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Technical Notes

Analysis of the effects of vehicle emission at heavily used intersections along Asian Highway 47 in Indore, India

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Abstract

Vehicular emissions are a major contributor to urban air pollution, necessitating continuous monitoring and assessment to formulate effective mitigation strategies. This study evaluates air pollution levels at two critical traffic divergence points along Asian Highway 47 in Indore, India—IDTL Toll Manglia and Bicholi Mardana—during the winter months of November and December 2022. The study focuses on the simultaneous measurement of Respirable Suspended Particulate Matter (RSPM - PM10), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), and Total Vehicular Pollution Load (TVPL), along with the Air Quality Index (AQI). These pollutants were selected due to their strong correlation with vehicular emissions, their adverse effects on human health, and their contribution to environmental degradation. The sampling process, conducted twice a week for one month, followed Central Pollution Control Board (CPCB) guidelines, employing gravity and absorption principles for particulate and gaseous pollutants, respectively. The results indicate a clear diurnal variation in pollutant concentrations, with significantly higher levels recorded during the evening peak hours compared to the morning period. RSPM concentrations ranged from 101.45 µg/m³ to 152.78 µg/m³ in the morning, while evening values peaked at 190.82 µg/m³ at IDTL Toll Manglia and 173.38 µg/m³ at Bicholi Mardana. Gaseous pollutants (SO_2, NO_2, and CO) showed a similar trend, with higher concentrations at IDTL Toll Manglia, likely due to a greater volume of diesel-powered vehicles and congestion-induced emissions. AQI analysis classified morning pollution levels as moderate, while evening levels indicated severe air pollution, posing increased health risks to the urban population. The study identifies traffic congestion, vehicle density, fuel composition, and idling time as primary contributors to elevated pollution levels at these intersections. The findings highlight the urgent need for strategic urban planning interventions, including traffic decongestion strategies, stricter vehicular emission regulations, improved public transportation infrastructure, and green buffer zones to mitigate the adverse effects of vehicular pollution. The comprehensive dataset generated through this study serves as a critical resource for policymakers in designing evidence-based air quality management policies to ensure sustainable urban development and better public health outcomes in high-traffic corridors.

Keywords – Particulate Matter (PM10), Sulfur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO), Total Vehicular Pollution Load (TVPL), and Air Quality Index (AQI)

1.0 Introduction

The rapid industrialization, urbanization, and increase in vehicular traffic in Central Asia over recent decades have led to significant air pollution issues. The rise in industrial activities, expansion of urban areas, and growing transportation infrastructure have all contributed to the deterioration of air quality in the region. The effects of vehicle emission control programs (VECPs) on the environment have drawn more attention to changes in air pollutants and CO_2 emissions (Xu & Qin, 2023; Mukhitdinov et al., 2024). Vehicle Emission Control Plans (VECPs) are critical in mitigating the environmental impacts of transportation by targeting reductions in air pollutants and CO_2 emissions. These plans typically involve regulations and technological advancements aimed at improving the efficiency of vehicles and reducing their emissions.

Because there are so many cars on the road today, transportation contributes significantly to air pollution in many nations, including India. As the population grew, so did the number of vehicles, which raised the level of vehicular pollution (Sharmilaa & Ilango, 2024). Absolutely, vehicular emissions play a crucial role in exacerbating air pollution and contributing to greenhouse gas (GHG) emissions, with significant implications for public health and the environment. The impacts are profound, affecting millions of lives and encompassing a range of health problems such as mortality and morbidity, child health, interference in remote sensing data and air quality monitoring (Li et al., 2022). The health issues are particularly severe among vulnerable populations such as children and pregnant women. Air pollution poses serious risks to children, leading to respiratory problems, impaired lung development, and other health complications. Infants, children, and adolescents, are indeed more vulnerable to the harmful effects of air pollutants compared to adults such as developing organs, higher metabolic rate, immature immune systems, outdoor activity, neurological effects, etc. Youngsters, with their developing organs and higher intake of air relative to their body weight, are indeed more susceptible to the harmful effects of air pollutants. Protecting children from air pollution requires concerted efforts from governments, communities, and individuals to reduce emissions, improve air quality, and create healthier environments for future generations. Research has also been done with population weighted pollution indexes (Debbarma et al., 2024). There are restrictions, nevertheless, in cases where remote sensing data does not provide air pollution risk assessments based on several pollutants. Prior research solely addressed the concerns associated with air pollution, leaving out the integrative analysis of vulnerabilities and risks (Zabiulla & Kadali, 2022).

Vehicular emissions are a primary source of air pollution, contributing significantly to various harmful pollutants such as Carbon Monoxide (CO), Nitrogen Dioxide (NO_2), Sulfur Dioxide (SO_2), Volatile Organic Compounds (VOCs), Ozone (O_3), Particulate Matter (PM_{10}), and Lead (Andrade et al., 2024). Carbon monoxide is a poisonous gas that can have harmful health effects by reducing the amount of oxygen transported in the bloodstream to critical parts of the body. Preventing CO exposure through proper ventilation, maintenance of combustion appliances, and awareness of safety practices is essential to protect public health and safety. From 1990 to the present, PM_{10} and NO_2 have become major concerns due to their adverse health effects, environmental impact, and increasing concentrations in urban areas (Guttikunda & Mohan, 2024). Addressing these pollutants requires concerted efforts from governments, industries, and communities to reduce emissions, improve air quality, and protect public health. In addition to increasing the risk of respiratory infections and irritating human respiratory tract airways, NO_2 also plays a role in the creation of fine particulate matter and ground-level ozone. SO_2 can cause respiratory problems in humans and contribute to the formation of acid rain, which can harm ecosystems and man-made structures. Addressing SO_2 emissions requires comprehensive strategies to reduce pollution from various sources and mitigate the adverse impacts on human health and the environment (Jion et al., 2023). In summary, ground-level ozone is a significant component of smog and can cause respiratory problems, cardiovascular effects, and environmental damage. Addressing ground-level ozone pollution requires comprehensive strategies to reduce emissions of precursor pollutants and mitigate the adverse impacts on human health and the environment (Pandian et al., 2024). VOCs react with NO_x to form ozone, contributing to smog formation. Lead exposure can cause serious health issues, particularly in children, including cognitive impairment and developmental delays.

The significant traffic density along Asian Highway 47 (AH47) in Indore, India, presents major vehicular emissions and air pollution challenges, particularly at heavily used intersections such as High Vehicle Registration Rate, Traffic Composition and Intensity, Vehicular Emissions, Public Interest Litigation (PIL) (Singh et al., 2023). Asian Highway 47, which begins in Gwalior, Madhya Pradesh, and travels via Banglore to Matara, Sri Lanka, is part of the Asian Highway Network (AH), a collaborative initiative among Asian nations. Asian Highway 47, which runs through the Indore region for 34.5 km and passes through many residential townships, commercial complexes, and institutional buildings, is a heavily traveled route (Sharma & Gautam, 2024). Indore has the second-highest vehicle registration rate in India, with 560 vehicles per 1,000 population, exacerbating traffic congestion and emissions. Two-wheelers dominate the traffic, accounting for 54-67% of vehicles, while passenger cars constitute 22-33% (Kapse et al., 2023). Traffic intensity surges by 40-60% during peak hours, indicating severe congestion on AH47, particularly in the mixed vehicle lanes of the Indore BRT corridor. Vehicular emissions, especially PM_{10}, are a significant contributor to air pollution in Indore (Sharma & Dikshit, 2024). Studies show PM_{10} levels are highest at intersections, with the Manglia intersection having the maximum concentration. The poor traffic conditions led to a PIL demanding the scrapping of the BRT system in favor of mixed lanes for buses, highlighting the severe congestion issues. Upgrading AH47 to a paved 2-lane divided carriageway is expected to increase capacity and reduce travel time. However, traffic is projected to grow from 4,308 vehicles per day to 14,852 by 2029, which will continue to drive emissions.

