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

(LATUR CITY)

Prepared for

Maharashtra Pollution Control Board (MPCB), Sion, Mumbai

Prepared by

National Environmental Engineering Research Institute (CSIR- NEERI)

Indian Institute of Technology (IIT) Bombay

November, 2025

Executive Summary
Source Apportionment Study for Latur

This study was initiated by Maharashtra Pollution Control Board (MPCB) as a part of a State-wide effort in seven cities for NCAP (a total of 19 cities have been identified and studied under this initiative). Several aspects of the air pollution in these nineteen cities have been investigated with an intent to identify the key sources of pollutants, where Particulate Matter (PM) have been used to represent air pollution. The choice of PM was made based on historical monitoring data, where all other criteria pollutants have largely met the compliance requirements, except Particulate Matter (PM). Analyses have been carried by using the results from source apportionment, and also the results of inventory of air pollution sources (Table 7.1). The results and recommendations for Latur are listed in detail in Chapter 7, and summarized here in the following sections.

ES-01 Source Apportionment

a) Sampling for the source apportionment component of the work were carried out at three locations in Latur to quantify the sources of air pollution based on the chemistry.

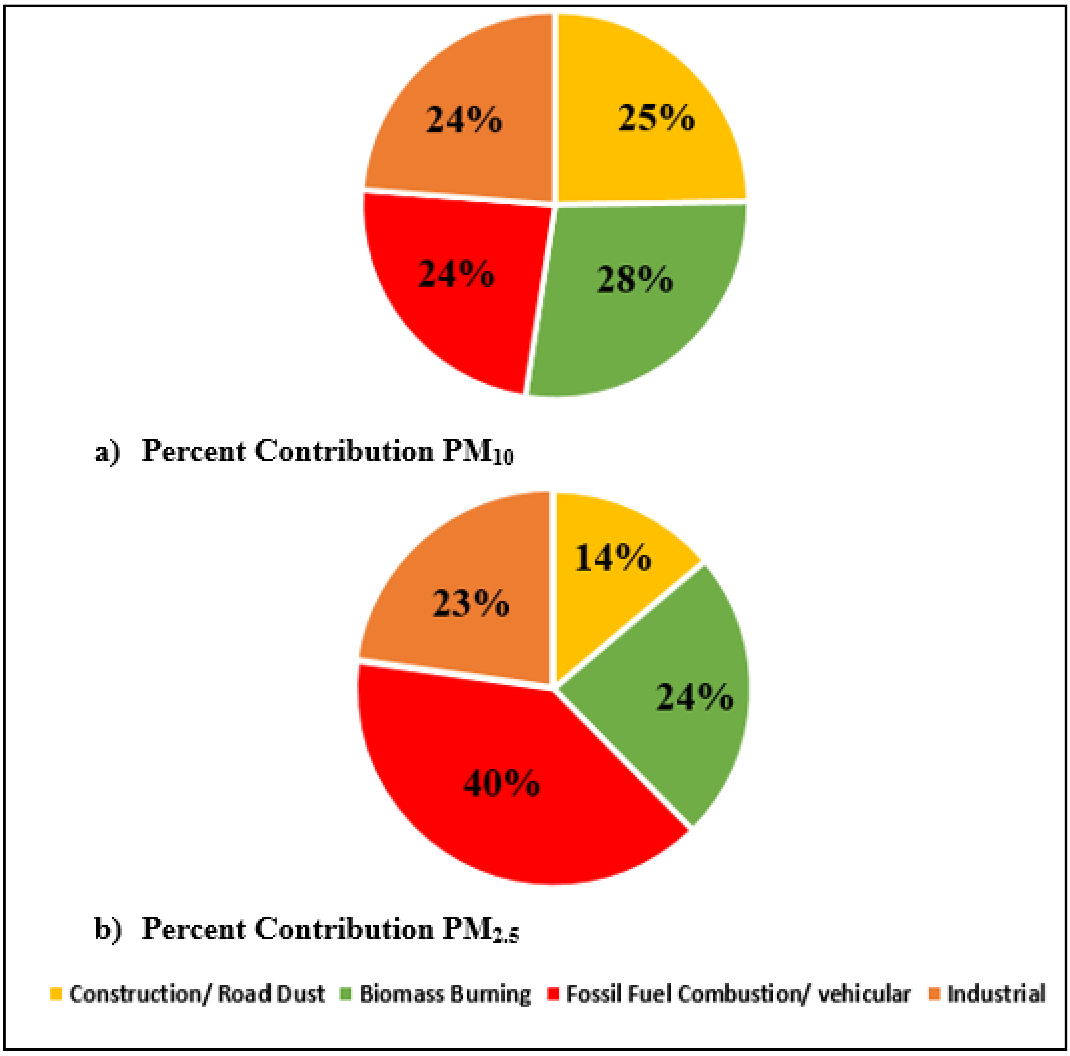
b) The chemical analyses were carried out as per CPCB guidelines. The receptor modelling was conducted employing the EPA Positive Matrix Factorization (PMF) method. The overall source apportionment of PM_{10} and $PM_{2.5}$ derived from emission inventory, dispersion modelling and receptor modelling are summarized as Figure ES-1.

c) The findings revealed that there are 4 major, almost equal contributors to the PM10, namely, Biomass burning, road dust and construction, fossil fuel/vehicular and industrial). Uncontrolled burning of solid wastes and also uncontrolled emissions from small scale industries in the unorganised sector are likely to be included as industrial sources. Fossil fuel also seems to have the largest contribution to PM2.5 followed by biomass burning.

ES-02 Inventory

a) The inventory for the point, line and area sources were compiled from secondary data made available by the offices of MPCB, ULB and RTO.
Inclusion of sources is limited to industrial point sources (MPCB), line sources (RTO data and preliminary traffic surveys), and area sources (ULBs). Large number of sources of air pollution are from the small scale, unorganised sector, and these, historically, have been rather difficult to quantify to include in the inventory. Thus, the concentrations of PM based on dispersion modelling are largely underestimated when compared with the actual measurements.

b) Further, there is a large uncertainty in the quantities, emission factors and the chemical profiles of garbage (wet and dry, often mixed), and biomass (shed leaves from trees etc.) that are burnt in the open. Burning of plastics and anthropogenic dry wastes in an uncontrolled manner is a serious matter of health concern, and requires immediate attention. Measurements and quantification of the emissions from such uncontrolled burning for inventory development is tedious, if not impossible. From a pragmatic perspective, therefore it is best to implement common sense actions required to strictly enforce ban on such uncontrolled burning.



c)

Figure ES-1: Percentage Contribution of Sources for (a) PM10 and (b) PM2.5 for Latur City

ES-03 Recommendations

a) The actions for short-term mitigation, and long-term control are listed in Chapter 6. The implementation of these is to be decided at the city level based on the key sources of air pollution and the resources.

b) For Latur, the key sources for control are shown in Table 7.1(a), with control of point, line and area sources being nearly distributed equally. However, the contribution for the point sources is not seen as much in the receptor model because emissions from area and line sources dominate the ground level concentrations.

c) Sweeping (manual or mechanised) is a temporary measure, and is useful for aesthetics (removal of trash and leaves fallen from trees). The activity of sweeping itself adds to the air pollution. Spraying of water has limited effectiveness. Focus needs to be on prevention of soil reaching the road surface by better shoulder design (for unpaved sections), left-overs from construction work, median divider with plantations (often a source of soil onto the road during watering). This effort of improving road design could be a part of the annual maintenance effort where over a period of about 5 years, 100% of roads in the city would become dust free by design.

d) Strict enforcement to ensure that open burning is prevented would be the most pragmatic approach to control emissions from this activity. Timely collection of collected biomass would minimise the need for such enforcement efforts. Further, burning of plastics and anthropogenic dry wastes in an uncontrolled manner is a larger matter of health concern, and requires immediate attention for prevention. Services of the Fire Brigade department may be sought through ward-specific telephone/web-based hotlines for quenching any uncontrolled garbage and/or biomass burning.

e) The analysis indicates that sustained and concerted efforts in all sectors is the key to reaching a point of acceptable air quality. Further, while the focus has largely been on primary sources of PM, the control of gaseous pollutants at source, across all sectors, would lead to a natural outfall of control on the pre-cursors which lead to the formation of secondary aerosols.

f) The strength of using the results of this study depends on the validation of the source inventory at the ground level. Control measures would need to be strategized accordingly. It is important that each stakeholder may validate the inventory at the ward level, especially for all municipal domain activities as well as small scale industries in the unorganised sector.

g) A significant part of the air pollution in urban centres is from vehicular emissions. The correct estimate of vehicular emissions is possible only if the vehicle type identification and its counting on each road can be carried out. Artificial Intelligence / Machine Learning (AI/ML) tool can be used for online identification and counting of vehicles. Such tools are already developed and ready. CCTV operators are required to give access to the IP address so that online counting of vehicles can be carried out and used in the emission inventory and source dispersion modelling.

h) Air Quality Management (AQM) is a new emerging problem for cities in India, and therefore asks for a new team and a new administrative structure. An AQM Cell could co-ordinate between regulatory authority (MPCB) and other department of ULB and Transport Department for regular data collection. This team could also monitor the progress laid out for the immediate as well as for the next 5 to 10 years, and pool in the resources for the entire state as through multiple agencies (MPCB, RTO, Fire Brigade, IoRs, Research Institutes and Industries and other stakeholders).

i) The timeframe for a sustainable system is typically about 10 years, and requires a programme-based approach, which would become mainstream with time.

j) Long term sustained success will require public participation and a reward-based approach (rather than enforcement based). This approach could be tested in a few wards where the pro-active citizen participation could set an example for success and replication.

ES-04 Organisation of the report is shown in Table ES-1

Table ES-1 Organisation of the Report

Chapter	Title
ES	Executive Summary
1	Introduction
2	Ambient Air Quality
3	Emission Inventory
4	Source Apportionment
5	Dispersion Model
6	Action Plans
7	Summary and Recommendations
Annex-1	Design of a Clean Tandoor
Annex-2	Air Pollution Control System for Green Crematorium
Annex-3	Dust Control Measures

Chapter 1
Introduction

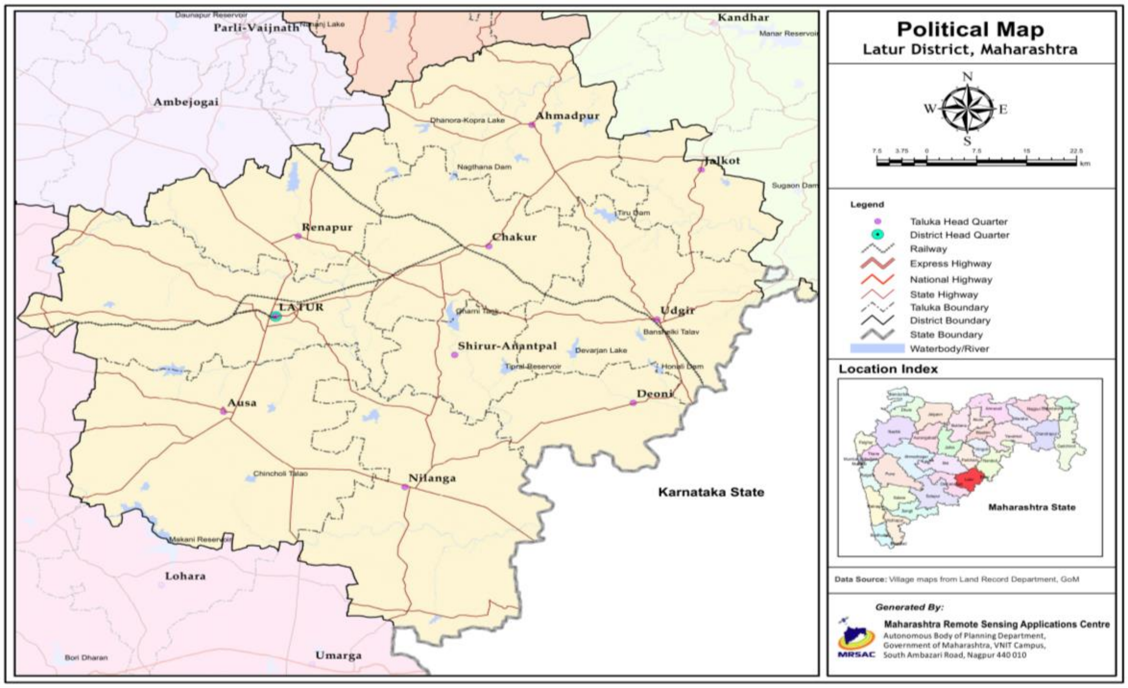
1. Preamble

Air quality in urban areas is a complex issue driven by diverse anthropogenic sources, including industrial emissions, vehicular exhaust, construction activities, agricultural practices, and waste burning. These sources contribute to fugitive and line emissions, which collectively lead to long-term reductions in productivity and deterioration of the economic condition of a country. Effective control of air pollution is essential to mitigate health risks, protect the natural environment, and enhance the quality of life, all of which are integral to sustainable development. Although air quality monitoring programs in India provide valuable data for policymakers, issues such as inadequate quality assurance/quality control (QA/QC) in monitoring processes, data collection, and interpretation further complicate the problem, highlighting the need for improved emission source identification and continuous, accurate air quality monitoring.

1.1 Latur District

Latur district, located in the Marathwada region of Maharashtra, is bordered by several districts. The district is situated on the Maharashtra Karnataka boundary. To the north, it shares its boundary with Osmanabad; to the east lies Parbhani, and to the southeast is Nanded. Beed district lies to the west, while Aurangabad is located to the northwest. Latur city serves as the administrative headquarters of its district and ranks as the 16th largest urban area in the state of Maharashtra. It is geographically situated at approximately 18°24' N latitude and between 76°25' and 77°25' E longitude, within the Deccan Plateau. The city is a notable tourist destination, surrounded by historical landmarks such as the Udgir Fort and Kharosa Caves.

The average elevation of the city is 631 meters (2,070 feet) above mean sea level. The entire Latur district lies within the Balaghat Plateau, with elevations ranging from 540 to 638 meters (1,771 to 2,093 feet) above mean sea level. The district covers a geographical area of 7,157 square kilometres, constituting 2.32% of Maharashtra's total geographical area and 11.04% of the Aurangabad region. Latur district is composed of 10 talukas: Latur, Ausa, Nilanga, Udgir, Ahmedpur, Jalkot, Chakur, Shirur Ananlpal, Deoni, and Renapur, and is divided into five administrative subdivisions, encompassing a total of 948 villages.



Physiographic

Latur district is situated partly in the Upper Godavari Basin, on the Balaghat Plateau, and lies within the Manjara River Valley. The Manjara River, along with its tributaries Terna, Tawarja, and Gharni flows through the Balaghat Plateau, while the northern plains are drained by additional tributaries, including Manyad, Teru, and Lendi. The region's physiography is dominated by the plateau and river valleys, which significantly influence the local landscape and hydrological systems.

Demography

As per the 2011 Census, Latur district has a total population of approximately 2,454,196, with a population density of 343 people per square kilometre. The urban population stands at 490,261, making up 25.46% of the total, while the remaining 74.53% live in rural areas. The district comprises several talukas, with Latur being the most populous (27.85%), followed by Udgir (12.76%), Ausa (12.61%), Nilanga (13.25%), and others. The district has a sex ratio of 928 females per 1,000 males, and the literacy rate is 77.26%, with a higher literacy rate in urban areas (83.56%) compared to rural areas (75.11%). Of the 481,572 households, 118,163 are urban, with a significant portion residing in Latur city (63.51%) and Udgir (17.89%). The male literacy rate is 84.39%, while the female literacy rate is 69.63%. About 25.46% of the population resides in urban areas, with Latur city and Udgir being the major urban centers. The rural areas account for the remaining 74.53% of the population, indicating the district's predominantly rural character.

Agriculture and Trade and Commerce

Latur district spans 6,523 square kilometres of cultivable land, with approximately 50% of this area devoted to soybean (182,900 hectares) and sugarcane (57,000 hectares). Other key crops include jowar, wheat, maize, bajra, and toor dal. The district is a prominent trading center for pulses such as urad, moong, toor, and channa, and is also known for its oilseed market, including sunflower, soybeans, and safflower. Additionally, Latur's industrial landscape includes brassware production, milk powder manufacturing, and ginning and pressing, alongside several sugar mills like Manjra, Saker Karkhana, Vikas, and Jagruti. Around 75% of the district's 430,188 farmers possess small or marginal landholdings, averaging 1.65 hectares, higher than the state and regional averages. The total workforce of 1,046,857 makes up 42.66% of the population, with 39.79% engaged in agriculture. Additionally, 39% of the population (808,190 individuals) falls within the 15-40 age group, contributing to a young and dynamic labour force.

Total/ Rural/ Urban	Total Workers	Main Workers	Cultivators	Agricultural Labourers	Household Industry Worker	Other Workers
Total	1,046,857	964,177	311,209	383,939	14,476	254,553
Rural	857,367	794,557	305,379	371,168	9,575	108,435
Urban	189,490	169,620	5,830	12,771	4,901	146,118

Source: Census, 2011

Transport

Latur district is well-connected through an extensive transportation network, which includes 831 kilometres of state highways, 1,518 kilometres of district major roads, and 2,704 kilometres of other roads, providing robust road connectivity across the region. The district's strategic location, equidistant from Aurangabad, Pune, and Hyderabad, enhances its accessibility. The key railway stations in Latur district are Latur, Latur Road, and Udgir, with the conversion of the Kurduwadi-Latur track from narrow gauge to broad gauge (148 km) providing direct rail connectivity to Mumbai. Other significant rail routes include Latur-Kurduwadi-Pune-Mumbai (west), Latur-Udgir-Hyderabad (south), Latur-Purna-Akola-Nagpur-Kolkata (east), and Latur-Manmad-Bhusawal-Delhi (north). Additionally, Latur is served by an air service to Mumbai, facilitating air connectivity to major cities across India. This well-developed multi-modal transport infrastructure supports both local and regional mobility, boosting economic and trade activities within the district.

Infrastructure

Latur district is renowned for its educational model, the "Latur Pattern," and hosts over 427 high schools, 33-degree colleges, 12 ITIs, 3 polytechnics, 2 engineering colleges, 2 medical colleges, and institutions for agriculture and biotechnology. The district generates 235.47 metric tons per day (MTD) of domestic solid waste, with 105.96 MTD of dry waste and 129.515 MTD of wet waste. Latur city, the largest contributor, generates 151 MTD, including 61 MTD of dry waste and 89 MTD of wet waste. The waste is collected by the municipal corporation, sent to a satellite station, and then transferred to a disposal site managed by the Jan Aadhar organization near Warwanti. Segregation occurs at the collection point, with biodegradable waste sent for composting and dry waste sold. Biomedical waste from the city is incinerated at Akshay Industries Pvt. Ltd. However, open waste burning along roadsides and stubble burning in agricultural fields remain significant issues.

The district also generates 8.1 MTD of street sweeping waste, with Latur city producing 5 MTD, and 32.2 MTD of drain silt, with Latur city contributing 10 MTD, the highest in the district. Latur city has implemented mechanical street sweeping. Additionally, Latur district produces 782.4 metric tons of construction and demolition waste annually, with 109.91 metric tons processed or recycled. A large portion, 921 metric tons, is disposed of by landfilling, and 248.5 metric tons is illegally dumped.

Climate

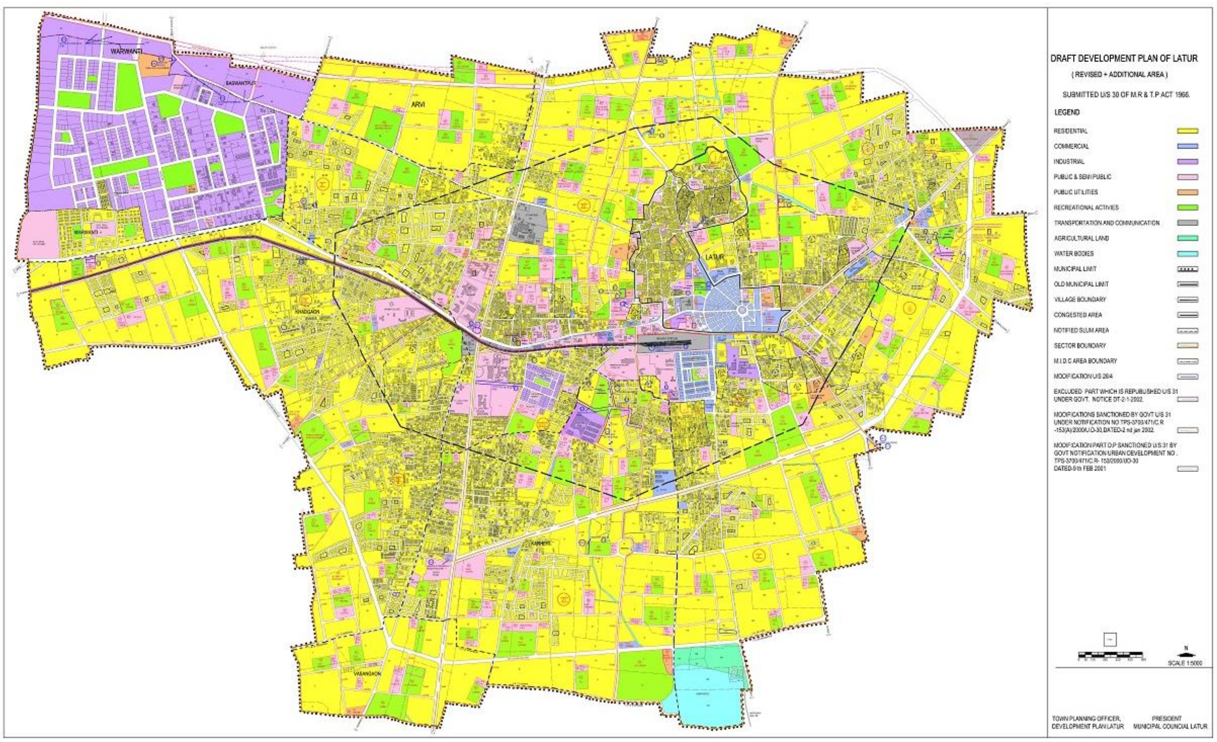
Latur district experiences a dry climate year-round, except during the southwest monsoon from June to September. The region has four seasons: monsoon, post-monsoon (October to mid-November), winter (mid-November to February), and hot dry (March to May). December is the coldest month with temperatures averaging 29.5°C during the day and 15°C at night, while May is the hottest month, with temperatures reaching 40°C. The district receives an annual rainfall of 650-800 mm, increasing from southwest to northeast, with 84% of it occurring during the monsoon season. Despite frequent droughts, the people are known for their resilience and adaptability.

1.2 Latur City

Latur Municipal Corporation (LMC) is the governing body responsible for the provision of essential civic services within the city. The corporation is organized into five administrative zones, further divided into 18 wards. The total area covered by the LMC is approximately 117.78 square kilometres, with a population of 382,950 people residing in 74,557 households with a density of 937 people per square kilometre.

The city includes 16,880 slum households, which accommodate about 86,139 individuals, representing 22.49% of the total population. Additionally, the Latur fringe area, comprising 37 villages, is under the jurisdiction of CIDCO, which has been designated as the Town Planning Authority. Around 14,000 houses have been constructed under the WAMBAY scheme by MHADA in this area.

Area in Square Kilometres	**Number of Households**	**Total population** (including institutional and houseless population)		
		Persons	Males	Females
117.78	74,557	382,940	197,737	185,203



Wordwise Latur City Municipal Corporation Map

The literacy rate stands at 83.1% in urban areas, with male literacy at 89.7% and female literacy at 76.36%. The sex ratio in Latur is 937 females per 1,000 males. The city's working population comprises around 1,046,528 individuals, with 964,177 being main workers. The working population in the city reflects a significant labour force contributing to various industries, including agriculture and household industries.

Total Workers	**Main Workers**	**Cultivators**	**Agricultural Labourers**	**Household Industry Worker**	**Other Workers**
116,044	104,528	2,756	3,038	2,802	95,932

Public-private partnerships in Latur have led to new ventures in pulp processing, starch, dairy, and cold storage industries. An agro-based SEZ is being developed by Ramkay International on 200 hectares, expected to generate 15,500 jobs. Additionally, India Bulls Ltd. is setting up a Food Park with facilities for agro-processing entrepreneurs. The region's strong linkages to agro-processing and raw material availability make contract farming a viable option. MIDC has also notified 840 hectares for the development of the SEZ and Food Park.

According to the 2011 Census, the primary fuel source for domestic households in Latur is LPG/PNG, accounting for 43.22% of usage, followed by firewood and kerosene. Similarly, the crematoriums at Siddheshwar Mandir, Ambedkar Chowk, Khadgav Road, and Nandgav predominantly utilize firewood for cremation purposes. The number and percentage of household by availability of fuel used for cooking are as follows:

Total/Rural/ Urban	**Total number of Household**	**Firewood**	**Crop Residue**	**Cowdung Cake**	**Coal/Lignite/ Charcoal**	**Kerosene**
Total (%)	130200	51202 (39.33%)	6904 (5.3%)	3725 (2.86%)	123 (0.09%)	10074 (7.74%)
Rural (%)	55647	36576 (65.73%)	6052 (10.8%)	3471 (6.24%)	54 (0.1%)	1156 (2.08%)
Urban (%)	74553	14626 (19.62%)	852 (1.14%)	254 (0.34%)	69 (0.09%)	8918 (11.96%)
		LPG/PNG	**Electricity**	**Biogas**	**Any other**	**No Cooking**
Total (%)	130200	56266 (43.22%)	100 (0.08%)	317 (0.24%)	355 (0.26%)	1154 (0.89%)
Rural (%)	55647	7.688 (13.82%)	42 (0.08%)	162 (0.29%)	157 (0.28%)	289 (0.52%)
Urban (%)	74553	48.57 (65.16%)	58 (0.08%)	155 (0.21%)	178 (0.24%)	865 (1.16%)

Source: *Latur District Census 2011*

1.3 Background of the Study

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

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

1.4 Objectives

CPCB has listed cities in India in which the RSPM levels are non-complaint with the NAAQS and has directed SPCBs to develop action plans and implement these to control air pollution in these cities; Latur is one of them. There is a strong need for city-scale emission inventories to assess the types and sources of emission loads and to develop control measure as well for the development of pollution control strategies and policies. Among all the criteria air pollutants, particulate matter has emerged as the most critical pollutant in almost all urban areas of the country. Thus, the main focus of this study was on characterization and source apportionment of particulate matter.

- To measure baseline air pollutants (Particulate Matter) in different parts of the city which include “hot spots” and kerbside locations.
- To develop emissions inventory of various air pollutants in the city.
- To conduct source apportionment study of PM.
- To prioritize the source categories for evolving city-specific air pollution management strategies/plan.
- To assess the impact of sources on ambient air quality under different management/ interventions/control options and draw a roadmap of short- and long-term measures as a part of action plan suggested.

1.5 Scope of the Project

- Air quality monitoring will be conducted across various locations in the city, including residential, commercial, outskirts, and sensitive areas, over a 5-day period, with 24-hour average data collected from each station throughout the sampling duration.
- An emission inventory estimation for all sources of air pollution will be carried out, with secondary data analysed for the preparation of the city's emission inventory.

- A source apportionment analysis for particulate matter will be conducted using an appropriate model, and relevant city-specific data will be collected for this purpose. The particulate matter filter samples will be analysed for marker elements such as anions, cations, trace metals, organic carbon and elemental carbon.
- Actual meteorological data must be obtained from weather monitoring stations and analysed for the dispersion modelling exercise, using models such as AERMOD or ISCST3 depending on the specific scenarios and conditions.
- 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.

1.6 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 7 cities of Maharashtra.

