DEVELOPMENT OF GRIDDED EMISSION INVENTORY FOR PUNE CITY

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<u>DECLARATION CUM CERTIFICATE</u>

I hereby declare that the project work entitled "Development of gridded emission inventory for Pune city" is an authentic record of my own work carried out at (IITM- Indian Institute of Tropical Meteorology, Pune) as requirements of one year project internship for the award of degree of MTech. (Environmental Science & Technology), TIET, Patiala, under the guidance of Dr. R. Latha and Dr. Gaurav Goel, during August 2021 to June 2022.

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ABSTRACT

The fundamental source of the alarming increase in air pollution is due to multi-way anthropogenic emissions. The emission inventory is a comprehensive quantification of estimated pollutant emissions in a specific location over a specific time period from various sources. The precision and reliability of emission estimation have a highly significant role in the quality of air quality forecasting. Emission inventories assist with air quality management and the development of environmental policies. The presented work is a detailed gridded Emission Inventory for particulate matter (PM) with a resolution of 100m x 100m for Pune Municipal Corporation (PMC). In order to run the air quality forecast models gridded emission inventories are the necessary input that matches the model resolution. An air quality forecast model produces output through the interactions of emission inventory (EI), its spread modified by meteorology, both input to the model to give pollutant concentrations at every grid. The last EI over Pune is for the PMR region that includes Pune and Pimpri-Chinchwad Municipal corporations and their fringe villages at a resolution of 400m x 400m. The present work is limited to PMC region at a resolution of 100m x100m; the emission data is collected and incorporated at the exact higher resolution. Including the higher resolution and standardized activity datasets, this works updates the gap by presenting detailed multisectoral emissions in PMC region. The methodology for inventory estimations of each subsector is extended based on its properties and the types of fuels used. A sector-wise comparison at the ward level for the current EI is also presented.

The current study used a bottom-up strategy to establish emission inventory estimates and then distribute them to grids using a GIS-based statistical model. This has made it possible to meet the aim of providing emissions for particulate contaminants with a resolution of 100m. The source-specific emission activity data repository has been used, together with the relevant emissions factor. The gridded emission inventories can give extensive information on emission hotspots and relative contributions of sources and sectors to target and pave the path for the policy framework. The extensive research demands a substantial amount of high-resolution activity data, emission variables, and understanding of basic scientific processes. To fill in the data gaps and validate data, two-year-long scientific field campaign data was used for uncertain secondary data., and to collect the available secondary data concurrently. The overall result delivered is the high resolution (100m x 100m) gridded EI of two air pollutants ($PM_{2.5}$, PM_{10}).

Remote sensing technologies are becoming more precise, powerful but broadly available and less expensive; there is a vast potential in using satellite data to analyse and visualize ambient air quality over broad geographic areas in real-time. We have discussed how to use a mixed strategy to create a $PM_{2.5}$ and PM_{10} emission inventory for the residential sector containing residential areas and slums across PMC at a resolution of 100m x 100m. The inventory gives emission estimates that are both geographically and temporally resolved. $PM_{2.5}$ and PM_{10} emissions for the Industrial sector, including hotels and restaurants, hawkers, bakeries, industries, and crematoriums, are quantified. Transport emissions are estimated based on a specific methodology. Emissions of a particular pollutant from a specific source category are evaluated using activity data, the Emission Factor (EF), combustion technology, and emission control removal efficiency. As far as public health is concerned, EI estimates provide a good tool for exposure estimates that daily, people are exposed to from various sources.

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NOMENCLATURE

List of symbols

a Sector Specific
EF Emission factor
FC Specific- fuel usage
HCV Heavy Commercial Vehicles
Nu Number of users
LCV Light Commercial Vehicles
PM Particulate Matter
PMC Pune Municipal Corporation
T Time duration
TE Total emissions
TEt Total Emissions, Transportation

Vehi Number of Vehicles
WHO World Health Organization

CHAPTER 1: INTRODUCTION

1.1 Air Pollution: The Global Scenario

Air pollution is a long-standing issue that has been documented for generations. When humans first discovered how to control fire and use combustion fuels for their own purposes, it was clear that dealing with the by-products of fossil fuel combustion would be a considerable challenge. Carbon dioxide, water vapor, trace gases, and aerosol emissions are derivatives that have far-reaching consequences for air quality, human health, and global climate. Pollutants in the air are aerosols or gases discharged into the atmosphere due to human or natural activities.(Mabahwi et al., 2014) The emission of air pollutants can be categorized by a variety of sources, variability in space and time, and the overall impact it has. These can hurt humans, plants, and animals, damage human-made materials and structures, affect weather and climate scenarios, and interfere with the comfortable enjoyment of life and other human activities. (Khue et al., 2019). The fine particles from vehicles, industries, and various sources strongly impact human health. WHO (World Health Organisation) reported that air pollution causes 4.2 million deaths per year. In India, 1 million people died due to air pollution, accounting for 17.8% of the country's total mortality. (Bourne et al., 2021). The deterioration of air quality, being one of the major environmental concerns of recent times, has been frequently highlighted by the scientific community. Indian megacities have long been plagued by air pollution problems with 21 polluting cities that are among the top 30 polluted cities in the world (World Air Quality Report, 2019). Since 1990, the emission of pollutants, such as SO_2 and NOx, increased by three and two folds, respectively. As far as the emission of particulate matter (PM) is concerned, a 20% rise in concentration was observed (Rafaj and Amann, 2018).

Moreover, as an issue of global concern, the United Nations also included the air quality and air pollution targets to achieve these three sustainable development goals (SDGs), viz., SDGs 3, 11, and 12 (United Nations, 2015). Accordingly, the thorough investigation of air quality issues became a quintessential task for balancing development and related air quality issues. Particulate matter concentrations exceeding WHO air quality limits are present in over 80% of the world's population. The health consequences of these exposures are estimated to account for 2-5 percent of the worldwide disease burden.

1) How will pollutant emissions evolve in the future, given the current rate of development, and how will environmental policies affect such emission trends?

2) What are the implications for the resulting exposures and health outcomes?

To answer these concerns, many tiers of air quality approaches and policies on universal access are required. To calculate sector-based pollutant emissions and produce an emission inventory, bottom-up approaches based on pollutant emissions modelling are utilised or preferred more.(Gawuc et al., 2021 ; Cheewaphongphan et al, 2019) The emission inventory is a detailed accounting of the estimated emissions from various sources of air pollution in a given place over a given time period. The precision and reliability of emission estimation determine the quality of air quality forecasting. Emission inventories could assist in the management of air quality and the development of environmental policies. To calculate ambient PM concentrations, emissions are spatially downscaled and coupled with a gridded model.

1.2 Emission Inventory

Examining the environmental impact of air pollutants emitted into the atmosphere requires meticulous data on their emissions. As a result, an assessment of the quantity of a specific component released at a particular area or geographic place at a given time period due to a specific action must be established. The compilation of emission inventories is used to make this assessment. Emission inventories are calculated using a variety of methods; for example,

(1) Individual source monitoring,

(2) Emission factors obtained from literature data are used in various inventory technique

According to Pulles and Builtjes (1998), emission inventory compilation is defined as "the collection of datasets representing the quantity of a certain pollutant being emitted to the atmosphere, caused by an economic, social, or natural activity, emitted at a specific geographic location at a given time, using a specific methodology and reporting in a specific format" (in the past, present or future).

The Emission Inventory (EI) for air pollutants is used to undertake source apportionment investigations and develop mitigation and control methods. (Garg et al., 2006; D'Avignon et al.,2010 ; Hillmer-Pegram et al., 2012) An emission inventory gives a source-specific contribution data list of individual pollutant species inside a given geographic region. Sources can be classified into broad categories such as the industrial and transportation sectors (Singh et al., 2017) or as separate sources. To verify the feasibility of pilot studies as ambient air quality monitoring and evaluation through PM_{10} and $PM_{2.5}$, air emission inventories can be produced for a single source or a region. Mass loadings at specific areas are often questioned due to a lack of interagency collaboration in monitoring techniques, which can obstruct site selection and, as a result, control tactics and response plans. (Beig et al., 2018 ; Utkarsh et al., 2014 ; Emission inventories can be utilised to achieve policy and scientific goals, as there are many different types of emission inventories, each with its own set of features. Emission inventories can track the environmental policies by demonstrating patterns in emissions over time and progress towards the established goal. Emission inventories can also be used to ensure that national and international conventions and protocols are being followed.

1.2.1 Air Quality Management

Inventories can be of various types e.g.; we can have spatial distribution of the emission in different locations or number of emissions at different locations. Emission inventory data created can be put into the air quality model along with meteorological dataset to obtain pollutant concentrations at specific locations and at resolutions. The concentrations/density of pollutant determines the air quality levels for its effect on human health and other effects including visibility. Inventory data helps identifying the major sources and is beneficial when talked on the terms of Air Quality Management as it helps identifies the control policies. (Gulia et al.,2015; Khan et al., 2021) Air quality management, particularly emission inventories, is frequently scrutinised and challenged. Current events frequently ascribe a level of science that is not based on reality. This report is designed to provide a condensed and personal account of the PMC region for the purposes of estimating emissions and comprehending the methods for reaching "as close to reality" as is practicable and scientifically attainable.

1.2.2. Role of Emission Inventory in Air Quality Modelling

The emission inventory of expected contaminants is one of the most important parameters for estimating air quality in any region. The gridded EI is the primary input necessary for forecasting modelling of air quality; hence the accuracy of emission estimates plays a vital role in the correctness of air quality forecast. A well-developed emission inventory decides the quality of model validation against observations. The emission inventory is a thorough record of air pollutants released into the air as a result of all activities that add pollutants into the air in a specific geographic location over a specific time period, organized by source and amount. Emissions data was collected out of both natural as well as anthropogenic sources.

The emission inventory is important for robust control techniques in science-based air quality management. This estimate assists in identifying the region's emission sources and their contributions to total emissions and helps authorities evaluate the availability of options to reduce pollution levels and create action plans. It's been utilized as one of the key components in air quality modelling and air quality management plans to track progress and changes over time in order to obtain cleaner air. Fairly built emission inventories are now widely acknowledged as critical instruments for preventing air pollution at the national, regional, and local levels.

EI has the goal of better understanding chemical and physical processes and the behaviour of air pollutants in the atmosphere. The Global Emission Inventory Activity (GEIA) is a global emission inventory created for this aim (Benkovitz et al., 1996). The data in the GEIA inventory comes from publicly available emission inventories. The Emission Database for Global Atmospheric Research (EDGAR) (Crippa et al., 1999) contains a substantial portion of the GEIA data and regional and national emission inventories.

India has to create and maintain a thorough inventory of baseline emissions to determine if its policy and technical initiatives can reduce air pollution. The study, which is based on a comparison of existing high-resolution inventories, finds that current estimates for India's emissions for $PM_{2.5}$ and PM_{10}, NOx, SO2, and CO vary by up to 37% for the pollutants studied with major sectorial differences. (CEEW Report ,2021). To reduce particle concentrations below prescribed thresholds, we must estimate emission reductions across sectors. We'll be able to estimate these reductions once we get an official, representative emission inventory for India. The Processes responsible for the emission of pollutants can be categorized into anthropogenic and natural. Anthropogenic activities belong to various sectors and lead to usage of variety of fuel types causing pollutant emissions.

1.3 Approaches and Tiers for Conventional Emission Inventory

1.3.1 Bottom-Up Approach:

This methodology is based on collection of specific information of "activity data" of individual sources, processes, activities and their levels, and estimates of emission factors. The accuracy of the emissions computed is improved by using more extensive data base of each activity, more classification of the same and use of better activity specific emission factors strategy for emissions inventories. It is based on a precise computation of emissions from all of an area's individual sources, which are then aggregated to get the entire area's emissions. Each activity's categorization necessitates the administration of a considerable number of data, which is not always available, as well as a significant amount of calculating effort. Bottom-up approach requires a large amount of data especially surveyed activity data to estimate the emissions. As generally experienced the field surveys are tedious to manage, as collection of information requires cooperation from third party, many man hours and it has to be filtered for wrong information using mindful filtration. All these further needs to be recorded digitally and classified to ensure data is available with all details or proper calculation and representation.

The advantages of bottom-up approach are:

1. Uses source-specific data (for point sources) and category specific data at most refined spatial level (for non-point and mobile sources).

2. Emission estimates for individual sources (and source categories) are summed up to obtain domain level inventory.

3. Produce more accurate emission estimates.

1.3.2 Top- Down Approach:

Top-down method is based on the principle to assess emission form the concentration of pollutant. It may also be called 'inverse modeling'. This method starts by monitoring the ambient pollution through the generation of data, thereafter utilizing models to relate measurements to specific sources of pollutants through chemical analysis of the samples. Top-down methods complement bottom-up methods. Top-down analysis requires real-world measurement and knowledge of potential sources compared to bottom-up analysis which requires knowledge of source and source strengths as well as information on meteorology and local conditions. Emission factors combined with high level activity data to estimates emissions scaled to inventory domain across a region based on surrogate data (economic, geographic etc.). Uncertainty and loss of accuracy is very high. Top-down approach is more helpful for quick preliminary decision making.

1.4 Geographical information system

The first phase is to identify sources to track changes in the quantity and variety of emission sources over time so that emissions may be assessed and obtain adequately representative and trustworthy emissions estimates from such a large number of heterogeneous sources. The second step is to distribute emissions throughout multiple regions. We used a "bottom-up" approach to inventory development to increase accuracy, reliability, and uncertainty. The current process is based on calculating emissions at the grid level using activity data. A Geographic Information System (GIS) is a computer-based data collection, modeling, manipulation, analysis, and presentation system for spatially connected data. The easy-to-understand component of GIS meets the study and development of emission inventory requirements. Statistical approaches based on geographic information systems (GIS) are frequently used in today's air quality and emission inventory efforts. Because of its ability to handle technical challenges, GIS is a fantastic tool. The geo-referenced grid is was used to map cells the spatially distributed emissions from several sectors. The emission value for gridded cells is calculated in a GIS environment based on the contributions of various sources inside the grid cells. Spatial allocation of emission and points are required for model application and analysis. It is a process for translating large and irregularly shaped emission data into consistent data using GIS tools.

1.4.1 Digital Data and Geo-referencing

Before entering computed emission into the GIS context, several pre-processing activities are necessary, such as geo-referencing, digitization, and attribute database building. In GIS, spatial objects such as points, lines, and polygons are required. A polygon can be used to represent a source of area. This facility creates pollutants of interest, each of which is defined as a point object with a single XY coordinate and a set of attributes. The whole slum and household areas are digitized in order to extract the vector map and map the Residential sector's emissions using a GIS tool. Grid cells with a resolution of 100m*100m that surround Pune are also created using GIS methods. Application and analysis of models necessitate spatial allocation (gridding). GIS provides excellent spatial and geographical layering possibilities when given the relevant source data and is ideal for creating data in the intended region. Spatial emission allocation can be accomplished by superimposing the discrete point layer over the grid cell and aggregating each cell. Using GIS technologies, it is a procedure for transforming vast and irregularly shaped emission data into consistent data. We've developed geo-referenced grid cells with a resolution of 0.1km*0.1km for gridded data extraction in the Pune region. The regionally dispersed emissions from several industries were superimposed using a GIS program. The contribution of various sources situated within the grid cells is used to calculate the emission value for gridded cells in the GIS context.

1.5. Study Area

The Pune Municipal Corporation (PMC) has an area of 484.61 square kilometres and lies between latitudes of 18.52°N and longitudes of 73.85°E. It's on the leeward side of the Sahyadri hills, on the western edge of the Deccan plateau. Pune had a population of 39 lakhs according to the 2018 census. Between 1991 and 2001, the decadal population growth rate was 50.08 percent, more than double the national rate. Migration is one of the reasons behind rapid growth of PMC. Other reasons include educational boom, particularly in professional domain, industrialization and the creation of IT industry.

PMC has a pleasant climate, with a maximum temperature of less than 40°C in May and mild winters. The vegetation cover varies from moist deciduous to dry deciduous because this place is in the semi-arid monsoon zone. Rainfall occurs from June through September. Pune's ever-increasing population has put a pressure on the city's land supply. As a result, the City's boundaries are expanding, and neighbouring villages are encroaching on the corporation's territory.

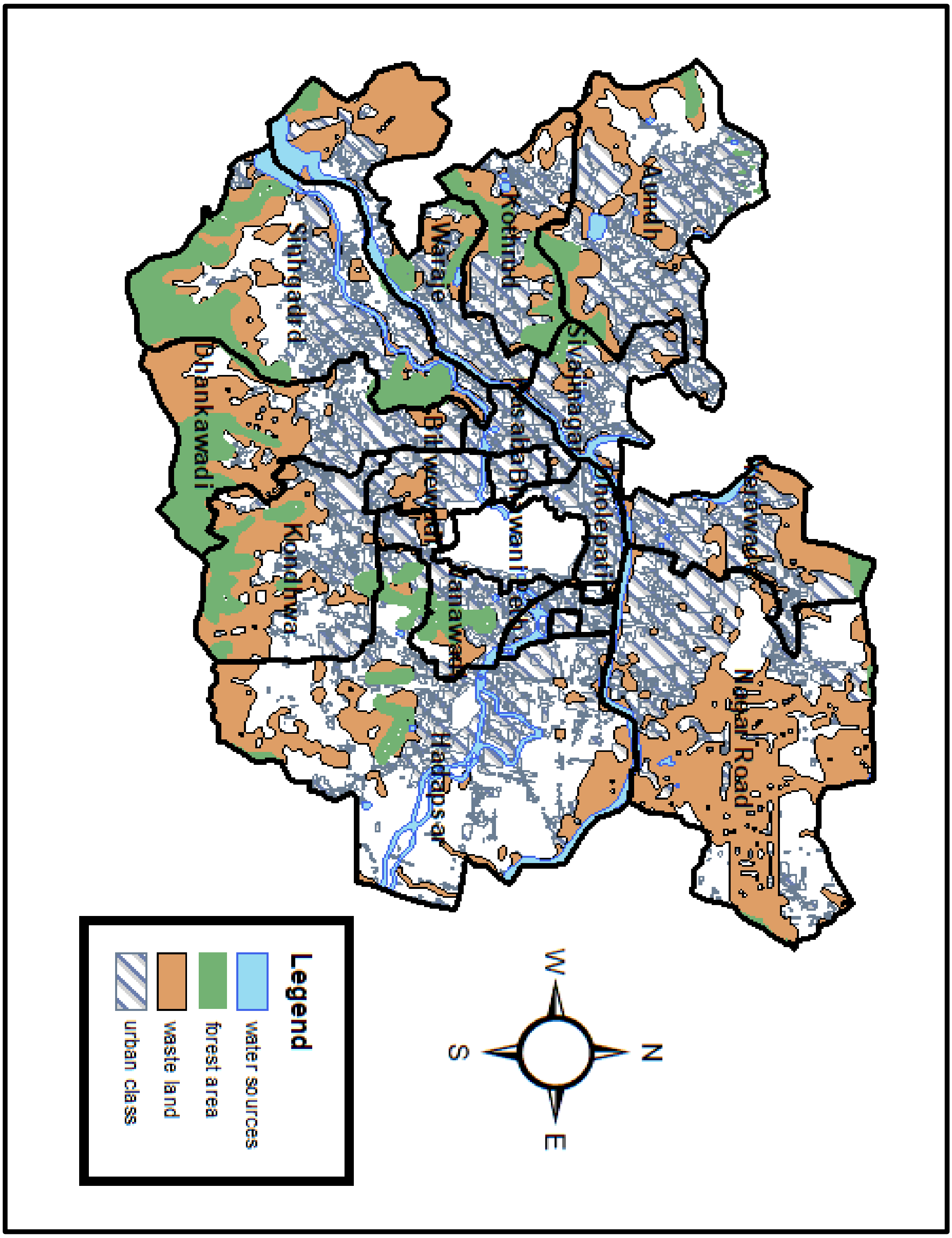
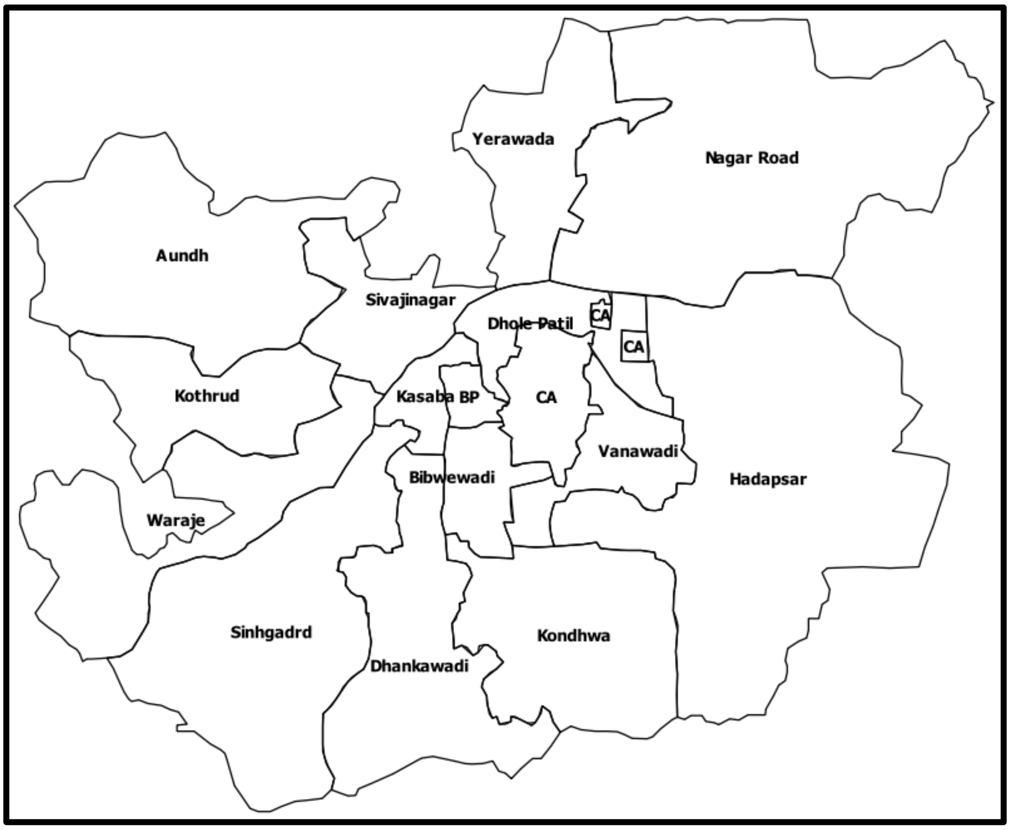


Figure 1: Official Map for Pune Municipal Corporation (PMC)



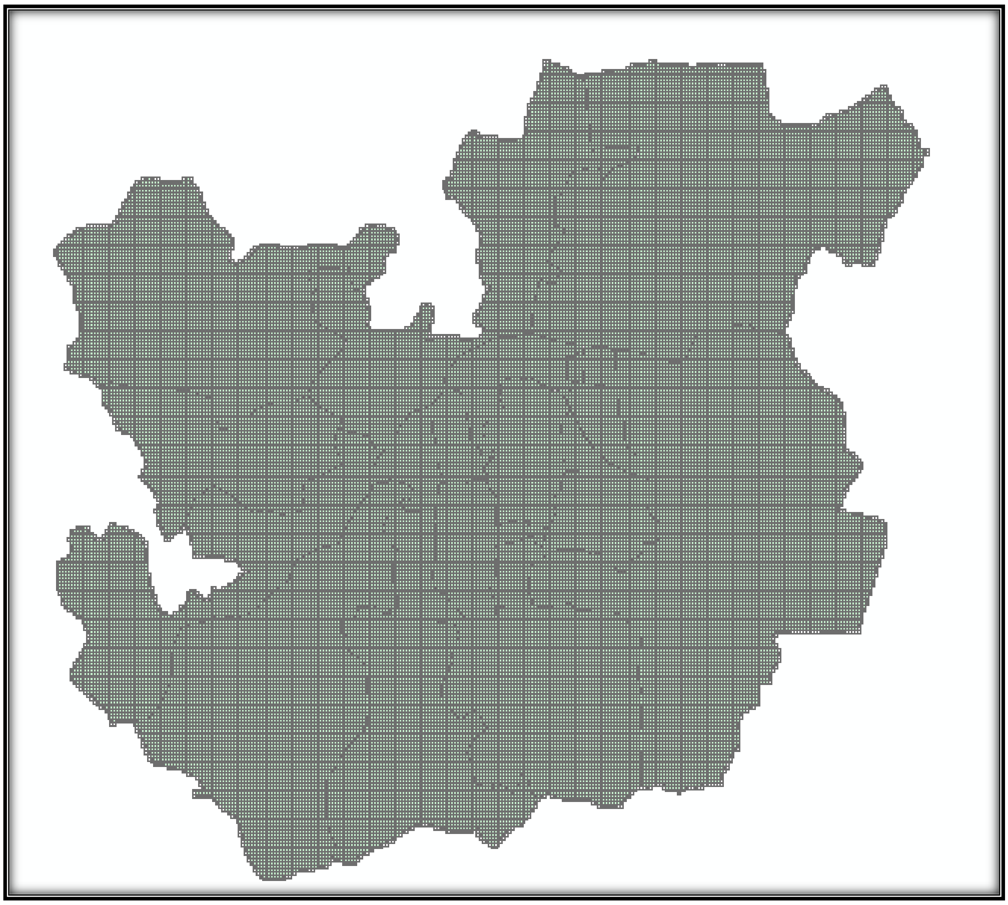


Figure 1(b): GIS (Sectorial & Gridded) representation of PMC

1.5.1 Sources of Emissions

There are several small and significant sources of emissions, both natural and anthropogenic. However, following the industrial revolution and rapid economic growth, anthropogenic emissions became the most pressing concern of human activities (Beig et al., 2018). Air emission sources are often categorized based on source attributes: area source, point source, and line or mobile source.