The sources of local air pollution were identified in the current study, and the analysis concentrated on the effects of changes in traffic load on vehicle pollution levels. The study area was chosen as IDTL toll Manglia and Bicholi Mardana on Asian Highway 47 corridor at Indore. Together with the overall vehicle pollution load on each divergence on Asian Highway 47, the air quality index for each location was computed. In the future, this data can assist in the formulation of policies pertaining to road infrastructure, traffic management, and significant traffic volume reduction strategies. In compliance with the CPCB's recommended limit, it may also be used to examine the present level of vehicular pollution with the matching traffic divergence sites.

2.0 Methodology Adopted

A methodical and exacting sampling technique must be used in order to track and evaluate pollution concentrations in accordance with Central Pollution Control Board (CPCB) regulations (Table 1) and (Fig 1).

Table 1: Summary of Sampling Frequency, Duration, Schedule, and Analytical Principles

Parameter	Details
Sampling Frequency	Twice a week
Duration	Up to one month
Daily Sampling Time	Two sessions per day
Morning Session	4 hours in the morning
Evening Session	4 hours later in the day
Principle Used – Particulate Matter (PM10)	Gravity Principle
Principle Used – Gaseous Pollutants	Absorption Principle

2.1 Sampling Devices

For effective ambient air quality monitoring, different instruments are employed based on the target pollutants and required precision. Each device operates on specific principles, has defined operational parameters, and requires regular calibration to ensure reliable measurements. The following table provides a consolidated overview of three commonly used instruments such as Respirable Dust Sampler (RDS), High-Volume Sampler (HVS), and Gas Absorption Tubes covering their technical specifications, measurement accuracy, and calibration protocols in compliance with CPCB and USEPA guidelines (Table 2).

Table 2: Specifications, Accuracy, and Calibration Details of Ambient Air Quality Monitoring Instruments

Instrument	Key Specifications	Accuracy	Calibration & Error Tolerance
Respirable Dust Sampler (RDS)	Flow rate: 1.0–1.5 m^3/min; PM10 cut-off ≤10 µm; Glass fiber/membrane filters; Single-phase 220–230 V, 50 Hz; Stainless steel casing; Operating temp: 5–50 °C; Auto time & flow control; CPCB/USEPA compliant	Flow rate: ±5%; PM10 cut-off via impactor plate	Every 3 months or after heavy use; Flow rate via bubble flow/orifice meter; Filter weights on ±0.01 mg microbalance; Error: ±5% (flow), ±2 µg/m^3 (concentration)
High-Volume Sampler (HVS)	Flow rate: 1.1–1.7 m^3/min; Cascade impactor for ≤100 µm; Glass microfiber filters (≥99% for PM10 & PM2.5); AC 220–240 V, 50 Hz; Rotary vane/diaphragm pump; 0–50 °C, RH ≤85%; CPCB/USEPA compliant	Flow rate: ±5%; Mass measurement: ±0.2 mg	Quarterly or after changes; Flow via orifice meter; Pre/post filter weights on ±0.01 mg microbalance; Error: ±5% (flow), ±2% (concentration)
Gas Absorption Tubes	Media: Reagent-coated silica gel/activated carbon; Flow: 0.2–1.0 L/min; Tube: 10–15 cm × 6–8 mm; SO_2 range: 5–2000 µg/m^3; NO_2 range: 10–3000 µg/m^3; SO_2 reagent: TCM; NO_2 reagent: Triethanolamine; Glass; 0–50 °C, RH ≤85%	Gas efficiency: ≥95%; SO_2: ±2 µg/m^3; NO_2: ±5 µg/m^3; Repeatability: ±5%	Before major campaign or monthly; Calibrate with certified gas mixtures; Analyze via UV-Vis or colorimetry; Error: ±2% (SO_2), ±5% (NO_2)

Fig 1 depicts the methodology used to monitor and analyse pollution concentrations.

Fig.1 Methodology Flowchart

2.2 Site Selection Standards

When selecting monitoring sites in commercial or traffic-dense areas, it is important to position them so that the readings truly represent the air quality of the entire zone, rather than the influence of a single pollution source. The site should be far enough from locations with exceptionally high traffic emissions to prevent skewed results from localized pollution hotspots. At the same time, it should remain close to commercial hubs such as shopping complexes, business districts, or industrial clusters, where human activity and vehicular movement are consistently high.

To accurately capture traffic-related air pollution, the chosen site should be near a roadway that carries a large volume of vehicles, ideally more than 10,000 cars per day. This placement ensures the data reflects emissions under typical heavy-traffic conditions, offering a reliable picture of air quality in busy urban environments.

2.2.1. Site Locations

To assess air quality in areas affected by significant vehicular movement, two high-traffic monitoring locations were selected based on their strategic importance and surrounding land use (Table 3). Both sites experience continuous heavy traffic and are situated near densely populated residential zones, making them ideal for capturing representative data on pollution exposure in urban environments.

Table 3: Selected Monitoring Sites and Corresponding Traffic Volumes

Site	Location Description	Traffic Volume (cars/24 hours)
IDTL Toll Manglia	Busy traffic divergence point surrounded by residential townships	40,224
Bicholi Mardana	Congested traffic divergence junction surrounded by large residential townships	36,197

These locations were chosen due to their high traffic volumes, proximity to residential and commercial areas, and significant two-wheeler and passenger car traffic composition, making them representative of the region's vehicular pollution challenges.

2.2.2 Air Quality Index (AQI)

The Air Quality Index (AQI) is a valuable tool that plays a crucial role in communicating air quality information effectively to the public, raising awareness about the importance of clean air, and guiding actions to protect public health and the environment. Its simplicity, comprehensiveness, and real-time monitoring capabilities make it an essential resource for individuals, communities, and policymakers alike. It simplifies complex data on various air pollutants into a single, easy-to-understand number and corresponding color code, reflecting the health impacts of air quality on a scale from 0 to 500 (EPA, 2010).

2.2.3 Total Vehicular Pollution Load (TVPL)

The CPCB reported that the quantum of pollutants emitted by vehicles is directly proportional to The number of automobiles circulating in the city. The three and four-wheelers were observed to be highly polluting, which may be due to poor fuel quality, adulteration of kerosene in 3-wheelers, as well as poor maintenance of these vehicles. A correlation (r=0.975) between Total Vehicular pollution load (TVPL) and Total no. of vehicles plying in an area. It indicates a straight-line relationship (CPCB Revised Draft Report, 2010)

This study's goal was to evaluate the degree of air pollution at two significant traffic-diversion locations along AH47 in Indore, India. These points, IDTL Toll Manglia and Bicholi Mardana, are known for their high traffic volumes, especially of two wheelers and passenger cars. Using a respirable dust sampler (RDS) and following CPCB guidelines, the concentrations of nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM_{10}) were measured for this evaluation. The choice of November and December as the study period is justified based on their significance in winter pollution patterns, where temperature inversion typically exacerbates pollutant concentration. Additionally, data collection during both holiday and non-holiday periods ensures a comprehensive understanding of traffic volume and pollution variability.