Chapter 2

Ambient Air Quality

2. Ambient Air Quality

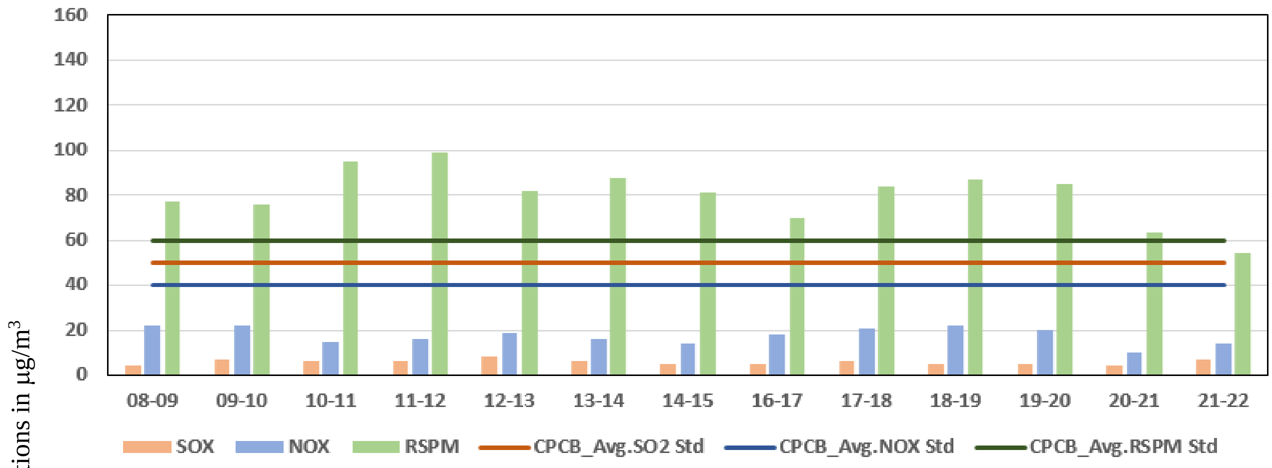
Monitoring of air quality in the region has been going on for a considerable period. Many of the stations have been collecting data through manual systems and some industries also monitor the ambient air through their manual/automatic stations.

2.1 Past Air Quality Monitoring Data

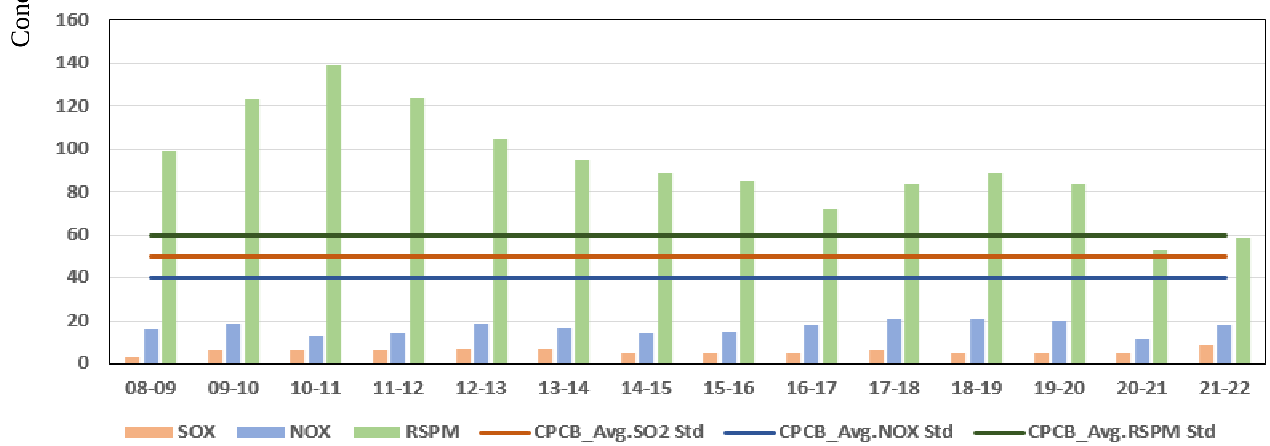
Ambient air quality is being monitored under the National Ambient Air Monitoring Program (NAMP), coordinated by the Central Pollution Control Board (CPCB) or SAMP (State Ambient Air Monitoring Program) stations. Presently 3 stations are operated under the NAMP program at MIDC Water Works - Latur (Industrial), Shyam Nagar-Kshewraj Vidyalaya (Residential), and Ganj Golai - Sidhheshwar Bank (Rural and other areas) in Latur. At present, there are no CAAQMS (Continuous Ambient Air Monitoring Stations) installed at Latur.

The trend analysis of the ambient air quality of Latur at NAMP was carried out. SOx (Oxides of Sulphur), NOx (Oxides of Nitrogen), and RSPM (Respirable Suspended Particulate Matter) have been identified for regular monitoring at all locations. The monitoring of pollutants is carried out for 24 hours (4-hourly sampling for gaseous pollutants and 8-hourly sampling for particulate matter) with a frequency of twice a week, to have around 100 observations in a year. Air quality monitoring NAMP database of Latur over the 13 years i.e., from 2008 to 2022, is available from MPCB air quality data portal. Due to the Covid scenario some month monitoring was not carried out. NAMP (National Air Quality Monitoring Programme) data for the annual average trend of SOx, NOx, and RSPM for the period 2008-22 is plotted and is shown in **Figure 2.1** for different sites.

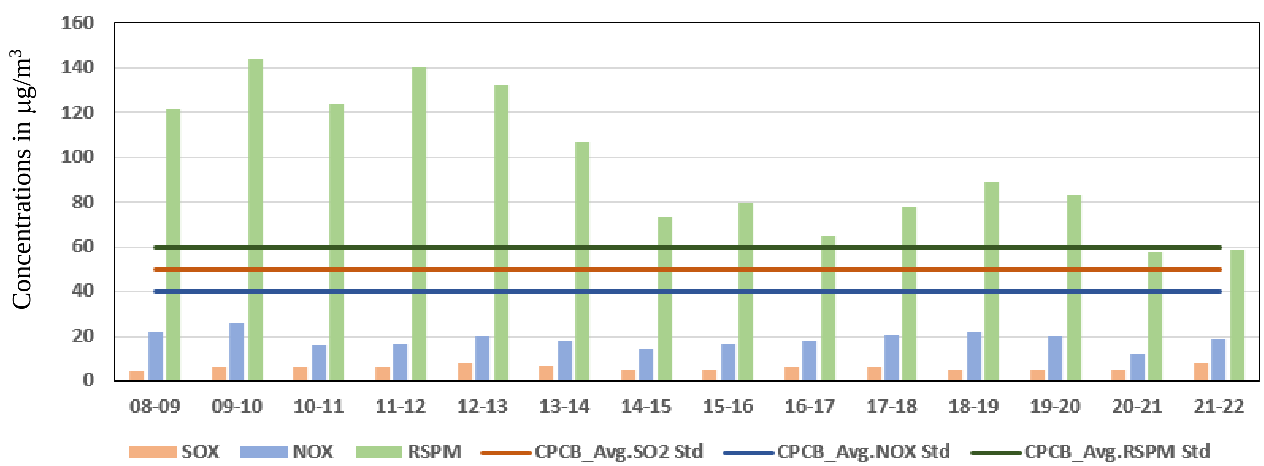
Station Code	Station name	Type	Latitude	Longitude
641	MIDC Water Works - Latur	Industrial	18° 24' 53.0" N	76° 32' 49.4" E
642	Shyam Nagar-Kshewraj Vidyalaya	Residential	18° 24' 21.6" N	76° 33' 50.2" E
643	Ganj Golai - Sidhheshwar Bank	Rural and other areas	18° 23' 58.0" N	76° 35' 02.6" E



MIDC Water Works –Latur (Industrial)



Shyam Nagar- Kshewaraj Vidyalaya– (Residential)



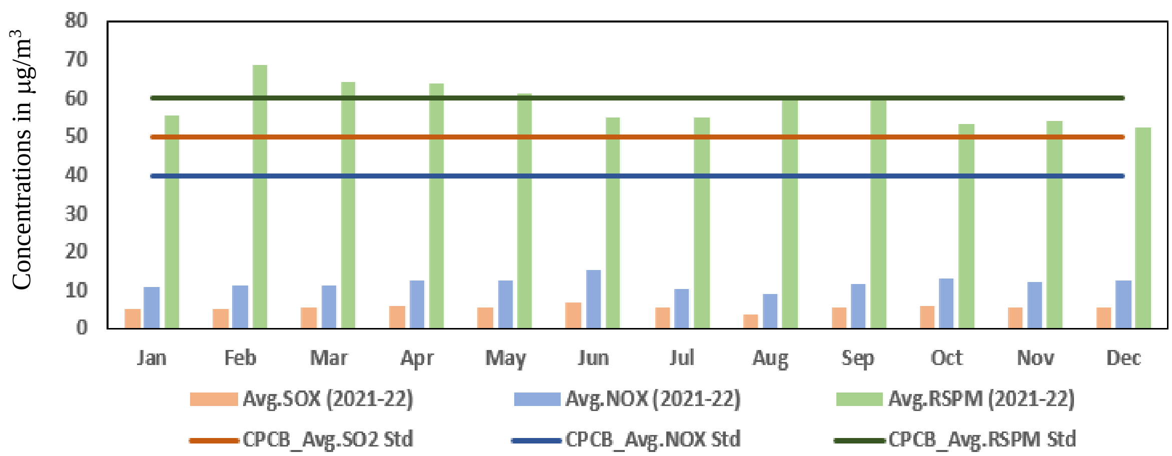
Ganj Golai - Sidhheshwar Bank- (Rural & Other)

Figure 2.1: Trend of Annual Average Concentrations of Different Pollutants During (2009-2022) at NAMP Stations

The three NAAQM stations established by the MPCB in Latur city are located in areas with distinct land use patterns. The MIDC Water Works - Latur site is predominantly industrial, with adjacent commercial and residential areas. The Shyam Nagar - Kshewraj Vidyalaya site is primarily residential, with a mix of commercial activities nearby. The Ganj Golai - Siddheshwar Bank site is predominantly rural, characterized by agricultural activities, with some commercial establishments in the vicinity.

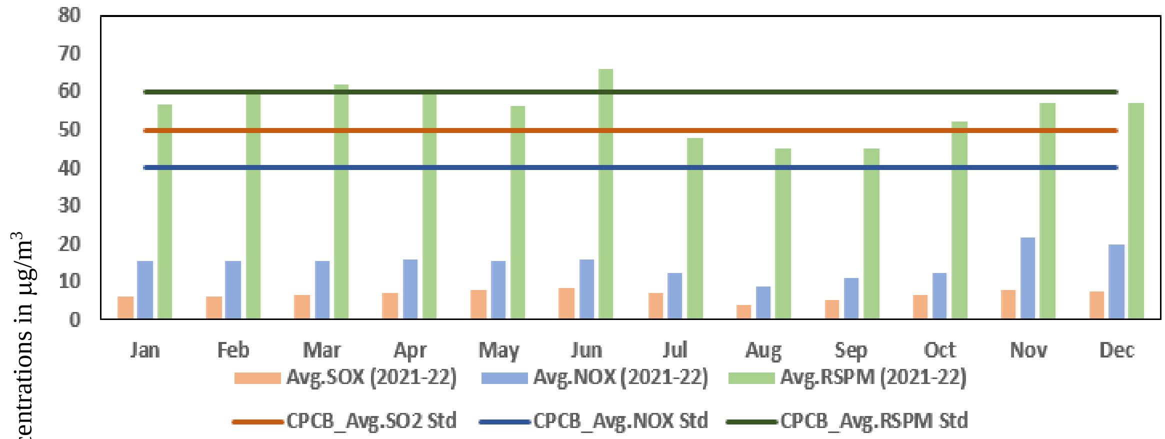
- At all three sites, annual average concentration was reported as (6-7; 17-19; and 80-97 µg/m^3 for SOx, NOx, and RSPM respectively for given years.
- The average RSPM levels were found to be elevated from 2009 to 2013 at the Shyam Nagar and Ganj Goli stations, with a decreasing trend observed after 2013. In contrast, at the MIDC Water Works site, RSPM concentrations were reported in the range of 76 to 87 µg/m³. The highest RSPM concentrations recorded during 2009-2012 were 144 µg/m³ at Ganj Goli (Rural and Other), 139 µg/m³ at Kshewraj Vidyalaya (Residential), and 99 µg/m³ at MIDC Water Works (Industrial), after which a declining trend was noted. At all monitoring sites, RSPM concentrations consistently exceeded the annual average standard of 60 µg/m³.

The monthly variation trends of above mentioned NAAQM station for the year 2021 -2022 are presented in **Figure 2.2**.

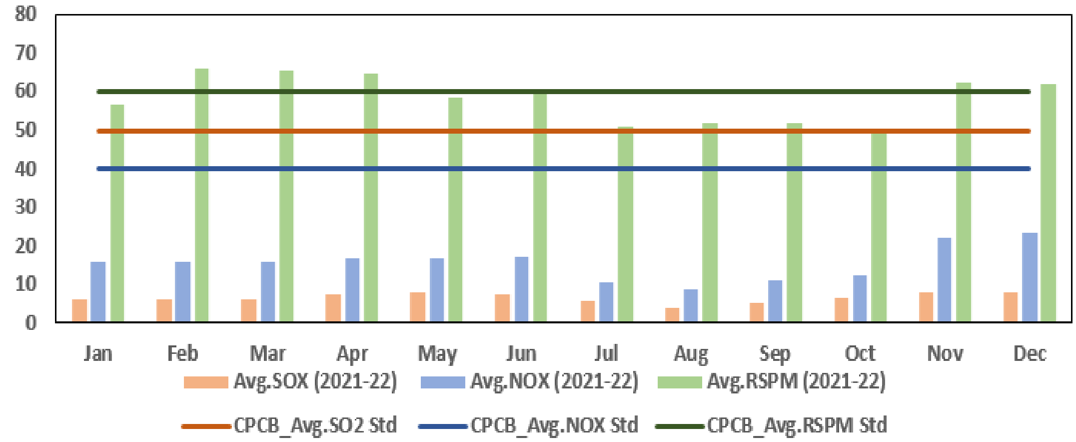


MIDC Water Works –Latur (Industrial)

Figure 2.2: Monthly Variation Trend of Different Pollutants During (2021-2022) at NAMP Stations



Shyam Nagar- Kshewaraj Vidyalaya– (Residential)



Ganj Golai - Sidhheshwar Bank – (Rural & Other)

Figure 2.2 (Contd..): Monthly Variation Trend of Different Pollutants During (2021-2022) at NAMP Stations

- The monthly averages indicate a significant increase in RSPM concentrations during April and May, with values recorded at MIDC Water Works ranging from 124-126 µg/m³, Shyam Nagar from 109-121 µg/m³, and Ganj Golai from 100-120 µg/m³, all exceeding the NAAQM standard for RSPM of 60 µg/m³. A declining trend in RSPM concentrations was observed during the monsoon and post-monsoon seasons. However, a subsequent rise in RSPM levels was noted during the winter season, with concentrations increasing in range by 82-93 µg/m³.
- At all sites, the average monthly concentrations of SOx and NOx were reported to range from 5-7 µg/m³ and 16-22 µg/m³, respectively, both of which are below the CPCB standard limits.

Figure 2.3 AQI Class percentage exceedance of parameters for the years 2021-22, indicates that the exceedance for RSPM at MIDC Waterworks, Shyam Nagar, and Ganj Goli stations were 21%, 18%, and 17% respectively. At MIDC Waterworks, Latur, Shyam Nagar Kshewraj Vidyalaya, and Ganj Golai Siddheshwar Bank more than 75% of observations were Satisfactory AQI, and almost only 4% observations were under the Good category and the remaining observations were Moderate AQI.

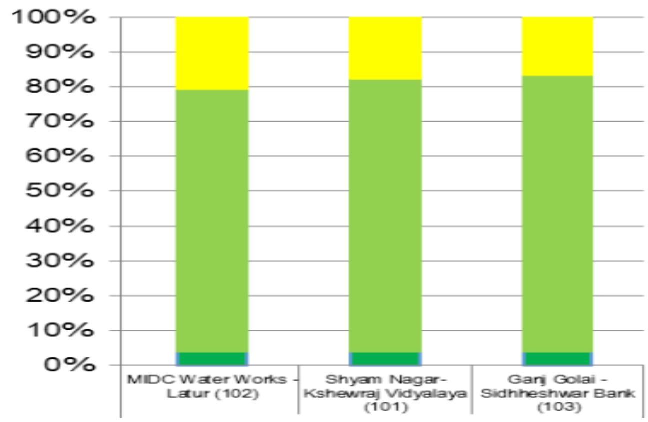


Figure 2.3 Percentage Occurrence for Classes of AQI across Latur NAAQM station (2021-2022)

2.2 Monitoring Sites

Population density, climatology, topography, and other factors all have a role in air quality monitoring design and assessment. The monitoring stations were chosen based on region demography, consideration of activities, and standard sampling procedure. The representative three sampling sites were selected i.e. Residential at Moti Nagar, Traffic in the vicinity near the Tehsildar Office, and the Industrial site at MIDC Office area in Latur city area. The study area is presented in **Figure 2.4** and site characteristics are:

- As per filed observations the Moti Nagar (Residential) area having stubble burning and demolition of house was reported during sampling. Latur bypasses the road on the southern side 600 m (aerial distance) away and 400 m aerial distance on the east side market area where truck movement was observed.
- Traffic site sampling was carried out at the terrace of the Tehsildar office, MG Road which is the major road of the city. Road condition is good (2+2 lane) but unpaved shoulder. The area near 600 m is Shivaji Chowk which is an important junction where four highways meet (Latur - Ambajoai, Ausa, Nanded, and Barshi). Shivaji Chowk has a layered traffic system. One bridge, One underpass, and a road on ground level. There were 3-4 tandoors noticed in the vicinity of 500 m and many hotels in this area. Old railway line road runs parallel to MG road (50 m) which acts as an alternative for MG road and has a significant amount of Traffic.

- The Industrial site is located at the MIDC Office where several industries are located, dal mill plot existed next to the MIDC office and was working throughout the monitoring. Dal Mill dominated MIDC approximately 35-40 units are present. There were two solvent extraction plants (Soyabean to oil), an Edible oil refinery, and one Dairy. The Fabrication plant for pipe, paver blocks, and granite and stone cutting shops were also located. Approximately 10-11 stacks were noticed around the area.

Sr.	Site Name	Type	Latitude	Longitude
1	Moti Nagar	Residential	18° 23' 28.060" N	76° 34' 38.283" E
4	Tehsildar Office	Traffic/Kerbside	18° 23' 53.865" N	76° 34' 5.552" E
2	MIDC office area	Industrial	18° 24' 42.505" N	76° 32' 48.685" E

Figure 2.4: Air Quality Monitoring Locations During Study Period in Latur City

2.3 Measurement and Frequencies

Air quality was monitored following CPCB guidelines, with details of the chemical analysis methods given in **Table 2.1**. Portable air samplers (Airmetric) were used to measure PM_{10} and $PM_{2.5}$. At each site, four samplers were set up to collect both types of particles on two kinds of filters (Teflon and Quartz). The sampling process considered two things: (i) collecting enough particles for accurate analysis, and (ii) avoiding too much build-up on the filters, which could cause issues with airflow. The equipment had a constant flow control and tracked the sampling time.

A flow rate of 5.0 litres per minute was ideal, allowing about 7.2 cubic meters of air to be sampled in 24 hours, with the total collected mass staying below 1500 µg. Monitoring was carried out for 24 hours at each site from 23 Jan to Feb 1, 2021.

Table 2.1: Target Physical and Chemical Components (groups) for Characterization

<table>
<tr><th>Particulate Matter for Source Apportionment</th><th colspan="2">$PM_{2.5}$</th><th>OC/EC</th><th>Element /Ions</th></tr>
<tr><td>Sampling Instrument</td><td colspan="2">Air Metric MiniVol Portable Sampler</td><td>Particulate collected on Quartz filter paper</td><td>Particulate collected on PTFE Filter paper</td></tr>
<tr><td colspan="3">Sampling Principle</td><td colspan="2">Inertial impaction</td></tr>
<tr><td colspan="3">Flow Rate</td><td colspan="2">5 LPM</td></tr>
<tr><td colspan="3">Sampling Period</td><td colspan="2">24-Hour</td></tr>
<tr><td colspan="3">Sampling Frequency</td><td colspan="2">Total 5 days; using Quartz and PTFE Filter Simultaneously</td></tr>
<tr><td>Analytical Instrument</td><td>Electronic Microbalance</td><td>Electronic Microbalance</td><td>OC/EC Analyzer</td><td>Ion Chromatography (Ions) and ED-XRF (Elements)</td></tr>
<tr><td>Minimum Reportable Value</td><td>5 µg/m^3</td><td>5 µg/m^3</td><td>0.2 µg/ 0.5 cm^2 Punch</td><td>NA</td></tr>
</table>

Components	Required Filter Matrix	Analytical Methods
$PM_{2.5}$	Teflon (PTFE) filter paper. Pre and post-exposure conditioning of filter paper is mandatory.	Gravimetric
Elements (Na, Mg, Al, Si, P, S, Cl, Ca, Br, V, Mn, Fe, Co, Ni, Cu, Zn, As, Ti, Ga, Rb, Y, Zr, Pd, Ag, In, Sn, La Se, Sr, Mo, Cr, Cd, Sb, Ba, Hg, and Pb)	Teflon (PTFE) filter paper	ED-XRF
Ions (Na^+, NH_4^+, K^+, Mg_2^+, Ca_2^+, F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-}	Teflon (PTFE) filter paper (Same Teflon filter paper can be utilized if ED-XRF is used for elements analysis)	Ion chromatography with conductivity detector
Carbon Analysis (OC, EC, and Carbonate Carbon)	Quartz filter. Prebaking of quartz filter paper at 600 ºC is essential	TOR/TOT method

2.4 Monitoring Results

Air quality results at three sites in terms of PM_{10} and $PM_{2.5}$ concentrations which was compared with the NAAQM Standard are given in **Figure 2.5**.

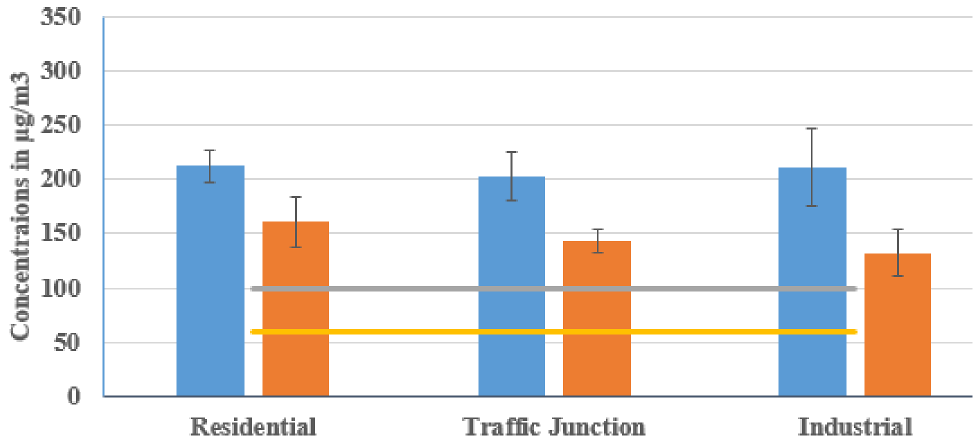


Figure 2.5: PM_{10} and $PM_{2.5}$ Concentrations Concerning NAAQM Std. at Monitoring Sites

- The average ambient concentration of $PM_{2.5}$ and PM_{10} is 146 and 209 µg/m^3 respectively reported for Latur. It can be seen that PM_{10} and $PM_{2.5}$ concentrations violated the CPCB threshold (100 and 60 µg/m^3) during the entire study period at all the sites. $PM_{2.5}/PM_{10}$ ratio is 0.7 which suggests the dominance of combustion activities at the sampling sites. A high ratio generally suggests the presence of combustion activity at or near the site. The exceedance of RSPM above the regulatory limit value indicates the non-attainment.
- The concentrations range from 184 to 239 µg/m^3 reported for PM_{10} with an average of 213 µg/m^3 at the residential site (Moti Nagar),
- whereas it was 181 to 242 µg/m^3 at the Traffic Junction (Tehsildar Office) area with an average of 203 µg/m^3.
- The average concentration of PM_{10} at the Industrial site (MIDC Office Area) was 211 µg/m^3 and concentration varies between 154 to 256 µg/m^3.
- A similar trend was observed for $PM_{2.5}$; the average concentrations of 161, 144, and 132 µg/m^3 were measured at residential, traffic junction, and industrial sites respectively. The concentrations ranged between (121-199 µg/m^3; 125-158 µg/m^3 and 94-166 µg/m^3) at Moti Nagar, Tehsildar Office, and MIDC Office Area respectively.

At all the locations, the reported concentrations exceeded the reported trend observed by the pollution control board and were above the permissible CPCB limits.

Chapter 3

Emission Inventory

3. Emission Inventory

An air emission inventory systematically compiles emissions from anthropogenic and biogenic sources, classified into point, area, and line (mobile) categories. The emission inventory offers robust estimates of total pollutant emissions, detailing their spatial and temporal distributions while identifying and characterizing primary sources. This data is essential for air quality modelling, supporting the development of effective strategies and policies for air quality management.

3.1 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, emissions inventories help to identify the emission sources and estimates their contribution to total emissions in the region. This information eventually guides 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. In addition to the above, it has been used as one of the important fundamental components in the dispersion modelling application. No emission inventory for Latur district is available till today.

3.2 Objective

The objective of the study is to develop a high-resolution (2 km X 2 km) emission inventory for Latur city for PM_{10}, $PM_{2.5}$, CO, NOx, SO_2, HC and NMVOCs.

3.3 Generation of Activity Data

The activity data consists of two types: (1) Primary Data and (2) Secondary Data, with the CSIR-NEERI team collecting both on sources. Primary data was gathered through detailed site-specific surveys conducted from 2018 to 2020. This data includes information on sources such as brick kilns, vehicular traffic, bakeries, hotels, open eateries, MSW burning, road dust, and construction activities. Field surveys, including road dust sampling at 10 locations, and satellite imagery were used for validation. The goal of collecting primary data was to enhance the accuracy and authenticity of secondary data and fill gaps in the existing information. Data collection sheets were developed to estimate emissions from various sources.

Secondary data was readily available from the respective offices and was collected. However, the available datasets contain limited information. For instance, corporations have data on hotels, restaurants, and bakeries but lack details on the type of fuel used. Targeting fuel reduction to lower pollution emissions would be easier with this information. Secondary data was gathered from all credible sources for the selected departments in the city. Data from industries with stacks and DG sets was obtained from the Maharashtra Pollution Control Board (MPCB), while vehicle registration data was sourced from the Vahan Dashboard of the Parivahan Portal. Other sources include the Census of India, CPCB portal, Public Works Department (PWD), toll plaza data, and MAHARERA, along with additional online resources.

3.4 Role of GIS

GIS plays a crucial role in emission inventory by creating maps of the city, road network, population by ward, and a 2 x 2 km grid **(Figure 3.1)**. This tool helps visualize emission impacts and implement control policies to reduce them. Geo-mapping of emissions aids in developing accurate inventories, which help track when and where emissions occur and identify ways to reduce or control them. These inventories are key to improving air quality in areas most affected by pollution.

