Special Scientific Report
SAFAR-Pune-2020

SAFAR-INDIA (Pune)

SAFAR-HIGH RESOLUTION GRIDDED EMISSIONS INVENTORY OF PUNE, PIMPRI AND CHINCHWAD REGIONS

Indian Institute of Tropical Meteorology, Pune

2020

SAFAR-HIGH RESOLUTION GRIDDED EMISSIONS INVENTORY OF PUNE, PIMPRI AND CHINCHWAD REGIONS

System of Air Quality and Weather Forecasting And Research (SAFAR) - PUNE

Principal Lead Authors

Gufran Beig[1], Suresh Gosavi[2]

Lead Authors

U.S. Mukkannawar[1], S.K. Sahu[3], S. Tikle[1], S. Dole[1]

Contributing Authors

P. Kamble[2], S. Kale[2], B. S. Murthy[1], R. Latha[1], P. Mangaraj[3], R. Ambulkar[1], D. Jadhav[1], I. Basheer[1], A. Yadav[1], N. Shinde[1], D. Palampalle[1], D. More[1] and S. Athulya[1]

Partner Institutions:

[1]Indian Institute of Tropical Meteorology, Pune -411008

[2]Savitribai Phule Pune University, Pune-411007

[3]Utkal University, Bhubaneswar -751004

Cover design: Gaurav Shinde, ENVIS-IITM, Pune

Peer Review Panel

Peer review is an integral part of scientific publishing that confirms the validity of the science reported. Peer review ensures publishing good science and benefits the entire scientific community. We are indebted to the following panel of reviewers for taking out time to review this report and providing constructive comments and valuable suggestions to make this work in its current form. They are known experts in the subject areas and "who is who" in air quality.

(1) ***Prof. Guy P. Brasseur***
Former Director, Max Planck Institute for Meteorology (MPI), Germany; Associate Director, National Centre for Atmospheric Research (NCAR), USA; Former Chairs, WCRP Joint Scientific Committee and IGAC of IGBP

(2) ***Prof. Greg G. Carmichael***
Chair of WMO/GAW SSC and Director, University of Iowa Informatics Initiative, Professor of Chemical & Biochemical Engineering, College of Engineering, University of Iowa, USA

(3) ***Prof. Ranjeet S Sokhi***
Director of the Centre for Atmospheric and Climate Physics Research, Director of the Centre for Climate Change Research, Chair of WMO/GAW GURME Science Advisory, University of Hertfordshire, Hatfield, UK

(4) ***Prof. Shyam Lal***
Former Professor and Area Chairman, Physical Research Laboratory (ISRO), Ahmedabad

(5) ***Prof. Mukesh Khare***
Member -Commission for Air Quality Management in National Capital Region and Adjoining Areas and Professor, Indian Institute of Technology (IIT), New Delhi

(6) ***Dr. Ying Chen***
Scientist, The University of Exeter, UK

(7) ***Prof. (Mrs.) Nilima Rajurkar***
Former Head, Environmental Science Department, Savitri Bai Phule Pune University, Pune

(8) ***Dr. Chhemendra Sharma***
Chief Scientist and Division Head, CSIR-National Physical Laboratory, New Delhi

(9) ***Mr. Sanjay Kulkarni***
Head, Environment Department and Executive Engineer (Environment), Pimpri-Chinchwad Municipal Corporation (PCMC), Pune

(10) ***Mr. Mangesh Dighe***
Environment Officer, Pune Municipal Corporation (PMC), Pune

ACKNOWLEDGEMENT

This report is the outcome of a national project 'System of Air Quality and Weather Forecasting And Research (SAFAR), funded by Indian Institute of Tropical Meteorology, Pune, Ministry of Earth Sciences, Government of India. This report is prepared with all reasonable skills, knowledge, care, and diligence by SAFAR Team of Indian Institute of Tropical Meteorology (IITM), Pune in association with SPPU, Pune and other stakeholders. At the outset, we acknowledge with gratitude the motivation provided by the Dr. M. Rajeevan, Secretary, Ministry of Earth Sciences, Govt. of India, and Prof. Ravi Shankar Nanjundiah, Director IITM, Pune. We are thankful to Dr. Nitin Kalmlkar, Vice-Chancellor, SPPU for facilitating the campaign, a vital part of the emission inventory project. The campaign has been managed by the active support of Department of Environment Sciences, SPPU, which need to be applauded. This report's primary data has been generated through the campaign involving around 200 graduate and postgraduate students after providing them with the orientation training on the methodology and quality assurance and control protocol. We sincerely acknowledge the hard work of all student volunteers from different colleges and universities who have participated in the field campaign and collected the primary data in adverse condition on several occasions. The secondary data has been collected from reliable resources and government agencies which have been further validated by sampled primary data bins as per the work scope. We thanks all those agencies who have provided us the secondary data.

The inferences, analysis and final product made in this report are based on the primary data generated by us and secondary data collected as mentioned above. The project could not have been completed without the active support in providing various information and secondary data from Pune Municipal Corporation (PMC), Pimpri Chinchwad Municipal Corporation (PCMC), Pune Metropolitan Region Development Authority (PMRDA), Regional Transport Office (RTO) of Pune & PCMC, Maharashtra Pollution Control Board (MPCB), and other agencies and individual in and around Pune. We record our sincere thanks to all the above agencies. A gridded emission inventory has been developed through the Geographical Information System (GIS) based statistical model developed by the SAFAR and Utkal University teams. We sincerely thanks all those young scientists who have put their effort to develop the comprehensive GIS based model in 2010 itself which has gone several value additions with time and became a benchmark of SAFAR. Last but not the least, we greatly value and express our gratitude to all reviewers, whose details are provided in pre-page, who have provided their valuable and constructive comments to make this report in its present form.

Contents

List of Tables

List of Figures

Indian Institute of Tropical Meteorology
Ministry of Earth Sciences
Government of India

EXECUTIVE SUMMARY

SAFAR-HIGH-RESOLUTION (400m x 400m) GRIDDED EMISSIONS INVENTORY FOR PUNE, PIMPRI AND CHINCHWAD REGIONS

Air pollution research is increasingly becoming a topic of immediate interest due to its close linkages with Human health and ecosystem. Unlike several other irreversible processes, anthropogenic sources (human-made) can be inverted as a major cause of air quality deterioration. When the local concentrations of air pollutants exceed a specific threshold limit, it can harm the health of human beings, plants and animals. Most of the mega-cities worldwide are experiencing the deterioration of air quality. The various natural and anthropogenic sources account for environmental pollutant emissions load. The anthropogenic emission is on the rise. Emission Inventory is a comprehensive listing by local sources of air pollutant emissions and the number of air pollutants released into the air due to a specific process in a particular geographic region during a specific period. It is one of the most critical factors required for air pollution forecasting models and meteorological input to forecast the air quality and frame the mitigation strategy. Quality of forecasting depends on the accuracy and reliability of emission estimation. Emission inventories could also be used for air quality management and formulating environmental policy.

Emission inventory development is an area of current interest but a complex process due to numerous, diverse and widely dispersed emission sources in Pune region. Region covers multiple megapolis like Pune, Pimpri and Chinchwad (includes PMC, PCMC, KCB, PCB, DCB & adjoining region), called as "Pune Metropolitan Region (PMR)" in the rest of this report. The widespread campaign requires a vast amount of ultra-high-resolution activity data, emission factors, and knowledge of fundamental scientific processes. An extensive scientific field campaign has been carried out in PMR by involving more than 200 student volunteers from different colleges along with SPPU for several months jointly organized by IITM and SPPU. An orientation workshop has been arranged for the volunteers. Total campaign covered ~250,000 hours of data collection. The campaign's main focus was to generate missing primary data, validate some uncertain secondary data, and collect the available secondary data. The final product delivered was a high resolution (400m x 400m grid) gridded emission inventory of eight crucial air pollutants ($PM_{2.5}$, PM_{10}, NOx, CO, SO_2, BC, OC, VOCs as NMVOCs). Emissions inventory is developed for the PMR-region of 50km x 50km. During the campaign, following activity data and relevant information related to major / minor sources from 26 different targets have been collected as part of an elaborate exercise in a mission mode.

PMR is rapidly growing region of India, experiencing remarkably high vehicular density. The traffic volume has been calculated using click counters on different major and minor roads of the study area. The current campaign has covered more than 200 primary and minor roads from Municipal Corporation limits and fringe areas.

To develop the emission inventory, a bottom-up approach has been adopted. The Geographical Information System (GIS) based statistical model developed by SAFAR earlier has been used to prepare high-resolution gridded emission inventory. The emissions of PM_{10} and $PM_{2.5}$ from various sources along with relative % share of various sources are given in **Table-a**. Current emission estimates (Gg/Yr) in the PMR region for different pollutants, namely, BC, OC, NOx, CO, SO_2, and VOCs for the year 2019-20 are given in **Table-b.**

Table-a: Absolute Emission (Gg/yr) and Relative sectoral share of $PM_{2.5}$ & PM_{10} Emissions for Yr 2019-20

	$PM_{2.5}$		**PM_{10}**	
Sources	Emissions (Gg/Yr)	Sectoral Share	Emissions (Gg/Yr)	Sectoral Share
Transport	21.2	45.6%	21.8	25.2%
Industrial	11.3	24.4%	20.6	23.8%
Residential*	06.0	12.9%	10.8	12.4%
WBR Dust	02.9	06.2%	27.2	31.4%
Other#	05.0	10.8%	06.2	07.2%
Total	**46.4**	**----**	**86.6**	**----**

** **Residential Sector** - Residential cooking, Slum, Trash. Burning, Cow Dung, Street Vendor, Household, Wood burning, etc. # **Other Sector** - MSW Plants, MSW Open Burning, Crematory, Aviation, Incense Stick, Brick Clams, etc. WBR Dust- Wind Blown Re-suspended Dust*

Table-b: Absolute Emission in Gg/Yr of Different Pollutant Emissions from Different sectors Yr 2019-20

Sector (Gg)	BC	OC	NOx	CO	SO_2	VOCs
Transport	3.18	4.93	162.69	194.05	30.27	146.82
Industry	2.31	4.76	45.21	5.03	157.72	26.29
Residential*	1.33	2.708	6.94	65.67	1.97	16.125
Other#	0.65	3.10	7.17	28.10	1.61	1.20
	7.47	**15.50**	**222.01**	**292.85**	**191.57**	**190.44**

** **Residential Sector** - Residential cooking, Slum, Trash. Burning, Cow Dung, Street Vendor, Household, Wood burning, etc. # **Other Sector** - MSW Plants, MSW Open Burning, Crematory, Aviation, Incense Stick, Brick Clams, etc. WBR Dust- Wind Blown Re-suspended Dust*

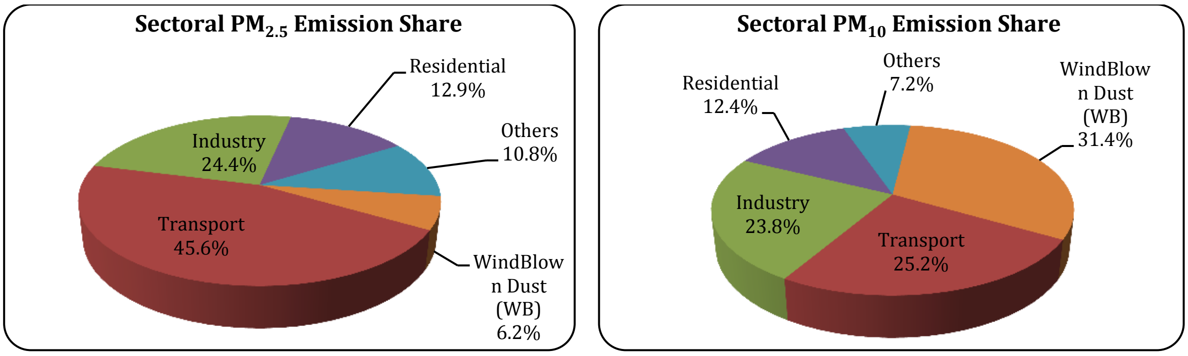


Figure-a: Relative Contribution of $PM_{2.5}$ & PM_{10} Emissions

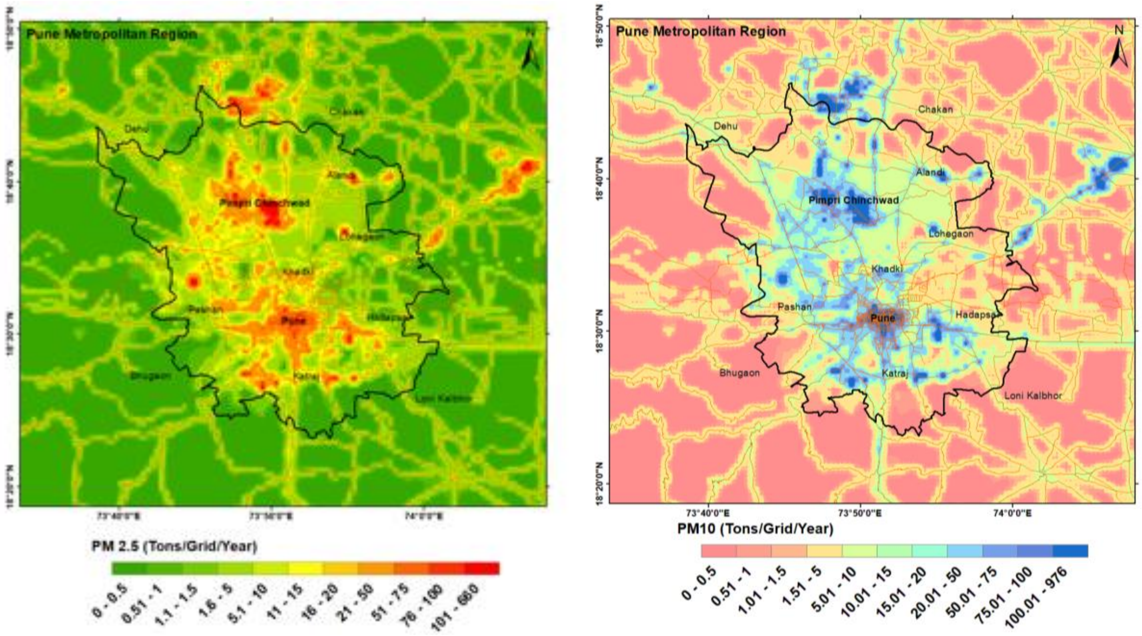


Figure-b: Geographical distribution of $PM_{2.5}$ & PM_{10} Emissions

Sectoral share illustrates – transport and vehicular movement induced re-suspended dust accounted for >50% of the particulate load (**Figure-a**). Residential and industrial contribute identical for PM_{10} and $PM_{2.5}$. Particulate concentration have spatially distributed all over the PMR region (**Figure-b**). Densely populated central areas have accounted for higher emissions. The transport being prominent source, found to be spread all across the study region. Northern areas are characterized with an industrial cluster along with associated residences and eateries. Some green cover i.e. hills, cantonment, university, gardens – spread across the region curtails the pollution at some extent. Out of city limits, predominantly Eastern and northern part have major state highways with heavy traffic.

Emissions Growth from 2012-13 to 2019-20: The percentage growth of emissions of various pollutants during seven year period has been estimated which is found to be highly significant. The % growth in 2019-20 as compared to 2012-13 is found to be 81.3% for OC, 72.8% for NOx, 69.8% for VOCs), and 30.2% for SO_2. (**Table-c**) The overall increase in the emissions of PM_{10} and

$PM_{2.5}$ over PMR region, which includes Pune, Pimpri and Chinchwad region, from 2012-13 to 2019-20 is found to be 61% and 70% respectively. Pune is a mix of land use province, ranging from commercial, residential, agricultural, reserved forests and water bodies. Given the extensive reforms in an industrial sector, it managed to control the emissions leading to moderate growth. Vehicles remain the major contributor of $PM_{2.5}$ emissions, followed by industries.

