Draft Report On

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

(NAGPUR CITY)

for

Maharashtra pollution Control Board

By

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Introduction

1.1 Preamble

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

1.2 Background of the Study

The Central Government launched National Clean Air Programme (NCAP) as a long-term, time-bound, national level strategy to tackle the air pollution problem across the country in a comprehensive manner with targets to achieve 20% to 30% reduction in Particulate Matter concentrations by 2024 keeping 2017 as the base year for the comparison of concentration. Under NCAP, 122 non-attainment cities have been identified across the country based on the Air Quality data from 2014-2018. Maharashtra Pollution Control Board (MPCB) and Government of Maharashtra (GoM) wish to have Source Apportionment and Emission Inventory studies for all non-attainment cities in Maharashtra state. The city specific air pollution reduction action plans needs to be prepared which, inter-alia, include measures for strengthening the monitoring network, reducing vehicular/industrial emissions, increasing public awareness etc. Implementation of the city specific action plans will be regularly monitored by Committees at Central and State level namely Steering Committee, Monitoring Committee and Implementation Committee.

1.3 Objectives

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

1.4 Scope of the Project

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

Nagpur is the third largest city and the winter capital of the Indian state of Maharashtra. It is the 13th largest city in India by population and according to an Oxford's Economics report; Nagpur is projected to be the fifth fastest growing city in the world from 2019 to 2035 with an average growth of 8.41%. It has been proposed as one of the Smart Cities in Maharashtra and is one of the top ten cities in India in Smart City Project execution. Nagpur is famous for its oranges and also known as 'Orange City of India’. Nagpur has officially become the greenest, safest, and technologically developed city in the Maharashtra state. Nagpur is named after the Great River Nag which flows through the city. The old Nagpur city (today called 'Mahal') is situated on north banks of the river Nag. The suffix pur means "city" in many Indian languages. After India gained independence in 1947, Central Provinces and Berar became a province of India. In 1950, the Central Provinces and Berar was reorganized as the Indian state of Madhya Pradesh with Nagpur as its capital. When the Indian states were reorganized along the linguistic lines in 1956, Nagpur and Berar regions were transferred to the state of Bombay, which was split into the states of Maharashtra and Gujarat in 1960.

1.6 Demographic Structure of the City

The Nagpur district consists of Nagpur Municipal Corporation, 10 municipalities, 13 panchayat samitis and 778 gram-panchayat. The total area covered is about 9897 sq. km. of which Nagpur city accounts for 217.65 sq. km. (2.2%). As of the 2011 census, Nagpur municipality has a population of 2,405,665. The total population constitutes 1,225,405 males and 1,180,270 females. The total children (ages 0–6) are 247,078, of whom 128,290 are boys and 118,788 are girls. The total number of slums number 179,952, in which 859,487 people reside. This is around 35.73% of the total population of Nagpur. The municipality has a sex ratio of 963 females per 1,000 males and child sex ratio of 926 girls per 1,000 boys. 1,984,123 people are literate, of whom 1,036,097 are male and 948,026 are female. Average literacy rate of Nagpur city are 91.92%. Men are 94.44% and women are 89.31% literate.

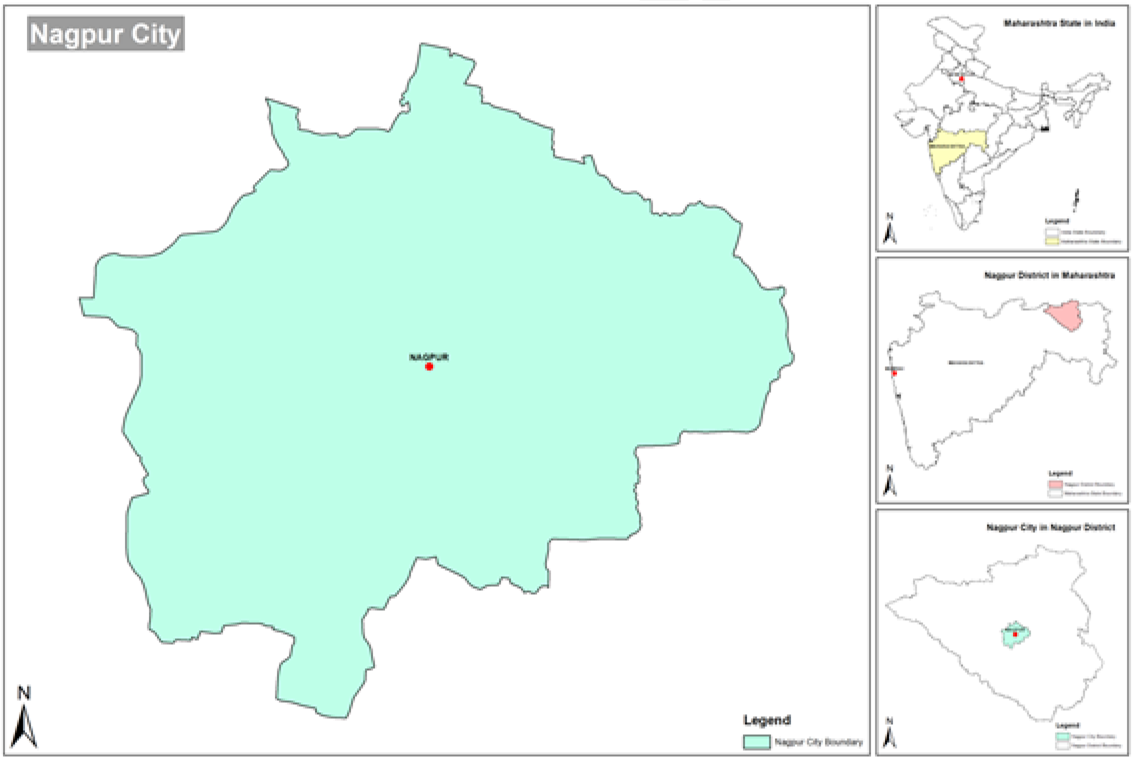


Figure 1.1 : Location of Nagpur City

1.7 Transportation

Nagpur was a portion of central railway line (Bombay-Bhusawal-Nagpur) in 1867. Today, a total of 254 trains stop at Nagpur railway station. Almost 1.6 lakh passengers board/leave Nagpur Railway Station. Nagpur is a major junction for roadways as India's two major national highways, Srinagar-Kanyakumari (NH44) and Mumbai-Kolkata (NH47). The new proposed Mumbai–Nagpur Expressway between Nagpur and Mumbai will be 800 Km (500 mi) and projected to cost ₹30,000 crore is under construction. Maharashtra State road transport Corporation (MSRTC) runs cheaper transport service for intercity, interstate, and intrastate travel. It has two bus stations in Nagpur: Nagpur Bus Sthanak (CBS-1) at Ganeshpeth and MorBhawan (CBS-2) at Jhansi Rani Square, Sitabuldi. It operates 1600 daily services from CBS-1 to long and short distances within the state and to places in other surrounding states. It also operates 750 daily services from CBS-2 to short distances within Vidarbha.

Dr. Babasaheb Ambedkar International Airport (IATA: NAG, ICAO: VANP) is operated by Mihan India Private Limited (MIPL) and owned by Airports Authority of India. Nagpur's Air Traffic Control (ATC) is the busiest in India, with more than 300 flights flying over the city every day in 2004. In October 2005, Nagpur's Sonegaon Airport was declared an international airport and was renamed Dr. Babasaheb Ambedkar International Airport. Nagpur is currently witnessing an economic boom as the Multi-modal International Cargo Hub and Airport at Nagpur (MIHAN) is under development. MIHAN will be used for handling heavy cargo coming from Southeast Asia and the Middle East.

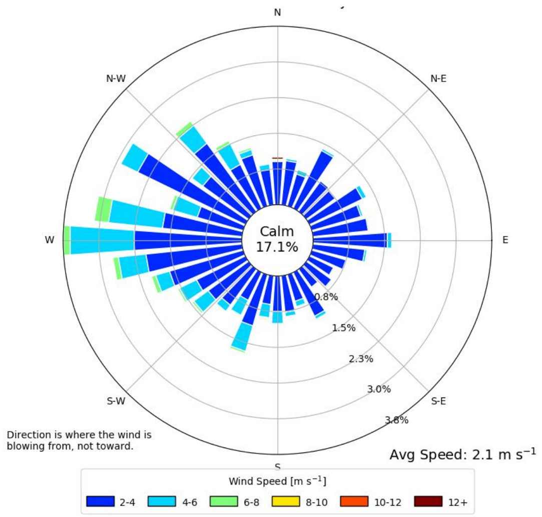
1.8 Municipal Corporation

Nagpur Municipal Council was established in 1864. The duties of the Nagpur Municipal Council include maintaining cleanliness, supplying street lights, and water supply with government assistance. In 1922, the Central Provinces & Berar Municipalities Act was framed for the proper functioning of the Municipal Council. NMC divides the city into 10 zones and which are served by zonal offices Laxmi Nagar, Dharampeth, Hanuman Nagar, Dhantoli, Nehru Nagar, Gandhi Baugh, Sataranjipura, Lakkadganj, Ashi Nagar and Mangalwari.

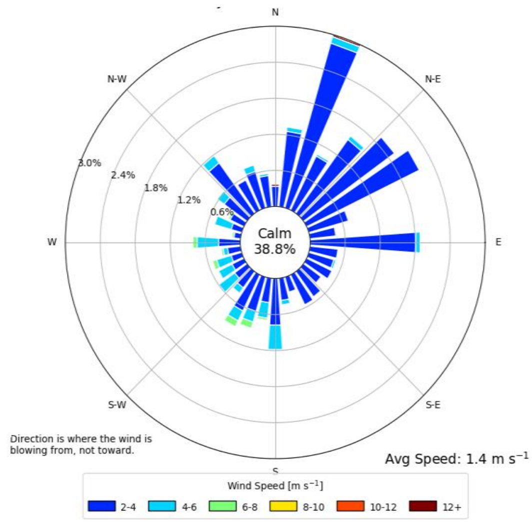
1.9 Climate and Meteorology

The city of Nagpur, in the middle of the Bay of Bengal and the Indian diaspora that runs away from the Arabian Sea, is in its wet and dry conditions. The city has dry weather for most of the year. During the monsoon of June to September, Nagpur has 1205 mm of rain. The city had recorded a record rainfall of 304 mm on July 14, 1994. May is the highest temperature in May. November to January is the period of winter. In winter the temperatures below 10 degrees are below. On May 29, 2012, the city recorded 48.6 degrees Celsius and the lowest temperature was 3.9 degree Celsius in 1937.

Nagpur district has an average annual rainfall of 1064.1 mm. In Umred, Kuhiy and Bhivapur Tehsil, the maximum rainfall occurs, whereas in the district of Katol and Narkhed Tehsil, less rainfall occurs compared to other Tehsils of the district.



Windrose During Summer 2019



Windrose During Winter 2019

The wind speed and wind direction during the sampling period were monitored with the weather monitoring station installed at CSIR-NEERI premises. In winter, it can be seen that the predominant wind direction is from N-NE sector followed by East direction with an average wind speed of 1.4 m s-1 and calm condition of 38.8%. During summer, the predominant wind direction is from W–NW sector with an average wind speed of 2.1 m s-1 and calm condition of 17.1%. Low wind speed and higher percentage of calms during winter suggests lower dispersion and dilution capacity of the atmosphere causing high air pollution at ground.

1.10 Industrial Growth

Nagpur is an important industrial city of Maharashtra that plays a major role in providing economic stability both to the city and the state. Butibori industrial area, which is considered as the largest industrial area in entire Asia in terms of area, homes units of several big industries such as Indo Rama Synthetics, the power transmission company Gammon India Limited, Central Workshop, Hyundai Unitech, KEC, ACC Nihon Casting Ltd, Woolworth (I) Limited Woolen Yarn, SSP Pvt Limited Industrial Dryers, Voltas Limited Washing Machine, Munis Forge Limited Forging etc. Other important industrial area on the western fringes of Nagpur, Hingna industrial estate, homes around 900 small and medium industrial units including VIP Industries Luggage casting unit of NECO Ltd, tractor manufacturing plant of Mahindra and Mahindra, Bajaj Auto group, Ajanta toothbrushes, Candico, Sanjay Group and Sharda Ispat Limited Rolling Mills etc.

1.11 Trade and Commerce

Nagpur is an emerging Metropolis of India and the fastest growing millionaire city also. Nagpur has been the main centre of commerce in the Vidarbha region since early days and is an important trading location. The city is ranked 11^{th} most competitive city in the country by the Institute for Competitiveness in its 2012 report. The city is important for the banking sector as it hosts the regional office of Reserve Bank of India, which was opened on 10 September 1956. The Reserve Bank of India has a branch in Nagpur in which India's entire gold assets are stored.

Sitabuldi market in central Nagpur, known as the Heart of the city, is the major commercial market area Itwari; Mahal areas also host large number of small businesses and are very famous for shopping. Kalamna is one of the largest wholesale markets for oranges and grains in Asia. Nagpur district is moderately rich in minerals. Deposits of coal, manganese Ore, Dolomite, Limestone, Iron Ore, Clay, Copper Ore, Chromites, Tungsten Ore, Zinc Ore and Quartz etc. are found in the district. Coal reserves have been found in the North-West belt of the district i.e. from Saoner to Kanhan (Kamptee apart from the high grade coal found in Umred Tehsil. Nagpur district is richly endowed with Manganese ore and the district is well placed in the country as far as production of Manganese ore is concerned. Manganese ore is found particularly in Ramtek and Saoner tehsils. Good quality lime stones are found in Kandri and Deolapar, Mica and Tungsten are also found in the district. The sand from Kanhan River is considered to be of high quality as far as the construction of buildings is concerned.

1.12 Need of the Study

The present study examines the contribution of the sources to aerosol mass, which is an important factor in the development of effective strategies for the control of aerosol-associated problems. Besides PM, other pollutants and their sources are needed to be inventoried with a view to ascertain the point of generation. Pollutants of all origin should be considered in entirely for any implementing agency to formulate strategies and embark upon the action plan. The complexities of sources and their impact on receptors are interlinked with source, strength, meteorology, elevation of release, atmospheric transformations etc.

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

Chapter 2

Ambient Air Quality

2.1 Introduction

The status of ambient air quality of the city is studied using secondary data obtained through various data sources and primary data. Data analysis is carried out to understand the spatial and temporal variations in the city for parameters namely particulate matter of size less than 10 micron and 2.5 micron (PM_{10}, $PM_{2.5}$) and gaseous pollutants (Sulphur Dioxide - SO_2, Nitrogen Dioxide - NO_2, Carbon Monoxide - CO and ground Ozone - O_3). Maharashtra Pollution Control Board (MPCB) carries out manual monitoring for particulate matter &/or respirable suspended particulate matter (RSPM), SO_2 and NO_2 at four locations in the city. Besides this a Continuous Ambient Air Quality Monitoring Station (CAAQMS) at GPO Civil Lines, Nagpur is also operated by MPCB. Central Pollution Control Board (CPCB), New Delhi sponsored National Air Quality Monitoring (NAQM) program is operated by NEERI at three locations, which involves manual monitoring of PM_{10}, SO_2 and NO_2. All data for one year is analysed and is presented here.

2.1.1 Manual Ambient Air Quality Data collected by MPCB

The summary of SO_2, NO_2 and PM_{10} concentration during 2017-2020 (till March) is plotted in **Figure 2.1.** It can be seen that both SO_2 and NO_2 are well below the standard stipulated as 80 $\mu g/m^3$ by CPCB whereas PM_{10} concentration exceeded the standard of 100 $\mu g/m^3$ at North Ambazari road, MIDC Hingna and Sadar. Further, SO_2 and NO_2 are increasing during the 2017-2019 but during 2020 the concentration of both the pollutants are observed to be reduced despite of the data period being the critical for air pollution. PM_{10} concentration is observed to have been reduced in 2019 but increased in 2020. As the data during 2020 is considered only for January to March which is mostly the winter period, this seems to be the reason for higher particulate matter concentration. Secondary data analysis indicates that the city has a particulate pollution problem.

2.1.2 Continuous Ambient Air Quality Monitoring Station (CAAQMS)

MPCB operates a Continuous Ambient Air Quality Monitoring Station (CAAQMS) at GPO Civil Lines, Nagpur. Several parameters namely PM_{10}; $PM_{2.5}$; SO_2; NO_2; Ozone (O_3); CO; Benzene; Ethyl Benzene; m, p-Xylene; Toluene are being monitored at different sampling frequencies. 24 hourly AAQ for all these parameters for each month during 2019-2020 is given in **Figure 2.2 through 2.6**. The statistical summary of ambient air quality data during 2019-2020 is given in **Table 2.1**. It can be seen that the % of missing values varies from 0 - 20% for all the parameters. The % of exceedances is also observed to be high for PM_{10} and NO_2 concentration followed by $PM_{2.5}$ and Benzene concentration.

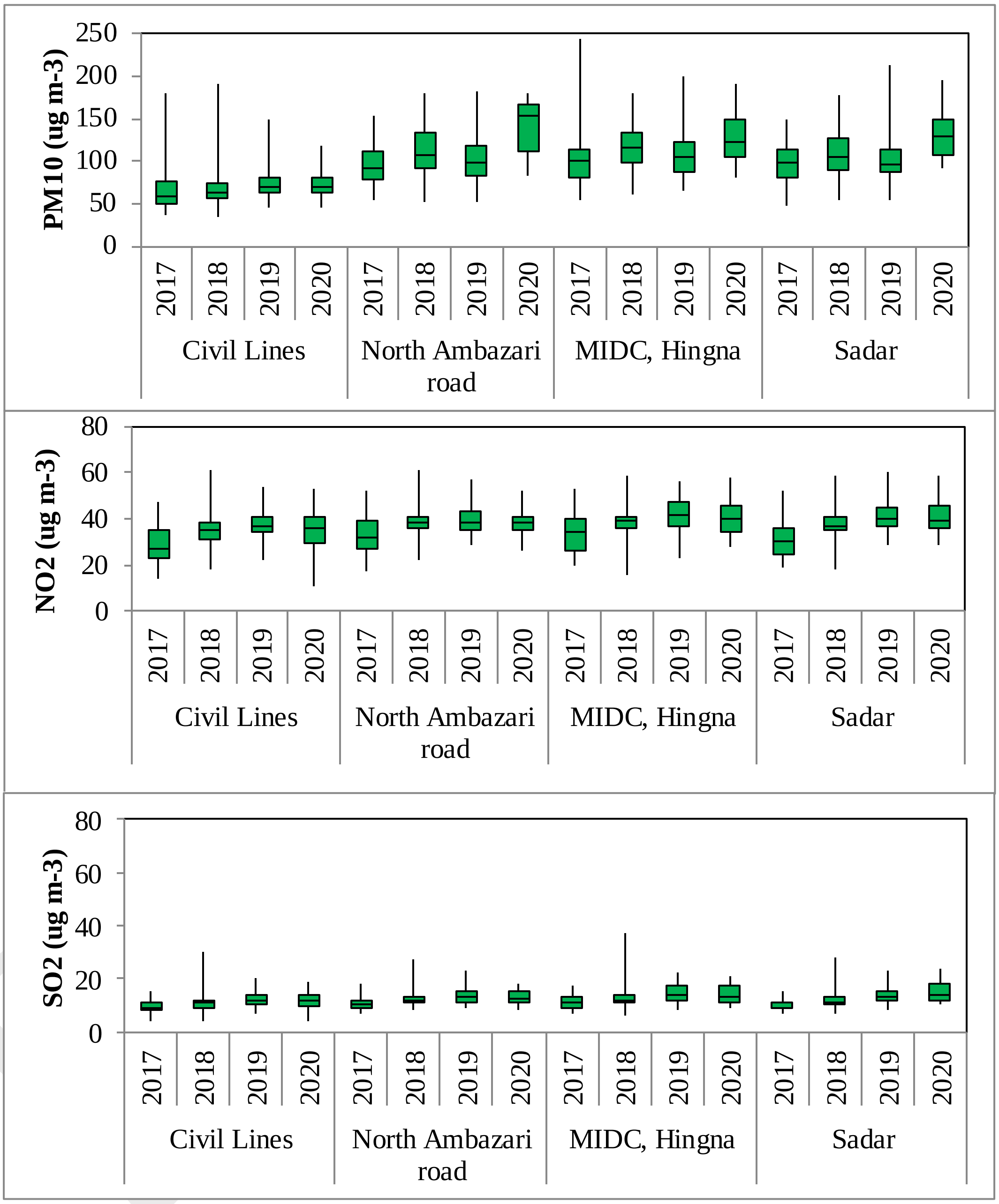


Figure 2.1 : SO_2, NO_2 and PM_{10} Concentration During 2017-2020 (till March) at Few Locations in Nagpur *(Data Source: www.mpcb.gov.in)*

Table 2.1 : Statistical Summary of CAAQMS Data at Civil Lines, Nagpur

Parameter	Average ± SD	95th Percentile	Max	Missing values (%)	% of Exceedances	CPCB Standard
PM_{10} (µg/m^3)	68.8 ± 28.3	121.8	161.5	6.4	56.4	60
$PM_{2.5}$ (µg/m^3)	35.0 ± 17.5	68.2	95.9	5.8	35.5	40
NO_2 (µg/m^3)	43.5 ± 19.2	68.0	220.6	20	56.7	40
SO_2 (µg/m^3)	7.4 ± 8.0	22.2	56.7	5.5	0.3	50
CO (µg/m^3)	741.6 ± 43.0	1460.0	2710.0	0	0.8	2000*
NH_3 (µg/m^3)	24.7 ± 11.0	43.9	83.0	20	--	100
O_3 (µg/m^3)	37.2 ± 43.6	136.1	180.4	11.2	14.9	100*
Benzene (µg/m^3)	4.4 ±2.9	10.1	16.1	5.8	32.1	5
Ethyl Benzene (µg/m^3)	3.7 ± 4.1	11.8	24.1	10.9	--	--
m, p-Xylene (µg/m^3)	5.1 ± 5.8	15.6	32.2	17.4	--	--
Toluene (µg/m^3)	10.2 ± 7.2	23.6	38.6	5.8	--	--

** For 8 hours, - CPCB standard not available*

PM_{10} and $PM_{2.5}$ concentration is observed to be higher during November- February and lower in monsoon months. SO_2 and NH_3 concentrations are observed to be lower in monsoon months except in September, NH_3 is observed to be quite high. NO concentration is observed to be higher in November-January, whereas NO_2 concentration is observed to be higher in October-April. As expected, higher ozone concentration is observed in April and May when high solar insolation is usually observed. CO is higher during October-May, whereas Benzene and Ethylbenzene concentration is higher during November-January. A decreasing monthly trend is observed in m, p Xylene and Toluene from April to March.

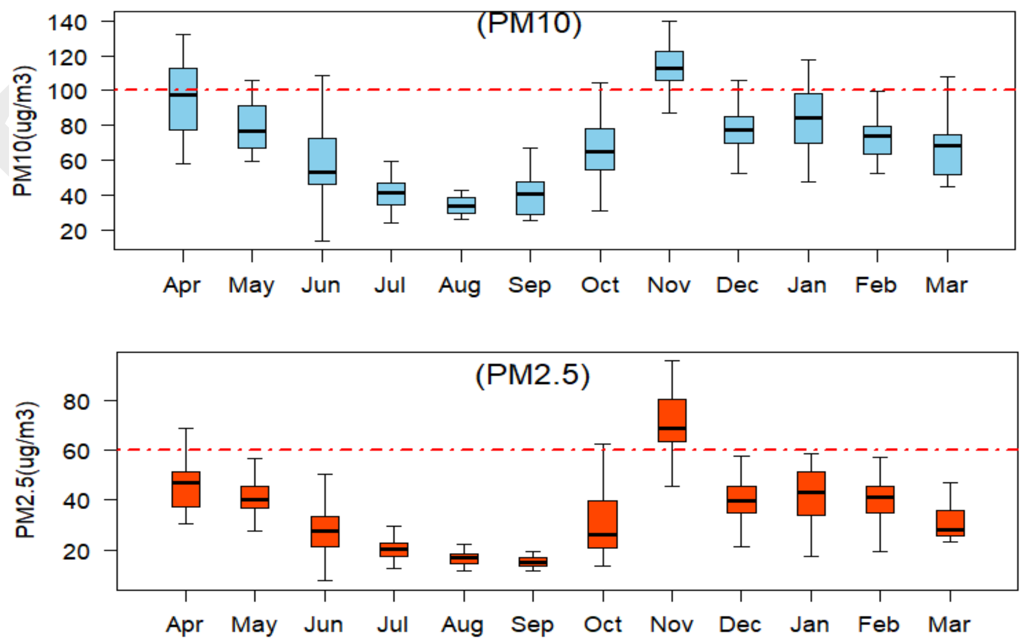


Figure 2.2 : Monthly Variation of PM_{10} and $PM_{2.5}$ Concentration During 2019-2020 at Civil Lines, Nagpur *(Data Source: www.cpcb.nic.in).*

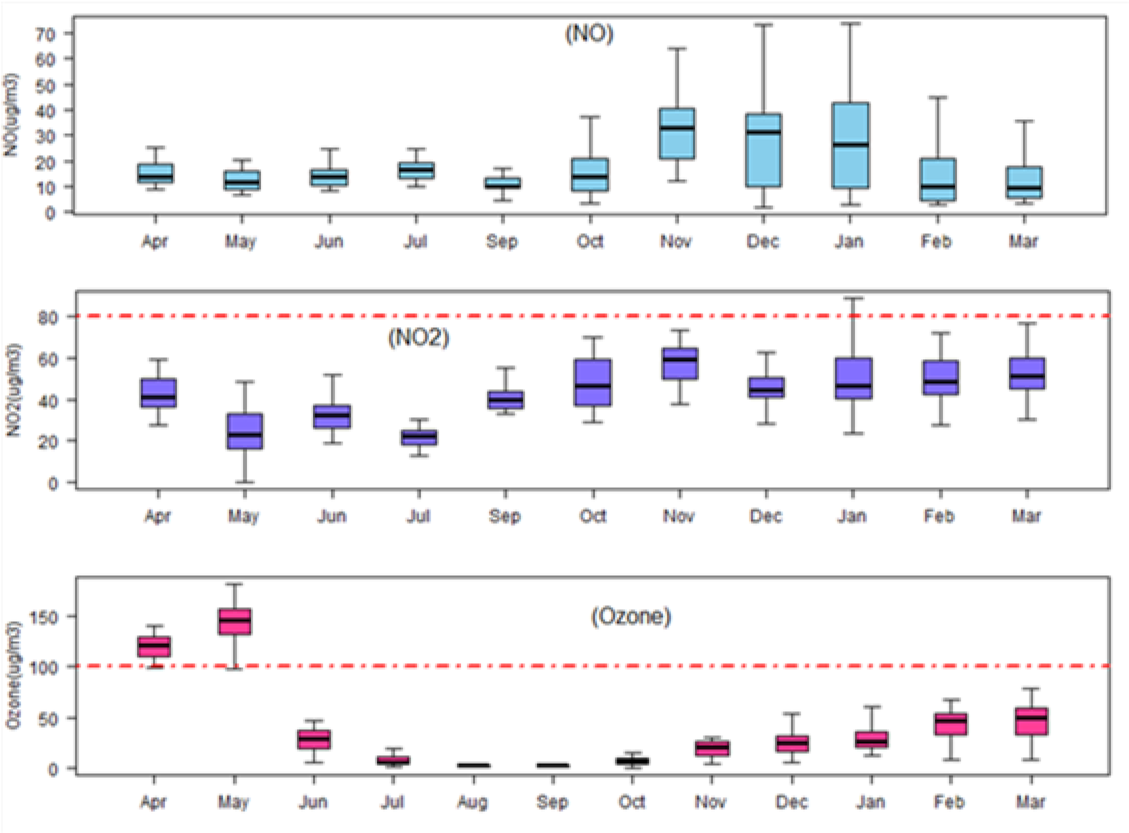


Figure 2.3 : Monthly Variation of NO, NO_2 and O_3 Concentration during 2019-2020 at Civil Lines, Nagpur *(CAAQMS Data Source: www.cpcb.nic.in)*

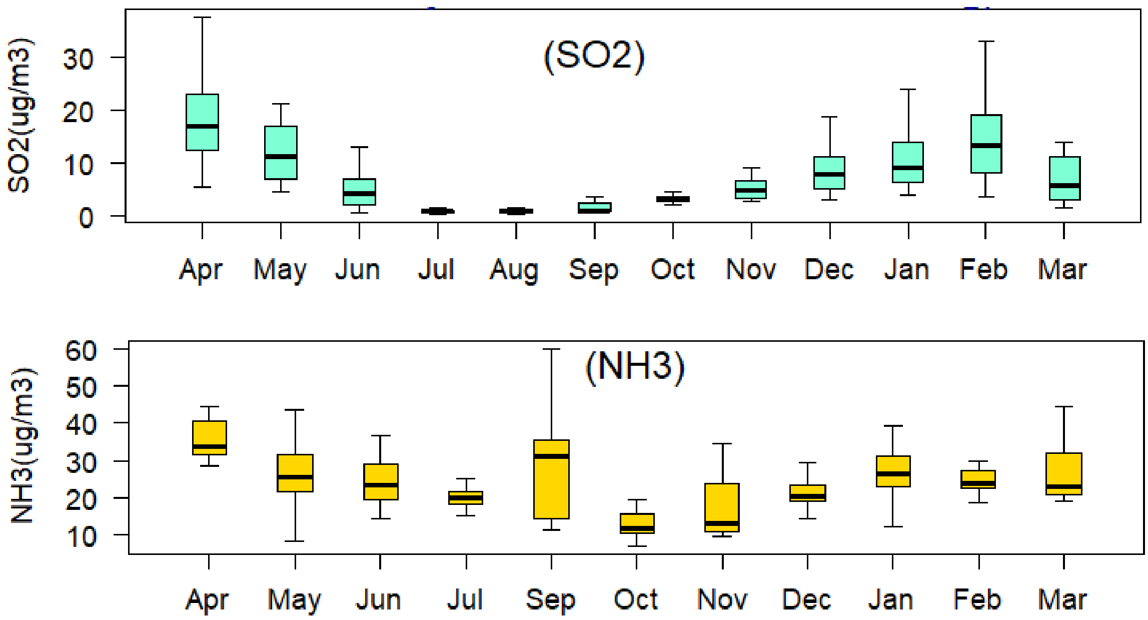


Fig. 2.4: Monthly Variation of SO_2 and NH_3 Concentration during 2019-2020 at Civil Lines, Nagpur *(CAAQMS Data Source: www.cpcb.nic.in)*

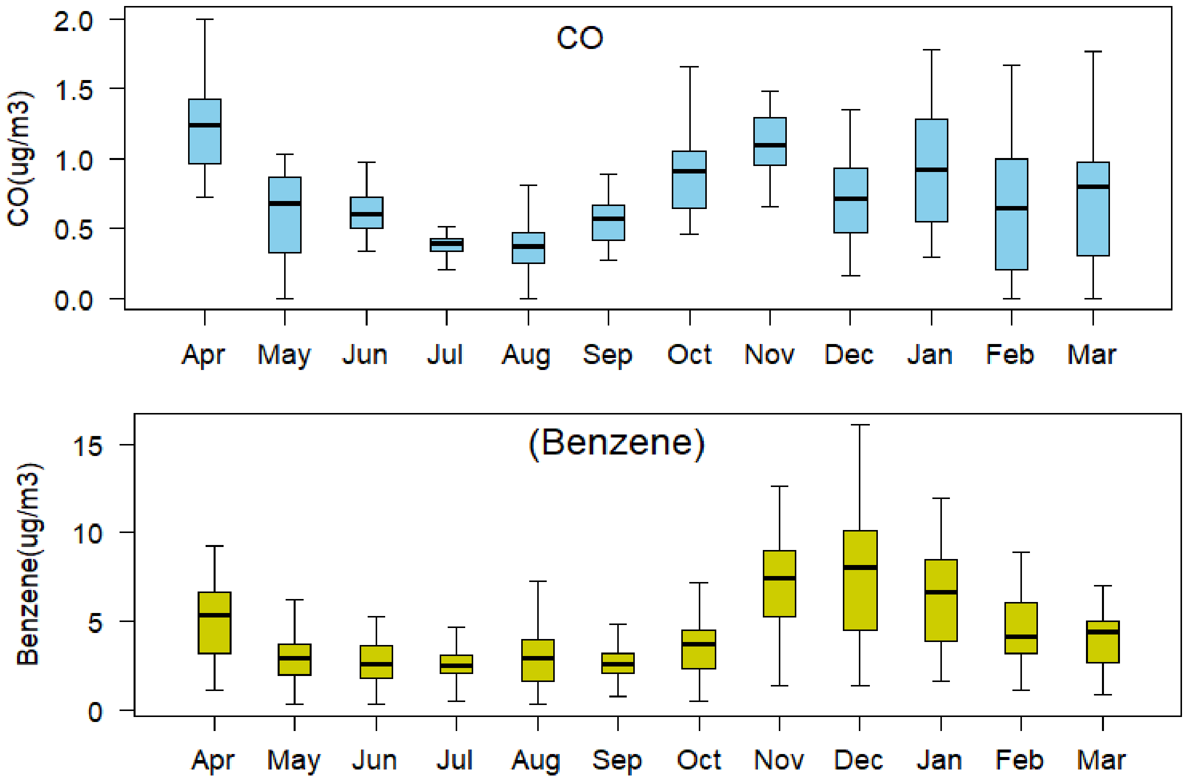


Figure 2.5: Monthly Variation of CO and Benzene Concentration during 2019-2020 at Civil Lines, Nagpur *(CAAQMS Data Source: www.cpcb.nic.in)*

