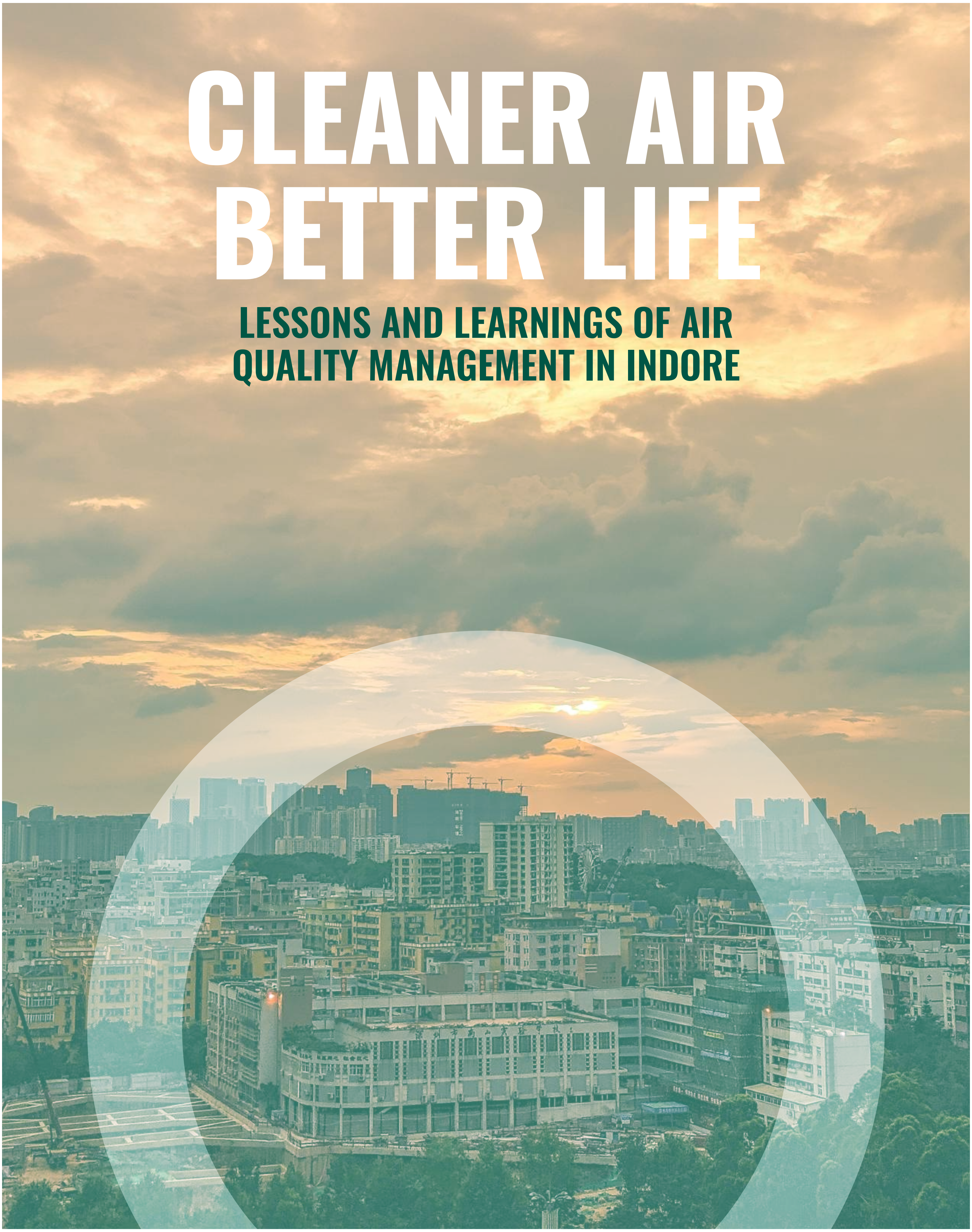
Cleaner Air Better Life

स्वच्छ वायु, दीर्घायु

Confederation of Indian Industry

CLEANER AIR BETTER LIFE

LESSONS AND LEARNINGS OF AIR QUALITY MANAGEMENT IN INDORE



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Lessons and Learnings of Air Quality Management in Indore

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LIST OF ABBREVIATIONS

AiCTSL	Atal Indore City Transport Services Limited
ANPR	Automatic Number Plate Recognition
AOD	Aerosol Optical Depth
AQ	Air Quality
AQI	Air Quality Index
BAM	Beta Attenuation Monitor
BIS	Bureau of Indian Standards
BS6	Bharat Stage 6
CARB	California Air Resources Board
CAZ	Clean Air Zone
CBD	Central Business District
CGTMSE	Credit Guarantee Fund Trust for Micro and Small Enterprises
CII	Confederation of Indian Industry
CLCSS	Credit Linked Capital Subsidy Scheme
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CPCB	Central Pollution Control Board
CUSUM	Cumulative Sum Control Chart
DM	District Magistrate
EPA	Environmental Protection Agency
ERA5	European Reanalysis 5th Generation
EV	Electric Vehicle
GFS	Global Forecast System
GRAP	Graded Response Action Plan
HCs	Hydrocarbons
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory Model
ICAR	Indian Council of Agricultural Research
ICE	Internal Combustion Engine
IITD	Indian Institute of Technology Delhi
IMC	Indore Municipal Corporation
IMR	Indore Metropolitan Region
ISCDL	Indore Smart City Development Limited
ISSW	Institute for Sustainable Systems and Waste Management
LEZ	Low Emission Zone
MAPE	Mean Absolute Percentage Error
MERRA	Modern-Era Retrospective analysis for Research and Applications
MEZ	Medium Emission Zone
ML	Machine Learning
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEFCC	Ministry of Environment, Forest and Climate Change
MoRTH	Ministry of Road Transport and Highways
MPPCB	Madhya Pradesh Pollution Control Board
MSME	Micro, Small, and Medium Enterprises
MSW	Municipal Solid Waste
NAAQS	National Ambient Air Quality Standards
NCAP	National Clean Air Programme

NMT	Non-Motorized Transport
NO_2	Nitrogen Dioxide
PCC	Pearson Correlation Coefficient
PM_{10}	Particulate Matter 10 micrometres or less in diameter
$PM_{2.5}$	Particulate Matter 2.5 micrometres or less in diameter
PUC	Pollution Under Control
RF	Random Forest
RMSE	Root Mean Square Error
RTO	Regional Transport Office
RWEM	Real-World Emission Monitoring
SCM	Smart City Monitors
SD	Standard Deviation
SO_2	Sulphur Dioxide
SOPs	Standard Operating Procedures
SPCB	State Pollution Control Board
SPM	Suspended Particulate Matter
TF	Task Force
TEZs	Tiered Emission Zones
TVC	Traffic Volume Count
VIIRS	Visible Infrared Imaging Radiometer Suite
WHO	World Health Organization

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01

INTRODUCTION: Air Quality in Indore

1.1 RATIONALE AND OBJECTIVES

Air pollution emerged as the most serious health issue across the majority of developing nations, including India. It is a complex environmental health issue that affects people all over the world, especially middle-low-income countries who are not equipped with adequate resources and expertise to tackle air pollution. The World Health Organisation [1] reported in 2022 that indoor and outdoor air pollution together were responsible for around 6.7 million premature deaths, with 63% of those deaths occurring each year[1]. Only 1% world population is living in an area with healthy air quality as per WHO prescribed limits. This finding demonstrates that air pollution has grown to become the single largest environmental health concern in the world, which is almost double the prior estimated health risk of polluted air. Thus, an action for clean air would lead to saving of millions of lives.

India is among the world's fastest growing economies, and this growth is accompanied by rapid development including urbanization and industrialization [2]. As both developed and developing countries are predominantly dependent on fossil fuels for energy and transportation needs, those processes globally have steady impact on the composition of the atmosphere. Therefore, air pollution creates a serious and dangerous hazard for the living environment which affects the natural ecosystem, agriculture, human health and change the regional and global climate. This has had a detrimental impact on the health of the public living in or near urban centres and has been linked to a range of respiratory and cardiovascular diseases.

For that reason, a dynamic planning-cum-action approach was proposed for Indore to address the air pollution, where solutions are designed as part of the graded response action plan, using a community-led and multi-stakeholder participatory approach. The focus of this programme under Confederation of Indian Industry (CII) was on deploying effective solutions, building capacity for lasting change, and providing science-based evidence. Three broad sets of activities under this program included- (1) participatory planning and action, (2) citizen engagement, (3) data and research. The main objectives of the project are as follows:

a. To develop a machine learning-based model to estimate ambient fine particulate matter ($PM_{2.5}$) over the Indore Municipal Region (IMR) at an ultra-high resolution (sub-km) which will be used to generate ward-level heatmaps of air pollution.

b. Measuring impact of clean air interventions, including- activities by city authorities under the National Clean Air Programme (NCAP), community-scale action and street-level pilot intervention to be able to improve the effectiveness of air pollution management and control from city-based sources.

1.2. NATIONAL CLEAN AIR PROGRAMME (NCAP) AND INDORE'S AIR QUALITY

Due to rapid urbanization and industrialization, many cities in India are facing severe air pollution and its harmful effects. To address this, the National Clean Air Programme (NCAP) [3] was launched by the Ministry of Environment, Forests and Climate Change (MoEFCC) in 2019 which provides cities targets to reduce particulate matter (PM_{10}) exposure by 20-30% by 2024 (with 2017 as baseline) through city-specific air quality management plans. In 2022, this target has been updated to 40% by 2026. NCAP has designated 131 cities [4] as non-attainment across 24 states and union territories based on the ambient monitoring data from the network operated by the Central Pollution Control Board (CPCB) (Figure 1.1). Six cities in Madhya Pradesh, namely Bhopal, Dewas, Gwalior, Indore, Sagar, and Ujjain, have been designated as non-attainment cities under NCAP.

Indore is one of the fastest developing urban centres in Central India with projected population in 2023 worth 2.8 million inhabitants (1,99,2,535 as per latest published census in 2011) [5]. It has been consistently ranked as the cleanest city (for municipal solid waste) in the country for the last seven years due to its well-established waste segregation model and this has improved Indore's image significantly in the recent past. With 3 out of 8 urban centres (Indore, Ujjain and Dewas) in the Indore Metropolitan Region exceeding National Ambient Air Quality Standards (2019) (Figure 1.2) (non-attainment cities by CPCB) [6], prioritisation of clean air in Indore's action agenda can make it an exemplary urban development model for clean environment. These efforts will be crucial for protecting the future of Indore's children, improving productivity and well-being of its citizens, and sustaining Indore as an attractive investment and business destination.

1.3. RELEVANT STUDIES IN THE PAST

There has been no such detailed scientific research on air quality in Indore conducted in recent years. However, an early study was conducted in 2015 by Urban

[1] In 2019, the World Health Organization (WHO) estimated that outdoor air pollution caused approximately 37% of premature deaths from ischemic heart disease and stroke, 23% from acute lower respiratory infections, 18% from chronic obstructive pulmonary disease, and 11% from cancer affecting the respiratory tract.

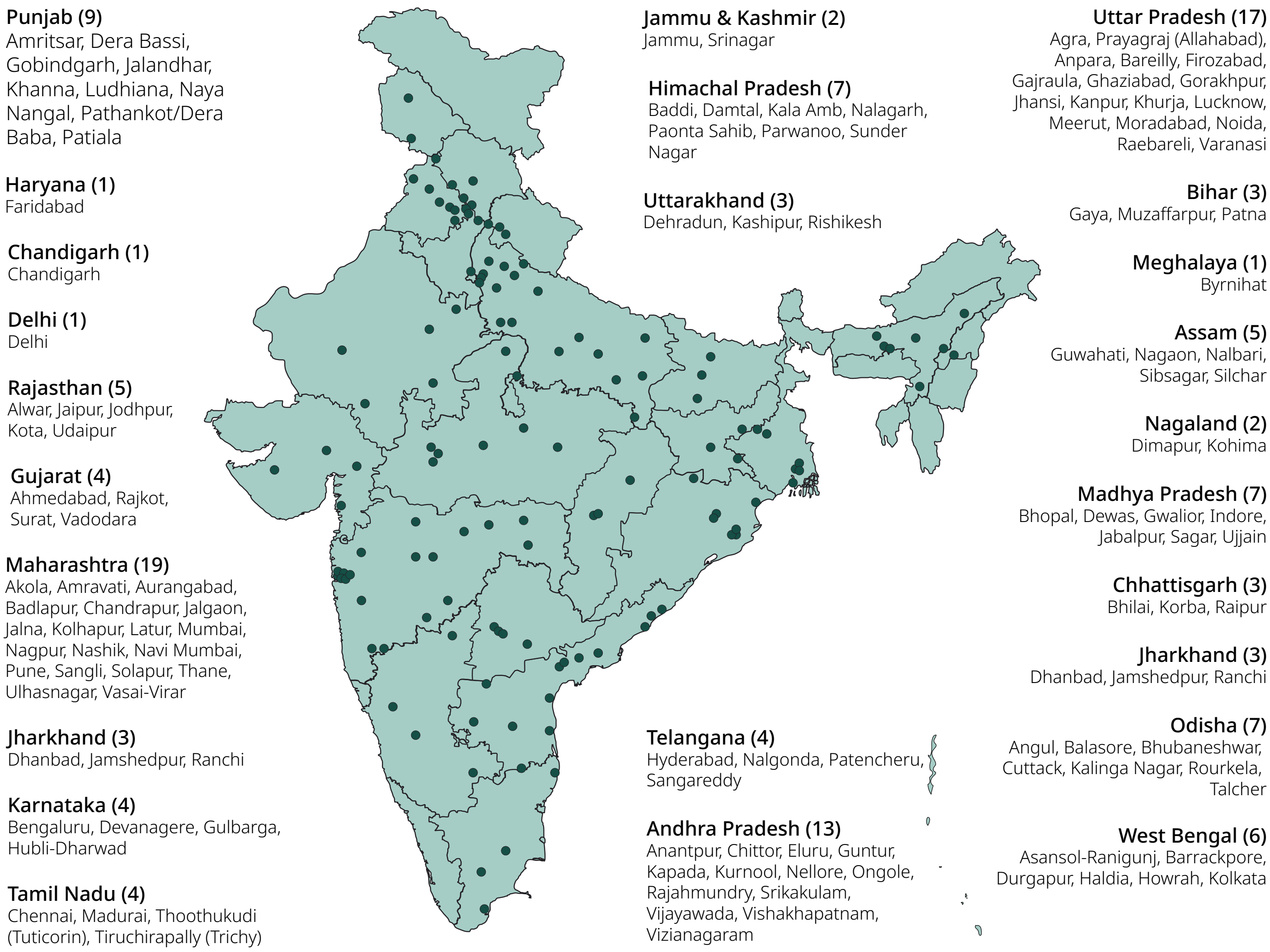
Emission [7]. The study found that the annual average $PM_{2.5}$ concentration was 66.3 ± 12.3 μg/m³, which was higher than the NAAQS (2019) (40 μg/m³) and roughly six times the global standard (WHO guideline) [8]. The research-focused study also found that 28% of the ambient annual $PM_{2.5}$ pollution originated outside the urban airshed, namely from coal-fired power plants, large metal and non-metal processing industries, and brick kilns. Transport (27%) and dust (22.7%) were the second and third major contributors of the fine particulate matter.

1.4. BACKGROUND: HISTORIC AQ TRENDS

Indore is the biggest and the most populous urban centre in the state of Madhya Pradesh in Central India with projected population in 2023 worth 2.8 million inhabitants (1,99,2,535 as per latest published census in 2011) [5]. This city also is the central economic hub connecting trade from Delhi in the North; and Ahmedabad & Surat in West to Mumbai & Pune in the South.

The air quality in the city of Indore remains a concern for public health and environmental well-being. The city essentially experiences high levels of air pollution due to

Figure 1.1: List of 131 non-attainment cities under National Clean Air Programme (2023)



Source: CII CABL (2024) Analysis

concentrated human activities such as industrialization, urbanisation, and high traffic movement in the city and neighbouring areas in the region.

According to historical air quality data as shown in Figure 1.3, the air quality has not significantly changed i.e. improved or worsened in recent years except nitrogen dioxide (NO_2). Indore City has experienced a substantial increase in annual average NO_2 concentrations between 2017 and 2023. Data analysis reveals an upward trend, with NO_2 levels exceeding the NAAQS (2019) of 40 µg/m³ since 2017, which is a concern. This represents a significant increase from 20.06 µg/m³ in 2017 to 60.89 µg/m³ in 2023, reflecting an increase of over 200% (Figure).

1.5. CLEANER AIR BETTER LIFE-INDORE

The Cleaner Air Better Life (CABL) Airshed Management Project – Indore, is attempting to bring scientific approach for planning and management of urban air quality with the ultimate aim to demonstrate effective pollution reduction strategies and create a replicable model for other cities. The program aims to deploy cost-effective solutions and build capacity of local stakeholders for lasting change in airshed management, while providing science-based evidence for informed decision-making. By promoting cleaner air, our aim is to create a healthier and more sustainable environment for the residents of Indore. It is a highly collaborative effort with involvement of partners including-Indore Smart City Development Office (ISCDL), Madhya Pradesh Pollution Control Board (MPPCB), Indian Institute of Technology-Delhi (IIT-D), Indore School of Social Work (ISSW), California Air Resource Board (CARB) and Airvoice.

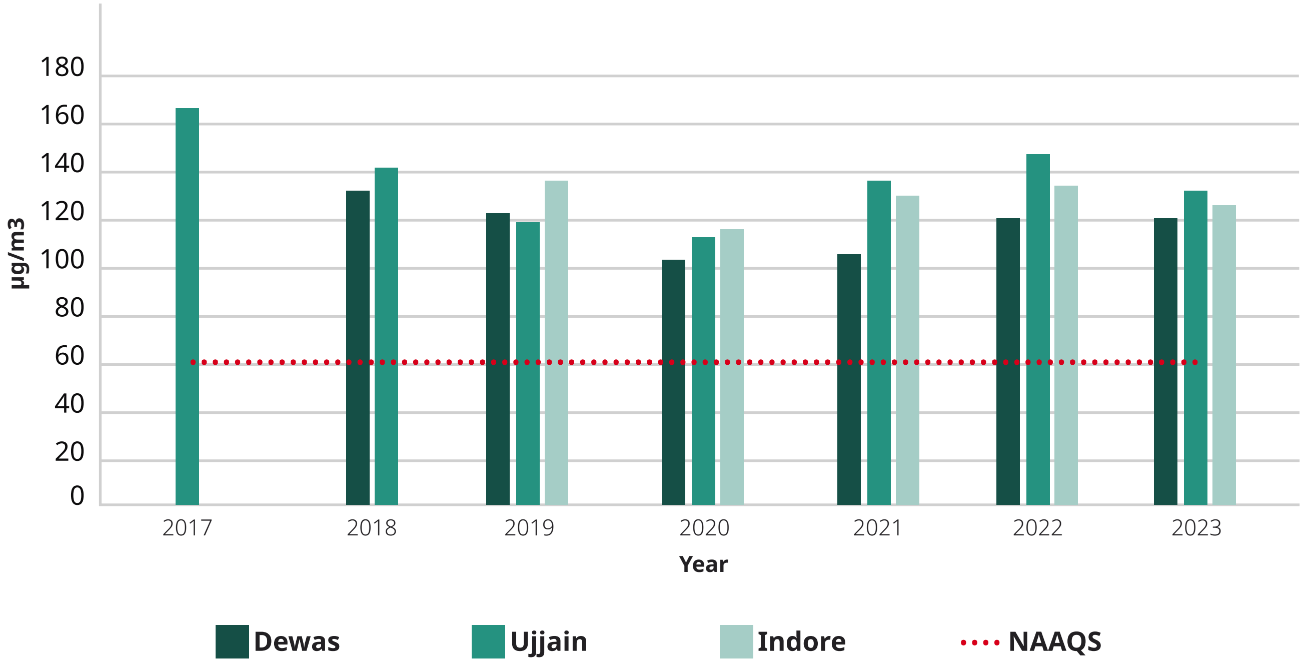
This CABL Indore Programme focuses on $PM_{2.5}$ concentrations, as this pollutant is widely recognized for its significant adverse health effects than PM_{10} due to its smaller size. $PM_{2.5}$ is defined as ambient airborne particles measuring up to 2.5 microns in size. Its microscopic size allows the particles to penetrate beyond the alveolar epithelium, allowing systemic translocation via the respiratory system and travel throughout the body, causing far-reaching health effects, including asthma, lung cancer, and heart disease. It has also been associated with low birth weight, increased acute respiratory infections, and stroke.

Under the programme, stakeholders consultation was carried out in 16th December, 2020 to identify key challenge being faced for air quality management. Lack of availability of local level AQ data was highlighted as a major gap for air quality management in Indore. Subsequently, 30 real-time air quality sensors were installed by CII CABL across Indore urban area. In April 2022, the Confederation of Indian Industry (CII) partnered with Smart City Indore and additionally, 20 Smart City sensors were integrated into the city's network, further enhancing air quality monitoring capabilities of Indore city. In total, CABL Indore currently maintains 50 locations are monitored via sensor-based devices under the CABL Indore activities locations. These monitored locations play a significant role in capturing realtime data and facilitating a comprehensive understanding of air quality and environmental conditions across the city.

A comprehensive deployment plan for sensors was developed taking into consideration various factors, such as height from ground, type of location etc. Further, an air quality model was developed to analyse spatially dispersed data generated form these sensors.

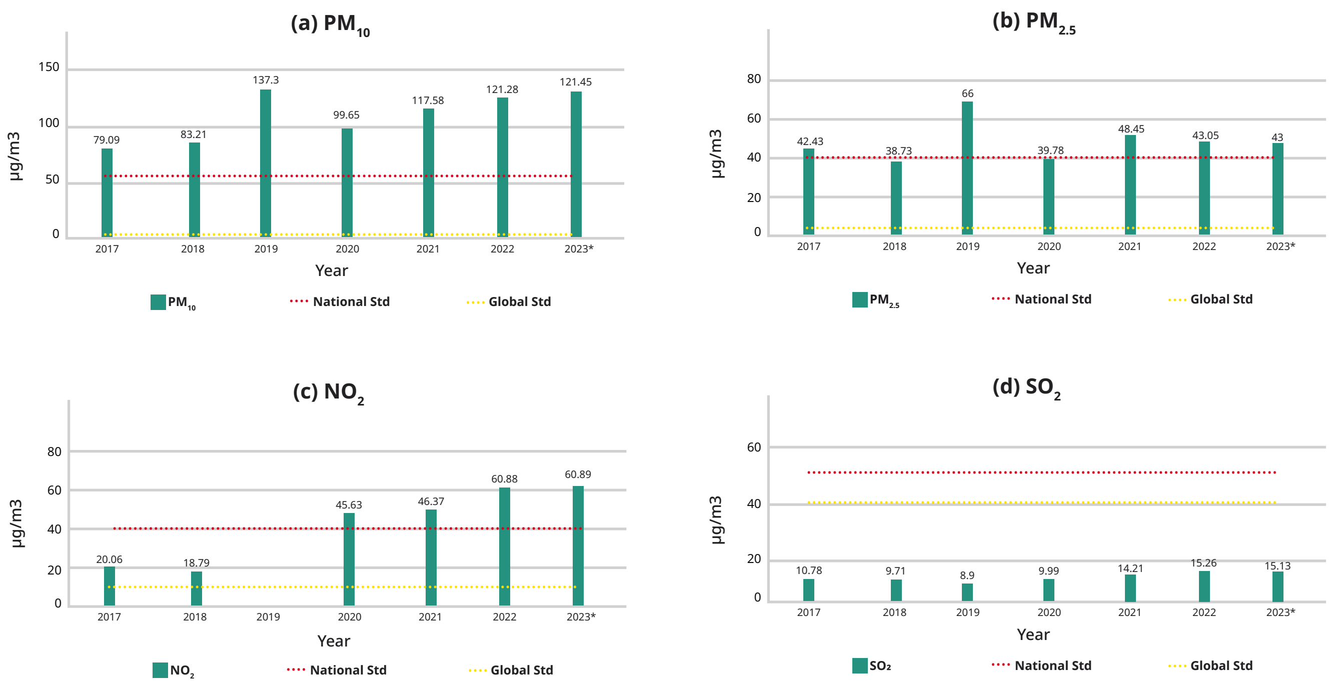
The data from these real-time AQ sensors is then fed into a machine learning based AQ model. Model further considers data from ground stations across IMR, Aerosol Optical Depth (AOD) from satellite data and weather datasets to provide AQ information with high spatial resolution. This information provided factual basis for our conclusions and recommendations.

Figure 1.2: Trends of annual average PM_{10} in three urban centres (Ujjain, Dewas and Indore) of Madhya Pradesh



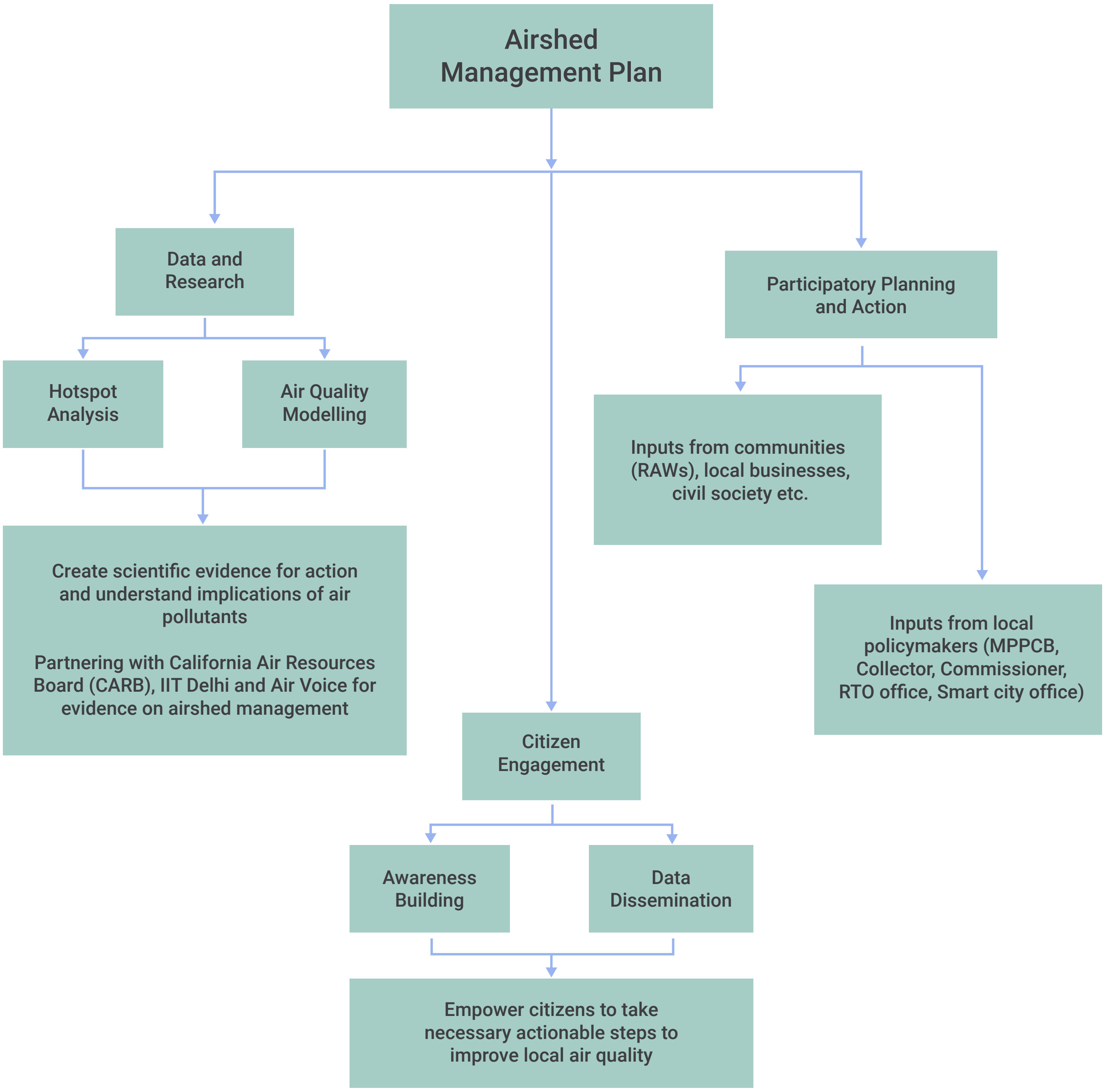
Source: Data are taken from the CAAQMS stations operated by MPPCB.

Figure 1.3: Annual average pollution level in Indore city (2017 to 2023) for (a) PM_{10} (b) $PM_{2.5}$ (c) NO_2 and (d) SO_2



Note: Data from 2017 to 2019 represent the average values from all three manual stations of the MPPCB in Indore City while the data from 2020 to 2023 represent the CAAQMS data stations operated by MPPCB in Indore City.*
** data based on information upto 8th Dec 2023.*

Figure 1.4: Diagram showing the road map of the study



CITY-LEVEL INTERVENTIONS

Under the National clean air program, Indore government i.e., IMC, MPPCB, Indore Smart City have implemented several actions to control and mitigate air pollution level in the city of Indore. From 2020 to 2023, Indore city received 191.75 crores under the NACP and utilized all the funds to improve the city's air quality. The primary objective of these actions is to improve the air quality as CPCB standard and create a cleaner and healthier environment for the citizens. The government has taken the following steps as a part of NCAP activities:

1. Daily Air Quality Public Information Dissemination System

The installation, maintenance, and civil works associated with Continuous Ambient Air Quality Monitoring Stations (CAAQMS). The public is provided with regular updates on air quality through this system.