Source Categorization:

- A non-moving facility or process that emits significant pollutants during operational activities is a point source.

- Stationary Non-Point Sources (Area sources) where emission may be from multiple point sources over an area. i.e., hotel, etc. Area sources do not move and are too tiny or spread out to be categorized as point sources. Paved and unpaved roads, are commonly characterized as area sources of emissions. Although the emissions are from mobile sources, they are classified as an area source because they originate from a fixed site.

- Any source that is generally meant to operate on public roads is considered a mobile source. This comprises 2-wheelers, 3-wheelers, cars, trucks, buses, and light commercial vehicles (LCVs). In most urban areas, on-road mobility emissions are the most significant source of pollution. Due to the enormous number and type of vehicles involved and the impact of traffic patterns on emissions, these emissions are also challenging to assess.

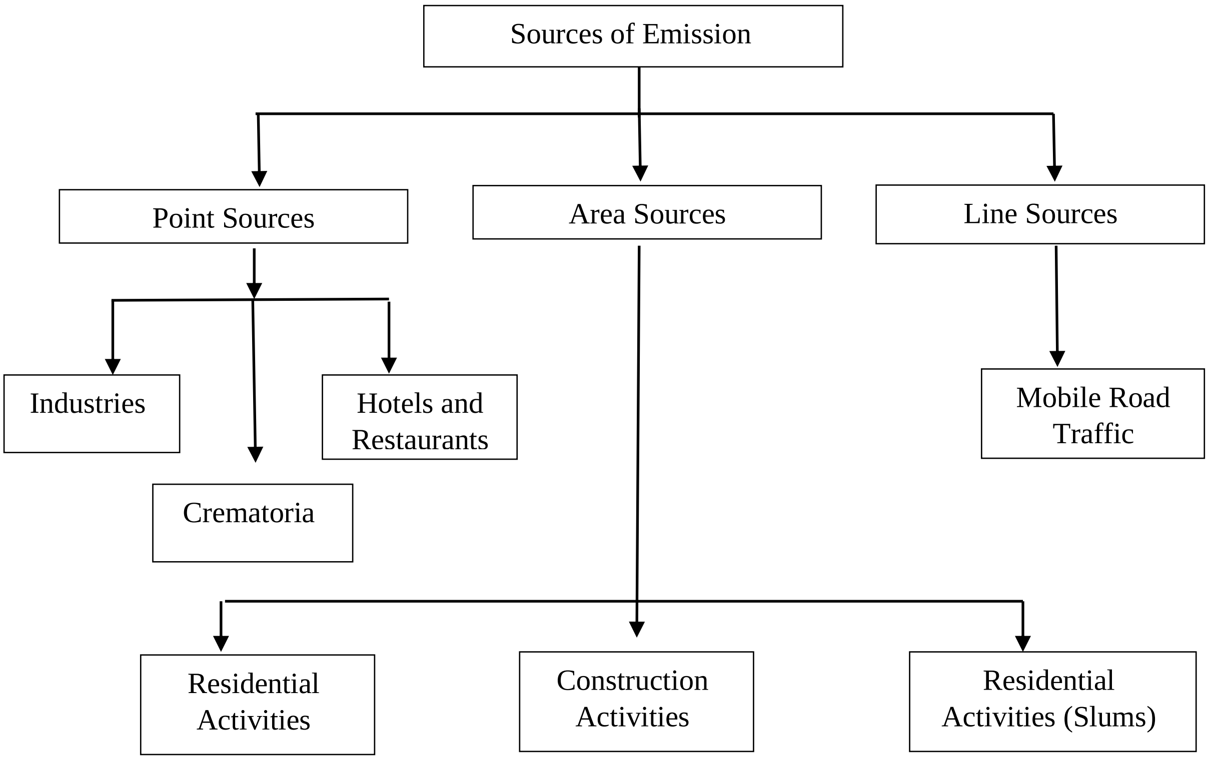
Sr. No.	Sectors	Important Factors and Data
1	Residential Households	Fuel Usage and population data
2	Slum areas	Fuel Usage and population data
3	Industries	Technology, Fuel usage and category

4	Hotels and Restaurants	Fuel Type, usage and Cuisine
5	Hawkers	Fuel Type, usage and movement approach
6	Bakeries	Type of Fuel used and Quantity
7	Crematorium	Number of deaths, crematory method and Fuel usage

Table 1: Target Sectors & Emission sources (Residential + Industrial)

1.6.General Methodology and Approach to Study

The main concern related to water heating in hilly regions is the traditional techniques people acquired, such as using Diesel, kerosene generators, or fuel woods.



Flowchart: 1

1.7. Scope of Work

With the continuous development and increasing energy demand in the various sectors need for clean and sustainable fuels has emerged significantly with rise in pollution. Emissions from various sources without any regulatory control and no inventory for mitigation measures becomes way tedious with varying external factors thus, paving the way for emission inventory development.

Scope of work

• The study's overall scope entails the development of city-specific inventories for extensive assessment of pollutants (PM_{10} and $PM_{2.5}$).

• Spatial distribution of emissions (source specific) and EI for the influence zone (100m x 100m) associated to various sectorial activities.

• Conduct a full EI for line, point, and area sources using information/data from secondary sources.

• To use a systematic methodological approach for data collection, validation, and interpretation of assimilated data, as well as to give a clear road map for measuring emission estimates in any location.

1.8 Gaps in Research

For the city of Pune and PMC region in the previous studies the main concern related to emission estimation is the methodological technique in distribution of emissions for particular sector.

Residential Sector:

- The emission distribution was not limited to the land use area but was considered for whole region.
- Population does not have grid specific distribution; the overall average was taken to quantify the emissions.
- For slums, population data needs an update.
- The usage distribution pattern for various fuels was not grid specific as an overall averaging was done.
- The coal pattern usage for slums in older study seems unnatural.

Industrial and Transport Sector:

- Ward specific emission Inventory characterization is missing.
- Need to update Industrial data is there.
- Hotels and Restaurants fuel usage was never distributed specifically based on cuisine type.
- Industrial sector emphasis on crematoria and bakeries which have high number in PMC region.
- Road Dust Emissions from transport sector in the previous studies was based on the assumption that there are $_{10}$% unpaved roads in Pune, to overcome this assumption based on road width shoulder width area of road was considered as unpaved and accordingly per meter emissions was established.

1.9 Objectives

Gridded emission inventory helps analyse the sectorial performance and understand the implication of different decisions related to control measures. Researchers are continuously working in this regard and the evolution of the "High resolution emissions" concept gave the uprise of mixed approach (Bottom up + Top down) for better results. This review focused on the Secondary data based on the study conducted by IITM, Pune using Bottom-up approach and collection through various means and is focused on the high resolution 100m for PMC region which enhances the detailed emission study and more accurate results with respect to older studies. The city's air quality has deteriorated due to increased automobile use, high demand for fossil fuels, biofuels, and anthropogenic activities. This increase is primarily due to increased population density, commercial zones, and industrial sectors. Any pollutant emission is an ongoing process whose magnitude depends on the variability of its sources and activity data. However, the development of emission inventory is a complex and laborious task. This study's scope is developing emission inventory for the Pune Municipal Corporation (PMC) area with an ultra-high-resolution of (100x100m). The emission inventory is designed for two major air pollutants, namely, Particulate Matter $<_{2.5}$ microns ($PM_{2.5}$); Particulate Matter $<_{10}$ microns (PM_{10}).

The main objectives of the study are

- To generate an Emission Inventory for baseline air pollutants for the PMC region.
- Identifying and categorising anthropogenic pollution sources for various sectors.
- Emission distribution based on various fuel type used
- Distribution of (100 m × 100 m grid) emissions load over PMC.

1.10 Report Structure

The creation of an emission inventory for the city of Pune is detailed in this study. There are five chapters in the report.

EI foundation, GIS study, Requirement, objectives, approach, study area, and scope of work are all covered in *Chapter One.*

In *Chapter Two*, a thorough review of the literature was presented.

The Emission Factors used for various emission estimations and their sources are discussed in *Chapter Three.*

The methodological foundation for developing emission inventories for diverse sectors with fuel-wise distribution of emissions is presented in *Chapter Four.*

The study and outcomes of emissions across several sectors are presented in *Chapter 5*, which is followed by a conclusion.

CHAPTER 2: LITERATURE SURVEY

2.1 Introduction

Researchers use a variety of approaches to analyse and create emission inventories all across the globe, taking into account a variety of polluting sources and study characteristics. The rapid growth and diversification all across the globe in past few decades has generated major pollution issues from diverse sectors. The global anthropogenic emissions and rapidly changing society need inventory development for various sectors and fuel types which plays a vital role for understanding the environmental pollution mitigation and health impacts on local populations. The key influential pollutant has been identified as particulate matter (PM_{10} and $PM_{2.5}$), having the most effect on the human body. These pollutants make breathing difficult for children, the elderly, and persons who have specific conditions including lung disease or heart disease. Furthermore, it causes discomfort to sensitive individuals, such as pregnant women and newborns (Nayak, 2015). According to (Jiang et al., 2020), there is a strong link between air pollution and respiratory and circulatory system disorders. Anthropogenic activities are the primary source of PM emissions, which surpass natural PM occurrence as a result of numerous sectorial activities. The residential sector utilises fuels such as LPG, kerosene, and wood, whilst the industrial sector uses Diesel, Furnace Oil, Coal, and other fuels, resulting in a rise in PM emissions. (Khillare and Sarkar, 20_{10}; Guttikunda et al., 2015; NEERI, 20_{10}). Natural PM emission increases are caused by resuspended road dust emissions, wind-blown dust emissions, and construction activities. (IITM, 20_{10}, ARAI, 20_{10}, and CPCB, 20_{10}). Because both natural and human-made activities contribute to pollution inventory, identifying the polluting sources is necessary before mitigation methods can be devised.

2.2 Global Studies for Emission Inventory

There are a number of Emission Inventories around the globe but the standards always land on few given in Table (2).

Emission Inventory	Area	Category type	Years	Spatial Resolution	Temporal Resolution
Emissions Database for Global Atmospheric Research (EDGAR)	Global	Anthropogenic	Active	0.1◦ × 0.1◦	Annual
IPCC-AR4 - IPCC-AR6	Global	Anthropogenic	Active	Country specific	Annual
HTAP_v2.2	Global	Anthropogenic	Active	0.1° × 0.1°	Annual

Table 2: Global Emission Inventory Database

Emissions Database for Global Atmospheric Research (EDGAR) (Crippa et al., 2018), is derived as a bottom-up approach where emissions are estimated based on the reported and surveyed activity data. The fuel usage, source specific approach to estimate gridded emissions. To enable the establishment of control mechanisms to reduce the impacts of specific high emissions, EDGAR has been utilised as a reference (Thera et al. 2019 ; Broken et al., 2007). EDGAR consists of particulate and gaseous air pollutant emissions from different anthropogenic sectors (1970-2012). The bottom-up methodology for compiling sector-specific emissions was used for global inventory development.

The IPCC inventory is based on the RAINS inventory's emissions at the country and sector level. (Cofala et al., 2007) Data collection, compilation, and reporting, as well as the organisation and administration of greenhouse gas inventories, are all discussed in the IPCC inventory providing guidelines. The EDGAR distributions were used to disperse RAINS emissions spatially at the country and sector levels.

On a worldwide basis, HTAP v2.2 provides air pollution gridded maps with regional datasets. Source information, sectorial division, and high geographical and temporal resolution are all supplied. Because HTAP v2.2 focuses more on high resolution gridded maps, it can be recommended as a global baseline emission inventory that is widely regarded as a reference and from which additional scenarios analysing global emission reduction programmes could start. An investigation of particular country derived emission characteristics reveals a significant disparity in air pollutant emissions from the energy and industry sectors between developed and developing countries. Particulate matter emissions in the residential sector, on the other hand, differ significantly among countries.

2.3 Indian Studies for Emission Inventory

Over the years, India has experienced fast expansion and diversity in every area. Whether it's the residential, industrial, or transportation sectors, with the world's third largest road network. Emissions have long been acknowledged as a major cause of pollution in Indian cities, with 21 of them being among the most polluted in the world. Geographical conditions vary over the Indian plateau, and meteorological conditions, economy, and residential living patterns all have an impact on the emission load in a given area. As a result, each boundary in the Emission Inventory analysis is distinct in its own way. Some of the leading explanations was provided in various Emission inventories created over the years shown in Table 3.

Emission Inventory	Spatial Resolution	Location and Sectors considered	Approach and Remarks
CPCB,ARAI 2010	2 km × 2 km	Pune, Transportation Industry Domestic Agriculture Construction Resuspension of dust Waste burning	Bottom Up Approach This is base for the Indian emission inventory scene. Bottom Up approach was followed with very limited data points to generate industrial specific results.
Behera et al., 2011 (Development of GIS-aided Emission Inventory of Air	2 km × 2 km	Kanpur, Transport Road dust Domestic Industries Brick kilns	Bottom Up and Top Down Approach Identification and categorization of pollution sources accountable for various contaminants

Pollutants for an Urban Environment)		Construction Generator sets Waste burning	Estimation methods for diverse sources of emissions and development of GIS-based digitized maps:
Singh et al., 2016 (GIS-Based On-Road Vehicular Emission Inventory for Lucknow, India)	2 km × 2 km	Lucknow, Transport Sector	Bottom Up Video recording at various traffic intersections to determine traffic volume After identifying the vehicle and its attributes, CPCB emission factors are calculated.
TERI & ARAI, 2018	4 km × 4 km	Delhi, Transport Industry Power plant Domestic Biomass & garbage burning Construction Crematoria Eateries Waste incinerator Landfill burning Diesel generators	Bottom Up Approach Source Apportionment of $PM_{2.5}$ & PM_{10} of Delhi, Model based study method depended on PM_{10} and $PM_{2.5}$ samples being monitored and chemically characterised to calculate source contributions, the chemically speciated samples were entered into the receptor model along with source profiles. On the other hand, a dispersion model is used to simulate PM_{10} and $PM_{2.5}$ concentrations using a source-by-source emission inventory and meteorological inputs.
NEERI, 20$_{10}$	2 km × 2 km	Mumbai, Transport Domestic Bakeries Eateries Crematoria Stone crushers Waste incinerators Diesel generator sets Open burning Landfill burning Construction Resuspension of dust	Bottom Up approach was followed with very limited data points focused more on industrial emissions.

Table 3: Indian Emission Inventory studies

The difference in approach and methodology can be seen from above studies. Parameters like fuel usage patterns and physical terrains may differ, some pollution sources stay consistent, assisting in mitigation methods for varied areas.

For various fuel kinds and activities, the United States Environmental Protection Agency (USEPA) (AP 42) has defined numerous emission factors. The Central Pollution Control Board (CPCB) of India has embraced the AP42 recommendations and created pollutant emission factors based on them. Other resources, such as research publications, focus on sectorial emissions, giving EF estimates additional depth and precision.

2.4 Utilization methods for Emission Inventory

ARAI has developed EFs for the transportation sector (ARAI, 20$_{10}$; TERI & ARAI, 2018). On a worldwide scale, EDGAR (Janssens-Maenhout et al., 2015) gives EFs for numerous contaminants. As evidenced by many literary works, the EF value varies with geographical conditions, technological changes, fuel changes, and other aspects (NEERI, 20$_{10}$; Mishra et al., 2015; Pandey & Venkataraman, 2014; Sahu, Schultz, et al., 2015; Sindhwani et al., 2015). Most pollutants were included in these EI studies to determine the impact of diverse sources on the cities' emission load. The technique used to produce the emissions inventory was authorised by the CPCB. Furthermore, the Emission Inventory was conducted in the city rather than in the airshed. The created EIs had a spatial resolution of 2 × 2 km and were useful in determining sectoral emission loads and their contribution to the total emission load of cities. A lot of studies have been carried out in various locations of India to estimate and quantify the emission load. Emission factors and country-specific emissions have been created by (Baidya and Borken-Kleefeld, 2009; Ramachandra and Shwetmala, 2009; Reddy and Venkataraman, 2002). These are the foundations for developing new emission inventories. In 2009-2011, the CPCB set a precedent in the compilation of emission inventories by developing city-specific emission inventories for key Indian cities. These cities are Bengaluru, Delhi, Chennai, Mumbai, Kanpur, and Pune. Understanding sectorial emissions was made easier thanks to the city-specific approach. For Delhi’s emission inventory numerous studies have been done to determine the emission load share of various polluting sectors (Guttikunda and Calori, 2013; Mishra & Goyal, 2015; TERI & ARAI, 2018a; TERI, 20$_{10}$.). Because all of this research had distinct goals, the overall emission load (PM_{10}) for Delhi assessed by these studies ranged from 38,230 tonnes per year to 114,000 tonnes per year. The change in the predicted PM_{10} emission load was attributable to differences in the study area (780 km2 to 6400 km2) and the polluting sectors taken into account. The National Environmental Engineering Research Institute created the sole EI for Mumbai in 20$_{10}$. (NEERI). The investigation included a total area of $_{10}$56 km2. PM_{10} emissions totalled 268$_{10}$.8 tonnes per year, according to estimates. The most polluting source of PM_{10} was identified as re-suspension of dust (from paved and unpaved roads), and the most polluting source of SO2 was identified as industrial emission. IIT Madras (IITM, 20$_{10}$) prepared the only inventory for Chennai, covering an area of 812 km2. The most contaminating source of PM_{10} has been discovered as dust re-suspension. Kanpur: Several studies have been undertaken to determine the city's pollution sources (Gaur et al., 2014; Goel et al., 2017).

General Utilization Methodology for Basic Emission Inventory Development:

- Gathering source data for area, line, and point sources (such as population, production, fuel use, height of discharge, temperature, and so on).
- In the second phase, a PM emission inventory with appropriate emission factors is created. The data from the traffic study was used to extrapolate the traffic count on

each route in each grid. The actual road lengths for each grid were calculated using ArcGIS software and the digitised map. On the basis of a parking-lot study conducted at four key locations throughout the city, the daily vehicular kilometre travelled (VKT) for all sorts of cars was estimated. The mean weight of the vehicle fleet (tonnes), vehicular kilometre travelled, and silt loading on the road were used to estimate PM pollution activity data from roads

- For each sampling day, run an air-quality simulation using the USEPA ISCST3 model, treating area, line, and point sources separately.
- Then, statistically compare experimental and model-calculated concentrations to evaluate and validate the model. Create maps of ambient PM_{10} concentration profiles and sources of PM_{10} pollution

CHAPTER 3: Emission Factors

3.1 Methodology

Emission factors (EFs) are a representative number that attempts to link the amount of a pollutant released into the atmosphere to a specific activity connected with that emission. The chemical properties of a fuel dictate its emission factor, which is influenced by combustion, temperature, and control system efficiency. Literature provides only a few measured EFs for India. Incorporating a country-specific suitable EF is a vulnerable aspect of the emission inventory development process. EF defines the source strength as emission per unit time and unit process activity. The EFs used in the present work for major sectors are outlined as following.

3.2 Emission Factors for Residential Sector

S.NO.	FUEL TYPE	$PM_{2.5}$	PM_{10}	SOURCE
1	LPG	0.33 g/kg	2.10 g/kg	Reddy & Venkataraman (2002)
2	Kerosene	1.9 g/L	1.95 g/L	Source Apportionment Report CPCB (2011)
3	Wood	11.76 kg/t	17.3 kg/t	Annexure 3.1, CPCB
4	Coal	20 g/kg	12.2 g/kg	TERI Report (2018)
5	Cow Dung	5.04 g/kg	6.3 g/kg	Source Apportionment Report, CPCB (2011)

Table 4

3.3 Emission Factors for Industrial Sector

S.NO.	FUEL TYPE	PM$_{2.5}$	PM$_{10}$	SOURCE
1	Diesel	0.97 g/kg	$_{2.5}$9 g/kg	Reddy & Venkataraman (2002), CPCB Report
2	Kerosene	1.9 g/L	1.95 g/L	Source Apportionment Report CPCB (2011)
3	Wood	1.5 g/kg	15.3 g/kg	Annexure 3.1, CPCB
4	Coal	1.36 g/kg	2 g/kg	IITM Report
5	Cow Dung	5.04 g/kg	6.3 g/kg	Source Apportionment Report, CPCB (2011)
6	Furnace Oil	0.65 g/kg	4.79	IITM Report
7	Natural Gas	0.31 g/kg	2.$_{10}$ g/kg	IITM Report

Table 5

3.4 Emission Factors for Transport Sector

Emission Factors (g/km)		**2W (Petrol)**	**3W-4S (Petrol)(Diesel)**	**3W (CNG)**	**4W (Petrol)**	**4W (Diesel)**	**4W (CNG)**	Source: IITM Report, ARAI, Air Quality Monitoring Project-Indian Clean Air Program, 2007 report /CPCB 20$_{10}$ Report/Sahu et
5 Year (BS-IV)	PM	0.015	0.015	0.118	0.002	0.015	0.01	
$_{10}$ Year (BS-II, BS-III)	PM	0.035	0.015	0.118	0.006	0.06	0.001	
15 Year (BS-I)	PM	0.035	0.015	0.118	0.008	0.06	0.001	

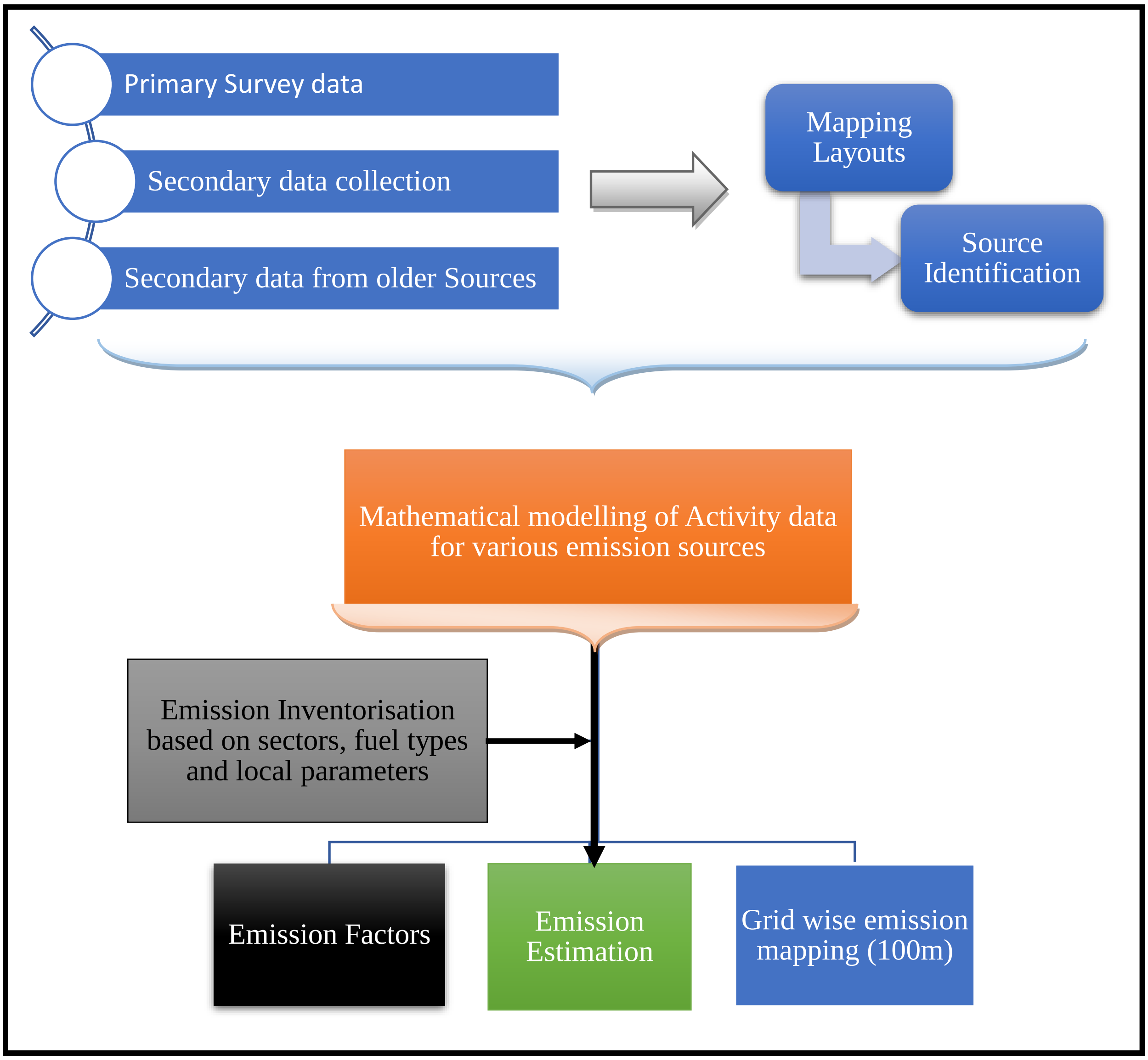
Emission Factors (g/km)		**LCV (Petrol)**	**LCV (Diesel)**	**Buses (CNG)**	**Buses (Diesel)**	**HCV (Diesel)**		al. (2011); Bond et al. (2004);
5 Year (BS-IV)	PM	0.63	0.475	0.044	1.075	1.24		
10 Year (BS-II, BS-III)	PM	0.63	0.475	0.044	1.213	1.96		
15 Year (BS-I)	PM	0.63	0.475	0.044	2.013	1.96		

Table 6

CHAPTER 4: Methodological Framework for EI development

4.1 Methodology

The general approach for compiling this emission inventory is depicted in Flowchart 2. As described in the introduction chapter addressing the division of distinct sectors depending on fuel type and sources, important influence zones around the PMC region have been discovered and divided. To create a baseline profile for the city, information was gathered from primary survey data collected by IITM Pune in 2018-19 as well as secondary sources. The information gathered from various sources was assembled in order to identify the sources and put the information into a useful format. The methodologies applied were discussed in upcoming sections. Emission Inventory has been prepared for the PMC region at 100m resolution.