3.0 Results & Discussions

The study revealed that, compared to midblock sections, the concentrations of RSPM (PM10) were significantly higher at busy crossroads along Asian Highway 47 (AH47) in Indore. The highest PM10 levels were recorded at the IDTL Manglia Toll, ranging from 103.17 μg/m³ in the morning to 190.82 μg/m³ in the evening, with the evening peak showing the maximum concentration. At Bicholi Mardana, although the levels were not as high as at the IDTL Manglia Toll, PM10 concentrations were still elevated, measuring 100 μg/m³ in the morning and 135 μg/m³ in the afternoon. The study further indicated that at both intersections, PM10 concentrations were consistently higher during evening peak hours compared to the morning peak hours, likely due to increased vehicular movement, particularly from two-wheelers and passenger cars, which accounted for approximately 54–67% and 22–33% of the total traffic, respectively.

The main reason for the higher PM10 levels at these crossroads along AH47 in Indore is the exceptionally high traffic volumes, with about 40,224 automobiles passing through IDTL Toll Manglia and 36,197 cars going through Bicholi Mardana per day. Compared to free-flowing traffic, the poor traffic conditions and congestion result in increased emissions. Overall, it was discovered that the IDTL Toll Manglia intersection and Bicholi Mardana had the highest RSPM (PM10) concentrations, both of which were over the permissible limits. Because of the increased traffic in the evening, PM10 levels were at their highest at peak hours. The high PM10 levels at these intersections are attributed to the extremely high traffic volumes. The traffic was dominated by two-wheelers (54-67%) and passenger cars (22-33%), as well as factors like the use of older vehicles and varying fuel quality. These contribute to high PM10 levels despite lower gaseous pollutant concentrations.The presence of a large number of vehicles, especially during peak hours, leads to significant emissions of particulate matter. This pollution poses a serious public health hazard as PM10 can cause respiratory and cardiovascular issues.

Table 5 provides the average RSPM concentration level for Bicholi Mardana (evening and morning peak hours). Figures 2 and 3 show the fluctuation trends with respect to time for the same site, and Table 5 also provides the average RSPM concentration levels for IDTL Toll Manglia. Table 6 shows the evening and morning peak hours, while Figures 4 and 5 demonstrate the variation patterns over time for the location IDTL Toll Manglia. However, the significant difference was not observed on holidays and non holidays which is may be due to people go for outing on holidays to office on working days.

Table 5: Bicholi Mardana's average RSPM (PM10) concentration in the morning and evening peak hours.

RSPM-Bicholi Mardana		
Date	**Morning ($\mu g/m^3$)**	**Evening ($\mu g/m^3$)**
21.11.22	110.39	156.31
26.11.22 (Holidy)	114.30	143.68
30.11.22	100.15	149.01
1.12.22	123.41	173.38
7.12.22	135.33	168.86

8.12.22	106.58	165.82
14.12.22	128.12	161.57
15.12.22	139.73	171.89

Table 6 At IDTL Toll Manglia, the average RSPM (PM10) concentration is measured during the morning and evening peak hours.

The average RSPM (PM10) concentration measured during the morning and evening peak hours at IDTL Toll Manglia is as follows:

RSPM-IDTL Toll Manglia		
Date	Morning ($\mu g/m^3$)	Evening ($\mu g/m^3$)
21.11.22	117.45	191.34
22.11.22	125.56	183.15
25.11.22	104.34	164.75
27.11.22 (Holiday)	131.78	182.39
05.12.22	155.23	188.73
06.12.22	126.76	175.84
10.12.22 (Holiday)	143.54	181.59
11.12.22 (Holiday)	127.13	188.93

These numbers show the amount of RSPM (PM10) present at IDTL Toll Manglia on the designated dates throughout the morning and evening peak hours.

Table 7 Acceptable recommendation issued by the CPCB

Pollutant	Weighted Average of Time	Residential, Commercial, Industrial, and Other Domains	Area of Environmental Sensitivity

Sulfur Dioxide (SO_2), $\mu g/m^3$	24 hours*	82	82
Nitrogen Dioxide (NO_2), $\mu g/m^3$	24 hours*	82	82
Particulate Matter (size less than 10 µm) or PM 10 $\mu g/m^3$	24 hours*	98	98

With the exception of two days in a row, monitored data at 24-hour, 8-hour, or 1-hour intervals must be gathered 97% of the time in a year and 3% of the time (Table 7).

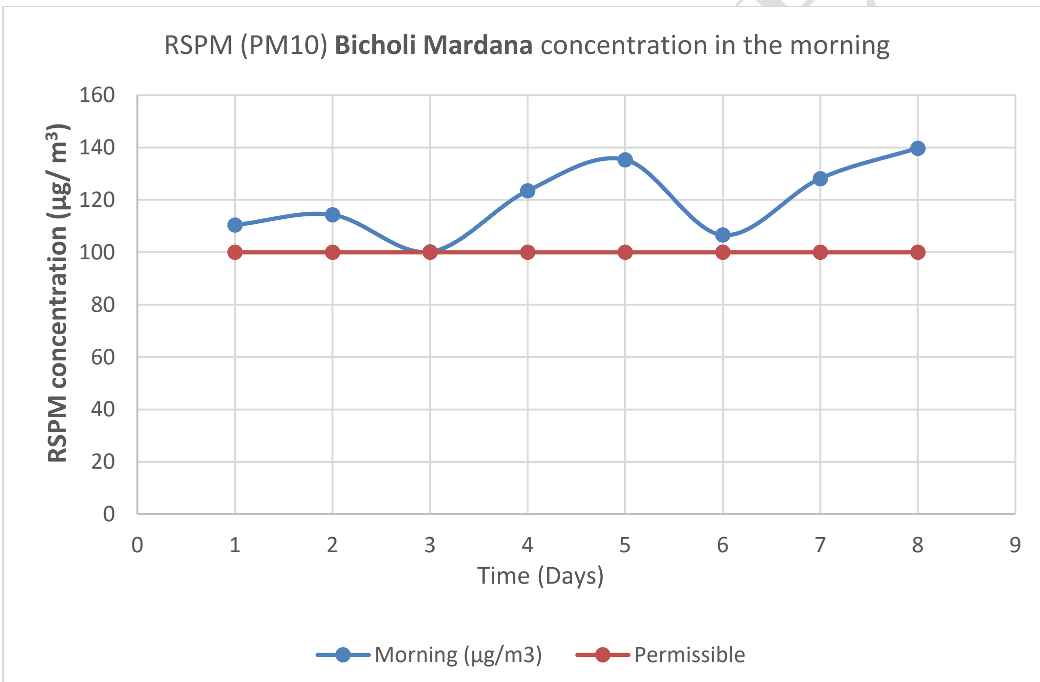

Fig 2 Variation of RSPM across time during the month (Bicholi Mardana Morning Peak Hours)