2. Solid Waste Management

The IMC has established a system for regular cleaning of solid waste generated in Indore city. This includes the proper collection, segregation, disposal and recycling of solid waste from residential, commercial and industrial areas.

3. Desilting

There are 67 tertiary storm water drains in the city, of which regular cleaning and desilting are carried out as per prepared roster.

4. Road Maintenance

Efforts are made to ensure that pothole-free roads are maintained, so that traffic flows smoothly and safely. Regular maintenance work is carried out as and when required on various patches to maintain.

5. Dust Suppression

Regular cleaning of street surfaces and spraying of water to suppress dust. More than 7500 manual sweepers are engaged 0.8 km/person/day. Also 800 km of mechanical road sweeping is carried out along with spraying water to control the air pollutants.

6. Road Design Improvement

To improve the quality of air IMC focuses on the road design improvement. Several initiatives have been taken to improve road design like junction development, left turn development, embankment reconstruction etc.

7. Water Fountain

To help reduce air pollution, water fountains using recycled water have been constructed at major traffic intersections in Indore. These fountains act as a sustainable solution to supress dust and airborne particulate matter, reducing their dispersion into the surrounding area. Water fountains for water recycling have been constructed at major traffic nodes such as Vijay Nagar Square, Sayaji, Marriott's Bar, and near Sharda Char to mitigate air pollution.

8. Road Widening

Under the urban development and planning road widening is an important step to improve the air quality by the IMC. It helps to reduce the traffic congestion and inefficient road network. This work is already started at various locatios such as Panchkuiya road to Hukumchand Colony and Tejaji nagar to Bhawarkuan.

9. Green Buffers

Green buffers are created through planting trees by the city administration which is one of the major activities to control the air pollutants. They act as a natural filter, absorbing pollutants and creating cleaner and healthier air. In the financial year 2020-2021 more than 5,00,000 plantations were carried out.

10. CNG and Electric Buses

CNG and electric buses are two cleaner transportation alternatives for Indore city, which is why 17,800 kg of bio-CNG has been allocated for city buses. At present, 380 CNG buses are procured, operated, and maintained on cluster basis. The city also currently operates 40 electric buses, with 120 charging stations to support their charging needs. In addition, 80 electric buses have been proposed for procurement which have been introduced to reduce fossil fuel consumption and carbon emissions.

11. Parking Management

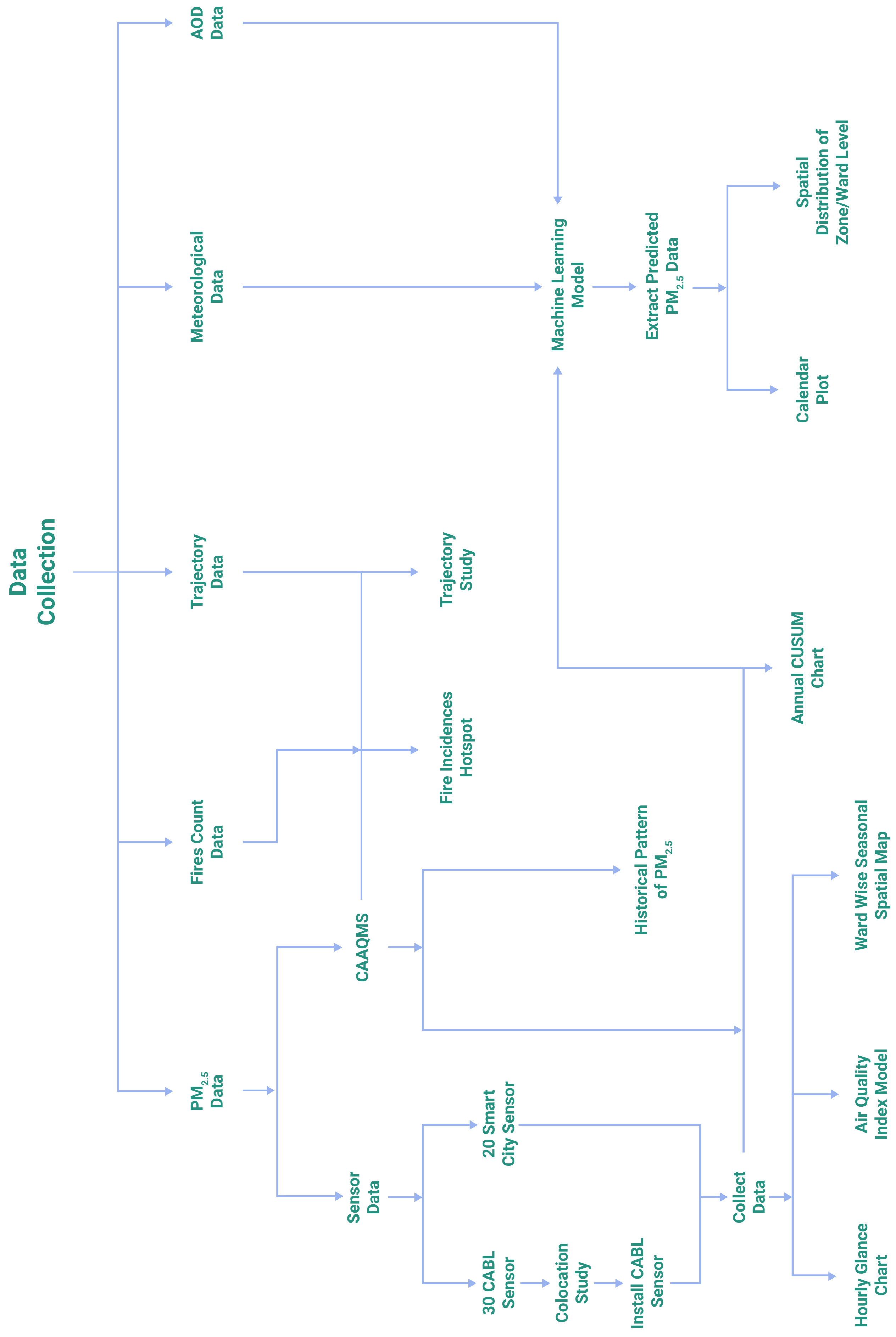
Parking facilities have been designed to make parking easier and more efficient. It also helps reduce pollution and traffic congestion in Indore city. There are currently 10 operational multilevel parking facilities, and an additional 2 have been constructed at Khajuri.

02

Methodology

To provide a visual representation of our research approach, Figure 2.1 details the overall flowchart for our study methodology.

Figure 2.1: Flowchart detailing the methodology of the study.



2.1.COLLOCATION OF SENSOR-BASED MONITORS

The key purpose of collocation experiment is to:

a. Screen and test the devices to ascertain their desired level of accuracy before deployment at planned location.

b. Whether or not any devices are in need of any immediate on-field calibration.

It is worth noting that control-based calibration is already by manufacturer or vendor of these devices. This method for the hardware level calibration includes- novel sensor fingerprint method called CurrentSense and is well documented in Marathe et al. (2021) [9] and results in 86% reduction in average PM error across all drifted sensors. As part of quality control procedures, the devices are further collocated and calibrated by manufacturer in Maharashtra. The field calibration is applied to all devices to improve their data quality. This involves applying linear regression coefficients across all sensors to correct for remaining data faults, resulting in an additional improvement of 2-10% for the collected $PM_{2.5}$ data [10].

The collocation experiment in Indore was conducted by CII Cleaner Air Better life over a period of three months, from 23rd March 2021 to 29th June 2021, during which 120 hourly data points were collected from each monitor to be deployed in Indore. The collected data was analysed to determine the accuracy of these monitors as per international benchmarks available to us-

a. Air Quality Sensor Performance Evaluation Centre (AQ-SPEC): Field Evaluation for AQ Sensors Guidelines, 2017 [11]

b. U.S. Environment Protection Agency (US-EPA), 2021 [12]

After the aforementioned collocation process, the collected data was assessed by using a series of performance-related parameters by taking the best of both set of international guidelines (AQ-SPEC, 2017; U.S. EPA, 2021). These evaluated parameters included used in our study and as adopted from two mentioned international benchmarks are summarised in Table 2.1 –

Upon successfully procuring the sensor-based monitors from an Indian vendor, they were tested and collocated the reference grade monitoring station (CAAQMS) from MPPCB at Chhoti Gwaltoli at a central location in Indore.

As shown in Figure 2.2, devices were mounted on to a railing of the air monitoring station in a batch of 5 following best practices for installing sensor-based devices as summarised in Figure 2.4. Sample data is then acquired collocated devices exposed to ambient air for a period of minimum 4 days. Data is monitored online in real time to ensure continuous data collection using the online dashboard provided by local vendor of these devices.

2.2.METHODOLOGY FOR AIR QUALITY MODELLING

2.2.1. Random Forest (RF) Model: High-Resolution ML Model

Random Forest (RF), a machine learning algorithm, has emerged as an ideal tool for air quality prediction due to its superior performance compared to standard regression models. In this study, the random forest model has been used to analyse air pollution data and evaluate air quality. The random forest model is better than other machine learning models for predicting air pollution data because it provides high accuracy. RF efficiently leverages historical air pollutant and meteorological data to capture spatiotemporal variability with low computational cost, facilitating accurate predictions for targeted regions. While traditional, reference-based monitoring provides valuable data at specific sites, it may not represent the actual public exposure which can vary spatially. RF addresses this gap by enabling the development of regression-based ML models trained on diverse predictor variables (e.g., pollutants, meteorology, land use) to estimate $PM_{2.5}$ concentrations at desired spatial and temporal resolutions.

In Indore city, a regression-based Machine Learning (ML) model is developed and trained on a given set of predictor variables to estimate $PM_{2.5}$ concentrations at a pre-decided spatial resolution (i.e. 1km) and temporal resolution (i.e. 24 hrs) was built and evaluated.

The study chose the Random Forest (RF) model as the machine learning tool to predict $PM_{2.5}$. RF is a supervised machine learning model that makes the best predictions based on a subset of predictors by averaging a group of decision trees [14]. One of the

Table 2.1: Field Evaluation and Collocation Study: Performance Evaluation Metric used in this study for $PM_{2.5}$ Sensors

Parameter	Description	Equation	Purpose	Mode of Evaluation	Acceptable Criteria
Bais	Systematic Measurement error for sensor values with respect to reference	$Bias = \left(\frac{x}{y}\right) - 1$	To test and improve sensor's data quality	Evaluated before and after field calibration	Should be close to zero
Mean	Arithmetic mean patterns of sensor & reference values	$Mean = \frac{\sum_{i=1}^{n} x}{n}$	To predict subsequent data and baseline trend	Compared daily average patterns of sensor data with the reference system.	N.A.
Mean Absolute Percentage Error (MAPE)	Absolute percentage difference between sensor & reference values	$MAPE = \left(\frac{1}{n}\right) \times \sum_{i=1}^{n} \left(\frac{x-y}{y}\right) \times 100$	To acess the accuracy of the sensor-based monitors	Calculated MAPE before and after field calibration	15-30
Correlation	Strength of the linear relationship between sensor & reference values by evaluating R2	$R^2 = \left[\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{\{n\sum x^2 - (\sum x)^2\}\{n\sum y^2 - (\sum y)^2\}}}\right]$	To measure the strength and direction of the linear relationship	Calculated the best-fitting regression curve between two sets of data i.e., sensor data nd reference data.	$R^2 \geq 0.70$
Intra-model Variability	Descriptive statisticsmean, median, and standard deviation (SD) between collocated sensors	$SD = \sqrt{\frac{\sum_{i=1}^{n}(x-\bar{x})}{n-1}}$	To determine the similarity	Calculated mean, median, and standard deviation of the same sensors collocated in the same sensors' batch	SD ≤ 5 µg/m³
Data Recovery	Data completeness rate	$Data\ recovery\ (\%) = \left(\frac{n_x}{t_x}\right) \times 100$	To be able to acquire reliable and comprehensive data for analysis	Assessed the percentage of usable sensor data points	>75%

Note:
1. x & y indicate observation points from the sensor and reference grade station respectively
2. n represents the number of data points
3. n_x and t_x are the number of valid sensor data points during the testing period and the total number of data points for the testing period (from start to end)

Source:
AQ-SPEC Field Evaluation of Low-Cost Air Quality Sensors (2017), U.S. EPA sensor evaluation report (2014), U.S. EPA Performance Testing Protocols, Metrics, and Target Values for Fine Particulate Matter Air Sensors (2021)

learning and classifying features, can include many input variables, and can output variable importance. The model selects a random subset of samples from all observations with replacement and subsequently selects the best set of predictors that provides the best split at each node [14]. The data set is divided into 70% and 30% for training and testing, respectively. The training part consist of the data which is comprise of data from CPCB sensor and the ground sensor installed over the Indore. The validation or test data which is 30% only consist of CPCB sensor data.

The study processes the 24-hr averaged $PM_{2.5}$ data from the available monitoring stations for 2019-2022 to train and validate the model. The output variable $PM_{2.5}$ is taken from CAAQMS monitoring stations of (Indore, Dewas, Pithampur, Ujjain) as well as 50 ground sensors installed in Indore city.

The predictor features used in the current model are as follows -

a. Meteorological data: The study considers meteorological data of nine variables- Temperature, Rainfall, Total cloud cover, Wind velocity, Surface pressure, Albedo, Surface solar radiation, Relative Humidity, Boundary-Layer Height at 28-30 km resolution from global databases- GFS (2023) [15] and ERA5 (2023) [16].

b. Aerosol optical Depth (AOD): AOD is one of the key predictor variables in this model. AOD data (MERRA 2) is retrieved by the Moderate Resolution Imaging Spectroradiometer (MODIS) with a spatial resolution of 1 km [17]. The national $PM_{2.5}$ database for India was created using MODIS AOD, which has previously been validated in India [18]. $PM_{2.5}$ components (MERRA2) include surface mass concentrations of black carbon, dust, organic carbon, sulfate, sea salt [19].

It is known that essential predictor variables like AOD affect $PM_{2.5}$ non-linearly. Therefore, a non-linear tree-based ensemble model Random Forest was implemented. Root mean squared error (rmse), R-square (r^2), and Pearson Correlation Coefficient (pcc) were used as performance metrics for evaluation of the model to compare with observed values.

2.3.METHODOLOGY FOR DELINEATING INDORE'S AIRSHED

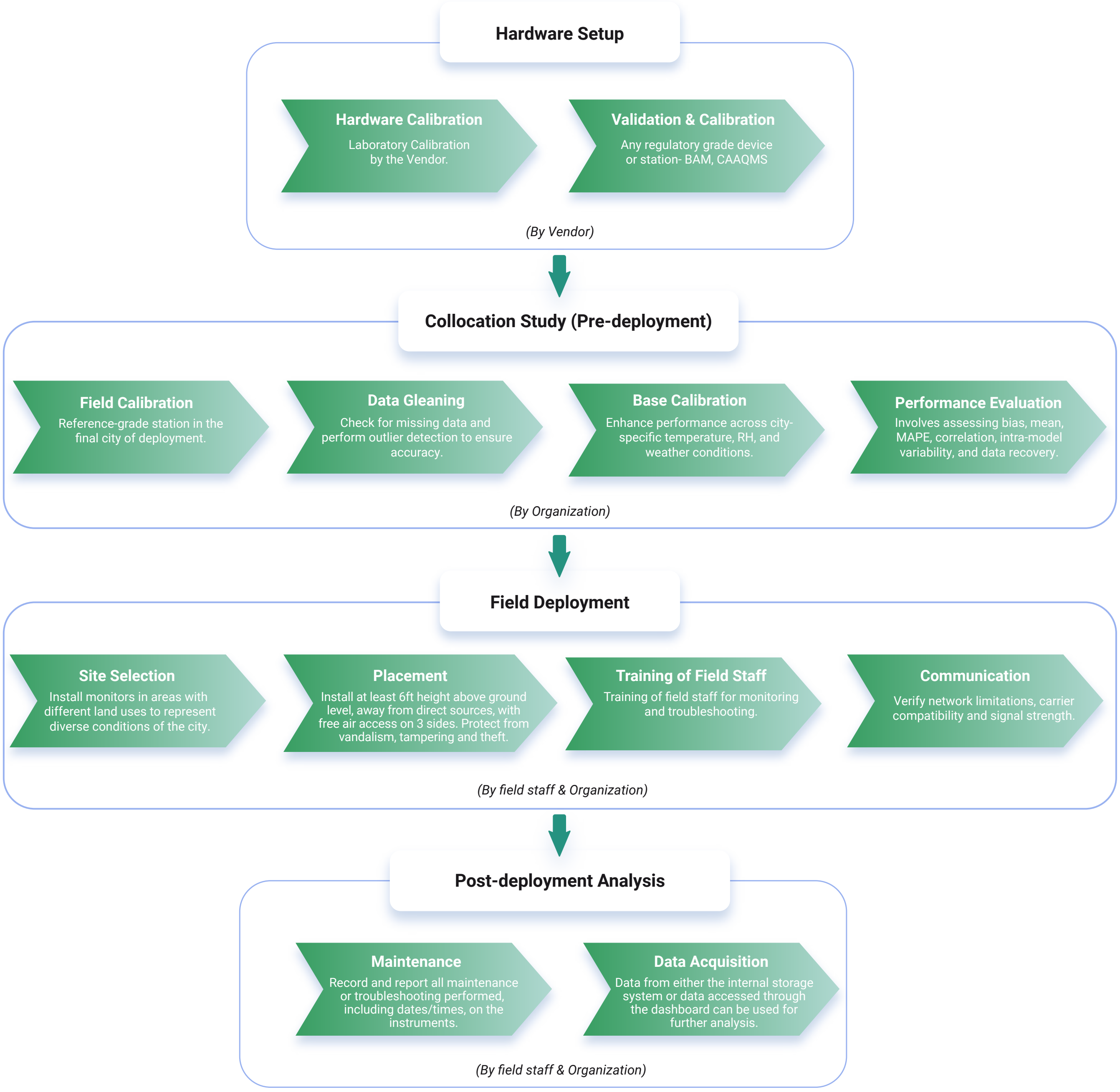
Air parcels transported over long distances cannot be addressed by in-situ parameters and meteorology, even though they provide information about potential local source influences. Air parcels while passing from one region to another accumulate and deposit pollutants. The back - trajectory analysis of air parcels is widely used to establish the source - receptor relationship by determining their origin and their transport path. The HYSPLIT model is a tool that allows tracking the path of air mass back in time from any particular point of origin. It is a combination of the Lagrangian approach that uses a moving frame of reference for the advection and diffusion calculations and the Eulerian approach that uses a fixed 3-D grid as a frame of reference to estimate the concentration of a particular pollutant. It allows tracking individual air mass as well as clusters of trajectories in ensemble mode. Air mass back trajectory has been calculated starting from the central location of Indore for every 3-hour interval during different seasons at an altitude 500 metres. The location of the air parcels every hour is tracked. The resulting clustered trajectories help identify significant source regions and

Figure 2.2: Sensor based air quality monitors collocated with the reference-grade air quality monitoring station in Indore.

probable sources that contribute to the concentration of particulate matter at the site under consideration [20, 21, 22].

Pearson's correlation of all 1-km grid squares in and around the city with respect to the city centroid grid square was calculated based on 20 years of data at a seasonal scale. The grids with a correlation significant at 90% Confidence Interval were identified. A 24-hour back trajectory for a city centroid at every 6-hourly interval for 2017-2018 was computed using the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model. The trajectory data was then transformed from line to grid by counting the number of points of each trajectory within each 0.2° by 0.2° grid. The spatial correlation raster layer was overlaid on the trajectory raster layer, and a convex hull was created out of the non-null grid points in the extracted raster that represent the local airshed of Indore city.

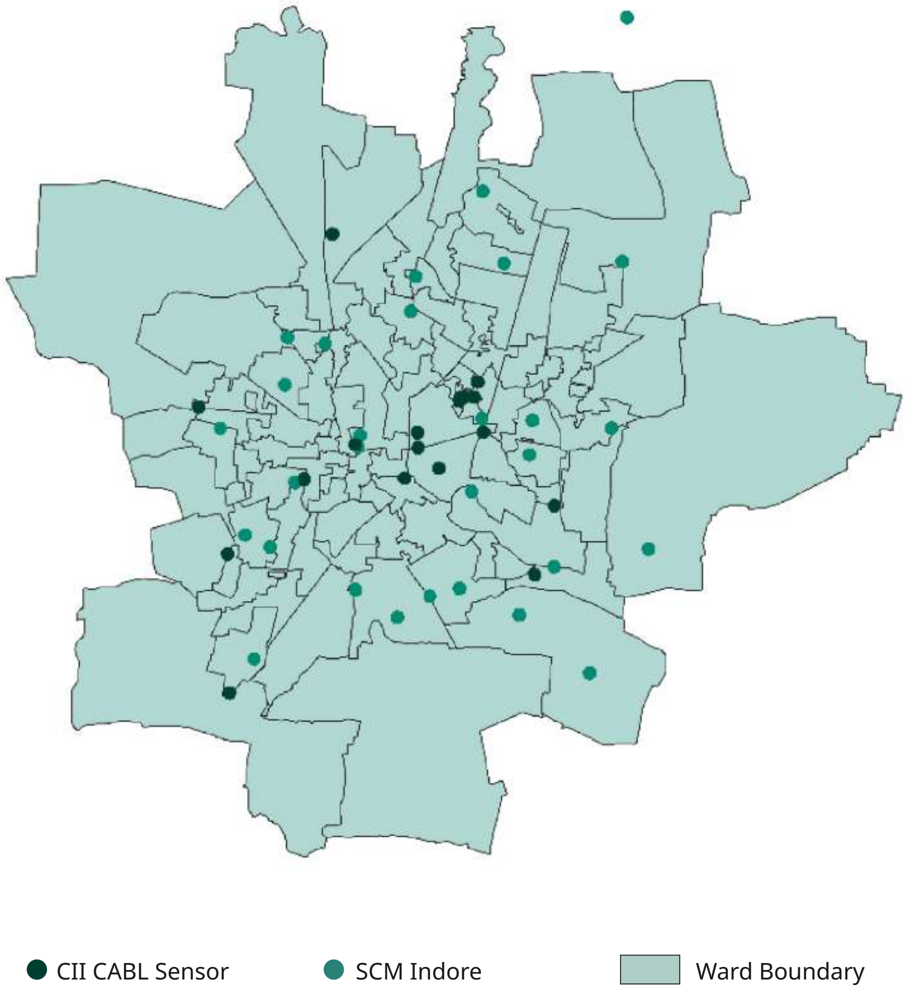
Figure 2.3: Installation protocols for $PM_{2.5}$ Air quality Sensor in Field



Note: Reference grade stations represent the BAM and/or CAAQMS; BAM: Beta Attenuation Monitors; CAAQMS: Continuous ambient air quality monitoring system; RH: Relative Humidity; MAPE: Mean Absolute Percentage Error

Key resources on air sensor installation protocol: Zheng et al., (2018) [10], AQ-SPEC Field Evaluation of Low-Cost Air Quality Sensors (2017) [11], U.S. EPA Performance Testing Protocols, Metrics, and Target Values for Fine Particulate Matter Air Sensors (2021)[12], U.S. EPA sensor evaluation report (2014)[13].

Figure 2.4: Sensor location in Indore City



2.4. CITIZEN ENGAGEMENT

2.4.1. Zonal Meetings

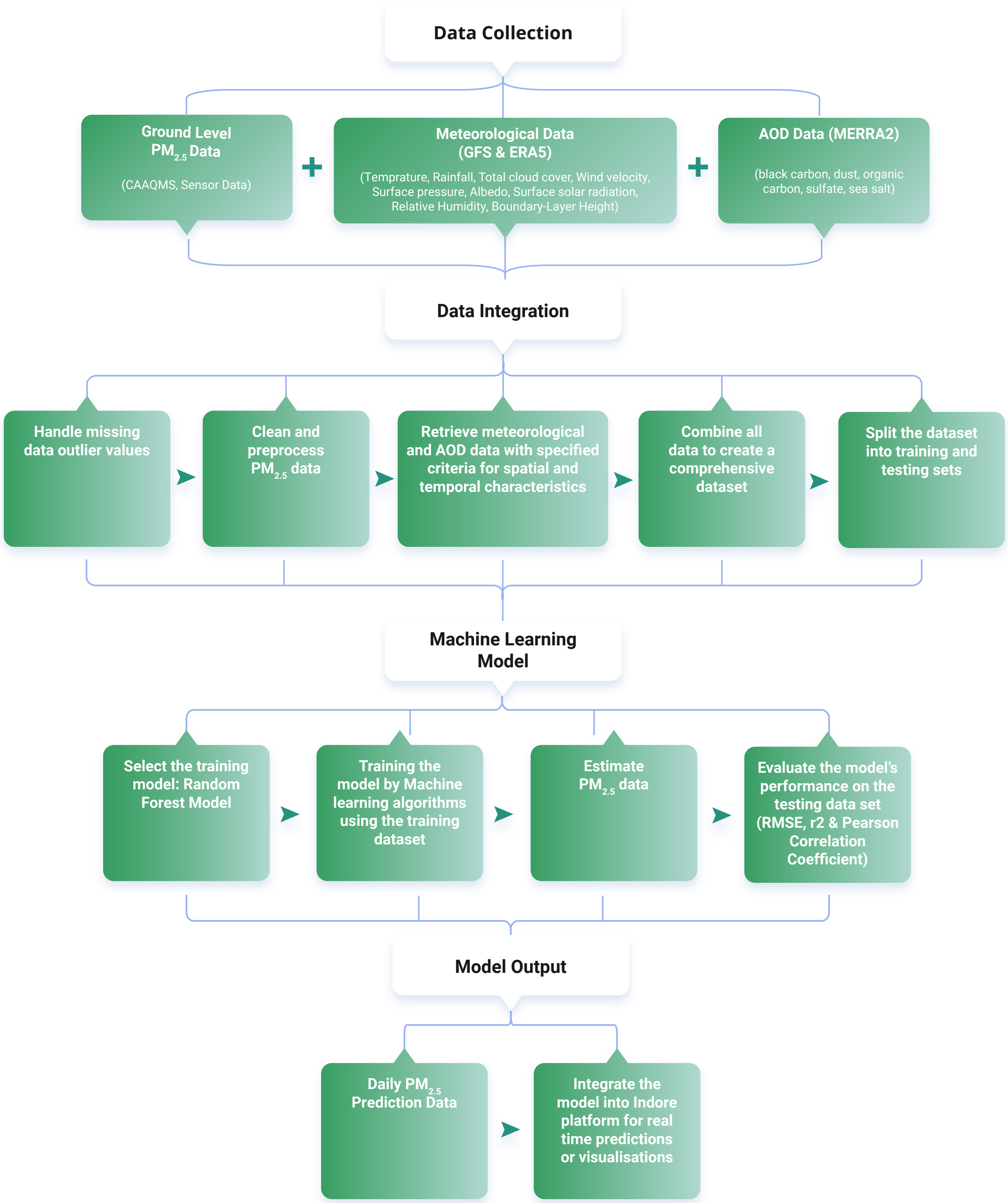
Engaging stakeholders, such as community members, local leaders, and zonal officers, is essential for effectively identify environmental issues at local level and devise simple cost-effective solutions. It is possible to identify air pollution's potential sources and solutions through this stakeholder engagement and assessment process. The zonal meetings were organised to promote collaboration and the sharing of information among stakeholders and to determine the sources of air pollution in each of the 19 zones. In addition, the meeting aims to acquire a comprehensive understanding of each zone's air pollution sources. Eventually, this approach will help in the development of effective and sustainable solutions to address the critical issue of air pollution.

2.4.2. Citizen Survey

A community based cross-sectional survey was conducted in the city of Indore to investigate air pollution. To accomplish the goals of the study, a 40-question standardized questionnaire was used over the course of four months, from October 2022 to February 2023. The questionnaire was divided into two sections. The first section captured basic sociodemographic details of the study population, such as age, gender, occupation, and other relevant characteristics. The second section assessed air pollution-related variables, such as participants' awareness of air pollution, sources of air pollution, and the impact of air pollution on their health. Clean Air Champions (CAC) conducted one-to-one interviews with participants to gather the data.

Note: A total of 50 real-time monitoring sensors were installed in Indore city, comprising 20 Smart City Monitors (SCM) and 30 CII CABL sensors.

Figure 2.5: Flowchart detailing the ML methodology of the study including the data, models, and procedures used



Note: MERRA2: Modern-Era Retrospective Analysis for Research and Applications, Version 2; GFS: Global Forecast System;
• The spatial resolution was 1 km, and the temporal resolution was 24 hours.
• The data set is divided into 70% and 30% for training and testing. The training part consists of the data which is comprised of data from the CPCB sensor and the 50 ground sensors installed over the Indore. The validation or test data which is 30% only consists of CPCB sensor data.