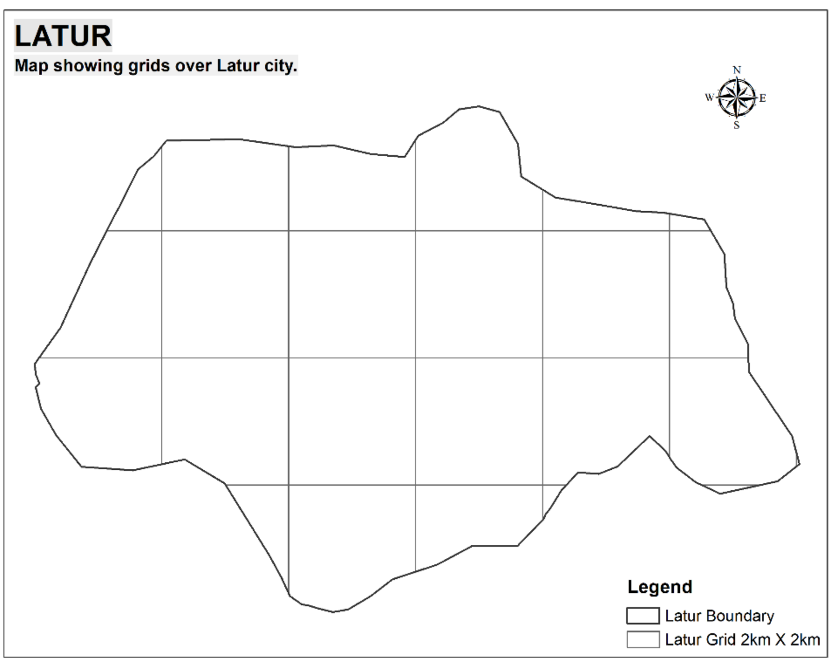


Figure 3.1: 2 x 2 Km grid Over Latur City *(Source: ArcGIS, CSIR-NEERI, Nagpur)*

3.5 Emission Factor

An emission factor (EF) is a representative value that links the quantity of a pollutant released to the atmosphere with an activity associated with its release. These factors, usually expressed as the mass of pollutant per unit of raw material, volume, distance travelled, or activity duration (e.g., grams of particulate emitted per kilogram of coal burnt), help estimate emissions from various pollution sources. Typically, EFs are based on average data of acceptable quality, representing long-term averages for all facilities within a source category. EFs vary depending on the chemical composition of fuel, combustion type, temperature, and efficiency of emission control devices. However, country-specific technology-based EFs are not widely available for India. Therefore, in developing emission inventories, factors are often sourced from reports by the Central Pollution Control Board (CPCB), Automotive Research Association of India (ARAI), United States Environmental Protection Agency (USEPA) Air Pollution (AP)-42, and studies by CSIR-NEERI for different Indian cities.

Emissions are estimated by using the basic Eq. 1

$$Emission = \sum activity\ data\ x\ emissions\ factor\ x\ control\ efficiency\ x\ percentage\ of\ units\ controlled$$

3.6 Vehicular (Line) Source Emissions

As urban populations grow, the demand for transportation rises, leading to an increase in the number of vehicles on the road. The migration from rural areas to urban centers concentrates both population and economic activities in cities, which intensifies commuting needs. Economic growth further fuels vehicle ownership as individuals and businesses invest in personal and commercial vehicles. Inadequate public transportation systems often push people to rely on private vehicles, exacerbating road congestion. Poor urban planning, sprawling cities, and insufficient infrastructure contribute to longer commutes and higher vehicle usage. Additionally, societal attitudes, the rise of ride-sharing, and the affordability of personal vehicles further increase traffic, especially when cities lack viable alternatives like walking, cycling, or efficient public transit.

Estimating emissions from mobile sources requires digitizing the road network map to analyse traffic density and road patterns. Latur city has a well-developed road infrastructure, with a total network of 1,008 kilometres, including major, minor, state, district, and national highways, supporting efficient connectivity (**Figure 3.2).**

Latur city experiences significant traffic due to its connectivity to key highways. National Highway 65 (NH-65) connects the city to Solapur, Pune, and Hyderabad, facilitating the transport of agricultural and industrial goods. National Highway 161 (NH-161) links Latur with Nanded, Parbhani, and Hingoli, supporting the movement of crops like soybeans and cotton. State Highways 2, 6, and 138 further contribute to congestion, as they connect Latur to Aurangabad, Osmanabad, and Solapur, facilitating the flow of agricultural products and industrial goods to and from the city's markets. These routes are vital for regional trade, making them key traffic corridors.

Latur city also faces heavy traffic due to key roads passing through its commercial and residential zones. Latur-Mumbai Road is a major route connecting the city to Mumbai, passing through commercial areas and markets. Shivaji Chowk, near Sadar Bazar and Zilla Parishad Chowk, is a traffic hotspot due to its central location and proximity to local businesses and the MIDC area, which supports industrial activities. Latur-Ausa Road experiences significant intercity traffic, while Baba Chowk and Shastri Nagar face congestion due to nearby local businesses, schools, and residential areas. Sambhaji Nagar Road, near College Road, sees heavy traffic due to its proximity to colleges, hospitals, and commercial establishments. Latur is well-connected by rail through Latur Junction, with trains linking it to major cities like Mumbai, Pune, and Hyderabad. The Latur Bus Stand provides road access to nearby towns and cities via MSRTC and private buses, and both the railway station and bus stand are easily reachable from each other by local transport.

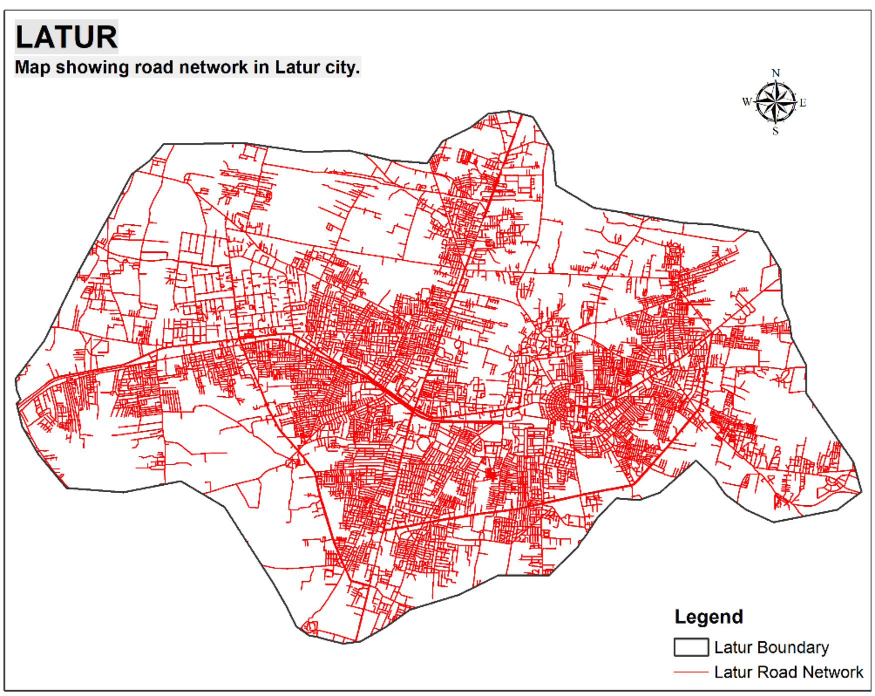


Figure 3.2: Road Network of Latur City

3.6.1 Vehicular Count

Bharat Stage VI engine technology was introduced in India in April 2020, replacing the Bharat Stage IV technology that had been in use from April 2017 to March 2020. In Latur city, the distribution of vehicles with various engine technologies was estimated using a combination of a parking lot survey and data from the transport department. Manual vehicle counts were conducted along selected road networks in 2019, supplemented by the analysis of CCTV footage from both government and private agencies. Vehicle kilometres travelled were calculated using GIS tools to estimate gridded road length. To assess grid-wise vehicular emissions, vehicle counts were conducted at 15 key locations along major traffic corridors, while road width, length, and traffic intensity were also analysed to identify hotspots and major sources of emissions. The data collected was then used to estimate vehicular emissions per hour and mapped to its corresponding grid position. The number of registered vehicles till April 2023 is shown in the **Table 3.1.**

Table 3.1: Number of Registered Vehicles in Latur city upto April 2023

No.	Vehicle Category	BS I	BS II	BS III	BS IV	BS VI	Total
1	Two Wheelers	447	757	1,90,401	67,375	1,17,043	3,76,023
2	Three Wheelers	24	233	4,135	3,529	3,704	11,625
3	Four Wheelers	425	2,176	52,907	12,428	23,685	91,621
4	Light Duty Vehicles	16	43	999	773	1,077	2,908
5	Heavy Duty Vehicles	18	134	7,863	86	69	8,170
6	**Total**	**930**	**3,343**	**2,56,305**	**84,191**	**1,45,578**	**4,90,347**

No.	Vehicle Category	CNG	Diesel	LPG	Petrol	EV	Total
1	Two Wheelers	0	0	0	3,72,658	3,365	**3,76,023**
2	Three Wheelers	3,268	2,741	2,303	3,224	89	**11,625**
3	Four-Wheeler	651	60,556	1,566	28,748	100	**91,621**
4	Light Duty Vehicles	2	2,137	55	714	0	**2,908**
5	Heavy Duty Vehicles	38	8,132	0	0	0	**8,170**
6	**Total**	**3,959**	**73,566**	**3,924**	**4,05,344**	**3,554**	**4,90,347**

Source: Vahan Sewa dashboard

Grid wise emission inventory preparation includes the following procedural steps:

- Division of study area into grids of 2 Km X 2 Km size
- Identification of major nodes which represent major traffic junctions
- Calculation of road length between the nodes and estimation of grid-wise road length
- Collection of data on number and type of vehicles traveling between nodes through field studies
- Estimation of vehicle kilometers (Km) traveled by each type of vehicle in each grid

$$VKTI = RLj * NI$$

Where, VKTI = Vehicle Km traveled by vehicle type I,
RLj = Road length in grid j
NI = Number of vehicles travelling between nodes for vehicle type I per day,

- Selection of appropriate emission factors from the ARAI vehicle emission study.
- Estimation of emissions from each grid m

$$PMj = N * \sum_{j=1}^{m} VKTI * Ef_I$$

Where, PMj = Pollutant load in tones/year for grid j
N = Number of activity days in a year
Ef_I = Emission factor for a vehicle type I

Emission factors provided by ARAI are utilized to estimate vehicular emission loads. Considering that vehicles within the same category use different types of fuel, it is assumed that 55% of the vehicles use diesel and 45% use petrol. (Reference: "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).

3.6.2 Emission Factors

Emissions from the on-road vehicles depend mainly on the type of vehicle and fuel used in the vehicle. ARAI, Pune has made available the emission factor for vehicular emission load estimation. This EF are used to estimate the emission load from transport sector. All Bharat Stage norms implemented in the state of Maharashtra are used for estimation **(Table 3.2)**.

Table 3.2: Emission Factors Considered for Emissions Estimation

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

Table 3.2 *(Contd..)*: Emission Factors Considered for Emissions Estimation

Emission Factor for BS-IV Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2-Wheeler	0.1	0.1	0.13	1.81	g/km
2	3W_Petrol	0.035	0.5	0.3	0.75	g/km
3	3W_Diesel	0.035	0.5	0.3	0.75	g/km
4	4W_Petrol	0.08	0.1	0.1	1.00	g/km
5	4W_Diesel	0.08	0.1	0.1	1.00	g/km
6	HDV	0.06	0.39	0.42	0.74	g/km
Emission Factor for BS-VI Stage Engine						
No.	**Vehicular Type**	**PM**	**NOx**	**HC**	**CO**	**Unit**
1	2-Wheeler	0.0045	0.090	0.068	0.50	g/km
2	3W_Petrol	0.0250	0.100	0.100	0.22	g/km
3	3W_Diesel	0.0045	0.080	0.100	0.50	g/km
4	4W_Petrol	0.0045	0.060	0.100	1.00	g/km
5	4W_Diesel	0.0045	0.080	0.100	0.50	g/km
6	HDV	0.0100	0.080	0.100	0.50	g/km

Source: Indian Clean Air Pregame (ICAP), Automotive Research Association of India (ARAI), 2007

3.6.3 Emission Load

The emission load from transport sector in the city is provided in the **Figure 3.3.** The PM_{10}, $PM_{2.5}$, SO_2, NO_x and NMVOCs/HC emissions from transport sector in city are 293, 263, 117, 2412 and 6364 kg/day, respectively.

It was also observed that the inspection and maintenance program for vehicles, which primarily is implemented through PUC certification, was insufficient in the city. It is suspected that the emission load from plying of vehicles older than 15 years may be significant. Most of the heavy-duty vehicles are plying in the outskirt of the city area. Due to highways is passing through the city area the vehicles movement more within city mostly 2 wheelers and auto-rickshaw are observed contributing substantial vehicular pollution. The observed dust pollution was primarily attributed to the resuspension of road dust resulting from vehicular movement throughout the city.

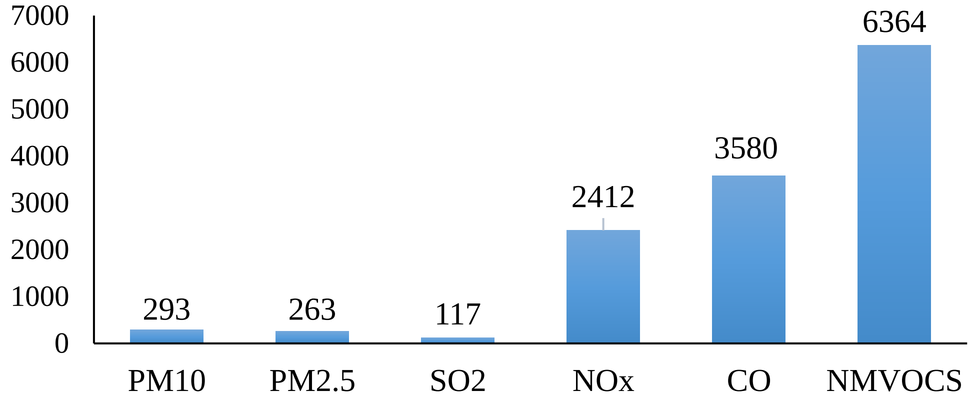


Figure 3.3: Emission Load from Vehicular Source (kg/day)

3.7 Industry (Point Source)

Latur city is allotted with three industrial areas under Maharashtra Industrial Development Corporation (MIDC) namely Latur Industrial Area; Additional Latur Phase I Industrial Area and additional Latur Phase II Industrial Area. Out of these industrial areas, nearly 50 % of the industrial area comes under municipal limits. The additional industrial clusters are located out of municipal corporation boundary. Industries located inside the municipal boundary are segregated based on air polluting industries. Air polluting industries are those industries which have a stack to release pollutants into atmosphere and who are using diesel generator (DG) sets in case of power failure. Industries such as edible oil, sugar factories, agro products etc. are seen into operation at Latur city. Latur city is the largest trading hub for Soyabean, therefore large number of edible oil plants are located. The fuel and process data for each industry is collected form concerned pollution control board office. **Table 3.3** gives the quantity and type of fuel used in industries in Latur MIDC region

Table 3.3: Quantity of Fuel Consumption in Industries at Latur

Fuel	Quantity	Unit
Bagasse	16.13	Ton/Day
Briquettes	7.31	Ton/Day
Coal	11.525	Ton/Day
Diesel	2.9	KL/Day
FO	14	KL/Day
HSD	175	KL/Day
LPG	3800	Kg/Day
Wood	26	Ton/Day

The sector wise and fuel-wise emission factors were taken from CPCB national summary reports, old source apportionment studies report prepared by CSIR-NEERI and USEPA AP-42. The estimated daily emission loads for pollutants are approximately 399 kg for PM_{10}, 175 kg for $PM_{2.5}$, 245 kg for SOx, 612 kg for NOx, 2703 kg for CO, and 279 kg for NMVOCs **(Figure 3.4).**

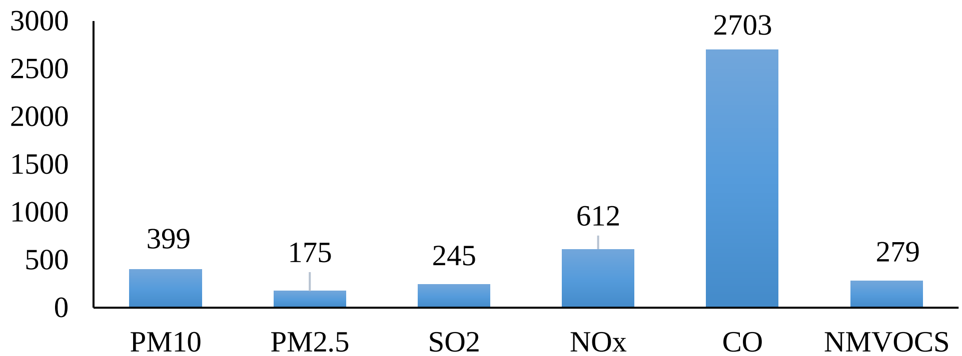


Figure 3.4: Emission Load from Point Source (kg/day)

3.8 Area Source Emissions

Latur city has rapidly urbanized over the past decade and a half, leading to high demand for quality civic infrastructure. Strained by issues like water shortages, traffic congestion, and pollution, Latur now seeks institutional and financial reforms to enhance resources, improve infrastructure, and attract investments. Area sources encompass emissions from numerous, diffuse sources that are challenging to quantify individually, including residential and commercial sectors. To assess these emissions, the region was partitioned into 2 km x 2 km grids, integrating factors such as population density and sector-specific fuel consumption patterns from crematories, hotels, outdoor eateries, restaurants, and bakeries. Fuel consumption data (coal, kerosene, wood, and LPG) was gathered by the Municipal Corporation and surveys in 2021. Using emission factors from the CPCB, emission loads were calculated. Additionally, emissions from construction activities, road dust resuspension, solid waste burning, stone crushing, and brick kilns were incorporated. This comprehensive data set enables analysis of cumulative emissions from these dispersed sources.

3.8.1 Bakery

Baked products are an essential item in urban areas. These units are operated in all parts of the city. But there are very few units which are manufacturing the baked products and are generally located near the industrial areas. Through survey, it is found that there were 5 number of units who are actually baking the products and supplying to other bakeries for selling. Considering the operation of bakeries, it was observed the fuel consumption pattern is of mixed nature. Consumption of LPG and coal as fuel in manufacturing process is seen in bakeries. Through survey it was observed, mostly bakeries operate for 12-16 hours per day and the peak season of business is during festivals. The annual consumption of LPG bottles of 19 kgs was 260 numbers and the coal/wood consumption was reported as 500 kg/year. In case if LPG is not available, the coal/wood is being used for baking items. The data of number of bakeries in operation was obtained from LMC and through survey fuel consumption information was collected. The emission load from bakeries is depicted in **Figure 3.5**. The emissions are estimated using the below eq.

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

The emission load from bakeries for PM_{10}, $PM_{2.5}$, SO_2, NOx, CO and NMVOCs/HC and is estimated to 6, 3, 13, 69. 91 and 264 kg/day respectively.

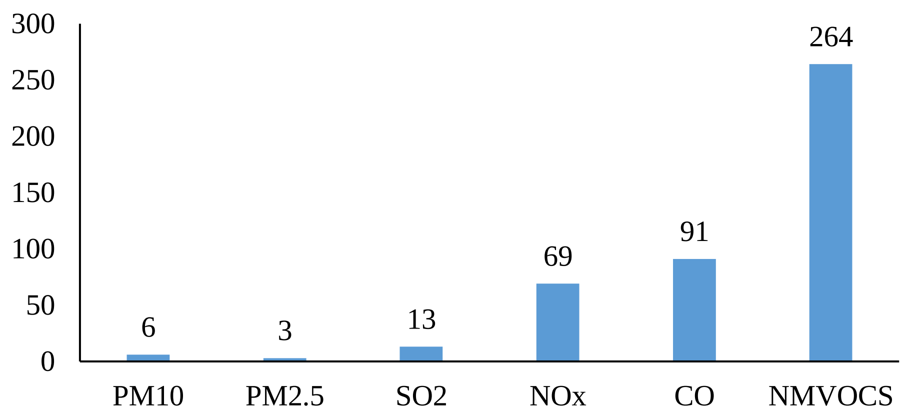


Figure 3.5: Emission Load from Bakeries (kg/day)

3.8.2 Domestic Sector

Latur is the largest trading centre for soyabean in India. The total population of Latur city in 2019 was approximately 5 lakhs. The number of households in 2011 were 59,329 which raised to 81,047 in year 2019. The total number of households residing in slum areas is 16,880 households. As reported by the ULB, the monthly consumption of the domestic gas for Latur city is 1088 tons which is equal to 80,000 LPG domestic bottles (cylinders) per month. Due to implementation of Pradhan Mantri Ujjawala

Yojana (PMUY), the use of LPG has increased in slum areas also. This has reduced fossil fuel consumption in these areas.

Emission Estimation
PM emission load from LPG = Nos. of LPG cylinders consumed x Capacity of the cylinder (14.6 Kg) x EF (Kg/T)
Total emissions (PM) from Kerosene = Nos. of households x kerosene consumption (tons/day) x emission factor (Kg/T

The overall emission load from domestic sector is found to be 16, 8, 1, 136, 151 and 1825 kg/day for PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO and NMVOCs respectively and emission load is shown in **Figure 3.6.**

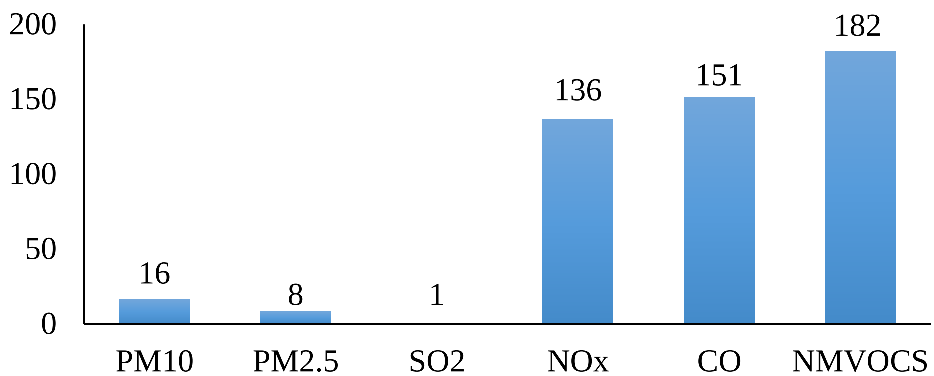


Figure 3.6: Emission Load from Domestic Sector (kg/day)

3.8.3 Open Eat outs, Hotels and Restaurants

The hotel and restaurant sector is well-established and organized, with data on location, names, and fuel consumption available from the Urban Local Body (ULB). This information was collected, and the team conducted visits to select restaurants for additional data gathering. Hotels and restaurants primarily use LPG cylinders and coal for cooking, with commercial LPG cylinders of 19 kg commonly employed. The primary survey indicated an average annual consumption of 500 LPG cylinders and 0.3 tons of coal per establishment. Typically, open eateries experience high traffic during weekday mornings and evenings, while hotels and restaurants are busiest on weekends.

Estimation of Emission Load Hotels & Restaurants
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).

In any city, open eat-outs are numerous and lack fixed locations, leading to significant variability in their numbers. Despite requiring minimal space, their fuel consumption is high. Due to limited registration data, local surveys were conducted to estimate the number of open eat-outs and gather information on daily or monthly fuel consumption. A majority (90%) use LPG, while others use coal and kerosene, with coal commonly used for grilling, tandoors, and roasting sweetcorn. Street vendors typically operate for around 12 hours daily, with a high concentration of unregistered and informal outlets near industrial and commercial zones.

Estimation of Emission Load from Open Eat outs

Total emissions = Emissions from LPG burning + Coal burning + Kerosene burning
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
Emission from kerosene burning (PM) per day
= Number of street vendors operating on kerosene x fuel consumption per day x EF

The overall emission load from domestic sector is found to be 14, 8, 1, 14, 30 and 4 kg/d for PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO and NMVOCs respectively and emission load is shown in **Figure 3.7.**

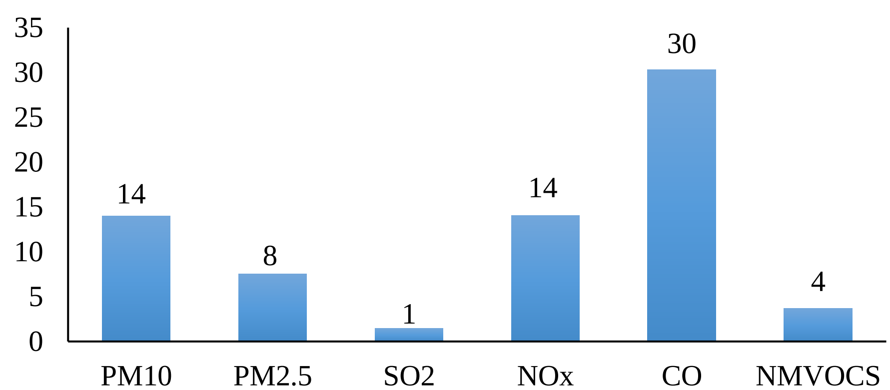


Figure 3.7: Emission Load from Open Eat outs, Hotels and Restaurants (kg/day)

3.8.4 Crematoria

The process of corpse cremation generates numerous harmful air pollutants, including particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs). These pollutants could have severe effects on the surrounding environment and human health. The energy source for the cremation is typically wood, diesel/ kerosene, cow dung cakes or natural gas. 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 lakes. There are total 4 wood-based crematories located in the city. In the year 2022, 6 to 8 dead-bodies were cremated daily. For cremating one dead body, 300-400 kg of wood, 5 litres of Kerosene /petrol, 10 kg of cow dung cakes are required *(CSIR-NEERI SA reports)*. The number of deaths occurred in a year data is collected from birth and death cell of municipal corporation. Based on the population and data collection from each crematorium, the emissions are estimated.

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

The emission load from Crematoria is estimated around 121, 67, 10, 163, 699 and 1754 kg/day for PM_{10}, $PM_{2.5}$, SO_2, NOx, CO and NMVOCs respectively **(Figure 3.8)**.

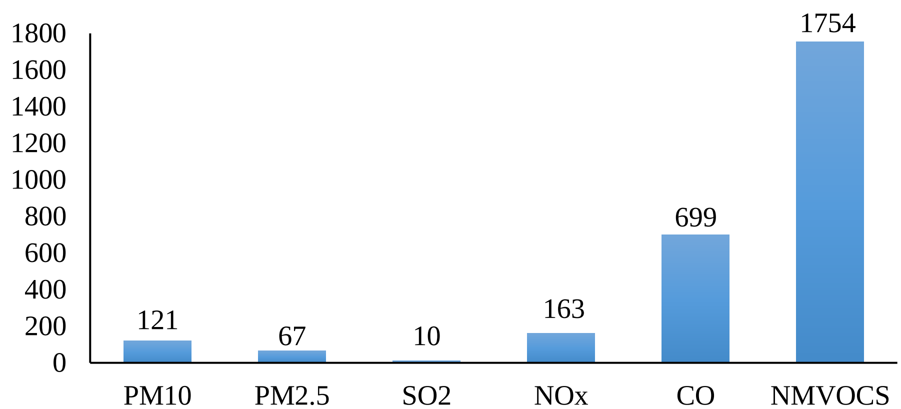


Figure 3.8: Emission Load from Crematoria (kg/day)

3.8.5 Building Construction & Demolition

As Latur city progresses towards smart city development, extensive infrastructural advancements are underway, leading to a surge in the real estate sector and the establishment of new commercial and residential complexes. Construction and demolition activities release fine dust particles and airborne contaminants, including particulate matter, into the atmosphere, with dispersal influenced by wind direction, affecting nearby neighbourhoods. These particulates can travel significant distances quickly, with emissions primarily generated during site preparation, plastering, painting, and cutting. Emission estimates require data on construction location, site area, and plot size, sourced from the MahaRERA portal and Urban Local Bodies (ULBs). In 2022, surveys and municipal data indicated 105 active construction sites exceeding 100 sq. ft, with each project typically lasting 8 months or more.

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 Municipal Office
- **Step 2:** Acres disturbed
- **Step 3:** Months of activity (Buildings construction activity = 8-12 months)
- **Step 4:** Acre x months of activity Buildings construction activity = 8 x total number of acres disturbed
- **Step 5:** PM_{10} Tons/years = 1.2 x total number of acre-months
  (AP42, Section 13.2.3.3– PM_{10} - 1.2 tones/ acres months).