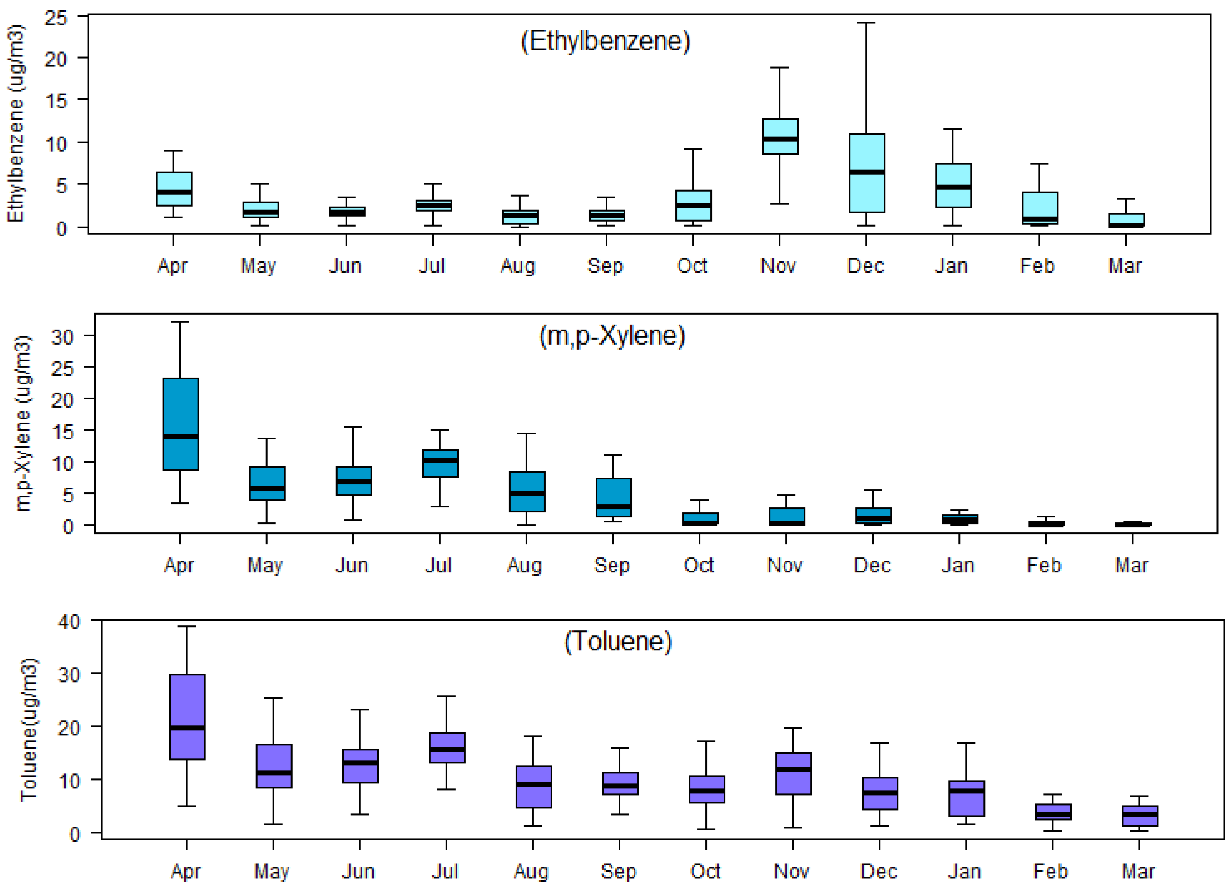
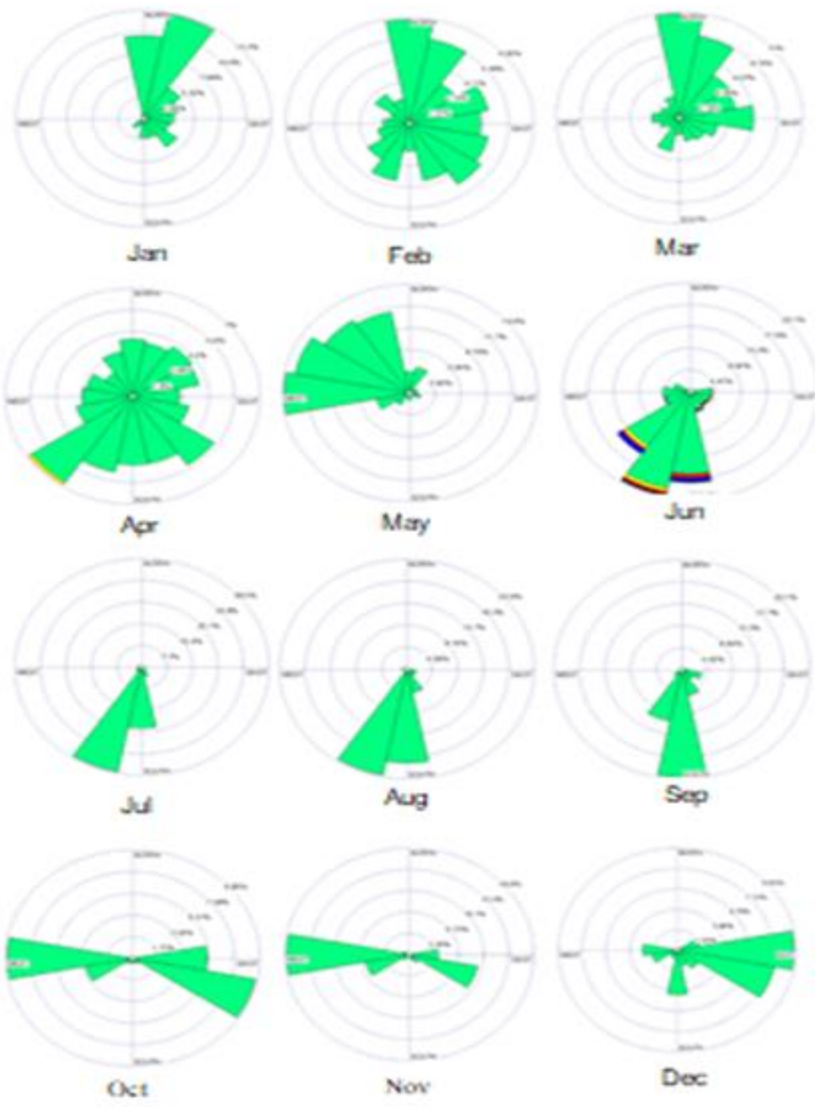
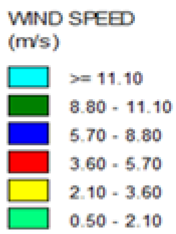


Figure 2.6 : Ethyl Benzene; m, p-Xylene; and Toluene During 2019-2020 at Civil Lines, Nagpur *(CAAQMS Data Source: www.cpcb.nic.in).*

2.2 Meteorology

The wind speed and wind direction as gathered at CAAQMS at Civil Lines, operated by Maharashtra Pollution Control Board (MPCB) is used for plotting the windrose diagram. **Figure 2.7** shows the windrose diagram for different months of 2019. It can be seen that the predominant wind direction is from N, NE and E direction during winter months and W, ESE direction during post-monsoon months. The predominant wind direction during monsoon is from S and SSW direction. During summer, the predominant wind direction is mostly from W, N and S-SW sector. The wind speed is mostly in the category 0.5-2.10 m/s in all the months. In June, the wind speed is also moderately observed in the higher categories from 2.10-8.80 m/s. High percentage of calms during winter and post-monsoon suggests lower dispersion and dilution capacity of the atmosphere causing high air pollution at ground.





Month	Calm %
Jan	49.80
Feb	46.73
Mar	38.25
Apr	40.0
May	31.92
Jun	13.92
Jul	29.19
Aug	46.70
Sep	52.62
Oct	72.15
Nov	58.44
Dec	64.03

Figure 2.7 : Monthly Windrose Diagram for Nagpur (2019)
(CAAQMS Data Source: www.cpcb.nic.in)

2.3 Manual Ambient Air Quality Monitoring by NEERI

To carry out the air quality sampling across the city, the sampling stations were selected based on the land-use characteristics, meteorology, logistics facilities such as security, power supply etc. The location of the stations is given in **Figure 2.8**. The description and characteristics of the selected stations is given in **Table 2.2**.The spread of the stations across the city was also one of the criteria for sampling. The sampling locations were selected to represent major activity zones as Industrial; Residential/ kerbside and Commercial. In all the sampling was carried out at 10 locations with 6 sampling stations representing residential/kerb site, 2 stations representing commercial, 1 station representing mixed-use of residential and commercial activities and 1 station representing industrial activity. Ambient air quality sampling has been carried out for criteria pollutants viz., PM_{10}, $PM_{2.5}$, NO_2, SO_2, NH_3, CO, BaP and Heavy metals (As, Ni and Pb) during Jan-May 2019. The sampling was carried out as per the methods and protocols prescribed by CPCB.

Table 2.2: Characteristics of AAQ Stations

No.	Station Name	Geographic Location	Station Classification	Observed Sources
1	MIDC Hingna	21° 6'59.12"N 79° 0'44.25"E	Industrial	Purely an industrial location with influence of traffic
2	NEERI	21° 7'20.00"N 79° 4'17.21"E	Residential	Under influence of very few vehicles
3	NBSS Office (Near Amravati road)	21° 9'9.99"N 79° 1'32.42"E	Residential	Residential area with heavy and LDVs
4	Pipla	21° 4'45.65"N 79° 7'3.98"E	Residential	Situated 9km away from sub-district headquarter, house hold emissions are the major sources
5	Asi Nagar (NMC)	21°10'24.21"N 79° 6'17.69"E	Residential	Domestic cooking and sweeping etc. are the major sources
6	Manewada (Near Manewada Square)	21° 6'9.80"N 79° 6'11.05"E	Kerbside-Residential	Very populated and heavy traffic area with close proximity to crematorium
7	Sadar	21° 9'37.54"N 79° 5'3.74"E	Residential-Commercial	Very populated and heavy traffic area with regular traffic congestion, has commercial shops
8	Maskasath (Near Itwari)	21° 9'42.88"N 79° 6'57.92"E	Commercial-Traffic	A busy commercial area with congested roads and traffic
9	Sitaburdi (At Commissioner Off.)	21° 8'45.47"N 79° 4'51.16"E	Commercial-Kerb side	Very populated and heavy traffic area
10	Shankar Nagar Square	21° 8'11.03"N 79° 3'36.63"E	Kerbside	Very populated and heavy traffic area with regular traffic congestion

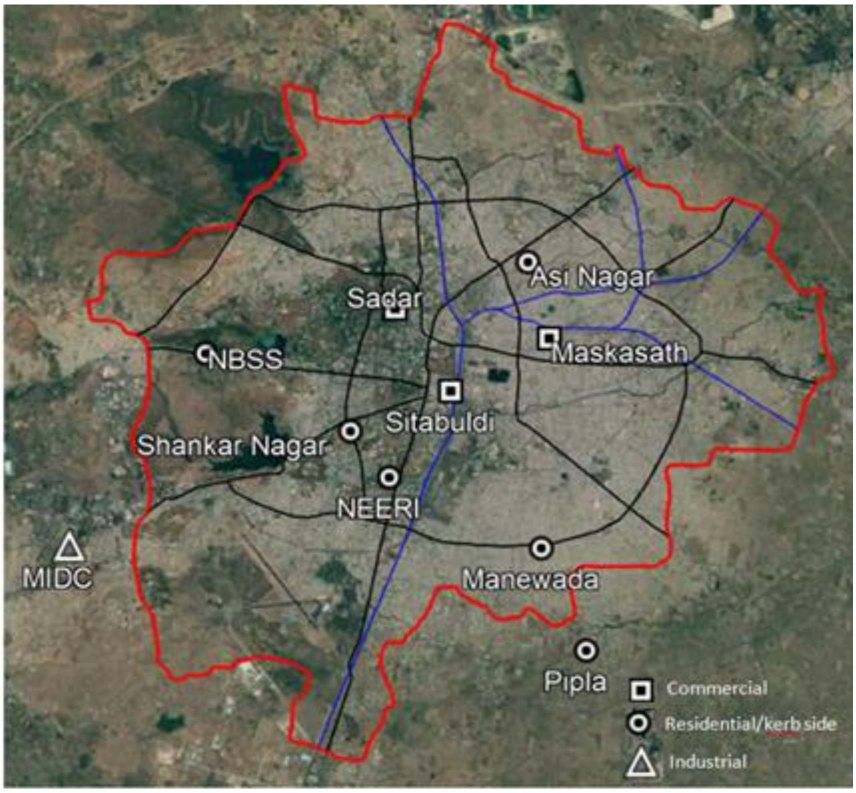


Figure 2.8 : Location of AAQ Monitoring Stations

2.3.1 Air Quality Status

The air quality status in terms of PM_{10}, $PM_{2.5}$, SO_2, NO_2, NH_3 and CO is given in at 10 locations in Nagpur during January-May 2019 is depicted in **Figure 2.8**. The status of gaseous pollutants and particulate matter is described below separately.

2.3.2 Status of Gaseous Pollutants

The status of gaseous pollutant concentrations in ambient air is given in **Figure 2.9**. It can be observed that SO_2, NO_2 and NH_3 concentrations are well below the CPCB standard of 80, 80 and 400 $\mu g\ m^{-3}$ (as given in **Table 2.3**), respectively except at Sitabuldi where two outliers of 80 $\mu g\ m^{-3}$ and 96 $\mu g\ m^{-3}$ were observed. The lowest average SO_2 concentration is observed at Asi Nagar whereas at Sitabuldi, the SO_2 concentration is 2-fold higher. NO_2 concentration is observed to be minimum at Pipla and Asi Nagar and 2 to 3-times higher concentration is observed at NBSS, Sitabuldi and Manawada. NH_3 concentration is observed to be minimum at NBSS and Hingna and highest at Sitabuldi and Manewada. Lowest CO concentration is observed at NBSS and Asi Nagar and highest CO concentration exceeding the CPCB standard of 4 ppm (for 1 h) is observed at Sitabuldi. The high gaseous pollutant concentration at Sitabuldi can be attributable to the overcrowded traffic pattern at the site.

Table 2.3 : National Ambient Air Quality Standards (NAAQS, 2009)

Sr.	Pollutants	Time Weighted Average	Concentration in Ambient Air	
			Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area
1.	Sulphur Dioxide (SO_2), µg/m^3	Annual * 24 Hours **	50 80	20 80
2.	Nitrogen Dioxide (NO_2), µg/m^3	Annual * 24 Hours **	40 80	30 80
3.	Particulate Matter, (PM_{10}), µg/m^3	Annual * 24 Hours **	60 100	60 100
4.	Particulate Matter, ($PM_{2.5}$), µg/m^3	Annual * 24 Hours **	40 60	40 60
5.	Lead (Pb), µg/m^3	Annual * 24 Hours **	0.50 1.0	0.50 1.0
6.	Ammonia (NH_3), µg/m^3	Annual * 24 Hours **	100 400	100 400
7.	Carbon Monoxide (CO) mg/m^3	8 Hrs** 1 Hr**	02 04	02 04
8.	Benzo (a) Pyrene Particulate Phase only, ng/m^3	Annual *	01	01
9.	Arsenic (As), ng/m^3	Annual *	06	06
10.	Nickel (Ni), ng/m^3	Annual *	20	20

* Annual Arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals. ** 24 hourly or 8 hourly or 1 hourly monitored values, as applicable, shall be complied with 98 of the time in a year. 2 of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigations.

2.3.3 Status of Particulate Matter

PM_{10}, $PM_{2.5}$ along with their ratio is plotted in **Figure 2.10**. PM_{10} concentration exceeded the CPCB standard limit of 100 µg/m^3 stipulated for 24 hrs at all the stations except at NEERI, which is a residential location. Average $PM_{2.5}$ concentration is observed to be below the CPCB standard limit of 60 µg m^{-3}. $PM_{2.5}/PM_{10}$ ratio is also plotted to have an understanding of the prevalence of particulate size in the sites. It can be seen that $PM_{2.5}/PM_{10}$ ratio is less than 0.5, which suggests that coarser size particulates are dominating at all the locations.

Summarizing the above results, it can be seen that particulate pollution is significant in Nagpur. It is therefore desirable to compare it with the most polluted city in India to assess its extent. **Figure 2.11 (a&b)** shows the PM_{10}, $PM_{2.5}$ and $PM_{2.5}/PM_{10}$ ratio averaged over few stations in Delhi and averaged respective concentration in Nagpur. It can be seen that PM pollution in Delhi is 2-times higher than in Nagpur. Average $PM_{2.5}/PM_{10}$ ratio is observed to be almost similar but

Delhi has higher variability in the ratio as compared to Nagpur. The maximum ratio is observed to be quite high in Delhi suggesting the presence of combustion activities, whereas in Nagpur the prevalence of combustion activities seems to be less as fine particulate concentration is not in abundance.

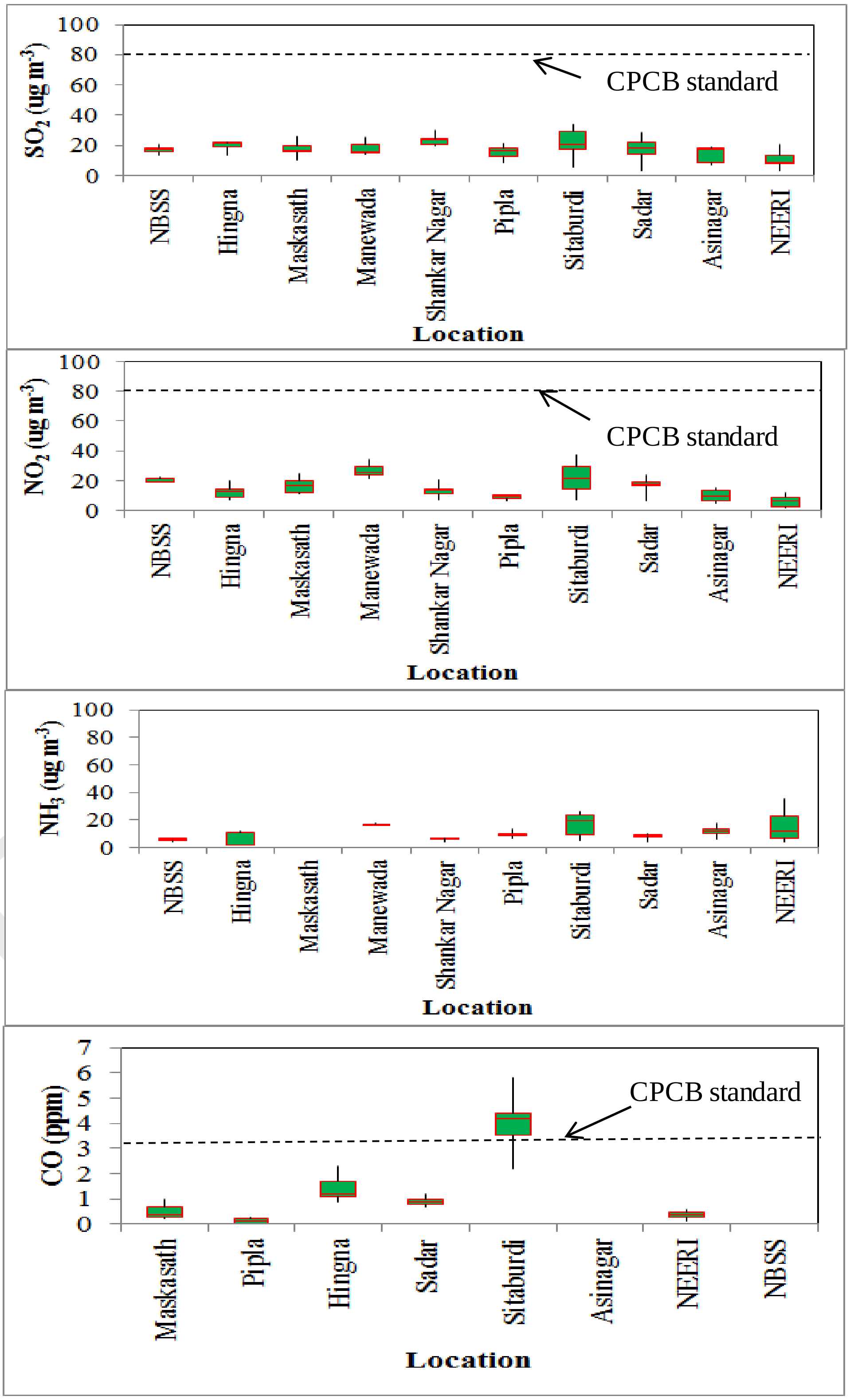


Figure 2.9 : Gaseous Pollutant Concentration at Various Locations in Nagpur

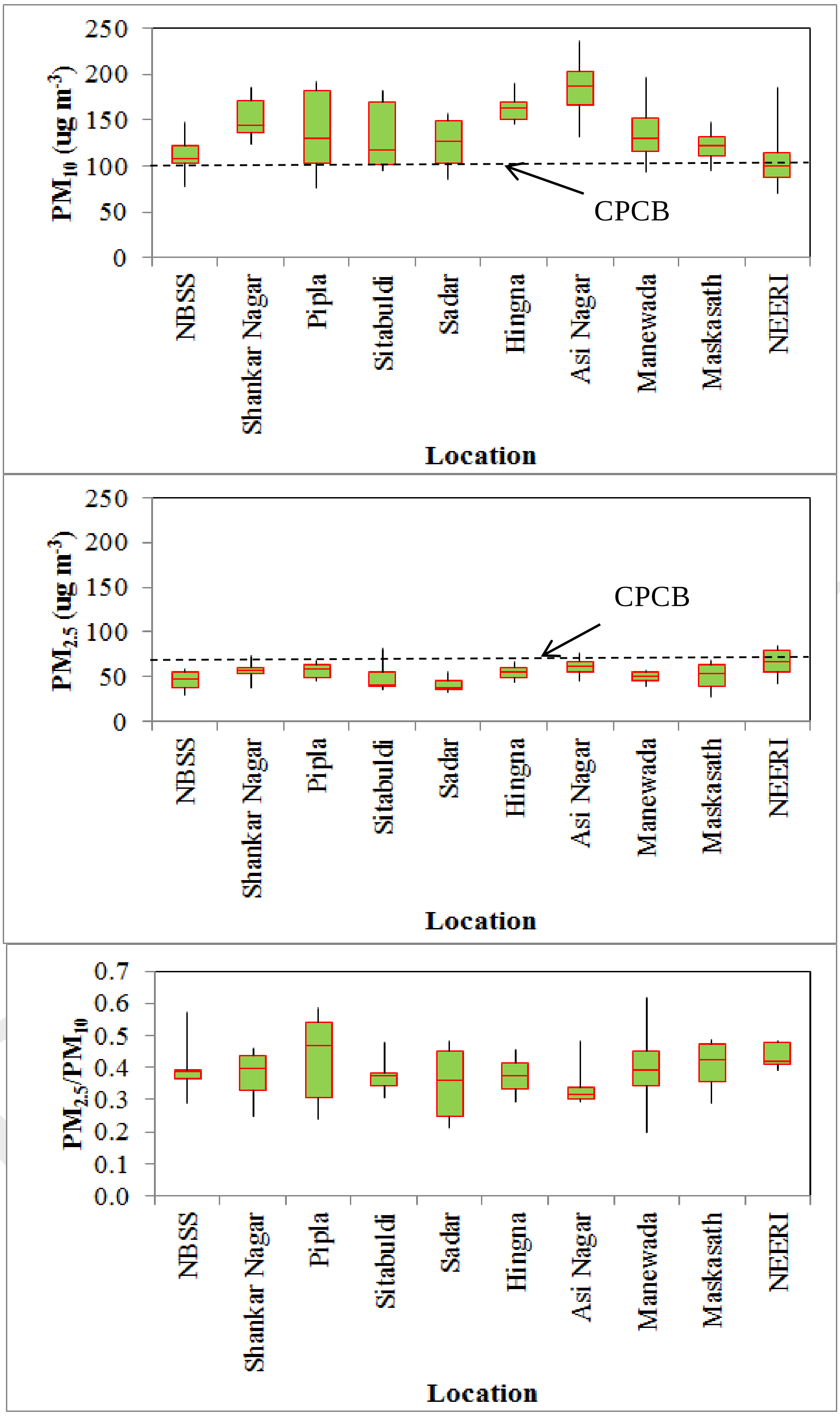


Figure 2.10: PM_{10}, $PM_{2.5}$ Concentration and their Ratio at various Locations in Nagpur

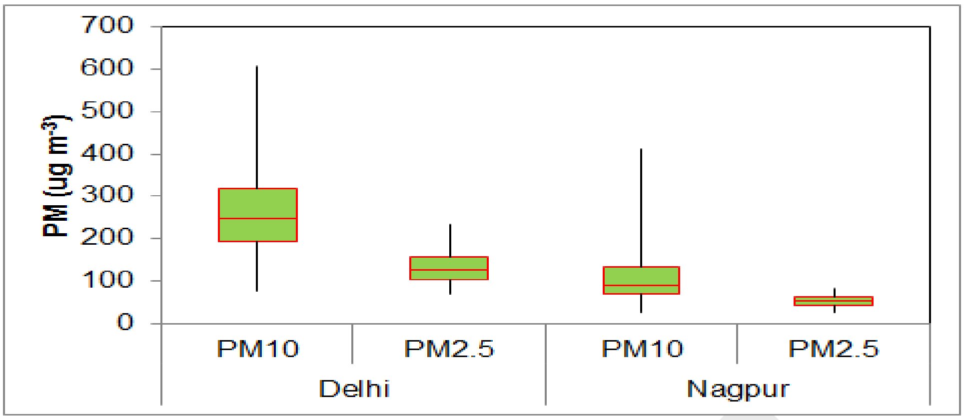


Figure 2.11(a): PM_{10}, $PM_{2.5}$ Concentration and their Ratio at Various Locations in Nagpur

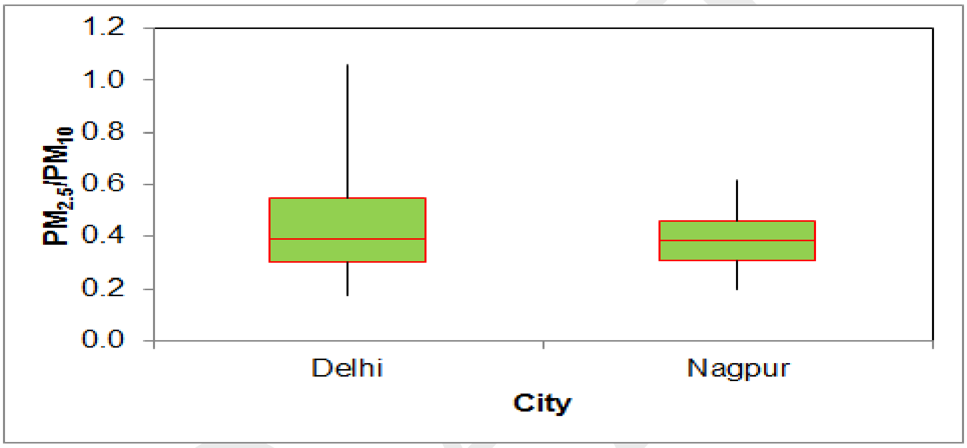


Figure 2.11(b): PM_{10}, $PM_{2.5}$ Concentration and their Ratio at Various Locations in Nagpur

2.4 Effect of Diwali on Ambient Air Quality of Nagpur

In order to assess the effect of Diwali when usually huge number of fireworks is burnt, the ambient air quality of Nagpur is studied during the event. As the Diwali festival fell on 27th October 2019, the period from 19th October to 24th October is considered as before the event, the period from 25th October to 30th October is considered as during the event as it is usually celebrated for five-six days and the period from 31st October to 5th November is considered as after the festival. The data of National Ambient Air Quality Monitoring Programme of CSIR-NEERI (called as NAAQM) and data of CAAQMS, MPCB (called as CAAQMS) is considered to assess the influence. It can be seen from **Figure 2.12** that PM_{10} concentration increases during and after the event. The increase is more pronounced in the after period as on 27th October, 2019 (i.e. on Diwali), rainfall was witnessed which would have resulted in only the slight increase in the PM_{10} concentration. $PM_{2.5}$ concentration also has increased during the Diwali period but NAAQM data shows sudden decrease in the period after Diwali, whereas CAAQMS data shows significant increase. Further, NO_2 concentration also shows slight increase in during and after period but the increase in not significant.

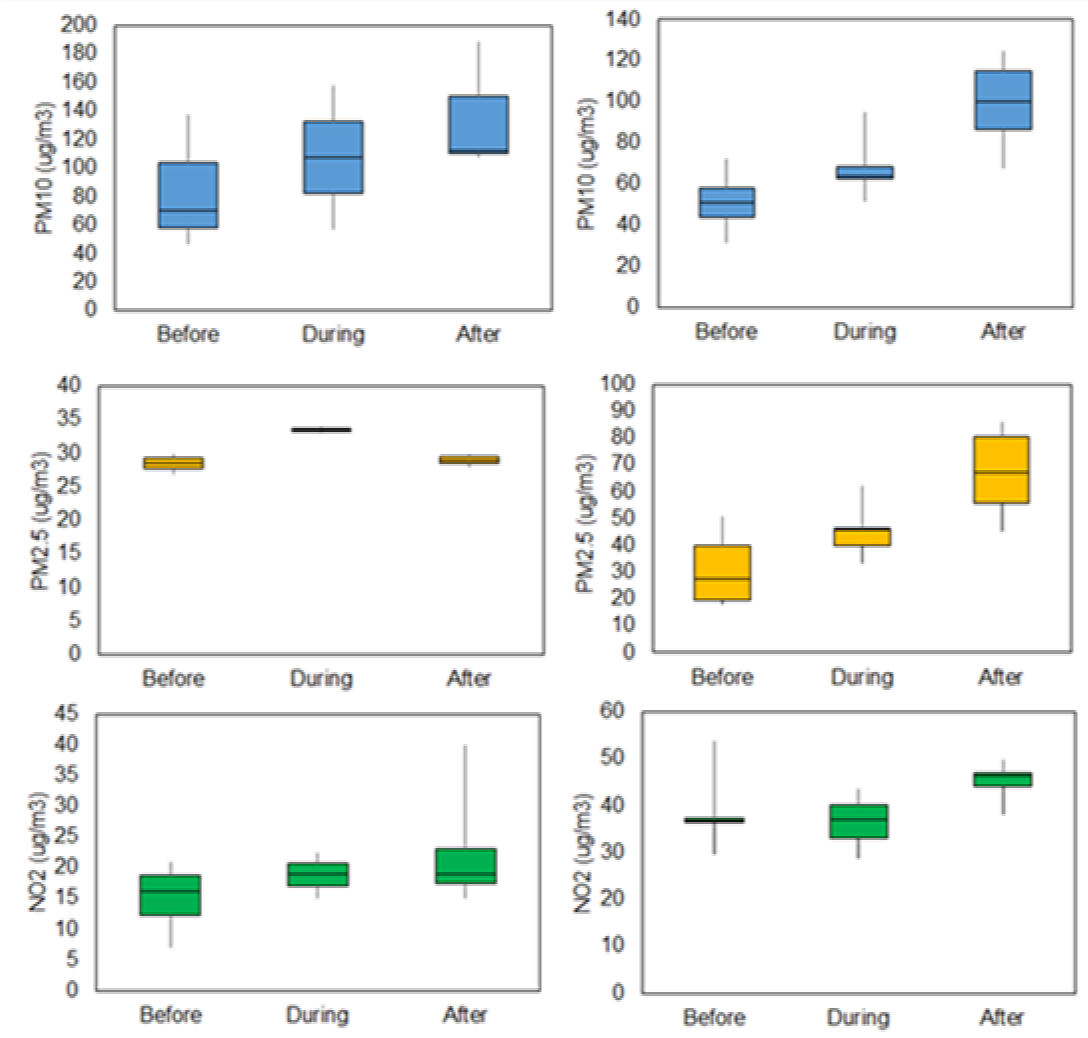


Figure 2.12 : Ambient Air Quality during Diwali Festival Period of 2019 at Nagpur

Chapter 3

Emission Inventory

3.1 Preamble

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

Due to violation of permissible limit of particulate matter standards, CPCB has listed Nagpur 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. Nagpur city has no emission inventory estimate report earlier published. Keeping in view the lack of exclusive emission inventory estimates for Nagpur, 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 Nagpur 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 Nagpur 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 Nagpur level 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 Nagpur city for source data collection. The same data is used for the estimation of emission inventory. To make the emission inventory more accurate a large number of site specific primary data has been collected. The secondary data sets have been collected from all possible authentic sources for the selected departments in the city.