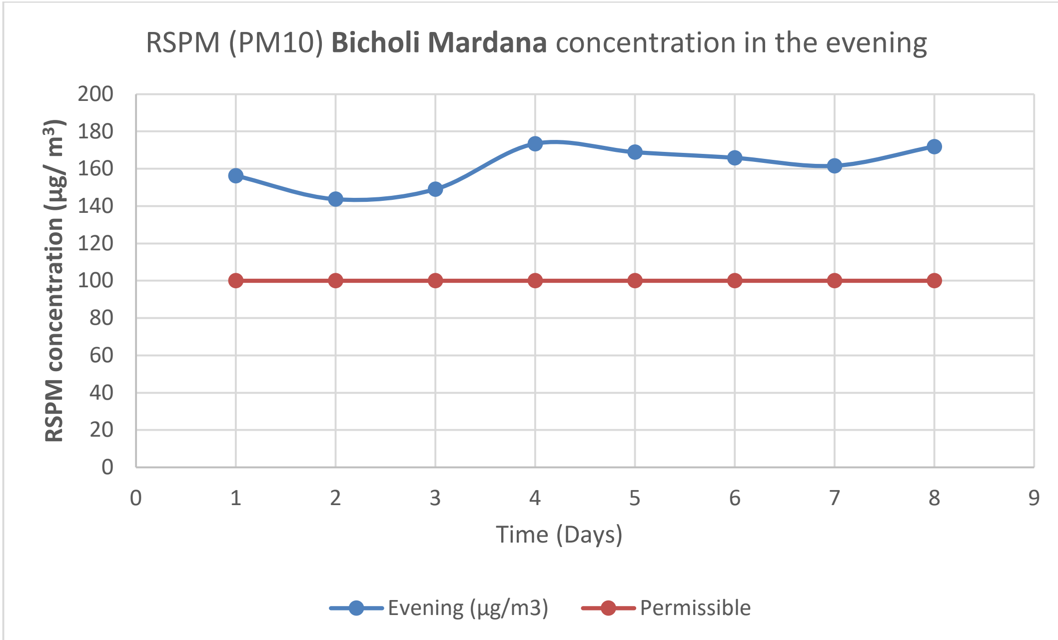

Fig 3 Variation of RSPM regarding time during the month (Bicholi Mardana in the Evening)

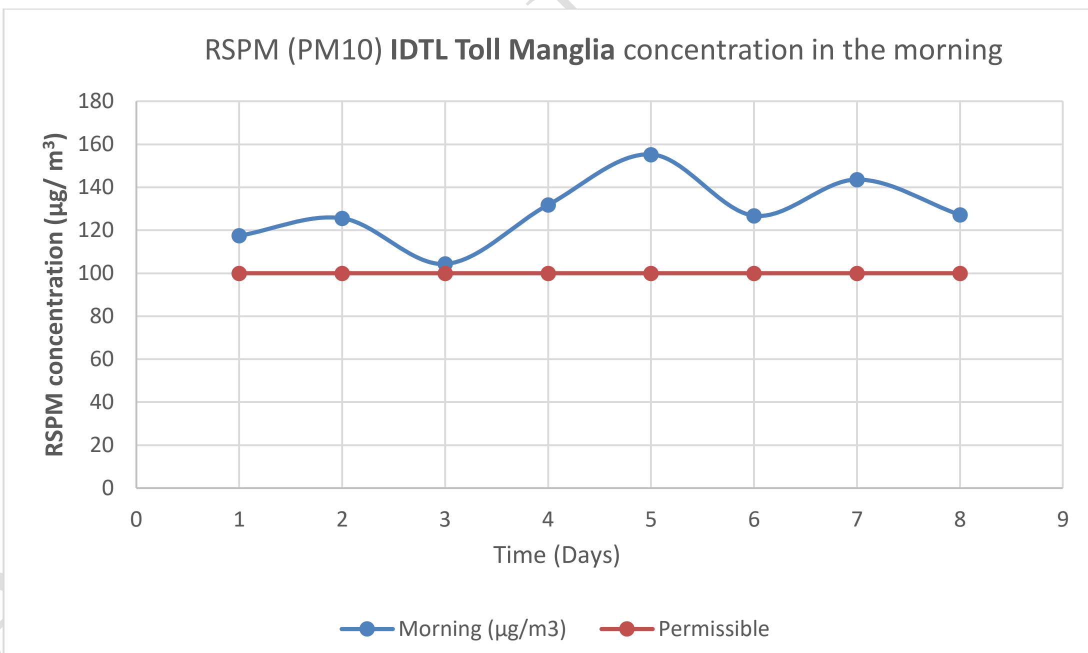

Fig 4 Variation of RSPM regarding time during the month (IDTL Toll Manglia in the Morning)

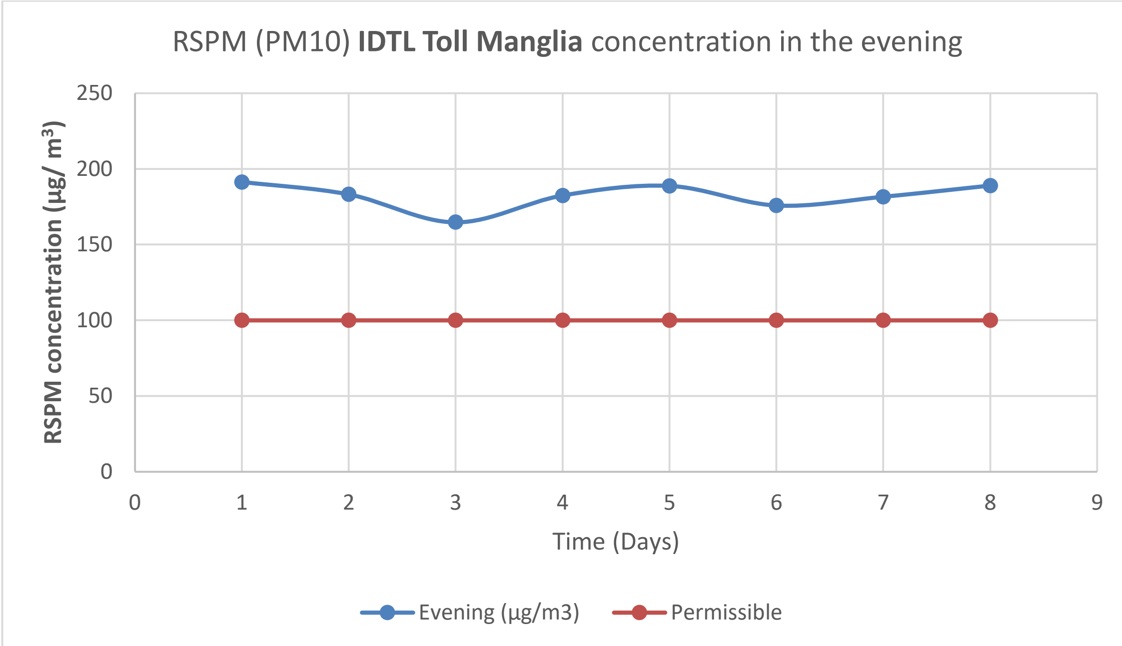

Fig 5 Variation of RSPM regarding time during the month (IDTL Toll Manglia in Evening)

The average SO_2 and NO_2 concentrations at Bicholi Mardana (morning and evening) were found to be below the CPCB's permitted limits. During morning traffic peak hours, SO_2 concentrations ranged from 17.36 µg/m^3 to 29.88 µg/m^3, while NO_2 concentrations ranged from 23.22 µg/m^3 to 37.91 µg/m^3. However, both gaseous pollutants were lower than during evening traffic peak hours. At Bicholi Mardana in the evening, SO_2 concentrations range from 25.59 µg/m^3 to 38.18 µg/m^3, while NO_2 concentrations range from 33.25 µg/m^3 to 46.87 µg/m^3.

