

# Decarbonizing urban transport using traffic and transport data from ICCC

## A Pilot Study in NOIDA

**FINAL REPORT**  
8th April 2025



*Knowledge Partner*



TRANSPORTATION  
RESEARCH & INJURY  
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IIT Delhi



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**VISION ZERO:** Road Safety &  
Decarbonisation programme



# Acknowledgment

This report demonstrates the powers of collaboration, data and shared vision. It is a joint effort of three organisations that are united by their commitment to decarbonisation and road safety.

The Infravision Foundation is dedicated to creating transportation infrastructure and mobility services that meet the highest standards. In order to be a developed country by 2047, it is imperative that the deployment of smart technologies and conversion of operational knowledge and data into policy insight is accelerated through advancement of science & technology and support for R&D and innovation.

The 'Vision Zero: Road Safety & Decarbonization' program at EFKON STRABAG is a timely effort to promote R&D for smart management of urban roads and highways infrastructure. Safeguarding the public from the harmful effects of congestion as well as unruly behaviour of road users requires interventions based on accurate and appropriate data. Reliable R&D must be conducted through partnerships between local governments, technology operators, universities and thinktanks.

This study originated in the observation that the Integrated Command-and-Control Centres established in numerous Indian cities are ingesting huge amounts of data on a daily basis but using a fraction of the data being collected. While the interpretation of the data is driven by prescribed use cases, there is scope to derive much greater insight by mining the data and evolving methodologies that are fit-for-purpose.

We are thankful to Mr Rajat Mishra, CEO of EFKON STRABAG, for providing the vision and impetus for the study. We are grateful to the EFKON STRABAG team, in particular Mr Rajat Manchanda, Mr Manish Saini, Ms Sneha Lata and Mr Keshav Jangra, for their technical insights and steadfast support.

We are fortunate to have the TRIP Centre at IIT-Delhi as our Knowledge Partner. Dr Geetam Tiwari, Emeritus Professor, Dr Deepty Jain, Assistant Professor, and Ms Ranjana Soni, Research Scholar, have ensured that the data analysis is rigorous and the synthesis of insights is derived from best practice and deep knowledge of decarbonizing transport. We are deeply grateful for their partnership.

We hope that the growing ecosystem of administrators, planners, experts, policymakers and civil society concerned with urban India will be motivated to convert the research into action for creating greener and safer cities.

**JAGAN SHAH**

CEO, The Infravision Foundation



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## List of abbreviations

1. AI – Artificial Intelligence
2. ANPR – Automatic Number Plate Recognition
3. BC – Black Carbon
4. B-TRAC – Bangalore Traffic Improvement Project
5. CBDR-RC – Common but Differentiated Responsibilities and Respective Capabilities
6. CII – Confederation of Indian Industry
7. CMP – Comprehensive Mobility Plan
8. CNG – Compressed Natural Gas
9. CO – Carbon Monoxide
10. CO<sub>2</sub> – Carbon Dioxide
11. CPCB – Central Pollution Control Board
12. DMRC – Delhi Metro Rail Corporation
13. DND – Delhi-Noida Direct Flyway
14. DSC – Dadri-Surapur-Chalera
15. EFKON STRABAG – Company name (provider of ITMS in NOIDA)
16. ERP – Electronic Road Pricing
17. EV – Electric Vehicle
18. FNG – Faridabad-NOIDA-Ghaziabad
19. GDP – Gross Domestic Product
20. GHG – Greenhouse Gas
21. GIS – Geographic Information System
22. GPS – Global Positioning System
23. HC – Hydrocarbons
24. HGV – Heavy Goods Vehicle
25. HPV – Heavy Passenger Vehicle
26. ICCC – Integrated Command and Control Centre
27. IDW – Inverse Distance Weighting
28. IISc – Indian Institute of Science
29. IMAF – ICCC Maturity Assessment Framework
30. IMTS – Integrated Multi-Modal Transit System
31. IoT – Internet of Things
32. ITS – Intelligent Transport System
33. ITMS – Intelligent Traffic Management System
34. IUDX – India Urban Data Exchange
35. IVRS – Interactive Voice Response System
36. KRDCCL – Karnataka Road Development Corporation Limited
37. LEZ – Low-Emission Zone
38. LGV – Light Goods Vehicle
39. LMV – Light Motor Vehicle
40. LPV – Light Passenger Vehicle
41. LT-LEDS – Long-Term Low Emission Development Strategy
42. MET – Meteorological Systems
43. MGV – Medium Goods Vehicle
44. ML – Machine Learning
45. MoHUA – Ministry of Housing and Urban Affairs
46. MPV – Medium Passenger Vehicle
47. NCR – National Capital Region
48. NDC – Nationally Determined Contribution
49. NH – National Highway
50. NMT – Non-Motorized Transport
51. NO<sub>2</sub> – Nitrogen Dioxide
52. NO<sub>x</sub> – Nitrogen Oxides
53. O<sub>3</sub> – Ozone
54. ORF – Observer Research Foundation
55. PM – Particulate Matter
56. PM<sub>10</sub> – Particulate Matter (10 micrometres)
57. PM<sub>2.5</sub> – Particulate Matter (2.5 micrometres)
58. PPP – Public-Private Partnership
59. RFP – Request for Proposal
60. SCM – Smart Cities Mission
61. SCODP – Smart Cities Open Data Platform
62. SD – Standard Deviation
63. SO<sub>2</sub> – Sulphur Dioxide
64. SVD – Speed Violation Detection
65. UNFCCC – United Nations Framework Convention on Climate Change
66. UV – Ultraviolet
67. VMS – Variable Message Sign
68. WKT – Well-Known Text (GIS format)

# 1. Executive Summary

## 1.1 Background and Context

India's rapid urbanization has placed immense pressure on urban transportation systems, leading to severe congestion, deteriorating air quality, and rising carbon emissions. The ORF Report on Energy Transition in India's Transport Sector (Dec 2024) highlights transport sector as a significant contributor to India's greenhouse gas (GHG) emissions, accounting for 14% of the country's energy-related CO<sub>2</sub> emissions, with road transport alone responsible for 87% of passenger traffic and 60% of freight movement. The exponential growth of private vehicles, coupled with inadequate public transport infrastructure, has exacerbated traffic congestion and pollution in major urban centres.

A pilot study has been undertaken for NOIDA (New Okhla Industrial Development Authority), a key satellite city in the National Capital Region (NCR), which is apt for study being a city in National Capital Region. The city's data-rich ecosystem makes it an ideal testbed for leveraging analytics to achieve sustainable urban mobility. NOIDA has implemented an Intelligent Traffic Management System (ITMS) to monitor and manage traffic flow using real-time data from cameras, sensors, Emergency Call Boxes (ECBs), Meteorological Systems (MET), Integrated Command and Control Centre (ICCC) and Data Centre. With its population projected to reach 2.5 million by 2031, as per NOIDA Master Plan 2031 and a booming industrial and commercial sector, NOIDA faces escalating traffic congestion, longer commute times, and worsening air pollution. Despite ITMS initiatives in transport, including the deployment of Integrated Command and Control Centres (ICCCs) for real-time traffic monitoring, the potential of data-driven strategies for transport decarbonization remains largely untapped.

This study leverages NOIDA's Intelligent Traffic Management System (ITMS), which integrates:

- i. Meteorological (MET) Data: Real-time air quality monitoring (NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>).
- ii. Automatic Number Plate Recognition (ANPR): Vehicle type, fuel, and emission norms.
- iii. Speed Violation Detection (SVD): Traffic flow and congestion patterns.

By analysing these datasets, the study aims to bridge the gap between data availability and actionable policy interventions, providing a model for sustainable urban mobility that can be replicated across other Indian cities.

## 1.2 Objectives of the Study

The study is guided by four key objectives:

1. Assess Emission Patterns
  - a. Quantify pollutants (NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>) across NOIDA's major traffic corridors.
  - b. Correlate emissions with traffic volume, speed, and vehicle composition.
2. Identify Pollution and Congestion Hotspots
  - a. Use Geographic Information Systems (GIS) to map high-emission zones.
  - b. Analyse diurnal and weekday-weekend variations in traffic and pollution levels.

3. Evaluate Fleet Composition and Emission Trends
  - a. Profile vehicle types (petrol, diesel, CNG, electric) and their emission factors.
  - b. Assess the impact of vehicle age and fuel type on air quality.
4. Formulate Data-Driven Decarbonization Strategies
  - a. Recommend traffic management interventions (e.g., speed management, signal optimization, congestion pricing).
  - b. Propose fleet modernization (e.g., EV adoption, CNG transition).
  - c. Advocate for policy measures (low-emission zones, restriction on cars and prioritization of public transport vehicles).

The study focuses on **Below Mahamaya Flyover**, a critical junction connecting NOIDA's expressway and caters to high volumes of regional traffic (Exterior – Exterior trip), as a case study to derive scalable insights for decarbonisation strategies.

## 1.3 Key Findings and Recommendations

### Key Findings

Air quality exceedances were observed at major intersections, with  $PM_{2.5}$  and  $PM_{10}$  levels surpassing CPCB standards. For instance, at Below Mahamaya,  $PM_{2.5}$  reached  $251.7 \mu\text{g}/\text{m}^3$ , far exceeding the permissible limit of  $60 \mu\text{g}/\text{m}^3$ . While  $NO_2$  and  $SO_2$  generally remained within regulatory limits, they exhibited weekend spikes. Further investigation was needed to conclude whether this change was due to traffic patterns or meteorological conditions. The mean speed of  $58.3 \text{ km/hr}$  was observed at this location and the speeds dropped to  $9 \text{ km/hr}$ , linking to elevated PM emissions. Diesel vehicles, despite constituting only 22% of the fleet, disproportionately contributed to  $NO_x$  emissions ( $0.14 \text{ g/km}$  compared to  $0.02 \text{ g/km}$  for petrol/CNG vehicles). In terms of fleet composition of cars, petrol vehicles dominated at 55%, followed by CNG (23%) and diesel (22%). Spatial and temporal trends revealed that Sector 93 emerged as a high-emission hotspot, recording  $PM_{2.5}$  levels of  $302.2 \mu\text{g}/\text{m}^3$ . Additionally, nighttime pollution was notably higher for  $SO_2$  and  $NO_2$ , a trend attributed to freight movement and industrial activities.

Urban transport decarbonization in NOIDA is essential for achieving sustainable mobility and reducing emissions. This report presents a comprehensive approach integrating technology, policy, and behavioural change for transitioning towards a cleaner, more efficient transport system.

### Decarbonization Strategies

#### 1. Transition to Efficient Technology

Efficient transportation technologies play a pivotal role in emission reduction. AI-powered traffic management, adaptive traffic signals, and predictive analytics can optimize traffic flow and minimize idling emissions. The study's ANPR data analysis revealed that hybrid and EV vehicles constitute a negligible fraction of the car fleet (543 vehicles sampled), underscoring the need for stronger incentives and infrastructure improvements. Additionally, leveraging intelligent

transport systems (ITS), GPS-based vehicle tracking, and open data platforms like the India Urban Data Exchange (IUDX) can drive innovations in emission reduction.

## **2. Fleet Modernization and Electrification**

Modernizing NOIDA's vehicle fleet is crucial for reducing air pollution. The study found PM<sub>2.5</sub> and PM<sub>10</sub> levels exceeded permissible limits, peaking during congestion hours, while diesel vehicles recorded the highest NO<sub>x</sub> emissions (0.14 g/km). Strategies such as expanding EV charging infrastructure, incentivizing EV adoption, enforcing Bharat Stage VI norms, and introducing Low-Emission Zones (LEZs) can accelerate the transition to cleaner transport.

## **3. Traffic Management Interventions**

Implementing dynamic traffic control measures, to prioritize public buses, non-motorized transport (NMT) through pedestrian pathways, safe infrastructure for bicycles and integrated bike-sharing systems will promote low carbon sustainable mobility. Electronic road pricing (ERP) and synchronized signal system have potential to reduce congestion and emissions. Data gaps in speed and traffic volume hinder effective management; thus, strengthening data collection and analysis is essential.

## **4. Policy Recommendations for Sustainable Urban Mobility**

A robust policy framework is required to institutionalize decarbonization efforts. Strategies include mandating EV quotas for public transport, enforcing congestion pricing, and fostering public-private partnerships for smart mobility solutions. Aligning NOIDA's Comprehensive Mobility Plan (CMP) with national initiatives like PM Gati Shakti and the Smart Cities Mission can enhance multi-modal connectivity. Additionally, implementing nocturnal emission controls, LEZs, and public awareness campaigns will mitigate air pollution.

## **5. Behavioural Change and Awareness Campaigns**

Public engagement is crucial to shifting commuter behaviour toward sustainable transport such as bicycling and use of public transport. Awareness campaigns highlighting the health and economic benefits of EVs, eco-driving techniques, and car-free initiatives can encourage behavioural change. Successful cases e.g., Hyderabad and Bhubaneswar using ITMS for sustainable mobility required a lot of public engagement and awareness that brought about behavioural change.

# **Conclusion and Next Steps**

NOIDA has the potential to become a model pilot city for data-driven decarbonization by integrating technology, policy, and behavioural strategies. Key next steps include piloting ERP and EV zones in high-impact corridors, establishing a dedicated task force for CMP implementation, and monitoring key performance indicators (KPIs) via ICCC dashboards.



## 2. Context

In recent years, the rapid advancement of data-driven technologies has significantly transformed the landscape of urbanization in India especially the smart cities. These innovations have reshaped urban management by offering efficient solutions to complex urban problems across multiple sectors, including transportation, energy, waste management, and water conservation. AI is revolutionizing India's urban landscape through data-driven development, optimizing city administration with smart analytics. AI-powered traffic management, using predictive analytics and adaptive signals, enhances vehicle flow and reduces congestion.

### 2.1 Data as a resource for Multi-Sectoral Development

Data has emerged as a valuable resource that can be tapped for diverse applications, including infrastructure development, decarbonization, public safety, healthcare, education, agriculture, transportation, finance, manufacturing, and urban planning. By harnessing the power of data, these sectors can drive innovation, improve efficiency, and support sustainable growth. The use of Geographic Information Systems (GIS) for spatial mapping of air pollution levels allows policymakers to identify high-emission zones and implement targeted mitigation strategies. Similarly, meteorological data, when integrated with traffic analytics, enables accurate forecasting of pollution hotspots, aiding in proactive interventions.

The integration of data analytics in cities' development has led to enhanced decision-making and operational efficiency. For instance, real-time traffic monitoring systems leverage Automatic Number Plate Recognition (ANPR) and Speed Violation Detection (SVD) to regulate vehicular movement and optimize traffic flow. Similarly, in the energy sector, smart grids utilize predictive analytics to balance electricity demand and reduce energy wastage. In waste management, sensor-based bins help cities like Pune and Indore streamline collection schedules, thereby reducing operational costs and improving sanitation outcomes. These examples highlight how urban infrastructure development has become increasingly data-centric, leading to smarter, more adaptive city planning.

Advanced security systems with facial recognition and anomaly detection improve public safety. Integration of technology into energy-efficient buildings promotes seamless operations and resource optimization. Smart grids leverage digital technology to monitor electricity distribution, integrate renewable energy sources, and efficiently balance supply and demand. Additionally, smart grids and energy management systems help minimize waste by optimizing energy consumption in buildings, streetlights, and public facilities. IoT sensors optimize waste collection, recycling, and disposal processes, minimizing environmental impact. Applications like Geographic Information Systems (GIS) and predictive modelling allow planners to assess the impact of new developments while balancing economic growth with environmental preservation. Infrastructure monitoring systems track the health of assets like bridges and roads to prevent failures through proactive maintenance. Data-driven platforms empower citizens to participate in decision-making processes by providing real-time feedback on urban services.

## 2.2 Government initiatives leveraging Data

Smart Cities Mission (SCM) has promoted the use of Integrated Command and Control Centres (ICCCs) to monitor and manage urban functions in real time. Launched in 2015, SCM aimed to develop 100 smart cities across India by integrating technology to enhance urban infrastructure, sustainability, and quality of life. **Integrated Command and Control Centres (ICCCs)** function as the “nerve centre” for real-time city management, leveraging AI, IoT, and data analytics for traffic management, waste disposal, disaster response, and more.<sup>1</sup> Established in 70 out of 100 smart cities, these ICCCs serve as hubs for real-time data analysis and urban management. By Jan 2021, 53 cities had operational ICCCs.<sup>2</sup>

As per the CII Report (2025)<sup>3</sup>, Phase I of the SCM successfully implemented technology-driven solutions for urban services, while Phase II focuses on integrating AI/ML applications for improved efficiency, cost reduction, and better citizen experiences. Building on these achievements, Phase II of the SCM envisions leveraging AI and ML-driven applications to optimize city services. A key focus area is multimodal journey planning, integrating buses, metros, and e-bikes to provide seamless urban mobility. Fleet optimization through data-driven route and occupancy management to enhance transport efficiency. The establishment of green corridors for emergency vehicles to ensure faster response times. Air quality-based action plans to drive environmental sustainability. Real-time parking and EV charging solutions to cater to the growing need for smart mobility infrastructure. Flood prediction and management systems to strengthen urban resilience against climate change impacts. Safe travel routes to be identified using predictive analytics, enhancing pedestrian and commuter safety. Predictive health management to allow early detection and intervention in public health issues. Revenue leakage detection in tax and utility billing will improve financial efficiency. Additionally, smart solid waste collection using dynamic routing will ensure timely and effective waste disposal, contributing to cleaner urban spaces.

The SCM partnered with IISc Bengaluru in 2018 to develop the **India Urban Data Exchange (IUDX)**, an open-source platform for secure data sharing across over 50 cities, integrating 800+ data resources. IUDX enables internal and external data exchange, fostering innovative applications and new revenue models. Private players have leveraged it for solutions like emergency vehicle prioritization, waste management, multimodal journey planning, flood prediction, and traffic management, enhancing city operations and citizen well-being.

Urban Data Platforms, such as the Smart Cities Open Data Platform (SCODP) under the SCM, enable cities to visualize, share, and exchange data. These platforms provide actionable insights for coordinated governance, resource optimization, and innovative applications, including pollution monitoring and public safety enhancements. Additionally, the **National Data Governance Framework Policy** aims to establish a structured approach for data sharing among various governmental and private entities to enhance service delivery and urban efficiency.

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1. World Economic Forum (2020), Technology and Data Governance in Cities Indian Smart Cities at the Forefront of the Fight Against COVID-19 INSIGHT REPORT DECEMBER 2020, In collaboration with the Ministry of Housing and Urban Affairs, Government of India and Deloitte. Access on 24.03.2025 available at [https://www3.weforum.org/docs/WEF\\_Technology\\_and\\_Data\\_Governance\\_in\\_Smart\\_Cities\\_India\\_2020.pdf](https://www3.weforum.org/docs/WEF_Technology_and_Data_Governance_in_Smart_Cities_India_2020.pdf)
  2. The ICCC Maturity Assessment Framework (IMAF) (2021), Ministry of Housing and Urban Affairs, Government of India. Accessed on 24.03.2025 available at <https://smartcities.gov.in/sites/default/files/2023-07/MoHUA%20ICCC%20Maturity%20Assessment%20Framework%20IMAF.pdf>
  3. CII (Jan 2025), India's Smart Cities Mission: Issues and Recommendations based on Learnings from 50 Smart Cities.

Ministry of Housing and Urban Affairs (MoHUA), under the SCM has developed ICCC Maturity Assessment Framework (IMAF), a comprehensive toolkit designed to evaluate the maturity of Integrated Command and Control Centres (ICCCs) within smart cities. The IMAF is divided into several key components – Functional Capability Assessment, Technology Assessment, Governance Assessment, and Citizen Engagement & Outreach. The assessment process consists of two main stages. Stage I involves a self-assessment toolkit that enables cities to evaluate their current maturity levels against established indicators. This stage allows cities to identify gaps, strengths, and areas for improvement based on predefined benchmarks. Stage II builds upon this by conducting an on-site maturity assessment, providing a more in-depth evaluation through real-world applications and observed outcomes. This stage ensures a comprehensive understanding of a city's progress, validating the self-assessment findings and offering actionable insights for further development.

Several smart cities, including Pune, Hyderabad, Bhubaneswar, Bhopal, Surat, and Pimpri-Chinchwad, have emerged as leaders in implementing data-driven governance. These cities have received certifications recognizing their advanced technological integration. Hyderabad and Bhubaneswar have implemented innovative solutions to tackle urban traffic congestion, leveraging technology and integrated systems. However, challenges remain, including disparities in digitalization among cities with fewer resources, coordination issues between multiple urban data platforms, and the need to balance data monetization with accessibility while ensuring cybersecurity.

A key aspect of ICCCs is their capacity to enhance coordination among different city departments. Essential sectors such as Traffic Police, Health, Water, Solid Waste Management, and Irrigation have been linked with ICCCs. Among these, integration with the Police department stands out as one of the most significant in most cities. Hyderabad implemented an AI-powered Adaptive Traffic Control System (ATCS) to tackle congestion and improve traffic flow. Led by the Hyderabad Traffic Police and GHMC, the system replaced static signals with AI-driven ones, inspired by Singapore's GLIDE model. IoT sensors and cameras collect real-time data, allowing AI to dynamically adjust signal timings, managed through a centralized control centre. Travel times in pilot areas dropped by 20–25%, easing congestion and making commutes more predictable. Reduced idling at traffic signals also led to a ~15% decrease in CO<sub>2</sub> emissions, contributing to cleaner air. Emergency response times improved as well, with ambulances and fire trucks clearing traffic 30% faster, enhancing public safety. Additionally, a survey conducted by GHMC reported an 85% approval rate from commuters, who experienced shorter wait times and smoother traffic flow. Details of the case study of Hyderabad ATCS is enclosed at **Annexure 1**.

Bhubaneswar, Odisha's rapidly growing capital, tackled rising traffic congestion by implementing an AI-driven Adaptive Traffic Signal Control System (ATSCS) under its Smart City Mission. Developed by C-DAC, the Composite Signal Control Strategy (CoSiCoSt) dynamically adjusts signals using real-time data from embedded sensors, replacing outdated static systems. Funded with INR 14.7 crore, the project was first piloted at 58 intersections, 14 pelican crossings, and 5 blinker zones before scaling. Key features include AI-based synchronization, solar-powered infrastructure, and integration with Bhubaneswar's Central Command Centre for citywide monitoring.