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

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

3.5 Secondary Data Collection

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

3.6 Role of GIS

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

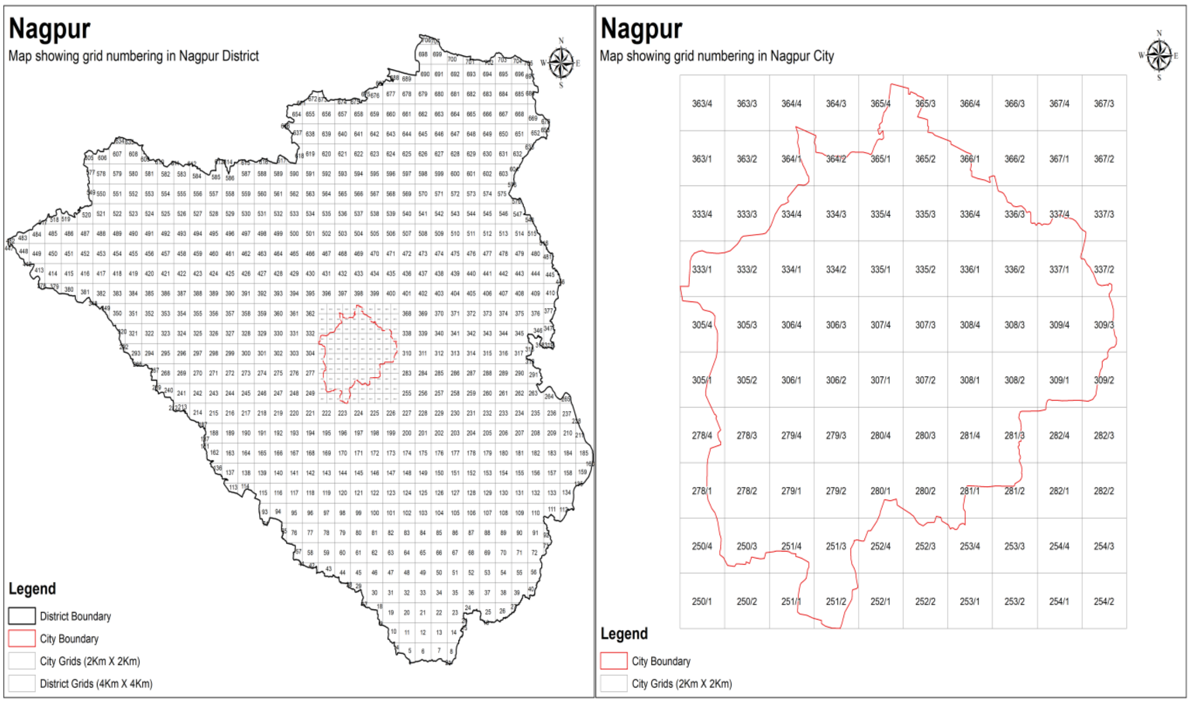


Figure 3.1 : Grid Over Nagpur District and City Boundary

3.7 Emission Factor

An emission factor (EFs) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with the associated activity responsible for emission. Typically, EFs of a fuel depends on the chemical composition of fuel, combustion type, temperature and efficiency of any emission control device. There are very limited measured EFs available in literature for India. EF defines the source strength as emission per unit time and per unit activity of the process. Country specific technology based EFs for most of the sectors are not yet available for India. Hence, in the development of emission inventory, emission factors are selected from CPCB, ARAI, USEPA AP42 and old SA study reports prepared by CSIR-NEERI on SA study **(Table 3.1)**. EF used in the present work is collected with valid scientific judgments and acceptability by global community. The used EFs for the estimation of pollution load from different sources are discussed in respected sector. The emission estimation for pollution load is calculated by available emission factors. The required data is collected from surveys and secondary data in a unique format. A grid wise emission load in Kg/Day for the specific source is being generated.

3.8 Line Source Estimates

The increase in the vehicular population resulted in rapid increase of vehicles in Nagpur city. Nagpur district has three Regional Transport Offices located at Nagpur Urban (MH 31), Nagpur Gramin (MH 40) and Nagpur east (MH 49). Following vehicle categories are considered in the present study.

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

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

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

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

The survey locations are shown in the **Figure 3.2**:

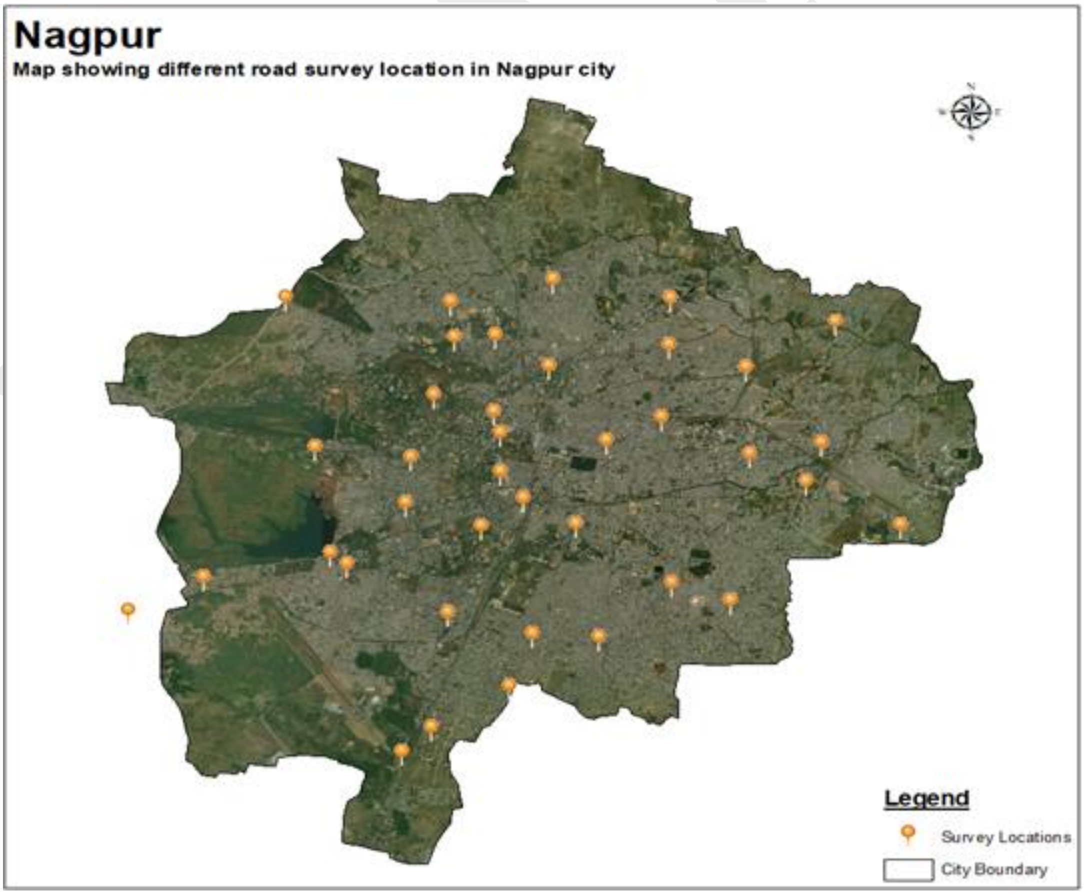


Figure 3.2: Vehicular Count Survey Location in Nagpur City

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

Table 3.1: Emission Factors Considered for Emissions Estimation

Emission Factor for BS-III Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2 Wheeler	0.035	0.27	0.61	1.65	g/km
2	3W_Petrol	0.05	1.2	0.7	1.20	g/km
3	3W_Diesel	0.05	0.5	0.5	0.50	g/km
4	4W_Petrol	0.05	0.12	0.19	3.01	g/km
5	4W_Diesel	0.12	0.67	0.2	0.51	g/km
6	HDV	1.24	9.3	0.37	6.00	g/km
Emission Factor for BS-IV Stage Engine						
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						
1	2 Wheeler	0.0045	0.09	0.068	0.5	g/km
2	3W_Petrol	0.025	0.1	0.10	0.22	g/km
3	3W_Diesel	0.0045	0.08	0.10	0.5	g/km
4	4W_Petrol	0.0045	0.06	0.10	1.00	g/km
5	4W_Diesel	0.0045	0.08	0.10	0.5	g/km
6	HDV	0.01	0.08	0.10	0.5	g/km

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

Ref: *"A Report on Total Fuel Consumption by Transport Sector in India", Press Information Bureau, Government of India, Ministry of Petroleum & Natural Gas, dated January 28, 2014. The hourly emission load from different types of vehicle is estimated.*

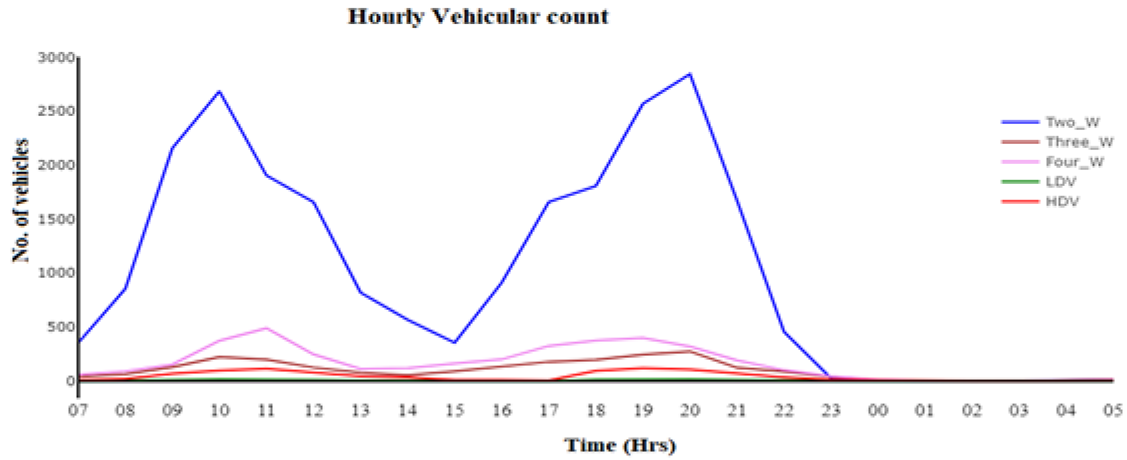


Figure 3.3 : Hourly Vehicle Count at a Traffic Intersection

From the above **Figure 3.3**, it can be concluded that the major count of traffic is from 2 wheelers. Two major peaks are seen for 2 wheelers, one during the early morning from 7:00 Hrs to 13:00 Hrs and the other from 15:00 Hrs to 20:00 Hrs. The major groups of working people travel to their offices using 2 wheelers. The same peak but at a smaller number is seen for private 3 wheelers. From the figure it is also clear that the city traffic starts at 7:00 Hrs in the morning and lasts till 23:00 Hrs. After that the city traffic is nearly zero. As Nagpur city has outer ring roads to connect other cities, the major traffic of heavy duty commercial vehicles passes through these roads. This has reduced the numbers of heavy duty commercial vehicles entering into city.

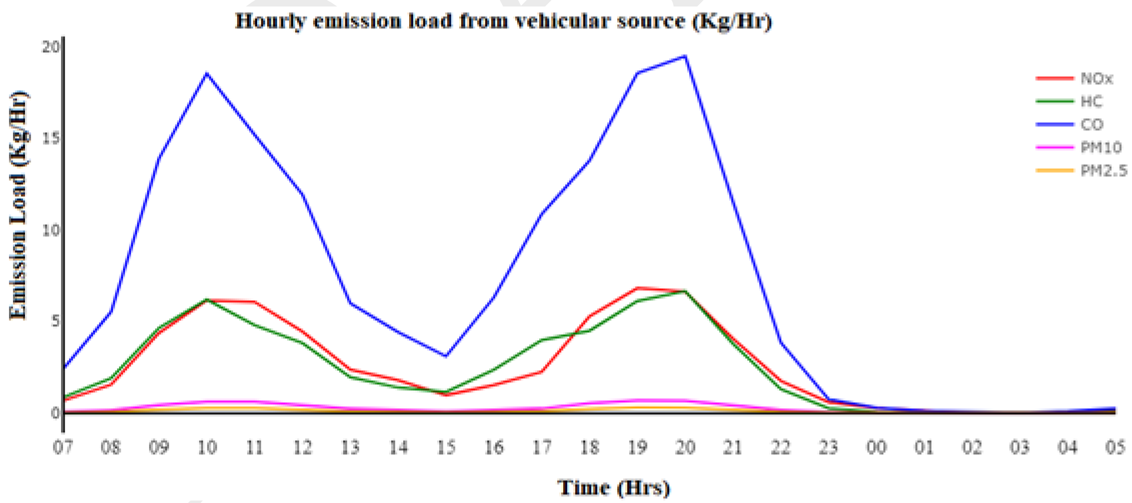


Figure 3.4: Hourly Emission load (kg/hr) Due to Vehicular Traffic Flow at a Traffic Intersection

From the vehicular count, the variation is seen in hourly emissions of all pollutants. Maximum emission load is for CO. Particulate emission load is varying from 0 to 3 kg per hour during 7:00 Hrs to 23:00 hrs **(Figure 3.4)**. The emission load during night is seen to be zero due to very low numbers of vehicles moving on road. The total emission load from vehicular flow from the monitored vehicles at traffic count locations of the city estimates for PM_{10}, $PM_{2.5}$, NOx, CO and

HC is estimated to be 644.2, 275.94, 6451.11, 13095 and 4212.78 Kg per day **(Figure 3.5)**. Out of the total emission load estimated, 53.1% emission load is from HDVs followed by LDVs (19.94%), 4 wheelers (9.97%), 2 wheelers (9.36%) and 3 wheelers (7.68%) respectively **(Figure 3.6).**

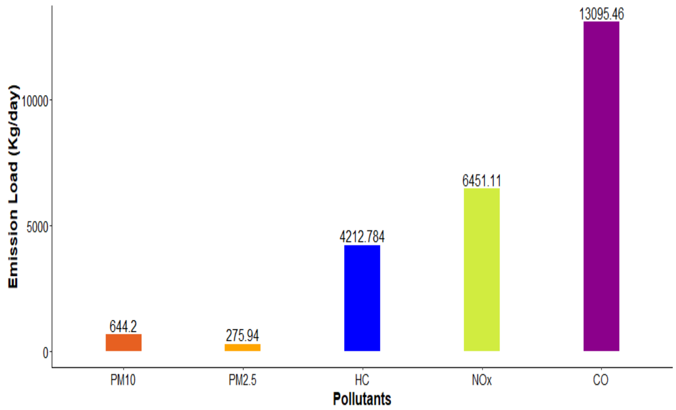


Figure 3.5 : Total Emission Load from line Source

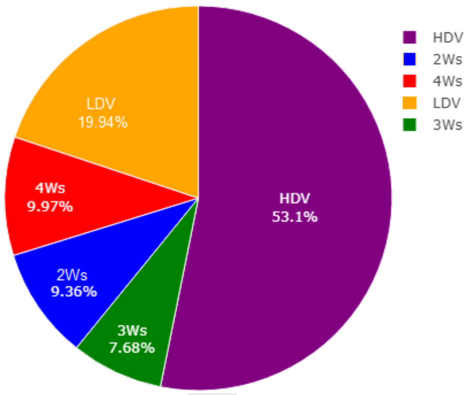


Figure 3.6: Vehicular Emission Load (%)

The grid-wise emission load due to vehicular traffic flow is shown in following **Figure 3.7.**

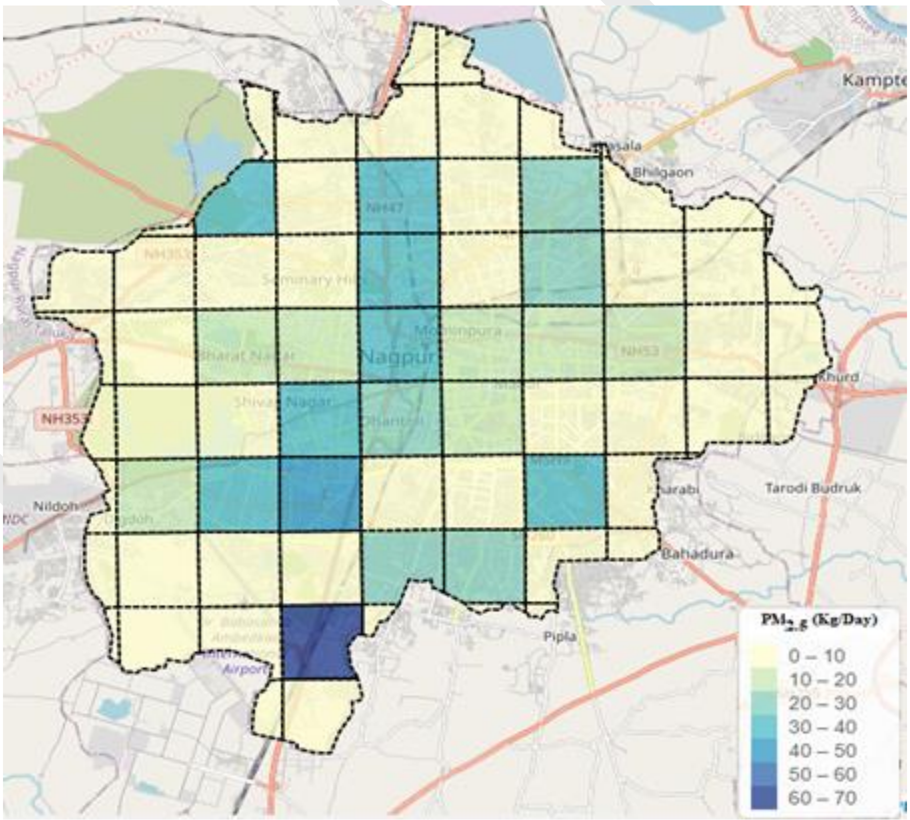


Figure 3.7: Grid-wise Emission Load for PM from Line Source

3.9 Point Source

The state is gearing up for the rapid infrastructural as well as industrial development; likewise Nagpur is changing it's identify of being an industrial hub. The decadal population growth is tremendous owing to this industrialization of the region. The Maharashtra Pollution Control Board Regional office is functioning at Nagpur. There are three industrial areas in Nagpur city, namely Hingna MIDC, Butibori MIDC and Kamptee MIDC.

There are about 10,356 registered units, out of which 213 units fall under medium and large scale industries. Out of these, a total of 74 registered industries are seen to be air polluting. The Butibori industrial area serves to be one of the major venues where a large number of industries have been put up. The major industries of Nagpur includes Texprint Overseas Limited, ACC Nihon Casting Limited, KEC International Limited, Woolworth (I) Limited, Uniworth Power Limited, SSP Pvt Limited, Munis Forge Limited, Maharashtra Organo, Voltas Limited, ACC Refractory Limited, Indorama Synthetics (p) Limited, Premier Irrigation Equipment Industries Limited, Morarji Mills Limited, Ferrow Alloys Corporation, Industrial Oxygen Limited, Fabworth (I) Limited, SKG Refrigerators etc. The fuel consumed is coal, bagasse, furnace oil, LDO, HSD, LPG and Diesel (DG sets, if any). As coal is majorly used in thermal power plants, the consumption is seen to be highest.

Thermal Power Plants

There are two thermal power stations located to the North of Nagpur city. Koradi Thermal Power Plant (KTPS) is one of the power plants in Vidarbha -a power surplus region of India. The power station began operations in 1974 and is one of the nine active power stations operated by Maharashtra State Power Generation Company Limited (MAHAGENCO), a subsidiary of Government of Maharashtra. The plant operates 5 units and has a total power generation capacity of 2400 MW. Two units of 210 MW and three units of 660 MW are in operation.

Khaparkheda Thermal Power Plant (KTPS) is located in Nagpur district in the Indian state of Maharashtra. The coal for the power plant is sourced from Saoner and Dumri Khurd mines of Western Coalfields Limited. The plant operates 4 units of 210 MW capacities and one unit of 500 MW capacities.

Emission load from point source kg/day is presented in **Figure 3.8**. As industries are located outside the municipal boundary of the city, the grid-wise emission load for PM_{10} and $PM_{2.5}$ from point sector is shown in **Figure 3.9**. Maximum emission load is from thermal power plants only.

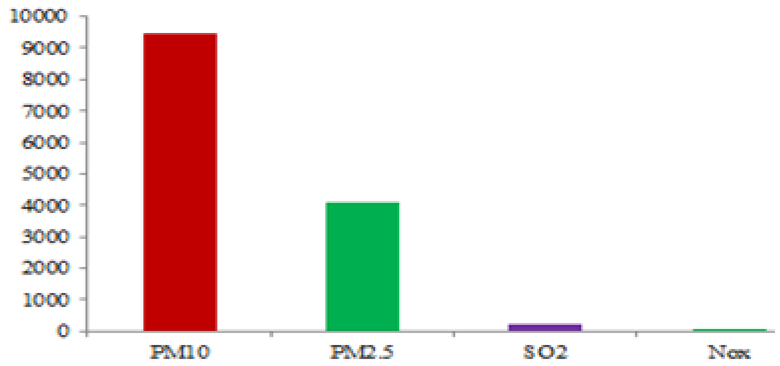


Figure 3.8 : Emission Load from Industries (Kg/day)

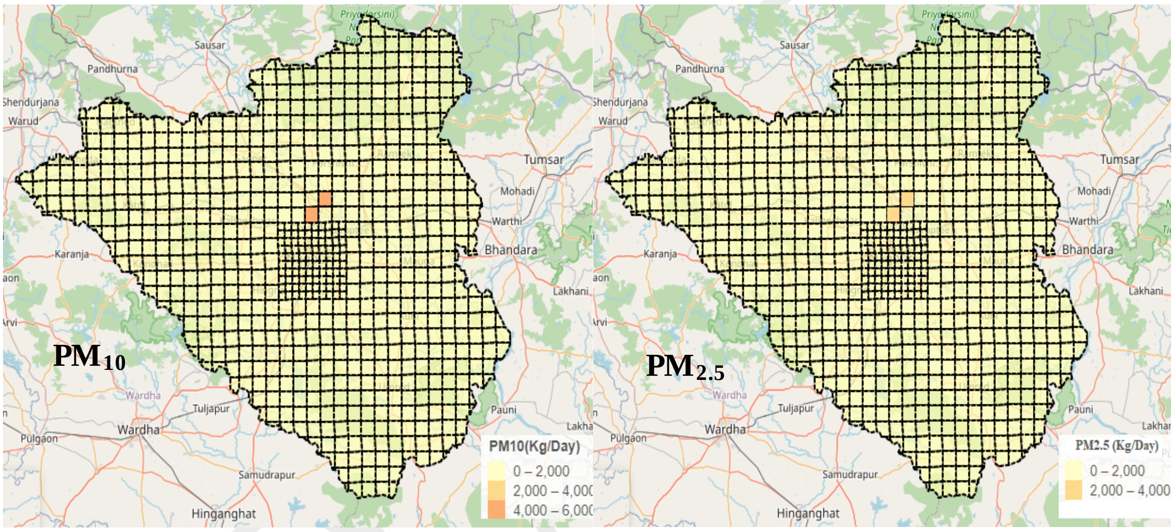


Figure 3.9 : PM_{10} & $PM_{2.5}$ Emission Load from Industries

3.10 Area Sources

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

3.10.1 Bakery

Bakery industry is mainly concentrated in the state of Maharashtra, West Bengal, Karnataka and Uttar Pradesh, out of which more than 60% of bakery is accounted to be unorganized. Being an essential item in urban areas, bakeries mainly operate from the midst of the city. An initial survey was arranged city wide to assess bakery related activities taking place in the jurisdictions of the city. There are 34 large and medium scale bakeries spread all across the city. Considering the operation of bakeries, it was observed the fuel consumption pattern is of mixed nature. There have been reported cases of unorganized bakeries comprising small bakery units characterized by low levels of packing and distribution mainly in neighbouring areas. These small time bakeries operate mainly on out-dated combustion technologies and traditional methods of manufacturing baked goods that utilize solid fuels in large quantity without any control measures for emission. Consumption of wood and coal as fuel in bakery processes is one of the major source for PM emission loads from bakeries. Through survey it was observed, mostly bakeries operate for 12-16 hours per day and the peak season of business is during Ramzan festival. Being a semi-urban region, the fuel consumption in the bakeries was low as compared to other metro cities. All bakeries were LPG oven based units. Data regarding bakeries was obtained from NMC, and ground level survey. The study area was divided into array of 2 km x 2 km grid to quantify the average fuel consumption and their subsequent emission across region. In our study, fuel that came into survey was taken into account for emission load.

Emission Estimation (Kg/d) = No. of Bakeries x Fuel Consumption (Kg/d) x Emission Factor. The total emission load for PM_{10}, $PM_{2.5}$ and CO from bakeries is estimated to be 3.5, 2.3 and 15.8 Kg/Day respectively.

Estimated and grid wise emission load from bakeries are shown in **Figures 3.10 and 3.11**.

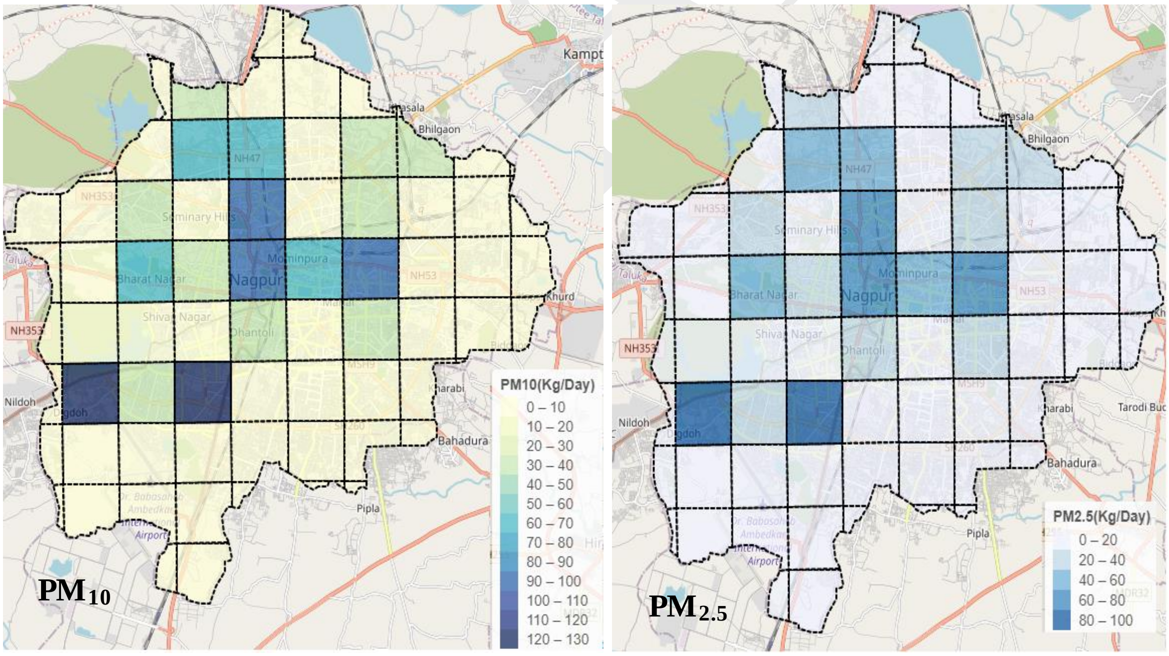


Figure 3.10 : Grid wise Emission Load for PM_{10} & $PM_{2.5}$ from Bakeries

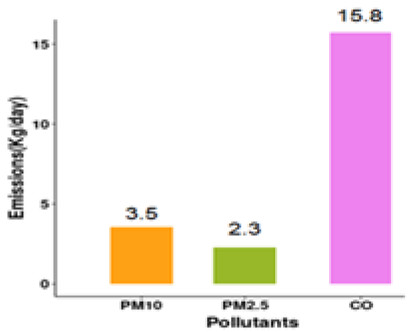


Figure 3.11 : Estimated Emission Load from Bakeries of Different Pollutant (Kg/day)

3.10.2 Crematoria

The fiery dissolution of the body is considered as death rite in Hindu religion**.** Existing cremation grounds of city are located along the bank of rivers or nallahs. There are total 16 wood based cremation centers located in the city. As per the assumption from previous studies and in consultation with NMC the average wood requirement for burning a dead body is about 300 Kg and additives like kerosene is used to burn the dead bodies. In this study, emission from wood and kerosene is considered. Emission from this category of area source release major pollutants like PM_{10}, $PM_{2.5}$, SOx, NOx and CO**.** Data regarding number of death cremated was obtained from Birth and Death cell of Nagpur Municipal Corporation. The emission load from different pollutants is shown below. Estimated and grid wise emission load from crematoria are shown in **Figures 3.12 and 3.13**.

