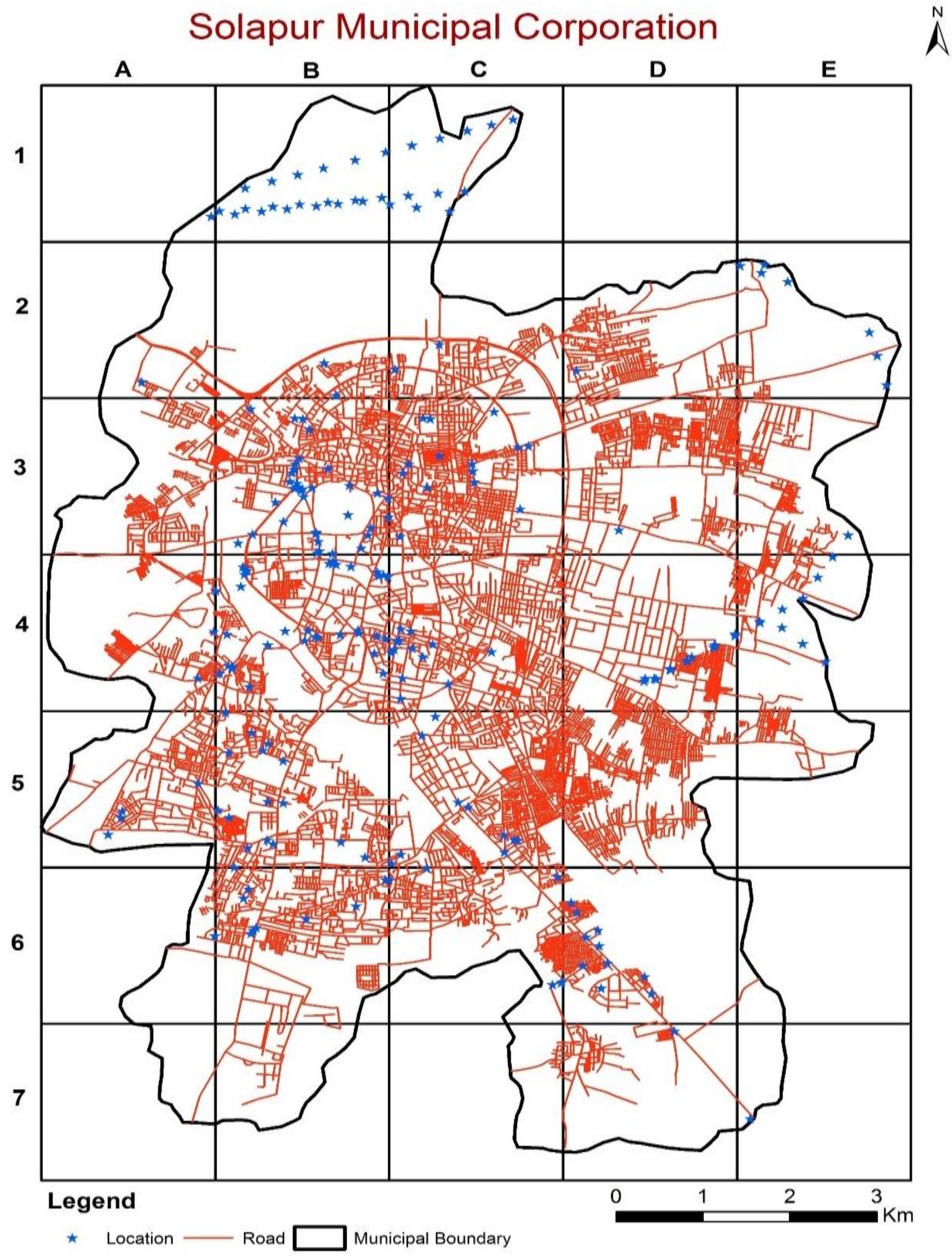


Figure 1.2 : Gridded Solapur City

1.6 Population

Solapur with an area of 178.6 Sq. Km has a population of 951,118, as per 2011 census. The demographic details are as follows:

Population	Total	Male	Female
City	951,558	481,064	470,494
Slum	266232	-	-
Literates	82.80 %	89.62 %	75.88 %
Sex Ratio		978 (Male to Female)	

Presently there are 41 villages and 1 town in Solapur. The literacy rate of Solapur district is 82.80 %. The economy of the district is mainly depended on Agriculture 63.0 % of the total workers are engaged in primary sector.

Ward wise population of Solapur in ascending order is given in the following **Table 1.1** and **Figure 1.3**. The minimum population of ward No. 25 is 27884 and maximum is 41077 of ward No. 6. Average population of all the 28 wards is 36599, with a standard deviation of 3184 persons. This suggests that the population is more or less uniformly distributed in equal size wards. There is no denser population set up at Solapur, thereby indicating that the commercial activities are not very prominent in the city, thereby not letting air pollutant built up. If ward-wise area is made available, population density can be determined that may give better picture of socio-economic distribution.

Table 1.1 : Ward wise population in Solapur City

Ward No.	Total Population	Ward No.	Total Population
1	37955	14	36135
2	34603	15	37844
3	38715	16	34651
4	33681	17	37226
5	33869	18	35555
6	41077	19	34893
7	37273	20	36283
8	39086	21	40696
9	37409	22	41032
10	34150	23	40842
11	35064	24	40723
12	36783	25	27884
13	37320	26	30809

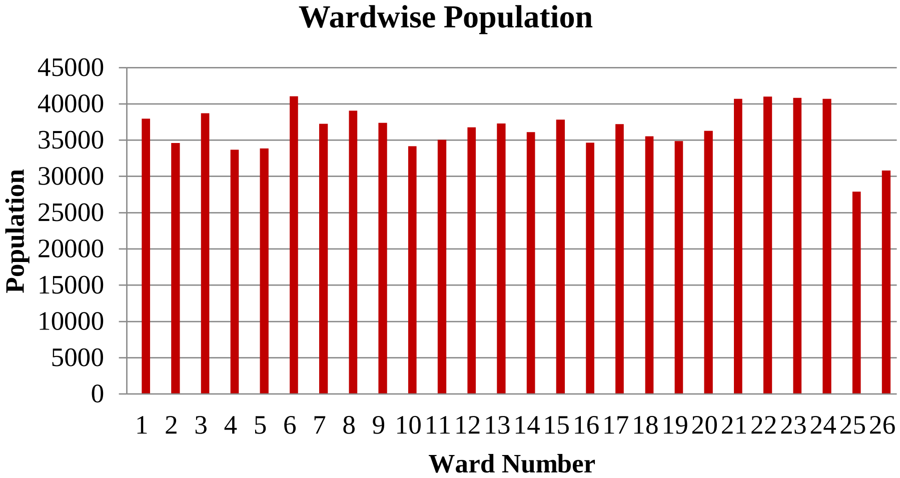


Figure 1.3 : Ward-wise Population in Solapur City

1.7 Industry

Solapur leads Maharashtra in production of Indian cigarettes or beedi. Solapur district has the highest number of sugar factories (total 33) in Maharashtra state as well as in India. These sugar mills are away from the district head quarter thereby not polluting the urban air environment.

Solapuri Chadars (Bedsheet) and towels colouring, dying industry are famous in India and also at a global level, however there has been a significant decline in their exports due to quality reasons. "Solapuri Chadars" are the famous and first product in Maharashtra to get a Geographical Indication tag. It has been a leading centre for cotton mills and power looms in Maharashtra. Solapur had the world's second-largest and Asia's largest spinning mill. All these colouring and dying industries use hot water for colour mixing and application.
The National Research Centre on Pomegranate (NRCP) of India is located in Solapur and pomegranate farming is done on a large scale in Solapur District. The Science Centre in Kegaon (Solapur) is the third largest and prominent scientific association in Maharashtra. The Raichur-Solapur Power Transmission line of 765 kV power capacity suffices the power grid accessing need of the southern states of Karnataka and Andhra Pradesh. The first waste-to-energy electricity plant in Maharashtra is situated in Solapur.

In light of the relatively good ambient air quality trend over a decade in Solapur, the socio-economic condition needs to be assessed. Relatively good air quality in Solapur may also be considered as an indicator of low economic growth as clean industry like Information Technology, Business Process Outsourcing (BPO) etc. are not expected to come up in Solapur due to scarce availability of human resource. Industries that does not require high end of technology thereby demanding large manpower can only come up in Solapur. Such industries and associated population, its transportation can only pollute the ambient air of Solapur. Good air quality indicates low economic growth, or large horizontal clear space availability, or high technological industrial development. Details of workers in Solapur city is given in **Figure 1.4**.

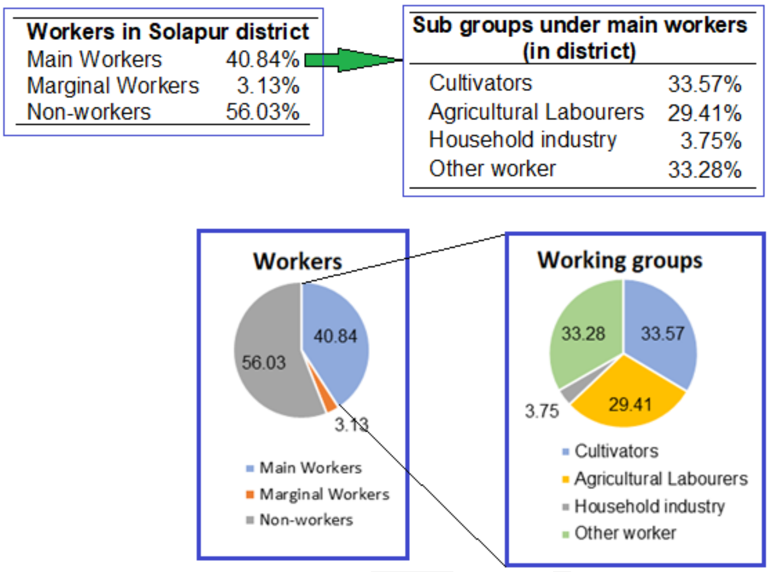


Figure 1.4: Details of Workers in Solapur City

1.8 Transport Facilities in Solapur

Solapur, which is the headquarters of Solapur district in Maharashtra, is a famous pilgrim city. Solapur serves as a base to reach pilgrimage spots like Tuljapur, Pandharpur and Ganagapur. Solapur shares its borders with famous cities like Ahmednagar, Gulbarga, Osmanabad, Satara, Sangli and Pune. All these reasons make Solapur the main transportation hub connecting Karnataka, Maharashtra and Andhra Pradesh. Solapur is well connected by neighbouring cities and districts and states with all possible ways like rail, road and air.

Solapur, which is one of the largest train junctions on the Mumbai -Hyderabad and Mumbai-Chennai lines, is also one of the five divisions of the Central Railway Zone. Solapur is also a terminal point of the Solapur -Bijapur line. The Solapur Railway Division is an important division that connects South India to North Western India and Western India. There are direct trains to most of the important cities like Mumbai, Bangalore, New Delhi, Chennai, Pune, Thiruvananthapuram etc. from here. Solapur city, which is 456 Kms away from Mumbai and 264 km away from Pune by rail, is located on major rail routes between Hyderabad and Mumbai. The local and out-station trains from Solapur railway station connect the city with all important towns within and outside Maharashtra. Regular trains are available to Pune, Mumbai, Hyderabad and other parts of the state and the country from Solapur railway station.

Pune International Airport in Maharashtra is the nearest international airport from Solapur. We can reach to Pune airport with roughly four hours' drive from Solapur. This airport is well connected to all major cities like Bangalore, Chennai, Nagpur, Delhi, Ahmedabad, and

Hyderabad by flights. Various airline services like Air India Express, Air India, Jet Airways, Indigo and Spice Jet etc. provide flight services from and to Solapur. Chhatrapati Shivaji Airport is another option for tourists, as they get connecting flights to Solapur from here. Even though there is an airport on the Southeast side of Solapur city, currently no commercial flights provides services here.

Before 1946, the transportation facilities in Solapur were provided by private companies. Solapur Corporation had implemented local bus services in Solapur in 1949 and it was extended to Hotgi Road, sugar factories, industrial places, airport, Vijapur and adjacent villages. Many private bus services are also functioning in Solapur with regular services to major cities. You can also depend on hired taxi or auto rickshaw for local transportation.

1.9 Climate and Meteorology

Solapur falls under the category of dry (arid and semiarid) climate according to the Koppen climate classification. The city experiences three distinct seasons: summer, monsoon and winter. Typical summer months are from March to May, with maximum temperatures ranging from 30 to 45 °C (86 to 113 °F). The warmest months in Solapur are April and May. The highest temperature ever recorded is 46.0°C (114.8 °F) in May 1988. Although summer does not end until May or even the midst of June, the city often receives locally developed heavy thundershowers in May (although humidity remains high). The monsoon lasts from June to the end of September, with moderate rainfall. The city of Solapur receives an average rainfall of 545 mm (21.5 in) per year. Winter begins in November and lasts until the end of February, with the temperatures occasionally dropping below 10 °C (50 °F). Solapur lies very close to the seismically active zone around Khillari, Latur District, about 100 km (62 mi) east of the city. The meteorological data derived from prognostic model is used for determining the predominant wind direction. For this purpose, a windrose diagram is plotted and is shown in **Figure 1.5**. Predominantly the wind is from West to West-North-West.

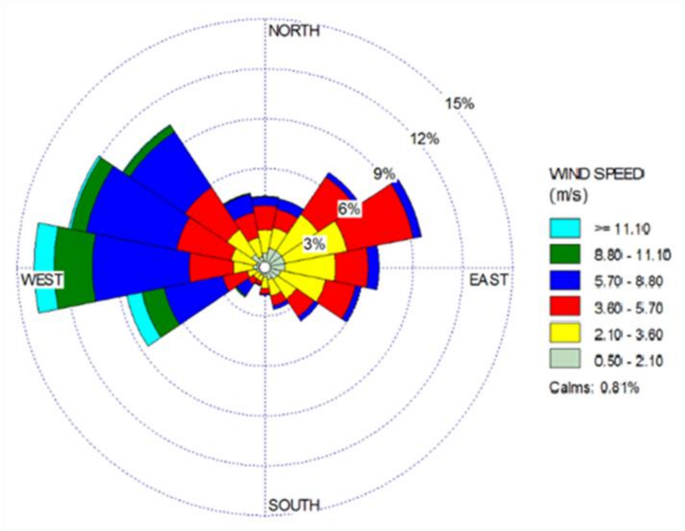


Figure 1.5 : Annual Windrose Diagram of Solapur City

1.10 Need of 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 & IIT (B) to jointly execute the source apportionment studies for 10 cities of Maharashtra.

Chapter 2
Ambient Air Quality

2.1 Air Quality at Solapur City

Ambient air quality data of Solapur city is gathered from web search and data for three sites in Solapur is found. The three sites are Solapur Municipal Council (SMC) building, Saat Rasta near Bus stand and Walchand Institute of Technology (WIT). The data were downloaded and analysed and found that the monitoring at WIT and Saat Rasta is carried out using manual method; however, monitoring at SMC is carried out using automatic continuous monitoring system. The data is available from 2007 to 2017 at daily average level. At the Saat Rasta and WIT site, four parameters are monitored which are SO_2, NO_2, RSPM and SPM. At the continuous monitoring site (SMC), only three parameters are monitored, which are SO_2, NO_2, and RSPM. **Figure 2.1** shows the average of 10 year's SO_2 data. It can be seen that at all the three sites, median value of SO_2 is 15 µg/m^3 with maximum value around 20 µg/m^3. This data is further analysed at yearly level for a better insight and is graphically presented in **Figure 2.2**. Annual variation of SO_2 over 10 years shows that the variation at manual monitoring station i.e. WIT and Saat Rasta is more or less same. This raises doubt over the data quality of these two stations, whereas at the continuous monitoring station there appears to have some variation over the years.

Similar to SO_2, the NO_2 values at the three stations are analysed and presented in **Figure 2.3** and **Figure 2.4**. The visual presentation of data at monitoring site i.e. at WIT and Saat Rasta shows the same trend and values, whereas there is large variation of NO_2 at SMC, which is a continuous monitoring site. Observing Fig. for annual variation of NO_2, it can be seen that at continuous monitoring station, the values are gradually increasing indicating the growth of vehicles in the urban area of Solapur. The NO_2 values at WIT and Saat Rasta does not suggest that there is any variation and therefore no growth of number of vehicles. This again concludes that the two manual monitoring sites are not monitored properly.

Figure 2.5 through **Figure 2.8** shows the decadal and annual variation of Respirable Suspended Particulate Matter (RSPM) and Suspended Particulate Matter (SPM). It can be seen that the data at WIT and Saat Rasta are similar, again indicating that the monitoring at two stations are not appropriate and the money spent towards monitoring at these two sites are a waste. Over the years, the pollution concentration is shown to falling down at these two stations, which is contrary to the continuous monitoring site (SMC). If the pollution concentration is falling down, the need for this study does not arise. However, the SMC data shows the median value of RSPM is above 100 µg/m^3, and therefore calls for management plan so as to prevent further decline in air quality. Analysis of data reveals that the manual monitoring at two sites (WIT and Saat Rasta) does not show any variation and therefore data of the two sites is not included in the analysis. Data of air quality monitoring at SMC building for 2007 to 2017 is analysed and its monthly variation is presented in **Figure 2.9**. It can be seen that SO_2 levels are much lower than the stipulated regulatory limit (annual average 50 µg/m^3) over the last ten years and therefore does not indicate presence of any major SO_2 emitting source. Monthly variation of NO_2 levels is high during winter (December – February) due to relatively low wind and higher inversion duration. NO_2 values start declining during summer due to higher ventilation and falls to lowest levels during rain period (July - August). Similarly RSPM data is analysed for each month of ten years and is found to follow the same trend as NO_2.

The exceedance of RSPM above the regulatory limit value indicates the non-attainment. The increase of RSPM in Solapur is up to 125 µg/m^3, which is not significant compared to other cities in India. The increase in ambient air particulate matter may also be due to geological material, road dust etc. However, for other gaseous parameters, Solapur does not indicate non-attainment character. As a first observation from the available data, Solapur city is yet to attain urban maturity in terms of increased anthropogenic activity that can be controlled by policy intervention. However, as a preventive measure, the infrastructure can be improved, strengthened so as to face the future air pollution related challenge. This may include road / transport development, slum development, regularisation of illegal encroachment by proper facility etc.

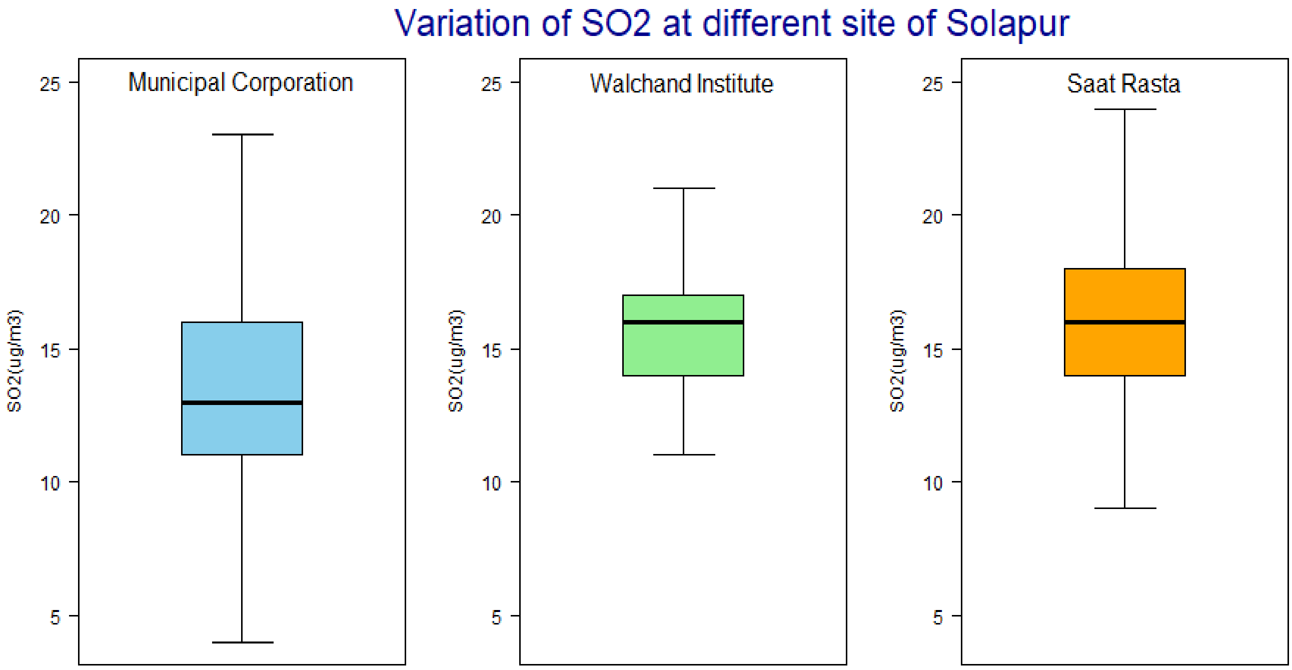


Figure 2.1: Ambient Air SO_2 at Different Sites of Solapur (2007 to 2017)

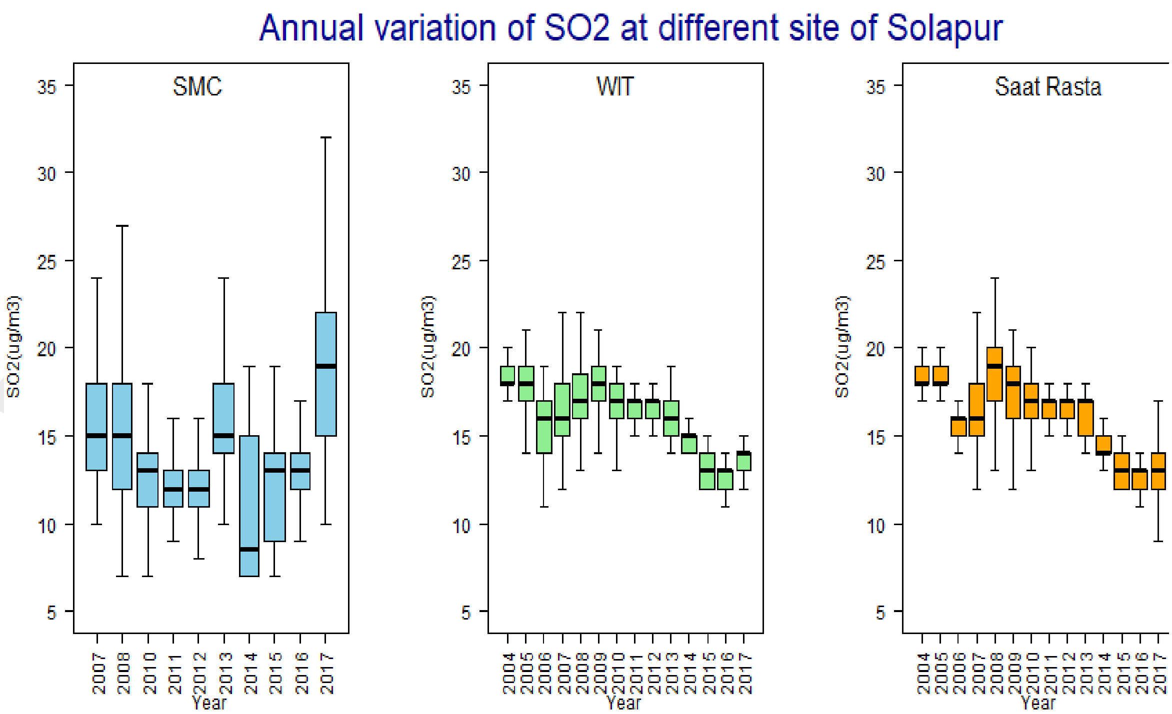


Figure 2.2 : Annual Variation of SO_2 at Different Sites of Solapur (2007 to 2017)

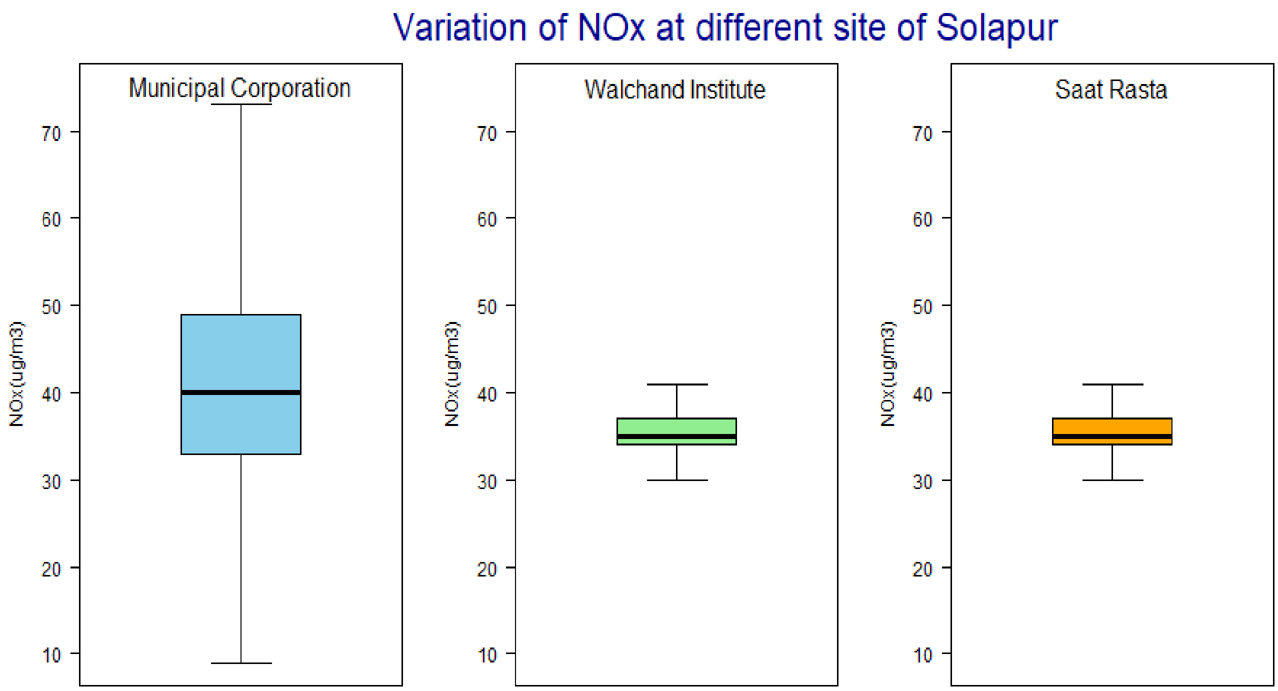


Figure 2.3 : Ambient Air NOx at Different Sites of Solapur (2007 to 2017)