Table-c: Percent Change in PM_{10} & $PM_{2.5}$ Emissions during Past 7yrs (Yr2012-13 to Yr2019-20)

SECTORS	PM_{10}	$PM_{2.5}$
Transport	↑ 87.9%	↑ 91.0%
Industrial	↑ 33.8%	↑ 32.9%
Residential*	↑ 107.7%	↑ 57.9%
WBR Dust	↑ 49.5%	↑ 38.1%
Other#	NA$	NA$
Total	**↑ 61.3%**	**↑ 70.0%**

** **Residential Sector -** Residential cooking, Slum, Trash. Burning, Cow Dung, Street Vendor, Household, Wood burning, etc. **# Other Sector -** MSW Plants, MSW Open Burning, Crematory, Aviation, Incense Stick, Brick Clams, etc. WBR Dust- Wind Blown Re-suspended Dust **$** Many sources newly added so not appropriate to show growth.*

-Gufran Beig
SAFAR-India, IITM, Pune

CHAPTER 1
INTRODUCTION

1.1. Air Pollution and Emissions

Air pollution is not a current issue, but it has recognized since ages. When human first discovered that fire could be controlled and combustion fuels can be used for heating and cooking, it became clear that the by-products of fossil fuel combustion will be a big challenge to safeguard our environment. These by-products include the major combustion products of carbon dioxide and water vapor, along with a variety of trace gasses and aerosol emissions that have far-reaching impacts on air quality, human health, and global climate. Moses Maimonides, a Jewish leader, philosopher, and physician living in the middle ages in Cairo, Egypt from 1165 to 1204, noted in his writings (Finlayson-Pitts, 1986): *"...Comparing the air of cities to the air of deserts and arid lands are like comparing waters that are befouled and turbid to good and pure waters. In the City, because of the height of its buildings, the narrowness of its streets, and all that pours forth from its inhabitants and their superfluities... the air becomes stagnant, turbid, thick, misty, and foggy... If there is no choice in this matter, for we have grown up in the cities and have become accustomed to them, you should... select from the cities one of the open horizons... endeavor at least to dwell on the outskirts of the City..."* His discussion indicates that, in the twelfth century, air pollution already associated with urban environments and their higher population densities. It has continued since then, till date. Air pollutants are defined as tiny substances in the atmosphere, resulting from human activity or natural processes. These can cause harm to humans, plants, or animal lives, or damage to human-made materials and structures, or changes in the weather and climate, or interfering with the comfortable enjoyment of life or other human activities. (Bang and Khue, 2019). Fine particles produced through emissions from cars, industrial plants, and numerous other sources are hazardous to human health. The World Health Organization (WHO, 2019) stated that exposure to outdoor air pollution accounts for 4.2 million deaths each year. In 2019, 1·67 million deaths in India were attributable to air pollution, accounting for 17·8% of India's total deaths (Dandona et al., 2021).

The key reason for the alarming increase in air pollution is anthropogenic sources of emissions. The emission inventory is an itemized list of emission estimates for air pollution sources in a given area for a specified period. The quality of forecasting depends on the accuracy and reliability of emission estimation. Emission inventories could also be used for air quality management and formulating environmental policy. SAFAR had developed the first gridded Emission Inventory for Pune and surrounding regions in 2012-13. This comprehensive study based on the scientific knowledge made to develop emission inventory with 1.67km x 1.67km resolution of all major air pollutants for a domain of ~50km×50km Pune and its adjacent regions including Pimpri and Chinchwad (Beig et. al. 2013). Henceforth, a region will be called Pune Metropolitan Region (PMR) in the rest of this report.

1.2. Role of Emission Inventory in Air Quality Modelling

The concept of air quality forecasting is evolved much later than weather forecasting as it was not considered as essential as weather forecast. The air quality forecasting model is highly dependent of many factors starting from weather, geographical location to reliable monitoring of different concentrations present in ambient air. However, one of the most critical parameters required for predicting air quality of any location is emission inventory of predicted pollutants. Hence, gridded emission inventory becomes one of the essential and integral components of any effective air forecasting framework. Emission inventory is a comprehensive listing by sources of air pollutant and amount of air pollutants released into air because of a specific anthropogenic process in a particular geographic region during a specific time period. It mainly includes surface emission data compiled from both anthropogenic and natural sources. It is one of the most critical and sensitive components of air quality forecasting system. Meteorological forecast is associated with prediction of condition of the atmosphere for a given location and time. Many models are used world over for local weather forecast but most widely used model is WRF (Weather Research Forecast) model. A chemical transport model stimulates various physical and chemical processes that are important for understanding atmospheric trace gas and particle distribution. Chemical transport model usually rely on a meteorological model for description of atmospheric states and motion, and depends on an emission model for the description of anthropogenic or biogenic emissions. Any forecasting model is incomplete without its validation with observations for which robust monitoring network is required.

An effective science based air quality management requires emission inventory for robust control strategies. Emission inventories not only helps to identify the emission sources in the region and contribution of each source to the total emission but also eventually guide us to set priorities for the action plan for different sources, evaluating the various options available to reduce the emissions from identified potential sources, formulate, and implement the appropriate action plan. It has been used as one of the important fundamental components in air quality modeling application and also for air quality management plans to measure progress/changes over time to achieve cleaner air. Emission inventories are now regarded as indispensable tools for prevention of air pollution at national and regional/city scale.

1.3. Scope of the Report

Any pollutant emission is an ongoing process whose magnitude depends on the variability of their sources and activity data. However, the development of emission inventory with current data and generating the primary data is a very complicated and cumbersome task. Hence, it is attempted for PMR region after a gap of about seven years. The scope of present study is to develop an emission inventory for the Pune Metropolitan Region with ultra-high resolution (400x400m) for Pune, Pimpri and Chinchwad regions (50kmx50km) for the year 2019-20. The emission inventory is developed for eight major air pollutants namely, Oxides of Nitrogen (NOx); Carbon Monoxide (CO); Black Carbon (BC); Organic Carbon (OC); Particulate Matter <2.5 microns ($PM_{2.5}$); Particulate Matter <10 microns (PM_{10}); Sulfur Dioxide (SO_2) and non-methane Volatile Organic Compounds (NMVOCs) will be termed as VOCs in the rest of this report. Primary data collection is of crucial importance. It requires preliminary ground verification of the activity data. It confirms the authenticity of available secondary data to date through representative primary surveys. The verification is conducted with the representative baseline data collection. It helps to develop a firm framework to account for air pollutants. To understand the variability of these pollutants' emissions from 2012-13 to 2019-20, we have also estimated the percentage change (%) during the past seven years.

CHAPTER 2 - STUDY AREA AND SOURCES OF EMISSIONS

2.1. Study Area

Pune Metropolitan Region (PMR) covers the area between (18.55°N – 18.49°N) latitudes and (73.49°E – 74.11°E) longitudes. It is located at the western margin of the Deccan plateau on the leeward side of the Sahyadri hills. The mean sea level height is from 500m to 1400m. Present work considers the part of PMR covering three towns viz. Pune, Pimpri and Chinchwad including cantonment boards – KCB, PCB, & DCB. **Pune,** a historic town has a favorable site at the confluence of Mula and Mutha rivers. These rivers, along with two other rivers viz. Pavana and Indrayani are responsible for bringing the water resource to the region from Western Ghats' heavy rainfall areas. The area is part of the upper Bhima basin. The highest point within the City is the Vetal hill (800 m) whereas the urban area's highest point is the Sinhagad fort. Pune City has an area of 492km^2 at an altitude of 560m, above mean sea level on the eastern slope of Sahyadri hills in Pune district (Mukkannawar, 2014). As on 2020, the city area is 332.56km^2 (ESR-Pune City 2019-20). Town is blessed with Mula and Mutha Rivers. Two more rivers, Pavana and Indrayani, flow through the northwestern periphery of the urban area. Khadakwasala, Panshet, Varasgaon, and Temghar dams are on the upstream of Mutha River, which provides drinking water to the City and irrigation to many villages along downstream. According to the census 2011, the population of Pune city was 31.15 lakhs and as on date it is ≃33.71lakhs (https://www.pmc.gov.in/). More than six times in the City's population in the last 60 years; from 4.85 lakhs in 1951 to 31.15 lakhs in 2011. The decadal population growth rate from 1991 to 2001 was 50.08 %, more than double the national rate. A large part of this rapid growth has been due to the high level of migration, expansion of educational institutions, particularly in professional courses, expansion of many government institutions, the industrialization of PMC/PCMC after 1960, and expansion of information technology (IT) industry.

Pimpri Chinchwad is known by many nomenclatures worldwide. Widely famous as Industrial Township, it also recognized as Detroit of the East with many national and multinational automobile companies. The Maharashtra Industrial Development Corporation (MIDC) has its base in Bhosari. The township situated at the height of 530m above the sea level. It is blessed with a salubrious climate all year-round. PCMC has an area of 181km^2 located on the northern boundary of Pune city. According to the census 2011, the population of the PCMC area was 17.29lakhs and as on date it is ≃20lakhs. At the same time, the present population has raised to ≃20lakhs (https://www.pcmcindia.gov.in/). The corporation is experiencing substantial growth in migration, educational institutions, industrialization; along with information technology (IT) industry.

The climate of PMR can be considered pleasant because its maximum temperature in May is less than 40°C and winters are not severe. This region is lying in the semi-arid monsoon zone and hence marked by the vegetation cover ranging from moist deciduous to dry deciduous. It receives rainfall from June to September. Pune metropolitan region established in July 1967; urban area or agglomeration as recognized by the central government includes the areas under Pune and Pimpri-Chinchwad corporations. The total area of the Pune metropolitan region was 1,605 Km^2. Under the settlement, the area has increased 2-4 times during the period of 30 yrs. The areas under agriculture and grassland-scrubs have been decreased by 31% and 39% respectively. The area under hills and forest and some hill slopes are encroached by the settlements. It shows that an increasing Pune city population has created a lot of pressure on available land in the City. Thus, the City's limits are increasing, and adjacent villages are merging into the corporation limit. In 1997, 23 villages added to the old municipal limit, and the total area of Pune city had increased from 145.92 km^2 to 243.96 km^2. The land use pattern shows that around 43 % area is residential, 2% under the commercial zone, 4% under the industrial zone, and 16% under the public, semi-public and recreational zone. Despite rules banning the construction activity on hilltops and slopes, the encroachment of settlement in such areas has observed in the last decade.

2.2. Sources of Emissions

There are several small and significant sources of emissions, both natural and anthropogenic. However, after the industrial revolution and fast economic development, anthropogenic emissions became the primary concern of human activities (Beig et. al. 2018). Based on the source attributes, air emission sources typically divided into three main categories: area source, point source, and line or mobile source. Each source includes many subcategories based on its distributed characteristic, shown in detail in **Figure 1**.

Point sources are stationary sources typically large manufacturing or production plants that include confined, chimney, or stack emission points. Within a given point source, there may be several units of combustion, such as several boilers. The point sources are hospital incinerators, hospital boilers, hotel boilers, crematorium, and industries.

Area sources defined as too small and too numerous to be considered point sources (US EPA, 1996). In aggregate, these sources may contribute a significant proportion of the total air-shed emissions. Area sources include a wide range of sources, such as residential cooking facilities, rice straw/biomass burning, gas stations, construction activities, printing facilities, auto repair facilities, paint spraying facilities, and so on.

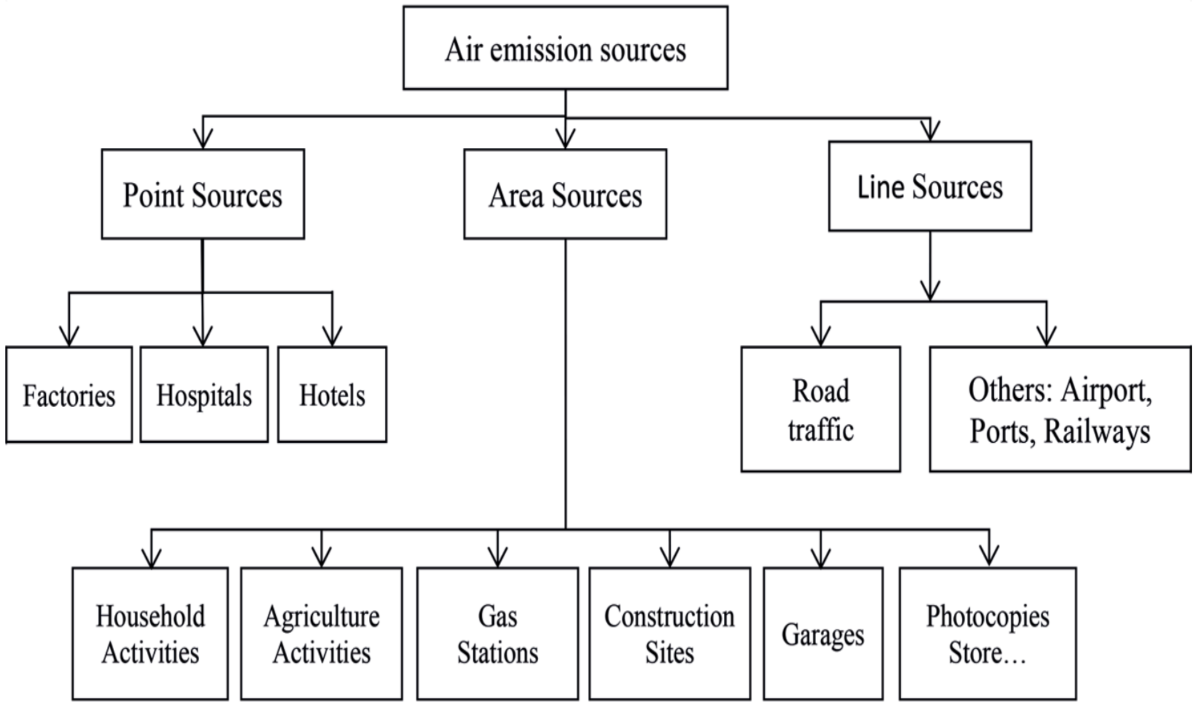


Figure 1: Sources and Subcategories

Line sources also called mobile sources, are vehicles, engines, and equipment that generate air pollution and move from place to place. Mobile sources classified under two smaller sources: on-road and non-road sources. On-road sources include vehicles plying on roads to transport passengers or freight, such as passenger cars, trucks, and motorcycles. These run with fuel gasoline, diesel fuel, or alternative fuels, such as natural gas. Non-road sources include gasoline and diesel-powered vehicles, engines, and equipment used for construction, agriculture, transportation, recreation, and many other purposes. For example, non-road sources include marine vessels, aircraft, railways, tractors, etc. They presented as a line shape on the map.

In all, around 26 different sectors along with their primary emitting sources considered in this work. **Table 1** provides the listing of these sectors and related parameters:

Table 1: Details of Target Sectors & Emission sources considered in this work

Sr. No.	Sectors	Important Factors and data
1.	Transport	— Category, Fuel Type & Quantity — Vehicle/hour/Road type/VKT
2.	Slum	— Type and fuel used quantity for cooking
3.	Brick Industry	— Type, Technology and Fuel used quantity
4.	Street Vendor	— Type and Fuel Quantity — Coal for Tandoor
5.	Hotel (Dhabas)	— Type of Fuel & Quantity used for cooking
6.	Construction Sites	— Type of Fuel & Quantity used for cooking activity

7.	Speed Breaker	— No. of Speed Breakers per Km — Road Type
8.	Major Hospitals	— Number of outdoor patients — Vehicle load and DG sets
9.	Tourist places	— Tourist Load, Vehicle load
10.	Shopping Malls	— No. of vehicles parked
11.	Traffic Junctions	— No. of Traffic Junctions
12.	Railway Stations	— Passenger load — Vehicle load in the station area
13.	Airport	— Vehicle No. (Pune & Out-side vehicle No.)
14.	Industry	— Type, Technology, and Fuel used
15.	Local Transport (Ola/Uber/Taxi)	— Km run per day and Numbers
16.	Household	— Type of Fuel used
17.	Waste Burning	— Quantity per capita
18.	Biomedical Waste	— Quantity generated
19.	Power plant	— The technology used, coal used
20.	Crematorium	— Spatial locations, No. of Cases
21.	Large hotels	— Fuel used for cooking
22.	Large school/college	— Students no. & Travel load
23.	Wind Blown Road Dust	— Road condition, vehicle load, etc
24.	Diesel Generator	— Fuel used for no. of hours
25.	Mobile tower	— Fuel Used & numbers
26.	Routine Milk & Vegetable Van	— No of vehicles (outside)

CHAPTER 3 - METHODOLOGY

To build a technological emission inventory is a complex process due to numerous, diverse and widely dispersed emission sources where the population is growing with rapid urbanization. Therefore, emission estimation efforts face enormous challenges in terms of inclusion of essential sources in the estimation. To develop reasonably representative and accurate emissions estimates from such a large number of diverse sources, how to keep track of changes in the number and nature of such emission sources, so that emission can be estimated for a particular period. During the preparation of the complex inventory, the first step includes recognizing sources; the second step consists of distributing emission geographically. In the current inventory development, we have followed "Bottom-up" approach to improve the accuracy; reliability and uncertainty in inventory (Kalimont et al. 2002, Sahu et al., 2011 & Bond et al., 2004). The present work is done by estimating the emissions based on activity data at the grid level.