The emission load from building construction sector for PM_{10} and $PM_{2.5}$ is 9 and 6 Kg/Day respectively.

3.8.6 Road Dust Resuspension

Road dust is generated through a combination of natural and anthropogenic processes, where vehicle movement and environmental conditions play significant roles. As vehicles traverse road surfaces, friction from tires leads to abrasion, releasing fine particles from the road material, including asphalt and concrete. Additionally, environmental factors such as rain and wind gradually erode road surfaces, breaking down materials into smaller, dust-like particles that can become airborne. Vehicle exhaust emissions also contribute particulate matter, with fine particles like soot and metals settling on roads. Brake and tire wear especially in drum brakes further add to the fine particulate load, enhancing the composition of road dust.

Construction and maintenance activities on and around roads are also key contributors to road dust, releasing particles through excavation, grading, and other mechanical processes. Nearby unpaved areas, agricultural land, and industrial sites can indirectly contribute to road dust through soil and particulate matter transported by wind or other means. In Latur city, the road network spans approximately 1008 kilometers, with 910 kilometers paved and 98 kilometers unpaved. Many of the paved roads lack continuous pavement along the edges, allowing dust from unpaved areas or settled particulates on paved surfaces to resuspend when disturbed by vehicle-induced turbulence.

Estimations of road dust emissions depend on the silt loading on paved surfaces and the mean weight of vehicles on the road, with road length calculated using GIS tools. High traffic density, particularly from two-wheelers, further contributes to particulate suspension as vehicles travel along these roads. Using a gridded approach to estimate Vehicle Kilometers Traveled (VKT), silt load values were adapted from a recent Nashik city study to estimate dust emissions for Latur. The silt loading was determined to be 0.756 g/m^2 for unpaved roads and 0.431 g/m^2 for paved roads, aiding in the assessment of particulate emissions due to road dust resuspension.

Emission Estimates:

Paved Road dust

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

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

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

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

(Source: NEERI Report-Mumbai, 2010)

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

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

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

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

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

Emission Estimation for Unpaved Dust

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

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

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

S=mean vehicle speed (mph);

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

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

C= Break and tire wear correction ($PM_{2.5}$=0.00036, PM_{10}=0.00047) - lb/VMT
a for $PM_{2.5}$=1, PM_{10}=1;
c for $PM_{2.5}$=0.2, PM_{10}=0.2;
d for $PM_{2.5}$=0.5, PM_{10}=0.5.
Emission from Unpaved Road (g/d)= E_Unpavd (g/VKT) x VKT (km/d)

The PM_{10} and $PM_{2.5}$ emission load from paved and unpaved road dust-resuspension in Latur city is estimated to 218 and 121 Kg/Day respectively.

3.8.7 Stone Crushers and Brick Kilns

There are 2 number of registered brick manufacturing units and 11 numbers of registered stone quarries in Latur city. There are stone crushers and brick kilns located outside the municipal boundary. Therefore, the emission load is not considered while estimating emission inventory.

3.8.8 Open Burning

The Municipal Solid Waste (Management and Handling) Rules, 2000 prohibit MSW littering in cities, requiring municipal authorities to establish infrastructure for waste collection, segregation, transportation, and disposal. Latur city generates around 120-150 MT of solid waste daily, primarily from residential, commercial, and market areas. Household waste makes up the largest share, around 50-70 MT/day, with organic waste, plastics, and paper being predominant. Commercial areas contribute 15-20 MT/day, while hotels and markets add another 40-50 MT/day, mainly organic material and packaging waste. Collection efficiency is about 85-90%, but some areas face lower efficiency, leading to 10-15% uncollected waste, which is often left on streets or burned, posing environmental and health risks.

In Latur, the waste composition is similar to other cities, with organic waste comprising 45-55%, including food scraps and vegetable peels. Plastic waste makes up 8-12%, mostly from single-use items, while paper and cardboard contribute 5-10%. Glass and metal account for 3-5%, and inert waste, such as construction debris, is around 3-5%. E-waste is minimal but increasing. To improve waste management, Latur has launched composting and recycling programs, focusing on reducing plastic use and promoting alternatives. The city is also investing in waste processing infrastructure, including composting units and recycling facilities.

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

The emission load from open burning is found to be 4, 2, 0.5, 2, 14 and 69 kg/day for PM_{10}, $PM_{2.5}$, SO_2, NOx, CO and NMVOCs respectively and shown in **Figure 3.9**.

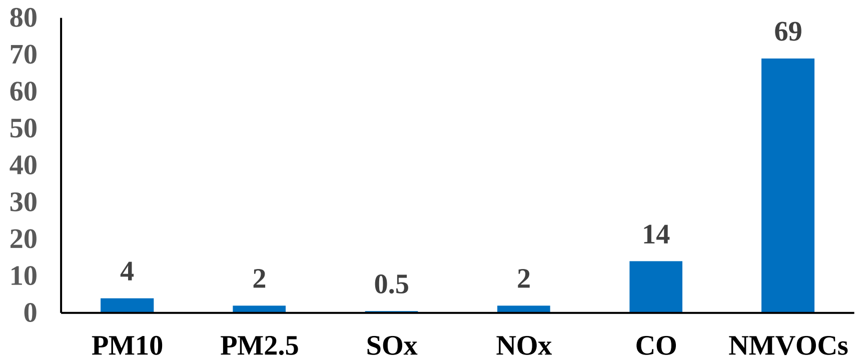


Figure 3.9: Emission Load from Open Burning (kg/day)

3.9 Total Emission Inventory (Latur City)

Cumulating all the emission loads from significant sources viz., Area, Point and Line sources for Latur city vide emission inventory is developed as shown in **Table 3.4**. The percent contribution for different pollutants in Latur city is depicted in **Figure 3.9 through 3.11**.

Table 3.4: Total Emission Load from All Sources (All Units in Kg/Day)

Sources	**PM_{10}**	**$PM_{2.5}$**	**NOx**	**SO_2**	**CO**	**NMVOCs /HCs**
Area Source						
Bakeries	6	3	69	13	91	264
Crematoria	121	67	163	10	699	1754
Domestic	16	8	136	1	151	182
Building Construction	9	6	0.0	0	0	0
Open Burning	4	2	0.5	2	14	69
Resuspension of Road Dust	218	121	0.0	0	0	0
Hotels. Restaurants and Open eat-outs	14	8	14	1	30	4
Line Source						
Vehicular Emissions	293	263	2412	117	3580	6364
Point Source						
Industries	399	175	612	246	2703	279
Total Emission Load (TPD)	**1080**	**653**	**3406.5**	**390**	**7268**	**8916**

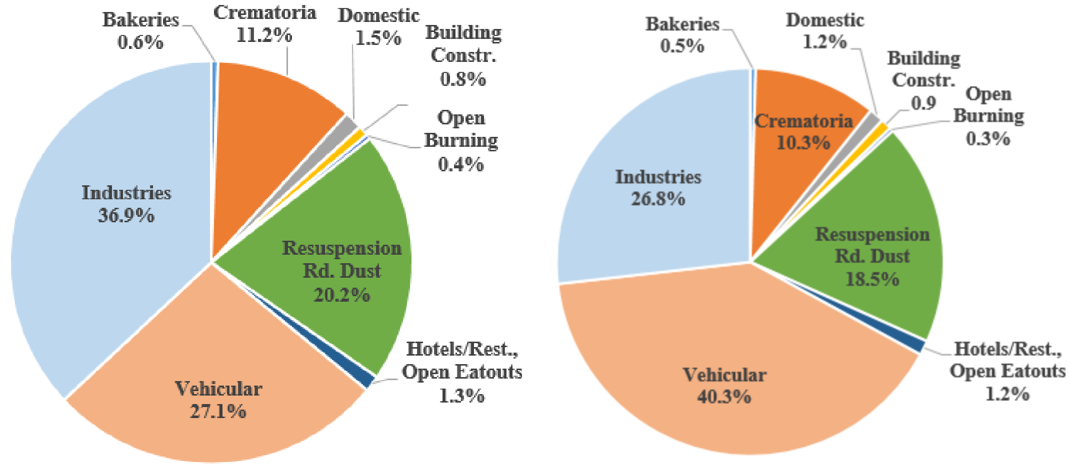
The total particulate matter (PM) emissions for PM_{10} are approximately 1080 kg/day, with primary contributions from point sources (36.9%) and line sources (27.1%). $PM_{2.5}$ emissions are estimated at approximately 653 kg/day, with line sources contributing 40.3% and point sources 26.8%. Road dust contributes to PM emissions, accounting for 18.5% for $PM_{2.5}$ and 20.2% for PM_{10}. Additional PM sources include crematoria, contributing roughly 10%. For NO_x, emissions are predominantly derived from line sources, which account for 70.8% (approximately 2412 kg/day) of the total 3406.5 kg/day from all sources. Industrial activities contribute 18% (612 kg/day), while crematoria and domestic cooking contribute 4.8% and 4%, respectively. The SO_x emissions are estimated at 390 kg/day, primarily from point sources (63%, or 246 kg/day) and line sources (30%, or 117 kg/day), with minor contributions (2-3%) from bakeries and crematoria. Lastly, CO emissions are predominantly from line sources (49.3%), as are hydrocarbons/non-methane volatile organic compounds (HC/NMVOCs) at 71.4%. Other sources of CO include industrial activities, contributing approximately 37.2%, while bakeries, crematoria, and domestic cooking contribute additional emissions.

3.10 Grid-wise Emission Inventory

To understand precisely, a detailed grid-wise emission inventory was created for the relevant pollutants, as shown in **Figures 3.12 to 3.17**. The sources used to estimate the emission loads included point, area, and line sources. This grid-wise data will be valuable for informing policy decisions aimed at significantly reducing air pollution.

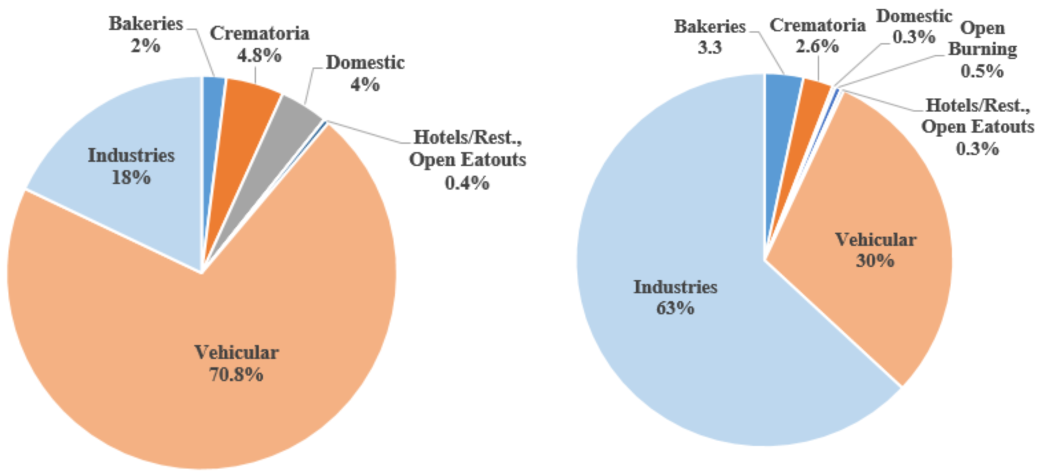
Conclusions

- Emission inventory results for Latur City for the year 2019-20 reveals that in the case of particulate matter (PM_{10} and $PM_{2.5}$) pollution, in a city, contributed by industrial sector, vehicular pollution and road dust resuspension.
- For SO2 emission load, 63% of the emission load is from industries is a major emitter.
- The NOx emissions are majorly from the mobile source contributing around 70%.
- The Carbon monoxide emission and HC is majorly from vehicular sources.
- The hotspots w.r.t to PM10 and PM2.5 are Latur industrial area, Mantri Nagar etc.



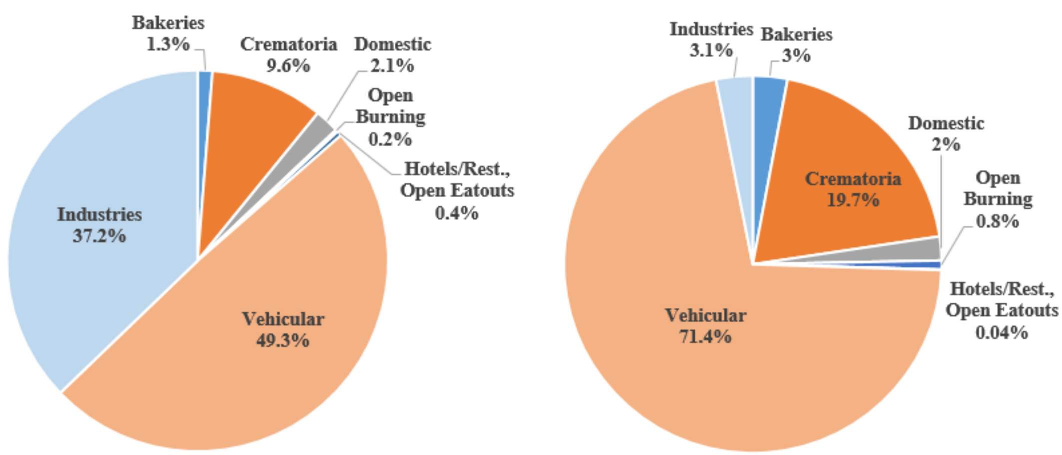
PM_{10} **$PM_{2.5}$**

Figure 3.9 : Sectoral PM_{10} and $PM_{2.5}$ Emission Load



NOx **SOx**

Figure 3.10 : Sectoral NOx and SOx Emission Load



CO **NMVOCs /HCs**

Figure 3.11 : Sectoral CO and NMVOCs /HCs Emission Load

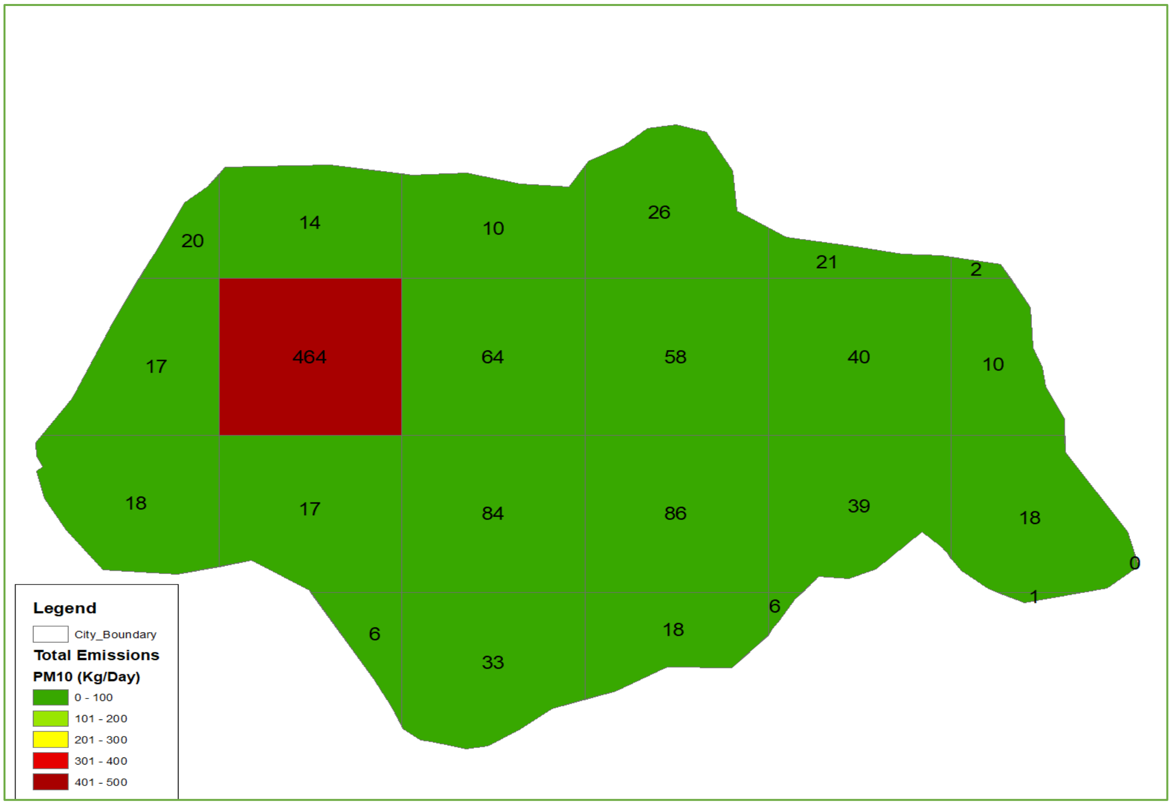


Figure 3.12: Total PM_{10} Emission Load for Latur City (kg/day)

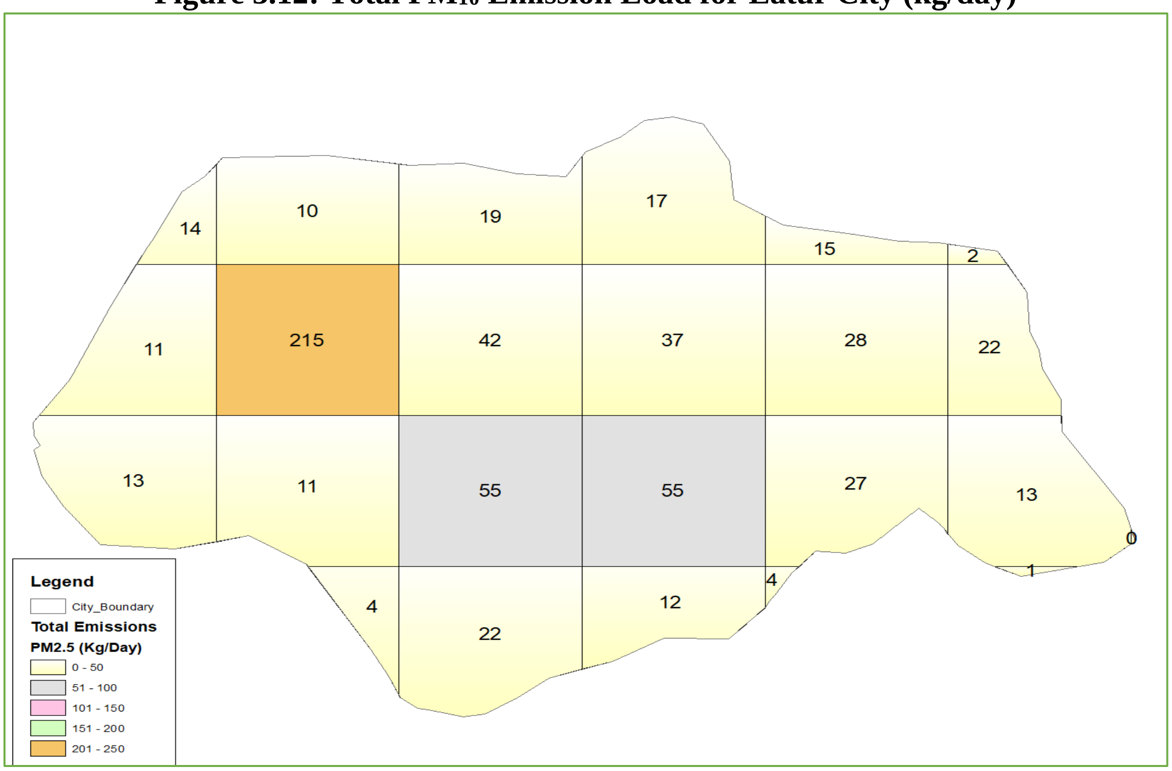


Figure 3.13: Total $PM_{2.5}$ Emission Load for Latur City (kg/day)

Figure 3.14: Total NOx Emission Load for Latur City (kg/day)

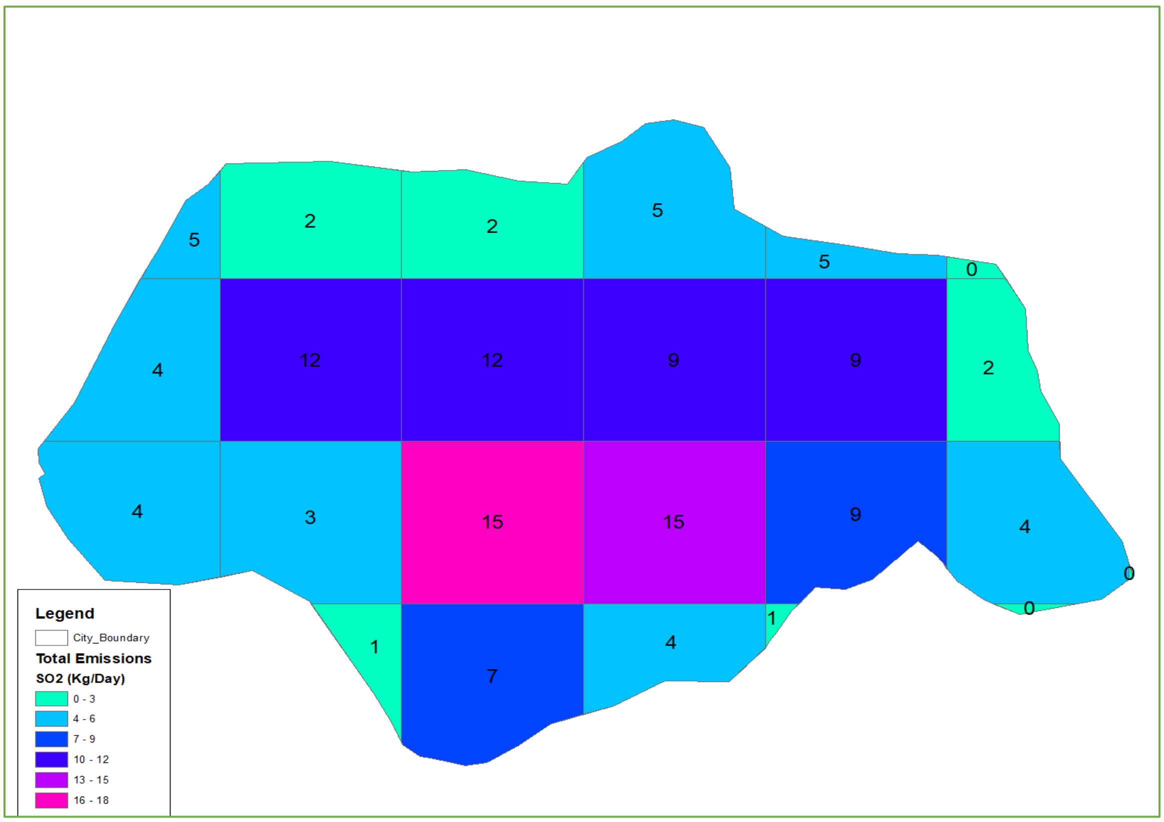


Figure 3.15: Total SOx Emission Load for Latur City (kg/day)

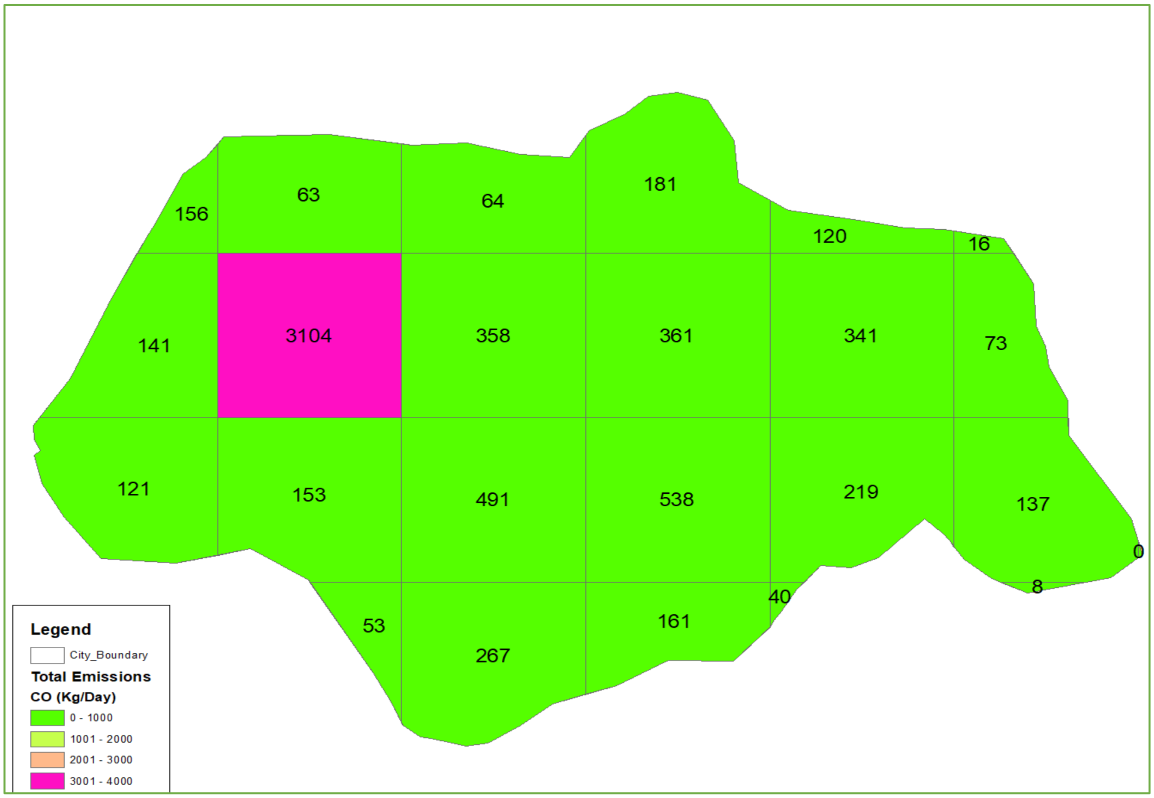


Figure 3.13: Total CO Emission Load for Latur City (kg/day)

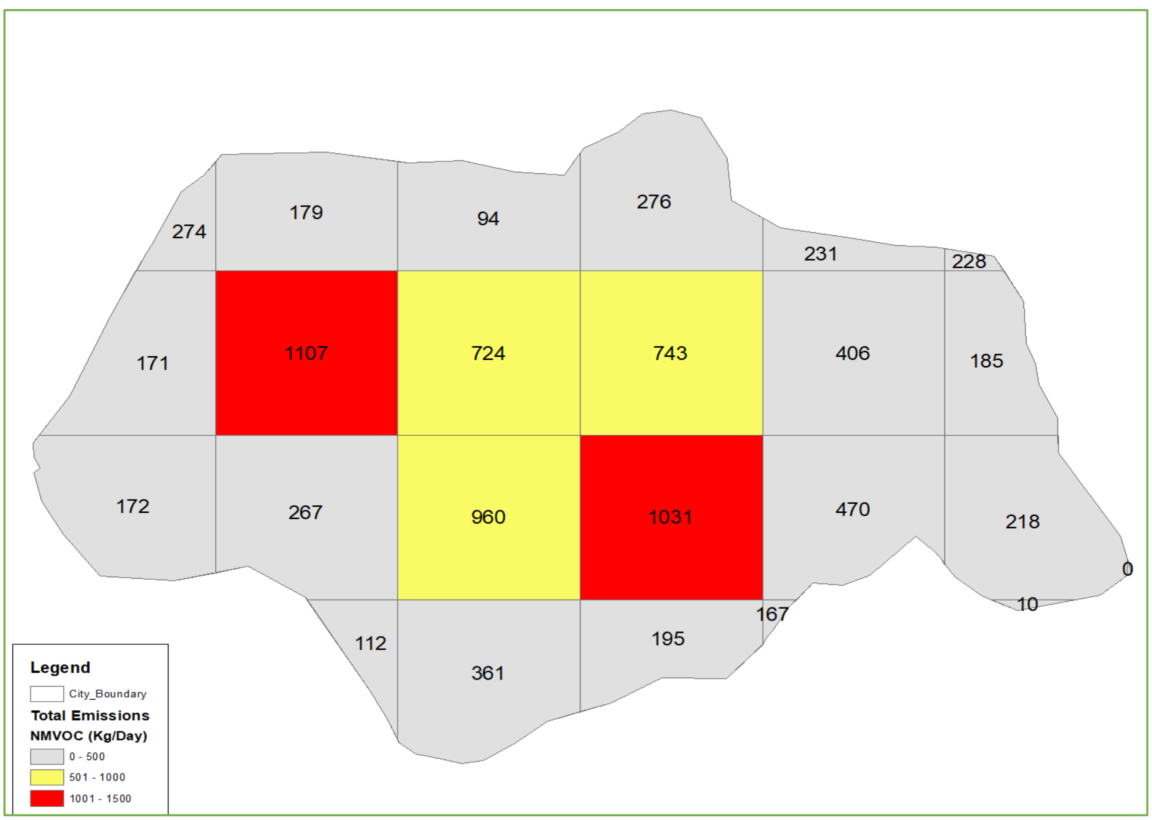


Figure 3.13: Total NMVOCs /HCs Emission Load for Latur City (kg/day)

Chapter 4

Source Apportionment Study using EPA PMF v5.0

4. Source Apportionment Brief

Positive Matrix Factorization (PMF) is a tool used to identify and quantify sources of pollution. It's a popular statistical method for source identification, relying on observed data without prior knowledge of emission profiles. In this study, U.S. PMF 5.0 was used for a preliminary analysis of source apportionment *(USEPA, 2014)*. PMF considers uncertainties in measured data and determines source contributions based on observations at the receptor site. The method utilizes two user input files, one for species concentrations and uncertainties. The chemical mass balance of species concentrations and source profiles is then solved using an Eq. 1.1. The air samples, with chemical speciation, are represented as a data matrix 'X' with dimensions i x j, where i is the number of samples and j is the number of chemical species measured during analysis.