Flowchart 2: General EI Methodology

The Flowchart 2 explains the general methodology used. Primary and Secondary data sources from survey, official reports and research work is used to build map layouts and define sources for the regional area. The General EI methodology for our study sets on the mixed data collection approaches including secondary and primary ways. The source identification can only be done when coordinates of the location are available. From Point type data source to area type collection was based on previously done surveys and data gathering from various official sources to create a base location map for the PMC region. The sectorial division was the next step in the process which led to activity data, which is based on the population, time, usage, fuel type distribution, and other local parameters to create a mathematical model to help understand the fuel use and activities across the region. Division of this modelled data was then distributed along 100m grid sections for emission estimates.

A detailed emission inventory is created for three major sectors, 11 subsectors, and nine fuel types. For PMC 51300 grids, different land use patterns and population densities have been identified. Estimates of emissions from each grid were used to determine the sources. A comparison of different wards in PMC was based on these estimates. To calculate emission loads, data such as fuel usage, traffic counts, and activity data are employed, but parameters such as population, road length, and land cover are used to maintain its local character.

4.2. Mathematical Algorithm:

Based on the sectorial division for various wards following data is used to evaluate the emissions from a fuel type and source.

- Residential sector: Population, Land use, Fuel usage, Family size, Fuel Type
- Industrial Sector: Industry type, Fuel usage, Activity duration, Fuel Type
- Hotels and Restaurants: Source type, Fuel usage, Cuisine type, Activity duration, Fuel Type
- Crematoria: Source type, Fuel usage, Number of deaths, Fuel Type
- Transport Sector: Vehicle Count, Vehicle Kilometre travel, Fuel usage, Fuel Type, Engine type, Vehicle Category

Based on the above-mentioned data, governing equations for estimating emissions from various sources have been established and solved using an iterative numerical method that considers interactions between parameters. Pollutant emissions in different sectors were calculated as a function of activity data, emission factor, combustion technology, and emission control removal efficiency. For each sector, all emissions are aggregated over a given grid. The equation 1 is used to estimate the spatial distributions and sectorial emission loads. The basic idea of equation is consistent to adopted approaches in several studies and modelling framework. (Bond et al., 2004 ; Kalimont et al., 2002).

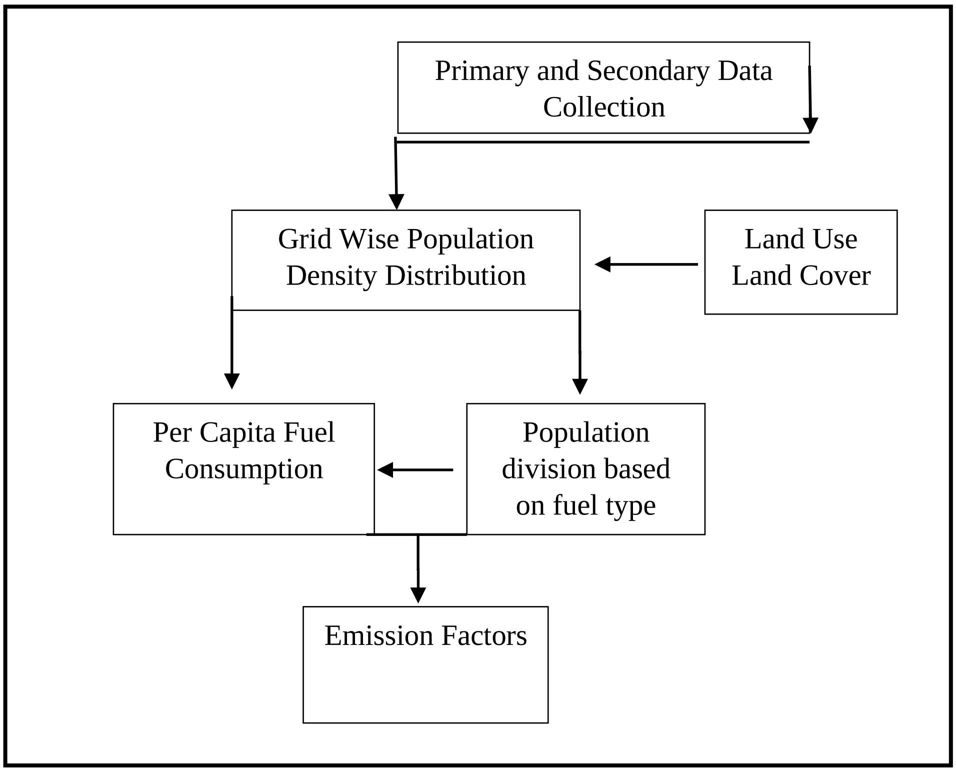
$$TE = \sum FC \sum nU_a \sum EF \sum T_a \quad \text{...... (Eq.1)}$$

- **TE**= Total emission **Nu**= Number of users **a** – Sector specific
- **FC**= Specific- fuel usage **EF**= Emission factors **T**= Time duration

4.3. Mathematical Algorithm (Sectorial Division):

4.3.1 Residential Sector

The methodology followed to establish emission estimates from the residential cooking is shown in the flowchart 3.



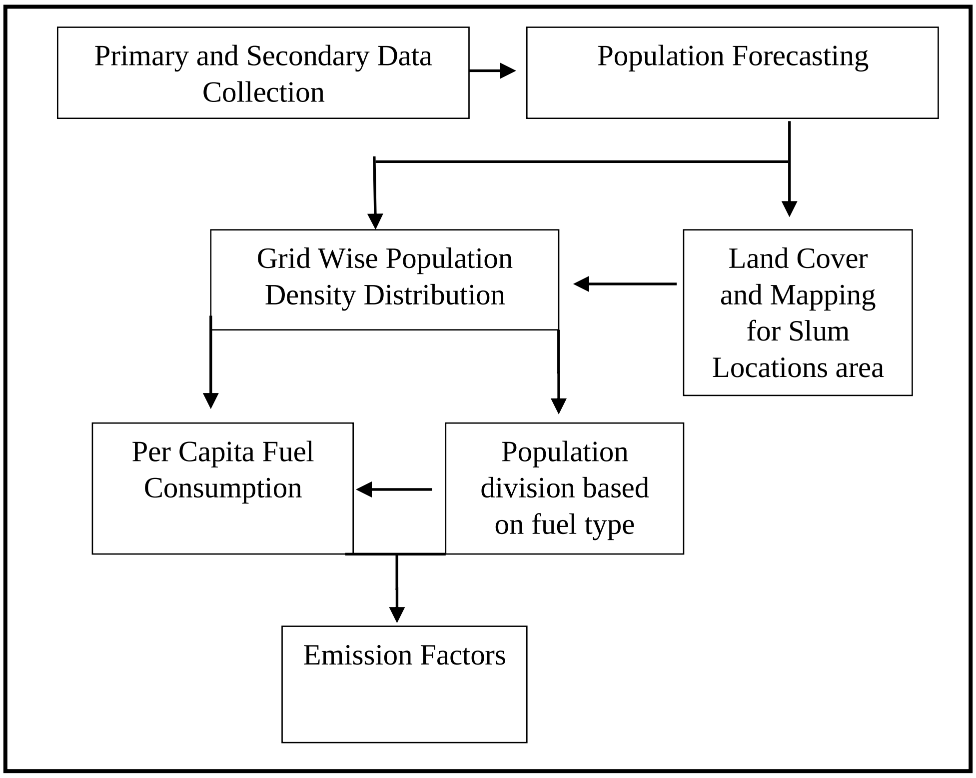
Flowchart 3: Methodological approach for Residential Sector

On the basis of collected data (primary and secondary) and land use land cover area for residential sector a grid wise distribution of PMC was carried out. The population distribution and family size for each grid section (100m) help define the fuel usage and activity data. For the grid wise estimation out of the total population, To estimate the population in a grid, the area of each ward falling within it was computed. Equation 2 describes the algorithm used to identify the grid population.

$$\sum_{i}^{N}(\textbf{Intersected ward area} * \textbf{Density of Ward})$$

4.3.2 Residential Sector (Slums)

The methodology followed to establish emission estimates from the slum areas is shown in the flowchart FC 4.



FC 4: Residential Sector (Slums) EI Methodology

Population Forecasting was done for the slum population data as the last updated inventory data available was for 2012. The ARITHMETICAL INCREASE METHOD was used in this scenario to forecast the results over slum areas. This technique is suited for large, historic cities that have experienced tremendous growth. If it is used for small, average, or new towns, it will have a lower influence than the actual worth. In this technique, the average increase in population per decade is approximated using data from prior census reports. This growth is added to the present population to determine the population of the next decade. As a result, the population is thought to be steadily increasing.

$$P_n = P + n.C \qquad \text{.............Eq. (3)}$$

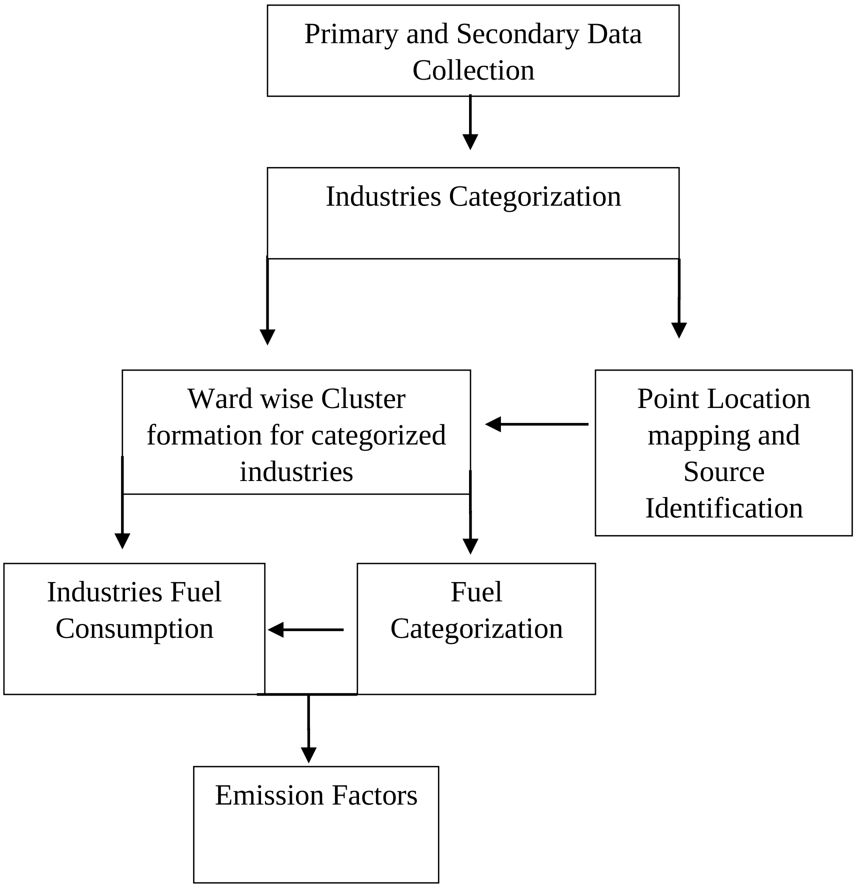
- **P** = Present population. **P_n** = Population after n decade
- **C** = Rate of change of population

The slum areas were mapped using a gridded sectorial division, and parameter-based activity data, such as population, fuel usage, and fuel type, was provided. The coal, wood and kerosene usage is normal in slum areas. The categorization was made based on survey data. The emissions from slum regions were calculated using Equations 1 and 2.

4.4 Industrial Sector

4.4.1 Industries

The flowchart 5 depicts the process used to calculate emission estimates for point source industries. Small and medium-sized firms are increasingly encroaching on the PMC region, generating industrial clusters. Due to resource development, PMC is becoming the epicentre of considerable industrial clustering. Industry categorization based on MIDC data available. Industries with stack heights greater than 30 metres were excluded. The industries were assigned to the gridded PMC map region based on their locations. Point source industries are found in the PMC region.

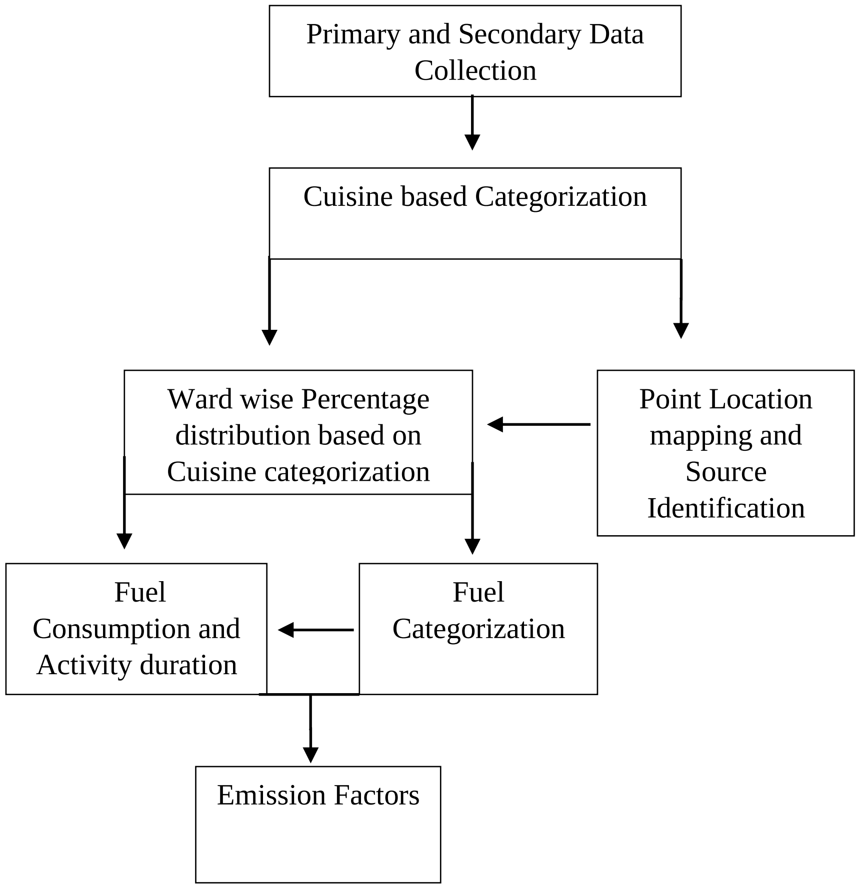


Flowchart 5: Industries EI Methodology

For the industrial sector, Equation 1 is used to estimate the emissions in the grid section while the formula remain same approach varies represented by various flowcharts.

4.4.2 Hotels and Restaurants

The methodology followed to establish emission estimates for Hotels and Restaurants is shown in the flowchart 6.

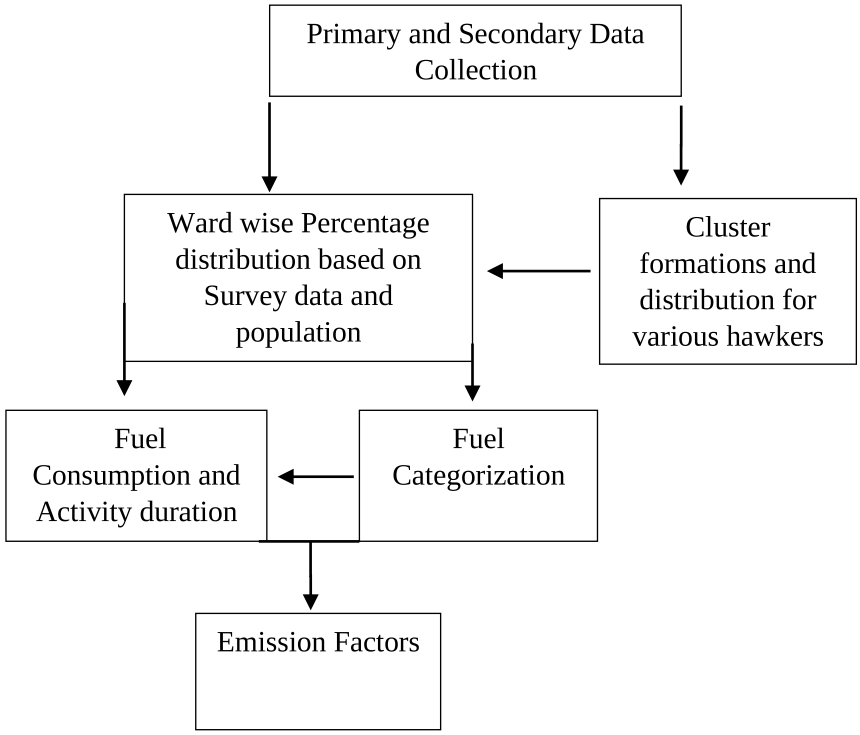


Flowchart 6: Hotels and Restaurants EI Methodology

Pune is the migration hub for various reasons hence the Hotel business is booming. The data collected was distributed and the classification of fuel types served as the basis for the Cuisine Categorization. The presence of tandoor activities, barbeques, and grills in hotels and restaurants is a crucial feature in categorisation. The ward division point mapping was based on georeferencing criteria. Fuel usage was used to determine the overall percentage distribution. The daily running or activity time was use to analyse the fuel demand and usage along with the data gathered.

4.4.3 Hawkers

The methodology followed to establish emission estimates from Hawkers/Vendors is shown in the flowchart 7.

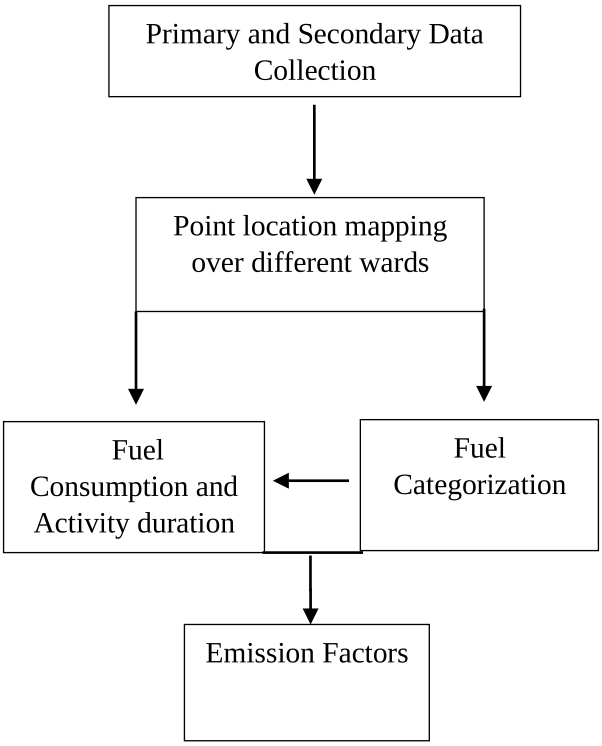


Flowchart 7: Hawkers EI Methodology

Street vendors/hawkers can be considered as mobile or stationary sources. Many of these street vendors were granted permits by the Municipal Corporation and given permanent locations. In contrast, sizable proportions are unlicensed and constantly changing locations. There are more than 38000 hawkers in the PMC area. This makes analysis of hawkers a challenge as there is no permanent specific location for the source, so approach of cluster formation based on the weighted average of the population was adopted. Based on the fuel type, quantity, cooking oil type, hours of cooking the emissions were evaluated. The distribution of emissions was clustered and random.

4.4.4 Bakeries

The methodology followed to establish emission estimates from Bakeries shown in the flowchart 8

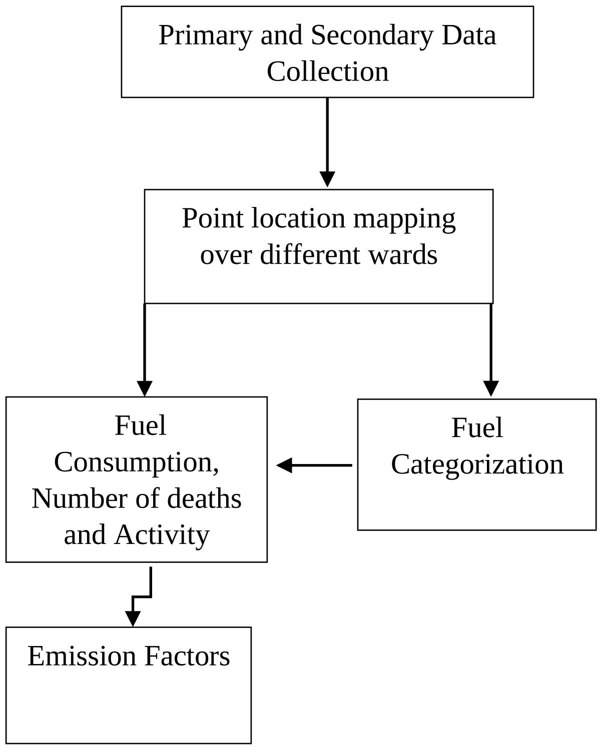


Flowchart 8: Bakeries EI Methodology

Customers go to a series of convenience stores for prepared foods, freshly baked products, and vital groceries; the PMC region has over 500 bakeries. Point data locations mapped on PMC region and gridded emissions were estimated based on Equation 3.

4.4.5 Crematorium

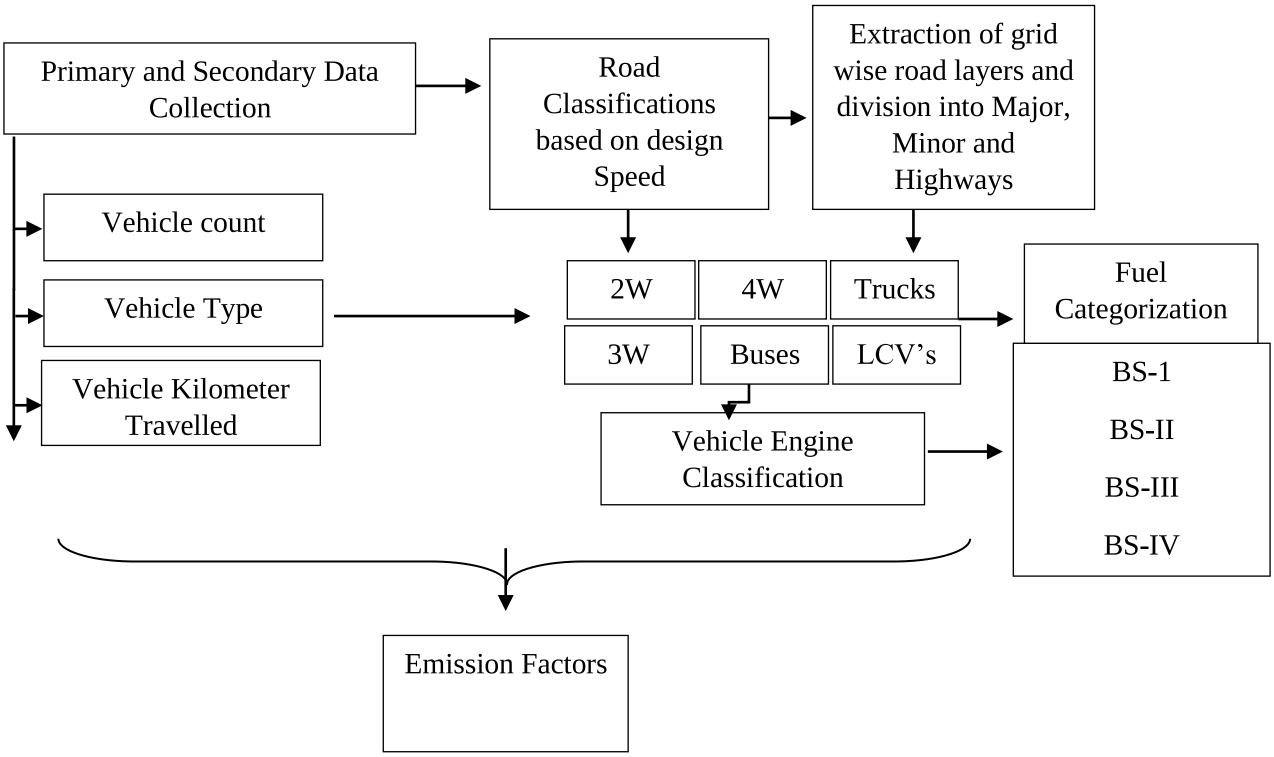
The methodology followed to establish emission estimates from Crematorium shown in the flowchart 9. In Pune, deceased remains are burned either electrically or using dung-cake and fuel wood. 40% of corpses are incinerated without the use of electricity, using wood and dung cake as fuel. This results in an increase in emissions. 60% of corpses are burned using electricity and Diesel. This results in a significant reduction in emission.



FC 9: Crematorium EI Methodology

4.5 Transport Sector

The methodology followed to establish emission estimates from vehicular movement or the transportation sector is shown in the flowchart 10.