Figure 2.6: Flowchart showing the citizen engagement programme methodology of this study

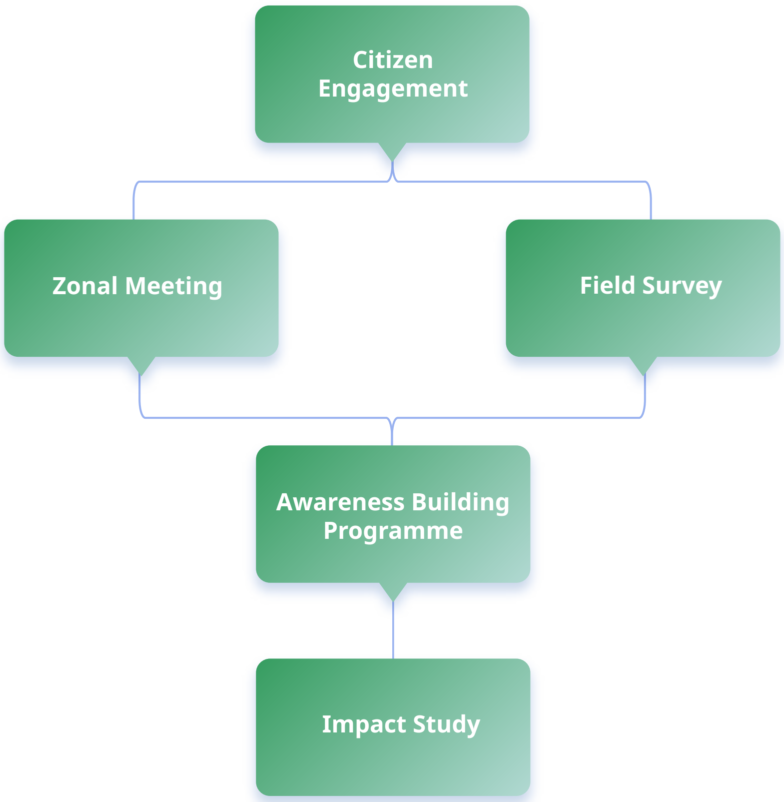
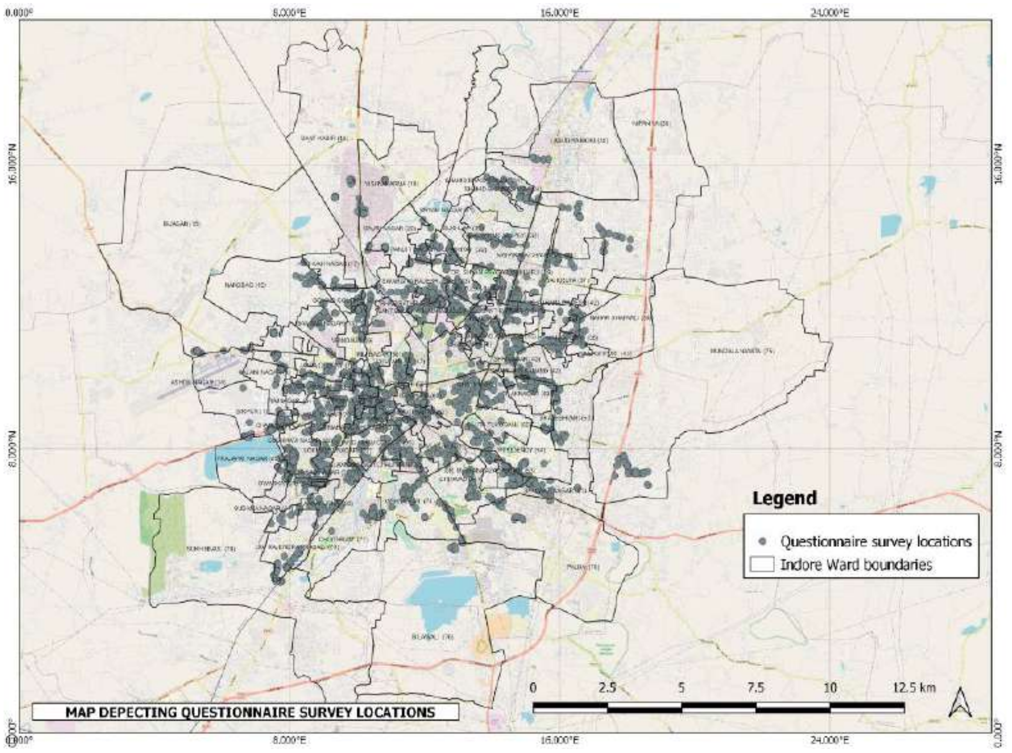


Figure 2.7. Map displaying the geographic distribution of all survey questionnaire samples collected in Indore, India.



Note: A total of 19 zonal meetings were conducted, along with 85 ward-level field surveys consisting of 2,777 questionnaires. Additionally, a total of 11 awareness programs were also conducted, and the subsequent impact study was based on a sample of 907 participants.

03

Results

3.1. COLLOCATION RESULTS

This study evaluates the performance of 30 low-cost air quality sensors deployed near the MPPCB monitoring station. Following the colocation process the key findings include:

3.1.1.Time Series

Analysing the time series graph with the reference data provides valuable insights into the sensor's behaviour at the preliminary stage, including how its readings fluctuate over time and the accuracy of the data. The sensor readings represent similar patterns with reference monitor in terms of hourly $PM_{2.5}$ concentration range and overall trend.

3.1.2.Bias

The bias values for monitors, both calibrated and uncalibrated, are presented in Table 2.1. Sensor bias decreased significantly after calibration, with values close to 0 for all monitors.

3.1.3.Mean and MAPE

Hourly $PM_{2.5}$ concentrations measured by the sensors were within a similar range compared to the reference monitor for all batches and showed similar trends. MAPE values improved after calibration, ranging from 16-25 compared to 20-34 for uncalibrated data.

3.1.4.Correlation

R^2 values for calibrated data points exceeded 0.85 for 15 sensors, meeting the expected value of >0.70 as per U.S. EPA guidelines. Lower R^2 values observed in some monitors were due to precipitation during data collection and a lower $PM_{2.5}$ concentration range. Scatter plots in Figure 22 and Table 3 show correlations.

3.1.5.Intra-model Variability

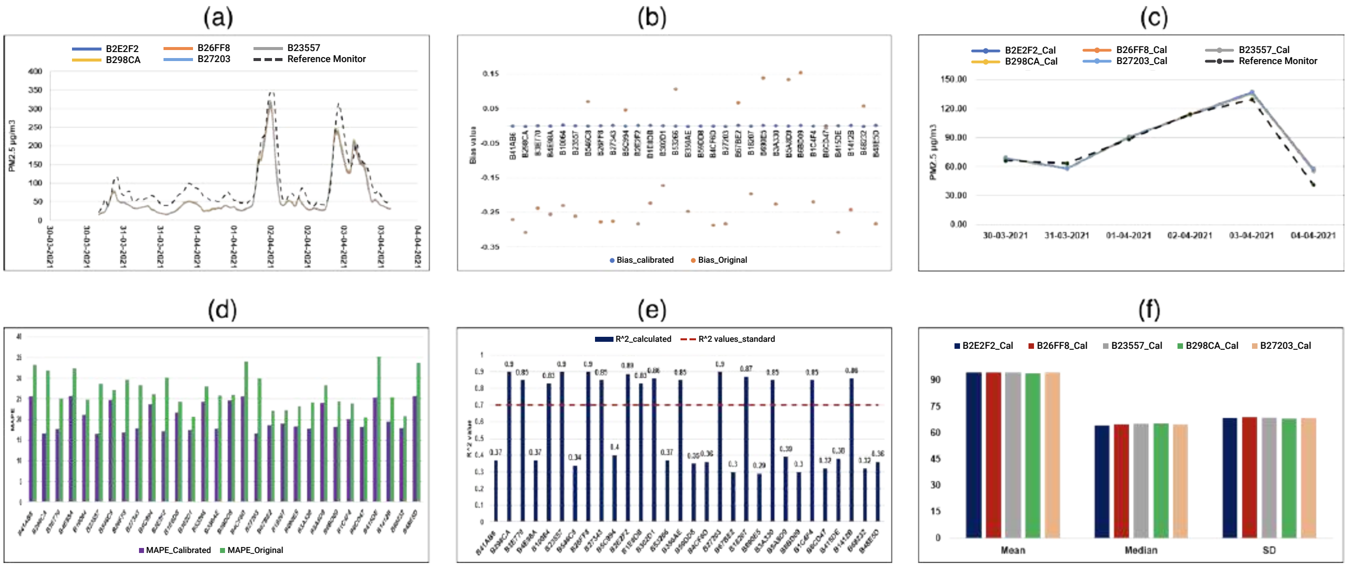
Low variability was observed across all batches regarding mean, median, and standard deviation. R^2 values for five sensors within each batch were all >0.85, except for one case in batch 4 with 30% of data missing.

3.1.6.Data Recovery

Data recovery was 100% for all batches except batch 1 (79.1%), batch 4 (70% for one sensor), and batch 5 (90% for one sensor). The low data recovery in batch 1 was attributed to high precipitation and a lack of proper sensor casing.

Overall, the $PM_{2.5}$ air quality sensors performed well in Indore after calibration, demonstrating good accuracy with the reference monitor in terms of bias, mean, MAPE, and correlation. Intra-model variability was low, and data recovery was high for most sensors. However, improvements in sensor casing and data collection protocols during precipitation events are recommended.

Figure 3.1: $PM_{2.5}$ Sensor Performance Evaluation Results from Collocation Study



Note:
(a) Time series comparison of $PM_{2.5}$ data (1-hour intervals) between the reference station and Batch 2 monitors. See the supplementary section for more details.
(b) Bias of monitors with both calibrated and uncalibrated data compared to the reference station.
(c) Daily average $PM_{2.5}$ data (6 hours) from the reference station and Batch 2 monitors. See the supplementary section for more details.
(d) Mean Absolute Percentage E rror (MAPE) for all monitors.
(e) R-squared (R^2) values of 30 monitors compared to the U.S. EPA permissible value.
(f) Intra-model variability (mean, median, and standard deviation) for Batch 2 monitors. See the supplementary section for more details.

3.2. DELINEATING INDORE'S AIRSHED

3.2.1.Demarcating Airshed for Indore

Airshed identified for air quality management over Indore city and nearby districts are shown in Figure 3.2. It is prioritized on the basis of pathways of Air mass trajectory which are analysed using Cluster based HYSPLIT[2]. The pathways of Air mass in different seasons and their contribution towards Indore are also shown. The areas which are in the direction of air mass pathways should be focused upon for improving the air quality in Indore. This is because Indore is more likely to be affected by these areas.

$PM_{2.5}$ levels in Indore region is influenced by the wind direction. During the March to May period, when the wind is predominantly north-westerly, $PM_{2.5}$ levels remain high. This is because these winds carry pollutants from the surrounding agricultural areas and industries into the city. During the monsoon rain (from June to September) cleans the atmosphere as revealed by low $PM_{2.5}$ levels. However, during the post-monsoon, easterly and north-westerly wind travel through the places where industries are located and $PM_{2.5}$ levels can again increase. In addition, 24% of the time, wind comes from areas affected by agricultural waste burning, enhancing $PM_{2.5}$ level in Indore.

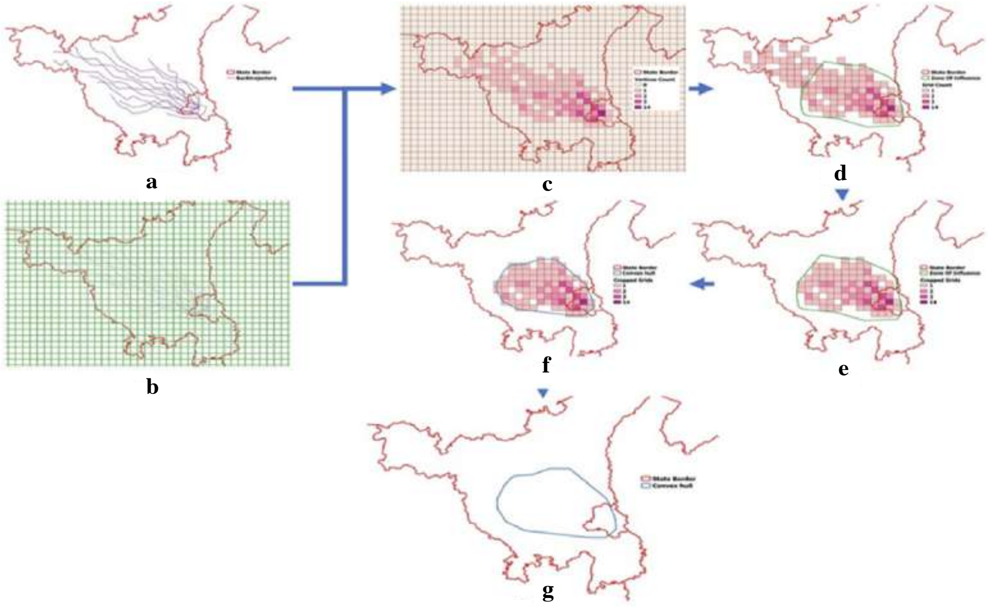
3.2.2.Fire Incidences and their Impact in Indore City

The detection of open fires[3] within the Indore airshed using VIIRS in 2021 [23] is a concerning finding, as it indicates the presence of significant sources of air pollution within the region. To better understand the extent of this problem, we performed an analysis daily variation in fire counts from 2019 to 2021 (Figure 3.3), which showed a clear seasonal trend with a peak in burning activity during March to May. Furthermore, the study examined the correlation between open fires upwind and $PM_{2.5}$ levels within the city during peak burning season i.e., March and April months. Our analysis revealed a strong positive correlation between the two variables, indicating that the open fires upwind are a significant contributor to the elevated $PM_{2.5}$ levels observed within the city.

3.3. PATTERNS OF AMBIENT PM2.5 IN INDORE

The three-year daily average $PM_{2.5}$ values from 2020 to 2022 exhibit consistent trends, except for 2020, notably impacted by COVID-19 lockdowns. March-April data showed notable increases attributed to open stubble burning outside Indore city (Figure 3.3). Transboundary sources likely contributed. May-September $PM_{2.5}$ concentrations in Indore remained below the NAAQS limit (60 µg/m^3) due to increased precipitation, facilitating wet deposition. Winter months saw pollution resurgence, with some data discrepancies noted since November 2022, attributed to technical issues with CAAQMS.

Figure 3.1: Major air mass pathways to Indore in different seasons



Note:
(a) calculate the 24-hour back trajectories for a season (the figure includes some example trajectories for representative purpose),
(b) The grid over the region at ~10km resolution,
(c) Counting the vertices of trajectories lying inside the grids,
(d) Removing the zero count grids and overlaying the zone of influence (ZoI) estimated by Lekinwala et al (2020),
(e) Removing the grids lying outside the ZoI,
(f) Constructing a convex hull from the left grid points, and
(g) Demarcating local airshed of the city.

[2] The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) model is a tool that allows tracking the path of air mass back in time from any particular point of origin. It is a combination of the Lagrangian approach that uses a moving frame of reference for the advection and diffusion calculations and the Eulerian approach that uses a fixed 3-D grid as a frame of reference to estimate the concentration of a particular pollutant. It allows tracking individual air mass as well as clusters of trajectories in ensemble mode. Air mass back trajectory has been calculated for every 3-hour interval during different seasons at an altitude of 500 m.
This model is used to compute 24-hour back trajectories from the city center at 6-hourly intervals for the period 2017-2018. These trajectories are transformed into gridded data by counting the frequency of each trajectory point within each 0.2° x 0.2° grid cell.

Figure 3.2: The demarcation process for local airshed for Indore city

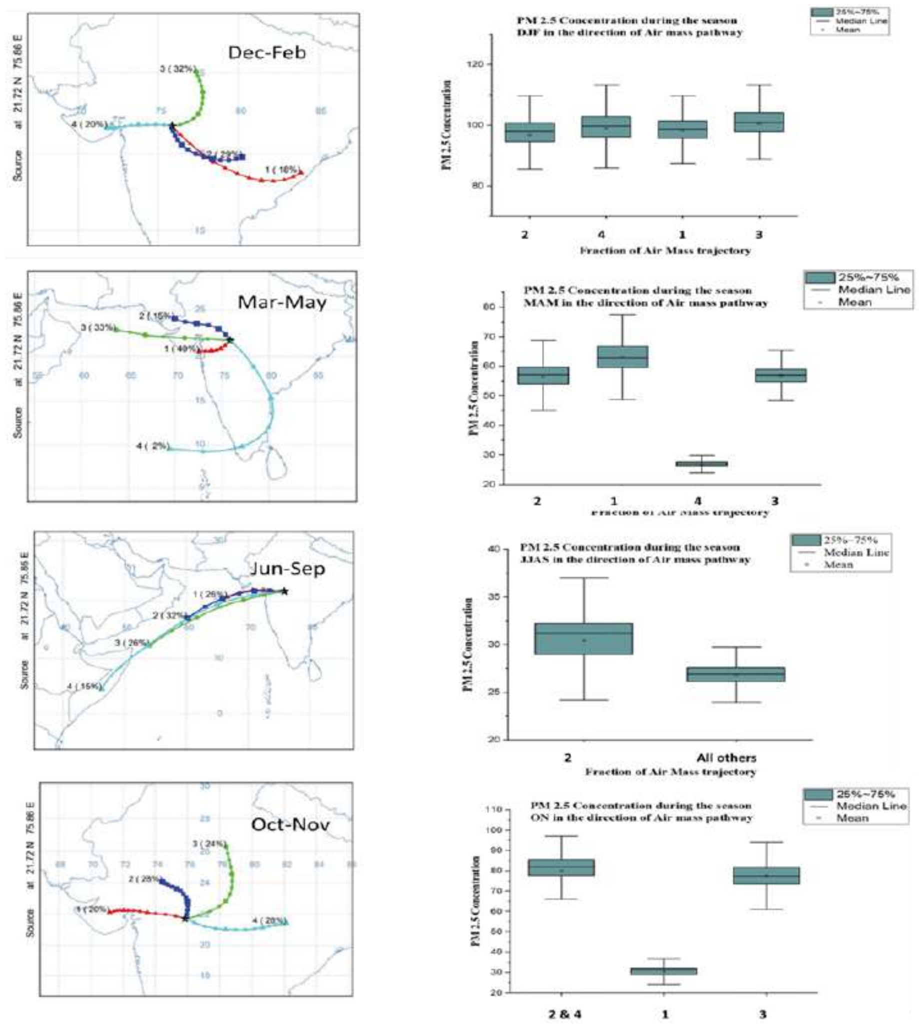
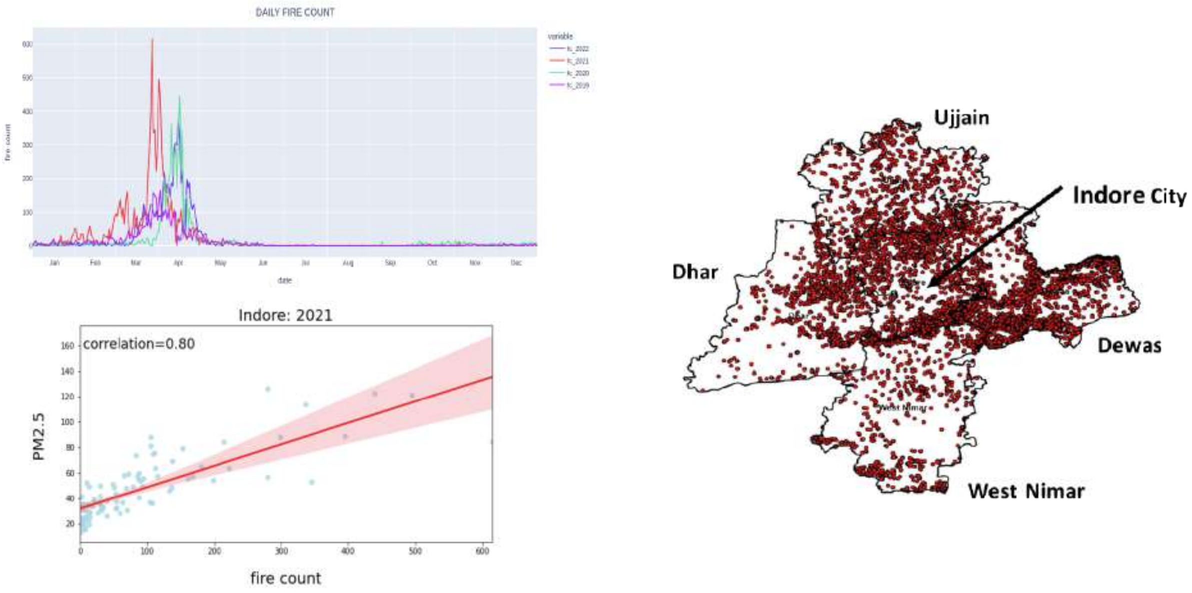
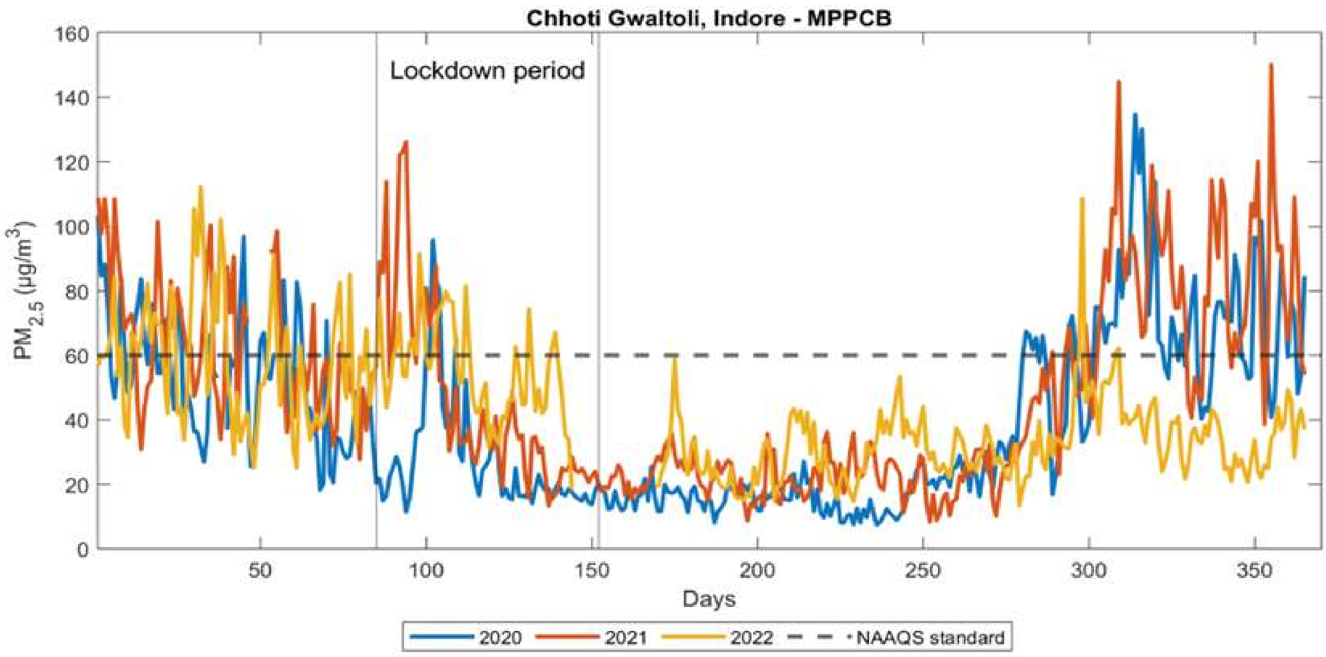


Figure 3.3: Fire incidences in the Indore city and nearby districts



Note:
a) Daily fire count data for the years 2019, 2020, and 2021.
b) Locations of open burning incidents in Indore and surrounding areas during 2021.
c) The correlation between $PM_{2.5}$ and fire count, demonstrates a positive correlation.

Figure 3.4: The variation in daily average $PM_{2.5}$ concentrations, based on data from the regulatory grade station (CAAQMS), in Chhoti Gwaltoli, Indore, from 2020 to 2022



3.4. TIME-SERIES ANALYSIS

3.4.1. Analysis of Air Quality Sensors' Data

The mass concentration of $PM_{2.5}$ from sensors were measured continuously at 50 sites from November 2021 to December 2022. The sensor data from 50 sites were analysed to observe the seasonal and diurnal variation and the influence of meteorological conditions on $PM_{2.5}$ behaviour.

Seasonal Variation of $PM_{2.5}$ concentrations

In Figure 3.5 wards are coloured based on seasonal average of all monitor readings located within each ward. The data from sensor-based monitors is not necessarily representative of the whole ward. This can be seen in some locations in the figure, where nearby monitors show different average concentrations. Following key observations can be made from this figure-

- The highest pollution levels are seen in the wards located in the North of the city namely- (1) Sant Kabir and (2) Swargiya Rajesh Joshi. This is especially the case for winter and autumn seasons when meteorological factors limit dispersion of pollutants. Additionally, the territory within the Sanwer Road industrial area consistently experiences higher pollution levels.
- Better air quality is observed in the vicinity of Mahatma Gandhi Marg.

Daily Variation of $PM_{2.5}$ concentrations

The Figure 3.6 shows that the daily variation of $PM_{2.5}$ levels in the Indore city. The results also show that the levels of $PM_{2.5}$ peaks in the Winter months of October and November. The daily average levels in the period were recorded as much as twice the national standard (at 60 μg/m³ Daily Average). Maximum concentration of $PM_{2.5}$ was recorded at 179 μg/m³ in 2021, and 140 μ g/m³ in 2022.

Identification of Changes in Air Pollution Levels (CUSUM Chart)

Cumulative Sum (CUSUM) chart is helpful for identifying the effects of policy changes on air quality. CUSUM chart[4] on Figure 3.7 clearly shows the seasonal character of air pollution. While the period from October till February is characterized by levels of pollution far above NAAQS annual ambient air quality standard (40 μ g/m³), May and June are the months when the air quality exceeds not only the National standard but also the WHO Interim target 1 level of 35 μg/m³ [24] for average annual concentrations of $PM_{2.5}$.

[3] Open fire data are taken from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor onboard SUOMI National Polar-orbiting Partnership (NPP) satellite, which has equatorial crossing time of 1:30 PM and 1:30 AM.9 Fires are detected using a combination of thermal, middle infrared and visible bands. VIIRS has two products – one (VPN14) provides data at 750 m spatial resolution, and the other (VNP14ING) provides data at 375 m resolution from 2012 onwards. The data are archived and distributed through LP DAAC.

Compared to other satellite fire detection products, the VIIRS 375-m data provides greater results over fires of relatively micro regions. Hence, in this report, we process the 375-m resolution product, which identifies a fire event (shown by the red dots in Figure 3.3) . Each red dot represents a fire event in a 375- m by 375-m area. For every swath of the sensor, the fire coordinates are processed and collated to generate the statistics over the desired spatial and temporal scales.