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

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

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

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

Where, u_{ij} is an estimate of uncertainty in the j^{th} variable in i^{th} sample. The uncertainty u_{ij} 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, $\mu g/m^3$

4.1 Methodology

The present study was carries out for representative samples of $PM_{2.5}$ and PM_{10} collected during the sampling campaign in June, 2021 at 3 locations: Residential (S1); Traffic Junction (S2) and Industrial. PM_{10} and $PM_{2.5}$ were collected on 47 mm Whatman quartz and PTFE filters using samplers with 5 LPM flow rate (Air Metrics - Minivol Sampler) for 24-hour sampling period at all locations simultaneously. Further the gravimetric analysis is carried out for all the collected samples to obtain total PM_{10} and $PM_{2.5}$ concentration levels.

Further to carry out source apportionment Elemental carbon and Organic carbon analysis (DRI); Elemental analysis (ED-XRF) and Ionic Analysis (IC) is conducted for all samples. The input file is prepared using concentration data set of samples and associated uncertainty. Here note that PMF works on non-negative aspect so if the concentration of any species is below detection limit or zero then that value needs to be replaced by 0.5 x Minimum Detection Limit (MDL) of that species.

The model uses input files to display the summary of concentration data species in the form of minimum value, 25^{th}, 50^{th} and 75^{th} percentile value, maximum value and 'Signal to Noise' (S/N) ratio. Based on this ratio the species are assigned as strong, weak or bad, as error is minimum in strongest variable and maximum in weakest variable, those labelled bad are excluded from the analysis *(Paatero & Hopke, 2003)*. The Species having S/N ratio more than 3 are assigned Strong, ratio between 1 to 3 are assigned as weak and species with ratio less than 1 are assigned as bad species for running of the model. Species with 80% values below MDL are considered Bad species. he MDL of all the elements is given in **Table 4.1.**

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. This ratio when close to 1.0, signifies good solution and negligible influence of outlier whereas if ratio is greater than 1.5 indicates non-negligible influence *(Paatero & Hopke, 2003)*. The correlation coefficients (R^2)

between measured and modelled metal concentration were checked for >0.80, which indicate better fit of the model to the measured data.

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

Elements (a)	**μg/cm^2**	**μg/m^3#**	**Elements (a)**	**μg/cm^2**	**μg/m^3#**
Na	0.0876	0.211	Ag	0.0192	0.046
Mg	0.0414	0.1	Cd	0.0260	0.063
Al	0.0128	0.031	Sn	0.0488	0.118
Si	0.0050	0.012	Sb	0.0700	0.169
P	0.0134	0.032	Te	0.0866	0.209
S	0.0090	0.022	I	0.1176	0.283
Cl	0.0100	0.024	Cs	0.0040	0.01
K	0.0162	0.039	Ba	0.0092	0.022
Ca	0.0048	0.012	La	0.0054	0.013
Sc	0.0074	0.018	W	0.0060	0.014
Ti	0.0020	0.005	Au	0.0022	0.005
V	0.0042	0.01	Hg	0.0020	0.005
Cr	0.0020	0.005	Pb	0.0056	0.013
Mn	0.0110	0.026	In	0.0274	0.066
Fe	0.0102	0.025	Pd	0.0126	0.03
Co	0.0044	0.011	**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. 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 to identify the sources. These results were used for further analysis to determine percentage contributions of each source at receptor locations and percentage of elemental contribution from that source.

4.2 Results

After the EPA PMF run analysis, 4 factors were identified in the study location for PM_{10} and $PM_{2.5}$ samples as shown below. The percent source contributions are presented in **Table 4.2** and **Figure 4.1 (a and b)** and factor fingerprints are shown in **Figure 4.2 (a and b)**.

Factor 1: Construction/Road Dust

Factor 1 is identified as a construction /road dust source, contributes significantly to both PM_{10} and $PM_{2.5}$ emissions, accounted for 25% and 14%, respectively. This was identified by significant levels of Al, Si, P, Ca which are major indicators of resuspended Road dust from surface soils and paved roads. This factor is consistent with findings from previous studies, such as those by *(Bhuyan et al., 2018; Gupta et al., 2012; Rai et al., 2016)*. Also, construction dust is indicated by Ca and Si *(Mukherjee et al., 2018; Sharma et al., 2016)*.

Factor 2: Biomass Burning

Factor 2, representing approximately 28% and 24% of total PM_{10} and $PM_{2.5}$ emissions respectively. This factor is characterized by a combination of elements associated with biomass burning with indicators such as EC, OC, K^+, Al, Si, K, P, Ti, Mn, Fe. The identification of OC, K^+, and K in this factor serves as clear indicators of biomass burning. These elements are consistently found in biomass burning emissions, as noted in studies by *Garaga et al., 2020*; *Jain et al., 2017; Mukherjee et al., 2018; Police et al., 2016; Shukla & Sharma, 2008*.

Factor 3: Fossil Fuel Combustion/ Vehicular Emissions

Factor 3 was identified by significant levels EC, OC, NO_3^{2-}, SO_4^{2-}, NH_4^{3-}, K^+, S, K, Br, Ca^+, Zn, S, K contributed to 24% and 40% of total PM_{10} and $PM_{2.5}$ emissions respectively. Zn, S, and Fe are deposited by vehicular emissions, which are re-suspended due to wind-driven airborne dust from paved roads. The emissions from vehicles are typically a combination of tailpipe emissions and wear and tear of tires. The presence of EC, SO_4^{2-}, and OC in this factor strongly suggests contributions from the burning of fossil fuels in vehicles, as highlighted in studies *(Jain et al., 2019; Keerthi et al., 2018; Mehta et al., 2022)*.

Factor 4: Industrial Source

Factor 4 is identified as an industrial source, contributes significantly to both PM_{10} and $PM_{2.5}$ emissions, accounted for 24% and 23%, respectively. The key indicators for this source encompassed NH_4^{3-}, SO_4^{2-}, S, Sn, Ag. Earlier studies, including those by *(Gupta et al., 2012; Sharma et al., 2016; Taghvaee et al., 2018; Zong et al., 2016)* have emphasized NH_4^{3-}, SO_4^{2-}, S as key indicators of use of fuel in industrial emissions. Locations of industries surrounding the study region such as UltraTech Cement, Latur Thermal Power Station, Sakharanagar Oil Mill, Latur Textile and Agro Industries further justify the influence of industrial activities on this observed factor.

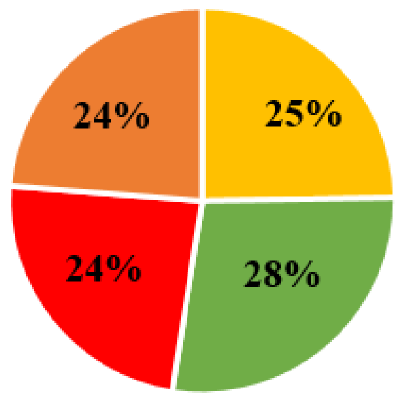
Table 4.2: Percentage Source Contribution for Latur City

Most likely Source(s)	% Contribution	
	PM_{10}	$PM_{2.5}$
Construction/ Road Dust	25	14
Biomass Burning	28	24
Fossil Fuel Combustion/ Vehicular	24	40
Industrial Source	24	23

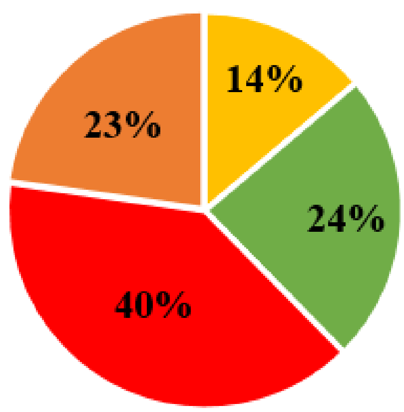
The base factor profiles and their contributions are presented in **Figure 4.3 (a & b for PM_{10})** and **Figure 4.4 (a & b for $PM_{2.5}$)**.

4.3 PMF Analysis Conclusion

Positive Matrix Factorization (PMF) analysis identified four key factors contributing to both $PM_{2.5}$ and PM_{10} fractions. Industrial emissions and biomass burning were found to contribute similarly to both size fractions around 24-28%, while other sources exhibited distinct contributions based on particle size. Fossil fuel combustion and vehicular emissions were more prominent in $PM_{2.5}$, accounting for approximately 40%, reflecting the dominance of fine particles from combustion processes. In contrast, construction and road dust contributed about 25% to PM_{10}, consistent with the larger, coarser particles generated by these activities. The analysis also revealed significant overlap in the chemical species associated with different sources, complicating source differentiation.



a) Percent Contribution PM_{10}



b) Percent Contribution $PM_{2.5}$

■ Construction/ Road Dust ■ Biomass Burning ■ Fossil Fuel Combustion/ vehicular ■ Industrial

Figure 4.1: Percentage Contribution of Sources for PM_{10} and $PM_{2.5}$ for Latur City

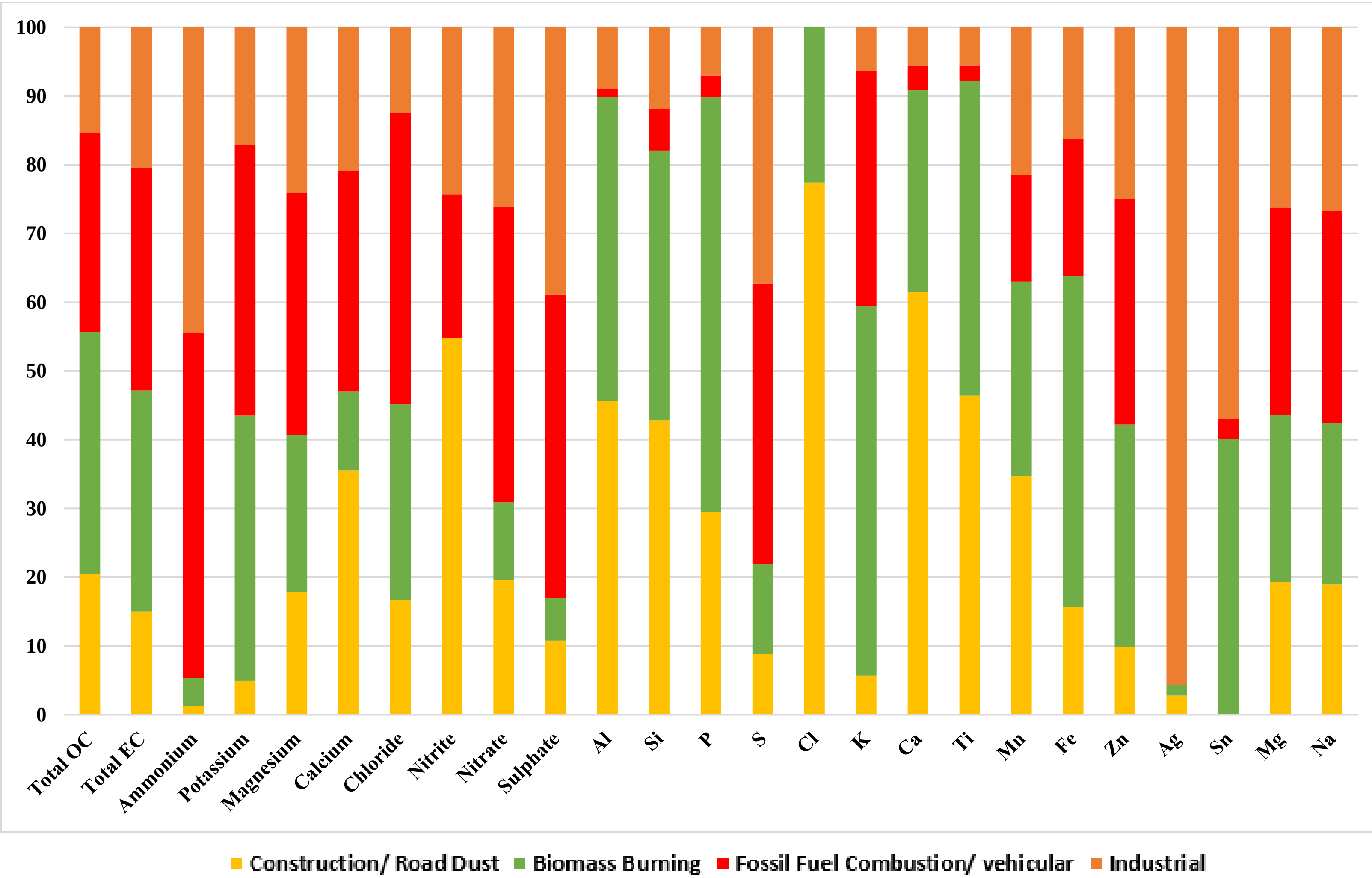


Figure 4.2 (a): Percentage Contribution of Sources & Factor Fingerprints for PM_{10} in Latur City

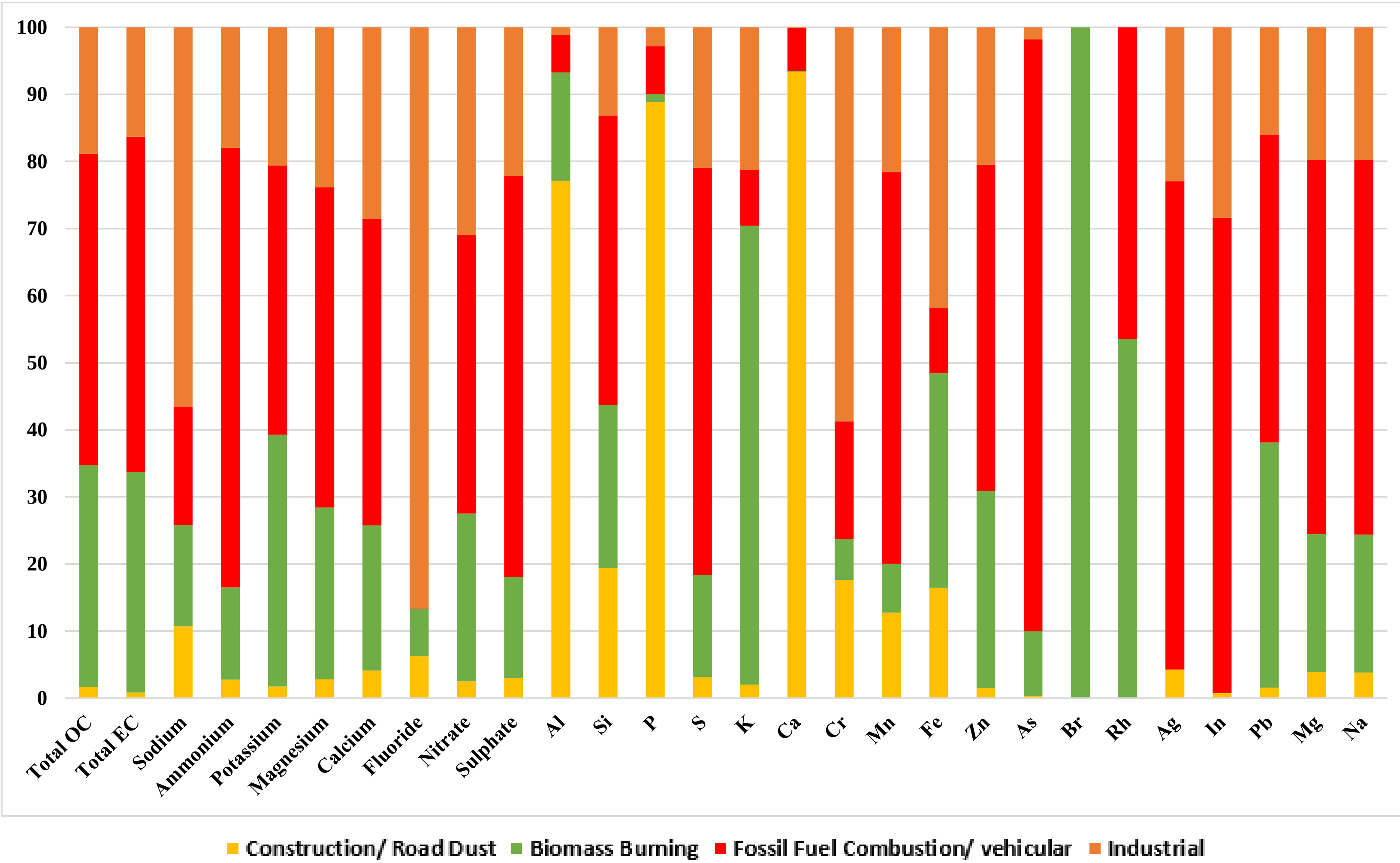


Figure 4.2 (b): Percentage Contribution of Sources & Factor Fingerprints for $PM_{2.5}$ in Latur City

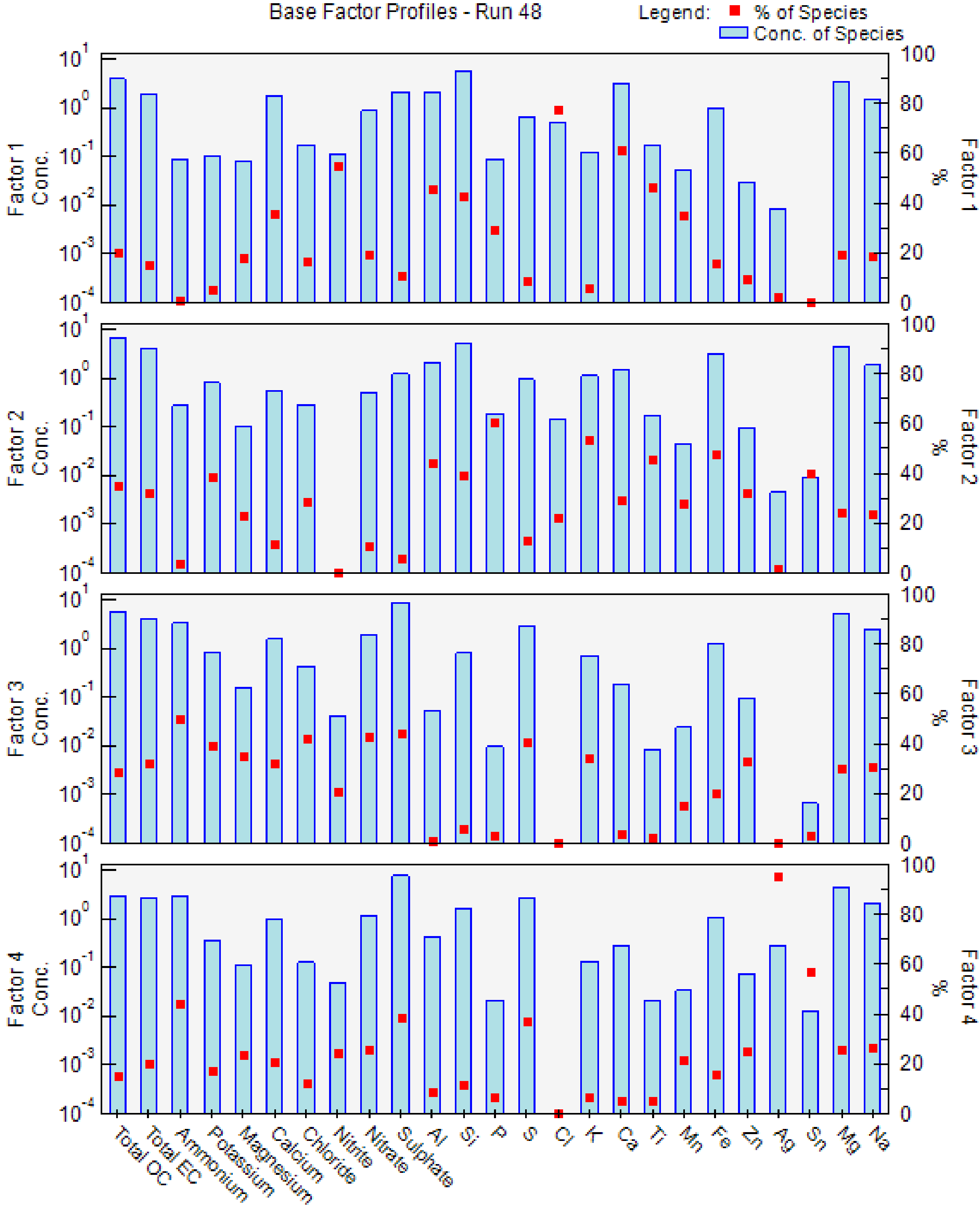


Figure 4.3 (a): PM_{10} Base Factor Profiles

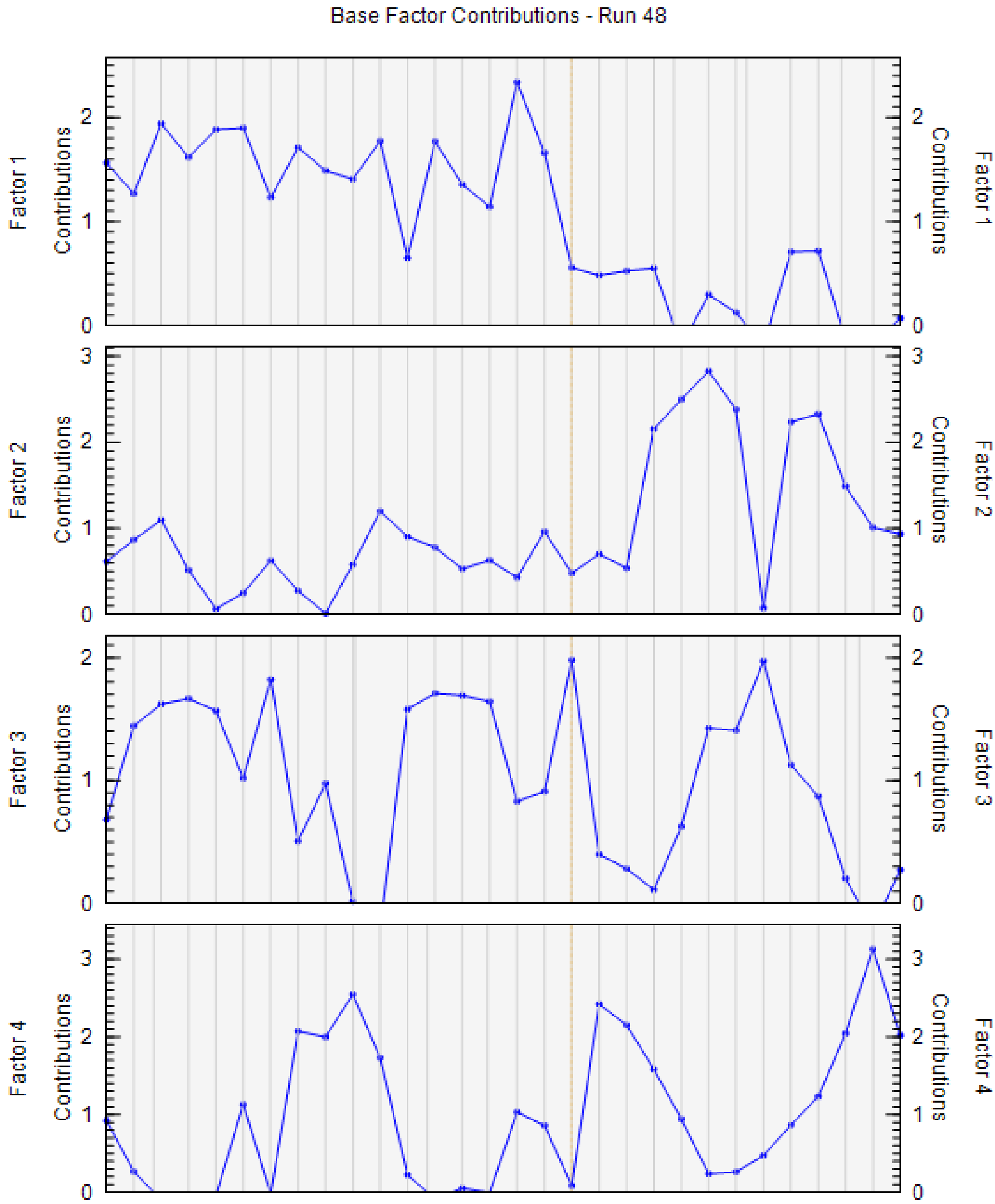


Figure 4.3 (b) : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	Al, Si, Cl, Ca, Ti	25	Construction/Road Dust
Factor 2	EC , OC, K^+, Al, Si, K ,P, Ti, Mn, Fe	28	Biomass Burning
Factor 3	EC, OC, NO_3^{2-}, SO_4^{2-}, NH_4^{3-}, K^+, S, K, Br, Ca^+, Zn, S, K	24	Fossil Fuel Combustion/ vehicular
Factor 4	NH_4^{3-}, SO_4^{2-},S, Sn, Ag	24	Industrial Source