Emission Estimations:

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

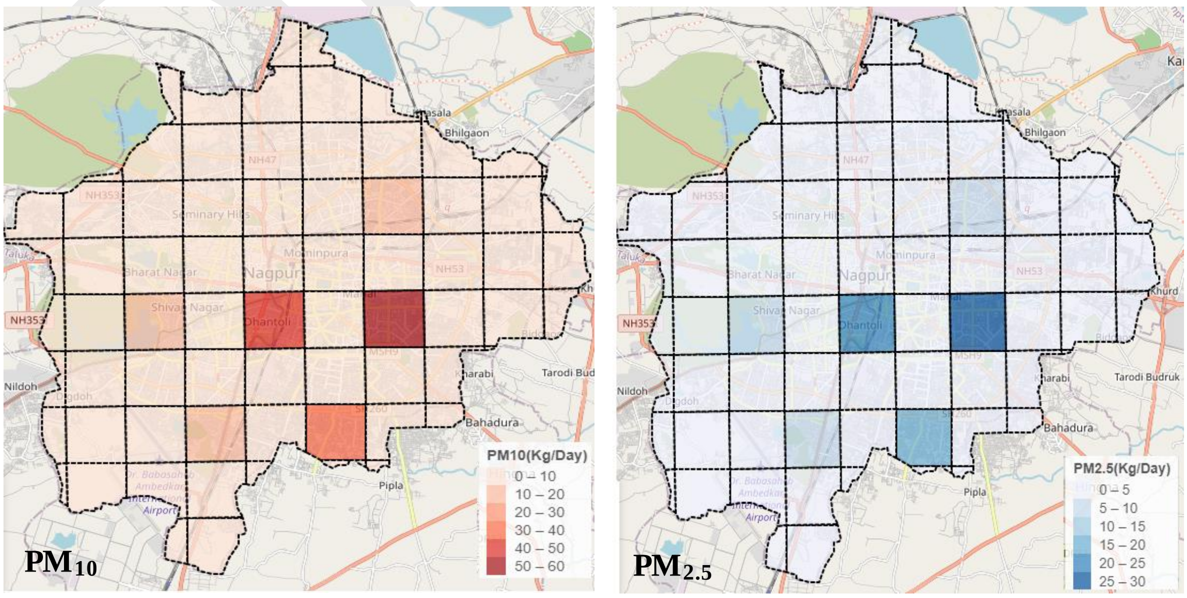


Figure 3.12 : Grid wise Emission Load for PM_{10} & $PM_{2.5}$ from Crematories

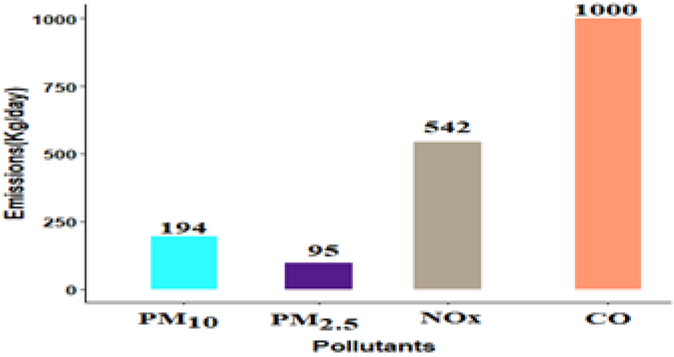


Figure 3.13 : Estimated Emission Load from Crematoria of Different Pollutant (Kg/day)

3.10.3 Open Eat outs

This informal sector even though being small in size, contribute emission load on large area because of the variable fuel consumption pattern for their operations and absence of any control measures for these emissions. On the basis of primary survey, the fuel preference for open eats out in Nagpur 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 438 registered open eat outs in the city. Estimated emission load from open eat outs are shown in **Figures 3.14.**

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

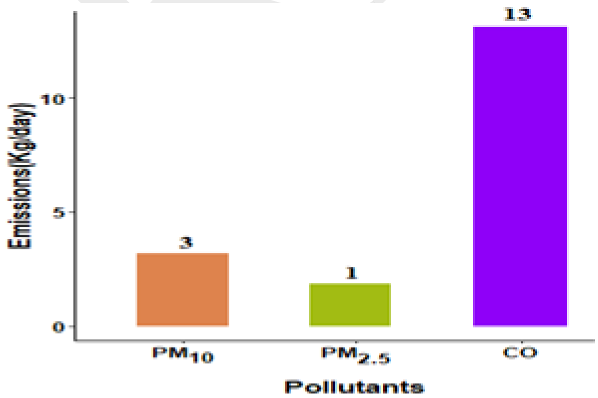


Figure 3.14 : Estimated Emission Load from Open Eat outs of Different Pollutant (Kg/day)

3.10.4 Domestic Sector

Attributing to the demography of the region and standard of living of the population, the fuel consumption pattern is varied at individual level. As non-slum population is more organized considering their source of income, their primary domestic fuel is LPG. Due to the recent policy change from the government under PMUY, the consumption of LPG has grown in slum areas.

Along with LPG, slum population use locally available resources such as wood, coal, kerosene etc. There are total 29 nos. of domestic gas distributors in the city. Based on survey it was found that the consumption of kerosene, coal and wood is prevalent in slum areas. They have registered gas connection, but rent the cylinders for extra income and cook food on chulha by using coal, wood or kerosene. Estimated and grid wise emission load from domestic sector are shown in **Figures 3.15 and 3.16**.

Emission Estimation

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

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

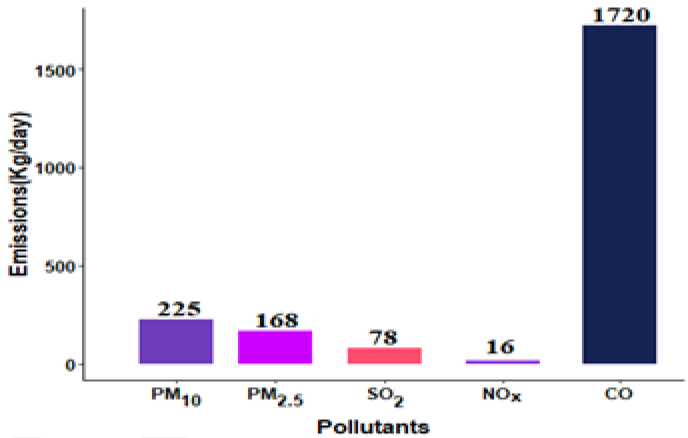


Figure 3.15 : Estimated Emission Load from Domestic Sector of Different Pollutant (Kg/day)

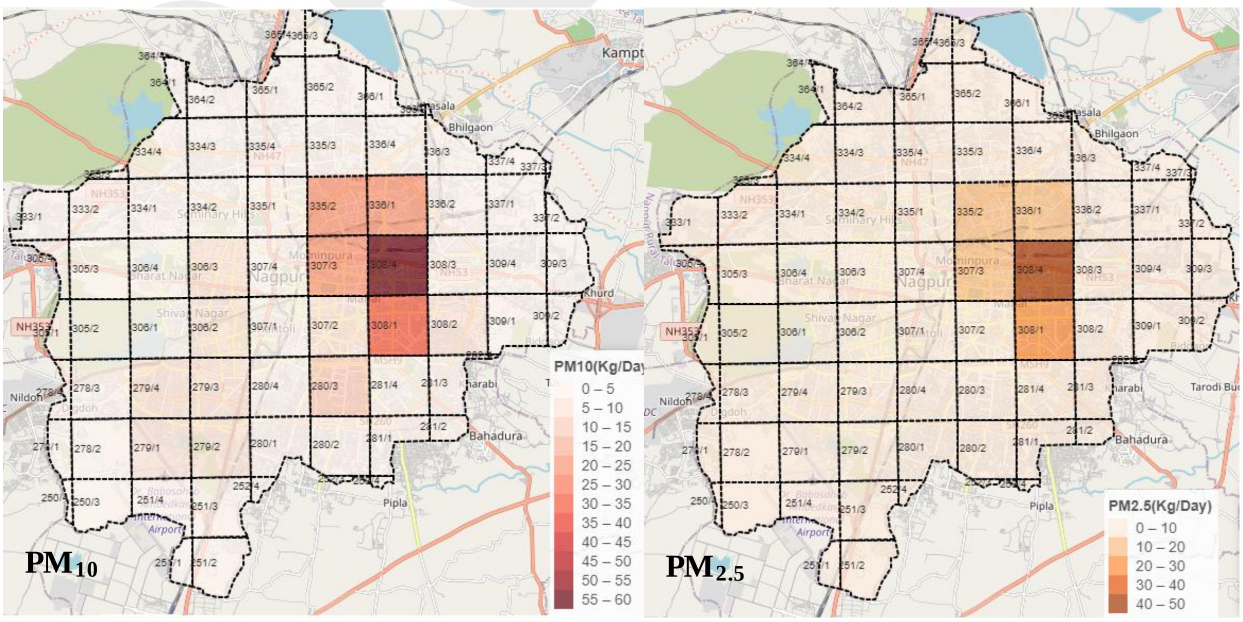


Figure 3.16 : Grid wise Emission Load for PM_{10} & $PM_{2.5}$ from Domestic Sector

3.10.5 Building Construction

With a scope of being developed as smart city, there are drastic infrastructural developments taking place in Nagpur 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 NMC and from RERA website. During survey, 256 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).

Estimated emission load from building construction are shown in **Figures 3.17.**

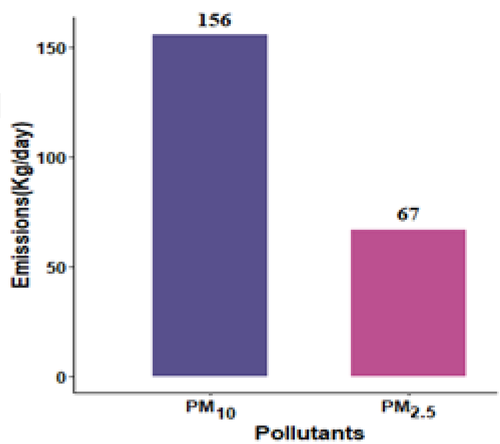


Figure 3.17 : Estimated Emission Load -Building Construction of Different Pollutant (Kg/day)

3.10.6 Hotels and Restaurants

There are around 55 hotels registered with the NMC License department. It was observed that the large number of tea stalls/snack corners/fast food centres, which have fuel consumption almost same as a hotel, could be more than twice the registered number and remains unaccountable. In addition, institutions and organizations have their own canteen/hotels within their premises and their fuel consumption patterns are unknown. Hotels and Restaurants use LPG cylinders and coal for their operation. LPG commercial cylinders of 19 kg are used for cooking and coal is used in the tandoor bhattis. Domestic cylinders are also consumed in the commercial sector illegally for which data was not easily available. Estimated and grid wise emission load from hotels and restaurants are shown in **Figures 3.18 and 3.19**.

Emission Estimations

- Emission Load from LPG

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

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

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

  However, for calculation purposes, it has been referred to as PM_{10}.
- Emission Load from Coal

  Total emissions (PM) due to coal burning in Hotels

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

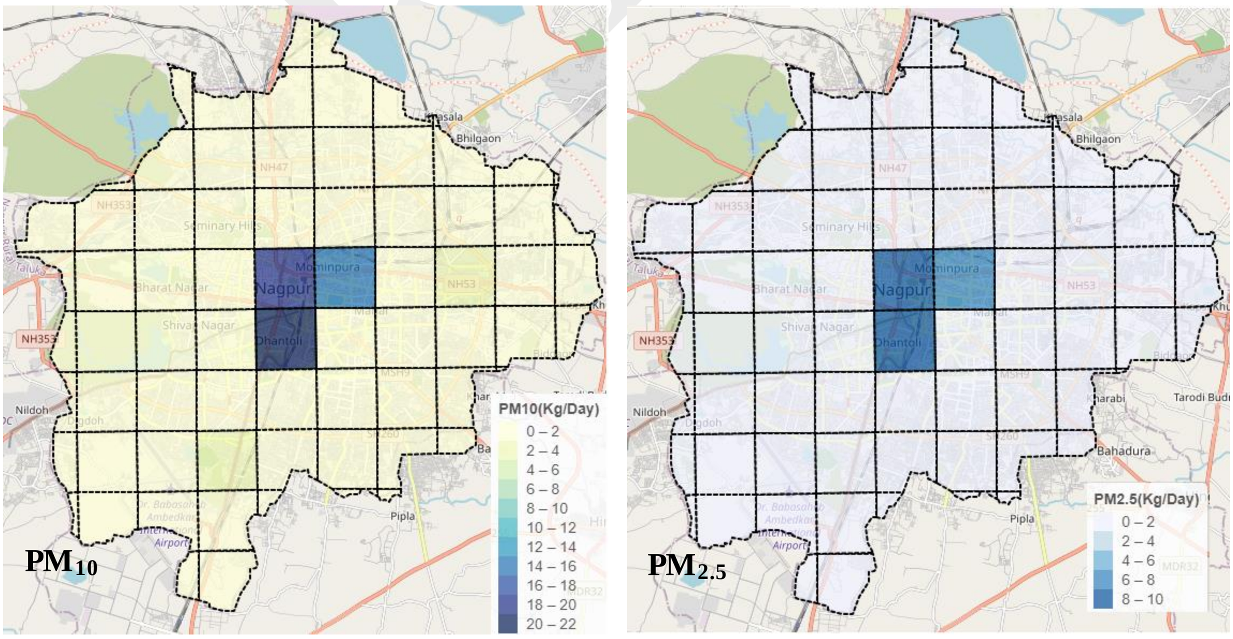


Figure 3.18 : Grid wise Emission Load for PM_{10} & $PM_{2.5}$ -Hotels and Restaurants

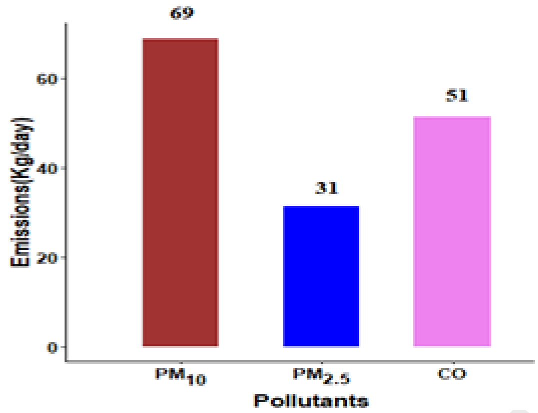


Figure 3.19 : Estimated Emission Load - Hotels & Restaurants of Different Pollutant (Kg/day)

3.10.7 Brick Kilns

India is the second largest producer of clay fired bricks, accounting for more than 10 present 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 labor 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.

In Nagpur, there are 18 registered brick kilns. The data is collected by visiting the number of brick kilns. The total emission load from brick kiln is calculated. Estimated emission load from brick kilns are shown in **Figures 3.20.**

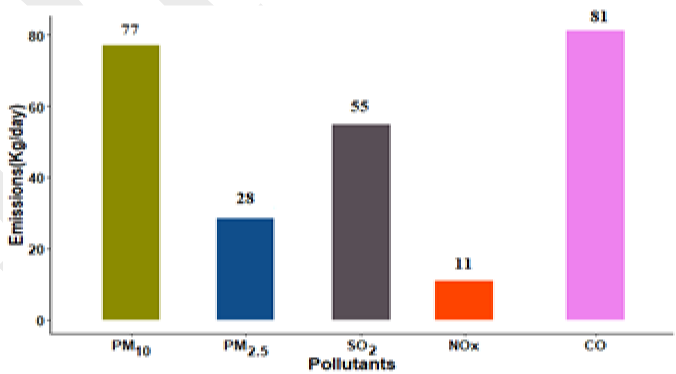


Figure 3.20 : Estimated Emission Load from Brick Kilns of Different Pollutant (Kg/day)

3.10.8 Road Dust Resuspension

Nagpur being almost at the geographical centre of India, all major highways and railways pass via Nagpur. Nagpur city is the junction of two National Highways NH-6 and NH-7. This has resulted in the city being a major trade and transportation centre. It is connected to all metropolitan cities of India by air route as well. The total length of roads in the city is 3356 kms, of which the length of major roads is 500 kms, the remaining being the internal roads.

Road Length in Nagpur City

No.	Particulars	Length (kms)
1	Total length of roads	3356
2	Paved roads	2752
3	Unpaved roads	604

Total constructed road length within corporation area is 3356 Kms. 82% (2752 kms) of the total road are paved, while remaining was accounted as unpaved (604 kms)**.** As motor vehicle moves over road surface, it leads to resuspension of dust from unpaved roads or settled dust from the paved surface by the turbulent wake of the vehicle and emitted as particulate matter. Emissions are estimated as a function of the silt loading of the paved surface and mean weight of the vehicles travelling over the surface. Data source such as road length was obtained using GIS tools and the information for roads was received from Nagpur Municipal Corporation and Nagpur improvement. Estimated and grid wise emission load from hotels and restaurants are shown in **Figures 3.21 and 3.22.**

Emission Estimates for Road Dust

Vehicle registered (2017)		% Vehicle count (A)	Average Weight (B) (kg)	Vehicle Weight by % (A*B) (kg)
2 W	1451863	0.64	175	112.04
3 W	98541	0.043	450	19.56
Cars	419785	0.185	1425	263.8
HDDV	297427	0.13	20000	2623.26
Total	2267616			**3018.66**
Total				**3.012 tonnes**

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

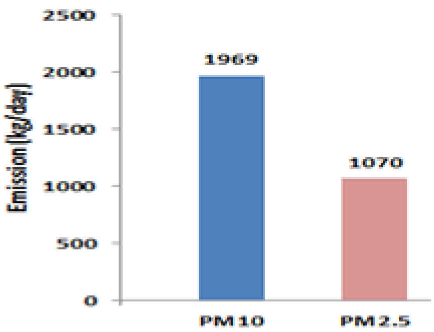


Figure 3.21 : Estimated Emission Load-Road Dust Resuspension- Different Pollutant (Kg/day)

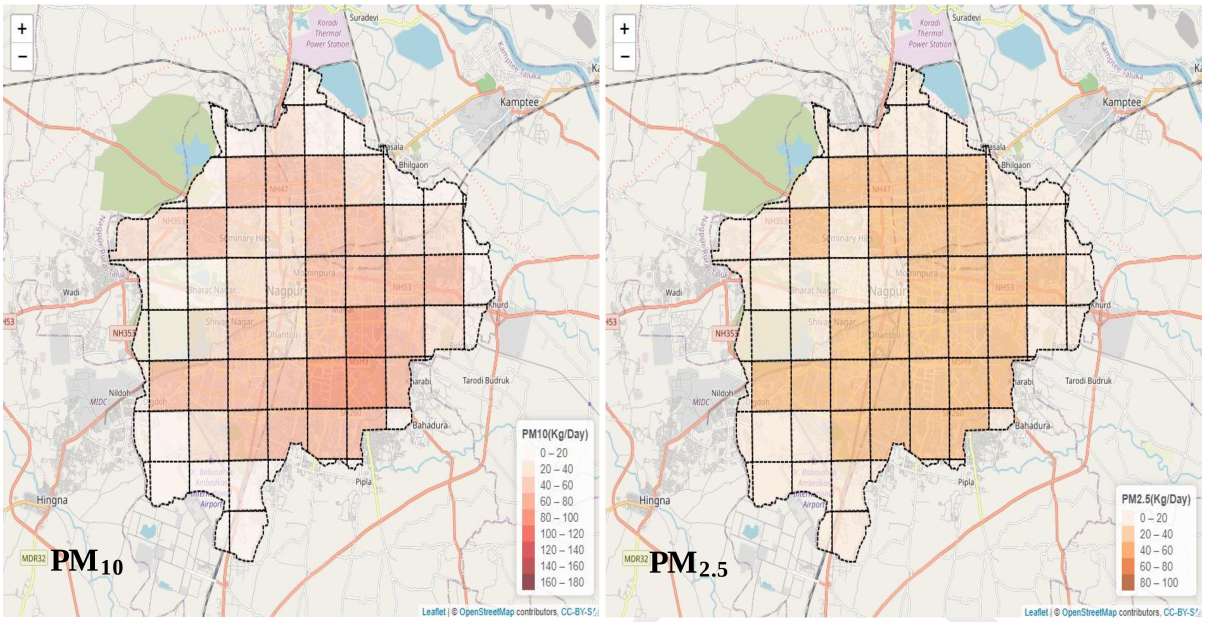


Figure 3.22 : Grid wise Emission Load for PM_{10} & $PM_{2.5}$ - Road Dust Resuspension

3.10.9 Road Construction

The road sector is one of the main sources of air emissions in the atmosphere during both construction and operation. Roads in the city are being transformed from asphalt to concrete roads. During construction of roads, the particulate matter is released to atmosphere. During the survey it is found that the 28 kms of road length was under construction. The average width of the road was 7 meters. The emission load for particulate matter is estimated to be 3.3 and 1.5 Kg/day for PM_{10} and $PM_{2.5}$. Estimated emission load from brick kilns are shown in **Figures 3.23.**

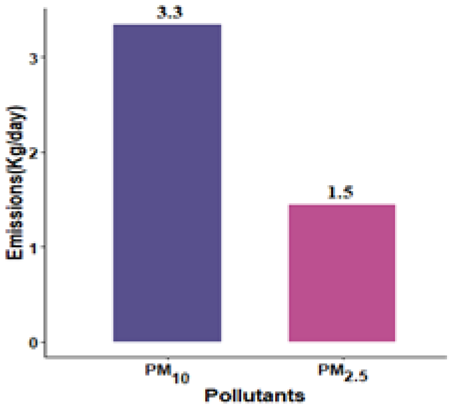


Figure 3.23 : Estimated Emission Load -Road Construction for Different Pollutant (Kg/day)

3.10.10 Open Burning

Open burning of Municipal Solid Waste (MSW) is a potential non-point source of emission, which causes greater concern especially in developing countries such as India. Lack of awareness about environmental impact of open burning, and ignorance of the fact, i.e. 'Open burning is a source of emission of carcinogenic substances' are major hindrances towards an appropriate municipal solid waste management system in India. Pollutants like particulate matter, carbon monoxide, sulphur oxides, nitrogen oxides are emitted from burning of MSW. The survey was conducted with the locals in different city area. The overall data of the survey was added and it was concluded that the maximum quantity of solid waste is burnt in commercial areas which includes plastic, papers, dry leaves and sometimes oily clothes are also seen. The areas like Bhandewadi, back side of Nagpur Airport and area near to Nagpur railway station has counted for more burning activities. The total emission load for particulate matter PM_{10} and $PM_{2.5}$ due to burning of municipal solid waste is estimated 881 and 377 Kg per day Estimated and grid wise emission load from open burning are shown in **Figures 3.24 and 3.25.**

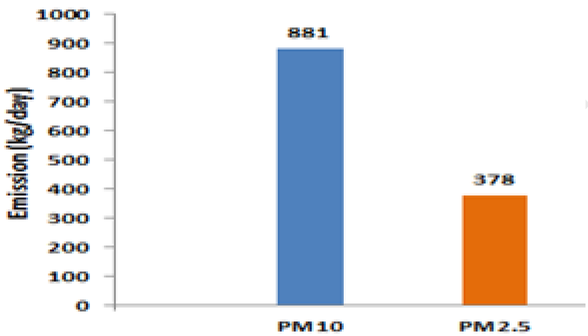


Figure 3.24 : Estimated Emission Load -Road Construction for Different Pollutant (Kg/day)

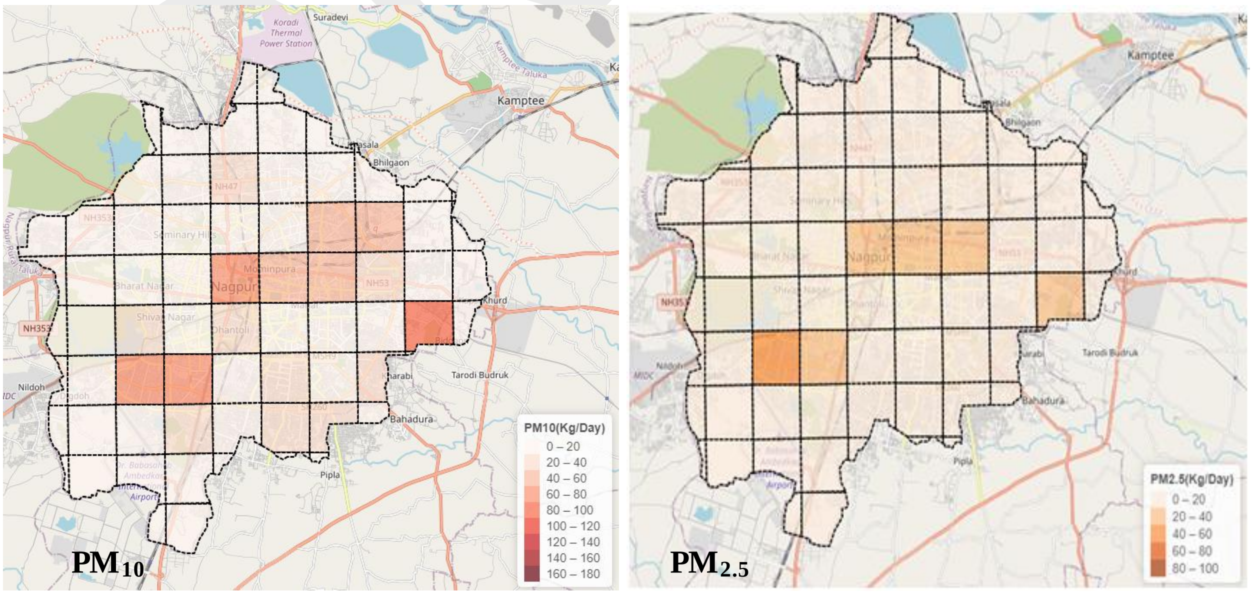


Figure 3.25 : Grid wise Emission Load for PM_{10} & $PM_{2.5}$ -Open Burning

3.11 Total Emission Inventory

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Nagpur city vide emission inventory is developed as shown in **Table 3.2**. Total tons /day emission load for pollutants in Nagpur city is depicted in **Figure 3.26**.

Table 3.2 : Total Emission Load for all Pollutants

No.	Sector	PM_{10}	$PM_{2.5}$	SOx	NOx	CO
		(Kg/Day)	(Kg/Day)	(Kg/Day)	(Kg/Day)	(Kg/Day)
1	**Line Source**	644	276	0	6451	13095
2	**Point Source**	9474	4066	234	48	0
3	**Area Sources**					
i	Bakeries	3.5	2.3	0	0	15.8
ii	Crematoria	194	95	1	542	1000
iii	Open Eat-outs	3	2	0	0	13
iv	Domestic	225	168	78	16	1720
v	Building Construction	156	67	0	0	0
vi	Hotels & Restaurants	69	31	0	0	51
vii	Brick Kilns	77	28	55	11	81
viii	Road Resuspension	1969	1070	0	0	0
ix	Road Construction	3	1	0	0	0
x	Open Burning	881	378	0	21	2400
4	**Total Emission Load (Kg/day)**	**13698.5**	**6184.3**	**368**	**7089**	**18375.8**
	Total Emission Load (Ton/day)	**13.70**	**6.18**	**0.37**	**7.09**	**18.38**

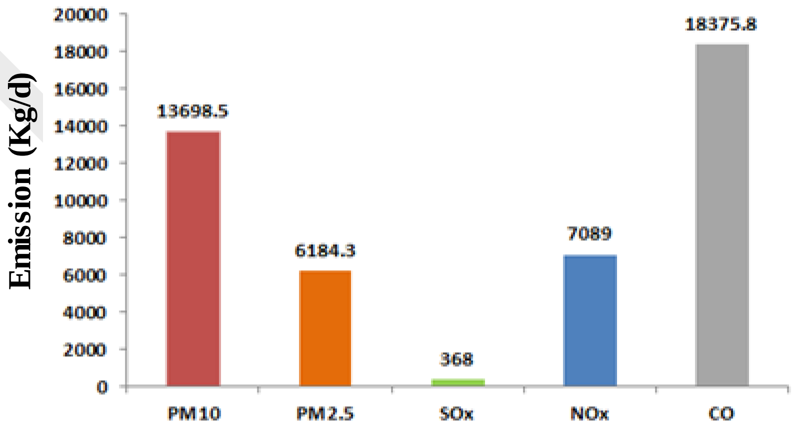


Figure 3.26 : Total Emission Load (Tons/Day) for Pollutants in Nagpur City

3.12 Grid-wise Emission Inventory

Grid-wise Emission inventory is a scientific way to identify aggregated local source contribution and their region-specific spatial distribution within a confined boundary. 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 and effective tool to identify hot spots. To understand this precisely, the details of the sources responsible for emission inventory are presented for respective pollutants **(Figure 3.27 to Figure 3.31)**.

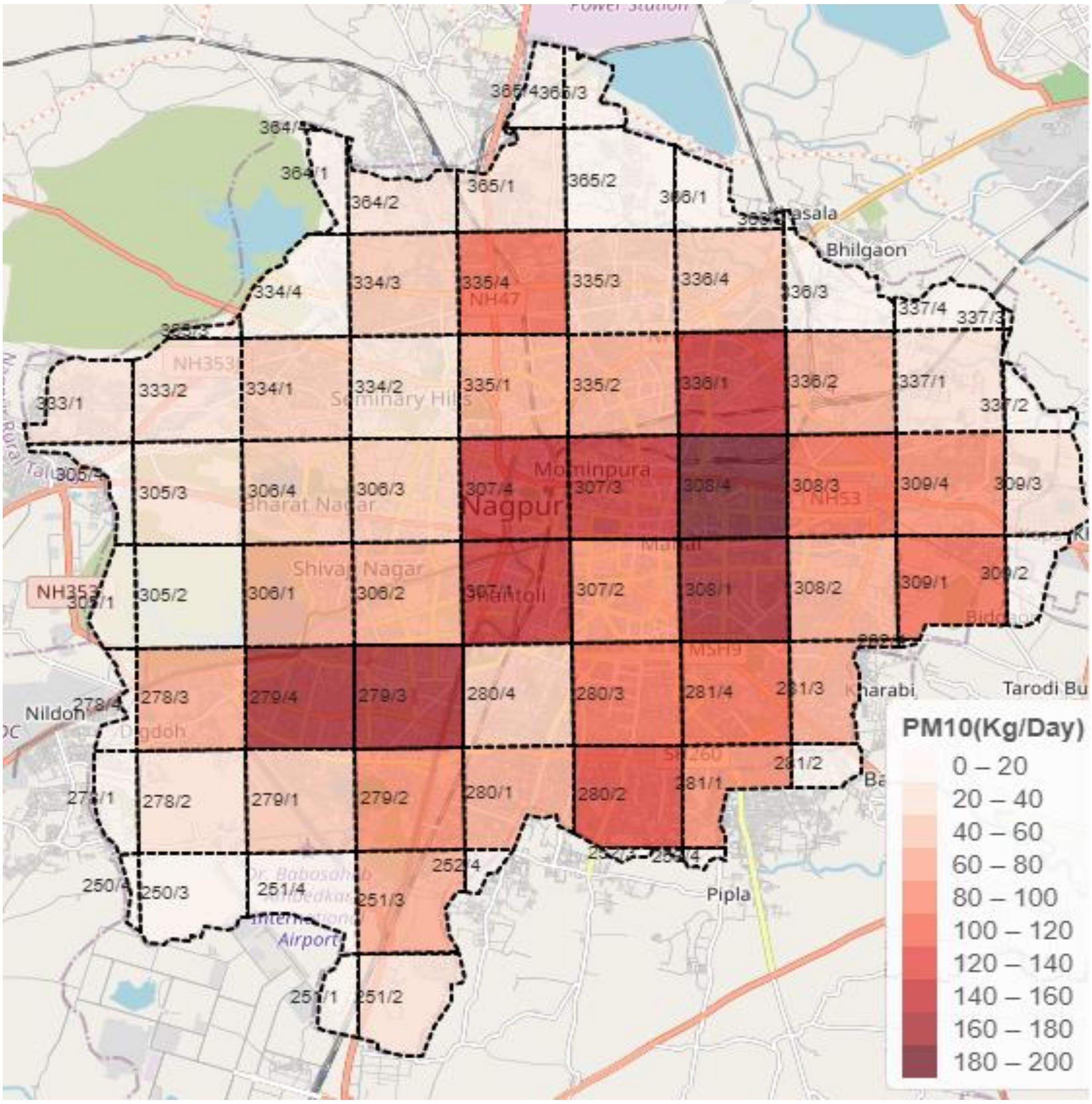


Figure 3.27 : Total Grid-wise Emission Load for PM_{10} (Kg/day) for Nagpur City

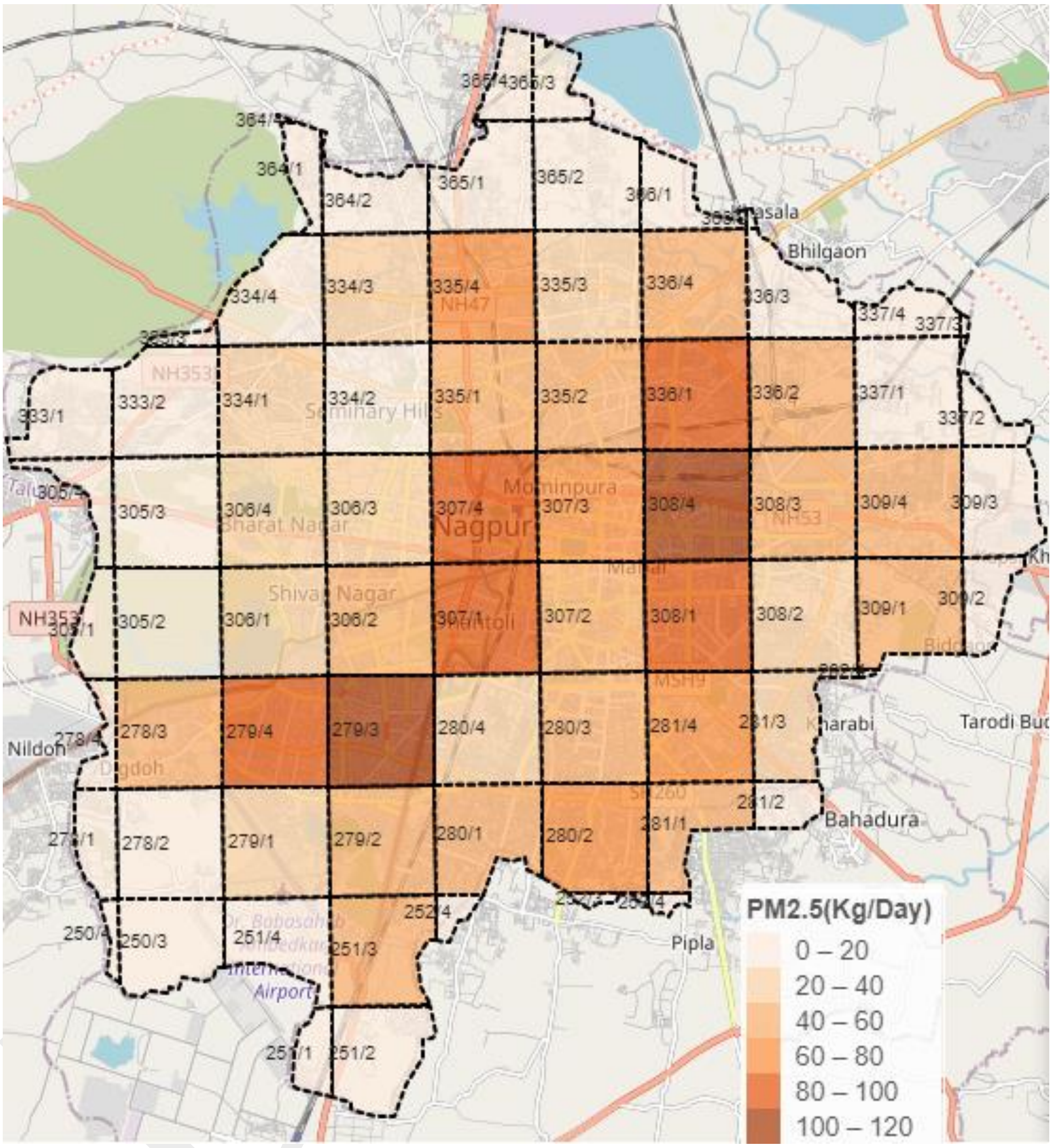


Figure 3.28 : Total Grid-wise Emission Load for $PM_{2.5}$ (Kg/day) for Nagpur City