Figure 3.5: Seasonal average $PM_{2.5}$ concentrations based on 50 monitor data

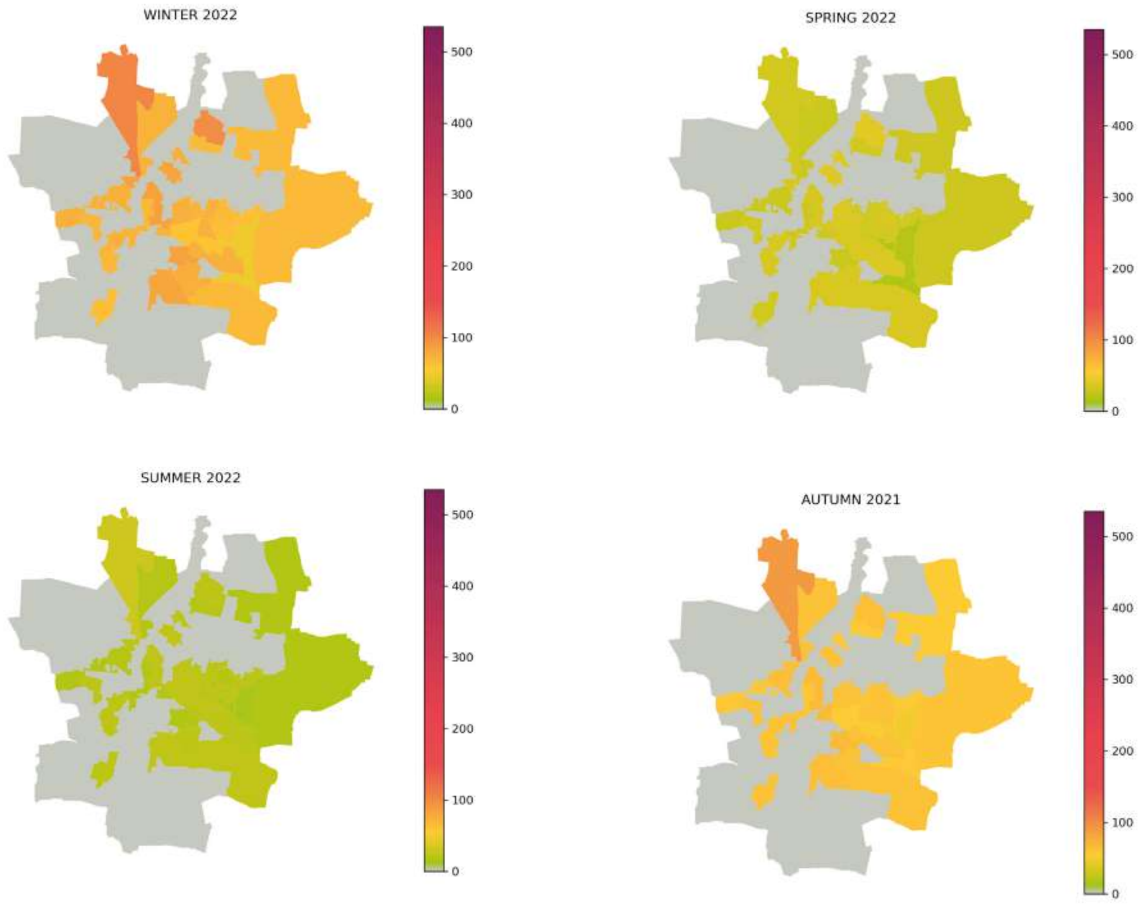
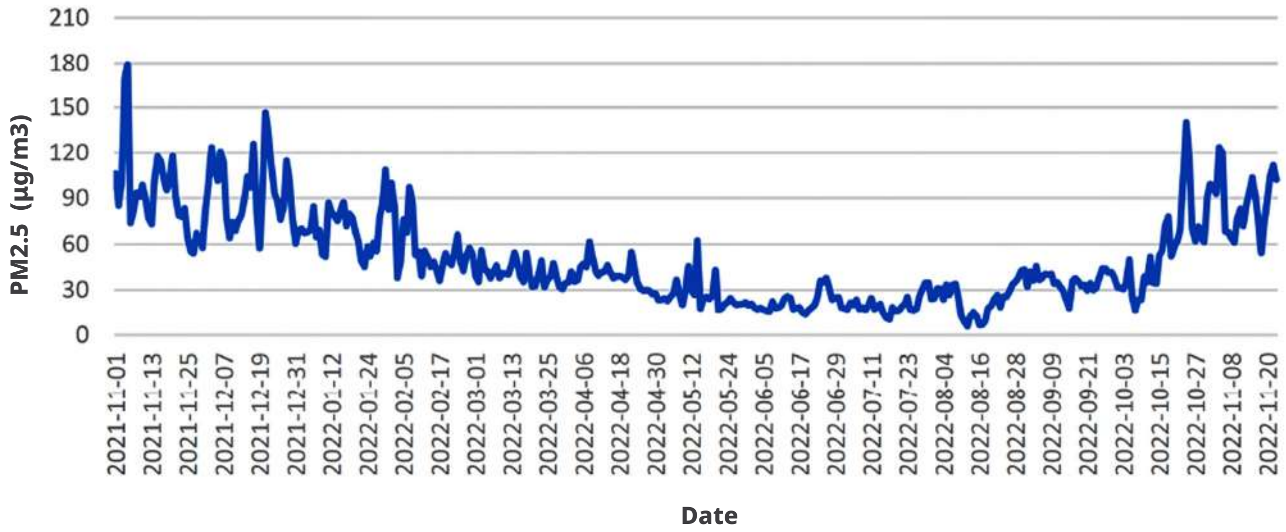
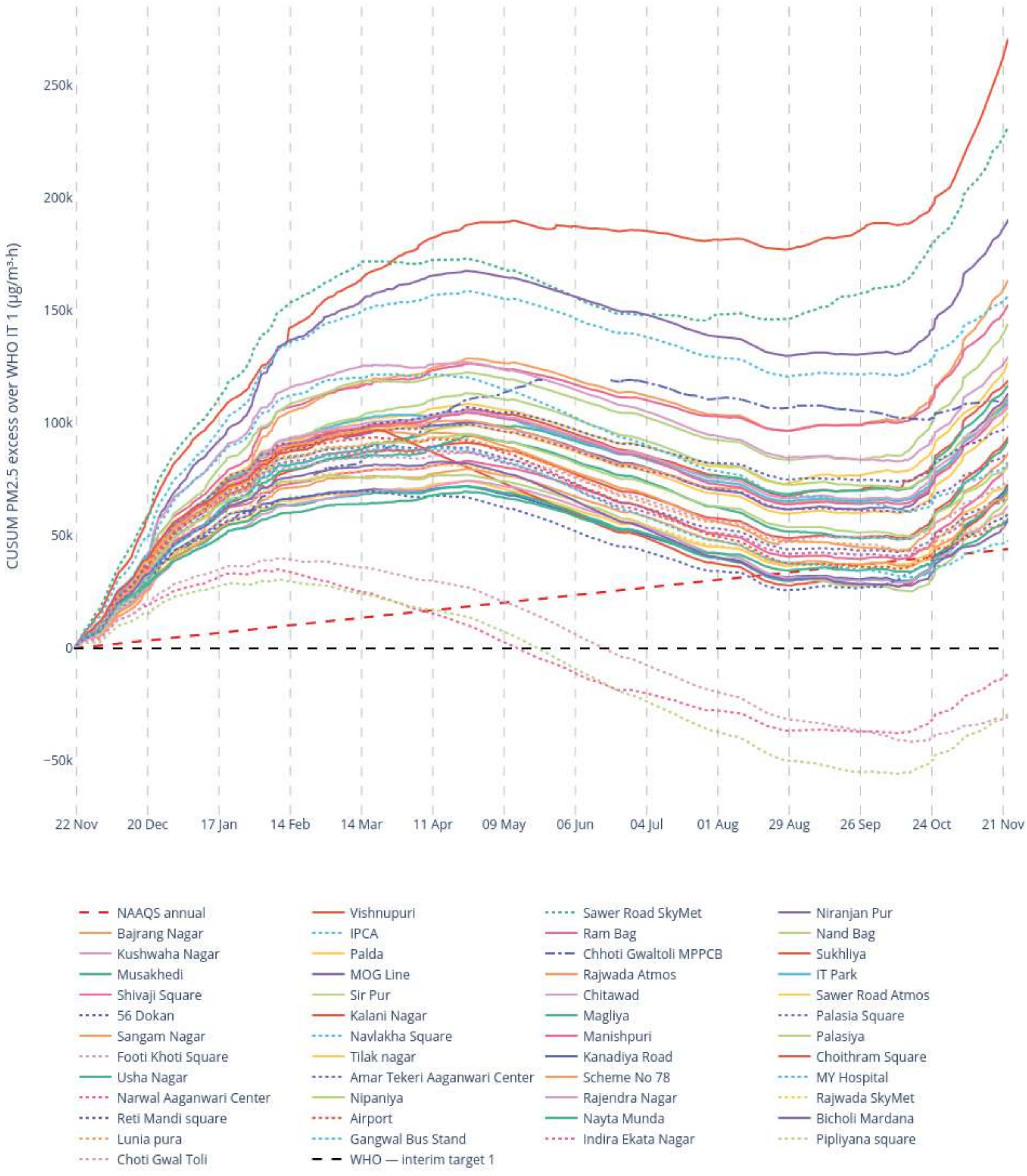


Figure 3.6: Variation of daily average $PM_{2.5}$ concentrations (Sensor)



Note:
In 2022, the spikes in $PM_{2.5}$ pollution were observed on Diwali (October 24) and Choti Diwali (November 4) in Indore city.

Figure 3.7: Annual CUSUM chart for the $PM_{2.5}$ monitors installed in Indore city from October 2021 to November 2022



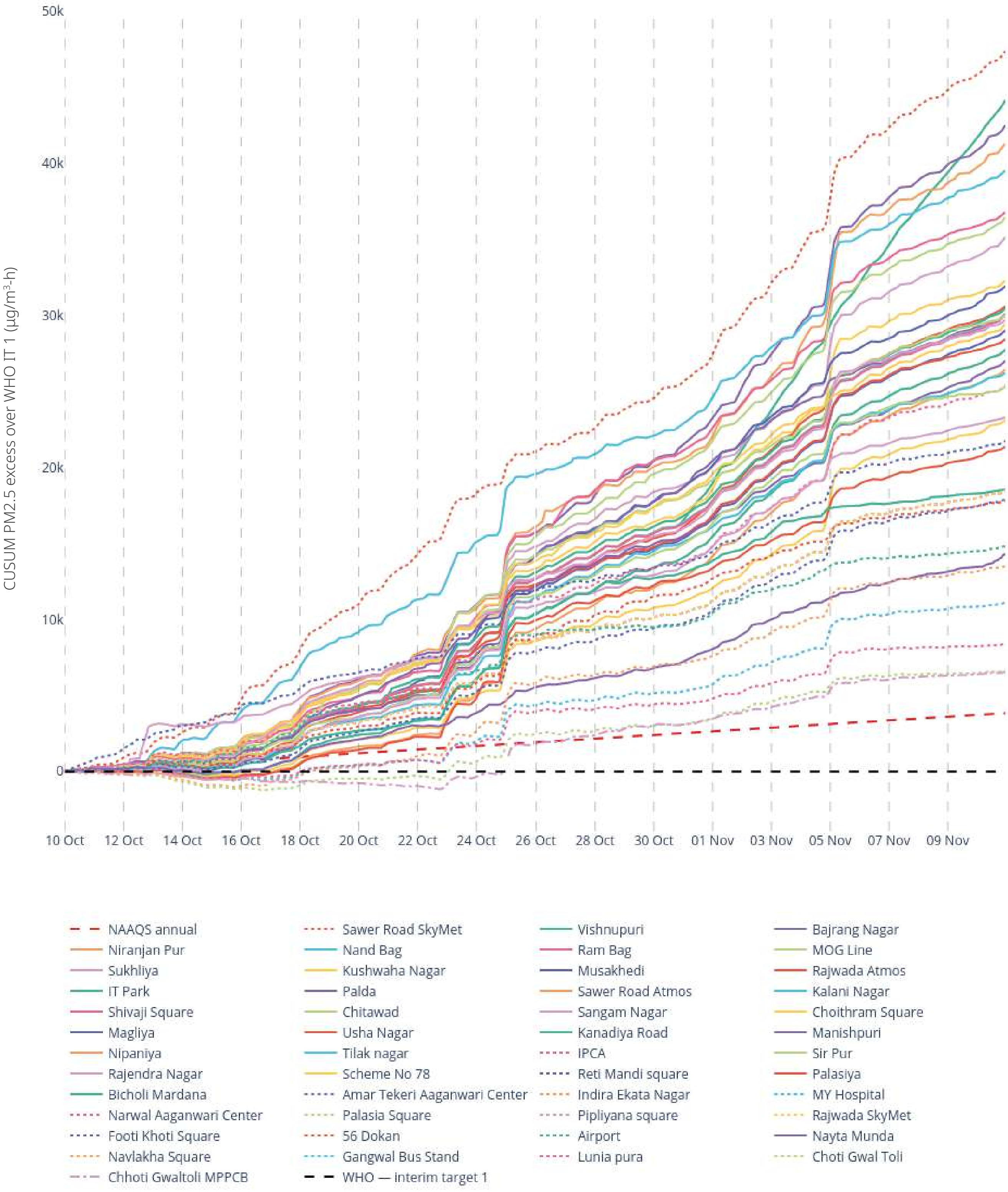
Source: CII CABL (2024) Analysis

The Figure 3.7 shows that most of the monitors in the city demonstrate similar concentrations, some areas show exceptional air quality, these are Indira Ekata Nagar, Pipliyana Sq., and Choti Gwal Toli.

[4] *In order to identify and investigate the changes in air pollution levels due to different interventions we prepare* ***cumulative sum (CUSUM) chart*** *following a technique which is helpful for identifying the effects of policy changes on air quality. Since the data from the sensors contains gaps due to various local factors, the missing values for the preparation of CUSUM charts were filled with average values across the city for the specific point in time.*

CUSUM chart for the period around the Diwali episode in 2022 (Figure 3.8) shows steep steps on Diwali in the evening of October 24, 2022 and Choti Diwali during the night on November 4 – November 5, 2022.

Figure 3.8: CUSUM charts for Diwali episode in Indore city (10.10.2022 to 10.11.2022)



Source: CII CABL (2024) Analysis

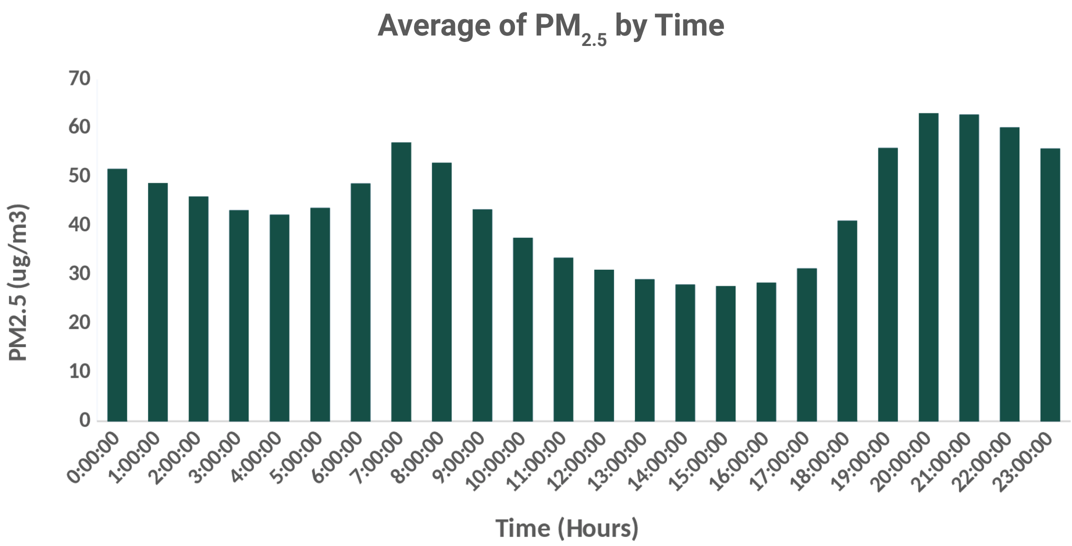
$PM_{2.5}$ Diurnal Pattern

Indore, being a tier-II city, experiences significant vehicular traffic during workdays, contributing to elevated $PM_{2.5}$ concentrations, a common urban air quality concern. Sensor data indicates that peak $PM_{2.5}$ levels occur during morning rush hour (6-9 AM) with an average concentration of 58 µg/m³. Similarly, evening commute (7-11 PM) witness elevated $PM_{2.5}$ levels, averaging 64 µg/m³. Conversely, the lowest $PM_{2.5}$ concentrations are observed between 2-4 PM, averaging 28 µg/m³ (Figure 3.9). These findings suggest a distinctive diurnal pattern in $PM_{2.5}$ driven by increased traffic emissions during peak commuting hours.

Number of Polluted Air Days

According to the Air Quality Index (AQI)[5]-$PM_{2.5}$ concentrations ranging from 0-30 µg/m³ are considered 'good', 31-60 µg/m³ as 'satisfactory', 61-90 µg/m³ as 'moderate', 91-120 µg/m³ as 'poor', 121-250 µg/m³ as 'very poor', and anything above 250 µg/m³ is classified as 'severe' (See Figure 3.10) [25]. Under 'satisfactory' conditions, sensitive individuals may experience minor breathing discomfort, while 'severe' AQI can cause respiratory impacts even in healthy individuals, and serious health issues in people with existing respiratory problems, according to NAAQS.

Figure 3.9: $PM_{2.5}$ Diurnal pattern at one-hour resolution based on the Sensor data



Source: CII CABL (2024) Analysis

Figure 3.10: National Air Quality Index defined by the Central Pollution Control Board (CPCB)

AQI Category	AQI	Concentration Range*							
		PM_{10}	$PM_{2.5}$	NO_2	O_3	CO	SO_2	NH_3	Pb
Good	0-50	0-50	0-30	0–40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory	51 - 100	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.5-1.0
Moderately Polluted	101-200	101-250	61-90	81-180	101-168	2.1-10	81-380	401-800	1.1-2.0
Poor	201-300	251-350	91-120	181-280	169-208	10-17	381-800	801-1200	2.1-3.0
Very Poor	301–400	351-430	121-250	281-400	209-748*	17-34	801-1600	1200-1800	3.1-3.5
Severe	401-500	430+	250+	400+	748+*	34+	1600+	1800+	3.5+

* CO in mg/m³ and other pollutants in µg/m³; 24-hourly average values for PM_{10}, $PM_{2.5}$, NO_2, SO_2, NH_3, and Pb, and 8-hourly values for CO and O_3.

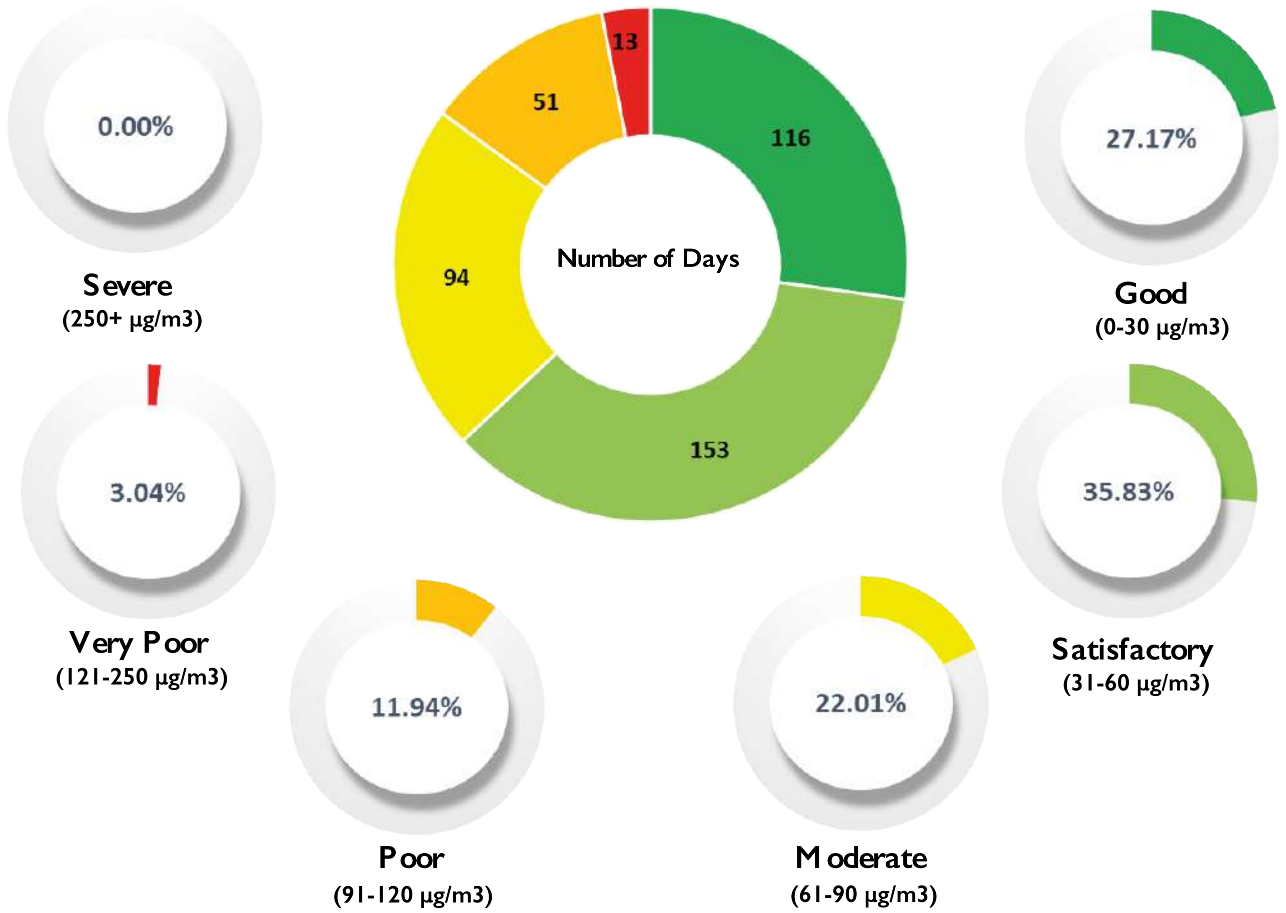
Source: CII CABL (2024) Analysis

[5] The air quality index (AQI) is a useful tool for understanding the levels of air pollution based on the concentration of eight pollutants in the ambient air and their potential impacts on human health. The AQI is determined by the sub-index of the pollutant with the worst concentration, which becomes the prominent pollutant.

Figure 3.11. Out of the 427 days, 153 days were classified as having 'satisfactory' air quality, while 94 days were classified as having 'moderate' air quality, 51 days were classified as having 'poor' air quality, and 13 days were classified as having 'very poor' air quality.

It is noteworthy that the highest spikes in $PM_{2.5}$ pollution levels were observed during the Diwali period, with clear evidence of firecracker burning being observed and the air quality slipping from moderate to poor category during that time.

Figure 3.11: Number of days with different $PM_{2.5}$ severity in Indore



Source: CII CABL (2024) Analysis

3.4.2.Air Quality Analysis based on Machine Learning Model Data

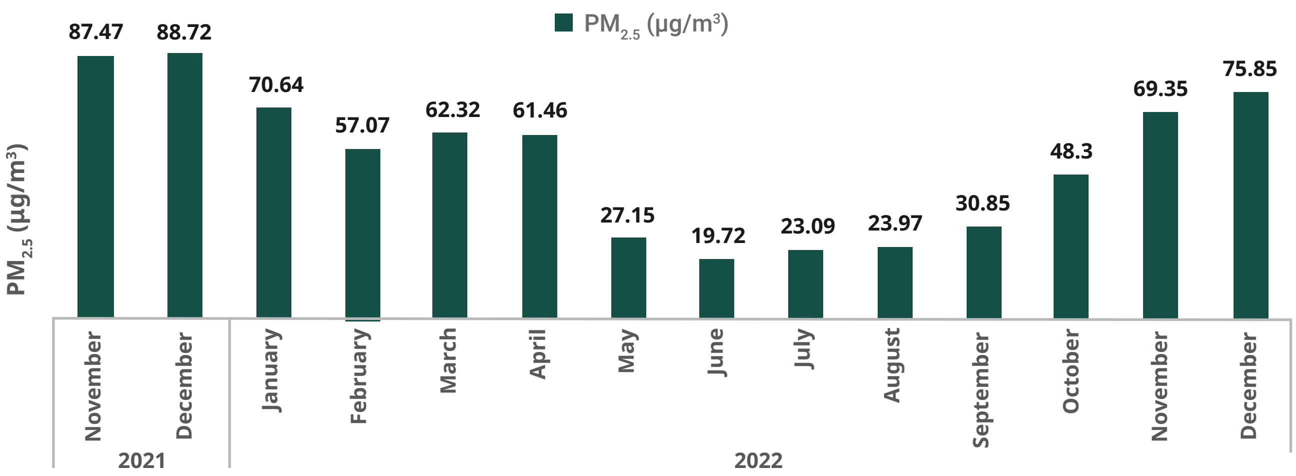
Monthly Variation

Observations (Figure 3.3) indicate that during March and April, there were reports of a notable increase in the incidents of open stubble burning in the agricultural area outside the city limits of Indore city. As a result, it is likely that transboundary sources of pollution contributed to the increased levels of $PM_{2.5}$ observed during this period. This is supported by data presented in Figure 3.15, which clearly shows the higher $PM_{2.5}$ concentrations during March (62.32 µg/m³) and April (61.46 µg/m³) months of the year.

Figure 3.12 also shows that between May to September, the monthly average concentration of $PM_{2.5}$ in Indore remained below the NAAQS limit of 40 µg/m³, likely because of high levels of precipitation during this period (Figure 3.13). During this period the range of $PM_{2.5}$ is between 19.72 µg/m³ to 30.85 µg/m³. The wet deposition of particulate matter and associated pollutants is a well-established mechanism for reducing PM concentrations in the atmosphere [26]. Therefore, the observed decrease in $PM_{2.5}$ levels during the rainy season was attributed to the effectiveness of this natural process in mitigating the impact of human activities on air quality in the region.

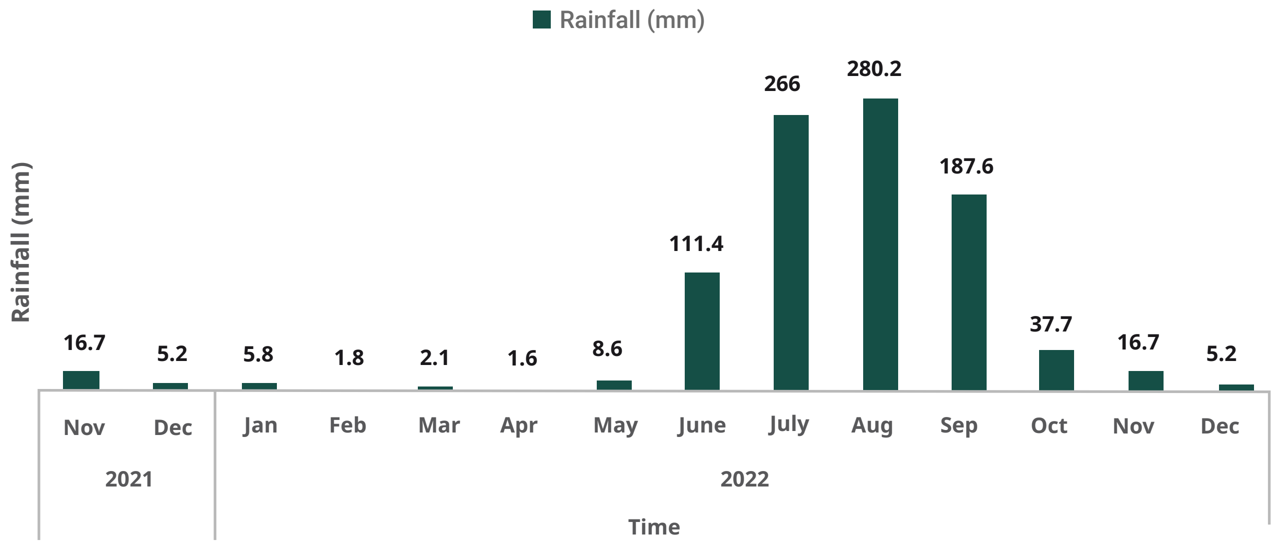
Note:
The chart with six slices represents air quality categories. The largest slice (35.8%) showing "satisfactory," followed by "moderate" (22.01%), "poor" (11.94%), and "very poor" (3.04%).

Figure 3.12: Monthly Average $PM_{2.5}$ Concentration



Source: CII CABL (2024) Analysis

Figure 3.13: Monthly average Rainfall of Indore city (Jan 2022 to Dec 2022)

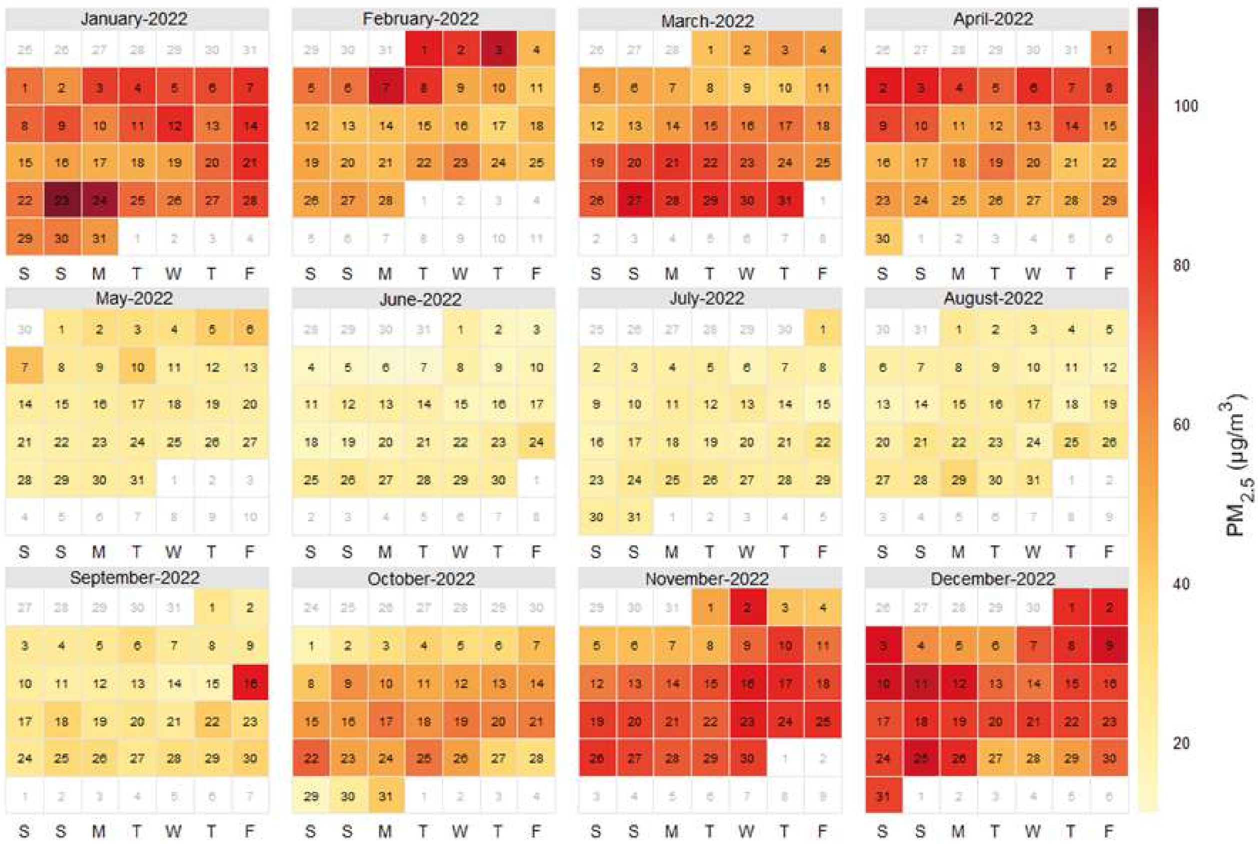


Source: India-WRIS || IMD Data [27]

Calender Plot:

The calendar plot, for the model derived $PM_{2.5}$ data in 2022, provides valuable insights into the temporal trends and variations of air pollution levels within the Indore city (Figure 3.14). The plot demonstrates the potential utility of modelling techniques in accurately characterizing the spatiotemporal distribution of $PM_{2.5}$, which can help inform effective policy and mitigation strategies. Furthermore, the calendar plot also reveals that there are some noticeable seasonal trends in $PM_{2.5}$ levels.