3.1. Geographical Information System Methodology

A Geographic Information System (GIS) is a computer-based information system that enables capture, modelling, manipulation, analysis and presentation of geographically referenced data. Better organization of data being an essential aspect that allows GIS to become one of the essential tools for research purpose. The easy understanding feature of GIS fulfils the need of the study and the development of emission inventory. The GIS-based statistical methodology is widely used in air quality or emission inventory related activities nowadays. The ability of GIS to answer technical questions also makes GIS an excellent tool. The user-friendliness of GIS is a feature that has made GIS one of the most used platforms for planning worldwide.

As per the recent road network over the PMR domain in the present work, we have prepared the road network in and around the city limits. Thus, grid cells having a 0.4km×0.4km resolution covering PMR prepared and used as a gridded input for the regional atmospheric chemistry transport models. Spatial allocation (gridding) is essential for model application and analysis. It is a process to transform large and irregularly shaped emission data into consistent data using GIS tools. The geo-referenced grid cells superimposed over the spatially distributed emission from different sectors. The emission value for the gridded cells based on the corresponding contribution of different sources lying inside the grid cells calculated in the GIS environment. The emission values from different sources are organized asset of thematic layers for refined analysis.

3.2. Mathematical Algorithm:

Preparation of authentic database with the highest possible resolution is one of the most challenging tasks. Emission of a particular pollutant from a particular source category estimated as a product of activity data, EF, application of combustion technology and removal efficiency of emission control. All the sources summed over all sources categories. The above calculation is similar to that described by Kalimont et al. (2002) and Bond et al. (2004). Hence, the total emission can be expressed by following **Equation 1** for all the pollutants unless specified otherwise;

$$\boldsymbol{TE = \sum_a \sum_b FU_{a,b} \left[\sum_c EF_{a,b,c} \;\; U_{a,b,c}\right]} \qquad \textbf{Equation 1}$$

Where,

a, b, c = sector, fuel type, technology;

TE= Total emission;

FU= Sector and fuel-specific amount;

EF= Technology specific EFs;

U = fuel fraction for a sector with a particular technology, where $\sum U = 1$ for each fuel-sector.

In the presence of technology-specific vehicular EFs for the transport sector for India developed by ARAI, the EF using vehicular technology information applied to the vehicle technology information and numbers. The emission from the transport sector has calculated as per **Equation 2**.

$$\boldsymbol{E_t = \sum (veh_l \times D_l) \times EF_{l,km}} \qquad \textbf{Equation 2}$$

Where,

Et = Total Emission of a compound;

Veh_l =Number of Vehicle per type;

D_l=Distance travelled in a year per different vehicle type;

EF_l, km= emission of a compound, vehicle type per driven kilometre

The paved (**Equation 3**) and unpaved (**Equation 4**) road dust emission factors have been cited from USEPA AP42, Section 13.2.1; March 1993.

$$\boldsymbol{E = [k(sL \div 2)^{0.91} (W)^{1.02}] \left(\frac{1-P}{4N}\right)} \qquad \textbf{Equation 3}$$

Where,

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

k = particle size multiplier for particle size range and units of interest;

sL = road surface silt loading (grams per square meter) (g/m2);

W = average weight (tons) of the vehicles traveling on the road;

P = number of "wet" days with at least 0.254 mm (0.01 in) of precipitation during the averaging period;

N = number of days in the averaging period (e.g., 365 for annual, 91 for seasonal, 30 for monthly)

$$\boldsymbol{E} = \left[\frac{k\left(\frac{s}{12}\right)^{a}\left(\frac{s}{30}\right)^{d}}{\left(\frac{M}{0.5}\right)^{c}} - \boldsymbol{C}\right]\left[\left(\frac{365-P}{365}\right)\right] \qquad \textbf{Equation 4}$$

Where,

EF = size-specific emission factor (lb/VMT) (per vehicle mile travelled);

s = surface material silt content (%)

M = surface material moisture content (%)

S = mean vehicle speed (mph)

C = emission factor for 1980's vehicle fleet exhaust, brake wear and tire wear.

P = number of days in a year with at least 0.254 mm (0.01 in) of precipitation

k, a, c and d are empirical constants	**PM_{10}**	**$PM_{2.5}$**
k (lb/VMT) for unpaved road	1.386	0.21
k (g/VKT) for paved road	0.62	0.15
a	1	1
c	0.2	0.2
d	0.5	0.5
C(lb/VMT)	0.00047	0.00036

3.3. Emission Factors

Emission factors (EFs) is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with a particular activity associated with the release of that pollutant. Typically, EFs of fuel depend on the fuel's chemical composition, combustion type, temperature, and efficiency of any emission control device. There are very limited measured EFs available in the literature for India. Incorporating a country-specific appropriate EF is a susceptible part of the development of emission inventory. EF defines the source strength as emission per unit time and unit activity of the process. Country specific technology-based EFs for most of the sectors are not yet available for India. Hence, in the development of emission inventory, selecting appropriate EF for a fuel type is exceptionally meticulous work for a specific country. Even a minor change in the EFs has the potential to alter the total emission inventory. The details of the data, along with the sources used, have discussed in the subsequent sections. The EFs used in the present work for major sectors are outlined in **Table 2**, **Table 3**, **Table 4**, **Table 5**, and **Table 6**.

Table 2: Emission Factors for Different Fuel Type and Vehicular Categories

2W- Two-wheelers; 3W- Three-wheelers; HCV- Heavy commercial vehicles; LCV- Light commercial vehicles;

Emission Factor			2W	3W-2S (CNG)	3W-4S	Buses (CNG)	Buses (Diesel)	P Cars (Petrol)	P Cars (Diesel)	C Cars (CNG)	C Cars (Diesel)	HCV (Diesel)	LCV (Diesel)	MSLV (Diesel)	On road Vehicles (Petrol)	On Road Vehicles (Diesel)
Emission Factors (g/km)	5yr	CO[a]	0.4	0.69	1	3.72	3.97	0.84	0.06	0.6	0.06	6	3.66	6	-	-
		NOx[a]	0.25	0.19	0.5	6.21	6.77	0.09	0.28	0.01	0.28	9.3	2.12	9.3	-	-
		PM[a]	0.015	0.118	0.015	0.044	1.075	0.002	0.015	0.002	0.015	1.24	0.475	1.24	-	-
		VOC[c]	2.03	0.1	-	0.01	-	0.24	0.28	0.01	0.28	0.85	0.01	0.85	-	-
	10yr	CO[a]	1.65	0.69	1	3.72	4.48	2.74	0.3	0.85	0.3	12.65	3.66	12.65	-	-
		NOx[a]	0.27	0.19	0.5	6.21	15.25	0.21	0.49	0.53	0.49	11.57	2.12	11.57	-	-
		PM[a]	0.035	0.118	0.015	0.044	1.213	0.006	0.06	0.001	0.06	1.96	0.475	1.96	-	-
		VOC[c]	4.31	0.1	-	0.01	-	1.88	0.41	0.01	0.41	1.97	0.01	1.97	-	-
	15yr	CO[a]	1.65	0.69	1	3.72	13.06	4.53	0.3	0.85	0.3	12.65	3.66	12.65	-	-
		NOx[a]	0.27	0.19	0.5	6.21	15.25	0.75	0.49	0.53	0.49	11.57	2.12	11.57	-	-
		PM[a]	0.035	0.118	0.015	0.044	2.013	0.008	0.06	0.001	0.06	1.96	0.475	1.96	-	-
		VOC[c]	4.31	0.1	-	0.01	-	1.88	0.41	0.01	0.41	1.97	0.01	1.97	-	-
g/kg		BC[d]	0.02	-	0.19	-	0.49	0.05	0.05	NA	0.05	0.34	0.19	1.24	-	-
		OC[b]	-	-	-	-	-	-	-	-	-	-	-	-	5.4	1.1
g/km		SO_2	0.013[e]	-	0.029[e]	-	1.42[e]	0.053[f]	0.149[g]	-	0.149[g]	1.42[e]	1.42[e]	1.94[e]	-	-

MSLV- Miscellaneous vehicles

Source: [a]ARAI, Air Quality Monitoring Project-Indian Clean Air Program, 2007 report /CPCB 2010 Report/Sahu et al. (2011); [b]Bond et al. (2004); [c]HEAT, ICLEI, Local Government for sustainability; [d]Umed et al. (2016); [e] T.V. Ramachandra et al. 2009; [f]Indian Institute of Petroleum (IIP), Automotive Research Association of India (ARAI) used in UNEP, 1999; [g] S. Baidya et al.2009

Table 3: Industrial Sector Emission Factors

Sr. No	Fuel Type	CO [a] kg/kl	NOx [a] kg/kl	SO_2[a] kg/kl	$PM_{2.5}$ [b] g/kg	BC [e] g/kg	OC [c] g/kg	VOC [d] kg/GJ	PM_{10}[f] kg/kl
1	CNG/NG	0.000272*	0.0028*	0.0000096*	0.34	0.216	0.001	0.005	0.00
2	LPG	0.19	1.45	0.00	0.31	0.0002	0.04	0.00	0.00
3	Wood	-	-	-	-	-	3.20	0.60	-
4	Diesel	0.63	2.75	31.05	0.97	0.35	1.40	0.15	0.0009
5	Coal	1#	7.5#	9.5#	1.36	1	0.90	0.001	-
6	Kerosene	-	-	-	0.34	0.03	0.04	0.90	-
7	FO	0.63	7.50	77.00	0.65	-	-	0.00	-

** kg/m³, # kg/MT*

Source: [a]TERI, New Delhi; [b]Reddy & Venkataraman (2002); [c]Bond et al. (2004); [d]HEAT, ICLEI, Local Government for sustainability; [e]Cook et al. (1999); [f]AP-42

Table 4: Residential Sector Emission Factors

Sr. No.	Fuel Type	CO [d] g/kg	NOx [d] g/kg	VOCs [c] kg/GJ	$PM_{2.5}$ [a] g/kg	PM_{10} [d] g/kg	BC [b] g/kg	OC [b] g/kg	SO_2 [d] g/kg
1	LPG	0.25	1.80	0.00	0.33	2.10	0.0002	0.05	0.40
2	Wood	115.40	14.00	0.60	1.50	15.30	1.1	7.80	0.20
3	Coal	24.92	3.99	0.20	12.20	20.00	2.28	4.30	13.30

Source: [a]Reddy & Venkataraman (2002); [b]Bond (2004); [c]HEAT, ICLEI, Local Government for sustainability; [d]Source Apportionment Report, ARAI

Table 5: Aviation Sector Emission Factors

Emission Factors	CO_2	CH_4	N_2O	NO_x	CO	NMVOCs	SO_2
LTO (kg/LTO)	2560	0.04	0.1	11	5.3	0.4	0.8
Cruise (g/kg)	3150	0	0.1	17	5	2.7	1

*LTO – Landing and Take-Off

Table 6: Calorific value for different fuel types

Fuel Type	Calorific Values (GJ/kg)
CNG	0.0335
LPG	0.0438
Wood	0.0176
Diesel	0.043
Coal	0.0175
Kerosene	0.0438
FO	0.041858

3.4. Data and Analysis

The study had numerous data collection formats and handling points—questionnaires submitted to the data management cell of IITM for double data entry. Questionnaire data entered into Microsoft Excel Software, linked together based on the PMR area and respective sources. Data involved classification, the responses in a unique and abbreviated way. The approach made data entry easier. Each set of questionnaires were compared and cross-checked by coordinators. It was for ensuring accuracy and reducing bias. Each vertical, like source-specific survey sheets and health questionnaire data, were analyzed independently and then grouped. Statistical data analyzed using MS-Excel and SPSS 11.5. Statistics test used for the study, were descriptive statistics, odds ratio, etc.

3.5. Digital Data and Geo-referencing:

Before incorporating calculated emission into the GIS environment, some pre-processing tasks like geo-referencing, digitization, and attribute database building are required. The necessary spatial objects in GIS are points, lines, and polygons. An area source can be represented as a polygon. This industrial facility emits pollutants of interest represented by a point entity consisting of a single XY coordinate and several attributes. To map the transport sector's emission is one of the significant contributors to total emission; the entire major and minor road network over the area of interest is digitized to extract the line's vector map using GIS tool. As per the recent road network over Pune domain in the present work, we have prepared the road network of around 33250 km. Gridded input prepared for the regional atmospheric chemistry transport models, grid cells having 0.4km×0.4km resolution covering Pune are also prepared using GIS tools. Spatial allocation (gridding) is essential for model application and analysis. GIS has strong spatial overlay capabilities and is ideal for deriving data in the target unit, given the relevant source data. Spatial allocation of emissions can be accomplished by overlaying the facility location layer with the grid cell layer and aggregating each cell's facility points. It is a process to transform large and irregularly shaped emission data into consistent data using GIS tools. We have prepared geo-referenced grid cells of 0.4km×0.4km resolution for the gridded data extraction covering Pune area. GIS tool used to superimpose over the spatially distributed emission from different sectors. The emission value for the gridded cells based on the corresponding contribution of different sources lying inside the grid cells calculated in the GIS environment. The emission values from different sources are organized asset of thematic layers to be analyzed separately.

CHAPTER 4 - CAMPAIGN AND DATA GENERATION

4.1. Study Design

It is essential to carry out preliminary ground verification of the activity data to confirm the authenticity of available secondary data to date through representative primary surveys. The campaign's main focus was to generate missing primary data and validate it with uncertain secondary data. Along with the same, collection of the latest available secondary data was also of crucial emphasis. Baseline data collection carried out through surveys of representative samples for identified sectors contributing to regional emissions. A review of earlier secondary data and methodology adopted for its collection has also done before carrying out the surveys. To facilitate similar methodologies and approach considering the earlier method and its scientific suitability for the purpose, to avoid any further ambiguity to the whole process of surveys, some have been carried out through questionnaires supplementing it with certain aspects of air pollution such as health to elaborate our air quality concerns.