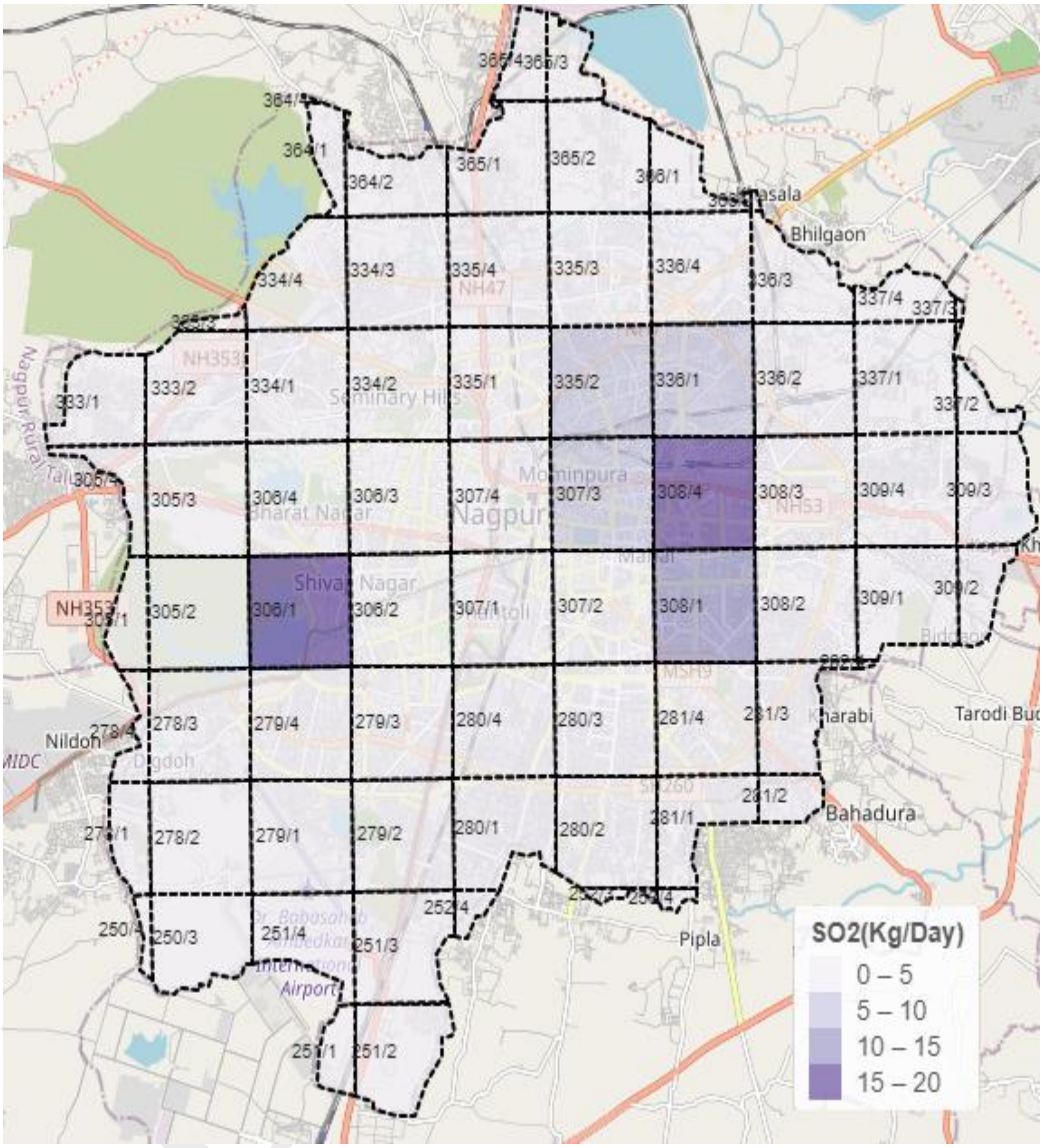


Figure 3.29 : Total Grid-wise Emission Load for SOx (Kg/day) for Nagpur City

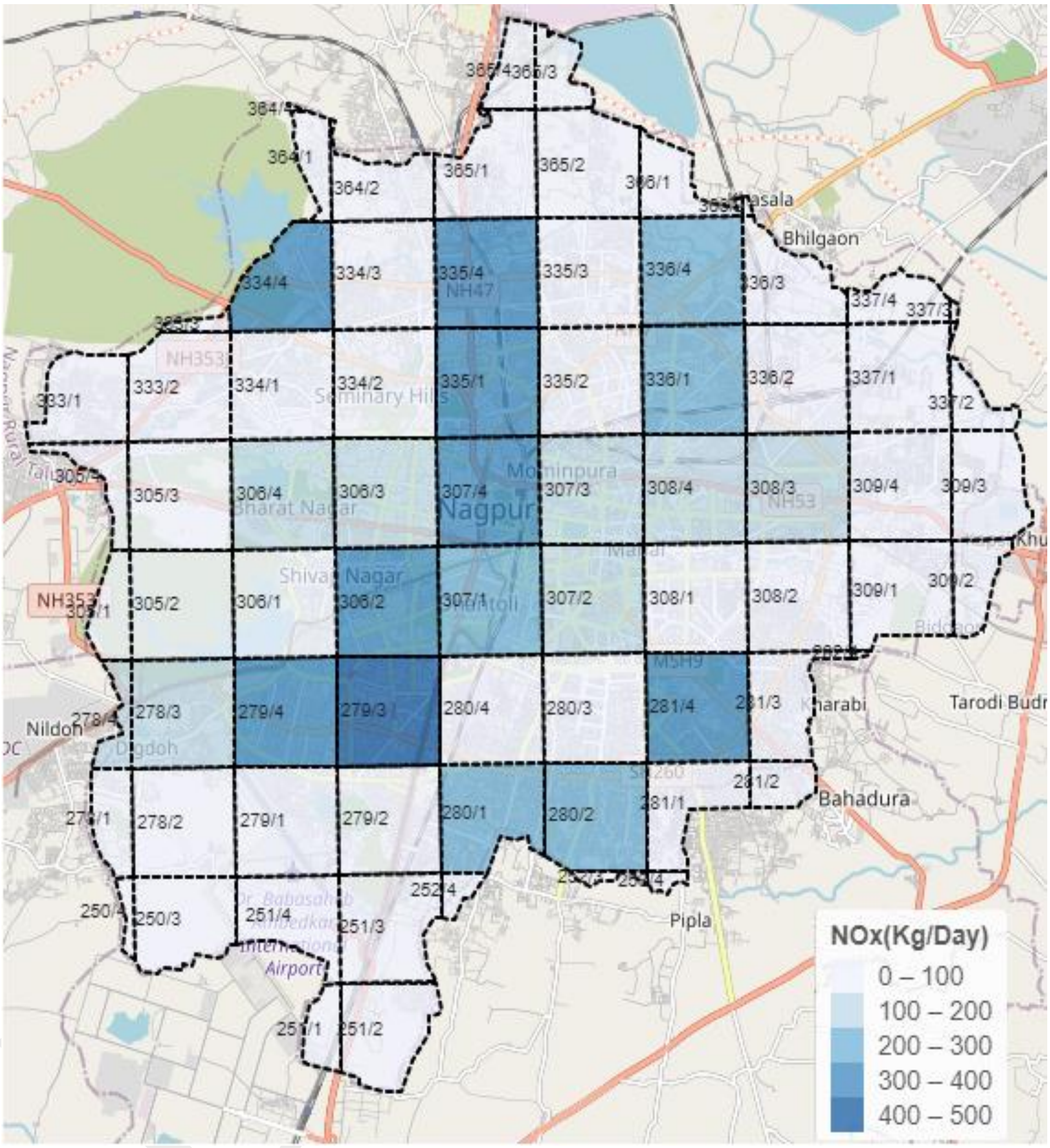


Figure 3.30 : Total Grid-wise Emission Load for NOx (Kg/day) for Nagpur City

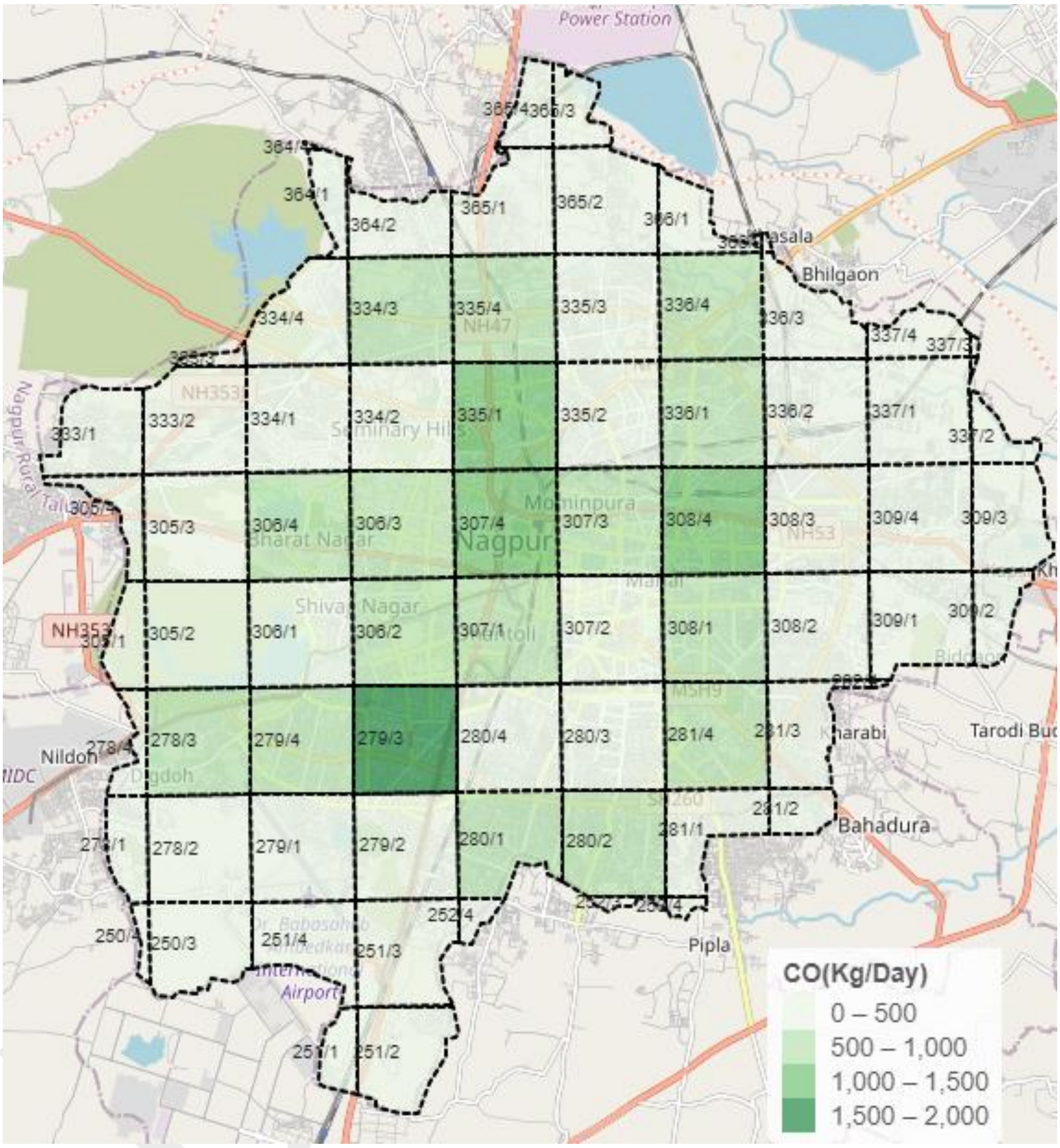


Figure 3.31 : Total Grid-wise Emission Load for CO (Kg/day) for Nagpur City

Chapter 4

Receptor Modelling & Source Apportionment

4.1 Source Apportionment Study Using EPA PMF v5.0

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

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

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

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

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

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

4.2 Methodology

For the present study EPA, PMF v.5.0 developed by US EPA (URL 1) was used. This model predicts the source profiles or fingerprints as Factors, relative contributions, and uncertainties for the identification of sources and their positive contributions to ambient air pollution. The study was carries out for representative samples of $PM_{2.5}$ and PM_{10} collected during the Jan-May 2019 to 10 May, 2019 sampling campaign at 10 locations: MIDC Hingna [Ind.]; NBSS Office (Near Amravati road), NEERI, Pipla, Asi Nagar (NMC) [Res.]; Manewada (Near Manewada Square) [Kerb Resi.]; Sadar [Res. Comm.]; Maskasath (Near Itwari) [Comm. Traffic]; Sitaburdi (At Commissioner Off.) [Comm. Kerb] and Shankar Nagar Square [Kerb]. The concentration and uncertainty data were obtained from the gravimetric analysis ($PM_{2.5}$ and PM_{10}); Elemental carbon and Organic carbon analysis; Elemental analysis by ED-XRF (46 elements: Na, Mg, Al, Si, P, S, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, I, Cs, Ba, La, W, Au, Hg, Pb, Bi, Th and In); and Ionic Analysis (9 ions: Na^+, NH_4^+, Ca^{2+}, Mg^{2+}, F^-, Cl^-, Br^-, $NO_3^{2-}$and SO_4^{2-}) for both PM_{10} and $PM_{2.5}$ for all sources as listed above.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4.3 Results

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

4.3.1 PM_{10}

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

Factor 1: Industrial emissions/Fossil fuel Combustion

First factor was identified as Industrial emissions by the presence of tracers, such as OC, Al, Si, Ca and Fe (~25.8%, 7.2%, 15.26%, 8.7%, 8.7%) with minor indicators such as Co, Y, Ti, Br, Mo. This factor contributed to about 18.38% of total PM_{10} Pollution. S and SO_4^{2} Earlier studies reported that Y, Mo, Cr are the indicators of the industrial emissions^{-} *(Kumar et al., 2001; Patil et al., 2013; Rai et al, 2016; Sharma et al., 2016; Jain et al., 2018*). Location of industrial regions in some of this study area could be the possible reason of this source.

Factor 2: Biomass Burning

Second Factor is represented by the significant levels of OC (57.74%), Si (11%), NO_3^{2-}(4%), Mg^{-} (4.5 %), Fe(4.5%) and Mg(14.29%), K(3%) contributing to about 19.25% of total PM_{10} Pollution. There have been many studies in the past suggesting that OC and K 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).*

Factor 3: Fossil Fuel Combustion

Third factor accounted for 27.09% of total PM_{10} contribution with indicators of Si, S, Mg, NH_4^{2-} and SO_4^{2-} (6.8%, 9.22%, 11.77%, 21.03% and 32.19%). S, NH_4^{2-} along with SO_4^{2-} have been widely used as a marker of fossil fuel combustion *(Patil et al., 2013; Rai et al., 2016; Sharma et al., 2016; Jain et al., 2018).*

Factor 4: Resuspension Road Dust

Forth factor was identified as Resuspend Road dust in the presence of tracers, such as Al, Si, K Fe, Mg, NH_4^{2-} and Ca^{2+} (~7%, 13.53%, 3.22%, 4.62%, 6.47%, 32.64%, 7.15%) with minor indicators such as Sr, I, V, Pb contributing to about 15.29%. of total PM_{10} Pollution. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor. Paved road dust is resuspended by vehicular movements which is indicated by minor markers such as Fe, OC 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.

Factor 5: Vehicular Tail pipe Emissions

Fifth factor accounted for 19.98%, with major indicators such as OC (6.65%), S (6.09%), NH_4^{2-} (18.62%), SO_4^{2-} (21.58%) and Mg(9.70%) and minor indicators such as EC, Cr, Zn, Cl and Pb. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of tyre and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Patil et al., 2013; Jain et al, 2017; Mukherjee et at., 2018, Pawar et al., 2020.)* Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles (Keerthi *et al.*, 2018; Jain *et al.*, 2017).

4.3.2 $PM_{2.5}$

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

Factor 1: Secondary Aerosol

First Factor is represented by the significant levels of OC (44.62%), NO_3^{2-}(6.8%), NH_4^{2-}(24.8%) contributing to about 6.45% of total $PM_{2.5}$ Pollution. The studies indicated that NO_3^{2-} and NH_4^{2-} - are major indicators for secondary aerosols (*Patil et al., 2013; Pipalatkar et al., 2014; Police et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020)*. The formation of secondary aerosols is due to the chemical transformation. These secondary ions are derived from gas to particle conversion processes involving photo-chemical reaction of gaseous precursors such as NOx which are largely emitted from local and regional *sources (Garaga et* *al., 2020).* Since these are background pollutant sources, they are found in all samples for entire study duration..

Factor 2: Biomass Burning

Second factor is identified as Biomass burning which accounted for contributions of 24.29%. Major proportions of K^+, OC, K, NO_3^{2-}, SO_4^{2-} and Mg^{2+} (~11.1%, 19.8%, 15.7%, 10.8%, 7.1%, 11.7%) were contributed to this factor. There have been many studies in the past suggesting that OC, K^+ and SO_4^{2-} are clear indicator of biomass burning. (*Shukla and Sharma, 2008; Police et al., 2016; Sharma et al., 2016; Jain et al., 2017; Mukherjee et at., 2018; Garaga et al., 2020).* It is a known fact that biomass is a widely used energy source as well as there is issue of illegal litter burning in India which has resulted in the nominal contributions of biomass burning in this location.

Factor 3: Construction Dust

Third factor is identified as Construction dust which accounted for contributions of 22.65%. Major proportions of Ca^{2+}, Mg, NH_4^{2-}, SO_4^{2-} and Si (~2, 11% , 29%, 21.9%, 6%) and minor species such as Na, Ca and Cl- contributed to this factor. 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 4: Industrial emissions/Fossil Fuel Combustion

Forth factor was identified as Industrial emissions/ fossil fuel combustion the presence of tracers, such as S, Mg, OC, NH_4^{2-} and SO_4^{2-} (~13.5%, 12.6%, 6%, 18.50%, 34.4%) with minor indicators such as Y, Mo, P, and Br. This factor contributed to about 20.71% of total $PM_{2.5}$ Pollution. S and SO_4^{2-} have been widely used as a marker of coal combustion in power plants (Kumar *et al.*, 2001; Patil *et al.,* 2013; Rai et al, 2016; Sharma *et al.,* 2016; Jain *et al.*, 2018). Earlier studies reported that Y, Mo, Cr are the indicators of the industrial emissions. Location of industrial regions in some of this study area could be the possible reason of this source.

Factor 5: Re-suspension of Road Dust /Wind Blown Dust

Fifth Factor is represented by the significant levels of SO_4^{2-} (18.3%), Al (10.4%), S(6.%), K(9.26%), NH_4^{2-}(23.9%) and Mg(10.5%) and minor indicators such as Si, Sr, I, V and Pb contributing to 17.74% of total $PM_{2.5}$ pollution. The wind-driven airborne dust from surface soils would have resulted in the considerable emissions of this factor. Paved road dust being resuspended by vehicular movements is indicated markers such as Al, Si, S and Pb *(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).*

Factor 6: Vehicular Tail pipe Emissions

Sixth factor accounted for 8.15%, with major indicators such as OC (23.4%), EC(24.05%), S (6.5%), NH_4^{2-}(8.4%), SO_4^{2-} (16.82%) and Mg(8.6%) and minor indicators such as Cr, Zn, Cl and Pb. Emissions arising from road vehicles are generally contributed by a mixture of tailpipe emissions, and wear and tear of tyres. Zn is usually used as an additive in lubricating oil in two-stroke engines and is also a major trace metal component of tyre and Pb is the indicator of emission due to engines in vehicles *(Shukla and Sharma, 2008; Patil et al., 2013; Jain et al, 2017; Mukherjee et at., 2018, Pawar et al., 2020)* Also, EC & OC were present in this factor indicating emissions from burning of fossil fuel from vehicles (Keerthi *et al.*, 2018; Jain *et al.*, 2017). The said major contributing metals are tracers of vehicular exhaust emissions as shown by various previous studies *(Gupta et al., 2012 ; Sharma et al., 2016; Jain et al., 2018; Keerthi et al., 2018; Jain et al., 2017; Pawar et al., 2020).*

Table 4.2 : Percentage Source Contribution for Nagpur

Most likely source(s)	PM_{10}	$PM_{2.5}$
Industrial Emissions	--	18.40
Biomass Burning	24.29	19.25
Fossil Fuel Combustion	--	27.09
Resuspended Road Dust	17.74	15.29
Vehicular Tail pipe Emissions	8.15	19.98
Secondary Inorganic Aerosols	6.45	--
Construction Dust	22.69	--
Industrial/ Fossil Fuel Combustion	20.71	--

4.4 Positive Matrix Factor Analysis Conclusion

The contribution of Biomass burning is more in $PM_{2.5}$ (24.29%) is found to be higher than PM_{10} (19.25%) whereas Fossil fuel combustion in contributions were dominated by PM_{10} (27.09%). The construction dust (22.69%) and Secondary inorganic Aerosols (6.45%) was found in $PM_{2.5}$. As these sources are colinear and indicative markers are similar so it is difficult to separate them using PMF-

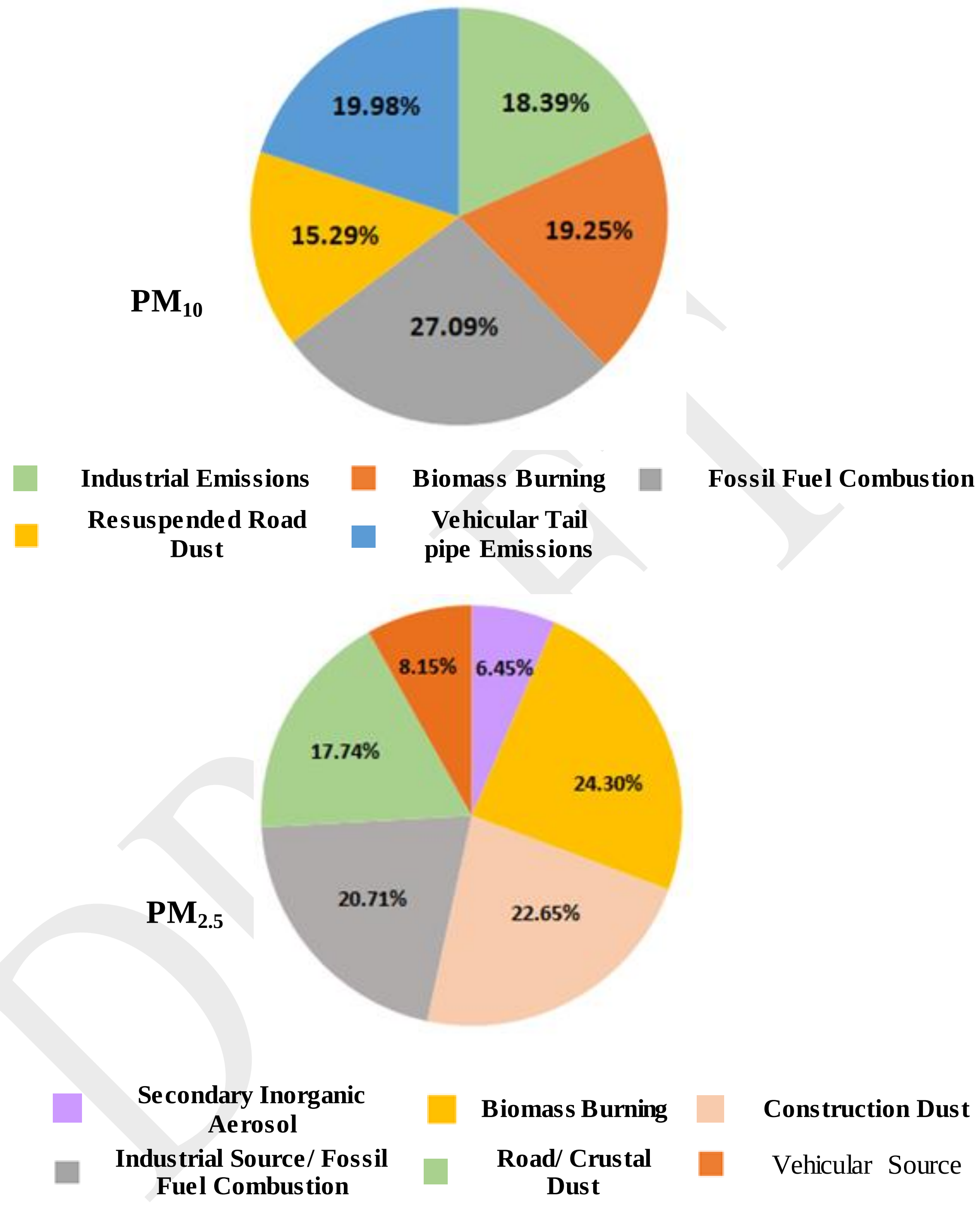
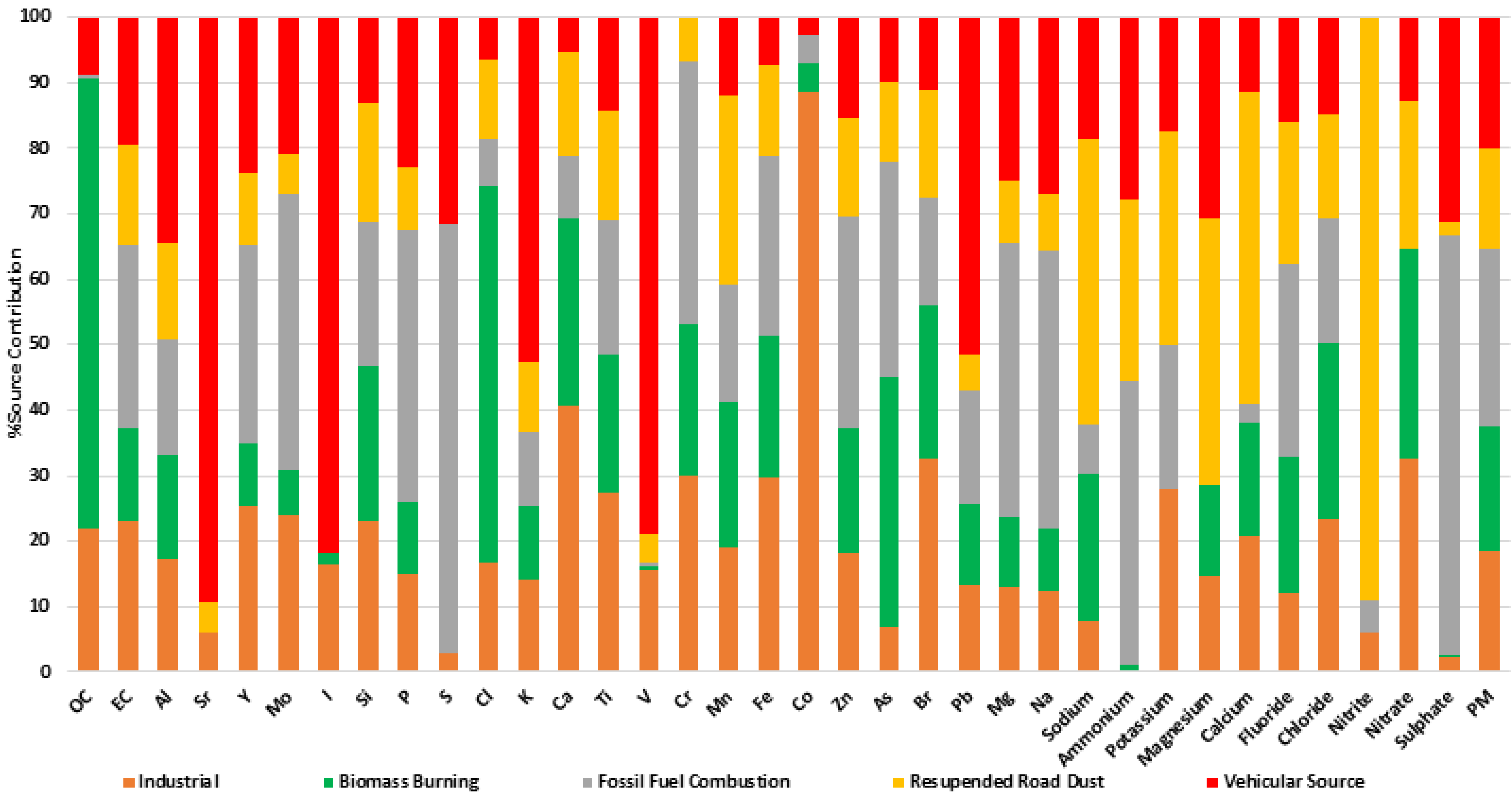
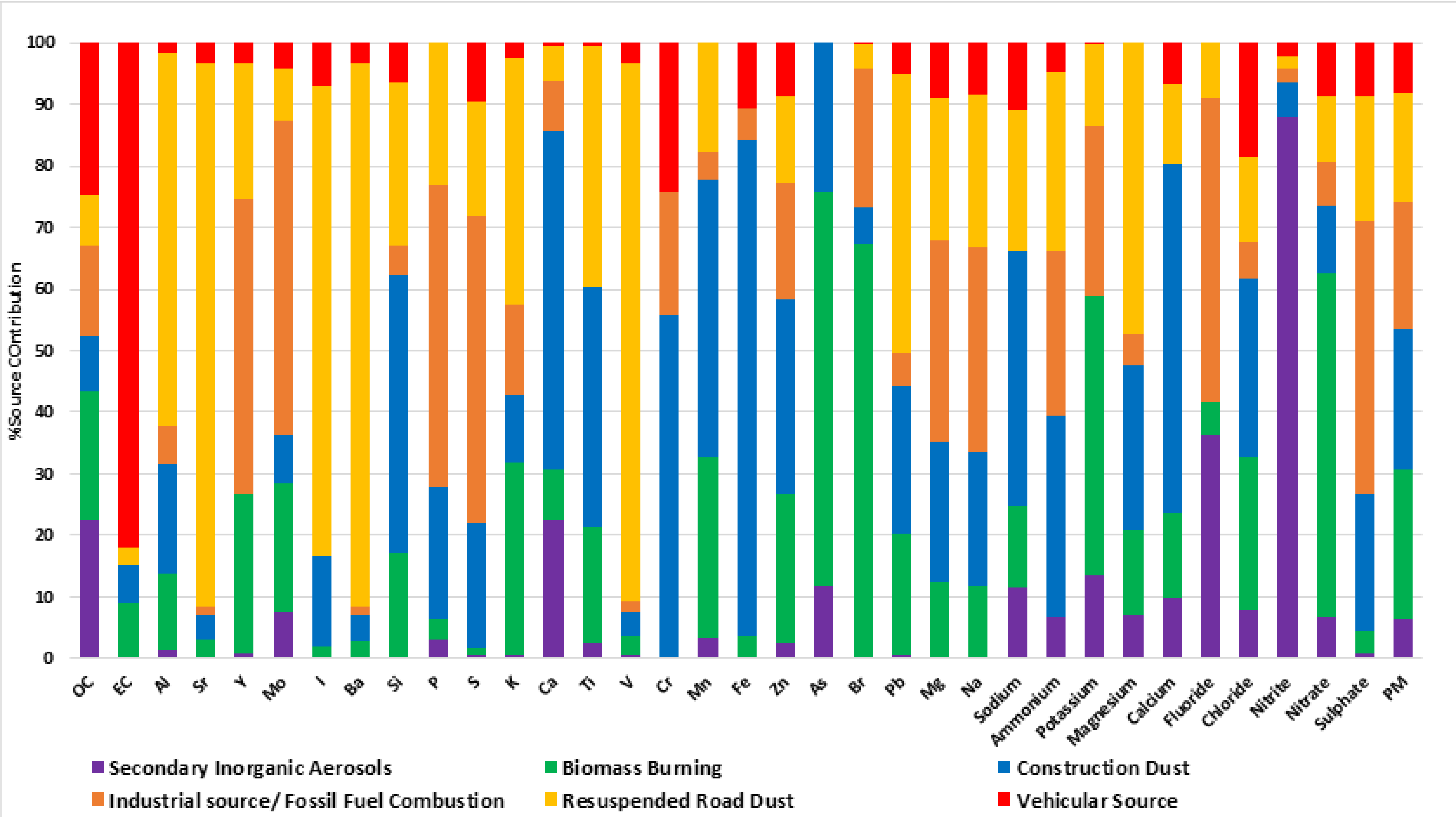