Figure 3.14: Monthly glance - Calendar Plot - $PM_{2.5}$ concentration based on machine learning data



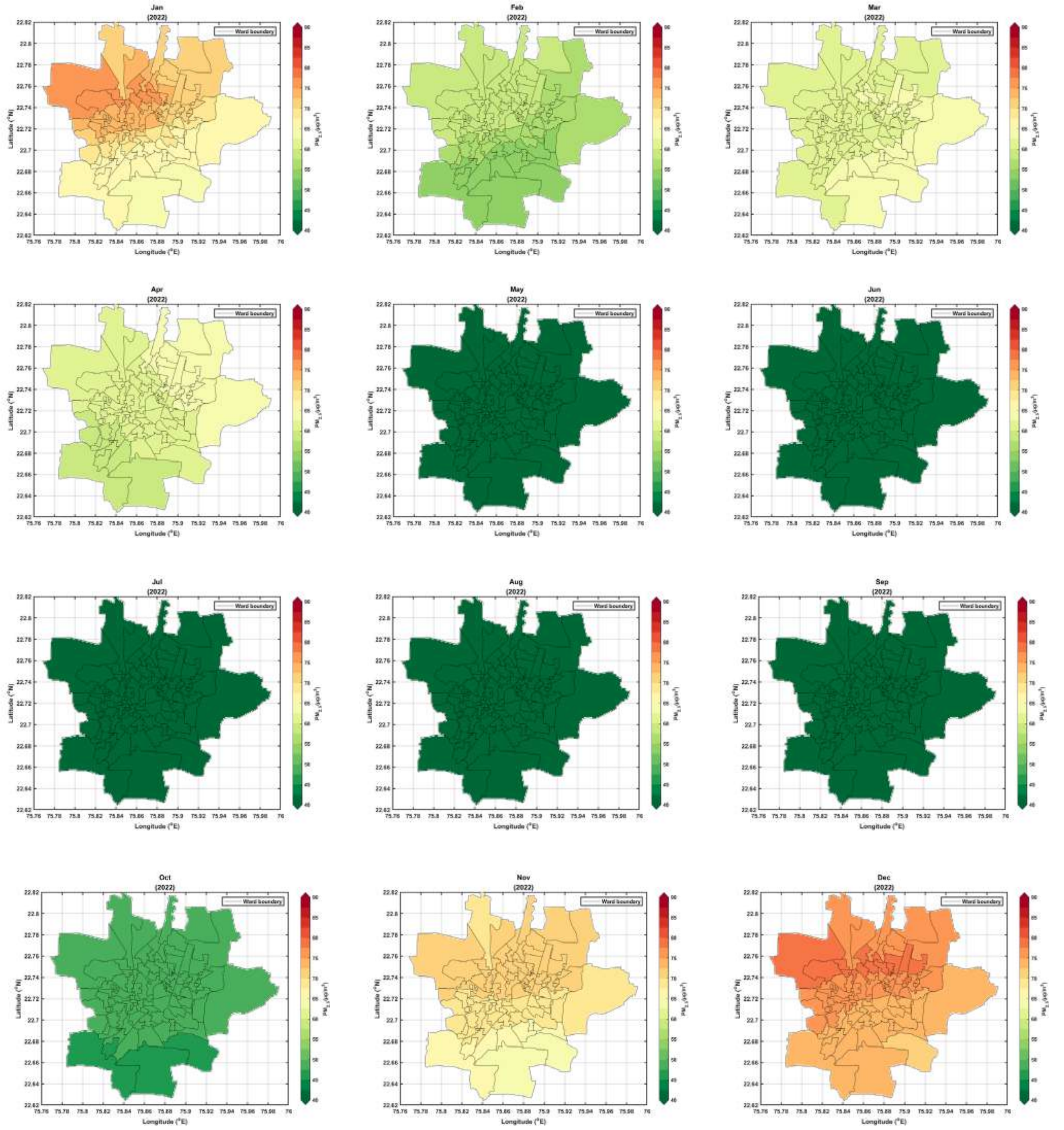
Source: CII CABL (2024) Analysis

Spatial distribution of Zone/Ward Level Monthly AQ trends in Indore:

Spatial analysis revealed significant variability in $PM_{2.5}$ concentrations across the city, clearly showing both high and low pollution zones. Figure 3.15 illustrates this spatial distribution with monthly variations within each of the 85 wards. In 2022, during January, February, and December, higher $PM_{2.5}$ concentrations were observed in northern wards. This pattern may be attributed to factors such as relatively stagnant air, burning of polluting fuels for thermal comfort (Figure 3.3), and wind direction predominantly towards north (32% winds comes from the north side) (Figure 3.2).

Note:
The calendar visualization reveals the daily variation of $PM_{2.5}$ concentrations in Indore city throughout the year. Lighter colours indicate better air quality, while darker colours represent poorer air quality. The data suggests two distinct periods: January to April and October to December experience higher $PM_{2.5}$ concentrations, likely due to various factors like seasonal changes, agricultural practices, and increased anthropogenic emissions. Conversely, May to September exhibit significantly lower $PM_{2.5}$ concentrations, potentially influenced by monsoon rains and reduced outdoor activities.

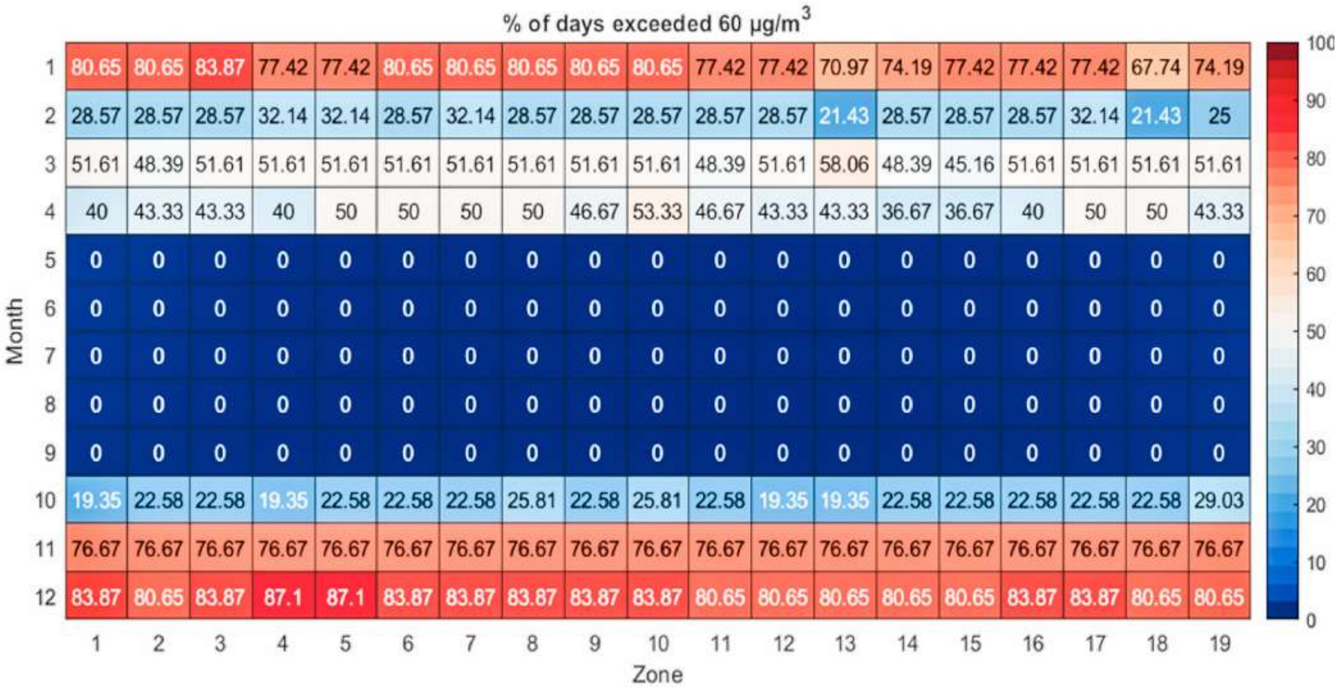
Figure 3.15: Monthly $PM_{2.5}$ Spatial distribution in zone and ward level using machine learning data



Source: CII CABL (2024) Analysis

Figure 3.16 shows zone-wise percentage of days exceeding NAAQS standard which is 60 µg/m³ for each month. Figure suggests that there is no exceedance in the month of monsoon when meteorology is favourable, but entire month exceeds the limits except few of the days in the peak pollution months like November to January.

Figure 3.16: Machine learning-driven zonal percentage (%) of days exceeding NAAQS Limits (60 µg/m³)

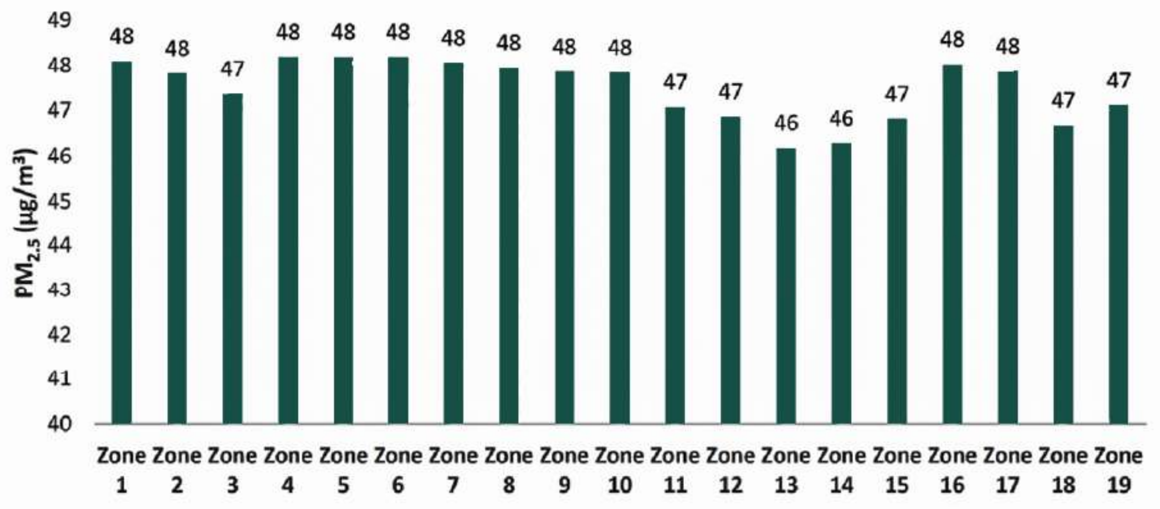


Source: CII CABL (2024) Analysis

The findings of the study indicate that annual average $PM_{2.5}$ levels in all 19 zones exceed the permissible limits (40 µg/m³) set by the NAAQS. City zone 4 had the highest annual average level of $PM_{2.5}$ pollution with a maximum value of 48.17 µg/m³ (Figure 3.17).

On the other hand, zone 13 had the lowest annual average level of $PM_{2.5}$ pollution with a minimum value of 46.15 µg/m³. The difference in PM concentration level between 19 zones were found to be minimal because the PM pollution is fairly distributed across the city.

Figure 3.17: Machine learning-based prediction data of Annual average $PM_{2.5}$ levels of zone in Indore city (Nov 2021 to Dec 2022)



Source: CII CABL (2024) Analysis

Note:
The annual average $PM_{2.5}$ level in all 19 zones of Indore City exceeded the NAAQS limit of 40 µg/m³ during November 2021 - December 2022

3.5. CITIZEN ENGAGEMENT

Citizen engagement was an important part of the project, facilitated by collaborative participation between citizens, local leaders, government officials, and the project team. Residents in specific areas, due to their daily experiences, possess unique knowledge about local air pollution sources. Through this partnership, they provided valuable insights and assisted the project team in various ways. Additionally, participatory approaches proved useful for improving awareness of air pollution and its associated health implications. This engagement also empowered the community to enhance their capability to gain and use scientific tools to address local air pollution issues.

3.5.1.Citizen Survey

A total of 2,777 individuals between the ages of 18 and 77 participated in this survey. Among them, 1,933 were male (69.61%) and 844 were female (30.39%). Of the respondents, 58% came from residential areas and 37% came from commercial areas.

Mode of Transportation

In this study, respondents were queried regarding their preferred modes of commuting within the urban confines of Indore daily. The results reveal a predominant reliance on 2-wheelers or biking as the primary mode of commuting, with approximately 54% of respondents indicating its preference.

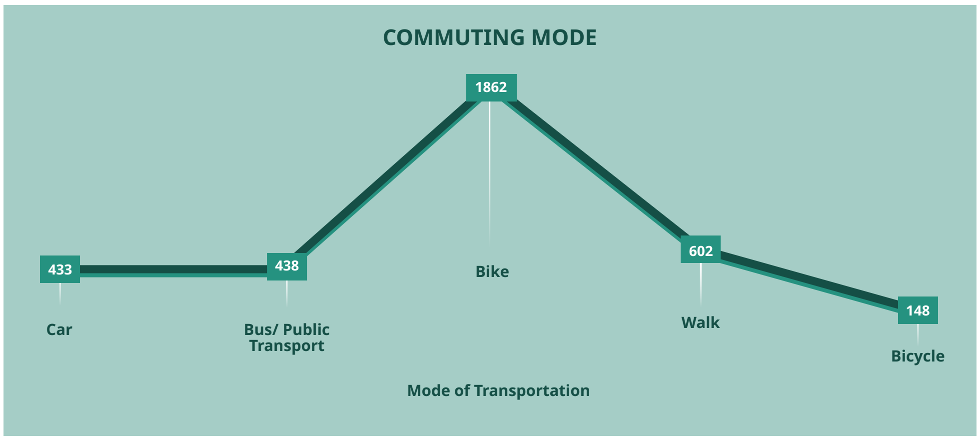
Type of fuel used for cooking

The majority of participants in the Indore area prefer to use clean fuel for cooking purposes, with LPG being the most popular choice (74%), followed by induction cooktops (11%) and electric heaters (5%).

Perceived Causes of Air Pollution

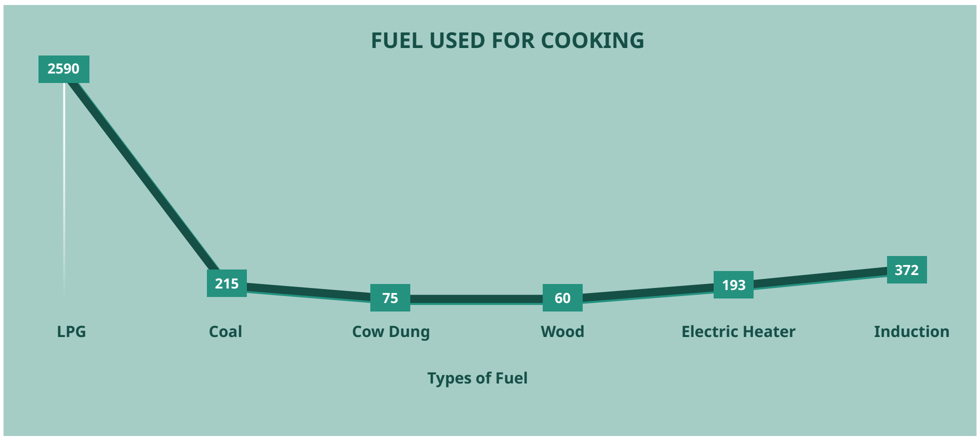
Responding citizens were asked to indicate what they thought were the main causes of air pollution in their local area. The results indicated that motor vehicle & traffic (30%) and construction activities (22%) are considered the most significant local sources of air pollution.

Figure 3.18: Mode of Transportation in Daily Life



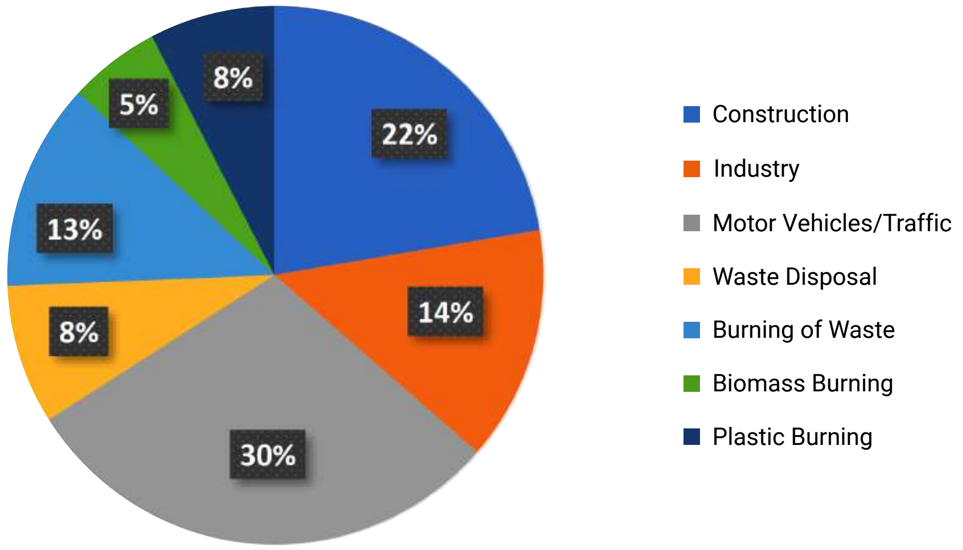
Source: CII CABL Indore Survey

Figure 3.19: Types of Fuel used for Cooking by the Study Population



Source: CII CABL Indore Survey

Figure 3.20: Perceived Causes of Air Pollution in Indore

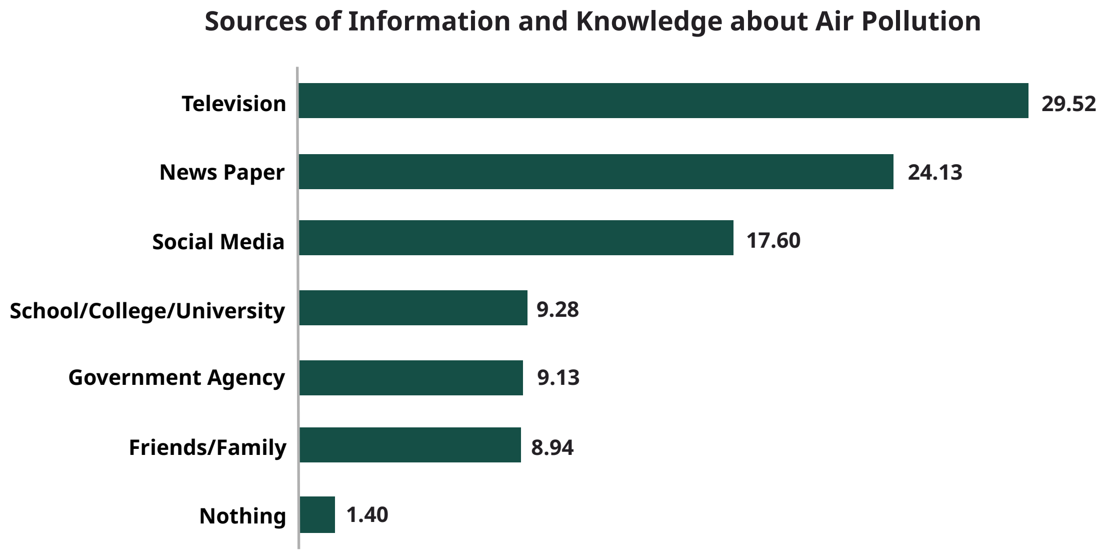


Source: CII CABL Indore Survey

Information and Knowledge about Air Quality

Related to information and knowledge about air quality and air pollution, the questionnaire asked participants to self-assess their level of information about air quality. A large proportion of the study participants in Indore city believed air pollution is a serious issue at present. 54.38%, 39.07%, and 6.55% considered it a very important, important, and quite important issue, respectively. 93.1% of respondents strongly agreed that air pollution seriously affected their health, whereas 6.99% disagreed. Regarding sources for receiving information on air pollution- television (29.52%), newspapers (24.13%), and social media (17.60%) were important information channels for educating the local community about air pollution and its health impacts (Figure 3.21). These findings suggest that traditional media and emerging platforms play a significant role in shaping public understanding of environmental issues.

Figure 3.21: Sources of Information/Knowledge on Air Pollution



Source: CII CABL Indore Survey

3.5.2.Impact Study

19 zonal meetings and 11 community awareness campaigns were conducted with the participation of zonal officers, counsellors, ASHA workers, and local communities, with a specific focus on women. These awareness programs aimed to empower citizens to combat air pollution. Following these community awareness campaigns, an impact study was conducted in August 2023 through a survey. The survey in 85 wards targeted individuals who had previously attended the community meetings. This ensured data collection from participants directly engaged in the program.

Figure 3.22: Community Awareness Programmes Conducted by CABL Indore

THE IMPACT STUDY REVEALED A DIVERSE RANGE OF POSITIVE BEHAVIOURAL CHANGES

8%
increase in adopting sustainable transportation practices like carpooling and public transport, leading to reduced emissions and a lower environmental footprint.

3%
incorporated active modes of transportation (walking, cycling, e-vehicles), promoting cleaner air, improved health, and reduced dependence on personal vehicles.

3%
upgraded to BS6 vehicles, adhering to stricter emission standards and contributing to cleaner air.

5%
transitioned from traditional chulas to cleaner-burning LPG gas, reducing indoor air pollution and associated health risks.

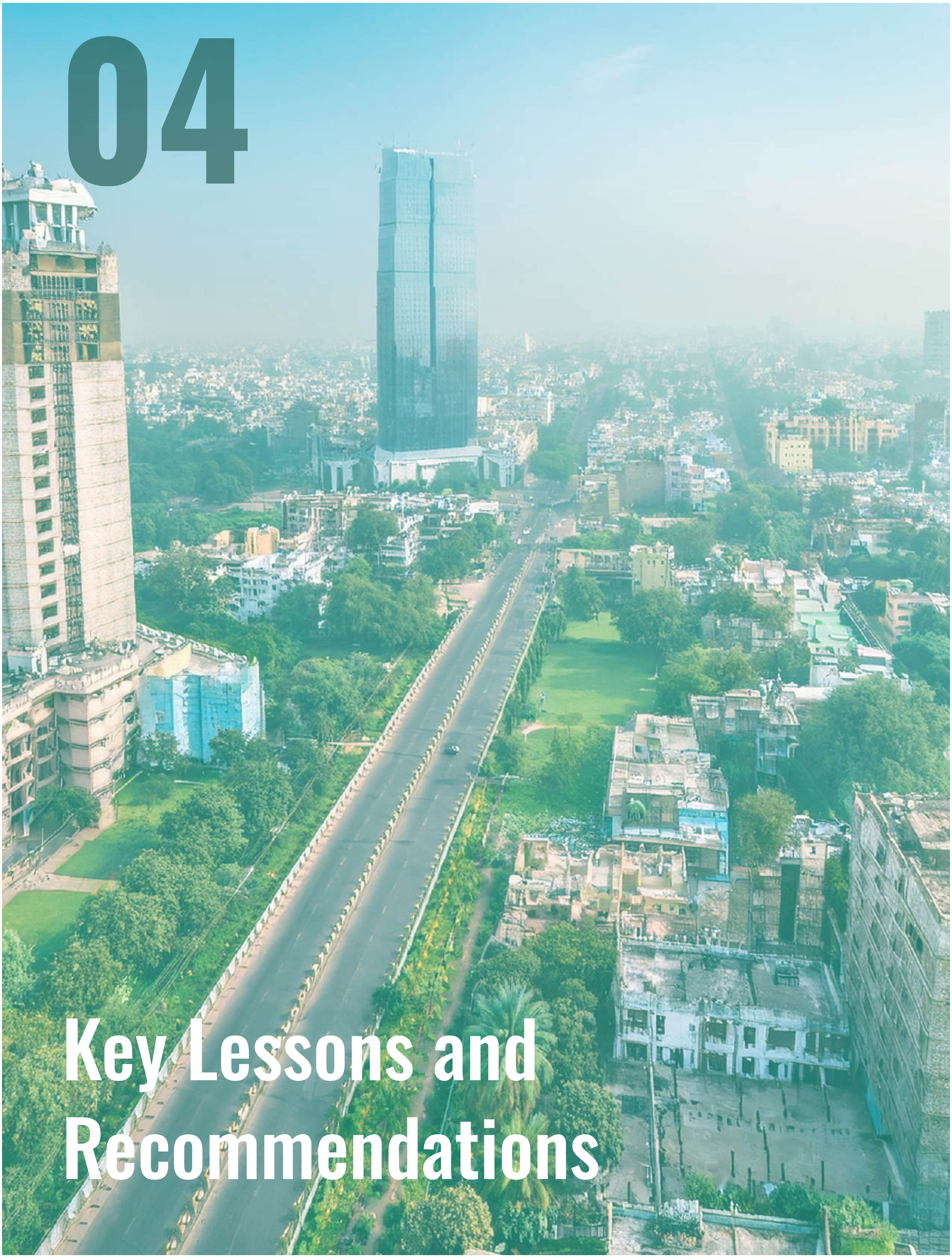
6.7%
improve in implementing proper waste segregation, minimizing land fill burden and potential air pollution from waste decomposition.

24%
of participants actively planted trees, contributing to improved local air quality.

3%
replaced plastic bags with cloth alternatives, mitigating plastic pollution and its contribution to air pollution through waste burning.

1%
positively adopted practices like water sprinkling for dust control, green netting in construction zones, and electric machinery, reducing dust and emissions associated with traditional construction methods.

1%
increase in the adoption of sustainable construction practices, such as water sprinkling for dust control, green netting in construction zones, and electric machinery, resulted in a reduction in dust and emissions associated with traditional construction methods.



04

Key Lessons and Recommendations

4.1. NATIONAL LEVEL ACTION

NO_x Limits and Targets for NCAP Cities

Rapid urbanization often leads to increased vehicular activities, resulting in higher emissions of traffic emission including PM, NO_2, HCs, CO etc. NO_x is a good proxy for overall contribution of traffic emissions [28, 29, 30] while NO_2 being the major component- it is a good approximation of overall NO_x emissions. By the year 2023, Indore's NO_2 levels increased significantly- by 200% since 2017 and figure 1.2 (See Section 1) indicates this concerning trend of outdoor air quality in Indore. This observation corroborates with the data on registered vehicles in Indore [31] indicating a sevenfold increase in vehicle registrations within the Indore district over the same time period. A strong positive correlation observed between NO_2 levels and vehicle registrations signifies a clear link between traffic and deteriorating outdoor air quality. In response to this, establishing city-level limits and targets for NO_x, with nitrogen dioxide (NO_2) as a primary indicator, becomes essential for effective air quality management. So, it is recommended that NO_x is prioritised for clean air action within the NCAP at both state and national levels targets[6] as following-

1. Considering 40 micrograms per cubic meter on annual average limit- baseline year and reduction target can be designed by the competent national authority (MoEFCC) for all NCAP cities. Additionally, state-level targets can be designed by respective State Pollution Control Boards under the NCAP or the Air Act 1981.

2. Considered 80 micrograms per cubic meter as the daily average limit for NO_x- clean/safe streets can be designated as part of the overarching policy directive and mechanism.

Multi-Level Emission Inventories

Emission inventory is a key which is crucial for action planning at the city level and serves as a necessary input for air quality model to spatially resolve air pollution. Currently, limited guidance for emission inventories exists as part of the CPCB (2011) Guidelines[7] for Source Apportionment Studies in Indian Cities. It is worth noting that only 34%[8] have completed source apportionment studies to identify sources of air pollution and their share [3] which means that emission inventories are not available for roughly two-third of the NCAP cities. Even for one-third NCAP cities where emission inventories exist, they are hardly updated on regular basis despite their direct utility in source level action and planning e.g. micro action plans focused on different sources and their implementation.

It is suggested that a dedicated set of SOPs or guidelines are designed for city–level emission inventories with a mechanism to periodically update them, as emission patterns and activity levels can drastically change over time in context of urban India. Also, air pollution transcends judicial boundaries, so emission inventories need to be parallelly co-developed at district and state level to account for sources of air pollution at different levels. These recommendations are summarised below-

1. Design dedicated set of guidelines or SOP for air pollution emission Inventories at different levels. This may include - standardized methodologies for mapping of sources e.g. type of activity (brick kiln, coal thermal power station etc.), locations with GIS coordinates and loading factors in kilogramme per day or kilogramme per day.
   a. City level inventories to be developed by urban local bodies with support from SPCBs
   b. District level emission inventories to be developed by concerned DM or collectors with support from SPCBs
   c. State levels inventories to be developed by SPCBs
2. Above overarching framework to also explicitly state-
   a. Mechanism by which inventories need to be updated regularly and periodic interval at which regular updates are undertaken
   b. Additional guidelines for facilitating data sharing between authorities and partnering agencies supporting clean air research and implementation. A centralised portal can ensure easy access and provides a single point of access to emission Inventories data

Networks of Sensors & AI-based Modelling for Decision Support

Air quality sensors provide reasonably accurate results for the purposes of air quality management at the local level. A correlation of 85% is observed for $PM_{2.5}$ sensors in Indore[9] which exceeds the global benchmarks (70%) (Refer Figure 3.1, Section 3 for summary of these results). The sensor technologies coupled with advanced machine learning or AI-based models are especially helpful for creating high-resolution heat maps of air pollution concentrations across local areas or city wards (as demonstrated in Indore under this

[6] along with existing targets for Particulate Matter (PM) especially the coarse PM or PM10
[7] 'Conceptual guidelines and common methodology for air quality monitoring, emission inventory & source apportionment studies for Indian cities'
[8] 44 out of 131 NCAP cities

project) which is otherwise not feasible and practical with expensive, high precision and regulatory-grade stations. The primary information, that is the hyperlocal or decentralised air quality data, is useful for- (1) implementing real-time air quality management interventions in hotspot areas (by the city administration) (2) planning long-term sustainable land use or urban planning focussed interventions to improve air quality e.g. clean air or special mobility zones (3) Measuring impact of any interventions on ground to improve city air quality especially those under the National Clean Air Programme (NCAP) and the Graded Response Action Plan (GRAP).