Flowchart 10: Transport EI Methodology

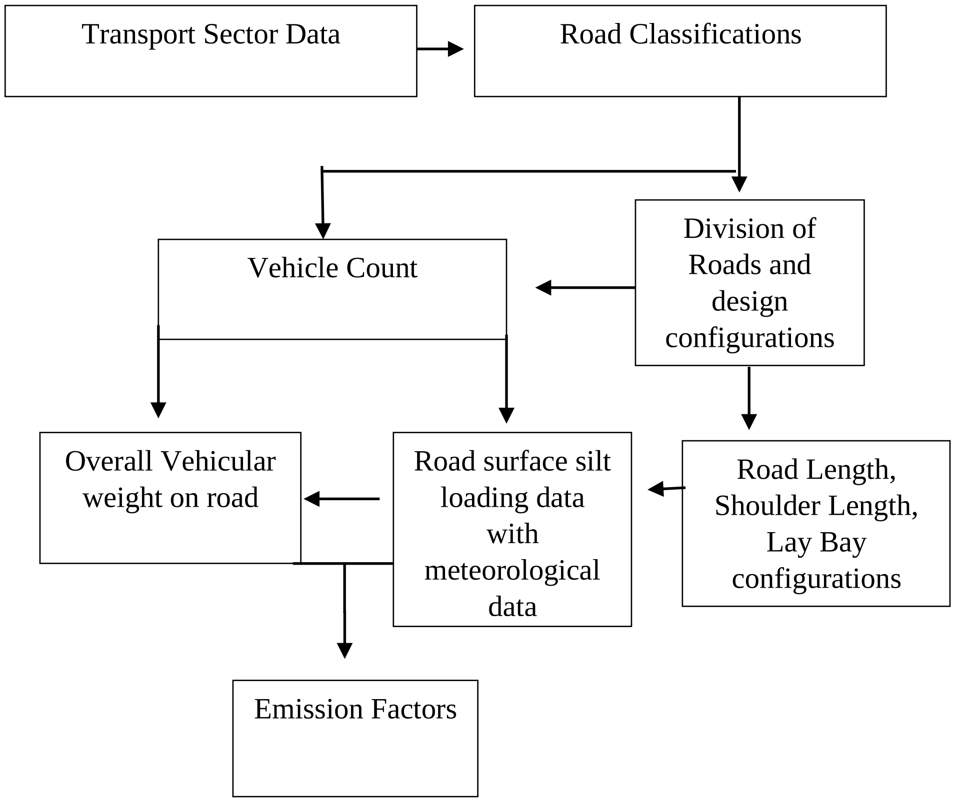
The governing equations for estimating transportation emissions from diverse vehicular sources are presented in Equation 4. It considers parameter interactions. Emissions were computed as a function of activity data, emission factor, vehicle kilometre travelled, and vehicle count. The distribution among different road types was based on the survey data. The road type distribution was based on road design speed.

$$TE_t = \sum(vehi \times Di) \times EF$$ **……Eq. (4)**

- **TEt** = Total emissions, Transportation **Vehi** = Number of Vehicles
- **Di** – Distance travelled in a year per different vehicle type **EF**= Emission factors

4.6 Fugitive Road Dust (Paved and Unpaved Roads)

The methodology followed to establish emission estimates from road dust due to vehicular movement is represented in the flowchart 11.



Flowchart 11: Fugitive Road Dust (Paved and Unpaved Roads) EI Methodology

Eq.5 shows the governing equations for estimating road dust emissions. Particle size, climatic parameters, silt loading, and vehicle numbers, vehicle type, and vehicle weight were all used to calculate emissions. This equation is utilised for paved roads, but a different technique is employed for unpaved roads. The shoulder area around the paved part was used to calculate the length of the unpaved road. This segment of unpaved road aids in determining the exact percentage of route length that is unpaved. The g/m2 silt loading was variable along paved and unpaved road sections because the width of the paved and unpaved sections differed depending on the road type. The equation was taken from the USEPA publication AP42 for paved roads.

$$E = \sum (k(sL/2)^{0.91} \times W^{1.02})(1-P/4N)$$

- **E** = particulate emission factor (having units matching the units of k);
- **k** = particle size multiplier for particle size range and units of interest;
- **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)

k is a empirical constant	**PM_{10}**	**$PM_{2.5}$**
k (g/VKT) for paved road	0.62	0.15

CHAPTER 5: Results and Discussions

Study Model

5.1 Residential Sector

5.1.1 Residential Activities and Emissions

This section discusses fuel use, which includes emissions from homes. In India, the residential sector is the greatest source of ambient $PM_{2.5}$ pollution (Upadhyay et. al. 2018). In PMC region, the emissions from the residential cooking were found to be mainly due to cooking and lighting activities. Liquefied petroleum gas (LPG) was the primary cooking fuel in the most of the residential regions. Data revealed that use of kerosene is there in some parts of the residential areas for specific activities related to cooking, heating and lighting.

For estimating the emissions from residential fuels, predominant fuel usage was for (LPG, Kerosene). This data was collected as a secondary source for this study, actual survey data collection was done by IITM. The data collection for residential activities followed a mixed both top down and bottom-up approach. LPG and Kerosene consumption by residents was spatially distributed on the basis of population density

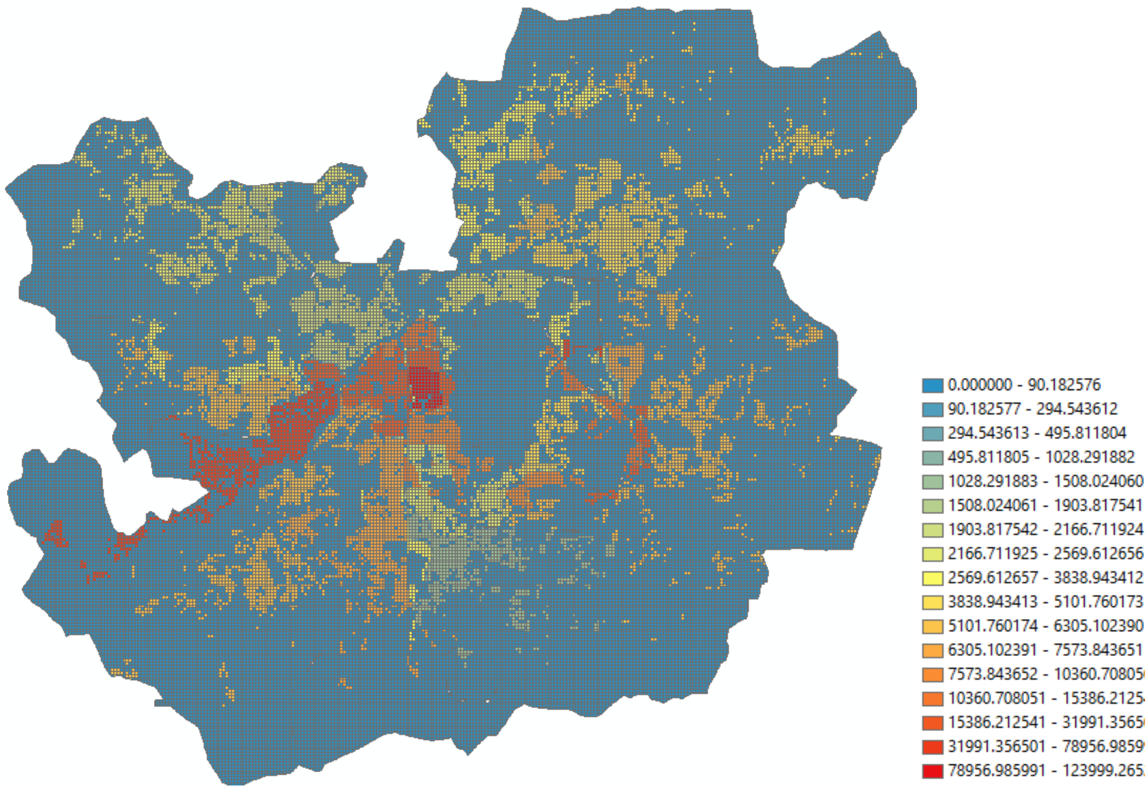


Figure 5.1 (a): $PM_{2.5}$ Emission distribution over PMC (gm\yr.)

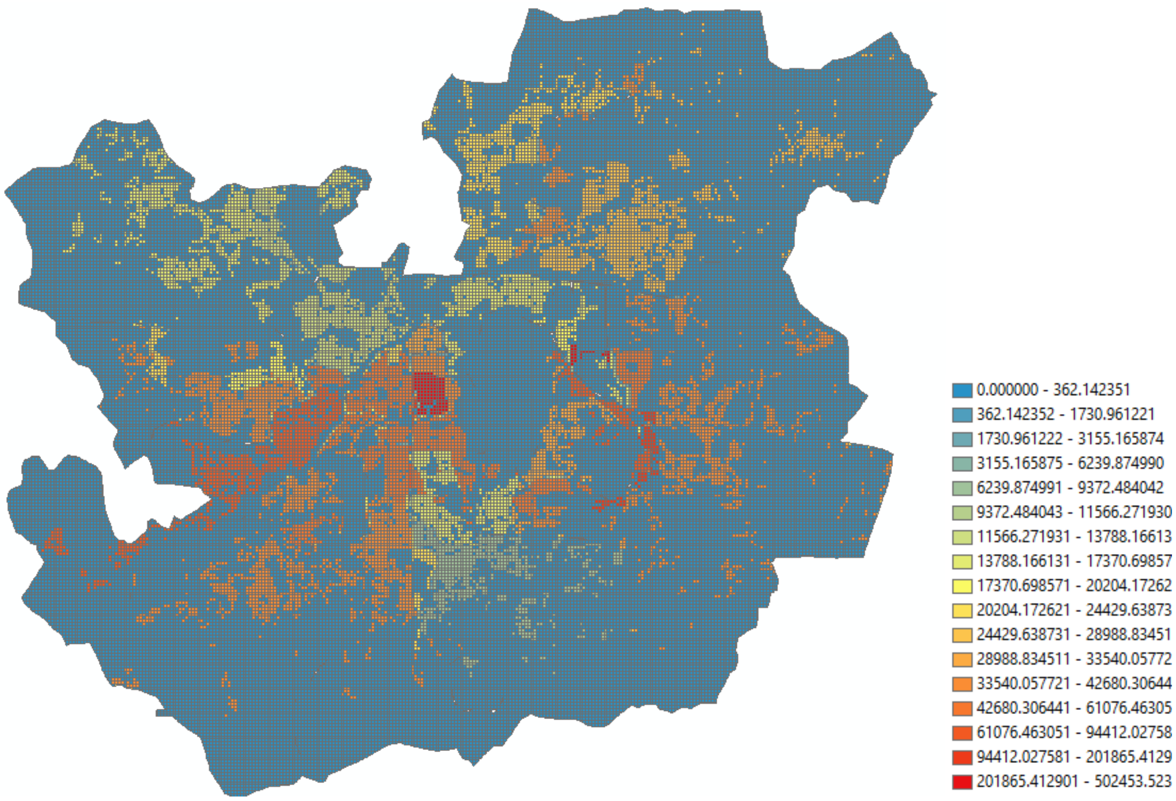


Figure 5.1 (b): PM_{10} Emission distribution over PMC (gm\yr.)

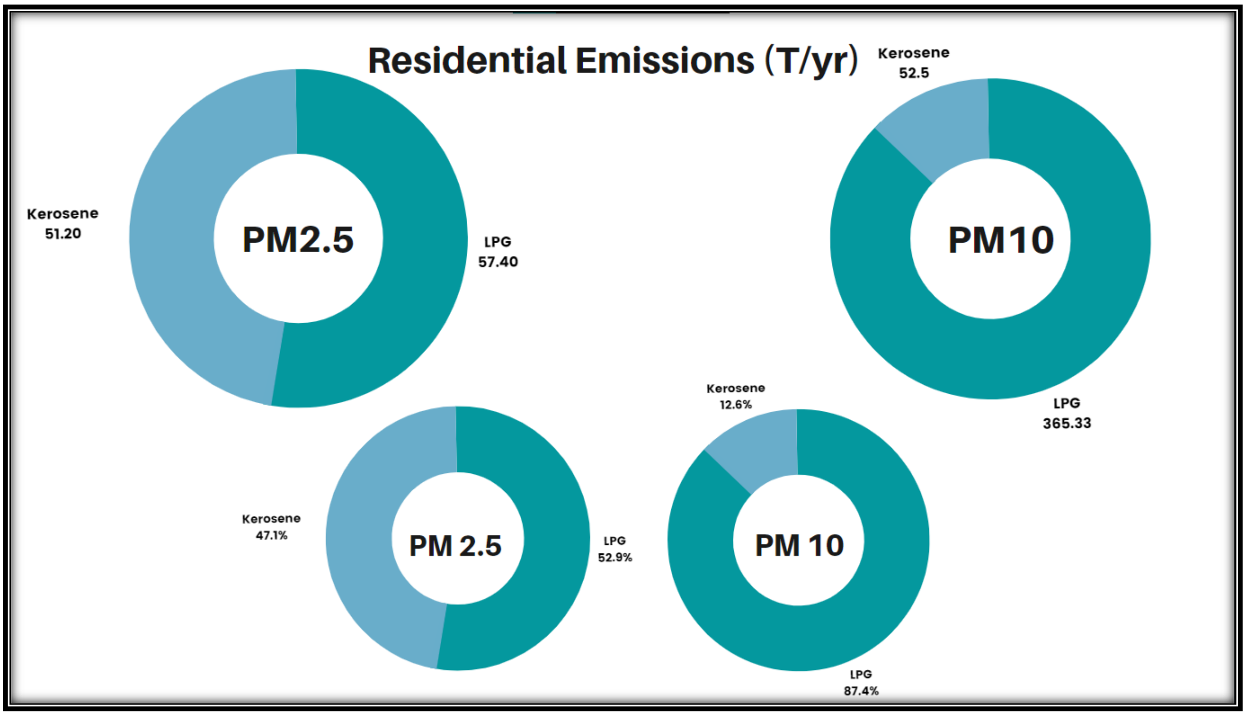


Figure 5.1 (c): $PM_{2.5}$ and PM_{10} emissions from different fuels

The $PM_{2.5}$ from the residential cooking turns out to be 57.40T/yr. for LPG and 51.20T/yr. for kerosene. The PM_{10} from the residential cooking turns out to be 365.33T/yr. for LPG and 52.7T/yr. for kerosene. The percentage distribution and quantitative emission display is given through donut charts Fig.5.1(c). Figure 5.1(a,b) depicts the regional distribution pattern of $PM_{2.5}$ and PM_{10} emissions from different sources. Particulate pollution loads are evenly distributed throughout the PMC region, but are concentrated in the residential sector. Emissions have been found to be higher in densely inhabited places.

5.1.2 Slums and Emissions

This section discusses biofuel consumption, which includes emissions from Slum Population expansion and is one of the main causes of environmental concerns since it necessitates the use of more and more (non-renewable) resources. There has been a parallel development in slum communities as the population has grown. The low urban population (slum population) in Pune is estimated to be 30-35 percent of the overall population; the fast proliferation of slums has a capacity for economic activity and employment generation. The non-slum population in PMC are stagnant on fuels with respect to slum population as Wood, kerosene, Coal are fuels used by slum population along with LPG. The average household slum consumes around 3.69 kg of wood causing 42% of the slum emissions.

The $PM_{2.5}$ from the slums turns out to be 63.01T/yr. for LPG, 27.06T/yr. for kerosene,65.99T/yr. for wood and 0.12T/yr. for coal. The PM_{10} from the slums turns out to be 196.26T/yr. for LPG, 28.60T/yr. for kerosene,97.08T/yr. for wood and 0.20T/yr. for coal. The graphical distribution pattern of $PM_{2.5}$ and PM_{10} emissions from these sources are shown in Fig.5.1(d).

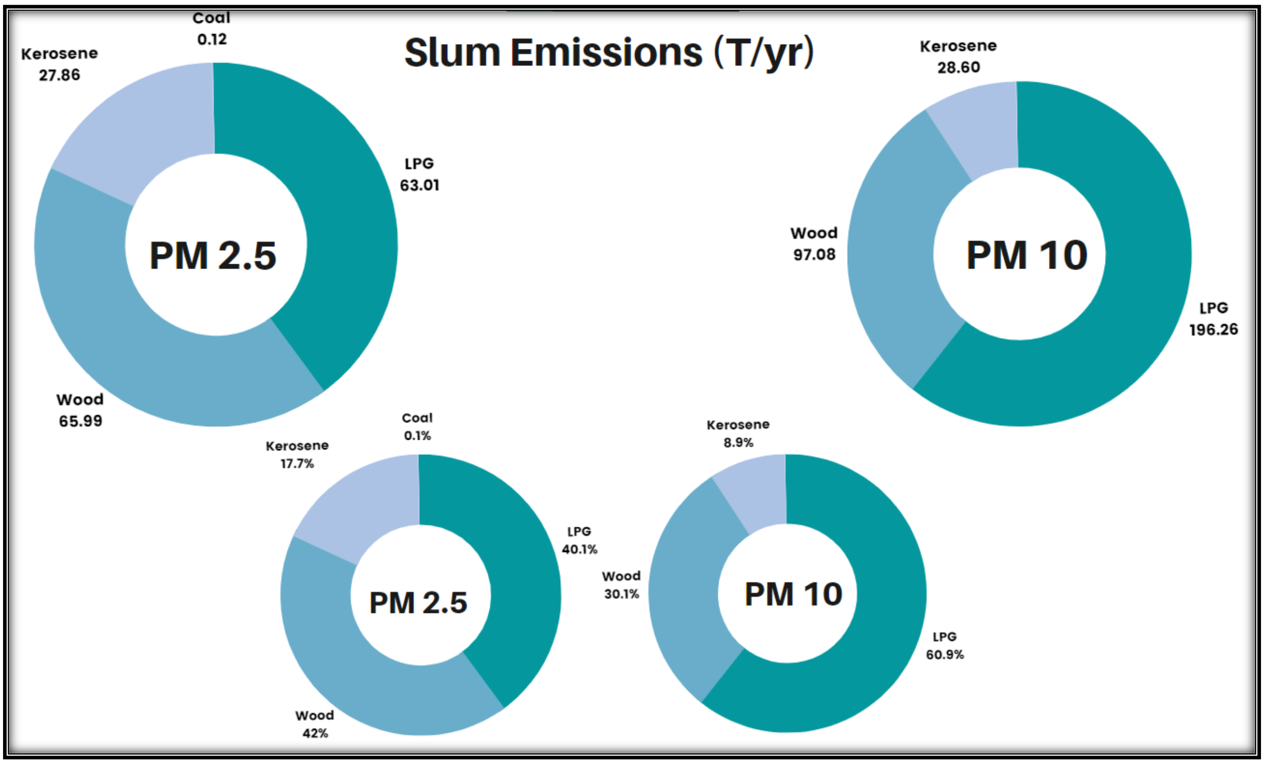


Figure 5.1 (d): Slum $PM_{2.5}$ and PM_{10} emissions for different fuels

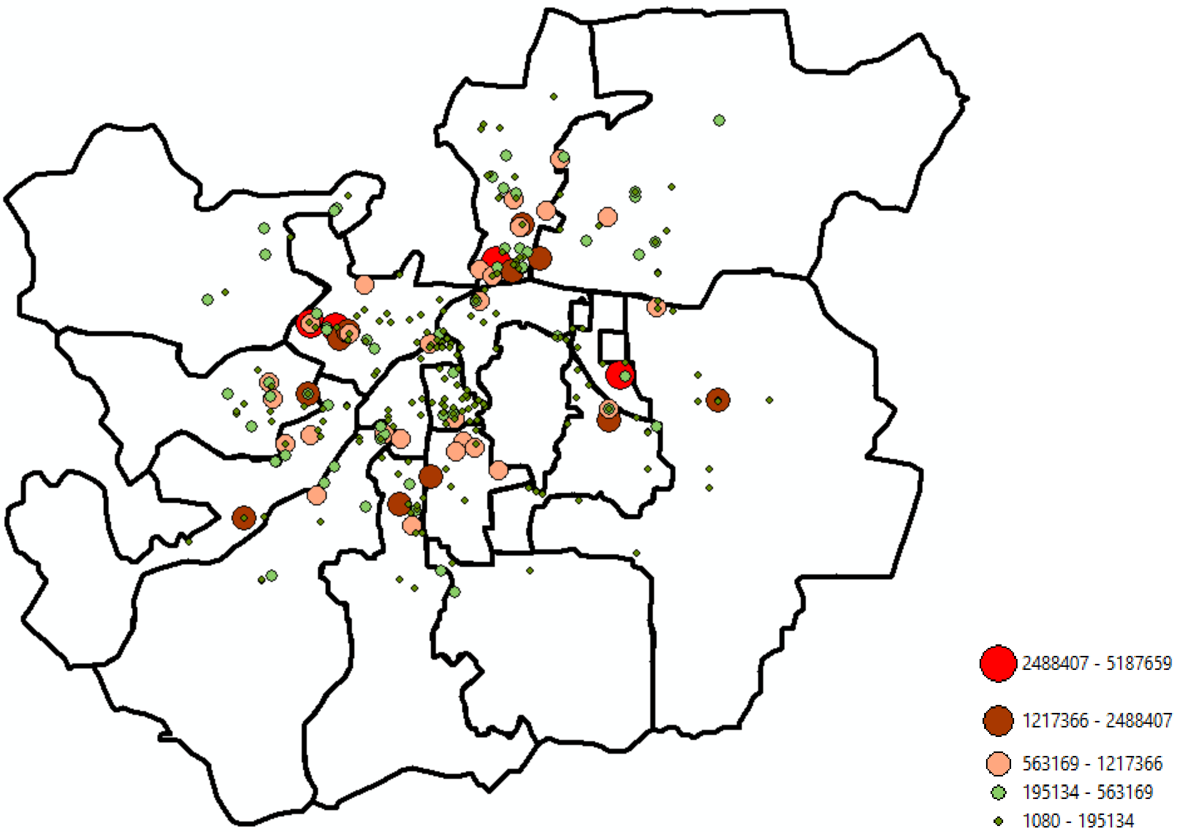


Figure 5.1 (e) : $PM_{2.5}$ Slum Emission distribution over PMC (gm\yr.)

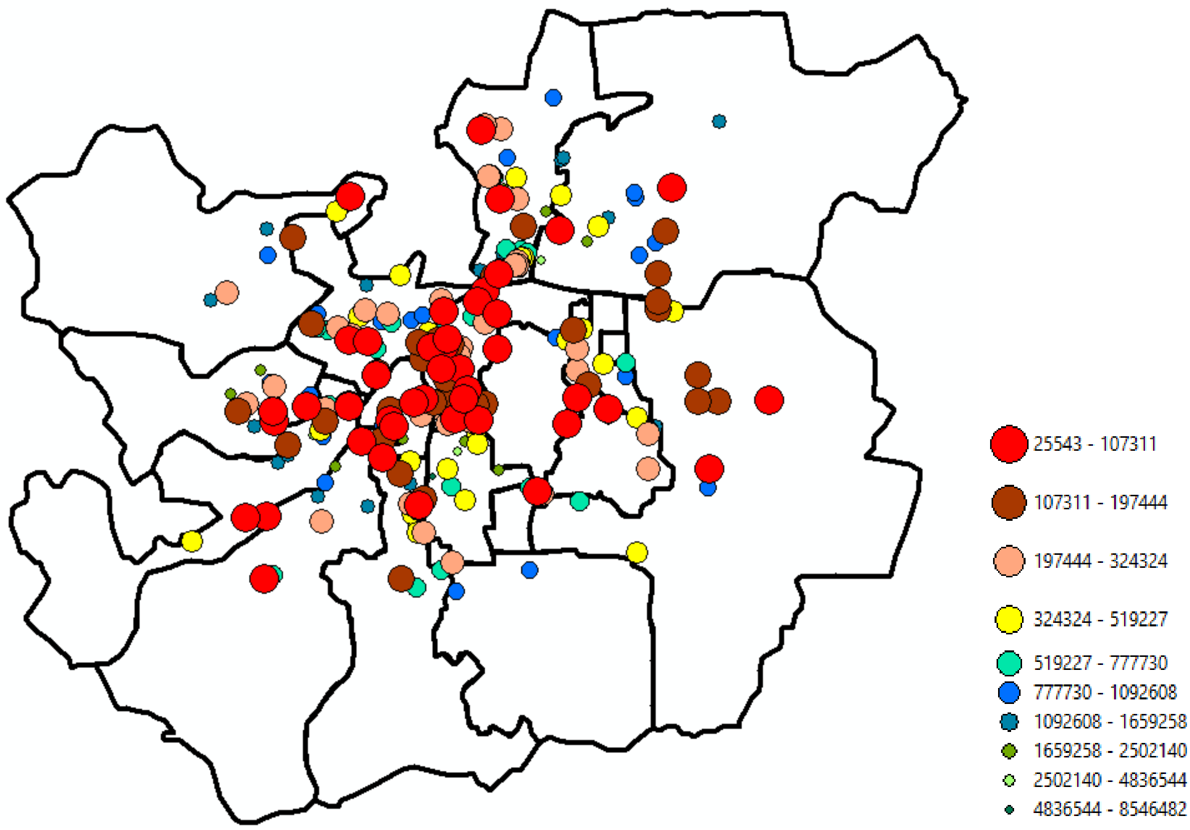


Figure 5.1 (f) : PM_{10} Slum Emission distribution over PMC (gm\yr.