Figure 4.1: A) Percentage Contribution of Sources & Factor Fingerprints for B) PM_{10} C) $PM_{2.5}$ for Nagpur City



PM$_{10}$
(B)

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



$PM_{2.5}$ (C)

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

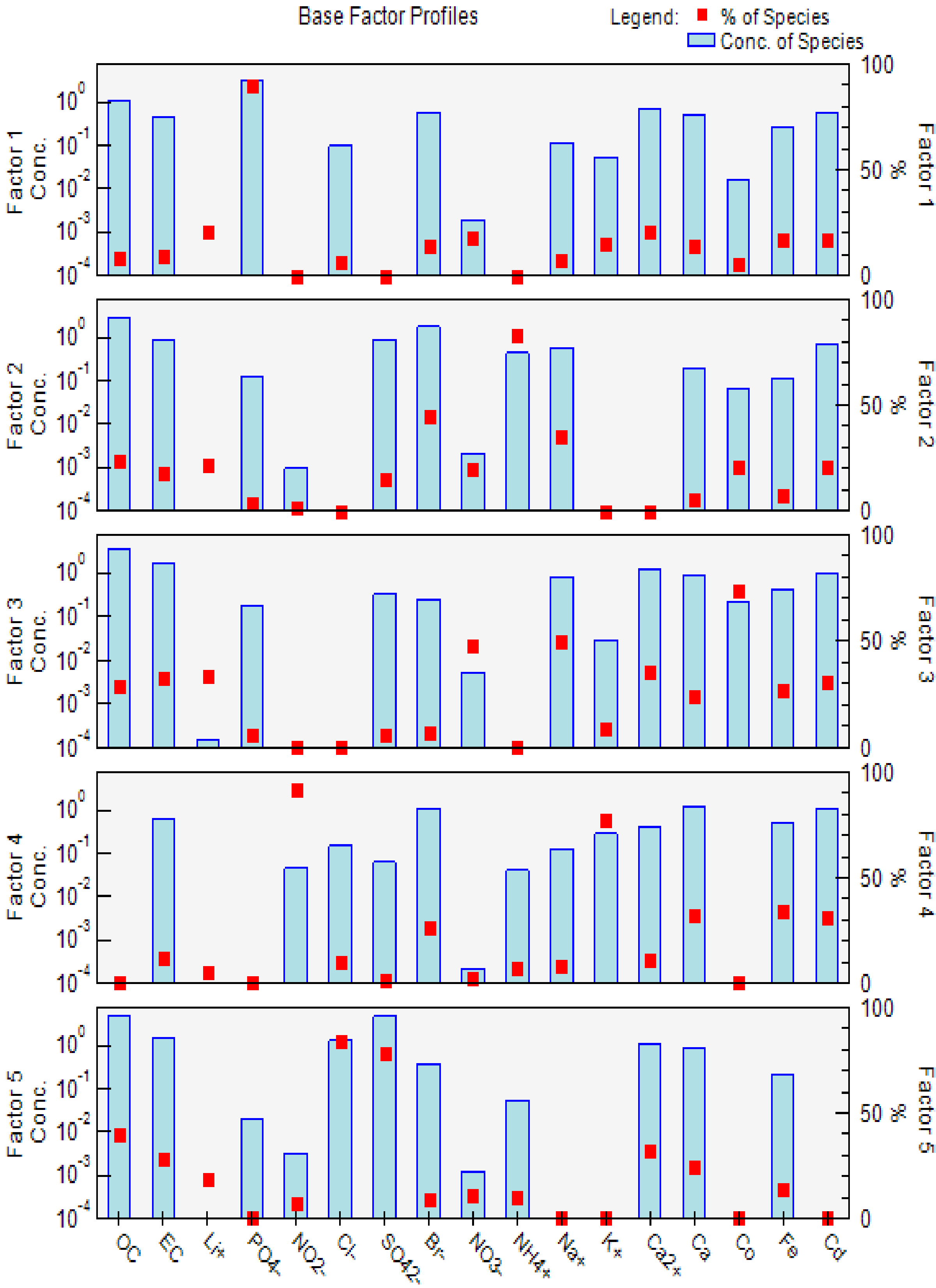


Figure 4.2 a : PM_{10} Base Factor Profiles

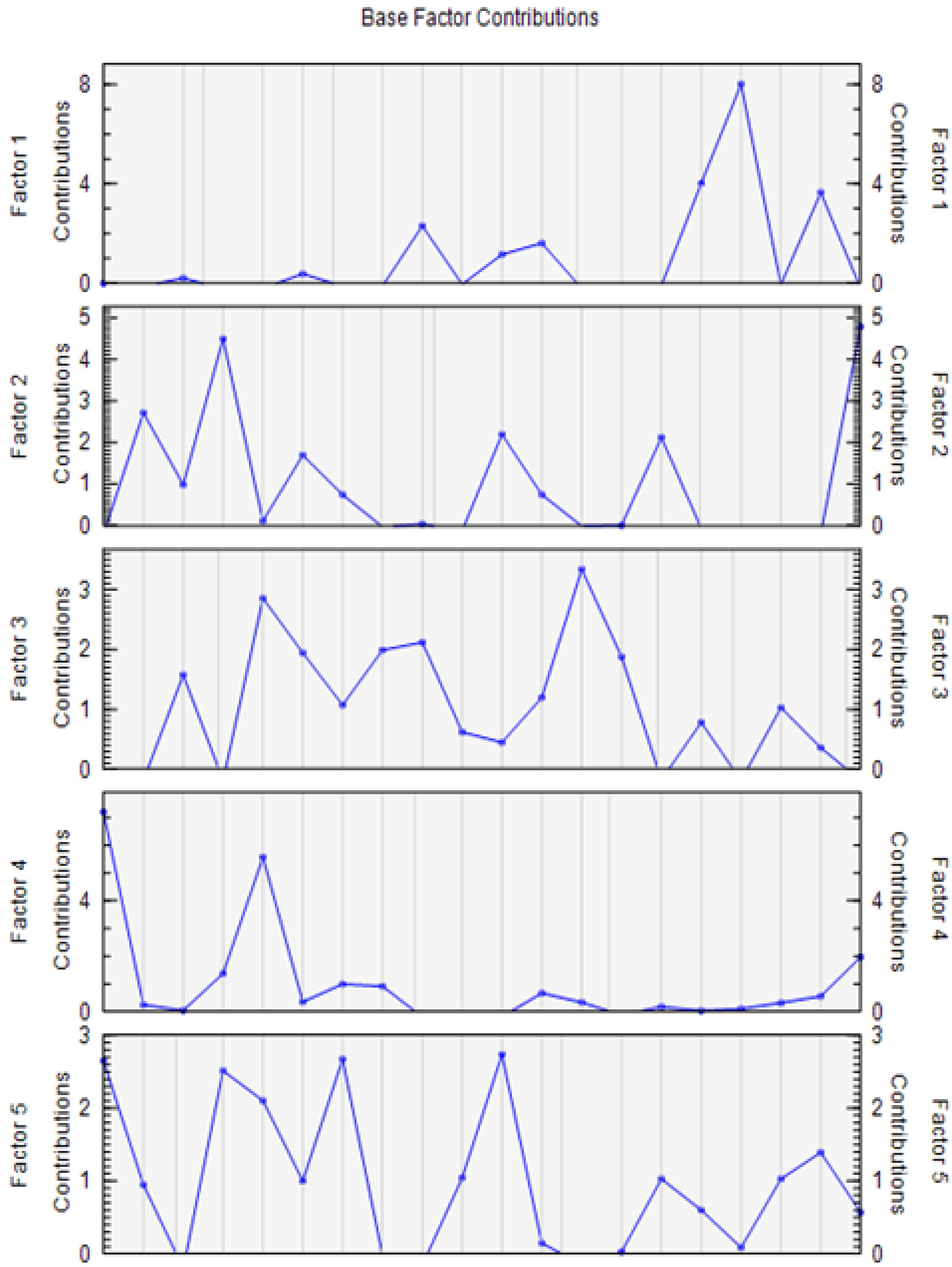


Figure 4.2 b : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, Al, Si, *Ca, Fe, Co*, Ti, *Br^-*	18.38	Industrial Emissions/ Fossil Fuel Combustion
Factor 2	OC, *Si, NO_3^{2-} Mg^-, Fe*	19.25	Biomass Burning
Factor 3	*Si, S, Mg, NH_4^{2-}, SO_4^{2-}*	27.09	Fossil Fuel Combustion
Factor 4	*Al, Si, K Fe, Mg, NH_4^{2-} and Ca^{2+}*	15.29	Resuspended Road Dust
Factor 5	OC, EC, NH_4^{2-}, *SO_4^{2-}, Mg*	19.98	Vehicular Emissions

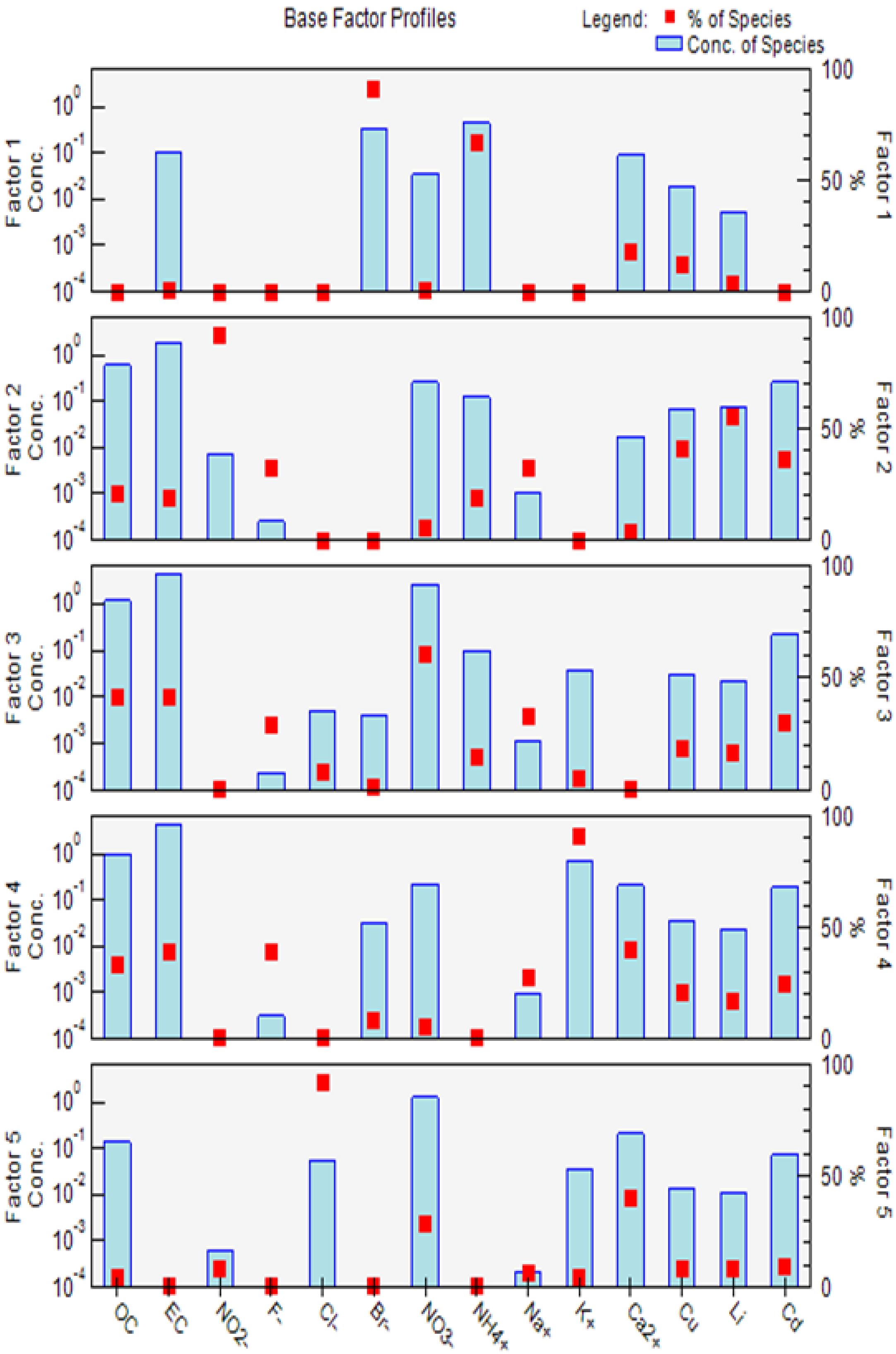


Figure 4.2 c : $PM_{2.5}$ Base Factor Profiles

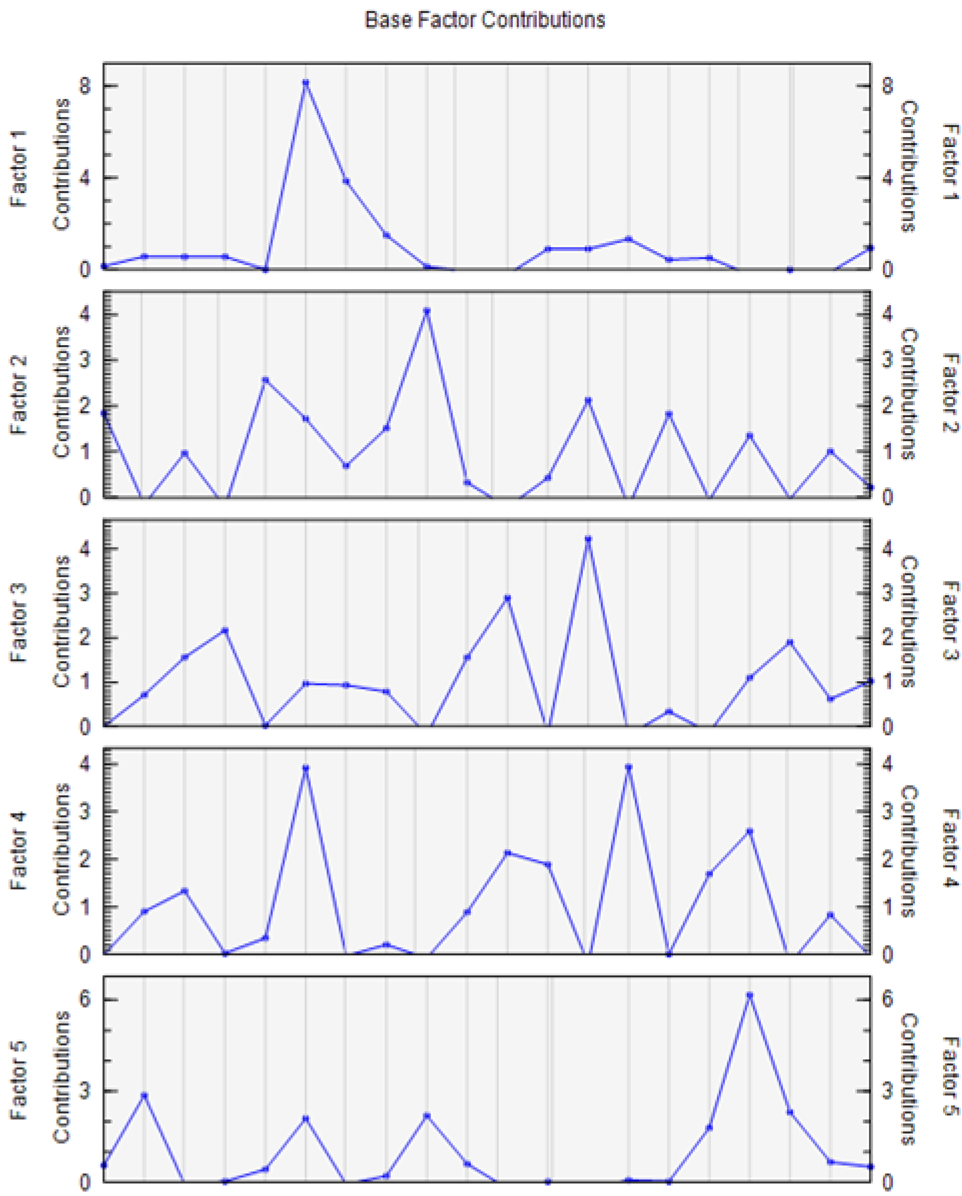


Figure 4.2 d : $PM_{2.5}$ Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	OC, EC, NO_3^{2-}, NH_4^{2+}, *Cd*	6.45	**Secondary Aerosol**
Factor 2	K^+, OC, EC	24.29	**Biomass Burning**
Factor 3	Ca^{2+}, Mg, NH_4^{2-}, SO_4^{2-}, Si	22.65	**Construction Dust**
Factor 4	OC, EC, NO_3^{2-}, NH_4^{2+}, *Cd*	20.71	**Industrial Emissions/ Fossil Fuel Combustion**
Factor 5	SO_4^{2-} *Al, S, K, Si, Sr*	17.74	**Re-suspension of Road Dust/Wind Blown Dust**
Factor 6	OC, *S*, NH_4^{2-}, SO_4^{2-}	8.15	**Vehicular tail pipe Emissions**

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 PM10 and PM2.5 emission load estimated in emission inventory from vehicle tail pipe sources is around 0.6 TPD and 0.3 TPD, respectively. Out of the total emission load estimated, 53.1% emission load is from HDVs followed by LDVs (19.94%), 4 wheelers (9.97%), 2 wheelers (9.36%) and 3 wheelers (7.68%) respectively. The main types of fuel consumed in Nagpur Industries are coal, bagasse, furnace oil, LDO, HSD, LPG and Diesel (DG sets, if any). As coal is majorly used in thermal power plants, the consumption is seen to be highest. There are two thermal power stations located to the North of Nagpur city.

The highest PM_{10} of 0.2 TPD, emission load contributed by Area Source is from Domestic fuel combustion sources. The total emission load emitted from crematorium for PM_{10}, $PM_{2.5}$ and CO is found to be 0.2, 0.01and 1 TPD and emission load that from Hotel & restaurants of the study area was found to be around 69kg/day, 31 kg /day and 51 kg/day, respectively. The Area Source contribute about 5% of total emissions load from all the sources of the study area. The highest emission load was estimated from Point source (70%), followed by Resuspension of road dust (14%) and Open Burning (7%). The PM_{10} emission load from Open burning was estimated to be around 0.9 TPD and 1.9 TPD from road dust resupsension.

Ambient Air quality was monitored at four sites in study area for PM_{10} and $PM_{2.5}$ concentration. In EPA during the PMF run analysis, some of the factors identified in the source apportionment research were found to be in a mix contribution form, indicating that the factor species from distinct sources were collinear. Hence, couldn't be further resolved to particular source of emission load in the vicinity. Various Sources were identified from the vicinity of the monitoring locations for in Source Apportionment Study from the analysis of their Elements, Ions and Carbon (Elemental and Organics) factor species contributions to the corresponding sources.

With which, 5 factors were identified in the study location for PM_{10} and 6 factor for $PM_{2.5}$ samples. The highest factor contribution in both PM_{10} and $PM_{2.5}$ emission load is found from tailpipe emission of Fossil Fuel combustion (~27%) and Biomass Burning (~24%), respectively. The other factor identified for $PM_{2.5}$ load is Secondary Aerosol (~6%), Construction Dust (~23%), Industrial Emissions/Fossil Fuel Combustion (~21%) and Resuspended of Road Dust (~18%) and Vehicular Emission (~8%) . For PM_{10}, factor identified were Re-suspesnion of Road dust (~15%), Biomass Burning (~19%), Vehicular Emission (~20%) and Industrial Emission (~19%). Both source categories were found to be contributing almost the same for both $PM_{2.5}$ and PM_{10}. These results are well corroborated with apportionment of particulate matter; considering nature and quantum of the activities that is carried out in and around the study area.

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URL

- URL 1: EPA PMF v5.0 Software link: https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses
- URL 2: DRI EC-OC Manual : https://www.epa.gov/sites/production/files/2018-10/documents/csn_improvea_model2015_2-231r0_053118_508comp-dri.pdf
- URL 3 : US EPA Speciates: https://www.epa.gov/air-emissions-modeling/speciate-0

Chapter 5

Source Dispersion Modeling

5.1 Overview

Dispersion modeling uses mathematical formulations to characterize the atmospheric processes that disperse a pollutant emitted by single or multiple sources. Air quality dispersion modeling has been undertaken with a view to identify the impact and the important sources on ambient air quality in Nagpur 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 Nagpur 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 Nagpur city on its east side grids. Monthly windrose diagram is plotted and the same is shown in **Figure 5.1**. It can be seen that January to February is a period of very low wind with no predominant in wind direction. Persistent wind starts in March from west and becomes stronger in April, May, June with wind direction from west-north-west (WNW). The maximum wind speed during summer remains around 6 m/s. July bring monsoon wind, with wind speed up to 6 m/s. October to December are calm months with wind dispersed in all directions. In order to understand the monthly variation of wind speed, its frequency distribution is plotted and is shown in **Figure 5.2**. It can be seen that April to August shows relatively higher wind speed where as for other months, the wind speed is relatively lower.

5.4 Modelling Domain & Results

A 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	4641	9474	644	14759
$PM_{2.5}$	60	2537	4066	276	6879
SOx	80	134	234	0	368
NOx	80	590	48	6451	7089

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

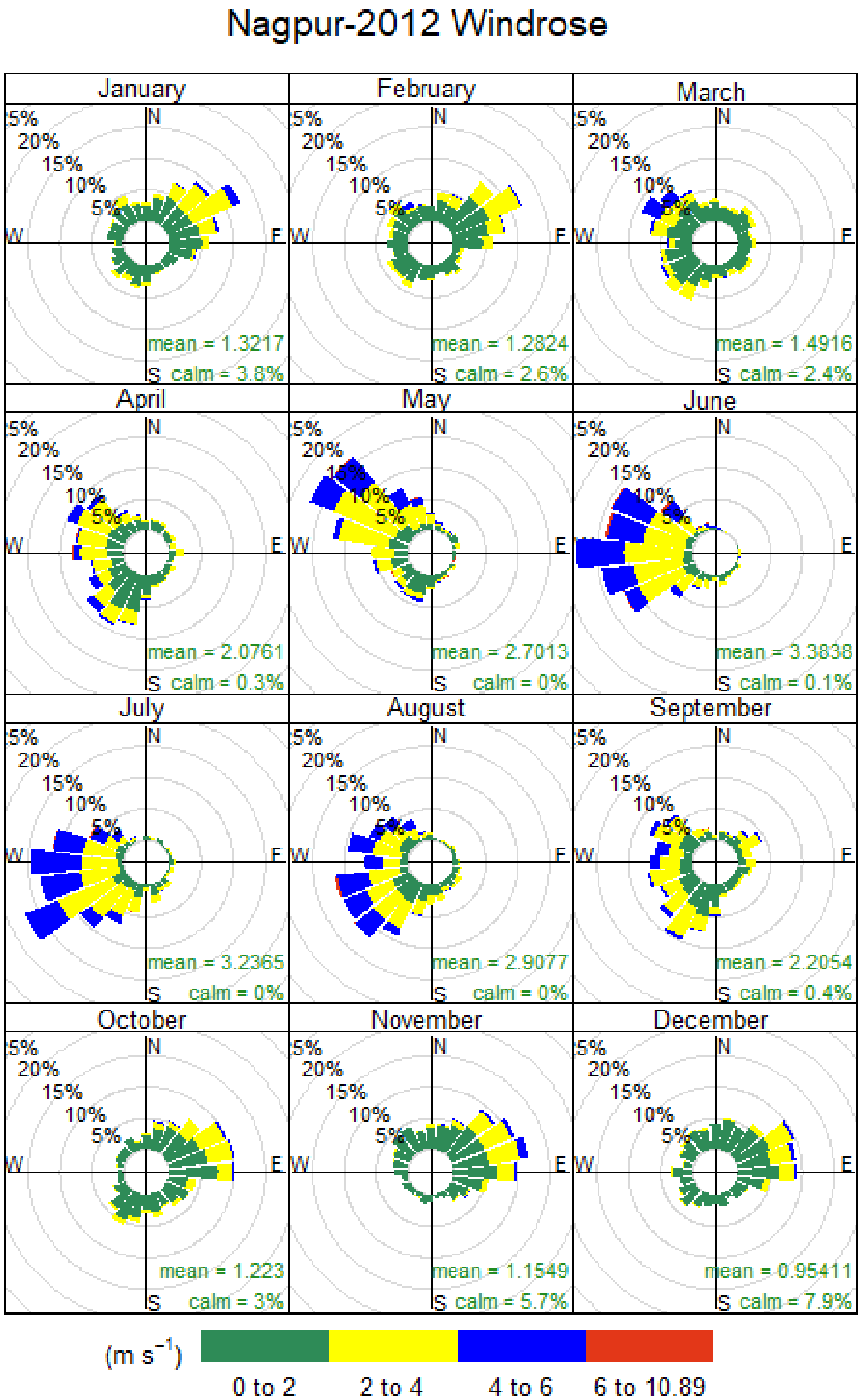


Figure 5.1: Monthly Wind rose Diagram of Nagpur (MM5 Data)

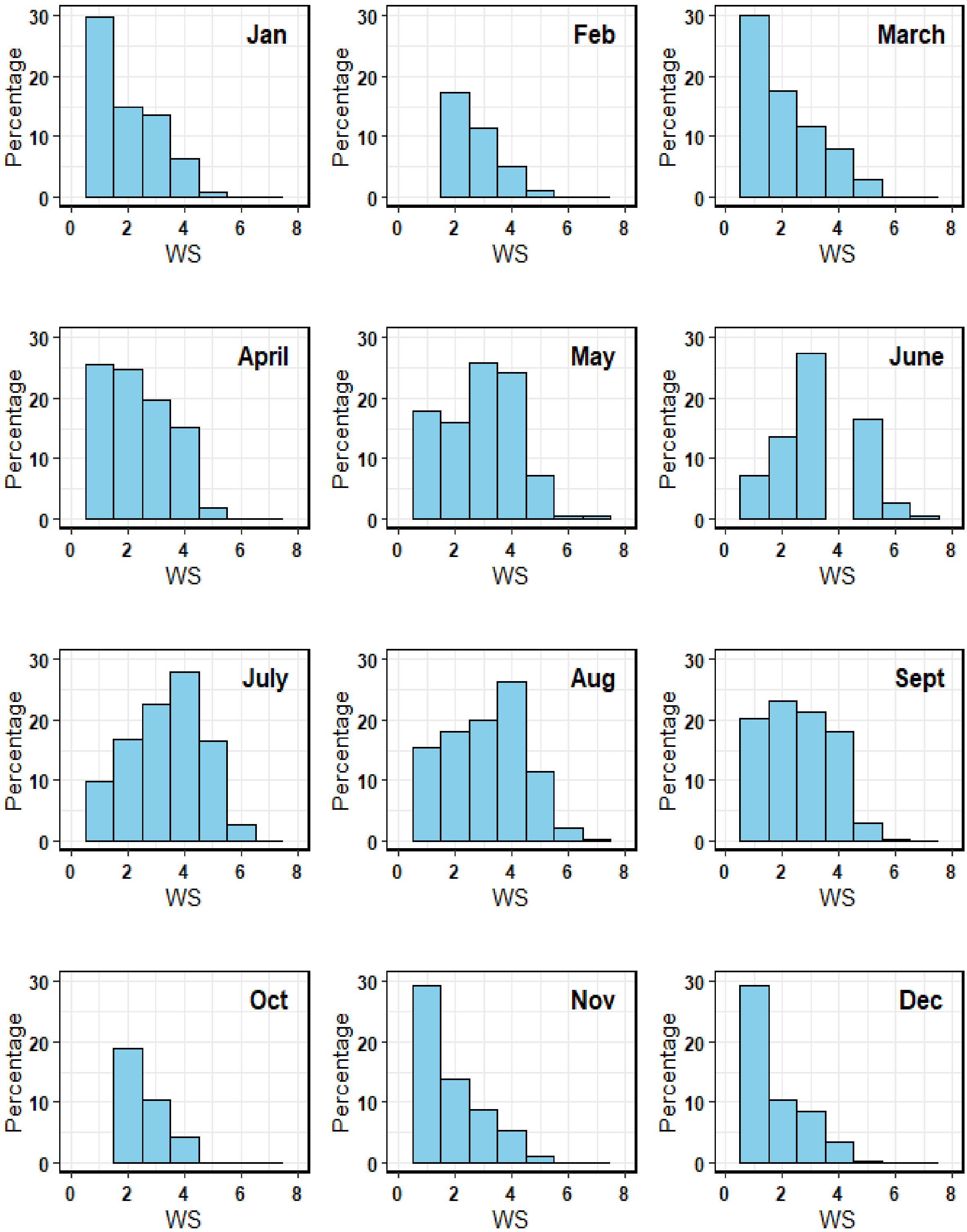


Figure 5.2 : Monthly Wind Speed Frequency in Nagpur (MM5 Data).

Sources of emission is divided into two groups namely area source and elevated point source. Area source includes all sources that emit pollutants at ground level and elevated sources are of thermal power plant. Ground level concentration (GLC) of PM_{10} for both area source and point source is estimated together and is presented in **Table 5.2** and **5.3** and is shown on map in **Figure 5.3**. Daily emission of PM_{10} from Nagpur is 3296.32 kg.