The study indicates that the extremely high traffic volumes at these intersections are the primary cause of elevated PM_{10} and NO_2 levels. The congestion and poor traffic conditions lead to higher emissions compared to free-flowing traffic. The highest pollution levels occur during evening rush hours when there are more cars on the road. The findings demonstrate that PM_{10} and NO_2 concentrations at IDTL Toll Manglia and Bicholi Mardana intersections exceed safe limits, posing a significant public health risk. The report emphasizes how vital it is to take action at these crucial AH47 locations to reduce vehicle emissions and enhance air quality. The average concentration level of gaseous pollutants at Bicholi Mardana (evening and morning peak hours) is presented in Table 8, and the variation patterns relating time for the above site are displayed in Fig 6 and 7.

Table 8 Average concentrations of NO_2 and SO_2 at Bicholi Mardana during Morning & Eveningpeak hours

BICHOLI MARDANA				
	MORNING		EVENING	
Date	SO_2 (μg/m³)	NO_2 (μg/m³)	SO_2 (μg/m³)	NO_2 (μg/m³)
24.11.22	17.36	23.22	25.59	34.71
25.11.22	22.72	31.60	29.02	40.10
30.11.22	21.04	28.61	32.80	41.34
1.12.22	29.41	35.19	37.19	46.84
7.12.22	29.88	37.91	38.18	45.29
8.12.22	26.72	33.0	29.08	39.17
14.12.22	20.75	28.95	27.71	33.25
15.12.22	20.55	27.78	27.73	37.85

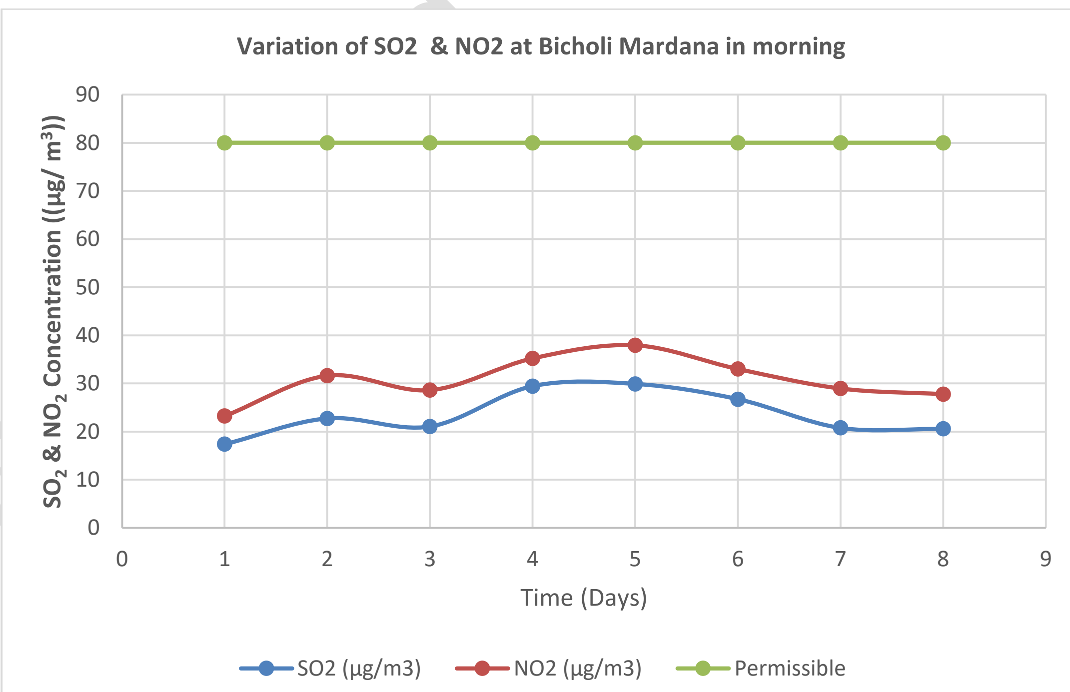

Fig 6 Variation of SO_2 & NO_2 concerning time during the month at (Bicholi Mardana inMorning Peak Hours)

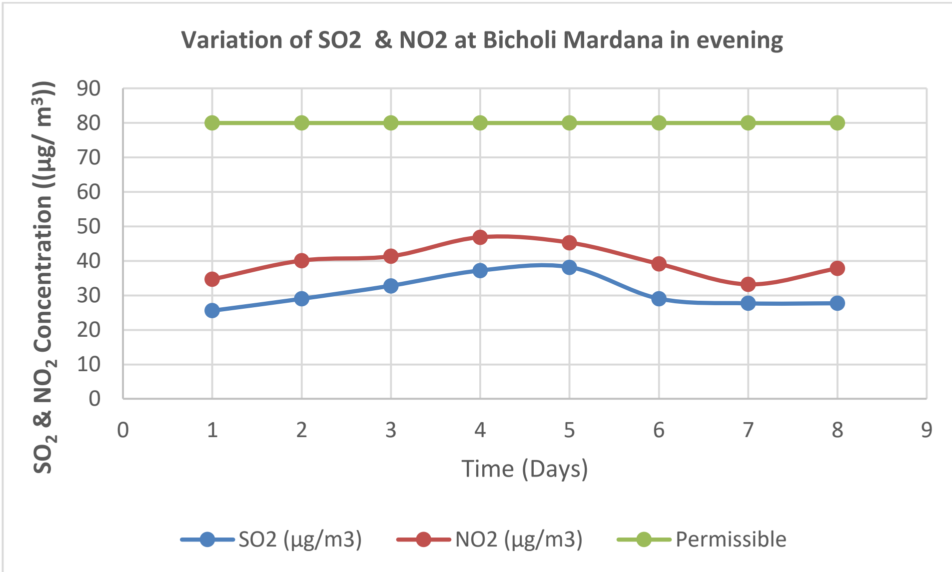

Fig 7 Variation of SO_2 &NO_2 concerning time during the month at (Bicholi Mardana in Evening Peak Hours)

3.1 Average Concentration of $SO_2$and NO_2 at IDTL Toll Manglia

The average SO_2 and NO_2 concentrations at IDTL Toll Manglia (morning and evening) were found to be below the CPCB's permitted limit. Morning traffic peak hours saw concentrations of SO2 µg/m^3 ranging from 20.89 µg/m^3 to 33.91 µg/m^3 and NO_2 µg/m^3 ranging from 29.41 µg/m^3 to 41.50 µg/m^3. However, both gaseous pollutants were found to be lower in the morning than in the evening. At IDTL Toll Manglia in the evening, SO_2 concentrations range from 28.72 µg/m^3 to 39.64 µg/m^3, while NO_2 concentrations range from 36.89 µg/m^3 to 48.86 µg/m^3. Table 9 shows the mean concentration of Gaseous Pollutants throughout the evening and morning peak hours at IDTL Toll Manglia, along with the time-varying trends for the same. Additionally, it has been noted that the concentration of SO_2 is lower than that of NO_2 due to a higher proportion of gasoline-powered vehicles going through the divergence point than diesel-powered vehicles.