Air quality sensors have the potential to become a powerful tool for above practical purposes, despite their known limitation in the regulatory applications due to high- precision requirements. Sensor-based monitors are currently imported into the country from elsewhere and are primarily assembled in the country by almost all device manufacturers. This limits the ability to customise and exploit the hardware fully and for better integration of software as per local needs. The market is currently proliferated with sensors of different makes and lack of standardisation across AQ sensors-based devices further pose a major challenge for their deployment on the field. Following actions can be proposed to improve practical application of air quality sensors for air quality management-

1. It is recommended that **domestic manufacturing capabilities for key air pollutants like particulate matter ($PM_{2.5}$ and PM_{10}) and gases (SO_2, NO_X etc.)** are encouraged. Under the Modified Scheme for Setting up of Sensors Fab [32], fiscal support of 50% of the capital expenditure for setting up sensor fab facilities among others. Given the social or environmental nature of the sector and high investment needs to set up a manufacturing facility, it is suggested that Semi-Conductor Laboratory (SCL) under the Ministry of Electronic and Information Technology and industries partnerships is leveraged to develop these capabilities and commercialising successful prototypes. Also, in the long-term, the India Semi-conductor Mission (ISM) may consider setting up a dedicated Centre of Excellence[10][33] specific to environmental sensors and monitoring devices to promote and facilitate indigenous Intellectual Property (IP) generation and cutting-edge research & development in this area.

2. **Standard Operating Procedures(SOPs) for sensor manufacturers** to lab test and validate the sensor-based devices will be helpful. Proposed SOP, by a competent authority such as NPL or NEERI, can consider guidelines suited to Indian climate forcalibration of AQ sensors at manufacturer's end, that is-

    a. Prescribe method to calibrate sensor-based devices at manufacturer's end

    b. Provide satisfactory or acceptable ranges for important parameters. These decisive parameters include air flow rate, scatting angle, and laser wavelength for the particulate matter sensors based on the optical particle counting method

3. Bureau of Indian Standards (BIS) may look at national **standard and guidelines for performance evaluation and local deployment of AQ sensors** taking into consideration India-specific conditions such as- high humidity conditions prevalent around Monsoon and high regional background air pollution. Standard may provide relevant parameter and practical guidelines on field evaluation of AQ sensors including but not limited to-

    a. Testing and validating accuracy of sensor-based monitor with respect to reference grade or certified monitor- either a BAM device or a CAAQMS station

    b. Testing and validating accuracy of sensor-based monitors by analysing statistical relationship between collocated devices

    c. Guidelines to test and calibrate monitors, at the time ofl ocal deployment and periodically at fixed intervals (say, every year), if significant bias exists as understood from steps 3.a and 3.b

    d. Guidelines and best practices to site sensor-based monitors for hyperlocal AQ monitoring

As summarised in Table 2.1 (See Section 2), we utilised parameters including- bias, mean, MAPE, corelation, intra-model variability between collocated monitors and data recovery to evaluate the performance of AQ sensors as adopted from two sets of international standards[11]. Set of good practices as followed for local deployment in Indore are summarised in Box 4.1 here. Deployment needs careful considerations. monitoring the device health, quality control for sensor data and troubleshooting sensor- based devices is manpower intensive[1].

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[9] *as collocated at regulatory-grade or CAAQM station in Indore city before deployment*
[10] *As part of ISM's mandate noted in MEITY (2022)*
[11] *AQ-SPEC (2017) [11] and US-EPA (2021) [12]*

BOX 4.1 GOOD PRACTICES FOR LOCAL DEPLOYMENT OF AQ SENSORS BASED ON INDORE LEARNINGS

- Plan local deployment in different land use types as much as possible (e.g. commercial, residential- low income, residential middle-high income, industrial, mixed land use, green buffers etc.) to be able to generate dataset representative of entire city or study area.

- Make sure that the reference monitor i.e. BAM or CAAQMS being utilised for collocation study are properly calibrated and is not sited in close proximity to a source of air pollution such as- traffic junction, diesel generator, parking lot, drop off/pick up point etc.

- Data gaps due to power and signal outages can be mitigated to a large extent by deploying onboard battery as well as memory while choosing a reliable network service provider with good signal strength in the local area.

- Thefts and malfunctioning in electronic parts due to weather exposure and degradation can be minimised by deploying a proper enclosure to secure the device and protect it from water during rainy season. Such enclosure should be provided by device manufacturer and need to be implemented at field so that device is properly secured from weather and possible tempering attempts, while making sure that the air flow rate is not impacted.

- Drift in sensor's readings/data due to restricted air flow or high background dust as prevalent in Indian cities and degradation of electronics (beyond 3 years of standard device life) is major concern for data quality monitoring using AQ sensors. Sensors' data need to be carefully monitored well for such possible drifts as part of the quality control procedures and would need corrective action on field for cleaning and resetting devices or else replacing them.

- Field team need to check and validate spikes or surges in local-level air quality at the field. Sensors may behave erratic, with rapidly fluctuating readings, when they are placed in close proximity to a stationary or mobile source or objects/equipment that can alter humidity or temperature. Citation of sensors therefore needs careful considerations to avoid places such as- parking lots, smoking zones, vents/exhaust, drop off points etc. while ensuring that unrestricted flow of ambient air exists from three sides.

A complementary machine learning based modelling technique was used in tandem with deployment of sensors in Indore. This approach has potential to cost-effectively determine air quality in the local areas in any of the NCAP cities at even higher spatial resolution while taking inputs from multiple sources including sensors' network as well as satellites, regulatory grade stations in the airshed and weather datasets. The model developed in Indore using a machine-learning technique (Random Forrest model) showed 85% accuracy with reference to the actual $PM_{2.5}$ readings. Machine learning or AI based techniques are fast evolving and it has the potential for highly contextualised city specific AQ models which are able predict regional or local AQ patterns and provide real time source apportionment information.

4.2. SEASONAL ACTION PLAN FOR TRANSBOUNDARY SOURCES

Our study indicates a distinct seasonal trend characterised by higher $PM_{2.5}$ concentrations in pre-monsoon period (March & April) and during winter months (October to February). While the higher $PM_{2.5}$ concentration in winter months is predominantly due to the temperature inversion, the higher concentration in the pre- monsoon period (See Figure 3.12) is related to the wheat straw burning across the agriculture-dominated region surrounding Indore city which are driven to city center majorly from the Western and Northern region.

The region is situated in Malwa plateau where most of agriculture land is uneven. As most of the agricultural land is irrigated through canals, it is divided by ridges into smaller fields for canal water distribution. After wheat harvest, majority of the standing wheat straw is removed through reaper and utilised as cattle feed basis the livestock availability. However, ridges in the field restrict the mechanized harvesting operation leaving behind 3"-5" of standing stubble. Farmers face challenges managing this standing straw and resort to burning as a convenient straw management option. Analysis of satellite data from 2019 to 2022 reveals significant fire counts in the post-harvest period. As detailed in section 3, a positive correlation at 80% is observed between open fire counts in rural areas in Indore and nearby districts (predominantly Dewas and Ujjain) and $PM_{2.5}$ mass concentrations in Indore city during the burning season (March-April) (Refer Figure 3.3). Similar positive correlations were found in the neighboring cities of Dewas (79%) and Ujjain (73%) situated in the North and North-East of Indore regions respectively. These findings highlight a strong interlinkage between open farm burning incidents and higher air pollution levels in Indore City in the months of March and April.

Following course of actions is recommended to mitigate agricultural burnings-

1. Given the bulky nature of biomass and logistical challenge involved in transporting straw, the most cost-effective method of sustainable straw management is direct reuse in the field. Given limitation with in-field composting[12] and mulching, soil incorporation of the wheat straw and standing stubble before sowing of soybean remains the only practical option for farmers in the region. Although few farmers have tried this method driven by their personal motivation and on an ad-hoc basis by using the existing tools, results of these trials vary. While such techniques have improved soil quality for a few farmers, others have faced issues in sowing the subsequent crop that is soyabean. These mixed results have limited the scale of this solution. In this regard, it is recommended that -

    a. Customization of farm implements for wheat-soybean cropping system is needed urgently. We recommend ICAR institutes and machine manufacturers to take the lead and design these solutions which are best fit for the wheat soybean cropping system and agroclimatic conditions prevalent in the region.

    b. As a second step dedicated field trials for in-situ management are suggested with farmers in the region documenting key impacts, benefits and risks associated with soil incorporation.

2. Utilisation of biomass outside agricultural fields is imperative for addressing this source of air pollution entirely. Few actionable solutions for this include- bio- CNG, co-firing biomass in boilers and silage or feed for dairy animals. While the major concern is the collection of wheat straw, building the biomass value chains and establishing end use markets is imperative and will play a key role in scaling these applications. Second generation energy conversion technologies work better with wheat straw due to its relatively higher calorific value and these processes are more matured in the market compared to those for rice straw. Besides developing decentralized infrastructure for biomass management in affected rural areas, this agriculture residue can also be co-digested along with MSW in Bio-CNG plants existing in Indore. Agricultural biomass has a high carbon content which can balance the nitrogen-rich MSW and increase productivity of exiting bio-CNG plants, but

[12] *The CII CABL Team tested bio-decomposer, sourced from IARI, on select half to one acre plots in rural areas surrounding Indore. These efforts were not successful due to low moisture levels (because of high surface temperatures in region in this period) in the fields which limited microbial growth. Also, mulching wheat straw is not feasible for the wheat-soybean cropping system predominant in this region basic understanding on the field.*

plants may require additional storage space to accommodate biomass feedstock.

4.3. STRENGTHENING ON-ROAD VEHICULAR EMISSION CONTROL

As per our observations on the field and stakeholder inputs, Indore faces a key infrastructure gap related to insufficient number of Pollution Under Control (PUC) testing centres and lack of online or real-time PUC data. As a result, significant number of commercial vehicles and two-wheelers on the road are non-compliant. There are also inherent challenges with the PUC regime as centres often operate without proper protocols or standardized software. There is a general lack of guidelines for periodic calibration of equipment and many centres remain shut due to frequent breakdowns of equipment and lack of capacity.

To effectively manage transportation emissions, it is crucial to measure and manage real-world vehicle exhaust emissions accurately. Current on-road vehicle emission testing method i.e. PUC may not reflect the actual driving conditions and on-road emissions accurately. Additionally, these methods often overlook key pollutants of concern here, namely- NO_x (Nitrogen Oxides) and PM (Particulate Matter) emissions. To bridge this gap and enhance air quality both in Indore, implementation of Real-World Emission Monitoring (RWEM) [34] is proposed in Indore on a pilot basis. Real-world data offers a more precise understanding of vehicle emissions compared to the static conditions of PUC tests, allows for targeted enforcement on the most polluting vehicles, and ultimately reducing the overall vehicle emissions and leading to cleaner air. It emphasizes dynamometer test-based measurement systems, on-board emission measurement systems, data and sample collection, processing, and analyses in real time. Additionally, RWEM systems are designed to calibrate automatically and ensuring consistent over time without needing any human intervention.

Following sets of actions are recommended at the state and city levels in order to control the on road vehicular emissions more effectively.

State specific actionable steps-

1. There is need of PUC infrastructure that is robust and able to meet the expected demand. To improve the testing accuracy, calibration of PUC equipment needs to be performed at regular periodicity by authorised third parties in line with the MoRTH advisory. Finally, to improve PUC enforcement, integrating the State and Indore's PUC database to Vahaan PUCC Portal and dashboard [35] by taking the PUC data online[13] will be crucial for control of on-road vehicular emissions. Suggested integration will enable real time monitoring, enforcement and public engagement for better compliance.

2. As per the MoRTH's advisory in 2021, the M.P. State Transport Department may mandate a pre-payment of PUC fee. This will ensure that financial burden of pollution control is placed on the polluters themselves and may help improving the business viability of PUC centres.

City specific actionable steps-

3. Indore can leverage active citizens for cleaner air and improve vehicle emission compliance. It is suggested that the local government and Indore RTO collectively leverage the Indore311 app [36] (given its huge success in engaging citizens for waste management in Indore) for the citizen reporting on visibly polluting vehicles in Indore.

4. Design public awareness campaigns for Indore citizens to emphasize the importance of regular vehicle maintenance and emission testing to reduce air pollution.

5. Despite the availability of CNG, illegal diesel usage persists in Indore, emitting significantly higher levels of particulate matter (PM) compared to CNG. It is recommended to establish a clear and achievable timeline for phasing out existing diesel Auto- rickshaw vehicles in Indore. Implementing heavy fines for vehicles fraudulently displaying the CNG logo but found using diesel. Regular inspections by traffic police and the Regional Transport Office (RTO) are essential to enforce this rule effectively.

6. Diesel-fuelled buses in many schools remain a significant concern in Indore. To protect children's health and the environment, school bus fleets in the city needs to prioritise clean fuel vehicles. Guided by the Indore Municipal Corporation, diesel- based school bus fleets can be expeditiously phased out and replaced with cleaner E-bus and CNG alternatives.

7. Electric road sweeping machines are better alternative to diesel-powered machines (24 units which are in use for covering 800 km road length) currently in use within Indore city. It is suggested that the Indore City Authority shifts to e-sweeping machines which do not incur harmful tailpipe emissions.

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[13] *five states and three Union Territories including M.P. are yet to complete this integration and this had already been notified at the time of the report's publication*

8. RWEM technology can be strategically installed at select locations across Indore, especially in areas with dense traffic and limited alternative routes for traffic e.g. central business district, ring road and major toll booths on city outskirts. Vehicles found exceeding the established emission limits will immediately be sent a notice with warning for undertaking a PUC test and maintaining their vehicles. Second offence may accrue heavy fines for repeat offenders, reinforcing the importance of adhering to emission norms.

4.4. PARKING POLICY FOR CLEAN AIR IN INDORE

Based on via citizen surveys and available traffic flow prediction data [37] -MG Road, Rajwada, Vijay Nagar, Shivaji Square, Navlakha Square and Khajreana Square, Jawahar Marg, Dhar road, Mahu Naka Road, Imli Bazar Road, Indore-Ichapur Road, Resham Gali, Tilak path, Hakumchand Marg, Maulana Azad Marg, Dhangali Road are identified as areas with very high traffic. Evidence gathered during community meetings also points to concerns regarding road encroachment by illegally parked vehicles. This practice further disrupts traffic flow and exacerbates congestion issues in already congested areas. It is suggested that a comprehensive parking policy is notified by the Indore Municipal Corporation (IMC), while the following specific actions are recommended to alleviate congestion and optimise traffic flows-

1. Establish clear guidelines for on-street and off-street parking regulations including designated zones and enforcement mechanisms.

2. Designate pick-up and drop-off points, and loading/unloading zones and dedicated parking lanes to prevent unexpected stops and encourage predictable traffic movement.

3. Make real-time parking information available on public information systems and promote off-street parking options so that drivers spend less time circling for on-street parking thus reducing traffic congestion. The following key information can be displayed along with a map of parking locations-

    - Nearby parking places- off-road and on-road facilities with their distance

    - Total number of parking bays available with number of EV charging bays available

    - Current or real time availability of parking bays (ICE and EV) in above facilities

4. Implement on-road dynamic parking fees, adjusting fees based on local demand, to free up road space for moving vehicles. Give priority to areas with adequate off-road parking facilities as suggested below-

    - Higher fees during peak hours (e.g. commuting hours) and lower fees during off-peak hours to discourage parking during high-demand periods.

    - Differentiated parking fees in areas with varying demand e.g. CBD or commercial area vis-à-vis less dense residential area

5. Develop parking infrastructure strategically based on Total Volume Count (TVC) data and resulting congestion hotspots including the multi-level off-road facilities and designated on-street areas. Additional strategies include-

    - Convert vacant lots or underutilized public spaces into parking areas.

    - Develop parking areas (Park-and-ride facilities) on the outskirts of the city connected with public transport, encouraging commuters to leave their vehicles and use buses or trains.

6. Strengthen enforcement measures with dedicated personnel, technological solutions like automated number plate recognition (ANPR) and stricter penalties for non-compliance. It requires deploying parking enforcement personnel more frequently in high-violation areas to deter illegal parking. ANPR technology can efficiently detect and penalize parking violations eliminating need of a human intervention.

7. Launch campaigns to educate citizens on responsible parking practices, emphasizing the negative impacts of illegal parking on traffic flow and air quality, while promoting alternative transportation options.

4.5. TIERED EMISSION ZONES TO MANAGE LOCAL AIR QUALITY

Indore city displays a distinct spatial distribution of land uses across its wards as summarised below. A combined analysis of the latest Development Plan 2021, citizen survey data from Cleaner Air Better Life: Indore project and modelling of monitored air quality data in the Indore reveals specific land-use types with the potential for high traffic generation.

Wards 27, 29, 32, 34, 12, and 10 are characterised by dominant commercial and industrial activities, are projected to experience significant traffic influxes and outflows in the near future. These factors collectively suggest a high likelihood of these wards emerging as air quality hotspots. This underscores the urgent need for targeted interventions to address this critical environmental concern. Tiering of zones in Indore urban area aims to reduce air pollution and improve public health outcomes by restricting vehicular access to these zones by considering pre-defined vehicle emission standards (BSVI, BSIV etc.) as well as fuel types (EV, CNG, Diesel etc.). Implementation of **dedicated Tiered Emission Zones (TEZs)** within identified areas as below is recommended as a strategic approach to improve air quality in Indore-

A. Moderate Emission Zones (MEZ)

Ward Govind Colony (12) and Banganga (10) are designated as Industrial-Public/Semi- Public. These wards potentially feature a mix of industrial establishments along with public or government institutions. This combination can lead to air quality concerns due to higher industrial emissions and traffic emissions from public/semi-public activities.

B. Low Emission Zones (LEZ)

Ward Atal Bihari Vajpayee (32), Shahid Bhagat Singh (34), Dr. Shyama Prasad Mukherjee (29), and Pashupati Nath (27) which are designated as Commercial Central Business Districts (CBDs) experience high concentration of commercial activities and dense traffic, both of which contribute to air quality problems. These wards are proposed to be positioned within the Indore LEZ.

C. Clean Air Zones (CAZ)

Indore's green areas including- Nanda Nagar (25), Residency (54), Snehalaya Ganj (56), Devi Ahilya (57) and Imli Bazar (58) play a critical role in maintaining the city's ecological balance and act as city lungs. Recognizing their importance in preserving pan-city air quality, establishment of Clean Air Zones (CAZs) is proposed in these green areas to promote healthier urban environments and further conserving them for clean air in Indore.

Key considerations for proposed emission zones in Indore include-

1. **Define** boundaries of proposed tiered emission zones on Geographical Information System in such a way that specific restrictions in proposed zones do not affect the city traffic flows or create traffic related bottlenecks for surrounding areas. This will entail detailed baseline study of the affected local areas. Another important set of parameters to be considered for defining emission zones are- availability of public transport (including multi-modal integration and exchange points), parking infrastructure, pedestrian/cycling lanes & facilities which need to be properly planned in tandem with the TEZs implementation. The task would require concerted efforts by key agencies in Indore including- Indore Development Authority, Traffic Police, RTO, Indore Municipal Corporation, City Bus Indore (AiCTSL), M.P. Pollution Control Board etc. A city level task force headed by the Municipal Commissioner is recommended with representation of all relevant agencies and citizen/civil society groups to supervise the planning and implementation of TEZs.

2. **Notify** tiered emission zones (TEZs)with specific set of restrictions that will apply in different zones from a stipulated date (say, six-months after the notification). Illustrative draft framework for notified zones is provided below and needs to be evolved with dedicated local consultations in concerned areas-

    - MEZ: use of private vehicles lower than or equal to BS-IV restricted throughout notified MEZ areas while only BS-VI diesel vehicles are allowed. Only BS-VI commercial vehicles allowed.

    - LEZ: use of private vehicles lower than BS-VI vehicles restricted including all diesel vehicles. Only BS-VI commercial vehicles except diesel are allowed.

    - CAZ: only zero tailpipe emission private vehicles allowed that is- EVs and non-motorised modes of transportation. Only zero tailpipe emission commercial vehicles to be allowed in the clean air zone.

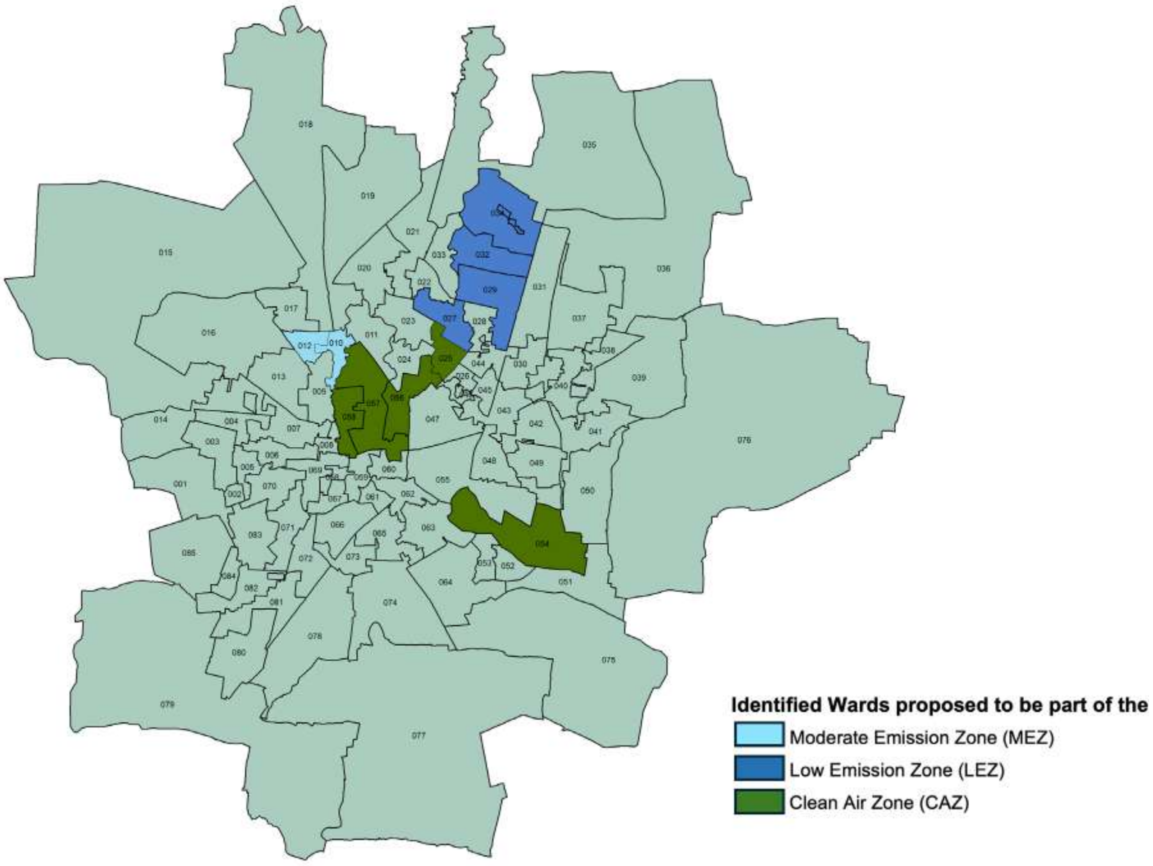
In addition, the proposed TF may publish penalty mechanism and structure for non- compliant vehicles or repeat offenders, while suggesting list of exemptions so that important public services and essential economic activities do not get disrupted during the TEZ implementation.

4. **Augment** public transport, NMT and parking infrastructure: This is important to ensure that adequate options are available to public once the specific vehicle restrictions come into force in these zones. Public authorities may have to consider augmenting capacities within the defined zones for public (say, number of buses or multi-modal exchange points) as well as non-motorised transport (pedestrian & cycling facilities) and vehicle parking at borders of three defined TEZs or in the neighbouring areas/wards. While the baseline study at the stage of defining TEZs may suggest initial requirements; the demand may further increase and need to be reviewed annually and can be supported via funds generated from penalties collected during TEZs enforcement.

5. **Enforce** tiered emission zones with vigilance from traffic police and active citizen groups, while utilising or leveraging infrastructure such as ANPR cameras & drones to identify and penalise non-compliant vehicles and ensuring compliance throughout the zones as notified by the city authority.

6. **Monitor** and evaluate the emission zones for environmental impacts in terms of reduced air pollution & greenhouse gases, while monitoring non-compliance, traffic bottlenecks and any emission leakages or rebound effect. AQ sensors network in the local areas and ML based air quality models will be useful to delineate the air quality impacts or gains from TEZ implementation. City would need a real-time feedback mechanism with a grievance system for citizens to provide inputs on TEZ implementation, ensuring community involvement and support for sustained air quality improvement efforts. Indore 311 app can be leveraged for this. Finally, socioeconomic impact analysis would be useful during different phases of implementation to mitigate any unintended impacts of TEZ implementation.

Figure 4.1: Proposed city wards as part of three-tiered emission zones



4.6. ADDRESSING INDUSTRY EMISSIONS

Stone Crushers

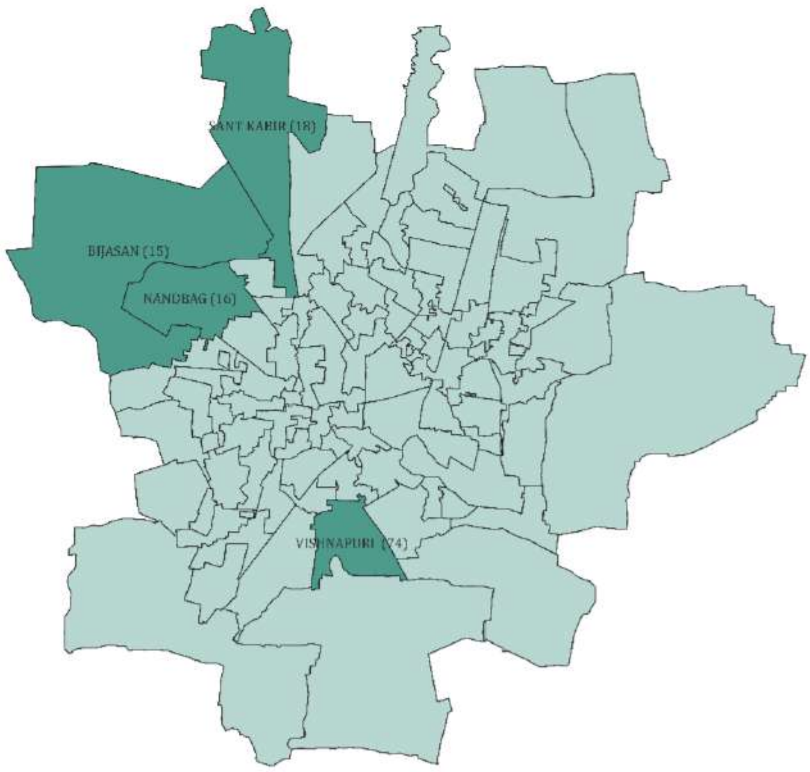
Multiple stone crusher units are present specifically in North-Western region or wards- Bijasan (15), Nandbag (16), Sant Kabir (18) and Vishnapuri (74) in Indore as depicted in the Figure 4.2. Stone crushers generate significant emissions, primarily consisting of dust and fine particulate matter which can travel long distances depending on the prevailing wind direction[14]. These activities increase pollution levels in wards 15 and 16 and further impact air quality in downwind wards. Between December and February, approximately 20% of winds blow from the west, carrying this pollution directly towards the centre of Indore City and especially affecting the neighbouring wards which include- Bangangh (10), Bhagirathpura (11), Govind Colony (12), Kushvan Nagar (17), Gouri Nagar (20), Swargiya Ragesh Joshi (23), and Pashupati Nath (27). The stone crushers are therefore identified as a major upwind source of air pollution in northern and central parts of the city.

These stone crusher plants are not included in the proposed plan for these wards under Indore Development Plan 2021, as these areas are identified as residential zones. Indore may relocate these stone crusher units outside the city boundary or to designated industrial area in the city down wind. All plants will nonetheless need to adhere to the latest Environmental Guidelines for Stone Crushing Units (as published by CPCB in 2023[15]) [39] to reduce pollution and safeguard public health. MPPCB and IMC may identify unlicenced stone crusher plants operating without proper approvals and environmental clearance from the Board.

Brick Kilns

A significant number of brick kilns are distributed across various wards in Indore, particularly in the northern and southern parts of the city. These wards include Visvakarma (19), Shyam Nagar (21), Lasudiya Mori (35), and Sukh Niwas (79) as highlighted in various zonal meetings and depicted in Figure 4.3 here. These kilns primarily use coal, agricultural waste, pet coke/furnace oil etc. as fuel contributing significantly to air pollution emissions in Indore.