The system is expected to reduce intersection delays by 20–30%, cut CO<sub>2</sub> emissions by 12–15%, and improve emergency vehicle response times. Challenges like initial sensor calibration issues and public adaptation were addressed through iterative testing and awareness campaigns. A pilot-first approach minimized risks, while collaboration between Bhubaneswar Smart City Limited, traffic police, and C-DAC ensured smooth execution. Bhubaneswar's ATSCS demonstrates how indigenous AI solutions can enhance urban mobility while supporting

decarbonization. The project serves as a scalable model for other cities, proving that adaptive traffic systems are vital for smarter, sustainable transport. The details of the case examples of Bhubaneswar are enclosed at **Annexure 2**.

## 2.3 Challenges in Data Utilization for Urban Management

Urban management increasingly relies on data to improve decision-making and services. However, several critical challenges hinder the effective use of data in this context. Despite its transformative potential, data utilization in urban management faces several challenges, including fragmented data systems, restrictive access, privacy concerns, and inefficient data mining, governance gaps and technological bottlenecks.

Data fragmentation arises from diverse sources like IoT devices, administrative records, and satellite imagery, which produce varied formats and quality, making integration difficult. Restrictive access due to legal, institutional, or competitive concerns further limits collaboration and innovation. Privacy concerns also emerge, as smart city applications collect sensitive data, requiring a careful balance between compliance and utility. Inefficient data mining presents another challenge, with unstructured data needing advanced techniques like machine learning, which demand resources and expertise. Governance gaps, including unclear roles, inconsistent policies, and weak collaboration, further weaken data management. Additionally, outdated technology and financial constraints limit the adoption of advanced solutions, making scalability difficult as cities expand.

For instance, while cities collect vast amounts of mobility data through surveillance cameras and GPS tracking, these datasets are often siloed and underutilized. A case in point is Delhi's air pollution crisis—had real-time vehicular emission data been systematically analysed and integrated with transport policies, more effective congestion pricing or vehicle restriction strategies could have been implemented earlier (CSE, Nov 2024).<sup>5</sup>

Based on the study of 50 Smart Cities in India by CII (Jan 2025), one major challenge is sub-optimal implementation, often caused by poorly defined Requests for Proposals (RFPs), leading to ineffective deployments. Additionally, a lack of integration in systems such as traffic control further hampers efficiency. Another significant hurdle is the limited technical capacity among city officials, who often lack the expertise to monitor, evaluate, and certify smart city solutions, resulting in disputes over implementation quality and delays in project execution. Furthermore, the absence of a comprehensive data policy creates complications in data ownership, sharing, and monetization. For instance, ambulance data is not integrated into traffic management systems due to privacy concerns & resistance by service providers, limiting its potential benefits.

To address these challenges, several recommendations were made by CII for future smart cities. First, an improved RFP framework should be established, defining clear technical specifications and data-sharing requirements while ensuring real-time monitoring and API integration for better interoperability. Second, robust implementation and maintenance protocols must be enforced, including continuous calibration of environmental and surveillance sensors, along with strong monitoring Key Performance Indicators (KPIs) for system integrators. Additionally, a well-defined data policy and governance structure should be developed, outlining data

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5. <https://www.cseindia.org/mobility-crisis-is-behind-the-pollution-in-delhi-12455#:~:text=Despite%20taking%20several%20technology%20measures,to%20the%20growing%20mobility%20crisis.>

ownership and a standardized data-sharing policy, while also establishing monetization models to encourage private sector participation. The integration of Artificial Intelligence (AI) and Machine Learning (ML) in city operations can further enhance efficiency by enabling predictive analytics in areas such as waste management, traffic control, and revenue collection. Furthermore, smart governance platforms should be developed to track performance metrics and improve decision-making processes. Lastly, key smart city datasets play a crucial role in optimizing urban management and services. These datasets include environmental data (air quality, flood levels, and rainfall), traffic data (surveillance cameras, violation detection, and smart signals), and public transport data (bus, metro, and e-bike availability). Additionally, revenue and taxation data (property tax and trade licenses), emergency response data (ambulance tracking and fire response), and infrastructure and utilities data (streetlights, water distribution, and GIS mapping) are essential for effective city planning and operations. By addressing these challenges and implementing these recommendations, smart cities can achieve greater efficiency, sustainability, and improved quality of life for citizens.

## 2.4 Data-Driven Transportation Management for Decarbonization and Road Safety

The effective utilization of data in transportation management has immense potential to improve urban mobility, reduce emissions, and enhance road safety. However, Indian cities have yet to fully leverage data analytics for optimizing transportation networks, mitigating congestion, and achieving decarbonization goals.

Real-time traffic data, vehicle telematics, and AI-powered predictive analytics can be instrumental in reducing carbon footprints by optimizing route planning, enhancing public transport efficiency, and promoting non-motorized transport. For instance, dynamic traffic light control systems based on real-time congestion data can minimize vehicle idling time, thereby reducing fuel consumption and emissions. Additionally, integrating public transport data with real-time passenger information systems can encourage higher ridership, reducing dependence on private vehicles and leading to lower emissions.

**Case Example: Singapore's Smart Mobility Framework.** Singapore has effectively utilized data-driven transportation management through its Intelligent Transport System (ITS). The city-state employs a combination of GPS-based vehicle tracking, Electronic Road Pricing (ERP), and AI-driven traffic forecasting to optimize road usage and reduce congestion. The ERP system dynamically adjusts toll rates based on real-time traffic conditions, discouraging excessive vehicle use during peak hours and promoting public transport adoption. This initiative has significantly reduced congestion and vehicular emissions, making Singapore a global leader in smart mobility.

Singapore's Intelligent Transport System (ITS) and Electronic Road Pricing (ERP) have significantly improved urban mobility by reducing congestion, cutting CO<sub>2</sub> emissions by 15%, and increasing public transport use to 75% during peak hours. These advancements have positioned Singapore as a global model for data-driven decarbonization (ITF, 2023). Details of the Singapore case study are enclosed at **Annexure 5**.

**Data for Road Safety Enhancement.** Data analytics plays a crucial role in identifying high-risk zones and implementing targeted safety measures. Collision and incident data, coupled with predictive modelling, can help authorities design safer roadways, optimize speed limits, and implement proactive measures such as automated traffic enforcement and hazard detection systems.

**Case Study: Vision Zero Initiative in Sweden.** Sweden’s Vision Zero initiative is a benchmark in using data for road safety. Swedish parliament adopted vision zero policy in 1997. The policy is based on the understanding of human frailty and errors that road users make and therefore the importance of ensuring safety by designing forgiving infrastructure. By analysing crash data, traffic patterns, and pedestrian movement, authorities have redesigned urban road infrastructure to prioritize safety. The initiative has led to a significant reduction in road fatalities through measures such as speed reduction in high-risk areas, improved pedestrian crossings, and intelligent traffic monitoring systems. Implementing similar data-driven strategies in Indian cities could drastically improve road safety and reduce traffic-related fatalities.

Sweden has one of the lowest road fatality rates globally, with 2.2 deaths per 100,000 people in 2022, compared to 11.4 in the U.S. and 15.3 in India. Since the introduction of road safety initiatives, pedestrian deaths have dropped by 50% (Swedish Transport Administration, 2023). Effective speed management and infrastructure redesign have further enhanced safety, with the implementation of 30 km/h (18 mph) speed limits in urban areas reducing fatal crashes by 25%. Additionally, replacing high-risk intersections with roundabouts has led to a 75% reduction in severe injuries (OECD, 2020). Intelligent traffic monitoring has also played a crucial role, with automated speed cameras and AI-based traffic analysis improving enforcement and cutting speeding violations by 40%. Details of the case study of Sweden at **Annexure 5**.

**Potential for India.** Cities in India, especially the metropolitan cities generate vast amounts of transport-related data through GPS-enabled public transport systems, electronic toll collection, and surveillance cameras. However, the integration of this data for actionable insights remains limited. A structured approach to data utilization and innovations in utilization of data can enhance urban mobility by reducing congestion, lowering emissions, and improving road safety; and explore other opportunities for transport data utilization like decarbonization.

## 2.5 Conclusion

Despite the vast potential of data-driven urban management, its full utilization remains unrealized due to systemic challenges. The fragmented nature of data systems, restrictive access policies, and privacy concerns limit its seamless integration across sectors. While initiatives like the Smart Cities Mission and Integrated Command and Control Centres (ICCCs) have improved urban governance, data remains underutilized due to governance gaps and outdated technology. For example, mobility data collected through surveillance cameras and GPS tracking is often siloed, preventing cities from leveraging it for effective traffic decongestion and air quality management.

To maximize the benefits of urban data, cities must prioritize interoperability by developing standardized frameworks for data sharing across departments and sectors. Strengthening governance mechanisms is equally crucial—establishing clear policies for data ownership, security, and ethical use can foster trust among stakeholders. Additionally, investment in advanced analytics, AI-driven insights, and real-time processing capabilities will enhance decision-making and urban service delivery. Public-private collaborations can also drive innovation by facilitating open data platforms and incentivizing the development of smart applications.

Maximizing the potential of data in transportation management can significantly improve mobility, reduce emissions, and enhance road safety in Indian cities. Learning from global examples like Singapore’s Intelligent Transport System and Sweden’s Vision Zero initiative. Singapore’s Intelligent Transport System (ITS) and Electronic Road Pricing (ERP) have greatly enhanced urban mobility by alleviating traffic congestion, lowering CO<sub>2</sub> emissions by 15%, and

boosting public transport usage to 75% during peak hours. These innovations have established Singapore as a leading example of data-driven decarbonization (ITF, 2023). Similarly, Sweden's Vision Zero Initiative, introduced in 1997, has become a global standard for data-driven road safety. Through urban infrastructure redesign, speed management strategies, and intelligent traffic monitoring, Sweden has achieved one of the world's lowest road fatality rates, with notable declines in pedestrian deaths, fatal accidents, and severe injuries. India can leverage real-time analytics, predictive modelling, and AI-driven solutions to optimize traffic flow and prevent accidents. However, the current underutilization of transport-related data limits these advancements, requiring stronger integration, policy support, and investment in smart mobility solutions. By adopting a data-driven approach, India can create safer, more efficient, and sustainable urban transport systems, aligning with its broader decarbonization and urban development goals.

A future-ready approach requires not only improving data infrastructure but also fostering a culture of data-driven decision-making among policymakers, urban planners, and citizens. By overcoming the barriers to data utilization, Indian cities can transform into truly smart, resilient, and sustainable urban ecosystems, ensuring efficient governance, improved quality of life, and long-term economic growth.



## 3. Need for the Study

India stands at a critical juncture in its development trajectory, experiencing rapid urbanization alongside robust economic growth. With urban population projected to reach 600 million by 2031, representing approximately 40% of the total population, Indian cities are undergoing unprecedented transformation. This urban expansion brings with it inevitable challenges related to transportation infrastructure, mobility patterns, and environmental sustainability.

The transportation sector has become indispensable to India's socioeconomic fabric, contributing around 10% to the national GDP and serving as the backbone for industrial and commercial activities. Road transport alone accounts for approximately 87% of passenger traffic and 60% of freight movement across the country. However, this growth in transportation demand has resulted in significant environmental costs, with the sector contributing between 12-14% of India's energy-related CO<sub>2</sub> emissions.<sup>6</sup>

In rapidly growing satellite cities like NOIDA, where the population has been doubling every decade since 1991 and is expected to reach 25 lakhs by 2031, transportation challenges are particularly acute. The city's strategic location within the National Capital Region (NCR) and its development as an integrated industrial township have created unique mobility demands that necessitate innovative solutions.

Despite various policy initiatives aimed at promoting sustainable transportation, there exists a critical gap in the implementation of data-driven approaches for decarbonization. Current interventions often lack the granularity and real-time insights necessary to effectively target high-emission zones and develop context-specific strategies. This study addresses this gap by leveraging comprehensive traffic and transport data collected through NOIDA's Integrated Command and Control Centre (ICCC).

Conventionally, traffic and transport data have been utilized for traffic management, congestion reduction, and security surveillance. However, their application in decarbonization remains largely unexplored. The need for a data-driven approach is further underscored by the complex interplay of factors influencing urban transportation emissions, including vehicle fleet composition, traffic congestion patterns, infrastructure quality, and modal preferences. By analysing granular data from Meteorological (MET) Systems, Automatic Number Plate Recognition (ANPR), and Speed Violation Detection (SVD), this study aims to develop a nuanced understanding of emission hotspots and identify targeted intervention points. Moreover, as NOIDA continues to expand its transportation infrastructure under various development initiatives, including the Comprehensive Mobility Plan for a perspective of 50 years (Plan Document to be prepared by 2027, existing version 2015), there exists a unique opportunity to integrate decarbonization principles into the city's mobility framework.

This study is both essential and timely for several key reasons. First, the rising carbon footprint from urban transport demands targeted strategies for emission reduction. Second, leveraging advanced analytics on vehicle movement, fleet composition, and pollution levels can enable data-driven policy decisions. Third, NOIDA serves as an ideal testing ground due to its robust data infrastructure managed by EFKON STRABAG, providing a rich dataset for developing

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6. India's Long-Term Low-Carbon Development Strategy [https://unfccc.int/sites/default/files/resource/India\\_LTLEDS.pdf](https://unfccc.int/sites/default/files/resource/India_LTLEDS.pdf)

and validating decarbonization models. Fourth, the study aligns with India's national and global climate commitments, including the pledge to achieve net-zero emissions by 2070, as announced at COP26. Additionally, India aims to cut its projected carbon emissions by one billion tonnes by 2030.

The research will focus on two primary strategies to reduce transport-related emissions. The first is transitioning to a more efficient vehicle fleet, encouraging a shift from CNG or diesel-powered shared transport modes to electric vehicles. The second involves reducing emissions from motorized transport by implementing measures to optimize vehicle speeds. Maintaining steady speeds within legal limits and minimizing congestion duration can significantly lower emissions.

By harnessing the power of traffic data, this study has the potential to drive transformative research and policy interventions, paving the way for sustainable urban transport decarbonization in India.

### 3.1 Significance of Decarbonization

The significance of transportation decarbonization extends beyond local environmental benefits, representing a critical component of India's broader climate commitments and sustainable development aspirations. During COP-28, India presented its Long-term Low Greenhouse Gas Emissions Development Strategy (LT-LEDS), which articulates the country's pathway toward achieving its Nationally Determined Contribution (NDC) goals by 2030 and net-zero emissions by 2070.

As one of the world's fastest-growing economies and home to approximately one-sixth of humanity, India's development trajectory carries significant implications for global sustainability efforts. While India's historical contribution to global warming has been minimal, the country has demonstrated remarkable commitment to combating climate change by making development choices that promote economic growth along low-carbon pathways.

India's approach to climate action is firmly rooted in the principles of equity and Common but Differentiated Responsibilities and Respective Capabilities (CBDR-RC), as enshrined in the United Nations Framework Convention on Climate Change (UNFCCC).

Within this broader framework, decarbonizing the transportation sector emerges as a strategic priority due to its significant contribution to national emissions. The transport sector in India, particularly road transport, represents one of the fastest-growing sources of greenhouse gas emissions.

The current policy landscape in India demonstrates a multi-faceted approach to transportation decarbonization, encompassing improved fuel efficiency, cleaner fuel adoption, modal shifts toward public transport, electrification across multiple modes, and intelligent transport systems. Key initiatives include:

- i. An indicative target of 20% ethanol blending in petrol by 2025
- ii. Leapfrogging from Bharat Stage V emissions standards directly to Bharat Stage VI
- iii. Comprehensive support for electric vehicle manufacturing and adoption
- iv. Indian Railways' commitment to achieve net-zero emissions by 2030
- v. National Master Plan for Multi-modal Connectivity under PM Gati Shakti
- vi. Integration of transport networks through various programs including Bharatmala and Sagarmala

This study's focus on data-driven decarbonization strategies with pilot study in NOIDA represents a practical application of these national priorities at the city level. By developing a framework that leverages real-time traffic and transport analytics, the study contributes to India's broader decarbonization agenda while addressing the specific challenges of rapidly growing urban centres.

Furthermore, the methodologies and insights generated through this pilot study have the potential for wider application across other Indian cities facing similar urbanization and transportation challenges. By demonstrating the efficacy of data-driven approaches in identifying emission hotspots and evaluating intervention strategies, this study can inform the development of more targeted and effective decarbonization policies nationwide.

## 3.2 Role of ICCC Data in Decarbonization Strategies

The Integrated Command and Control Centre (ICCC) serves as a vital data repository that underpins decarbonization strategies in urban transport. In this pilot study, high-resolution, continuous, and geo-tagged traffic data from NOIDA's Intelligent Traffic Management System (ITMS) is leveraged to identify high-emission corridors and pollution hotspots. The ITMS, developed by EFKON STRABAG, integrates data from Meteorological (MET) systems, Automatic Number Plate Recognition (ANPR) cameras, and Speed Violation Detection (SVD) units deployed 677 devices at 112 locations. This diverse data set enables the application of machine learning models, spatial analytics, statistical techniques, and simulation-based scenario building to formulate targeted interventions. Specifically, the data facilitates evidence-based recommendations for optimizing signal timings, reducing idle emissions, and promoting eco-friendly traffic policies. Additionally, it supports the formulation of strategies for fleet modernization and a modal shift in private transport, which are critical for reducing carbon footprints. By transforming raw traffic data into actionable insights, the study demonstrates how ICCC data can function as a strategic asset in achieving decarbonization. This pioneering approach not only fills the current gap in using granular traffic analytics for emission reduction but also lays the foundation for replicable, data-driven decarbonization frameworks in other urban centres, thereby contributing to sustainable urban mobility and environmental resilience.

## 3.3 Significance of NOIDA as a Pilot Study Location

NOIDA, the New Okhla Industrial Development Area, represents an ideal pilot study location for exploring decarbonization strategies in urban transport. Established as a census town in 1991, NOIDA's population has been doubling every decade, with projections indicating a rise from 6.37 lakh in 2011 to 25 lakh by 2031. Spanning 81 revenue villages and approximately 20,316 hectares, NOIDA was designed as an integrated industrial township with subsequent commercial development. The Master Plan-2031 has allocated 4,761.31 hectares for industrial, commercial, and institutional purposes, attracting a significant influx of migrants. NOIDA's strategic proximity to Delhi and its inclusion in the CNCR zone of the National Capital Region further enhance its importance as a testbed. This setting enables the collection of high-resolution traffic and transport data through the ICCC, which is instrumental in developing innovative decarbonization strategies. By piloting these interventions in NOIDA, the study can validate models for reducing emissions and enhancing road safety, offering a blueprint that can be replicated across other urban centres in India and beyond. **This study, conducted as a pilot in NOIDA, explores how data collected by the Integrated Command and Control Centre (ICCC) can be instrumental in developing a first-of-its-kind decarbonization framework.**

The installed devices for the collection of the three types of data used in the study including Meteorological Systems, Automatic Number Plate Recognition and Speed Violation Detection, are shown in Table 1 as follows:

**Table 1: Details of devices installed in NOIDA (details of devices relevant to the study)**

<b>No. of Devices</b>	<b>627</b>	<b>25</b>	<b>25</b>
<b>Location</b>	<b>83</b>	<b>4</b>	<b>25</b>
<b>Device</b>	<b>ANPR</b>	<b>ANPR + SVD</b>	<b>MET</b>

The system integrates Automatic Number Plate Recognition (ANPR) cameras, Speed Violation Detection (SVD) units, and Meteorological (MET) sensors to monitor traffic flow, enforce regulations, and collect real-time data along with other devices as per the requirement provided by NOIDA Development Authority. The ANPR system, installed at 83 locations, helps in vehicle tracking and congestion management. The ANPR + SVD combination, at 4 locations, ensures speed compliance, reducing road accidents and emissions. Meanwhile, MET sensors at 25 locations provide climate-related insights. By leveraging data analytics, the ITMS supports the decarbonization process by optimizing signal timings, reducing idle emissions, and promoting eco-friendly traffic policies, thus contributing to a greener and smarter urban transport ecosystem.

The availability of high-resolution, continuous, and geo-tagged traffic data from NOIDA makes it an ideal pilot case for this study. The analysis will employ machine learning models, spatial analytics, statistical techniques and simulation-based scenario building for targeted decarbonization interventions.

The study utilizes Meteorological (MET) Systems, Automatic Number Plate Recognition (ANPR) and Speed Violation Detection (SVD) to identify high-emission zones and evaluate intervention strategies. The pilot study aims to bridge this gap by utilizing high-resolution traffic and transport data collected through the Integrated Command and Control Centre (ICCC) in NOIDA to devise innovative decarbonization strategies which includes Transition to Efficient Technology, Fleet Modernization, and Modal Shift Strategy for Emission Reduction in Private Transport Modes.

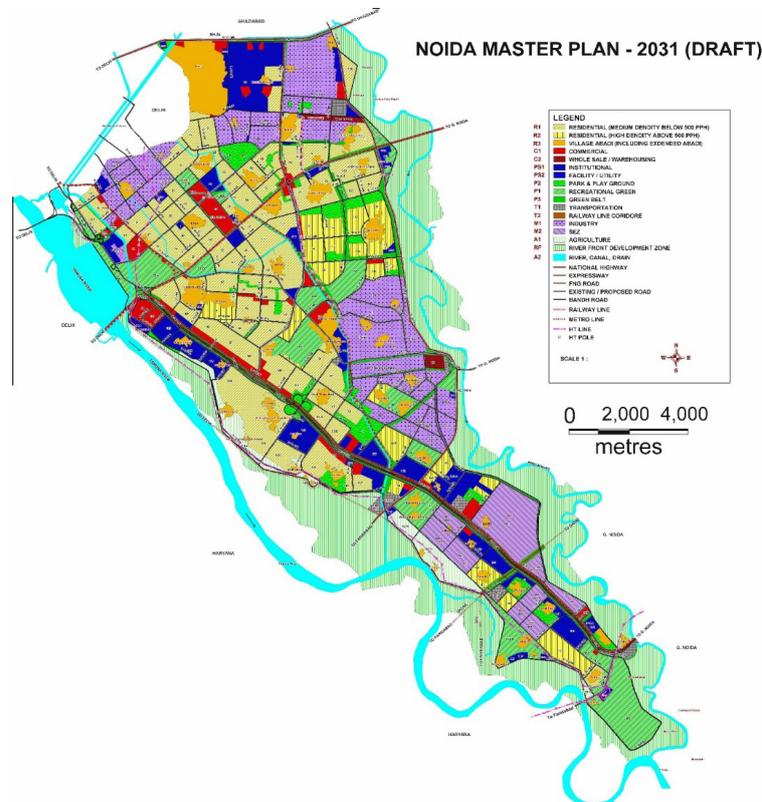
# 4. Profile of NOIDA

The New Okhla Industrial Development Area (NOIDA) was first classified as a census town in 1991 with a population of approximately 1.46 lakh. Since then, its population has exhibited a decadal doubling trend, reaching 6.37 lakh as per the 2011 Census. Projections from the NOIDA Master Plan-2031 estimate that the population will rise to 25 lakhs by 2031. The city spans 81 revenue villages and covers approximately 20,316 hectares.