Table 9 Average Concentration of SO_2 and NO_2 at IDTL Toll Manglia during Morning & Eveningpeak hours

IDTL TOLL MANGLIA				
	MORNING (µg/m^3)		EVENING (µg/m^3)	
Date	SO_2	NO_2	SO_2	NO_2
20.11.22	20.89	29.41	29.17	40.02
21.11.22	27.71	34.31	35.86	46.66
27.11.22	24.09	30.23	28.72	36.89
28.11.22	33.91	41.50	39.64	48.86
4.12.22	27.42	32.96	32.01	43.73
5.12.22	32.65	41.19	39.04	48.36
11.12.22	28.28	33.35	36.99	42.49
12.12.22	29.40	36.91	32.40	42.66

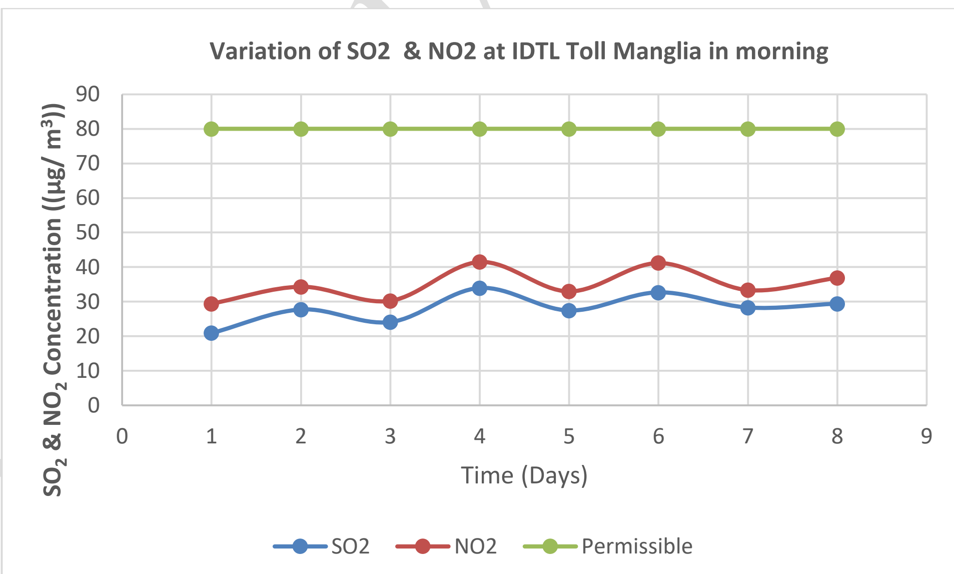

Fig. 8 Variation of SO_2 & NO_2 concerning time during the month at (IDTL Toll Manglia inMorning Peak Hours)

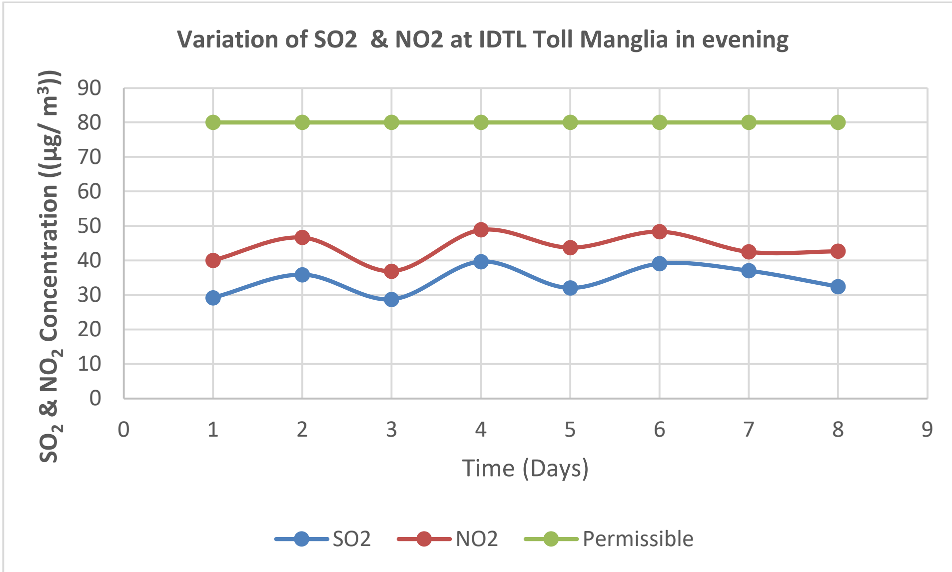

Fig. 9 Variation of SO_2 & NO_2 concerning time during the month at (IDTL Toll Manglia in Evening Peak Hours)

The average SO_2 and NO_2 concentrations at Toll Manglia (morning and evening) were found to be below the CPCB's permitted limits (Fig 8 & 9). During morning traffic peak hours, SO_2 concentrations ranged from 21.36 µg/m^3 to 30.93 µg/m^3, while NO_2 concentrations ranged from 39.33 µg/m^3 to 46.21 µg/m^3. However, both gaseous pollutants were lower than during evening traffic peak hours. At Toll Manglia in the evening, SO_2 concentrations range from 29.66 µg/m^3 to 33.48 µg/m^3, while NO_2 concentrations range from 49.24 µg/m^3 to 52.51 µg/m^3.

However, The Air Quality Index at both traffic divergence points on the AH 47 was observed to show moderate pollution in the morning and heavy pollution in the evening at both sites (Table 10). And the total vehicular pollution load was found to be more in Toll Mangalia than Bicholi Mardana (Table 11).

Table 10 During morning and evening peak hours, the Air Quality Index is measured at both traffic divergence locations on the AH 47 corridor in the Indore region.

Sr No	Sampling Stations	PM 10 (µg/m³)	SO_2 (µg/m³)	NO_2 (µg/m³)	AQI Value	Remarks
1	IDTL Toll Manglia Morning	128.61	28.04	34.98	68.66	Moderate Air Pollution
2	IDTL Toll Manglia Evening	182.15	34.22	43.70	92.65	Moderate to Heavy Air Pollution
3	Bicholi Mardana Morning	119.75	23.55	30.78	62	ModerateAir Pollution
4	Bicholi Mardana Evening	161.31	30.91	39.81	82.66	Moderate to Heavy Air Pollution

Table 11 Total Pollution from Vehicles in the Study Area

Sr No	PLACE	NO.OF VEHICLES PASSES OR PRESENT	TOTAL POLLUTION LOAD (TONNES/DAY)
1	IDTL Toll Manglia	40,224	13.68
2	Bicholi Mardana	36,197	10.29

3.2 Comparison with Traffic Measurement Data

This study represents the first comprehensive assessment of vehicular pollution at the selected locations IDTL Toll Manglia and Bicholi Mardana on Asian Highway 47 in Indore. Since no prior studies or free-access traffic measurement data are available for this corridor, direct comparisons with existing datasets could not be performed. Additionally, no emission control measures, signal optimization strategies, restricted vehicle entry regulations, or peak-hour traffic management policies have been formally implemented or recorded in this area.