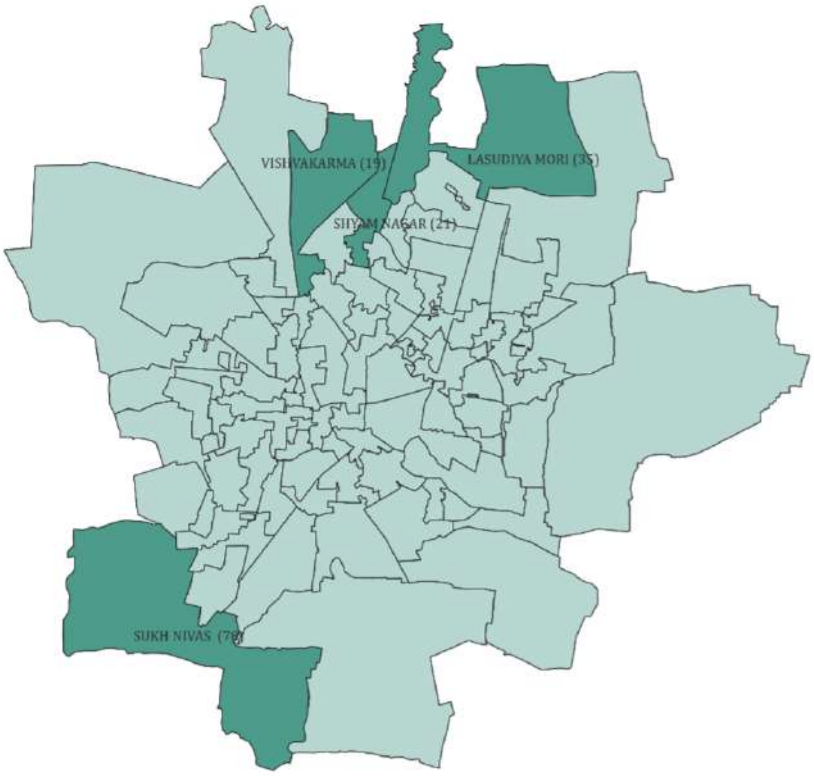
Figure 4.2: Identified Wards with stone crusher units



Source: CII CABL (2024) Analysis

[14] Daily average ambient observations ranged 342-2470 μg/m3 TSP near source, while ambient air readings ranged 86-257 μg/m3 TSP in ambient air (Sivacoumar et al 2006) [38]
[15] https://cpcb.nic.in/openpdffile.php?id=TGF0ZXN0RmlsZS8zNzhfMTY5MDgwNjIxOF9tZWRpYXBob3RvMjM0Mj EucGRm

Figure 4.3: Identified Wards with Brick Kiln Units



Source: CII CABL (2024) Analysis

It is recommended that the following actions be emphasised by the city authority and the State Pollution Control Board (SPCB) to control the pollution level in Indore.

1. Relocation of Brick Kilns

Encourage the relocation of brick kilns from within the city boundaries to areas outside the city limits maintaining at least 1km buffer from Indore urban area to reduce air pollution in residential areas[16] [40].

2. Adopting Cleaner Technologies & Phasing Out Polluting Technologies

Promote the implementation of cleaner technologies like the zigzag firing method in brick kilns to minimize pollution. This method reduces SPM and unburnt carbon emissions by 60-75% and decreases specific energy consumption by almost 20%, while also enhancing the output by increasing the number of good-quality bricks by up to 25% (CII- NITI 2019).

Despite its benefits, investment can be burdensome for small-scale kiln owners, particularly because this a seasonal activity. Also, this being a small-scale activity, brick kiln operators lack know how and may need handholding for switching to cleaner fuels such as LPG, BioCNG, biomass pellets etc. The state regulator MPPCB may consider phasing out polluting or Fixed Chimney Bull's Trench Kilns within next 1-2 years, while coming up with a dedicated supporting mechanism for technology upgradation in consultation with brick manufacturers or their associations.

Other MSMEs

Indore houses significant number of micro and small-scale industries, especially food processing and packaging, which are still dependent on biomass, coal or wood for fuel needs. There is an urgent need to shift to cleaner technologies and upfront investment remains a major constraint for smaller businesses. **It is therefore recommended to facilitate access to low-interest loans specifically suited for smaller players to upgrade to cleaner fuel technologies.**

[16] *https://pcbassam.org/Notice/brick/Guidelines%20of%20Brick%20Kiln%20in%20Assam.pdf*

Furthermore, concerned departments need to take initiatives to educate and empower small players to leverage existing schemes[17] that provide financial assistance for MSMEs. Major part of these efforts will inevitably focus on organising the unorganized informal sector players so that they could also avail these schemes for technology upgradation. These include-

1. Credit Linked Capital Subsidy for Technology Upgradation (CLCSS)
2. Credit Guarantee Fund Trust for Micro and Small Enterprises (CGTMSE)
3. 2% Interest Subvention Scheme
4. Madhya Pradesh MSME Development Policy (Amended, May 2022)

By providing access to low-interest loans through existing government schemes, the city can significantly mitigate the financial bottleneck for MSMEs to adopt clean energy and clean production technologies. **Further, it is recommended that brick kilns, who are in urgent need of technology upgradation, are considered as part of the applicable sectors/ subsector under the ongoing or existing CLCSS Scheme.**

[17] https://www.msmeindore.nic.in/SAMACHAR/eBook%20of%20Schemes%20for%20MSMEs.pdf

05

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06 Annexures

ANNEXURE 1

Collocation Study

Figure A1.1: Time series of PM2.5 data of 1-hour interval

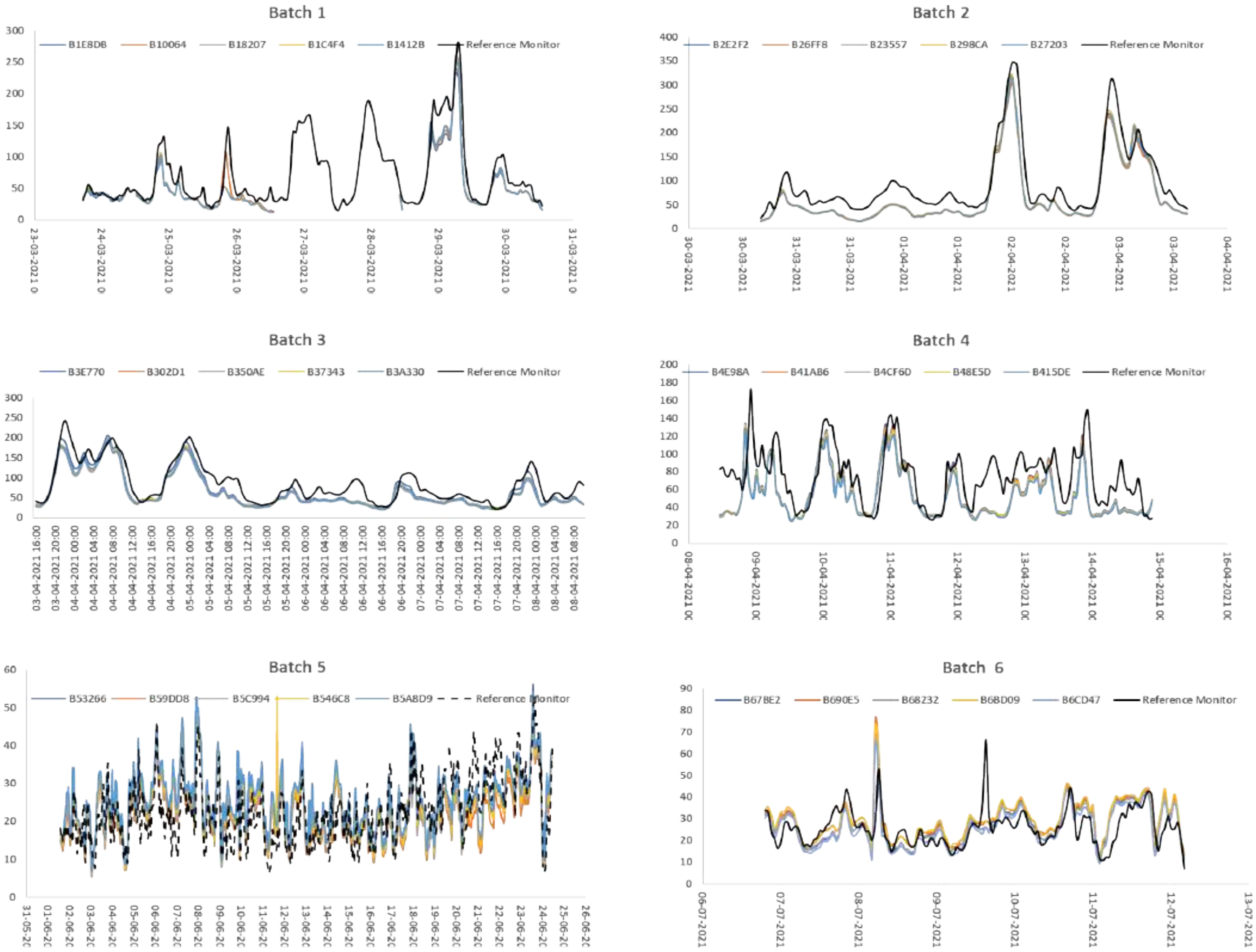


Table A1.1: Bias values of monitors with both calibrated and uncalibrated data points in comparison to the reference station

Monitor ID	Bias calibrated	Bias uncalibrated	Monitor ID	Bias calibrated	Bias uncalibrated
B41AB6	-0.0002	-0.3	B59DD8	0	0.0
B298CA	-0.0012	-0.3	B4CF6D	-0.0004	-0.3
B3E770	0.0006	-0.2	B27203	-0.0008	-0.3
B4E98A	0.0002	-0.3	B67BE2	0.0022	0.1
B10064	0.0024	-0.2	B18207	0.0002	-0.2
B23557	0.0006	-0.3	B690E5	0.0021	0.1
B546C8	-0.0003	0.1	B3A330	0.0004	-0.2
B26FF8	0.001	-0.3	B5A8D9	0.0001	0.1
B27343	0.0021	-0.3	B6BD09	0.0019	0.2
B5C994	0	0.0	B1C4F4	-0.0003	-0.2
B2E2F2	0.0014	-0.3	B6CD47	0.0011	0.0
B1E8DB	0.0015	-0.2	B415DE	0.0008	-0.3
B302D1	0.0008	-0.2	B1412B	0.0017	-0.2
B53266	0	0.1	B68232	-0.0009	0.1
B350AE	-0.001	-0.2	B48E5D	0.0017	-0.3

Figure A1.2: 6-hourly average daily of $PM_{2.5}$ data

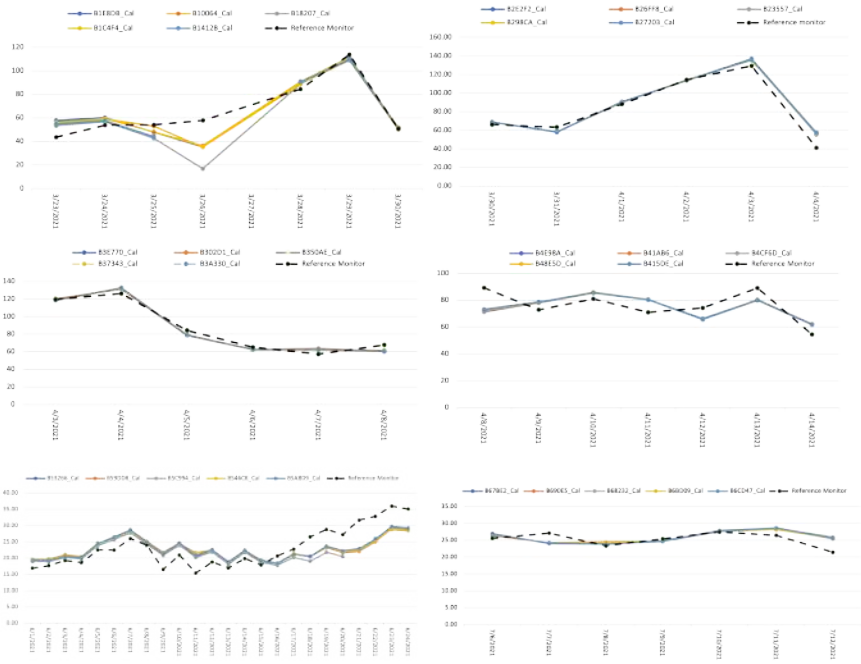


Figure A1.3: Scatter Plot for two low-cost monitors along with the reference monitor

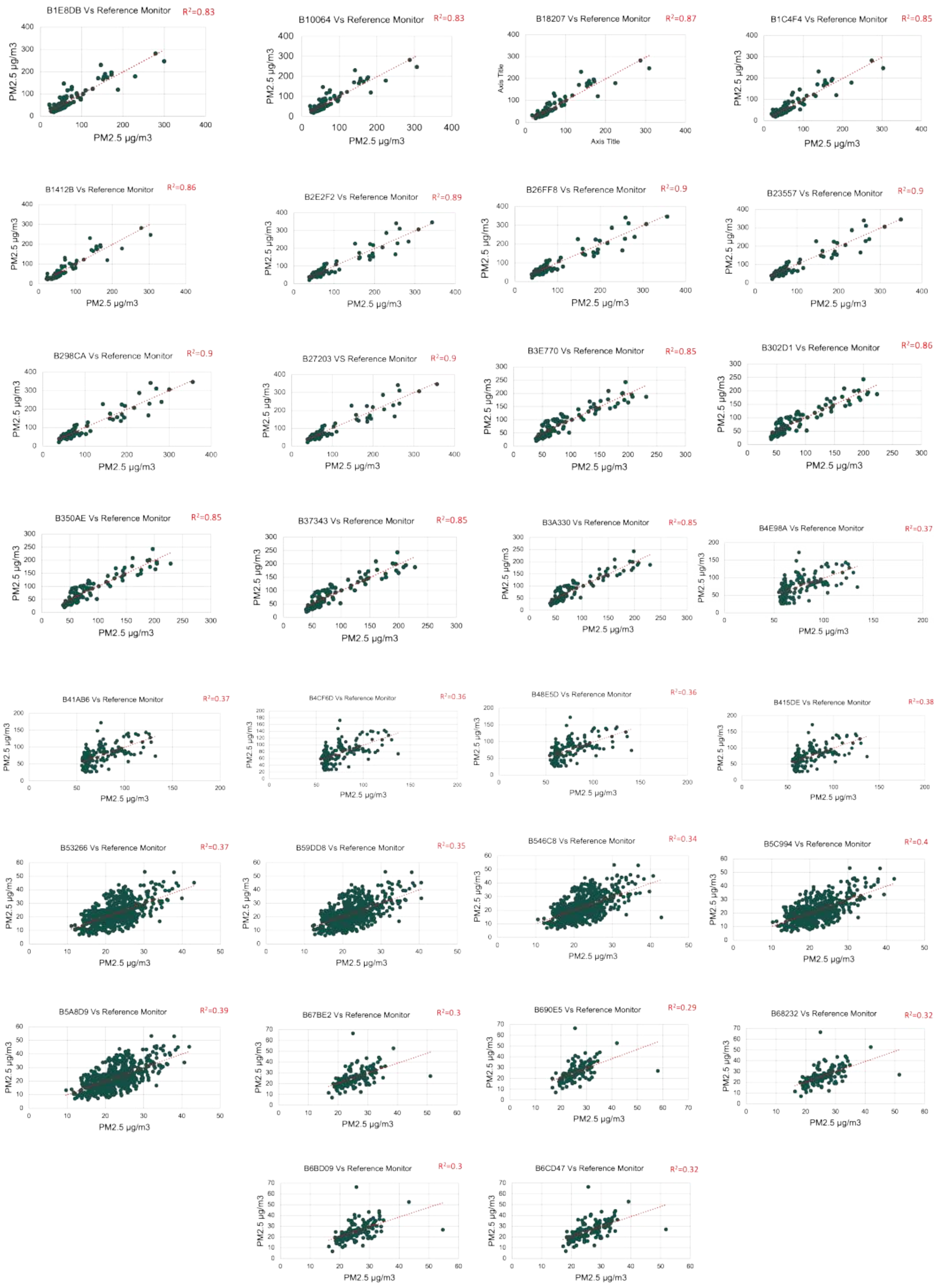


Figure A1.4: Intra-model variability

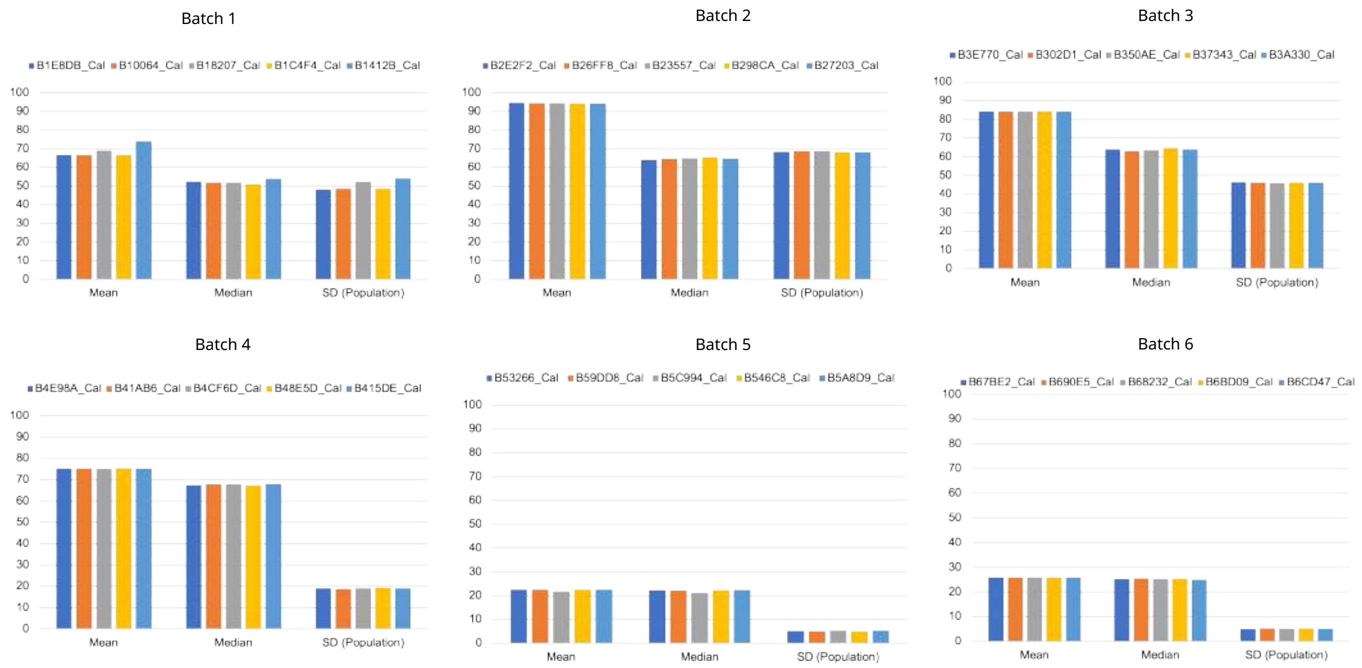


Figure A1.5: Correlation matrix for the six batches of sensor

Correlation coefficient (R^2)	B1412B	B1C4F4	B18207	B1E8DB	B10064
B1412B	1.00	0.95	0.92	0.93	0.93
B1C4F4	0.95	1.00	0.98	0.90	0.89
B18207	0.92	0.98	1.00	0.98	0.98
B1E8DB	0.93	0.90	0.98	1.00	0.99
B10064	0.93	0.89	0.98	0.99	1.00

Correlation coefficient (R^2)	B2E2F2	B27203	B298CA	B23557	B26FF8
B2E2F2	1.00	0.99	0.99	0.99	1.00
B27203	0.99	1.00	1.00	0.99	1.00
B298CA	0.99	1.00	1.00	0.98	0.99
B23557	0.99	0.99	0.98	1.00	1.00
B26FF8	1.00	1.00	0.99	1.00	1.00

Correlation coefficient (R^2)	B302D1	B350AE	B37343	B3A330	B3E770
B302D1	1.00	0.92	0.87	0.96	0.93
B350AE	0.92	1.00	0.98	0.98	1.00
B37343	0.87	0.98	1.00	0.95	0.98
B3A330	0.96	0.98	0.95	1.00	0.99
B3E770	0.93	1.00	0.98	0.99	1.00

Correlation coefficient (R^2)	B41AB6	B48E5D	B415DE	B4CF6D	B4E98A
B41AB6	1	0.72	0.25	0.99	0.99
B48E5D	0.70	1	0.12	0.71	0.72
B415DE	0.25	0.12	1	0.27	0.28
B4CF6D	0.99	0.71	0.27	1	0.99
B4E98A	0.99	0.72	0.28	0.99	1

Correlation coefficient (R^2)	B53266	B59DD8	B5C994	B546C8	B5A8D9
B53266	1	0.99	0.99	0.97	0.99
B59DD8	0.99	1	0.99	0.98	0.99
B5C994	0.99	0.99	1	0.98	0.99
B546C8	0.97	0.97	0.97	1	0.98
B5A8D9	0.99	0.99	0.99	0.98	1

Correlation coefficient (R^2)	B67BE2	B690E5	B68232	B6BD09	B6CD47
B67BE2	1	0.99	0.99	0.99	0.99
B690E5	0.99	1	0.99	0.99	0.99
B68232	0.99	0.99	1	0.99	0.99
B6BD09	0.99	0.99	0.99	1	0.99
B6CD47	0.99	0.99	0.99	0.99	1

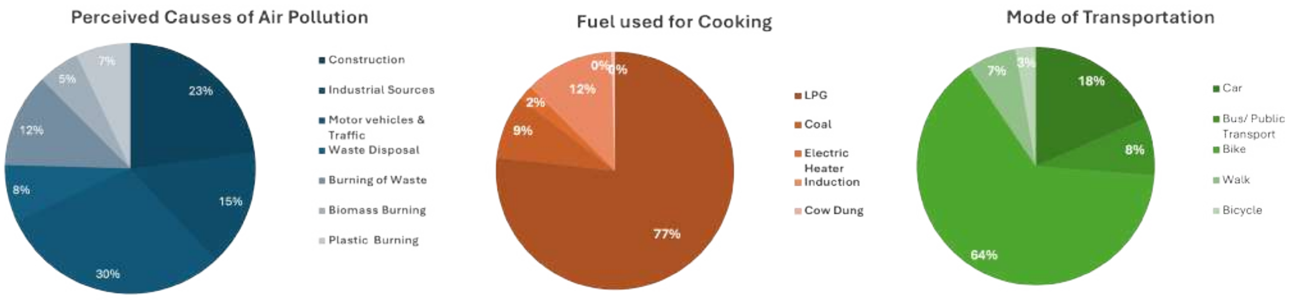
ANNEXURE 2

Zone-Wise Pollution Levels and Citizen Survey Information

Zone 1

Figure A2.1: Monthly and Annual average of $PM_{2.5}$ levels in Zone 1

Figure A2.2: Citizen Survey report in Zone 1

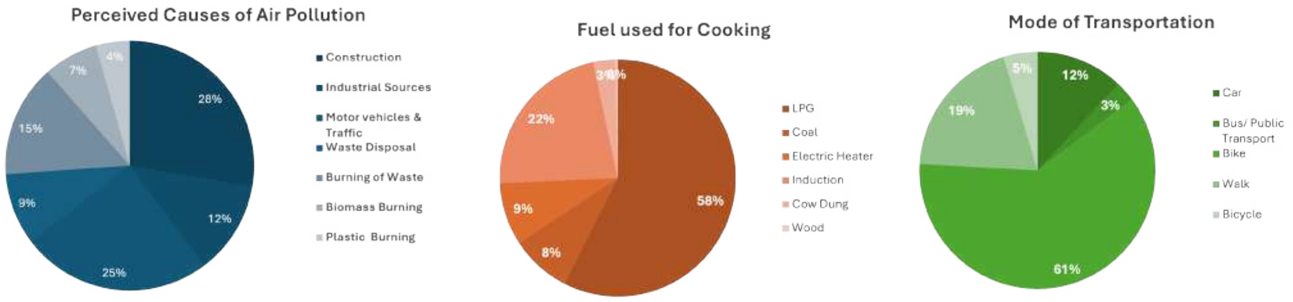


Source: CII CABL (2024) Analysis

Zone 2

Figure A2.3: Monthly and Annual average of $PM_{2.5}$ levels in Zone 2

Figure A2.4: Citizen Survey report in Zone 2



Source: CII CABL (2024) Analysis

Zone 3

Figure A2.5: Monthly and Annual average of $PM_{2.5}$ levels in Zone 3

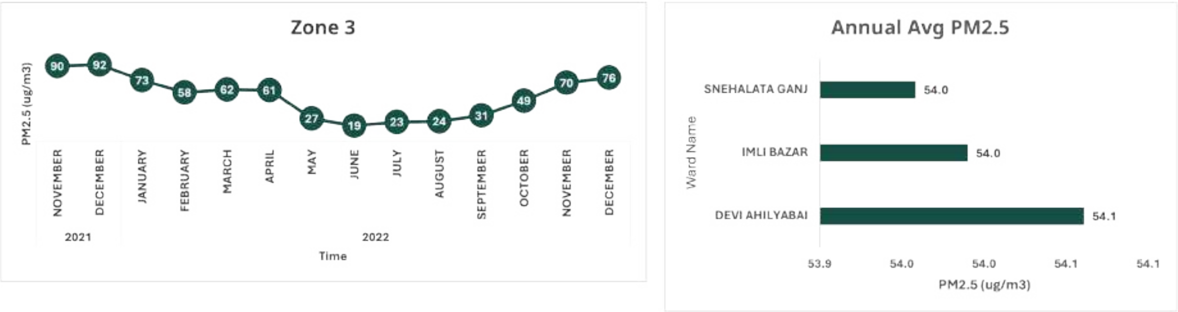
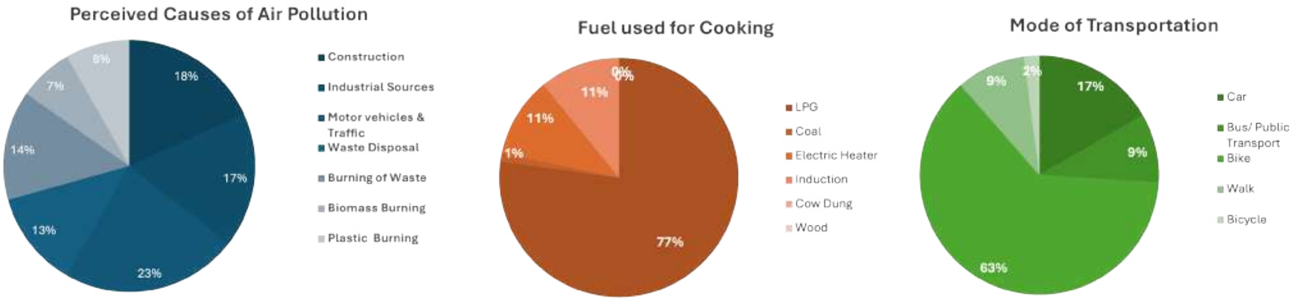


Figure A2.6: Citizen Survey report in Zone 3

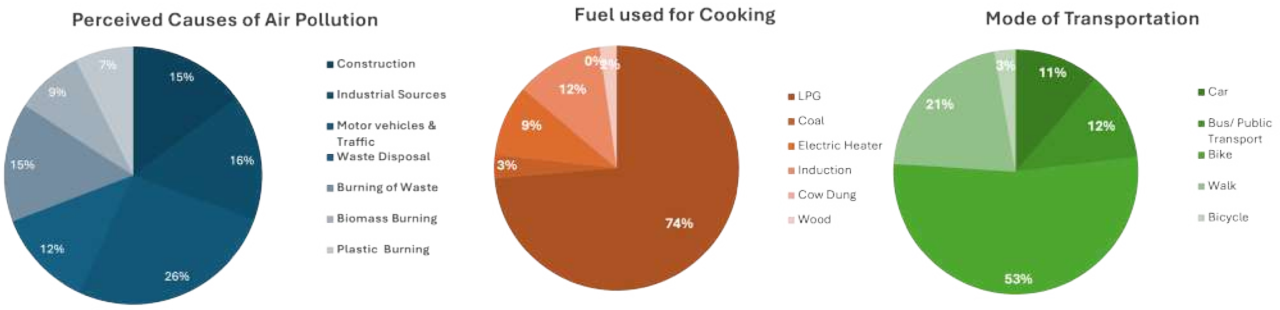


Source: CII CABL (2024) Analysis

Zone 4

Figure A2.7: Monthly and Annual average of $PM_{2.5}$ levels in Zone 4

Figure A2.8: Citizen Survey report in Zone 4



Source: CII CABL (2024) Analysis

Zone 5

Figure A2.9: Monthly and Annual average of $PM_{2.5}$ levels in Zone 5

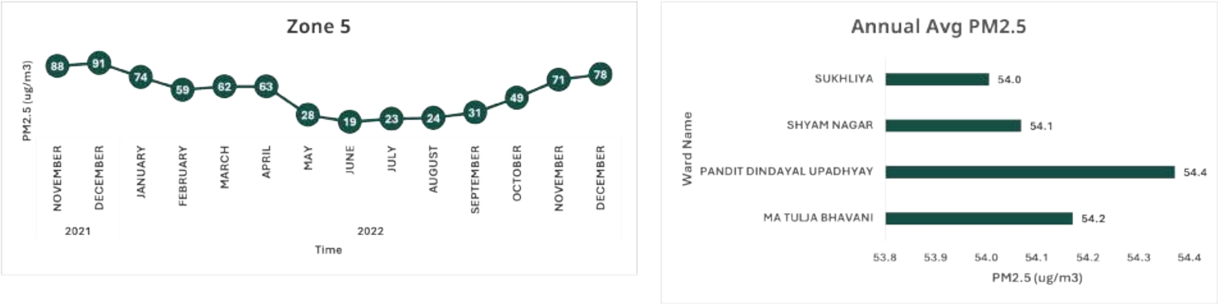
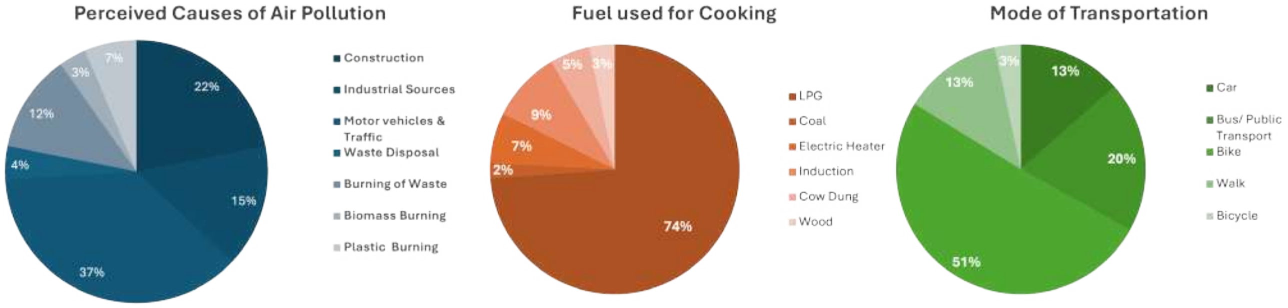