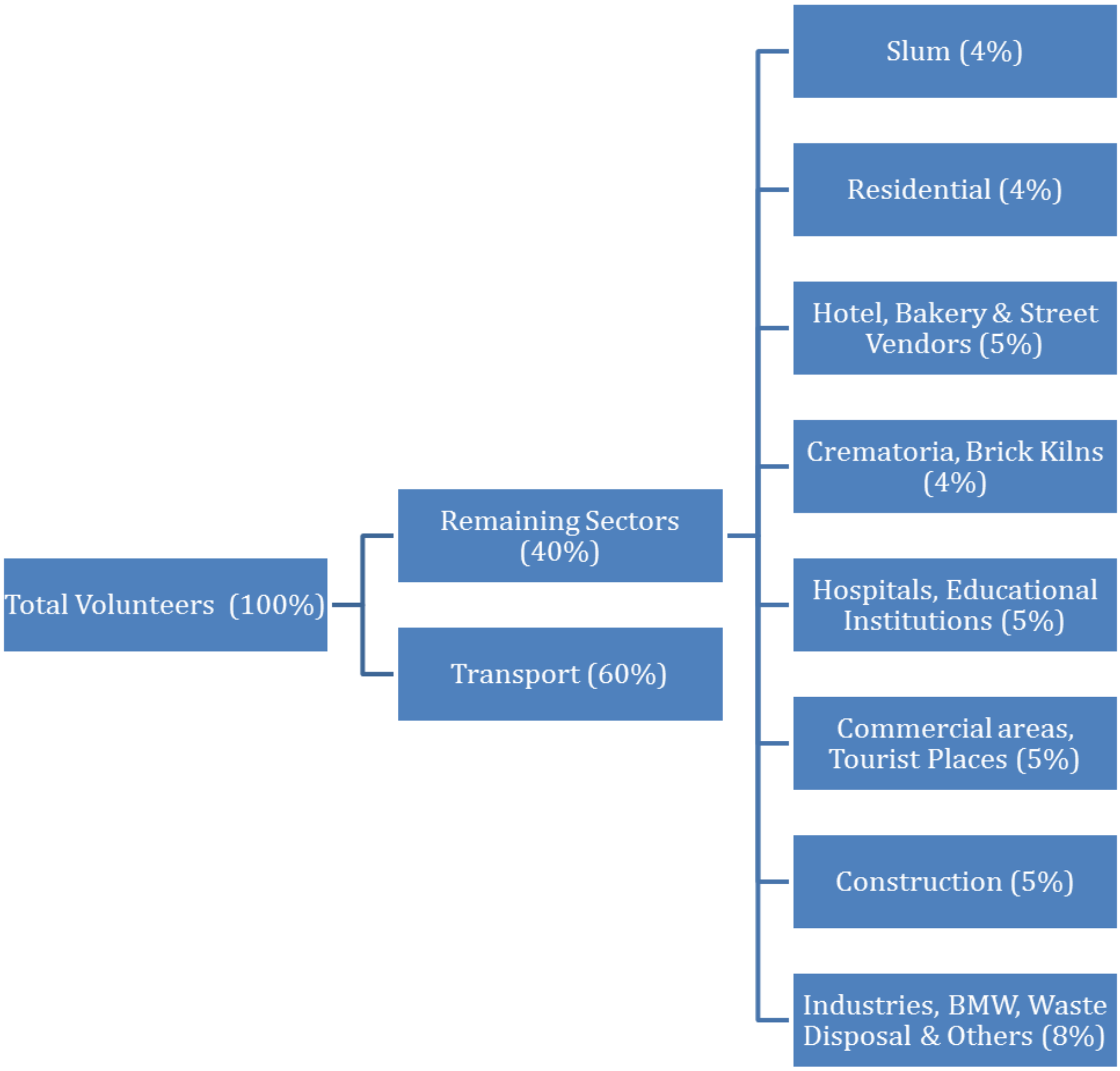


Figure 2: Task assignment to Volunteers

The campaign executed with generous support from respective local bodies, government organizations, and most importantly, the educational institutions across the PMR region. Savitribai Phule Pune University (SPPU) being primary collaborators eased the campaign effort. Department of Environmental Sciences, Fergusson College, Shri. Shahu Mandir Mahavidyalaya, Marathwada Mitra Mandal's Commerce College, Hutatma Rajguru Arts, Science & Commerce College, etc. provided enthusiastic student volunteers for the campaign. Summing up, about 200 student volunteers worked over 250,000 hours covering target sectors. **Figure 2** illustrates, the survey team disseminated covering the significant fraction (≃60%) for monitoring the on-road vehicles and the remaining was spread to cover other sectors.

Baseline data collection has carried out through surveys of representative samples for diverse emission source sectors. A review of earlier secondary data and methodology adopted for its collection has also done before carrying out the surveys to facilitate similar methodologies and approach considering the earlier method and its scientific suitability for the purpose, to avoid any further ambiguity to the whole process of surveys. Most of the surveys have been carried out through questionnaires supplementing it with certain aspects of air pollution, such as health, to elaborate our PMR air quality concerns.

4.2. Mobile sources

The vehicle fleet is the most critical parameter to quantify the emissions from mobile sources and the distance travelled by each vehicle, known as Vehicle Kilometers Traveled (VKT). Vehicle category wise VKT has been listed in **Table 7**. Emission factors of different types and origins have been used in the past by researchers. However, the most usual method and more appropriate method based on the data available is using the emission factor in terms of pollutant mass per kilometer run of the vehicle. In the present study, ARAI emission factors were used for emission estimation. Besides, the effect of idling condition, acceleration and deceleration on the emissions from vehicles taken into account during development of technological EFs. The current campaign has covered more than 200 primary and minor Municipal Corporation limits and fringe areas. Traffic monitoring conducted over an average 16hrs. The availability of volunteers, their commuting time, and the extent of the domain had restricted the target of 24hr monitoring.

Table 7: Vehicle category wise VKT

Vehicle category	VKT	Vehicle category	VKT	Vehicle category	VKT
2W	68	**Buses (Diesel)**	200	**C Cars (Diesel)**	125
3W (CNG) 2S	115	**P Cars (Petrol)**	60	**HCV**	70
3W 4S	115	**P Cars (Diesel)**	125	**LCV**	145
Buses (CNG)	180	**C Cars (CNG)**	180	**MSLV**	40

Traffic pattern in and around region

A thorough understanding of the road network attained with a review of the year 2012-13 Pune inventory. They were also reviewing several reports and studies conducted in the past by numerous agencies. The rationale of counting based on classifying the area into outer and inner cordon for the ease of evaluation of vehicles coming and going out of the core city area. (**Figure 3**) Vehicles counted by using manual methods with click-counters and videography followed by counting for one day at each of the junction except on the weekends or public holidays. Hourly classification of the number of vehicles in each of the junctions considered, distributed into two-wheelers, three-wheelers, four-wheelers (Personal/Commercial/Outstation), tempos & bus/trucks (**Figure 4**).

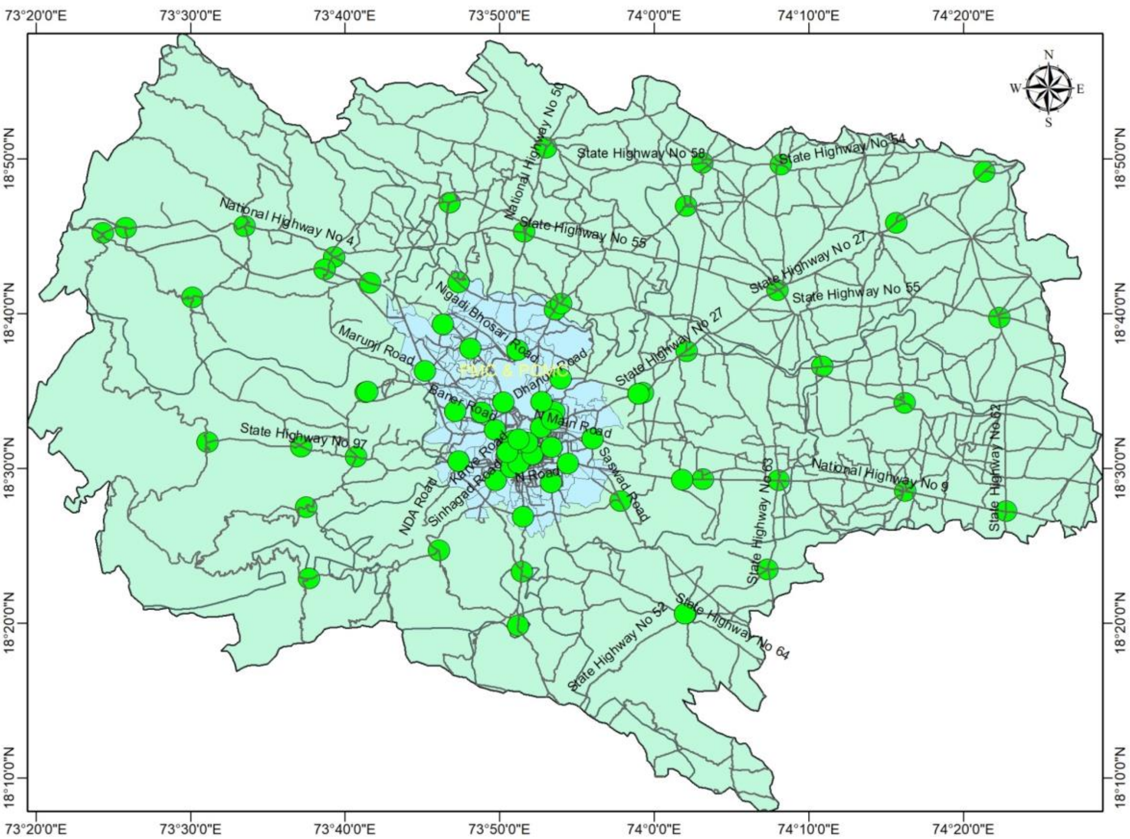


Figure 3: Traffic Monitoring Locations

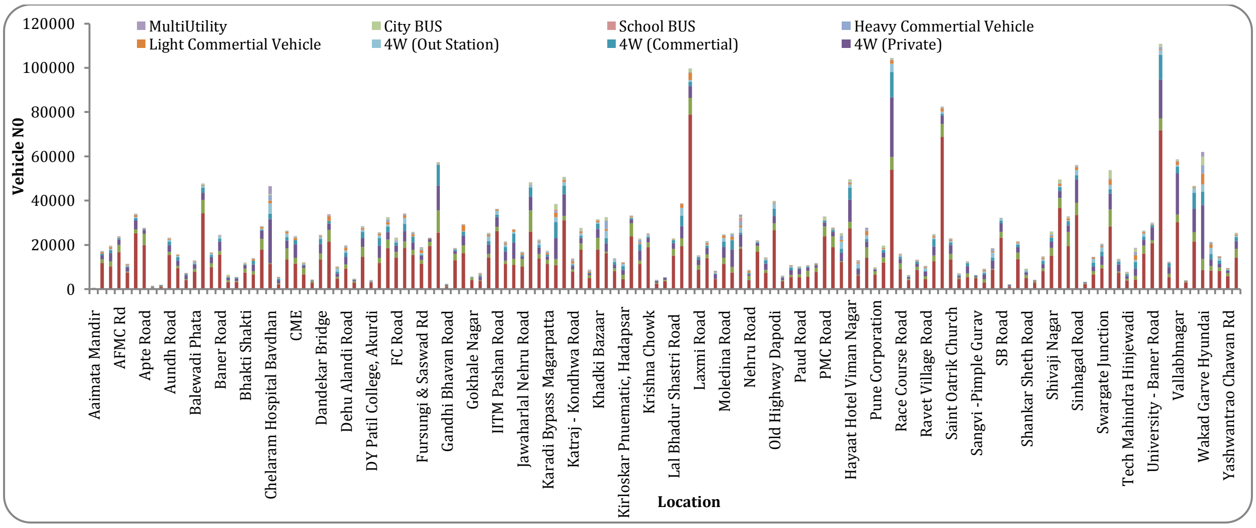


Figure 4: Vehicular load on PMR Roads

For Pune, vehicle population has increased from ~7 lakh in 2000 to ~45 lakhs in 2019-20. Daily more than 36lakh vehicles ply on PMR roads. Comparing vehicles running in city and fringe areas, the City has a larger proportion of two-wheelers (57%) than the rest of the PMR area (36%). The exciting finding observed in non-municipal limit four-wheeler share, and they seem less compared to two-wheelers. Nonetheless, summing up the three categories namely private, commercial and outstation account for ~42% of total on-road vehicles. Light and heavy commercial vehicles and multiutility play a significant role in emission contribution. They run on dirty fuel - diesel and cover a long distance with hardly any maintenance. The monitoring helped identify marked variations in peak and non-peak patterns in a vehicular population of PMR junctions.

Morning and evening peak account gives about a 10% variation in city vehicular numbers depicting that it is essentially a local trip; most of them being private vehicles returning to the starting point at the end of each day. The City is surrounded by industrial hubs both manufacturing and IT; accounting for many commuters with almost identical travel schedules.

4.3. Re-suspended Dust from Paved & Unpaved Roads

Pune Metropolitan Area characterized by a road network of 4,464km. About 10% of municipal unpaved roads and road shoulders account for higher dust load. The vehicle moves over the road surface, leading to dust from unpaved roads or settled dust from the paved surface by the turbulent wake of the vehicle and emitted as particulate matter. Emissions are estimated as a function of the silt loading of the paved surface and mean weight of the vehicles travelling over the surface. Information on Road network, vehicle km travel, depots and terminals gathered from respective local bodies, RTO divisions, and actual monitoring survey of roads. Emission estimations have based on the data roads in the PMR region that are paved and unpaved.

4.4. Continental Crustal Dust

Agricultural Land Preparation

Dust is emitted as a result of both natural processes (wind erosion, wildfires) and human activities. Common sources of regional dust emissions include traffic on unpaved roads; infrastructure; and handling of raw materials or finished products (e.g., crushing, screening, stockpiling, and loading/unloading). Though the agricultural activities are limited in the fringe areas of Pune, it might be interesting to note that these might be responsible for contributions to the total load. A few of the earlier studies estimated that agricultural related activities might be one of the significant sources. Therefore, the estimates for the same have attempted. The mechanical disturbance of the soil produces dust emissions by the wind.

4.5. Open Burning

In Pune city primary sources of solid waste are local households, commercial establishments, hospitals, hotels, restaurants, and markets. The total quantity of waste generated per day is about 1300 to 1400 metric tons (approximate generation per capita per day is 500 grams). In urban areas, the major fraction of MSW is compostable materials (40–60%) and inert (30–50%). Large amount of region's waste poorly disposed and untreated. Mixed biodegradable and inert waste is often dumped, with open burning a common practice. Part of solid waste generated is burnt openly emitting smoke and toxic fumes are released directly, affecting the environment. It is not just residents' but also the sweepers' burn dried leaves and roadside waste day in and day out. Garbage burnt late night settles down during the early hours with low temperatures and can pose a huge health risk.

Open Burning During Low Temperatures Along With MSW Burning

4.6. Hotels and Restaurants

There are more than 5,000 major hotels and restaurants in the PMR area. It considerably enhances the overall regional emissions. Though most of them use clean Fuel like LPG, the consumption is very high, and extensive outlets underwrite the biomass burning, promoting authentic chulha cuisine. It was obliging a neutral effort to estimate emissions from this sector.

Hotels Using Wood Fired Chulha

A Survey of roughly 800 hotels carried out considering various parameters such as fuel type, quantity, cooking oil type, hours of cooking, tandoor activity (if available). These classified as large and small based on the consumption of fuel. Hotels were consuming more than 15 cylinders per day grouped under broad categories. The survey also revealed that 26% of the hotels found to be large, whereas the remaining 74% of the smaller hotels scattered around PMR. Distribution of these hotels is carried out similar to that developed in the earlier inventory based on the actual postal address gathered from the survey and local bodies.

4.7. Street Vendors

The City known for its street food and Pune – a cosmopolitan city and nearby areas cannot be an exception. Numerous street vendors were catering gastronomic needs of locals, students, IT professionals, and many more across the City. The street vendors provide fast food that varied from simple tea/ coffee to groundnut and maize roasting. Some of them are seasonal depending upon the type of food item sold, whereas others usually found year-round. A large portion of these street vendors were authorized by Municipal Corporation and located at permanent places. In contrast, the equally significant fractions of them are unauthorized and keep shifting localities.

Street Vendors Using Variety of Cooking Fuel

Approximately 1,000 hotels surveyed, considering fuel type, quantity, cooking oil type, hours of cooking, etc. Distribution of the street vendors is done based on a weighted average from the population. The total number of street hawkers surveyed. Distribution of these vendors is carried out similar to that developed in the earlier inventory based on the actual postal address gathered from the survey and local bodies.

4.8. Residential Cooking

In this section we are dealing with bio-fuel usage which includes emissions from slums, other city areas. Population growth is one of the driving forces behind environmental problems because it demands more and more (non-renewable) resources for its application. With the increase in the population, there has been a concurrent increase in slum settlements. The low urban population (slum population) in Pune estimated at 30-35 per cent of the total population; the rapid growth of slums has an economic activity and job creation capacity. (City Development Plan 2006-2012) The density in slums is 6.32 times that of the overall city density while the percentage of area occupied by slums is marginal; slum dwellers provided with reasonable footprint. Total 28,716 no. of Slums in Pimpri and Chinchwad habitats accommodating 129,099

Data Collection from Slum Dwellers & Service Providers

resides. It is around 7.47% of the total population of Pimpri and Chinchwad city (Census 2011). Declared or recognized slums and undeclared or unrecognized slums population use different fuel categories in varying quantities. They were gathering the database of slum cooking based on the local body statistics, considered as secondary. The same found to be lacking actual usage or any change therein—more than 2,000 slum-households surveyed in the present study.

Apart from conventional fuels, few unusual media like wires, diesel has also been noticed. One of the most differentiating factors that came out of the survey is that most of the houses used mixed fuels, combining different fuel options available within the area. **Figure 5** represents the fuel usage scenario in slums. In the overall emissions estimation, only conventional fuel types have considered. This fuel usage ratio and per capita consumption are the weighted average fractions calculated through individual and mixed fuels.