However, the study's real-time traffic observations and measured pollutant concentrations provide a baseline dataset for future research and policy-making. The findings highlight the urgent need for systematic traffic data collection and management strategies, including:

1. Installation of Automated Traffic Counters (ATCs) to continuously monitor vehicle density and movement patterns.
2. Integration of real-time air quality and traffic flow data to assess the correlation between congestion levels and pollutant concentrations.
3. Implementation of emission-based traffic restrictions during peak hours, such as low-emission zones or alternate-day vehicle regulations.
4. Adoption of Intelligent Transportation Systems (ITS) to optimize signal timing, reduce idling emissions, and improve overall traffic efficiency.

Future studies should consider collaboration with municipal traffic departments to incorporate real-time traffic monitoring data. This will enable more robust analyses linking vehicular flow patterns with air quality variations, ultimately supporting data-driven policy interventions for traffic and pollution control.

3.3 Temporal Variations in Pollutant Concentrations

3.3.1 Morning vs. Evening Peak Hours

- Data from the study shows significantly higher pollutant concentrations during evening peak hours compared to the morning. This can be attributed to increased traffic density, particularly with more heavy-duty vehicles and commercial traffic during the evening.

- The morning peak (e.g., 7:00–10:00 AM) generally experiences smoother traffic flow due to staggered work start times, reducing idling and emissions compared to the evening peak (e.g., 6:00–9:00 PM), where stop-and-go traffic dominates.

3.3.2 Weekday vs. Weekend

On weekdays, vehicular emissions are predominantly influenced by commuter traffic, resulting in consistent high levels of pollutants. Weekends might exhibit slightly lower concentrations, particularly in commercial areas, due to reduced industrial and office-related traffic.

3.3.3 Seasonal Variations

Winter months (as covered in the study) typically exhibit higher pollutant concentrations due to temperature inversion. This meteorological condition traps pollutants closer to the ground, exacerbating their health and environmental impacts.

3.4 Spatial Variations in Pollutant Concentrations

The comparison between IDTL Toll Manglia and Bicholi Mardana shows that IDTL Toll Manglia consistently recorded higher PM_{10} and gaseous pollutant concentrations. This disparity is largely due to its higher vehicle density 40,224 vehicles per day compared to 36,197 at Bicholi Mardana and a greater proportion of heavy-duty vehicles. While Bicholi Mardana is still polluted, it benefits slightly from better dispersion conditions, possibly due to differences in road design or traffic flow. The study also found that intersections recorded significantly higher pollutant concentrations compared to midblock sections. This is attributed to increased vehicle idling, acceleration, and deceleration at intersections, which heighten emissions, whereas midblocks with smoother traffic flow exhibited lower pollutant levels. Both monitoring sites are located in dense residential and commercial areas, increasing the exposure risk for local populations and intensifying health hazards for vulnerable groups.

3.5 Correlation with Traffic Patterns

The analysis of traffic patterns reveals that two-wheelers, which account for 54–67% of traffic, and passenger cars, making up 22–33%, dominate vehicle composition. These modes contribute heavily to PM_{10} levels due to factors such as poor maintenance, older engines, and the use of adulterated fuels. Diesel-powered vehicles, on the other hand, are the primary contributors to NO_2 and SO_2 emissions because of incomplete combustion processes and the sulfur content in diesel fuel. The study also highlights a direct relationship between traffic volume and pollutant concentrations, with higher daily traffic volumes correlating to increased AQI values, especially during peak hours. Poor road conditions and congestion at intersections exacerbate this issue, as stop-and-go traffic increases fuel consumption and emissions compared to free-flowing conditions.

3.6 Potential Health Impacts

Prolonged exposure to elevated levels of PM_{10}, SO_2, and NO_2 can result in serious respiratory conditions such as asthma, bronchitis, and reduced lung function, as well as cardiovascular problems including hypertension and heart attacks. Vulnerable groups such as children, the elderly, and those with pre-existing health conditions face heightened risks. Children, due to their developing lungs and higher metabolic rates, are particularly susceptible to the harmful effects of particulate matter and gaseous pollutants, while elderly individuals often experience worsened symptoms of pre-existing respiratory and cardiovascular ailments when exposed to polluted air. In addition to these chronic health issues, short-term exposure during peak pollution periods can lead to irritation of the eyes, nose, and throat, and aggravate asthma symptoms.

3.7 Environmental Impacts

The environmental consequences of elevated pollutant levels are significant. High concentrations of particulate matter contribute to the urban heat island effect by trapping heat and altering local microclimates. Increased levels of SO_2 and NO_2 in the atmosphere can react with moisture to form sulfuric and nitric acids, leading to acid rain that harms ecosystems, degrades soil quality, and corrodes infrastructure. Particulate matter also reduces visibility, creating hazardous driving conditions and diminishing the aesthetic quality of urban areas. Furthermore, NO_2 emissions can promote eutrophication in nearby water bodies, triggering algal blooms that deplete oxygen levels and reduce biodiversity.

3.8 Analysis of Measured Pollutant Levels and Application in Urban Planning

The analysis of measured pollutant levels at the two selected traffic divergence points along Asian Highway 47 in Indore IDTL Toll Manglia and Bicholi Mardana shows clear diurnal and spatial variations in PM_{10}, SO_2, NO_2, CO, and AQI. Across both locations, pollutant concentrations were consistently higher during evening peak hours, a trend attributed to heavier vehicular activity, longer idling periods, and traffic congestion. For particulate matter (PM_{10}), the levels exceeded the National

Ambient Air Quality Standards (NAAQS) limit of 100 µg/m^3 for 24-hour exposure. At Bicholi Mardana, PM_{10} averaged 152.78 µg/m^3 during morning peaks and 173.38 µg/m^3 during night peaks. IDTL Toll Manglia recorded a morning minimum of 101.45 µg/m^3 and a night maximum of 190.82 µg/m^3. These elevated values highlight the urgent need for particulate matter mitigation strategies. Recommended measures include deploying mechanized road sweepers fitted with high-efficiency particulate air (HEPA) filtration and applying dust suppression agents such as magnesium chloride on unpaved surfaces. Automated water sprinklers and anti-smog guns, particularly during evening peaks, can help reduce re-suspended dust, while resurfacing damaged roads with porous asphalt would further minimize particle generation.

Vehicular emissions are a significant contributor to PM_{10} levels, especially from diesel-powered trucks. Retrofitting these vehicles with diesel particulate filters (DPFs) can significantly cut emissions. Transitioning public and commercial fleets to cleaner fuels such as compressed natural gas (CNG) or electricity, coupled with designated EV lanes, would further reduce particulate output. Intelligent Traffic Management Systems (ITMS) should be implemented to limit idling through FASTag-based automated toll collection and optimized vehicle queuing. Nitrogen dioxide (NO_2) levels also raise concern. Bicholi Mardana showed moderate concentrations of approximately 35–45 µg/m^3, while IDTL Toll Manglia exceeded 50 µg/m^3, surpassing the World Health Organization's (WHO) annual mean guideline of 40 µg/m^3. These elevated NO_2 levels are largely attributable to diesel exhaust. Mitigation measures include mandating Selective Catalytic Reduction (SCR) systems with AdBlue in heavy diesel vehicles, introducing low-emission zones during peak hours, and enforcing the use of ultra-low sulfur diesel (ULSD) with 10 ppm sulfur content. Fuel-switching to biodiesel blends (B5 or B10) can also help curb NO_2 and PM_{10} formation. Traffic dispersion techniques such as installing vertical exhaust stacks at toll plazas and synchronizing traffic lights to create "green wave" flows can further reduce NO_2 build-up from stop-and-go driving cycles.