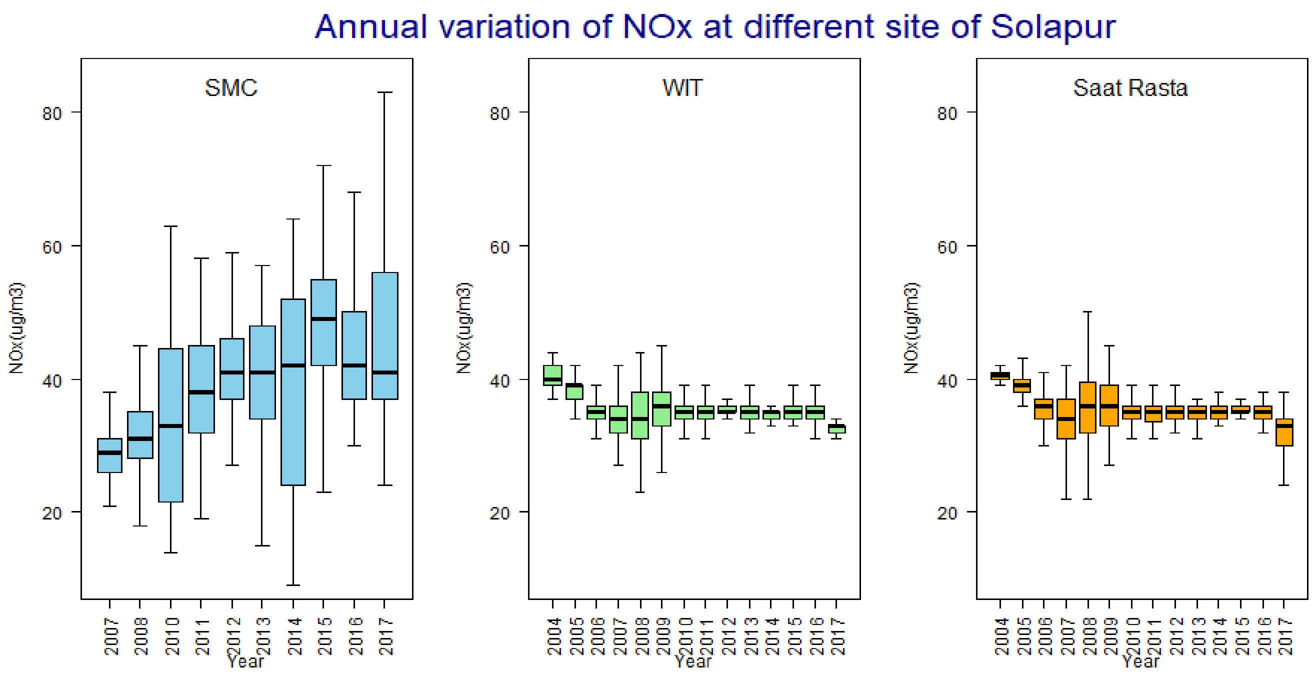


Figure 2.4 : Annual Variation of NOx at Different Sites of Solapur (2007 to 2017)

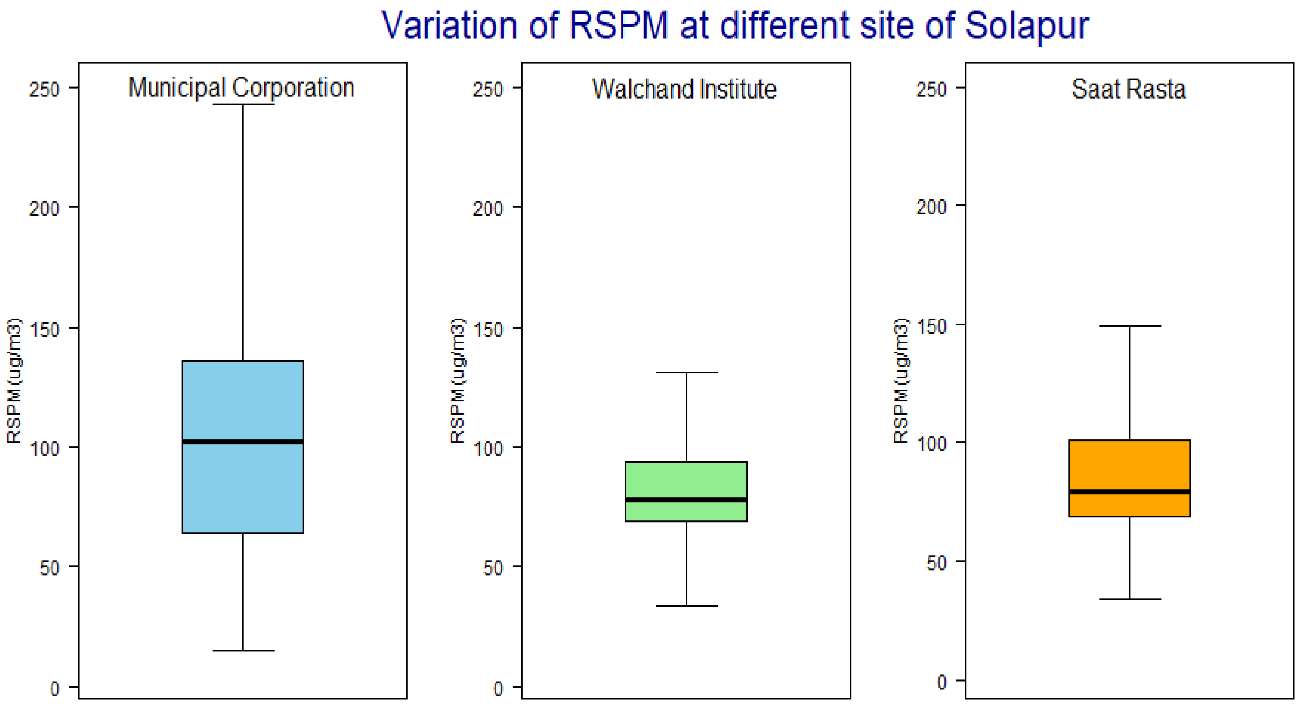


Figure 2.5 : Ambient Air RSPM at Different Sites of Solapur (2007 to 2017)

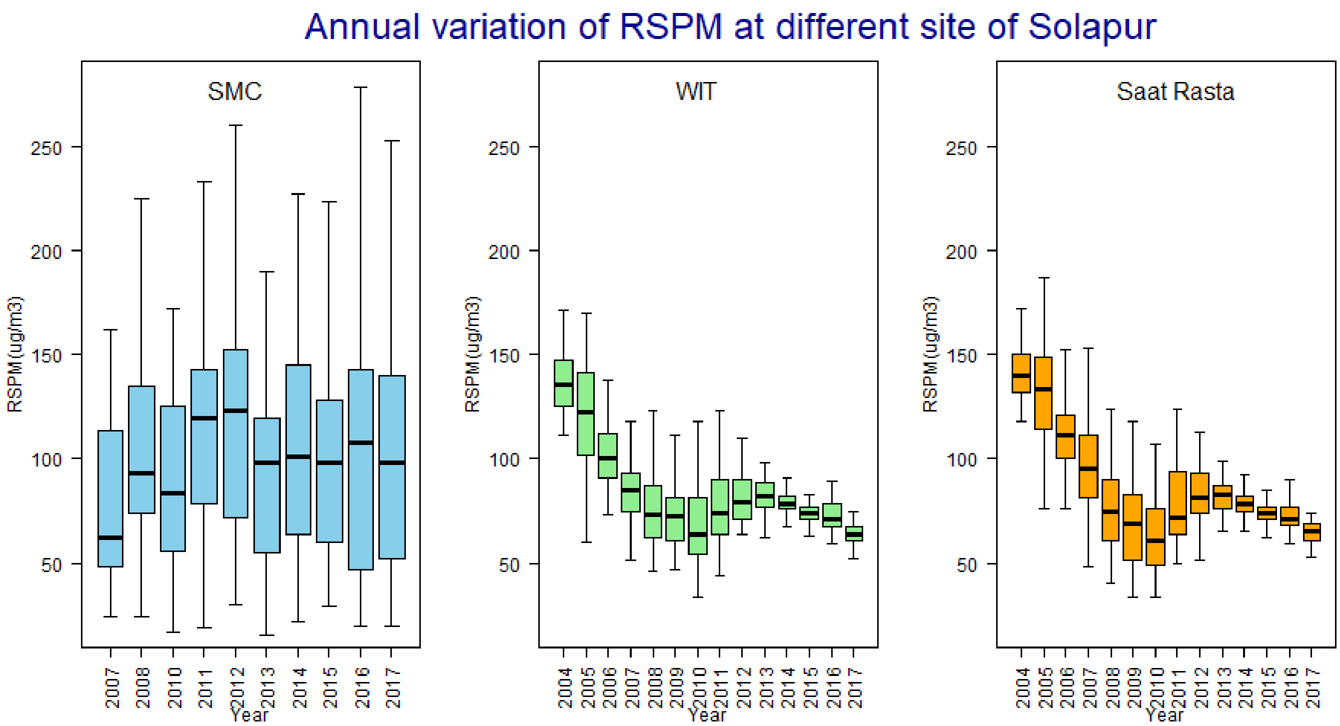


Figure 2.6 : Annual Variation of RSPM at Different Sites of Solapur (2007 to 2017)

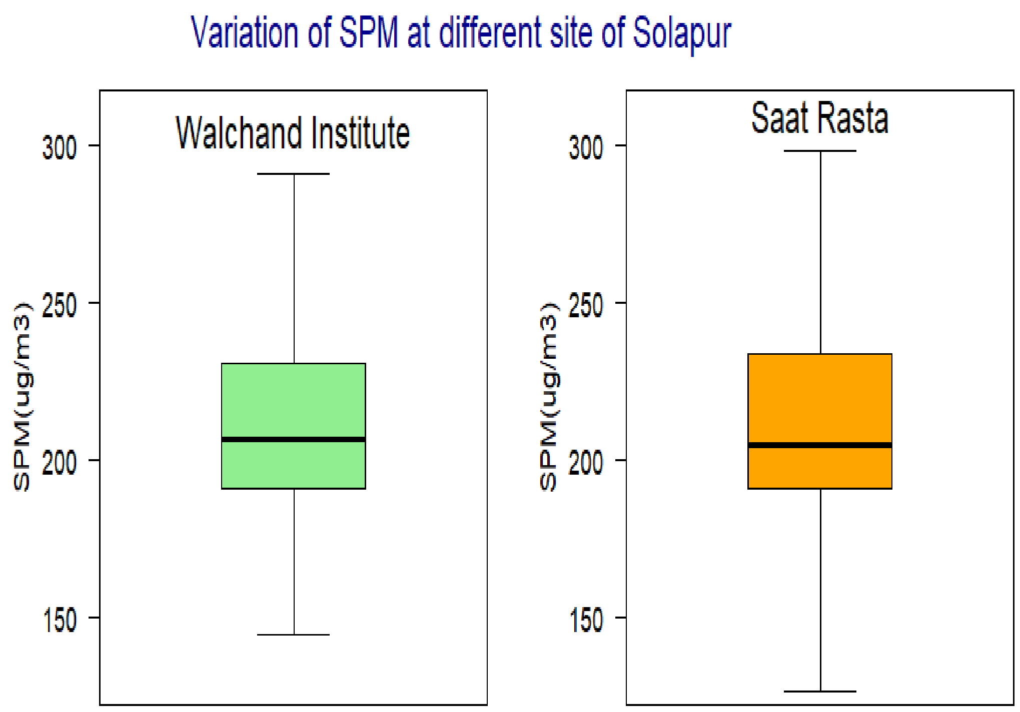


Figure 2.7 : Ambient Air SPM at Different Sites of Solapur (2007 to 2017)

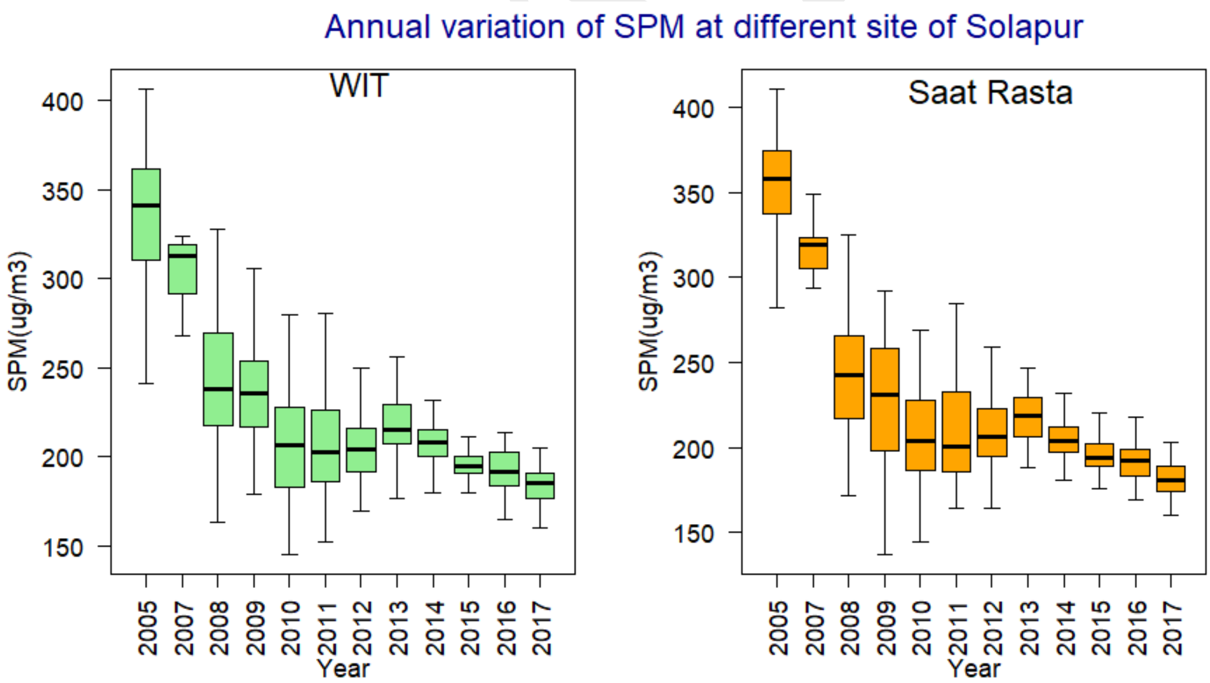


Figure 2.8 : Annual Variation of SPM at Different Sites of Solapur (2007 to 2017)

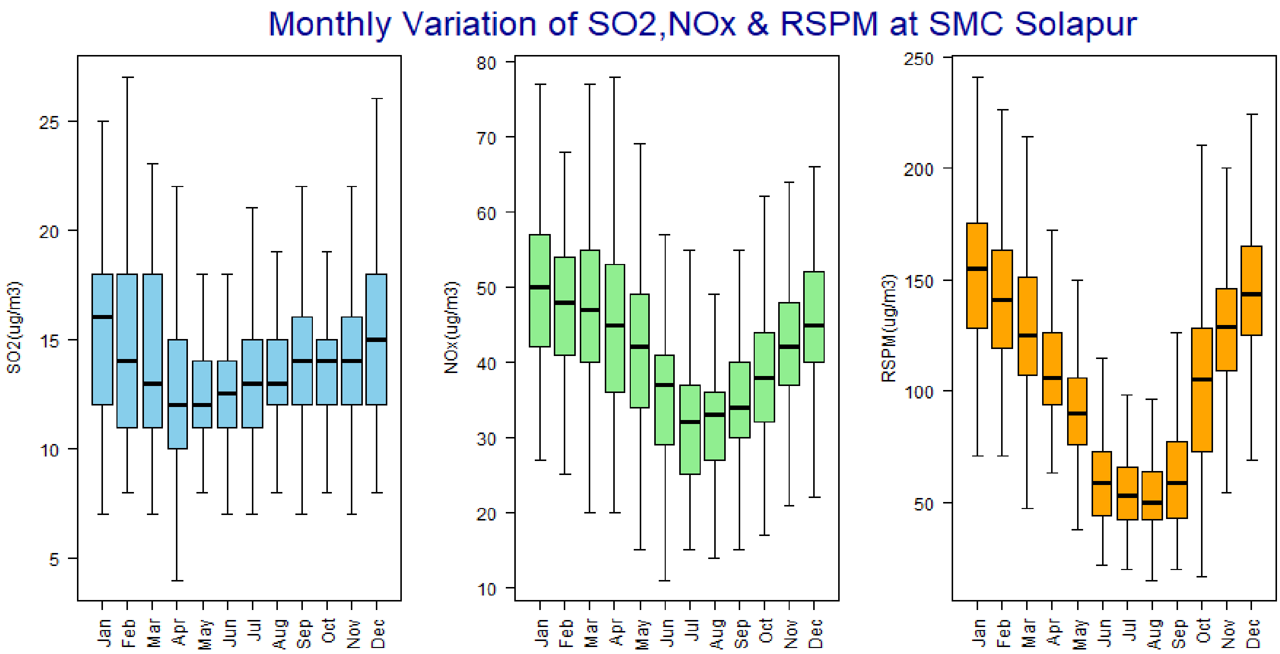


Figure 2.9 : Monthly Variation of SPM at Municipal Corporation Blg., Solapur (2007 to 2017)

2.2 Ambient Air Quality -Sampling During Summer 2019

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

Table 2.1 : Description of Sampling Sites

Sampling Location	Type	Characteristics
Near SMC	Residential Zone	All government offices with residential colonies
Near MIDC	Industrial Zone	Textile industries
Near WIT	Commercial Zone	1.1 kms away from the Akkalkot Sholapur highway
University	Reference Site	10 kms away from Sholapur city towards Northwest, 500 meters away from the main road.

Air quality status at four sites in terms of PM_{10} and $PM_{2.5}$ concentration is given in **Figure 2.10**. It can be seen that PM_{10} concentration violated the CPCB threshold (100 µg m^{-3}) during the entire study period at all the sites. $PM_{2.5}$ concentration exceeded the CPCB standard of 60 µg m^{-3} only at one occasions in MIDC.

$PM_{2.5}/PM_{10}$ ratio is also plotted in **Figure 2.11** to assess the dominance of combustion activities at the sampling sites. High ratio generally suggests the presence of combustion activity at or near the site. It can be seen that $PM_{2.5}/PM_{10}$ ratio is less than 0.5 at all the sites during the sampling period except once at University.

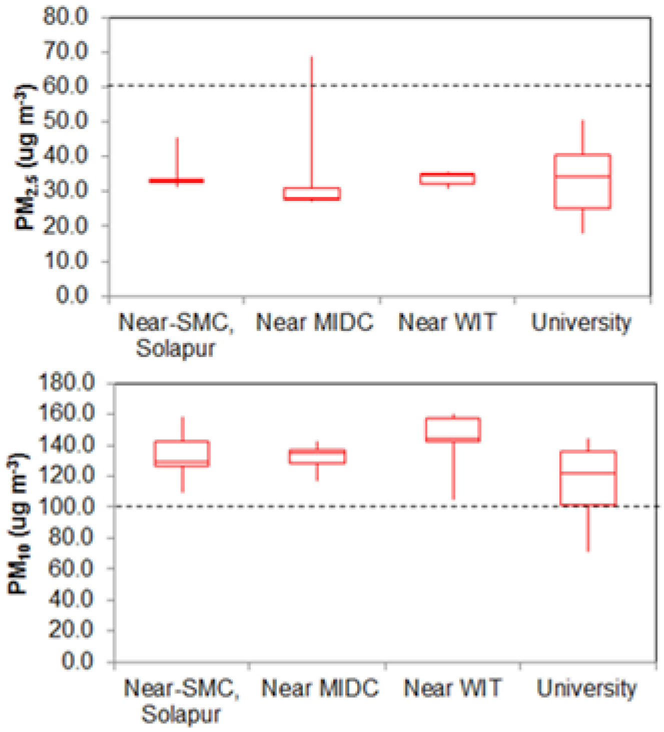


Figure 2.10 : Site and City wise Ambient Air $PM_{2.5}$ and PM_{10} in Solapur

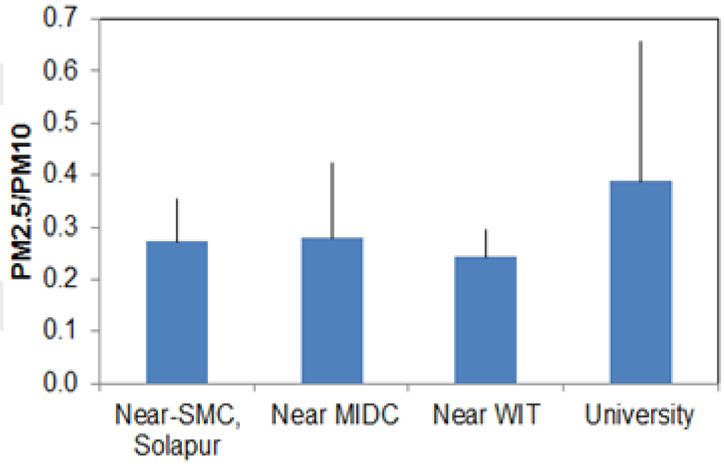


Figure 2.11 : $PM_{2.5}$ /PM_{10} Ratio in Solapur

Chapter 3

Emission Inventory

3.1 Outline

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

Extensive fossil fuel use and speedy growth of energy intensive sectors like power, steel, cement, chemicals and fertilizers, transport etc. have contributed to high growth rate of emissions at above 5% per annum during 2000s in India. National level emission inventories have been prepared by several researchers for metro cities in India. Solapur city has no emission inventory estimate report earlier published. Keeping in view the lack of exclusive emission inventory estimates for Solapur, 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 Solapur 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 Solapur 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 Solapur 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 Solapur city for source data collection. The same data is used for the estimation of emission inventory. To make the emission inventory more accurate a large number of site specific primary data has been collected. The secondary data sets have been collected from all possible authentic sources for the selected departments in the city.

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

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

3.5 Secondary Data Collection

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

3.6 Role of GIS

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

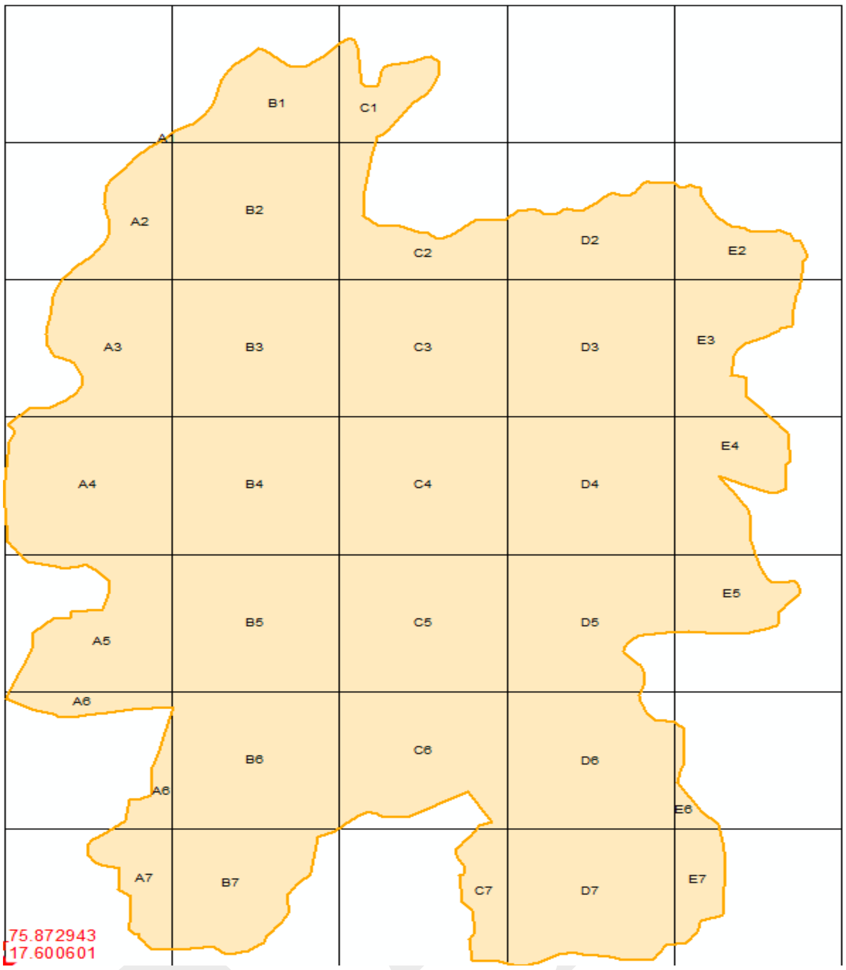


Figure 3.1 : Grid Map Solapur City

3.7 Road Condition in Solapur City

The data on road condition is provided by Solapur Municipal Council. **Table 3.1** provides the data on major roads of Solapur. In order to reduce the particulate matter air pollution, improvement in these road conditions will be helpful. The road is divided into two groups, one is based on the construction material of road and the other is road width. Construction material helps in identifying the road that can be improved to reduce the resuspension of road dust. The road length that can be swept using truck mounted vacuum cleaner.