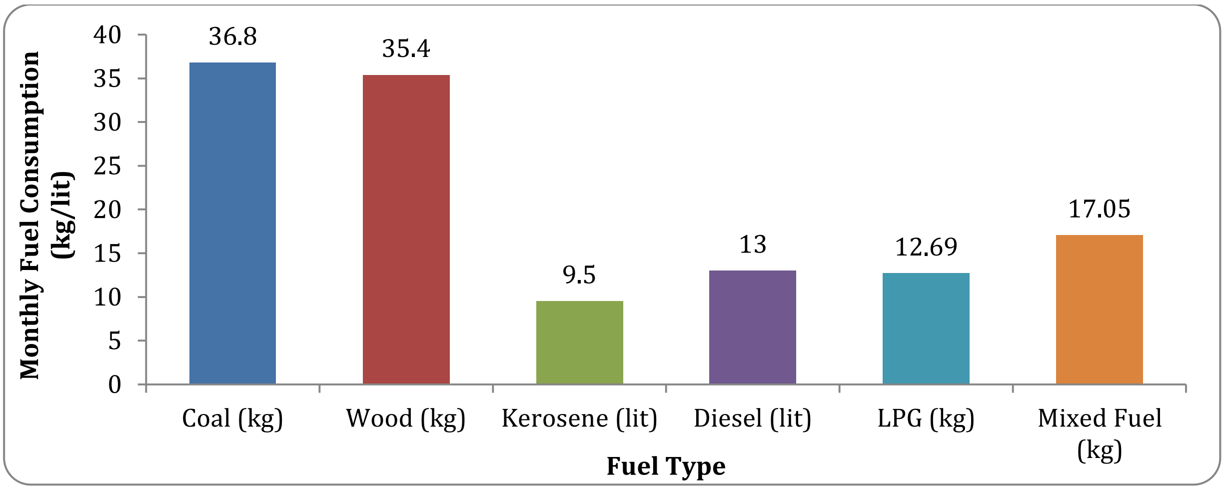


Figure 5: Average Bio-Fuel Usage Pattern in Residential Area

Residential sector is the largest contributor to ambient $PM_{2.5}$ pollution in India (Upadhyay et. al. 2018). Rest of the residential areas, liquefied petroleum gas was the chief cooking fuel (95%). remaining 5% households use electricity and mix fuels where LPG being foremost fuel in addition to kerosene, coal, wood, electricity. Along with the fuel use, we did collect some additional information regarding their lifestyle mainly – family size, mode of transport, use of AC, mosquito repellent. Average family size in city found to be 4.1 persons, whereas in fringe areas it was 4.8 persons per family. Almost 25% household had AC, which predominantly used in summer and that to during sleeping hours. Pune has good connectivity of road transport. Nearly 53.7% of the surveyed persons use public transport for their routine commute, followed by 22.1% use private vehicles. This cosmopolitan city has grown in all directions connecting industrial, IT and educational infrastructure. In view of the affordability and ease of transport, people opt multiple modes i.e. walk, auto, bus, company bus, etc.

4.9. Industries and Generator Sets

Industries are growing at common centers/estates/parks as the resources, manpower, transportation and marketing are feasible. Generally medium and small scale industries are developed at such areas and form industrial clusters. Pune is the epicenter of large industrial clusters like Talegaon, Pimpri-Chinchwad, Bhosari, Ranjangaon, Chakan, etc. Over 12,000 units operating from the Maharashtra Industrial Development Corporation (MIDC) areas in the Pune division and generated employment for nearly 5 lakh people. With reference to MPCB database, about 27.8% industries fall in RED category i.e. Pollution Index score of 60 and above. Followed by 17.9% ORANGE and remaining 54.3% were GREEN industries. Industry sector may involve as coal or gas based power houses in certain conditions. But, it is evident to note that there are no power plants present in the selected domain for our study.

Industrial Setting **Diesel Generator Set**

Generators cover both Industrial and non-industrial generators, these operated on diesel accounting for higher air pollution. Industrial generator usage duration and fuel consumption is different for each industry as they have variety in products and production capacity. As far as non-Industrial generators are concerned, these are most commonly found in apartments, shopping malls and also in the commercial area. The use of generators is varying depending upon the load shedding schedule so as to carry out the process without shutdown period. Generally is less during monsoon season as compared to the summer.

4.10. Secondary Data Collection:

Information or data for the number of slums, hotels, industries, number of registered vehicles etc., are collected from the secondary sources. Secondary data was collected from authentic government websites like CPCB, MPCB, Census of India, etc. along with some paid agencies like Indiastat and urban local bodies. The data related to the fuel consumption in industries has obtained from the published official governmental resources. In addition to this, in-house data repository and experiences gained during the past several years of effort as part of the ongoing emission inventory research of IITM has been utilized. The source agencies from where data is collected are listed in **Table 8**.

Table 8: Sources of Secondary Data Collection

SOURCE OF EMISSION	SOURCE OF SECONDARY DATA
Slum Cooking	Municipal Corporation, earlier studies
Hotels & Restaurants	Municipal Corporation, earlier studies
Street Vendors	Municipal Corporation, Encroachment Department
Non-Industrial Generators	Inspector of Generator, load shedding hours (electricity board)
Industrial Generators	Maharashtra Pollution Control Board
Industrial Stack	Maharashtra Pollution Control Board
Transportation (mobile)	Municipal Corporation, RTO
Paved Road Dust	AP42 & Earlier studies
Unpaved Road Dust	Earlier studies

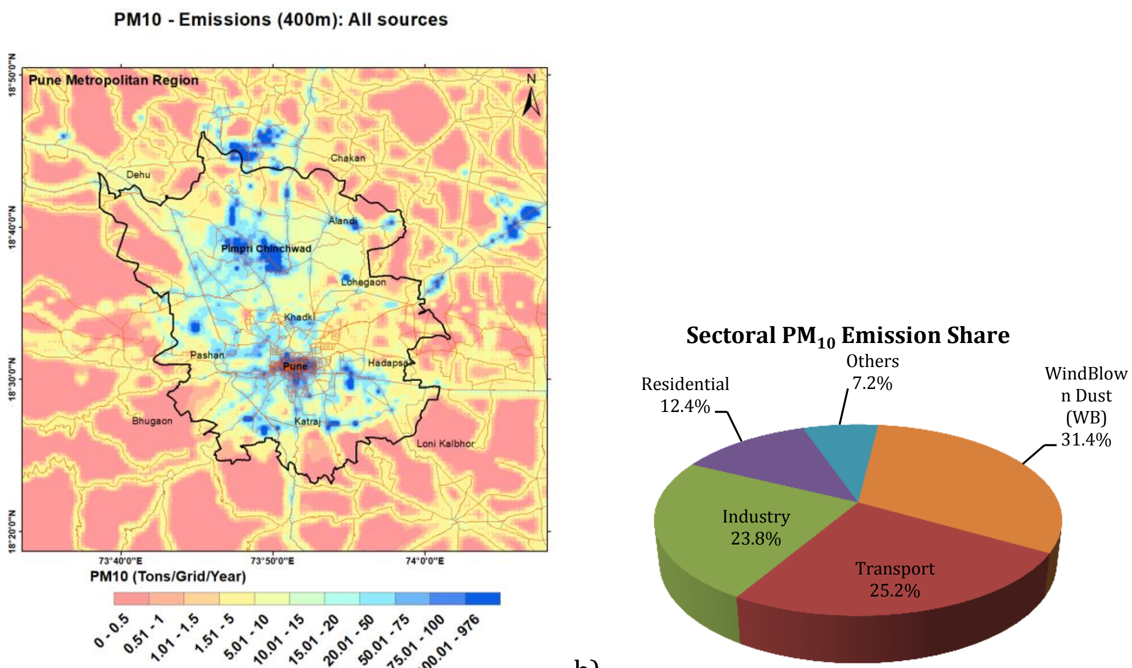
CHAPTER 5 - RESULTS

Based on the activity data (primary and secondary) collection in this work and combining them with the best available emission factors, we have estimated the emissions of 8 pollutants in this work. The methodology is discussed in earlier chapter. These emissions are further applied to the GIS-based statistical model developed by us earlier. This resulted in the gridded emission inventory of various pollutants with a grid resolution of 400m in the defined PMR region. These results are discussed in this chapter.

5.1. Emission Estimates for the Year 2019-20

A. Particulate Matter (PM_{10})

The cumulative total is estimated as 86.52Gg/yr. The spatial distribution pattern of PM_{10} emissions from all sources are shown in **Figure 6(a)**. Particulate concentration have spatially distributed all over the PMR region. Densely populated central areas have accounted for higher emissions. The transport being prominent source, found to be spread all across the study region. Out of city limits predominantly, eastern and northern part have major state highways with heavy traffic. In addition to re-suspended dust due to congestion on the roads, region is also experiencing several infrastructure development activities which might be the significant source of windblown dust.



a) b)

Figure 6: Geographical distribution & Sectoral contribution of PM_{10} emissions

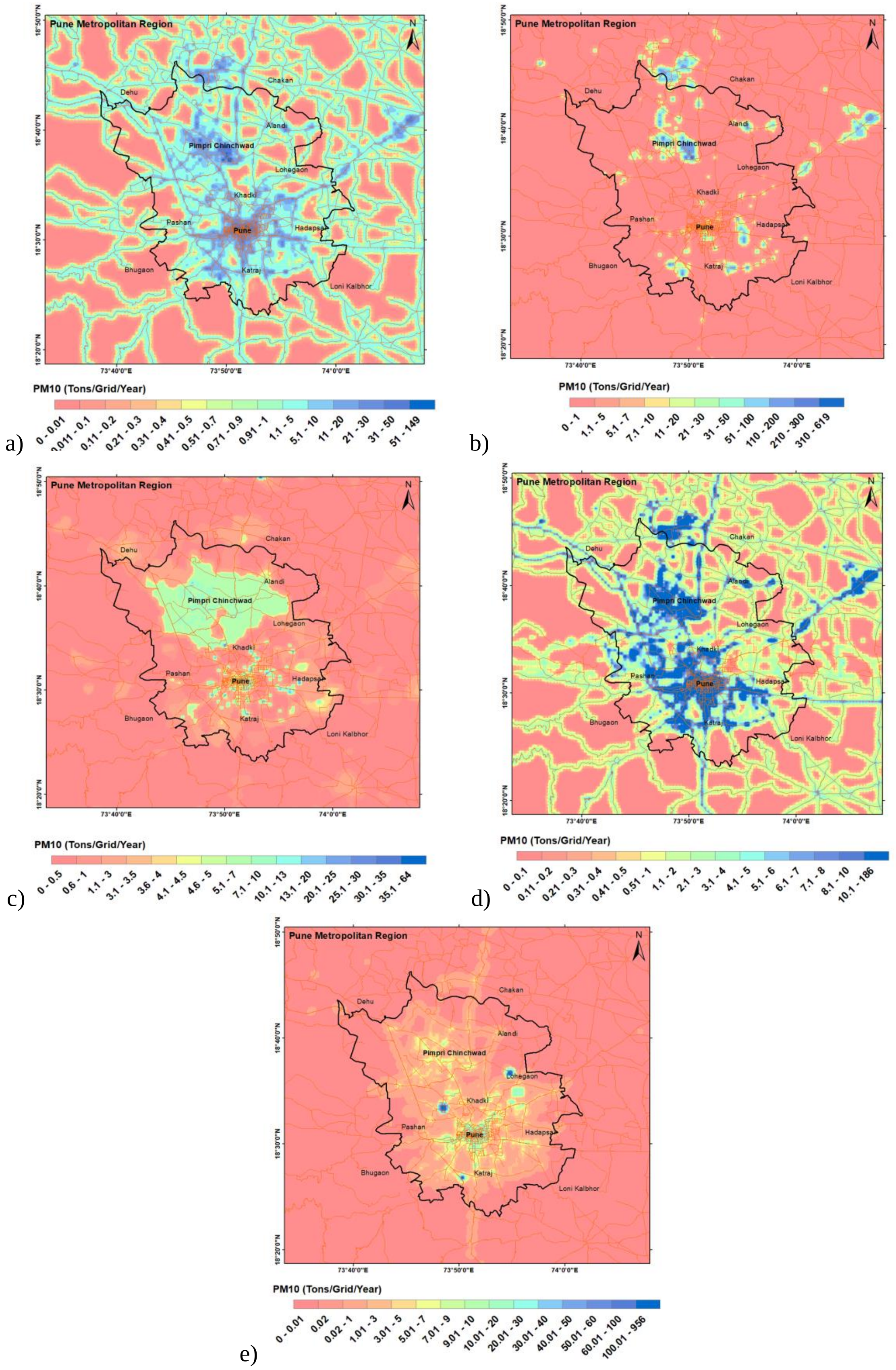


Figure 7: Sector-Specific Spatial Distribution of PM_{10} Emissions

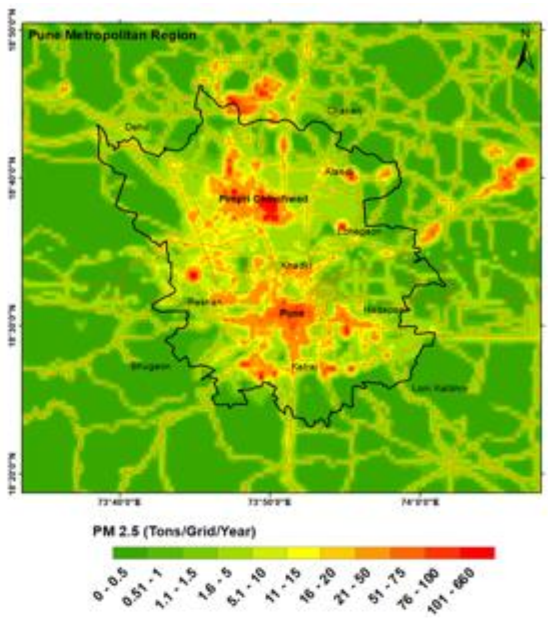
[a)Transport; b) Industrial; c) Residential; d) Windblown Dust & e) Other]

The Pune region surrounded by hills, which projects it as a bowl. This topographic scenario accounts for these receiving and self-generated emissions to trapped in the region. The transport and industries contribute almost half the total PM_{10} emissions in the study area. The residential and other sources contribute to 12.4% and 7.2% respectively. **Figure 6(b)**

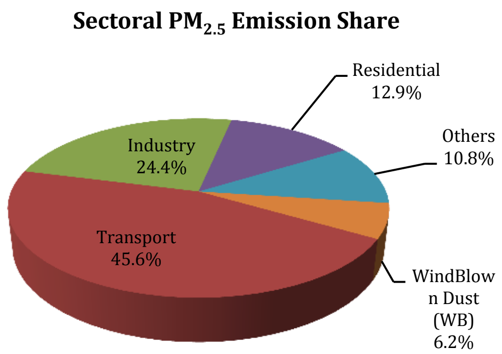
Figure 7 shows the spatial distribution of various sources of PM_{10} emissions. The hot spots from each source are clearly visible. City hotspots, like transport hub, commercial places along with City connecting roads justifies darker emission patches. However, the City manages to cater the emissions with an improved cooking technology with the widespread use of clean fuel. The sale of BS-VI vehicles mandated recently is likely to change the emissions scenario in the near future as the new vehicles take over the older one. As far as the BS-IV automobiles already been manufactured – there is a provision of taking back the model from an auto manufacturer and modify it according to BS-VI. The industrial pockets clearly signify emission hotspots (**Figure 7-b**). Also, Residential emissions found more prominent and quiet a spread in Pimpri Chinchwad. (**Figure 7-c**)

B. Particulate Matter ($PM_{2.5}$)

Total cumulative $PM_{2.5}$ emissions from all sources are estimated as 46.41Gg/yr. The spatial distribution of total $PM_{2.5}$ for the study region along with percentage share of different source sectors are shown in **Figure 8(a)**. About 46% of the total $PM_{2.5}$ emissions were from the transport sector, followed by industries (24.4%). The residential and other sources contribute to 12.9% and 10.8% respectively. **Figure 8(b)**. Windblown dust found to be the least contributing source for $PM_{2.5}$ emission in the study area.



a)



b)

Figure 8: Geographical distribution & Sectoral contribution of $PM_{2.5}$ emissions