NOIDA was strategically planned as an integrated industrial township, prioritizing industrial and residential development in its initial growth phases, with commercial expansion following subsequently. According to the Master Plan-2031, 4,761.31 hectares (31.17% of total land area) have been designated for industrial, commercial, and institutional activities, reinforcing NOIDA's role as a key urban and economic hub. This planned spatial distribution, coupled with NOIDA's strategic proximity to Delhi and its integration within the Central National Capital Region (CNCR) of the National Capital Region (NCR), has driven substantial migration and urban expansion.

Given this rapid urbanization and economic transformation, NOIDA's transport infrastructure is experiencing increasing pressure. The decarbonization of transportation within NOIDA requires a comprehensive, multi-modal strategy that aligns with its evolving urban dynamics, emphasizing low-emission mobility solutions, electrification of public transit, and integrated land-use planning to optimize transport efficiency and sustainability. The pictorial representation of the city as mentioned in the city is shown in Figure 1.

**Figure 1: NOIDA Master Plan 2031**



Prepared By :-  
 New Okhla Industrial Development Authority &  
 N.C.R. Planning Cell, Town & Country Planning Department, Ghaziabad

Note :-  
 1. Area of village shown in red colour only. Its extent shall be determined on the basis of actual field survey and revenue records.  
 2. Boundary of industrial area in red colour. It shall be determined on the basis of revenue records.

Source: NOIDA Master Plan 2031, NOIDA, Government of Uttar Pradesh)

## 4.1 Overview of Transportation Infrastructure and Traffic Characteristics

As per the provision of the Master Plan 2031 NOIDA the transportation infrastructure and traffic characteristics are as follows:

### 1. Transport Infrastructure in NOIDA

NOIDA lacks a direct railway station, with the nearest one located about 15 km away at Hazrat Nizamuddin. The city is primarily connected to Delhi, Uttar Pradesh, and Haryana through an extensive road network. From the east, NOIDA is accessible via the Dadri-Surajpur-Chalera (DSC) road. To the north, it is linked to Ghaziabad and Delhi through National Highway (NH-24), accessible via two main roads: one running along the left bank of the Yamuna River and the NOIDA Bypass near Ghazipur. An additional connection runs through Kondli Road between Sector VIII and IX, joining Patparganj Group Housing area.

From the southwest, the Okhla Barrage over the Yamuna River connects NOIDA with Delhi, Faridabad, and southern India through NH-2 (Mathura Road). Master Plan Road 3, extending from Kalindi Kunj to Greater NOIDA, enhances regional connectivity. Recent infrastructure improvements include the widening of the Nizamuddin Bridge and the construction of the DND Flyover, improving access to Delhi.

Additionally, several upcoming projects, such as the Faridabad-NOIDA-Ghaziabad (FNG) Expressway (a six-lane, 56-km-long corridor) and the revamping of the NOIDA-Greater NOIDA Expressway (a six-lane expressway expandable to 8 lane, 165.5 km long corridor), will strengthen connectivity. The proposed railway link from NOIDA to Tughlaqabad in Delhi and Dadri, along with the Mumbai-Dadri freight corridor, will further enhance connectivity and industrial growth.

### 2. Metro and Future Transport Developments

The Delhi Metro Rail Corporation (DMRC) has already begun metro services connecting Delhi to NOIDA City Centre via Mayur Vihar. Plans are underway for an extension linking NOIDA City Centre to Greater NOIDA through Sector 50, 78, 142, and the NOIDA-Greater NOIDA Expressway. This metro expansion aims to improve mobility and stimulate economic activity along the route. Furthermore, the ongoing development of the Yamuna Expressway will further boost connectivity and development prospects for both NOIDA and Greater NOIDA.

### 3. Traffic Volume and Characteristics

Most of the traffic (80%) along the NOIDA-Delhi corridor reflects the strong link between the two cities. Traffic studies indicate that morning hours experience higher traffic volume entering NOIDA, while evening hours see an increase in traffic leaving the city, reflecting a rise in commuter activity. Personal vehicles, including cars and scooters, contribute significantly to the traffic volume, with about 60,000 cars registered in NOIDA, and approximately 850 cars being registered monthly.

Current public transportation options include around 350 DTC buses, 250 UPSRTC buses, and the metro, which together help manage traffic. However, the growing use of personalized vehicles indicates a need for a more integrated public transport system to alleviate congestion.

## 4. Travel Patterns and Transport Demand

Traffic surveys reveal that 75% of trips in NOIDA cover less than 3 km, with only 4.6% of trips exceeding 10 km. The majority (91%) of trips are for work, education, and shopping. Walking is the most common mode for short intra-sectoral trips, followed by buses, two-wheelers, and cars. The high use of personalized vehicles calls for a better-managed public transport system to accommodate increasing demand.

## 4.2 Current Transportation Challenges in NOIDA

### 1. Traffic Congestion

The travel time between NOIDA and Delhi has experienced a substantial increase over the years. In the early 2000s, the commute time was between 35–40 minutes. However, today it has risen to 90–120 minutes, reflecting a significant deterioration in traffic conditions due to the growing demand on the transportation network.

### 2. Growing Population

The rapid population growth in NOIDA, Greater NOIDA and the Yamuna Expressway areas is anticipated to place considerable pressure on the existing transportation infrastructure, leading to further congestion and logistical challenges.

### 3. Infrastructure Strain

Despite the presence of major infrastructure projects such as the DND Flyway, NOIDA Expressway, and Delhi–Meerut Expressway, the area continues to face significant traffic congestion. This is primarily due to the rapid increase in the number of vehicles on the roads, outpacing the capacity of existing infrastructure to accommodate them efficiently.

## 4.3 Comprehensive Mobility Plan (CMP) for NOIDA and Greater NOIDA Region

Historically, NOIDA’s residents have predominantly relied on personal vehicles for transportation, primarily due to the city’s expansive layout. The city is connected to Delhi by three major speedways: the DND Flyway, NOIDA Expressway, and the Delhi–Meerut Expressway. However, over the last two decades, the travel time between NOIDA and Delhi has increased significantly, rising from 35–40 minutes in the early 2000s to 90–120 minutes today.

1. **Current Challenges:** By 2031, NOIDA’s population is projected to reach 6.6 million. This includes 2.8 million in NOIDA, 2.8 million in Greater NOIDA, and one million in the Yamuna Expressway area. Additionally, several major developments are underway, such as the Jewar International Airport and new industrial zones along the Yamuna Expressway. These factors will place significant pressure on the existing transport infrastructure, necessitating strategic upgrades and sustainable mobility solutions. The anticipated growth in population and infrastructure projects highlights the urgent need for enhanced regional connectivity and efficient transportation networks.
2. **Need for a Comprehensive Mobility Plan (CMP):** To address the growing challenges of traffic congestion, public transport enhancement, and freight movement optimization, the NOIDA Authority, in collaboration with the Greater NOIDA and Yamuna Expressway

authorities, plans to develop a Comprehensive Mobility Plan (CMP). The CMP will aim to integrate transport networks across NOIDA, Greater NOIDA, the Yamuna Expressway, neighbouring Delhi, Gurgaon, and Faridabad, thereby improving overall regional connectivity.

The CMP's objectives include:

- i. Reducing traffic congestion
- ii. Enhancing public transport systems
- iii. Optimizing freight movement to support industrial and commercial growth
- iv. Developing a dedicated freight corridor
- v. Establishing a multi-modal logistics and transport hub

The plan also encompasses the development of the Greater NOIDA Extension, new greenfield cities, and the expansion of the Yamuna Expressway area.

3. **Goals of the Comprehensive Mobility Plan:** The CMP seeks to address key transportation issues and ensure efficient, sustainable mobility for the next 50 years. The plan's primary goals include:
  - i. Reducing the travel time between NOIDA and Delhi to 30-40 minutes by 2031
  - ii. Expanding metro lines and integrating them with major projects such as the NOIDA International Airport
  - iii. Planning for sustainable urban growth
  - iv. Improving freight movement efficiency
4. **Timeline for Development:** The development of the Comprehensive Mobility Plan is expected to take place in stages over a 30-month period, with the final blueprint projected to be completed by 2027.

# 5. Data Description, Analytical Framework, and Methodology

## 5.1 Data Description

Three datasets were considered to study the decarbonization strategies in NOIDA. They were the Meteorological (MET) Data, speed data (SVD) and Automatic number plate recognition data (ANPR). The description, data gaps and available data pertaining to each of the datasets is discussed in the following sections.

### 5.1.1 Meteorological (MET) Data

Meteorological data are a set of information, which describes the characteristics of the atmosphere. The MET data was collected using an Environmental Sensor. This is a specialized device used to monitor air quality and environmental parameters in urban areas. For the current study location, NOIDA city, the MET data was collected from twenty-one locations over three months (Nov 2024, Dec 2024, and Jan 2025). The collection of parameters included Temperature, UV, CO, CO<sub>2</sub>, NO<sub>2</sub>, O<sub>3</sub>, SO<sub>2</sub>, Pressure, Noise(min/max), PM<sub>10</sub>, PM<sub>10</sub>, NO, O<sub>2</sub>, Light, and Humidity. This monitoring was done with the objective to identify pollution trends, enabling informed decisions for environmental policies and public health.

In the context of decarbonization, monitoring NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub>, and PM<sub>2.5</sub> was essential because these pollutants are directly or indirectly linked to fossil fuel combustion. Thus, the MET data considered for the current study were NO<sub>2</sub>, SO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub>. The description of the pollutants is tabulated in Table 2.

**Table 2: Description of pollutants**

Pollutant	Description	Unit	Data type	Sources	Effects
PM <sub>2.5</sub>	Fine particulate matter that is smaller than 2.5 micrometers in diameter	µg/m <sup>3</sup>	Continuous	Windblown dust, pollen grains, vehicular emissions, industrial combustion processes, construction industries	Can be inhaled deeply into the lungs, Respiratory problems, visibility reduction, heart stroke
PM <sub>10</sub>	particulate matter less than 10 micrometers, less dangerous than PM <sub>2.5</sub> since they are large	µg/m <sup>3</sup>	Continuous	Suspended road dust and construction dust	cause respiratory issues, likely to penetrate deep into the lungs
Sulphur Dioxide (SO <sub>2</sub> )	Colorless gas, sharp odor	µg/m <sup>3</sup>	Continuous	Diesel and coal combustion, power generation, motor vehicles	Respiratory problems, acid rain, irritation in eyes, mucus secretion
Nitrogen Dioxide (NO <sub>2</sub> )	Toxic gas produces a fraction of PM <sub>2.5</sub>	µg/m <sup>3</sup>	Continuous	Vehicle exhaust, Lightning Forest fires, burning of fossil fuels	Pulmonary disorders

The MET data sensors were established at 25 locations spread across NOIDA. The final data recording was done at 21 locations. These locations were Amrapali Golchakkar, Below Mahamaya, City Centre Botanical Metro (Speed), Degree College Tiraha, Hajipur Chouraha, Hoshiyarpur Tiraha, HTMS (Old) to 44 Golchakra, Indus Valley School Tiraha, Model town, Pathway School, Rajnigandha Chouraha, Samet 76 Internal Road, Sector 142, Sector 18 Metro, Sector 91 T Point, Sector 93, Phool Mandi Chouraha, Okhla bird sanctuary Metro, Aushadhi Park Chouraha (Bhutani), and Spice Mall Chouraha. The details pertaining to the locations about coordinates, location name, type of road are summarized in **Annexure 3**. The preliminary analysis included studying the dataset each of the twenty-one locations separately. The analysis included the summary statistics, weekday /weekend comparison and studying the diurnal variations. Summary of the preliminary analysis for the pollutant  $PM_{2.5}$  is shown in Table 3.

**Table 3: Data description of  $PM_{2.5}$**

Location	Valid Available Data Points	% available
<b>Botanical Metro</b>	10773	100
<b>Degree College Tiraha</b>	10459	100
<b>Model town</b>	10377	100
<b>Sector 18 Metro</b>	10288	100
<b>Sector 91 T Point</b>	1974	100
<b>Sector 93</b>	10333	100
<b>Okhla bird sanctuary Metro</b>	9840	100
<b>Spice Mall Chouraha</b>	9011	100
<b>Pathway School</b>	5862	56.9
<b>Amrapali Golchakkar</b>	2630	26.6
<b>Below Mahamaya</b>	2266	23.5

Summary of the preliminary analysis for the pollutant  $PM_{10}$  is shown in Table 4.

**Table 4: Data description for  $PM_{10}$**

Location	Valid Available Data Points	% available
<b>Botanical Metro</b>	10773	100
<b>Degree College Tiraha</b>	10459	100
<b>Model town</b>	10377	100
<b>Sector 18 Metro</b>	10288	100
<b>Sector 91 T Point</b>	1974	100
<b>Sector 93</b>	10333	100

Location	Valid Available Data Points	% available
<b>Okhla bird sanctuary Metro</b>	9840	100
<b>Spice Mall Chouraha</b>	9011	100
<b>Pathway School</b>	5862	56.9
<b>Amrapali Golchakkar</b>	2630	26.6
<b>Below Mahamaya</b>	2266	23.5

The patterns pertaining to data observed in  $PM_{10}$  and  $PM_{2.5}$  were similar. The table with respect to  $PM_{2.5}$  showed that at the 8 locations: Botanical Metro, Degree College Tiraha, Model Town, Sector 18 Metro, Sector 91 T point, Sector 93, Okhla bird sanctuary metro and Spice Mall Chouraha, 100% of the data was available. Apart from this, the locations. Pathway School, Amrapali Golchakkar and Below Mahamaya had data availability between 20 to 60%.

**Table 5: Data description for  $NO_2$**

Location	Valid Available Data Points	% available
<b>Below Mahamaya</b>	9622	100
<b>Botanical Metro</b>	10773	100
<b>City Centre</b>	10444	100
<b>Degree College Tiraha</b>	10459	100
<b>Hoshiyarpur Tiraha</b>	10349	100
<b>Model town</b>	10377	100
<b>Samet 76 Internal Road</b>	10410	100
<b>Sector 142</b>	10459	100
<b>Sector 18 Metro</b>	10288	100
<b>Sector 91 T Point</b>	1974	100
<b>Sector 93</b>	10336	100
<b>Okhla bird sanctuary Metro</b>	9842	100
<b>Spice Mall Chouraha</b>	9011	100
<b>Phool Mandi Chouraha</b>	5856	61.7
<b>Hajipur Chouraha</b>	5957	57.3
<b>Amrapali Golchakkar</b>	5321	53.7
<b>HTMS (Old) to 44 Golchakra</b>	4460	45.9
<b>Aushadhi Park Chouraha (Bhutani)</b>	3289	34
<b>Pathway School</b>	3354	32.5

The data summary table for NO<sub>2</sub> showed that data was available at all locations. The availability was as high as 100% in 13 locations. The locations: Phool Mandi Chouraha, Haipur Chouraha, Amrapali HTMS(Old) to 44 Golchakra, Anushadi Park Chouraha(Bhutani) and Pathway School had substantial data ranging from 30% to 62%. Summary of the preliminary analysis for the pollutant SO<sub>2</sub> is tabulated in Table 6.

**Table 6: Data description for SO<sub>2</sub>**

Location	Valid Available Data Points	% available
Amrapali Golchakkar	9903	100
Below Mahamaya	9622	100
Botanical Metro	10773	100
City Centre	10444	100
Degree College Tiraha	10459	100
Hoshiyarpur Tiraha	10349	100
HTMS (Old) to 44 Golchakra	9726	100
Model town	10377	100
Pathway School	10310	100
Rajnigandha Chouraha	10468	100
Samet 76 Internal Road	10410	100
Sector 142	10459	100
Sector 91 T Point	1974	100
Sector 93	10335	100
Okhla bird sanctuary Metro	9842	100
Aushadhi Park Chouraha (Bhutani)	9674	100
Spice Mall Chouraha	9011	100
Hajipur Chouraha	10352	99.6
Phool Mandi Chouraha	9349	98.6
Sector 18 Metro	1857	18.1

It was observed from the table that SO<sub>2</sub> dataset was available 100% at 18 locations. At the locations: Phool Mandi Chouraha and Hajipur Chouraha, the data availability was close to 99%.

## 5.1.2 Speed Violation Detection (SVD) Data

Speed Violation Detection (SVD) is a system used to identify and monitor vehicles exceeding speed limits on roads. It is a critical component of traffic management and enforcement, helping to improve road safety and reduce accidents. In the current study, the Speed Violation Detection (SVD) system extracted the speed data from the ANPR (automatic number plate recognition). The system identifies vehicles exceeding speed limits by capturing license plates and matching them with speed data.

The SVD data was available for 4 locations: Kalindi Kunj, Yamuna Bridge, Chilla Gate-14 A and Below Mahamaya. The SVD/ANPR data table also included a column where the maximum speed limit at each location was monitored. Any vehicle exceeding this limit was highlighted and recorded in a separate table, which was further used for issuance of challans.<sup>7</sup> The usability

7. A formal notice or ticket (a "challan") issued to a driver for a traffic offense, often resulting in a fine or other penalties

of this system was in enforcing traffic laws, reducing accidents, and improving the road safety through automated monitoring. The details pertaining to the data availability tabulated in Table 7.

**Table 7: Summary of SVD data**

Location	Valid Available Data points	Available (%)
Kalindi Kunj	10008	2.23
Yamuna Bridge	10038	1.73
Chilla Gate - 14A	9605	3.49
Below Mahamaya	10003	1.91

The table showed that the speed data was available for approximately 10000 vehicles at each location.

### 5.1.3 Automatic Number Plate Recognition (ANPR)

Automatic Number Plate Recognition (ANPR) is a surveillance technology used to capture and analyse vehicle license plates for traffic monitoring and enforcement. In NOIDA city, ANPR data was collected from eighty-three locations over a one-week period (11<sup>th</sup> Nov to 17<sup>th</sup> Nov 2024), including key junctions like Spice Mall Chauraha, NOIDA City Centre, Botanical Garden, Sector 18 Metro, Kalindi Kunj and many more. The dataset included parameters such as Junction Name, ANPR Text, Vehicle Colour, Speed, Vehicle Class, Make, Model, and Speed Limit. The information extracted from Automatic Number Plate Recognition (ANPR) data was done by using the license plate number. This plate number was needed to get the details pertaining to type of vehicle, fuel type, registration year, emission norms and model from the Vahan Dashboard (<https://vahan.parivahan.gov.in/vahan4dashboard>). The weblink used for the data extraction was <https://parivahan.gov.in/parivahan/en/content/license-registration-details>.

### 5.1.4 Data summary

The preliminary analysis helped in understanding the data prior to the data analysis. The summary from studying the data was:

1. Extreme high and low values in the MET and speed datasets were identified as anomalies and corrected using the Z-score statistical method approach<sup>8</sup> for better accuracy.
2. The MET data was available per minute, which made the dataset exceptionally large. A longer time period (15 or a 30-minute time interval) would have streamlined the analysis much quicker.
3. The PM<sub>10</sub> and PM<sub>2.5</sub> datasets were not available between the time periods :12-11-2024, 14:47:05 and 17-11-2024,23:59:00. Thus, the weekend impact analysis for the dates (13<sup>th</sup> and 14<sup>th</sup> of November) and (16<sup>th</sup> and 17<sup>th</sup> of November) could not be conducted.
4. Summarizing pollutant wise: SO<sub>2</sub> had the most complete dataset with 100% availability at 18 locations, PM<sub>2.5</sub> and PM<sub>10</sub> followed a similar pattern, NO<sub>2</sub> had varied availability, with some locations having full data and others showing gaps ranging from 30-62%.
5. The SVD data was available at four locations, and the valid data points varied between 9000-10000 vehicles.

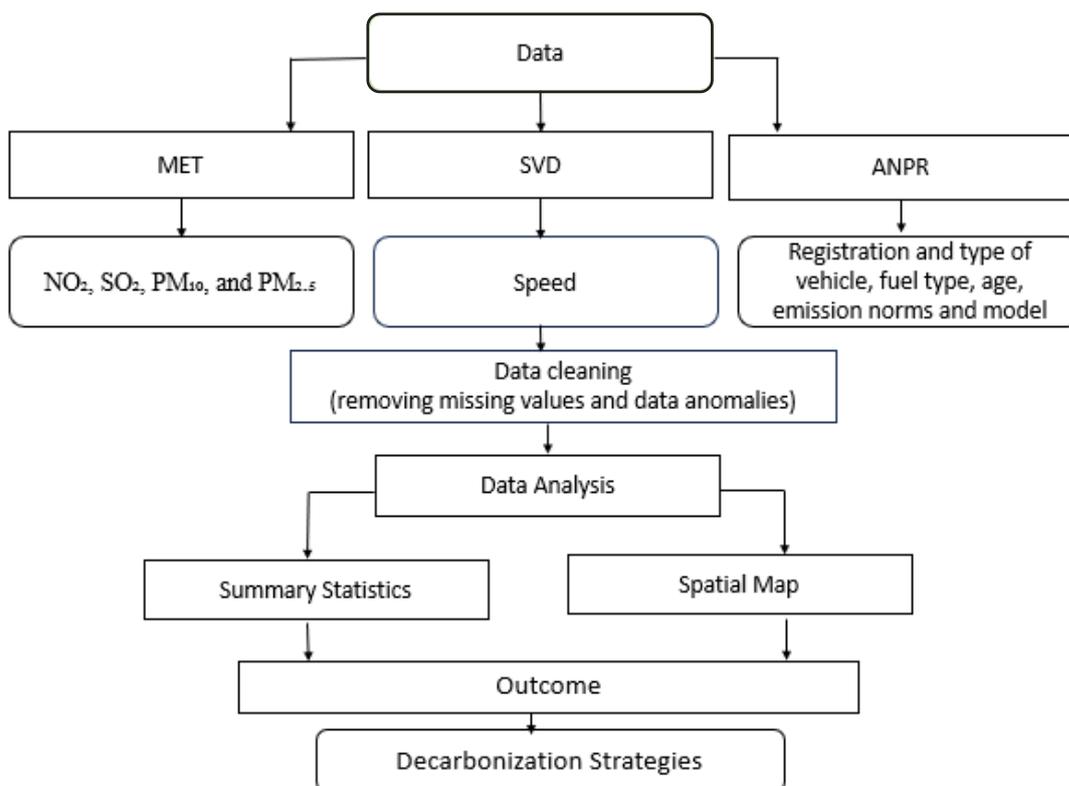
8. Z-score (or standard score) measures how far a data point is from the mean in terms of standard deviations.