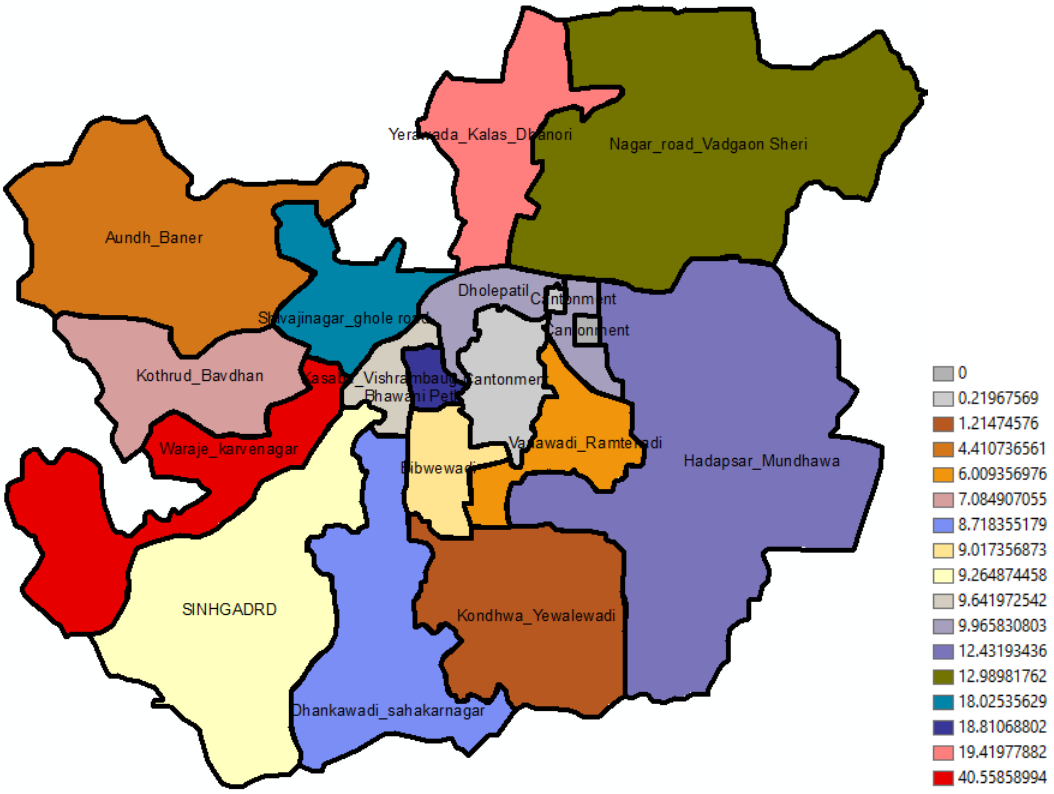


Figure 5.1 (g) : $PM_{2.5}$ Ward wise Emission distribution (T\yr.)

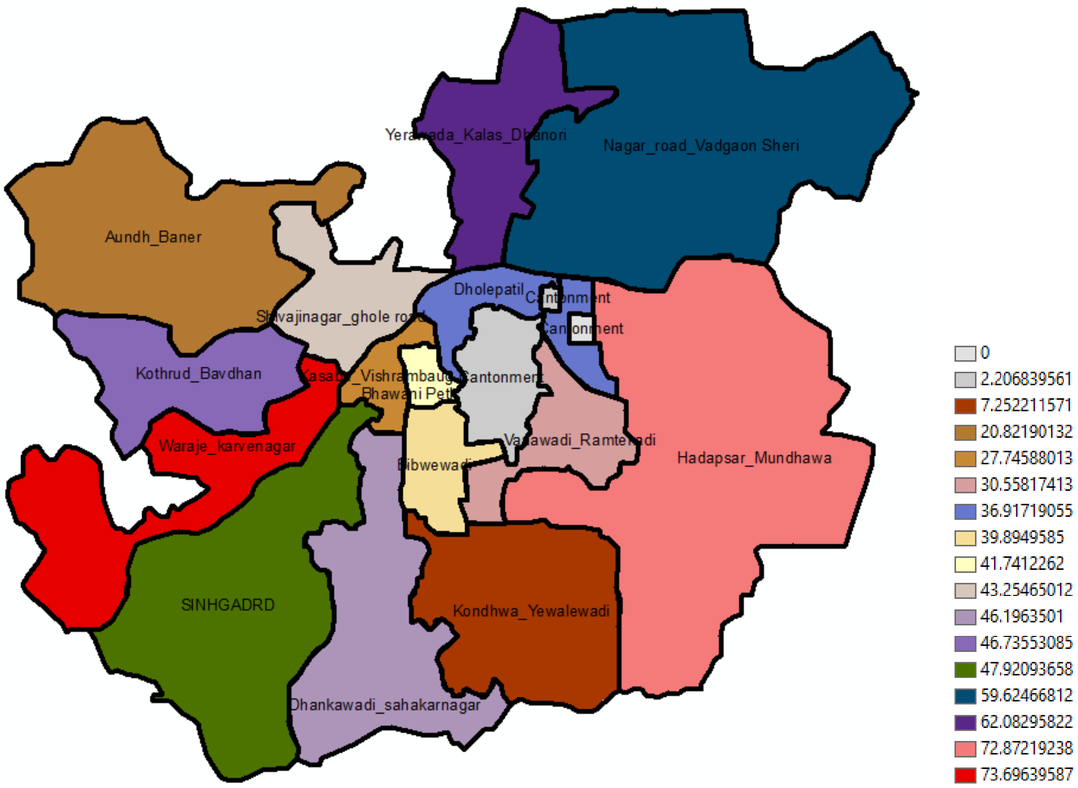


Figure 5.1 (h) : PM_{10} Ward wise Emission distribution (T\yr.)

The household sector was projected to emit $_{10}$8.6 tonnes of $PM_{2.5}$ and 417.83 tonnes of PM_{10} per year in the PMC region. On the basis of population density, the overall emissions were distributed across the air-shed area. Emissions from biomass burning were distributed to wards with a higher number of economically disadvantaged stratum. The spatial distribution of pollution emissions over the PMC areas is depicted in the Fig.5.1(e,f). Household emissions are significantly higher in places with a huge population and a large number of designated slum zones.

From the ward wise distribution Fig.5.1(g,h), it is evident that Waraje has the highest PM emissions having population density and slum areas. Although the majority of the PMC households use comparatively cleaner fuels (LPG) 96.9% reach (Economic Times, 2020). However, Slum areas use mixed LPG, biomass, and kerosene and the cumulation of both are responsible for much higher emissions in the wards like Waraje, Kothrud, Kothrud, Dholepatil than that from the surrounding wards with higher population density like Sinhgdard, Hadapsar, Yewalewadi.

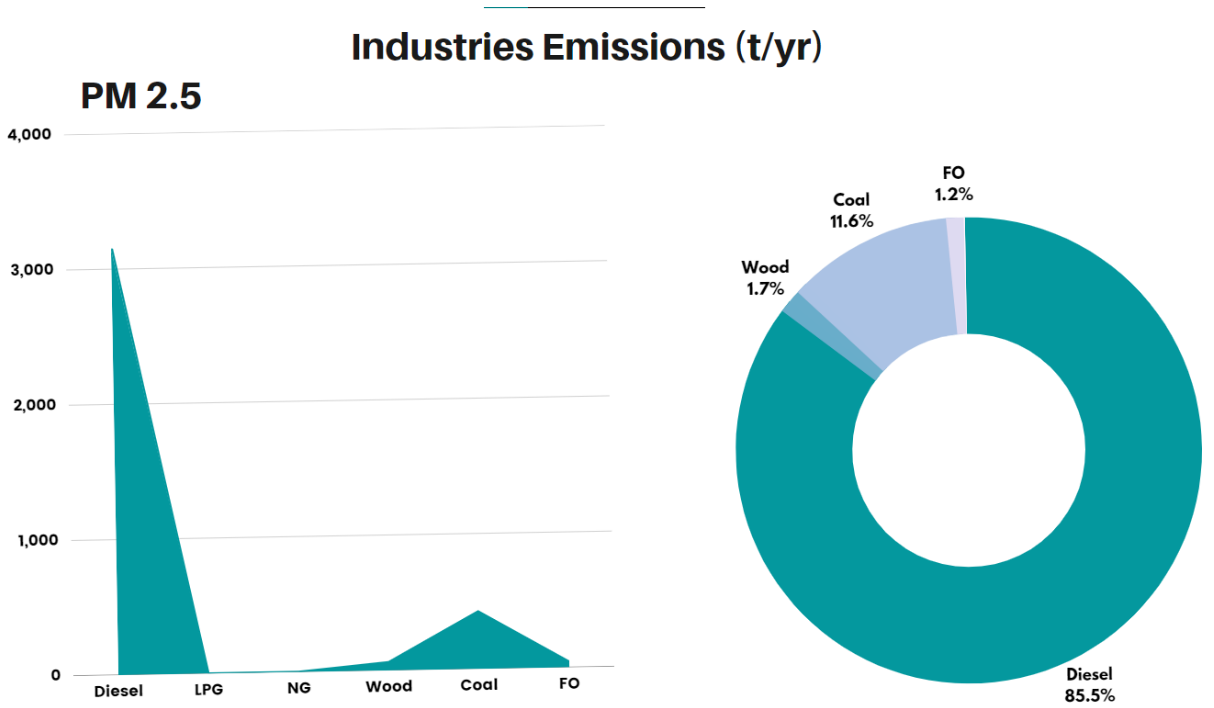
In PMC, the use of solid fuels has the greatest impact on residential emissions. The abundant availability of wood, coal, and kerosene is a major source of concern. This exacerbates health problems in the most vulnerable segments of society (asthma, COPD, heart disease, bronchial disorders, and so on). If, instead of solid fuels, electricity-based appliances were encouraged by offering low-cost access, it may be a gamechanger in the PMC region.

5.2 Industrial Sector

5.2.1 Emissions from Industries

Infrastructure development has made resources more accessible. The expansion of common estates is increasing dramatically from the transportation sector to the industrial sector. In general, small and medium-sized businesses thrive in these areas, generating industrial clusters. In the Pune division, about 1500 units operated from Maharashtra Industrial Development Corporation (MIDC) locations, employing almost 5 lakh people. In some circumstances, the industry sector may be involved as coal or gas-based power plants. However, it should be noted that there are no power plants in the chosen domain. The data collected from the secondary sources was scrutinize depending upon the height of stack for major commercial industries the industries in PMC region are point source. We approximated emissions using main and secondary activity data, as well as the best available emission factors. The approach is covered in a previous chapter. These emissions are then spread fed into the previously built GIS-based statistical model. This resulted in a gridded emission inventory of different contaminants in the designated PMC region, with a grid resolution of 100m.

The industrial fuel includes Diesel, natural gas, LPG, wood, coal and furnace oil. The PM_{10} from the industries turns out to be 8399.96T/yr. for Diesel, 8.25T/yr. for LPG, $_{10}$.9T/yr. for natural gas, 623.64T/yr. for wood, 331.43T/yr. for Furnace oil and 625.13T/yr. for coal. The $PM_{2.5}$ from the slums turns out to be 3145.9T/yr. for Diesel, 1.21T/yr. for LPG, 1.61T/yr. for natural gas, 61.14T/yr. for wood, 44.97T/yr. for Furnace oil and 425.09T/yr. for coal. The spatial and graphical distribution pattern of $PM_{2.5}$ and PM_{10} emissions from these sources are shown in Fig.5.2(a - d).



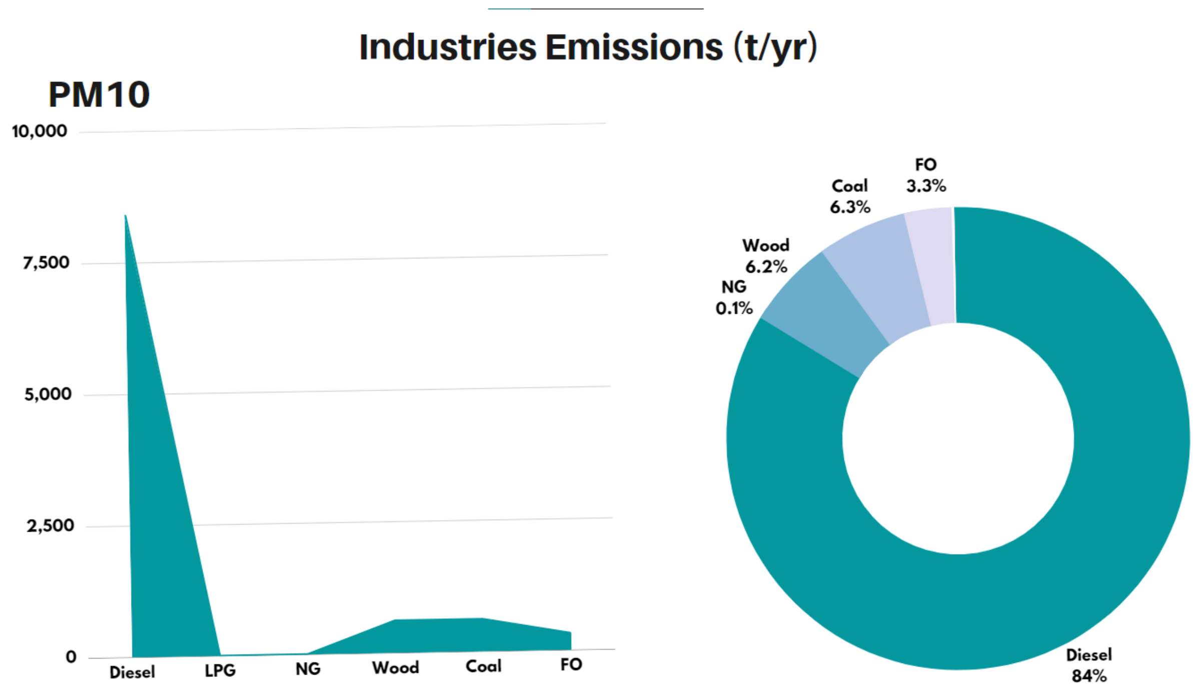


Figure 5.2 (a) : $PM_{2.5}$ and PM_{10} emissions from different fuel for industries

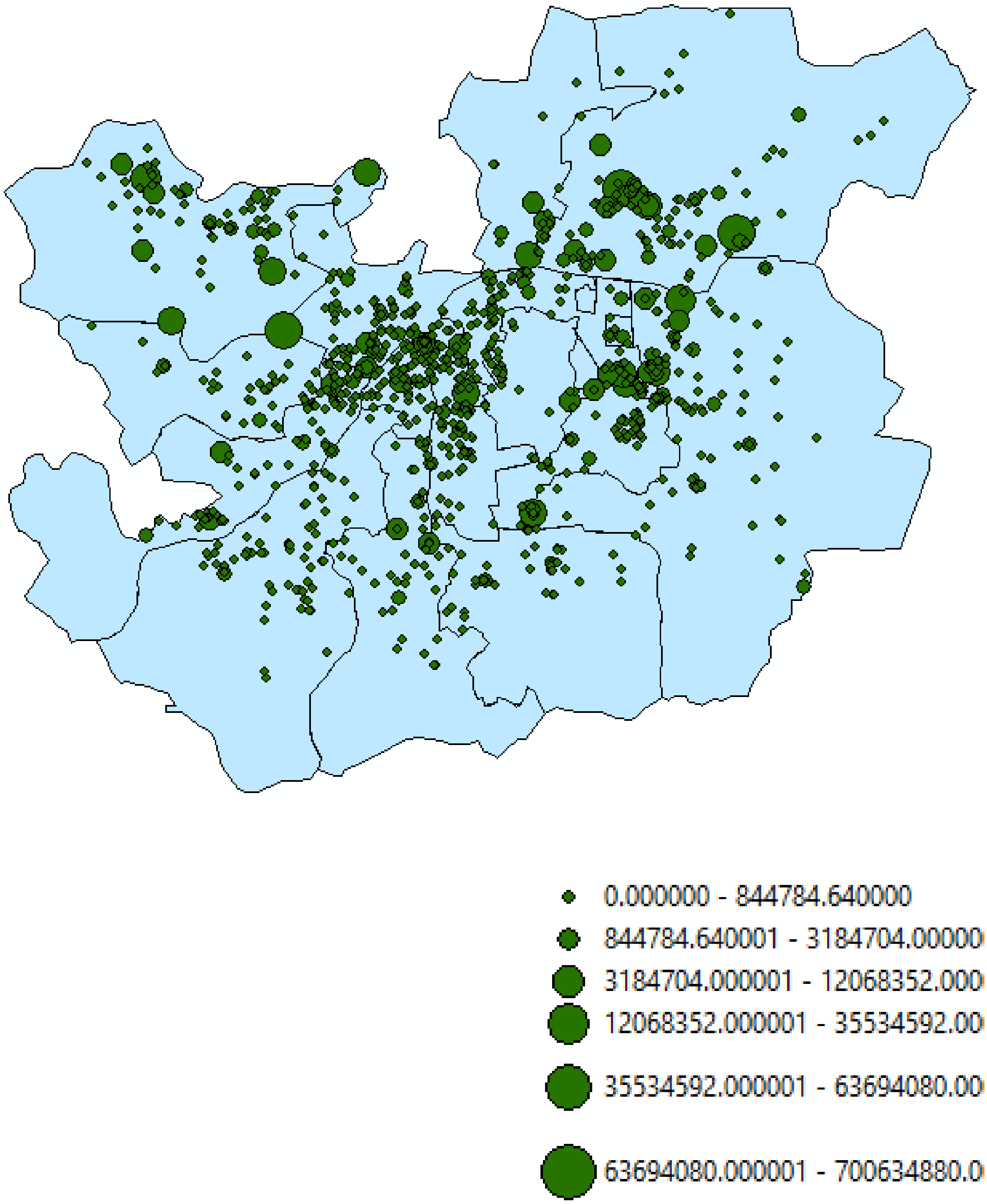


Figure 5.2 (b) : $PM_{2.5}$ Emissions distribution over industries (gm\yr.)

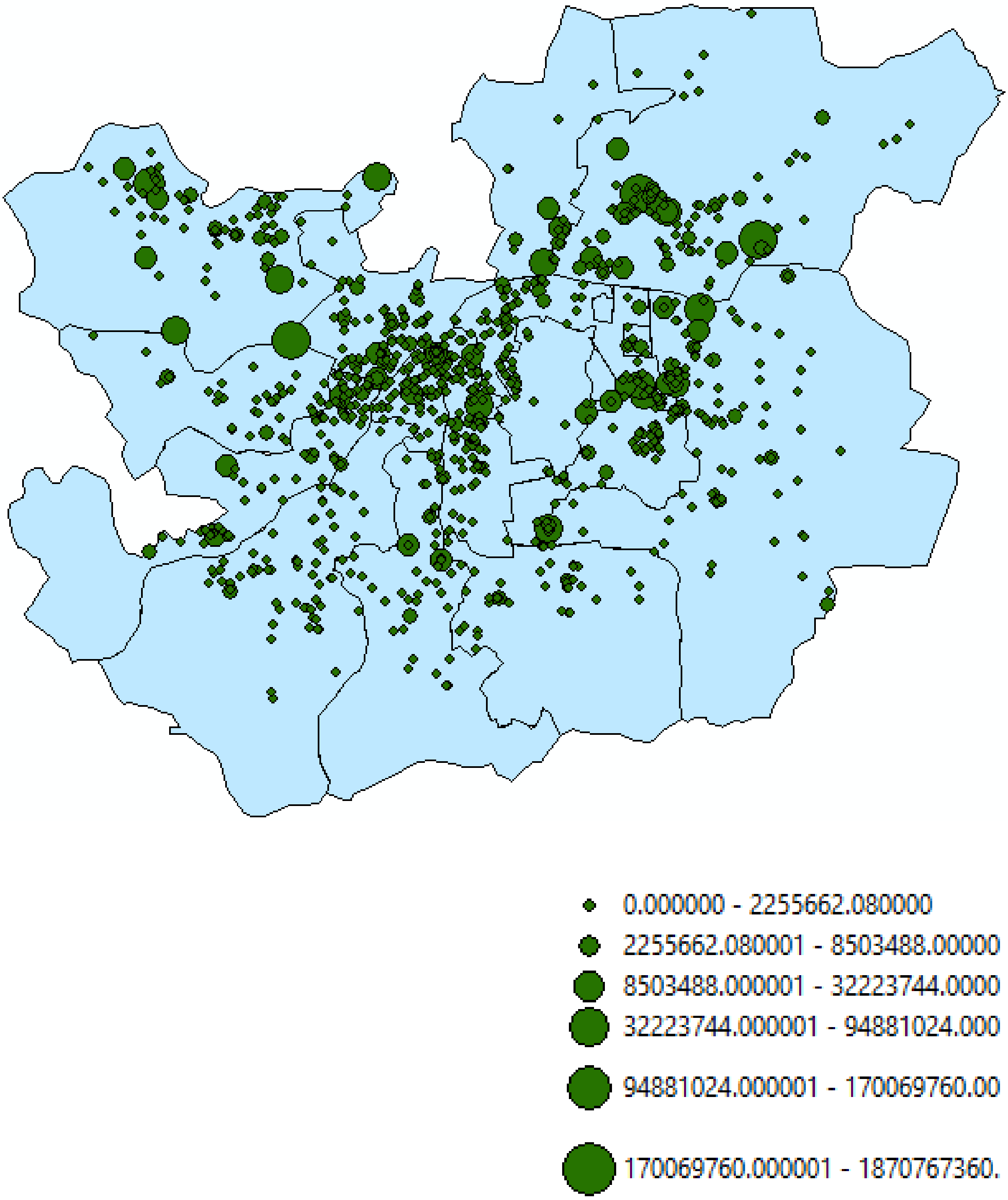


Figure 5.2 (c) : PM_{10} Diesel- emissions distribution over industries (gm\yr.)

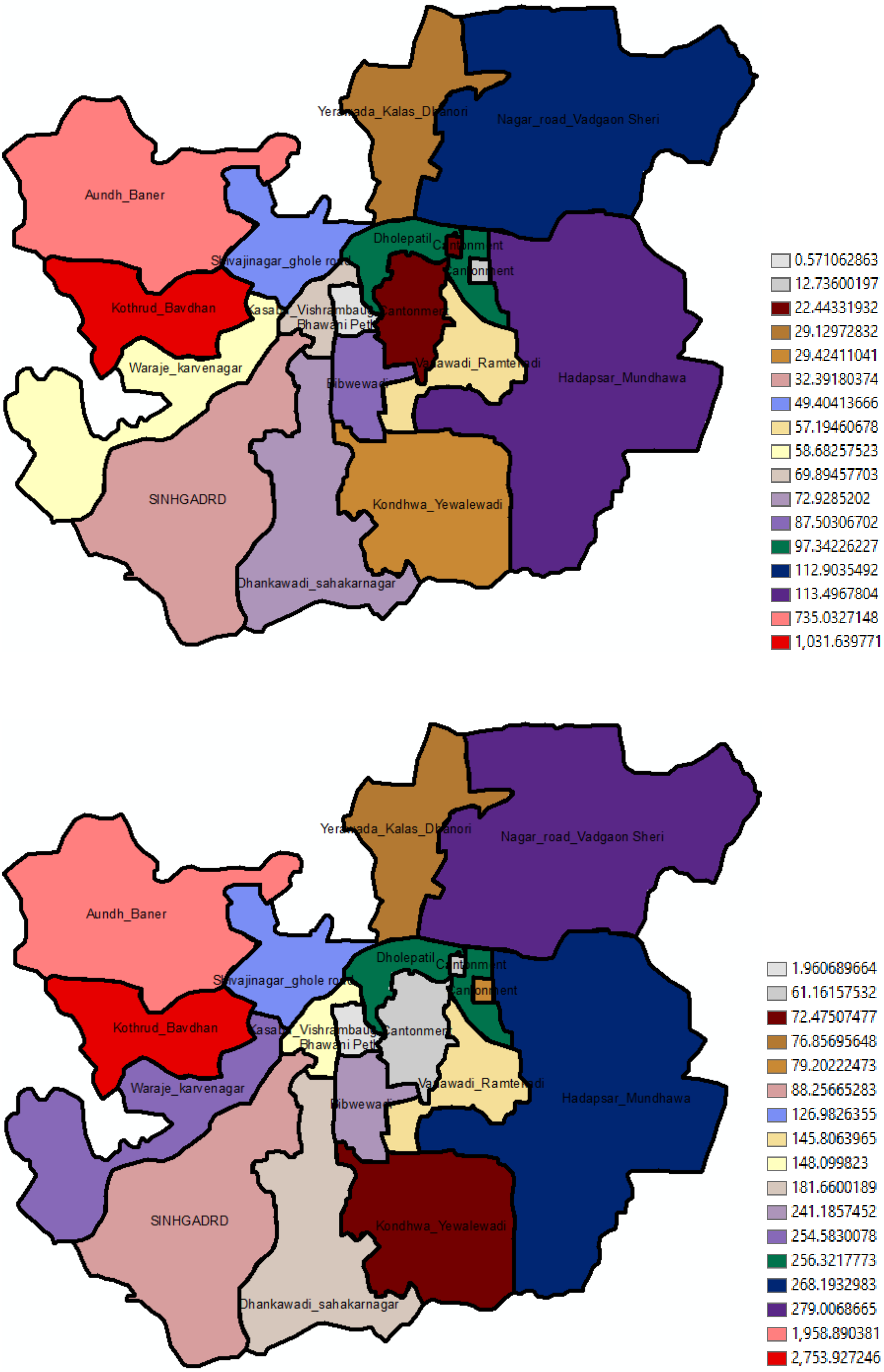


Figure 5.2 (d) : $PM_{2.5}$ and PM_{10} Ward wise Emission distribution (T\yr.)