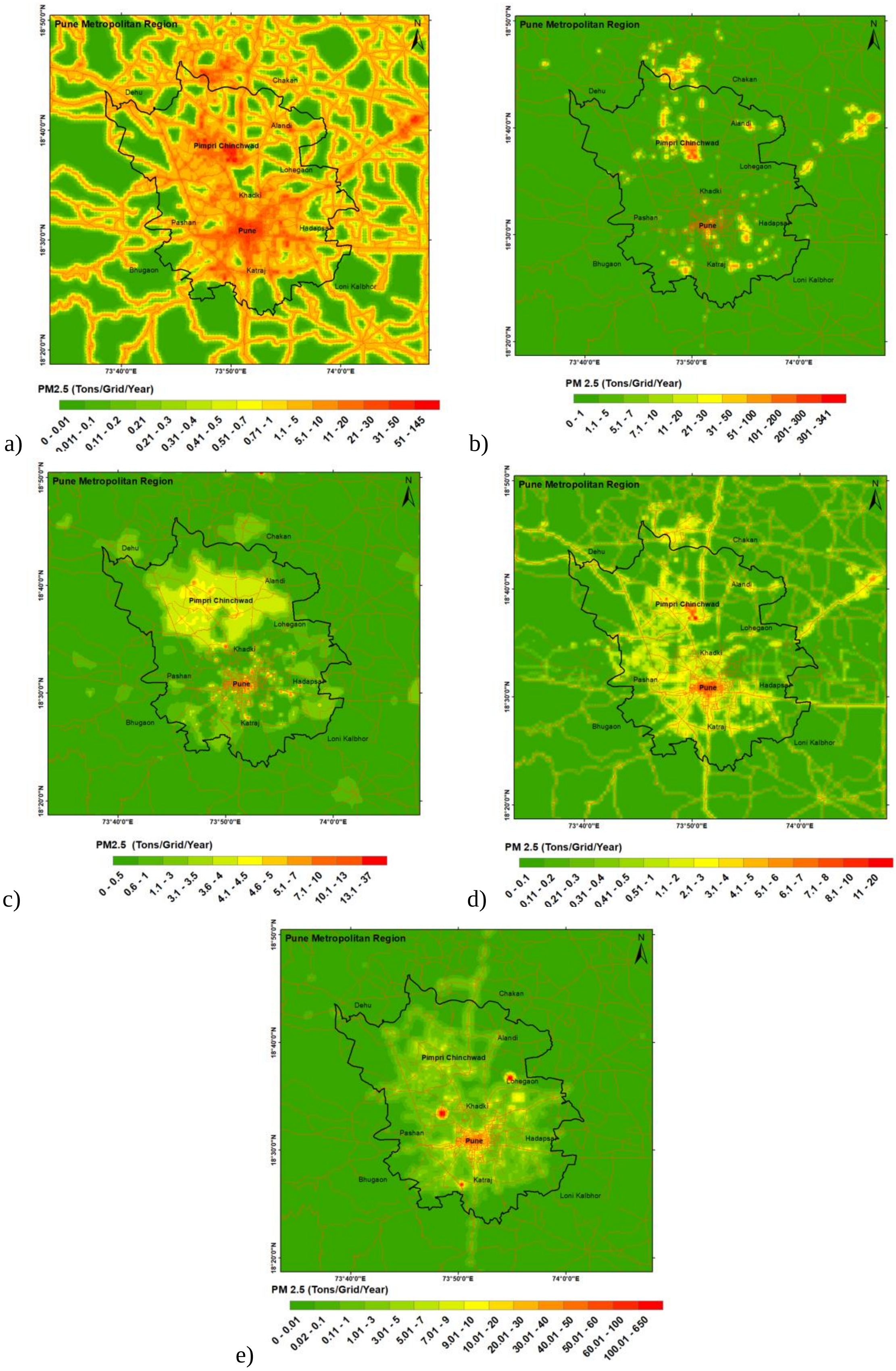


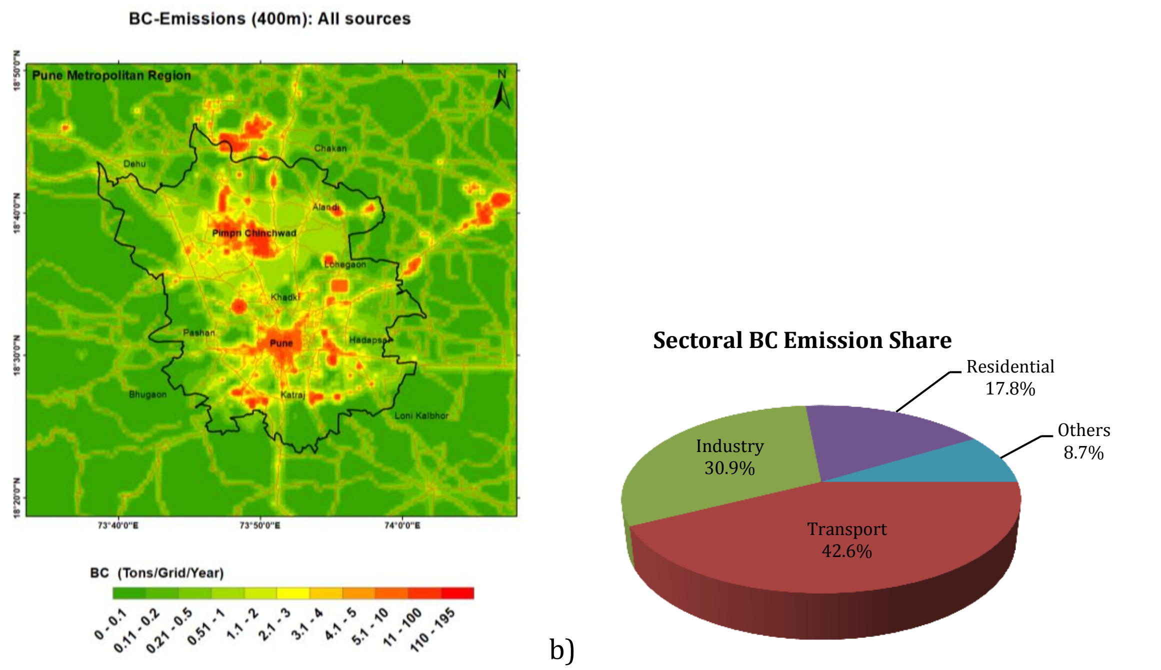
Figure 9: Sector-Specific Spatial Distribution of $PM_{2.5}$ Emissions

[a)Transport; b) Industrial; c) Residential; d) Windblown Dust & e) Other]

The spatial distribution of $PM_{2.5}$ emissions as estimated in this work from different sectors is shown in **Figure 9**. Transport show wide spread emissions over the PMR. Vehicular movement pattern has changed considerably in recent years, mainly due to the infrastructure and other development activities along with increasing number of job opportunities all across region (**Figure 9-a**). Pimpri Chinchwad and some northern and north eastern industrial cluster have more industries as compared to rest of the areas accounting for higher industrial emissions (**Figure 9-b**). Windblown and on-road dust show somewhat similar pattern as transport. It is due to the ongoing metro work and routine amenity maintenance along the roads. Other source hotspots found mostly in Pune city and some areas of Pimpri Chinchwad. These are mainly open solid waste / biomass burning activities, crematories, etc. (**Figure 9-e**)

C. Emission Estimates of BC & OC Pollutants

Figure 10 shows the geographical distribution and percent contribution of BC emissions over the PMR region. Total emissions calculated to be 7.47Gg/yr. Northern areas are characterized with an industrial cluster along with associated residences and eateries. In BC emissions, transport sector account to 42.6%, which is the maximum among all sources of BC, followed by industries (30.9%). The residential and other sources contribute to about 26.5%. The BC emitted naturally and by human activities due to the incomplete combustion of fossil fuels, biofuels, and biomass. Primary sources include emissions from diesel engines, along with cook stoves, biomass burning.



a) b)

Figure 10: Geographical distribution & Sectoral contribution of BC emissions

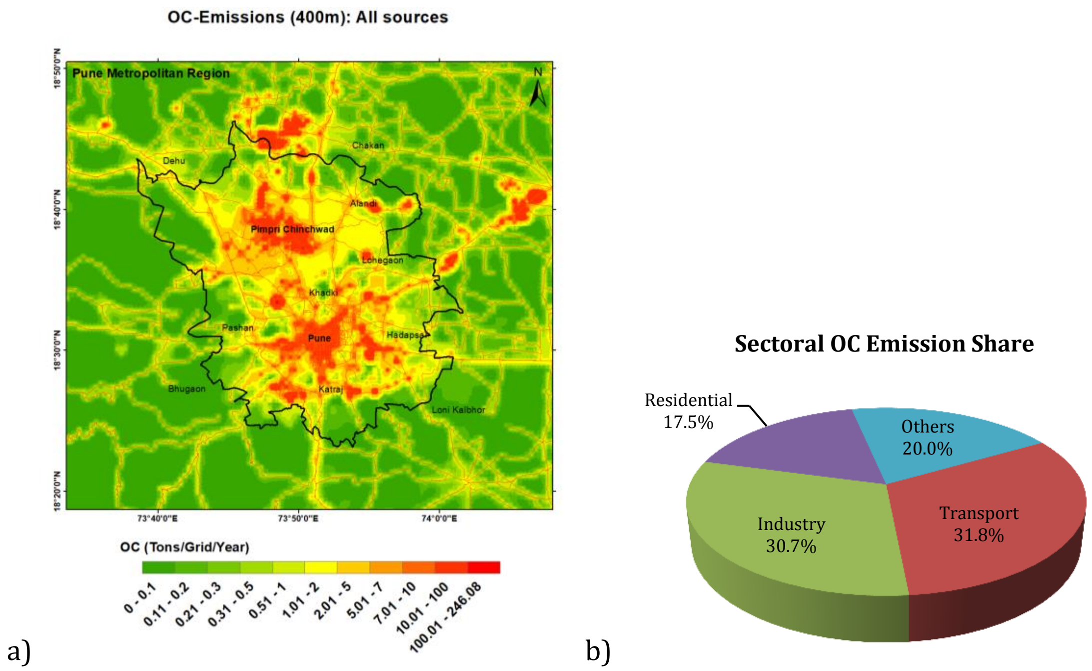


Figure 11: Geographical distribution & Sectoral contribution of OC emissions

Figure 11 depicts spatial allocation of OC emissions along with sectoral contribution over PMR. OC emissions found to be well distributed over the region and double the emissions compared to BC i.e. 15.50Gg/yr. The OC is a major atmospheric aerosol component, primarily formed by incomplete combustion and the oxidation gas-phase precursors. The trend of low emission found over the city outskirts, where population density and agricultural lands were driving to limited combustion activity. Sectoral share shows that the transport and industrial sectors account identical i.e. ~30% share in total organic carbon emissions.

D. Emission Estimates of NOx

Cumulative NOx emission from all sources in the PMR region is estimated to be around 222.01Gg/yr. **Figure 12** shows the emissions spread and share of various sources of emissions in NOx. It is clear from this figure that the maximum emission of 73.3%, is from the transport sector. NOx produced from the reaction of nitrogen and oxygen gases in the air during combustion, spatially at high temperatures. In areas of high motor vehicle traffic, an emission rate of nitrogen oxides can be significant. NOx is formed whenever combustion occurs in presence of nitrogen. Remaining is shared among residential, other (~3% each) and industries (20.4%). Major traffic areas i.e. state transport bus stations along with busy business pockets show higher NOx concentration. Residential areas have equally distributed in the region; even then their contribution is negligible.

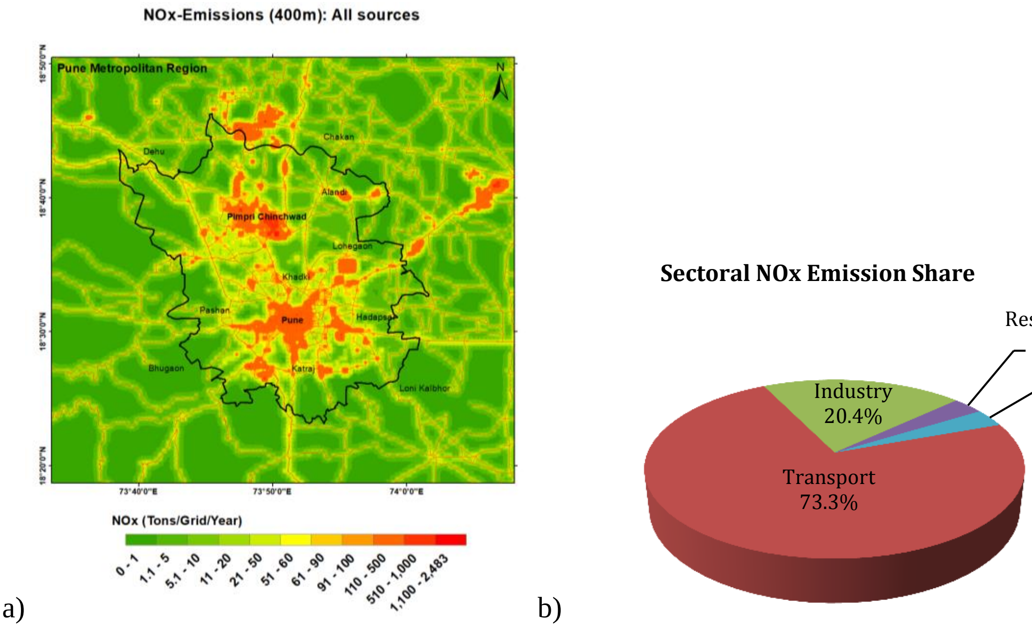


Figure 12: Geographical distribution & Sectoral contribution of NOx emissions

E. Emission Estimates of CO

Cumulative CO emission estimated to be around 292.85Gg/yr. Central municipal regions show dense to light emission patches. The emissions are well distributed irrespective of land use characteristic. (**Figure 13-a**) Maximum emission contribution of 66.3% was recorded from the transport sector, followed by residential (22.4%) and others (9.6%) (**Figure 13-b**). Industries were the least contributing with just 1.7% share. Carbon monoxide (CO) is a colorless, odorless gas that is very stable. Like organic compounds, it formed when fuel not burned completely.