6. The ANPR and SVD data sheets had common data from which speed and the licence plates data were extracted for analysis.
7. The zero values were removed to refine all the datasets, to improve analysis accuracy.

## 5.2 Methodology

The comprehensive methodology, covering all the steps necessary to achieve the outcome, is shown in Figure 2.

**Figure 2: Methodological Framework**



The methodology involved a structured approach analysing the MET, SVD and ANPR data to assess air quality and traffic-related parameters. The MET data considered for the study were for the pollutants  $\text{NO}_2$ ,  $\text{SO}_2$ ,  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$ . The vehicular speeds were extracted from the SVD data sheets. The details pertaining to the vehicle registration, type of vehicle, fuel type, age and emission norms and model were extracted using the license plates, from the ANPR sheet. This was done with the help of the website <https://parivahan.gov.in/parivahan/en/content/license-registration-details>. The data was cleaned from unavailable values and other anomalies. Post this, the data analysis was done which included summary statistics and building spatial maps using GIS. The location “Below Mahamaya” had the availability of the three datasets and thus was chosen for detailed analysis. The decarbonization strategies, both generic and specific were suggested as an outcome of the study.

## 5.3 Analytical Framework

The analysis of the work was location-specific focused. The preliminary analysis helped in segregating the locations which had missing and available data. As mentioned in the methodological framework, the data was analyzed using descriptive statistics and creating spatial maps using Geographical Information Systems (GIS) technology. The study examined locations having a high concentration of different pollutants and speed. The diurnal analysis of the MET data helped in capturing the variations in emissions throughout the day, also studying the weekdays and weekends separately. A comparative assessment of the location specific pollutant levels was done with the permissible levels established by CPCB. The final outcomes helped in the suggestion of mitigation strategies for the decarbonization process.

### 5.3.1 Results and conclusion

The results from the study were compilation of the various pollutants for different locations and are arranged in **Annexure 4**. The location, "Below Mahamaya" was identified and was found potential after analysing 3 data sets namely, MET, ANPR & SVD, for further detailed study. The data description is discussed below.

## 5.4 Analysis of Mahamaya Area in NOIDA

The road below Mahamaya Flyover in NOIDA is a major interchange with a two-way road divided by a median. This road connects NOIDA-Greater NOIDA Expressway, DND Flyway, and NGN Expressway, and has very heavy traffic flow. The analysis included descriptive, weekday / weekend, diurnal variations of the MET data. The average MET values were compared with the permissible limits as prescribed by CPCB. For the speed data, the variations during the day were studied and for the ANPR analysis, the distribution of vehicle type and age was studied.

### 5.4.1 MET data

#### Descriptive statistics

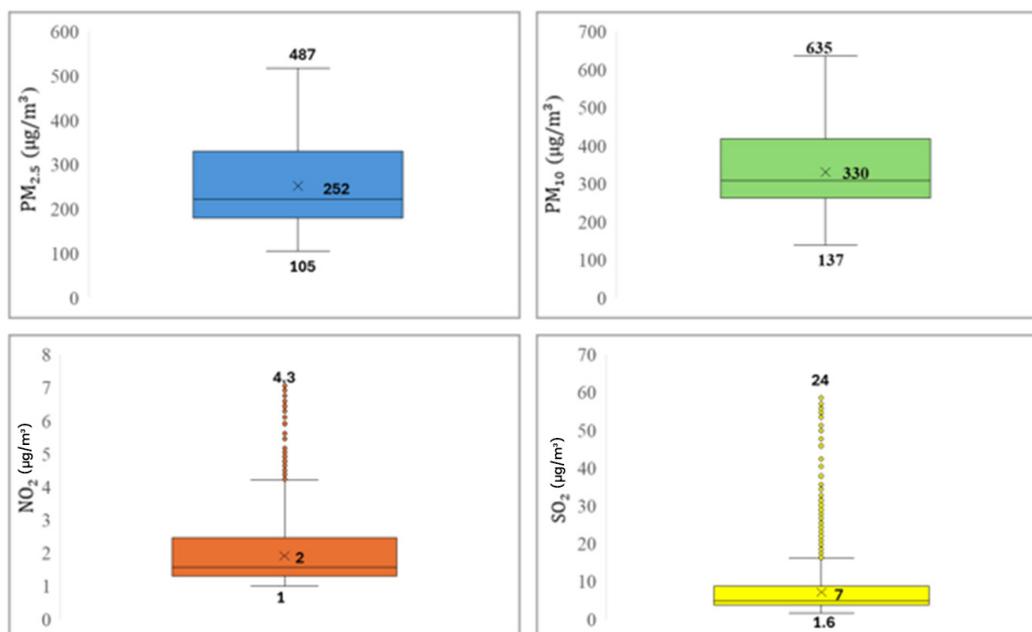
The summary statistics of the pollutants ( $PM_{2.5}$ ,  $PM_{10}$ ,  $NO_2$  and  $SO_2$ ) was prepared by averaging them individually for each location. The data spanned from 11<sup>th</sup> to 17<sup>th</sup> November'2024 from 0000hr (midnight) to 2400 hrs, available at every minute. These values were compared with the permissible limits as set by CBCB (CPCB, 2012). The table showing the summary statistics of the four pollutants is shown in Table 8.

**Table 8: Summary Statistics of MET data at Below Mahamaya (updated)**

Below Mahamaya	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limit)	PM <sub>10</sub>	PM <sub>10</sub> (60 µg/m <sup>3</sup> ) (permissible limit)	NO <sub>2</sub>	SO <sub>2</sub>
Mean	251.7	Above the permissible limit	329.9	Above the permissible limit	1.9	6.7
Median	222.9		308.4		1.6	4.8
Mode	158.5		279.4		1.2	4.2
Standard Deviation	91.9		93.5		0.8	4.5
Minimum	105.6		137.4		1	1.6
Maximum	487.7		635.5		4.3	23.9

According to CPCB data, the NO<sub>2</sub> levels at Sector 125, Noida—near the Mahamaya Flyover, for the month of November, 2024 showed an average concentration of 132.1 µg/m<sup>3</sup>. However, the observed values in the study appeared to be unexpectedly low. Some of the factors that contributed to this discrepancy could be: malfunctioning or non-operational sensors, sensors not being calibrated or sensor drift (the gradual change in a sensor's output over time). Given these possibilities, it was essential to re-evaluate the data for accuracy and locations.

The results showed that the observed averages of pollutants PM<sub>2.5</sub> and PM<sub>10</sub> exceeded the permissible limits for the 24-hour average. However, NO<sub>2</sub> and SO<sub>2</sub> levels were below the 24-hour average. The pictorial representation of each of the pollutant (PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub> and SO<sub>2</sub>) is shown in Figure 3.

**Figure 3: Box and whisker plot depicting MET data**

### Weekday/Weekend impact of MET data

The study of air pollution considering the weekday -weekend effect was further investigated. As per the literature, the weekend experiences a change in human activity and hence traffic patterns compared to weekdays. This reduction in traffic could be attributed to the weekend effect, where many people either stay at home or leave the city (Cools et al., 2007).<sup>9</sup> This weekend

9. Cools, M., Moons, E., & Wets, G. (2007). Investigating effect of holidays on daily traffic counts: Time series approach. Transportation Research Record, 2019, 22–31. <https://doi.org/10.3141/2019-04>

impact has been instrumental in altering the pollution levels. A study in Milan indicated that ambient air concentrations reduced during the weekend and reduction in traffic was one of the main reasons (Lonati et al., 2006).<sup>10</sup> Thus, the analyses of the pollutants (PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub> and NO<sub>2</sub>) between weekdays and weekends was important. The results could help the policymakers identify the major pollution sources and hence suggest intervention strategies.

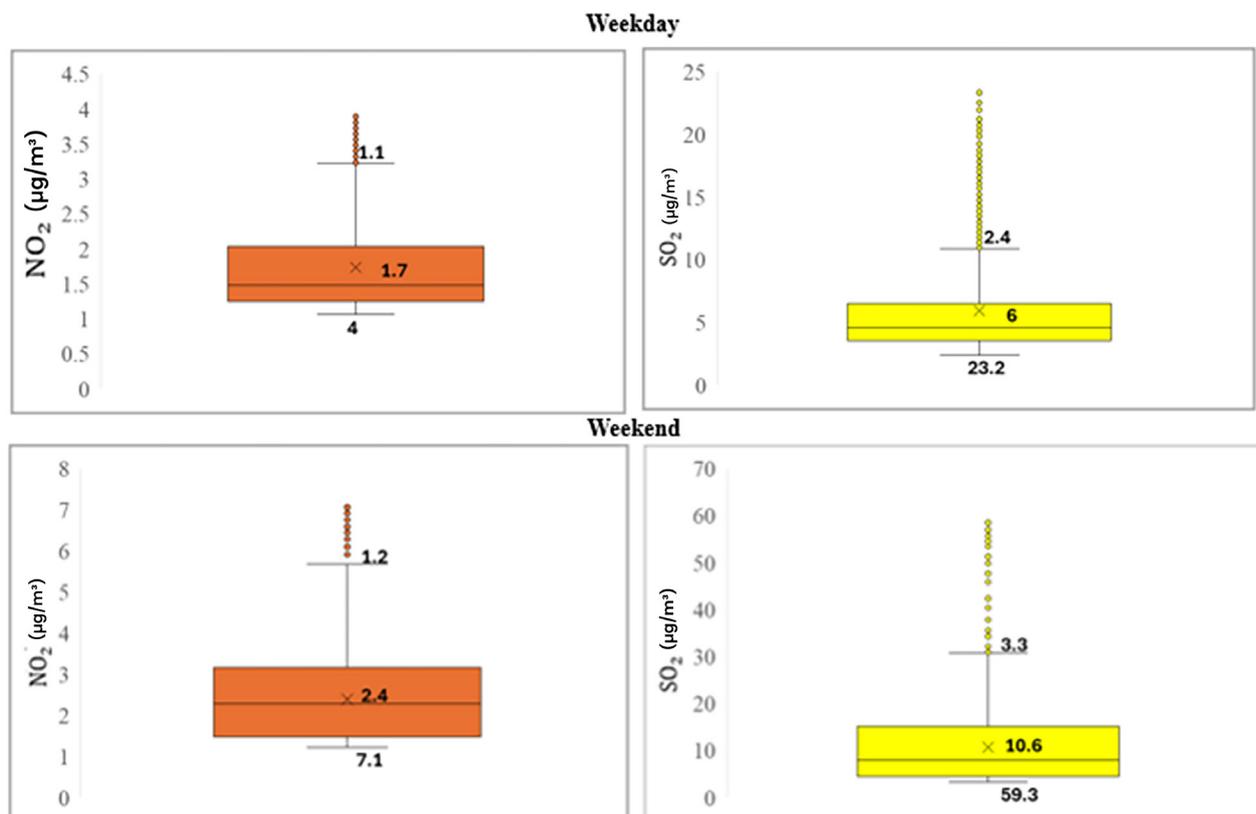
For the current study, the days selected for data analysis were.

- i. Weekday- 13<sup>th</sup> (Wednesday) and 14<sup>th</sup> (Thursday), November
- ii. Weekend- 16<sup>th</sup> (Saturday) and 17<sup>th</sup> (Sunday), November

As mentioned earlier the pollutants PM<sub>2.5</sub> and PM<sub>10</sub> was not available for the analysis dates, thus, their weekend impact could not be calculated. The results from the analysis of NO<sub>2</sub> and SO<sub>2</sub> showed that their magnitude increased during the weekend compared to the weekday. These results were contrary to the earlier studies where the pollutants reduce during the weekend. Further investigation was needed and thus the retrieval of temperature and humidity data was done.

The temperature and humidity observed during the weekday was (25.2°C, 65.5%) and during the weekend was (23.5°C, 64%). The lower temperature during the weekend could have contributed to the observed increase in NO<sub>2</sub> and SO<sub>2</sub> levels by trapping pollutants near the surface. Meanwhile, the slight drop in humidity could have reduced the natural removal of airborne pollutants. The air quality thus did not improve on weekends, despite the lower traffic. However, the results would have been explained better if there was access to traffic volume data for this location. The weekday-weekend impact is summarized in Table 9 and the pictorial representation is shown in Figure 4.

**Figure 4: Box and whisker plot depicting weekday- weekend impact of MET data**



10. Lonati, G., Giugliano, M., & Cernuschi, S. (2006). The role of traffic emissions from weekends' and weekdays' fine PM data in Milan. *Atmospheric Environment*, 40(31), 5998–6011. <https://doi.org/10.1016/J.ATMOENV.2005.12.033>

**Table 9: Weekday -weekend impact at Below Mahamaya**

	Mean	Standard Deviation	Median	Mode	Minimum	Maximum	Count
<b>Weekday</b>							
PM <sub>2.5</sub>	null	null	null	null	null	null	null
PM <sub>10</sub>	null	null	null	null	null	null	null
NO <sub>2</sub>	1.73	1.48	1.24	0.64	1.06	3.89	2964
SO <sub>2</sub>	5.94	4.56	3.42	3.76	2.37	23.34	2964
<b>Weekend</b>							
PM <sub>2.5</sub>	null	null	null	null	null	null	null
PM <sub>10</sub>	null	null	null	null	null	null	null
NO <sub>2</sub>	2.39	2.28	1.36	1.03	1.21	7.13	2380
SO <sub>2</sub>	10.63	7.84	4.42	8.05	3.26	59.3	2380

Null: no values recorded

### Impact of diurnal variations on MET data

The diurnal variations in traffic speed and volume significantly influenced the urban air pollution levels. The increased traffic volume and reduced speeds during the morning and evening peak hours, led to higher emissions of pollutants such as nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO), and particulate matter (PM). This was supported by a study in Boston which observed that the black carbon concentrations peaked during the morning peak hours which correlated with high traffic volume (Buonocore et al., 2009).<sup>11</sup> The results from the current study showed that the NO<sub>2</sub> levels showed less variations during the 24-hour period and were comparatively more evident during the nighttime. Since vehicle emissions is one of the key sources of NO<sub>2</sub> data on the traffic volume would further give a better understanding.

The SO<sub>2</sub> pollutant was the highest during the night hours and the magnitude was the highest at midnight. This could have been due to the continuous emissions from industries or diesel trucks. The levels started to reduce after 600 hrs up to noon, dispersing the pollutants. There was an unusual increase in the SO<sub>2</sub> levels from noon up to 1400 hrs which needs more data for an explanation. Following this, there was a reduction in the SO<sub>2</sub> levels from 1400 hrs up to 1800 hrs. Post this period, the SO<sub>2</sub> levels increased steadily up to midnight trapping pollutants.

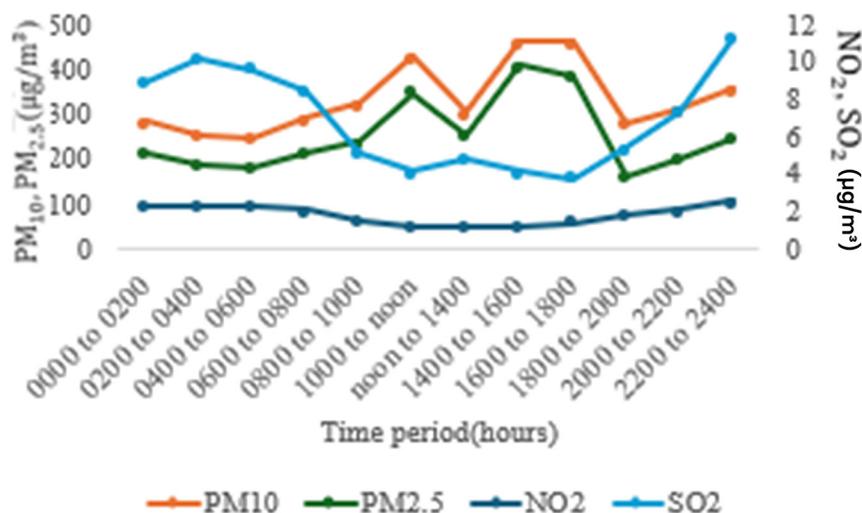
The trend for PM<sub>2.5</sub> and PM<sub>10</sub> was like each other and followed the traffic patterns within the city. The PM<sub>2.5</sub> and PM<sub>10</sub> were observed to be the highest around midnight, possibly due to the trapped pollutants near the surface and the traffic emissions. After this, the levels started to decrease until 0600 hrs which was supported with a low traffic activity. The levels started to increase from 0600 hrs reaching its peak at noon. Owing to the morning peak hours traffic, a decline in the PM levels was observed from noon up to 1400 hrs. However, from 1400 to 1600 hrs, the PM levels started to increase, possibly due to after congestion. A stability was observed between 1600 to 1800 hrs. A sharp decline was observed from 1800 hrs to 2000 hrs which could have been due to better dispersion of metrological influences. Further, the PM levels started to increase reaching peak at midnight, possibly attributed to increased emissions from nighttime traffic or household fuel burning.

11. Buonocore, J. J., Lee, H. J., & Levy, J. I. (2009). The influence of traffic on air quality in an urban neighbourhood: a community-university partnership. *American Journal of Public Health*, 99(S3), S629-S635.

Thus, in conclusion, the PM levels were at the peak levels when the traffic was at peak during the morning congestion hours (12 noon) and evening peak hours (1800 hrs). They were at the lowest level at 1400 hrs and 2000 hrs when the traffic congestion started to ease.

The current study results were compared with another study done to understand the diurnal variations of BC and PM<sub>2.5</sub> pollutants in Delhi. It showed a similar trend with decline in the PM<sub>2.5</sub> during the midnight to morning, and evening rise in PM levels (Tiwari et al., 2013).<sup>12</sup> The diurnal variations of pollutants at Below Mahamaya are shown in Figure 5.

**Figure 5: Line chart depicting diurnal variations**



Apart from studying the daytime, the study of nighttime pollution was an important aspect. A study mentioned that the nitrogen radical chemistry was dominant at night and was instrumental in the combustion and generation of PM<sub>2.5</sub> and other pollutants which altered their daytime behaviour (Nature Geoscience, 2023).<sup>13</sup> In the current study, all the four pollutants were summed up separately for nighttime (8 pm to 8 am) and daytime (8 am to 8 pm). The ratio of nighttime to daytime pollutants was calculated for each of the pollutant. The result showed that the nocturnal impact was more pronounced for SO<sub>2</sub> and NO<sub>2</sub> compared to PM<sub>2.5</sub> and PM<sub>10</sub>. A similar pattern was observed when the pollutants Black carbon (BC) and PM<sub>2.5</sub> were studied in New Delhi. The results showed that the ratio between nighttime (1900 to 0600 LST) and daytime (0700 to 1800 LST) of BC mass concentrations was estimated and found to be larger than the unity (1.58). This result indicated a nocturnal peak which was evident by changes in emission sources and variability in meteorological conditions (Tiwari et al., 2013). The nighttime with daytime ratio calculations is shown in Table 10.

**Table 10: Ratio of nighttime and daytime pollutant calculations**

Pollutants	Nighttime	Daytime	Ratio	Result
PM <sub>10</sub>	1752	2261.1	0.8	<1
PM <sub>2.5</sub>	1249.2	1801.5	0.7	<1
SO <sub>2</sub>	55.9	27.6	2	>1
NO <sub>2</sub>	13.7	8.7	1.6	>1

12. Tiwari, S., Srivastava, A. K., Bisht, D. S., Parmita, P., Srivastava, M. K., & Attri, S. D. (2013). Diurnal and seasonal variations of black carbon and PM<sub>2.5</sub> over New Delhi, India: Influence of meteorology. *Atmospheric Research*, 125–126, 50–62. <https://doi.org/https://doi.org/10.1016/j.atmosres.2013.01.011>

13. Nature geoscience. (2023). Night-time clues to pollution. In *Nature Geoscience* (Vol. 16, Issue 3). <https://doi.org/10.1038/s41561-023-01157-8>

## 5.4.2 Interpretation of speeds from SVD data

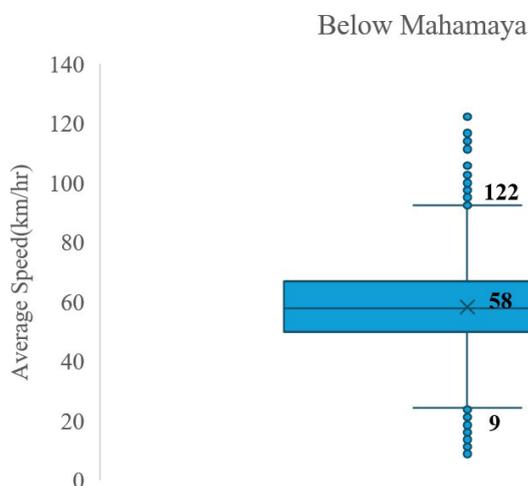
The location "Below Mahamaya Flyover" in NOIDA serves as a critical junction, connecting various arterial routes, including the NOIDA–Greater NOIDA Expressway. The speeds for the study were investigated extracting the same from ANPR data sheets. This location was analysed using descriptive statistics, diurnal variations, and spatial analysis. The descriptive statistic of this location is summarized in Table 11.

**Table 11: Summary statistics of speeds**

Summary Statistics	Speed(km/hr.)
<b>Mean</b>	58
<b>Median</b>	58
<b>Mode</b>	60
<b>SD</b>	14
<b>Minimum</b>	9
<b>Maximum</b>	122.4

A higher average speed was observed at this location at 58.3 km/hr. The speeds varied from 9 km/hr (minimum) to 122.4 km/hr (maximum). A box and whisker plot showing the speed variation is shown in Figure 6.

**Figure 6: Box and whisker plot depicting speed variations**



Study of the box and whisker plot revealed some interesting findings.