Figure A2.2: Citizen Survey report in Zone 1

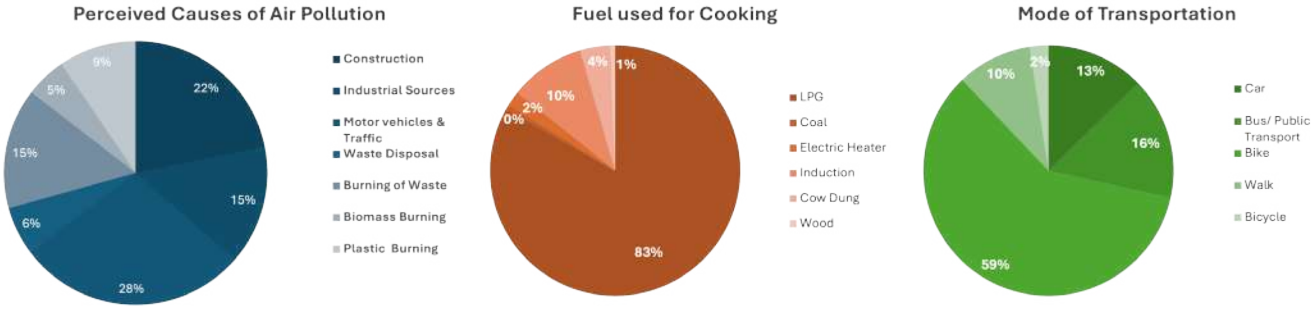


Source: CII CABL (2024) Analysis

Zone 6

Figure A2.11: Monthly and Annual average of $PM_{2.5}$ levels in Zone 6

Figure A2.12: Citizen Survey report in Zone 6



Source: CII CABL (2024) Analysis

Zone 7

Figure A2.13: Monthly and Annual average of $PM_{2.5}$ levels in Zone 7

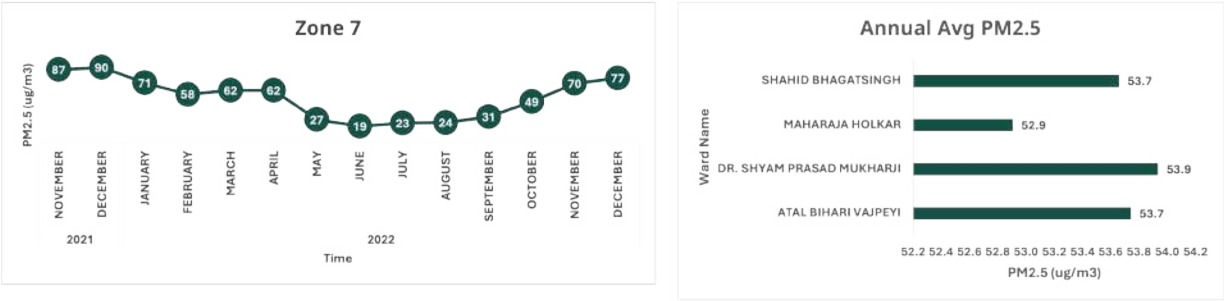
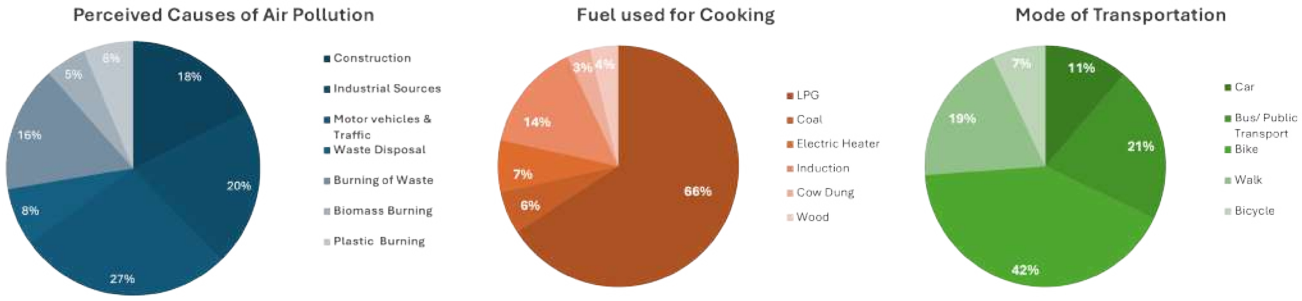


Figure A2.14: Citizen Survey report in Zone 7

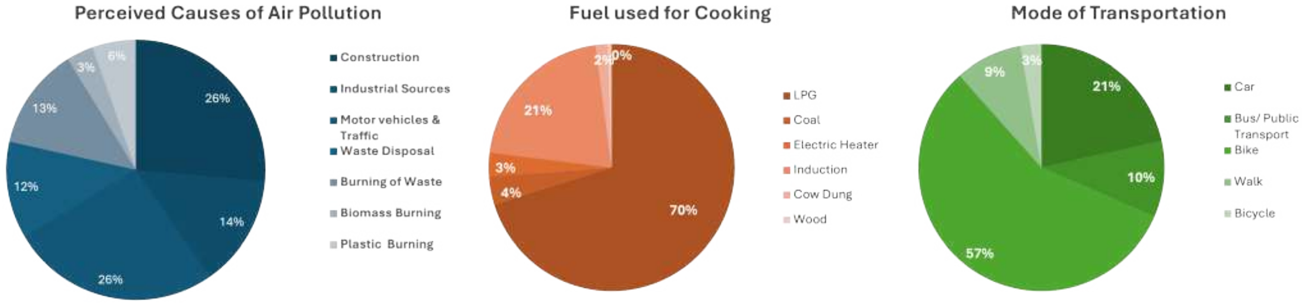


Source: CII CABL (2024) Analysis

Zone 8

Figure A2.15: Monthly and Annual average of $PM_{2.5}$ levels in Zone 8

Figure A2.16: Citizen Survey report in Zone 8



Source: CII CABL (2024) Analysis

Zone 9

Figure A2.17: Monthly and Annual average of $PM_{2.5}$ levels in Zone 9

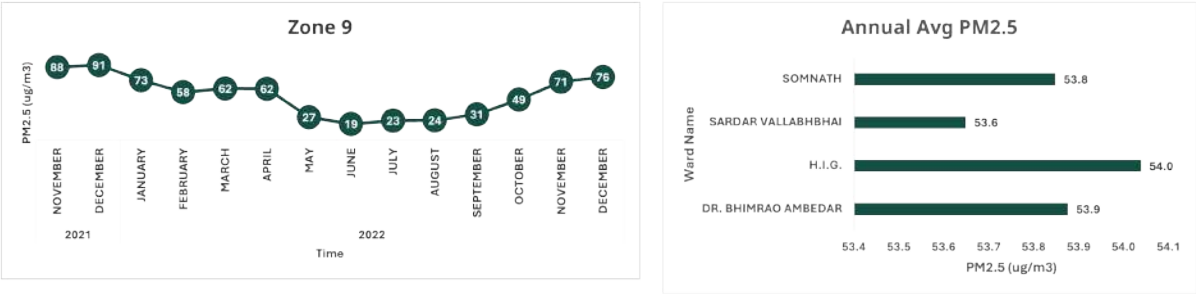
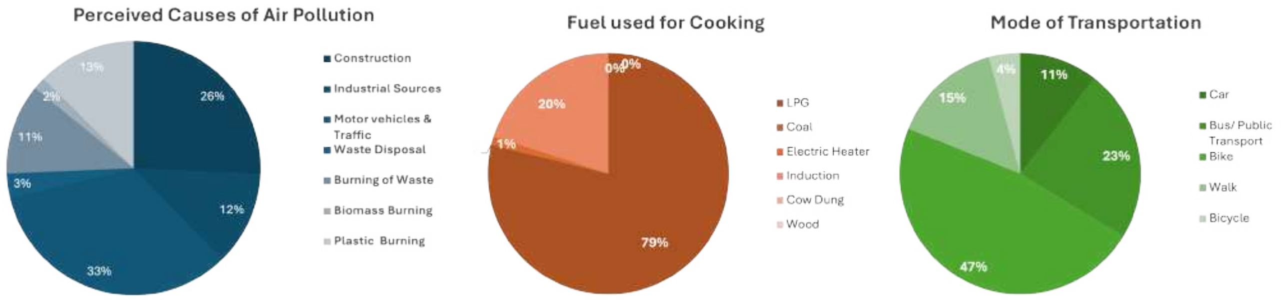


Figure A2.2: Citizen Survey report in Zone 1

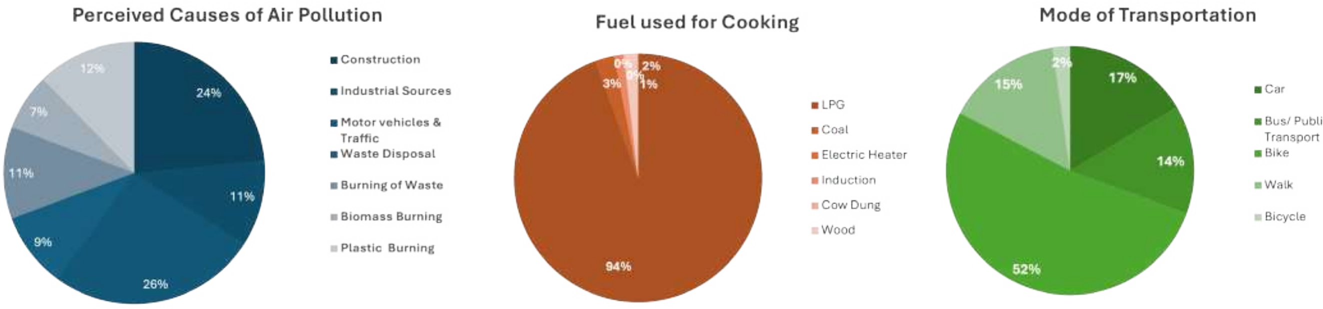


Source: CII CABL (2024) Analysis

Zone 10

Figure A2.19: Monthly and Annual average of $PM_{2.5}$ levels in Zone 10

Figure A2.20: Citizen Survey report in Zone 10

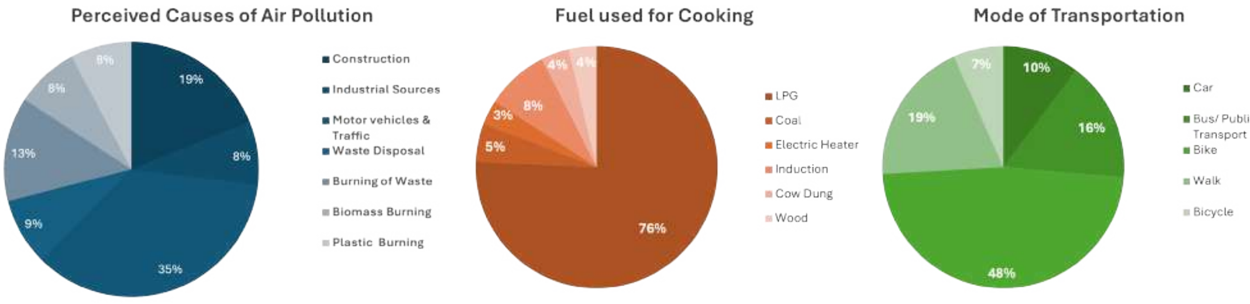


Source: CII CABL (2024) Analysis

Zone 11

Figure A2.21: Monthly and Annual average of $PM_{2.5}$ levels in Zone 11

Figure A2.22: Citizen Survey report in Zone 11

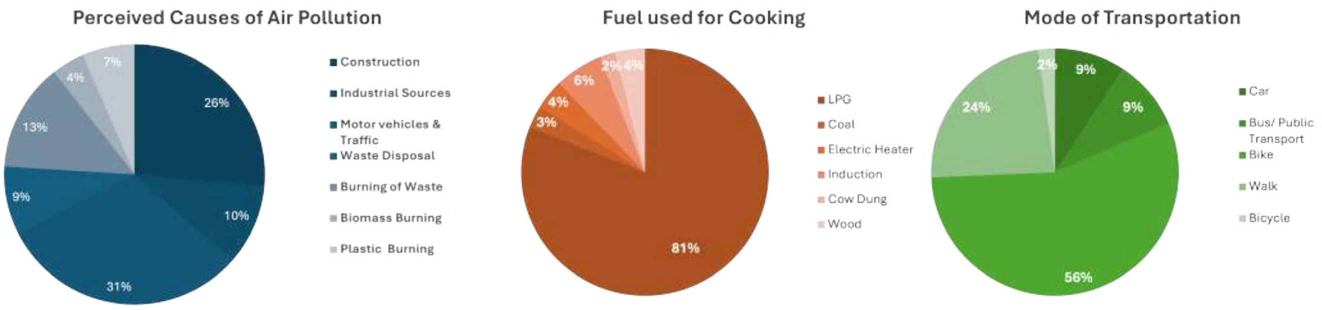


Source: CII CABL (2024) Analysis

Zone 12

Figure A2.23: Monthly and Annual average of $PM_{2.5}$ levels in Zone 12

Figure A2.24: Citizen Survey report in Zone 12



Source: CII CABL (2024) Analysis

Zone 13

Figure A2.25: Monthly and Annual average of $PM_{2.5}$ levels in Zone 13

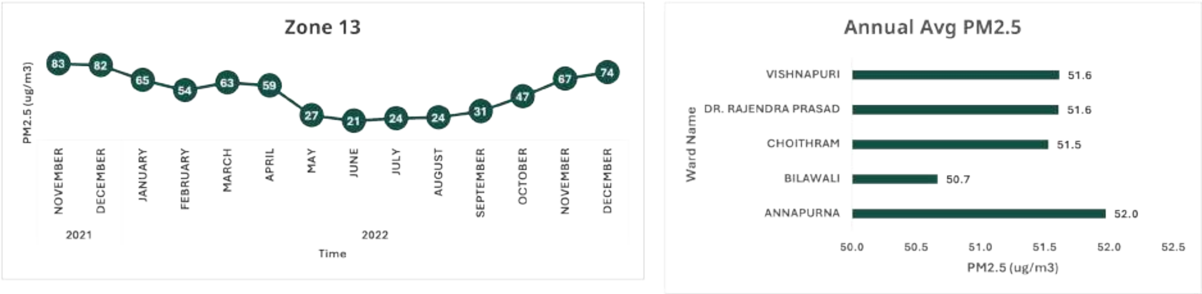
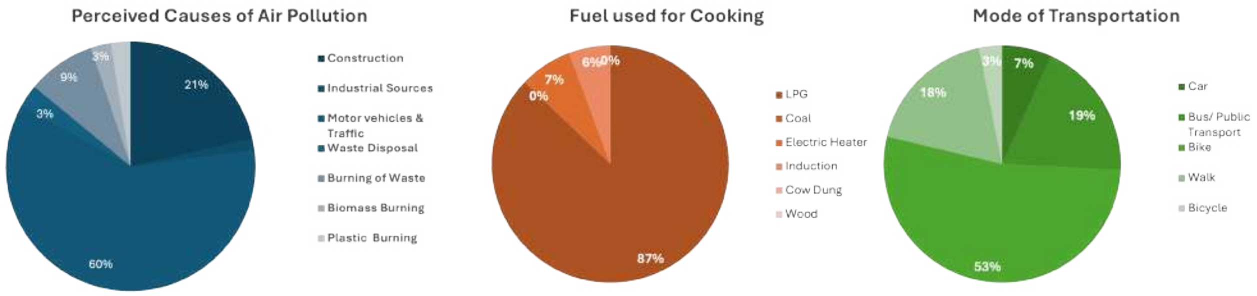


Figure A2.26: Citizen Survey report in Zone 13

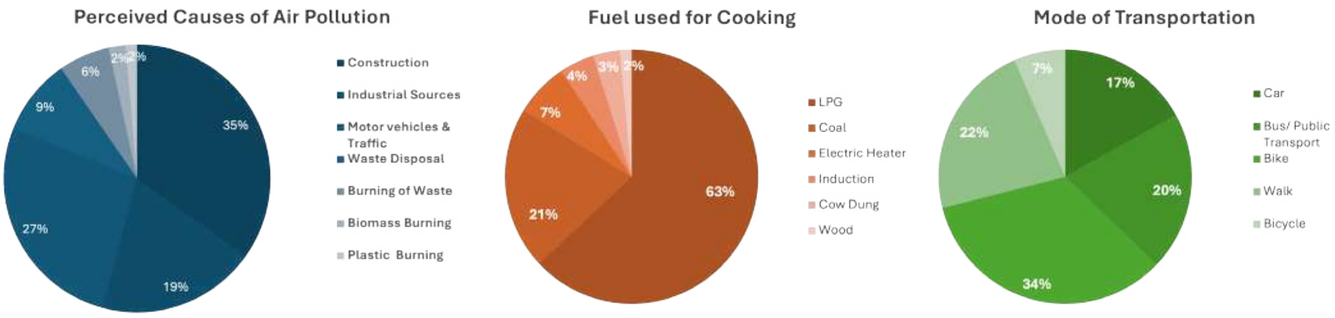


Source: CII CABL (2024) Analysis

Zone 14

Figure A2.27: Monthly and Annual average of $PM_{2.5}$ levels in Zone 14

Figure A2.28: Citizen Survey report in Zone 14

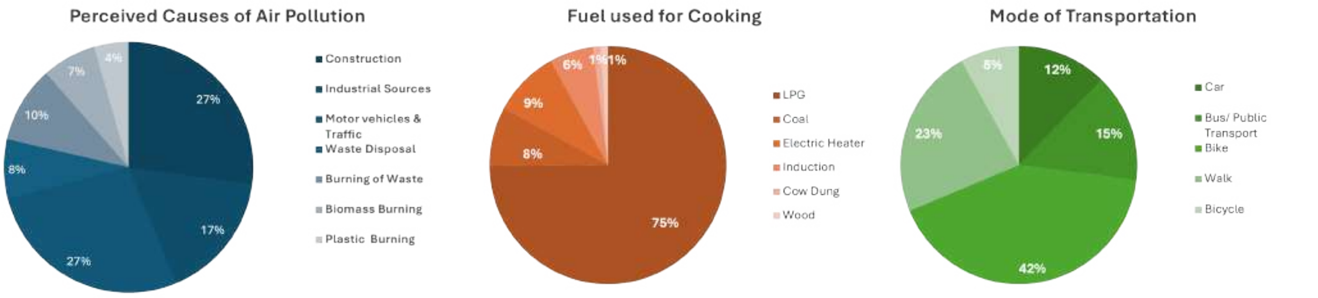


Source: CII CABL (2024) Analysis

Zone 15

Figure A2.29: Monthly and Annual average of $PM_{2.5}$ levels in Zone 15

Figure A2.30: Citizen Survey report in Zone 15

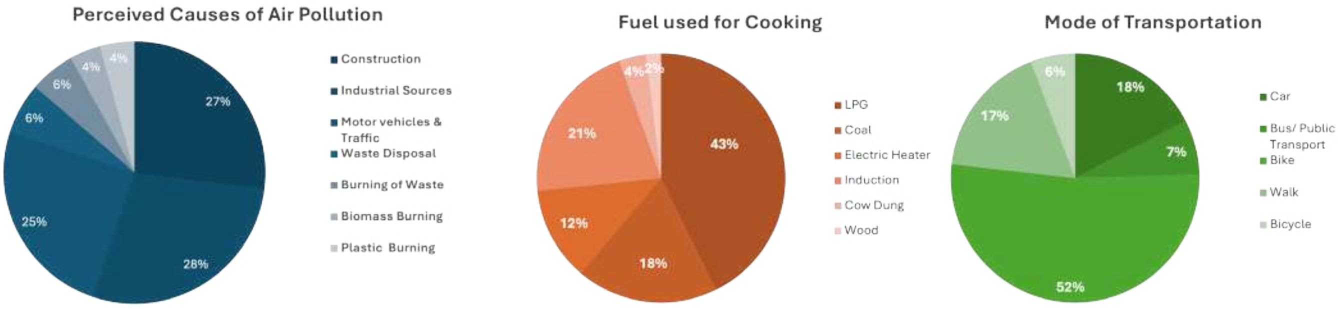


Source: CII CABL (2024) Analysis

Zone 16

Figure A2.31: Monthly and Annual average of $PM_{2.5}$ levels in Zone 16

Figure A2.32: Citizen Survey report in Zone 16

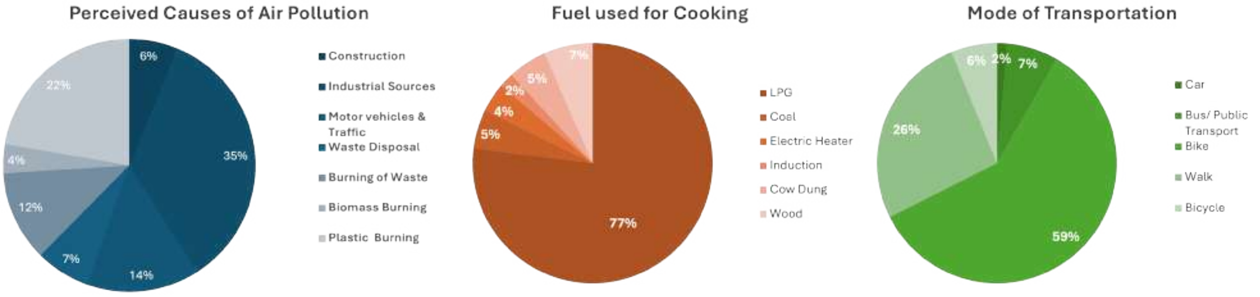


Source: CII CABL (2024) Analysis

Zone 17

Figure A2.33: Monthly and Annual average of $PM_{2.5}$ levels in Zone 17

Figure A2.34: Citizen Survey report in Zone 17



Source: CII CABL (2024) Analysis

Zone 18

Figure A2.35: Monthly and Annual average of $PM_{2.5}$ levels in Zone 18

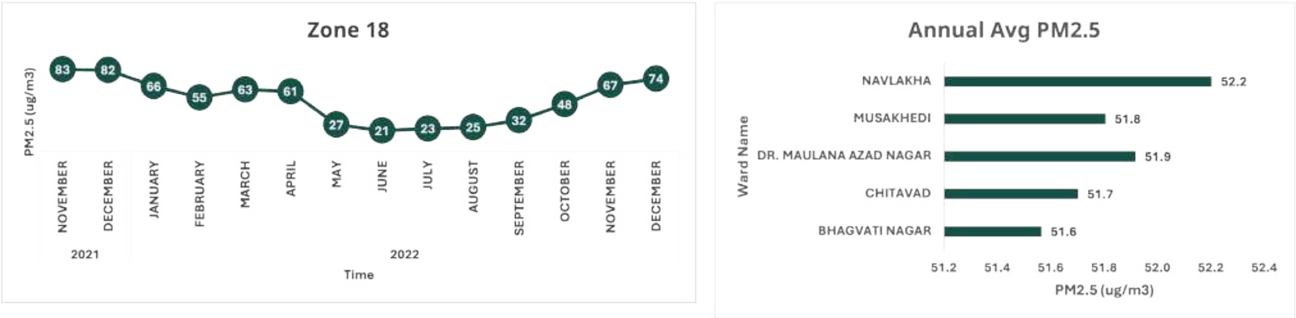
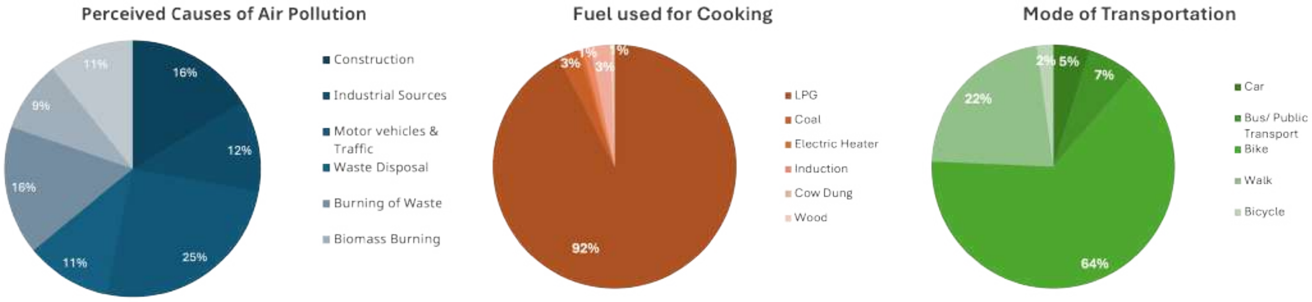


Figure A2.36: Citizen Survey report in Zone 18



Source: CII CABL (2024) Analysis

Zone 19

Figure A2.37: Monthly and Annual average of $PM_{2.5}$ levels in Zone 19

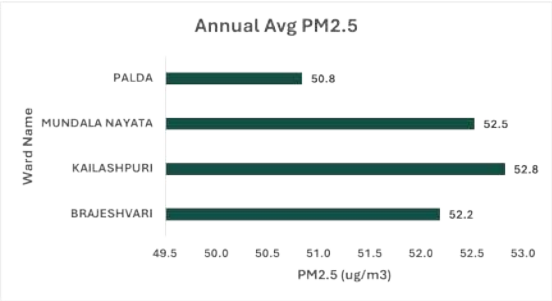
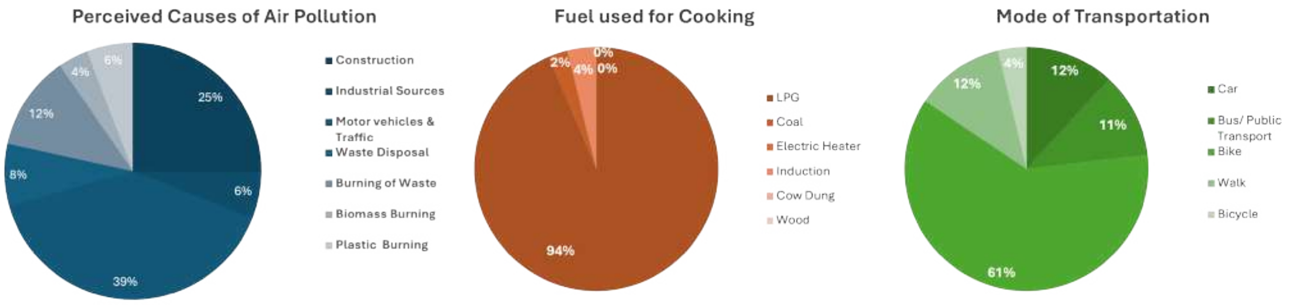


Figure A2.38: Citizen Survey report in Zone 19



Source: CII CABL (2024) Analysis

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CII स्वच्छ वायु, दीर्घायु

CII
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In the journey of India's economic resurgence, CII facilitates the multifaceted contributions of the Indian Industry, charting a path towards a prosperous and sustainable future. With this backdrop, CII has identified "Globally Competitive India: Partnerships for Sustainable and Inclusive Growth" as its Theme for 2024-25, prioritizing 5 key pillars. During this year, it would align its policy recommendations, initiatives, and activities with this overarching framework to facilitate strategic actions for driving India's global competitiveness and growth through a robust and resilient Indian Industry.

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CESD leverages its role of all-inclusive ecosystem player, partnering industry, government, and civil society. It has been a pioneer of Climate Change, environment management systems, biodiversity mapping, sustainability reporting, integrated reporting, and social & natural capital valuation in India, thus upgrading business in India to sustainable competitiveness. CESD operates across the country and has also been active in parts of South and South-East Asia, Middle East, and Africa. It has held institutional partnerships and memberships of the United Nations Global Compact, Global Reporting Initiative, International Integrated Reporting Council, Carbon Disclosure Project, development agencies of Canada, the USA, the UK, and Germany.

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