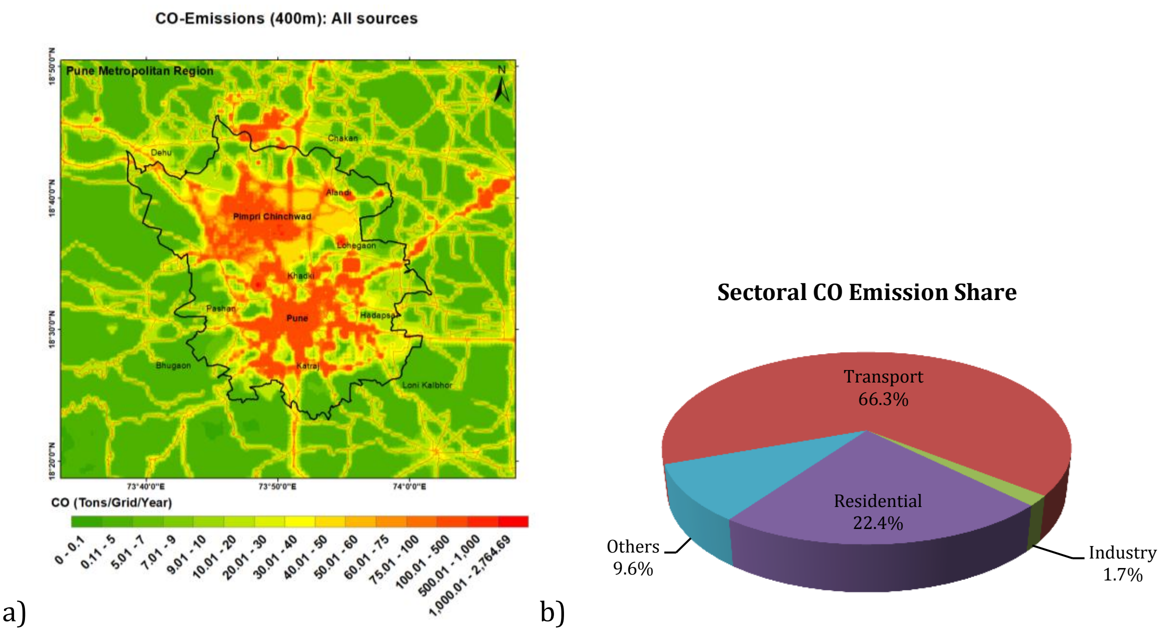
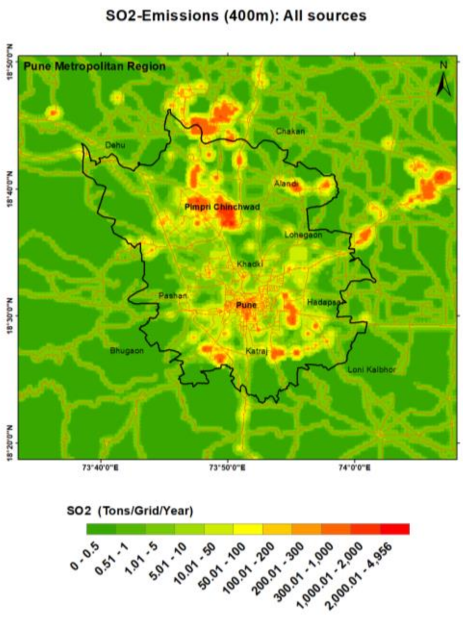


Figure 13: Geographical distribution & Sectoral contribution of CO emissions

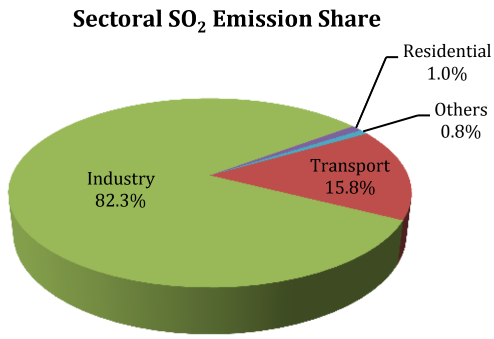
It is a component of motor vehicle exhaust, with non-road engines and vehicles. High concentrations of CO occur in areas with heavy traffic congestion. Carbon monoxide emissions from coal-fired boilers are generally low. Like organic hydrocarbon emissions, CO formed during system start-ups or upsets. Also, systems with reasonable combustion control, typical of power generation plants, produce little CO.

F. Emission Estimates of SO_2

The cumulative SO_2 emission from all sources is estimated as 191.57Gg/yr. Spatial allocation of SO_2 shows countable hotspots over Pune and Pimpri Chinchwad along with some patches in fringe areas (**Figure 14-a**). Mainly Nasik road and Nagar road show the overriding emissions. The percentage share of various sources of emissions in SO_2 is shown in **Figure 14-b**. Industrial emission is the major sector for SO_2 emissions (82.3%), followed by the transport sector (15.8%). Major industries include power plants, metal processing units and smelting facilities. Diesel vehicles and equipment have long been a significant source of sulfur dioxide. Lately, the regulations helped reduce the sulfur content of diesel fuels have significantly improved emissions from this sector. Residential and other sources account for just 1% each. Usage of different kind of fuels like coal, oil, and diesel along with other materials that contain sulfur are major reason for SO_2 emissions.



a)

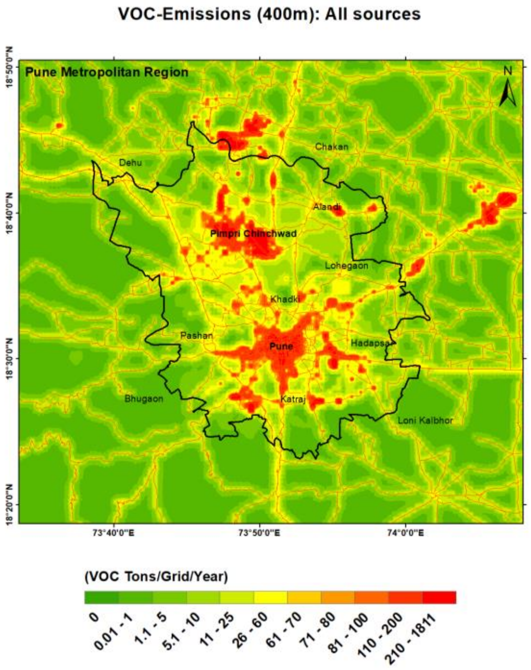


b)

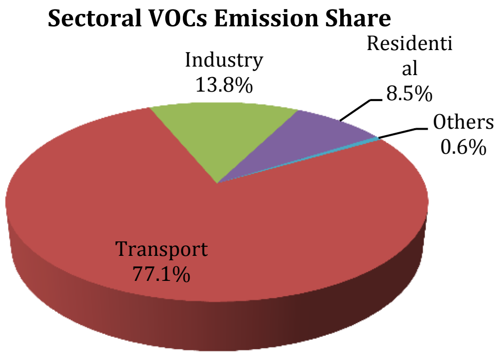
Figure 14: Geographical distribution & Sectoral contribution of SO_2 emissions

G. Emission Estimates of VOCs

Cumulative emissions of VOCs from all sources are estimated to be around 190.44Gg/yr. The spatial allocation confirms comparatively higher levels city center and industrial areas. Few emissions can be observed superimposed over road network. (**Figure 15-a**) Transport sector is identified as a dominating source of VOCs emissions (77.1%), followed by industrial (13.8%), residential (8.5%) and other sources (**Figure 15-b**). The vehicle exhaust and industrial sources contribute to ambient VOCs levels in urban areas. Many VOCs have identified as toxic, carcinogenic or mutagenic which are found in an urban environment. Recent studies have revealed that biomass and biofuel's burning is a significant source of air pollutants in a rural area, releasing significant amounts of VOCs and CO into the atmosphere, particularly after harvest seasons.



a)



b)

Figure 15: Geographical distribution & Sectoral contribution of VOCs emissions

5.2. Growth in Gaseous, BC&OC Emission(2012-13 to 2019-20)

The emissions inventory campaign is a continual improvement practice. The development in Indian cities is taking place rapidly, which is required to boost the economy. The population, high-quality infrastructure development, industrial production technology and fleet of transport are increasing with time. In view of this, we must estimate the growth rate in emissions of various pollutants so that mitigation strategies are prioritized. This section deals with this issue.

Previous inventory was done in 2012-13, where emissions of various gaseous pollutants CO, NOx, SO_2 and VOCs and particulate matter $PM_{2.5}$, PM_{10}, BC, and OC were estimated at 1.67km^2 resolutions (approx. 0.0150 ×0.0150 degrees attitude and longitude). A comparative analysis of earlier (2012-13) results with the current (2019-20) estimate reveals a significant increase in overall emissions at PMR region, as shown in **Figure 16**. The growth in past seven years are found to be as follows: Organic Carbon (81.3%), NOx (72.8%), VOCs (69.8%), $PM_{2.5}$ (69.7%), SO_2

(30.2%). The growth rate in SO_2 emissions are found to be lowest indicating that stricter norms are working for industries.

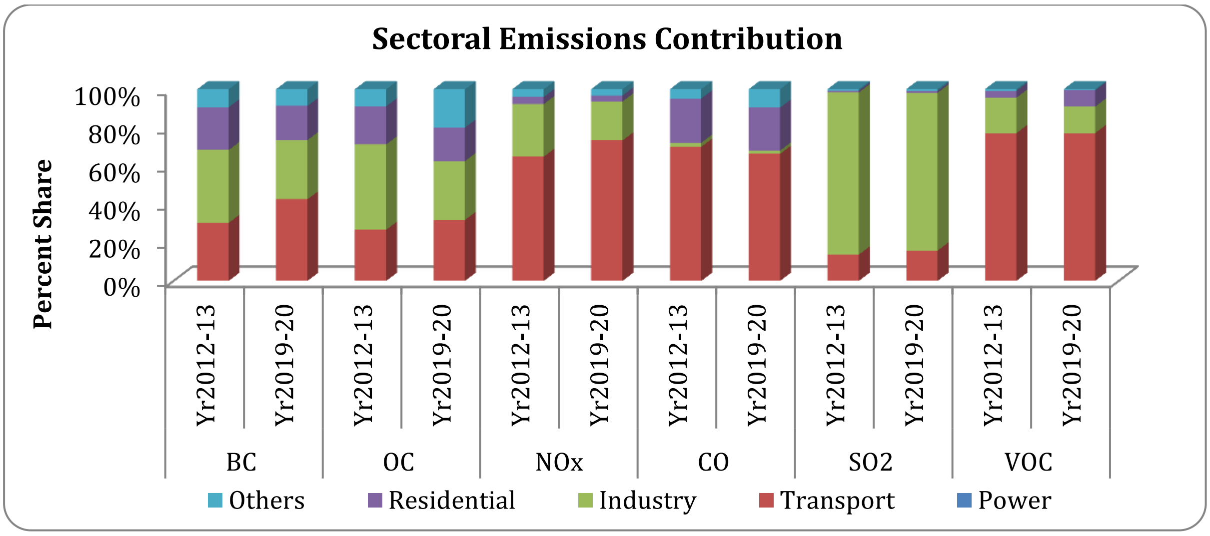


Figure 16: Sectoral Emission Contribution (Yr-2012-13 & Yr-2019-20)

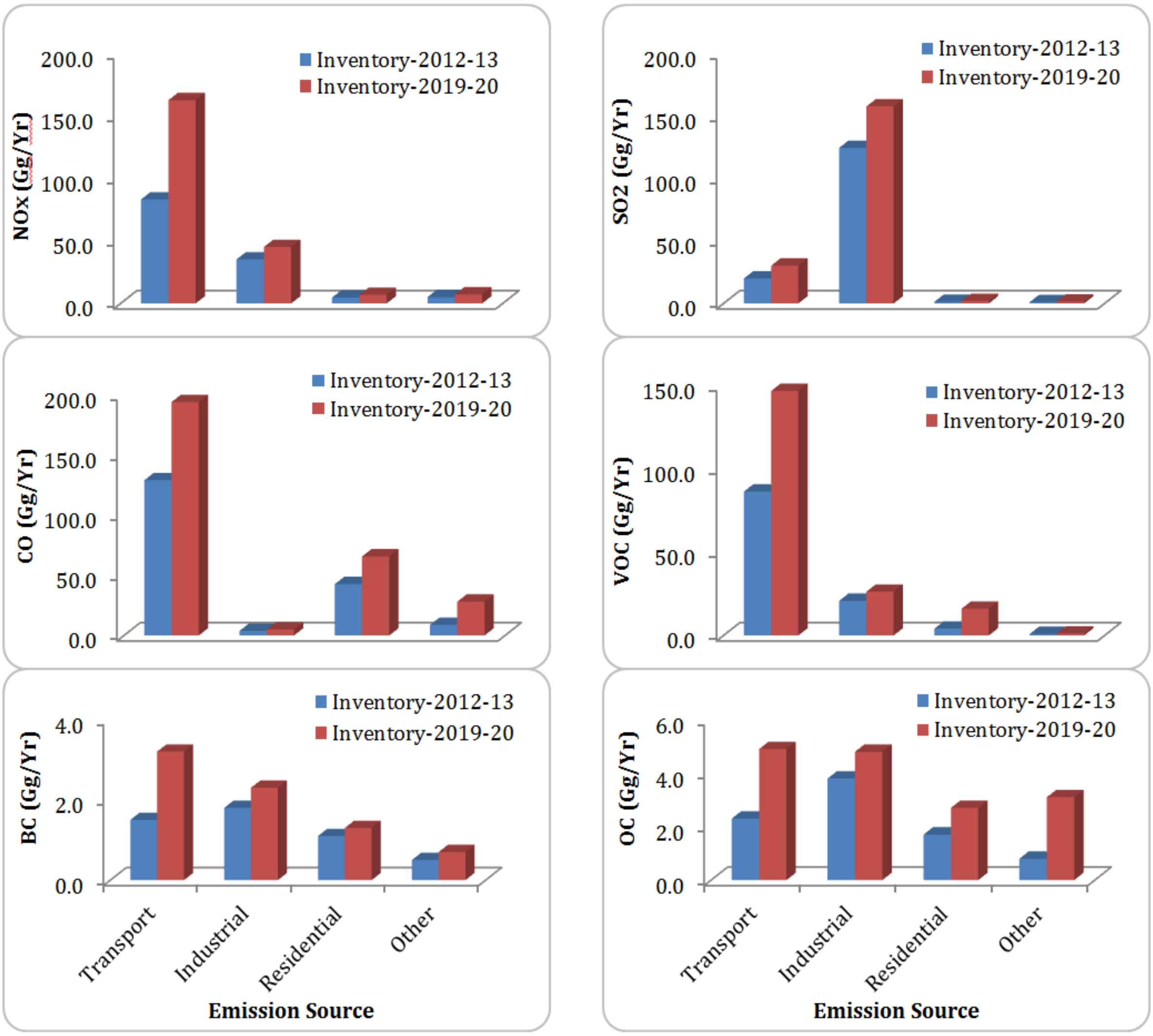


Figure 17: Sectorial Pollutant Total Emissions (Yr-2012-13 & Yr-2019-20)

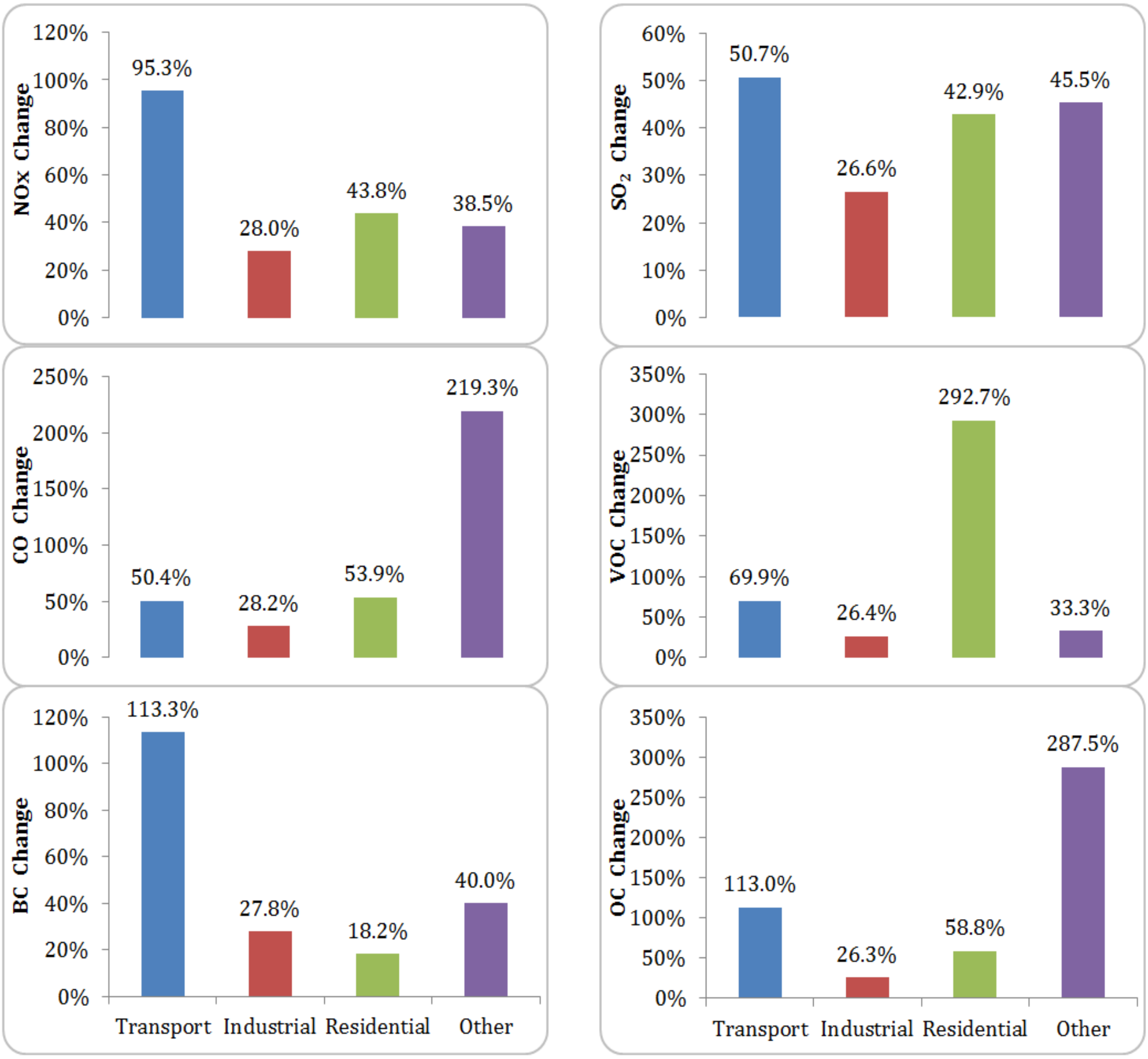


Figure 18: **Sectorial Pollutant Emissions %Change Over Yr-2012-13**

Figure 17 depicts annual estimated emissions over seven year period. CO and OC emissions have considerable increase in other sources; along with the transport VOCs & BC. Even though the particulate matter has an additional source, as windblown dust under consideration, several gaseous pollutants show higher growth rate over the last seven years. The improved fuel usage and attentive pollution abetment practices in the near future will positively minimize the gap. The City experienced a significant rise in overall vehicular traffic. This trend is reflected in vehicular emissions for pollutants, BC, OC, NOx, CO, SO_2, and VOCs, where growth in past seven year is found to be 113.3%, 113.0%, 95.3%, 50.4%, 50.7% and 69.9% respectively (**Figure 18**).