- The median speeds of 58 km/hr indicated that half of the vehicles travelled below this speed.
- The presence of outliers at the higher and lower end in the study showed that the vehicles experienced congestion and travelled below 10km/hr. Some vehicles also travelled at a speed as high as 120 km/hr or even higher, indicating over speeding.
- The Interquartile Range (IQR): The middle 50% of speeds were between approximately 50 km/hr and 70 km/hr, showing moderate variation.
- Most speeds were between 40–80 km/hr, with a few extreme cases crossing 100 km/hr.

This data suggested moderate traffic flow with occasional congestion (low-speed outliers) and instances of over-speeding.

The speeds were further investigated to study the diurnal patterns. The time was segregated in five diverse groups. The first time was before the peak hours traffic (before 800 hrs), the second was during the peak hours (800 to 1100 hrs), the third was between 1100 to 1700 hrs, which accounted for the time between two peak hours. The fourth time was between 1700 to 2000 hrs which was also during the peak evening hours. The fifth time was after 2000 hrs when the traffic peak generally reduces. The summary statistics of the diurnal variations in traffic volume are shown in Table 12.

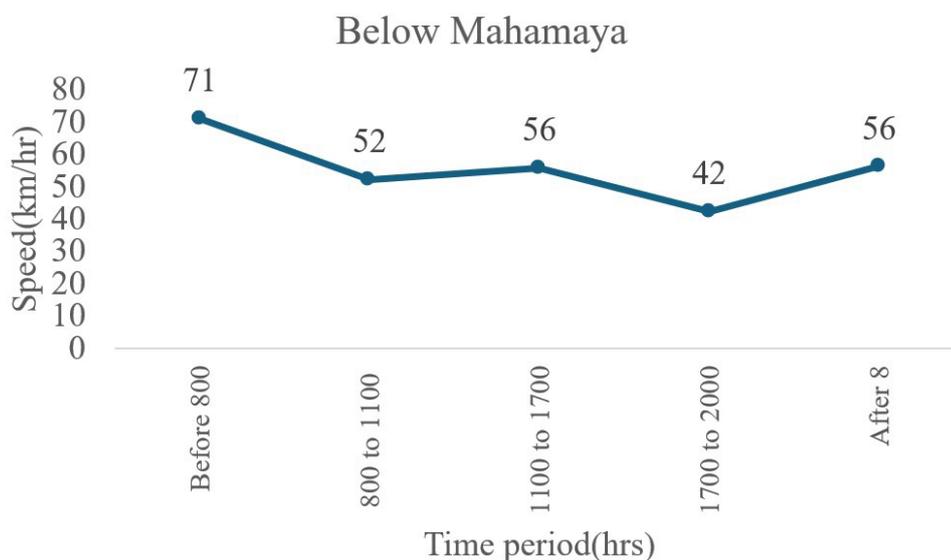
**Table 12: Summary statistics of the speed diurnal variations**

Statistics	Before 800 hrs.	800 to 1100 hrs.	1100 to 1700 hrs.	1700 to 2000 hrs.	2000 hrs.
Mean	<b>71</b>	52	56	<b>42</b>	56
Median	71	54	56	45	55
SD	12	14	10	14	6
Minimum	12	9	20	10	48
Maximum	122	92	94	81	64
Count	2504	2805	4214	291	5

(Green- Highest, Red-Lowest speed)

The maximum average speed was observed before 800 hrs in the morning at 71 km/hr. This was also the time of the day, when the location experienced the maximum speed (122 km/hr). The minimum speeds were observed in the time period between 1700 to 2000 hrs. The graphical representation of speeds using a line chart as shown in Figure 7.

**Figure 7: Line chart depicting diurnal variations of speed**



The line chart followed an up and down path, where the speed was high before the morning peak hours, decreasing during the peak period, increasing during the afternoon hours, decreasing during the evening peak hours and finally increasing during the after-peak hours. This trend indicated the increase during the non-peak hours and decrease during the peak hours. The traffic volume data could be used to validate the above results.

## Interpretation of SVD data

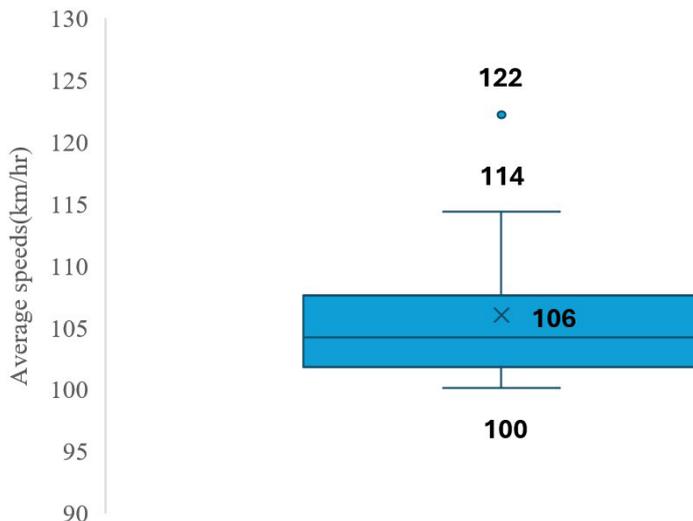
The speed limits at location Below Mahamaya is 100 km/hr. As observed earlier, the highest average speed observed at the study location was 122.4 km/hr before the 800 hrs. The SVD analysis was done by investigating the speeds exceeding the speed limits at this location. Out of the 9821 (relevant) speed data observations, 35 vehicles exceeded the speed limits of 100 km/hr. This meant that around 0.36% of vehicles exceeded the speed limit of 100 km/hr. The summary statistics of the 36 speed observations is shown in Table 13.

**Table 13: Summary statistics of SVD data**

Summary Statistics	Speeds(km/hr)
Mean	106
Median	104
Mode	100
Standard Deviation	6
Minimum	100
Maximum	122
Count	35

The box and whisker plot capturing all the speeds, which were observed above the speed limit is shown in Figure 8.

**Figure 8: Box and whisker plot depicting the speed violations**



The speeds ranged between 100 km/hr to 114km/hr, with 122 km/hr at the maximum and an outlier. This result hinted towards the enforcement of speed control measures to enhance safety.

## Interpretation of ANPR data

The ANPR data was studied, and the registration of number plates was downloaded. For every hour approximately, fifty number plates were extracted starting from midnight (0000 hrs) to 1500 hrs. The total data extracted from the retrieval is tabulated as below. The analysis of the ANPR data was done for cars. The distribution of the type of vehicles extracted from the ANPR license plate downloads is shown in Table 14.

**Table 14: Total sample of ANPR (speed) at Location Below Mahamaya**

Type of vehicle	Description	Data downloaded
<b>2WN</b>	Two-Wheeler (non-geared)	7
<b>3WT</b>	Three-Wheeled Transport	1
<b>HGV</b>	Heavy Goods Vehicle	9
<b>HPV</b>	Heavy Passenger Vehicle	11
<b>LGV</b>	Light Goods Vehicle	11
<b>LMV</b>	Light Motor Vehicle car	346
<b>LPV</b>	Light Passenger Vehicle cab	150
<b>MGV</b>	Medium Goods Vehicle	6
<b>MPV</b>	Medium Passenger Vehicle	2
<b>Total</b>		543

The maximum number of registrations observed in the sample were from the category car (346). The car fuel types could be Diesel, Diesel/hybrid, petrol, petrol/hybrid, petrol/cng, petrol/LPG cng only and strong hybrid/EV. However, in our study, the cars of the type of petrol, diesel, and CNG were observed. The fleet ratio was calculated using the equation:

$$\text{Fleet Ratio (\%)} = \left( \frac{\text{No of vehicles of a specific fuel type}}{\text{Total Vehicles}} \right) * 100$$

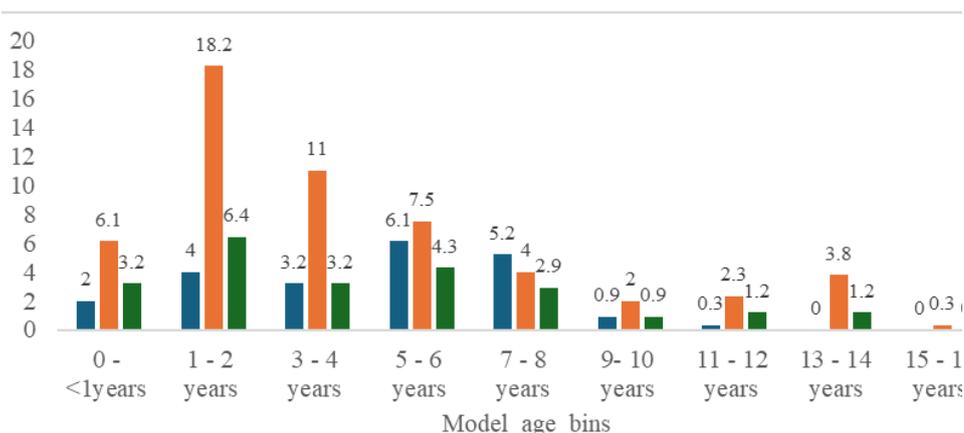
The fleet distribution of cars based on fuel type and year of the model is shown in Table 15.

**Table 15: Distribution of car by fuel type and vehicle**

Age bins	Year	Diesel	Petrol	CNG	Emission norms
<b>0 - &lt;1years</b>	2024	<b>2%</b>	<b>6%</b>	<b>3%</b>	<b>BS VI</b>
<b>1 - 2 years</b>	2022-2023	<b>4%</b>	<b>18%</b>	<b>6%</b>	<b>BS VI</b>
<b>3 - 4 years</b>	2020-2021	<b>3%</b>	<b>11%</b>	<b>3%</b>	<b>BS VI</b>
<b>5 - 6 years</b>	2018-2019	<b>6%</b>	<b>8%</b>	<b>4%</b>	<b>BS VI/BS IV</b>
<b>7 - 8 years</b>	2016-2017	<b>5%</b>	<b>4%</b>	<b>3%</b>	<b>BSIV</b>
<b>9 - 10 years</b>	2014-2015	<b>1%</b>	<b>2%</b>	<b>1%</b>	<b>BS III/BS IV</b>
<b>11 - 12 years</b>	2012-2013	<b>0%</b>	<b>2%</b>	<b>1%</b>	<b>BS III/BS IV</b>
<b>13 - 14 years</b>	2010-2011	<b>0%</b>	<b>4%</b>	<b>1%</b>	<b>BS III/BS IV</b>
<b>15 - 16 years</b>	2008-2009	<b>0%</b>	<b>0%</b>	<b>0%</b>	<b>BS III</b>
<b>Total</b>		<b>22%</b>	<b>55%</b>	<b>23%</b>	

The table showed that the maximum number of car registrations were observed to be of petrol cars followed by CNG, diesel. The bar chart showing the fleet ratio of cars in the sample of different fuel types is shown in Figure 9.

**Figure 9: Cars by vehicle type and model year**



Further, the average emissions were calculated for each vehicle and pollutant type using the equation

$$\text{Average Emissions per Vehicle} = \text{Fleet Ratio} * \text{Emission Factor} \dots\dots\dots (2)$$

where

- **Fleet Ratio** is the proportion of a specific vehicle type in the total vehicle population (shown in Table 14)
- **Emission Factor**: The emission rate of a pollutant per kilometre driven (g/km) for a specific vehicle type and fuel type (extracted from (ARAI, 2016)<sup>14</sup>

The summation of the average emissions was calculated for each vehicle type with respect to CO(g/km), NOx (g/km) and (HC +NOx(g/km)). The results are shown in Table 16.

**Table 16: Average emissions based on type of vehicle**

Fuel type	Average emissions (CO, g/km)	Average emissions (Nox (g/km)	Average emissions (HC + Nox (g/km)
<b>Car Petrol</b>	0.24	0.02	0.042
<b>Car Diesel</b>	0.30	0.14	0.17
<b>Car CNG</b>	0.29	0.02	0.04

The observations from the table were:

The highest NOx emissions (0.14 g/km) were observed in Diesel cars compared to petrol and CNG. The least CO (0.24 g/km) was emitted by petrol cars, while CNG had the slightly higher CO emissions (0.29 g/km). The CNG and Petrol cars had similar NOx and HC + NOx emissions, making them cleaner alternatives to diesel.

These results were extended by creating three more scenarios which would help to explore different possible futures by analysing how various factors and decisions impacted outcomes. The four scenarios considered for decarbonization were:

- **Base (Scenario 1)**- As per the calculated fleet ratio.
- **Scenario 2**: 20% of the diesel vehicles shift to EV.
- **Scenario 3** : 20% of the petrol vehicles shift to EV.
- **Scenario 4**: Stringent fuel policy where all the diesel vehicles are converted to petrol.

14. ARAI. (2016). Indian Emissions Regulations. [www.efaidnbmnnnibpcajpcglclefindmkaj/https://www.araiindia.com/pdf/Indian\\_Emission\\_Regulation\\_Booklet.pdf](http://www.efaidnbmnnnibpcajpcglclefindmkaj/https://www.araiindia.com/pdf/Indian_Emission_Regulation_Booklet.pdf)

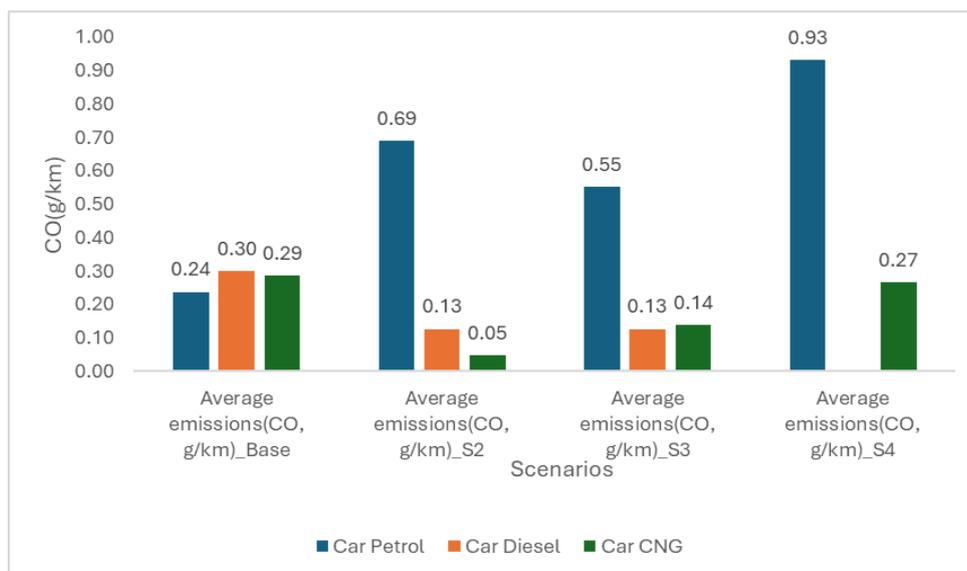
These scenarios were analyzed for CO (g/km), NOx emissions (g/km) and Hydrocarbons + NOx (HC + NOx) emissions (g/km). The average emissions calculated for each type of pollutant is summarized in Table 17.

**Table 17: Average emissions calculations based on type of vehicle for different scenarios**

Fuel Type	Car Petrol	Car CNG	Car Diesel
<b>Average emissions (CO, g/km)</b>			
<b>Base(S1)</b>	0.24	0.29	0.30
<b>S2</b>	0.69	0.05	0.13
<b>S3</b>	0.55	0.14	0.13
<b>S4</b>	0.93	0.27	
<b>Average emissions (Nox, g/km)</b>			
<b>Base(S1)</b>	0.02	0.02	0.14
<b>S2</b>	0.05	0.00	0.06
<b>S3</b>	0.04	0.01	0.06
<b>S4</b>	0.07	0.02	
<b>Average emissions (HC + Nox (g/km)</b>			
<b>Base(S1)</b>	0.04	0.04	0.17
<b>S2</b>	0.12	0.01	0.07
<b>S3</b>	0.09	0.02	0.07
<b>S4</b>	0.16	0.04	

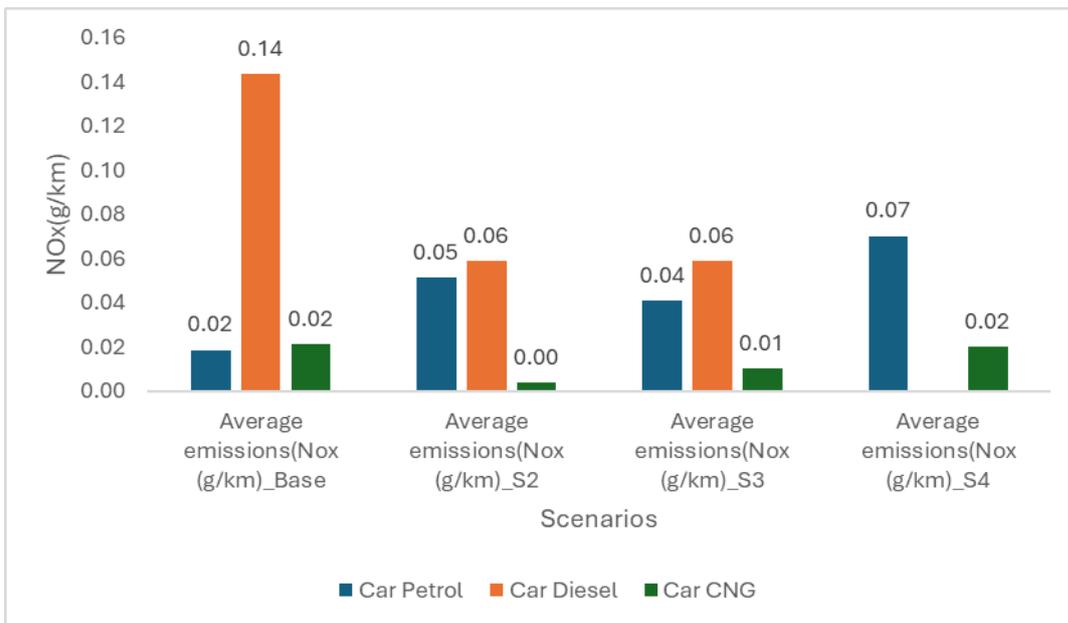
The observations from the study of Carbon Monoxide (CO) Emissions (g/km) indicated that the scenario (S4) (Diesel to Petrol) was not a good scenario for CO emissions and scenario (S2) (Diesel to EV) was the best because it significantly reduced diesel-related CO emissions. The representation of these is shown in Figure 10.

**Figure 10: Average emissions of CO for all scenarios**



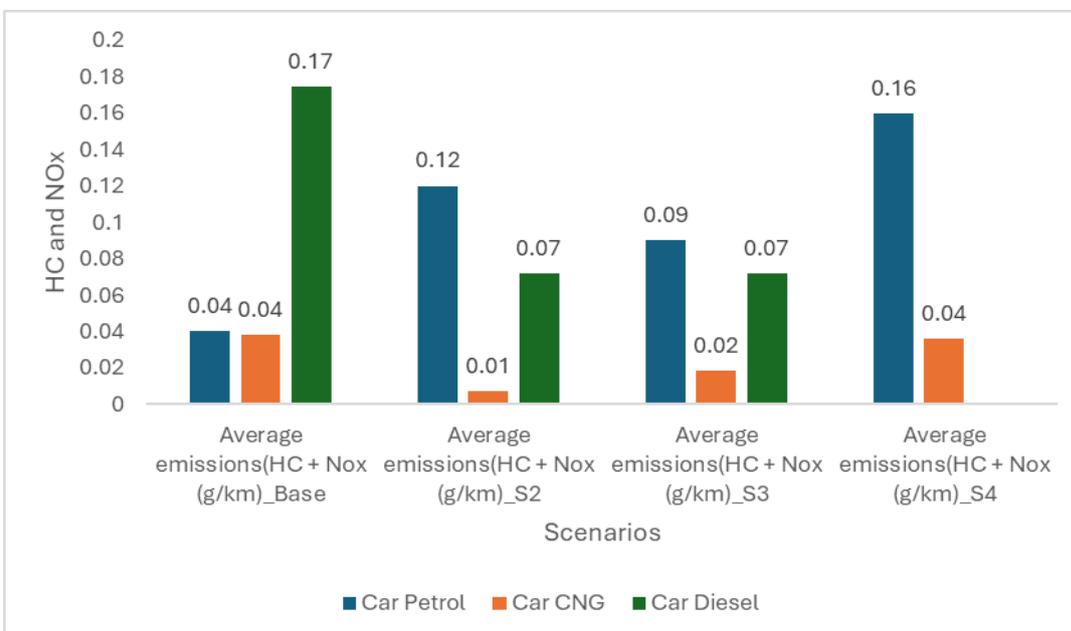
The observations of the Nitrogen Oxides (NOx) Emissions (g/km) showed that the scenario S4 (Diesel to Petrol) significantly increased the NOx emissions, making it a poor choice. The scenario S2 (Diesel to EV) had the biggest improvement as diesel NOx emissions which reduced from 0.14 to 0.06 g/km. The representation of this is shown in Figure 11.

**Figure 11: Average emissions of NOx for all scenarios**



Lastly, the study of the Hydrocarbons + NOx (HC + NOx) Emissions (g/km) showed that the scenario S4 (Diesel to Petrol) did not have a good impact, increasing HC + NOx emissions drastically. Further, the scenario S2 (Diesel to EV) provided the best emission reductions, in diesel-related pollutants. The representation of this is shown in Figure 12.

**Figure 12: Average emissions (HC and NOx) for all scenarios**



In conclusion, the scenarios where all the Diesel vehicles would be converted to petrol was the worst scenario since all the emissions (CO, NOx, and HC + NOx ) would become higher .The scenario where 20% of the petrol vehicles were proposed to be converted to EV was moderately beneficial. However, the scenario where 20% of the diesel vehicles convert to EV could prove to be the best since the emissions would get reduced.