In PMC region, Hadapsar, Kothrud and Aundh turns out to be the areas with highest emissions from industrial sector. Despite the lack of major industries, small-scale industries have a stronghold in populous regions, exposing residents to industrial pollution at a higher rate than residents in other locations. PM particles are emitted in high quantities by pharmaceutical, electrical component manufacturing, hospitals, oil businesses, and paint manufacturing facilities in different wards with different emissions.

5.2.2 Emissions from Hotels and Restaurants

In the PMC region, there are about 5,000 large hotels and eateries. It has a significant impact on overall regional emissions. Many establishments use biomass burning, promoting traditional tandoor cuisines. Taking into account variables such as fuel type, quantity, cooking oil type, cooking hours, and tandoor activity (if available). The $PM_{2.5}$ from the hotels and restaurants turns out to be 17.24T/yr. for LPG, 1.09T/yr. for kerosene, 22.66T/yr. for wood, for Diesel 0.33T/yr. and 72.09T/yr. for coal. The PM_{10} from the hotels and restaurants turns out to be $_{10}$9.72T/yr. for LPG, 1.12T/yr. for kerosene, 33.3T/yr. for wood, for Diesel 1.86T/yr. and 118.18T/yr. for coal. The spatial and graphical distribution pattern of $PM_{2.5}$ and PM_{10} emissions from these sources are shown in Fig. 5.3 (a, b).

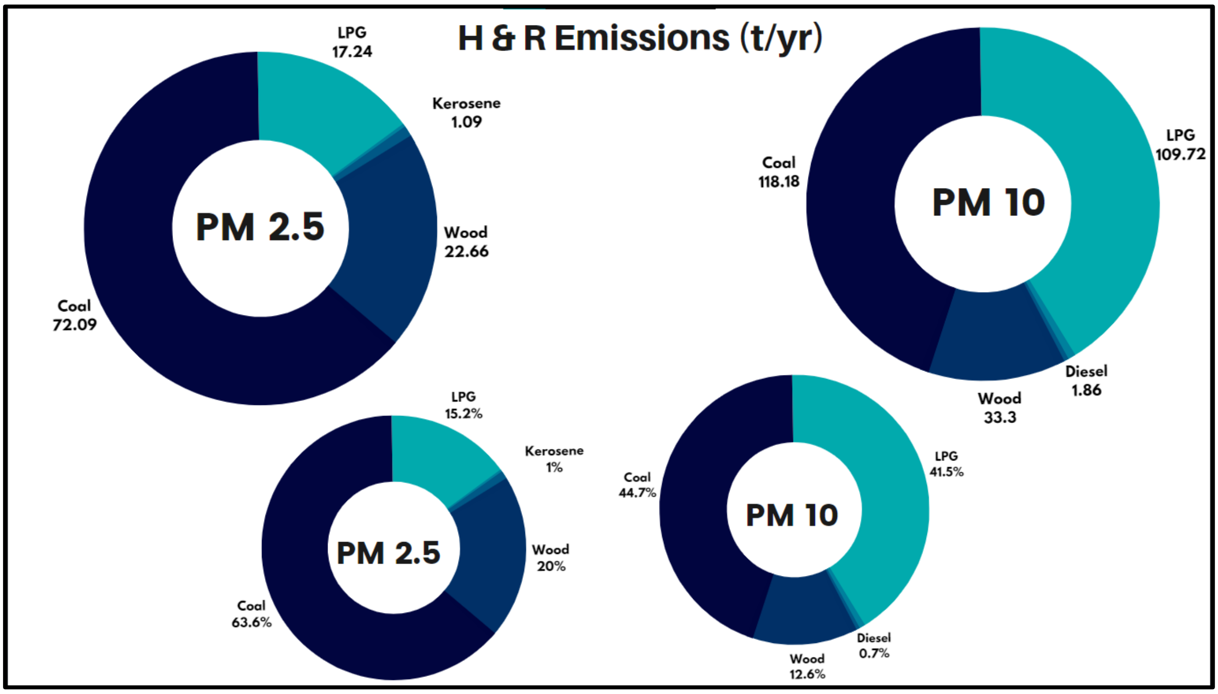
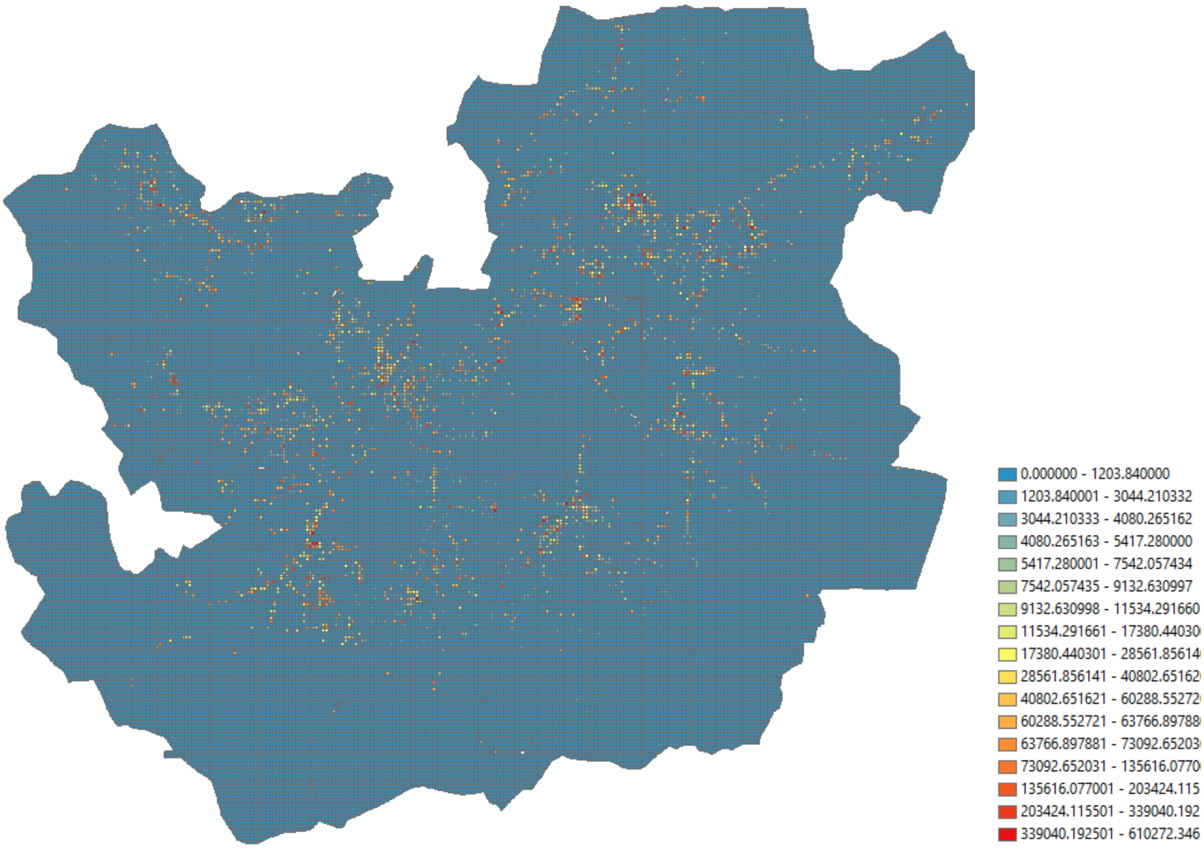


Figure 5.2.2 (a) : $PM_{2.5}$ and PM_{10} Fuel based emission distribution



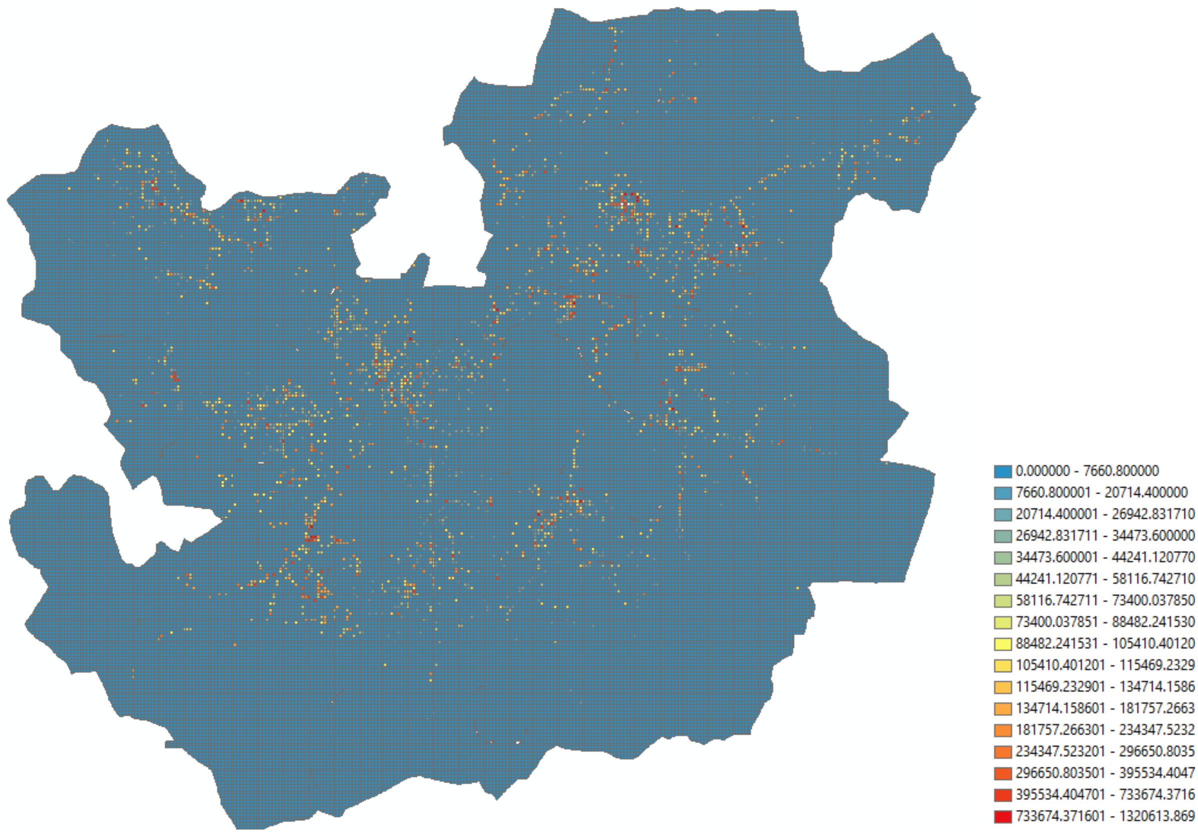


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Figure 5.2.2 (b) : $PM_{2.5}$ and PM_{10} emissions from different fuels

5.2.3.Hawkers Emissions

The city recognized for its street cuisine, as well as Pune, a cosmopolitan metropolis and its surrounding surroundings, cannot be overlooked. Throughout the city, a plethora of street sellers catered to the culinary demands of locals, students, IT professionals, and others. Fast food is available from street sellers, ranging from basic tea/coffee, roasted corn, and complete main course meals. Some are seasonal, depending on the sort of food item sold, while others are available all year. A considerable number of these street vendors were granted permits by the Municipal Corporation and were given permanent locations. In contrast, sizable proportions of them are unlicensed and are constantly changing locations. There are more than 38000 hawkers in the PMC area. 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 $PM_{2.5}$ from the hawkers based on these fuel types turns out to be 9.21T/yr. for LPG, 1.66T/yr. for kerosene, 3.2T/yr. for coal. The PM_{10} from the hotels and restaurants turns out to be 58.66T/yr. for LPG, 1.70T/yr. for kerosene, 5.40/yr. for coal. The graphical distribution pattern of $PM_{2.5}$ and PM_{10} emissions from these sources are shown in Fig. 5.2.3(a)

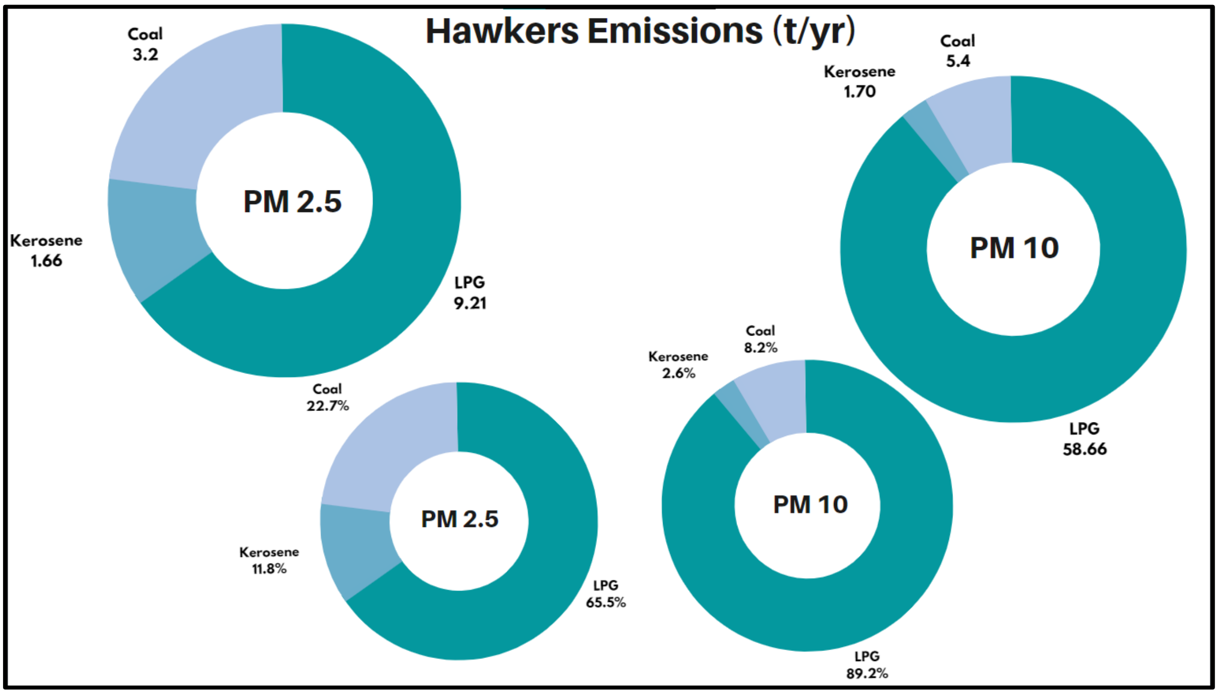


Figure 5.2.3 (a) : $PM_{2.5}$ and PM_{10} Fuel based emission distribution

5.2.4. Bakeries Emissions

Ready-to-eat meals, freshly baked goods, and essential groceries draw loyal customers to a chain of convenience stores; there are more than 500 bakeries in PMC region with full time usage of fuels like wood and diesel. The $PM_{2.5}$ from the bakeries based on these fuel type turns out to be 0.252T/yr. for wood, 0.00015T/yr. for Diesel. The PM_{10} from the hotels and restaurants turns out to be 0.371T/yr. for wood, 0.000403T/yr. for Diesel. The spatial distribution pattern of $PM_{2.5}$ and PM_{10} emissions from these sources are shown in Fig. 5.2.4(a)

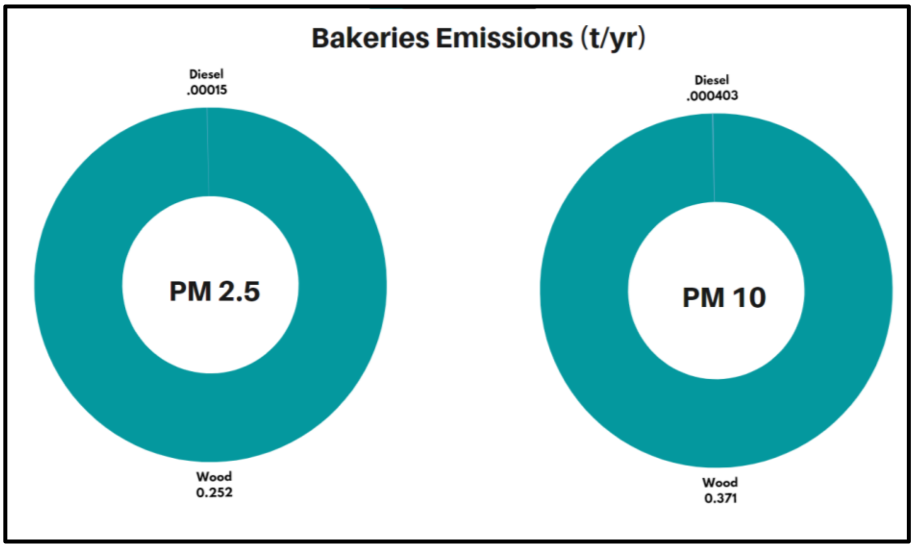


Figure 5.2.4 (a) : $PM_{2.5}$ and PM_{10} Fuel based emission distribution

5.2.5. Crematorium emissions

In Pune, deceased remains are burned either electrically or using dung-cake and fuel wood. 40% of corpses are incinerated without the use of electricity, using wood and dung cake as fuel. This results in an increase in emissions. 60% of corpses are burned using electricity and diesel. This results in a significant reduction in emissions. The $PM_{2.5}$ from the Crematorium based on these fuel type turns out to be 46.11T/yr. for wood, 0.40T/yr. for Diesel and 3.3T/yr. for cow dung. The PM_{10} from the hotels and restaurants turns out to be 67.83T/yr. for wood, 1.08T/yr. for Diesel and 4.2T/yr. for cow dung. The spatial distribution pattern of $PM_{2.5}$ and PM_{10} emissions from these sources are shown in Fig. 5.2.5(a)

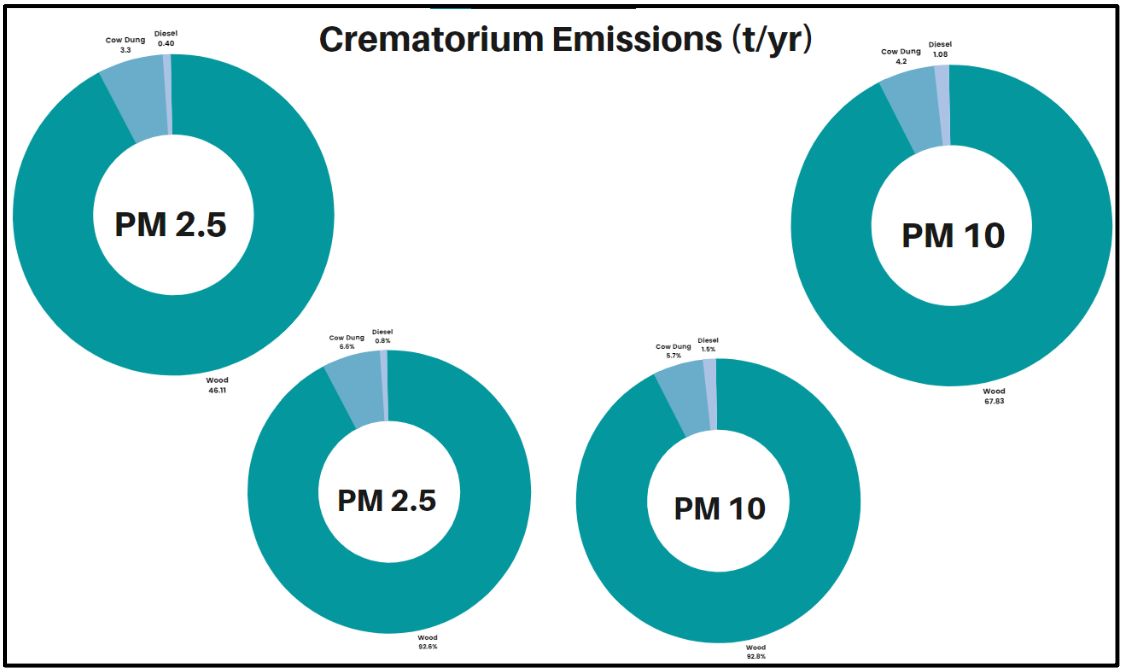
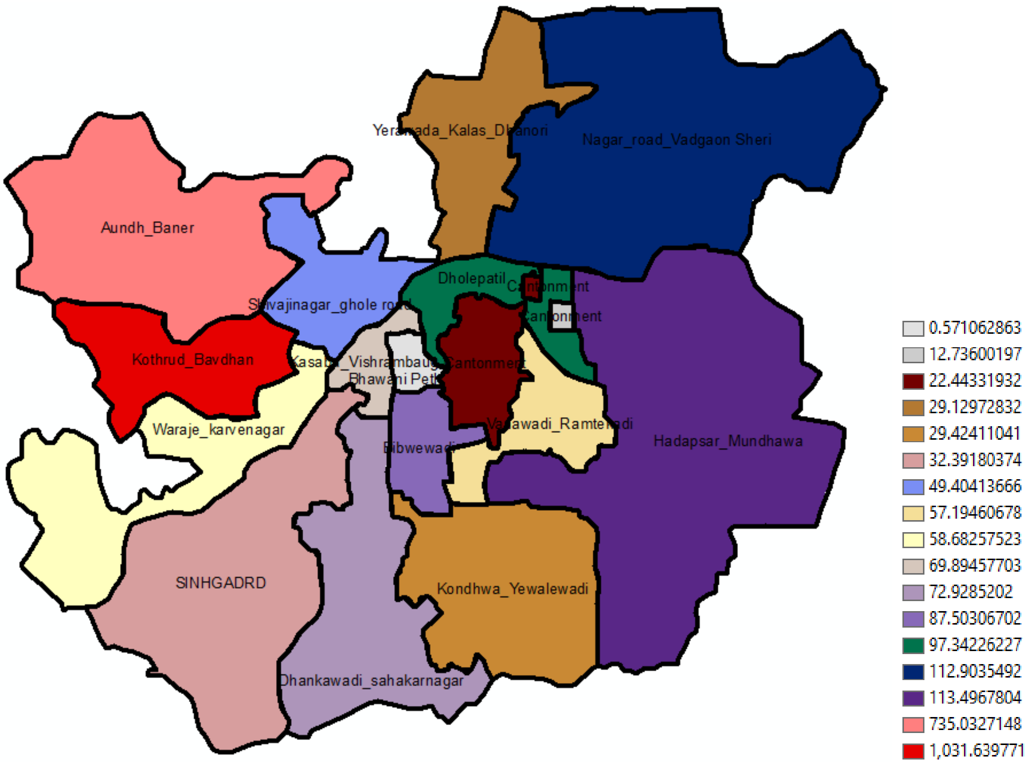


Figure 5.2.5 (a) : $PM_{2.5}$ and PM_{10} Fuel based emission distribution

5.2.6 Total Estimated Emissions

	Sector	PM 2.5 (tons/year)	PM 10 (tons/year)
Residential sector	Residential	108.6	417.83
	Slum	156.98	322.14
Industrial sector	Hotels and Restaurant	113.36	264.22
	Hawkers	14.16	65.7
	Bakeries	252.88	371.40
	Industries	3128.97	8652
	Crematorium	49.80	73.11

Table 7: Total emission estimate (Residential + Industrial)



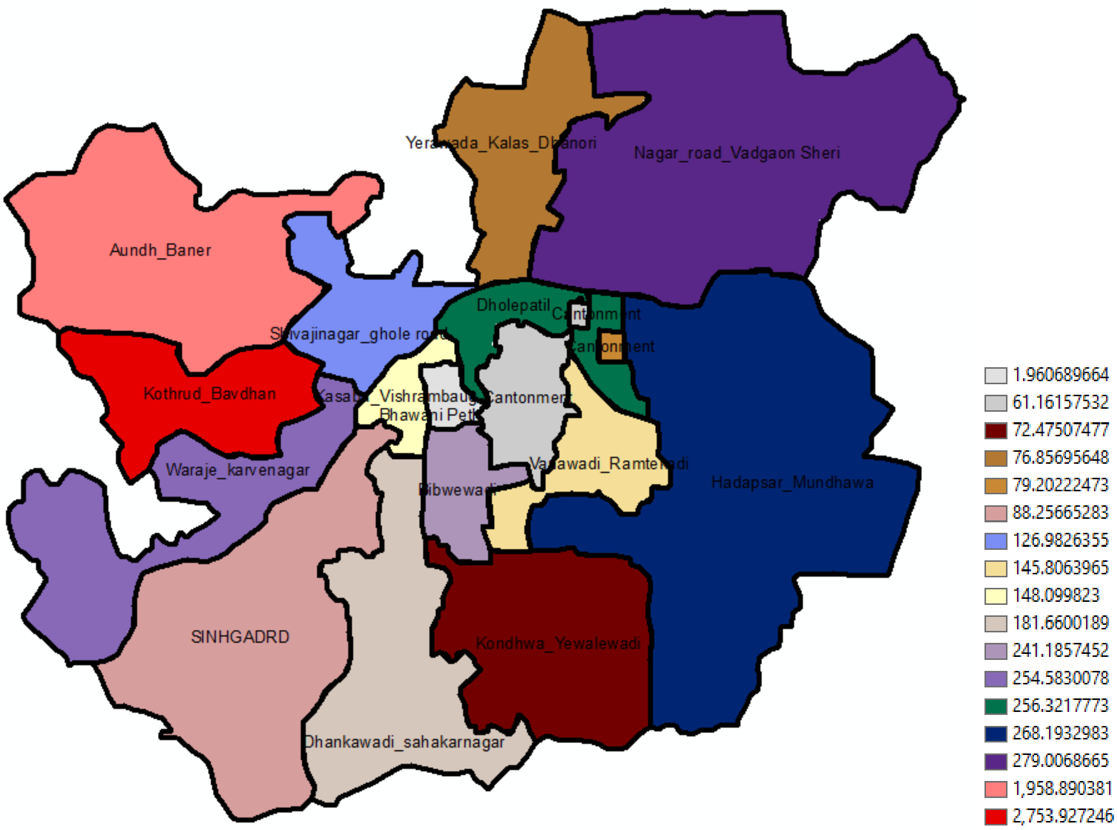


Figure 5 (o): $PM_{2.5}$ and PM_{10} Ward wise Overall

5.3 Transport Sector

Line source emissions, which are one of the most significant contributors to air pollution in India, are included in the transportation sector. Understanding the traffic composition, including vehicle numbers, age, fuel type, and usage statistics, i.e., VKT, is required to evaluate the transportation sector's emission loading, as mentioned in Chapter 3.