Table 3.1 : Major Roads of Solapur

Road Name	Length (Km)	Road Name	Length (Km)
Hyderabad Mumbai highway	9.9	Vijapur - Mangalore Highway	6.6
Solapur road	5.8	Solapur Akkalkot Marg	5.6
Hotgi road	4.9	Old Kumbhari road	4.8
80 foot road	4.7	Hyderabad Bijapur Bypass	4.0
Old Hyderabad road	3.5	Rupa bhawani road	3.4
Solapur Railway station road	3.3	Beed-Auranagabad road	3.1
Sangola Mangalwedha road	2.9	Solapur Pune flyover	2.1
MIDC road	1.8	Jule Solapur	1.8
Dahitna Road	1.7	Shivgan Mandir road	1.3

(Source: Solapur Municipal Corporation, 2018)

Table 3.1 (Contd..) : Major Roads of Solapur

Road Name	Length (Km)	Road Name	Length (Km)
Hydrabaad-Pune Bypass	1.3	Old Wangi road	1.1
VIP road	1.1	Siddheshwar Mandir road	1.0
Vijapur road	1.0	Government Polytechnique College	1.0
MG Road	0.9	Yunus Masjid road	0.7
New Bypass road near Hotgi	0.7	Seth L.J. Chandak road	0.6
Dadasaheb Gaikwaad road	0.6	Killa road	0.5
Seva Sadan Prashala road	0.5	Bhola Marg	0.5
Utkarsh Nagar road	0.5	MH Chattarki road	0.5
Bhadravati Peth Road	0.4	Amba Bai road	0.4
Vithoba Niwas Road	0.4	Sanjay Gandhi Nagar road	0.3
Ram Ling Nagar road	0.2	Limayewadi road	0.2
Kshtriya galli	0.2	Ahemad Raza road	0.1
Yemul road	0.1		

(Source: Solapur Municipal Corporation, 2018)

3.8 Vehicle Count

As per line sources, vehicle counting was carried out in 20 different locations across the city boundary. Traffic Counting was carried out as per the methodology. The collected data is used for vehicular emission estimation per hour and then identified for its grid position. The percentage of different type of vehicle viz. 2w, 3w, 4w, etc. operating with different fuel is estimated as per "A Report on Total Fuel Consumption by Transport Sector in India", Press Information Bureau, Government of India, Ministry of Petroleum & Natural Gas, dated January 28, 2014. The road length and road width was measured to identify the traffic flow pattern of the city. The vehicular count at one such location is shown in **Figure 3.2**. Timely fractional variation of traffic is presented in **Figure 3.3.**

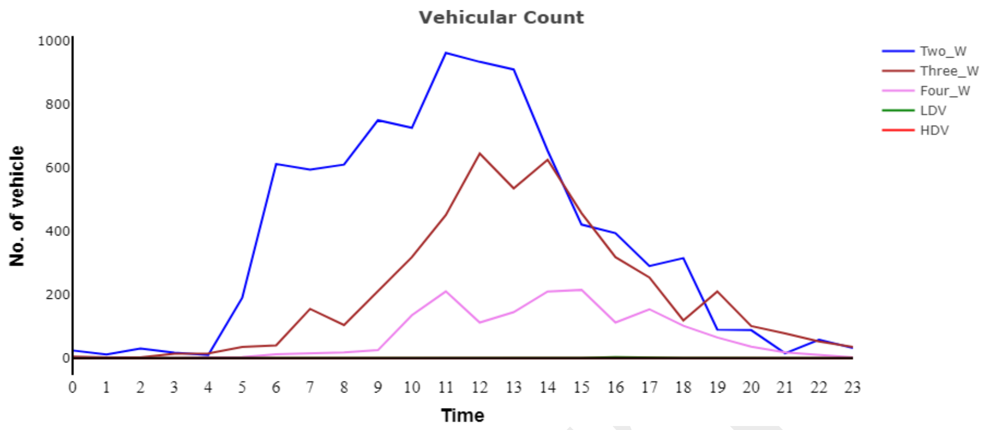


Figure 3.2 : Hourly Vehicular Count at one Selected Location

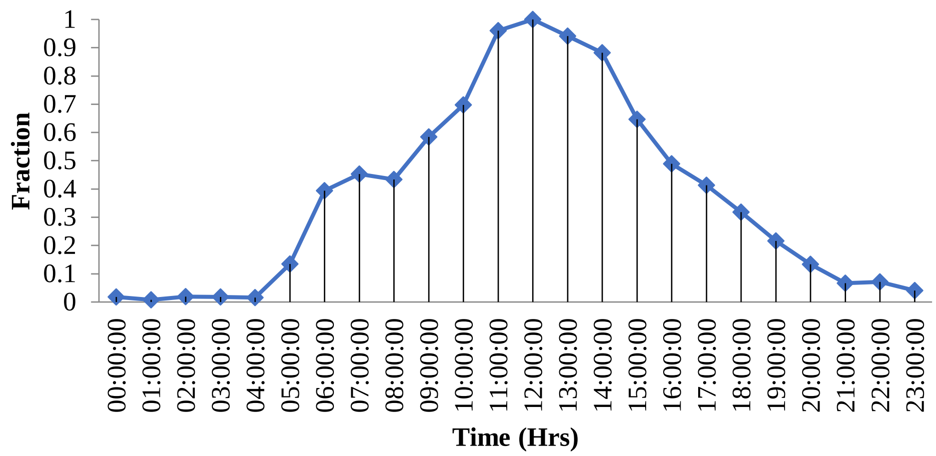


Figure 6: Timely Fractional Variation of Traffic at a Location

Following emission factors are used to calculate emission load from line sources **(Table 3.2)**. The emission factors derived by ARAI, Pune are used for calculations.

Table 3.2 : Emission Factors Considered for Emissions Estimation

Emission Factor for BS-III Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.035	0.27	0.61	1.65	g/km
2	3W_Petrol	0.05	1.2	0.7	1.20	g/km
3	3W_Diesel	0.05	0.5	0.5	0.50	g/km
4	4W_Petrol	0.05	0.12	0.19	3.01	g/km
5	4W_Diesel	0.12	0.67	0.2	0.51	g/km
6	HDV	1.24	9.3	0.37	6.00	g/km
Emission Factor for BS-IV Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.1	0.1	0.13	1.81	g/km
2	3W_Petrol	0.035	0.5	0.3	0.75	g/km

3	3W_Diesel	0.035	0.5	0.3	0.75	g/km
4	4W_Petrol	0.08	0.1	0.1	1.00	g/km
5	4W_Diesel	0.08	0.1	0.1	1.00	g/km
6	HDV	0.06	0.39	0.42	0.74	g/km
Emission Factor for BS-VI Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.0045	0.090	0.068	0.50	g/km
2	3W_Petrol	0.0250	0.100	0.100	0.22	g/km
3	3W_Diesel	0.0045	0.080	0.100	0.50	g/km
4	4W_Petrol	0.0045	0.060	0.100	1.00	g/km
5	4W_Diesel	0.0045	0.080	0.100	0.50	g/km
6	HDV	0.0100	0.080	0.100	0.50	g/km

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

Figure 3.4 and 3.5 shows the hourly emission load pattern from line source for different pollutants.

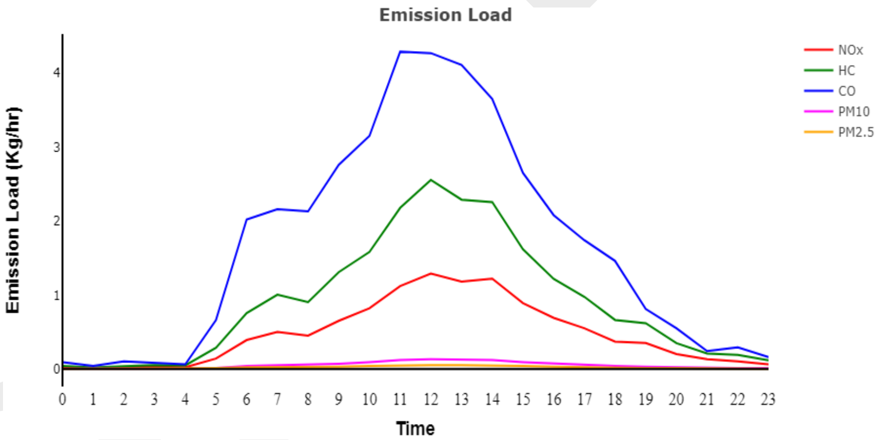


Figure 3.4: Hourly Emission Load from Vehicular Source for One Location

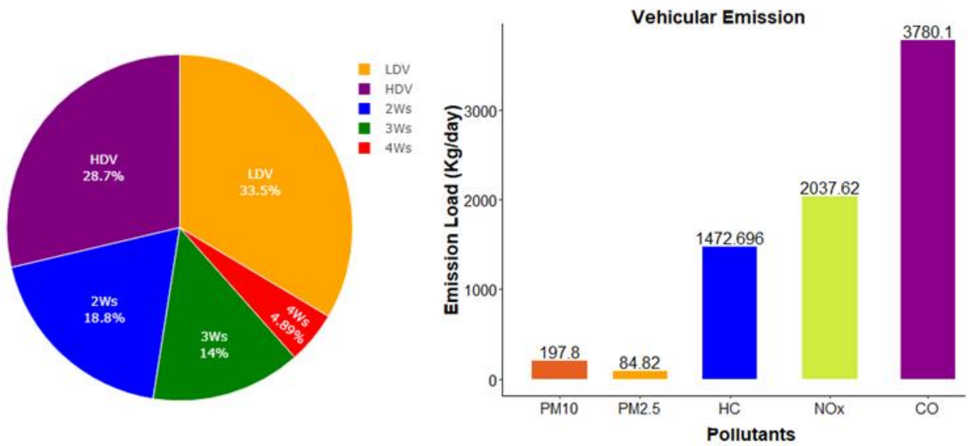


Figure 3.5 : Emission Load from Line Source for Different Pollutants

The figure above represents the hourly emission load emitted from vehicular sector. The particulate matter emission load starts increasing during night hours and gets decreased around 18:00 hrs. From figure it can be seen that from 18:00 hrs to 21:00 hrs the emission load is very less. Same peaks are also seen for NOx, HC and CO emission load.

3.8.1 Grid-wise Line Emission Load

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

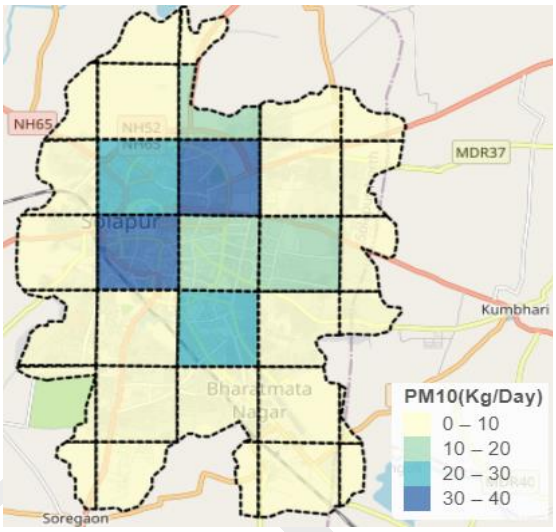


Figure 3.6 : Grid-wise Emission Load from Line Source

3.9 Point Source

Solapur is the home of Handloom and Power-loom weaving industry which provides employment to a large number of workers. There are around 6000 power-loom industries operational in the district. Out of these 300 establishments are registered under Mumbai Shops and Societies Act 1948 and the other 3000 are registered under factories Act 1948. There are about 25000 Power loom and about 30000 workers are employed. On the Jackard power loom the main production is Chadders, Towels and Napkins. Most of the power loom industries are operational in day shift only from 8 a.m. to 6 p.m. with two hours break for lunch and recess. Some of the industries are operational in two shifts from 8.00 a.m. to 4.00.p.m. and from 4.p.m. till 12.00 midnight. The employees working on the handloom/power loom machines mainly manufacture Jackard Chadders, Towels and Napkins. Beedi industry is the second important industry in Solapur. There are 115 units of 29 various beedi factories. The type of fuel used in industries is wood **(Figure 3.7)**.

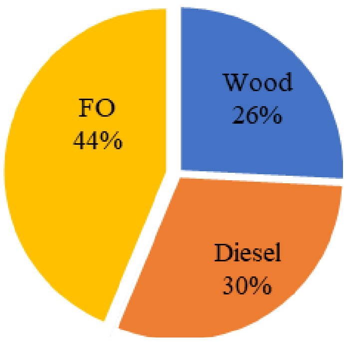


Figure 3.7 : Type of Fuel Used in Industries for Production

The emission load from these types of industries is shown in **Figure 3.8.**

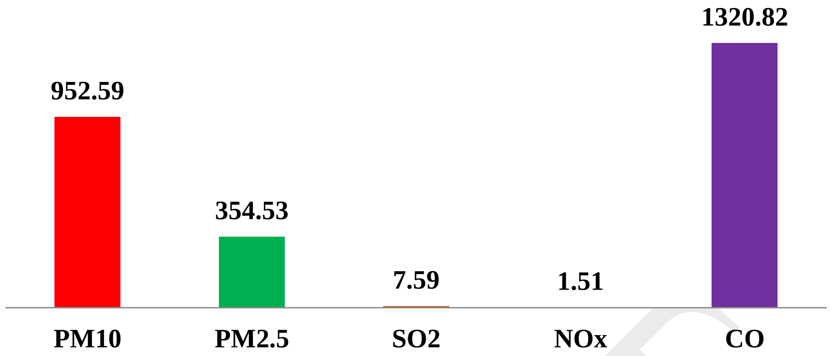
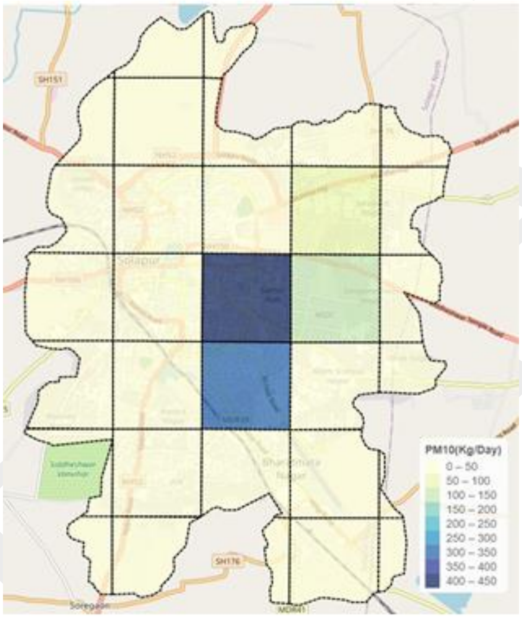


Figure 3.8 : Emission Load from Point Sources

The total grid-wise emission load from point sector is shown below. The maximum particulate matter (PM_{10}) is 952.59 Kg/Day and for $PM_{2.5}$ is 354.53 Kg/Day respectively **(Figure 3.9 & 3.10)**.



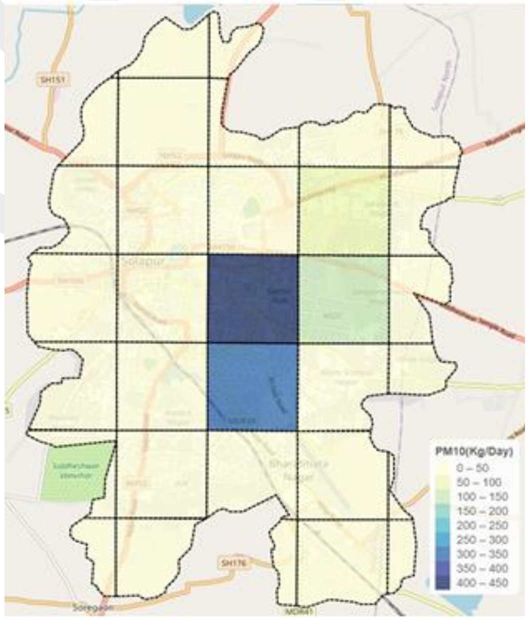


Figure 3.9 : (Point Source) Gridded Emission Load for PM_{10}

Figure 3.10 : (Point Source) Gridded Emission Load for $PM_{2.5}$

3.10 Area Sources

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

Municipal Corporation. This consumption data and corresponding emission factors given by CPCB were used for calculating emission load from respective sources.

3.10.1 Bakery

Even though Bakeries emit less pollution but for the ovens, boilers, hot water generators, DG sets emit flue gases through small stacks. Bigger plants with more than two or three production line of Bread or Biscuit ovens emits considerable amount of flue gases which consists of particulate matters, Sulphur dioxides, Nitrogen oxides. There are 30 large and medium scale bakeries spread all across the city. Considering the operation of bakeries, it was observed the fuel consumption pattern is of mixed nature. There have been reported cases of unorganized bakeries comprising small bakery units characterized by low levels of packing and distribution mainly in neighbouring areas. These small time bakeries operate mainly on out-dated combustion technologies and traditional methods of manufacturing baked goods that utilize solid fuels in large quantity without any control measures for emission. Consumption of wood and LPG as fuel in bakery processes is one of the major source for PM emission loads from bakeries. Through survey it was observed, mostly bakeries operate for 12-16 hours per day and the peak season of business is during festivals. The information on fuel used in combustion process was collected from survey of bakery units. For the calculation of emission load, the fuel information provided during survey was only considered.

Emission Estimation (Kg/d) = No. of Bakeries x Fuel Consumption (Kg/d) x Emission Factor
The total emission load for PM_{10}, $PM_{2.5}$, SOx, NOx and CO from bakeries is estimated to be 1495.49, 1022.53, 3.35, 0.67 and 9616.58 Kg per day respectively **(Figure 3.11)**.

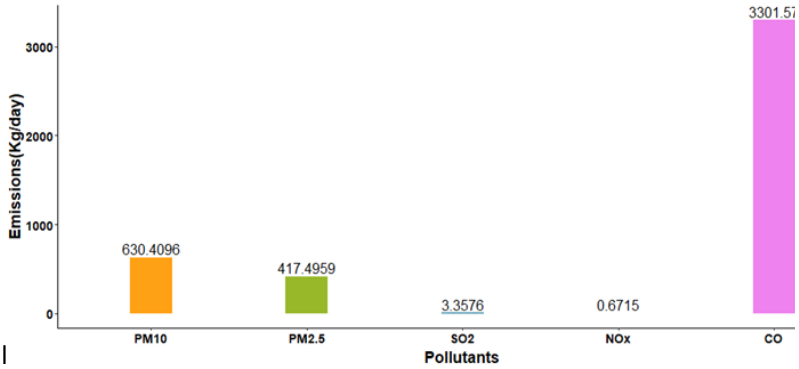


Figure 3.11 : Emission Load from Bakeries

Grid-wise emission load from bakeries for different pollutants is shown in **Figure 3.12 & 3.13.**

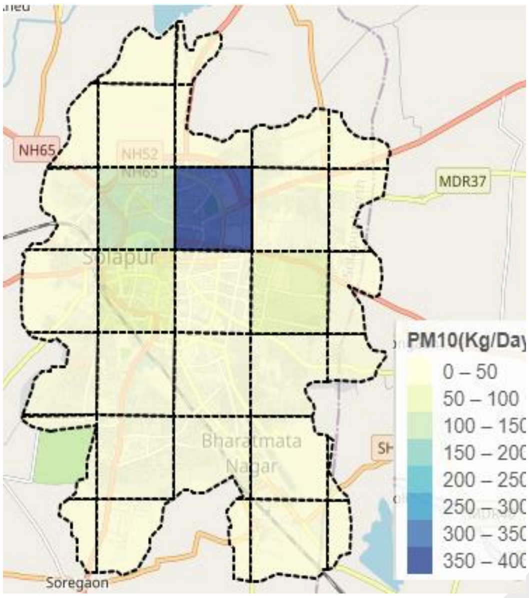


Figure 3.12 : (Bakeries)
Gridded emission load for PM_{10}

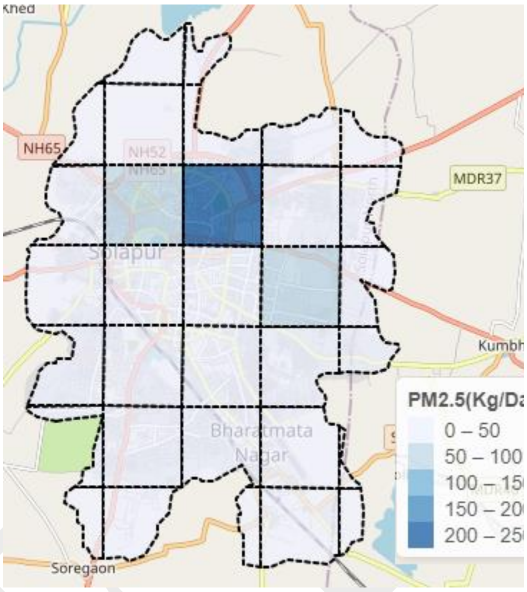


Figure 3.13 : (Bakeries)
Gridded emission load for $PM_{2.5}$

3.10.2 Crematories

A traditional Hindu funeral pyre takes six hours and burns 500-600 kg of wood to burn a body completely. Every year, 50-60 million trees are burned during cremations in India. Cremation is a process where a cadaver, human rests or arid human rests are subjected to high controlled temperatures with the main objective to reduce them to ashes. The cremation process generates particulate matter and gaseous pollutants such as PM_{10}, $PM_{2.5}$, carbon monoxide (CO), nitrogen oxides (NOx). Particulate matter and gaseous pollutant emissions depend on the type of fuel used for cremation and eventually the emission control equipment. There are 7 crematories in Solapur city. The average dead bodies burnt per day are 15 nos. The daily wood consumption required to burn a single dead body is assumed as 300 Kg, 5 Litres of Kerosene and 2 Kgs of cowdung cakes (NEERI SA report for Mumbai).

Emission Estimations:

Emission (TSP) =No. of Hindu Death /yr * wood required per body (kg) * emission factor
Emission Factor (PM_{10}) Wood Consumption = 17.3 (kg/t)
Emission Factor (SPM) Kerosene = 1.95 (kg/t)
Emission Factor (PM_{10}) Kerosene = 0.61 (kg/t)

Number of dead bodies cremated per day was obtained from Birth and Death cell of Solapur Municipal Corporation. The total emission load for PM_{10}, $PM_{2.5}$, SOx, NOx and CO is estimated to be 45.74, 22.55, 0.9, 0.18 and 233.76 Kg/Day. The graphical representation of the same is given in **Figure 3.14**. The emission load from crematories is also calculated grid-wise **(Figure 3.15 & 3.16)**. This will help for policy makers to arrive at a decision to control emission from crematories, if required.

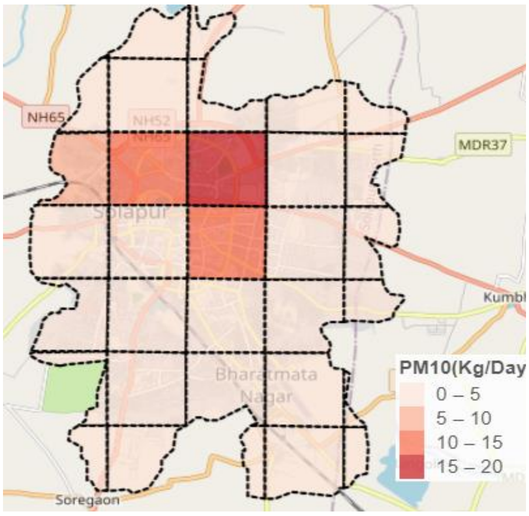


Figure 3.15 : (Crematories) Gridded Emission Load for PM_{10}

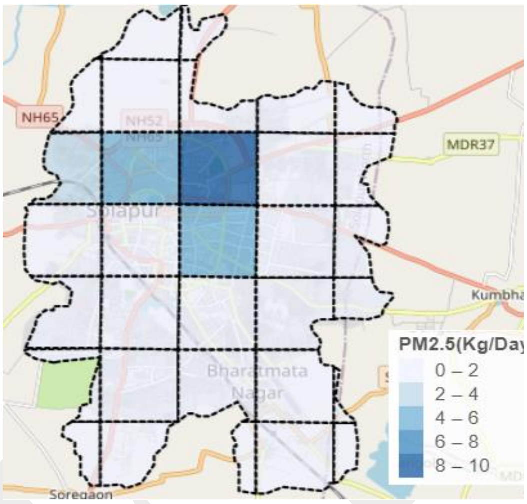


Figure 3.16 : (Crematories) Gridded Emission Load for $PM_{2.5}$

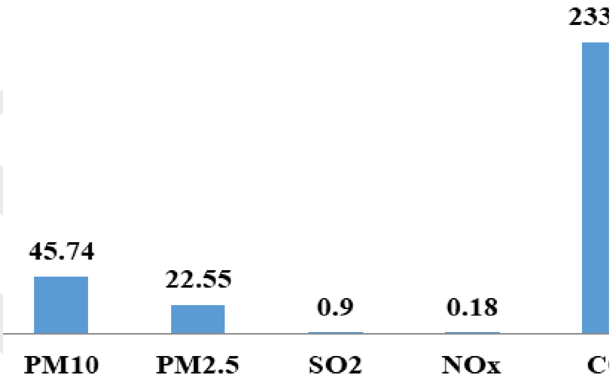


Figure 3.14: Emission Load from Crematories (kg/d)

3.10.3 Open Eat outs

Many of us have a favourite cooking smell. Maybe yours is baking bread or frying bacon but new types of equipment are revealing how restaurants contribute to our air pollution. Eat-outs cook with large amounts of oils and other organic matter, which is aerosolized and ventilated. This carries the organic aerosol produced in the cooking process into the urban environment. On the basis of primary survey, the fuel preference for open eats out in Solapur city is LPG, followed by coal. Average operating hours of street vendors is 12 hours. A questionnaire survey was carried out to collect necessary data for the estimation of emission load from this source. There are total 31 registered open eat outs in the city.

Emission Estimation

Emission from LPG burning (PM) per day

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

Emission from Coal burning (PM) per day

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

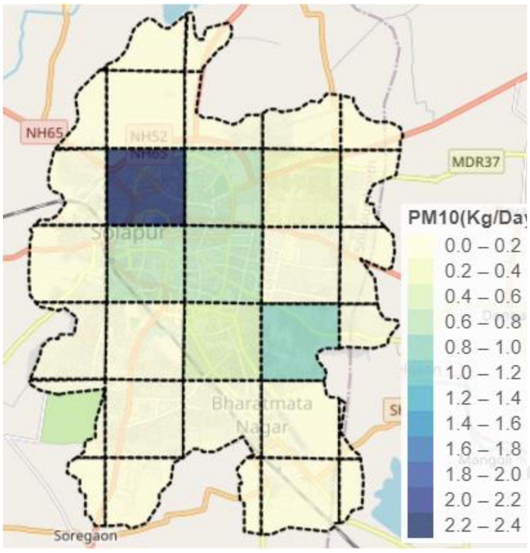


Figure 3.18: (Open Eat-outs) Gridded Emission Load for PM_{10}

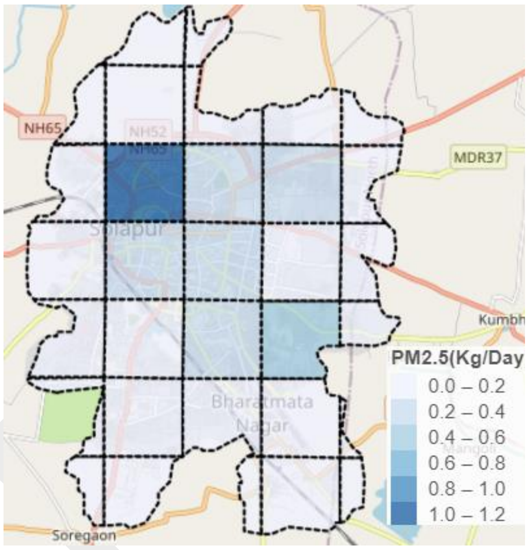


Figure 3.19: (Open Eat-outs) Gridded Emission Load for $PM_{2.5}$

The total emission load for PM_{10}, $PM_{2.5}$, SOx, and CO is estimated to be 6.48, 3.29, 0.108 and 10.66 Kg/Day. The graphical representation of the same is given in **Figure 3.17**. The emission load from crematories is also calculated grid-wise **(Figure 3.18 and 3.19)**.