Table 5.2 : Grid-wise Emission Load for PM_{10} in Nagpur

Grid No.	PM_{10} (Kg/D)	Easting	Northing	Grid No.	PM_{10} (Kg/D)	Easting	Northing
251/2	21	297903.18	2329229.7	308/3	106	305903.18	2339229.7
251/3	69	297903.18	2331229.7	308/4	181	303903.18	2339229.7
278/1	17	291903.18	2333229.7	309/1	117	307903.18	2337229.7
278/2	21	293903.18	2333229.7	309/2	13	309903.18	2337229.7
278/3	71	293903.18	2335229.7	309/3	21	309903.18	2339229.7
278/4	10	291903.18	2335229.7	309/4	81	307903.18	2339229.7
279/1	53	295903.18	2333229.7	333/1	29	291903.18	2341229.7
279/2	94	297903.18	2333229.7	333/2	29	293903.18	2341229.7
279/3	163	297903.18	2335229.7	334/1	59	295903.18	2341229.7
279/4	164	295903.18	2335229.7	334/2	31	297903.18	2341229.7
280/1	71	299903.18	2333229.7	334/3	47	297903.18	2343229.7
280/2	130	301903.18	2333229.7	334/4	19	295903.18	2343229.7
280/3	110	301903.18	2335229.7	335/1	69	299903.18	2341229.7
280/4	60	299903.18	2335229.7	335/2	77	301903.18	2341229.7
281/1	83	303903.18	2333229.7	335/3	57	301903.18	2343229.7
281/2	16	305903.18	2333229.7	335/4	112	299903.18	2343229.7
281/3	76	305903.18	2335229.7	336/1	154	303903.18	2341229.7
281/4	100	303903.18	2335229.7	336/2	76	305903.18	2341229.7
305/4	14	291903.18	2339229.7	336/3	16	305903.18	2343229.7
306/1	76	295903.18	2337229.7	336/4	60	303903.18	2343229.7
306/2	77	297903.18	2337229.7	337/1	33	307903.18	2341229.7
306/3	49	297903.18	2339229.7	337/4	6	307903.18	2343229.7
306/4	50	295903.18	2339229.7	364/2	38	297903.18	2345229.7
307/1	158	299903.18	2337229.7	365/1	29	299903.18	2345229.7
307/2	83	301903.18	2337229.7	365/2	12	301903.18	2345229.7
307/3	143	301903.18	2339229.7	365/4	10	299903.18	2347229.7
307/4	152	299903.18	2339229.7	366/1	2	303903.18	2345229.7
308/1	164	303903.18	2337229.7	366/2	1	305903.18	2345229.7
308/2	69	305903.18	2337229.7				

Table 5.3 : Point Source Emission in Nagpur

No.	ID	Height [m]	Diam [m]	Exit_Vel [m/s]	Exit_Temp [K]	PM_{10} [g/s]	X1 [km]	Y1 [km]
1	KTPS_1	275	6.5	18	310	50	302.18	2349.41
2	KTPS_2	275	6.5	18	310	50	302.18	2349.41
3	KTPS_3	275	6.5	18	310	50	302.18	2349.41
4	KTPS_4	90	3.47	18	310	200	302.703	2350.9
5	KTPS_5	90	3.47	18	310	200	302.703	2350.9
6	KKTPS_1	220	3.47	18	310	90	304.549	2354.46
7	KKTPS_2	220	3.47	18	310	90	304.549	2354.46
8	KKTPS_3	220	3.47	18	310	90	304.549	2354.46
9	KKTPS_4	220	3.47	18	310	90	304.549	2354.46
10	KKTPS_5	275	6.5	18	310	42	305.342	2353.97

*KTPS: Koradi Thermal Power Station; KKTPS: Khaperkheda Thermal Power Station

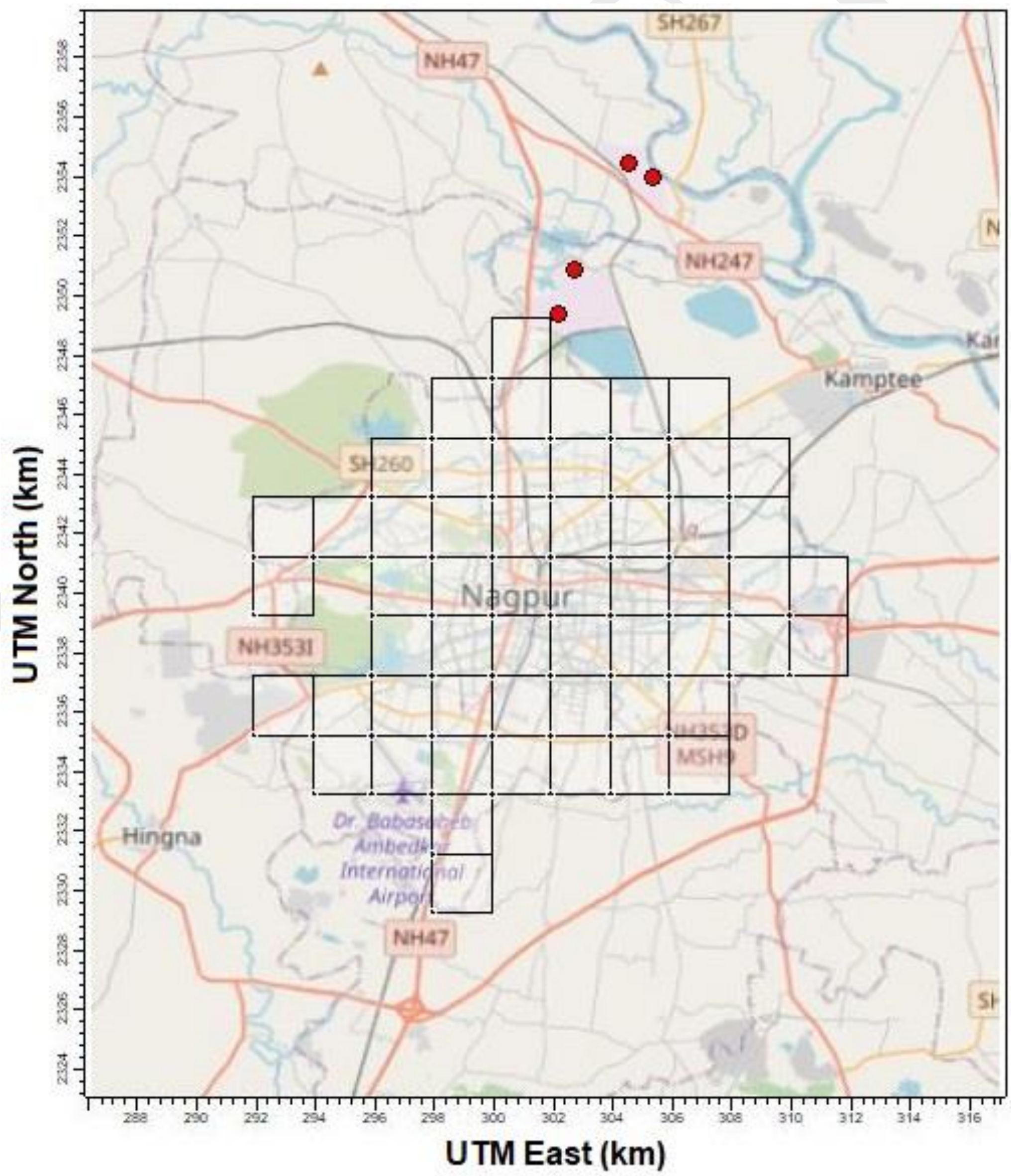


Figure 5.3 : Area Source Grid and Power Plant Stack over Nagpur City for Emission

Initially, both area and point sources are put together for simulation and GLC of PM_{10} determined. **Figure 5.4** shows the GLC of PM_{10} due to combined emission from area and point sources from power plant. It can be seen that the GLC near the Power plant exceeds the regulatory limit value in the vicinity of Koradi and Khaparkheda power plant. Besides this, the central area of Nagpur also has PM_{10} levels above 70 μg/m^3. It indicates that there's a need to look after the air quality management for the city.

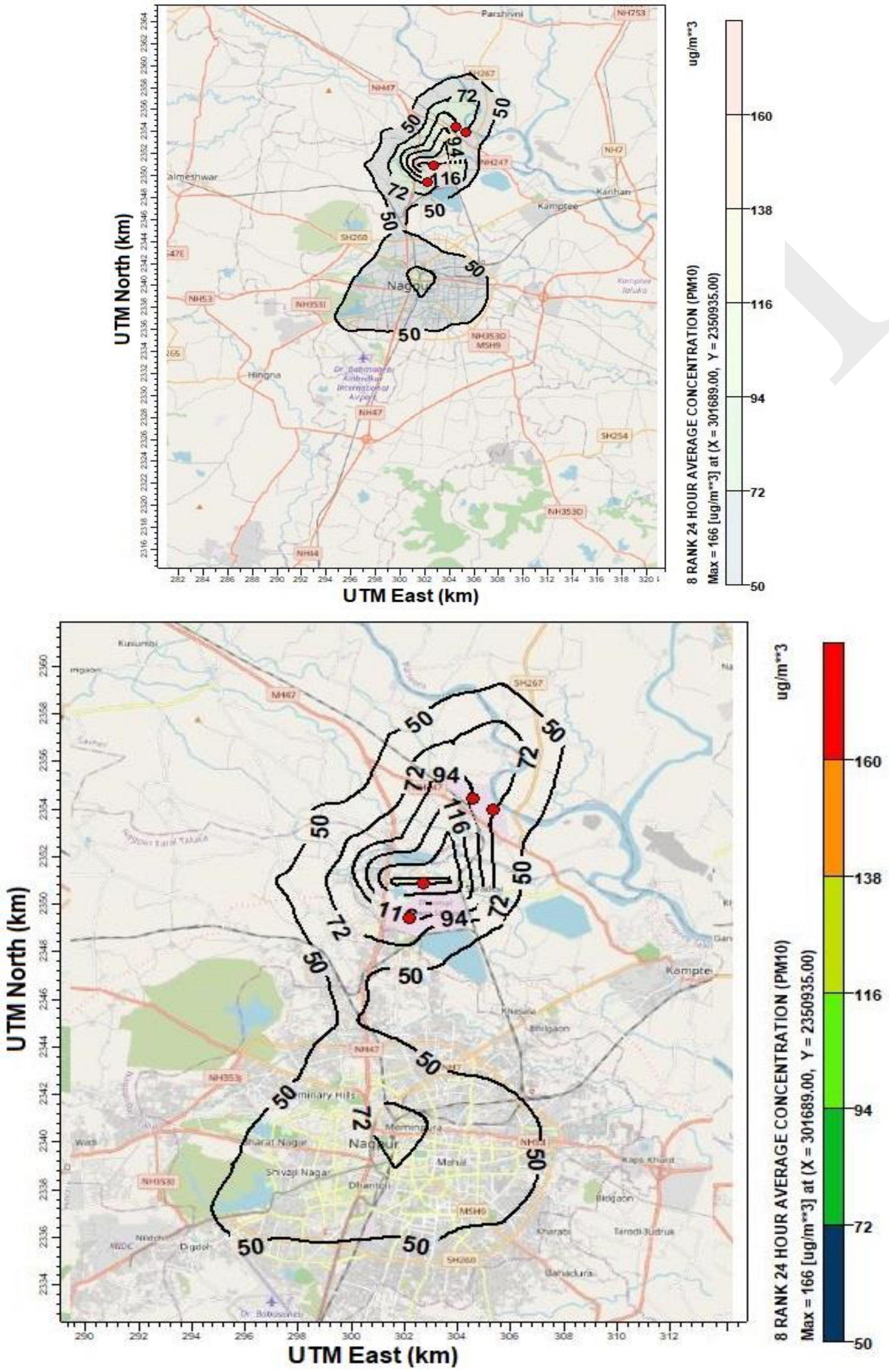


Figure 5.4 : GLC of PM_{10} in Nagpur Determined by Simulation using AERMOD (Emission Source: Area + Point)

New units of Koradi (660 MW) have taller stack height (275 m) and lesser emission (50 g/s) rate, however, old units have shorter stack height (90 m) and higher emission rate (200 g/s). This typical old power plant contributes to a very large extent towards the ground level PM_{10} and therefore emission control in these old units needs to be considered.

Emission load calculated for one day is distributed for twelve day-time hours and night time emission are considered to be absent. Area source emission activity starts 8:00 AM to 8:00 PM. Vehicles do not ply at Nagpur at night so as to cause high levels of pollution like a metro city like Delhi. Presence of international flights, train and interstate bus services, invite large number of vehicles in metro city thereby requiring night time emission also. The emission rate of PM_{10} in area source is considered to vary diurnally.

Figure 4.5 shows the GLC of PM_{10} due to area source emission only. The GLC of PM_{10} in the central Nagpur area due to area source emission is simulated to be above 70 $\mu g/m^3$

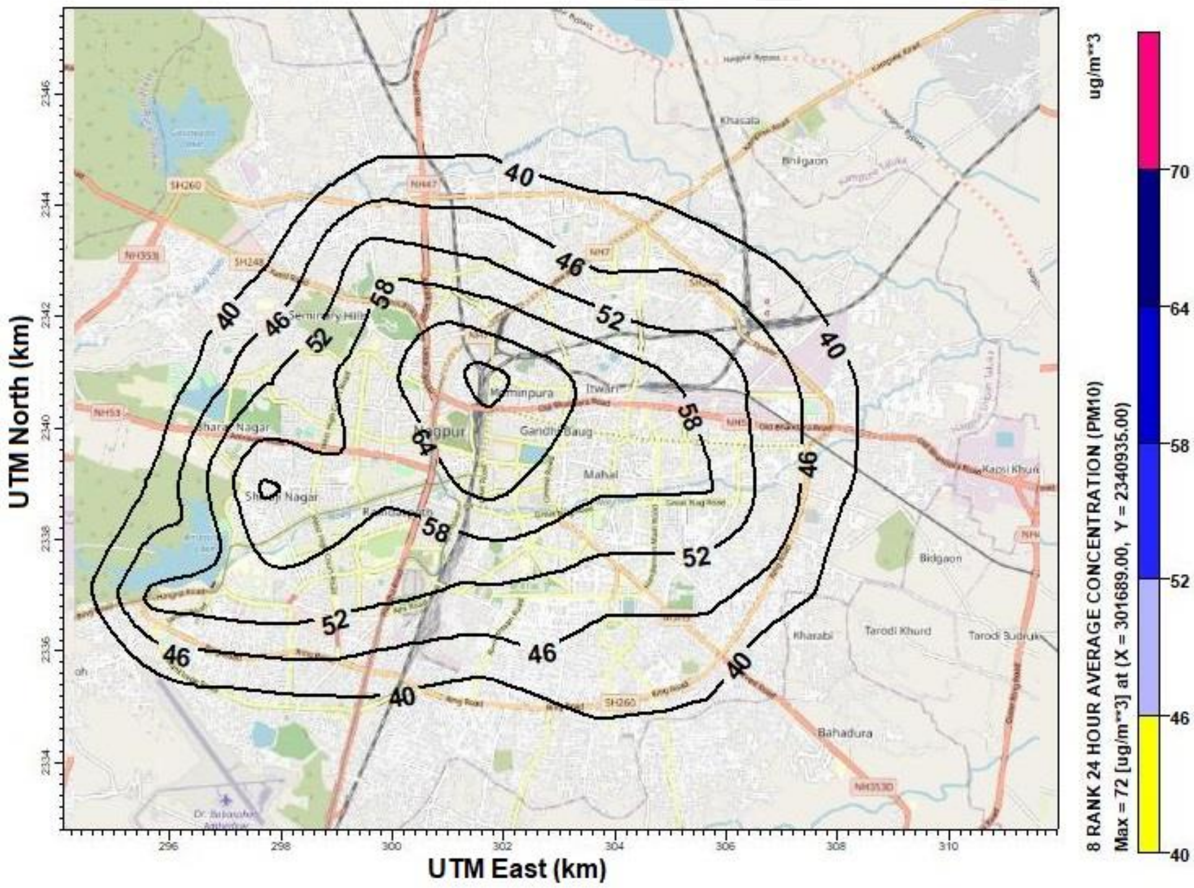


Figure 5.5: GLC of PM_{10} in Nagpur Determined by Simulation using AERMOD (Emission Source: Area)

Chapter 6

Action Plan for Control of Air Pollution

6.1 Emission Reduction Action Plan for Nagpur City

Major source of air pollution in Nagpur city is:

- Industrial Emission
- Vehicular emission

Minor emission is from

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

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

Table 6.1 : Action Plan to Control Emissions from Various Sources

Control Option	Action	Responsible Agencies
Vehicular Emission		
Launch extensive drives against polluting vehicles for ensuring strict compliance	RTO to have portable monitors for PM and gaseous air pollutants, random checking of polluting vehicles and take strict action against them to make maintenance compulsory. At present the vehicle manufacturers have to comply with the BS IV standards applicable to all since April, 2017.	RTO, Smart city NMC
Launch public awareness campaigns for vehicle emission control through proper vehicle maintenance, minimising use of personal vehicles, lane discipline etc. stopping of engines while idling in intersections	NMC buses, display boards at various traffic intersections to be used for the advertisement	Traffic Engineer, NMC/Smart city, Advertise Dept. NMC, MSRTC
Prevent parking of vehicles at Non designated areas. Identification of areas where space for more parking is required and developing parking facility	In addition to existing NMC parking facility it is proposed to develop parking lots in Dhantoli and along Ramdas Peth to Kanchipura square. Similar parking facility to be developed in other congested areas.	Traffic Engineer, NMC DCP Traffic
Initiate steps for retrofitting of particulate filters in Diesel vehicles	Policy making decision. Upto some extent light motor vehicle and auto rickshaw are presently running on petrol and LPG dual combination. to reduce the impact of air pollution by public transport vehicles the use of CNG, battery operated system, E rickshaws are the options which will be implemented in future step by step.	GoI, GoM, NEERI, IIT/VNIT
Prepare action plan to check fuel adulteration and random monitoring-of fuel quality data	Checking fuel adulteration with coordination of anti-adulteration cell which is a continuous process.	Residence Deputy Collector (RDC), Anti Adulteration Cell, RTO

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

Control Option	Action	Responsible Agencies
Vehicular Emission (Contd..)		
Prepare action plan for widening of road and improvement of Infrastructure for decongestion of Roads. Development of bicycle tracks along roads to promote use of cycles. Separate bicycle tracks will ensure safe cycling along busy roads and will result in increased use of bicycles.	Total 26.26 km length concrete roads are being developed in Phase I, 155.42 km length will be developed in Phase II and 41.22 km length will be developed in Phase III in Nagpur.	Executive Engineer NMC, Chief Engineer PWD, Project Director National Highway Authority Nagpur (NHAI)
Identification of traffic congestion hot spots and prepare plan for the construction of expressways/bypass/flyovers to avoid congestion		
Steps for Promoting electric, Battery operated vehicles.	Already initiated electric fleet of 200 electric vehicles, including taxis, buses, e rickshaws and autos in Nagpur since last 1 year. To promote electric fleet GoM waived VAT, road tax and registration for all electric vehicles in the state.	RTO, Nagpur
Install weigh in Motion bridges at the borders of the cities/fawns and states to prevent overloading of vehicles.	Plan to install weighing check post for heavy goods carrying vehicles has to be carried out in consultation with Regional Transport Office.	NMC, RTO, Nagpur
Synchronize Traffic movements / Introduce Intelligent Traffic systems for Lane Driving	Intelligent CCTV surveillance and automated Traffic Management systems already installed at traffic intersections.	DCP Traffic, EE Nagpur Smart city
Installation of Remote Sensor based PUC systems,	Policy making Decision. The installation of Remote Sensor RFID based PUC systems are proposed under consultation of Transport Commissioner. Agency will take expertise of CSIR-NEERI for its installation, Geo tagging of locations for its implementation and monitoring.	Transport Commissioner, GoM, MPCB, DCP Traffic, NEERI, RTO
Sulphur reduction in diesel Introduction of new technology vehicles	Policy making Decision.	GoI, GoM
Introduction of new technology vehicles	In a major step in spreading the use of green energy, India's first electric vehicle (EV) charging station was started by Indian Oil Company. It is proposed that to substantially increase electric vehicles soon.	RTO, Transport Department, NMC

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

Control Option	Action	Responsible Agencies
Vehicular Emission (Contd..)		
Provide good public transport system	At present 202 standard buses, 150 mini buses and 25 Ethanol AC green buses are on road. 25 Ethanol AC green buses and 35 mini buses are proposed for increasing the capacity of bus transport system. The Metro rail construction is already going which consists of 41.7 km Metro length with 40 stations and 19 feeder bus routes covering 160 km length.	Maha Metro Rail Corporation Ltd., Nagpur Transport Department, NMC, RTO, MSRTC.
Alternative fuels	Policy Making Decision	Ministry of Road Surface transport and National Highways
Implementation of BS-VI norms	Policy Making Decision	Ministry of Road Surface transport and National Highways
Hybrid Vehicles	Policy Making Decision	Ministry of Road Surface transport and National Highways
OE-CNG for new public transport buses	Partial conversion of polluting Auto Rickshaws with CNG / Gas engine / kits may be implemented.	Ministry of Road Surface transport and National Highways
Ethanol blending (E10-10% blend)	25 Ethanol AC green buses are proposed for increasing the capacity of bus transport system. However, comparison of these fuels with conventional fuels with respect to their environmental benefits should be done	Ministry of Road Surface transport and National Highways
Bio-diesel (B5/Bl0:5-10% blend)	25 Ethanol AC green buses are proposed for increasing the capacity of bus transport system. However, comparison of these fuels with conventional fuels with respect to their environmental benefits should be done	Ministry of Road Surface transport and National Highways
Retro-fitment of Diesel oxidation Catalyst (DOC) in 4 wheeler public transport (BS II and BS III)	Catalytic converter and particulate trap may be provided to existing polluting vehicles after checking technical feasibility	Ministry of Road Surface transport and National Highways
Retro-fitment of Diesel particulate filter in 4 wheeler public transport (BS II and BS III)	Catalytic converter and particulate trap may be provided to existing polluting vehicles after checking technical feasibility	Ministry of Road Surface transport and National Highways
Banning of 15 year old commercial vehicles	Buses and heavy vehicles more than 15 years old are still plying. The transport department to undertake drive to check fitness of such vehicles	Ministry of road surface transport and national highways
Inspection / maintenance to all BSII and BSIII commercial vehicles	Policy making decision	RTO, MSRTC

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

Control Option	Action	Responsible Agencies
Vehicular Emission (Contd..)		
Restrict commercial vehicle entering city by having ring roads	Already existing	DCP traffic Project Director, NHAI
Other (City Specific)		
Waste water treatment plant Bhandewadi	This will reduce emission of foul gases and other pollutants from the running as well as stagnant sewage	NIT
Industry Source		
Identification of brick kin and their regular monitoring including use of designated fuel and closure of unauthorised units. About 130 kilos of which 25 (fixed concrete chimney) and 75 (metal chimney)	No brick units within NMC limit however other nearby located units in periphery of 10 to 20 km from NMC boundary	Revenue dept. RDC, MPCB
Conversion of natural draft brick kilns to induced draft	The quantification of reduction in emission should be done by monitoring emission prior and after the conversion feasibility to be checked	
Action against non-complying industrial units	Hingna, Koradi, Khaparkheda, butibori, kalmeshwar road. Directions as proposed direction 01 no. and show cause notice	MPCB
Sulphur reduction in fuel	will significantly reduce SO2 emissions	Policy matter MPCB, RDC
Improved combustion technology		Revenue dept, RDC
Efficacy of use of solar power in industries and other control measures need to be studied	Alternative option for use of biogas/other renewable solid fuels such as MSW briquettes etc. May be probed for co-firing in LSI,MSI along with control measures	Revenue dept, RDC
Promote cleaner industries	Green white industries	ADTP, NMC
Location specific emission	3rd party audit for emission reduction	HO(S) NMC Nagpur, Joint director, industries, Office of directorates industries Nagpur division, Nagpur
Fugitive emission control	Major large scale industries have internal tar road and sprinkler system for vehicular movement. Transportation is done in closed container for raw material, by-products, products etc.	HO(S) NMC Nagpur, Joint director, industries, Office of directorates industries Nagpur division, Nagpur
Installation/up gradation of air pollution control systems	Probing studies for reduction of gaseous emissions	HO(S) NMC Nagpur, Joint director, Ind., Office of directorates industries Nagpur division, Nagpur

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

Control Option	Action	Responsible Agencies
Industry Source (Contd..)		
Use of high grade coal	Periodic audit (3rd party) of quality of coal, coal beneficiation to be done	RDC, HO(S) NMC Nagpur, Joint director, industries, Office of Directorates Industries Nagpur division, Nagpur
Regular audit of stack emissions for QA/QC		HO(S) NMC Nagpur, Joint director, industries, Office of directorates industries Nagpur division, Nagpur
Dust Resuspension		
Prepare plan for creation of green buffers along the traffic corridors. The total road length in the city is 3465 km, of which 213 km is partially paved/unpaved. The present annual PM2.5 emission is 1.5 tons which will decrease after paving	The green buffers will act as air pollution sinks and reduce the pollution load. Partially done. 16758.53 sq.m green buffers at road dividers, channelizes, traffic islands and on both sides of the road were developed. This work may be extended to other highly polluted roads.	Garden dept. NMC,NEERI,MPCB. garden dept. NIT
Maintain potholes free roads for free traffic	The NMC's hot mix department collected data of potholes from 10 zones for repairing the craters and bad surface layers in coming days. As per the report, there were 1377 potholes of 736 were repaired and only 641 remain	EE(Hot Mix plant) NMC, Nagpur, NIT Nagpur
Introduce water fountain at major traffic intersection wherever possible	The water fountains may be installed at spaces near traffic lights where space is not available at the centre of the road	EE(Construction) Traffic Dept. NMC
Greening of open areas, garden, community, places, schools, and housing societies	Total 95 gardens are developed in city with 126.46 acres area. Total 22 new gardens are proposed in the city out of which under Amrut mission, development of new 8 gardens with an area of 62.46 acre is going on and 14 gardens to be developed under chief ministers' special fund. Total 32671 trees were planted in 2017-18 and 25000 trees are proposed to be planted in year 2018-19	Garden dept. NMC/Garden dept. NIT, education dept. NMC
Black topping of metaled roads including pavement of road shoulders	Majority of metaled roads have blacktopping	NMC, NIT

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

Control Option	Action	Responsible Agencies
Wall to wall paving(brick)	Already done for majority of roads and on-going for present roads under construction	City engineer, NMC
More concrete roads are made in the city with planning of over 50% main roads to be concretized. Total 51 major roads with length of 67.43km is being covered under the project HDM4 model for performance of concrete roads/pavement over vehicle emissions to be studied		City engineer, NMC

Activity	Control Option	Action	Responsible Agencies
Area Source			
Bakeries / Crematoria	Use of electric/gas crematoria should be promoted	If wood is replaced with briquettes then around 35% reduction in PM emission will take place	NMC
	Promote use of briquettes instead of wood		
Household	Shift to LPG from solid fuel and kerosene for domestic applications		RDC
	Better cook stove designs		
DG sets	Monitoring of DG sets and action against violations		DCP traffic, MPCB
	Reduction DG set operation/uninterrupted power supply		Director, MSEDCL(Electrical inspector)
Construction and Demolition Activities	Enforcement of construction and demolition rules, implementation of measures for control of emissions during activity		ADTP, NMC, NIT, MPCB, Nagpur Metro
	Better construction practices with PM reduction of 50%		ADTP,NMC,MPCB

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

Activity	Control Option	Action	Responsible Agencies
Area Source (Contd..)			
Construction and Demolition Activities	Control measures for fugitive emissions from material handling, conveying and screening operation through water sprinkling, curtains, barriers and suppressing units		ADTP,NMC
	Banning of operation of Brick kilns in city area		Revenue RDC
	Ensure carriage of construction material in closed/covered vessels	Depending on state or local bylaws, member of corporation can organize regional co-operation according to their specific needs. Through corporation, public and private decision makers can be brought together to consider regional strategy in direction of MPCB. If regionalist seems promising the corporation can then plan and implement the program	RTO
Biomass, Trash burning, Landfill, Waste burning	At landfill site, increase capacity of waste to energy project. Presently, 1150 TPD solid waste is generated in city. Assuming 41% of unmanaged waste is burnt so releasing 773 kg/yr PM 2.5 emissions.	Increased to 1000 TPD the PM2.5 emissions will reduce to 196 kg/yr in 2022	
	Launch extensive drives against burning of biomass, crop residue, garbage, leaves	Presently few cases of open waste burning were already detected and fine imposed, however this should be done on regular basis and area wise volunteers could be identified for the same	HO(S), NMC, Punjabrao Krushi Vidyapeeth(PKV)
	Regular check and control of burning of municipal solid waste	Pix transmission manufacturer of industrial belts, has been entirely running on steam totally produced using agro waste for last two years	HO(S) NMC Nagpur

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

Activity	Control Option	Action	Responsible Agencies
Area Source (Contd..)			
Biomass, Trash burning, Landfill, Waste burning	Proper collection of Horticulture waste and its disposal following composting cum gardening approach		Health office(S)/Garden suptd, NMC, Nagpur
	Ensure ban on burning of agricultural waste and crop residues and its implementation		Health office(S)/Garden suptd, NMC, Nagpur
	Strict compliance of ban on open burning		Health office(S)/Garden suptd, NMC, Nagpur
	Biomethanation and biogas plant need to be installed	Plastic bituminous roads option to be exercised, option of decentralised small scale plant unit may be exercised	Health dept NMC, Environmental dept NMC

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)

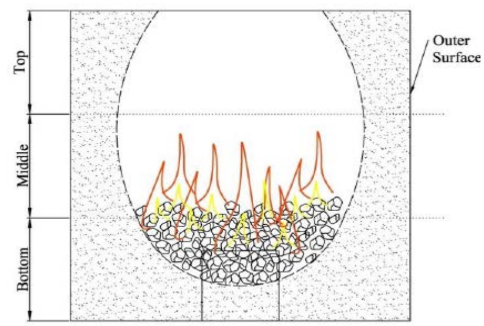
Design of a Clean Tandoor Community Kitchen System (CTCKS)

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.