### 5.4.3 Conclusions from the detailed analysis at location Below Mahamaya

The study results from the analysis of Below Mahamaya, were summarized and would help in proposing the decarbonizing strategies. Some of the conclusions were:

- i. The observed averages of pollutants  $PM_{2.5}$  and  $PM_{10}$  exceeded the permissible limits for the 24-hour average. However,  $NO_2$  and  $SO_2$  levels were below the 24-hour average.
- ii. The weekend -weekday effect showed that the pollution levels of  $NO_2$  and  $SO_2$  increased during the weekend.
- iii. The diurnal variations of the pollutants gave different results for each. The  $NO_2$  pollution levels showed less variations during the daytime period and were comparatively more evident during the nighttime. The  $SO_2$  pollutant was the highest during the night hours and the magnitude was the highest at midnight. The PM levels were at the peak levels when the traffic was at peak during the morning congestion hours (12 noon) and evening peak hours (1800 hrs). They were the lowest level at 1400 hrs and 2000 hrs when the traffic congestion started to ease.
- iv. The nighttime /daytime pollutant ratio was  $>1$  for the pollutant  $NO_2$  and  $SO_2$  which indicated nocturnal fluctuations but was  $<1$  for  $PM_{2.5}$  and  $PM_{10}$ .
- v. A higher average speed at 58 km/hr was observed at the location. The average speeds varied from minimum (9 km/hr) to maximum (122 km/hr).
- vi. The diurnal variation of the speeds indicated that they were the highest (71 km/hr) before 800 hrs and 56 km/hr (after 2000) hrs when the traffic was comparatively low.
- vii. The SVD data analysis showed that around 0.36% of vehicles exceeded the speed limit of 100 km/hr.
- viii. The ANPR data extraction of registration plates sample showed that the maximum number of car registrations were observed to be of type petrol, followed by CNG and diesel.
- ix. The highest  $NO_x$  emissions (0.14 g/km) were observed in Diesel cars compared to petrol and CNG. The least CO (0.24 g/km) was emitted by petrol cars, while CNG had the slightly higher CO emissions (0.29 g/km). The CNG and Petrol cars had similar  $NO_x$  and HC +  $NO_x$  emissions, making them cleaner alternatives to diesel.
- x. In addition to the base scenario as discussed in the study, three more scenarios were created. The scenario where all the diesel vehicles would be converted to petrol was the worst scenario since all the emissions (CO,  $NO_x$ , and HC +  $NO_x$ ) would become higher. The scenario where 20% of the petrol vehicles were proposed to be converted to EV was moderately beneficial. However, the scenario where 20% of the diesel vehicles are converted to EV could prove to be the best since the emissions would get reduced.
- xi. The spatial analysis of speed,  $PM_{2.5}$ ,  $PM_{10}$ ,  $NO_2$  and  $SO_2$  indicated that Sector 93 was the location where the targeted emission control, traffic management strategies and decarbonizing strategies were needed to be prioritized.

Thus, based on the results from the study, there was a need to focus on electrification of vehicles and traffic management at location Below Mahamaya, This location could also benefit from expanding public transport to reduce emissions and encouraging CNG vehicles over diesel. Apart from these, regular emission checks, stricter vehicle norms could enhance the air quality at the location. Some of these decarbonization strategies are discussed in detail in the next section.

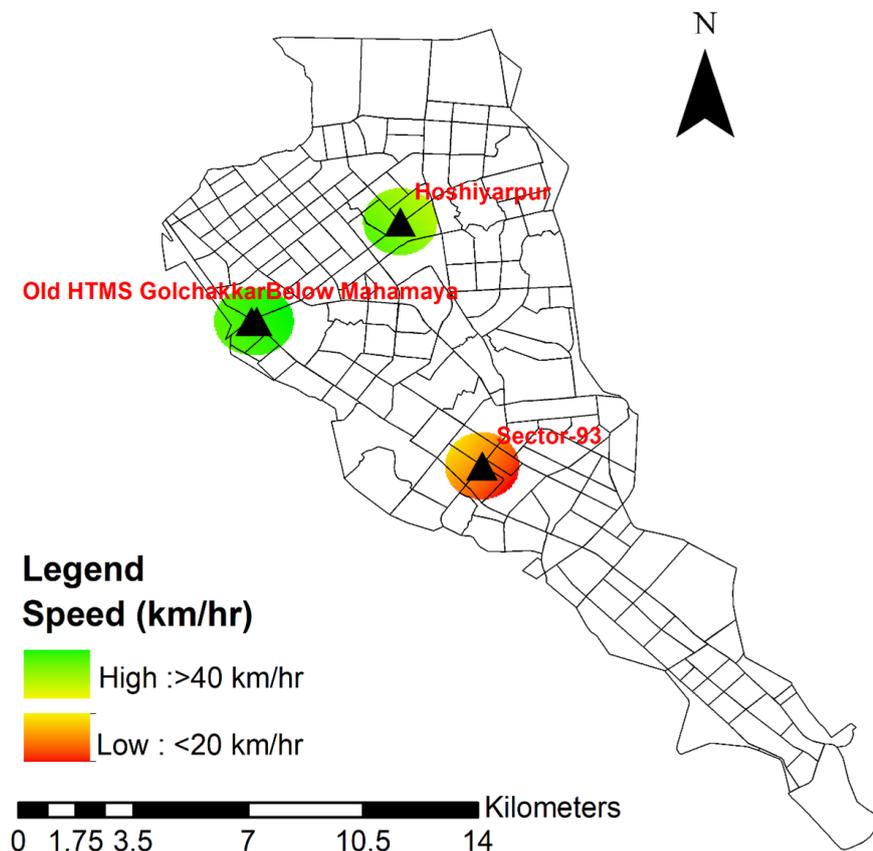
### 5.4.4 Spatial Mapping using Geographical Information Systems (GIS)

The objective of spatial analysis using GIS technology is to create the visual maps and interpret the relationship between the two or more variables. The variables in the current study were vehicle speed and pollutants. The analysis would help in identifying high-emission zones and studying the interrelations between speed variations and pollution levels. Based on the results, the hotspot locations would be identified for implementing the suitable transport interventions and suggesting suitable decarbonization strategies. The map and the method corresponding to each of the of these variables is discussed below.

#### Spatial analysis of speed

The spatial analysis of the speed was carried out for the four locations. These locations and their average speeds were Below Mahamaya (58 km/hr), Hoshiyarpur (30 km/hr), Old HTMS Golchakkar (15 km/hr) and Sector 93 (18 km/hr). To understand the speed variation around these locations, a buffer zone of 500 m, 1 km and 2 km was built. The objective of creating a buffer zone was to establish a zone of influence around the locations. It was observed that 500 m buffer was too small, capturing only a localized effect. The buffer distance of 2 km was observed to be too large, mixing different road types (highway, arterial roads etc). Between the three, the 1 km buffer was found to capture meaningful speed variations. It was thus developed around the vicinity of each of these locations using Arc/GIS. Thus, in the vicinity of 1 km, all the vehicles passing through this buffer contributed to this calculated speed. The speed locations along with the buffer zones is shown in Figure 13.

**Figure 13: Spatial Variations of Speed using 1 km buffer**

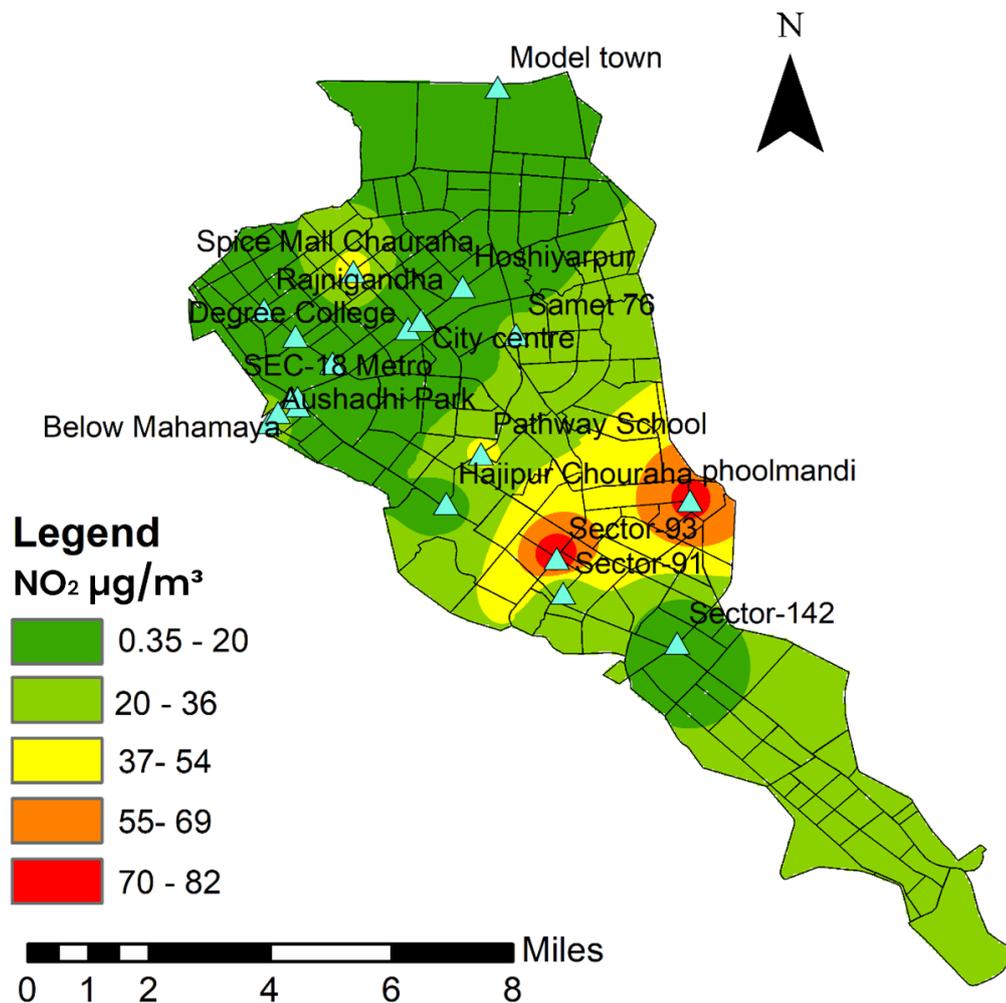


## Spatial analysis of the four pollutants

Like the speeds, the method of buffer was built to understand the spatial analysis of the four pollutants. However, it was observed that the method of buffer created a lot of overlapping and clustering, hence was not used for analysis. Another reason for not adopting this method was that the locations were more towards the North and there were very less locations in the South. Thus, to avoid these shortcomings, an alternate method of IDW was adopted. The IDW (Inverse distance weighting) method is best for environmental and pollution data (ESRI, 2024).<sup>15</sup> Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable. This method assumes that the variable being mapped decreases in influence with distance from its sampled location.

A spatial map pertaining to the pollutant levels NO<sub>2</sub> is shown in Figure 14.

**Figure 14: Spatial analysis of NO<sub>2</sub> using IDW**

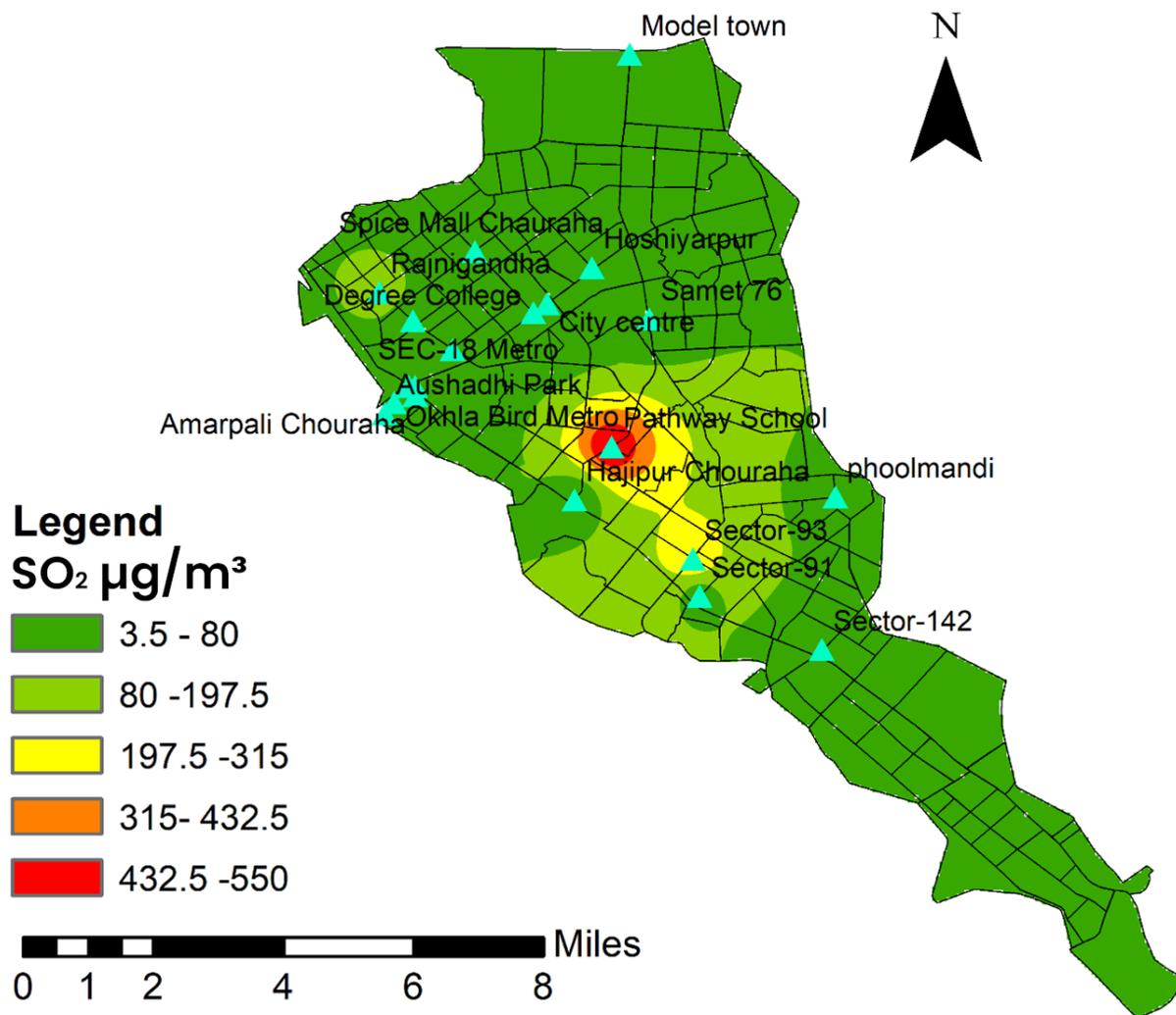


15. ESRI. (2024). How IDW works. <https://Pro.Arcgis.Com/En/pro-App/Latest/Tool-Reference/3d-Analyst/How-Idw-Works.Htm?>

The map showed that most of the area in Noida had NO<sub>2</sub> levels within the permissible limits. However, the area in the vicinity of locations: Sector 93 and Phoolmandi witnessed high pollutant levels.

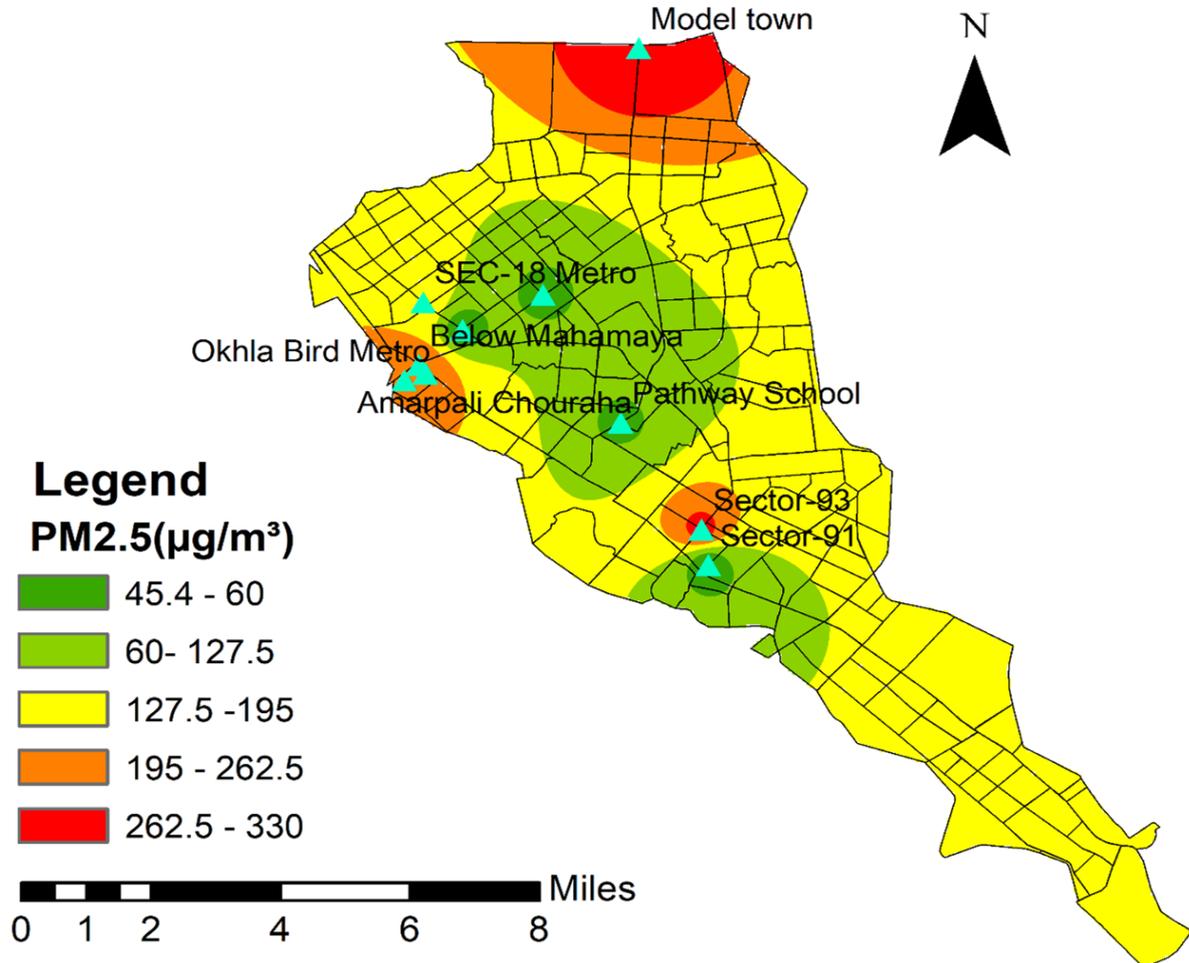
With respect to the pollutant SO<sub>2</sub> the levels were observed to be within the permissible levels in most of area spread across Noida. However, the area in the vicinity of the location Pathway school witnessed higher levels. The map depicting the spatial variation of SO<sub>2</sub> is shown in Figure 15.

**Figure 15: Spatial variation of SO<sub>2</sub> using IDW**



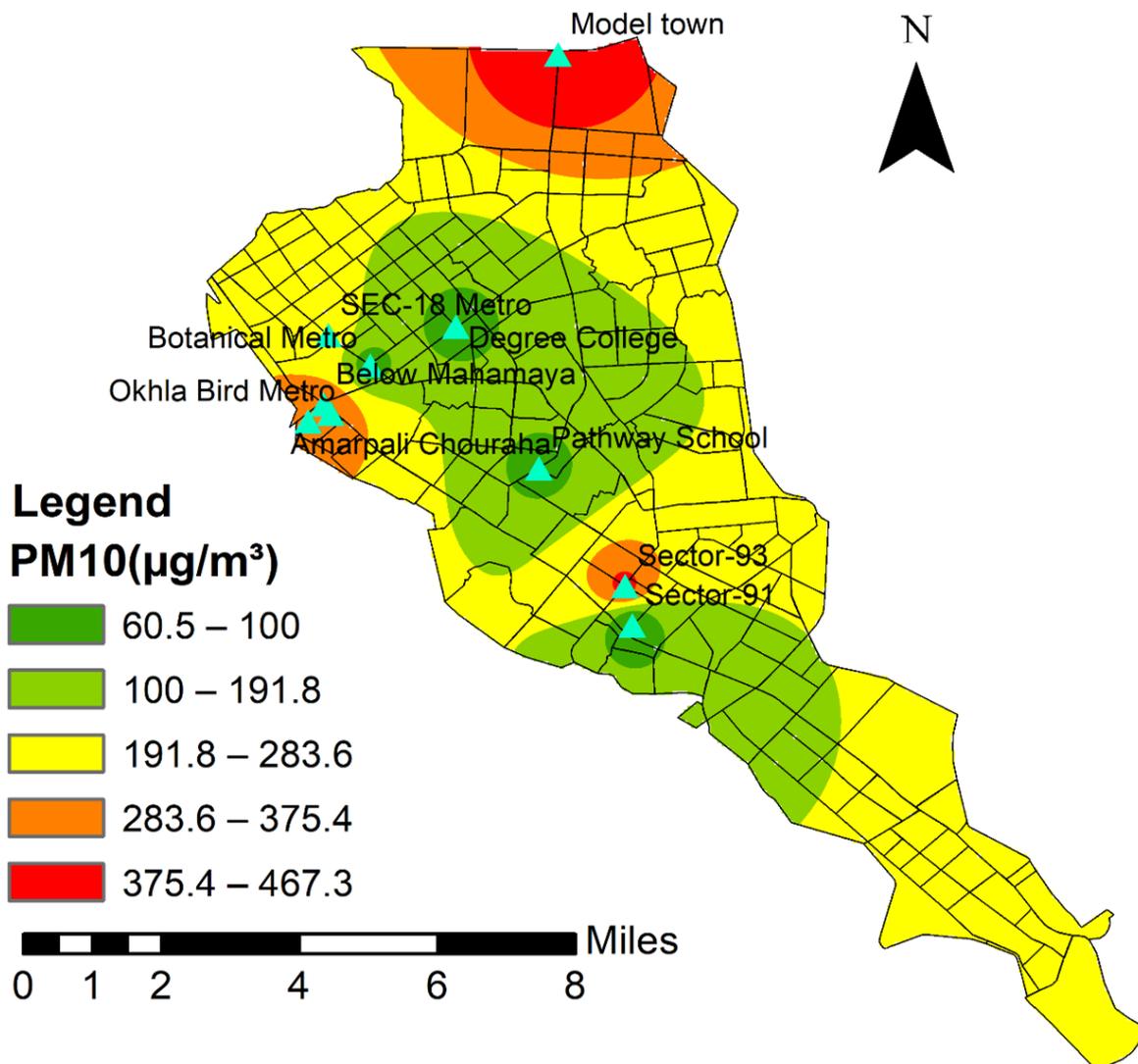
As observed in the descriptive statistics, the patterns in  $PM_{2.5}$  were like  $PM_{10}$ . The spatial map pertaining to  $PM_{2.5}$  is shown in Figure 16 and pertaining to  $PM_{10}$  is shown in Figure 17.