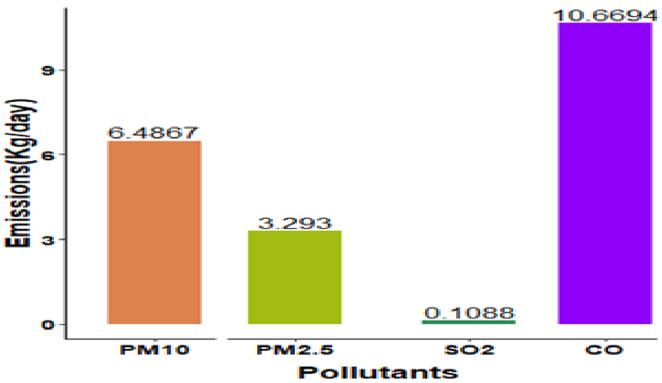


Figure 3.17 : Emission Load from Open Eat-outs (kg/d)

3.10.4 Domestic Sector

Burning solid fuels like firewood in homes for cooking, heating, and other energy services is the single largest source of air pollution exposure in India. When families burn solid fuels (like wood, dung, and agricultural waste) in their homes, various kinds of air pollutants are generated.

One of the many pollutants emitted by this combustion of solid fuels is fine particulate matter (PM2.5, particulate matter with aerodynamic diameter 2.5 µm). A residential survey was carried out in the city to find the consumption of fuel pattern used for household activities. 90% of the household have domestic gas connections for cooking and water heating. In slum areas, kerosene and pieces of wood were used to cook food.

Emission Estimation

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

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

The total emission load for PM_{10}, $PM_{2.5}$, SOx, NOx and CO is estimated to be 66.47, 39.57, 0.55, 0.11 and 580.49 Kg/Day. The graphical representation of the same is given in **Figure 3.20**.

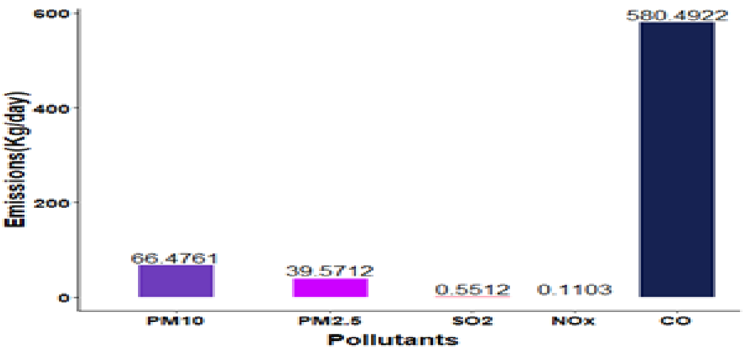


Figure 3.20 : Emission Load from Domestic Sector (kg/d)

3.10.5 Building Construction

With a scope of being developed as smart city, there are drastic infrastructural developments taking place in Solapur city. Real estate sector is booming in the city. The handling and construction activities contribute towards fugitive dust particulate matter in large proportions. Particulate emissions are predominantly due to site preparation work, which includes heavy construction activities. Data related to construction activity was obtained from Building construction department of SMC and from RERA website. During survey, 22 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 total emission load for PM_{10} and $PM_{2.5}$ are 5.7 and 2.45 Kg/Day. The graphical representation of the same is given in **Figure 3.21.**

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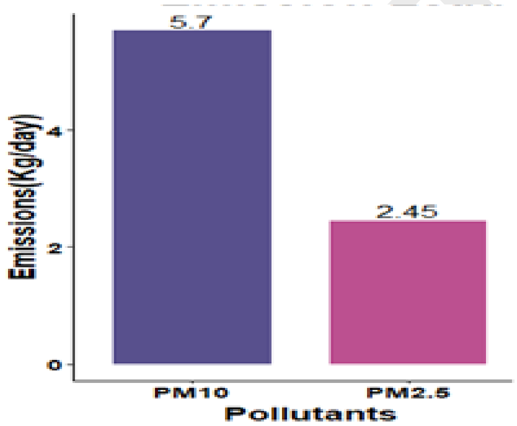


Figure 3.21 : Emission Load from Building Construction (kg/d)

3.10.6 Hotels and Restaurants

The hospitality industry encompasses a wide range of services and activities such as lodging, restaurants, food services, and convention centres. The lodging sector consists of hotels, motels, resorts, and bed and breakfasts. These operational activities release pollutants into the air. There are around 31 hotels registered with the SMC License department. Most of the hotels and restaurants use commercial LPG cylinders and coal for tandoors for their operation.

Emission Estimations

- Emission Load from LPG

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

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

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

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

- Emission Load from Coal

Total emissions (PM) due to coal burning in Hotels

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

The total emission load for PM_{10}, $PM_{2.5}$ and CO is estimated to be 62.89, 27.53 and 24.31 Kg/Day. The graphical representation of the same is given in **Figure 3.22**. The emission load from crematories is also calculated grid-wise **(Figure 3.23 & 3.24)**.

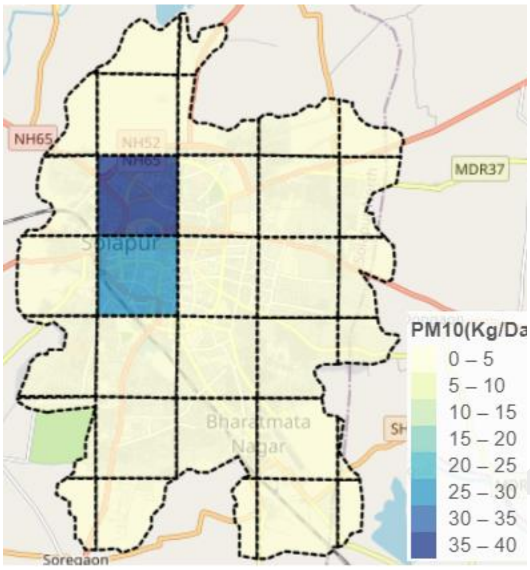


Figure 3.23 : (Hotels & Restaurants) Gridded Emission Load for PM_{10}

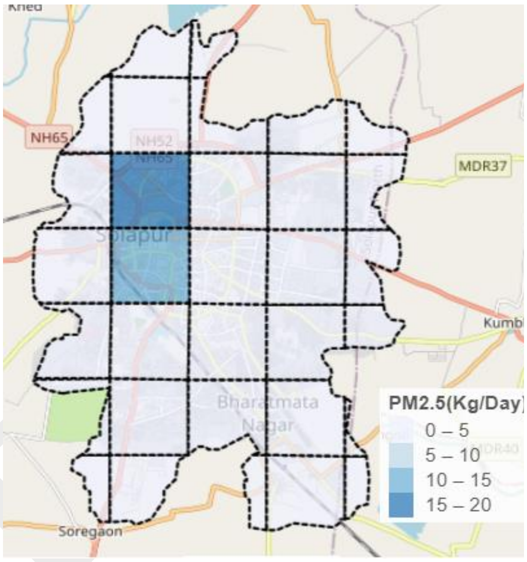


Figure 3.24 : (Hotels &Restaurants) Gridded Emission Load for $PM_{2.5}$

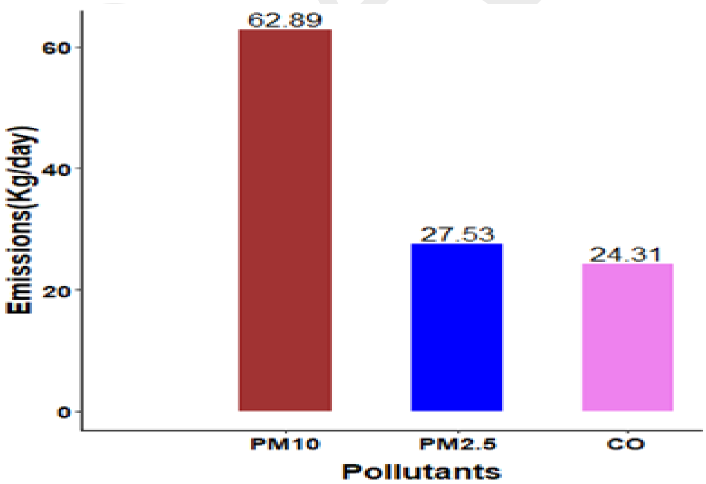


Figure 3.22 : Emission Load from Hotels and Restaurants (kg/d)

3.10.7 Brick Kiln

India is the second largest producer of clay fired bricks, accounting for more than 10 percent of global production. India is estimated to have more than 100,000 brick kilns, producing about 150-200 billion bricks annually, employing about 10 million workers and consuming about 25 million tons of coal annually. India's brick sector is characterized by traditional firing technologies; environmental pollution; reliance on manual labour and low mechanization rate;

dominance of small-scale brick kilns with limited financial, technical and managerial capacity; dominance of single raw material (clay) and product (solid clay brick); and lack of institutional capacity for the development of the sector. There are 18 brick kilns seen in operation near Solapur city. The data is collected by visiting the number of brick kilns. The total emission load from brick kiln is calculated and is given in **Figure 3.25**. As the brick manufacturing units are located outside the municipal limit, they are not considered while grid wise emissions load.

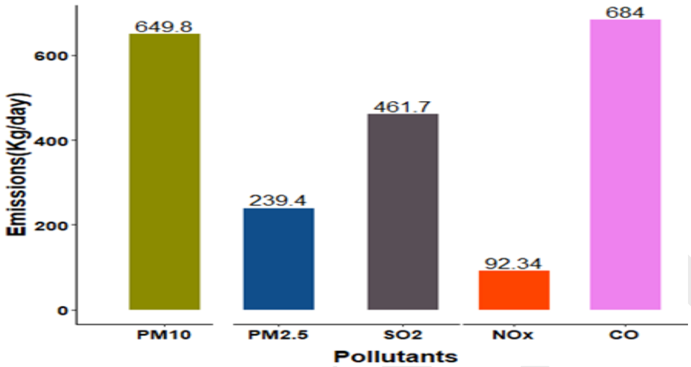


Figure 3.25 : Emission Load from Brick Kiln (kg/d)

3.10.8 Stone Crushers

There are no stone crushers found nearby the city. All are the outskirts of the city.

3.11 Total Emission Inventory (Solapur City)

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Solapur city vide emission inventory is developed as shown in **Table 3.3**. Total tons /day emission load for pollutants in Solapur city is depicted in **Figure 3.26**.

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

	Sector	PM_{10}	$PM_{2.5}$	SOx	NOx	CO
A.	**Area Source**					
	Bakeries	630.0	417.0	3.35.0	0.671	3301.56
	Open Eat-outs	6.48	3.29	0.11	0.02	10.66
	Hotels & Restaurants	62.89	27.53	0.1	0.02	24.31
	Crematoria	45.74	22.55	0.9	0.18	233.76
	Domestic	66.47	39.57	0.55	0.11	580.49
	Building Construction	5.7	2.45	0	0	0
	Brick Kilns	649.8	239.4	461.7	92.34	684
B.	**Line Source**					
	Vehicular flow	197.8	84.82	0	2037.6	3780.1
C.	**Point Source**					

	Industries	952.0	354.0	7.59	1.51	1320.8
	Total Emission Load (Kg/day)	2616.9	1190.6	471.0	2132.5	9935.7
	Total Emission Load (Ton/day)	**2.62**	**1.19**	**0.47**	**2.13**	**9.94**

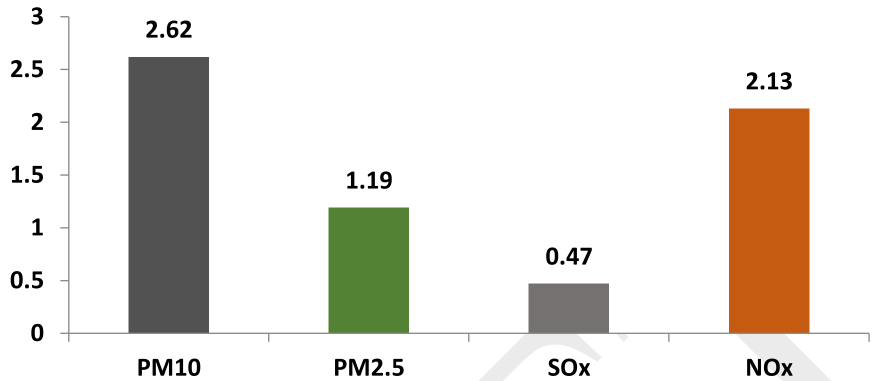


Figure 3.26 : Total Emission Load (Tons/Day) for Pollutants in Solapur City

3.12 Grid-wise Emission Inventory

Pollution in the atmospheres of megacities has become a major source of concern for public authorities. To understand this precisely, the details of the sources responsible for emission inventory are presented for respective pollutants (**Figure 3.27 to Figure 3.30)**. The sources considered for estimation of emission load were point, area and line sources. These grid wise emission loads will be effective in consideration of policy making decisions for reducing air pollution to a great extent.

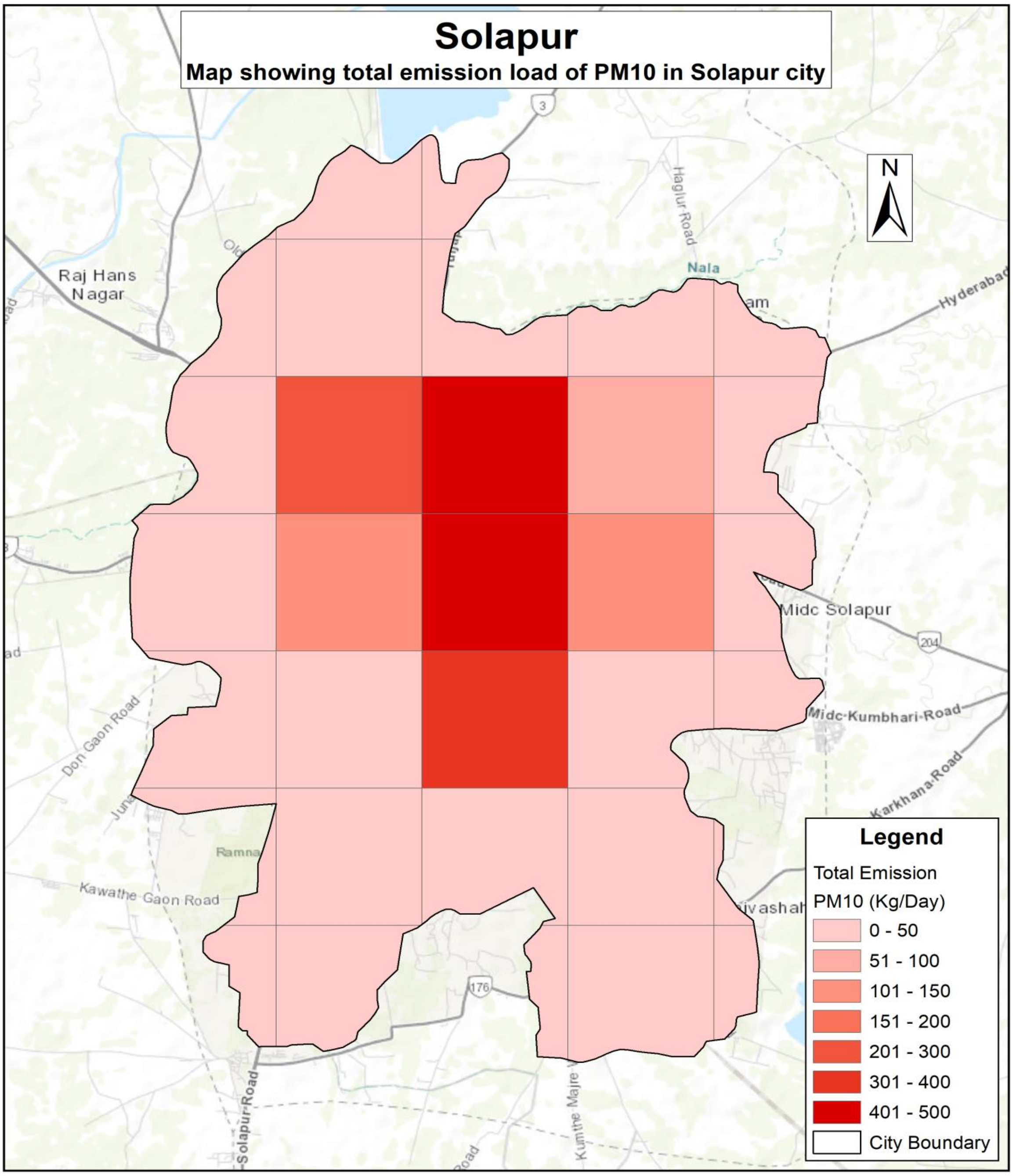


Figure 3.27 : Total Grid-wise Emission Load for PM_{10} (Kg/day).

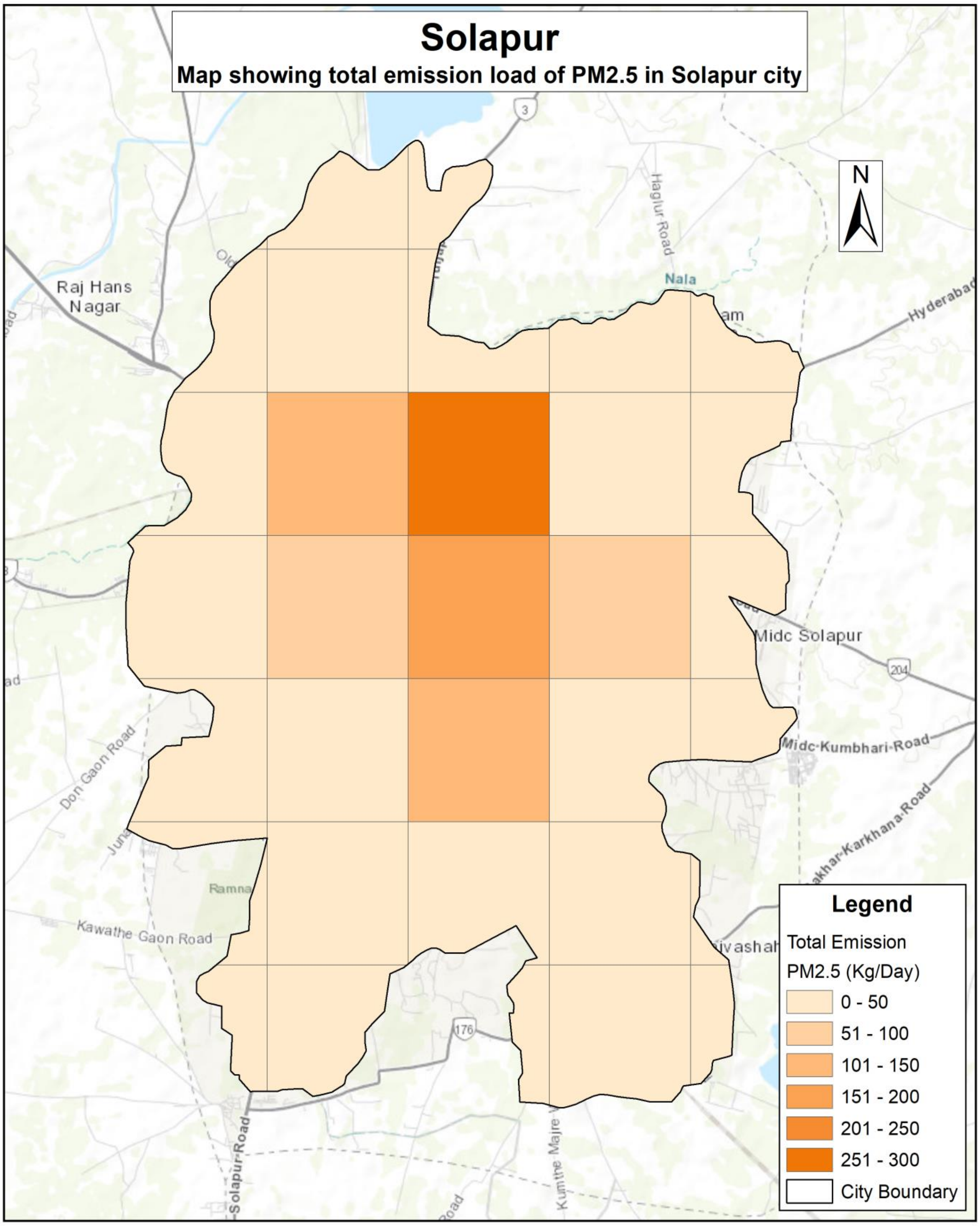


Figure 3.28 : Total Grid-wise Emission Load for $PM_{2.5}$ (Kg/day)

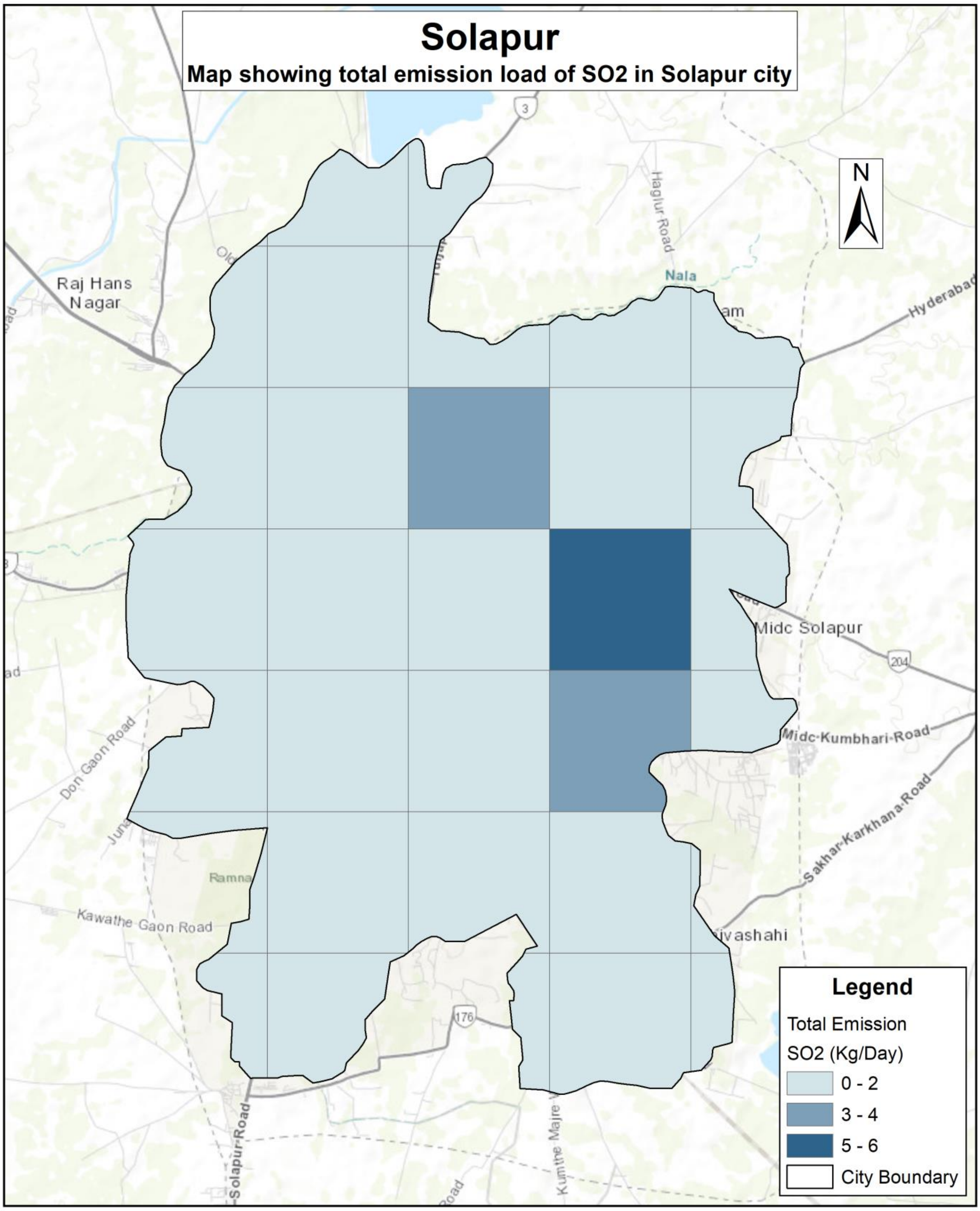


Figure 3.29 : Total Grid-wise Emission Load for SOx (Kg/day)

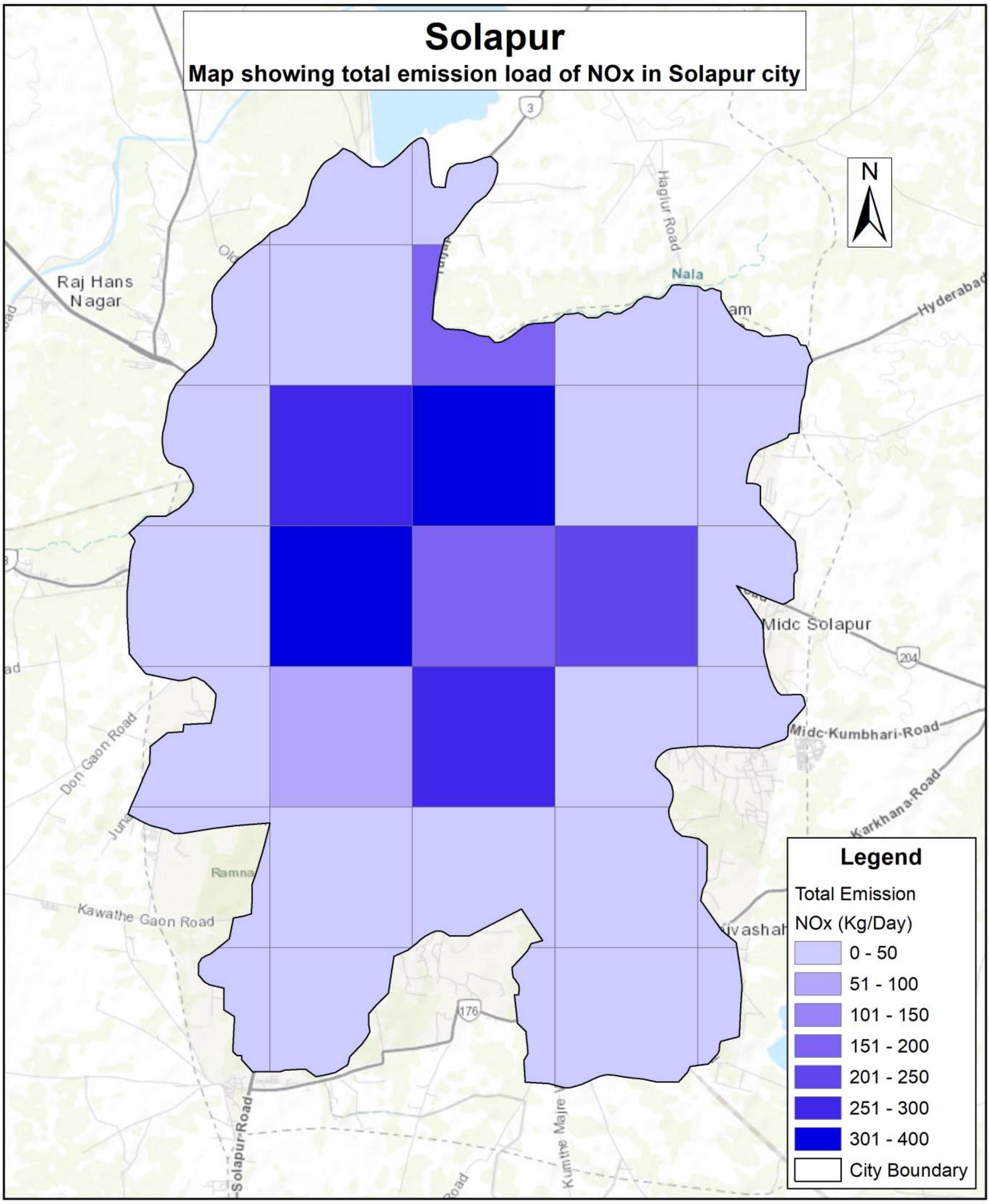


Figure 3.30 : Total Grid-wise Emission Load for NOx (Kg/day)

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study Using EPA PMF v5.0

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

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

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

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

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

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

4.2 Methodology

For the present study EPA PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for identification of sources and their positive contributions to ambient air pollution.