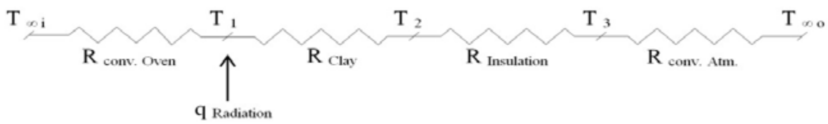
Advantages of pellet based tandoor also leads to reduced ash generation. Pellets based tandoor will also generate market for pellet industry and enable the use of agro-waste residues for development of an alternative fuel, promote employment generation in rural areas and would partly contribute to emission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

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



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

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

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

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

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

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

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

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

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

Design of Forced Draft Stove

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Tandoor Design Details

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

Illustrative materials for different parts of CTCKS

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

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

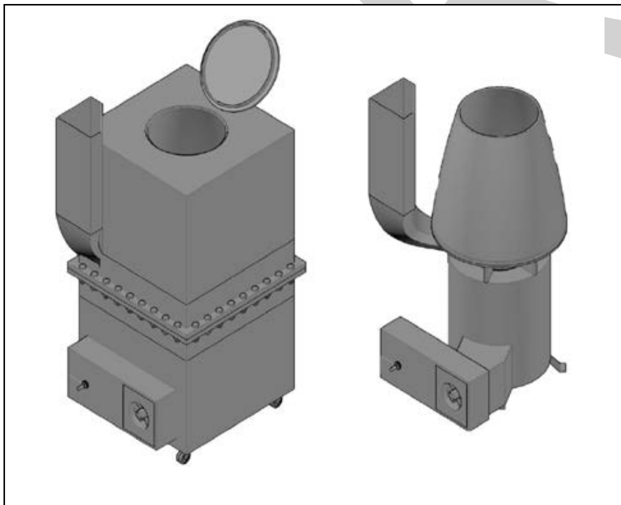


Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing

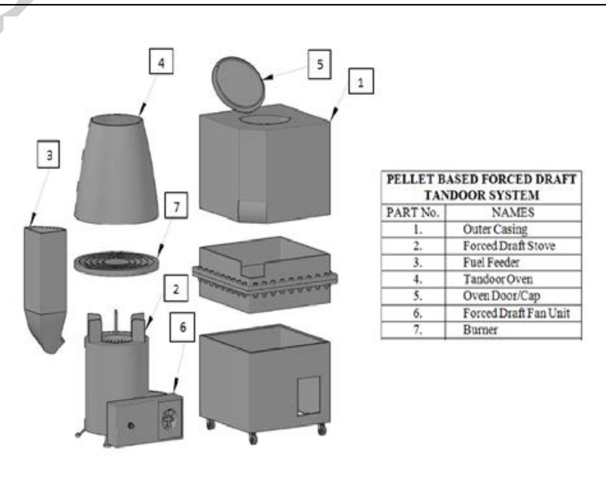


Fig. 2 Exploded view CTCKS: Inner Assembly & Outer Casing

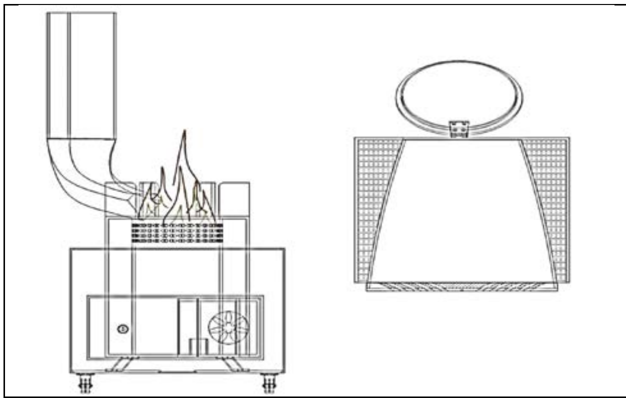
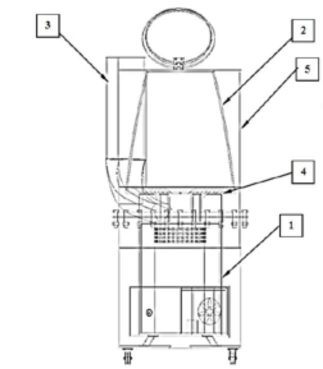
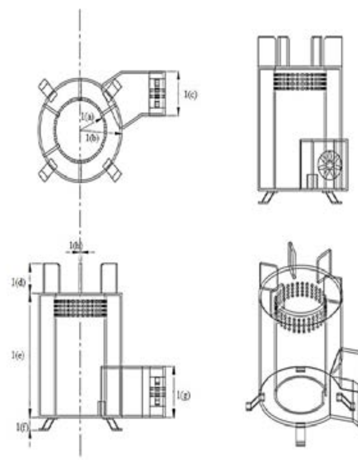


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)



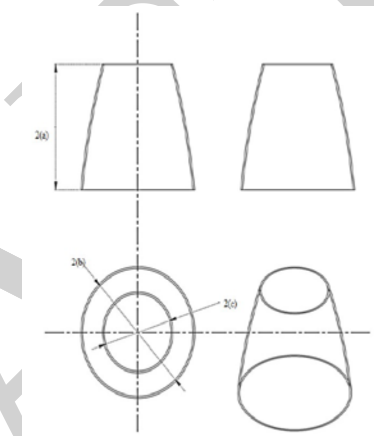
PELLET BASED CLEAN TANDOOR COMMUNITY KITCHEN SYSTEM	
PART No.	NAME
1	COOKSTOVE
2	OVEN
3	HOPPER
4	BAFFLE PLATE
5	CASING

Fig. 4 Line diagram of CTCKS



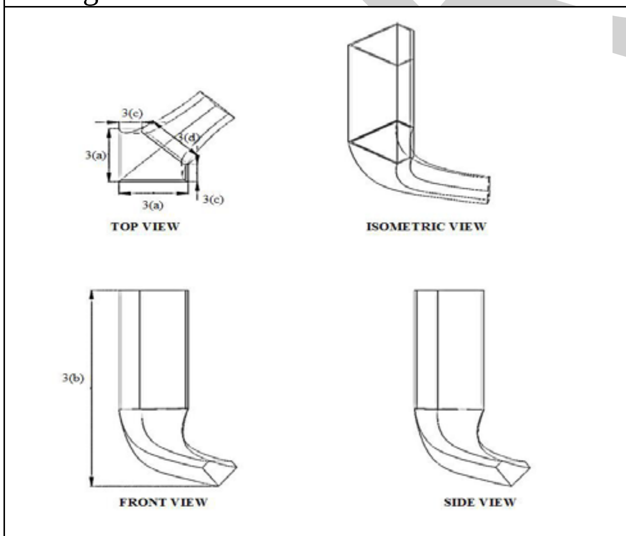
Part. No.	Dimensions (mm)	
3.15	a	170
	b	250
	c	80
	d	50
	e	400
	f	40
	g	80
	h	4

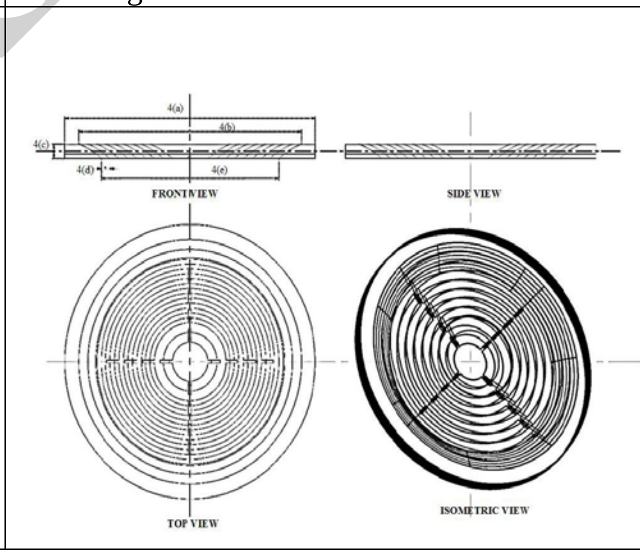
Fig. 5 Child Parts of CTCKS: Cookstove



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

Fig. 6 Child Parts of CTCKS: Oven



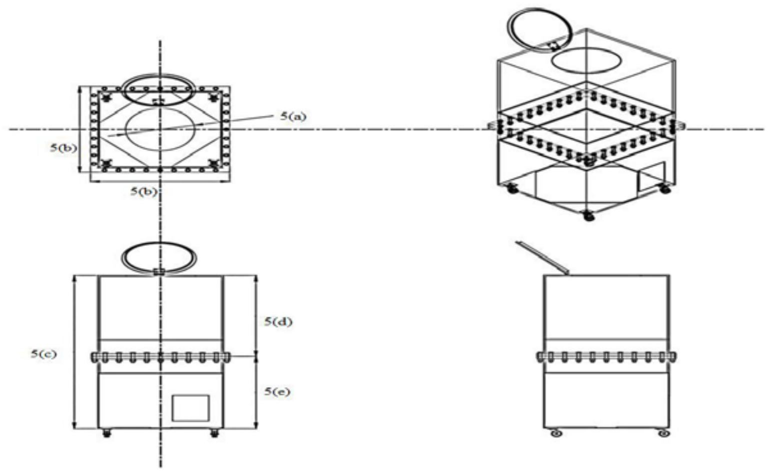


Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

Fig. 7 Child Parts of CTCKS: Hopper

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

Fig. 8 Child Parts of CTCKS: Baffle Plate



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

Fig. 9 Child Parts of CTCKS: Casing

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

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

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

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

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

Annexure :

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

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

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

Annexure – II

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

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

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

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

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

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

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

Electric Cremation vs The Traditional Funeral Pyre

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

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

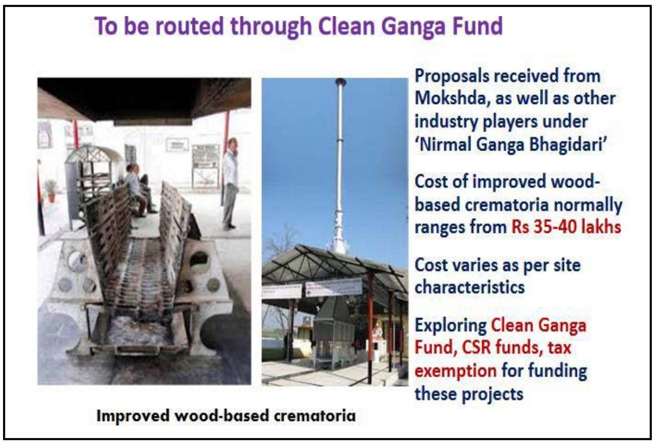
According to a report, all the year round, around 50 to 60 million trees are burned during cremations in India. While burning the wood, there is also emission of million tonnes of carbon dioxide gas which is not good for the environment. Also, cremation in open grounds generates large amounts of ashes,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

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

Green Cremation system

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

In the Green Cremation system, a man sized metal grate is constructed beneath a roof and a chimney, and woods are placed on the metal base. The use of chimney enables better air circulation and reduces heat loss. It uses much lesser amount of wood (around 150-200 kg) to burn a body as compared to the wood (500-600 kg) used in the traditional funeral pyre. Also, it takes less time for the entire cremation, somewhere around 2 hours, as compared to 6-8 hours in the traditional cremation. While the emissions are reduced by 60%, the cost is also reduced significantly. Further the



emission control system attached to the hood of the open pyre shed and dome constructed may help in reducing the emissions vis a vis ambient air quality around the cremation unit. Detailed diagram of emission control system for open type with side enclosed crematoria **(Figure 1)**.

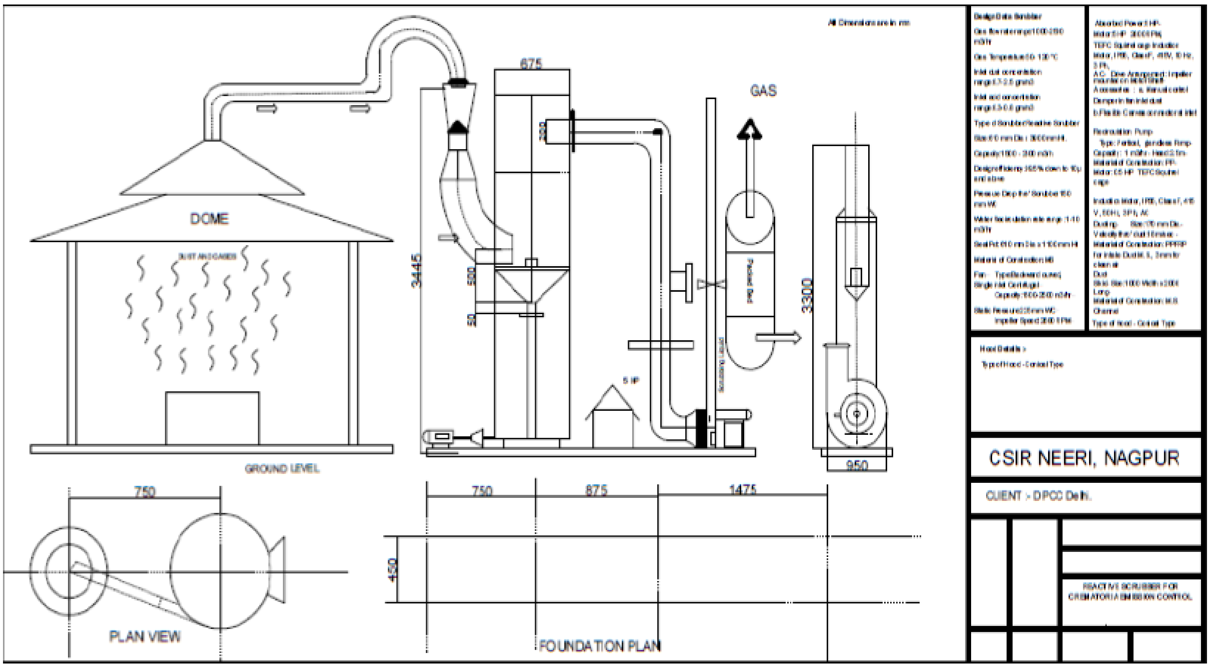


Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

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

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

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

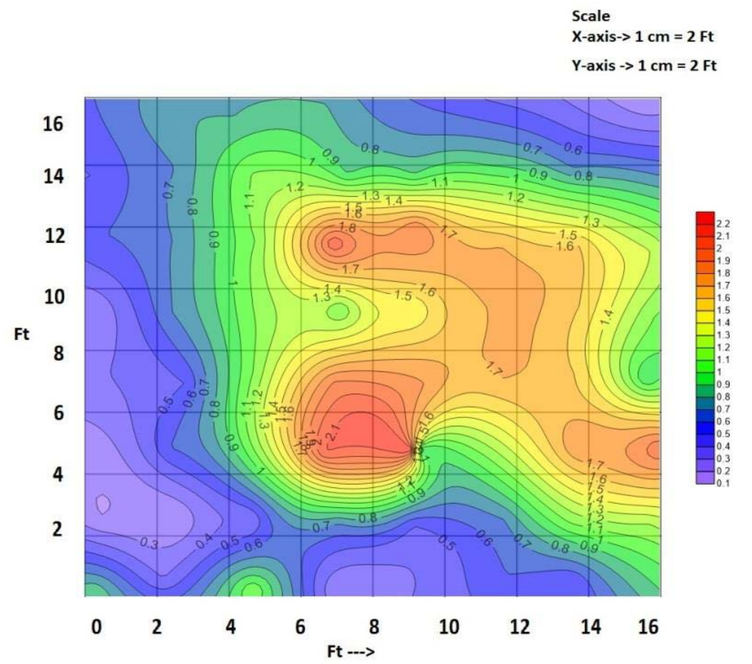


Figure 2 : Velocity profile of fumes during cremation

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

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

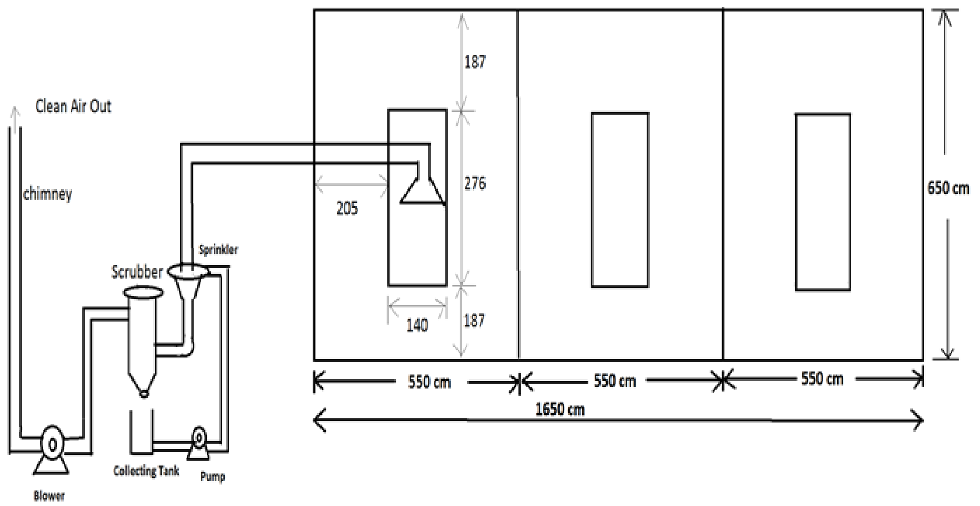


Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

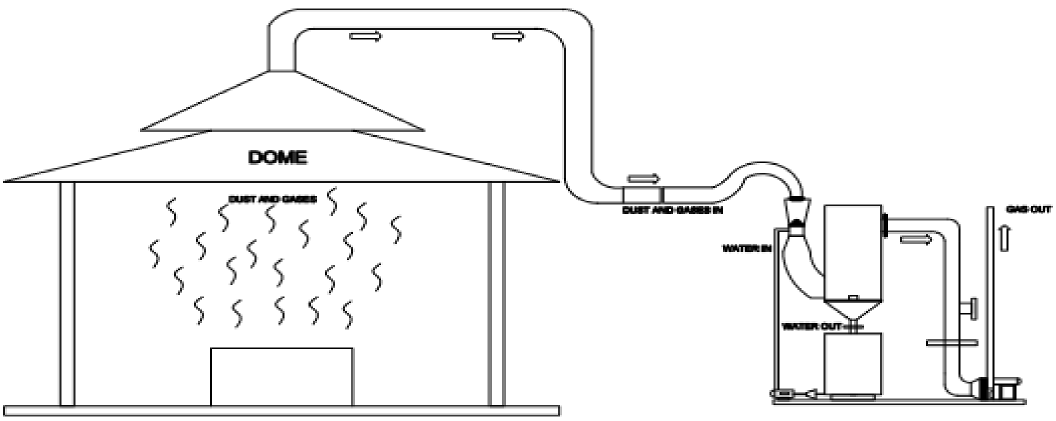


Figure 4 : Schematic view of Air Pollution Control System

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

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

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

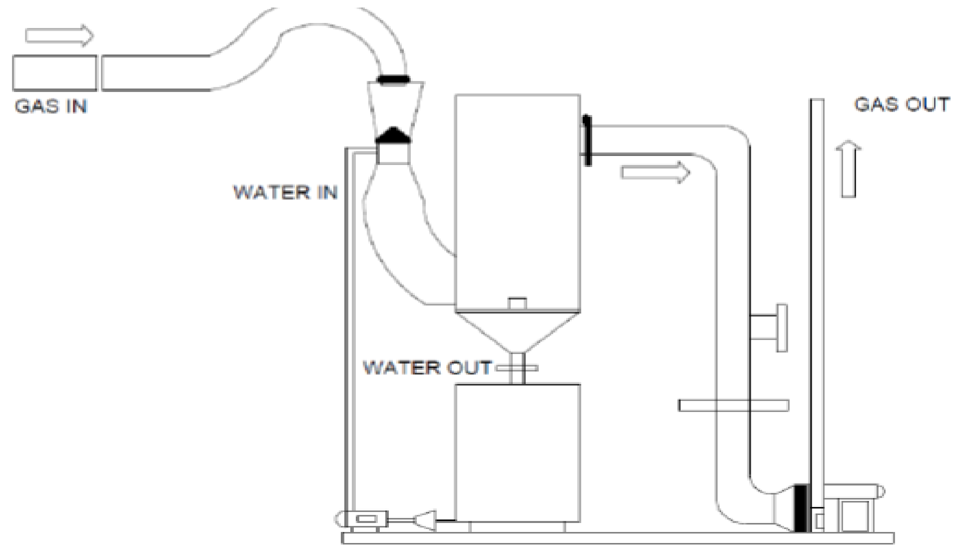


Figure 5 : Schematic of Reactive Scrubber

Gaseous Emission Control System

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

Design of APC System Emission capture system

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

The canopy hood volume is expressed by the following equation:

Hood Volume = T_d (Qp-Qs) Where,

T_d = duration of plume surge (s)

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

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

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

Where:

DC = column diameter at hood face.

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

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

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

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

Where:

DS = diameter of hot source, ft

Emission control system

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

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

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

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

d_d = droplet diameter, m

μg= gas viscosity, ($msec^{-1}$)

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

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

L & G are liquid & gas densities.

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

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

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

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

Annexure – III

Design of Passive Gas Venting System for Landfill Sites

Design of Passive Gas Venting System for Landfill Sites

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

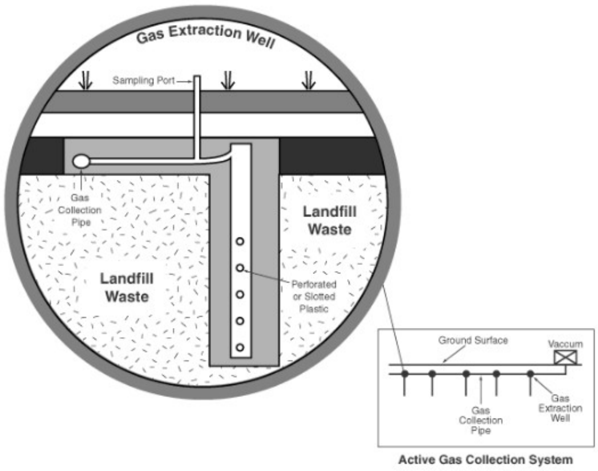
Most of the MSW generated is disposed of non-scientifically in open dumps, which causes a serious threat of landfill gas (LFG) emissions. The present note will focus on the landfill sites for the LFG emissions and designing the appropriate gas venting for the landfill sites.

Landfill Gas Collection System

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

Active Gas Collection System

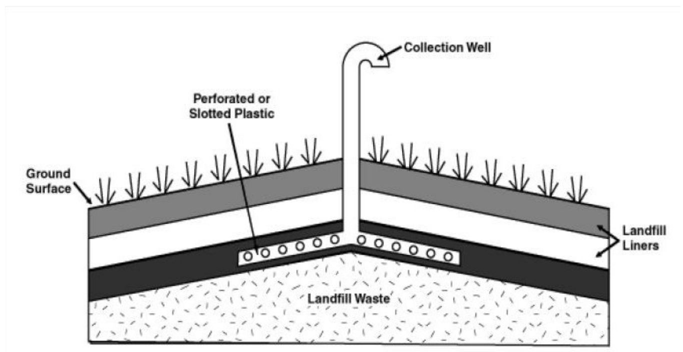
Well-designed active collection systems are considered the most effective means of landfill gas collection (EPA 1991). Active gas collection systems include vertical and horizontal gas collection wells similar to passive collection systems. Unlike the gas collection wells in a passive system, however,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



Active venting systems

Passive Gas Collection System

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



Passive Venting Systems

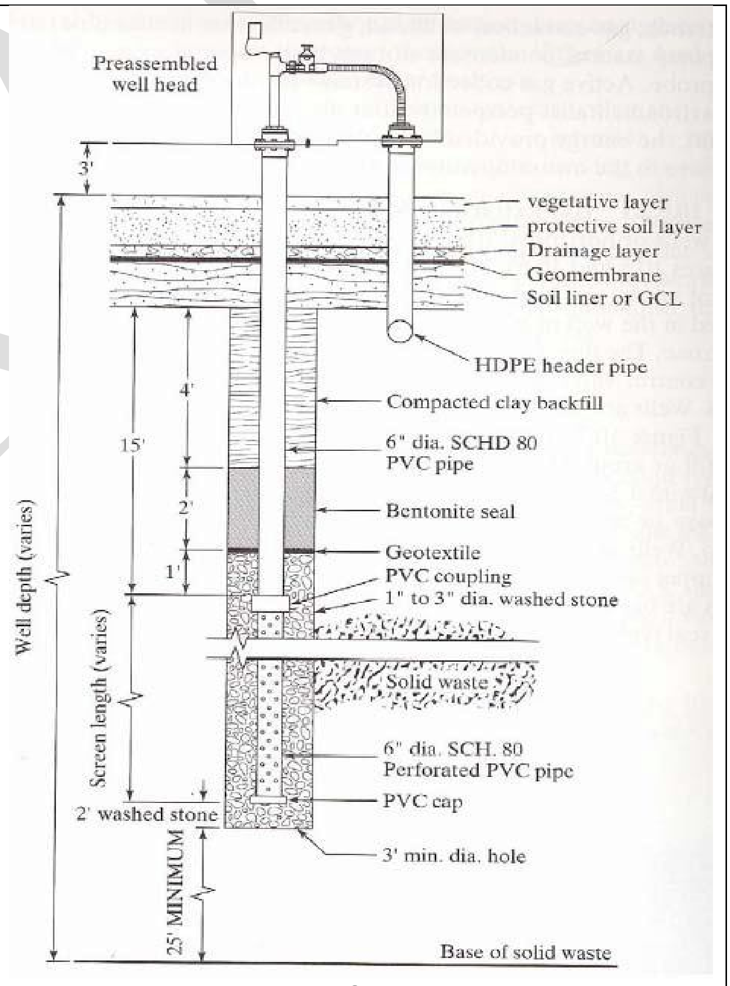
groundwater table. Vertical wells are typically installed after the landfill, or a portion of a landfill, has been closed. A passive collection system may also include horizontal wells located below the ground surface to serve as conduits for gas movement within the landfill as shown below. Horizontal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

Criteria and Process Diagram of Passive Vents

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

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

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



Typical Design of Passive Vent System

Data Requirement and Design of Passive Vent System for Landfill Sites

✓ ***Data Requirement***

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

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

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

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

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

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

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

Methods to Treat Landfill Gas

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

Combustion Methods

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

Non-combustion Methods

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

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

Annexure – IV

Dust Control Measures

Dust Control Measures

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

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

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

Dust Control Agents

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

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

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

Selecting dust control agents

When selecting materials for dust control consider these basic requirements:

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

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

Table 1: Application rates of dust control chemicals

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

Methods of Application

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

Figure 1 : Road side sprinkling of dust control agents

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

Figure 2 : Covered transportation vehicles

Other references

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

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

Specifications/ Application

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

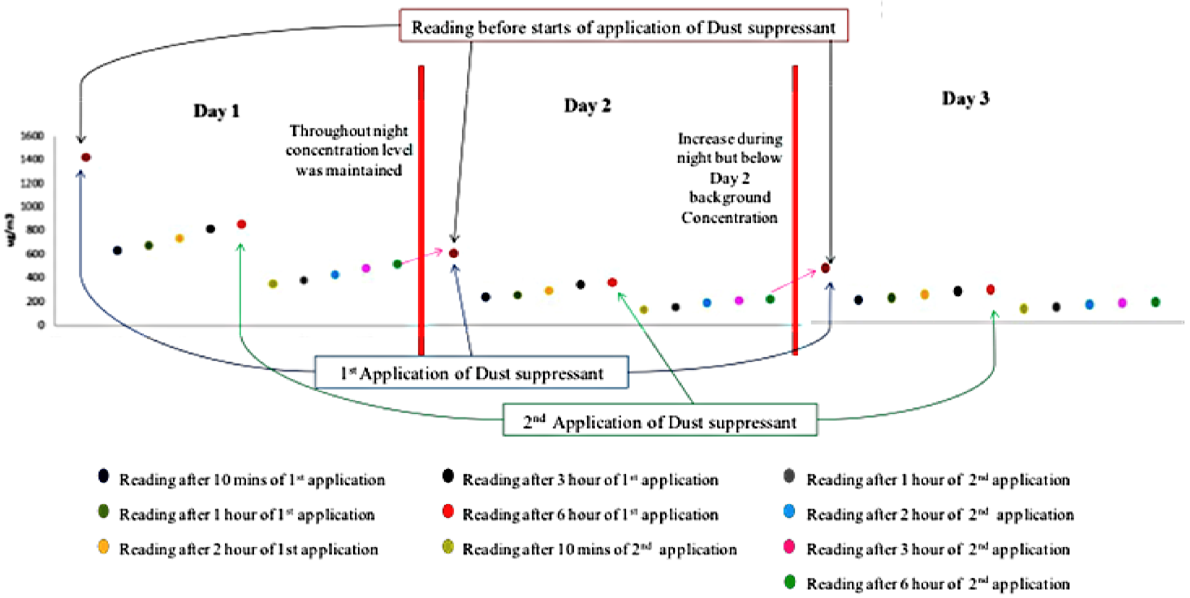
Advantages

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

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

Application of Dust Suppressant using Tanker at Delhi

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



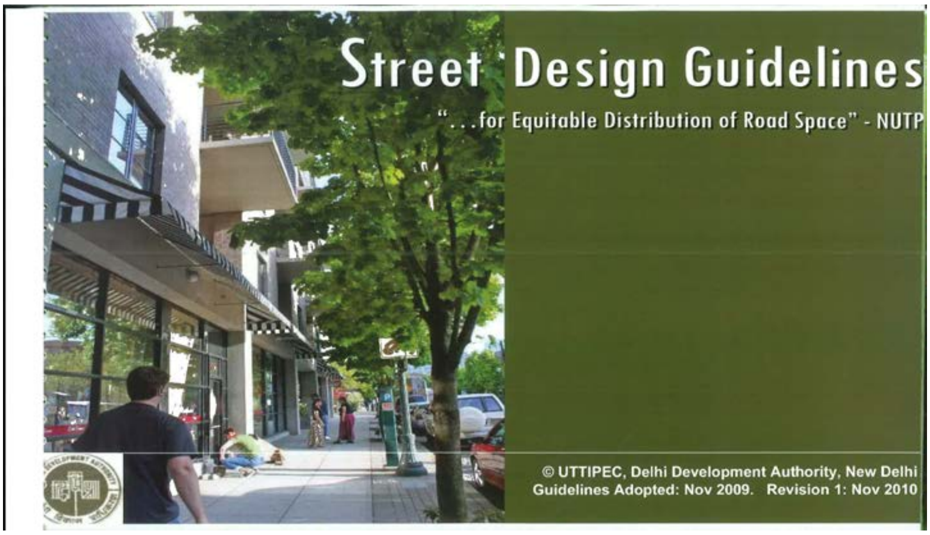
Bioswale : System for Storm Water and Dust Suppression Road Side

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

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

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

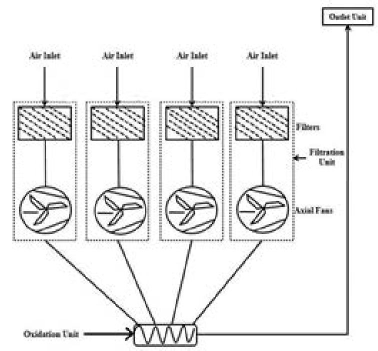
Air pollution is a local problem and its solution can be derived from technologies coupled with local conditions and requirements. Creating change in meteorological parameters like wind with the help of devices such as fans and also removal of the pollutant near to the source may help in reducing ambient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



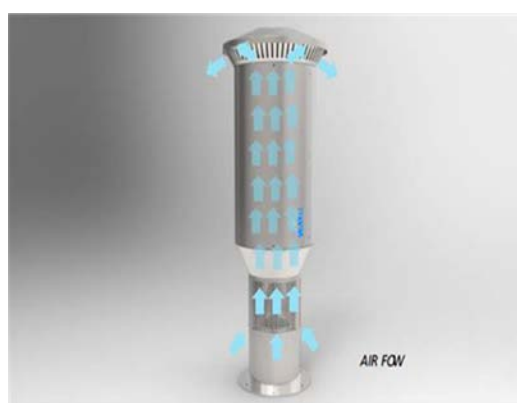
UV- TiO2 adsorption-photocatalytic oxidation has a lot of advantages. They are very efficient in removal of VOCs. Pichat et al. (2000) have shown that ozone can be directly eliminated by TiO_2 nanoparticles in a process that is promoted by both heat (in the ambient temperature range of 0° to 50°C) and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

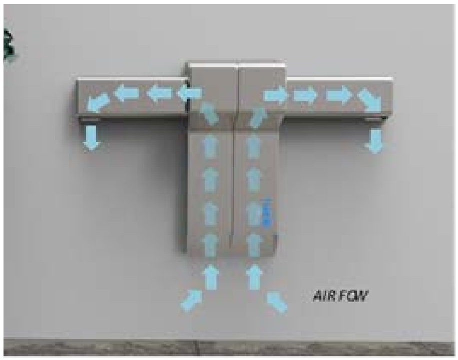
WAYU is a device jointly developed by IIT-CSIR-NEERI focused on controlling pollution in ambient air. WAYU has been successfully tested in a pilot project of 25 devices in Mumbai in collaboration with Maharashtra Pollution Control Board (MPCB). With an aim to solve the ever rising menace of air pollution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



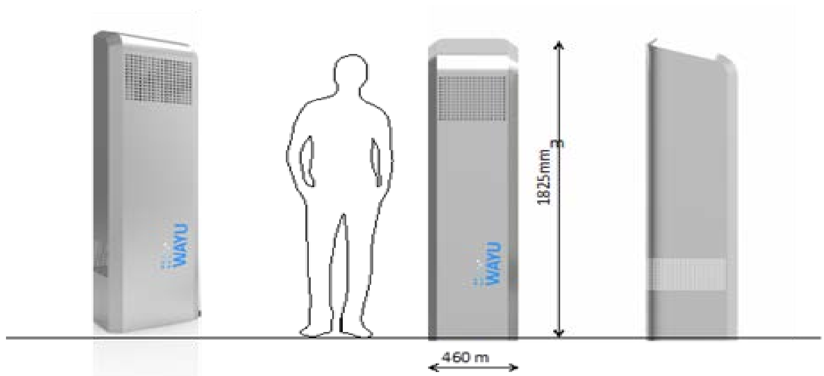
WAYU device improved design



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.