Sulfur dioxide (SO_2) concentrations were found to be within NAAQS limits at both locations but remain a concern due to their role in secondary particulate formation. Higher SO_2 levels were noted at IDTL Toll Manglia, driven by diesel vehicle emissions and nearby industrial activity. Control measures should focus on strict ULSD enforcement, banning high-sulfur fuels, and requiring nearby industries to install flue gas desulfurization (FGD) systems, preferably wet scrubbers. Innovative approaches such as sulfur-absorbing road pavements could also be explored. Complementing these interventions, urban greening strategies particularly planting high SO_2-absorbing species like Tamarindus indica, Delonix regia, and Azadirachta indica would enhance pollutant absorption and provide long-term environmental benefits.

Overall, the findings emphasize the need for a multi-pronged approach involving road dust control, cleaner fuels, advanced vehicular emission technologies, industrial regulation, and urban greening. This integrated strategy would not only help bring pollutant concentrations closer to permissible limits but also contribute to healthier urban living conditions along one of Indore's busiest traffic corridors (Table 12).

Table 12: Summary of Measured Pollutant Levels at IDTL Toll Manglia and Bicholi Mardana

Pollutant	Location	Morning Peak (µg/m³)	Evening/Night Peak (µg/m³)	Relevant Standard / Guideline*	Status
PM_{10}	Bicholi Mardana	152.78	173.38	NAAQS: 100 µg/m³ (24h)	Exceeds limit at all times
	IDTL Toll Manglia	101.45	190.82	NAAQS: 100 µg/m³ (24h)	Exceeds limit at all times
NO_2	Bicholi Mardana	~35–45	~35–45	WHO Annual Mean: 40 µg/m³	Borderline to exceeding
	IDTL Toll Manglia	>50	>50	WHO Annual Mean: 40 µg/m³	Exceeds guideline
SO_2	Bicholi Mardana	Within limit	Within limit	NAAQS: 80 µg/m³ (24h)	Compliant
	IDTL Toll Manglia	Within limit	Within limit	NAAQS: 80 µg/m³ (24h)	Compliant

3.9 Suggestions Based on Measured Pollutant Levels

The analysis of pollutant levels at Bicholi Mardana and IDTL Toll Manglia along Asian Highway 47 in Indore underscores the urgent need for location-specific and time-sensitive interventions. Elevated concentrations of PM_{10}, NO_2, and SO_2—particularly during evening peak hours—point to traffic congestion, diesel emissions, and road dust as primary contributors. At IDTL Toll Manglia, where PM_{10} levels reached 190.82 µg/m³ at night, mechanized road sweeping and regular application of dust suppression agents such as magnesium chloride should be prioritized on unpaved and deteriorated road sections. Installation of water sprinklers and anti-smog guns during evening peaks, coupled with the use of porous asphalt for resurfacing, could further reduce particle re-suspension at both sites. High PM_{10} and NO_2 levels, especially during night peaks, warrant mandatory retrofitting of diesel vehicles with Diesel Particulate Filters (DPFs), promotion of CNG and electric alternatives, and implementation of automated toll collection systems like FASTag to minimize idling. Dedicated EV lanes for commercial and public transport near the toll plaza could also be piloted during peak hours. Given that NO_2 levels at

IDTL Toll Manglia exceed WHO limits, particularly due to diesel exhaust, the introduction of Selective Catalytic Reduction (SCR) systems with AdBlue for heavy trucks, establishment of time-restricted low-emission zones, and enforcement of Ultra-Low Sulfur Diesel (ULSD) alongside B5/B10 biodiesel blends should be considered. While SO_2 concentrations remain within NAAQS limits, the higher levels at IDTL Toll Manglia necessitate stricter ULSD enforcement, installation of scrubbing technologies for nearby industrial units, and potential use of sulfur-absorbing road surfacing materials. Additionally, strategic urban greening—particularly the plantation of pollutant-absorbing vegetation such as *Tamarindus indica* and *Azadirachta indica*—could serve as a long-term bio-filtration measure, while also enhancing air circulation and aiding the dispersion of NO_2 and PM_{10} through the creation of green belts.

4.0 Conclusions

The study on vehicular pollution at IDTL Toll Manglia and Bicholi Mardana on Asian Highway 47 provides valuable insights into the sources and impact of traffic-induced air pollution. By quantifying pollution levels and understanding their correlation with traffic load, the findings can guide effective policy and infrastructure decisions to mitigate pollution and improve public health in the Indore region. Following the conclusions reported:

1. The morning and evening RSPM concentrations at the Bicholi Mardana divergence site exceeded the CPCB's allowed limits.

2. The morning RSPM concentration at IDTL Toll Manglia divergence point exceeds the allowed limit. Palasia has the greatest concentration of RSPM in the evening, exceeding the CPCB's permissible limit.The SOx concentration pattern in IDTL Toll Manglia Square is within the permitted level in both the morning and evening, but it may exceed the limit if traffic pollution continues to increase.

3. SOx concentrations in Bicholi Mardana are within the acceptable limit in the morning and evening, but may exceed the limit if traffic pollution continues to increase.

4. In the morning, the NOx concentration pattern at IDTL Toll Manglia Point is appropriate. At Bicholi Mardana Square, the NOx content is acceptable in the morning and high but not over the CPCB guideline in the evening. Conversely, it is high in the evening but stays within the CPCB-permitted threshold.Both research areas had

moderate air pollution levels. However, both places in the evening had significant air pollution levels.

5. A separate traffic survey found 40224 cars passing through IDTL Toll Manglia and 36,197 passing through Bicholi Mardana sampling site. As a result, the total pollutant load at the IDTL Toll Manglia sample location was assessed to be 13.68 tons/day, while at Bicholi Mardana it was 10.29 tons/day, indicating a significant TVPL at both locations.

5.0 Challenges and Future Directions

Implementing Vehicle Emission Control Programs (VECPs) often faces significant economic and technological challenges, particularly in developing countries where resources are limited. Substantial investments in technology and infrastructure are required, which can be costly. Continuous research and development are crucial to making cleaner vehicle technologies more affordable and accessible. Furthermore, integrating VECPs into broader urban planning strategies is essential for creating sustainable cities. This involves promoting efficient public transportation systems, designing pedestrian-friendly spaces, and minimizing urban sprawl to support long-term environmental and social well-being.

Declaration

All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors"

Ethical Approval

We approve that all the authors mentioned in the manuscript have agreed for authorship, read and approved the manuscript, and given consent for submission and subsequent publication of the manuscript.

Consent to Participate

We, the undersigned, give our consent for the publication of identifiable details, which can include photographs within the text to be published in the Environmental Science and Pollution Research. We confirm that we have seen and been given the opportunity to read both the Material and the Article to be published by Environmental Science and Pollution Research.

Consent to Publish

We hereby provide consent for the publication of the manuscript detailed above, including any accompanying images or data contained within the manuscript that may directly or indirectly disclose our identity.

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Competing Interest

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