The study was carried out for representative samples of $PM_{2.5}$ and PM_{10}, collected between 8 May, 2019 to 16 May, 2019 sampling campaign at 3 locations: Walchand Institute; Municipal Council and Solapur University. The concentration and uncertainty data were obtained from the gravimetric analysis ($PM_{2.5}$ and PM_{10}); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (46 elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb, Bi, Th and In); and Ionic Analysis (9 ions: Na^+, NH_4^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, Br^-, $NO_3^{2-}$and SO_4^{2-}) for both PM_{10} and $PM_{2.5}$ for all sources as listed above.

EPA PMF requires 2 input files : 'Concentration' file and 'Uncertainty' file. The input file is prepared using concentration data set of samples and associated uncertainty and both these data sets should be in same format (csv or xls) with all the elements analysed for the study in same units (µg/m3). The Concentration file is prepared by multiplying the concentration data as well as the uncertainty (i.e., standard deviation of analysis) obtained in µg/cm2 with area of Filter paper (i.e., 11.9 cm2 @ 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 m3 , taking the sampling time as 24 hours @ 5lpm. Here note that PMF works on non-negative aspect so if the concentration of any species is below detection limit or zero then that value needs to be replaced by 0.5 x Minimum Detection Limit (MDL) of that species. The MDL of all the elements is given in **Table 4.1**.

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

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

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

These two files are then used as input for EPA PMF v5.0 software. The model uses input files to display the summary of concentration data species in the form of minimum value, 25th, 50th 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 error is minimum in strongest variable and maximum in weakest variable, those labelled bad are excluded from the analysis *(Paatero and Hopke, 2003; Jiang et al., 2015)*. The Species having S/N ratio more than 3 are assigned Strong, ratio between 1 to 3 are assigned as weak and species with 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 good solution and negligible influence of outlier whereas if 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 indicate better fit of the model to the measured data.

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

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

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

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

Elements (a)	**µg/cm^2**	**µg/m^3#**	**Ions (b)**	**PPM**	**µg/m^3#**
Ni	0.0030	0.007	Na^+	0.008	0.001
Cu	0.0050	0.012	NH_4^+	0.009	0.001
Zn	0.0020	0.005	K^+	0.02	0.003
Ga	0.0020	0.005	Mg^{2+}	0.02	0.003
Ge	0.0010	0.002	Ca^{2+}	0.03	0.004
As	0.0092	0.022	F^-	0.002	0.0002
Se	0.0010	0.002	Cl^-,	0.005	0.001
Br	0.0010	0.002	NO_2^-	0.01	0.001
Rb	0.0102	0.025	Br^-	0.02	0.003
Sr	0.0086	0.021	NO_3^{2-}	0.06	0.008
Y	0.0090	0.022	SO_4^{2-}	0.02	0.008
Zr	0.0100	0.024	**EC-OC (c)**	**PPM**	**µg/m^3#**
Mo	0.0104	0.025	EC	0.06	0.063
Rh	0.0108	0.026	OC	0.45	0.013

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

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

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

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

4.3 Results

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

4.3.1 PM_{10}

After the EPA PMF run analysis, 5 factors were identified in the study location for PM_{10} Samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and b)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for $PM_{2.5}$ and PM_{10} is presented in **Figure 4.2 (a to d).**

Factor 1: Biomass Burning /Industrial Emission

Factor 1 is identified as Biomass Burning /Industrial Emission, which accounted for contributions of 23.1% of the total load. The Major proportions of Factor Profiles (% of species sum) identified were K^+ (72.5%), Ca^{2+} (49.4%); while SO_4^{2-}, NH_4^+, Na^+, and Cr were in the range of 41% to 46%. The identified Minor proportions of Factor Profiles (% of species sum) for the factor were Na (30%); Mg, Al, K, Mn, Sn, Br (20% - 28%). There have been many studies in the past suggesting that K, EC, OC, Br, Cl and SO_4^{2-} are clear indicator of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016)*. Earlier studies reported that K, EC, OC, Al, Br etc., are the indicators of wood based and biomass based boilers for industrial process, probably in looms *(urbanemissions.info)*. Presence of heavy metals and location of industrial regions in some of this study area could be the possible reason of this source. NH_4^{-2} along with SO_4^{2-} have been widely used as a marker of coal combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. Factor 1 represented by collinearity of the species, which reflect the mix contribution from Biomass Burning and Industrial Emission.

Factor 2: Fossil Fuel Combustion/ Vehicular Emission/ Re-suspension of Road Dust

Factor 2 is represented by collinearity of the species, which reflect the mix contribution from Fossil Fuel Combustion, Vehicular and Resuspension Road Dust as sources, which accounted for 19.9% to the total PM_{10} mass. The significant level of contributions of Factor Profiles (% of species sum) is from NO_3^- (77%), Ca (61.5%); whereas SO_4^{2-}, Cl^-, EC (46% to 50%); Cl, OC, Pb, Br collectively share 20% to 30%. The Minor contribution of Factor Profiles (% of species sum) is from Zn, Mg, Ag, K^+ Na, Ca^{2+}, Mn, and Sn (10-20%). As per studies, EC, Br, K^+ and OC are the factors indicating emissions from burning of fossil fuel and vehicles *(Jain et al., 2018; Keerthi et al., 2018)*. S, Fe, Cl^- along with SO_4^{2-} has been widely used as a marker of fossil fuel combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016)*. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017)*. K, Mn, Sn and Ca are the good tracer of crustal dust *(Kothai et al., 2008)*; whereas substantial amount of paved road dust is being resuspended by vehicular movements which is indicated by minor markers such as Fe, Zn and Al are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*.

Factor 3: Vehicular Emission

Factor 3 is represented by Vehicular Emission, contributing around 17.1% of the total load. The Major Factor Profiles (% of species sum) identified are Mo (74%), Br^- and Cl (39 to 42%); As, EC, Ag and NH_4^+ (30% to 35%), and Br, Si and K (20% to 25%). The Minor Factor Profiles (% of species sum) identified were Sn, OC, Na, Cl-, Mn, Pb, Al and Mg. As per research paper Mo and Br are the indicators of the gasoline vehicle emission source *(Das R. et. al., 2015)*. Emissions from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of wear and tear of tyres and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Jain et al., 2017; Mukherjee et at., 2018, Pawar et al., 2020)*. Also, EC, Br and OC were present in this factor indicating emissions from burning of fossil fuel from vehicles *(Jain et al., 2018; Keerthi et al., 2018)*.

Factor 4: Industrial Emission/ Biomass burning/ Re-suspension of Road Dust

Factor 4 is represented by collinearity of the species, which reflect the mix contribution from Industrial Emission, Biomass burning and Re-suspension of Road Dust which accounted for 20.9% of the total. Major Factor Profiles (% of species sum) identified were As and Br^- (50%), Zn (47.2%), Pb (38.3%), Ca, Mn, Sn & Fe (30%), and Cr, Mg, OC, Na, Br & K (20% to 30%). Minor Factor Profiles (% of species sum) identified in the range of 10-20% were Cl, Si, Ag, EC, NH_4^+, Na^+ Al, K^+, Ti and Cl^-. There have been many studies in the past suggesting that K, EC, OC, Br, Cl and SO_4^{2-} are clear indicator of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016)*. Earlier studies reported that K, EC, OC, Al, Cu are the indicators of wood based and biomass based boilers for industrial process, probably in looms *(urbanemissions.info)*. Studies show 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)*. Fe, Ca, Na and Al are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*.

Factor 5: Secondary Aerosol /Construction Dust

Factor 5 is identified as Secondary Aerosol and Construction dust which accounted for contributions of 19.1%. Major Factor Profiles (% of species sum) are identified in the analysis were Ti, Al, Ca^{2+}, Fe, Mo, and Zn (~87.5%, 58.5%, 38.2%, 35.3%, 26%, and 21.5%). The Minor Factor Profiles (% of species sum) contributions is around 10% to 20% from NO_3^-, Mg, Na^+, Si, NH_4^+, Na, EC, Cl, OC, SO_4^{2-}. 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)*. Ca^{2+}, Mg, Si, 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)*. Several Construction activities like infrastructure development projects and renovation of old structures was observed in and around the city contributing to this source.

4.3.2 $PM_{2.5}$

After the EPA PMF run analysis, 5 factors were identified in the study location for $PM_{2.5}$ samples as shown below. The factor finger prints are shown in **Figure 4.1 (a and c)**. The final source contributions are shown in **Table 4.2**. Base factor profiles and their contributions for $PM_{2.5}$ and PM_{10} is presented in **Figure 4.2 (a to d)**.

Factor 1: Industrial Emission/ Secondary Aerosol / Biomass Burning

Factor 1 represented by collinearity of the species, which reflect the mix contribution from Industrial sources and Secondary Aerosol, which accounted for 26.8% to the total $PM_{2.5}$ mass. These sources couldn't be resolved further because of the overlapping factors. The Major Factor Profiles (% of species sum) are Cl^-, SO_4^{2-}, Na^+, EC and Br (~64.1%, 52.5%, 50.1%, 46.5% and 40.6%). Other Factor Profiles (% of species sum) were Cl, K, Mg, Ca, Na, Br^-, Ca^{2+}, K^+ were in the range of 30 to 40%. The Minor Factor Profiles (% of species sum) like NO_3^- and OC (25-30%), and Pb, Sn, Zn, Si, Al, NH_4^+ (10 to 15%) are also reported. The modal could not differentiate these sources as there were many overlapping species. S, Fe, Cl^- along with SO_4^{2-} has been widely used as a marker of Fossil fuel combustion in the vicinity. *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016)*. Earlier studies reported that K, EC, OC, Al, Cu are the indicators of wood based and biomass based boilers used for industrial process, probably in looms *(urbanemissions.info)*. The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols *(Sharma et al., 2016; Jain et al., 2017, Mukherjee et at., 2018; Garaga et al., 2020)*. 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)*. Past studies suggesting that K, EC, OC, Br, Cl and SO_4^{2-} are clear indicator of biomass burning *(Shukla and Sharma, 2008; Police et al., 2016.)*

Factor 2: Re-suspension of road dust/ Construction Dust

PMF analysis fractionate Factor 2 as Re-suspension of road dust and Construction Dust accounting for 17.8%, the Major Factor Profiles (% of species sum) are Al, Mn, Cr, Fe, Si, Cl^-, Br, Sn and OC (~54.7%, 36.4%, 34.1%, 33.4%, 33.0%, 31.5%, 31.3%, 28.4% and 27.6%). The Minor Factor Profiles (% of species sum) are Mg, Na, Ca, Cl, Zn and Pb. As per past studies, Mn, Si, Cr and Ca are significant tracer of crustal dust *(Kothai et al., 2008; Patil et al., 2013; Keerthi et al., 2018; Garaga et al., 2020)*, whereas substantial amount of paved road dust is being re-suspended by vehicular movements which is indicated by minor markers such as Pb, Zn and Al are indicators of road dust re-suspension *(Jain et al., 2017, Pawar et al., 2020)*. Road dust gets re-suspended due to natural gust of winds or moving objects like vehicles *(Zhang, 2008; Kothai, 2011; Banerjee et al., 2015; Ashrafi et al., 2018)*. Since the study was done in dry conditions wind-blown dust has large influence on this source. Ca, Si, Ca^{2+}, Mg, Cl^- are major indicators of construction dust from cement and aggregate mixing *(Patil et al., 2013; Buyan, 2018; Jain et al., 2018; Keerthi et al., 2018, Garaga et al., 2020)*. Construction dust is mainly contributed from all infrastructure development projects going in and around the city.

Factor 3: Vehicular Emission/ Secondary Aerosol

Factor 3 is identified as Vehicular Emission and Secondary Aerosol due to collinearity of the species, which reflect the mix contribution, which accounts for 16.1% of the total. Major Factor Profiles (% of species sum) identified are NH_4^+, Br^-, Sn, SO_4^{2-}, Na (~84.1%, 34.5%, 30.8%, 24.4% and 23.2%), others are Pb, Cr, Mn, Cl (20-25%). The Minor Factor Profiles (% of species sum) are NO3-, Mg, As, K, Fe, OC, Zn and EC were identified for this factor. Emissions from road vehicles are generally caused by a combination of exhaust emissions and tyre wear and tear. Zn is commonly employed as a lubricant additive in two-stroke engines and is also a major trace metal component of tyre wear and tear, whereas Pb is a measure of emissions from automobiles' engines, whereas Zn and Fe are deposited by vehicular emissions *(Shukla and Sharma, 2008; Jain et al., 2017; Mukherjee et at., 2018, Pawar et al., 2020)*. The studies indicated that NO_3^{2-}, NH_4^{2-} and SO_4^{2-} are major indicators for secondary aerosols *(Patil et al., 2013; Police et al.,2016; Sharma et al., 2016; Jain et al., 2017, Mukherjee et at., 2018; Garaga et al., 2020)*.

Factor 4: Industrial Emission/ Crustal Earth Dust

Factor 4 represent as mix source reflecting Industrial Emission and Crustal Earth Dust which contributing around 17.1%. The Major Factor Profiles (% of species sum) are Ti, As, Fe, Cr, Pb, Sn, Na^+ and Si (~93.6%, 49.1%, 35.4%, 28.3%, 28%, 22.8, 22.6% and 22.2%). The Minor Factor

Profiles (% of species sum) identified are Br-, Cl, Mn, Mg, SO_{42-}, K, Zn, Na and OC. S, Cl^- along with SO_4^{2-} have been widely used as a marker of coal combustion *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018)*. Earlier studies reported that K, EC, OC, Al, Cu are the indicators of wood based and biomass based boilers for industrial process, probably in looms *(urbanemissions.info)*. Location of industrial regions in some of this study area could be the possible reason of this source. Earlier studies indicate Ca, Mg, Ti and Fe are major indicators of crustal dust/ soil *(Kothai et al., 2008; Sharma et al., 2016; Jain et al., 2017; Mukherjee et al., 2018; Pawar et al., 2020)*. K, Mg, Si and Ca are good tracer of crustal dust *(Kothai et al., 2008; Patil et al., 2013; Jain et al., 2017; Keerthi et al., 2018; Garaga et al., 2020)*

Factor 5: Fossil Fuel Combustion/ Wind Blown Dust

Factor 5 is identified as Fossil Fuel Combustion/ Wind Blown Dust due to collinearity of the species, which reflect the mix contribution, which accounts for 22.2% of the total. The Major Factor Profiles (% of species sum) contributing to the source are Zn, K^+, Ca^{2+}, Ca, EC, Al, and Pb (~59.6%, 57.4%, 57%, 55.1%, 43.5%, 36%, and 29.6%). The Minor Factor Profiles (% of species sum) for this source are Si, OC, Mn, Na^+, Fe, Na, Cl, Cr, Mg and SO_4^{2-}. Earlier studies reported as S, Fe, Cl^- along with 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)*. Since the study was done in dry conditions windblown dust has large influence on this source. Substantial amount of paved road dust is being resuspended by vehicular movements which are indicated by minor markers such as Fe, OC and Al are indicators of road dust re-suspension *(Zhang, 2008; Kothai, 2011; Jain et al., 2017, Pawar et al., 2020)*.

Table 4.2 : Percentage Source Contribution for Solapur

Most likely source(s)	PM_{10}	Most likely source(s)	$PM_{2.5}$
Biomass Burning / Industrial Emission	23.06	Industrial Emission/ Secondary Aerosol / Biomass Burning	26.81
Fossil Fuel Combustion/ Vehicular Emission/ Re-suspension Road Dust	19.89	Re-suspension of road dust/ Construction Dust	17.75
Vehicular Emission	17.08	Vehicular Emission/ Secondary Aerosol	16.05
Industrial Emission/ Biomass Burning/ Re-suspension of Road Dust	20.86	Industrial Emission/ Crustal Earth Dust	17.14
Secondary Aerosol / Construction Dust	19.11	Fossil Fuel Combustion/ Wind Blown Dust	22.25

4.4 Positive Matrix Factor Analysis Conclusion

After PMF analysis, five factors were identified contributing to both fraction of the PM. The identified factors are co-existing; modal could not differentiate the sources due to many overlapping species. Both source categories were found to be contributing almost the same for both $PM_{2.5}$ and PM_{10}. The imprecise contribution of Resuspended Road Dust is around (~17-19%), Secondary Aerosol (~16-19%) Vehicular Emission (~16-17%), Biomass Burning (~23-26%) and Fossil Fuel Combusti

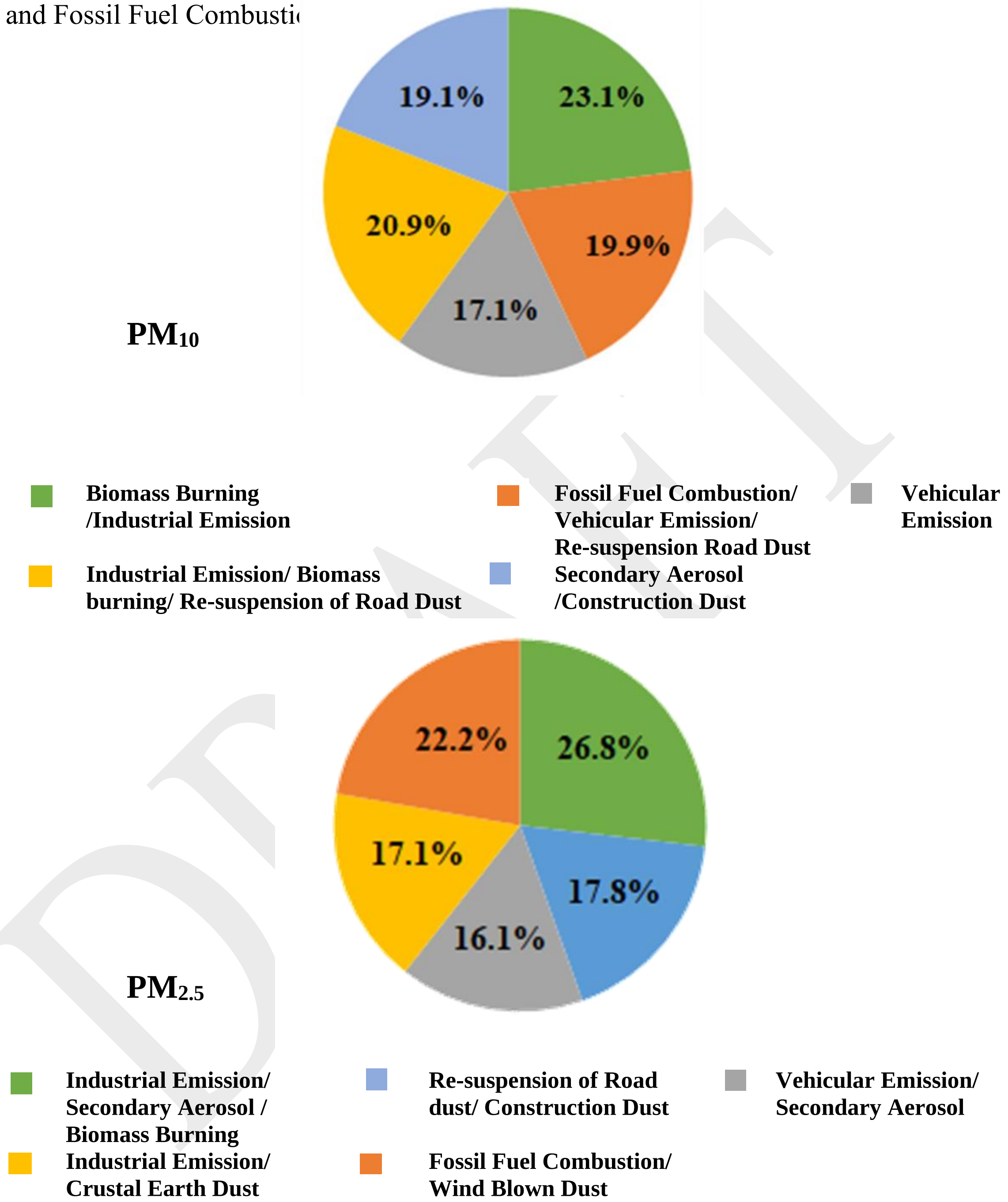
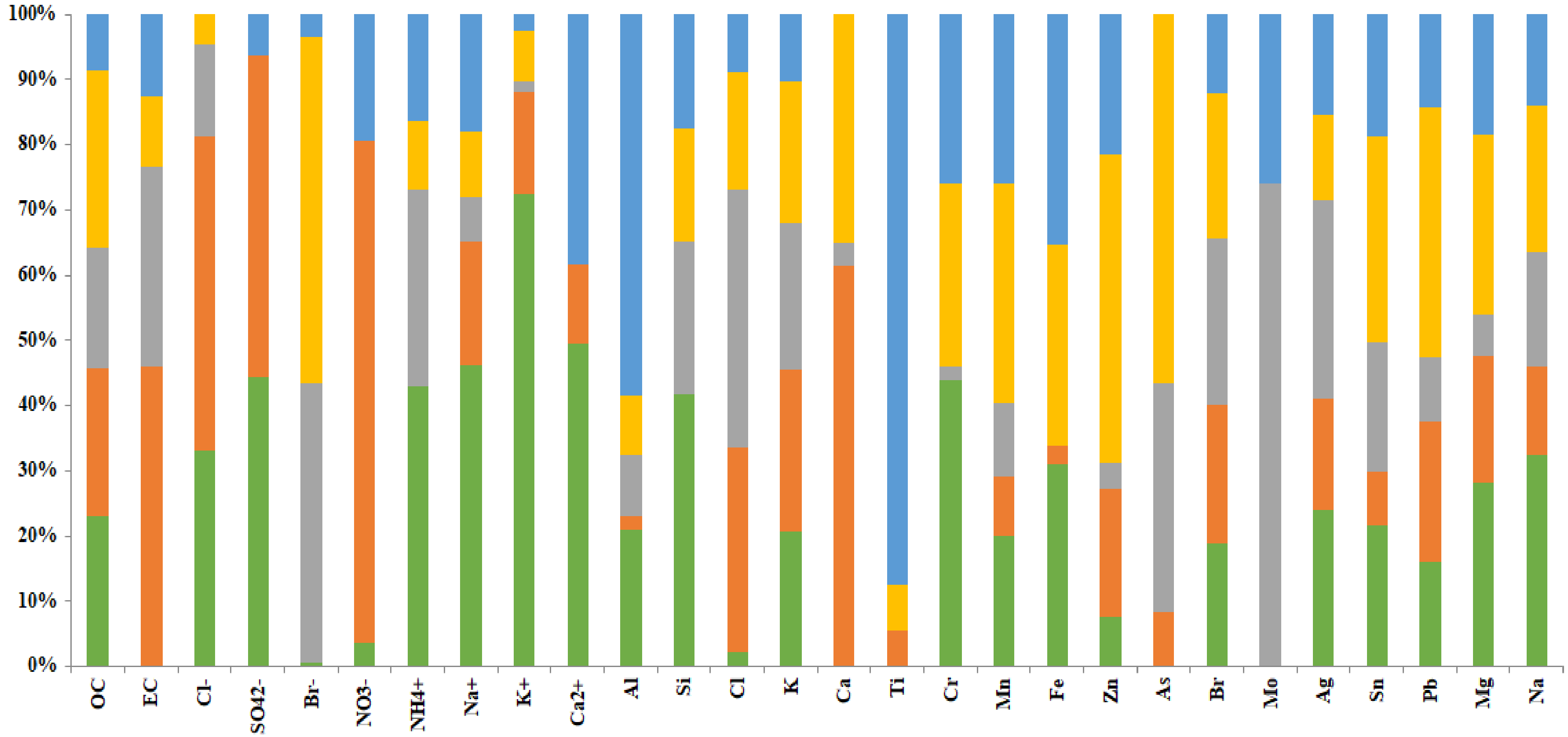