5.3. Growth in Particulate Emission (2012-13 to 2019-20)

The total sectoral and relative contributions of particulate emission PM_{10} and $PM_{2.5}$ for the year 2012-13 and 2019-20 are provided in **Table 9** - **Table 10** respectively along with sectorial percentage share in the total emissions of these pollutants. The difference in emission of PM_{10}

and $PM_{2.5}$ is due to emission factors. In residential, the incomplete combustion lead to generate more PM of larger size as compared to smaller particulate matter. The percentage growths of PM_{10} and $PM_{2.5}$ in each sector from 2012-13 to 2019-20 are shown in **Table 11** & **Figure 19**. Windblown re-suspended dust (WBR Dust) emissions from road and other sources grouped. A sectoral rise in 'Other' sector is mentioned as NA. It meant many minor unattended sources/sectors have not been taken into account in our past study, which are incorporated in the present study, as with course of time sources of emission increase. Hence a comparison with exact values is not appropriate to address.

Table 9: Comparative estimated PM_{10} emission (Yr-2012-13 & Yr-2019-20)

	Yr-2012-13		Yr-2019-20	
Source	Emissions (Gg/Yr)	Sectoral Share	Emissions (Gg/Yr)	Sectoral Share
Transport	11.6	21.6%	21.8	25.2%
Industrial	15.4	28.7%	20.6	23.8%
Residential	5.2	9.7%	10.8	12.4%
WBR Dust	18.2	33.8%	27.2	31.4%
Other	3.3	6.2%	6.2	7.2%
Total	**53.7**	**----**	**86.6**	**----**

Table 10: Comparative estimated $PM_{2.5}$ emission (Yr-2012-13 & Yr-2019-20)

	Yr-2012-13		Yr-2019-20	
Source	Emissions (Gg/Yr)	Sectoral Share	Emissions (Gg/Yr)	Sectoral Share
Transport	11.1	40.6%	21.2	45.6%
Industrial	8.5	31.1%	11.3	24.4%
Residential	3.8	14.1%	6.0	12.9%
WBR Dust	2.1	7.7%	2.9	6.2%
Other	1.8	6.6%	5.0	10.8%
Total	**27.3**	**----**	**46.4**	**----**

Table 11: Sectoral Rise in Particulate emissions over 7yrs (2012-13 & 2019-20)

SECTORS	PM_{10}	$PM_{2.5}$
Transport	↑ 87.9%	↑ 91.0%
Industrial	↑ 33.8%	↑ 32.9%
Residential*	↑ 107.7%	↑ 57.9%
WBR Dust	↑ 49.5%	↑ 38.1%
Other#	NA$	NA$
Total	**↑ 61.3%**	**↑ 70.0%**

***Residential Sector -** *Residential cooking, Slum, Trash. Burning, Cow Dung, Street Vendor, Household, Woodburning, etc.* ***#Other Sector -** *MSW Plants, MSW Open Burning, Crematory, Aviation, Incense Stick, Brick Clams, etc. WBR Dust- Wind Blown Re-suspended Dust* ***$** *Many sources newly added so not appropriate to show growth.*

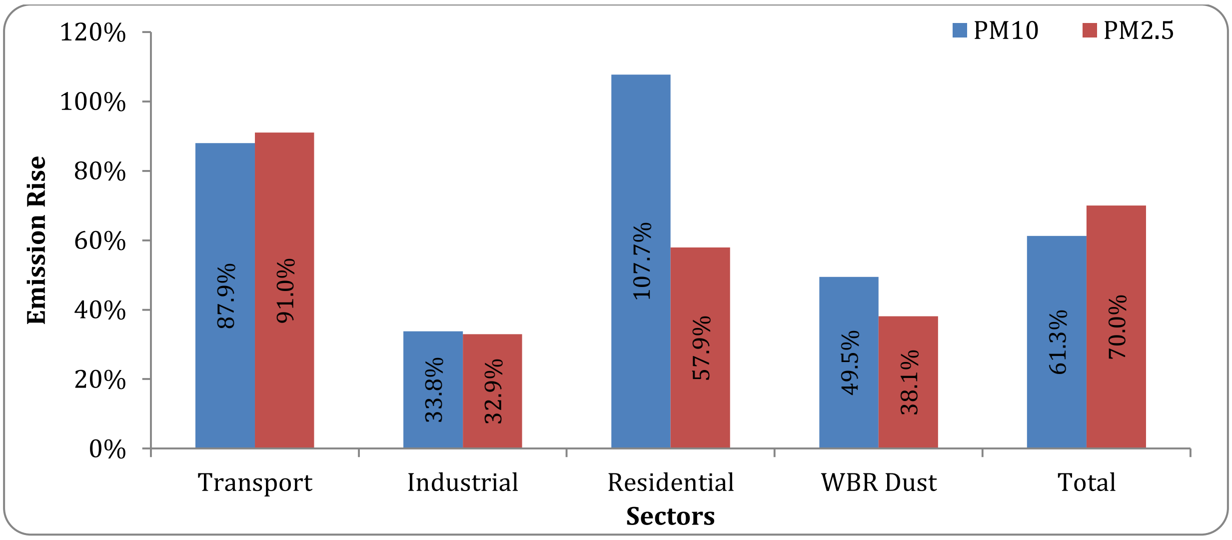


Figure 19: Sectoral Rise in Particulate emissions over 7yrs (2012-13 & 2019-20)

The overall increase in the emissions of PM_{10} and $PM_{2.5}$ over PMR region is found to be 61% and 70% respectively. Pune is a mix of land use province, ranging from commercial, residential, agricultural, reserved forests and water bodies. Windblown dust contributed from paved-unpaved roads to agricultural sector remained the top contributor in PM_{10} with >30% growth in emissions during the past seven years. Given the extensive reforms in an industrial sector, it managed to control the emissions bit by bit. Vehicles remain the major contributor of $PM_{2.5}$ emissions in 2020, followed by industries. Windblown dust accounts for ~6% emission. The industrial emissions of two particulate fractions have increased by ≃33% over the last seven years.

CHAPTER 6 - CONCLUSION

Present work adopted a bottom-up approach for developing emission inventory estimates and then to allocate on grids with GIS-based statistical model developed by us earlier. This has paved the way to achieve the goal to provide emissions of all eight pollutants in a resolution of 400m. The repository of source-specific emission activity data and appropriate emissions factor has been applied. The gridded emission inventories can provide detailed information about emission hotspots and relative contributions of sources and sectors to target and pave the way for the policy framework, which has been achieved in this work. Overall, the high emission hotspots directly or indirectly linked with various sources of emissions which mainly include high vehicular density in a densely populated area, high biofuel and coal, industries, kerosene practices by slum areas, and commercial cooking. This work also briefly reviews all the possible EFs used by different researchers in the past and in some cases proposed new emission factors based on the recently available information on development activities. The methodology to calculate the emissions from various sources using the activity data and emissions factors is discussed in this report. The GIS based statistical model developed earlier by SAFAR has been used to generate the gridded emission inventory of different pollutants in this work. A GIS based methodology is also formulated in order to attain the aim. This methodology is used to develop the gridded emission inventories for all the major air pollutants mentioned in this report. The current analysis demonstrates that a science based integrated steps are likely to achieve improved air quality on a sustainable basis. Current emission inventory for 50km x 50km domain in 2019-20 provides the overall estimates of PM_{10}, $PM_{2.5}$, BC, OC, NOx, CO, SO_2, and VOCs as 86.52Gg/yr, 46.41Gg/yr, 7.47Gg/yr, 15.50Gg/yr, 222.01Gg/yr, 292.85Gg/yr, 191.57Gg/yr and 190.44Gg/yr respectively.

A comparison of earlier (Yr-2012-13) emission inventory with the current (Yr-2019-20) inventory suggests a significant increase in Pune's overall emission load. The air quality of Pune is mainly regulated by particulate pollutants ($PM_{2.5}$ and PM_{10}). A significant growth in the emissions of particulate pollutants has been observed during the past seven years. An increase of 70% and 61% is found in $PM_{2.5}$ and PM_{10} respectively from 2012-13 to 2019-20. There has been an enormous growth in the number of vehicles in PMR during the past decade. Transportation sector is found to be the major contributor in $PM_{2.5}$ emissions as compared to rest of the sources. Though industrial production has increased over the years, emissions show a minimal rise as compared to other sectors. This might be due to the improved fuel quality used in units, efficient technological innovations and stringent enforcement of standards. Similarly, a significant increase is observed in the emissions of Organic Carbon (81.3%), NOx (72.8%), and VOCs (69.8%). Sulfur dioxide emissions show a 30.2% increase, lowest amongst the eight pollutants considered in this work.

The comprehensive comparison of emissions estimations conducted in other similar cities or for the sake an average national emissions is complicated; though it will be a mark of significant importance. Each and every region/city has its own specific dominating sector in terms of emission. Since, sources of emission vary from region to region; the source specific comparison may not be very useful for mitigation planning. Overall growth rate of $PM_{2.5}$ and PM_{10} for PMR region for the year 2013-2020 is compared with the growth rate with Delhi-NCT (2011-18). The growth rate in PMR region for $PM_{2.5}$ & PM_{10} is found to be 10% per year, 8.7% per year, whereas for Delhi it is around 2% per year, 4% per year. As evident, the growth rate (percent) of particulate matter in PMR region is bound to be significantly higher as compared to Delhi-NCT, although the magnitude of emission (Gg/yr) for PMR region is still significantly lower as compared to Delhi-NCT, but the higher growth rate of PMR region is a matter of grave concern.

We wish to conclude by stating that although we made an attempt to collect as much primary data as possible and collected the available recent secondary data and methodology, it is pertinent to mention here that present results are not free from some amount of uncertainty which is not easy to comprehend due to many confounding factors and complicated methodology of estimation. Nevertheless, we firmly trust that within the constraint, the emission estimates in such high resolution by SAFAR are likely to serve as an essential information base for scientists and policymakers. This report also provides the rate of change in anthropogenic emissions of atmospheric constituents during the past seven years. It is expected that results would go a long way in helping the air quality management system, environmental policymakers, and improving accuracy of air quality forecasting.

References

1. Beig et al., Development of High Resolution Emission Inventory for Pune Metropolitan Region (PMR) – Pune. Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Government of India, SAFAR-Pune-2013.
2. Finlayson-Pitts, B.J., Pitts Jr., J.N., 1986. Atmospheric Chemistry: Fundamentals and Experimental Techniques. John Wiley & Sons, New York.
3. Ho Quoc Bang and Vu Hoang Ngoc Khue (April 24th 2019). Air Emission Inventory, Air Pollution - Monitoring, Quantification and Removal of Gases and Particles, Jorge Del Real Olvera, IntechOpen, DOI: 10.5772/intechopen.79928.
4. Indian Council of Medical Research, Public Health Foundation of India, Institute for Health Metrics and Evaluation. GBD India Compare Data Visualization. New Delhi: ICMR, PHFI, and IHME, 2019
5. India State-Level Disease Burden Initiative Air Pollution Collaborators, Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019, Lancet Planet Health 2019
6. Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Government of India. Air quality monitoring, emission inventory and source apportionment study for Indian cities—national summary report. New Delhi: CPCB. February 2011.
7. Upadhyay A, Dey S, Chowdhury S, Goyal P. Expected health benefits from mitigation of emissions from major anthropogenic $PM_{2.5}$ sources in India: statistics at the state level. Environ Pollut 2018; 242: 1817–26.
8. GBD MAPS Working Group. The burden of disease attributable to major air pollution sources in India. Spatial report 21. Boston: Health Effects Institute. January 2018.
9. The Automotive Research Association of India, The Energy and Resources Institute. Source apportionment of $PM_{2.5}$ and PM_{10} of Delhi NCR for identification of major sources. August 2018.
10. Beig et al., SAFAR-high resolution emission inventory of Delhi mega-city—2018 (SAFAR-Delhi-2018-A). Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Government of India, SAFAR-Delhi-2018A, 2018.
11. World Health Organization (WHO) Report/ News (2018)
12. Dandona et. al. Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. Lancet Planet Health 2021; 5: e25–38
13. Mukkannawar Utkarsh, Ojha Ajay, Shenvi Vikram and Rakesh Kumar (2014). Network design and evaluation through PM_{10} & $PM_{2.5}$ mass loading, Int J Curr Microbiol App Sci, 3(11), 675-682.

14. ARAI, Pune, 2007. Air Quality Monitoring Project - Indian Clean Air Programme (ICAP). Emission Factor Development for Indian Vehicles, CPCB, MoEF
15. Kalimont, Z., Cofala, J., Bertok, I., Aman, M., Heyes, C. and Gyarfas, F. (2002) Modeling Particulate Reductions in Europe: A Framework to Estimate Reduction Potential and Control Costs. Interim Rep IR-02-076, International Institute for Applied Systems Analysis, Laxenburg, Austria.
16. Bond, T. C., Streets, D. G., Yarber, K.F., Nelson, S.M., Woo, J.H., and Klimont, Z., 2004. A technology-based global inventory of black and organic carbon emissions from combustion, Journal of Geophysical research
17. Central Pollution Control Board (CPCB), 2010. Air Quality Monitoring, Emission Inventory and Source Apportionment Study for Indian Cities. National Summary Report. 2010.
18. Cook, W. F., Liousee, C., Cachier, H., 1999. Construction of a 1° ×1° fossil fuel emission data set for carbonaceous aerosol and implementation and radiative impact in the ECHAM4 model. Journal of Geophysical Research, Vol.-104, No.D18, pp. 22137-11162.
19. Reddy, M.S., Venkataraman, C., 2002. Inventory of aerosol and Sulphur dioxide emissions from India: Part-I, Fossil fuel combustion. Atmospheric Environment, Vol.36, pp. 677-697
20. Reddy, M.S., Venkataraman, C., 2002. Inventory of aerosol and Sulphur dioxide Emissions from India. Part-II, Biomass combustion. Atmospheric Environment, Vol.36, pp.699-712.
21. Sahu, S.K., Beig, G. and Parkhi, N. (2011). Emissions Inventory of Anthropogenic PM2.5 and PM_{10} in Delhi during Commonwealth Games 2010. Atmos. Environ. 45: 6180–6190.

Weblinks

http://www.cleanairasia.org/

http://www.cpcb.nic.in/

https://mpcb.gov.in/

http://www.epa.gov/

http://www.heat.iclei.org/

http://www.youthforcleanair.com/

https://www.data.gov.in/

https://www.indiastat.com/

https://www.mha.gov.in/

https://www.pmc.gov.in/

https://www.pcmcindia.gov.in/

SAFAR

SYSTEM OF AIR QUALITY & WEATHER FORECASTING AND RESEARCH

UNDERSTANDING
Atmospheric Processes of Air

FORECASTING
Air Quality & Weather

ASSESSING
Impacts on Health & Crop

APPLICATIONS
Product Development

SERVICE
Dissemination to Society

Indian Institute of Tropical Meteorology
Ministry of Earth Sciences Govt. of India
Dr. Homi Bhabha Road, Pashan, Pune 411 008, Maharashtra, India
Phone: +91-020-2590-4200 | Website: http://safar.tropmet.res.in | E-mail: safar@tropmet.res.in