The Data for Vehicular statistics were obtained based on registered vehicles in the PMC area. Vehicles older than 15 years old were excluded from the current scenario in order to provide a realistic picture following BS standard. The generated vehicle count was spread across the road network using IITM survey data and offered as a secondary data source for this study. Two-wheelers, three-wheelers, four-wheelers, light-carrying vehicles (LCV), trucks, and buses are divided based on BS engines into different categories. Vehicle movement in each grid was used to calculate emissions. Each grid's emission was computed separately. This was accomplished by multiplying the VKT and EF for each vehicle type, then summing all of the emissions.

More than 38 lakh vehicles are registered in the PMC region. With more than (60%) registered, vehicles the city has the biggest population of two-wheelers. The PMC region's vehicular base is made up of two-wheelers, three-wheelers, four-wheelers, light commercial vehicles, trucks, and buses. Trucks in the region primarily travel on major roads and highways, with very little contribution to minor roads, as construction trucks and municipal trucks are the only vehicles that travel on local roads.

Categories

5.3.1 Two Wheelers

The PMC region has dominant number of 2 wheelers in the whole vehicular system. Petrol and electric are the two fuel/energy types on which most of the 2 wheelers run in PMC region. The total emissions from the 2 wheelers turn out to be 1870 T/year. Fig.5(a) represents the PM emissions on various roads in PMC region and it's clear that minor roads and major roads are heavily dominated by two wheelers as its convenient way to travel in traffic. Out of 22 lakhs plus 2 wheelers, 70 thousand plus vehicles turn out to be of BS-I category which are about to get banned in a year. More than 5 lakh automobiles are classified as BS-II. The emissions from BS-I vehicles contributed 80T because they have a lower density than other operating engines, followed by BS-IV 234T, which is less than BS-II, but the number of vehicles is more, demonstrating the fourth-generation engine's technical competence. BS-III is the source of the greatest emissions, accounting for roughly 1063T of the total. Fig 5(b) Represents ward wise difference for the two-wheeler emissions. The greater VKT cause more emissions across the region. Nagar Road area has the highest two-wheeler emissions followed by Hadapsar, Kothrud and Waraje the wards with highest population activities. The VKT for 2 wheelers petrol vehicles is 43.11km/day.

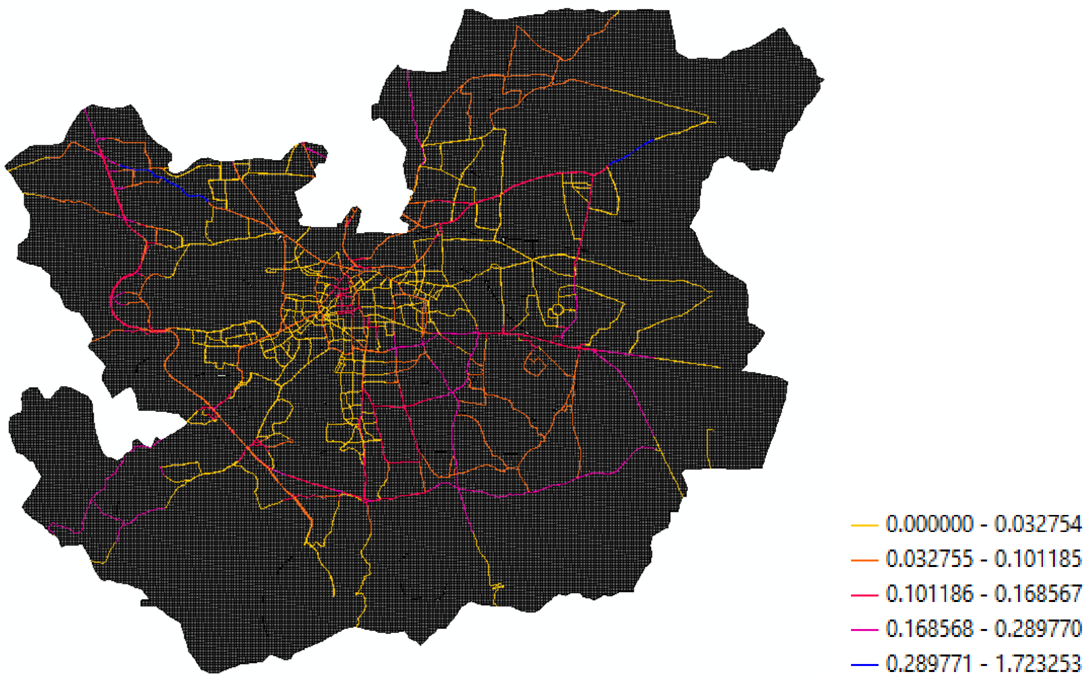


Figure 5.3 (a) :2W Emissions across the Roads in PMC

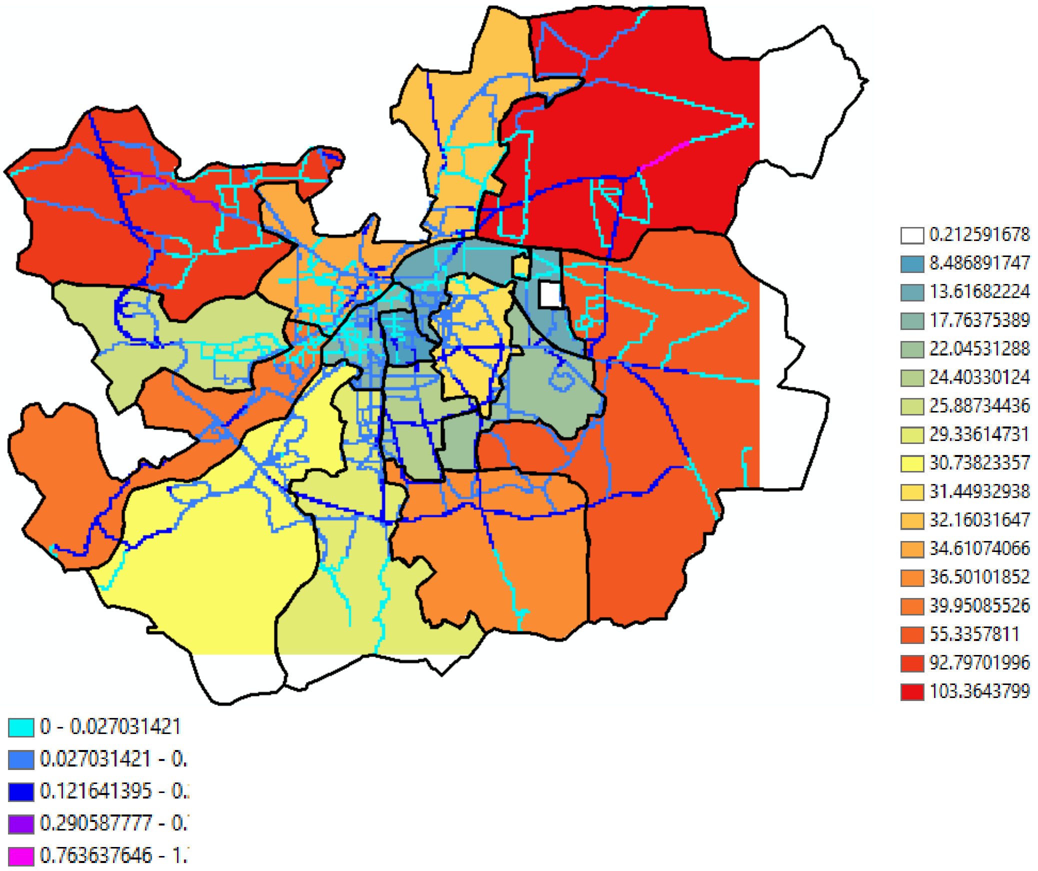


Figure 5.3 (b) : Ward wise distribution of 2W

5.3.2 Three Wheelers

The most used public source for minor and major roads are three wheelers in the PMC region. There is a lot of improvement in this category over the years and PMC region has significant cleaner fuel three wheelers. Petrol, Diesel, LPG and CNG are the fuel types on which most of the three wheelers run in PMC region. The total emissions from the three wheelers turn out to be 282 T/year which is lesser than the one portion of two wheelers. The reason behind this is adoption of CNG and LPG over other fuel types. Out of total Three wheelers 4.4% used Diesel, 9.46% use LPG, 32.6% use Petrol and 53.2% runs on CNG. The engine wise categorization confirms BS-I 6.46%, BS-II 49.35%, BS-III 23.66% and BS-IV 20.4%. Fig.5(c) represents the PM emissions on various roads and it's clear that minor roads and major roads are heavily dominated by three wheelers as its convenient way to travel for public. Fig 5(b) Represents ward wise difference for the three-wheeler emissions. The greater VKT cause more emissions across the region. Aundh, Sinhgdard, Kothrud, Waraje area has the highest three-wheeler emissions. The VKT for three wheelers petrol vehicles is 69.71km/day, for diesel its 90.73 km/day and for LPG and CNG 79.29 km/day.

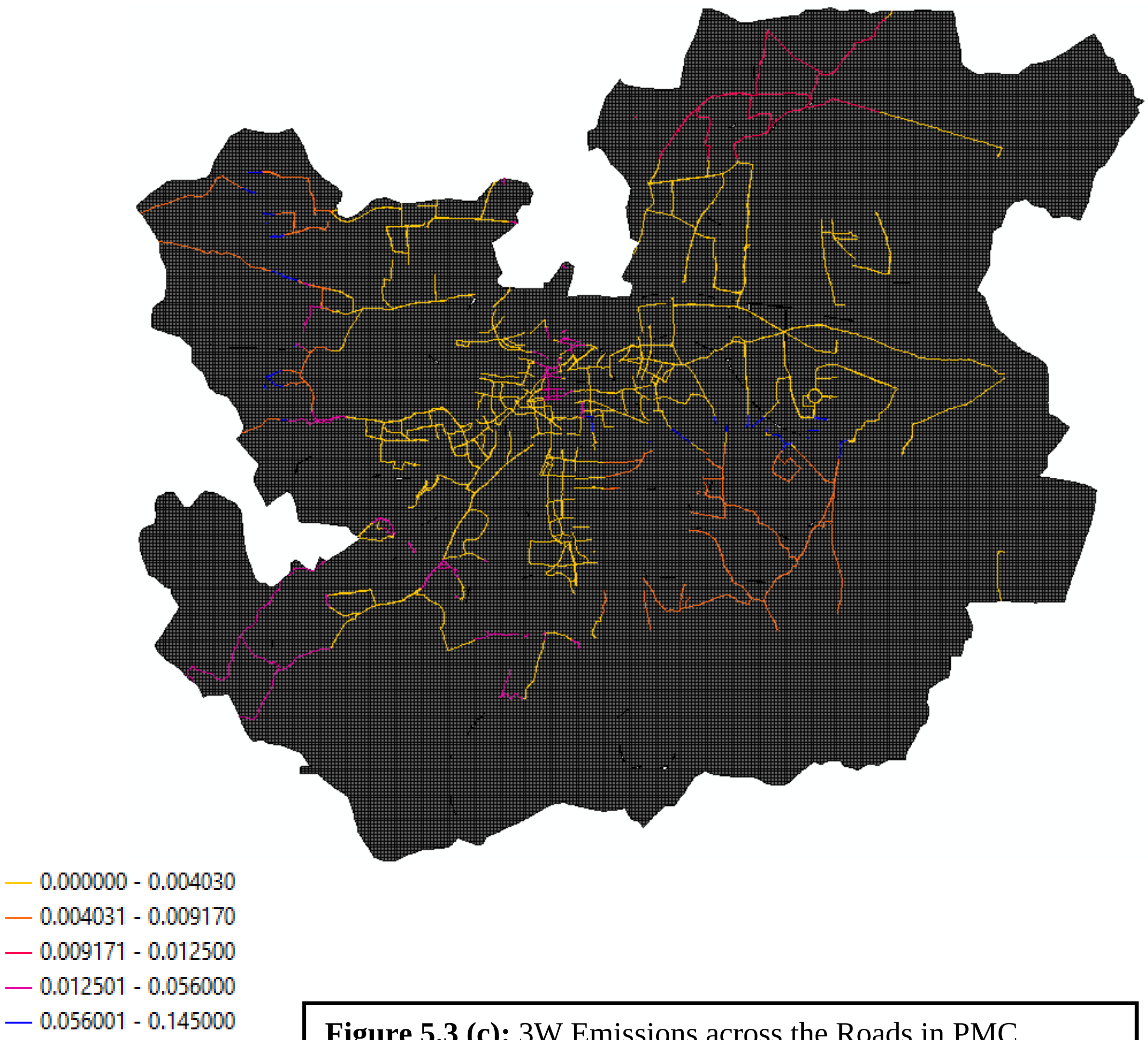


Figure 5.3 (c): 3W Emissions across the Roads in PMC

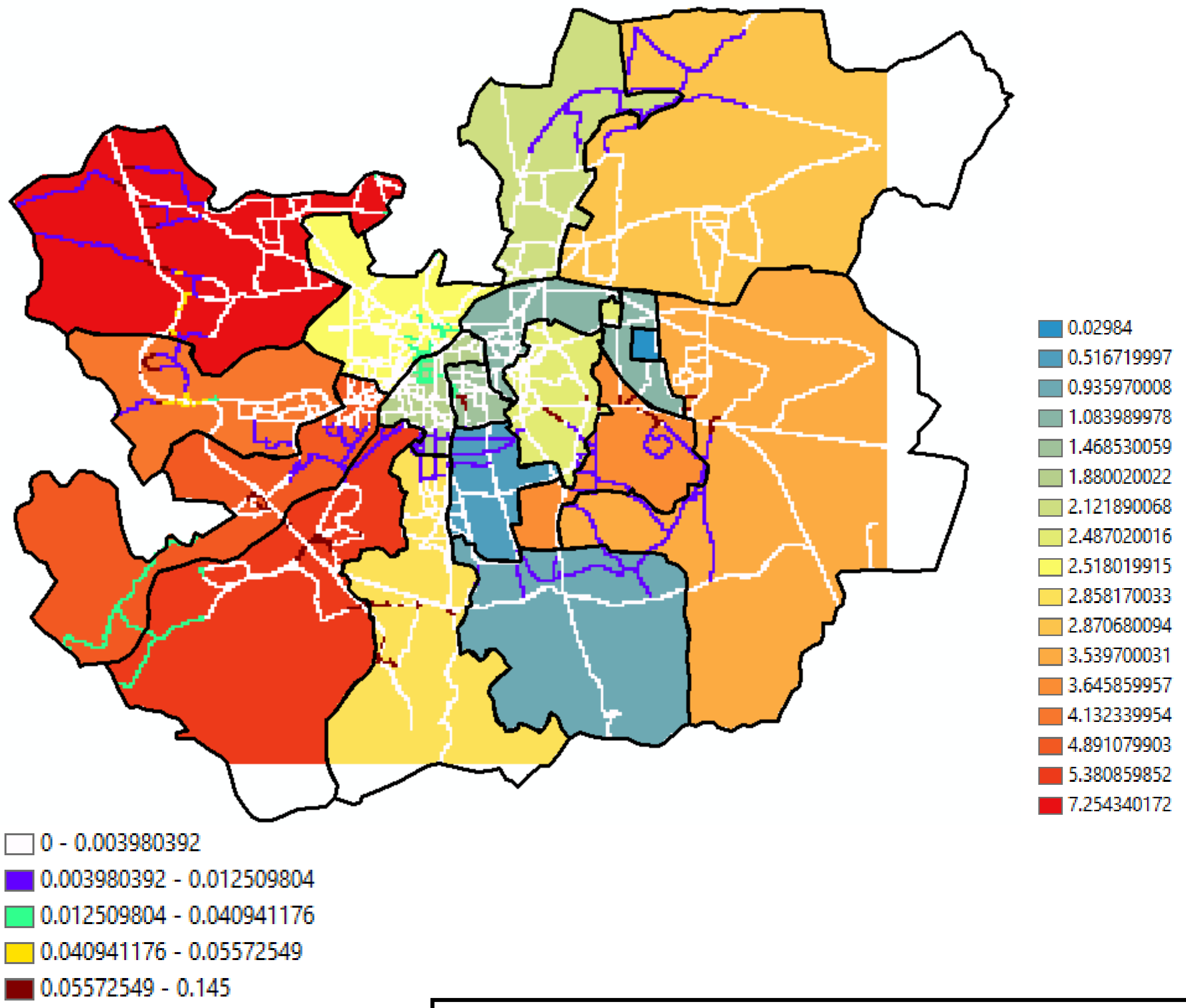


Figure 5.3 (d) : Ward wise distribution of 3W Emissions

5.2.3 Four Wheelers (Passenger Cars)

Passengers' cars are extensively used for personal and commercial use. It's one of the biggest contributors in the line source emissions and number of these vehicles keeps increasing every year. The BS recommendations are mainly focused on these vehicles and over the years different ways to control and reduce tailpipe emissions is the major concern. Petrol, Diesel, LPG and CNG are the fuel types on which most of the four wheelers run in PMC region. The total emissions from the four wheelers turn out to be 1452 T/year having significant impact in the overall emissions. The contributions of different fuel type four-wheeler cars have 4.4% used Diesel, 9.46% use LPG, 32.6% use Petrol and 53.2% CNG. The engine wise categorization confirms BS-I 1.97%, BS-II 17.2%, BS-III 68.5% and BS-IV 11.5%. Fig.5(e) represents the PM emissions on various roads. Fig 5(f) Represents ward wise differentiation over various roads. The VKT for four wheelers petrol vehicles is 72.22 km/day, for diesel its 93.7 km/day and for LPG 38.65 km/day and CNG 94.14 km/day.

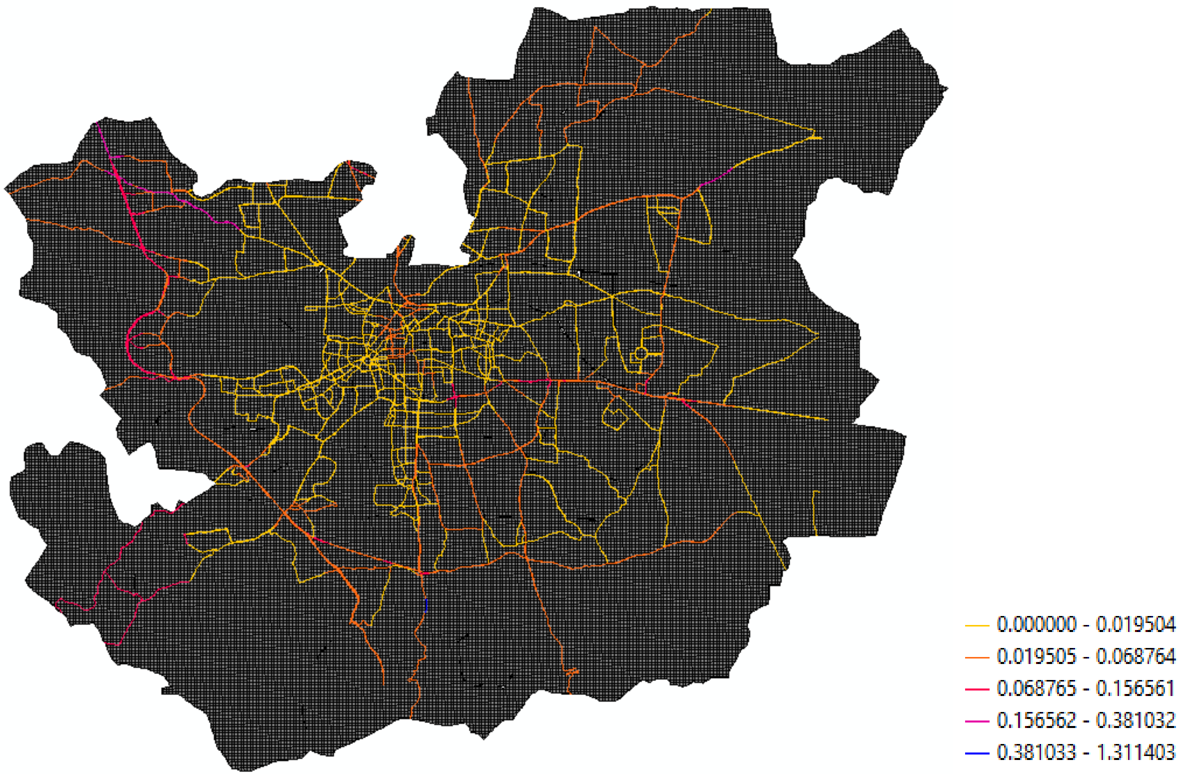


Figure 5.3 (e) : 4W Emissions across the Roads in PMC

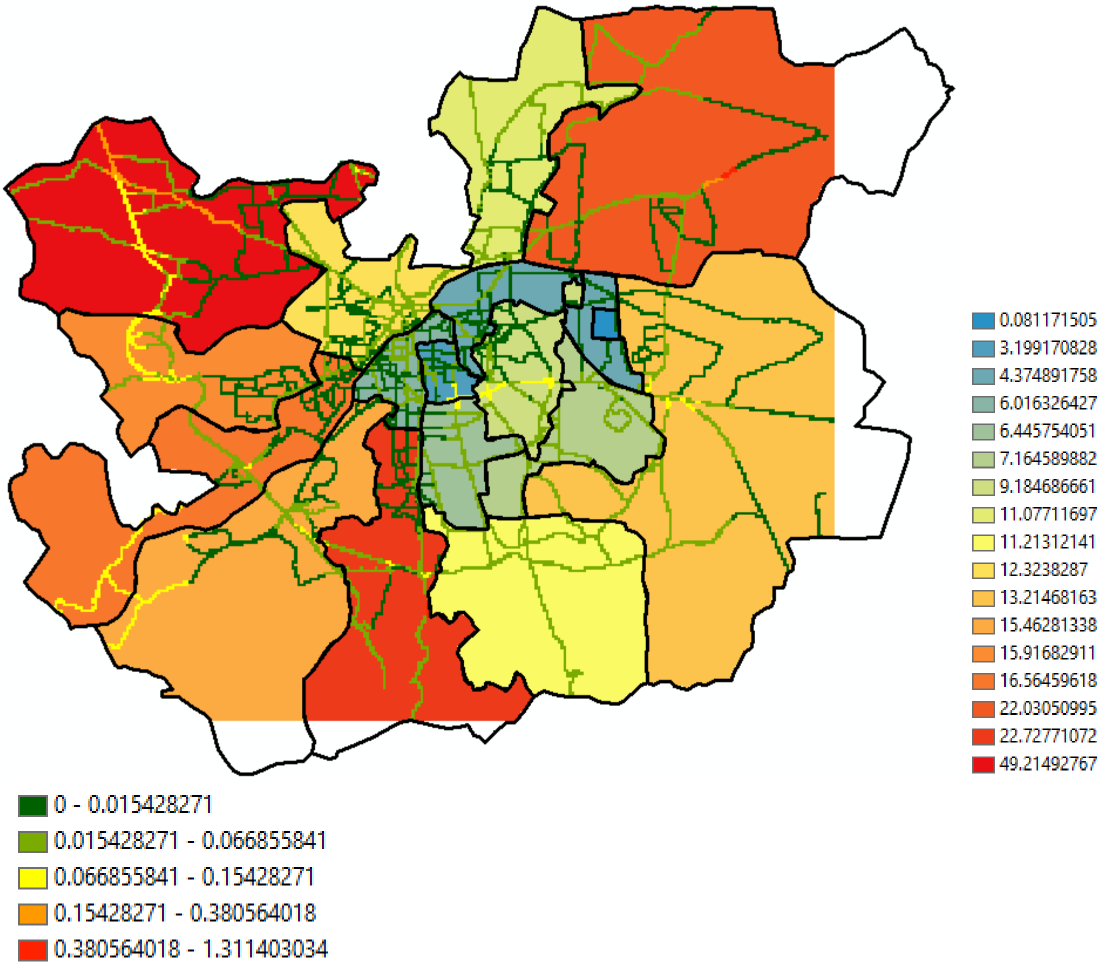


Figure 5.3 (f) : Ward wise distribution of 4W Emissions

5.2.3 LCV (Light Commercial Vehicle)

The Light commercial vehicles are the off road, on road vehicles having range from lorries, carriages, small utility vehicles and wagons. Petrol and Diesel are the only fuel types these vehicles run. The total emissions from the LCV's turn out to be 1879.3T/year having higher pollution capability than four wheelers. The reason for this is new innovations in four wheelers as electric and cleaner fuel vehicles take portion from conventional vehicle base. The engine wise categorization confirms BS-I 0.13%, BS-II 2%, BS-III 84.6% and BS-IV 13.2%. This categorization implements that older vehicle are being replaced with newer ones. Fig.5(g) represents the PM emissions by LCVs on various roads. Fig 5(f) Represents ward wise differentiation over various roads. The VKT for LCV's petrol vehicles is ${}_{10}$1 km/day, for diesel its 350 km/day.