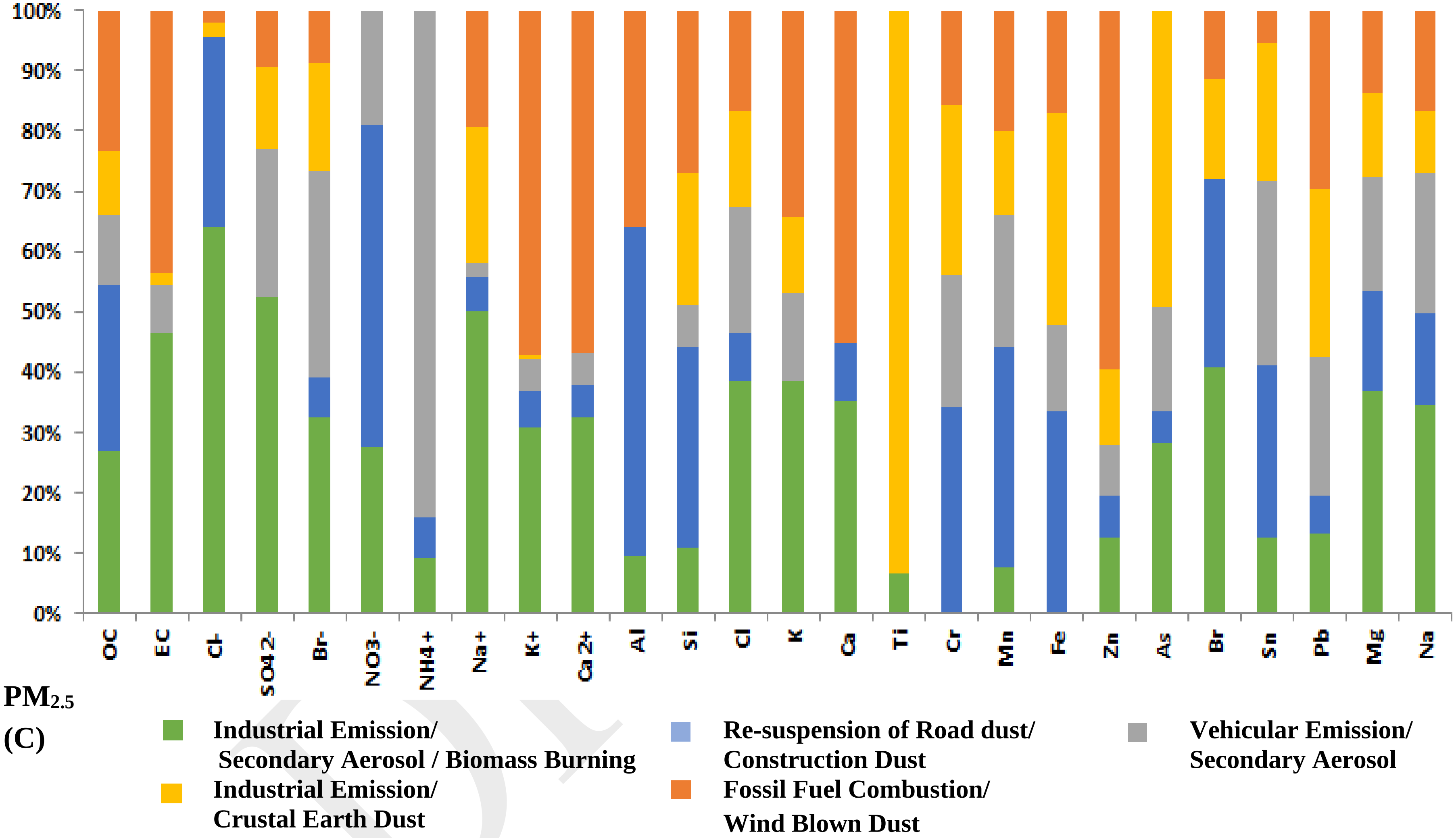
Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Solapur City



PM_{10} (B)

- **Biomass Burning /Industrial Emission**
- **Fossil Fuel Combustion/ Vehicular Emission/ Re-suspension Road Dust**
- **Vehicular Emission**
- **Industrial Emission/ Biomass burning/ Re-suspension of Road Dust**
- **Secondary Aerosol /Construction Dust**

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



$PM_{2.5}$ (C)

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

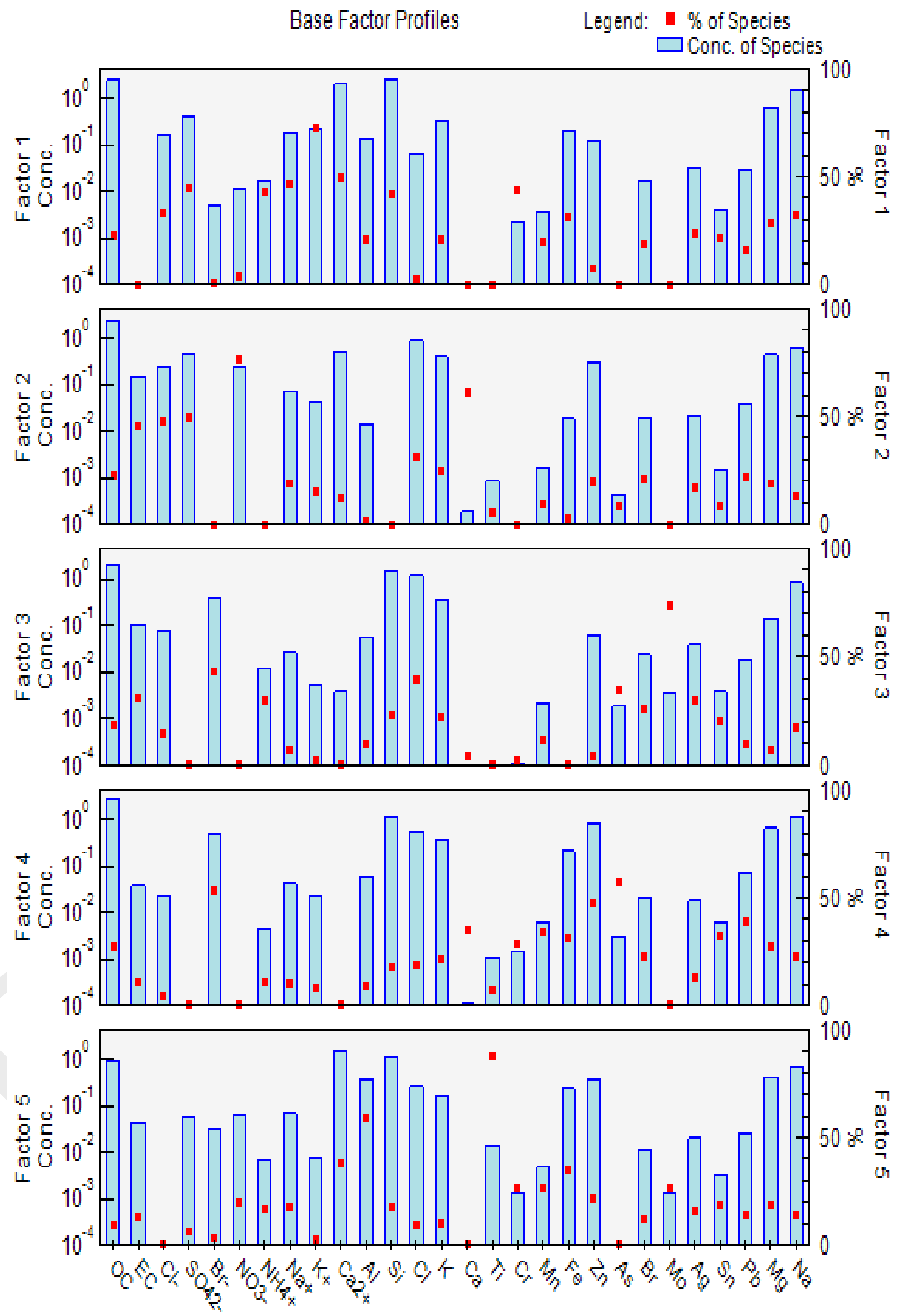


Figure 4.2 a : PM_{10} Base Factor Profiles

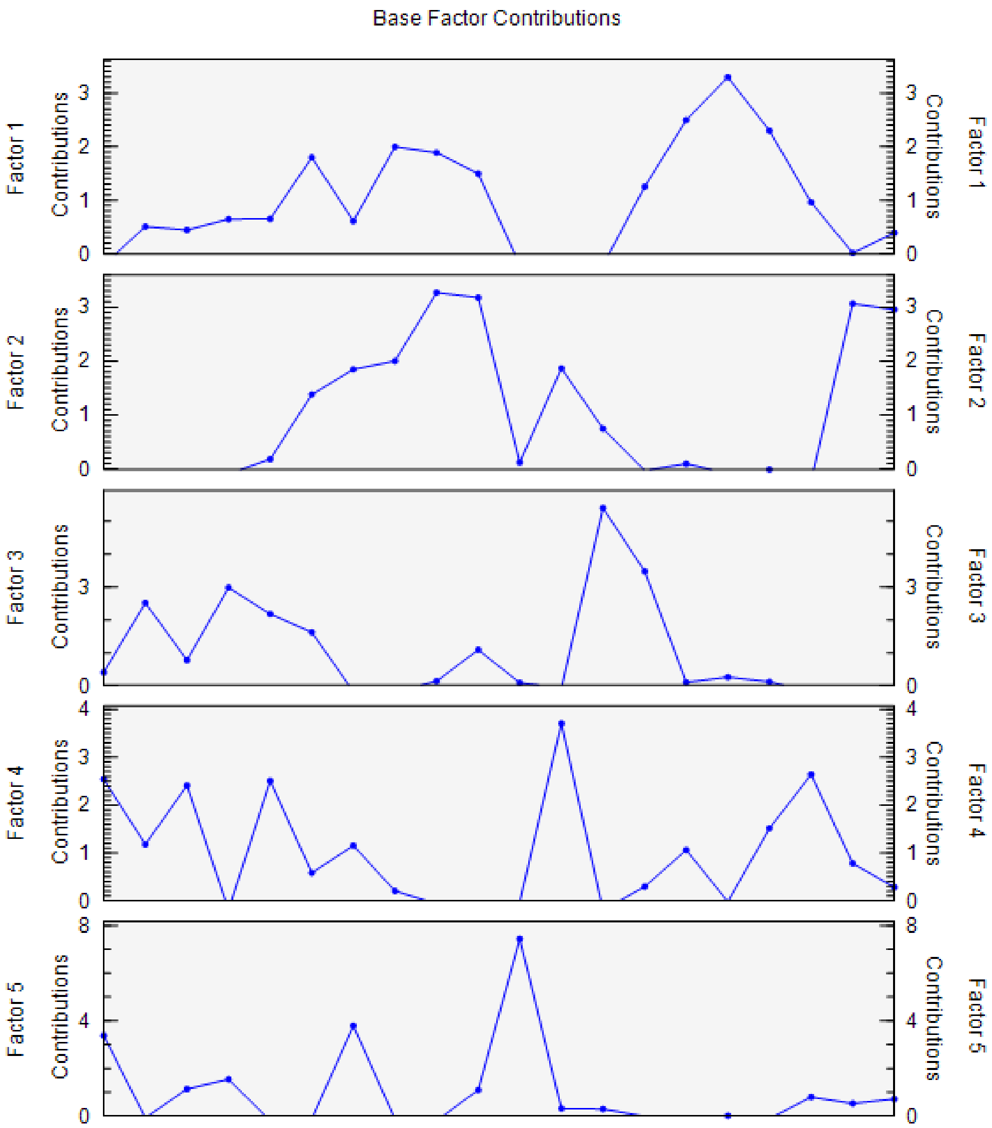


Figure 4.2 b : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	K^+, Ca^{2+}, SO_4^{2-}, NH_4^+, Na^+, Cr *Na, Mg, Al, K, Mn, Sn, Br*	23.06	Biomass Burning / Industrial Emission
Factor 2	NO_3^-, Ca, SO_4^{2-}, Cl^-, EC, Cl, OC, Pb, Br *Zn, Mg, Ag, K^+ Na, Ca^{2+}, Mn, Sn*	19.89	Fossil Fuel Combustion/ Vehicular Emission/ Re-suspension Road Dust
Factor 3	Mo, Br^-, Cl, As, EC, Ag, NH_4^+, Br, Si, K *Sn, OC, Na, Cl-, Mn, Pb, Al, Mg*	17.08	Vehicular Emission
Factor 4	As, Br^-, Zn, Pb, Ca, Mn, Sn & Fe, Cr, Mg, OC, Na, Br & K *Si, Ag, EC, NH_4^+, Na^+ Al, K^+, Ti, Cl^-*	20.86	Industrial Emission/ Biomass Burning/ Re-suspension of Road Dust
Factor 5	Ti, Al, Ca2+, Fe, Mo, Zn, *Cl* *NO_3^-, Mg, Na^+, Si, NH_4^+, Na, EC, OC, SO_4^{2-}*	19.11	Secondary Aerosol / Construction Dust

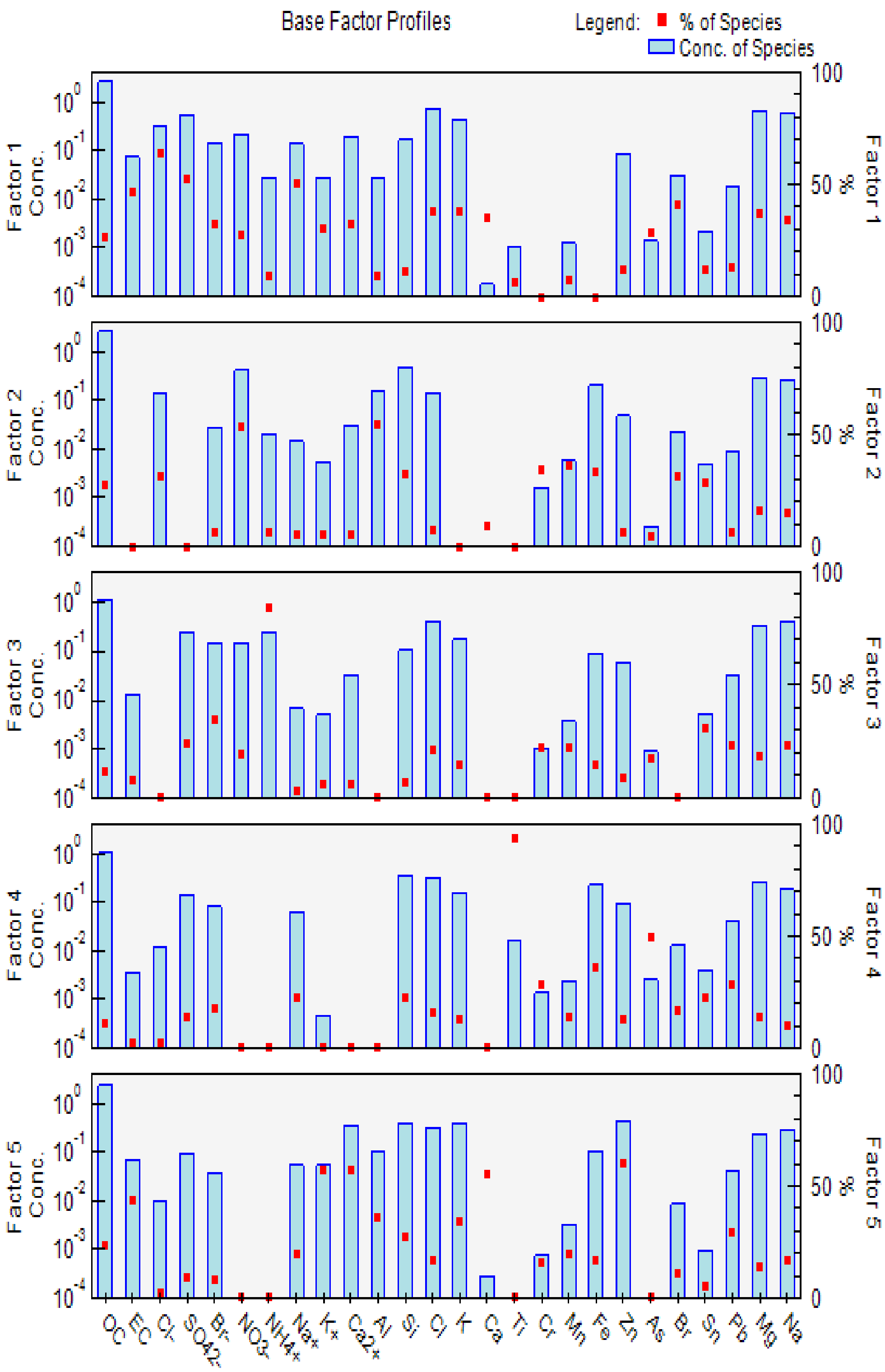


Figure 4.2 c : $PM_{2.5}$ Base Factor Profiles

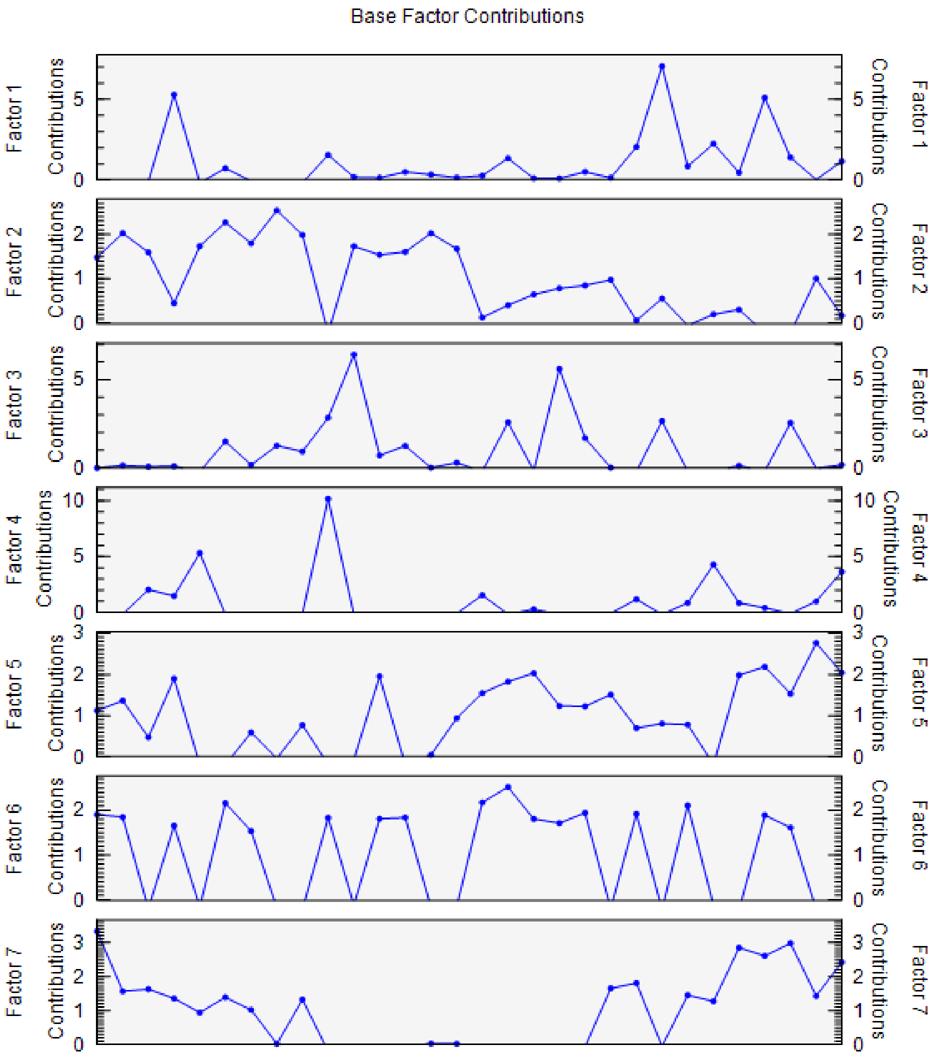


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	Cl^-, SO_4^{2-}, Na^+, EC, Mg, Ca, Na, Br^-, Ca^{2+}, K^+ *NO_3^-, OC, Pb, Sn, Zn, Si, Al, NH_4^+*	26.81	Industrial Emission/ Secondary Aerosol / Biomass Burning
Factor 2	Al, Mn, Cr, Fe, Si, Cl^-, Br, Sn, OC Mg, Na, Ca, Cl, Zn, Pb	17.75	Re-suspension of road dust/ Construction Dust
Factor 3	NH_4^+, Br^-, Sn, SO_4^{2-}, Na Pb, Cr, Mn, Cl *NO_3^-, Mg, As, K, Fe, OC, Zn, EC*	16.05	Vehicular Emission/ Secondary Aerosol
Factor 4	Ti, As, Fe, Cr, Pb, Sn, Na^+, Si *Br^-, Cl, Mn, Mg, SO_4^{2-}, K, Zn, Na, OC*	17.14	Industrial Emission/ Crustal Earth Dust
Factor 5	Zn, K^+, Ca^{2+}, Ca, EC, Al, Pb *Si, OC, Mn, Na^+, Fe, Na, Cl, Cr, Mg, SO_4^{2-}*	22.25	Fossil Fuel Combustion/ Wind Blown Dust

4.5 Emission Inventory and Source Apportionment

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

The highest contribution of PM_{10} is estimated from Area source (56.1%), followed by Industrial source (36.4%) and Line source (7.6%). Accounting all the Area sources in the region, the total emission load from Area Source is estimated to be around 1.5 TPD and that of $PM_{2.5}$ is around 0.8 TPD. The significant amount of emission load from area source is mainly from Brick Kiln (44.3%) and Bakeries (42.9%). The Industrial source emission load of PM_{10} was calculated to be around 1 TPD and $PM_{2.5}$ of around 0.35 TPD. Line sources of the study area contribute around 0.2 TPD of PM_{10} and 0.09 TPD of $PM_{2.5}$.

Most of the factors identified in source apportionment study of Solapur City were observed to be in as mix contribution form, which reflected collinearity of the factor species from different sources. Hence, couldn’t be further resolved to particular source of emission load in the vicinity. The highest contributing source identified in source apportionment study for PM_{10} is from mix of Biomass Burning & Industrial Emission (23.06%) and that for $PM_{2.5}$ is identified as mix of Industrial Emission, Secondary Aerosol, & Biomass Burning (26.8%). In PM_{10}, other major sources identified from the proportion of factor profile are mix of Industrial Emission, Biomass Burning & Re-suspension of Road Dust (20.9%), mix of Fossil Fuel Combustion, Vehicular Emission & Re-suspension Road Dust (19.9%), mix of Secondary Aerosol & Construction Dust (19.1%), and from Vehicular Emission (17.1%). While for $PM_{2.5}$, the other sources identified are mix of Fossil Fuel Combustion & Wind Blown Dust (22.3%), mix of Re-suspension of road dust & Construction Dust (17.8%), mix of Industrial Emission & Crustal Earth Dust (17.2%) and mix of Vehicular Emission and Secondary Aerosol (16.1%).

The 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. Because of the dispersion of smoke and emission in the direction of the wind and the prevailing meteorological conditions in the city, biomass burning in the area of Solapur city results in a significant pollution load at ground level in the city. As major infrastructural development is being carried out in the city, the contribution of construction dust and its re-supension, in total emission load is significant. Frequent open burning cases in Solapur have resulted in higher SPM and other air pollutants. Smaller commercial establishments and households use DG sets that operate mostly on kerosene, which is a cause of pollution in Solapur due to unburned hydrocarbons and carbon monoxide. Vehicle tail pipe emission, wear and tear, and resuspension of road dust from movement of these vehicles are one of the considerable sources of emission load. Slum inhabitants rely on any cheap fuel that becomes available to them, such as wood, bagasse, sawdust, discarded paper/boards, or any other garbage. Slum inhabitants add to air pollution from domestic sources because they use any available fuel. Use of different cooking fuels for cooking (liquefied petroleum gas (LPG), charcoal and wood) in tandoors/barbeques in hotels, open eat outs and restaurants generates emissions of different pollutants. Other major local sources of PM levels at this location are the combustion of different types of fossil fuels, oils etc in industrial processes and application. The major type of industries in the study area are textile manufacturing & power looms, food products and beverages and manufacturing of basic metals, chemical & chemical products are the key types of industries in the study area. The combustion of various types of fossil fuels, biomass, oils, etc as fuel in these industrial processes and applications are also substantial local sources of PM levels at this location. Brick kilns are one of the largest consumers of coal and were estimated to be significant contributor in emission inventory of the city and confirmed as contributing source.

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Chapter 5

Source Dispersion Modeling

5.1 Overview

Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by single or multiple sources. Air quality dispersion modeling has been undertaken with a view to identify the impact and the important sources on ambient air quality in Solapur 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 Solapur 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 Solapur city. Monthly windrose diagram is plotted and the same is shown in **Figure 5.1**. It can be seen that January to March is a period of very low wind with predominant wind from East. Strong winds starts in April from North-West. Gradually the summer sets with predominant wind of more than 6 m/s from the West. In order to understand the monthly variation of wind speed, its frequency distribution is plotted and is shown in **Figure 5.2**. It can be seen that April to August shows very high wind speed where as for other months, the wind speed is relatively lower.