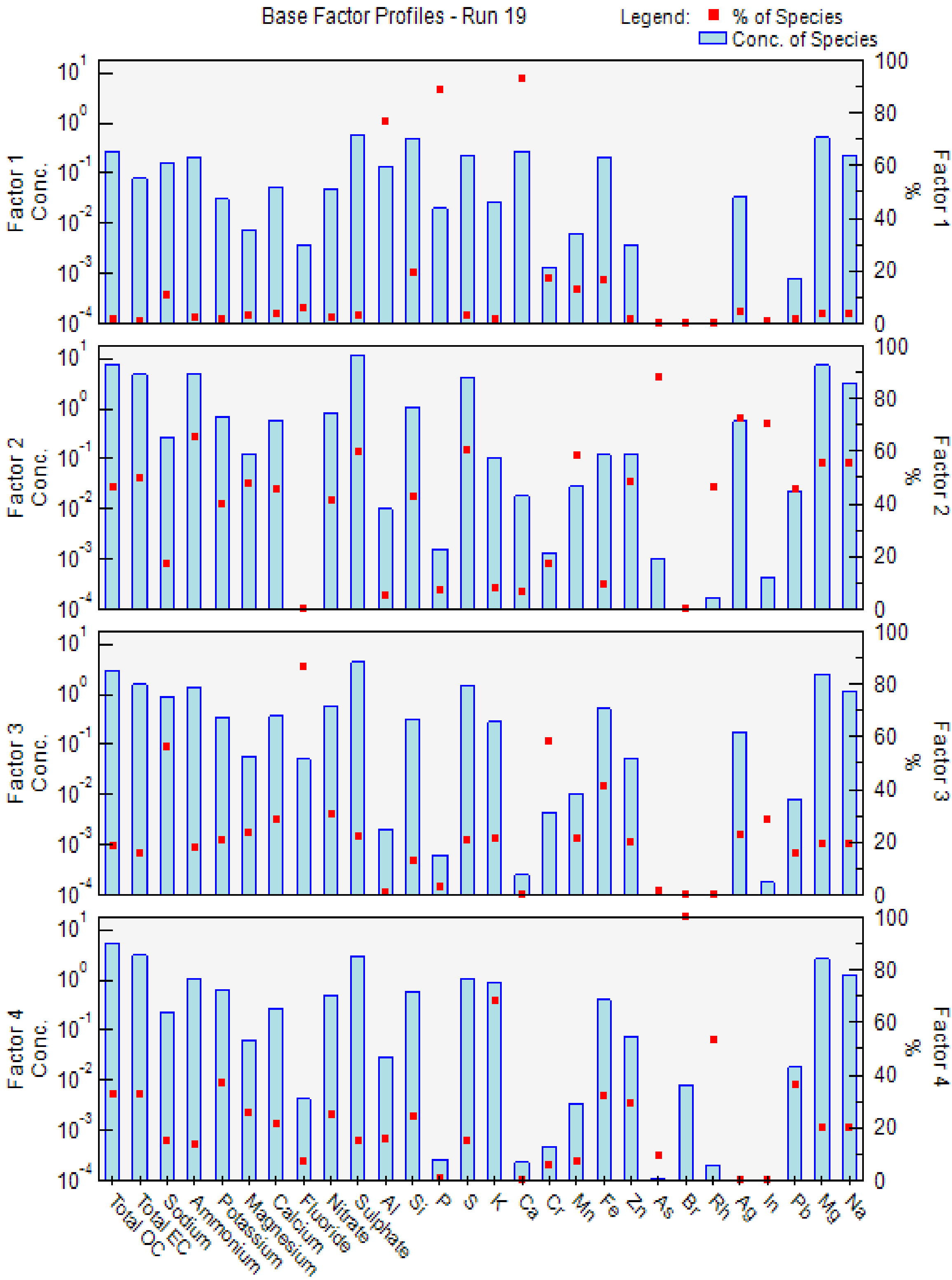


Figure 4.4 (a): PM2.5 Base Factor Profiles

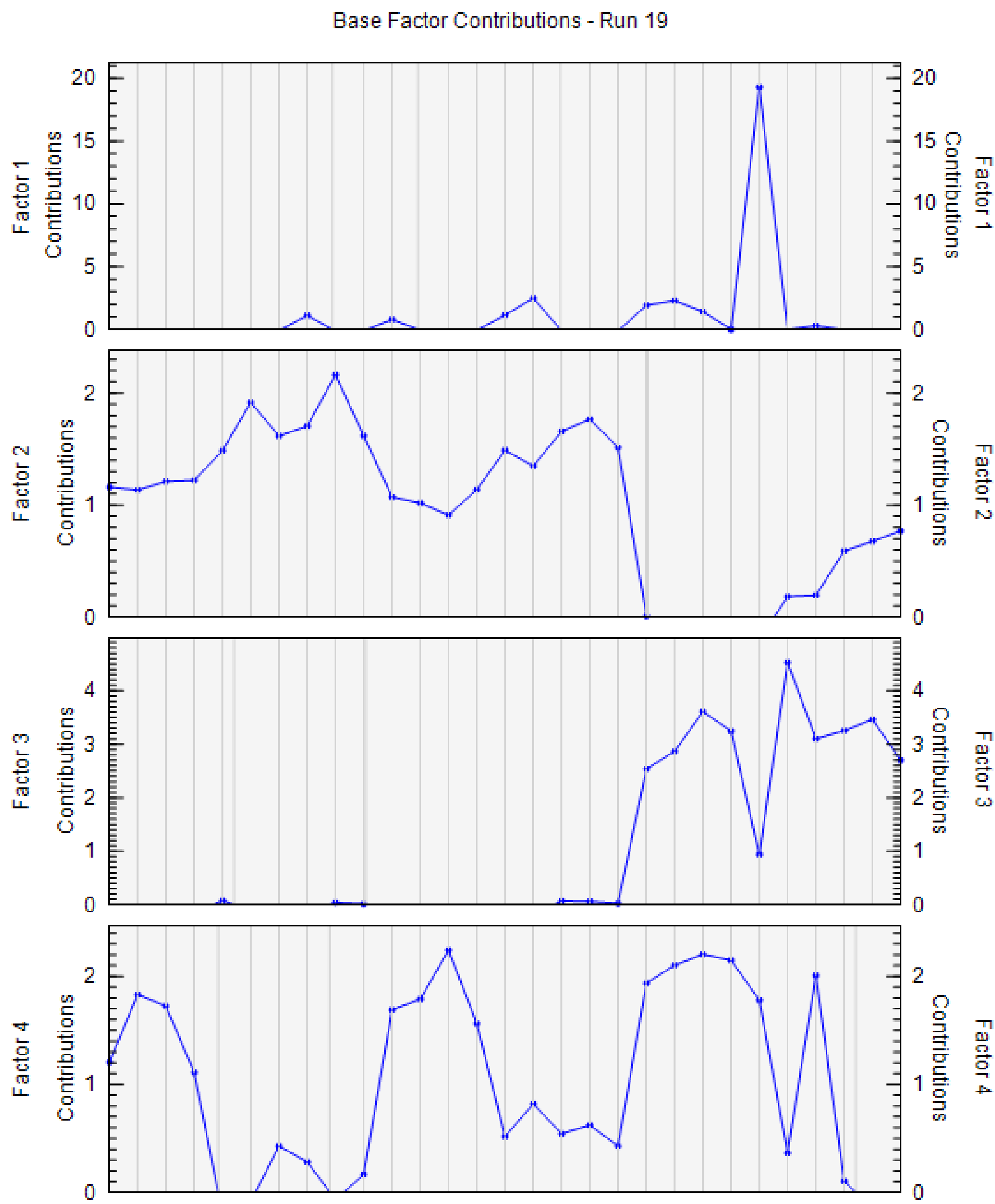


Figure 4.3 (b) : PM_{10} Base Factor Contributions

	Predominant Factors	% Cont.	Factor Name
Factor 1	Al, Si, P, Ca	14	Construction/ Road Dust
Factor 2	EC, OC, SO_4^{2-}, NH_4^{3-}, K^+, As, Ag, In, S, Pb, Na, Ca^{2+}, Mg^{2+}	40	Fossil Fuel Combustion/ vehicular
Factor 3	Na^+, F^-, Cr, K, Fe	23	Industrial
Factor 4	EC, OC, Br, K^+, K, Pb, Rh	24	Biomass Burning

4.4 Emission Inventory and Source Apportionment

The correlation between factors identified through Positive Matrix Factorization (PMF) in source apportionment and the emission inventory highlights the intricate relationships between different pollution sources and their associated chemical signatures.

Vehicular emissions contribute significantly to particulate matter, with $PM_{2.5}$ emissions estimated at 653 kg/day, of which 40.3% originates from line sources, and PM_{10} emissions amounting to 27.1% (293 kg/day). These emissions, primarily driven by fossil fuel combustion, account for 24% of PM_{10} and 40% of $PM_{2.5}$ levels and are associated with elevated concentrations of EC, OC, SO_4^{2-}, NO_3^-, Zn, Pb, Mg^{2+}, and other trace elements. Line sources are the predominant contributors to NO_x, 70.8%, (2412 kg/day) and significantly contribute to SO_x, 30%, (117 kg/day), carbon monoxide (49.3%), and hydrocarbons/non-methane volatile organic compounds (71.4%). These findings underscore the critical importance of implementing targeted vehicular emission control measures to effectively mitigate urban air pollution.

The emission inventory identifies industrial sources as major contributors to particulate emissions, accounting for 36.9% (399 kg/day) of PM_{10} and 26.8% (175 kg/day) of $PM_{2.5}$. Source apportionment analysis supports these findings, attributing 24% of PM_{10} and 23% of $PM_{2.5}$ to industrial activities. Key chemical markers of industrial emissions include NH_4^+, SO_4^{2-}, S, Sn, Ag, and trace elements such as Na^+, F^-, Cr, K, and Fe; with NH_4^+, SO_4^{2-}, and S strongly associated with fuel combustion processes. The SO_x emissions are estimated at 390 kg/day, primarily from point sources (63%, 246 kg/day), while NO_x emissions account for 18% (612 kg/day). Furthermore, industrial activities contribute approximately 37.2% of CO emissions, emphasizing their critical impact as reflected in both emission inventories and source apportionment studies.

Road dust is a significant source of particulate matter emissions, contributing 18.5% (121 kg/day) to $PM_{2.5}$ and 20.2% (218 kg/day) to PM_{10}, as reflected in the emission inventory. Source apportionment analysis further confirms road dust, including contributions from construction activities, as a major emitter, accounting for 25% and 14% of PM_{10} and $PM_{2.5}$ emissions, respectively. Key indicators such as Al, Si, P, Ca, and Ti are elevated in road dust, serving as markers for resuspended particles from surface soils and paved roads. Additionally, the re-suspension of Zn, S, and Fe from these surfaces intensifies particulate pollution. These results demonstrate the strong alignment between emission inventory data and source apportionment in attributing particulate pollution to road dust.

The domestic sector, including activities such as cooking, open burning, bakeries, and operations of hotels and restaurants, contributes 3 to 4% to particulate matter emissions according to the emission inventory. However, source apportionment reveals a significantly higher contribution from biomass burning, accounting for 28% and 24% of PM_{10} and $PM_{2.5}$ emissions, respectively. Biomass burning is characterized by key indicators such as EC, OC, K^+, P, and trace elements like Br, Pb, and Rh, which serve as definitive markers of biomass combustion. Additionally, crematoria contribute approximately 10% to PM and CO emissions and 19.7% to hydrocarbons (HC), underscoring their role as secondary sources of particulate matter.

In conclusion, both the emission inventory and source apportionment analyses offer complementary perspectives: the inventory quantifies pollutant emissions, while source apportionment reveals the chemical signatures associated with different sources. This integrated approach enhances the identification of primary contributors to air pollution and provides valuable information for the development of targeted and effective mitigation strategies.

References :

- Bhuyan, P., Deka, P., Prakash, A., Balachandran, S., & Hoque, R. R. (2018). Chemical characterization and source apportionment of aerosol over mid Brahmaputra Valley, India. *Environmental Pollution*, *234*, 997–1010. https://doi.org/10.1016/j.envpol.2017.12.009
- Garaga, R., Gokhale, S., & Kota, S. H. (2020). Source apportionment of size-segregated atmospheric particles and the influence of particles deposition in the human respiratory tract in rural and urban locations of north-east India. *Chemosphere*, *255*. https://doi.org/10.1016/j.chemosphere.2020.126980
- Gupta, I., Salunkhe, A., & Kumar, R. (2012). Source apportionment of PM10 by positive matrix factorization in urban area of Mumbai, India. *The Scientific World Journal*, *2012*. https://doi.org/10.1100/2012/585791
- Jain, S., Sharma, S. K., Choudhary, N., Masiwal, R., Saxena, M., Sharma, A., Mandal, T. K., Gupta, A., Gupta, N. C., & Sharma, C. (2017). Chemical characteristics and source apportionment of PM2.5 using PCA/APCS, UNMIX, and PMF at an urban site of Delhi, India. *Environmental Science and Pollution Research*, *24*(17), 14637–14656. https://doi.org/10.1007/s11356-017-8925-5
- Jain, S., Sharma, S. K., Srivastava, M. K., Chaterjee, A., Singh, R. K., Saxena, M., & Mandal, T. K. (2019). Source Apportionment of PM 10 Over Three Tropical Urban Atmospheres at Indo-Gangetic Plain of India: An Approach Using Different Receptor Models. *Archives of Environmental Contamination and Toxicology*, *76*(1), 114–128. https://doi.org/10.1007/s00244-018-0572-4

- Keerthi, R., Selvaraju, N., Alen Varghese, L., & Anu, N. (2018). Source apportionment studies for particulates (PM10) in Kozhikode, South Western India using a combined receptor model. *Chemistry and Ecology*, *34*(9), 797–817. https://doi.org/10.1080/02757540.2018.1508460
- Mehta, U. H., Kaul, D. S., Westerdahl, D., Ning, Z., Zhang, K., Sun, L., Wei, P., Gajjar, H. H., Jeyaraman, J. D., Patel, M. V., & Joshi, R. R. (2022). Understanding the Sources of Heavy Metal Pollution in Ambient Air of Neighboring a Solid Waste Landfill Site. *Aerosol Science and Engineering*, *6*(2), 161–175. https://doi.org/10.1007/s41810-022-00131-y
- Mukherjee, S., Singla, V., Pandithurai, G., Safai, P. D., Meena, G. S., Dani, K. K., & Anil Kumar, V. (2018). Seasonal variability in chemical composition and source apportionment of sub-micron aerosol over a high-altitude site in Western Ghats, India. *Atmospheric Environment*, *180*, 79–92. https://doi.org/10.1016/j.atmosenv.2018.02.048
- Paatero, P., & Hopke, P. K. (2003). Discarding or downweighing high-noise variables in factor analytic models. *Analytica Chimica Acta*, *490*(1–2), 277–289. https://doi.org/10.1016/S0003-2670(02)01643-4
- Paatero, P., Hopke, P. K., Song, X.-H., & Ramadan, Z. (n.d.). *Understanding and controlling rotations in factor analytic models*. www.elsevier.com/locate/chemometrics
- Police, S., Sahu, S. K., & Pandit, G. G. (2016). Chemical characterization of atmospheric particulate matter and their source apportionment at an emerging industrial coastal city, Visakhapatnam, India. *Atmospheric Pollution Research*, *7*(4), 725–733. https://doi.org/10.1016/japr.2016.03.007
- Rai, P., Chakraborty, A., Mandariya, A. K., & Gupta, T. (2016). Composition and source apportionment of PM1 at urban site Kanpur in India using PMF coupled with CBPF. *Atmospheric Research*, *178–179*, 506–520. https://doi.org/10.1016/j.atmosres.2016.04.015
- Sharma, S. K., Mandal, T. K., Jain, S., Saraswati, Sharma, A., & Saxena, M. (2016). Source Apportionment of PM2.5 in Delhi, India Using PMF Model. *Bulletin of Environmental Contamination and Toxicology*, *97*(2), 286–293. https://doi.org/10.1007/s00128-016-1836-1
- Shukla, S. P., & Sharma, M. (2008). Source apportionment of atmospheric PM10 in Kanpur, India. *Environmental Engineering Science*, *25*(6), 849–861. https://doi.org/10.1089/ees.2006.0275
- Taghvaee, S., Sowlat, M. H., Mousavi, A., Hassanvand, M. S., Yunesian, M., Naddafi, K., & Sioutas, C. (2018). Source apportionment of ambient PM2.5 in two locations in central Tehran using the Positive Matrix Factorization (PMF) model. *Science of the Total Environment*, *628–629*, 672–686. https://doi.org/10.1016/j.scitotenv.2018.02.096
- Zong, Z., Wang, X., Tian, C., Chen, Y., Qu, L., Ji, L., Zhi, G., Li, J., & Zhang, G. (2016). Source apportionment of PM2.5 at a regional background site in North China using PMF linked with radiocarbon analysis: Insight into the contribution of biomass burning. *Atmospheric Chemistry and Physics*, *16*(17), 11249–11265. https://doi.org/10.5194/acp-16-11249-2016

Chapter 5

Source Dispersion Modelling

5.1 Introduction

Dispersion modeling uses mathematical formulations, which 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 Latur 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 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 regional meteorology downscaled to local scale 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 Latur 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 (σ_x, σ_y) from the estimated atmospheric turbulence. For this study, a meteorological domain of 25 km radius is considered which covers the entire Latur city. **Figure 5.1** shows the annual windrose diagram. It can be seen the most of the wind is between north-east and west. Monthly windrose diagram helps understand the year-long variation and is shown in **Figure 5.2**.

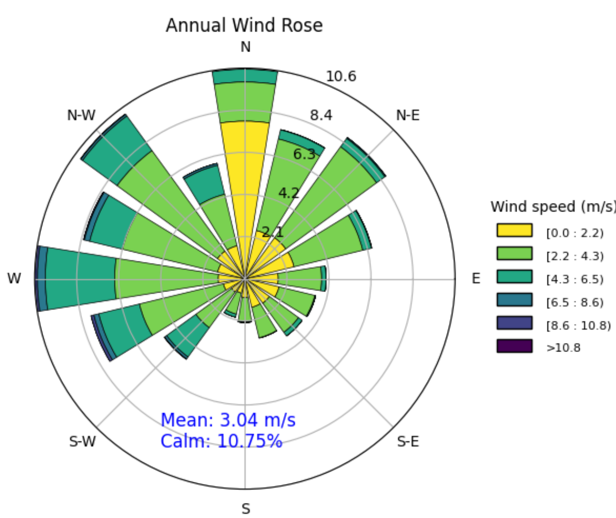


Figure 5.1: Annual Windrose Diagram for Latur City

To understand the ability of Latur atmosphere to dilute and disperse pollutants, the daily maximum mixing height is determined and plotted for each month. Ventilation (m^2/s), which is a product of mixing height (m) and wind speed (m/s) for each hour is determined. Maximum daily ventilation for each month is determined and shown in **Figure 5.3** along with corresponding mixing height.

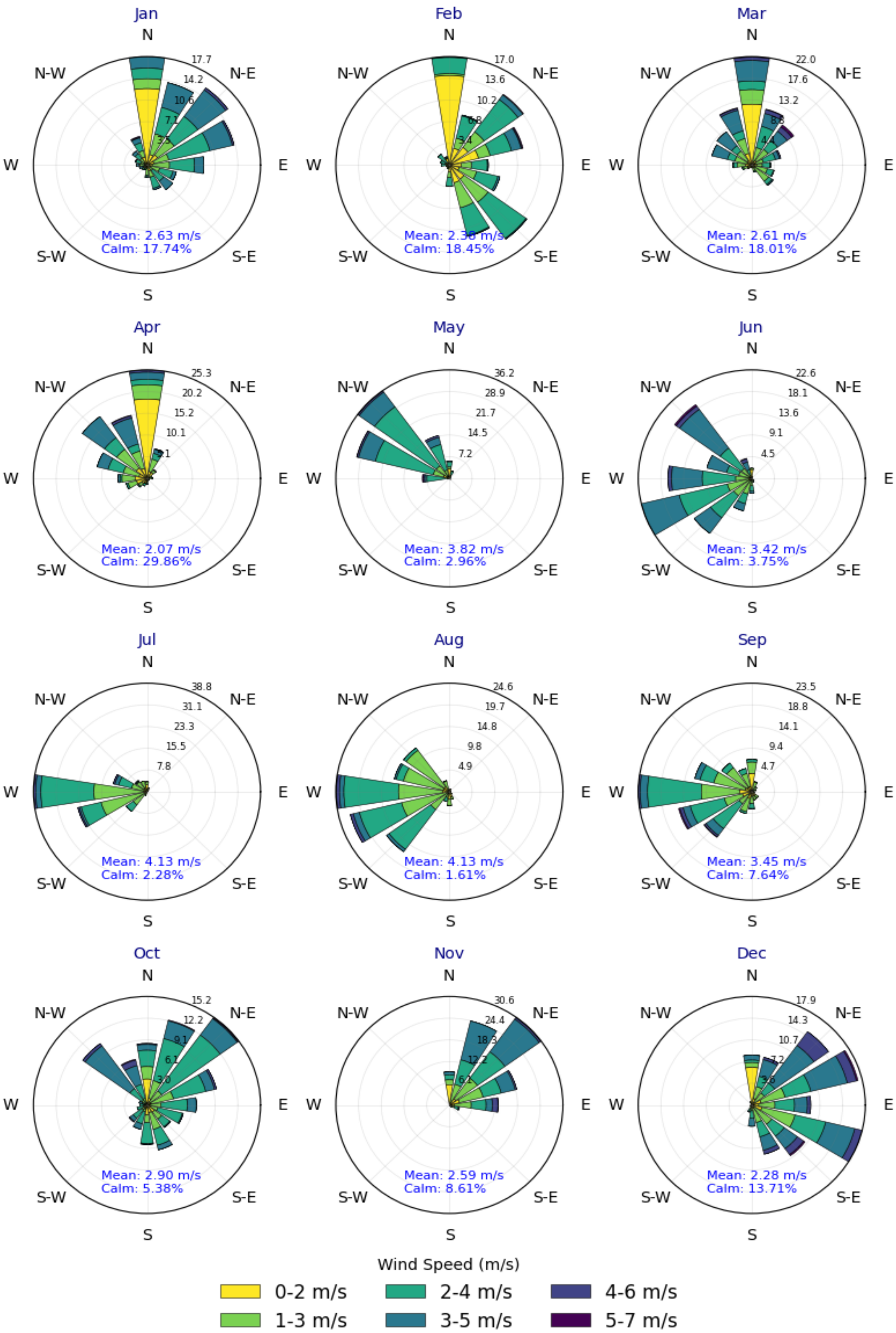


Figure 5.2: Monthly Windrose Diagram for Latur City

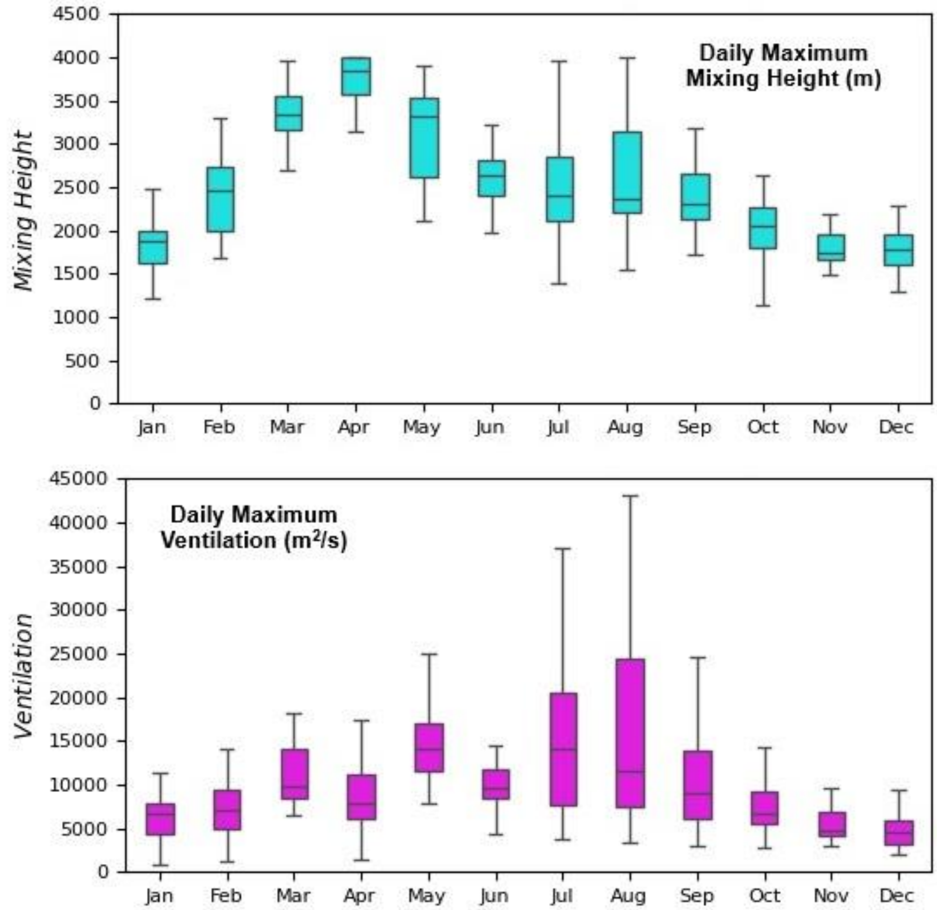


Figure 5.3: Maximum Monthly Mixing Height and Atmospheric Ventilation of Latur City

5.4 Modelling Domain & Result

A domain of 25 Km radium around the centre of the study area is considered for dispersion modelling. Receptor locations and area sources in the study area were arranged in a square grid pattern with 500 m spacing to ensure coverage of key sites around major urban growth centers, with emission rates assigned to each grid cell. 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 load were different **(Table 5.1)**. Therefore, it is considered suitable to model only the pollutant parameter with the highest emission rate, in conjunction with its corresponding regulatory limit value. If this pollutant parameter adheres to the regulatory standard, it can be inferred that the remaining pollutants will also comply with the applicable limits

.

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

Parameter	Regulatory Stand. 24 Hr. [µg/m^3]	Area Emission	Industry Emission	Vehicle Emission	City Emission
PM_{10}	100	388	399	293	1080
$PM_{2.5}$	60	215	175	263	653

Grids of 2 km x 2 km is placed over Latur city for ease in emission inventory and is shown in **Figure 5.4**. Source emission rate is estimated by first adding all emissions with a grid in terms of gram per second followed by its division with the area of grid i.e. 2000 m x 2000 m. This yields emission of pollutants in terms of g/s/m. The gridded emission rate of PM_{10} is shown in **Table 5.2**. This emission rate is used in the dispersion model to simulate the ground level concentration of PM_{10}.

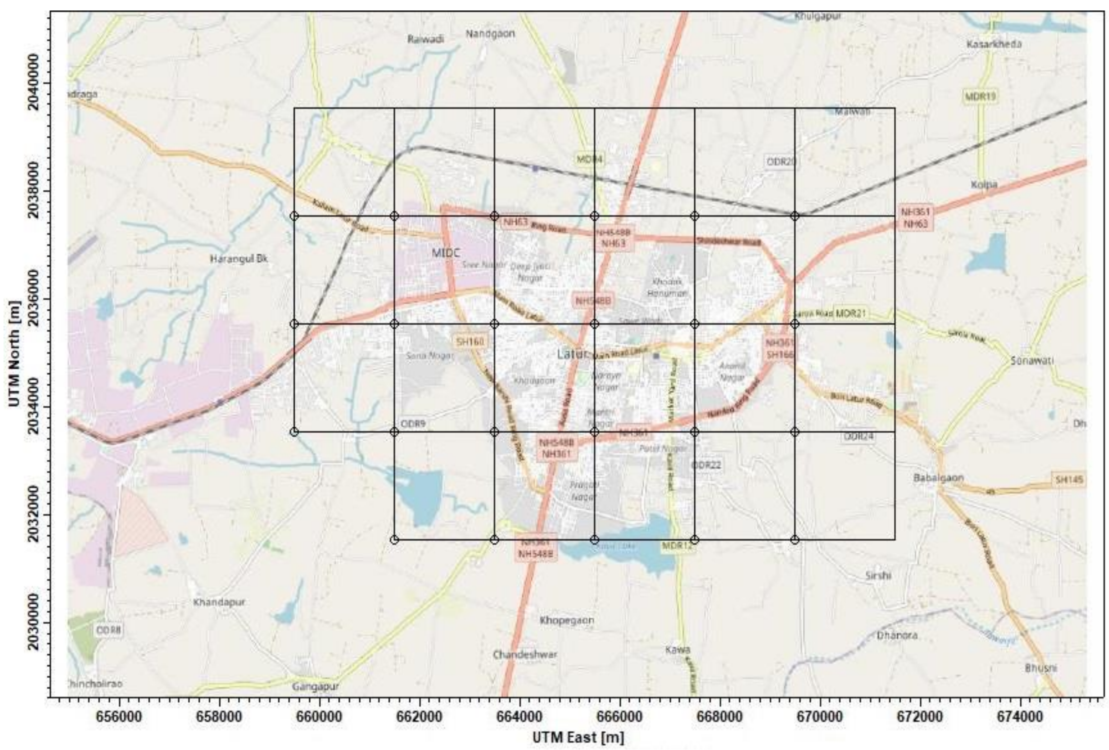


Figure 5.4: Area Source Emission Grid Over Latur City

Overall, from the city, grid B2 have largest PM emission as all the industries are located within grid B2. This emission rate is used in the dispersion model to simulate the ground level concentration of PM_{10}. **Figure 5.5** shows the GLC of PM_{10} and it can be seen that the maximum GLC is found to be 20 µg/m^3 in a very small patch for a small-time duration. Since this value is lower than the regulatory limit, all other pollutant's GLC will be below the regulatory limit value.