**Figure 16: Spatial variation of  $PM_{2.5}$  using IDW**



The locations for high PM<sub>10</sub> and PM<sub>2.5</sub> were Model Town and Sector 93. Thus, it was expected that the intersection in 1 km vicinity of these locations was also prone to high pollution due to the PMs.

**Figure 17: Spatial variation of PM<sub>10</sub> using IDW**



The results from the spatial analysis of the speed and the pollutants revealed that Sector 93 and Phoolmandi experienced high NO<sub>2</sub> levels. The SO<sub>2</sub> concentrations were high in the vicinity of Pathway school but were more than average for Sector 93. Apart from this, Sector 93 recorded low vehicle speeds, which also contributed to congestion-related emissions. The PM<sub>10</sub> levels were high in Sector 93 and Model Town. The PM<sub>2.5</sub> concentrations were also observed to be high in Model Town and Sector 93, indicating poor air quality in these areas. Thus, the spatial analysis identified the location “Sector 93” as a prospect where the decarbonization strategies were required to be implemented on priority. This was also the location which apart from the targeted emission control, the traffic management strategies could be implemented.

# 6. Decarbonization Strategies

Urban transport decarbonization in NOIDA is essential for achieving sustainable mobility and reducing emissions. This report presents a comprehensive approach integrating technology, policy, and behavioural change to transition toward a cleaner, more efficient transport system.

Based on the results achieved in the study and other recommendations, the following decarbonization strategies outline a comprehensive approach to decarbonizing urban transport in NOIDA. These would include leveraging data-driven insights, technological advancements, and policy interventions to achieve sustainable mobility,

## 6.1 Transition to Efficient Technology

### Strategies

1. **Adopt AI-Powered Traffic Management Systems**
  - i. Implementation of AI – driven ATCS (Adaptive Traffic Control System, using real time traffic data from Vehicle Detection Analytics & Spot Speed Data.
  - ii. Deploy predictive analytics to forecast congestion and dynamically adjust signal timings.
2. **Promote Intelligent Transport Systems (ITS)**
  - i. Integrate GPS-based vehicle tracking and Dynamic Congestion Pricing to discourage peak-hour traffic and incentivize off-peak travel.
  - ii. Use Variable Message Signs (VMS) to reroute vehicles from high-emission zones.
3. **Enhance Public Transport Efficiency**
  - i. Introduce real-time passenger information systems for buses and metros to improve ridership.
  - ii. Optimize bus routes using AI-driven occupancy and demand analysis.
  - iii. Prioritize buses movement at signalized crossings. Consider priority corridors for buses where buses are facing congestion.
4. **Leverage Open Data Platforms**
  - i. Utilize India Urban Data Exchange (IUDX) to share traffic and emission data for third-party innovations (e.g., route optimization apps).

With respect to the current study, the transition to efficient technology would mean that the number of hybrid and EV vehicles are increased in numbers in Noida. In our study sample of the ANPR data where the details pertaining to the number plates were extracted, the analysis showed that the number of hybrid and EV vehicles were in negligible numbers in a total fleet sample of 543 vehicles. This highlighted a gap in the transition to cleaner transportation. The lack of the electric vehicles suggested that the incentives and infrastructure improvements were crucial. Apart from this, an AI driven traffic management could help in reducing the emissions. The Adaptive signal control, predictive analytics, and GPS-based ERP could be proposed to reduce idling and optimize traffic flow.

## 6.2 Fleet Modernization and Electrification

### Strategies

1. **Accelerate EV Adoption**
  - i. Expand EV charging infrastructure, prioritizing high-traffic corridors and public transit hubs.
  - ii. Offer subsidies for electric buses, taxis, and shared mobility fleets.
2. **Phase Out High-Emission Vehicles**
  - i. Enforce stricter emissions standards (Bharat Stage VI) and retire older diesel/CNG fleets.
  - ii. Introduce low-emission zones (LEZs) where only EVs and hybrid vehicles are permitted.
3. **Promote Shared and Electric Mobility**
  - i. Incentivize e-bike and e-rickshaw sharing programs for last-mile connectivity.
  - ii. Partner with private operators to electrify ride-hailing and delivery fleets.
4. **Data-Driven Fleet Optimization**
  - i. Use ANPR and MET data to identify high-pollution vehicle models and target replacement programs.

The current study highlighted the need for fleet modernization and electrification since the  $PM_{2.5}$  and  $PM_{10}$  levels exceeded limits, peaking during congestion hours. Apart from this, the diesel vehicles showed the highest  $NO_x$  emissions (0.14 g/km). Thus, there was a need to replace the high emission fleet with the EV. The discussion about the four scenarios gave other viable options. Conversion from diesel to petrol was not a good option since it would lead more to more emissions. However, conversion of 20% of the diesel vehicles to EV could prove to be the best since the emissions would get reduced. Apart from these, the number of buses could be increased during peak hours to incentivize use of public transport.

## 6.3 Traffic Management Interventions for Decarbonization

### Strategies

1. **Dynamic Traffic Control**
  - i. Implement Singapore-style ERP to adjust tolls based on real-time congestion and pollution levels.
  - ii. Designate green corridors for emergency and public transport bus to reduce delays.
2. **Reduce Idling Emissions**
  - i. Enforce anti-idling policies at signals and congested zones using SVD cameras.
  - ii. Introduce "signal synchronization" to minimize stop-and-go traffic.

### 3. **Prioritize Non-Motorized Transport (NMT)**

- i. Expand pedestrian-friendly pathways and dedicated cycling lanes.
- i. Integrate bike-sharing with metro/bus networks (e.g., Pune's IMTS model)

One of the key objectives of Traffic management is to facilitate directing vehicles and pedestrians around some form of disruption. Traffic and speed data are very essential for studying and effectively implementing the traffic management. There were increased emissions, particularly from diesel vehicles, which recorded the highest NO<sub>x</sub> emissions (0.14 g/km). To mitigate these effects, dynamic traffic control measures such as ERP-based tolling and green corridors could be proposed.

## 6.4 Policy Recommendations for Sustainable Urban Mobility

### Strategies

#### 1. **Strengthen Regulatory Frameworks**

- i. Mandate EV quotas for public transport and commercial fleets.
- ii. Enforce congestion pricing in high-traffic zones (modelled after Delhi's proposed schemes).

#### 2. **Foster Public-Private Partnerships (PPPs)**

- i. Collaborate with tech firms to deploy smart parking and EV charging solutions.
- ii. Monetize traffic data (e.g., via IUDX) to fund decarbonization projects.

#### 3. **Align with National Initiatives**

- i. Integrate NOIDA's CMP with PM Gati Shakti for multi-modal connectivity.
- ii. Leverage Smart Cities Mission funding for AI-driven traffic solutions.

#### 4. **Incentivize Green Logistics**

- i. Promote electric freight vehicles and night-time deliveries to reduce daytime congestion.

In the current study, the PM<sub>2.5</sub> and PM<sub>10</sub> emissions were observed to be high during the noon and 1800 hrs. The policy recommendations based on our study results would be to establish stronger emission controls and monitoring. Another strategy could be the implementing the low-emission zones (LEZs) which would restrict the high NO<sub>x</sub> diesel vehicles into key areas. The high nighttime /daytime ratio for NO<sub>2</sub> and SO<sub>2</sub> would be smoothed if the nocturnal emission controls such as restrictions on heavy duty vehicle movement are implemented.

## 6.5 Behavioural Change and Awareness Campaigns

### Strategies

1. **Public Engagement Programs**
  - i. Launch campaigns highlighting the health and cost benefits of EVs and public transport.
  - ii. Use social media and IVRS (interactive voice response) for real-time pollution alerts.
2. **School and Corporate Partnerships**
  - i. Introduce “Car-Free Days” and subsidized transit passes for employees/students.
  - ii. Educate drivers on eco-driving techniques (e.g., smooth acceleration, reduced idling).
3. **Gamification and Rewards**
  - i. Develop apps to track carbon savings for users of public transport/NMT, offering redeemable points.
4. **Showcase Success Stories**
  - i. Highlight case studies (e.g., Pune’s 22% congestion reduction) to build public support.

Our study analysis revealed a high number of petrol and diesel vehicles. This highlighted the need for a shift to public transport, yet data on such transitions was currently unavailable. There was a need for a behavioural change through awareness campaigns. The emphasis should be on promoting public transport adoption, electric vehicles for supporting the decarbonization. Apart from this the policies aiming at reducing the petrol and diesel vehicle usage with the help of restrictions would be helpful. Awareness campaigns would definitely play an important role in the modal shift and commuters making better choices.

## 6.6 Conclusion

By integrating technology, policy, and public engagement, NOIDA can emerge as a model for data-driven decarbonization. These strategies align with India’s net-zero goals while addressing NOIDA’s unique challenges—rapid urbanization, traffic congestion, and industrial growth.

### Next Steps

1. Pilot ERP and EV zones in high-impact corridors.
2. Establish a dedicated task force for CMP implementation.
3. Monitor KPIs (e.g., emission reductions, EV adoption rates) via ICCC dashboards.

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# Annexure 1

## Hyderabad's AI-Powered Adaptive Traffic Signal System

### Introduction

Hyderabad, one of India's fastest-growing cities, has faced escalating traffic congestion due to rapid urbanization and increasing vehicular density. To address this, the Hyderabad Traffic Police and Greater Hyderabad Municipal Corporation (GHMC) implemented an **AI-powered Adaptive Traffic Control System (ATCS)**. This case study examines the project's design, implementation, and outcomes, drawing from reports by *Telangana Today* and comparable global initiatives like Los Angeles' ATCS.

### Project Concept and Implementation

The project aimed to reduce congestion, lower emissions, and improve commute predictability by replacing static traffic signals with dynamic, AI-driven signals. Inspired by successful models like Singapore's Green Link Determining System (GLIDE), Hyderabad's system was rolled out in phases, starting with high-traffic corridors such as Begumpet, Hi-Tech City, and LB Nagar.

#### Key implementation steps included:

1. Installing **IoT sensors and cameras** at junctions to collect real-time traffic data.
2. Deploying **AI algorithms** to analyse traffic flow and adjust signal timings dynamically.
3. Centralizing control through a **cloud-based monitoring system** for citywide coordination.

#### Key Components of the Project

1. Adaptive Signal Control: Signals adjust timings based on live traffic, reducing idle time (e.g., green extensions for congested routes).
2. AI and Machine Learning: Predictive analytics optimize signal cycles during peak hours, similar to Los Angeles' ATCS system.
3. Centralized Traffic Management: A command centre monitors all junctions, enabling rapid response to incidents.

## Impact and Achievements

1. Reduced Congestion: Travel times dropped by 20–25% in pilot areas (Telangana Today, 2023).
2. Lower Emissions: Idling time reduction cut CO<sub>2</sub> emissions by ~15% at major junctions.
3. Improved Emergency Response: Ambulances and fire trucks saw 30% faster clearance times.
4. Public Satisfaction: Surveys indicated 85% approval for shorter wait times (GHMC report, 2023).
5. Comparable outcomes were observed in **Los Angeles' ATSAC**, which reduced delays by **12%** (U.S. DOT, 2022), validating Hyderabad's approach.

## Challenges and Learnings

1. **Technical Hurdles:** Initial AI mispredictions caused signal glitches, resolved through iterative algorithm training.
2. **Public Awareness:** Commuters needed education on dynamic signal behaviour to prevent confusion.
3. **Scalability:** Expanding to 500+ junctions requires robust infrastructure, mirroring challenges faced by **Beijing's traffic system**.

## Lessons Learned

1. Pilot testing is critical before citywide rollout.
2. Stakeholder engagement (e.g., traffic police, civic bodies) ensures smoother adoption.

## Conclusion

Hyderabad's ATCS demonstrates how **data-driven traffic management** can decarbonize urban transport while enhancing efficiency. By leveraging AI and IoT, the city achieved tangible benefits in congestion reduction, emission cuts, and public satisfaction—paralleling global successes like Singapore and Los Angeles. Future integration with **public transit and gamified incentives** (e.g., rewards for using green modes) could further amplify its impact.

### Sources:

1. Telangana Today (2023). *New Traffic Signal System in Hyderabad*.
2. GHMC Report (2023). *Adaptive Traffic Control System Performance Review*.
3. U.S. Department of Transportation (2022). *Los Angeles ATSAC Evaluation*.
4. Land Transport Authority, Singapore (2021). *GLIDE System Case Study*.

# Annexure 2

## Bhubaneswar's Adaptive Traffic Signal Control System (ATSCS) for Smarter Mobility

### Introduction

Bhubaneswar, the capital of Odisha and a rapidly growing urban hub, faces escalating traffic congestion due to a surge in vehicular density and inefficient signal management. As part of its Smart City Mission, Bhubaneswar implemented an Adaptive Traffic Signal Control System (ATSCS) using Composite Signal Control Strategy (CoSiCoSt), an indigenous AI-powered solution developed by C-DAC. This case study explores the project's design, execution, and outcomes, supplemented by insights from comparable systems like Pune's Intelligent Traffic Management System (ITMS) and Bengaluru's AI-based signal optimization.

### Project Concept and Implementation

The project aimed to reduce human-hour losses, cut emissions, and enhance traffic flow by replacing static signals with dynamic, sensor-driven signal coordination. Funded under the Smart City Mission (INR 14.7 crore), the system was piloted at 58 intersections, 14 pelican crossings, and 5 blinker zones.

### Implementation Phases

1. **Pilot Testing:** Sensors and solar-powered signals installed at high-congestion junctions (e.g., Master Canteen Square).
2. **Real-Time Synchronization:** CoSiCoSt technology adjusted signal timings based on live traffic data from **embedded road sensors**.
3. **Centralized Integration:** Linked to Bhubaneswar's **Intelligent City Operations Centre** for citywide monitoring.

### Key Components of the Project

1. **CoSiCoSt Technology: AI-Driven Synchronization:** Adjusts green phases dynamically, akin to Pune's ITMS (Maharashtra Metro, 2022).
2. **Solar-Powered Infrastructure:** Ensures sustainability, reducing grid dependency.
3. **Future-Ready Upgrades:** Planned integration with automatic number plate recognition (ANPR) and emergency response systems.
4. **Central Command Centre:** Provides real-time analytics, similar to Surat's Integrated Traffic Management System (ITMS).

## Impact and Achievements

1. **Reduced Congestion:** Expected 20–30% drop in intersection delays post-full deployment (BSCL Report, 2023).
2. **Emission Reduction:** Optimized idling time projected to lower CO<sub>2</sub> emissions by **12–15%** at pilot sites.
3. **Improved Emergency Response:** Faster clearance for emergency vehicles, mirroring **Hyderabad's ATCS** (Telangana Today, 2023).
4. **Equitable Traffic Distribution:** Dynamic signal timing ensures fair green-phase allocation across directions.

## Challenges and Learnings

1. **Technical Limitations:** Initial sensor calibration issues caused signal misalignment, resolved through iterative AI training.
2. **Public Adaptation:** Commuters needed awareness campaigns to adjust to dynamic signal behaviour.
3. **Scalability:** Expanding to 300+ intersections requires robust funding and maintenance, a challenge noted in **Delhi's ITS** (DIMTS, 2020).

## Key Lessons:

1. **Pilot-first approaches** mitigate large-scale risks.
2. **Stakeholder collaboration** (e.g., traffic police, C-DAC) ensures smoother execution.

## Conclusion

Bhubaneswar's ATSCS exemplifies how indigenous AI solutions can transform urban mobility while aligning with decarbonization goals. By leveraging real-time data and solar energy, the city has laid a foundation for scalable, sustainable traffic management. Future integration with public transit and pollution sensors could further amplify its impact, offering a replicable model for other Indian cities.

## Sources:

1. Bhubaneswar Smart City Limited (BSCL). (2023). *ATSCS Project Report*.
2. C-DAC. (2022). *CoSiCoSt Technology White Paper*.
3. Pune ITMS. (2022). *Maharashtra Metro Impact Assessment*.
4. Telangana Today. (2023). *Hyderabad's Adaptive Traffic Signal System*.

# Annexure 3

## All location MET data

Locations	PM <sub>2.5</sub>	PM <sub>10</sub>	NO <sub>2</sub>	SO <sub>2</sub>	Latitude	Longitude
Botanical Metro	44.7	92.5	15	97.7	28.5644	77.33509
Sector-91	54.3	60.11	14.49	74.8	28.509	77.39008
Degree College	82.9	99	0.9	5.5	28.5726	77.35306
Pathway School	91	115.1	35.7	557.1	28.5425	77.37045
SEC-18 Metro	202.1	257.8	1	37.1	28.5709	77.32631
Below Mahamaya	251.7	329.9	1.9	6.7	28.5561	77.32529
Okhla Bird Metro	262.3	358.3	45.4	60.1	28.5525	77.32207
Amarpali Chouraha	274.01	382.37	0.41	64.06	28.5541	77.32684
Sector-93	302.2	413.9	82	304.3	28.5174	77.38855
Model town	330	467.4	0.35	82.3	28.6307	77.37452
Aushadhi Park	null	null	16.9	30.4	28.55	77.32
City centre	null	null	0.76	21.67	28.5747	77.35611
Hajipur Chouraha	null	null	10.9	22.5	28.5306	77.36224
Hoshiyarpur	null	null	3.63	19.63	28.5827	77.36609
Noida City Center	null	null	0.76	21.67	28.5747	77.35611
Old HTMS Golchakkar	null	null	1.28	11.41	28.5561	77.32677
phoolmandi	null	null	68.5	64	28.5313	77.42035
Rajnigandha	null	null	11.4	205.5	28.5772	77.31878
Samet 76	null	null	20.01	52.17	28.5712	77.37889
Sector-142	null	null	0.7	7.3	28.4971	77.41726
Spice Mall Chauraha	null	null	40.77	3.32	28.5864	77.34006

### 1. Speed data for spatial analysis

Location	Latitude	Longitude	Speed (km/hr)
Below Mahamaya	28.55609	77.32529	58
Hoshiyarpur	28.58274	77.36609	30
Old HTMS Golchakkar	28.5561	77.32677	15
Sector-93	28.5174	77.38855	18

## 2. MET and Speed Analysis for locations

There were three more locations where the speed and MET data were available. They are described as below.

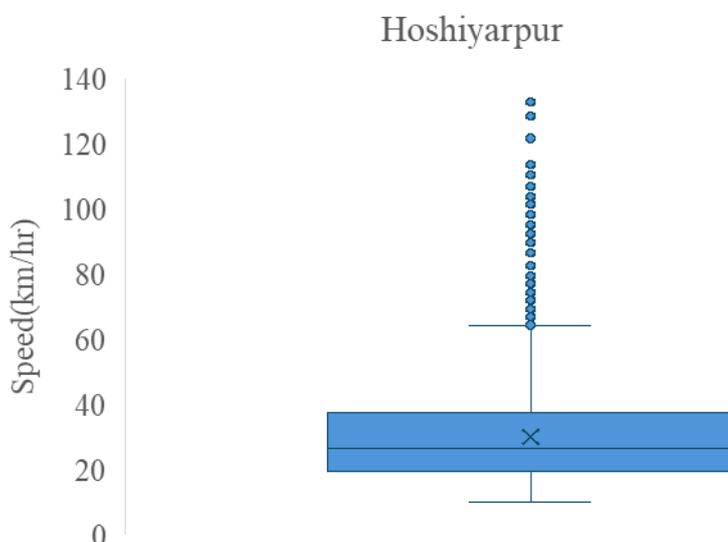
### HOSHIYARPUR

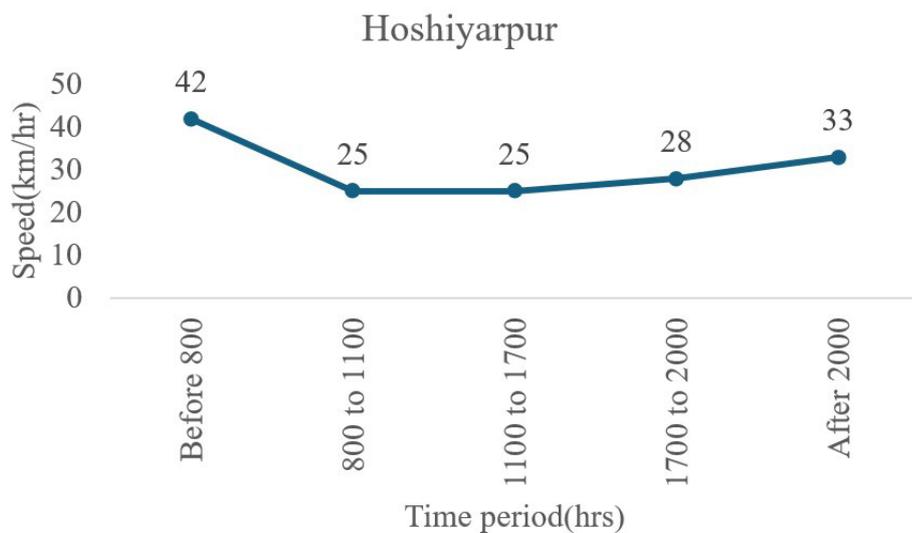
#### MET

	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
Mean	0	No records	0	No records	3.63	Below the permissible limit	19.63	Above the permissible limit
Median	0		0		3.46		16.33	
Mode	0		0		3.74		17.04	
Standard Deviation	0		0		0.44		8.04	
Minimum	0		0		2.78		11.66	
Maximum	0		0		4.63		47.76	

#### Speed

Summary Statistics	Average Speed(km/hr)	Before 800hrs	800 to 1100hrs	1100 to 1700hrs	1700 to 2000hrs	After 800hrs
Mean	30	42	25	25	28	33
Median	27	41	22	24	25	30
Mode	27	37	22	24	27	24
SD	15	17	12	11	13	16
Minimum	10	10	10	10	10	10
Maximum	133	133	122	99	116	173
Count	8772	1246	1278	1984	1319	1324