5.4 Modelling Domain & Result

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

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

Parameter	Regulatory Stand.[μg/m^3]	Area Emission	Industry Emission	Vehicle Emission	City Emission
PM_{10}	**100**	1467.1	952.0	197.8	2616.9
$PM_{2.5}$	60	751.8	354.0	84.82	1190.6
SO_2	80	463.4	7.6	0	471.0
NOx	80	93.3	1.5	2037.6	2132.5

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

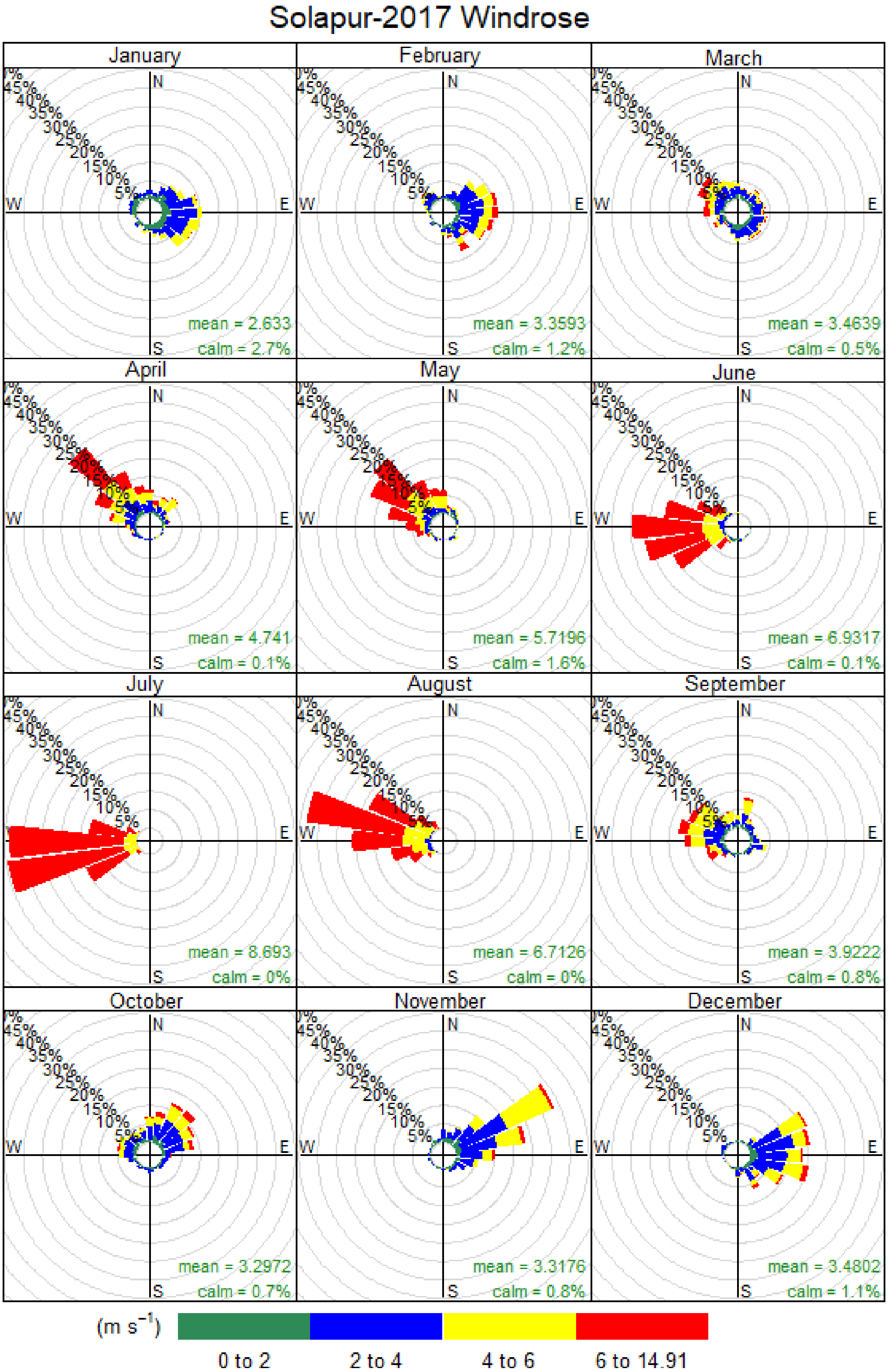


Figure 5.1 : Monthly Windrose Diagram of Solapur City

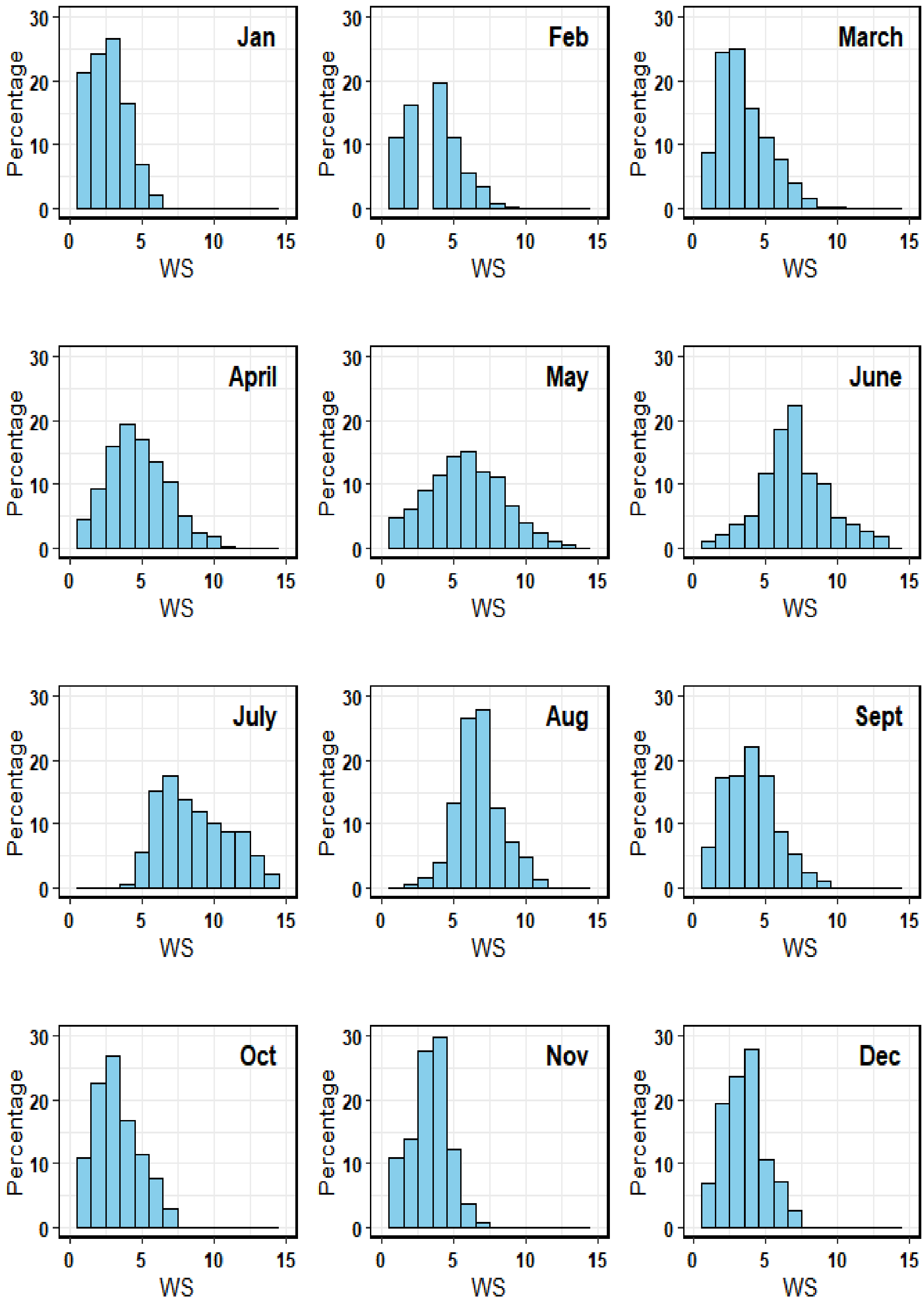


Figure 5.2 : Monthly Windrose Diagram in Solapur City

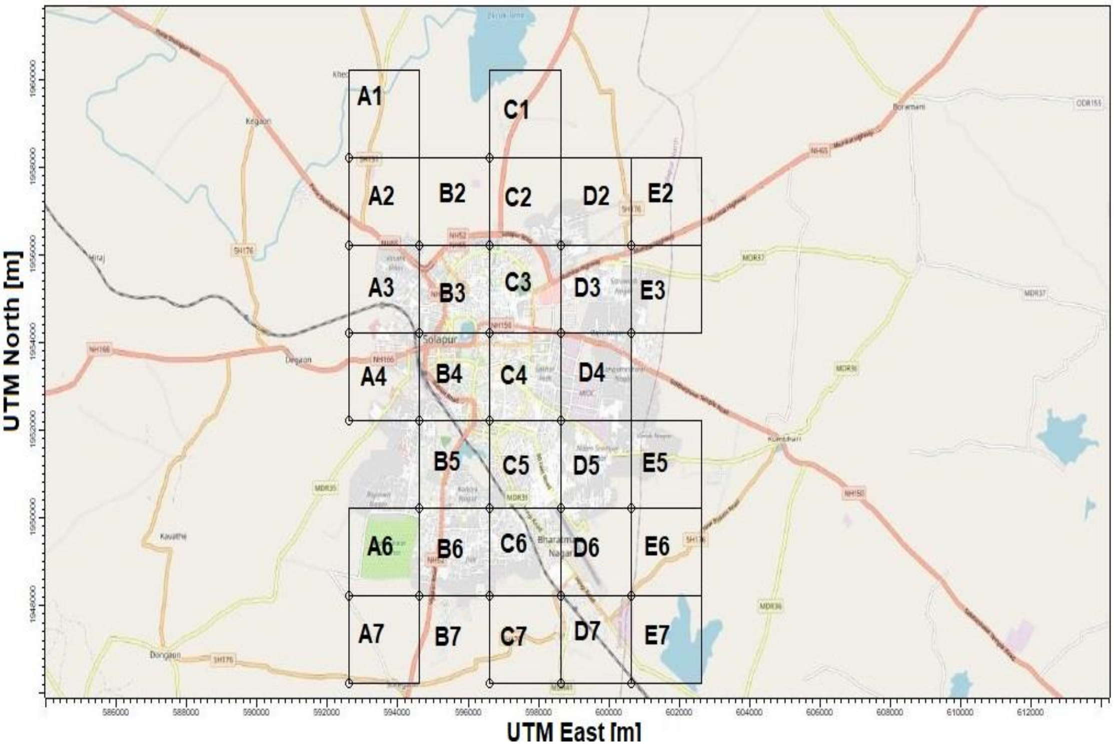


Figure 5.3 : Grid Map Solapur City for Area Source Emission

Area source emission rate is estimated by first adding all emissions within a grid in terms of gram per second, followed by its division with the area of grid i.e. 2000 m x 2000 m. This yields emission of pollutants in terms of g/s/m^2 **(Figure 5.3)**. **Table 5.2** shows the grid wise emission rate of PM_{10} in Solapur.

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

No.	ID	Emission Rate [g/s/m^2]	No.	ID	Emission Rate [g/s/m^2]
1	A1	0.00	16	C5	376.87
2	A2	0.00	17	C6	6.19
3	A3	5.72	18	C7	0.00
4	A4	0.18	19	D2	0.03
5	A6	0.00	20	D3	56.56
6	A7	0.01	21	D4	103.12
7	B2	0.00	22	D5	36.16
8	B3	220.86	23	D6	0.00
9	B4	130.34	24	D7	0.04
10	B5	18.72	25	E2	0.00
11	B6	12.32	26	E3	0.13
12	C1	0.10	27	E5	0.07
13	C2	18.89	28	E6	0.00
14	C3	409.27	29	E7	0.04
15	C4	451.66			

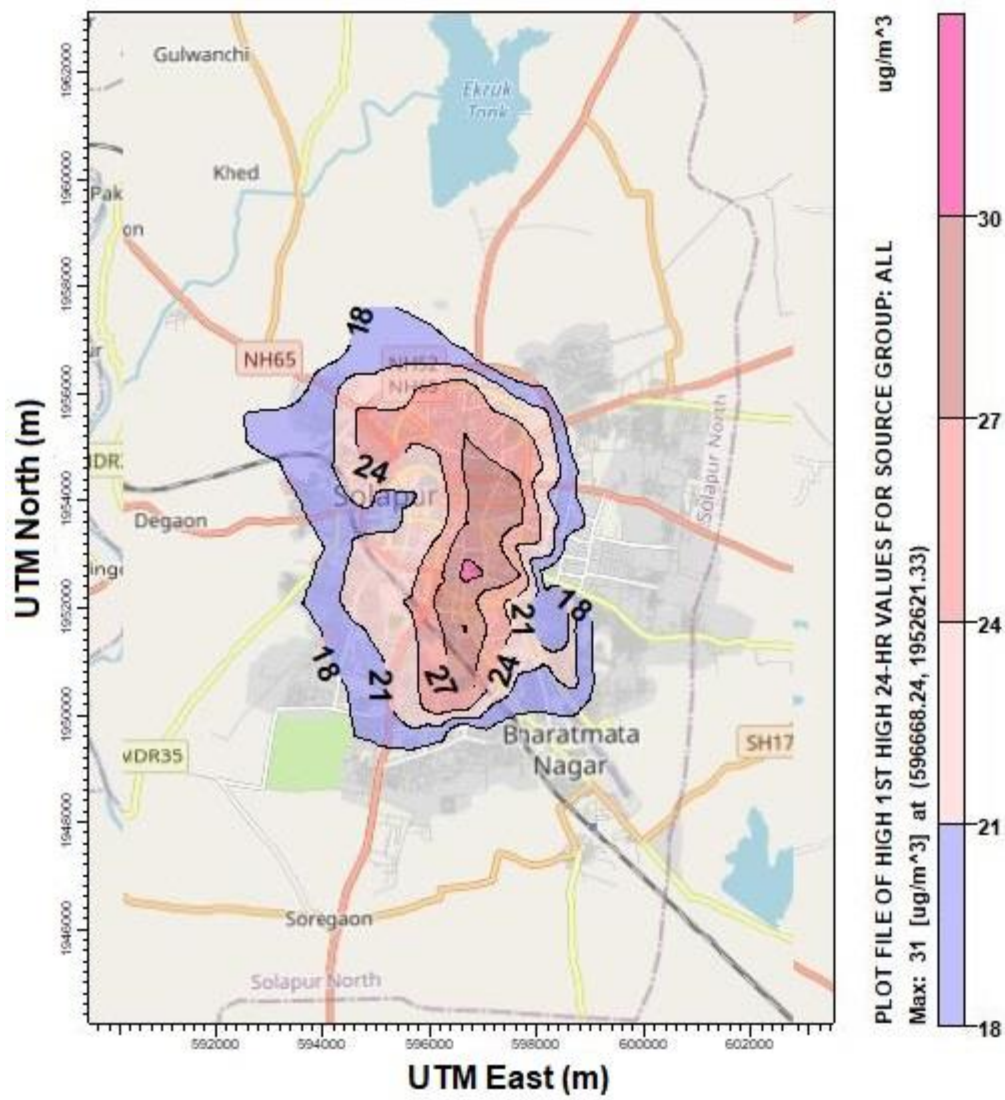


Figure 5.4: Isopleth of GLC of PM_{10} Over Solapur City Due to Area Source Emission

Simulation using AERMOD yields maximum ground level concentration less than 50 μg/m^3 **(Figure 5.4)**. Since this value is lower than the regulatory limit, all other pollutant's GLC will be below the regulatory limit value.

Chapter 6

Action Plan for Control of Air Pollution

6.1 Emission Reduction Action Plan for Solapur City

Major source of air pollution in Solapur city is:

- Household emission
- Industrial Emission
- Vehicular emission

Minor emission is from

- Road dust re-suspension
- 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

Sources	*Action Required*
Line Sources	• Inspection/maintenance of all commercial vehicles. Restrict commercial vehicle entering city by having ring roads. • Retro-fitment of Diesel Particulate Filter in 4- wheeler public transport. • With proper maintenance of 2 wheelers, the emissions are assumed to be same in spite of increase in number of vehicles. • For reducing the traffic congestion, no parking zones at the traffic areas need to be delineated. Roads hindering the smooth traffic movement need to be identified and either may be closed and traffic may be diverted or some other suitable option may be exercised. Roads need to be identified for widening. • Maintain potholes free roads for free flow of traffic. Introduce bi-cycle tracks/paths and encourage the use of bi-cycles. • Launch public awareness campaigns for air pollution control, vehicle maintenance, minimizing use of personal vehicles, lane discipline etc. NGOs need to be involved for this purpose. • Immediate launch of extensive fuel adulteration drive and random monitoring of fuel quality data.
Point Sources	• Industries are mostly in the outskirt of the city and uses wood for heating water in the boiler. It is less likely that such small scale water heating system would shift to high quality fuel. • Brick kilns: Shifting of natural draft brick kilns to induced draft, banning of operation of Brick kilns in city area is envisaged for the emission reduction.

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

Sources	***Action Required***
Area Sources	• Domestic: Majority of household uses LPG and only about 37% of house hold uses wood and kerosene that can be shifted to LPG. • Most of the cities are characterised by rich urban centres to economically weaker periphery. Central areas are mostly multi storied houses having high population density. Government land, corridor along rail line, road, water bodies are encroached and occupied by slums. Slums occupy horizontal space thereby wasting useful vertical space. Housing for slum can be planned and initiated. This will solve other pollution issues too. Some of the measures required for reduction of PM emissions are: ▪ Roads require re-carpeting and constructed pedestrian pathways. ▪ Encroachment from pedestrians walk way needs to be removed. ▪ The slums needs to be shifted beyond the pedestrian walkway as for smooth traffic flow, there should be sufficient space between the edge of pedestrian walk way and the houses. ▪ The slum dwellings are very small and congested. When they come out of there dwellings, it directly opens up on the road. Whereas for a dwelling of relatively higher income group, there is space within the boundary of house and therefore they confine themselves within their boundary. ▪ Slum is mostly government land and needs to be regularized. However, these houses need not be very small as it will again lead to encroachment outside the windows and gallery of upper story dwellings. • Bakery/hotels/eateries: In bakeries, reduction in wood usage is to be emphasized through replacement with other options such as electric-ovens. Use of LPG in hotels and eateries. • Crematoria: Renewable fuel/biomass briquette etc. in Crematories to be encouraged. • Solid Waste Management: In order to avoid the future emissions from solid waste burning, the following is suggested. ▪ Increase in segregation, collection and proper disposal with increased Green Belt. ▪ Launch extensive drives against open burning. Decrease in waste burning. Public awareness drives. ▪ Proper collection of Horticulture waste and its disposal following composting-cum-gardening approach.

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

Sources	*Action Required*
	• Road dust and Construction: ▪ Enforcement of construction & demolition rules. ▪ Reduction in unpaved roads by paving. ▪ Plantation drive along the road side, Greening of open areas, garden, community places, schools and housing societies. ▪ Wall to Wall paving (brick). ▪ Ensure carriage of construction material in closed/covered Vessels. Control measures for fugitive emissions from material handling, conveying and screening operations through water sprinkling, curtains, barriers and suppression units.

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)

Annexure – I

Design of a Clean Tandoor Community Kitchen System (CTCKS)

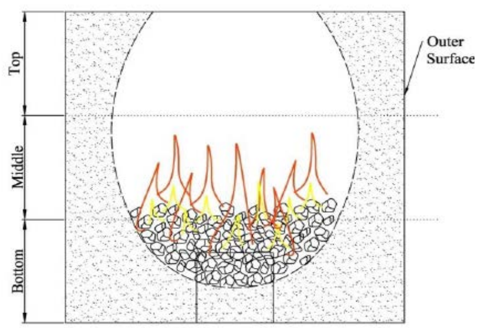
Design of a Clean Tandoor Community Kitchen System (CTCKS)

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

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

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

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



Classification of Temperature Zones in Tandoor Bhatti

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

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

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

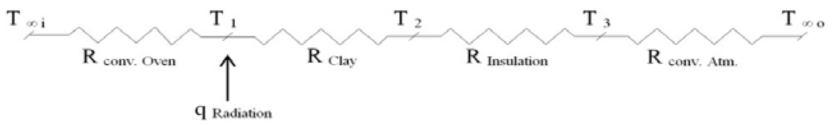
Advantages of pellet based tandoor also leads to reduced ash generation. Pellets based tandoor will also generate market for pellet industry and enable the use of agro-waste residues for development of an alternative fuel, promote employment generation in rural areas and would partly contribute to emission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

Design Methodology

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

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

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



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

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

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

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

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

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

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

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

Design of Forced Draft Stove

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Tandoor Design Details

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

Illustrative materials for different parts of CTCKS

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

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

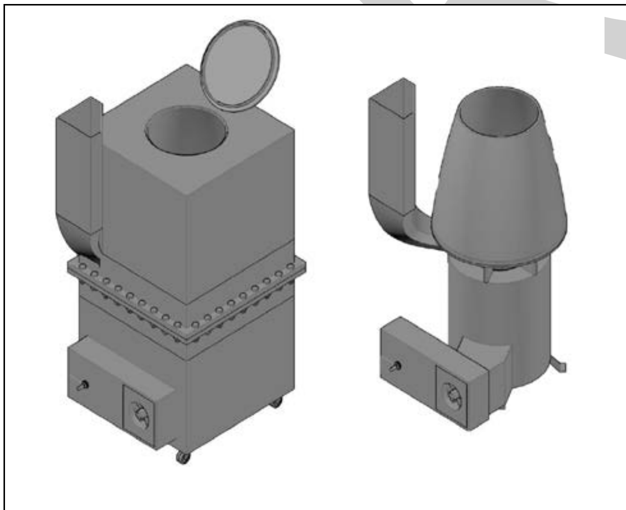
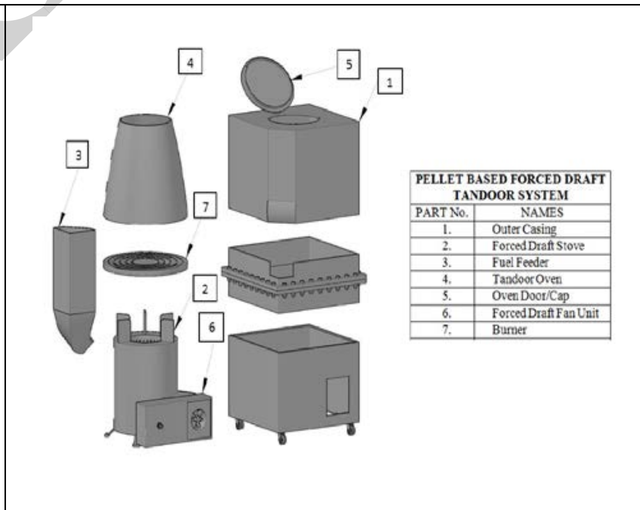
	

Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing	Fig. 2 Exploded view CTCKS: Inner Assembly & Outer Casing

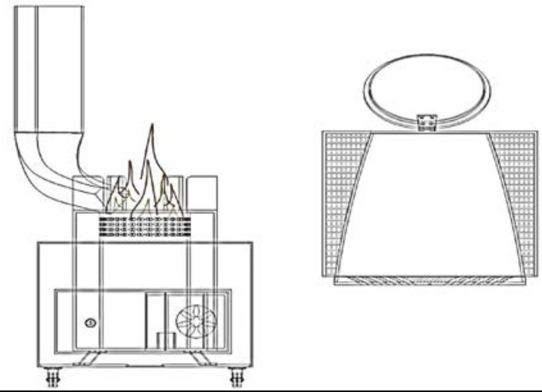
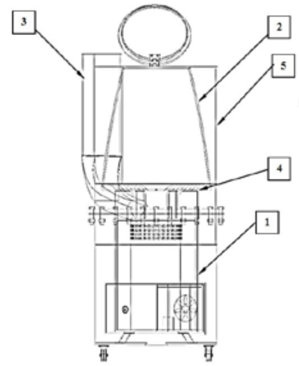
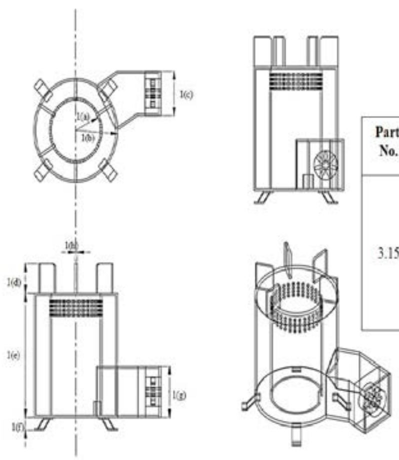


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)



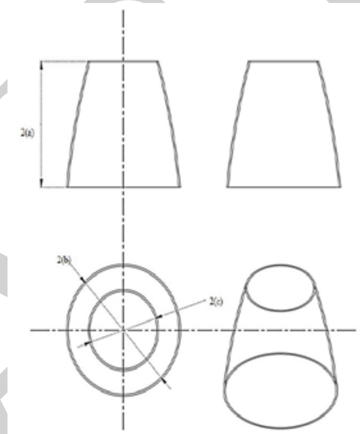
PELLET BASED CLEAN TANDOOR COMMUNITY KITCHEN SYSTEM	
PART No.	NAME
1	COOKSTOVE
2	OVEN
3	HOPPER
4	BAFFLE PLATE
5	CASING

Fig. 4 Line diagram of CTCKS



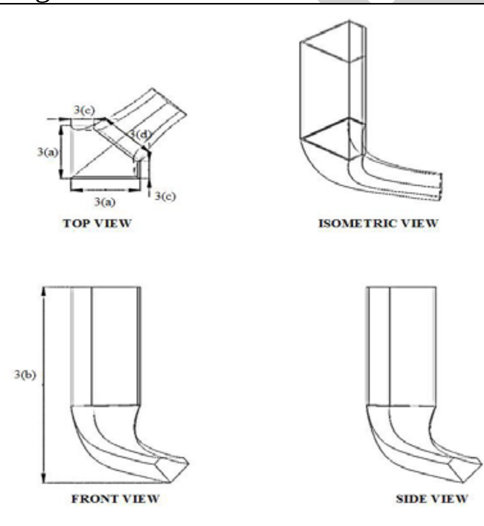
Part. No.	Dimensions (mm)	
3.15	a	170
	b	250
	c	80
	d	50
	e	400
	f	40
	g	80
	h	4

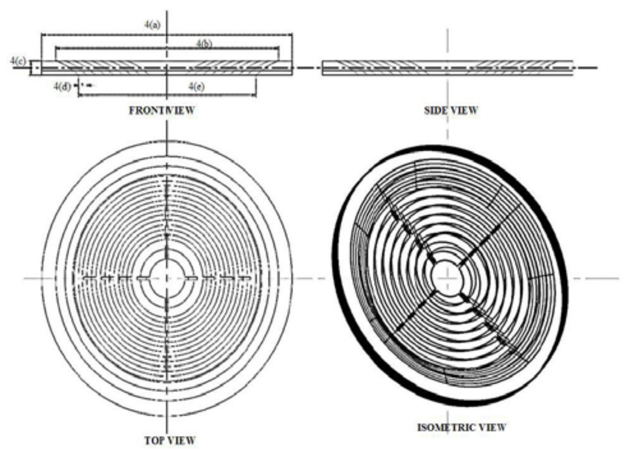
Fig. 5 Child Parts of CTCKS: Cookstove



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

Fig. 6 Child Parts of CTCKS: Oven



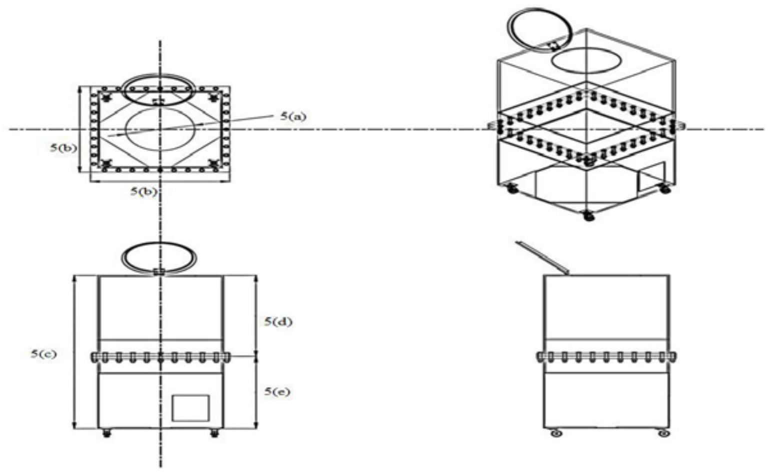


Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

Fig. 7 Child Parts of CTCKS: Hopper

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

Fig. 8 Child Parts of CTCKS: Baffle Plate



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

Fig. 9 Child Parts of CTCKS: Casing

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

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

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

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

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

Annexure :