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

No.	ID	Emission Rate [kg/d]	No.	ID	Emission Rate [kg/d]
1	B4	5.59	13	B2	463.57
2	C4	32.82	14	C2	64.23
3	D4	17.61	15	D2	57.634
4	E4	6.30	16	E2	40.003
5	F4	0.99	17	F2	9.519
6	A3	18.25	18	A1	20.290
7	B3	16.63	19	B1	14.456
8	C3	83.62	20	C1	10.393
9	D3	85.55	21	D1	26.160
10	E3	38.52	22	E1	20.854
11	F3	18.23	23	F1	2.288
12	A2	16.68			

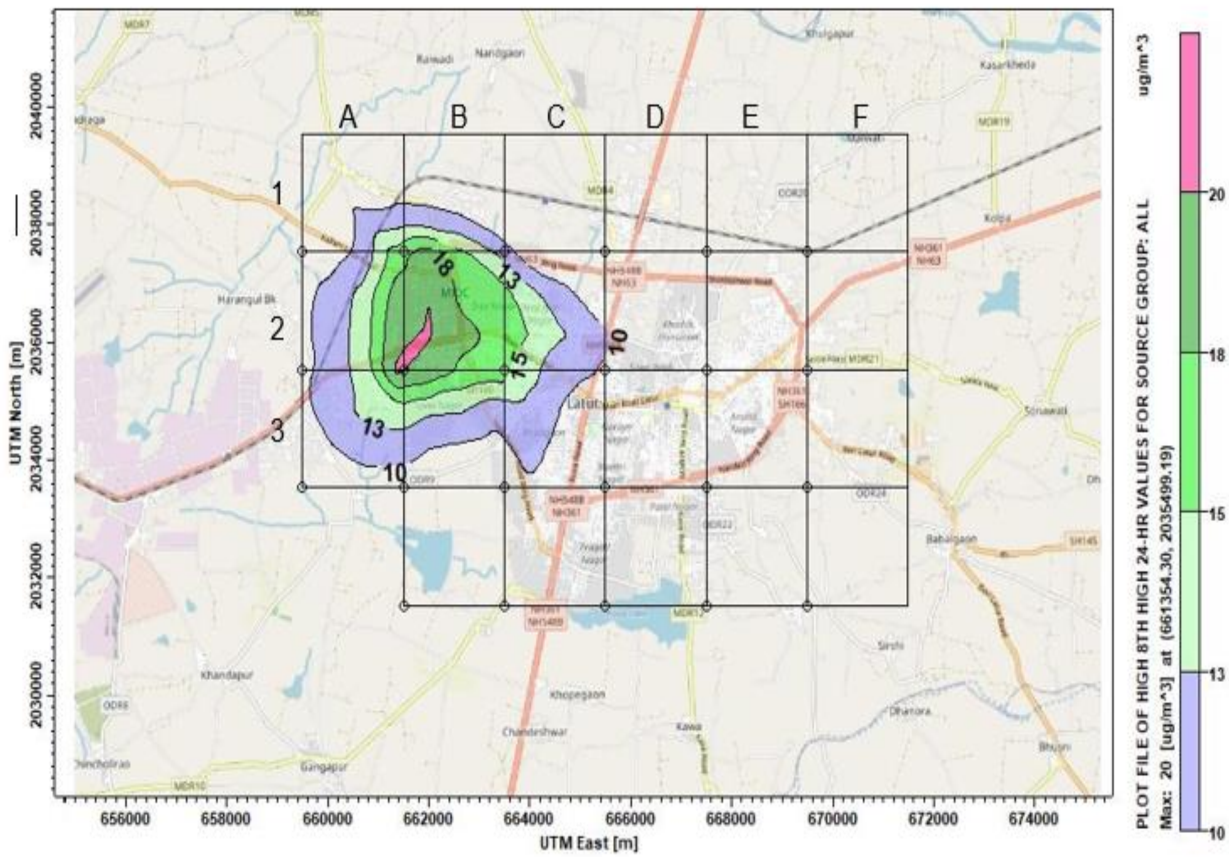


Figure 5.5: GLC of PM_{10} Over Latur City for Area Source Emission

Chapter 6

Action Plan for Control of Air Pollution

6.1 Emission Reduction Action Plan for Latur City

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

Table 6.1: Action Plan for Control of Air Pollution

Sr	**Source group**	**Technical Control option**	**Technical Feasibility /(Reduction & Impact)**	**Implementation Period (Short/Mid / Long-Term)**	**Responsible agency (ies)**	**Any Other Information**
1.	**Vehicular Sector**	Provide Good Public Transport	Feasible Req. higher Cost & Infra-structure Road & Bus Depot Space etc. (High)	Short-Mid (2 Yr.)	LMC, RTO, MSRTC, PWD	The Municipal Corporation operates a public bus service, but most residents rely on private options like auto-rickshaws for intermediate transport. A study could help analyse passenger demand on key routes. Replacing older public vehicles with CNG, electric, or retrofitted alternatives is also recommended
		Petrol /Diesel /Auto rickshaws to shift on CNG/LPG	Feasible (High)	Long Term (1 to 3Yrs.)	MoNG, RTO, LMC	Administrative measures and tax exemptions are encouraged to promote fuel shifts, with incentives for new owners to choose CNG/LPG vehicles. Infrastructure development is needed to ensure easy access to CNG refuelling stations and availability of conversion kits for older vehicles.

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

Sr	Source group	Technical Control option	Technical Feasibility /(Reduction & Impact)	Implemen-tation Period (Short/Mid/ Long-Term)	Responsible agency (ies)	Any Other Information
1.	**Vehicular Sector** ***(Contd..)***	Promote Electric/ Hybrid Vehicles	Feasible (High)	Short Term (1 to 2 Yrs.)	LMC, Auto Firms NGOs,	E-rickshaws have operated in the city since 2016 but lack capacity for efficient population transfer. Hybrid vehicles, ideal for frequent stops and idling, can reduce smog-forming pollutants by up to 90% and cut carbon emissions by 50%
		Bio-diesel (B5/B10:5-10% blend)	Feasible (High)	Short Term (1 to 2 Yrs.)	LMC, Auto Firms, BIS NGOs,	With the district's sugar belt, ethanol fuel has strong market potential. E10 (10% ethanol blend) can significantly reduce emissions compared to conventional fuels.
		Regular check of adulteration of fuel	Feasible (Moderate)	Short Term (1 to 2 Yrs.)	City Traffic cell/ RTO LMC	Many auto rickshaws mix oil and kerosene with petrol. Strict action, including surveys and random checks by LMC, Anti-Adulteration Cell, and RTO, is needed to address violations
		Regular check of PUCs of vehicles and installation of Remote Sensor based PUC system	Feasible (High)	Short Term (1 to 2 Yr.)	City Traffic cell/ RTO, LMC	The city has 16 approved PUC centres, but more are needed for strict compliance. LMC and the Transport Dept. propose RFID-based remote PUC systems.

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

Sr	Source group	Technical Control option	Technical Feasibility /(Reduction & Impact)	Implementation Period (Short/Mid / Long-Term)	Responsible agency (ies)	Any Other Information
1.	**Vehicular Sector** *(Contd..)*	Retro-fitment of Diesel Oxidation Catalyst (DOC) and Diesel Particulate Filter in HDDV	Feasible Req. higher Cost & Infra-structure (Moderate)	Long Term Retrofitting devices- 50% conversion In 2Yrs for HDDV in city new registered vehicles	Transport Commissioner Office, LMC	A pilot study is needed to test emission control devices in older vehicles. Restrictions on non-retrofitted trucks (based on age and engine) should be imposed. Stricter diesel sulfur standards (down to 50 ppm) and differential taxes based on after-treatment devices are recommended
		Banning of 15 year Old Commercial Vehicle	Feasible (High / Moderate)	Short Term 1 Yr. Initially 50% banning Encouragement by provision of incentives in form of scrap value.	Transport Commissioner Office, LMC	Vehicles need inspection every two years. Owners get incentives for phasing out vehicles over 15 years. Municipal and Metropolitan Authorities should allocate spaces for scrapped vehicles.
		Introduce Traffic Signal – Synchronization of traffic signals Sensor Based – Real time tracking	Feasible (High)	Short Term 1 Yr. Major & minor roads, excluding feeder roads (or about 50% of the all arterial roads)	Transport Commissioner Office, LMC	Conduct pre-feasibility studies for hotspots. Develop a detailed study on the signaling network with sensor-based monitoring and real-time modeling

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

Sr	Source group	Technical Control option	Technical Feasibility /(Reduction & Impact)	Implementation Period (Short/Mid/ Long-Term)	Responsible agency (ies)	Any Other Information
1.	**Vehicular Sector** *(Contd..)*	Inspection and Maintenance	Feasible (High / Moderate)	Short Term 1 to 2 Yrs. New I&M regulations (Initially 60% population of vehicles of a RTO region)	Transport Commissioner Office, LMC	Test design should focus on engine and vehicle fitness. Develop Vahan Depot for I&M with advanced emission and fitness testing. Ensure strict, cheat-proof compliance with computerized data capture, penalties for failures, and public awareness campaigns
		Regulating Road Site Parking	Feasible (High)	Road site parking to be reduced by 80% (On street parking spaces guidelines as per IRC: SP: 12:2015.)	Transport Commissioner Office, LMC	Regulate roadside parking, allow vehicle purchases only with available parking. Designate parking spaces, create elevated pay-and-park zones, and charge higher fees for longer stays. Ban commercial vehicles during peak hours.
		Intermediate Road Transport & Traffic Control	Feasible Req. higher Cost & Infra-structure (High/ Moderate)	Improve road connectivity to stations, residential blocks, and offices, covering 30% of the area.	Transport Commissioner Office, LMC	Road widening, bypasses, and flyovers are planned with LMC, PWD, and National Highway Authority. Shared autos and private cars will reduce congestion. A bicycle track is proposed on busy roads.

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

Sr	**Source group**	**Technical Control option**	**Technical Feasibility /(Reduction & Impact)**	**Implemen-tation Period (Short/Mid / Long-Term)**	**Responsible agency (ies)**	**Any Other Information**
2.	**Area Source** Paved & Unpaved Road Dust	Pot hole free road Blacktopping of tar and cement roads	Feasible (High)	Immediate action requires, basically after every monsoon 6 months	Transport Commissioner Office, LMC Civil Dept., PWD	The corporation maintains mostly bituminous roads with wall-to-wall pavement, especially in Old Latur. Future designs should follow the UTTIPEC manual. Roads should have full pavement, and the Traffic Department should monitor conditions and manage repairs. A better sweeping system with mechanical sweepers should be used, and contractors should be incentivized for advanced technologies
		Wall to wall road pavement with road widening	Feasible (High)	Short Term for Intermediate roads 6 m to 1 Yr. Long Term -2 Yrs. for Bigger roads		
		Mechanical Sweepers for road sweeping	Feasible (Moderate)	Short Term – 6 Months		
		Creating Green buffer zone along the road dividers	Feasible (Moderate)	Short Term – 6 Months	NGO, RTO, LMC, Horticulture dept, Forest dept	LMC is developing open gardening areas in collaboration with local bodies and NGOs to reduce dust. Large industries should be encouraged to use CSR funds for this. Treated sewage can support roadside bioswale systems, keeping kerb-side green and reducing air pollution.
		Major traffic intersections to have water fountains				

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

Sr	**Source group**	**Technical Control option**	**Technical Feasibility /(Reduction & Impact)**	**Implemen-tation Period (Short/Mid / Long-Term)**	**Responsible agency (ies)**	**Any Other Information**
2.	**Area Source** ***(Contd..)***	Open Burning Agricultural / Horticulture waste and Crop residues	Feasible (Moderate)	Short Term -6 Months	Latur Muni. Corpo.	Open burning should be penalized with strict vigilance. Daily disposal practices must prevent it. A 100MT processing unit for treatment is being set up
		Hotel & Bakeries / Open Eat outs / Bakeries	Feasible (High/ Moderate)	Short Term -6 Months 75% of Coal used in Dabba, Open-eat outs to replace by LPG	Latur Muni. Corpo. Hotel Owner Association	Hotels, bakeries, and open eateries should use alternative fuels like LPG/PNG, phased in with availability. Designated areas for coal and wood use, especially for Dhabas, should be set. A license system should control this, and stacks with air pollution control units should be installed
		Crematoria Presently SMKC is using briquettes &Wood for crematoria	Feasible (High)	Phase wise shifting to 50% Electric – 1 to 2 Yrs. 75% Electric – 2 to 3 Yrs.	Latur Muni. Corpo.	Crematoria should use efficient pyres, chimneys with filters, and explore NG burners or electric furnaces. Awareness and Green Crematoria concepts should be promoted

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

Sr	**Source group**	**Technical Control option**	**Technical Feasibility /(Reduction & Impact)**	**Implemen-tation Period (Short/Mid / Long-Term)**	**Responsible agency (ies)**	**Any Other Information**
2.	**Area Source** ***(Contd..)***	Domestic Cooking Sector	Feasible (High)	50% of slums to use LPG/ PNG 70% of non-slum to use LPG/PNG	LPG Cylinder Distributors MNRE, Latur Muni. Corpo.	Expand LPG/PNG infrastructure in the LMC region, with the Ujjwala scheme in operation. Provide improved cook-stoves at Rs. 2000 for residential use. Ensure easy access to cylinders for slum residents and prioritize proper ventilation to improve indoor air quality.
		Building & Road Construction	Feasible (High /Moderate)	Short Term -6 M to 1 Yrs. & Continuous process	Builders Association RERA, LMC	Enforce building and road construction codes to control PM. Spray water on truck tires at construction site entry/exit points and barricade sites to prevent dust dispersion. A penalty of Rs. 50,000 is imposed for violations.
3.	**Others**	Installation of display screens for AAQ of the city	Feasible (Low)	Short Term -6 Months	LMC, MPCB, NGO Stakeholder	Public awareness about the city's Air Quality (AAQ) is needed. During the survey, people suggested spreading information via signboards and NGOs. Additional actions by LMC should include plastic bans, proper waste disposal in drains, and addressing open burning.

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

Sr	**Source group**	**Technical Control option**	**Technical Feasibility /(Reduction & Impact)**	**Implemen-tation Period (Short/Mid / Long-Term)**	**Responsible agency (ies)**	**Any Other Information**
4.	**Industrial Sector**	Installation /up gradation of air pollution control systems in industries	Feasible High Cost to Small Scale Industries (High)	Short Term -1 Yr. Months	MPCB, Directorate of Small Scale Industries, LMC	Regular checks on APC efficiency, QA/AC, and stack emission dispersion are essential. Small-scale industries emitting uncontrolled pollution should be strictly banned, and a vigilance system should be implemented
		Shift to cleaner fuels - FO, LSHS, HSD to LDO Coal & Others to NG	Feasible High Cost to Small Scale Industries (High)	Short Term -1 Yr. Months	MPCB, Mahanagar Gas Small Scale Industries LMC	Shift from FO and coal to natural gas (NG) based on availability from M/s. Mahanagar Gas Pvt. Ltd. Feasibility studies for adapting combustion technology to use gaseous fuels should be conducted, with financial incentives provided.
		DG sets in LSI and MSI	Feasible High Cost to Small Scale Industries (High)	Short Term -1 Yr. Months	LMC, Director, MSEDCL, MPCB	Strictly enforce emission control norms. Explore solar power in industries; a 100 kW rooftop solar plant costs Rs 60 lakhs

6.2 The Overall PM Emission Management

- The primary factor in air quality degradation is particulate matter, predominantly originating from the growing industrial sector, brick kiln emissions, vehicular exhaust, and infrastructure-related activities such as road and construction projects.
- A significant gap exists in collaborative policy initiatives among government and organizational entities concerning air quality improvement. Effective and sustained progress in this domain necessitates a centralized governing body dedicated to the oversight and coordination of relevant departments. The Maharashtra State Pollution Control Board will execute this action plan, in collaboration with the Department of Environment and Forest, Urban Development and Housing Department, Regional Transport Office, Latur Municipal Corporation, Traffic Police, District Administration, Maharashtra Industrial Development Corporation (MIDC), Oil companies, Anti-adulteration units, and representatives from urban local bodies (ULBs), NGOs, and educational institutions. The regulatory framework should enable efficient communication of requirements to this apex body, facilitating prompt policy development.

  The Chief Secretary of Maharashtra is to convene inter-departmental meetings to ensure compliance with directives aimed at improving air quality in Latur. The Principal Secretary of Environment and Forests will similarly convene meetings to monitor the implementation of these directives. Additionally, the deputy Chief minister will review progress on enhancing ambient air quality in the region.

- Under Section 73(3), the Central Government holds the authority to restrict the number of contract carriers in urban areas with populations exceeding 500,000. Accordingly, the Government of Maharashtra has issued notifications limiting contract carriers in cities including Mumbai, Thane, Pune, Nagpur, Solapur, Nashik, and Aurangabad. Comprehensive review and amendment of pertinent acts and regulations are necessary to address challenges arising from urbanization and population growth. Additionally, redirecting heavy goods vehicle traffic around urban centres through the construction of bypasses and ring roads is advised to alleviate congestion.
- Industrial facilities should adhere to stack emission standards surpassing those established by the Central Pollution Control Board (CPCB). This compliance should be reinforced through systematic quality assurance, quality control (QA/QC) measures, and regular performance audits.
- The operation of diesel generator (DG) sets in industrial settings should be strictly regulated to ensure compliance with stack emission standards through the implementation of advanced air

pollution control technologies. Furthermore, dependency on DG sets during power outages should be reduced in favour of conventional energy sources.

- Monitoring air pollutant concentrations and identifying their sources alone is inadequate; it is equally essential to disseminate this information to the public via multiple platforms, such as web and mobile applications, information boards in public spaces, and by publishing key research on air pollution. Such dissemination promotes public awareness of environmental issues and can create pressure on authorities to implement corrective measures.

Some of the technologies developed by NEERI to curb air pollution loads are included as Annexures I, II and III. Action plan workshops with the stakeholders are proposed to enable effective implementation.

Chapter 7

Results and Recommendations

This study has addressed several aspects of the air pollution status in Latur City with an intent to identify the key sources of pollutants, where criteria pollutants have been used to represent the quality of air. An attempt for the analysis has been made by using the results from source apportionment analysis, and also the results from the source inventory (Table 7.1). The same are discussed in the following sections.

7.1 Source Apportionment (PMF and Dispersion Models)

7.1.1 Sampling for the source apportionment component of the work were carried out at four locations to cover representative air pollution (Chapter 2). Airmetrics (Mini-Vol TAS) samplers were procured specifically with a flowrate of 5 lpm to prevent filter overloading in the 24-hour averaged samples. The sampling period was during the January-February of 2021.

7.1.2 The chemical analyses were carried out as per CPCB guidelines (Table 2.1). The source apportionment analysis was conducted employing the EPA Positive Matrix Factorization (PMF) method and the results are summarised as Figures 4.1-4.3, and Table 4.2.

7.1.3 The findings revealed that there are 4 major, almost equal contributors to the PM10, namely, Biomass burning, road dust and construction, fossil fuel/vehicular and industrial). Uncontrolled burning of solid wastes and also uncontrolled emissions from small scale industries in the unorganised sector are likely to be included as industrial sources. Fossil fuel also seems to have the largest contribution to PM2.5 followed by biomass burning. Dispersion modelling was carried out using dispersion model (Chapter 5). The inputs for sources were taken from the inventory developed in Chapter 3 (Table 7.1(b)), and the industrial permitted emission datasets made available by MPCB. MM5 data were used for the meteorological inputs.

7.1.4 The three sampling locations are well within the inventory grid used, with MIDC as the centre of the hotspot. However, the results for GLCs for all the three locations from dispersion modelling results indicate far lower concentrations than those observed in the study, as well as historical monitoring data.

7.1.5 The GLC found by dispersion modelling is below the measured values, indicating that the geometrically well-defined sources (Point, Area and Line) are not adequately representing the actual conditions for the dispersion modelling. This is because several of these and other sources are fugitive in nature and not measured (or sometimes even measurable) and documented. Examples are road dust re-suspension, uncertainties due to incomplete coverage of vehicular emissions (hourly vehicle counts need to be carried out on each road stretch).

7.1.6 This is indicative of the contributions from a large number of ground level sources that are spread across the city – these could be small scale industries in the unorganised sector and/or burning of biomass and solid wastes. In the absence of data for such sources, the conclusions from chemistry-based source apportionment (Table 7.1(a)) become pertinent for action plan

Table 7.1 (a): Summary of Source Apportionment Results for Latur City (Source : Table 4.2)

Most likely Source(s)	% Contribution	
	PM_{10}	$PM_{2.5}$
Construction/ Road Dust	25	14
Biomass Burning	28	24
Fossil Fuel Combustion/ Vehicular	24	40
Industrial Source	24	23

Table 7.1 (b): Key Sources from Inventory for Latur City (Table 3.4)

Sources	PM_{10}	$PM_{2.5}$	NOx	SO_2	CO	NMVOCs /HCs
Area Source						
Bakeries	6	3	69	13	91	264
Crematoria	121	67	163	10	699	1754
Domestic	16	8	136	1	151	182
Building Construction	9	6	0.0	0	0	0
Open Burning	4	2	0.5	2	14	69
Resuspension of Road Dust	218	121	0.0	0	0	0
Hotels. Restaurants and Open eat-outs	14	8	14	1	30	4
Line Source						
Vehicular Emissions	293	263	2412	117	3580	6364
Point Source						
Industries	399	175	612	246	2703	279
Total Emission Load (TPD)	**1080**	**653**	**3406.5**	**390**	**7268**	**8916**

7.2 Observations and Recommendations

7.2.1 It is recommended that the inventory developed in this study may be digitalised and maintained as a dynamic dataset for impact assessment of new sources which result from activities related with population growth, industrial installations and/or mobility-transport related projects for Latur City and the region. Further, it is important that each stakeholder may validate the inventory at the ward level, especially for all municipal domain activities as well as small scale industries in the unorganised sector.

7.2.2 There is a large uncertainty in the quantities and types of garbage and biomass (shed leaves from trees etc.) that are burnt in the open. Further, since they are burnt in an uncontrolled manner, the emission factors and the associated source chemical profiles also add to the uncertainty. Strict enforcement to ensure that open burning is prevented would be the most pragmatic approach to control emissions from this activity, and the associated perception and nuisance value. Timely collection of garbage would minimise the need for such enforcement efforts.

7.2.3 Burning of plastics and anthropogenic dry wastes in an uncontrolled manner is a matter of health concern, and requires immediate attention. Measurements of the toxic emissions from these is rather tedious and in a pragmatic sense, does not require quantification for validating the need for prevention.

7.2.4 Services of the Fire Brigade department may be sought through ward-specific telephone/web-based hotlines for quenching any uncontrolled garbage and/or biomass burning.

7.3 Suggestions for Success of Sustained Efforts

The following recommendations have emerged from several discussions at meetings, conferences, stakeholder workshops throughout India with experts from multiple organisations (Numerous to list - All gratefully acknowledged).

Each city carries its own pulse and character, and therefore a "one size fits all" approach is not likely to be feasible or effective. However, some basic infrastructural and systemic additions in the concerned agencies may help streamline the efforts and start producing results in time, to be then sustained. While the experience of the present study and these recommendations are based on the work carried out in 19 cities in Maharashtra (supported through MPCB), the same would be applicable to all cities including the smaller cities that are presently not listed in the NCAP non-compliant list due to the criterion of the size of the city populations.

7.3.1 Realizing the impact of air quality on health, there is an urgent need for a system to control sources of air pollutants in the city. This should be led by urban local body (ULB), equipped with qualified and trained manpower. This calls for establishing an air quality monitoring cell (AQM Cell) in each ULB with dedicated responsibility (a similar effort is already operationalised by BMC).

7.3.2 Each AQM Cell should have air quality monitoring system for the city. This should include manual monitoring and CAAQMS, to include some collocated measurements for validation. The manual AQM needs to be based on the city needs, up-wind background monitoring, city down-wind monitoring, rotation of monitoring station depending on predominant wind direction (this would be beyond the requirements of the national air pollution monitoring programme). Source dispersion modelling based monitoring station needs to be set up. Integration of the meteorological data at local and city scales is required for local topography.

7.3.3 The monitoring network may also be designated for different kind /quality of data, possibly as:

- Residential areas (ward-specific)
- Kerb side
- Hot spot (say industrial region or high-density populated areas)
- Urban background and Research grade data. This may be integrated with National Network also.

7.3.4 A significant part of the air pollution in urban centres is from vehicular emissions. The correct estimate of vehicular emissions is possible only if the vehicle type identification and its counting on each road can be carried out. Artificial Intelligence / Machine Learning (AI/ML) tool can be used for online identification and counting of vehicles. Such tools are already developed and ready. CCTV operators are required to give access to the IP address so that online counting of vehicles can be carried out and used in the emission inventory and source dispersion modelling.

7.3.5 Dispersion modelling of the gridded emission should be carried out and be ready online with the AQM Cell. All additional emission load should be included regularly so as to improve the prediction of ground level concentration of pollutants.

7.3.6 Health data from primary health centre should be digitalised and made available for drawing correlation with air pollution and health condition. Hospitals, should be taken on-board by the AQM cell.

7.4 Further Work

7.4.1 The strength of using the results of this study depends on the validation of the source inventory at the ground level. Control measures would need to be strategized accordingly.

7.4.2 Long term sustained success will require public participation and a reward-based approach (rather than enforcement based) maybe attempted. This approach could even be tested in a few wards where the pro-active citizen participation could set an example for success and replication.

7.4.3 Management of air quality is a new emerging problem for cities in India, and therefore asks for a new team and a new administrative structure. The work is of a nature that would require day-to-day analysis and ground level control of sources through multiple agencies. This team could also monitor the progress laid out for the immediate as well as for the next 5 to 10 years, and pool in the resources for the entire state as through multiple agencies (MPCB, RTO, Fire Brigade, IoRs, Research Institutes and Industries and other stakeholders).

7.4.4 Use of satellite data is highly recommended as a mainstream analytical tool for the entire state of Maharashtra. Collaborations with ISRO, IMD and National Remote Sensing Agency are essential for this effort.

Annexure 1

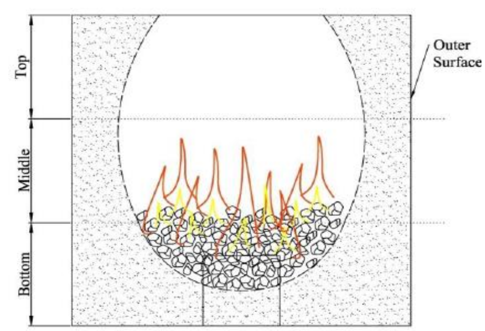
Design of a Clean Tandoor Community Kitchen System (CTCKS)

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.