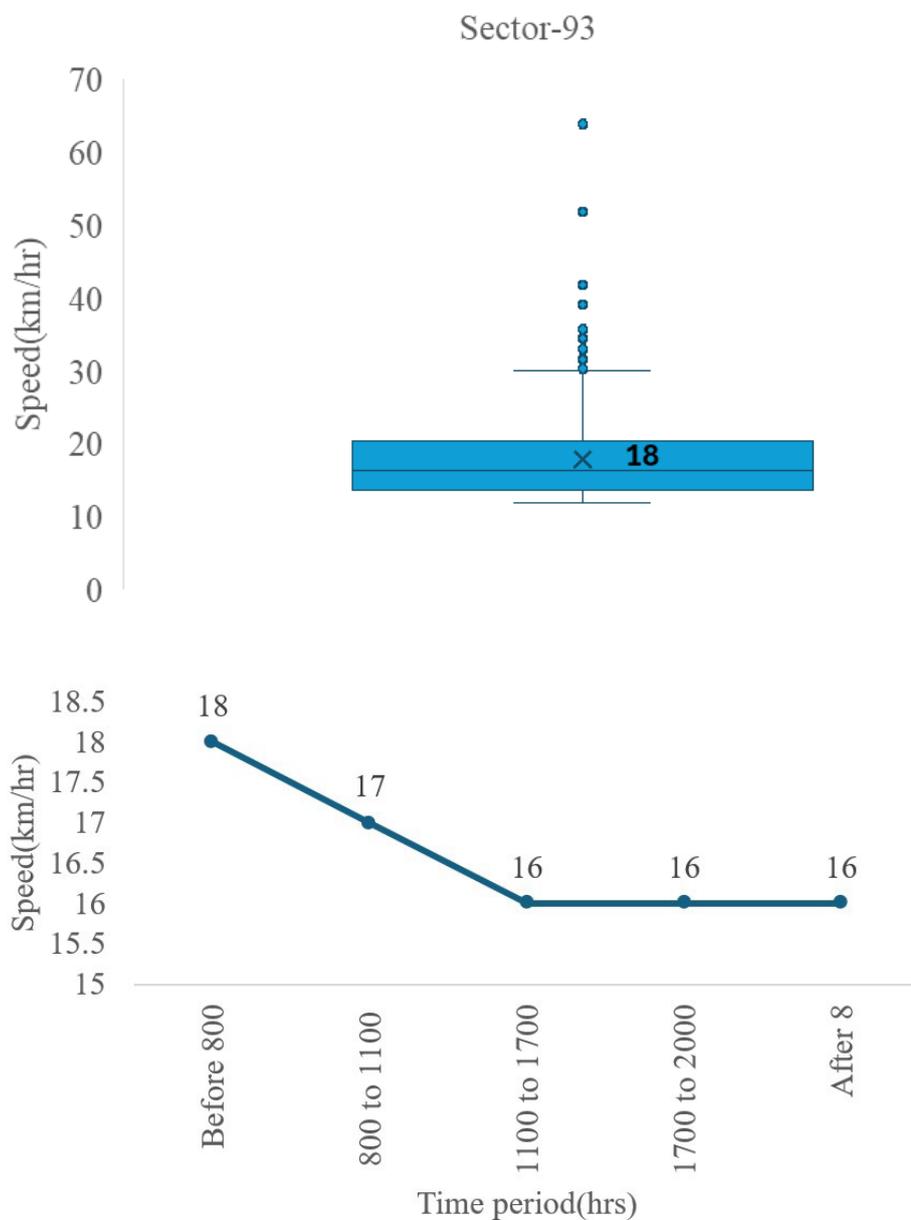
## SECTOR 93

### MET

Sector 93	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (60 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	302.2	Above the permissible limit	413.9	Above the permissible limit	82	Above the permissible limit	304.3	Above the permissible limit
<b>Median</b>	306.3		417.3		85		289.9	
<b>Mode</b>	215.6		291.5		84		250	
<b>Standard Deviation</b>	123.1		175.2		16.3		97.5	
<b>Minimum</b>	33.9		45.3		35.9		0.4	
<b>Maximum</b>	680.2		968.6		126.7		613.1	

### Speed

Summary Statistics	Average Speed (km/hr)	Before 800 hrs	800 to 1100 hrs	1100 to 1700 hrs	1700 to 2000 hrs	After 800 hrs
Mean	18	19	17	16	16	16
Median	17	16	15	15	15	14
Mode	12	10	11	10	11	11
SD	6	8	6	5	6	6
Minimum	10	10	10	10	10	10
Maximum	64	42	64	36	42	31
Count	1010	69	326	728	165	42



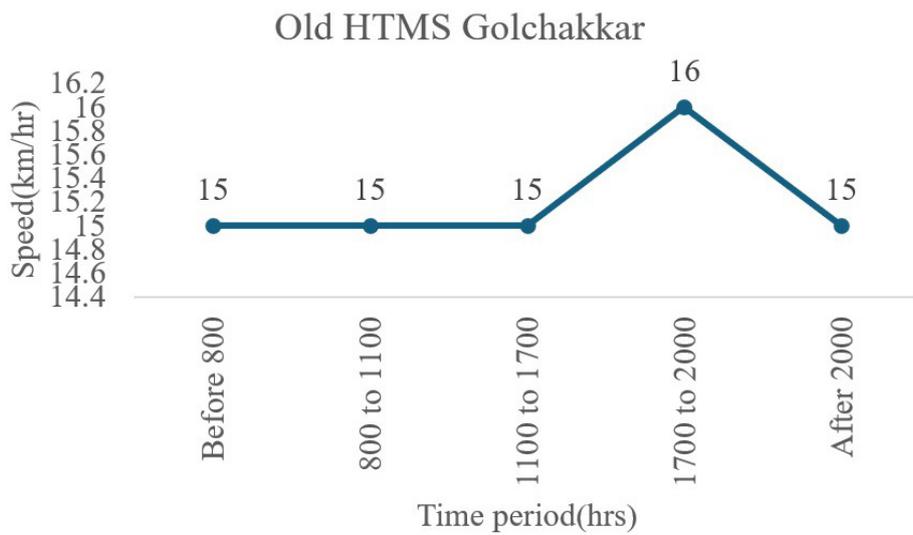
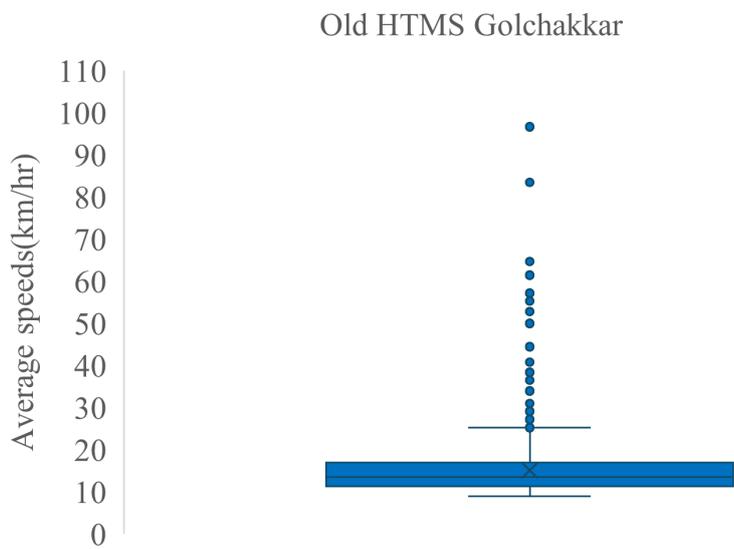
**OLD HTMS GOLCHAKKAR**

**MET**

HTMS (Old) to 44 Golchakra	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (60 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	0	No records	0	No records	1.28	Below the permissible limit	11.41	Below the permissible limit
<b>Median</b>	0		0		1.23		11.12	
<b>Mode</b>	0		0		0		18.51	
<b>Standard Deviation</b>	0		0		0.78		3.07	
<b>Minimum</b>	0		0		1E-06		1.46	
<b>Maximum</b>	0		0		3.98		56.67	

### Speed

Summary Statistics	Average Speed (km/hr)	Before 800 hrs	800 to 1100 hrs	1100 to 1700 hrs	1700 to 2000 hrs	After 800 hrs
Mean	15	15	15	15	16	15
Median	14	14	13	13	14	13
SD	6	7	7	6	6	6
Minimum	9	9	9	9	9	9
Maximum	97	62	97	84	57	62
Count	1731	131	379	674	287	274



### 3. Location wise MET Data

The summary statistics of pollutants and their comparison with the permissible limits as prescribed by CPCB are summarized herewith.

#### AMRAPALI GOLCHAKKAR

	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	274.01	Above the permissible limit	382.37	Below the permissible limit	0.41	Below the permissible limit	64.06	Below the permissible limit
<b>Median</b>	274.56		377.13		0.27		64.06	
<b>Mode</b>	94.58		135.4		1E-06		64.06	
<b>SD</b>	108.87		152.2		0.29		0	
<b>Minimum</b>	1.04		1.4		1E-06		64.06	
<b>Maximum</b>	531.14		734.48		1		64.06	

#### BOTANICAL GARDEN

Statistics	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	44.7	Above the permissible limit	92.5	Above the permissible limit	15	Below the permissible limit	97.7	Above the permissible limit
<b>Median</b>	42.8		86.5		12		62.9	
<b>Mode</b>	28.1		57.5		10.5		49.4	
<b>SD</b>	23.6		51		6.4		79.7	
<b>Min</b>	5.2		11.2		9.7		28.9	
<b>Max</b>	123.5		270		43.6		455.5	

#### CITY CENTER

City Center	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	0	No records	0	No records	0.76	Below the permissible limit	21.67	Above the permissible limit
<b>Median</b>	0		0		0.75		21.3	
<b>Mode</b>	0		0		0.76		23.58	
<b>SD</b>	0		0		0.08		1.94	
<b>Minimum</b>	0		0		0.54		17.67	
<b>Maximum</b>	0		0		1.06		29.19	

### DEGREE COLLEGE TIRAHA

	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	82.9	Above the permissible limit	99	Below the permissible limit	0.9	Below the permissible limit	5.5	Below the permissible limit
<b>Median</b>	80.9		94		0.9		5.2	
<b>Mode</b>	73.4		80.8		0.8		5.2	
<b>SD</b>	14.5		26.7		0.1		1.8	
<b>Minimum</b>	59.2		60.3		0.6		1.5	
<b>Maximum</b>	139.5		205.6		1.6		12.9	

### HAJIPUR CHOURAHA

	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
Mean	0	No records	0	No records	10.9	Below the permissible limit	22.5	Below the permissible limit
Median	0		0		6.4		21.9	
Mode	0		0		20.1		22.5	
Standard Deviation	0		0		11.4		4.8	
Minimum	0		0		2.3E-05		4.8	
Maximum	0		0		49.4		43.1	

### MODEL TOWN

Model town	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	330	Above the permissible limit	467.4	Above the permissible limit	0.3	Below the permissible limit	82.3	Above the permissible limit
<b>Median</b>	323		447.7		0.4		82.6	
<b>Mode</b>	61.3		347.9		0.4		81.8	
SD	128.6		185.3		0.1		6.8	
<b>Minimum</b>	47.5		64.6		0		60.1	
<b>Maximum</b>	707.7		1049.4		0.7		103.9	

### PATHWAY SCHOOL

	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
Mean	91	Above the permissible limit	115.1	Above the permissible limit	35.7	Below the permissible limit	557.1	Above the permissible limit
Median	65.3		78.8		29.1		480.5	
Mode	39.2		54		0.1		463.3	
SD	72		99.5		30.2		245	
Minimum	5.2		5.3		0.1		111.9	
Maximum	370.3		530.2		128.7		1505.2	

**RAJNIGANDHA CHOURAHA**

	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
Mean	0	No records	0	No records	15.3	Below the permissible limit	205.5	Above the permissible limit
Median	0		0		0.6			
Mode	0		0		0.6			
SD	0		0		25.4			
Minimum	0		0		0.6			
Maximum	0		0		44.6			

**SAMET 76 INTERNAL ROAD**

Samet 76 Internal Road	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	0	No records	0	No records	20.01	Below the permissible limit	52.17	Below the permissible limit
<b>Median</b>	0		0		15.37			
<b>Mode</b>	0		0		14.12			
SD	0		0		9.73			
<b>Minimum</b>	0		0		11.73			
<b>Maximum</b>	0		0		56.52			

**SECTOR 142**

Samet 76 Internal Road	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	0	No records	0	No records	0.7	Below the permissible limit	7.3	Below the permissible limit
<b>Median</b>	0		0		0.63			
<b>Mode</b>	0		0		0.58			
SD	0		0		0.23			
<b>Minimum</b>	0		0		0.32			
<b>Maximum</b>	0		0		1.82			

**SECTOR 18 METRO**

Sector 18 Metro	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	202.1	Above the permissible limit	257.8	Above the permissible limit	1	Below the permissible limit	37.1	Below the permissible limit
<b>Median</b>	195.6		246.6		1			
<b>Mode</b>	141.2		276.7		0.9			
<b>SD</b>	95.4		126.6		0.1			
<b>Minimum</b>	28.9		37.4		0.8			
<b>Maximum</b>	513.4		677.1		1.3			

### SECTOR 91 T POINT

Sector 91 T Point	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	54.3	Below the permissible limit	60.11	Below the permissible limit	14.49	Below the permissible limit	74.8	Above the permissible limit
<b>Median</b>	42.08		45.2		16.98		56.86	
<b>Mode</b>	131.45		53.98		7.12		28.68	
<b>SD</b>	40.75		47.39		6.39		48.81	
<b>Minimum</b>	4.22		4.42		1.55		21.94	
<b>Maximum</b>	279.19		332.22		22.88		252.53	

### SPICE MALL CHOURAHA

Spice Mall Chouraha	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	0	No records	0	No records	40.77	Below the permissible limit	3.32	Below the permissible limit
<b>Median</b>	0		0		41.05		3.04	
<b>Mode</b>	0		0		41.05		2.84	
<b>SD</b>	0		0		1.5		1.23	
<b>Minimum</b>	0		0		24.96		0.27	
<b>Maximum</b>	0		0		41.11		14.46	

### PHOOL MANDI CHOURAHA

Phool Mandi Chouraha	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	0	No records	0	No records	68.5	Below the permissible limit	64	Below the permissible limit
<b>Median</b>	0		0		76		64.1	
<b>Mode</b>	0		0		0		64.1	
<b>SD</b>	0		0		34.9		0.5	
<b>Minimum</b>	0		0		0.01		50.6	
<b>Maximum</b>	0		0		191		64.1	

### OKHLA BIRD SANCTUARY METRO

Okhla bird sanctuary Metro	PM <sub>2.5</sub>	PM <sub>2.5</sub> (60 µg/m <sup>3</sup> ) (permissible limits)	PM <sub>10</sub>	PM <sub>10</sub> (100 µg/m <sup>3</sup> ) (permissible limits)	NO <sub>2</sub>	NO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)	SO <sub>2</sub>	SO <sub>2</sub> (80 µg/m <sup>3</sup> ) (permissible limits)
<b>Mean</b>	262.3	Above the permissible limit	358.3	Above the permissible limit	45.4	Below the permissible limit	60.1	At the permissible limit
<b>Median</b>	252.7		348.2		49.3		63	
<b>Mode</b>	153.8		251.8		49.8		63.9	
<b>SD</b>	117.5		155.8		7.9		7.4	
<b>Minimum</b>	40		54		16.3		33.9	
<b>Maximum</b>	679.8		914.9		50.5		83.5	

**AUSHADHI PARK CHOURAHA (BHUTANI)**

<b>Aushadhi Park Chouraha (Bhutani)</b>	<b>PM<sub>2.5</sub></b>	<b>PM<sub>2.5</sub> (60 µg/m<sup>3</sup>) (permissible limits)</b>	<b>PM<sub>10</sub></b>	<b>PM<sub>10</sub> (100 µg/m<sup>3</sup>) (permissible limits)</b>	<b>NO<sub>2</sub></b>	<b>NO<sub>2</sub> (80 µg/m<sup>3</sup>) (permissible limits)</b>	<b>SO<sub>2</sub></b>	<b>SO<sub>2</sub> (80 µg/m<sup>3</sup>) (permissible limits)</b>
<b>Mean</b>	0	No records	0	No records	16.9	Below the permissible limit	30.4	Below the permissible limit
<b>Median</b>	0		0		13.7		23.2	
<b>Mode</b>	0		0		2.9		42.6	
<b>SD</b>	0		0		14.5		18.5	
<b>Minimum</b>	0		0		0.1		4.6	
<b>Maximum</b>	0		0		59.6		58.2	

# Annexure 4

## Location details for the study

The details of the location selected for the study are tabulated and summarized.

S.No.	Location	Coordinate	Landmark	Intersection / Midblock	Traffic Direction	Arms
1	Hajipur Chouraha	28.53061 77.36224	> NGN Eway Service Road (Mi) > Vishwakarma Rd (Ma)	Intersection	2 way / median present	4
3	Jhoondpura Chouraha	28.59779 77.32945	> Dallupura Road (Ma) > Udyog Marg (Mi)	Intersection	2 way / median present	3
5	Botanical Metro	28.56437 77.33509	> Dadri Main Road (Ma)	Midblock	2 way / median present	NA
6	Phoolmandi	28.53133 77.42035	> Mandi Road (Ma) > Unnamed Road (Mi)	Intersection	2 way / median present	4
7	Hoshiyarpur	28.58274 77.36609	> Cap Shashi Kant Sharma Marg (Ma) > Main Rd Gijhor (Mi)	Intersection	2 way / median present	3
9	Model Town	28.63066 77.37452	> Entry / Exit to DME (Mi) > DME Service Road (Mi) > Vishwakarma Road (Ma)	Intersection / Interchange	Two way / median present	4
10	Sector-142	28.49705 77.41726	> Service Road of NGN Eway (Mi) > Unnamed Road (Mi)	Intersection	Two way / median present	3
13	SEC-18 Metro	28.57085 77.32631	> Cap Vijayant Thapar Marg (Ma)  Presence of intersection in 150m >Maharaja Agrasen Marg/Noida Bypass Flyover (Ma)	Intersection / Interchange	Two way / median present	4
14	Below Mahamaya	28.55609 77.32529	> Mahamaya Flyover (Ma) > NGN Eway (Ma)	Interchange	Two way / median present	NA
15	Aushadhi Park	28.55003 77.32	> Sector Road (Mi) > Gautam Budh Road (Ma) > Sector Road (Mi) > Bandh Road (Ma)	Roundabout	Two way / median present	4

16	Old HTMS Golchakkar	28.5561 77.32677	> Mahamaya Flyover (Ma) > NGN Eway (present in the loop) (Ma)	Loop (Near Auxiliary Lane)	One way / no median	NA
17	Sector-93	28.5174 77.38855	> Sampark Marg (Ma) > Gejha Road / Forest Marg (Mi)	Intersection	Two way / median present	4
18	Amarpali Chouraha	28.55412 77.32684	> Gautam Budh Road (Ma) > Entry / Exit from NGN Eway (Mi) > Unnamed Road (Mi)	Roundabout	Two way / median present	3
19	Degree College	28.57261 77.35306	> Cap Shashi Kant Sharma Marg (Ma) > Noida Road (Ma)	Intersection	Two way / median present	3
20	Sector-91	28.50902 77.39008	> Shaheed Mangal Pandey Marg (Ma) > Forest Marg (Mi)	Intersection	Two way / median present	3
21	Noida City Center	28.57467 77.35611	> Cap Shashi Kant Sharma Marg (Ma) > Shivalik Marg (presence of intersection at 150m) (Mi)	Intersection / Interchange	Two way / median present	4
22	Samet 76	28.57118 77.37889	> Vishwakarma Road (Ma) > Sec 76 Road (Mi)	Intersection	Two way / median present	3
23	Pathway School	28.54253 77.37045	> Vishwakarma Road (Ma) > Shiv Marg (Mi)	Intersection	Two way / median present	3
24	Rajnigandha	28.57723 77.31878	> Captain Vijayant Thapar Marg (Ma) > Amaltash Marg (Ma)	Intersection / Interchange	Two way / median present	4
25	Spice Mall Chouraha	28.58636 77.34006	> Tulsi Marg (Mi) > Noida Road (Ma)	Intersection	Two way / median present	4

# Annexure 5

## 1. Impact of Singapore's Data-Driven Transport Management

Singapore's Intelligent Transport System (ITS) and Electronic Road Pricing (ERP) have delivered measurable improvements in urban mobility and emissions reduction:

1. **Congestion Reduction:** Dynamic toll pricing via ERP discourages private vehicle use during peak hours, smoothing traffic flow.
2. **Emission Cuts:** 15% reduction in CO<sub>2</sub> emissions from transport sector (ITF, 2023).
3. **Public Transport Shift:** 75% peak-hour commuter share now uses public transport, reducing reliance on cars.
4. **Global Benchmark:** Recognized by the International Transport Forum (ITF) as a model for data-driven decarbonization.

### Source:

- *International Transport Forum (ITF). (2023). "Decarbonising Transport in Emerging Cities: Lessons from Singapore."*

### Key Takeaways for Other Cities

- a. **Dynamic pricing (ERP)** effectively manages demand.
- b. **Real-time data integration (GPS/AI)** optimizes traffic.
- c. **Policy-public transport synergy** drives modal shift.

Singapore's success demonstrates how **technology + policy** can achieve **sustainable urban mobility**.

## 2. Impact of Sweden's Vision Zero Initiative

Sweden's Vision Zero Initiative, launched in 1997, has become a global benchmark for data-driven road safety. By analysing crash data, traffic patterns, and pedestrian movement, Sweden redesigned urban infrastructure to prioritize safety, leading to:

1. **Reduction in Road Fatalities**
  - a. Sweden has one of the lowest road fatality rates in the world (2.2 deaths per 100,000 people in 2022, compared to 11.4 in the U.S. and 15.3 in India).
  - b. Pedestrian deaths dropped by 50% since the initiative began (Swedish Transport Administration, 2023).

2. **Speed Management & Infrastructure Redesign**
  - a. 30 km/h (18 mph) speed limits in urban areas reduced fatal crashes by 25%.
  - b. Roundabouts replaced high-risk intersections, cutting severe injuries by 75% (OECD, 2020).
3. **Intelligent Traffic Monitoring**
  - a. Automated speed cameras and AI-based traffic analysis improved enforcement, reducing speeding violations by 40%.

### Relevance for Indian Cities

India, with **over 150,000 annual road deaths**, could adopt similar **data-driven strategies**, such as:

- a. Safe pedestrian crossings (like Sweden's raised crosswalks).
- b. Lower urban speed limits (30 km/h zones near schools & markets).
- c. AI-powered traffic monitoring (as seen in Hyderabad & Bhubaneswar).

### Sources

1. Swedish Transport Administration (2023). *Vision Zero Report*.
2. OECD (2020). *Road Safety Annual Report*.
3. World Health Organization (2023). *Global Status Report on Road Safety*.





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