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

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

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

Annexure – II

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

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

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

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

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

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

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

Electric Cremation vs The Traditional Funeral Pyre

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

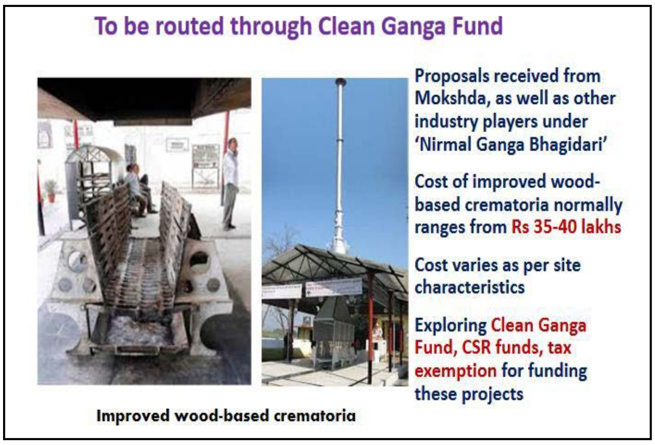
There has always been a controversy on the use of the electric crematoriums due to rituals as most persons follow the traditional burning of the bodies. In metropolitan cities it is promoted by the Government, private NGOs and environmentalists, but not to a great extent and most of these have failed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

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

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

Green Cremation system

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



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

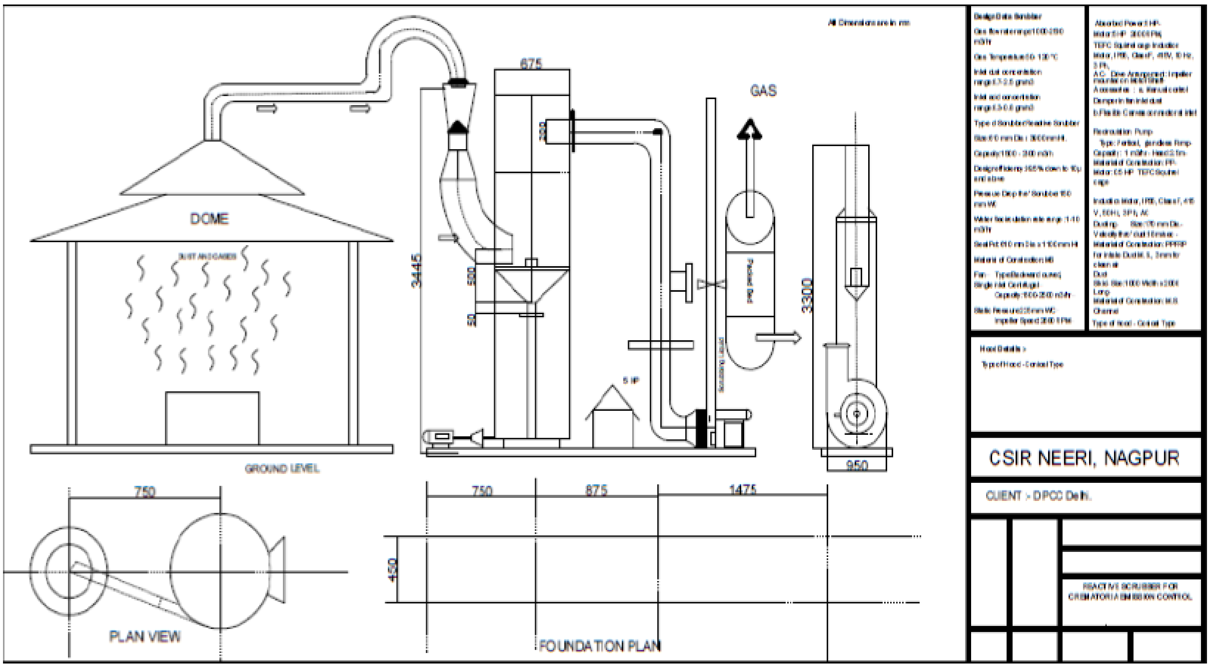


Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

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

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

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

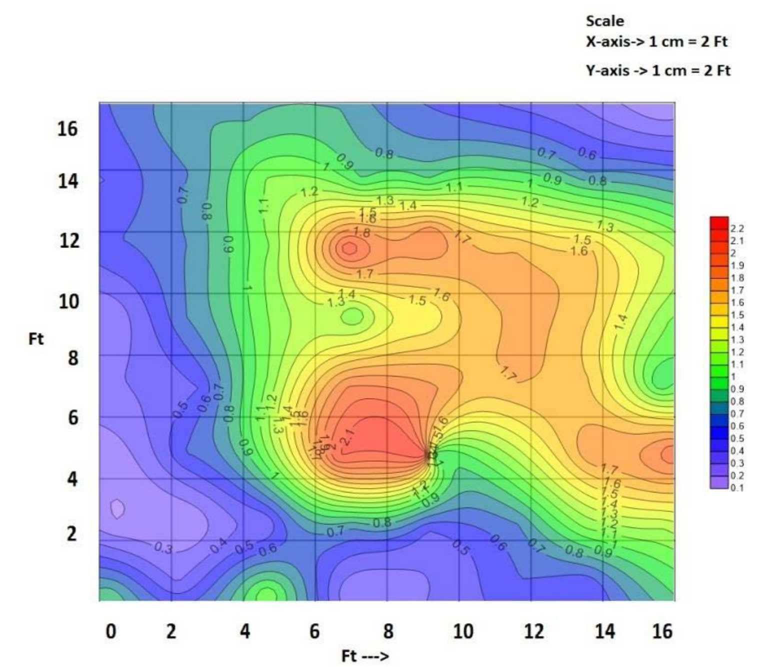


Figure 2 : Velocity profile of fumes during cremation

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

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

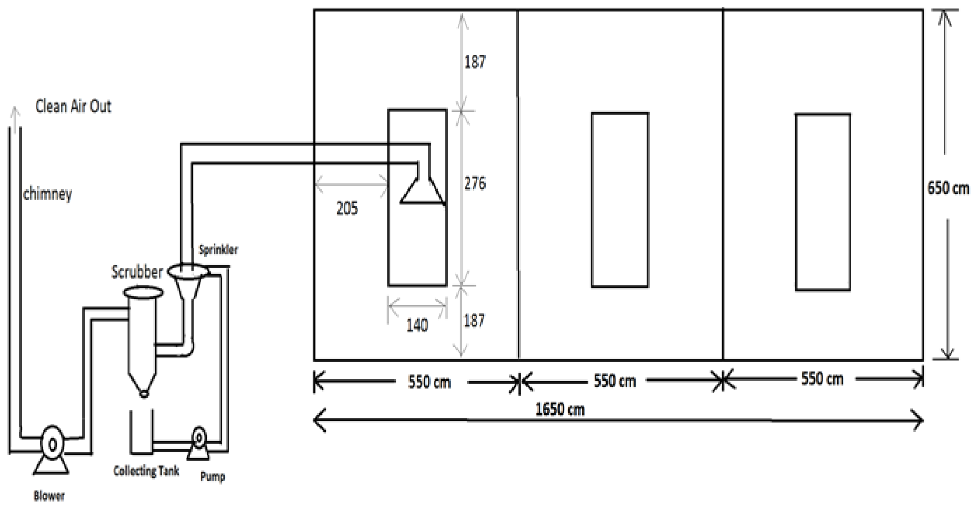


Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

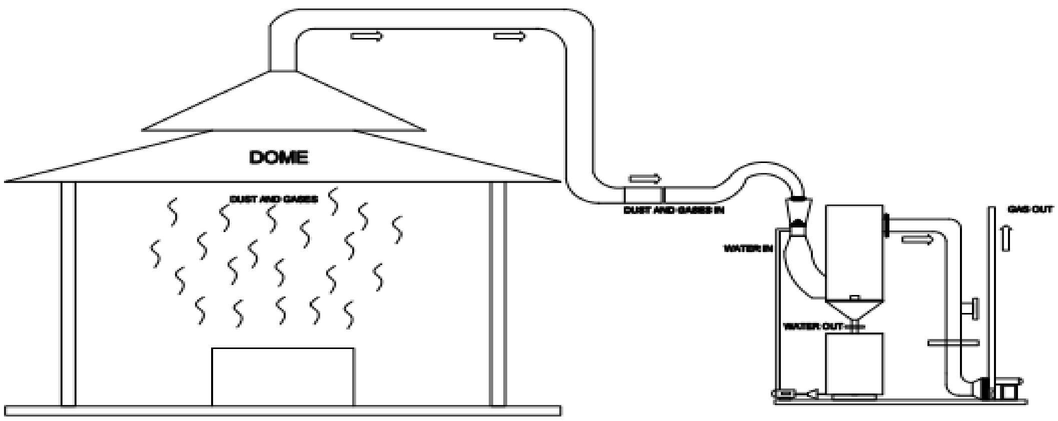


Figure 4 : Schematic view of Air Pollution Control System

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

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

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

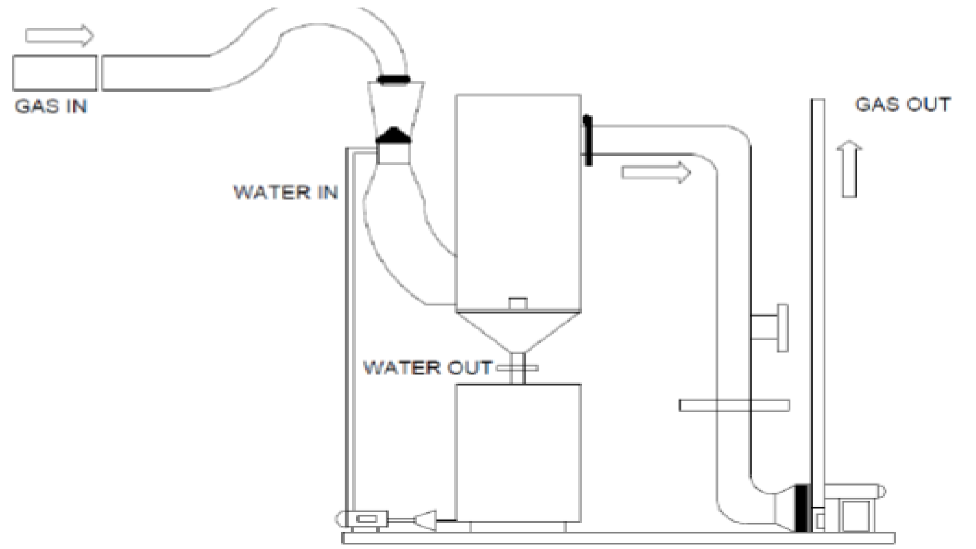


Figure 5 : Schematic of Reactive Scrubber

Gaseous Emission Control System

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

Design of APC System Emission capture system

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

The canopy hood volume is expressed by the following equation:

Hood Volume = T_d (Qp-Qs) Where,

T_d = duration of plume surge (s)

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

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

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

Where:

DC = column diameter at hood face.

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

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

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

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

Where:

DS = diameter of hot source, ft

Emission control system

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

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

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

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

d_d = droplet diameter, m

μg= gas viscosity, ($msec^{-1}$)

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

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

L & G are liquid & gas densities.

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

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

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

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

Annexure – III

Design of Passive Gas Venting System for Landfill Sites

Design of Passive Gas Venting System for Landfill Sites

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

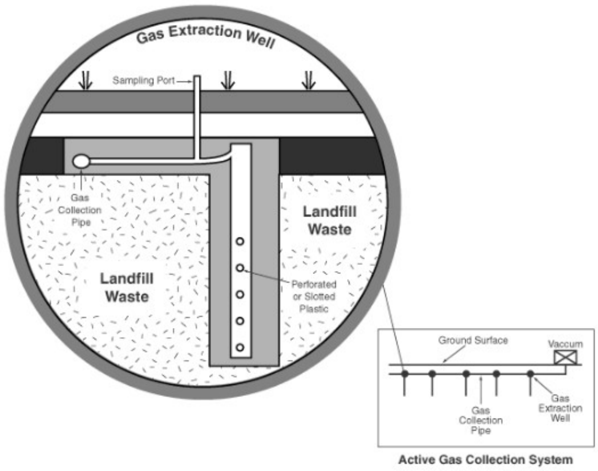
Most of the MSW generated is disposed of non-scientifically in open dumps, which causes a serious threat of landfill gas (LFG) emissions. The present note will focus on the landfill sites for the LFG emissions and designing the appropriate gas venting for the landfill sites.

Landfill Gas Collection System

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

Active Gas Collection System

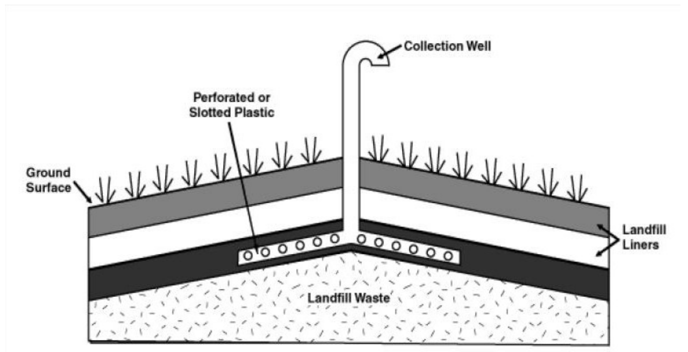
Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however,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



Active venting systems

Passive Gas Collection System

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



Passive Venting Systems

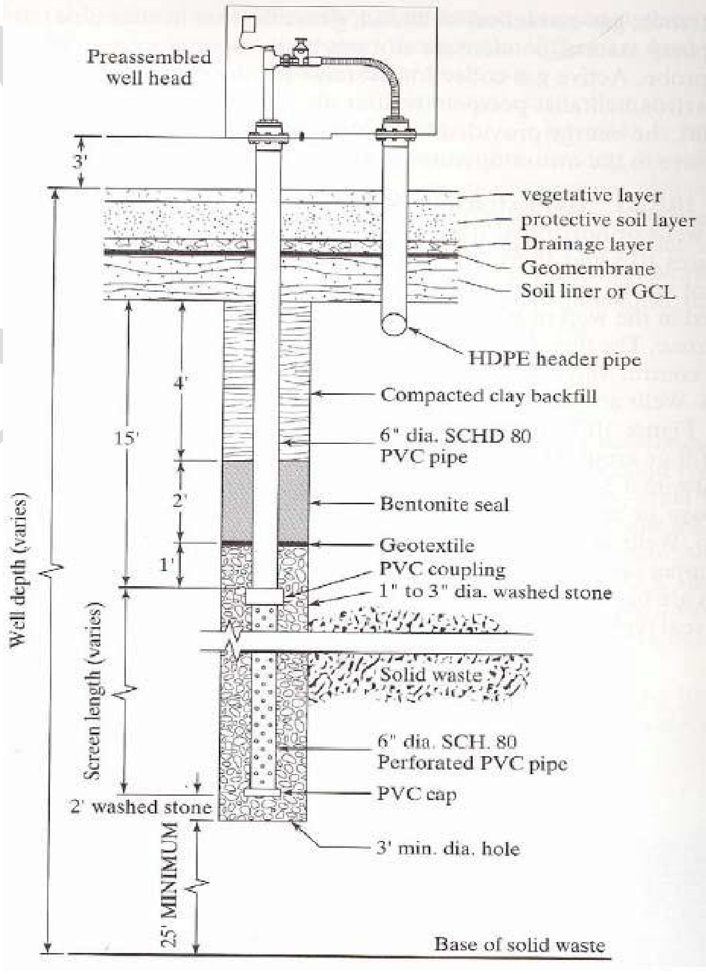
groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill as shown below. Horizontal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

Criteria and Process Diagram of Passive Vents

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

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

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



Typical Design of Passive Vent System

Data Requirement and Design of Passive Vent System for Landfill Sites

✓ ***Data Requirement***

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

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

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

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

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

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

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

Methods to Treat Landfill Gas

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

Combustion Methods

Combustion is the most common technique for controlling and treating landfill gas. Combustion technologies such as flares, incinerators, boilers, gas turbines, and internal combustion engines thermally destroy the compounds in landfill gas. Over 98% destruction of organic compounds is typically achieved. Methane is converted to carbon dioxide, resulting in a large greenhouse gas impact reduction. Combustion or flaring is most efficient when the landfill gas contains at least 20% methane by volume. At this methane concentration, the landfill gas will readily form a combustible mixture with ambient air, so that only an ignition source is needed for operation. At landfills with less than 20% methane by volume, supplemental fuel (e. g., natural gas) is required to operate flares, greatly increasing operating costs. When combustion is used, two different types of flares can be chosen: open or enclosed flares. Some public concerns have been raised about whether the combustion of landfill gas may create toxic chemicals. Combustion can create acid gases such as SO2 and NOX. The generation of dioxins has also been questioned. Because of the potential imminent health threat from other components of landfill gas, landfill gas destruction in a properly designed and operated control device, such as a flare or energy recovery unit, is preferable to uncontrolled release of landfill gas.

Non-combustion Methods

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

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

Annexure – IV

Dust Control Measures

Dust Control Measures

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

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

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

Dust Control Agents

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

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

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

Selecting dust control agents

When selecting materials for dust control consider these basic requirements:

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

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

Table 1: Application rates of dust control chemicals

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

Methods of Application

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

Figure 1 : Road side sprinkling of dust control agents

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

Figure 2 : Covered transportation vehicles

Other references

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

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

Specifications/ Application

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

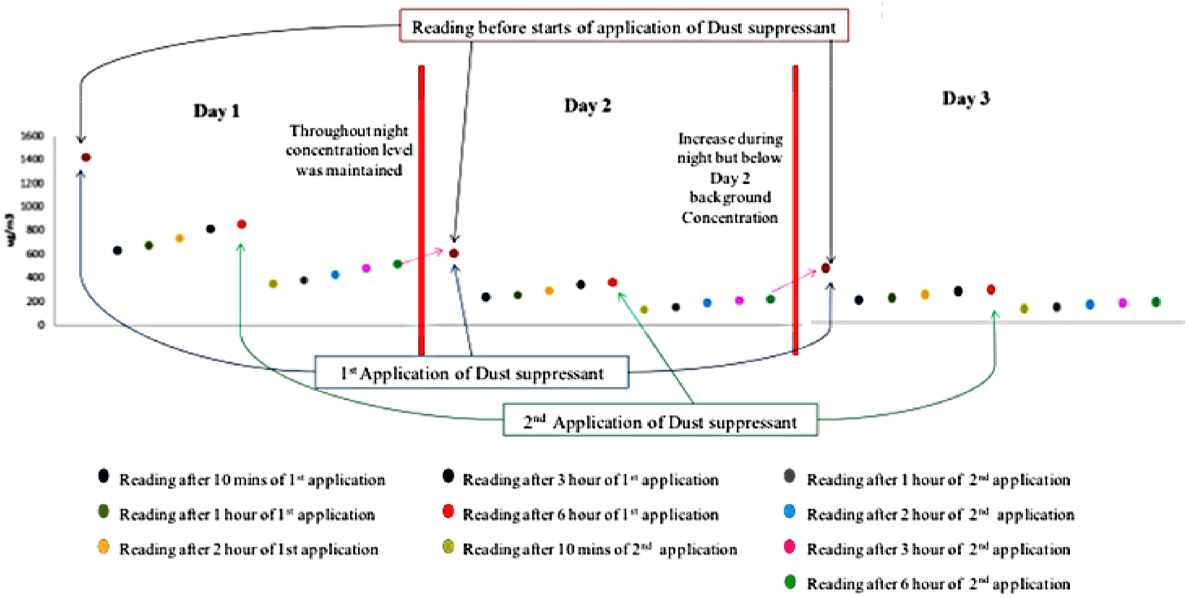
Advantages

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

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

Application of Dust Suppressant using Tanker at Delhi

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



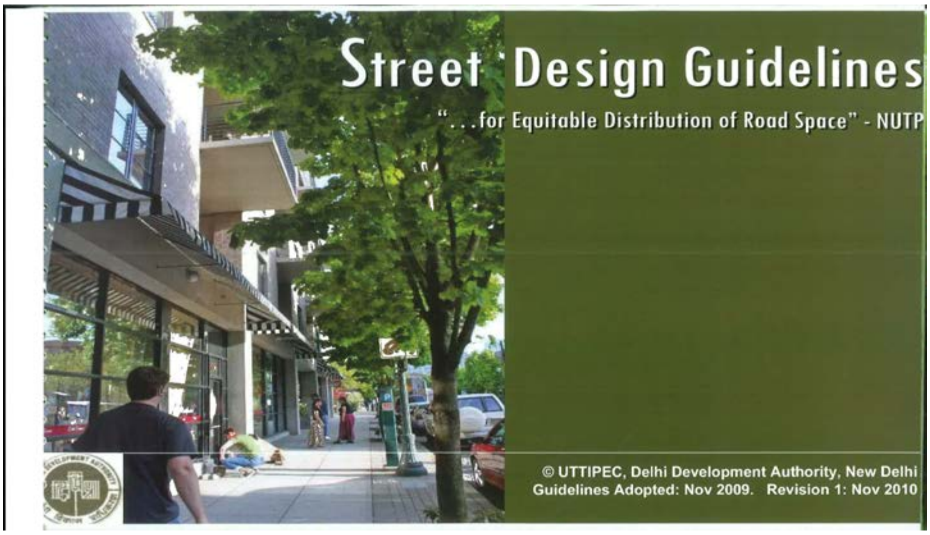
Bioswale : System for Storm Water and Dust Suppression Road Side

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

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

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

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



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

A) National Clean Air Programme (NCAP)

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

Dust management

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

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

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

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

Way Forward

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

B) Dust Mitigation Notification by MoEFCC

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

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

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

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

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

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

Use of Ready Mix Concrete

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

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

Annexure – V

Wind Augmentation and purifYing Unit (WAYU)

‘Wind Augmentation and purifYing Unit (WAYU)’

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

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

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

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

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

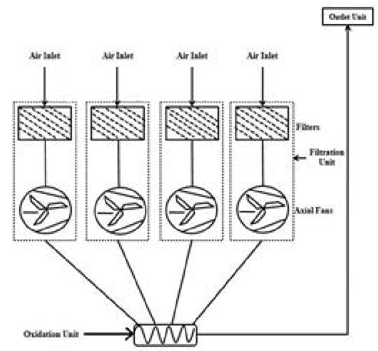
Air pollution is a local problem and its solution can be derived from technologies coupled with local conditions and requirements. Creating change in meteorological parameters like wind with the help of devices such as fans and also removal of the pollutant near to the source may help in reducing ambient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

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

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

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

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



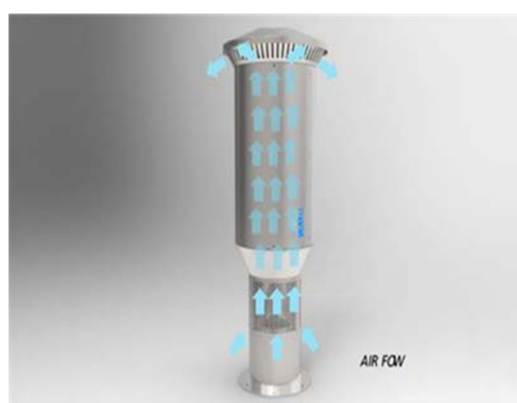
UV- TiO2 adsorption-photocatalytic oxidation has a lot of advantages. They are very efficient in removal of VOCs. Pichat et al. (2000) have shown that ozone can be directly eliminated by TiO_2 nanoparticles in a process that is promoted by both heat (in the ambient temperature range of 0° to 50°C) and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

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

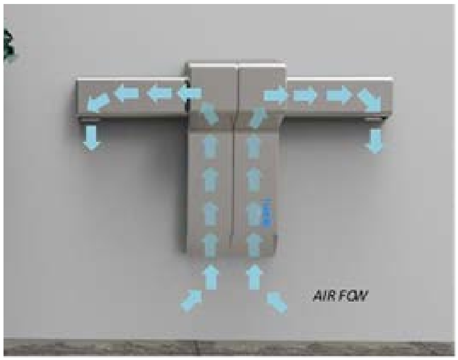
WAYU is a device jointly developed by IIT-CSIR-NEERI focused on controlling pollution in ambient air. WAYU has been successfully tested in a pilot project of 25 devices in Mumbai in collaboration with Maharashtra Pollution Control Board (MPCB). With an aim to solve the ever rising menace of air pollution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

Different Models

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



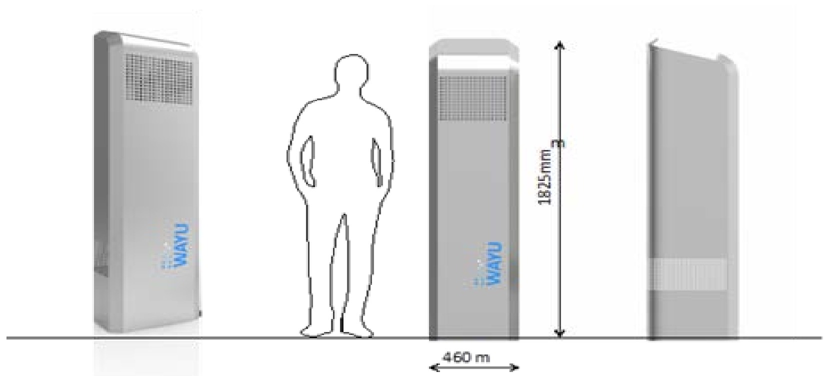
WAYU device improved design



Wall mounted/ Flyover Design

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

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.