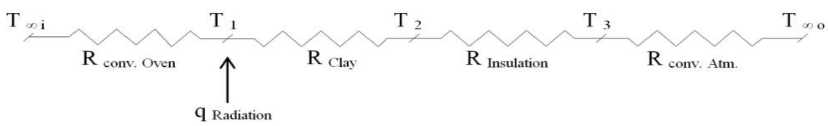
Figure 1 to 4 below shows the concept design of the tandoor drawn not to scale as the size of the tandoor may vary based on required power output. The proposed tandoor system also incorporates a continuous pellet/fuel fed mechanisms so as to enable the uninterrupted and automatic supply of fuel to the 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:

$$\dot{Q}_{cond.} + \dot{Q}_{conv.} + \dot{Q}_{rad.} = \dot{Q}_{total} \tag{1}$$



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

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

$$T_{w,s} = T_{w,f} \tag{3}$$

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

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

$$h = \frac{Nu_L * k}{L} \tag{5}$$

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

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

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

Design of Forced Draft Stove

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

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

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

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

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

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

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

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

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

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)):

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

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

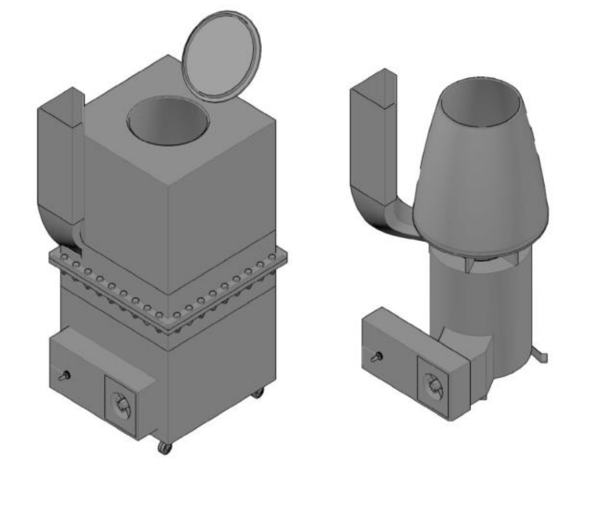
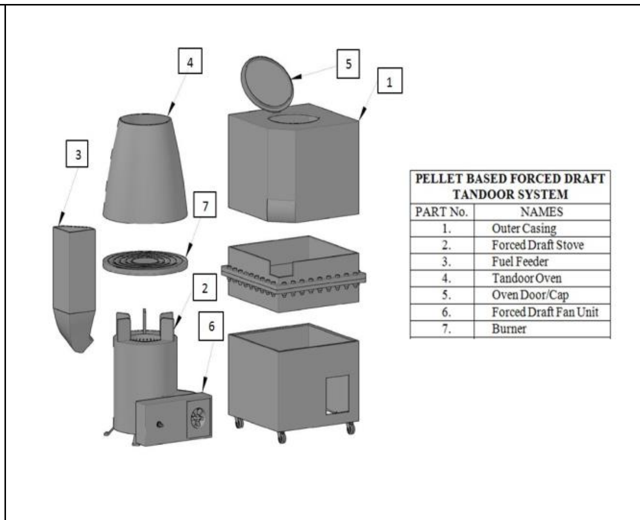


Fig.1 Pellet based Forced Draft Clean Tandoor Community Kitchen System (CTCKS) (a) With outer casing (b) Without outer casing



PELLET BASED FORCED DRAFT TANDOOR SYSTEM	
PART No.	NAMES
1.	Outer Casing
2.	Forced Draft Stove
3.	Fuel Feeder
4.	Tandoor Oven
5.	Oven Door/Cap
6.	Forced Draft Fan Unit
7.	Burner

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

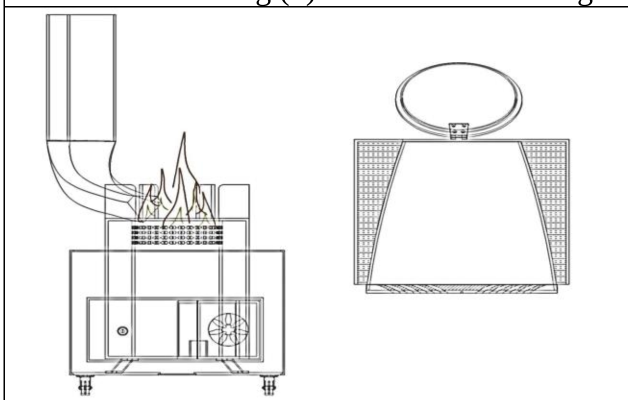
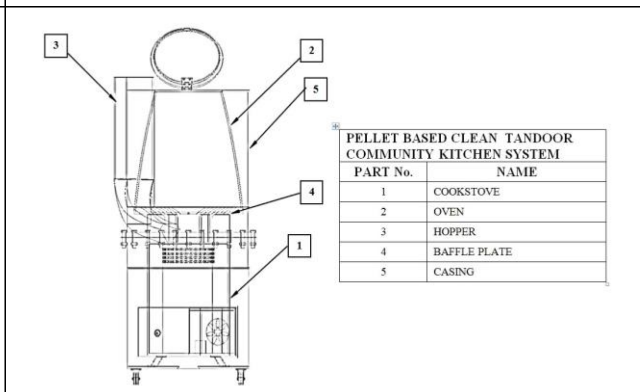
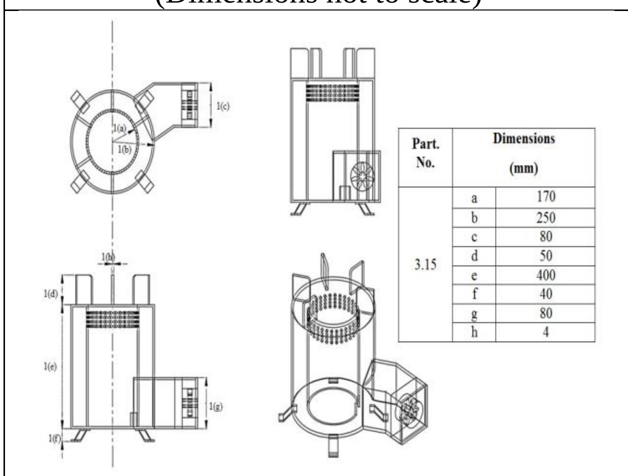


Fig. 3 Line diagram of CTCKS showing Combustion unit and Oven section (Dimensions not to scale)



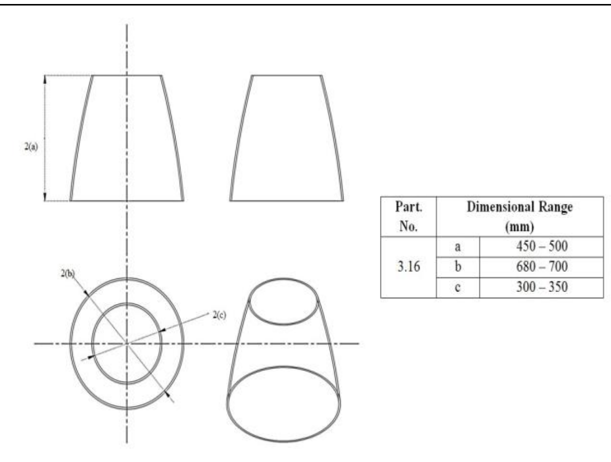
PELLET BASED CLEAN TANDOOR COMMUNITY KITCHEN SYSTEM	
PART No.	NAME
1	COOKSTOVE
2	OVEN
3	HOPPER
4	BAFFLE PLATE
5	CASING

Fig. 4 Line diagram of CTCKS



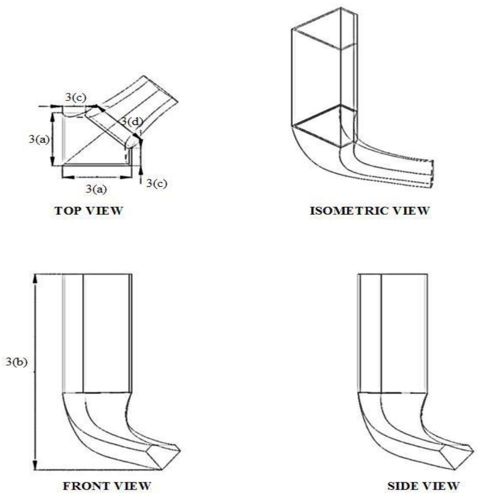
Part. No.		Dimensions (mm)
3.15	a	170
	b	250
	c	80
	d	50
	e	400
	f	40
	g	80
	h	4

Fig. 5 Child Parts of CTCKS: Cookstove



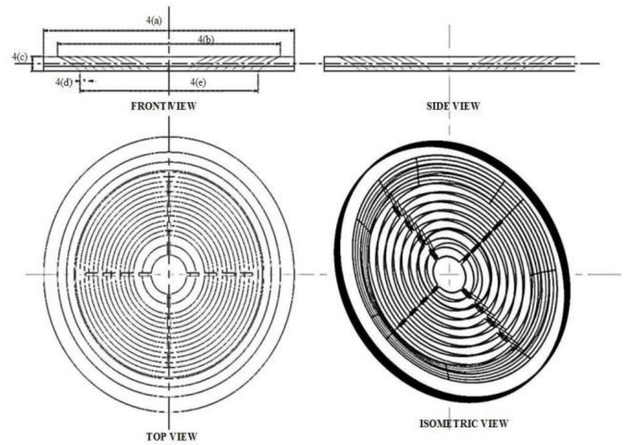
Part. No.		Dimensional Range (mm)
3.16	a	450 – 500
	b	680 – 700
	c	300 – 350

Fig. 6 Child Parts of CTCKS: Oven



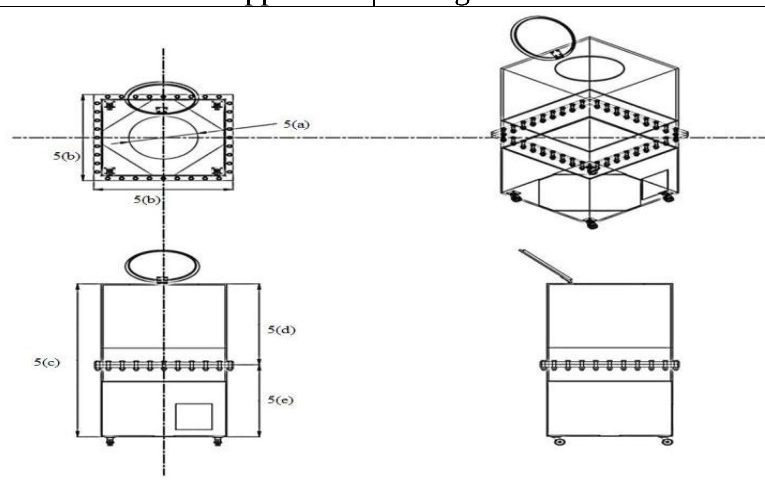
Part. No.	Dimensional Range (mm)	
3.17	a	160 – 180
	b	600 – 700
	c	80 – 100
	d	170 – 200

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 2
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.

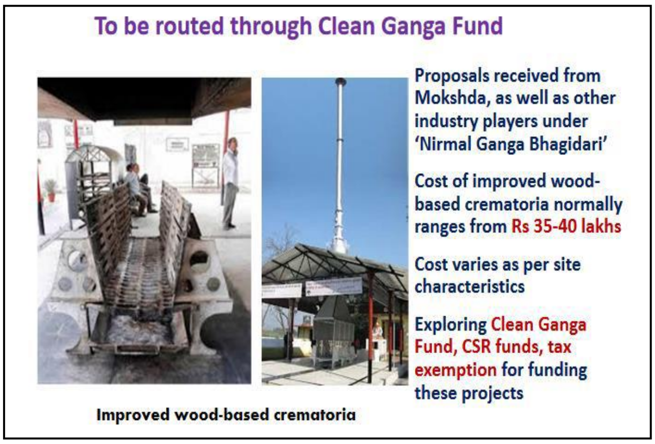
According to a report, all the year round, around 50 to 60 million trees are burned during cremations in India. While burning the wood, there is also emission of million tonnes of carbon dioxide gas which is not good for the environment. Also, cremation in open grounds generates large amounts of ashes, 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)**.

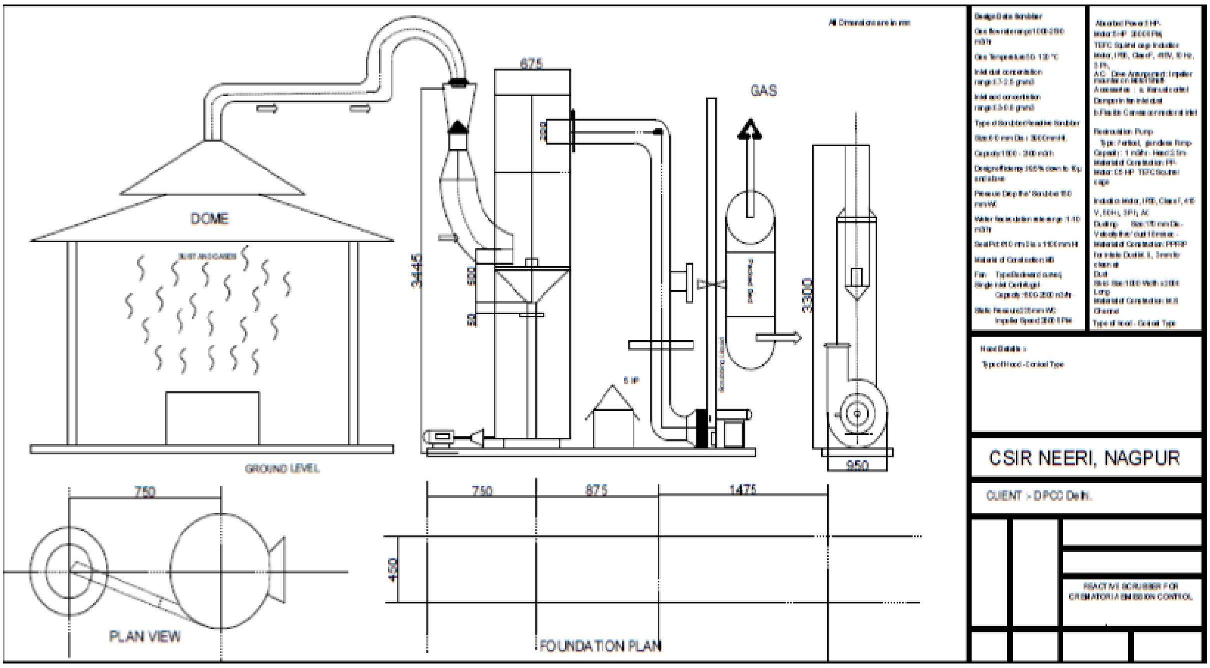


Figure 1 : Detailed diagram of emission control system for open type with side enclosed crematoria

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**.

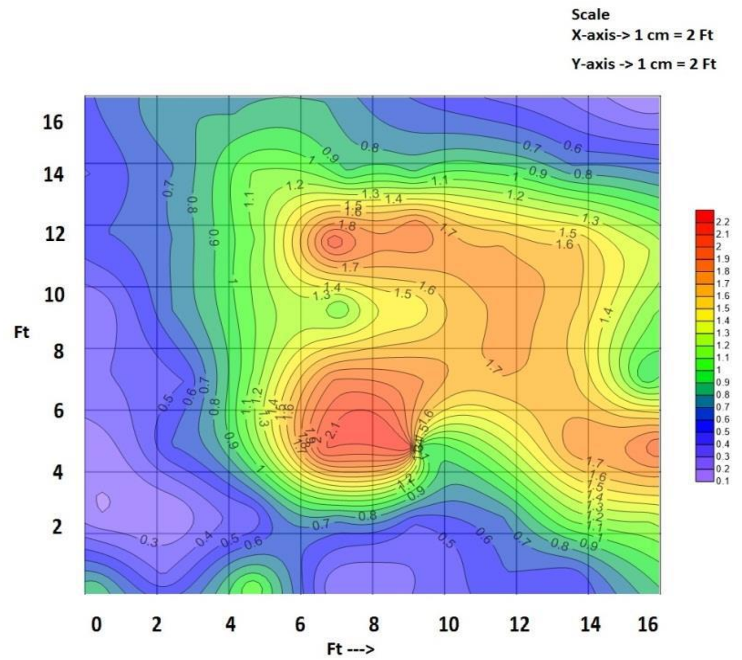


Figure 2 : Velocity profile of fumes during cremation

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.

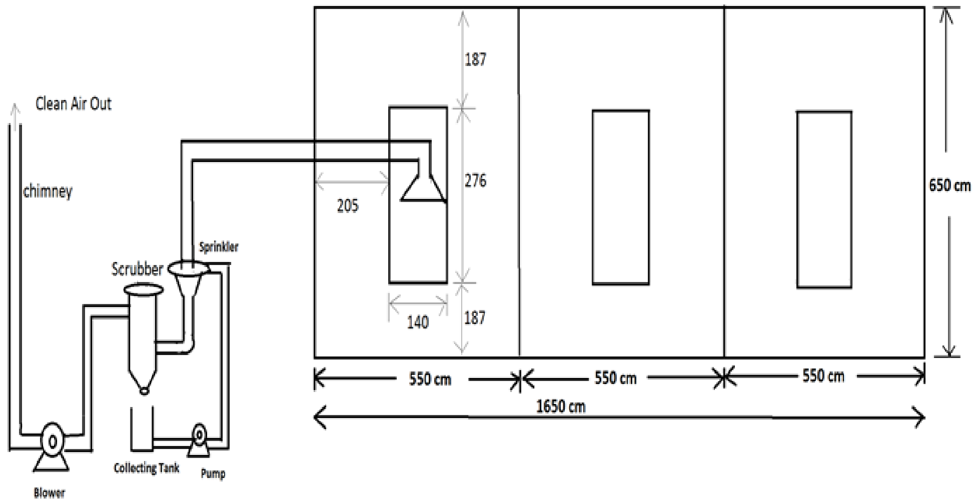


Figure 3 : Schematic view of Air Pollution Control System installed at Mokshadham Crematoria, Nagpur

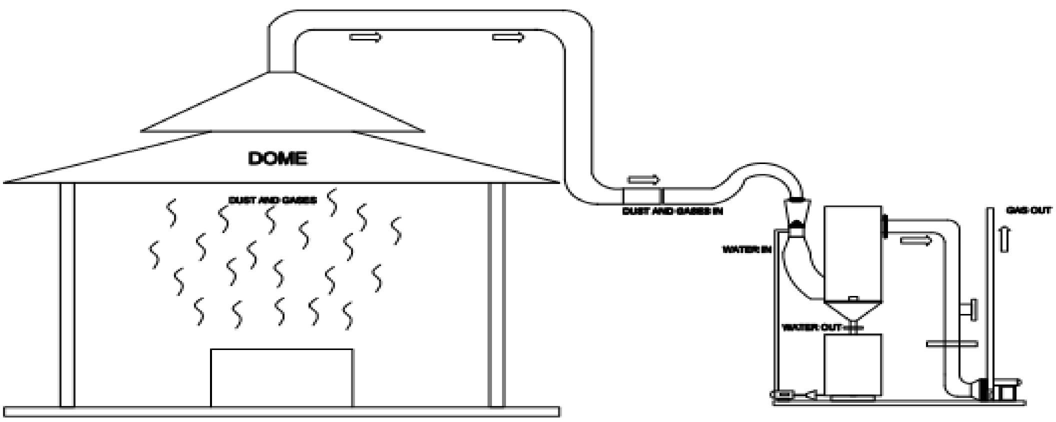


Figure 4 : Schematic view of Air Pollution Control System

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.

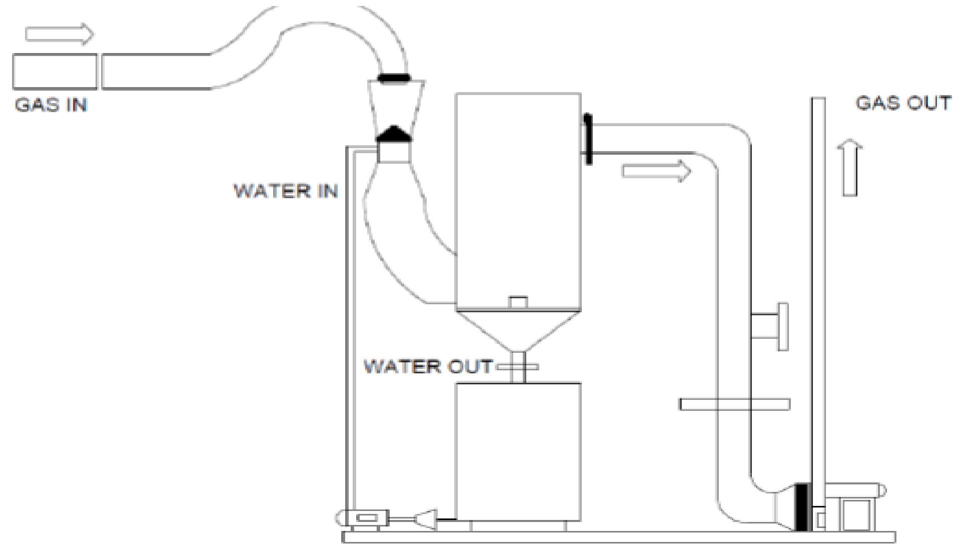


Figure 5 : Schematic of Reactive Scrubber

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 3
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).

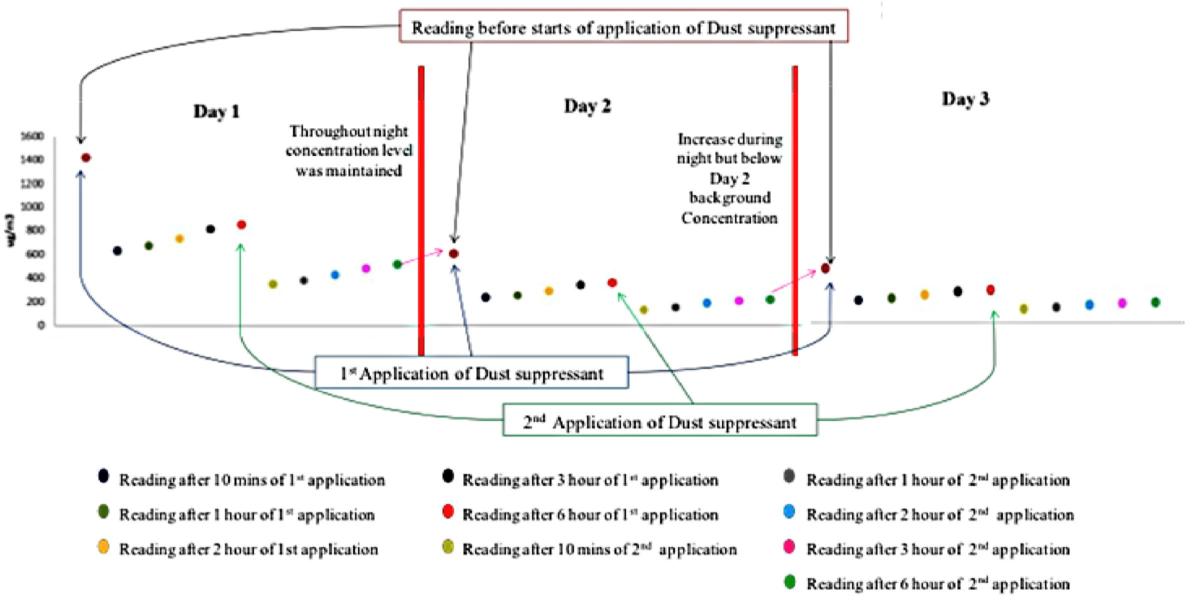
Advantages

- 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

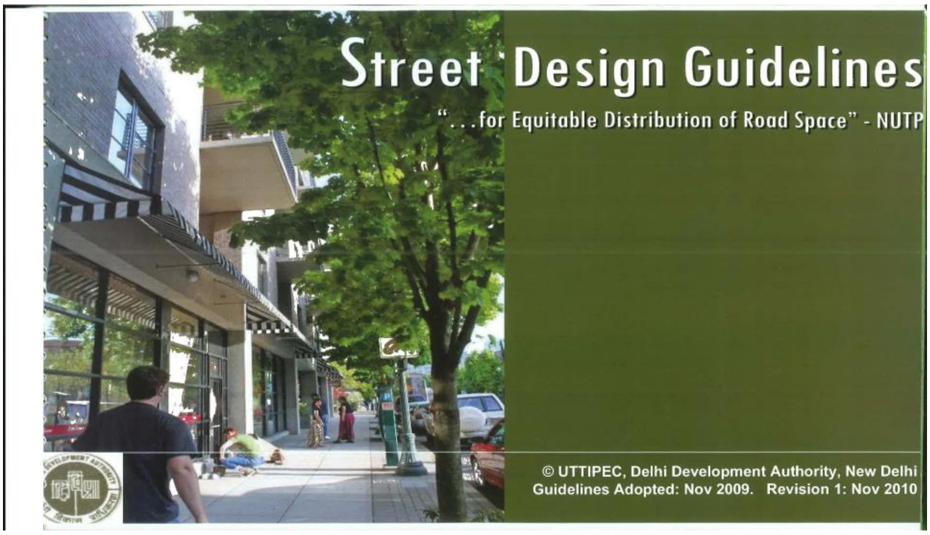
A biological filtration canal is a shallow depression created in the earth to accept and convey storm water runoff. A biological filtration canal uses natural means, including herbaceous vegetation and soil, to treat storm water by filtering out contaminants being conveyed in the water. Canals require 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.

Acknowledgements

This study was sponsored by the Maharashtra Pollution Control Board (MPCB) as part of the National Clean Air Programme (NCAP) source apportionment initiative titled "Air Quality Monitoring, Emission Inventory, and Source Apportionment Studies for Seven Cities in the State of Maharashtra."

The study was jointly undertaken by the Air Resource Sub-vertical of the ERP&M Vertical and the Mumbai Zonal Centre of CSIR-NEERI, Nagpur, in collaboration with the Environmental Science and Engineering Department (ESED), IIT Bombay. The progress of the project was impacted by the COVID-19 pandemic and subsequent lockdown restrictions; the extension granted by MPCB to facilitate completion of the work is gratefully acknowledged.

The authors sincerely express their gratitude to the MPCB Chairpersons, Member Secretaries, and Joint Directors (Air), for their constant support, guidance, and encouragement throughout the study. The cooperation extended by the Regional Officers of MPCB and officials from various Urban Local Bodies (ULBs**)** was invaluable in facilitating field activities and data collection for emission inventory development.

Special thanks are due to Ms. Snehal Gole (NCAP) for her kind assistance, coordination, and continuous support. The authors also extend heartfelt appreciation to all MPCB staff members for their dedication and extensive behind-the-scenes efforts that made this work possible.

Insightful discussions and valuable suggestions from Prof. Mukesh Khare, Dr. B. Sengupta, Dr. Rakesh Kumar, Dr. Ajay Deshpande, and Dr. Harish Gadhavi are gratefully acknowledged. Their expert advice significantly contributed to the quality and direction of this study.

CSIR-NEERI Scientific Staff

Dr. Atul N. Vaidya	Dr. S. Venkata Mohan	Dr. K.V. George
Dr. Nitin Goyal	Mr. Rahul V. Vyawahare	Dr. Neel Kamal
Dr. Asha P. Lalwani	Dr. Vaishali. V. Khaparde	
Mr. Madhur Manve	Mr. Abhishek Singh	Mr. Vaibhav Nandgaye
Mr. Anurag Tingre	Ms. Sweety Suryawanshi	Dr. Jay Singh Rajput
Ms. Prachi H. Trivedi	Mr. Pabitra Mondal	Mr. Aryan Verma
Ms. Bhagyashri Choudhary	Mr. Raj Sonarghare	Mr. Pranav Nair
Mr. Atharva Malode	Mr. Maneet Singh Khurana	Ms. Roshni Bang
Ms. Dhanshree Gaidhane	Ms. Pratiksha Wadaskar	

ESED, IIT Bombay Personnel

Ms. Pranalee More	Mr. Sarveshkumar Sharma	Ms. Sonali Borse
Mr. Vinod Bansode	Dr. Rasma K.	Dr. Darpan Das
Dr. B. Sreekanth	Ms. Umangi Mehta	Professor Virendra Sethi