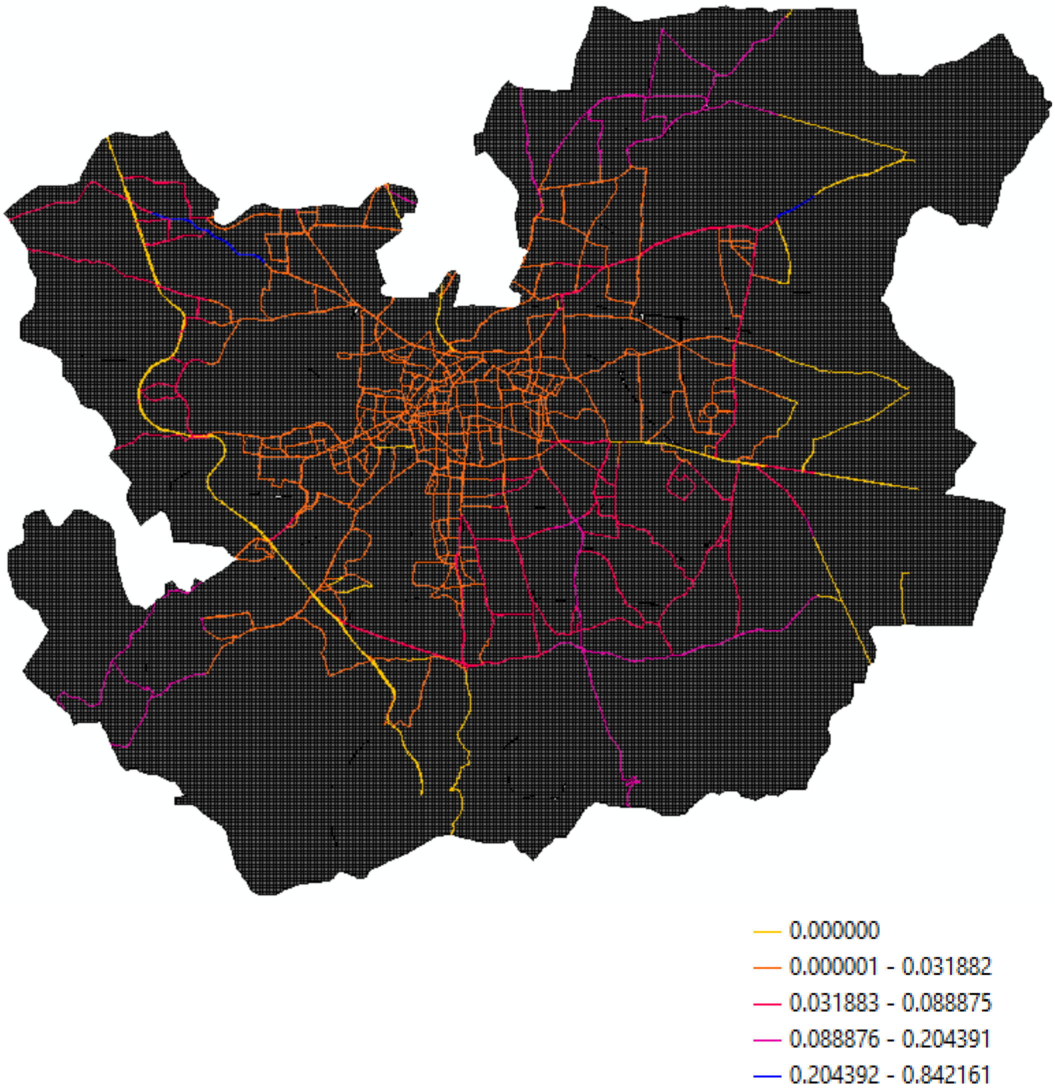


Figure 5.3 (g) : LCVs Emissions across the Roads in PMC

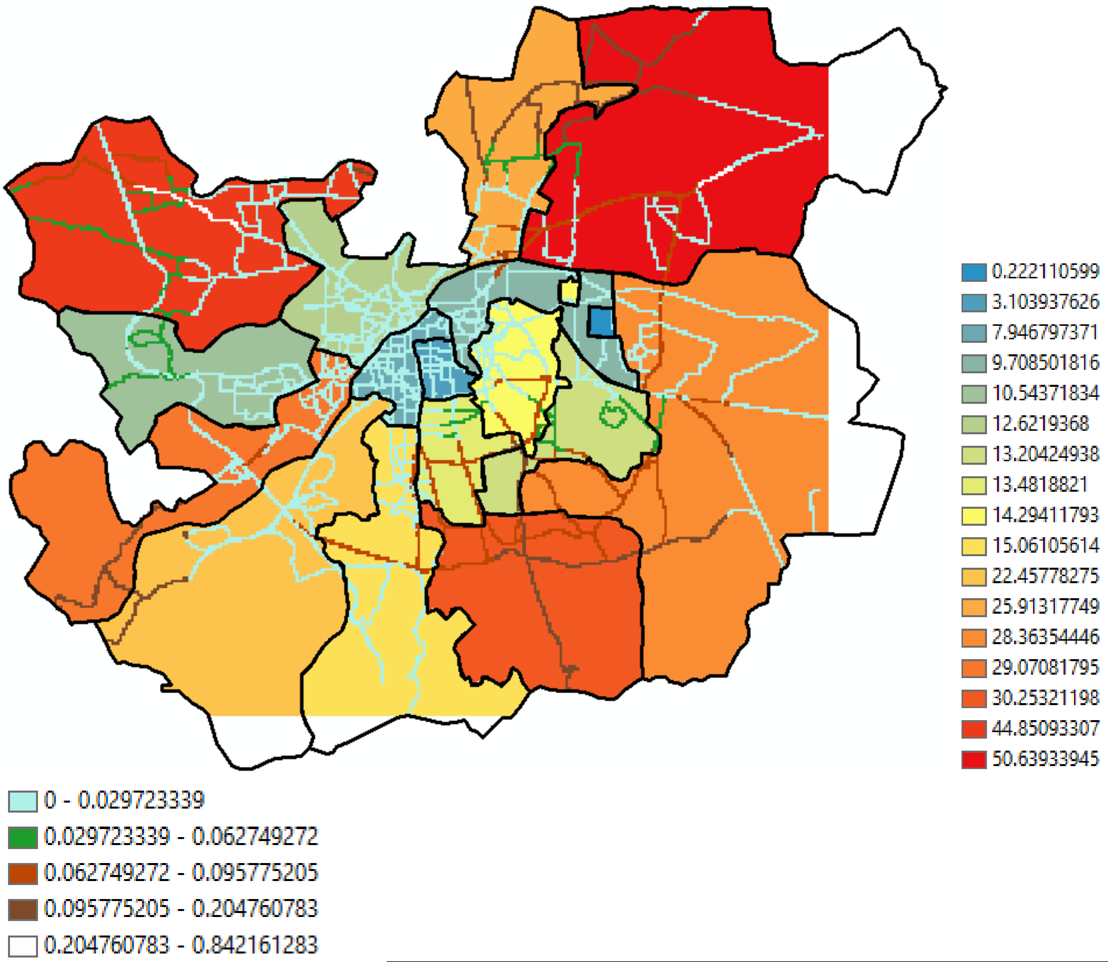


Figure 5.3 (h) :) Ward wise distribution of LCV Emissions

5.2.3 HCV (Heavy Commercial Vehicles: Buses and Trucks)

The Heavy commercial vehicles contain basically two major transport vehicles public buses and Trucks. The total emissions from the Buses turn out to be 12835 T/year and Trucks 12480T/year making these the most pollution capable vehicle. For HCVs the engine wise categorization confirms BS-I 0.6%, BS-II 6.2%, BS-III 78.5% and BS-IV 14.5%. This categorization implements that older vehicle are being replaced with newer ones, Governments are adapting buses with cleaner fuels to reduce pollution. Fig.5(i) represents the PM emissions by LCVs on various roads. Fig 5(j) Represents ward wise differentiation over various roads. The VKT for Buses with petrol engines are 170 km/day, for CNG its 97 km/day. Trucks have VKT of 114km/day for diesel engines and 65km/day for CNG.

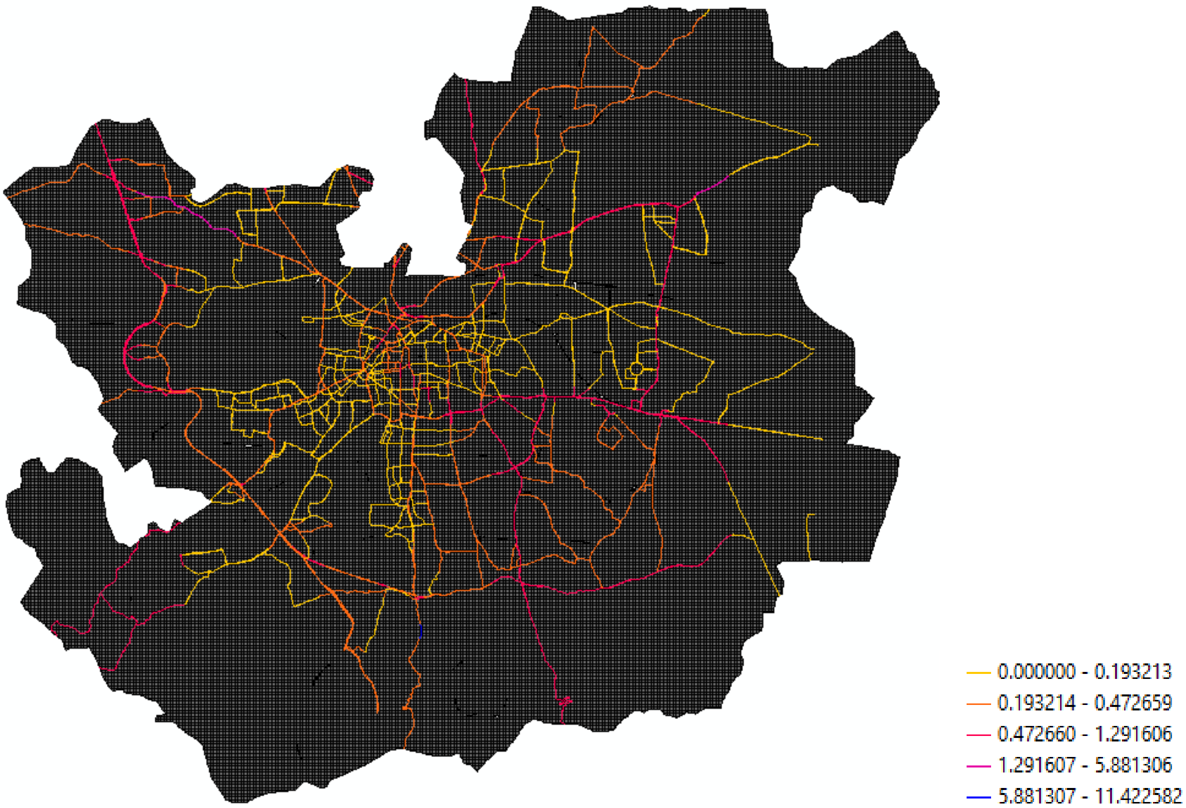


Figure 5.3 (i) : HCVs (Buses) Emissions across the Roads in

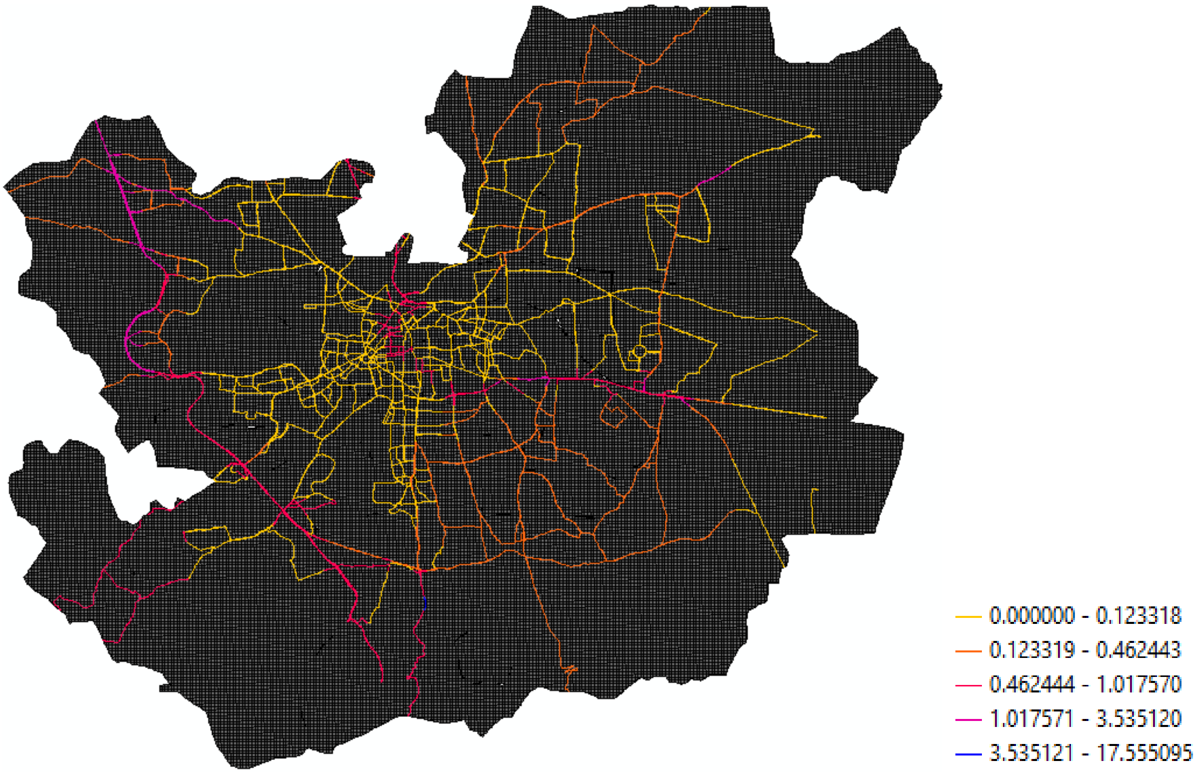


Figure 5.3 (j) : HCVs (Trucks) Emissions across the Roads in

Fig 5(k and L) represents the overall ward wise differentiation for the transport sector. Hadapsar turns out to be the ward with maximum emission load for PMC region. The overall activity of different vehicle types in the Hadapsar due to high population density and industrial reach contribute to make it so. Nagar Road, Sinhgdard, Kothrud, Waraje are the high transport emission zones and all fall under the major roads and highway areas. These are border areas for PMC region makes them entry and exit point for migrating vehicles on daily basis and also due to higher commercial activities in these areas. VKT for LCVs turn out to be quite high and long-range paths are mostly followed on major roads and highways including LCVs, buses and trucks. 2W and 3W dominate the minor road categories but emissions from these vehicle types are less in comparison to heavy vehicle categories.

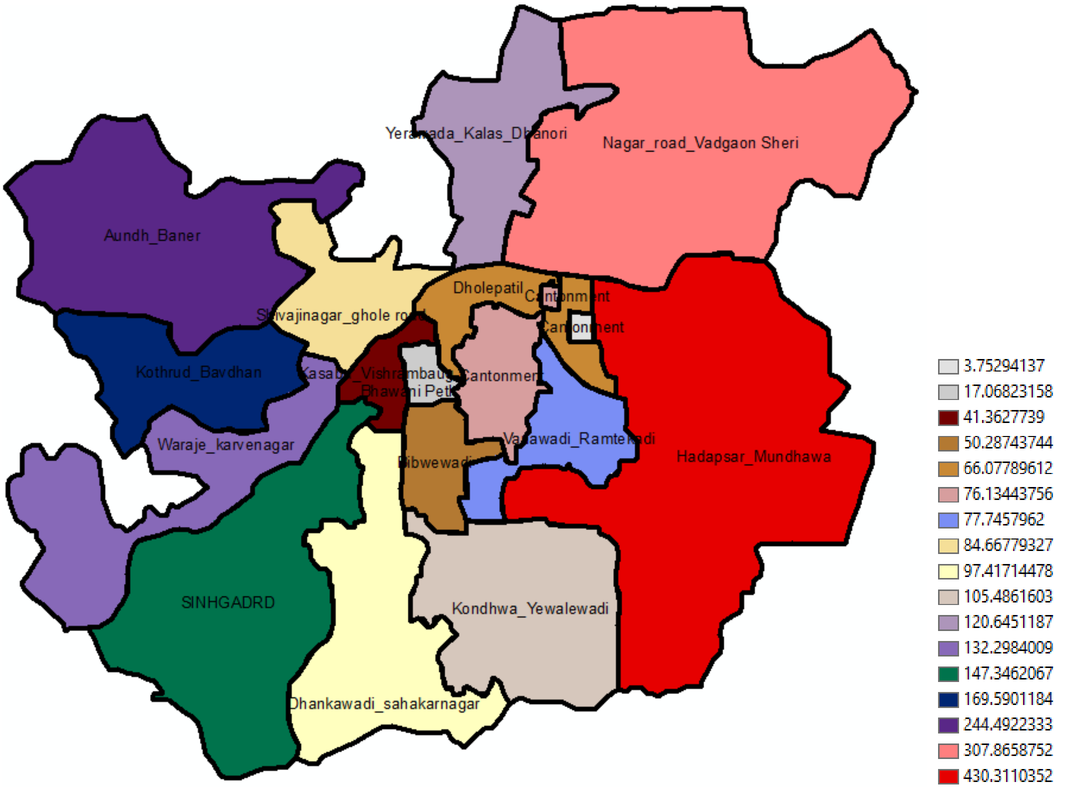
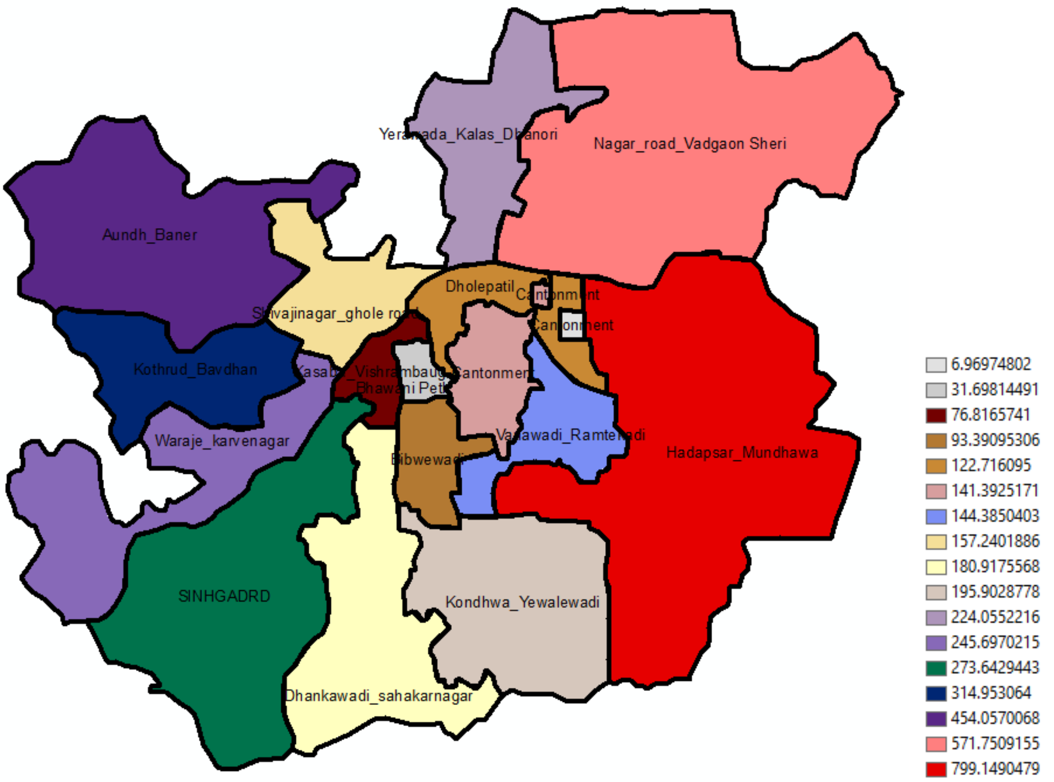


Figure 5.3 (k) : Overall $PM_{2.5}$ Ward Emissions for Transport Sector

Figure 5.3 (l) : Overall PM_{10} Ward Emissions for Transport Sector



Conclusion

This study adopted a mixed approach for developing emission inventory estimates for the PMC region. A GIS-based model for a 100m resolution was developed to establish the emissions from 3 major significant sectors, i.e., residential, industrial and transport. The methodology paved the way to achieve the emission estimate for PM_{10} and $PM_{2.5}$ for eleven subsectors under the major areas. 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 different sources and hotspots of the PM emissions were established and the reasons behind the emissions mainly include high vehicular density, high population density, and the use of coal, wood, and kerosene instead of cleaner fuels. A total of nine different types of fuels was included, which are heavily used in the PMC region. The methodology to calculate the emissions from various sources using the activity data and emissions factors is discussed in this study. GIS based methodology formulated to attain the total emission estimates is developed.

The study estimates around 23093 tonnes of PM_{10} and 7704 tonnes of $PM_{2.5}$ were emitted from the PMC area. We see sectorial and Ward division for the different emission sources and substantially higher emission was observed in the regions gridded with mixed residential and industrial facilities. The $PM_{2.5}$ from the residential cooking turns out to be 57.40T/yr. for LPG and 51.20T/yr. for kerosene. The PM_{10} from the residential cooking turns out to be 365.33T/yr. for LPG and 52.7T/yr. for kerosene.

The $PM_{2.5}$ from the slums turns out to be 63.01T/yr. For LPG, 27.06T/yr. for kerosene,65.99T/yr. for wood and 0.12T/yr. for coal. The PM_{10} from the slums turns out to be 196.26T/yr. for LPG, 28.60T/yr. for kerosene,97.08T/yr. for wood and 0.20T/yr. for coal.

The industrial fuel includes Diesel, natural gas, LPG, wood, coal and furnace oil. The PM_{10} from the industries turns out to be 8399.96T/yr. for Diesel, 8.25T/yr. for LPG, $_{10}$.9T/yr. for

natural gas, 623.64T/yr. for wood, 331.43T/yr. for Furnace oil and 625.13T/yr. for coal. The $PM_{2.5}$ from the industries turns out to be 3145.9T/yr. for Diesel, 1.21T/yr. for LPG, 1.61T/yr. for natural gas, 61.14T/yr. for wood, 44.97T/yr. for Furnace oil and 425.09T/yr. for coal.

The $PM_{2.5}$ from the hotels and restaurants turns out to be 17.24T/yr. for LPG, 1.09T/yr. for kerosene, 22.66T/yr. for wood, for Diesel 0.33T/yr. and 72.09T/yr. for coal. The PM_{10} from the hotels and restaurants turns out to be $_{10}$9.72T/yr. for LPG, 1.12T/yr. for kerosene, 33.3T/yr. for wood, for Diesel 1.86T/yr. and 118.18T/yr. for coal.

The $PM_{2.5}$ from the hawkers based on these fuel types turns out to be 9.21T/yr. for LPG, 1.66T/yr. for kerosene, 3.2T/yr. for coal. The PM_{10} from the hotels and restaurants turns out to be 58.66T/yr. for LPG, 1.70T/yr. for kerosene, 5.40/yr. for coal.

The $PM_{2.5}$ from the bakeries based on these fuel type turns out to be 0.252T/yr. for wood, 0.00015T/yr. for Diesel. The PM_{10} from the hotels and restaurants turns out to be 0.371T/yr. for wood, 0.000403T/yr. for Diesel.

The $PM_{2.5}$ from the Crematorium based on these fuel type turns out to be 46.11T/yr. for wood, 0.40T/yr. for Diesel and 3.3T/yr. for cow dung. The PM_{10} from the hotels and restaurants turns out to be 67.83T/yr. for wood, 1.08T/yr. for Diesel and 4.2T/yr. for cow dung.

This work improved on the previous generated emission inventories for Pune (IITM, 2020 and CPCB,20[10]), detailed analysis of activity data and major efforts in refinement of data revealed the difference in contributions by major sectors and sources. The data gaps and discrepancies found highlight the following:

PM Transportation-related emissions are higher along major roads and highways due to traffic conditions, which includes HCVs and LCVs, but emissions in the core minor road sections are primarily two- and three-wheelers and cars. Pollution reduction in transportation sector can be established by restricting older vehicles and implementing BS-VI as soon as possible. Electric mobility will significantly help in reduction of the pollution.

Increased public transportation connectivity combined with cleaner fuel vehicle options will help to further reduce pollution. The use of 100 percent CNG in three wheelers will reduce pollution in that area. For the residential sector, 100% LPG and lower prices for cleaner fuel would aid in the establishment of a pollution-free residential sector.

To sum up, while every attempt was made to collect as much precise data as possible, the current results are not without uncertainty due to a number of confounding factors and a complex estimating technique. Despite the limits, it is evident that high-resolution emission estimates will be a valuable source of information for scientists and policymakers.

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